D2.1 – Enabling conditions & consolidation factors for building electrification, 1st version

October 8, 2024

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Powering the METAmorphosis of BUILDings towards a decarbonised and sustainable energy system

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Preface

The overall vision is to operationalise energy efficiency first principle in the practical context of buildings, towards the decarbonisation of the EU building stock, through: Electrified low-carbon technologies such as heat pumps for the electrification of the building thermal energy demand; Integration of RES & storage; Building digitalisation and intelligence with smart energy management systems. To achieve the 'META BUILD of the building sector', we will develop and demonstrate at TRL 6-8 highly cost-effective, integrated, and replicable solutions (i.e. Heat Pumps coupled with RES and ES systems) for electrifying thermal energy demand in buildings. Social acceptance and strict adherence to energy efficiency measures will be ensured to promote a sustainable, efficient energy use and an affordable pathway to decarbonise the building-sector heating. A holistic approach addresses challenges throughout the building life cycle, including product manufacturing, energy solution design and engineering, construction, renovation, operation, and maintenance.

META BUILD will deliver:

- KPI-driven assessment methodology & LCA analysis on building electrification.
- Decarbonisation as a service decision support tool; sound Business Models combined with energy efficiency and electrification.
- Advanced HP technologies, PVTs & other RES solutions, thermal & second-life battery storage systems.
- Interoperable framework for electrified ready buildings; Energy management services for RT-monitoring & performance analytics.
- Demand response, grid interaction & flexibility planning tools.
- Pro-active maintenance & controls services.
- Digital Twins for maintaining / enhancing the buildings' performance; Blueprints & policy recommendations for replication & scalability.

Focus will be given on both construction and renovation phases of a building, while META BUILD solutions will be demonstrated and replicated in different types of buildings including 6 Front Runners and 7 Replication Multipliers.

Participants

ICCS	EREVNITIKO PANEPISTIMIAKO INSTITOUTO SYSTIMATON EPIKOINONION KAI YPOLOGISTON	EL		CARTIF	FUNDACION CARTIF	ES	
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INETUM	INETUM	FR		INETUM ES	INETUM ESPAÑA S.A.	ES	
BLUEPRINT	BLUEPRINT ENERGY SOLUTIONS GMBH	AT		IDM	IDM ENERGIESYSTEME GMBH	AT	
SOZIALBAU	SOZIALBAU GEMEINNUTZIGE WOHNUNGSAKTIENGESELLSCHAFT	AT		HOB	HAUSSERVICE OBJEKTBEWIRTSCHAFTUNGSGMBH	AT	
TUD	TECHNISCHE UNIVERSITAET DRESDEN	DE		UNIZAG	SVEUCILISTE U ZAGREBU, FAKULTET STROJARSTVA I BRODOGRADNJE	HR	
CER	CIRKULARNI ENERGETSKI RESURSI DOO ZA PROJEKTIRANJE I IZGRADNJU ENERGETSKIH POSTROJENJA	HR		HEPT	HEP-TOPLINARSTVO D.O.O.	HR	
GSG	GRADSKO STAMBENO GOSPODARSTVO VELIKA GORICA DOO	HR		GVG	GRAD VELIKA GORICA	HR	
EDF	ELECTRICITE DE FRANCE	FR		SAUTER	SAUTER REGULATION SAS	FR	
KMO	KMO	FR		ENOV CAMPUS	E-NOV CAMPUS	FR	
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INNOVA	INNOVA SRL	IT		INNENG	INNOVA ENGINEERING SRL	IT	

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ANIMA	ANIMA - FEDERAZIONE DELLE ASSOCIAZIONI NAZIONALI DELL'INDUSTRUSTRIA MECCANICA VARIA ED AFFINE	IT	ANIMA CONFINDUSTRIA MECCANICA VARIA	TECNALIA	FUNDACION TECNALIA RESEARCH & INNOVATION	ES	tecnalia MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE
ENDEF	ENDEF ENGINEERING SL	ES	enDef Solar Solutions.	CIRCU LI-ION	CIRCU LI-ION S.A.	LU	CIRCU LI-ION
EAP	ENERGY AGENCY OF PLOVDIV ASSOCIATION	BG		HELEXIA	HELEXIA CORPORATE	FR	Helexia
UNIPassau	UNIVERSITAT PASSAU	DE	UNIVERSITY OF PASSAU	THES	DIMOS THESSALONIKIS	EL	CITY OF THESSALONIKI
RPR	RIGAS PLANOSANAS REGIONS	LV	RĪGAS PLĀNOŠANAS REĢIONS	FASADA	PRZEDSIEBIORSTWO ROBOT ELEWACYJNYCHFASADA SP ZOO	PL	FASADA
GDYNIA	GDYNIA-MIASTO NA PRAWACH POWIATU	PL	GDYNIA moje miasto	VEOLIA	VEOLIA SERVICIOS LECAM SOCIEDAD ANONIMA UNIPERSONAL	ES	VEOLIA
ARTELYS	ARTELYS	FR	Artelys OPTIMIZATION SOLUTIONS	RAP	REGULATORY ASSISTANCE PROJECT	BE	RAP REGULATORY ASSISTANCE PROJECT
EHPA	EUROPEAN HEAT PUMP ASSOCIATION	BE	ehpa european heat pump association				

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Executive Summary

This report presents the preliminary work done on META BUILD project's Work Package 2 – "Electrified thermal energy demand integrated solutions & demonstration strategy", which focusing on developing and evaluating solutions for building electrification and decarbonisation. Work package 2 main objective is to compile and map all necessary data from technologies, and pilot sites and start the definition of the methodologies to be followed for the assessment of META BUILD solution performance. This report includes necessary data regarding user requirements, renewable energy resource mapping, and KPI-driven assessment. Additionally, it introduces the "Decarbonisation-as-a-service" approach aiming to optimise the design and integration of the technologies in buildings.

Special attention is paid to the requirements and needs of end-users from pilot sites, incorporating them into the design and specification of the technological solutions. A preliminary planning stage of the demonstrative actions for each pilot site has also been outlined.

The methodology for early-stage building energy demand and renewable energy production potential assessments is described, and storage technologies are then defined as part of the Demand Response services.

Furthermore, to assess building performance the report provides a preliminary list of Key Performance Indicators, as well as introduce the methodology to be followed to perform a Life Cycle Analysis.

As part of the conceptual design, the individual technologies that form the integrated solutions will be defined, with preliminary modelling approaches provided for the Front Runners. Since the project is in its early stages, updates and adjustments in sizing and operation is anticipated, with more detailed modelling results to be included in the next Work Package 2 deliverable, namely D2.2 – "Enabling conditions & consolidation factors for building electrification, final version", on M20 of the project (August 2025).

Finally, the functionalities, objectives, and technical specifications of the "Decarbonisation-as-a-service" tool for optimising integrated heating and cooling technologies are discussed.

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Table of Contents

Funded by the European Union

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List of Figures

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List of Tables

List of abbreviations

KPI	Key Performance Indicator
LCA	Life Cycle Assesment
FR	Front Runner
RES	Renewable Energy Sources
PV	Photovoltaic
PVT	Photovoltaic Thermal
PVT-a	air-based solar photovoltaic-thermal panels
BIPV	Building-Integrated Photovoltaics
HP	Heat Pump
DSHP	Dual Source Heat Pump
SOC	State of Charge
MPC	Monitoring and Predictive Control
PCM	Phase Change Material
COP	Coefficient of performance
SCOP	Seasonal Coefficient of Performance
IPMVP	International Performance Measurement and Verification Protocol
EPD	Environmental Product Declaration
EVO	Efficiency Valuation Organisation
HVAC	Heating, Ventilation, and Air Conditioning
WP	Work Package
BESS	Battery Energy Storage System
EV	Electric Vehicle
AWHP	Air-to-Water Heat Pump
EMS	Energy Management System
DR	Demand Response
°C	Celsius degrees
°K	Kelvin degrees
IoT	Internet of Things
TMY	Typical meteorological year
kW	kilowatt

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1 Introduction

1.1 Objectives of the deliverable

The purpose of Deliverable D2.1 - “Enabling Conditions & Consolidation Factors for Building Electrification” is to present the early work and findings from activities of WP2 – “Electrified thermal energy demand integrated solutions & demonstration strategy”. It addresses the enabling conditions necessary for widespread building electrification and offers insights into the factors that support the consolidation of such solutions. The document also provides an overview of the initial results and methodologies developed so far, which will continue to evolve as the project progresses.

1.2 Structure of the document

The document is organised in five different sections as follows:

Section 1 includes the objectives and the structure of the deliverable as well as the connection with other WPs.

Section 2 outlines the framework for achieving the alignment of user requirements with the specification of enabling technologies and eventually planning for their demonstration.

Section 3 showcases the Resource Mapping actions taken within META BUILD in order to identify the electricity demand of buildings and assess their potential in RES instalments and demand shifting scenarios.

Section 4 presents the overall framework under which the META BUILD performance will be assessed across multiple dimensions, including energy, economic and environmental impacts.

Section 5 introduces the first six integrated solutions, for electrification of the thermal energy demand of buildings, developed within META BUILD so far. Decarbonisation as a Service is also being presented, a cutting-edge decarbonisation recommendation engine designed to assist building stakeholders in optimising decarbonisation efforts within the built environment. Lastly, the general overview of the existing integrated solutions is being outlined which are planned to be installed in the six pilot sites.

1.3 Connection with other Work Packages

As deliverable D2.1 contains user requirements, buildings specifications, and evaluation of integrated solutions, it links with several activities regarding implementation of the existing integrated solutions as well as the development of new ones. Specifically, it has close connection with WP3 – “Technologies enabling electrification” as the monitoring of the META BUILD electrification technologies is closely linked with the development of new integrated solutions. It is also connected with WP4 – “Open modular energy management services”, as it will provide the framework under which the META BUILD services will be utilising the integrated solutions. Moreover, it is heavily connected with WP5 – “Deployment & demonstration in real cases” and WP6 – “Solutions adoption, replication, scalability & exploitation” which are responsible for the deployment and demonstration activities in META BUILD Front Runners (FR) and Replication Multipliers (RM) respectively.

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2 Specification of the enabling technologies & demonstration planning

2.1 Introduction and Methodology

This section lays the groundwork for aligning user requirements with the specification of enabling technologies and planning for their demonstration, to capture and incorporate the needs of end-users from various pilot sites across Europe into concrete use cases. The primary objective is to ensure that all technological solutions are designed with user-centric considerations and are primed for effective demonstration in diverse building environments.

The methodology employed here involves a systematic approach to gathering, analysing, and integrating user feedback into the development of technological solutions. Initially, a standard template based on IEC 62559 (1) was created to consistently capture user requirements across all pilots. This was followed by an extensive feedback collection phase, where each pilot site's specific use cases were documented and analysed. The feedback has been instrumental in shaping the preliminary planning of demonstrative actions, ensuring minimal disruption during deployment while maximising the relevance and applicability of the technologies involved.

2.2 Use Cases Template description

The Use Cases Template, structured in accordance with the IEC 62559 standard (1), serves as a fundamental instrument for the uniform collection of requirements and feedback from all pilot sites involved in META BUILD. The IEC 62559 standard provides a methodology for managing innovation in system technology projects. By adopting this standardised approach, the template

- ensures consistent data capture which minimises ambiguities and
- streamlines analysis across diverse technological implementations.

This systematic collection framework helps sustain a comprehensive and effective dialogue among stakeholders, thereby enhancing the clarity and effectiveness of communications throughout the project's lifecycle. The template aims to set the stage for a detailed exploration of user requirements across diverse pilot environments, each with unique operational and technological landscapes.

Here's a step-by-step analysis of the major sections of the template, elucidating why the sequence and structure are essential for effectively gathering and processing information:

Scope, Objectives and Rationale

- *Foundation setting:* This section sets the stage by clearly defining what the Use Case aims to achieve, laying a foundational narrative that guides the subsequent detailing of technical and operational specifics. This initial part is crucial because it establishes the foundation upon which all technical requirements and project activities are built. By starting with a clear definition of scope and objectives, the document aligns all stakeholders' expectations and directs the project's focus towards achieving specific, measurable outcomes.
- *Guidance for alignment:* By establishing the scope and objectives upfront, all stakeholders (including technical teams and decision-makers) gain a unified understanding of the project's goals and boundaries, ensuring that the subsequent activities and decisions are aligned with these predefined objectives. Additionally, to address the specifics of the available technological solutions and to ensure a comprehensive grasp of the project's requirements both vertically and horizontally, the template promotes the inclusion of relevant Assets and Features under Study. This approach not only honours

inclusivity but also enhances the collective understanding, enabling the team to effectively map out all necessary specifications.

Actors, Roles, Names and Types

Following the scope and objectives, this section identifies and describes all relevant stakeholders or actors involved in the use case. This is essential for understanding how different entities contribute to and benefit from the project, ensuring that each actor's needs and inputs are considered in the design and implementation phases. It also helps to set the project's networking channels and structures, facilitating effective communication and collaboration among all parties involved. In overall, this sets a foundation for understanding the interaction dynamics within the use case environment. The specific formulation is crucial because:

- *it establishes context:* It helps to clarify who is involved, with what role (maybe multiple hats) and what their responsibilities are within the system. This contextual grounding is essential for anyone reviewing the use case to grasp the operational landscape,
- *it sets the base for defining interactions:* Knowing the actors early helps in mapping out the interactions that occur between them, which is vital for designing the system's workflow and communication pathways, and
- *it suggests a user-centric design:* Starting with actors ensures that the use case development is user-centric and further contributes to the alignment of potentially collaborating parties.

Integration Profiles and Transactions:

The final major part deals with the technical specifics of how different systems and components will interact. It describes the integration profiles and specifies the transactions that will occur between different technological solutions and stakeholders. This section is vital for ensuring interoperability among diverse systems and for presenting the information exchange protocols that need to be in place for seamless operation. By concluding with this technical detail, the template ensures that all functional aspects of the project are grounded in a robust technical framework capable of supporting the stated objectives. This particular stage will be further enriched with specifics, regarding Data Types and Data Formats on deliverable D2.2. The current input in section 3.1 of the respective template has been addressed as indicative. Future iterations are expected to provide mature and enriched content in that front.

The near page-size images that illustrate the template example based on IEC 62559 standard (1) that was shared to each one of the six META BUILD pilots, is referenced in Annex A of this document.

2.3 Use Cases feedback by Front-runners (per Pilot)

For this section, each pilot has tailored the standard Use Cases template to reflect specific regional and technological contexts. The feedback captures the unique aspects and requirements of each site. All six pilots have honoured this preliminary exercise by meticulously following the formulation of the given template and the provided details reflect this as they span across the following dimensions:

- *Scope and technological fit:* Each pilot distinctly outlined how the technological solutions align with the local environmental and infrastructural peculiarities, ensuring that the technologies not only fit but are also sustainable and efficient within their specific settings.
- *Actor engagement and contributions:* Detailed accounts of how different stakeholders, from building operators to local energy providers, engage with the technology provide insights into the collaborative ecosystem that each pilot fosters. This engagement is crucial for the seamless integration of new technologies into existing systems and for maximising the benefits of these technologies.
- *Technological specifications and requirements:* The pilots provide a thorough examination of the technical requirements necessary to support the implementation of technologies like heat pumps (HPs), digital twins, and renewable energy systems. These specifications are tailored to meet the

energy demands and efficiency goals specific to each pilot site. This subsequently ensures that each implementation is optimised for its intended environment. As a future step, this vertical approach will be extended horizontally to identify and exploit any emerging schema of shared services.

- *Strategic Objectives Linkage:* The feedback directly ties the technological implementations to the broader strategic objectives of META BUILD, such as decarbonisation, energy efficiency, and the integration of renewable energy sources (RES). This alignment maintains the project's direction and ensures that all technological deployments contribute to energy sustainability and efficiency.

The results from all 6 Pilot Use Cases are provided in **Annex B** of this document.

2.4 Technological Solutions Description and Specifications

This section details the specific technologies and systems to be implemented across the pilots, outlining the specifications for HPs, photovoltaic (PV) panels, storage systems, and additional technologies, along with their capacity, expected performance, and integration requirements. This approach provides a clear understanding of how each technology contributes to the overall energy efficiency and sustainability goals of META BUILD. What follows is a comprehensive overview of the innovative technologies and approaches being employed.

- **Heat Pumps:**
    - **Austria** utilises R290 brine-to-water HPs, tailored for retrofitting in residential multi-family buildings to enhance thermal efficiency.
    - **Croatia** employs district-heating compatible HPs, integrating with local infrastructure to maximise energy distribution and thermal efficiency in residential single homes.
    - **France** uses reversible HPs in an office complex setting, demonstrating adaptability in commercial retrofits for optimal climate control.
    - **Greece** will use a Speed controlled/inverter-driven HP for the building demand electrification and to allow Demand Response (DR) strategies.
    - **Italy** will use Monobloc HP R290 for outdoor installation, with reversible cycle to supply both heating and cooling needs.
    - **Spain** pilot will use and develop Dual Source/sink HP produce heat without cooling devices.
- **Photovoltaic and Hybrid Systems:**
    - **PV** panels are selectively used across pilots, with France and Greece integrating them to reduce dependence on non- RES.
    - Croatia stands out by integrating Photovoltaic Thermal (**PVT**) panels, which simultaneously generate thermal and electrical energy, optimising efficiency for residential applications.
    - In the Austrian pilot, PV panels are used. An application of PVT panels is considered to minimise the number of needed boreholes, but not decided yet.
- **Italy** and **Spain**, both use PV systems, with Spain notably integrating substantial capacity to support their dual source/sink HPs, highlighting a strong commitment to reducing reliance on non- RES.

- **Storage Solutions:**

Energy storage is crucial for balancing the intermittency of RES and for DR services. It will include thermal energy storage on **Austria, Greece, Italy** and **Spain**, while second life electric batteries will be installed on **Austria** and **Italy**. Even though not foreseen for the moment, the Greek pilot may install batteries if feasible, and the **French** pilot may install thermal storage with the HP. More details are included in section 3.2.1 of the storage solutions for the demand shifting modelling tasks.

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- **Semantic Interoperability and System Integration:**

All pilots emphasise the importance of semantic interoperability enablers, ensuring that different technological systems can communicate effectively. This integration supports the seamless operation and management of energy systems, particularly with the inclusion of Monitoring and Predictive Control (MPC) frameworks that adapt to dynamic operational conditions.

- **Advanced Management and Digitalisation:**
    - Building Digital Twins are notably utilised in France and Spain, facilitating advanced management strategies and optimisation of building operations through digital replication and simulation technologies.
    - Decarbonisation as a Service is highlighted in several pilots, particularly in France and Spain, where digital tools and services are leveraged to enhance building performance, extend lifecycle management, and achieve stringent sustainability targets.

Additionally, the detailed progress and specific technological implementations per pilot provide further insights:

- **Austria** is focusing on replacing gas combi boilers with geothermal HPs and integrating a substantial PV system with battery storage to enhance energy efficiency.
- **Croatia's** project aims to retrofit residential buildings connected to a district heating network, focusing on improving building envelopes and integrating HPs and PVT systems.
- **France** is developing a prototype of a prefabricated shed with Building-Integrated Photovoltaics (BIPV) and integrated RES solutions, aiming to expand current building management systems towards a Digital Twin solution.
- **Greece** is exploring flexibility services and energy market operations, integrating smart Internet of Things (IoT) devices to increase awareness and optimise energy use behaviours.
- **Italy** is implementing INNOVA's air-to-water heat pumps (AWHP) and Phase Change Material (PCM) storage systems for heating, cooling, and domestic hot water, complemented by a building management system for PCM storage management.
- **Spain** focuses on thermally activating parts of a micropyle foundation and extending an existing biomass boiler with a dual-source HP, supported by storage vessels and hybrid PVT panels.

These pilot-specific implementations and objectives underscore the diverse yet unified approach of META BUILD in addressing energy efficiency and sustainability across various building types and regional contexts. This detailed understanding of technological implementations allows META BUILD to come closer to its energy efficiency and sustainability goals, ensuring that each pilot is equipped with the best-fit solutions that are scalable and replicable. These insights, suggest that the pilots are optimised for their specific regional and architectural context but also have the potential to contribute to the collective advancements in building technology and energy management within the EU.

2.5 Preliminary Planning of Pilot's Demonstrative Actions

This section outlines the preliminary timeline and major milestones for the implementation of demonstrative actions in each pilot. It highlights key phases such as procurement, installation, and testing, ensuring that the rollout of technologies minimises disruption and maximises efficiency. This planning phase sets the groundwork for the updated demonstrative actions to be detailed in D2.2 (2), aligning the project's technological deployments with the strategic milestones. The demo planning is illustrated in detail in the GANTT chart in Figure 1.

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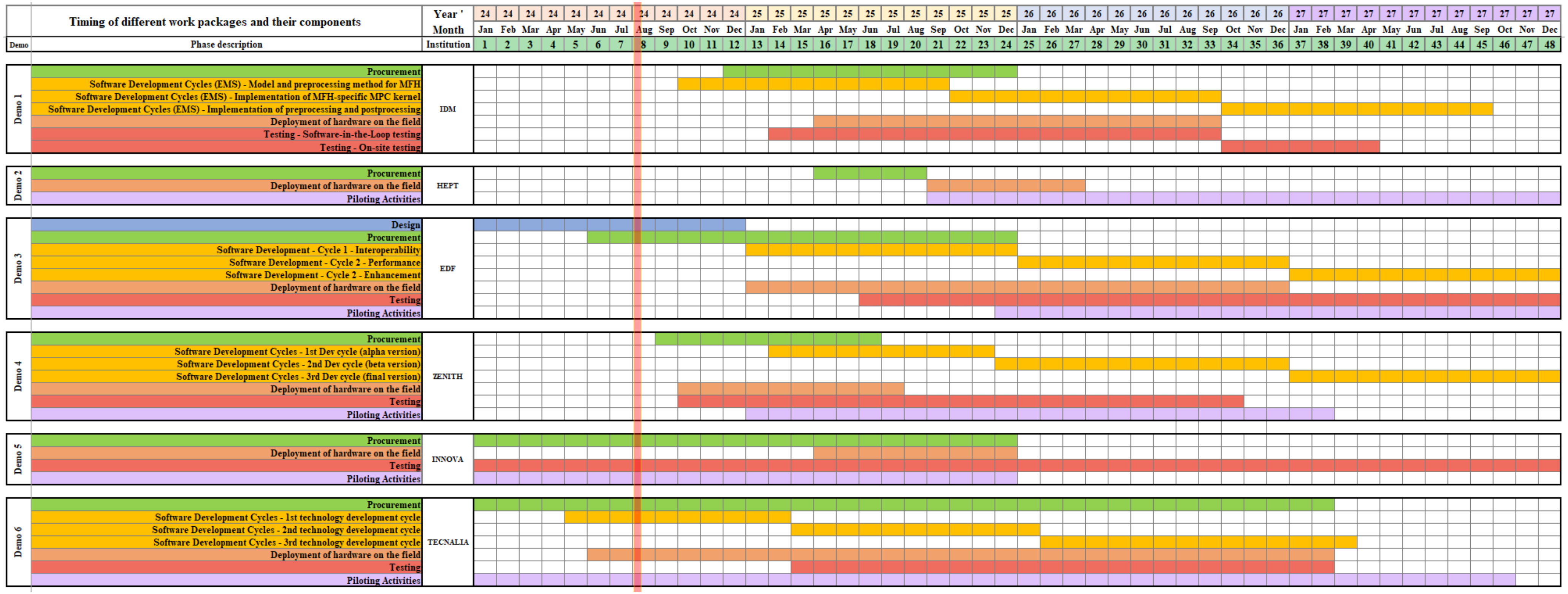

Figure 1 - GANTT chart of Pilot's Demonstrative Actions

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3 Resource mapping in buildings

To accurately assess the electricity demand and renewable energy production potential of a building, a comprehensive energy evaluation must be conducted. This typically involves the use of building simulation tools or similar methodologies, to model the building's heating, cooling, and electrical demands over the course of a year. By inputting detailed information regarding the building's structure, energy systems, climate conditions, and occupancy patterns, precise profiles of energy consumption can be generated by the energy evaluation and areas where energy efficiency improvements can be made are identified. The versatility of these methods allows for their application across a wide range of premises in the building sector.

Within META BUILD, this approach is initially being applied to the six FR, located in various countries, each with its own unique characteristics and environmental conditions. The methodology aims to be flexible and adaptable, capable of accurately capturing energy demand across different weather seasons and aligning with available RES. This process is particularly important for creating energy-efficient buildings, in which on-site renewable energy production can be integrated, while simultaneously minimising reliance on carbon-powered thermal energy sources.

Once the building's baseline energy demand is established, the next step involves analysing strategies for demand shifting. These strategies focus on aligning electrical demand with the intermittent production of renewable energy, by adjusting the timing of certain energy-intensive activities, such as heating, cooling, or battery charging. The assessment process allows the simulation of various demand-shifting scenarios, optimising energy consumption to better match renewable generation. This flexible approach ensures that the method can be effectively applied to a variety of buildings and climates, helping to maximise the use of renewable energy and improve overall energy efficiency.

3.1 Identification of electricity demand

For the simulations within this assessment, the open-source building simulation software SIM-VICUS is used to perform the required simulations. SIM-VICUS has been developed over the past 3 years at the Institute for Building Climatology (IBK), TU Dresden (3). It comprises a 3D graphical interface for modelling the building geometry and assigning all required parameters. Hereby, DXF files as well as IFC files can be imported, and the building model can be further refined based on that. SIM-VICUS includes databases for building materials, constructions, components, zone templates, schedules and many more. For each parameter, a false-colour view can be enabled, which allows to clearly see where a building component or zone properties are assigned. An example of the graphical user interface is shown in Figure 2.

Further, SIM-VICUS comprises a numerical solver for building energy simulation, which is called NANDRAD. It has been developed at the Institute for Building Climatology (IBK), TU Dresden as well. NANDRAD calculates the temperature in each room and within each wall by solving the respective differential equations. Hereby, a real climate for a whole year can be provided through a respective climate file (e.g., in epw format). This commonly includes the ambient temperature as well as short and long wave radiation and wind velocity in an hourly resolution. Based on the ambient climate and the given setpoints for heating and cooling, NANDRAD calculates all temperatures and heat fluxes of each room (or zone) and wall. Therefore, the numerical solver CVODE is employed. It uses a time-step adaptive, error-controlled, multi-order numerical solution scheme for solving ordinary differential equations.

With SIM-VICUS, a yearly simulation of the entire building can be conducted, and the results can be shown within SIM-VICUS or through using the external tool PostProc, allowing detailed evaluation of time-series curves. Eventually, the thermal comfort within each zone can be assessed, which is a common task for building physics planers. Particularly, for green building certificates, such as LEED and DGNB, this is mandatory.

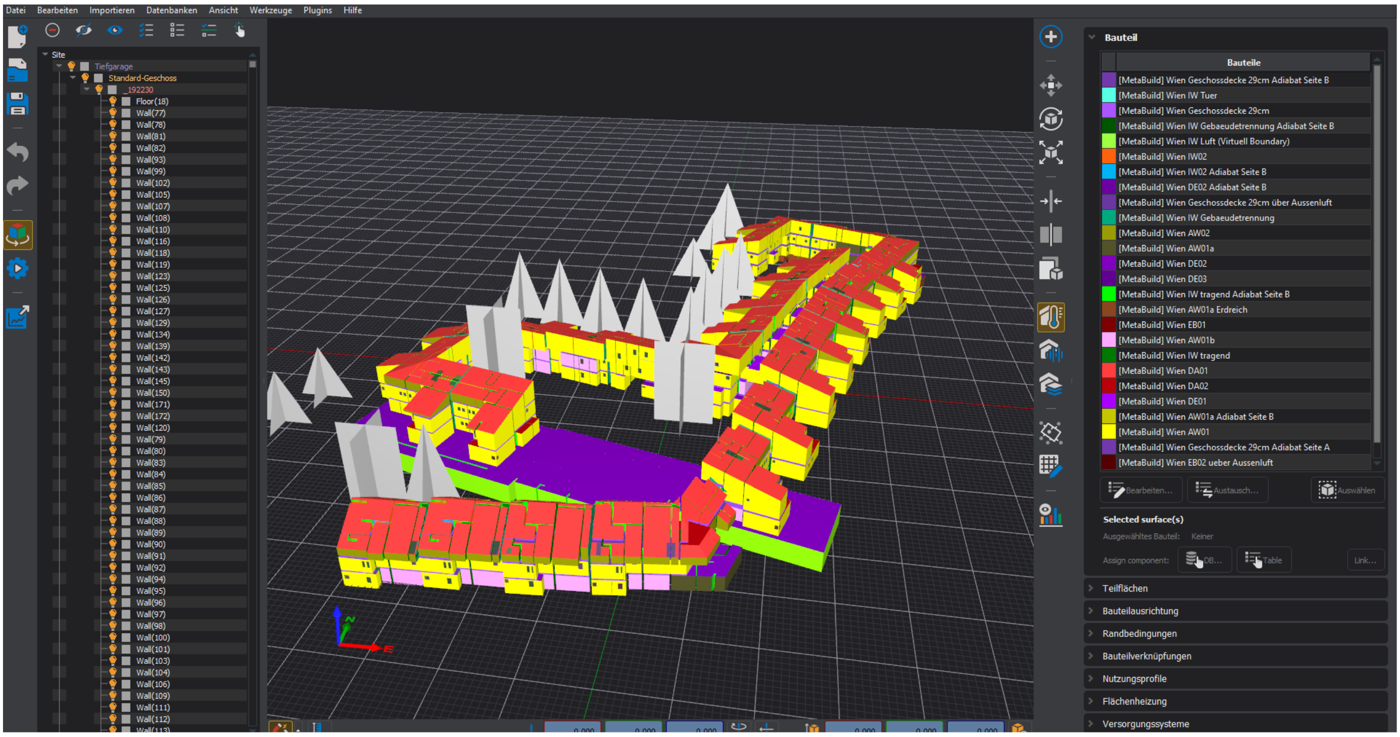


Figure 2 - SIM-VICUS graphical user interface in component view.

Further, the energy demand of each room and that of the whole building can be analysed in hourly resolution throughout the year. This allows to evaluate the impact of different properties such as the insulation thickness or the heating set point on the building energy demand.

The application of SIM-VICUS within the META BUILD project for modelling different front-runners is described in the following.

3.1.1 Generic Building Models

To obtain realistic time-dependent profiles of the heating and cooling demand, as well as the electrical energy demand and potential PV production of buildings at early design stage, the Institute for Building Climatology (IBK) at TU Dresden (3) has developed the method of generic building modelling. Hereby building simulation models with a sophisticated parametrisation are setup based on few available parameters. While the building geometry, envelope and floor plan of such a generic model does not exactly match reality, the approximation based on typical floor plans and building shapes is expected to be sufficient. As a software tool, the in-house development SIM-VICUS is used here, which allows to create a 3D building performance simulation model based on the following parameters:

1. *Type of building*: Residential or Office
2. *Approximate shape* (U-shape, L-shape, I-shape) or a detailed floor plan.
3. *Building height*, *length* and *width* or the *total floor area*. May also be provided for different blocks, if it is e.g. a U-shape.
4. Approximate *window height*, *length*, *width* and *sill height* as well as the *window-wall ratio* (the percentage of the window area in relation to the wall area).

5. *Wall constructions* containing the *thickness* and *material type* for each layer of the construction. If available, detailed material properties can be provided. The wall constructions are needed for:
    a. *outdoor walls*
    b. *inner walls* between *rooms*
    c. *inner walls* between *offices* or *apartments*
    d. *inner walls* for *fire protection* (in case of office buildings)
    e. *roof*
    f. *ceiling*
    g. *base plate* / *ground slab*.
6. *EPD datasets* of all used *wall materials*, if available. Standard values assumed otherwise.
7. *Temperature set points* for heating and cooling, if available. Standard values assumed otherwise.

At the current stage, a template has been setup and sent to the partners in each FR, in coordination with META BUILD deployment and demonstration activities. The required input parameter will be collected to start setting up the models for each FR. A typical example of a generic building model can be seen in Figure 3.

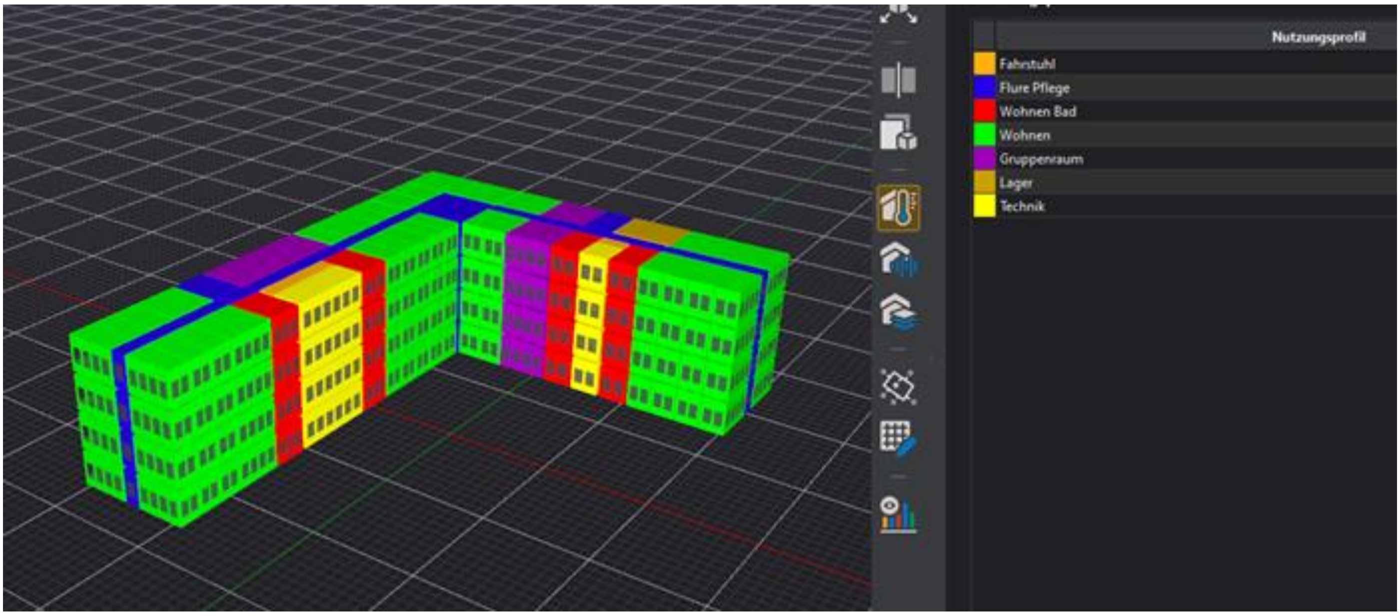


Figure 3 - Example of a generic building model with typical assigned floor plan and zone templates

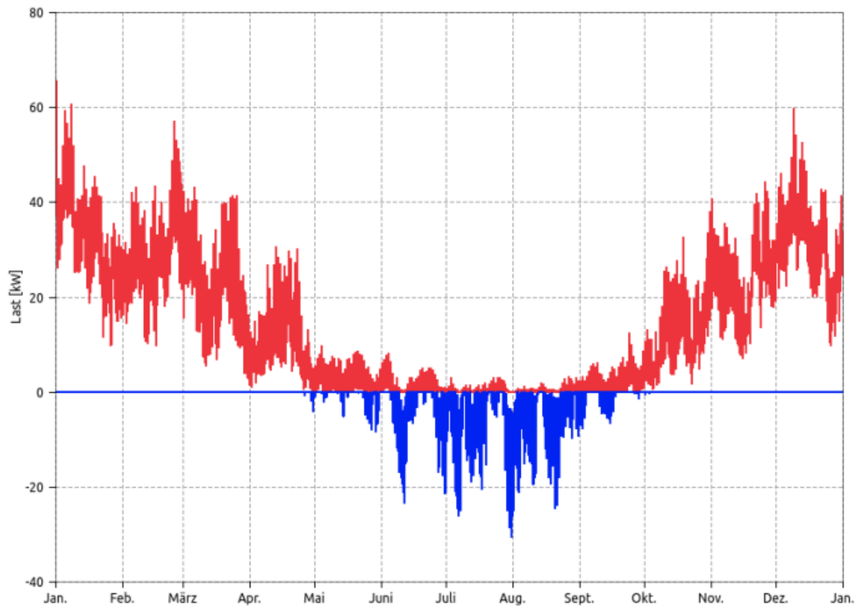
An overview of the pilots, the modelling approach and the expected results is provided in Table 1.

Table 1 - Pilot's building modelling approach

Front runner	Description	Model	Results
P1: Vienna, Austria	Existing stock of 15 semi-detached buildings, which is renovated and supplied through heat pumps	Detailed model	heating energy demand, PV yield
P2: Velika Gorica, Croatia	Retrofitting of six residential buildings connected to the local district heating network	Generic model	heating and cooling energy demand, PV yield

P3: Mulhouse, France	Retrofitting the KMØ office complex, installation of heat pumps, PV	Generic model	heating and cooling energy demand, PV yield
P4: Greece	Newly built, existing and renovated houses, installation of heat pumps and PV	Generic model	heating and cooling energy demand, PV yield
P5: Bolbeno, Italy	Multifamily residential building and commercial building, supply with AWHPs and PCM Storage	Generic model	heating and cooling energy demand, PV yield
P6: San Sebastián, Spain	Renovation of large office building with dual-sourced heat pumps	Generic model	heating and cooling energy demand, PV yield

The expected results commonly are comprised of the heating and cooling demand in hourly resolution. An example is provided in Figure 4, where the red curve represents the heating demand, and the blue curve the cooling demand.



8.

Figure 4 - Exemplary results of building energy simulation in terms of hourly heating and cooling demand in kW.

3.1.2 Detailed building model for Vienna Front Runner

The planning process of the Vienna FR has advanced already, so that more detailed information is required to design the energy supply system including the heat pump, borehole heat exchangers as well as the PV and battery storage system. It was therefore decided to setup a realistic detailed model of this FR, in order to obtain sophisticated results that can contribute directly to the design process.

The Vienna FR consists of 15 semi-detached buildings with more than 800 rooms, which shall be retrofitted and supplied through a ground-sourced heat pump. The building geometry was provided through an IFC file and DWG plans from the planning company (HOB). In coordination with HOB, the crucial parameters for building usage have been determined, and describe below.

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As ambient climate, a typical meteorological year (TMY) from Vienna Unterlaa is used, obtained from https://climate.onebuilding.org/. The data is shown in Figure 5.

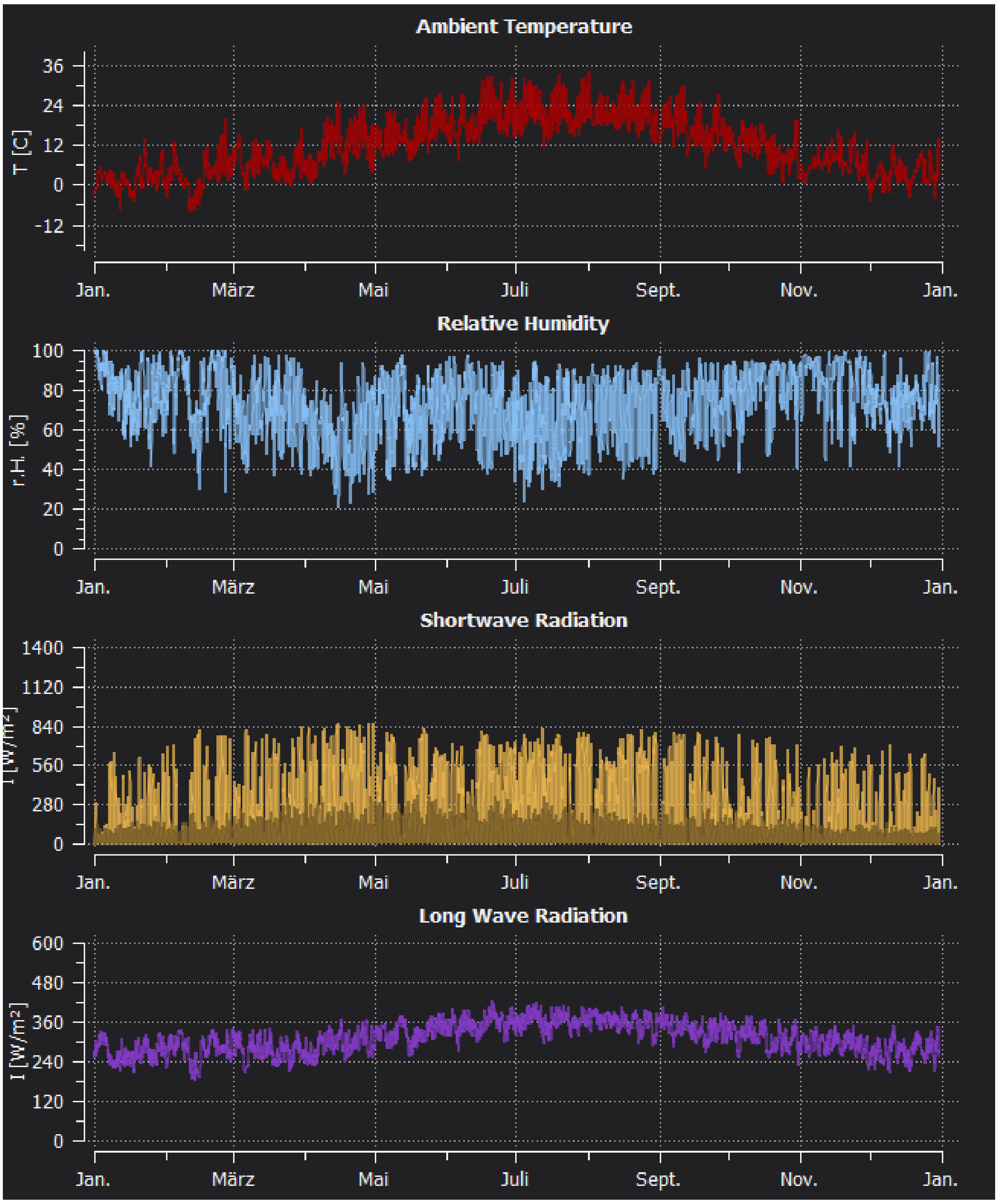

Figure 5 - Climate data of Vienna, Austria, used for building energy simulation

Figure 6 and Figure 7 showcases the simulation model in different false-colour views (constructions and zone templates).

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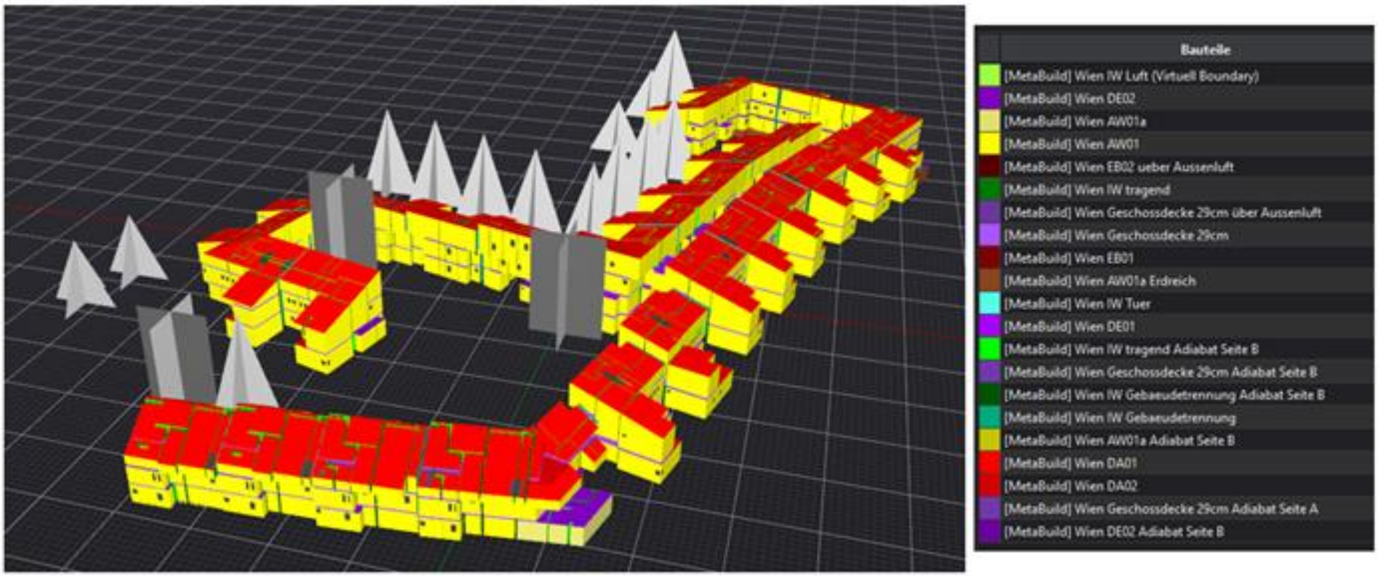

Figure 6 - Simulation model of the Vienna Front Runner, Screenshot from SIM-VICUS in construction view.

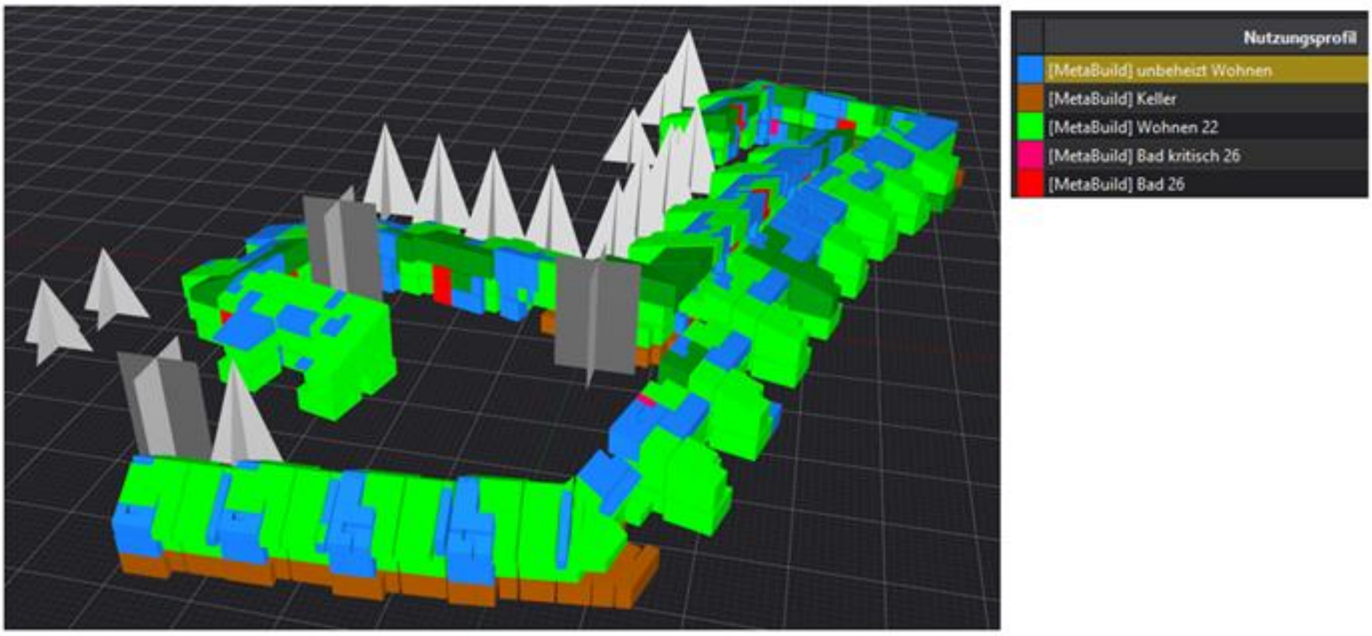

Figure 7 - Simulation model of the Vienna Front Runner, Screenshot from SIM-VICUS in zone template view.

Most crucial parameters are the wall constructions and material layers, which were provided by the planning company. Additionally, the following user requirements were considered:

- Natural infiltration rate 0.3 h^{-1}
- Window infiltration 0.1 h^{-1}
- Temperature set point living room 22 Celsius degrees (°C) constant
- Temperature set point bathroom 24°C constant
- Heating season from September to May

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- Climate according to TMY Vienna Unterlaa 2007-2021, as described above.
- There is no cooling system planned, thus cooling is not considered for this FR.

The results for an annual simulation as described are shown in Figure 8 and Figure 9. Key results are summarised in Table 2.

Table 2 - Summary of results of the simulation model of the Vienna Front Runner

Parameter	Model result	Unit
Heating energy demand	473	MWh/a
Maximum heating load	152.7	kW
Area heated	5384	m2
Area total	7746	m2
spec. heating demand	87.9	kWh/m2a

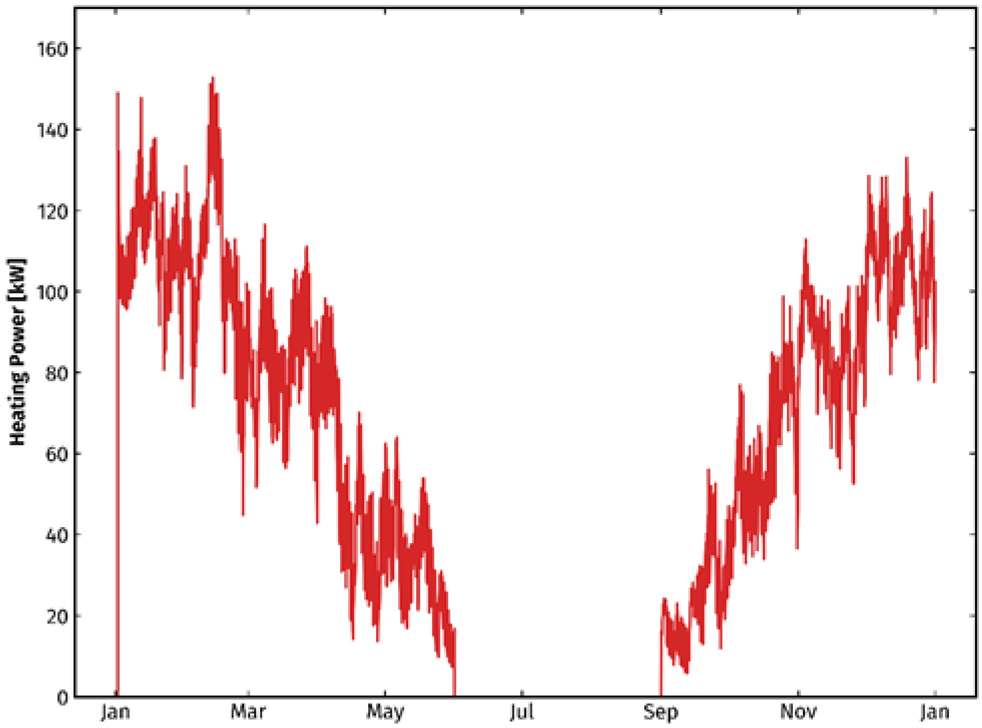

Figure 8 - Heating demand as result of building energy simulation

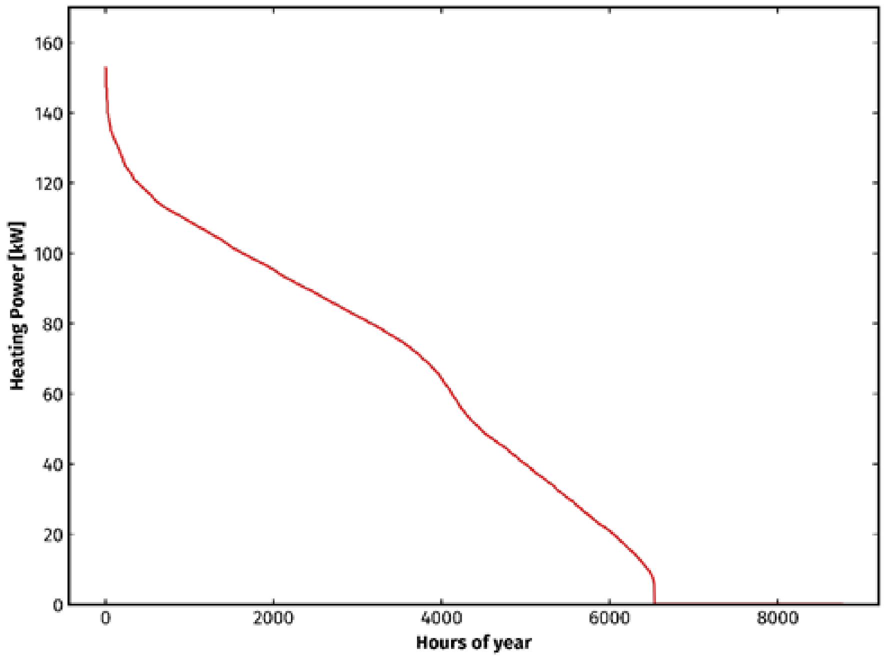

Figure 9 - Heating demand as result of building energy simulation

Based on these results the energy supply system will be designed as the next step. It is planned to cover the heat load of 150 kilowatt (kW) through a combination of ground-sourced and air-sourced heat pumps. Therefore, borehole ground heat exchanger shall be installed. Moreover, it is planned to use the roof for PV or PVT installations. This should partially cover the electrical energy demand for heating as displayed in Figure 10.

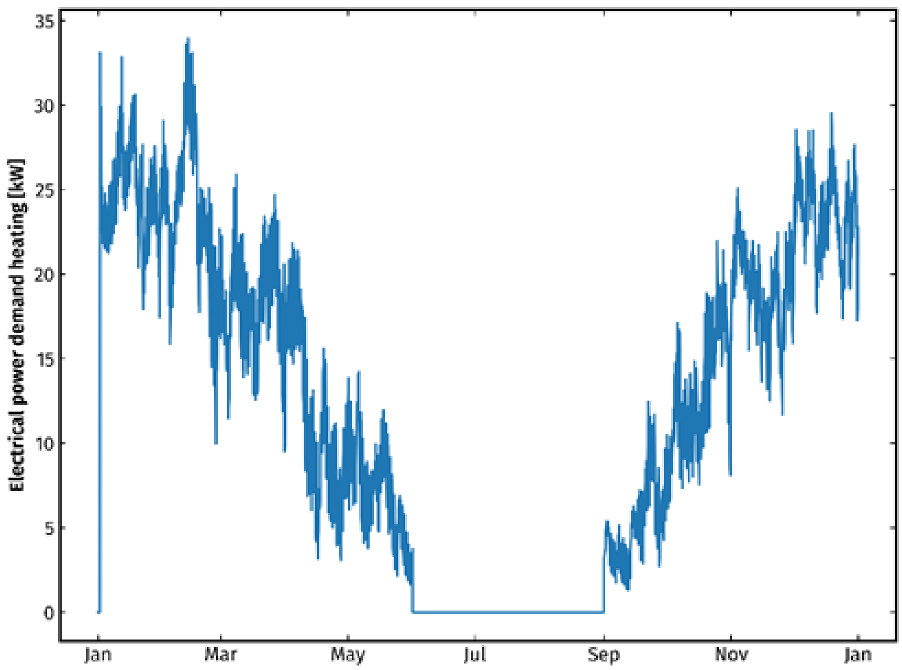

Figure 10 - Electrical power demand of heat pump for heating

3.2 RES potential & demand shifting

The objective of this process is to assess the potential for aligning electrical demand with renewable energy production through demand shifting strategies. This involves utilising both electrical and thermal energy storage systems within a generic building model, developed in SIM-VICUS, at the early design stage. The approach is described as follows:

1. Input data from detailed building models of FRs
2. Integration of storage models using TRNSYS
3. Development and implementation of demand shifting scenarios
4. Simulation and performance analysis
5. Sensitivity analysis and optimisation
6. Development of design and operational recommendations

These six steps are being analysed below:

Input data from detailed building models of FRs

For the purpose of this action, the following key data will be provided by the partners responsible for the modelling of buildings and simulation analysis:

- *Electrical Demand Profile:* Time-series data representing the building's electrical demand, typically on an hourly or sub-hourly basis, over a full year. This profile includes energy consumption for lighting, appliances, Heating, Ventilation, and Air Conditioning (HVAC) systems, and other electrical loads.
- *Thermal Demand Profile:* Time-series data for the building's thermal energy demand, including heating and cooling loads and domestic hot water load, again on an hourly or sub-hourly basis over a full year. This profile reflects the energy required to maintain indoor comfort conditions.
- *PV Production Profile:* Time-series data for the potential energy generation from the installed PV systems, considering factors such as orientation, shading, and local weather conditions. This profile is provided on an hourly or sub-hourly basis over a full year, aligning with the demand profiles.

Integration of storage models using TRNSYS

To explore the demand shifting potential, the provided demand and production profiles will be integrated into TRNSYS (4) models that include existing electrical and thermal storage systems. TRNSYS software functionalities are being described in section 5.1 along with the ways it will be utilised in META BUILD. The process involves:

- *Electrical Storage (Battery Models):* Utilising existing TRNSYS battery models, the electrical storage system will be configured to store excess PV generation and discharge during periods of high demand or low production. The model will simulate various battery management strategies, including charge/discharge cycles, SoC, and efficiency losses.
- *Thermal Storage:* Using existing TRNSYS models for thermal storage, such as stratified hot water tanks, the thermal storage system will be configured to store excess thermal energy for later use. The

thermal storage models will provide the ability to shift heating and cooling loads to periods of higher PV production.

Development and implementation of demand shifting scenarios

Several scenarios will be developed to assess how different demand shifting strategies can improve the alignment between demand and PV production. These scenarios will explore the impact of utilising both electrical and thermal storage systems to optimise energy use. A rule-based control strategy will be implemented initially to keep the complexity manageable, providing insights into the system's performance, before potentially introducing more advanced control techniques. These scenarios include:

- *Scenario 1: Baseline (No Demand Shifting):* This scenario will serve as a reference point, using the provided demand and PV production profiles, without any demand shifting or storage integration. This baseline scenario will allow to understand the existing level of alignment between demand and PV production, setting the stage for comparison with more advanced strategies.

- *Scenario 2: Electrical Storage Utilization:* In this scenario, the battery storage system will be optimised to absorb excess PV production and supply energy during peak demand times, utilising the Type48 control model in TRNSYS (4). The control model will manage real-time assessments of electrical production, consumption, and the state of charge (SoC) of the battery. When production exceeds consumption, surplus energy will be stored in the battery, unless it is fully charged, in which case it will be sent to the grid. Conversely, when demand surpasses production, energy will be supplied by the battery, with grid supply used only when the battery is fully discharged. We will test different operational strategies, such as time-of-use optimization and peak shaving, to maximise the benefits of energy storage.

- *Scenario 3: Thermal Storage Utilisation:* This scenario will examine how thermal storage can be used to shift heating and cooling loads, utilising a set-point control with hysteresis. This will involve storing excess thermal energy during peak PV production and releasing it during times of higher thermal demand. The control system will maintain temperatures within a predefined range to ensure efficient storage and release of thermal energy. While there may be some adjustments to the set-point to enhance performance, the control strategy will remain relatively simple at this stage.

- *Scenario 4: Combined Electrical and Thermal Storage:* This scenario will investigate the combined effect of both electrical and thermal storage systems will be investigated, coordinating their operations to optimise overall energy management. The aim will be to explore synergies between the two types of storage, such as using thermal storage to pre-condition spaces during periods of high PV production while simultaneously managing battery discharge to cover other electrical loads. The control strategies from the previous scenarios will be integrated to study how they can work together to enhance demand-shifting capabilities.

These scenarios will lay the groundwork for understanding how demand shifting can improve energy efficiency and balance supply with demand. This foundational control strategy will inform more advanced techniques, such as MPC, that will be introduced in future phases of the project under WP4 – “Open modular energy management services”.

Simulation and performance analysis

The scenarios developed in the previous step will be simulated using TRNSYS, leveraging the provided demand and production profiles. The simulations will run over a full annual cycle, considering the following Key Performance Indicators (KPIs):

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- *Demand-Production Alignment:* The degree to which energy demand is met by on-site PV production will be evaluated. This will include metrics such as self-consumption ratio, self-sufficiency ratio, and load matching index, which measure the effectiveness of demand shifting in reducing grid dependency.

- *Energy Savings and Efficiency:* The simulations are used to assess the potential for energy savings through demand shifting strategies, including reductions in peak demand, improved utilisation of on-site renewable energy, and potential cost savings from reduced energy bills.

- *Storage System Performance:* The performance of the storage systems will be analysed, focusing on metrics like the SOC dynamics, battery cycle life, thermal storage capacity utilization, and overall system efficiency. This analysis will help determine the viability and effectiveness of different storage strategies.

- *Economic and Environmental Impact:* A preliminary economic analysis will be conducted to assess the cost-effectiveness of each scenario. Additionally, the environmental impact will be evaluated, particularly the reduction in carbon dioxide emissions due to increased use of renewable energy and optimised demand shifting.

Sensitivity analysis and optimization

To ensure robustness and scalability, sensitivity analyses will be conducted on key parameters within the storage systems and demand profiles:

- *Storage Capacities:* The analysis will explore how varying the capacities of the electrical and thermal storage systems impacts the overall performance of demand shifting strategies. This will help identify the optimal storage sizes for different building types and usage patterns.

- *Control Strategies:* Different control strategies for managing the charge/discharge cycles of batteries and the timing of thermal energy storage will be tested to determine which strategies offer the best balance between energy savings, system efficiency, and operational flexibility.

The results from these sensitivity analyses will guide the optimisation of the demand shifting strategies, ensuring that they are tailored to the specific characteristics of the FRs and maximise both energy and cost savings.

Development of design and operational recommendations

Based on the simulation results and analyses, detailed design and operational guidelines will be developed for the implementation of demand shifting strategies in the FRs' building systems. These recommendations will include:

- *Optimal Sizing of Storage Systems:* Guidelines for determining the appropriate size of electrical and thermal storage systems based on the building's demand profile and PV production potential.

- *Operational Guidance:* Practical advice on how to operate the storage and demand shifting systems to achieve optimal performance, including strategies for system monitoring, maintenance, and adaptation to changing demand patterns.

These recommendations will be tailored to the specific needs and characteristics of each FR, providing actionable insights that can be directly implemented in the design and operation of their energy systems.

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3.2.1 Description of the energy storage solutions

In this section a more detailed definition of the electric storage solution is given for the pilots FR1 Austria, FR5 Italy and FR6 Spain.

Front Runner 1: Austrian pilot

The energy storage system at the pilot site consists of a 60 kW recycled battery currently under development. While the exact efficiency is still to be determined, this system is being designed to integrate seamlessly into the site's energy management strategy. In addition to the battery storage, the thermal storage system will consist of short-term buffer tanks due to space limitations. The proposed design includes five buffer tanks, each approximately 1 meter in diameter and 2 metres in height, with a combined storage capacity of around 5–6 kW. This capacity is based on a sensible temperature lift of 5 Kelvin degrees(°K), optimised for short-term heat storage.

The requirements of the *Austrian pilot* are presented below:

- The capacity of the battery will be 55-65 kW. The inverter model is not defined yet, but the power output will not be more than 30 kW.
- The charge profile must be determined/discussed with the Austrian partner but is expected to take a minimum of 4-6 hrs with around 12 kW charging power.
- High stress for the battery is expected for three hours a day where the battery is expected to go from full charge to discharge state. Expected SoC is, 90 % fully charged to 10% fully discharged.
- Thus, the expected discharging power is 15 to 20 kW.
- The exact configuration (high voltage low current or low voltage high current) is under examination and depends on the local regulation.
- The need of cooling/heating system is under investigation by the Austrian partner as it is not clear if the battery pack will be installed outside the building or not.

Front Runner 5: Italian Pilot

In Italian pilot site, INNOVA is considering having 16 thermal energy storage unit. The size of the unit is expected to be 60x60x200 square centimetres. The thermal energy storage unit will be based on PCM. The transition temperature around for the storage is expected to be at 48°C. The PCM type is still under consideration:

- Inorganic (hydrated salts), around 8/9 kW per module (128-144 kW)
- Organic (bio-based), around 6/7 kW per module (96-112 kW)

The requirements of the *Italian pilot* are presented below:

- The capacity of the battery will be 12 kW. The inverter model is not defined yet, but the power output will not be more than 6 kW.
- The charge profile must be determined/discussed with the Italian partner but is expected to take a minimum of 4-6 hrs with around 2.5 kW discharging power

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- The usage profile is not known for the moment and must be defined by the Italian partner.
- The exact configuration (high voltage low current or low voltage high current) is under examination and depends on the local regulation.
- The need of cooling/heating system should be defined by the Italian partner as it is not clear if the battery pack will be installed outside the building or not.

Front Runner 6: Spanish pilot

The Spanish pilot site will include a thermally activated foundation to store heat generate by the thermal PV that is not consumed instantly. The foundation will have 10 kW thermal exchange capacity. In addition to that there will be a water tank of 1000 litres capacity. The function of the water tank is to be the source of the dual-source heat pump when it is operating in water-to-water mode. The stored heat in the tank will come either directly from PVT or from the thermally activated foundation.

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4 KPI-driven assessment & LCA on building electrification & decarbonisation solutions

4.1 KPI-driven assessment

The approach taken is designed to establish a robust framework for assessing the performance of the META BUILD project across multiple dimensions, including energy, economic and environmental impacts. This involves a thorough definition of KPIs, the development of a consistent measurement strategy, and the identification of required data inputs to ensure that all relevant factors are considered in the evaluation.

A preliminary analysis was carried out to determine which KPIs are mandatory for each FR in a generic project framework. Within this process, the META BUILD objectives and expected outcomes have been reviewed and a FRs workshop will be performed to identify more specific targets.

Table 3 - Comprehensive Overview of KPIs for Energy, Economic, and Environmental Evaluation

Category	KPIs Description	Unit
Energy	Energy models of the META BUILD FRs, including the individual technologies (HP, PVT, storage, etc.) to be demonstrated	-
Energy	Total energy capacity of electric battery storage systems installed in FR buildings	kWh
Energy	Total power capacity of electric battery storage systems installed in FR buildings	kW
Energy	Thermal energy demand	kWh/m2/y
Energy	Electricity consumption	kWh/m2/y
Energy	Fossil fuel consumption	kWh/m2/y
Energy	Non-renewable primary energy use	kWh/m2/y
Energy	Electric and thermal RES contributions	%
Energy	Building electrification rate	%
Energy	Savings in non-renewable primary energy consumption	MWh
Energy	Ratio of renewable energy used to total consumption	%
Energy	Fraction of produced electricity that is self-consumed	%
Energy	Total energy savings by reducing grid consumption.	MWh
Energy	Amount of locally generated energy that is exported	MWh
Energy	Ratio of locally produced energy that is consumed on-site	%
Energy	Total installed capacity of renewable energy systems for thermal use	kW
Energy	PERT Primary energy renewable – total	MWh
Energy	PENRT Primary energy non-renewable - total	MWh
Economic	Energy bill [k€/y]	k€/y
Economic	Total annual costs required to operate the system	€
Economic	Total initial investment required for the project	€
Environmental	GHG emissions	kgCO2,eq/m2/y
Environmental	Global Warming Potential	kg CO_2 eq
Environmental	Ozone Depletion Potential	kg CFC-11 eq

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Category	KPIs Description	Unit
Environmental	Acidification Potential	kg SO_2 eq
Environmental	Eutrophication potential	kg PO_4^{3-} eq
Environmental	Photochemical Ozone Creation Potential	kg C_2H_4 eq

It is important to note that in Deliverable D5.1 – "Front Runners Report of Designing and Demonstration Activities" (5), additional KPIs have been selected to complement the KPIs outlined in this deliverable. These KPIs, identified in D5.1, will be analysed in parallel to provide a more comprehensive assessment of the project's outcomes and these KPIs will contribute to a deeper understanding of the effectiveness and scalability of the proposed solutions, facilitating informed decision-making as the project progresses.

4.2 Measurement and evaluation strategy

Based on Deliverable D5.1 – "Front Runners Report of Designing and Demonstration Activities", a measurement strategy and a monitoring process is proposed to assess and compare the performance of the FRs before and after the META BUILD implementation. The evaluation process is supposed to be partially based on a monitoring process considering energy consumption, indoor environment parameters and outdoor condition variables. The last two aspects are important mainly in terms of normalisation of the monitored variables. This evaluation strategy is just a general approach that will be further adapted to each FR in future works.

A general KPI calculation process and monitoring recommendations will be suggested to standardise the KPIs evaluation process in all FRs. All KPIs will be evaluated yearly for the whole building to validate the progress of the solutions implementation and compliance with the project objectives. However, it is commonly recommended to measure parameters in hourly basis with some zone disaggregation (e.g.: each floor, each thermal zone, etc.) to correctly evaluate the requested KPIs. This reaches further relevance in the case of energy savings.

To quantify the results of META BUILD solutions, the International Performance Measurement and Verification Protocol (IPMVP) endorsed by the Efficiency Valuation Organisation (EVO) could be used as a standardise reference. IPMVP provides best practice techniques for verifying energy efficiency, water efficiency, and renewable energy projects across various types of facilities (see Table 4). In cases where no baseline values are available (such as new constructions), Option D of IPMVP could be considered for generating baseline KPIs values.

Table 4 - IPMVP overview of M&V options.

IPMVP Options	Definition
Option A Retrofit Isolation: Key Parameter Measurement	**Savings determination:** • Field measurement of key parameter(s) related to energy consumption and demand • Baseline and reporting period energy based on measurement of key parameter(s) and/or estimated values. • Routine and non-routine adjustments required **Measurement frequency:** • Short-term or continuous • Depending on the expected variations in savings and length of reporting period

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IPMVP Options	Definition
	• Some estimations based on historical data, manufacturer specifications or engineering judgment. **Documentation or justification for estimated values:** • Required • Evaluation of saving error arising from estimation
Option B Retrofit Isolation: All Parameters Measurement	**Savings determination:** • Field measurement of energy consumption and demand • And/or related independent or proxy variables • Baseline and reporting period energy based on measurements of proxies of energy consumption and demand • Routines and non-routine adjustments required **Measurement frequency:** • Short-term to continuous • Depending on the expected variations in savings and length of reporting period
Option C Whole Facility	**Savings determination:** • Measurement of energy consumption and demand at the whole facility utility meter level • Continuous measurements of the entire facilities through the reporting period • Analysis of the whole facility baseline and reporting period • Routine adjustments as required (e.g.: simple comparison or regression analysis) • Non-routine adjustments as required
Option D Calibrated Simulation	**Savings determination:** • Simulation of the energy consumption and demand of the whole facility/sub-facility • Simulation routines are demonstrated to adequately model actual energy performance • Simulation outputs should be calibrated with hourly or monthly utility billing data • Energy end-use metering and metered performance data may be used in model refinement

4.3 Preliminary Outline of Required Variables and Data Needs

For each KPI, specific variables and data inputs are essential to ensure accurate monitoring and evaluation. A preliminary outline of the variables and data needs are mentioned in Table 5.

Table 5 - KPI required variables and data needs

Category	Variables and Data needs
Energy Models of META BUILD FRs	Building specifications, HVAC systems, installed renewable energy technologies, occupancy patterns
	Building design plans, energy system schematics, occupancy schedules, historical energy consumption data
Electric Battery Storage Systems (FRs)	Installed battery capacity, energy discharge profiles, seasonal variations in energy storage usage
	Battery system specifications, energy storage logs, discharge and charge cycles data

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Category	Variables and Data needs
Electric Battery Power Systems (FRs)	Installed battery power capacity, peak discharge rates, inverter efficiency
Electric Battery Power Systems (FRs)	Battery power specifications, inverter performance data, peak power output logs, system efficiency reports
Thermal Energy Demand (kWh/m²/y)	Indoor/outdoor temperature, insulation levels, heating/cooling system efficiency
Thermal Energy Demand (kWh/m²/y)	Temperature sensors, insulation quality reports, HVAC system performance data
Electricity Consumption (kWh/m²/y)	Electrical load profiles, peak demand times, appliance usage
Electricity Consumption (kWh/m²/y)	Smart meter data, appliance inventory, operational schedules
Fossil Fuel Consumption (kWh/m²/y)	Type of fuel, efficiency of combustion systems, seasonal fuel usage variations
Fossil Fuel Consumption (kWh/m²/y)	Fuel purchase records, system efficiency reports, weather data
Non-Renewable Primary Energy Use (kWh/m²/y)	Source of energy, energy mix, efficiency of energy conversion
Non-Renewable Primary Energy Use (kWh/m²/y)	Utility bills, energy source documentation, conversion efficiency data
Electric and Thermal RES Contributions (%)	Installed capacity of renewable systems, energy generation profiles, seasonal variations
Electric and Thermal RES Contributions (%)	Energy production logs, weather data, renewable system specifications
Building Electrification Rate (%)	Proportion of energy needs met by electricity, efficiency of electric systems, grid dependency
Building Electrification Rate (%)	Energy audits, grid connection reports, electric system performance data
Savings in Non-Renewable Energy Consumption (MWh)	Energy efficiency improvements, renewable integration, fossil fuel usage reduction
Savings in Non-Renewable Energy Consumption (MWh)	Pre- and post-installation energy audits, renewable energy generation records, fuel consumption reports
Ratio of Renewable Energy to Total Energy (%)	Total energy consumption, renewable energy generation, energy mix
Ratio of Renewable Energy to Total Energy (%)	Energy production logs, total energy consumption records, renewable energy system specifications
Fraction of Produced Electricity Self-Consumed (%)	On-site energy generation, energy storage capacity, grid export levels
Fraction of Produced Electricity Self-Consumed (%)	Solar/wind generation logs, storage system data, grid connection reports
Total Energy Savings by Reducing Grid Consumption (MWh)	Grid energy consumption, on-site energy generation, energy storage usage
Total Energy Savings by Reducing Grid Consumption (MWh)	Pre- and post-installation grid consumption data, renewable energy generation records, energy storage logs
Locally Generated Energy Exported (MWh)	On-site generation, local consumption, grid export capacity
Locally Generated Energy Exported (MWh)	Energy production logs, grid export records, local energy consumption data
Ratio of Locally Produced Energy Consumed On-Site (%)	On-site energy production, on-site energy consumption, energy export levels
Ratio of Locally Produced Energy Consumed On-Site (%)	Energy production logs, on-site consumption records, grid export data

Category	Variables and Data needs
Installed Capacity of Renewable Energy Systems for Thermal Use (kW)	Installed capacity of solar thermal, geothermal, biomass systems
	System specifications, installation reports, capacity testing data
PERT Primary energy renewable – total (MWh)	Total renewable energy generation, energy consumption
	Renewable energy production logs, total energy consumption records
PENRT Primary energy non-renewable – total (MWh)	Non-renewable energy consumption, efficiency of energy systems
	Utility bills, energy audits, non-renewable energy usage logs
Energy Bill (k€/y)	Energy consumption, utility rates, seasonal energy price variations
	Utility bills, energy consumption logs, historical energy pricing data
Total Annual Costs to Operate System (€)	Operational costs, maintenance costs, energy costs
	Operation and maintenance records, utility bills, system efficiency data
Initial Investment for the Project (€)	Capital expenditure, installation costs, equipment costs
	Financial reports, vendor contracts, installation invoices
GHG Emissions (kgCO_2 eq/m²/y)	Fuel types used, emission factors, energy consumption
	Emission factor databases, fuel consumption records, energy usage logs
Global Warming Potential (GWP) (kg CO_2 eq)	GHG emissions, energy consumption, carbon intensity of energy sources
	Emission factor databases, energy consumption logs, lifecycle analysis reports
Ozone Depletion Potential (ODP) (kg CFC-11 eq)	Use of refrigerants, leakage rates, lifecycle of equipment
	Refrigerant usage logs, maintenance records, equipment lifecycle analysis
Acidification Potential (AP) (kg SO_2 eq)	Emissions from energy production, fossil fuel consumption
	Emission factor databases, fuel consumption records, energy production logs
Eutrophication Potential (EP) (kg PO_4^{3-} eq)	Wastewater treatment processes, agricultural runoff
	Environmental impact assessments, wastewater treatment records, agricultural reports
Photochemical Ozone Creation Potential (POCP) (kg C_2H_4 eq)	VOC emissions, energy production processes
	Emission factor databases, energy production logs, environmental impact assessments

4.4 Life Cycle Assessment plan

The calculation of the environmental impact of a building (life cycle assessment) begins with the selection of the modelling method. Three methods are currently available in SIM-VICUS. The first method is the creation of a generic building. Here, modelling is based on a few building parameters. These are limited to the shape, number of storeys, dimensions of the floor area and the main use. All materials, templates and an ideal heating/cooling system are parametrised.

The second method is to model the building yourself step by step. This is the most time-consuming variant, as each zone is created individually, and the complete building is only created at the end. However, the user

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can give free rein to his creativity and test changes and variants at an early stage. Once the thermal zones have been modelled, the other parameters, such as materials, use and room conditioning, are assigned.

The last variant is based on the import of existing cubatures. IFC 2x3 and 4 are currently supported as formats, as well as the IDF file format from EnergyPlus (6) If already assigned, SIM-VICUS can take over already assigned designs and materials so that these work steps are no longer necessary. The detailed boundary conditions for zone use, i.e. presence, internal loads, etc., can currently only be parameterised retrospectively.

Regardless of the chosen method, it is essential in subsequent steps to link data from Environmental Product Declarations (EPDs). EPDs offer a standardised format for presenting the environmental impact of a product throughout its entire life cycle. They provide transparent and verified data on aspects such as raw material consumption, energy usage, emissions, and disposal. This information is crucial for architects, building owners, and planners to make informed decisions regarding sustainability. Consequently, the EPD format facilitates the comparability and ecological optimisation of products.

SIM-VICUS has an EPD interface and can therefore import EPD files at least from the German ÖKOBAUDAT database (7). This is a tested, standardised and rapidly growing database of the Federal Ministry of Housing, Urban Development and Building. This means that the building physics material parameters in the internal SIM-VICUS database can be combined with the data from an EPD. After assigning enriched data, selected modules of the Life Cycle Assessment (LCA) can be calculated in accordance with EN 15804 (8). Additional work steps are not necessary when parameterising designs; the assignment follows the previous design linking step.

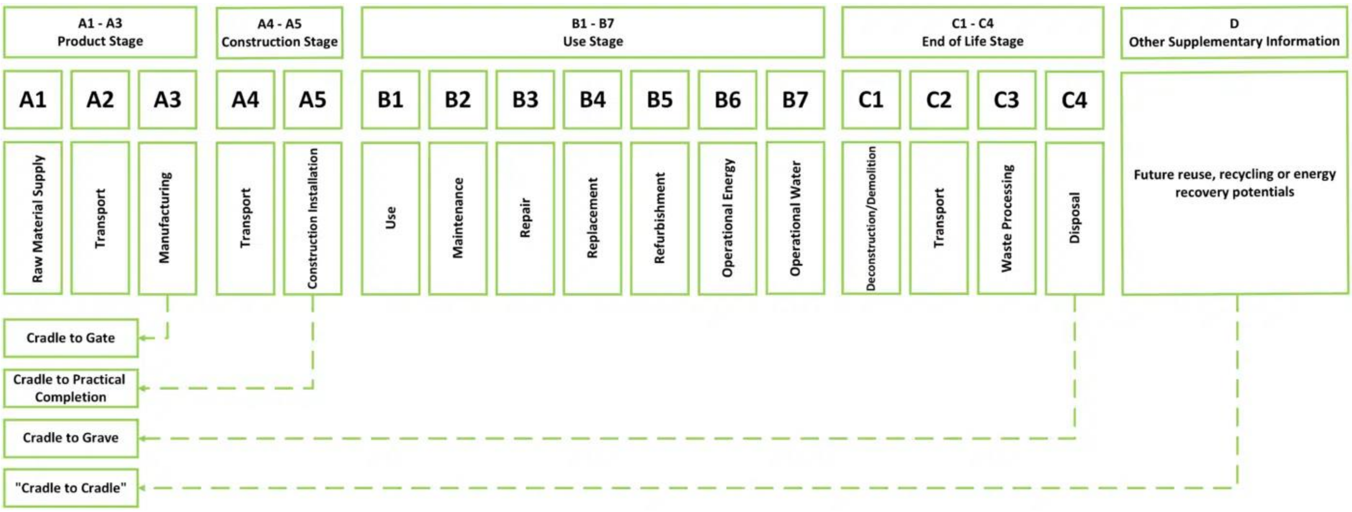

Figure 11 - Life cycle modules according to EN 15804 in SIM-VICUS. (Source: Circular ecology)

In Figure 11, the modules of the LCA are listed below, which can currently be taken into account by the LCA module in SIM-VICUS. Each module can be calculated individually, the results of which previously had to be transferred manually to a separate report.

- A1 Raw material supply,
- A2 Transport,
- A3 Manufacturing,
- B6 Operational Energy consumption,

- C3 Waste Processing,
- C4 Waste disposal, and
- D Potential for reuse, recovery and recycling

An overall report from SIM-VICUS is planned for further development steps and will only be available at a later stage of the research project.

	KPIs	KPIs Description	Gas	Coal	CHP	DHN	Other
Operational energy consumption	**PERT**	Primary energy renewable – total					
	PENRT	Primary energy non-renewable - total					
	GWP	Global Warming Potential					
	ODP	Ozone Depletion Potential					
	AP	Acidification Potential					
	EP	Eutrophication potential					
	POCP	Photochemical Ozone Creation Potential					

Figure 12 - Detailed calculations of environmental performance indicators of energy sources in SIM-VICUS

One advantage of Building Performance Simulation (BPS) is the calculation of energy requirements, which are also dependent on design decisions, usage and location. The factors of module B6 Operational energy consumption (included in Figure 12), can be calculated from the simulated energy requirements. Variant studies can be used to identify the building parameters that have the least impact. As already mentioned, an automated report is planned and will be available in the course of the project. As things stand at present, the calculated values are transferred manually. Depending on the energy source used in the building, the calculation of the values of module B6 changes.

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5 META BUILD integrated solutions

Within the META BUILD project, one of the key goals is to demonstrate innovative, flexible solutions for the electrification of thermal energy requirements in buildings, with the potential for extensive deployment across Europe. These solutions include state-of-the-art HP technologies, PVTs and storage able to operate within a common structure, thus reinforcing the decarbonisation of building thermal energy demand and improving energy efficiency of buildings.

In this section, the designed integrated solutions are being showcased, along with an explanation of the working principle and the data required for modelling each technology. Furthermore, "Decarbonisation as a service" is being introduced, an under-development recommendation engine which will be providing tailored guidance on integrating advanced energy-efficient technologies into existing building infrastructures. Lastly, the META BUILD FRs pilot description is represented, accompanied by the designs of the integrated solutions to be installed.

5.1 Conceptual design

In the following subsection, the preliminary design of integrated solutions for each FR will be outlined, which are a result of the combination of different technologies aimed at achieving energy efficiency, renewable energy integration, and sustainability. However, the final configuration is yet to be defined as the project is still in its early stages of development.

Final configuration, modelling approach and scenarios will be defined during project development to evaluate techno-economic parameters and environmental impact, as well as validating the dimensioning of the technologies to cover all the demand; these results will be reported on future versions of the deliverable D2.2 – "Enabling conditions & consolidation factors for building electrification. Final version". META BUILD project, due for August 2025 (2).

This approach enables iterative refinements in energy modelling and system design to ensure that the integrated solutions are adapted to the specific needs and operational challenges of each site.

MODELLING SOFTWARE & APPROACH

As described in section 1.1, the SIM-VICUS software will be utilised to evaluate the building energy demand, considering factors like building geometry, orientation, and climate. The next step of the assessment process will be to model the under evaluation integrated solutions and simulate their behaviour in the FR buildings.

For this exercise, a physics-based model will be developed using TRNSYS (4), which is a highly flexible and modular software designed to simulate the transient behaviour of energy systems, particularly those involving thermal, electrical, and renewable energy components. TRNSYS employs a component-based simulation approach, where systems are built by linking mathematical models, or "Types," that dynamically interact based on user-defined inputs. This allows for highly detailed and customisable simulations of complex energy systems. Each type represents a physical device, and users can adjust parameters such as efficiency, power output, or heat exchange rates, or upload real performance data files to reflect specific real technology characteristics. This ability to incorporate real operational data makes TRNSYS especially valuable for research and development (R&D) projects where validating technologies under realistic conditions is essential.

TRNSYS is widely used in R&D projects focused on energy efficiency, renewable energy integration, and building energy performance. Its flexibility and accuracy make it suitable for simulating systems such as HVAC, solar energy applications, and overall building energy use. The software supports simulations with time steps ranging from seconds to hours and enables the integration of real-world data, making it ideal for analysing both short-term and long-term performance of energy systems under varying environmental and operational conditions. Its extensive library of predefined components, such as pumps, heat exchangers, PV panels, and HVAC systems, can be further expanded by developing custom components, offering unparalleled versatility for detailed system-level analysis.

The final modelling approach is yet to be defined, some possible approaches would be to use simplified models for capacity definition of the individual technologies and to test their performance under different working conditions, another possibility would be to include some control strategies based on weather and thermal loads; or even fault detection analysis based on the technology performance or Coefficient of Performance (COP).

Final modelling approach and scenarios will be defined during project development to evaluate techno-economic parameters and environmental impact, as well as validating the dimensioning of the technologies to cover all the demand.

ASSUMPTION OF THE MODELS

Main assumptions that will be taken for the modelling process could be:

- *Occupancy patterns:* physics-based model will consider the variability of occupancy with a pre-defined schedule for working and non-working days.
- *Weather conditions:* simulations for this task will be carried out with the last annual weather file available from the nearest weather station.
- *Unknown constructive characteristics:* U-value and thickness will be defined for each building component, but if they are not available, reference values will be used based on typical national values.
- *Adjacent building:* the existing building will be simplified and modelled as a simple block. Boundary conditions will be defined based on normal building conditions (e.g.: 20ºC for winter season).

EXPECTED RESULTS OF THE SIMULATIONS

Expected results are the energy demand (heating rate, cooling rate, electricity rate of the different HVAC and lighting components of HVAC systems), indoor air temperature, relative humidity, etc.

Sub-hourly output data could be provided (minimum 15 min basis) and also aggregated data (daily, weekly, monthly, yearly etc).

The upcoming subsections will be organised as follows:

- Pilot Description
  - A brief overview of the pilot site.
  - Integrated Solution Components: This will describe the key features under study, identified by Use cases definition.
- Individual Technologies
  - General Working Principle of each technology
  - Data Requirements for Modelling: A breakdown of the input data needed to accurately simulate each technology's performance (e.g., efficiency metrics, operational data, weather inputs, etc.).

The abovementioned structure ensures a clear progression from the high-level overview of each pilot site to the in-depth analysis of the individual technologies involved. By following this format, each section will offer both a comprehensive understanding of the integrated solution and the specific technical details necessary for its implementation.

As the project progresses more detailed information will be available from the pilots, and the system design will have to be refined to meet the unique operational challenges of pilot site.

5.1.1 Brine-to-water HPs and second-life batteries

Technology description

The cold cycle (Figure 13) consists of a scroll compressor (M1), which is specialised for the HP, two plate heat exchangers (EP1, EP2), and an expansion valve (M80). The cold cycle is currently only designed for heating mode, as an active cooling mode is not required for the project. Passive cooling can be enabled by the hydronic cycle. However, other components are “ready for cooling”, like a bi-flow dryer (HQ1) and a bi-flow collector (CM1), so that only a 4-way valve would be needed to enable active cooling. The cold cycle as well as the hydronic connections are equipped with extensive pressure and temperature sensors for monitoring in operation.

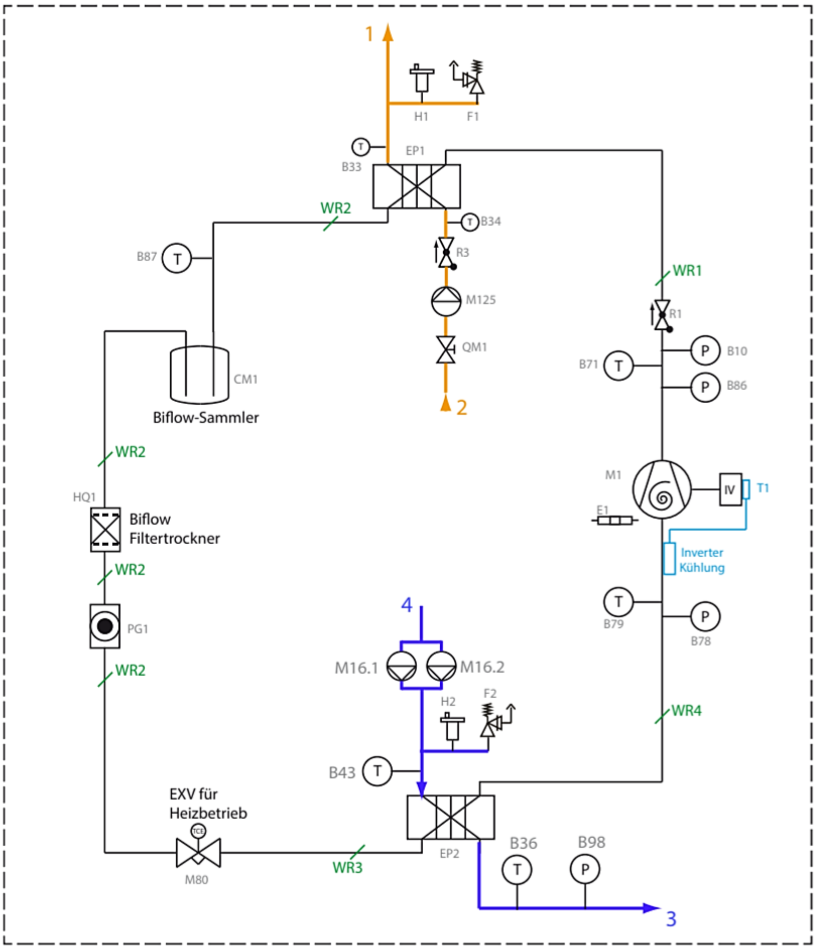

Figure 13 - R290 brine-to-water HP scheme

The heat pump is a novelty on the heat pump market, because no domestic heat pump of similar size and powered by a natural refrigerant has ever been brought to the market. The design of an environmentally friendly cold cycle using R290 (propane) as refrigerant was a complicated task, as there are currently only very few suitable components available and also the refrigerant, as being classified as highly flammable, needs some special considerations. Firstly, due to the required amount of charge for such powers, it is not allowed to place a heat pump like this inside a residential building without extensive and expensive safety measures. To avoid the costly safety measures, the IDM heat pump will be placed outdoor, which also has another advantage: In FR 1, where the heat pump, respectively several heat pumps, will be applied, there is only a small, very central cellar room available for technics. Placing the heat pumps there would mean to accept high distribution losses due to long distribution pipes in the heating network. A more efficient solution is to place several heat pumps in decentral places close to the heating sinks (dwellings) and distribute the source side. In FR 1, this option is currently evaluated (limiting might be the placement of buffer tanks).

R290, though being an efficient refrigerant with great properties, has not been used much in the past, because of its high flammability. This especially holds for bigger applications, which require tendentially high charges. Therefore, it was challenging to find components readily available, especially compressors. A comprehensive study of different suppliers showed that compressors in a size of up to 50kW are in the strategy of some suppliers, but none is readily available. Therefore, the current development focusses on the biggest readily available compressor size, which is around 35kW. Several of such compressors will be examined and the best will be chosen for the R290 brine-to-water heat pump. Other components were not that challenging to find, as the requirements for heat exchangers, expansion valves, etc., are not that specific for R290. The most important requirement, holding for all requirements in and around the cold cycle, is the absence of any ignition source (relays, mechanical switches, hot surfaces). This could be satisfied by all actuators, sensors and control hardware.

The Battery Energy Storage System (BESS) comprises a battery pack and an inverter. Depending on the specific requirements of the pilot partner, the deliverable may consist solely of the battery pack. The battery is constructed using second-life electric vehicle (EV) modules and a Battery Management System (BMS). To ensure consistency, modules of the same model will be utilised, with capacities ranging from 2 kWh to 7 kWh. These modules will be arranged in series and parallel configurations to meet the voltage specifications defined by the pilot partner and in compliance with local regulations. The BMS will monitor the voltage levels of the modules to ensure the safety of the battery system.

Due to the use of second-life EV modules, the power output of the battery will be limited to half of its total capacity. The modules are likely to use NMC chemistry (Nickel, Manganese, and Cobalt as cathode materials), although the use of LFP chemistry (Lithium, Iron, and Phosphate as cathode materials) is also a possibility.

State of development

The heat pump’s cold and hydronic cycles have been designed from a refrigeration technology point of view and also simulated in IMST-ART (9). The simulation results are not completely reliable, as the simulation must be calibrated from measurement values at the test bench, but they are promising. At a source temperature of 5 °C and a supply temperature of 45 °C, the heat pump should deliver 34.9 kW of heat at a coefficient of performance of 3.25. After the cold cycle design, a simple prototype construction has been set up. The prototype has been built and is at the moment of writing this report at the testbench.

Data needed for the modelling process

The data needed for modelling the heat pump (polynomials for heating power and electric power, parameters of the heat exchangers, control parameters, …) will be available as soon as the first tests on the test bench will be completed. The expected deadline at this stage of the project is December this year.

A preliminary data collection for the battery modelling tasks has been included into *Table 6* below, final values will be defined within the progress of the project.

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Table 6 - Data needed for the modelling work of Second life batteries

Data needed	Unit	Definition	Austrian pilot	Italian pilot
Energy storage capacity	kWh	The total amount of energy that the BESS can store	55-65	12
Extraction power rating (Pmax_in)	kW	The maximum amount of power that a BESS can store at any given moment (rate at which storage can be filled)	Around 12	Around 2.5
Charge duration	hours	The amount of time it takes to fully charge the battery from discharge state to full charge	4-6	4-6
Injection power rating (Pmax_out)	kW	The maximum amount of power that a BESS can deliver at any given moment (rate at which stored energy can be used)	15-20	<6
Discharge duration	hours	The amount of time it takes to fully discharge the battery from full charge to discharge state	3	n.d.
Expected SOC	%	Range of operative SoC of the BESS	10 to 90	n.d.
Input efficiency	%	The ratio of the energy stored in the battery to the amount of energy supplied (that accounts for energy losses during charging)	n.d.	n.d.
Output efficiency	%	The ratio of the energy delivered by the battery to the energy stored in the battery (that accounts for energy losses during discharging)	n.d.	n.d.
Loss rate	%/h	The % of the energy stored in the BESS that is lost each hour	n.d.	n.d.
Capacity-related CAPEX	M€	The capacity-related cost for purchasing, upgrading, or maintaining the BESS, that are proportional to the energy storage capacity	n.d.	n.d.
Power rating related CAPEX	M€	The power rating related cost for purchasing, upgrading, or maintaining the BESS, that are proportional to the power ratings	n.d.	n.d.
Annual OPEX	M€/year	The total annual cost required to operate the BESS (if possible, split the capacity-related annual OPEX and the power rating related annual OPEX)	n.d.	n.d.

5.1.2 District-heating connected HPs and Air-based PVTs

Technology description

This preliminary design specification outlines the first-of-its-kind implementation of high-capacity heat pumps (HPs) connected to a district heating system at the site of an existing 4.4 MW oil-fired boiler room in Velika Gorica. The current district heating system operates at a 90/60°C temperature regime, presenting a significant challenge for the heat pump design. To address this, CER, in cooperation with the district heating company HEPT, is developing an innovative solution capable of functioning within the existing temperature regime, while also being adaptable to potential future lower temperature regimes. The proposed nominal electrical capacity for the system is 1.5 MW.

However, as this is an early-stage design, no further detailed parameters or data can be provided at this time, as the team is still analysing the pilot's specific demands, needs, and the district heating system's temperature and operating regime.

The air-based solar photovoltaic-thermal panels (PVT-a) combine the solar PV and solar thermal technologies in a single panel to generate electricity and thermal energy simultaneously, using air as the heat transfer fluid (HTF). This system allows maximising the energy generated per unit of surface area, while improving PV performance thanks to the cooling effect (10) (11).

Compared to water, air as a HTF reduces the complexity and costs associated with PVT installations, making possible the implementation of systems where air can be used directly or indirectly, for different applications such as ventilation, heating and drying (12). *Figure 14* shows the basic concept of the ENDEF's air-based

PVT panel. It has a frontal PV layer or PV laminate, a rear air chamber, a back insulation and a closing back sheet. Using a fan, the inlet air circulates through this rear chamber, getting temperature thanks to the incident solar irradiance and the heat generated on the back side of the PV layer. The heated air is finally sent to the system demand, while at the same time, electricity is also produced through the PV-laminate.

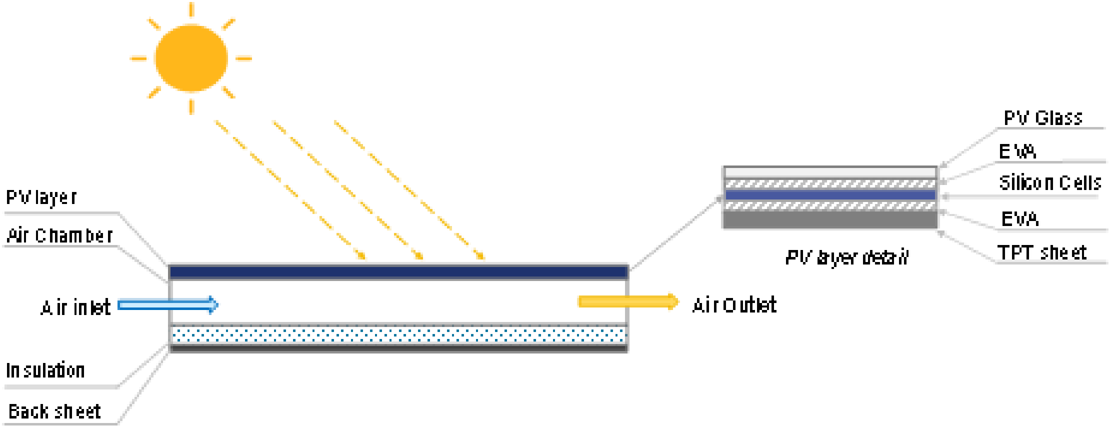

Figure 14 - Air-based PVT concept (Source: ENDEF)

Figure 15 - Implementation of an air-based PVT by ENDEF in a demonstrator in a previous project (Source: ENDEF)

Currently, ENDEF has an air-based PVT panel, whose absorber component is based on a new design, protected by the patent EP 3 809 591 A1. This first air-based PVT panel developed by ENDEF has undergone validation in relevant environments at two demonstration sites, with performance results recently published in a scientific journal (13).

ENDEF will redesign the PVT panel, to standardise their installation for different roof types while the energy production will be also optimised. The redesign concept is focused on two configurations: a system for flat roofs and a system for tilted roofs. For each configuration, a new PV laminate will be chosen to fit the final design (whether frameless or not, glass-glass, with back sheet, etc.), and the thermal absorber will be adjusted considering the specific restrictions linked to these configurations and the materials. *Figure 16* shows the current configuration used by ENDEF for flat roofs, in which the system has five air-based PVT panels, with two lateral inlets and a central outlet, following the air path shown in the figure.

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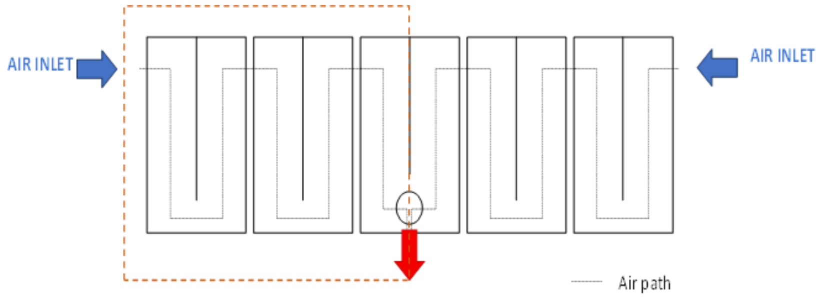

Figure 16 - PVT-air path in a bench with five air-based PVT panels

The re-design process is now being performed within METABUILD. After the redesign process, an air-based PVT prototype will be manufactured to carry out base energy test in ENDEF facilities, following the procedures described in the ISO 9806-2017 norm (14).

These testing results will be used to validate the ENDEF's internal software tool considering the redesigned PVT-a systems. After the validation, a set of simulations will be performed by ENDEF to obtain the PVT-a performance curves for different mass flow rates through the solar system and environmental variables (solar irradiance and wind velocity). *Figure 17* shows an example of the performance curves (electrical efficiency in red and thermal efficiency in orange), for a PVT-a prototype, developed by ENDEF in a previous project.

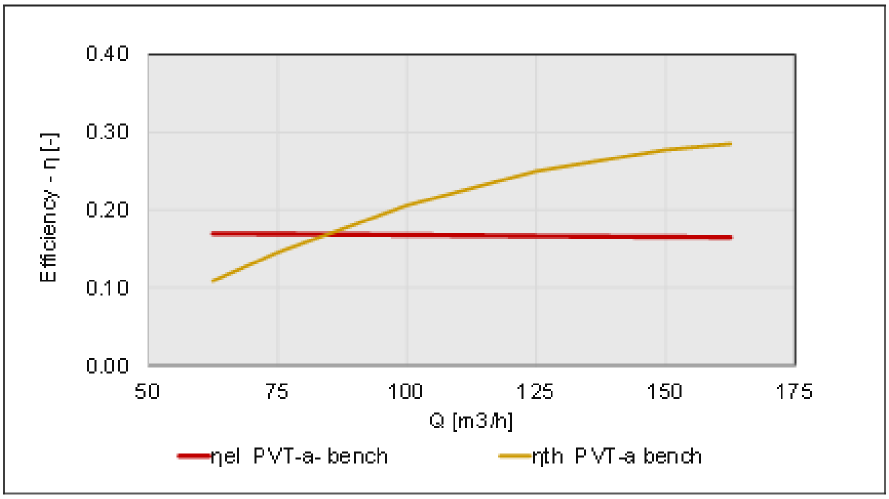

Figure 17 - Performance curves for a PVT-a prototype, developed by ENDEF in a previous project

Modelling approach

The PVT-a performance curves can be used as approach, to implement in TRNSYS a PVT-a component based on a performance map. The component can incorporate as inputs different variables such as solar irradiance, wind velocity, ambient temperature, and air-inlet temperature. As output can be calculated the outlet air temperature and the energy production (electrical and thermal). The details of the procedure to be applied will be studied and in the simulations in cooperation with the technology provider (ENDEF).

Finally, the implemented TRNSYS component could be incorporated to the overall energy system model to analyse the combination or integration of the air-based PVT panels with other HVAC technologies such as an air-source heat pump and ventilation systems.

Data needed for the modelling process

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The data required for the modelling of HPs will be comparable to that outlined in *Table* 8, from Speed controlled/inverter-driven HP developed by ARCELIK.

A template for data collection for air-based PVT modelling tasks has been included into Table 7 below, final values will be defined within the progress of the project.

Table 7 - Data needed for the modelling work of Air based PVTs

Data type	Definition	Unit
Thermal surface capacity	The amount of thermal energy (heat) that can be generated per unit area of the PVT panel	W/m²
PV surface capacity	The amount of electrical power generated per unit area of the PVT panel	W/m²
PVT surface	Total surface of the installed PVT panels	m²
Slope of the roof	The angle between the roof surface and the horizontal plane	°
Azimuth	The angle between the true north and the PVT location	°
Latitude	Angular distance from the PVT location to the equator (to specify the north-south position of the PVT location on the Earth's surface)	°
Longitude	Angular distance from the PVT location to prime meridian, east or west (to specify the east-west position of the PVT location on the Earth's surface)	°
Solar/electrical efficiency	The ratio of electrical energy generated by the PV component of the system to the total solar energy incident on the surface of the PVT panel	%
Solar/heat efficiency	The ratio of thermal energy (heat) generated by the thermal component of the system to the total solar energy incident on the surface of the PVT panel	%
Solar irradiance	The power per unit area received from the Sun in the form of electromagnetic radiation, measured on a surface perpendicular to the Sun's rays	W/m²
Wind speed	The speed of the wind	m/s
Wind direction	The direction from which the wind is coming, measured in degrees from true north	°
Ambient temperature	Temperature of the ambient air	°C
Air-inlet temperature	Temperature of the inlet air that comes in and circulate through the rear chamber	°C
CAPEX	The total cost for purchasing, upgrading, or maintaining the heat storage	M€
Annual OPEX	The total annual cost required to operate the heat storage system	M€/year

5.1.3 MW-size reversible HP systems

Technology description

This preliminary design specification outlines the heating and cooling solution under development by EDF, which will rely on a MW-size reversible heat pump (HP) system based on a cascade of commercial water-to-water heat pumps. The system will utilise HPs capable of accepting high-temperature heat (up to 50°C) at the evaporator, allowing for flexibility in the range of heat sources that can be used. One potential source will be air gathered through a remote air-to-water heat exchanger, which will feed the HPs' evaporator. Additionally, the use of low-temperature district heating as a heat source for the HPs' evaporator is being considered and will be assessed for potential future operation scenarios.

At this stage, it is important to note that detailed parameters and data cannot yet be provided, as the design is still in its preliminary phase. The project team is currently analysing the pilot's specific demands and needs, as well as the district heating network's temperature and working regime. These factors will be critical in

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determining the final specifications of the system, including its operational scenarios and the feasibility of integrating different heat sources.

Modelling approach

The data required for the modelling will be comparable to that outlined in *Table* 8, from Speed controlled/inverter-driven HP developed by ARCELIK.

5.1.4 Speed controlled/inverter-driven HPs

Technology description

The AWHP product can be examined in two cycles, the refrigerant line (A) and the water line (B), in heating and cooling modes. As depicted on the *Figure 18* below.

The refrigerant line (A) and all components on this line are called the external unit of the product and are placed outside. While the water line (B) and all components on this line are called the hydro unit or internal unit and are placed inside the house on the installation line. The critical component where the refrigerant and water transfer heat to each other in heating and cooling modes is the plate heat exchanger (7) in the external unit.

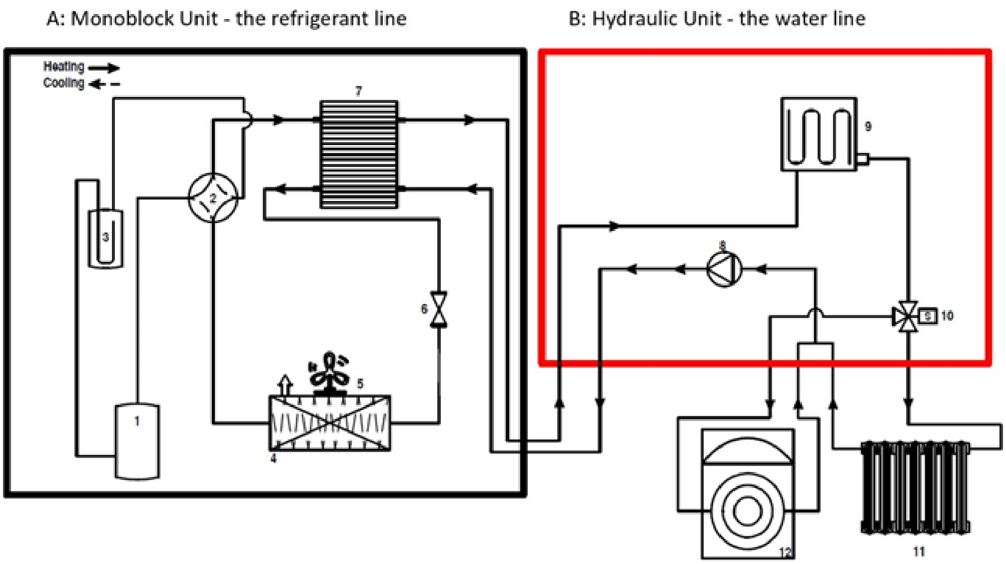

Figure 18 - Speed controlled/inverter-driven HP scheme

NO	COMPONENT
1	COMPRESSOR
2	4 WAY VALVE
3	GAS-LIQUID RECEIVER (ACCUMULATOR)
4	FIN AND TUBE HEAT EXCHANGER
5	FAN
6	ELECTRONIC EXPANSION VALVE
7	PLATE HEAT EXCHANGER
8	WATER PUMP
9	HEATER
10	3-WAY VALVE
11	RADIATOR
12	WATER TANK

Figure 19 - Speed controlled/inverter-driven HP component list

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- **AWHP- Working Principle in heating mode**

When the product is in *heating mode*, in the *refrigerant line*; the refrigerant that comes out of the compressor (1) in the gas phase and is compressed at high temperature is sent to the plate exchanger (7) with the four-way valve (2) and heat transfer is carried out between them and the water. The refrigerant at high temperature and pressure transfers heat energy to the water, thus the refrigerant changes phase and condenses and the water is heated. The pressure and temperature of the refrigerant that comes out of the plate exchanger (7) in liquid form is reduced with electronic expansion valve or eev (6). Then, the refrigerant at low temperature and pressure is passed over the finned-tube exchanger (4) with the help of the fan (5) to provide heat transfer and the refrigerant is completely vaporised. The refrigerant that comes out of the finned-tube exchanger (4) passes through the four-way valve (2) again and is sent to the compressor after the battery- accumulator (3). Thus, the refrigerant cycle is completed in heating mode.

When the product is in *heating mode,* in the *water line;* the water that comes out of the plate exchanger after being heated is sent to the indoor unit (B) with the help of the water pump (8). Here, the water leaving the plate heat exchanger (7) passes through the backup heater (9) which is activated according to the heating capacity requirement. The backup heater (9) does not operate continuously but is activated when high capacity is needed at very low ambient temperatures. The hot water leaving the heater goes to the three-way valve (10). According to the information received from the temperature sensor of the water tank (12), the water is directed either to the water tank (12) or to the fan coil (11). While the hot water in the water tank (12) is used as domestic water, the water going to the fan coil (11) is used for ambient heating. There is a serpentine inside the water tank (12) here and it is a closed cycle. The water leaving the fan coil (11) and the water tank (12) is sent back to the plate heat exchanger (7) by the pump (8) and the cycle is completed.

- **AWHP- Working Principle in cooling mode**

When the product is switched to *cooling mode*, the four-way valve (2) changes direction. While the product is in cooling mode, the high-pressure hot *refrigerant* in the gas phase coming out of the compressor (1) is sent to the finned-tube heat exchanger (4) instead of the plate heat exchanger (7) as a result of the change of direction of the four-way valve (2) in the refrigerant line. The outside air is passed over the heat exchanger (4) with the fan (5) to provide heat transfer between the refrigerant and the air. Then the refrigerant goes to the liquid tank. The liquid first passes through the eev (6) and its pressure is reduced, then it evaporates by using the heat in the water by transferring heat to the water in the plate heat exchanger (7).

While the product is in *cooling mode*, in the *water line*; The water that transfers its heat to the refrigerant cools down. The cooled water first goes to the backup heater (9). Since the system is in cooling mode, the heater (9) does not work. The three-way valve (10), which allows the water to be directed to the water tank (12) or fan coils (11), moves to the position that will direct the water directly to the fan coil (11) since the system is in cooling mode. In cooling mode, cold water is used only for ambient cooling. The system automatically switches itself to heating mode according to the temperature sensor in the water tank (12). The reason for this is that the domestic water is desired to be hot. When the water temperature drops below a certain value, the system switches to heating mode and the three-way valve (10) directs the water to the tank (12). From here, it is sent to the plate heat exchanger (7) again with the pump (8) and completes the cycle.

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Data needed for the modelling process

Table 8 - Data needed for the modelling work of Speed controlled/inverter-driven HP

Data needed	Definition	Unit
Heating demand	Heating demand time series for the building(s) of the FR	MWh.th
Heat source temperature	Temperature time series of the medium from which the HP extracts heat	°C
Bivalent temperature	The outdoor temperature at which the HP 's output (the HP nominal capacity) is exactly equal to the heating demand of the building(s). Below this temperature, a backup heating system is required to maintain the desired indoor temperature.	°C
Capacity of the HP	Nominal capacity of the HP	MW.th
COP	The ratio of the useful heating or cooling provided by the HP to the electrical energy consumed to operate it, that depends on the outdoor temperature	MW.th / MW.el as a function of °C
Backup heater efficiency	The ratio of useful heat output to the total energy input for a backup heating system.	%
Type of backup heater	Electric or gas backup	-
CAPEX	The total cost for purchasing, upgrading, or maintaining the HP	M€
Annual OPEX	The total annual cost required to operate the HP	M€/year

5.1.5 HP monobloc unit and RES integration

Technology description

Monobloc HP R290, with reversible cycle for winter heating, domestic hot water production, and summer air conditioning, offering high performance, elegant design, and minimal footprint for its category.

At this stage of development, detailed schematics are not being shared by the technology providers to protect proprietary information and ongoing improvements. Therefore, this subchapter includes only the plant functions and general features.

General features

- Heating/cooling HP control with full power modulation over the working range
- Inverter control for BLDC compressors (R410a/R32/R290)
  - 230 VAC single phase up to 5 kW electrical input
  - 400 VAC three phase up to 8 kW electrical input
- Two/four control outputs for 310 VDC modulating fans and pumps
- EEV control (with custom advanced control algorithms)
- Silent (reduced noise/power) mode
- Exchanger water flow control + exchanged power measurement feature

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Data needed for the modelling process

Table 9 - Data needed for the modelling process of Monobloc HP R290

Technology parameters	List of variables of the model
Cycle temperatures, on air and water	Compressor variable speed
Water flow and pressure	Fan variable speed
Compressor Suction pressure	Pump variable speed
Actual head (inlet-outlet differential pressure)	Electronic expansion valve
Electric power input	Back up heater (staged)
Thermal Power at condenser and evaporator	
Thermal power on water (including aux. electrical heaters)	
Instant COP	

5.1.6 Dual source HP and PVTs

Technology description

The new thermal installation is composed of a dual source HP of 10KW (DSHP developed by TECNALIA), a hybrid solar installation of approximately 24 PVT panels and thermal activation of the concrete wall. This new thermal system will be connected to the current thermal installation (300kW biomass boiler) and will be able to partially supply the heating demand for the extension of the laboratory. As shown in Figure 20, in addition to the thermal equipment, the installation consists of two thermal accumulators, a primary thermal store for the solar installation and geothermal exchange system, and a second accumulator in the secondary circuit to ensure the proper operation of the dual source HP.

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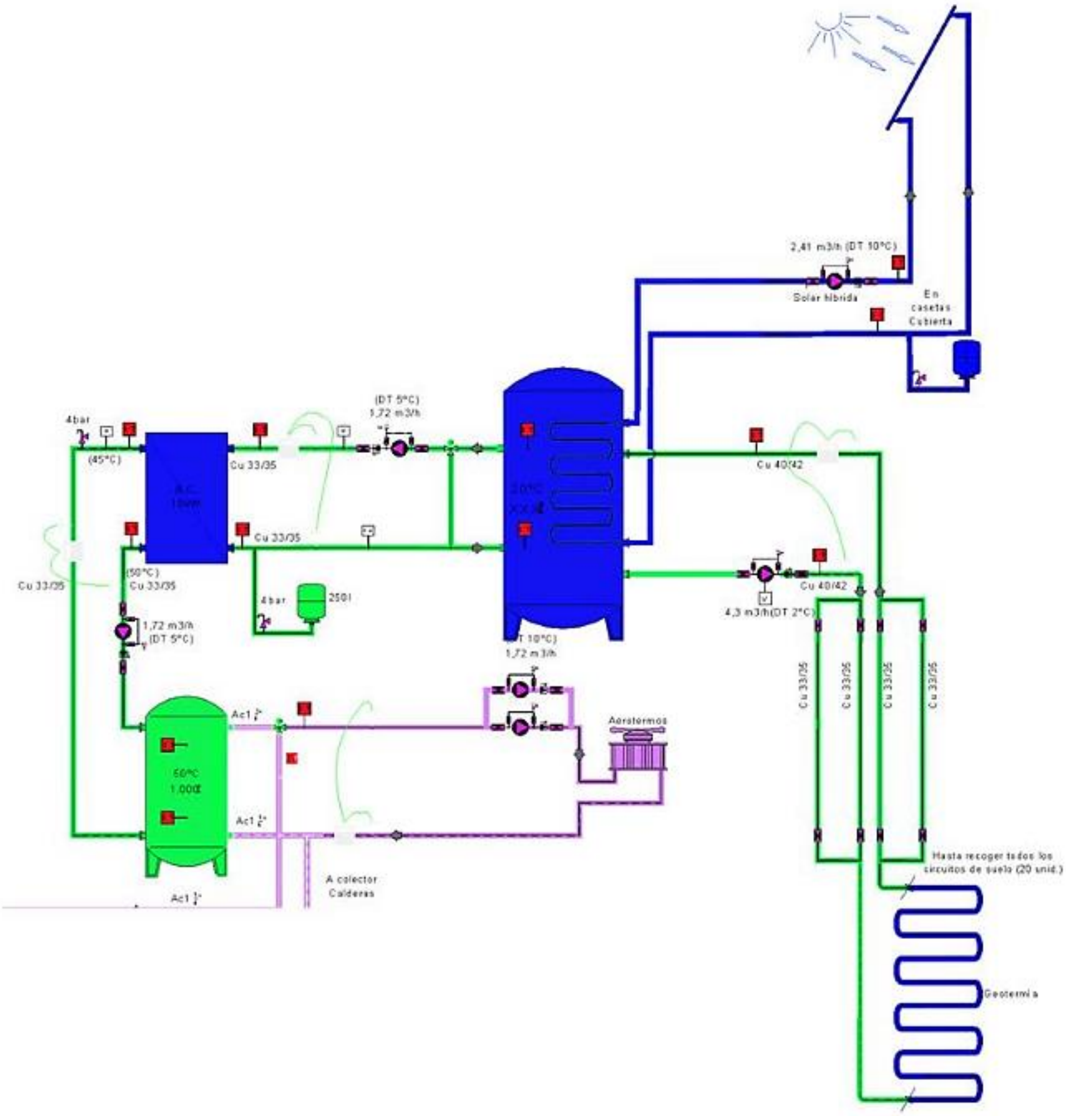

Figure 20 - Thermal energy system model

Modelling approach

A physics-based model (white-box model) will be developed on this task in order to simulate energy demand of the building. In future work, a simplified RC model (grey-box model) is planned to be developed for optimised dynamic control strategies implementation. Architectural and engineering data of the new extension will be gathered and processed by TECNALIA. This information is used to construct a transient energy model of the building in EnergyPlus v9.4 (6). The model represents main aspects affecting the building performance such as Indoor Air Quality (IAQ) parameters (temperature, CO2, humidity, etc.), the external weather conditions, the thermo-physical characteristics of the envelope, the occupancy patterns, the energy transformation, transmission, and emission components, and the HVAC systems and their operation.

The modelling will be carried out using the Transient System Simulation Tool (TRNSYS) (4). TRNSYS is an extremely flexible graphically based software environment used to simulate the behaviour of transient systems. These simulations will be focused on assessing the performance of thermal energy systems and they will be dynamic simulations. The model of the DSHP will be based on experimental test results which feed the performance map. However, the models of PVT panels and geothermal exchange system will be based on theoretical values. Once the installation is running and we obtain real data the model will be adjusted.

Expected results of the simulations

The expected results of the simulation for a hybrid PVT system combined with a HP include key performance indicators such as the Dual Source Heat Pump (DSHP) COP and the Seasonal Coefficient of Performance (SCOP). Additionally, the simulation will provide detailed data on both the electrical and thermal production of the PVT system, allowing for a comprehensive assessment of its energy contribution. System efficiency metrics will also be evaluated, encompassing the overall effectiveness of energy conversion and utilisation. These results will be instrumental in analysing the performance and feasibility of integrating hybrid PVT systems with HPs for optimised energy generation and utilisation.

5.2 Optimised design of integrated heating & cooling technologies as a service

Decarbonisation refers to the process of reducing or eliminating carbon dioxide emissions (CO2) into the atmosphere, primarily resulting from human activities such as the combustion of fossil fuels for energy production, transportation, and industrial processes. The overarching goal of decarbonisation is to mitigate the effects of climate change by transitioning to a low-carbon economy. Achieving this requires significant shifts in energy consumption patterns and production methods, with a central focus on transitioning from fossil fuels to RES. In the context of buildings, which account for a substantial portion of global energy consumption, decarbonisation efforts can be realised through the electrification of thermal demands. Components that contribute to this electrification include advanced technologies like HPs and PVTs, which convert renewable energy into usable heating and cooling for buildings.

As part of a comprehensive strategy to decarbonise the built environment, META BUILD project aims to develop a cutting-edge decarbonisation recommendation engine designed to assist building stakeholders - such as owners, managers, and policymakers - in optimising decarbonisation efforts within the built environment. The recommendation engine plays a pivotal role in this transition by providing tailored guidance on integrating advanced energy-efficient technologies into existing building infrastructures, helping to significantly reduce energy consumption and carbon emissions. This tool not only supports the implementation of RES, but also integrates modern heating and cooling solutions, DR mechanisms, and smart building technologies.

5.2.1 Key Objectives and Functionality of “Decarbonisation as a service”

At its core, the recommendation engine is designed to identify the most suitable high-decarbonisation technologies for individual buildings, factoring in a wide range of variables such as building type, geographical location, energy systems, and existing infrastructure. The central objective is to assist users in making informed decisions about reducing energy consumption and CO2 emissions. By analysing data related to both the physical and operational characteristics of buildings, the engine helps optimise the integration of RES, including solar, wind, and geothermal energy, alongside efficient energy storage and smart grid interaction.

The tool’s primary focus is on electrifying thermal demands in buildings, replacing carbon-heavy fossil fuel systems with renewable energy technologies. This can be achieved through the integration of advanced technologies such as HPs, solar thermal systems, energy-efficient HVAC systems, and PVT systems, all of which can convert renewable energy into usable heating and cooling solutions. These technologies form the backbone of the decarbonisation process, enabling significant reductions in CO2 emissions while ensuring high energy efficiency and comfort for occupants.

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5.2.2 Two-Stage Process of the Recommendation Engine

The tool is designed to operate through a structured two-stage process, ensuring comprehensive analysis and effective decarbonisation strategies, as depicted in Figure 21.

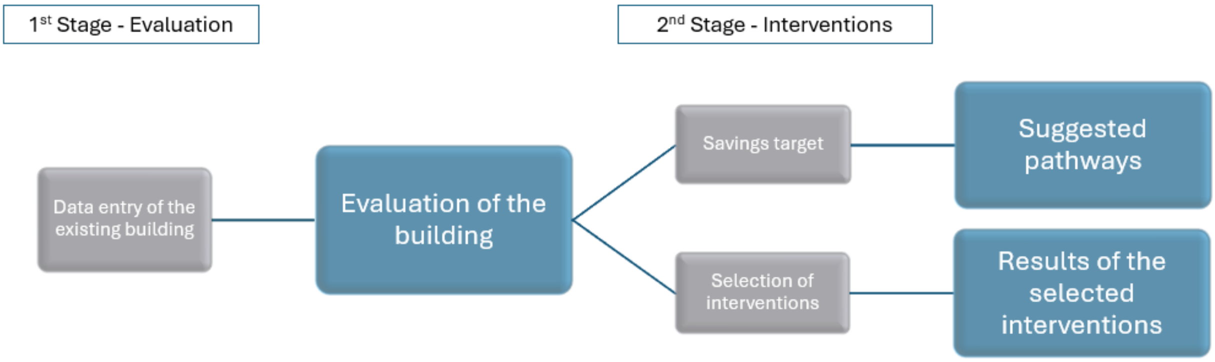

Figure 21 - The operation stages of the decarbonisation tool

Building Evaluation Stage

The first stage of the tool focuses on evaluating the current state of the building. This is accomplished through a form-based assessment, where users input key data related to the building's characteristics. The form collects a range of demographic and operational data, including the building's type, geographical location, floor number, age of the tenants, heating and cooling systems in place, Smart Readiness Indicator (SRI) level, and other relevant factors.

Once this information is gathered, the tool conducts an in-depth analysis of the building's current energy performance. This includes calculating the energy efficiency of the building, evaluating its existing energy consumption patterns, and determining the volume of CO2 emissions produced. This assessment provides users with a clear understanding of the building's current carbon footprint and energy usage profile, offering insight into areas where energy improvements can be made. The results of this stage serve as the foundation for moving forward with decarbonisation interventions.

Intervention and Strategy Development Stage

After the building's current performance has been evaluated, users can proceed to the second stage, which focuses on implementing decarbonisation measures. This stage allows users to approach decarbonisation in two distinct ways:

- *Savings Goal Mode:* In this mode, users can set a specific energy savings or carbon reduction target. Based on this goal, the tool will generate and suggest a set of optimal strategies, or pathways, that combine different technologies and interventions to achieve the target. The pathways are designed to integrate multiple decarbonisation solutions, including RES, energy-efficient systems, and DR mechanisms, to maximise the building's energy performance while minimising carbon output.
- *Intervention and Technology Selection Mode:* Alternatively, users can choose specific technologies or interventions they wish to implement. For instance, they may opt to install HPs, upgrade HVAC systems, or integrate solar panels for on-site renewable energy production. The tool will then evaluate the outcomes of these selected interventions, analysing their impact on energy consumption, cost,

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and environmental performance. This mode provides flexibility for users who may already have a preferred technology in mind but wish to understand its broader implications.

5.2.3 Integration with META BUILD Project and Front Runner Buildings

The recommendation engine is deeply integrated with the META BUILD project, which focuses on real-world decarbonisation efforts in the 6 FR buildings. These buildings serve as testing grounds for the proposed technologies and interventions, providing valuable data and insights into the effectiveness of different decarbonisation strategies. The interventions and technologies suggested by the engine are those being piloted in these FR buildings. During the early stages of the tool's development, information on these interventions will be sourced from academic literature and best practices in the field. As the project progresses, real-world data from the FR buildings will enhance the tool's accuracy and reliability, ensuring that the recommendations it provides are grounded in practical results and field-tested scenarios.

Additionally, Replicators will be involved in testing and implementing decarbonisation strategies in different buildings and contexts, further refining the pathways suggested by the tool.

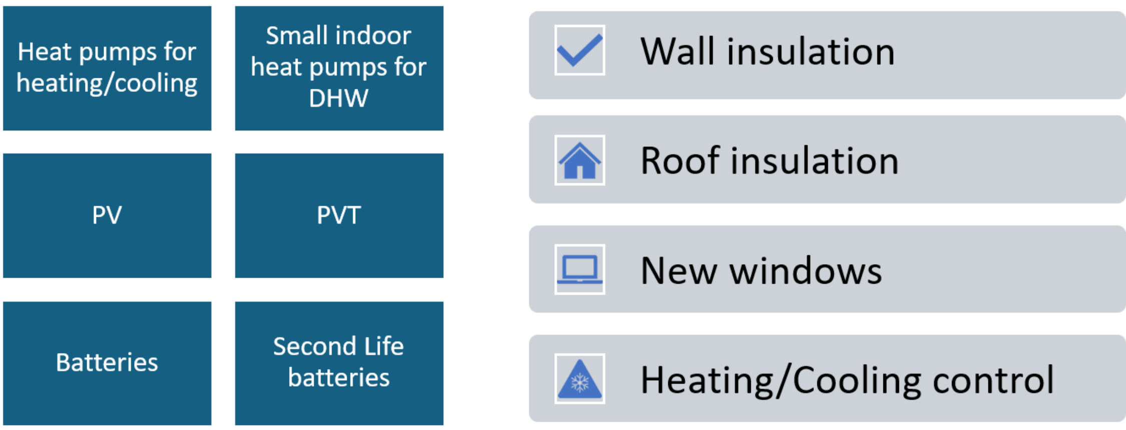

Figure 22 - Proposed technologies and interventions

Pathways and Graphical Analysis for Decision Support

One of the tool's most advanced features is the ability to generate strategic pathways, which are comprehensive combinations of multiple technologies and interventions that together form a holistic decarbonisation plan. These pathways are produced by analysing the results obtained from the FR buildings and Replicators, allowing the tool to suggest the most effective combinations of interventions based on real-world performance data.

To assist users in making informed decisions, the recommendation engine will also provide graphical comparisons of different pathways. These graphs will display key metrics, including:

- *Energy Savings:* The projected reduction in energy consumption achieved by each pathway.
- *CO2 Reduction:* The amount of carbon emissions that can be reduced by adopting a particular pathway.
- *Cost:* Both upfront investment costs and long-term operational costs associated with the technologies involved.
- *Payback Period:* The estimated time required for the user to recover their investment through energy savings and other financial benefits.

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These graphical insights will enable users to compare various strategies side by side, making it easier to select the most suitable pathway that aligns with their financial capacity, energy savings targets, and environmental goals.

Multi-Criteria Evaluation Framework

To ensure the recommendations are well-rounded and practical, the tool employs a multi-criteria evaluation framework. This framework takes into account several critical factors:

- *Energy Efficiency:* The tool prioritises systems and interventions that use minimal energy while maintaining high performance.
- *Cost-Effectiveness:* Recommendations are evaluated based on both upfront costs (installation, equipment) and long-term costs (maintenance, energy savings), ensuring that the financial implications are considered.
- *Environmental Impact:* Reducing carbon emissions and minimising the building's overall ecological footprint are central to the decision-making process.
- *User Comfort:* Ensuring that building occupants enjoy consistent and reliable heating, cooling, and ventilation is a top priority, especially when transitioning to new energy systems.

5.2.4 Continuous Improvement and Long-Term Impact and Benefits

As the META BUILD project evolves, real-time data from the FRs and Replicators will continuously feed back into the recommendation engine, improving the accuracy and relevance of its recommendations. This ongoing process ensures that the tool remains adaptable to changing technologies, evolving energy standards, and the latest insights from the field. By offering a comprehensive, data-driven approach to building decarbonisation, the recommendation engine ensures that users are equipped with the knowledge and tools necessary to make significant improvements in energy efficiency and carbon reduction. It bridges the gap between technical know-how, economic feasibility, and environmental responsibility, ensuring that decarbonisation efforts are both impactful and sustainable over the long term.

In summary, the recommendation engine is a powerful, adaptable tool that will have a lasting impact on the decarbonisation of buildings. Through its two-stage approach, integration with real-world projects, and detailed analysis of pathways, it provides a comprehensive solution for tackling the energy challenges of the future while ensuring financial and environmental sustainability.

5.3 Integrated solutions in real-life applications

Following the conceptual design of the integrated solutions outlined in section 5.1, this section presents the pilot sites where these solutions will be implemented and tested. The selected pilot sites represent a diverse range of building types, climates, and energy systems, providing a robust testing ground for the practical application of the proposed technologies. By applying the integrated solutions in real-world conditions across multiple sites, the project aims to validate their effectiveness, adaptability, and scalability. The results from these pilots will offer critical insights into how the conceptual designs perform in practice, informing future refinements and broader applications.

5.3.1 Austria

This project will extensively retrofit a Central-European residential building from 1983, with 58 apartments and a net heat area of 7015 m². The renovation aims to significantly reduce energy demand and carbon emissions by replacing gas combi boilers with R290 brine-to-water (HPs), which will be medium-sized (50kW) outdoor monobloc units combined with geothermal systems.

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The assets supporting these future installations will include PV systems with a capacity of 155 kWp, Storage systems, including second-life batteries, will also be implemented to enhance and help optimise load management providing 60 kWh of storage, and thermal storage systems with a capacity of 35 kWh. Energy Management Systems (EMS) will oversee and optimise the operation of these assets, while other RES will be explored to further diversify the energy mix and improve sustainability.

Front Runner 1
Location: Vienna (Austria)
Building: Multi-family Residential
Phase: Renovation
System configuration:
- **TE-1** R290 Brine-to-water HP
- **PV**
- **TE-9** Second life batteries
- Thermal storage

Figure 23 - Integrated Solution Overview, Front Runner 1[1]

5.3.2 Croatia

Pilot 2 involves the renovation of six residential buildings in Velika Gorica, Croatia, originally constructed in 1974. These buildings span 6,310 square metres and house 130 apartments. The primary focus of the renovation is to improve energy efficiency by insulating the buildings' external envelopes. Currently, the buildings rely on a district heating system for space heating and hot water, with local electricity powering the cooling systems. However, they do not yet incorporate renewable energy systems. The retrofitting project includes replacing the existing 4.4 MW oil-fired boiler with district-heating-connected and new natural gas boilers.

Figure 24 - Front Runner 2: Residential building in Velika Gorica, Croatia

As part of the retrofitting, the integration of new technologies will include district-heating-connected HPs with a planned capacity of 1.5 MW, replacing the current oil-fired system. An Energy Management System (EMS) will be installed at the boiler room level, with smart metres and sensory equipment to monitor and optimise

[1] Icons design based on LocalRES project Use cases definition (15), applied in all figures in this section.

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energy usage in real-time. Additional improvements include upgrades to thermal insulation, windows, and ventilation systems. The installation of hybrid PVT panels for dual energy generation is being considered, but it is unlikely they will be implemented in this pilot.

Finally, the introduction of a Building Energy Management System (BEMS) will enable seamless integration of energy systems, real-time performance monitoring, and enhanced occupant comfort, ensuring optimal energy use in the retrofitted buildings.

Front Runner 2
Location: Velika Gorica (Croatia)
Building: Single-family Residential
Phase: Renovation
System configuration:
- **TE-2** DHN connected HPs
- **PV**
- **TE-8** Air-based PVT

Figure 25 - Integrated Solution Overview, Front Runner 2

5.3.3 France

The KMØ office complex will undergo a comprehensive retrofit aimed at improving energy efficiency, sustainability, and reducing its environmental footprint, while preserving the building's historic features. Advanced thermal insulation solutions will be tailored to maintain the integrity of the iconic brick facades, and the shed roof will be refurbished using a prototype of prefabricated structures with BIPV.

The features under study include the replacement of the existing 2 MW gas boilers with MW-size reversible HP systems, including PV panels with a capacity of about 150 kWp as a step toward electrifying the building's energy profile. In addition, PVT systems and battery storage systems, although not part of the initial plan, will be considered in collaboration with related partners to enhance sustainability efforts.

The possibility of connecting to a future District Heating Network (DHN) will also be explored, alongside the potential use of geothermal or water sources as balancing mechanisms.

Furthermore, the integration of a water storage tank will be assessed as part of the HP solution, although further data is needed for final dimensioning. The upgraded systems will work in conjunction with an expanded Building Management System (BMS) that will evolve into a Digital Twin platform, enabling advanced monitoring and control of energy usage while fostering social inclusion. The overall goal of the retrofit is to reduce energy costs, cut carbon emissions, and create a sustainable, economically viable model that demonstrates how large industrial buildings can be decarbonised while preserving their historical significance.

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Front Runner 3
Location: Mulhouse (France)
Building: Office complex
Phase: Renovation
System configuration:
- TE-3 MW-size reversible HP
- BIPV Building integrated PV

Figure 26 - Integrated Solution Overview, Front Runner 3

5.3.4 Greece

The Greek pilot aims to establish an Energy-as-a-Service ecosystem by integrating newly built, existing, and renovated houses into a lab environment. This initiative will test innovative, cost-effective energy efficiency measures based on Passive House standards, building electrification, and DR solutions. The focus is on optimising synergies between electrified devices to enhance energy efficiency and grid sustainability, transforming residential buildings from passive consumers into active smart energy nodes. Key technologies include speed-controlled, inverter-driven HPs, solar thermal panels, rooftop PV systems, and thermal energy storage. While additional solutions like PVTs and second-life batteries are not yet planned, they remain open for implementation if feasible.

The study involves three to four residential buildings, comprising new, existing, and renovated ones. The energy systems include HPs with capacities between 14kW and 11kW, a 10.8kW rooftop PV system, and a 3.5kW solar thermal system. Thermal storage and Energy Management Systems (EMS) will manage and optimise energy flow, with smart metres, thermostats, and IoT sensory devices monitoring and controlling energy use. PVTs and second-life batteries are also under consideration, though their implementation will depend on their viability for the project

Front Runner 4
Location: Greece
Building: Single-family Residential
Phase: Construction & Renovation
System configuration:
- TE-4 Variable speed HP
- PV Rooftop
- TE-9 Electric batteries
- Thermal storage

Figure 27 - Integrated Solution Overview, Front Runner 4

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5.3.5 Italy

The 1970s multifamily building, comprising 13 apartments with a total net floor area of 2,300 m², will undergo a deep renovation to enhance energy efficiency and sustainability. The renovation will include an upgraded building envelope, new triple-pane windows, and full compliance with Italian building norms. Radiant floors will be installed for both space heating and cooling, while a concealed mechanical ventilation system (VMC) will handle latent cooling loads and air circulation needs.

The integrated solution will include a R290 monobloc unit for outdoor use on single dwellings' balconies, coupled with a PCM (phase change material) storage systems for heating, cooling, and domestic hot water (DHW) preparation. Radiant floor heating and cooling systems will also be implemented for improved thermal comfort. The building envelope will be upgraded, featuring triple-pane windows for improved insulation. Additionally, second-life batteries with around 12 kWh will be connected to the existing 20kW PV system, and its use will be optimised by an Energy Management Systems (EMS), to enhance the energy storage and sustainability. Also, a distributed Building Management System (BMS) will optimise PCM storage management using 24-hour energy forecasts.

Front Runner 5
Location: Bolbeno (Italy)
Building: Multi-family Residential
Phase: Renovation
System configuration:
- **TE-5** Monobloc air-to-water HP
- **PV**
- **PCM** Thermal energy storage
- **TE-9** Second life batteries

Figure 28 - Integrated Solution Overview, Front Runner 5

5.3.6 Spain

Pilot 6 building consists of a new construction building, the new extension of TECNALIA's headquarters in Donostia – San Sebastián, Spain. The city is characterised by an oceanic climate with mild, temperate temperatures throughout the year and high levels of humidity. The extension will be energy-efficient and connected to the existing building's energy systems, with a focus on electrifying thermal energy demand. The original construction project considered the use of the biomass boiler and chiller for the extended building to supply the heating and cooling needs of the extension building (offices and laboratory), and PV for electricity supply. The META BUILD project modified this initial approach by including a DSHP for heating/cooling in the laboratory facilities (1st story) enhanced by PVT and thermally activated foundation. Besides, enhanced operation will be also carried out including modifications regarding ventilation sectorisation, sensorisation, controllers and other functionalities. The project will thermally activate part of the foundation (200 m^2 approx.), achieving estimated 10 kW thermal exchange power. The existing biomass boiler will be extended and hybridised with a DSHP, designed by TECNALIA, utilising storage vessels and hybrid PVT panels. The heating and cooling system will be integrated with the existing building's systems to maximise performance. Monitoring and smart control will optimise the operation of the energy systems, thermal storage, indoor

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environmental quality, and renewable energy usage. To enhance the project, the construction process will consider the thermal activation of the concrete wall, and the DSHP will be tailored to heat the laboratories without cooling devices. Additionally, the PVT system will help improve the seasonal performance factor of the DSHP and the renewable energy production factor of the building´s energy system.

Energy demand of the building is the energy rate (kW) needed to maintain certain conditions in the building, considering heating, cooling, ventilation, and electricity needs. The energy demand for a building variate in accordance with weather conditions and occupancy periods. As a first instance, the limits for the indoor conditions will be considered as scheduled setpoint temperatures for different seasons (winter and summer) and days (working and non-working days). This approach will be adapted in the future as a novel approach for dynamic building performance optimisation will be implemented.

Front Runner 6
Location: San Sebastián (Spain)
Building: Office complex
Phase: Construction
System configuration:
- **TE-6** Dual source HP
- **TE-7** Liquid based PVTs
- **PV**
- Thermal storage

Figure 29 - Integrated Solution Overview, Front Runner 6

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6 Conclusions

This report has started the data collection process to support the initial modelling tasks and ensure that the defined outcomes are aligned with the META BUILD project's objectives on building electrification and decarbonisation solutions. This report has included user requirements, baseline building energy demand modelling, renewable energy generation potential estimation, preliminary definition of the KPIs to measure the performance and efficiency of the META BUILD solution as well as individual technologies performance, the definition and modelling approach to simulate the behaviour of the integrated solutions under different conditions and scenarios; and even has started the introduction of the future "decarbonisation-as-a-service" tool, that will be developed by the end of the project.

The report has collected the needs and requirements of end-users from the pilot sites and incorporated them into the design and specification of the technological solutions. Furthermore, a preliminary planning of the demonstrative actions has been completed for each pilot site.

A detailed methodology for early-stage demand and production assessment was described, which included building simulations for the Vienna pilot site and outlined the approach for the remaining pilot sites. Additionally, strategies for storage technologies and demand shifting as part of DR services were provided.

KPIs for assessment were defined, as well as the expected LCA approach to measure whole pilot site performance.

The conceptual design defined the individual technologies that will form the integrated solutions, and a preliminary modelling approach for the FRs was outlined. Since the project is in its early stages, updates and adjustments in the sizing and operation of these technologies are expected, with more detailed modelling results to be included in future versions of the deliverable.

Finally, the approach, functionalities, and technical specifications of the "Decarbonisation-as-a-service" tool for optimised design of integrated heating and cooling technologies were presented. The next steps will involve starting the modelling of the integrated solutions, updating the data as the project advances, validating the models, and further developing the decarbonisation tool.

The next steps for enhancing the conditions and factors for building electrification include the definition of building energy demand as baseline for the modelling of the integrated solutions to be adopted by each FR, as well as the development of the decarbonisation tool. The data collection showed in this deliverable will be adapted and updated along the progress of the project, to reflect final on-site systems and to validate the models.

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Annex A

Introduction

You are asked to describe the **high-level use case**. We follow the **IEC 62559 standard**. A *high-level use case* **describes** an innovative, **abstract function** but the actual technical implementation is not essential from this point of view. In the high-level use case, we follow a **top-down approach**. We start with the **development of the Business Layer** after analysing the use case and is **followed by the function to the component layer** in a sequential order.

Scope and objectives of "NoX UC" (Pilot | Partner)

SCOPE, OBJECTIVES AND RATIONALE
Describe briefly the Scope of the UC.
Describe briefly the objectives and rationale of the Use Case (UC). . **Features under study:** **Assets:** **Networks/Markets under study:** **Dependence on other BUCs:**
BUSINESS OBJECTIVES (discrete objectives narrow scope):

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Overview of integration profile "NoX UC"

Description of the action of the UC (from a business point of view), and the actors that participate in this action.

ACTORS & ROLES, NAMES AND TYPES
Indicate which actors contribute to the use case in the sense of providing inputs/outputs, processing or aggregation. In case the writer of the use case defines an own actor, the actor shall be classified and shortly described.
Roles: Optional additional roles for completeness:

SHORT DESCRIPTION
A short narrative focusing on the question «what», not «why». Intended only to get a brief overview.
Step wise approach: (Interactions between Actors and in certain cases with the systems/components) Additional flows:

Optional diagram (Create a schema where you show the actors and how they are connected)

Optional sequence diagram to represent the interactions between different components in the system for optimising energy usage and reducing costs through advanced energy management and integration in the Use Case.

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Overview of integration profiles and transactions "NoX UC"

Guidance:

This section should conclude the integration profile from an information exchange point of view (interoperability) and the relevant requirements for this to happen.

Integration profile "NoX UC"

	Information exchanged				
Info exchange ID	*Name of information*	*Description of information exchanged*	*Indicative Data Types*	*Data Formats*	*Requirement, R-IDs*

Integration profile "NoX UC"

Requirements (optional)		
Categories ID	*Category name for requirements*	*Category description*
Requirement R-ID	*Requirement name*	*Requirement description*

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Annex B

Use Case 1: Austria

Scope and objectives of “No1 UC: Extensive Retrofitting of a Central-European Residential Building” (Austria | IDM)

BUC-P1	ENHANCE THE ENERGY AND COST EFFICIENCY OF A BUILDING
SCOPE, OBJECTIVES AND RATIONALE	
Scope of the UC. Enhance energy efficiency and sustainability by extensively retrofitting a Central-European residential building in Austria. The project will integrate geothermal heat pumps, photovoltaic systems, and advanced energy storage systems to significantly reduce energy demand, carbon emissions, and cost efficiency.	
Objectives and Rationale of the Use Case (UC). This use case aims to minimize energy costs and carbon emissions by retrofitting a 1983 residential building with 58 apartments and a 7015 m² net heat area. The renovation involves replacing gas combi boilers with geothermal heat pumps, installing a 155 kWp rooftop photovoltaic system with battery storage, and implementing various energy efficiency measures such as window replacements and thermal insulation of roofs. These actions aim to enhance the feasibility and efficiency of heating urban building complexes. Additionally, two model-predictive control approaches for HP management enabling load shifting benefits for grid stability and renewable energy utilisation. **Features under study:** 1. R290 brine-to-water heat pumps (HPs) TE-1 2. Storage systems including second life batteries TE-9 3. Building model for planning and Model Predictive Control (MPC) TE-11 4. MPC control of MFH energy system TE-13 **Assets:** 1. Photovoltaic (PV) systems (155 kWp) 2. Second life battery storage systems (60 kWh) 3. Thermal storage systems (35 kWh) 4. Energy Management Systems (EMS) 5. Other Renewable Energy Sources (RES) 6. Residential buildings **Networks/Markets under study:** 1. Low Voltage (LV) Network 2. Retail market **Dependence on other BUCs:** N/A	

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BUSINESS OBJECTIVES (discrete objectives narrow scope):

- Minimize energy cost for tenants
- Minimize CO_2 emissions of building stock
- Increase resilience to energy price fluctuations and minimize risk exposure
- Improve overall building performance and indoor environmental quality
- Enhance user comfort and satisfaction

Child system use-cases and actions

- Decrease heat losses -> install building hull insulation
- Omit directly burned fossils and increase heating system efficiency -> exchange gas boilers for heat pumps
- Increase heating system efficiency -> use heat pumps, fine-tune heating system
- Utilize locally available renewables -> install photovoltaics
- Increase share of cheap, renewable energy -> use and store it when it's cheap and available
  - Include storages -> install battery storage, install storage tanks
  - Use storages smartly -> model-predictive control

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Overview of integration profile “No1 UC: Extensive Retrofitting of a Central-European Residential Building”

Description of the action of the UC (from a business point of view), and the actors that participate in this action.

ACTORS & ROLES, NAMES AND TYPES
Indicate which actors contribute to the use case in the sense of providing inputs/outputs, processing or aggregation. In case the writer of the use case defines an own actor, the actor shall be classified and shortly described.
• **Building operator:** Manages building operations and ensures systems are functioning efficiently. • **Building owner:** The legal owner of the building • **Facility managers:** Oversees planning and strategic decisions for energy systems i.e. the facility's infrastructure, maintenance, and services. • **Tenants (Dwellers):** Occupants of the residential buildings who use the energy systems. • **Energy provider:** Supply electricity and other energy forms to the building. • **Grid operator:** Ensure the distribution and stability of the electricity grid, facilitating the connection and integration of RES. • **Building modeller:** Models the building for simulation • **Technical planner:** Plans the technical details of the retrofit • **EMS provider:** Provider of the EMS • **Heat pump supplier:** Supplier of the intelligent heat pump(s) • **Public authorities:** Include all authorities which must be asked for authorisation, considered or asked for funding. In Case of pilot 1 this includes MA28 road construction, MA37 building police, MA51 public playgrounds, MA58 water law authorisation, Austrian legislative, Wohnfonds funding agency, and many more • **Implementing companies:** Includes construction companies, plumbers, electricians, drillers/well builders • **Demo operator:** Coordinates demonstration activities and collects data for analysis. • **IT service / Digital Solution providers:** Design and Develop EMS, manage data platforms, and ensure seamless integration of various systems.

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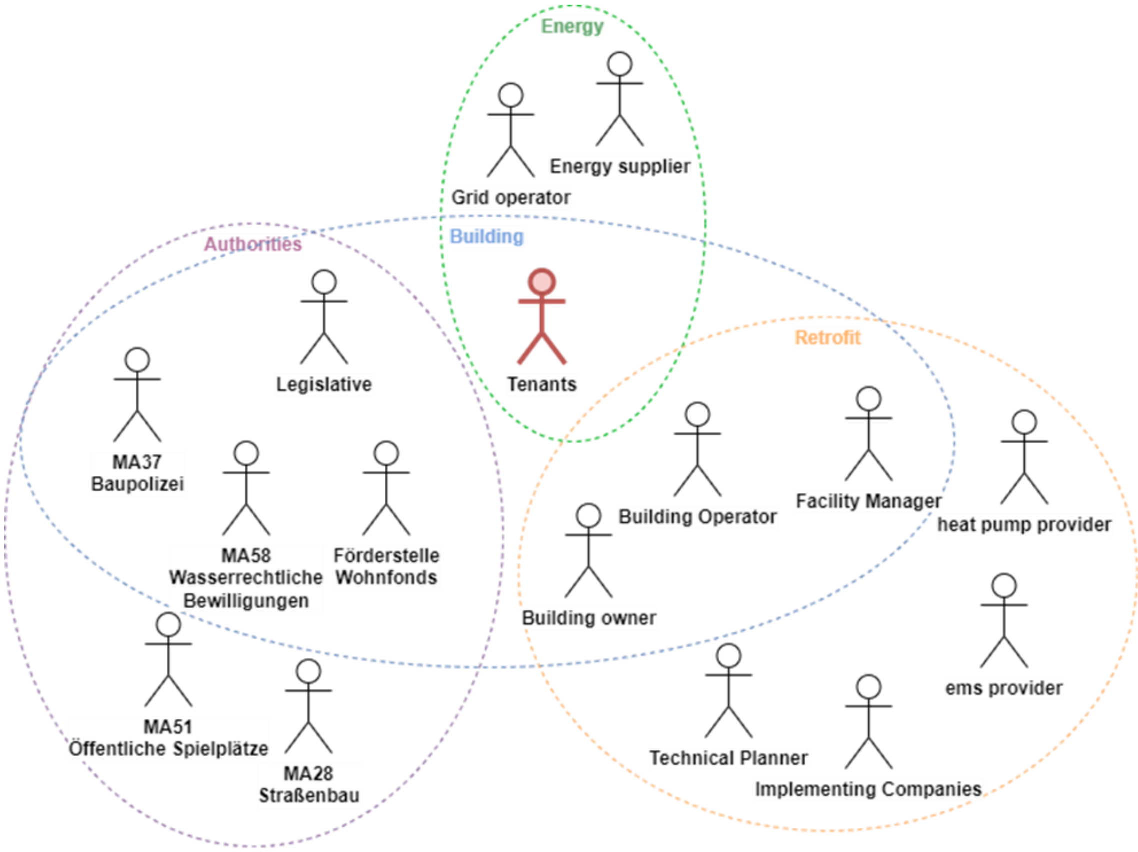

Figure 30 - FR 1 stakeholders and stakeholder-groups

SHORT DESCRIPTION
A short narrative focusing on the question «what», not «why». Intended only to get a brief overview.
The process is for better comprehensibility split up in four phases: 1. Pre-planning phase: The building owner come up with the idea or an electrification retrofit of the building and starts of with a rough planning for feasibility analysis (Figure 31). 2. Planning phase: The building owner starts off the detailed planning including budget-cost-impact analysis, request for promotions, and official authorisation (Figure 32). 3. Implementation phase: The planned and permitted retrofitting project is implemented on the building (Figure 33). 4. Operation phase: The building is operated smartly (Figure 34).

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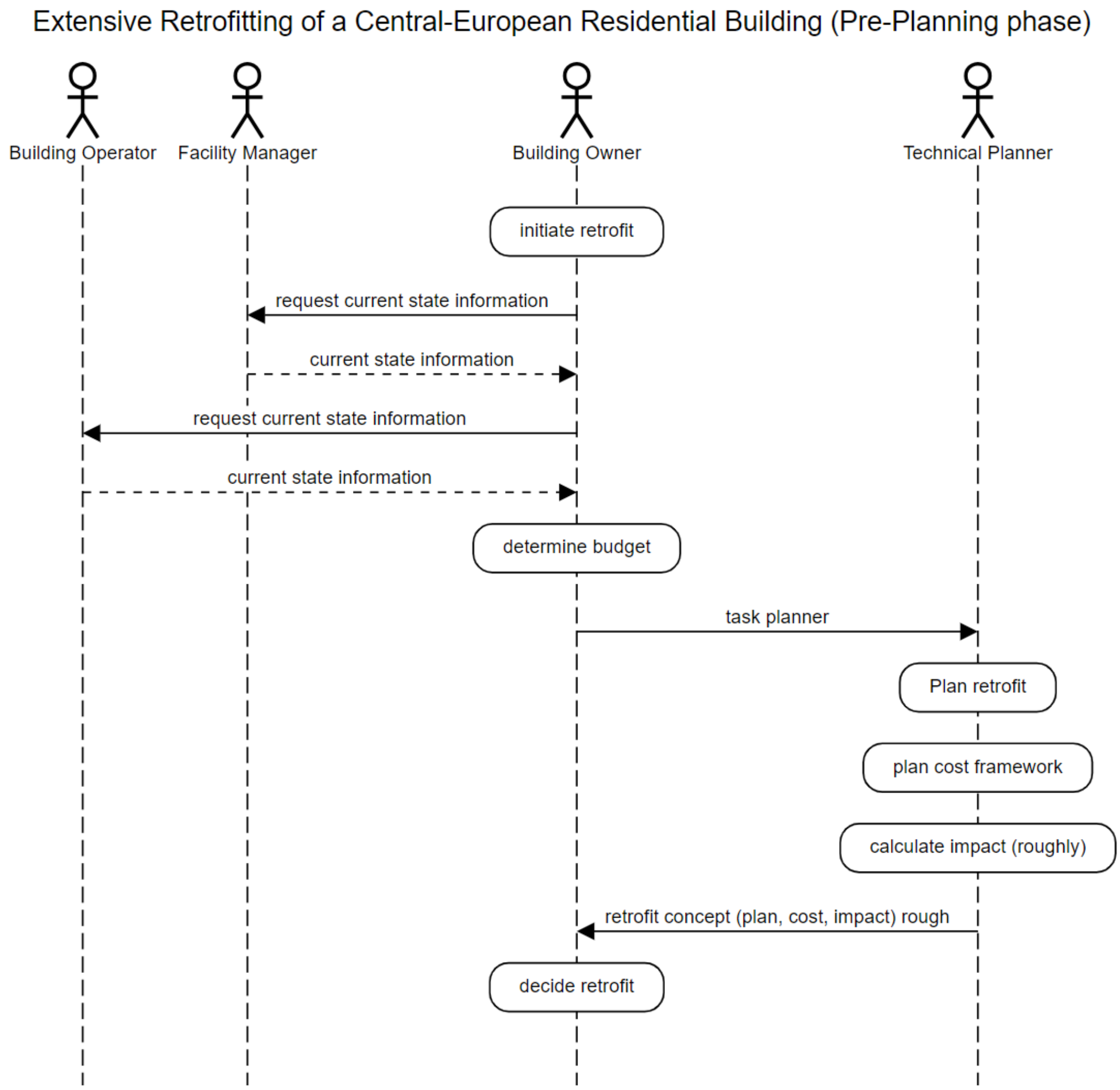

Figure 31 - FR 1 pre-planning phase

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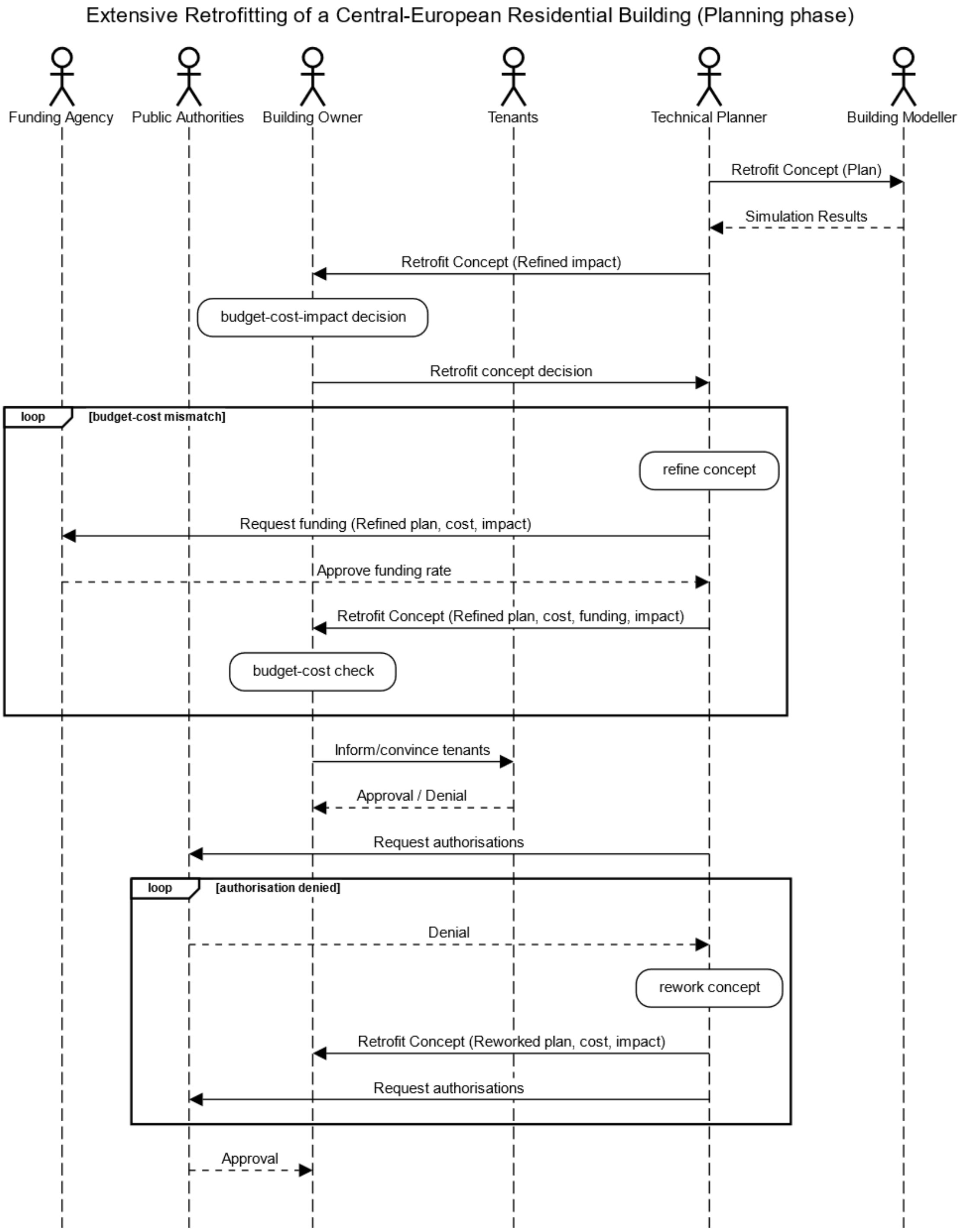

Figure 32 - FR 1 planning phase

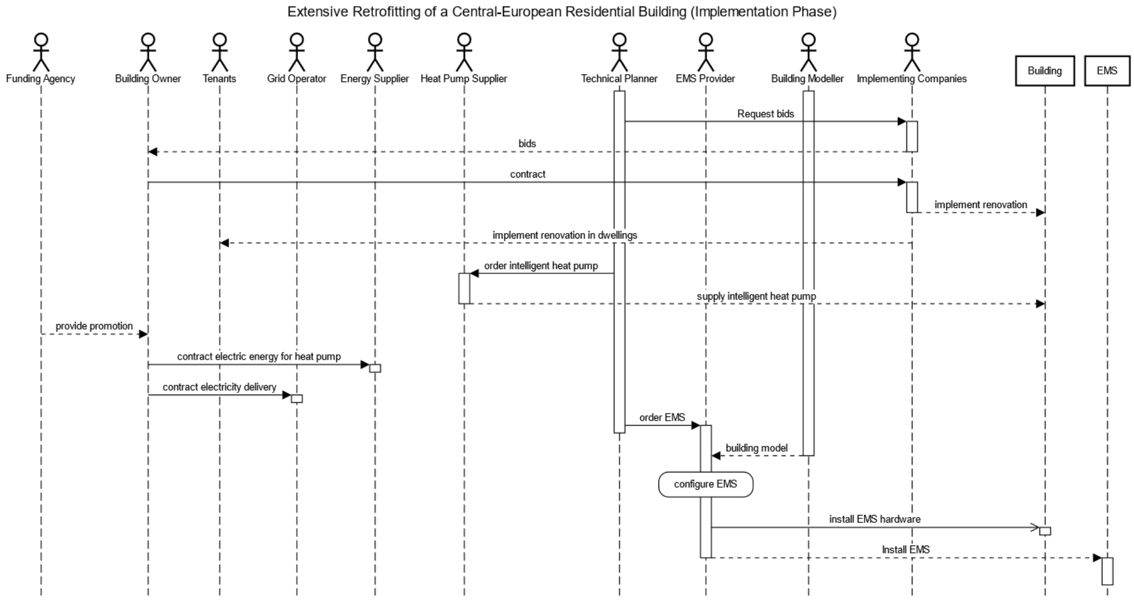

Figure 33 – FR 1 Implementation phase

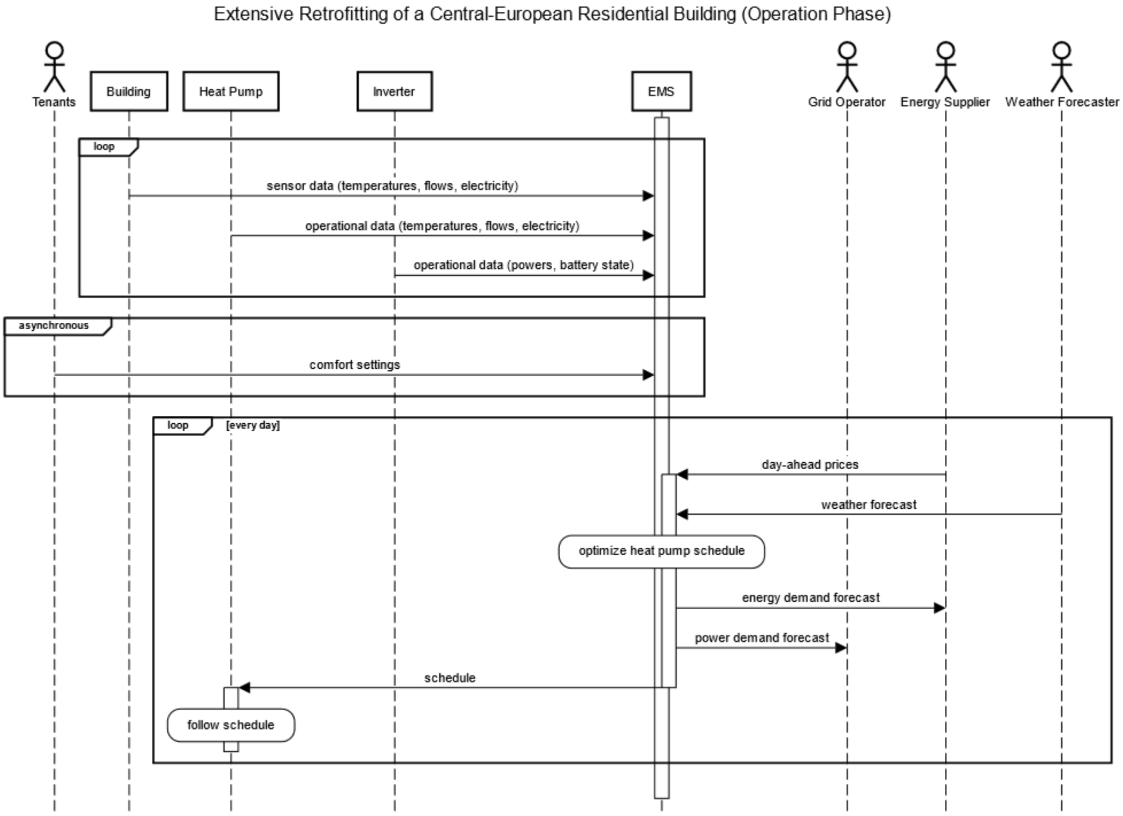

Figure 34 - FR 1 operation phase

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Overview of integration profiles and transactions “No1 UC: Extensive Retrofitting of a Central-European Residential Building”

INTEGRATION PROFILE “NO1 UC: EXTENSIVE RETROFITTING OF A CENTRAL-EUROPEAN RESIDENTIAL BUILDING” – INFORMATION EXCHANGED

	Information exchanged (EMS)				
Info exchange ID	**Name of information**	**Description of information exchanged**	**Indicative Data Types**	**Data Formats**	**Requirement, R-IDs**
1	Electricity Price	EMS needs the electricity price information from the existing electricity supplier once a day for 15 minutes.	Set of Tuples (Timestamp, Float)	CSV, API	
2	Weather Forecast	EMS needs the weather forecast for the next day in hourly resolution (timestamp, temperature, rel. humidity, global radiation, direct radiation, sun elevation, sun azimuth).	Set of n-tuples (timestamp, float, float, float, float, float, float)	CSV, API	
3	Heat pump operational data	EMS needs the aggregated operational data from the heat pump (timestamp, source, supply, evaporation, condensation temperatures, compressor speed, heating power, electric power consumption) in a 15s resolution.	Set of n-tuples (timestamp, float, float, float, float, float, float, float)	CSV, Database	
4	Data from the heating cycle(s)	EMS needs the aggregated operational data from the heating cycle(s) (timestamp, storage and supply temperature, opt. return flow temperature) in min. 1 minute resolution.	Set of quadruples (timestamp, float, float, float)	CSV, Database	
6	Operational data from the rooms	EMS needs measurement data of the building’s rooms (timestamp, room identifier, reference temperature) in min. 15 min resolution.	Set of triples (timestamp, string, float)	CSV, Database	
7	Operational data from the DHW supply lines	EMS needs operational measurement data from the building’s domestic hot water supply lines (timestamp, buffer temperature, dhw consumption since the last measurement) in min. 15 min resolution	Set of triples (timestamp, float, float)	CSV, Database	
8	Operational data from the inverter/PV	EMS needs operational measurement data from the inverter, respectively photovoltaics (timestamp, battery state of charge, pv production since the last measurement) in min. 15 min resolution	Set of triples (timestamp, float, float)	CSV, API, MODBUS, etc.	

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Milestones & Procurement Planning

Milestone Type		Date (DD-MM-YY)
Procurement	Starting Date	09-12-2024
	Ending Date	31-12-2025
Software Development Cycles (EMS)	Model and pre-processing method for MFH	01-10-2024
	Implementation of MFH-specific MPC kernel	01-10-2025
	Implementation of pre-processing and postprocessing	01-10-2026
Deployment of hardware on the field	Starting Date	01-04-2025
	Ending Date	01-10-2026
Testing	Software-in-the-Loop testing	01-02-2025 – 01-10-2026
	On-site testing	01-10-2026 – 01-05-2027

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Use Case 2: Croatia

Scope and objectives of “No2 UC: Retrofitting Residential Buildings Connected to the Local District Heating Network and integration of DH-connected Heat Pump” (Croatia | HEPT)

SCOPE, OBJECTIVES AND RATIONALE
Scope of the UC. Enhance energy efficiency and sustainability by retrofitting six residential buildings connected to the local district heating network (DHN) in Velika Gorica, Croatia. The project will integrate advanced district-heating-connected heat pumps and hybrid photovoltaic-thermal (PVT) technology.
Objectives and Rationale of the Use Case (UC). This use case aims to minimize energy costs and carbon emissions by improving the building envelope and renovating the existing oil-fired boiler system with district-heating-connected heat pumps. The project will also install hybrid PVT technology for electricity and heat generation and implement various energy efficiency measures on 6 residential buildings, such as window replacements and thermal insulation of roofs. **Features under study:** 1. District-heating-connected heat pumps (HPs) TE-2 (Six residential buildings) 2. Hybrid photovoltaic-thermal systems (Air-based PVTs) TE-8 3. Operation, control, and proactive maintenance TE-15 4. Decarbonisation as a service TE-17 5. Artelys Crystal Super Grid TE-18 **Assets:** 1. Energy Management Systems (EMS) – boiler room level 2. Thermal insulation improvements 3. District Heating (DH) connected heat pump 4. Smart metres and sensory equipment **Networks/Markets under study:** 1. Low Voltage (LV) Network 2. District Heating Network (DHN) **Dependence on other BUCs:** 1. Integration with existing BMS and DHN infrastructure 2. Coordination with local utility providers and ESCOs

BUSINESS OBJECTIVES (discrete objectives narrow scope):

- Reduce dependence on fossil fuels
- Minimize mismatches between supply and demand in terms of energy
- Create optimal schedules for energy usage and production
- Minimize CO2 emissions
- Increase resilience to energy price fluctuations and minimize risk exposure
- Ensure reliable and cost-effective outsourcing of required services
- Improve overall building performance and indoor environmental quality
- Enhance user comfort and satisfaction

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Overview of integration profile "No2 UC: Retrofitting Residential Buildings Connected to the Local District Heating Network and integration of DH-connected Heat Pump"

Description of the action of the UC (from a business point of view), and the actors that participate in this action.

ACTORS & ROLES, NAMES AND TYPES
Indicate which actors contribute to the use case in the sense of providing inputs/outputs, processing or aggregation. In case the writer of the use case defines an own actor, the actor shall be classified and shortly described.
• **Building (heating) operator:** Manages building operations and ensures systems are functioning efficiently. HEPT (HEP Toplinarstvo) plays a crucial role in the Croatian thermal energy market as the largest energy entity. Their strategy focuses on remaining a leading, environmentally conscious, and socially responsible company. HEPT's responsibilities include investing in efficient production capacities, replacing outdated district heating systems, and utilising renewable energy sources. They aim to integrate heat pumps (HPs) with electricity production systems to enhance energy efficiency and sustainability. • **Facility managers (Energy Planners):** Oversees planning and strategic decisions for energy systems i.e. the facility's infrastructure, maintenance, and services. CER (Circular Energy Resources) provides energy solutions suitable for a variety of facilities, including public sector institutions like hospitals and schools, as well as private sector entities like hotels and shopping centres. They focus on implementing new projects in district heating and electricity generation, primarily based on renewable energy sources (RES). CER collaborates with HEPT to develop innovative heat pumps (HPs) tailored for district heating connections. • **Tenants (Dwellers):** Occupants of the residential buildings who use the energy systems. The tenants of the residential buildings in Velika Gorica will use the benefits from the newly implemented system. • **IT service / Digital Solution providers:** Design and Develop EMS, manage data platforms, and ensure seamless integration of various systems. Leading research and technological development institutions are an essential part of the project. Regarding Croatian pilot, UNIZAG is the representative of such institutions. They focus on developing a research exploitation model to reuse the acquired research expertise in future activities. From a commercial perspective, they are interested in creating spin-offs to commercially capitalize on the research outcomes. • **Energy providers (Grid Operators):** Supply electricity and other energy forms to the building. Ensure the distribution and stability of the electricity grid, facilitating the connection and integration of RES. HEP Supply, along with HEPT, is a division within the HEP Group ensures electricity supply to various types of facilities in Croatia, including buildings and residential complexes. Their offer includes various tariff options and services tailored to different customer needs, such as residential electricity rates, business electricity plans, and solutions for large industrial consumers. HEP Supply manages and maintains the electricity distribution network in Croatia, ensuring that electricity is delivered safely and reliably to customers. **<u>Optional additional roles for completeness:</u>** • **Demo operator:** Coordinates demonstration activities and collects data for analysis. - UNIZAG

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- **Retailer:** Provides energy pricing and market data. - HEP Supply
- **Technology suppliers:** Provide the heat pumps, PVT systems, and other technological components.
- **ESCOs:** Provide energy efficiency services and manage retrofitting projects.
- **Construction Contractors:** Responsible for the retrofitting process, including building envelope changes and thermal insulation.
- **HVAC Specialists:** Experts in heating, ventilation, and air conditioning systems.

SHORT DESCRIPTION

A short narrative focusing on the question «what», not «why». Intended only to get a brief overview.

Step wise approach: (Interactions between Actors and in certain cases with the systems/components)

1. The Energy Management System (EMS) from the building operator collects energy consumption and production data from all tenants via an API every 15 minutes, storing it in a local database.
2. The EMS uses the stored data to calculate the net energy output.
3. The EMS retrieves combined signals for retail prices, grid tariffs, and demand response signals for the day-ahead from the retailer and aggregator.
4. This information (net load, prices, DR signals) is combined with forecasted models and guarantees of origin from the electricity supplier to derive a consumption schedule. The controller will activate or deactivate devices based on this schedule. Data will be stored on a data platform provided by the IT service.

Additional flows:

1. **Energy Consumption Analysis:** The system continuously monitors and records real-time tenant energy usage data.
2. **Renewable Energy Tracking:** Accurately measures the building's renewable energy generation from heat pumps and PVT systems.
3. **Advanced Energy Forecasting:** Predictive models forecast future energy needs using historical and environmental data.
4. **Sustainable Energy Verification:** The platform verifies real-time sustainability and the origin of electricity.
5. **Intelligent Load Management:** The system controls flexible loads based on the consumption schedule for efficiency.
6. **Integrated Data Management:** The IT platform manages and analyses all energy-related data based on decision support systems (DSS).

The process of enhancing energy efficiency in Croatian pilot involves two crucial activities: the implementation of heat pumps (HPs) and the revitalisation of buildings.

The implementation of heat pumps begins with the initial phase of research and development. This phase involves a detailed analysis of existing heating systems and the potential integration of heat pumps into these systems. Engineers and researchers work collaboratively to design heat pumps tailored specifically for district heating connections. These designs are focused on maximising efficiency and utilising renewable energy sources, ensuring that the heat pumps contribute to a sustainable energy future.

Once the design phase is complete, the project moves into the testing phase. Prototypes of the heat pumps are created and rigorously tested under various conditions to ensure they meet the required standards of performance and reliability. This phase is critical, as it allows for the identification and rectification of any issues before large-scale production begins. The feedback from the testing phase is used to refine the heat pump designs, enhancing their efficiency and effectiveness.

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Following successful testing, the production phase commences. Heat pumps are manufactured in line with refined designs, with a focus on maintaining high standards of quality. This phase involves close monitoring and quality control to ensure that each unit produced meets the specifications required for effective integration into district heating systems. Parallel to this, the logistics of deploying the heat pumps to their respective locations are planned and executed, ensuring a smooth transition from production to implementation.

In conjunction with the implementation of heat pumps, the revitalisation of buildings is conducted. This activity is initiated with a comprehensive assessment of the buildings to determine the necessary upgrades. Key areas of focus include improving insulation, upgrading windows, and enhancing ventilation systems. These upgrades are aimed at minimising energy loss and improving the overall thermal efficiency of the buildings.

The revitalisation process involves a series of coordinated steps. Initially, detailed plans are developed, outlining the specific upgrades required for each building. Contractors and construction teams are then engaged to carry out the necessary modifications. This phase is carefully managed to ensure that the upgrades are completed efficiently and to a high standard.

Optional diagram (Create a schema where you show the actors and how they are connected)

This sequence diagram represents the interactions between different components in the system for optimising energy usage, self-sufficiency, and demand response participation through advanced energy management and integration in the retrofitted residential buildings connected to the local district heating network in Croatia.

1. Tenant sends energy consumption and production data to EMS every 15 minutes.
2. EMS stores the energy data in the database.
3. EMS requests retail prices, grid tariffs, and demand response (DR) signals for the day-ahead from the Retailer.
4. Retailer sends the retail prices, grid tariffs, and DR signals to EMS.
5. EMS stores the price, tariff, and DR signal data in the database.
6. EMS requests an energy and DHN demand forecast from the Forecasting System.
7. Forecasting System sends the energy and DHN demand forecast to EMS.
8. EMS stores the forecast data in the database.
9. EMS sends the consumption schedule and DR actions to the Controller.
10. Controller activates/deactivates devices based on the schedule.
11. EMS optimizes energy usage, self-sufficiency, and DR participation.
12. EMS sends data to the IT Service for analysis and DHN integration.
13. IT Service stores the analysed data in the Data Platform.
14. EMS and IT Service ensure data integration and management.

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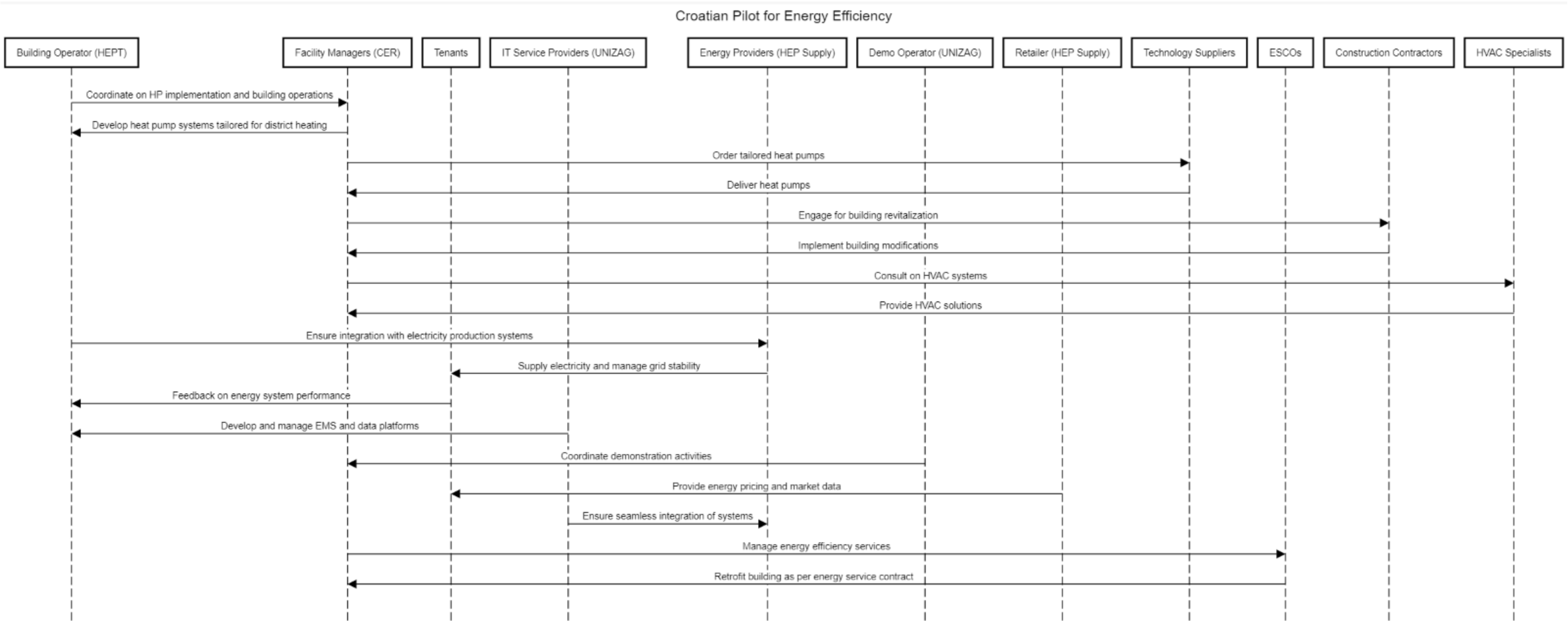

Figure 35 -FR 2 operation plan

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Overview of integration profiles and transactions "No2 UC: Retrofitting Residential Buildings Connected to the Local District Heating Network (DHN)"

Integration profile "No2 UC: Retrofitting Residential Buildings Connected to the Local District Heating Network (DHN)" – Information exchanged

	Information exchanged				
Info exchange ID	***Name of information***	***Description of information exchanged***	***Indicative Data Types***	***Data Formats***	***Requirement, R-IDs***
1	Electricity Price	EMS needs the electricity price information from the existing electricity supplier every 15 minutes.	Float	JSON, CSV	R2, R4
2	Electricity price from competitors	EMS needs the electricity price information from electricity supplier competitors at the same interval.	Float	JSON, CSV	R2, R4
3	RES energy forecast	EMS needs the upper and lower limit of energy forecast from the Open Energy Service. EMS needs historical and real-time environmental data (e.g., temperature, humidity, weather conditions) for accurate energy forecasts.	Float (Upper Limit, Lower Limit), Timestamp	JSON, XML, CSV	R2, R4
4	Aggregation load forecast	EMS needs the aggregated load forecast (depends on the business model).	Float	JSON, XML	R2, R4
5	Disaggregation load forecast	EMS needs the disaggregated load forecast (depends on the business model).	Float	JSON, XML	R2, R4
6	Power measurement data	EMS needs actual measurements of power from and to the site.	Float, Timestamp	JSON, CSV	R2, R4, R5
7	Thermal storage data	EMS needs data on thermal storage levels and performance from the integrated systems.	Float (Storage Level, Performance)	JSON, XML	R2, R4
8	Demand Response signals	EMS needs DR signals from the aggregator to manage load flexibility.	String, Boolean	JSON, XML	R2, R4
9	Operation conditions of the assets for maintenance	EMS needs the actual data of the environmental conditions (temperature, humidity etc.) that can affect the "health" of the asset.	Float (Temperature, Humidity), Timestamp	JSON, XML	R2, R4, R5
10	Data from smart metres and sensors installed in the building.	EMS should aggregate the data derived from the smart metres and sensors of the buildings.	Float, Integer, Timestamp	JSON, CSV, XML	R2, R4, R5

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3.2. Integration profile "No2 UC: Retrofitting Residential Buildings Connected to the Local District Heating Network (DHN)" – Requirements (optional)

Requirements (optional)		
Categories ID	**Category name for requirements**	**Category description**
Requirement R-ID	**Requirement name**	**Requirement description**
1	DSO regulations	Ensure that asset installation and operation fully comply with legal energy regulations and grid standards.
2	Energy performance requirement	Guarantee that energy performance aligns with established standards.
3	GDPR	Safeguard personal data in accordance with GDPR requirements
4	Cybersecurity	Maintain password protection for service access, with periodic updates as needed.
5	Level of control	Incorporate human oversight in the consent management process.
6	Subscription	Service provided on an annual subscription basis.

Milestones & Procurement Planning

Milestone Type		Date (DD-MM-YY)
Procurement	Starting Date	01.04.2025.
	Ending Date	31.08.2025.
Deployment of hardware on the field Testing	Starting Date	01.09.2025.
	Ending Date	30.03.2026.
Piloting Activities	Starting Date	01.09.2025.
	Ending Date	31.12.2027.

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Use Case 3: France

Scope and objectives of "No3 UC: Retrofitting an Office Complex in a Historic Peri-Urban Area" (France | EDF)

SCOPE, OBJECTIVES AND RATIONALE

Scope of the UC.

Enhance energy efficiency and sustainability by retrofitting the KMØ office complex, by integrating advanced heating, cooling, and energy management technologies for electrifying the building's energy profile (gas phase-out) while preserving the historic heritage of the building. These actions aim to activate economic benefits while decarbonising its environmental footprint and triggering social changes. The question to answer is how to decarbonize such big-sized industrial sites, while preserving the historic heritage and ensuring the rentability of the model, based on the renting of the spaces and associated services.

Objectives and Rationale of the Use Case (UC).

This use case aims to reduce energy costs and carbon emissions, by designing and implementing a retrofit of the KMØ office complex and its assets. This includes installing photovoltaic systems, integrating a MW-size reversible heat pump system, explore prefabrication, and advanced energy management systems, together with other possible assets. The goal is to create a balance between sustainable development, environmental preservation, and social inclusivity, securing acceptable investment and exploitation costs.

Features under study:

1. Energy efficiency
2. MW-size reversible heat pump systems TE-3
3. Other Renewable Energy Sources (RES)
4. Storage systems including second life batteries TE-9
5. Semantic interoperability enablers TE-10
6. Building Digital Twin for real-time monitoring TE-16
7. Decarbonisation as a service TE-17

Assets:

1. Office complex in a historic industrial peri-urban area
2. **Energy Management Systems (EMS)**
3. **Prototype of prefabricated shed with Building Integrated Photovoltaics (BIPV)**
4. **Photovoltaic Thermal (PVT) systems** (not part of the DoA/GA, but action to be explored with related Partners)
5. **Battery storage systems** (not part of the DoA/GA, but action to be explored with related Partners)
6. **Building Management Systems (BMS)**
7. **Office complex in a historic peri-urban area**

Networks/Markets under study:

1. Low Voltage (LV) Network
2. Retail market
3. Potential future connection to District Heating Network (DHN)

Dependence on other BUCs:

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1. Integration with existing Building Management Systems (BMS) 2. Coordination with local utility providers and ESCOs
BUSINESS OBJECTIVES (discrete objectives narrow scope): • Preserve historic architectural heritage for potential EE measures • Reduce the carbon footprint of the building • Improve overall building performance and indoor environmental quality • Electrify building usage to phase out gas (RES, HP and other potential assets), while integrating the connection to the future DHN • Increase resilience to energy price fluctuations and minimize risk exposure • Ensure reliable and cost-effective outsourcing of required services • Digital solution objective: social inclusion • Digital solution objective: digital testbed for new building planning/control/management solutions, improving O&M of assets and integrate the monitoring of the proof of performance.

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Overview of integration profile “No3 UC: Retrofitting an Office Complex in a Historic Peri-Urban Area”

Description of the action of the UC (<u>from a business point of view</u>), and the actors that participate in this action.

ACTORS & ROLES, NAMES AND TYPES
Indicate which actors contribute to the use case in the sense of providing inputs/outputs, processing or aggregation. In case the writer of the use case defines an own actor, the actor shall be classified and shortly described.
• **Building owner:** owns and manages the building, aiming at a scalable and replicable model for future investments in new industrial sites. • **Facility managers:** Oversees planning and strategic decisions for energy systems i.e. the facility's infrastructure, maintenance, and services. Manages building operations and ensures systems are functioning efficiently. • **Office tenants:** Occupants of the office buildings who use the energy systems and services. • **Energy providers (Grid Operators):** Supply electricity and gas and in the mid-term, heating via a DHN to the building. Ensure the distribution and stability of the related energy vector, facilitating the connection and integration of RES. **<u>Optional additional roles for completeness:</u>** • **Retailer:** Provides energy pricing and market data. • **IT service / Digital Solution providers:** design and develop EMS, manage data platforms, and ensure seamless integration of various systems and services. • **Technology suppliers:** Provide heat pumps, prefabricated sheds, BIPV, and other technological components. • **Demo operator:** Coordinates demonstration activities and ensures data are collected for analysis and verification. • **Heritage conservation experts:** Ensure retrofitting solutions are proposed, preserving the historic value of the building.

SHORT DESCRIPTION
A short narrative focusing on the question «what», not «why». Intended only to get a brief overview.
Step wise approach: (Interactions between Actors and in certain cases with the systems/components) 1. Centralisation of all relevant information into a middleware – Digital Twin (DT) - enabling to share information among the building related Energy Management System (BEMS) and related SCADA systems, as well as other information from other Building Management System (BMS) as Smart Work space, CCTV or other systems. 2. Assessment of EE relevant actions that could improve the energy performance and end-users’ comfort in the building complex (focus on specific building parts). 3. Assess and design an HP solution that can help to phase out part of the gas consumption and integrate the future planned DHN, ensuring the HP stays a long-term competitive solution for the local energy system. 4. Design and test a prototype of prefabricated shed with possibly BIPV, enabling retrofit large industrial surfaces more cost-effectively while reducing the environmental impact.

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5. Develop and test energy forecast and optimisation services (in-house or from third parties), aiming at integrating more effectively the various energy vectors (RES, grid, DHN) and related generation and storage assets.
6. Develop and test user relevant services, enabling to ameliorate comfort and wellbeing, raising awareness on end users' impact on the building's energy performance.

Additional flows:

1. **Renewable Energy Tracking:** Accurately measures the building's renewable energy generation from heat pumps, BIPV, and PVT systems (if installed) among others.
2. **Advanced Energy Forecasting:** Predictive models forecast energy loads/generation using historical, real time and environmental data.
3. **Sustainable Energy Verification:** The platform tracks real-time indicators and the origin of electricity.
4. **Intelligent Load Management:** The system controls flexible loads and assets.
5. **Integrated Data Management:** The IT platform manages and analyses all energy-related data based on decision support systems (DSS).

Optional diagram (Create a schema where you show the actors and how they are connected)

This diagram represents the interactions among the on-site layer on the left (OT used to measure and control assets), converging into the Digital Twin layer (middleware) and the service layer on the right (IT system for control and management of assets/systems) as wished in the best case by KMØ. This means the scheme does not represent the starting point, but the wished arrival stage. As can be evinced by the figure, the document is a working document and not the final definitive scheme to be implemented.

The scheme is yet the very first step towards a viable IT architecture for the monitoring and management of the KMØ via the Digital Twin methodology. Objective for the KMØ is to have a single-entry point for all data exchanges and interactions among ground and service layers concerning the environmental objectives, services and associated indicators. Current work focuses on the identification of the status and identification of additional OT and IT systems needed for the objective achievement and identification of modifications of existing interactions. This will lead to a ranking of the wished actions and a second step towards the definition of roles and responsibilities in the addition or development of OT/IT systems among involved Partners and third parties.

To be highlighted, is that existing contracts and the upcoming renegotiation of their scopes will be key to the feasibility of the endeavour targeted by the KMØ and thus, the main risk to be monitored for the work development.

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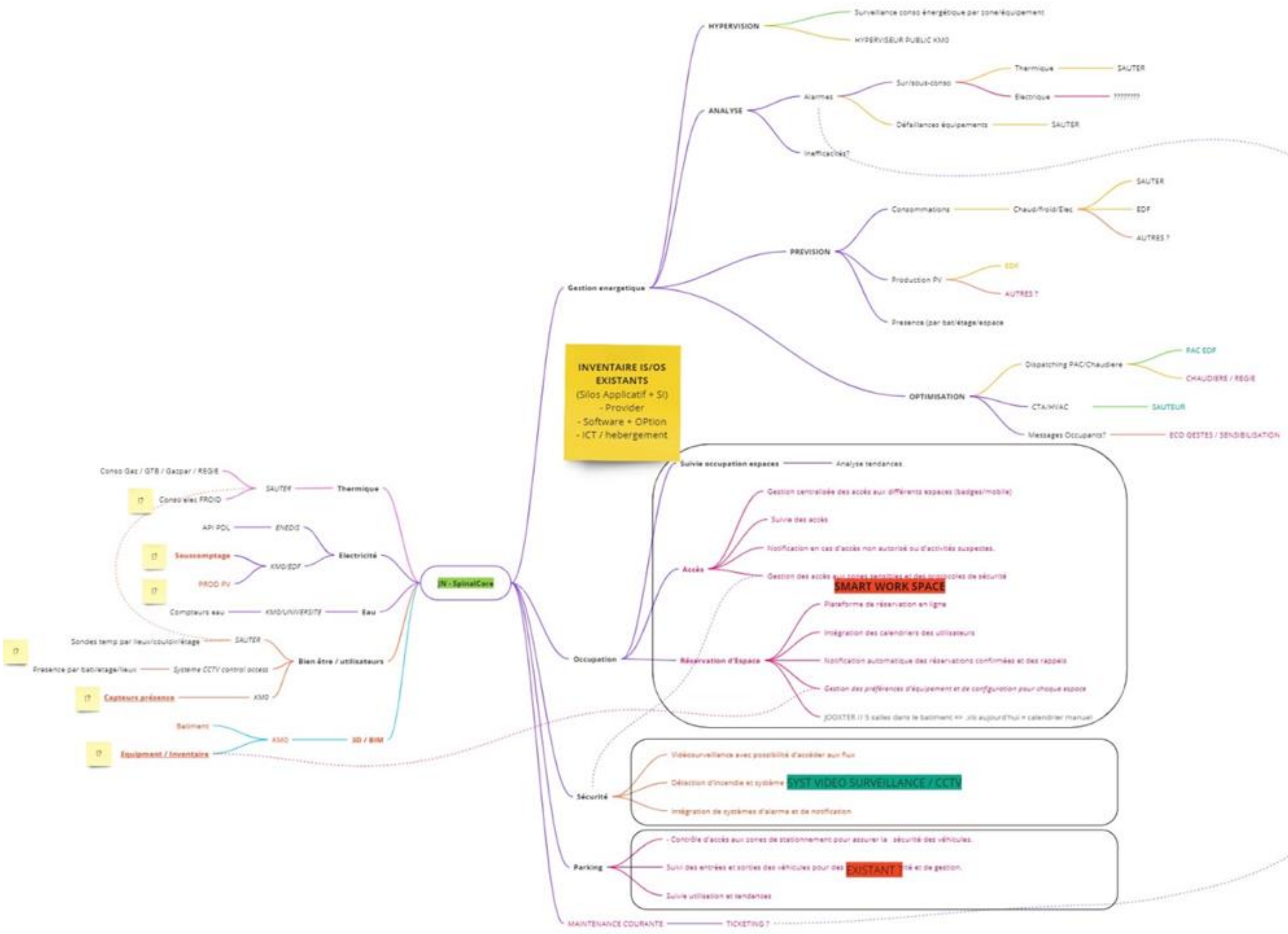

Figure 36 – FR 3 Flow chart

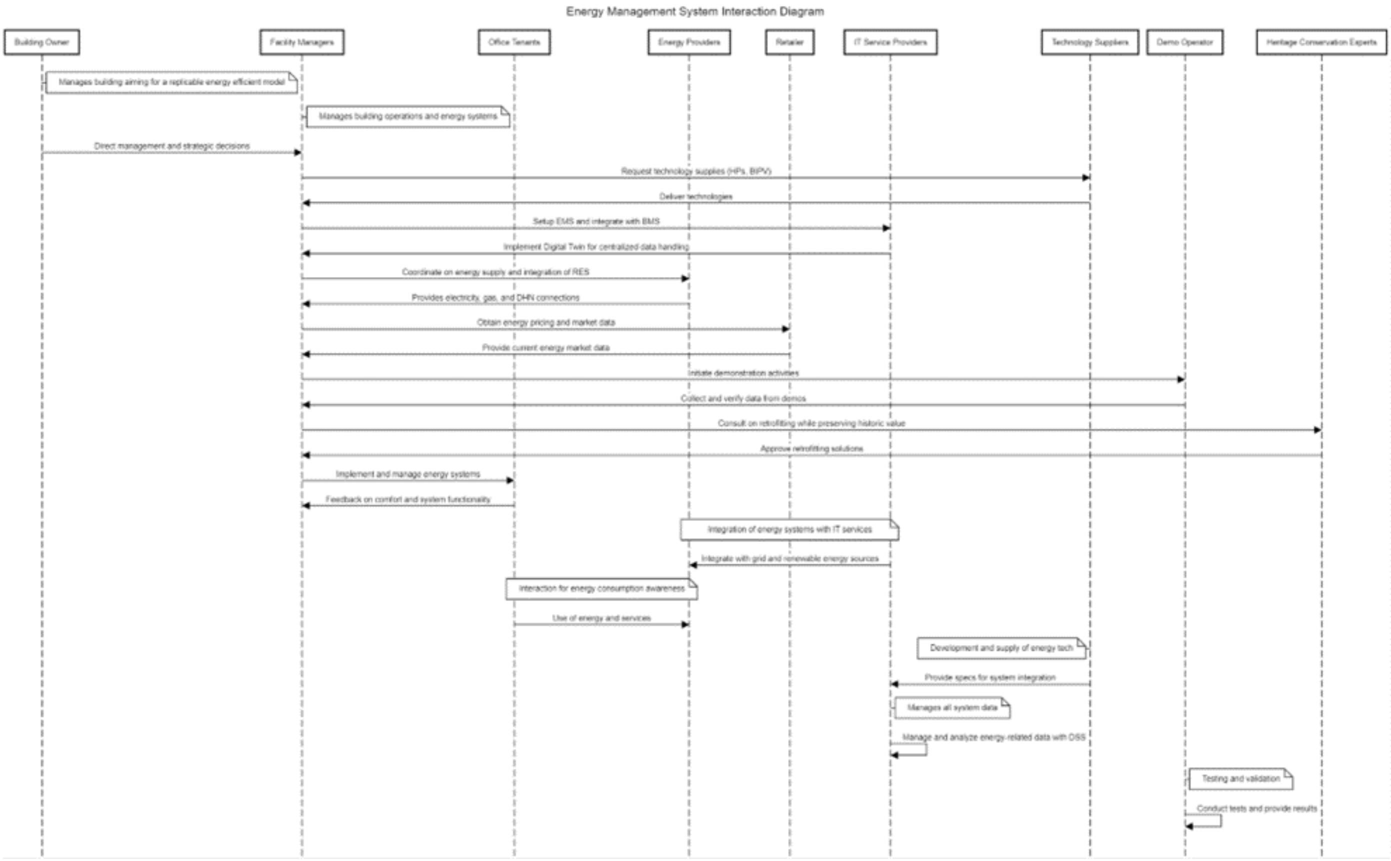

Figure 37 – FR 3 Energy management system

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Overview of integration profiles and transactions “No3 UC: Retrofitting an Office Complex in a Historic Peri-Urban Area”

Integration profile “No3 UC: Retrofitting an Office Complex in a Historic Peri-Urban Area” – Information exchange

The following list is not meant to be exhaustive nor are changes excluded, as the work is yet in progress and in the first design and feasibility stage. Nevertheless, the list concerns the engaged work as described above concerning the Digital Twin towards the fulfilling of KMØ’s objectives in terms of metering and control of their facilities and that of the involved partners and third parties.

	Information exchanged				
Info exchange ID	**Name of information**	**Description of information exchanged**	**Indicative Data Types**	**Data Formats**	**Requirement, R-IDs**
1	Building’s electricity load	Common areas electricity consumption as by smart meter	kW/kWh	TBD	
2	Chiller’s electricity load	Electricity consumption of chiller for cooling	kW/kWh	TBD	
3	Boiler room’s gas load	Gas consumption of boilers for heating	kW/kWh/ m^3	TBD	
4	Building’s Heat load	Heat generation of the building – global and by zone (departure of secondary distribution network from boiler room)	kW/kWh	TBD	
5	PV generation	Electricity generation after converter once PV installed	kW/kWh	TBD	
6	HP’s electricity load	Electricity consumption of HP to be developed	kW/kWh	TBD	
7	HP heat/cold generation	Heating/cooling generation of HP to be developed	kW/kWh	TBD	
8	Storage capacity	Heating/cooling storage level	kW/kWh/m^3	TBD	
9	Water consumption	Volume of water consumed	m^3/L	TBD	
10	SHW’s load	Electricity consumption of decentralized boilers for SHW preparation	kW/kWh/ m^3/L	TBD	
11	Temperature by room/zone/storey	Temperatures in the different rooms of the building, aggregated by zones a/o storeys	°C	TBD	
12	Presence (number of people)	Number of people present in the building (modality under study) and possibly by room/zone (modality under study)	number	TBD	
13	Pricing schemes (electricity, gas, water)	Different pricing schemes for different utilities (electricity, gas, water) for estimating “real-time” expenditures	EUR	TBD	
14	External temperature	External temperature meter	°C	TBD	
15	Meteorological forecast data	Third party service for energy relevant meteorological predictors (i.e. temperature or solar radiation) - to be defined	°C/kW/kWh	TBD	
16	Load forecasts	In-house a/o third party services for forecasting meaningful energy loads in the building (heating/cooling, electricity, gas) as overall a/o by zone - to be defined.	kW/kWh	TBD	
17	PV generation forecast	In-house a/o third party services for forecasting PV generation - to be defined	kW/kWh	TBD	

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18	Presence forecast	In-house a/o third party services for forecasting the occupancy rate of the building a/o by zone - to be defined	number	TBD	
19	Event program	Calendar information of time and duration of events and foreseen presence	date/time/h/number	TBD	
20	Smart workspace	Calendar information of time and duration of room reservations and foreseen/actual presence	date/time/h/number	TBD	
21	HP control	Setting values for the control of the HP to be developed (as well as for the potential storage)	TBD	TBD	
22	Boiler control	Setting values for the control of the boilers	TBD	TBD	
23	HVAC control	Setting values for the control of the HVAC system related assets	TBD	TBD	
24	BMS control	Alarms or other added value information generated by IT systems	TBD	TBD	

Integration profile "No3 UC: Retrofitting an Office Complex in a Historic Peri-Urban Area" – Requirements (optional)

Requirements (optional)		
Categories ID	***Category name for requirements***	***Category description***
Requirement R-ID	***Requirement name***	***Requirement description***
1	DSO regulations	Assets installation and operation conform to grid code
2	GDPR	Protect personal data according to GDPR.
3	Cybersecurity	Ensure services are protected as by state of the art.
4	Level of control	Include human decision-making in the loop for consent management.
5	Fire safety and security	Ensure all activities comply with guidelines for preserving the historic integrity of the building and its fire and security requirements.
6	Building regulations	Ensure systems answer to current building regulations requirements in terms of assets management, metering, certifications and possible official reporting
7	IT specific requirements	Each vertical IT system in the building has own providers and associated requirements. This perimeter is related to the contractual arrangements between KMØ and the concerned service provider (Partner a/o third party) and the upcoming negotiation in terms of interoperability or other requirements, that can potentially be achieved during the Project.

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Milestones & Procurement Planning

The following table shows the activity planning at the current state of knowledge. Changes might apply while the work matures, and once the scope of the work that can be developed under the project is settled and agreed under all involved parties (Partners and third parties).

Milestone Type		*Date (DD-MM-YY)*
Design	Starting Date	M1
	Ending Date	M12
Procurement	Starting Date	M6
	Ending Date	M24
Software Development Cycles	Cycle 1 – Interoperability - Starting Date	M13
	Cycle 1 – Interoperability - Ending Date	M24
	Cycle 2 – Performance - Starting Date	M25
	Cycle 2 – Performance - Ending Date	M36
	Cycle 3 – Enhancement - Starting Date	M37
	Cycle 3 – Enhancement - Ending Date	M48
Deployment of hardware on the field	Starting Date	M13
	Ending Date	M36
Testing	Starting Date	M18
	Ending Date	M48
Piloting Activities	Starting Date	M24
	Ending Date	M48

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Use Case 4: Greece

Scope and objectives of “No4 UC: Comprehensive Decarbonisation and Demand Response Strategy for Residential Buildings” (Greece | Zenith)

SCOPE, OBJECTIVES AND RATIONALE
Scope of the UC.   The Greek pilot aims to create an ecosystem of newly built, existing and renovated houses, gradually establishing an Energy-as-a-Service lab: a real-world and open innovation set of dwellings, in which innovative and cost-effective Energy Efficiency and Demand Response solutions will be tested in electrified energy solutions.
Objectives and Rationale of the Use Case (UC).   The primary objective of no. 4 use case is the optimal synergy between electrified devices' consumption patterns (emphasising in heat-pumps), local power generation from PVs (and other assets if available, such as batteries and solar thermal panels), and the power grid from the perspective of load and pricing. This balancing exercise is pivotal for advancing energy efficiency and sustainability of the grid, while gradually transforming residential buildings from passive consumer to active and smart energy nodes.   More in detail, the pilot aims at monitoring and controlling homes’ assets (e.g., heat pumps), so that their usage adapts dynamically to power generated locally (e.g., roof-top PVs), as well as the grid’s load demand and wholesale prices. As a result, the pilot envisages to offer optimal energy efficiency for the homes’ tenants, flexibility capacity for the supplier and grid stability for the operator. This dynamic integration of homes’ assets and grid conditions not only maximises reliance on local renewable energy sources, but also minimises costs associated with peak-hour consumption and the overall grid sustainability.   The overarching theme of the pilot is to leverage pricing signals and demand response mechanisms, so that residential consumers can make informed decisions regarding appliances’ use, energy generation and potentially storage. Through continuous refinement of such delicate balancing exercise, the pilot foresees innovative and targeted energy management strategies, with benefits extending to individual consumers, suppliers and policy makers.   In detail, the three main components of this pilot are the Home Energy Management System (HEMS), the Wholesale Power Market System (WPMS) and the user Dashboard. The Home Energy Management System (HEMS) integrates various smart devices and sensors to monitor and control energy usage in homes and provides the suggested scheduling of energy consumption according to energy efficiency and demand response events. The Wholesale Power Market System (WPMS) will interact with the energy market and provide valuable information to the HEMS. It focuses on price modelling, forecasting, and signal transmission, as well as load aggregation and financial analysis. The User Dashboard provides a comprehensive and easy-to-use monitoring experience for the end-user (tenant), as well as a consent and a feedback mechanism related to demand response and controlling experimentations during the project.   **Features under study:**   1. Speed controlled/inverter-driven heat pumps TE-4   2. PVTs TE-7 (if feasible)   3. Other RES (PVs) TE-8   4. Storage systems (e.g., solar thermal) including second life batteries TE-9 (if feasible)   5. Semantic interoperability enablers TE-10   6. Enhancing Comfort, Energy & Performance TE-12

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7. Demand response, Grid interaction & Flexibility Planning TE-14
8. Decarbonisation as a service TE-17
9. Artelys Crystal Super Grid TE-18

Assets:

1. New, existing, and renovated residential buildings, 7 in total
2. Advanced heat pumps (14kW and 11kW)
3. PV systems (10.8kW roof-top)
4. Solar thermal systems (3.5kW)
5. Thermal storage systems
6. Energy Management Systems (EMS)
7. Smart metres and thermostats
8. IoT and sensory devices

Power Market under study:

1. Greek wholesale power market (Day-Ahead)
2. Retail market
3. Energy Efficiency (EE) and Demand Response (DR) programs

Dependence on other BUCs:N/A

BUSINESS OBJECTIVES (discrete objectives narrow scope):

- Modulate the heat pump flow temperature ensuring continuous operation at optimal capacity (EE).
- Shift the heat-pump duty cycling following low wholesale power prices patterns and/or local PV generation curves (DR – load shifting).
- Adjust the heat pump set point temperature during critical grid condition and max. load demand (DR – load shedding).
- Structure future Time of Use (ToU) rates, matching local energy consumption/production patterns with wholesale peak and off-peak periods.
- Optimise user comfort balancing parameters, such as temperature, humidity, air quality, appliances use and personal preferences.
- Minimise imbalances between supply and demand.
- Minimise consumption and CO2 emissions.
- Increased customer loyalty.
- Increased energy awareness and more educated consumers.
- Improved grid stability.
- Potential additional revenue streams for the utility in future demand response programs.
- Possible contribution to national energy efficiency obligation scheme.

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Overview of integration profile "No4 UC: Comprehensive Decarbonisation and Demand Response Strategy for Residential Buildings"

Description of the action of the UC (from a business point of view), and the actors that participate in this action.

ACTORS & ROLES, NAMES AND TYPES
Indicate which actors contribute to the use case in the sense of providing inputs/outputs, processing or aggregation. In case the writer of the use case defines an own actor, the actor shall be classified and shortly described.
• **Tenants:** Occupants of the residential buildings who use the energy systems. • **ESCO (Energy Planner/Installer):** Oversees planning and implementation of energy systems i.e. the home's infrastructure, maintenance, and services. Provides the heat pumps, PV systems, and other technological components. • **IT service / Digital Solution providers:** Design and Develop EMS, manage data platforms, and ensure seamless integration of various systems. • **Energy supplier/aggregator:** Supplies electricity to homes, energy services, pricing and market data. Facilitates participation in demand response programs. • **Greek TSO and European Network of Transmission System Operators for Electricity**: Provide data for the Greek power system.

SHORT DESCRIPTION
A short narrative focusing on the question «what», not «why». Intended only to get a brief overview.
Step wise approach: (Interactions between Actors and in certain cases with the systems/components) 1. Home Energy Management System (HEMS): The ESCO together with the IT service/Digital Solution provider install controllers (if possible) and monitoring IoT devices to the heat pump. 2. Home Energy Management System (HEMS): The ESCO together with the IT service/Digital Solution provider install controllers (if possible) and monitoring IoT devices to the PV inverter and solar heater. 3. Home Energy Management System (HEMS): The ESCO together with the IT service/Digital Solution provider install a smart meter measuring the total consumption of the home with disaggregation functionality. 4. Home Energy Management System (HEMS): The ESCO together with the IT service/Digital Solution provider install an Indoor Air Quality sensor. 5. HEMS through a wifi-connected gateway integrates all the above data points and collects energy consumption/production data at regular intervals, storing it in a cloud server. 6. HEMS provides a monitoring, control (if possible) and communication dashboard to the tenant for piloted devices and sensors (i.e., heat pump, inverter data, IAQ, other appliances). 7. HEMS estimates a baseline consumption scenario of home appliances with an emphasis on the heat pump load/use. 8. HEMS models the home's renewable energy generation from roof-top PV and solar thermal systems. 9. HEMS provides predictive models forecasting future energy usage patterns using historical and environmental data.

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10. HEMS monitors and controls (if possible) certain parameters of the heat pump.
11. Wholesale Power Market System (WPMS): The Energy Supplier/Aggregator creates infrastructure to receive daily power market and power system datasets.
12. WPMS collects power market related datasets via APIs from TSOs/HENEX/ENTSO-e/etc. and stores the datasets in a server.
13. WPMS monitors and records DAM (Day Ahead Market)) data sets and grid conditions at regular intervals.
14. WPMS forecasts at a daily pace the next-day power market price.
15. WPMS sends to HEMS demand response signals according to DAM predictions.
16. HEMS receives demand response signals from the WPMS for the day-ahead.
17. HEMS combines devices (i.e., HP and other) baseline load estimation and creates a device/load/time schedule in accordance with the DR signal.
18. HEMS controls (if possible) certain parameters of the heat pump (and other devices) implementing load shifting/shedding of controlled devices.
19. HEMS monitors reduced/shifted energy consumption of participating devices in the DR call, stores the data in a database and sends reduced load verification to WPMS.
20. WPMS aggregates total load saved and calculates in a simulated manned the potential savings for the user.
21. User is notified of the savings in terms of kWs/CO2/cost per appliance.
22. WPMS schedules the reduced load to be represented in the intra-day power market in a simulated manner.
23. WPMS calculates the benefit of the supplier/aggregator in a simulated manner.

HP controlling and load shifting for maximum EE: This sequence diagram represents the interactions between different components in the system for optimising the heat pump energy efficiency according to market prices and local PV power production

1. HEMS estimates a baseline consumption model of the heat pump according to user behaviour and HP load data patterns.
2. HEMS models the home's renewable energy generation from roof-top PVs and solar thermal systems according to historical data and weather prediction.
3. The baseload model is corelated with various parameters and data feeds, such as Indoor Air Quality, external temperature, online weather forecast services, etc.
4. Tenant uses the smart dashboard to set the desired HP temperature.
5. HEMS predicts comfort preferences according to previous usage patterns and feedback loops.
6. WPMS models the DAM price at a one-hour interval.
7. WPMS forecasts at a one-hour interval the next-day power prices.
8. WPMS sends HEMS DAM price signals (hourly DAM prices)
9. HEMS schedules an hourly device scheduling activity trying to reduce consumption in certain peak hours according to DAM price and local consumption/generation predictions.
10. HEMS notifies the user using a smart dashboard and gets consent for scheduling.
11. HEMS activates the HP according to schedule.
12. HEMS prioritises the use of PV power production and suggests to the user using RES capacity.
13. HEMS utilises the PV inverter and/or battery storage to prioritise energy produced/stored locally.
14. Managed load data is stored and verified on the HEMS database and communicated to WPMS.
15. HEMS selects feedback from user on comfort levels.
16. HEMS feeds the new scheduled data into the predictive model dataset and sends the data to WPMS.
17. HEMS calculates saved energy in terms of kWs/€/CO_2.
18. WPMS aggregates reduced load and simulates its representation to intra-day power market.
19. WPMS based on aggregated load patterns performs a simulated cost-benefit analysis calculating the financial gains for the aggregator and for the user.
20. WPMS simulates a personalised Time of Use dynamic pricing rate structure.

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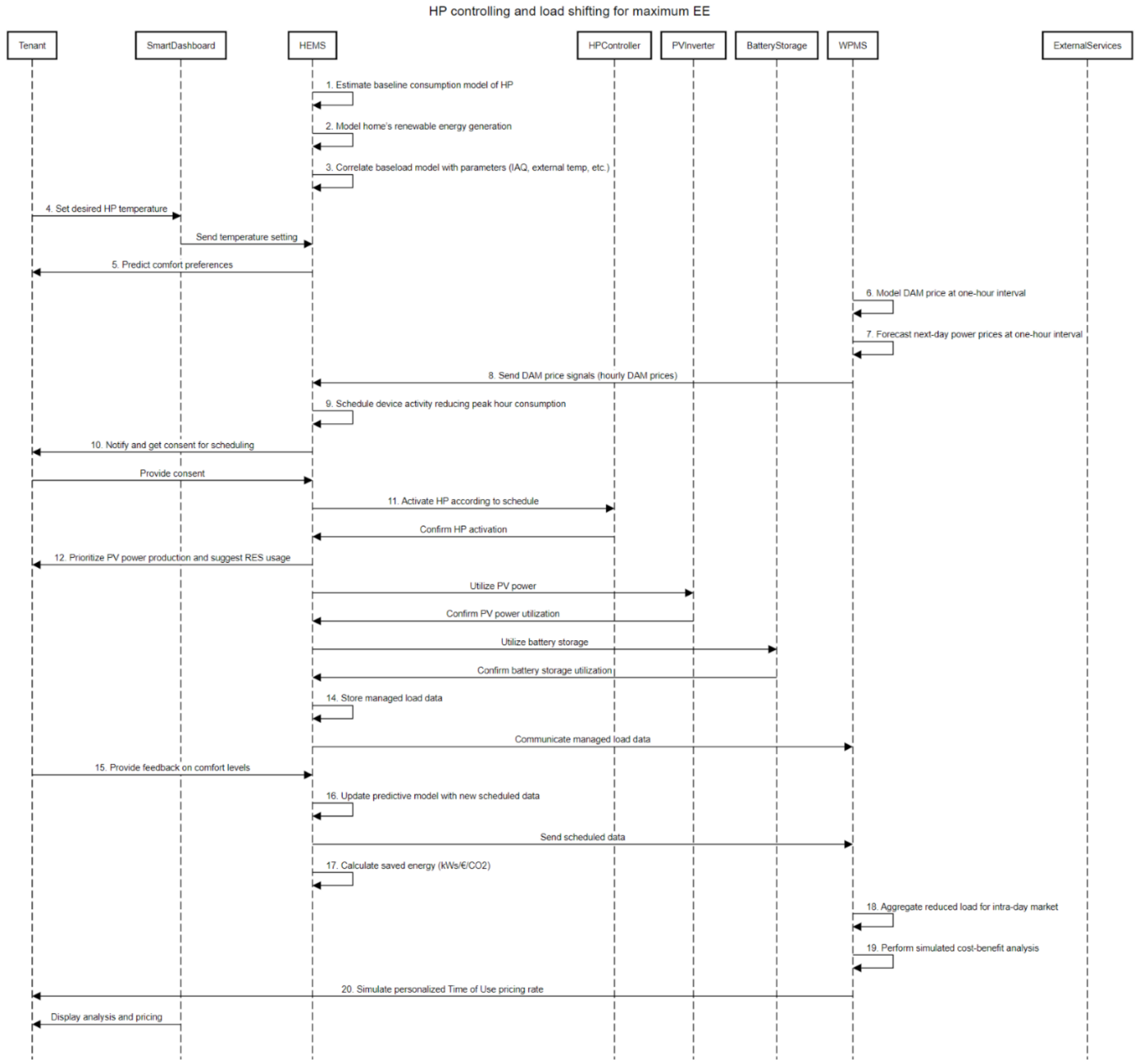

Figure 38 – FR 4 energy efficiency scenario

HP controlling in a high load demand and stressed grid context: This sequence diagram represents the interactions between different components in the system for Demand Response purposes where reducing electricity consumption of the HP is crucial for grid stability, and potential economic benefits.

1. HEMS estimates a baseline consumption model of the heat pump according to user behaviour and HP load data patterns.
2. HEMS models the home's renewable energy generation from roof-top PVs and solar thermal systems according to historical data and weather prediction.
3. WPMS models the DAM and daily load at a one-hour interval.
4. WPMS forecasts at a one-hour interval the next-day power prices.
5. Due to an upcoming emergency grid condition (e.g., unplanned production unavailability, grid lines disconnection, extreme weather, etc) WPMS predicts a significant DAM price movement.
6. WPMS sends HEMS an emergency price signal.
7. HEMS receives the emergency price signal from the WPMS and sets to reduce consumption in a particular timeframe for the day-ahead.
8. HEMS combines devices (i.e., HP and other) baseline load estimation and creates a device/load/time schedule trying to reduce load taking into consideration local RES capacity.

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9. HEMS communicates the emergency DR program to user and receives the tenant's consent (option to decline/override it).
10. HEMS communicates with the home's devices and HP adjusting their behaviour according to the schedule to reach the desired load reduction within the particular timespan.
11. Shed load data is verified, stored on the HEMS database and communicated to WPMS.
12. Occupant feedback indicates no noticeable discomfort during the load-shed period.
13. WPMS aggregates total load shed and simulates its representation to intra-day power market.
14. WPMS based on aggregated load shed performs a cost-benefit analysis calculating the financial gains for the aggregator and for the user.
15. WPMS suggests a credit discount to the user.

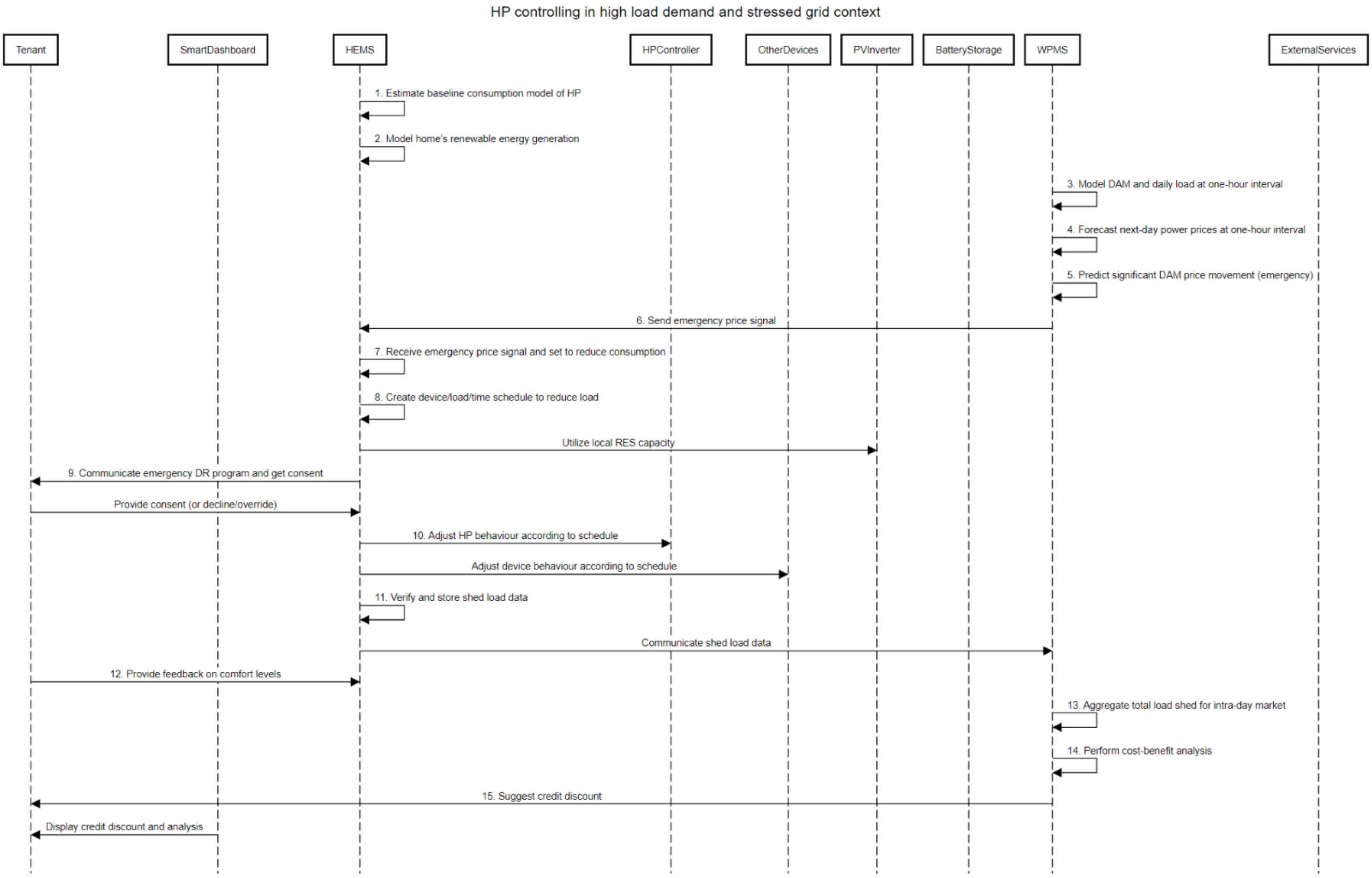

Figure 39 – FR 4 demand-response scenario

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Overview of integration profiles and transactions “No4 UC: Comprehensive Decarbonisation and Demand Response Strategy for Residential Buildings”

Integration profile “No4 UC: Comprehensive Decarbonisation and Demand Response Strategy for Residential Buildings” – Information exchanged

	Information exchanged				
Info exchange ID	***Name of information***	***Description of information exchanged***	***Indicative Data Types***	***Data Formats***	***Requirement, R-IDs***
1	Electricity Price	EMS needs the electricity price information from the existing electricity supplier every 15 minutes.	Float	JSON, CSV	R2, R4
2	Electricity price from competitors	EMS needs the electricity price information from electricity supplier competitors at the same interval.	Float	JSON, CSV	R2, R4
3	RES energy forecast	EMS needs the upper and lower limit of energy forecast from the Open Energy Service. EMS needs historical and real-time environmental data (e.g., temperature, humidity, weather conditions) for accurate energy forecasts.	Float (Upper Limit, Lower Limit), Timestamp	JSON, XML, CSV	R2, R4
4	Aggregation load forecast	EMS needs the aggregated load forecast (depends on the business model).	Float	JSON, XML	R2, R4
5	Disaggregation load forecast	EMS needs the disaggregated load forecast (depends on the business model).	Float	JSON, XML	R2, R4
6	Power measurement data	EMS needs actual measurements of power from and to the site.	Float, Timestamp	JSON, CSV	R2, R4, R5
7	Demand Response signals	EMS needs DR signals from the aggregator to manage load flexibility.	String, Boolean	JSON, XML	R2, R4
8	Operation conditions of the assets for maintenance	EMS needs the actual data of the environmental conditions (temperature, humidity etc.) that can affect the “health” of the asset.	Float (Temperature, Humidity), Timestamp	JSON, XML	R2, R4, R5
9	Data from smart metres and sensors installed in the building.	EMS should aggregate the data derived from the smart metres and sensors of the buildings.	Float, Integer, Timestamp	JSON, CSV, XML	R2, R4, R5

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Integration profile "No4 UC: Comprehensive Decarbonisation and Demand Response Strategy for Residential Buildings" – Requirements (optional)

Requirements (optional)		
Categories ID	**Category name for requirements**	**Category description**
Requirement R-ID	**Requirement name**	**Requirement description**
1	DSO regulations	Conform with the law and energy regulations.
2	Energy performance requirement	Ensure energy performance meets specified standards.
3	GDPR	Protect personal data according to GDPR.
4	Cybersecurity	Ensure service access is password protected, with regular updates every 6 months if needed.
5	Level of control	Include human decision-making in the loop for consent management.
6	Subscription	Annual subscription model for the service.
7	User activation	Media and consulting activities for end-user activation

Milestones & Procurement Planning

Milestone Type		Date (DD-MM-YY)
Procurement	Starting Date	September 2024
	Ending Date	June 2025
Software Development Cycles	1st Dev Cycle (Alpha Version)	February 2025
	2nd Dev Cycle (Beta Version)	December 2025
	3rd Dev Cycle (Final Version)	January 2027
Deployment of hardware on the field	Starting Date	October 2024
	Ending Date	July 2025
Testing	Ongoing	October 2024 – October 2026
Piloting Activities	Starting Date	January 2025
	Ending Date	February 2027

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Use Case 5: Italy

Scope and objectives of "No5 UC: Comprehensive Renovation of a Multifamily Building with Air-to-Water Heat Pumps and PCM Storage" (Italy | INNOVA)

SCOPE, OBJECTIVES AND RATIONALE
Describe briefly the Scope of the UC. Enhance energy efficiency and sustainability by performing a comprehensive renovation of a 1800s large complex, integrating advanced air-to-water heat pumps and phase change material (PCM) storage systems, along with other energy-efficient technologies.
Describe briefly the objectives and rationale of the Use Case (UC). This use case aims to minimize energy costs and carbon emissions by implementing a deep renovation that includes an upgraded building envelope, new windows, radiant floor heating, fancoils for cooling and VMCs for air circulation. The goal is to reduce dependency on traditional energy sources, improve thermal comfort, and enhance energy self-sufficiency. **Features under study:** 1. **R290** monobloc unit for outdoor installation TE-5 2. Other Renewable Energy Sources (RES) 3. Storage systems including second life batteries TE-9 4. Semantic interoperability enablers TE-10 5. MPC control of MFH energy system TE-13 6. Decarbonisation as a service TE-17 7. Artelys Crystal Super Grid TE-18 **Assets:** 1. Multifamily residential buildings 2. Commercial building (Hotel) 3. Air-to-water heat pumps 4. PCM storage systems 5. Radiant floor heating and cooling 6. Upgraded building envelope 7. Triple-pane windows 8. Energy Management Systems (EMS) 9. Photovoltaic (PV) systems 10. Electric storage systems **Networks/Markets under study:** 1. Low Voltage (LV) Network 2. Medium Voltage (MV) Network 3. Retail market **Dependence on other BUCs:**

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1. Integration with existing PV systems 2. Coordination with distributed Building Management Systems (BMS)
BUSINESS OBJECTIVES (discrete objectives narrow scope): • Minimize mismatches between supply and demand in terms of energy • Create optimal schedules for energy usage and production • Minimize CO2 emissions • Increase resilience to energy price fluctuations and minimize risk exposure • Ensure reliable and cost-effective outsourcing of required services • Improve overall building performance and indoor environmental quality • Enhance user comfort and satisfaction

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Overview of integration profile "No5 UC: Comprehensive Renovation of a Multifamily Building with Air-to-Water Heat Pumps and PCM Storage"

Description of the action of the UC (from a business point of view), and the actors that participate in this action.

ACTORS & ROLES, NAMES AND TYPES
Indicate which actors contribute to the use case in the sense of providing inputs/outputs, processing or aggregation. In case the writer of the use case defines an own actor, the actor shall be classified and shortly described.
• **Building (heating) operator:** Manages building operations and ensures systems are functioning efficiently. • **Facility managers (Energy Planners):** Oversees planning and strategic decisions for energy systems i.e. the facility's infrastructure, maintenance, and services. • **Residential Tenants:** Occupants of the residential buildings who use the energy systems. • **Commercial Tenants:** Occupants of the commercial part of the buildings who use the energy systems. • **IT service / Digital Solution providers:** Design and Develop EMS, manage data platforms, and tailor-made services that support the use case objectives and ensure seamless integration of various systems. • **Technology suppliers:** Provide the air-to-water heat pumps, PCM storage systems, and other technological components. • **Energy providers (Grid Operators):** Supply electricity and other energy forms to the building. Ensure the distribution and stability of the electricity grid, facilitating the connection and integration of RES.

SHORT DESCRIPTION
A short narrative focusing on the question «what», not «why». Intended only to get a brief overview.
Step wise approach: (Interactions between Actors and in certain cases with the systems/components) 1. The building operator provides services to both residential and commercial tenants. 2. The facility manager collects and study analytics from bot IT service data and from building operator feedback. 3. Falicity managers negotiate and interface with energy provider and tenants to buy energy. 4. Building operator (in collaboration with the facility managers) acquire consent for data collection and collects feedback from the tenants 5. IT service collects, store and provide access to data from every actor to improve service and facilitate performance improvement. 6. Building managers and operators collaborate to plan and provide services. **Additional flows:** 1. **Energy Consumption Analysis:** The system continuously monitors and records real-time tenant energy usage data. 2. **Renewable Energy Tracking:** Accurately measures the building's renewable energy generation. 3. **Advanced Energy Forecasting:** Predictive models forecast future energy needs using historical and environmental data.

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4. **Sustainable Energy Verification:** The platform verifies real-time sustainability and the origin of electricity.
5. **Intelligent Load Management:** The system controls flexible loads based on the consumption schedule for efficiency.
6. **Integrated Data Management:** The IT platform manages and analyses all energy-related data based on decision support systems (DSS).

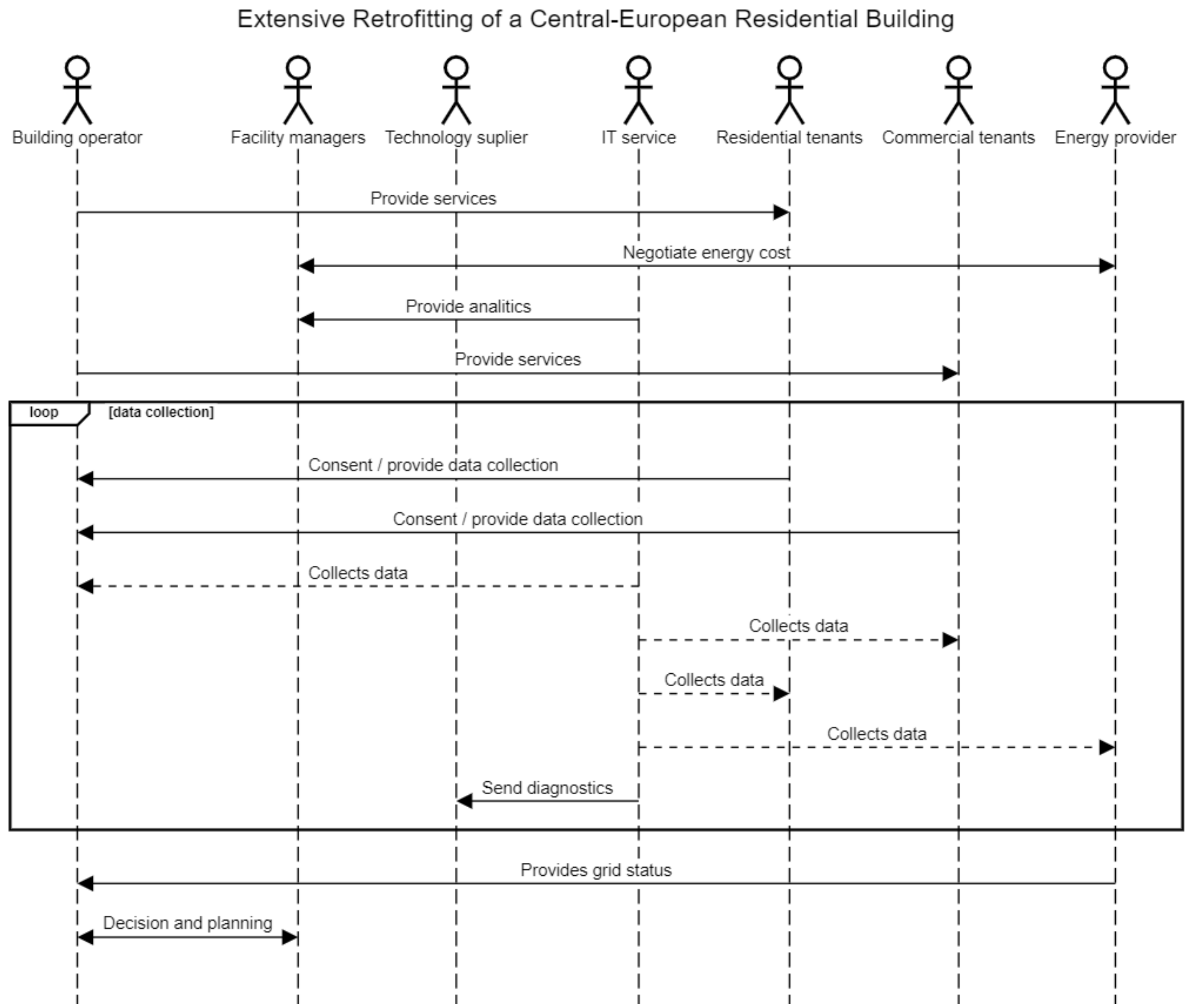

Figure 40 - FR 5 retrofitting process

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Overview of integration profiles and transactions “No5 UC: Comprehensive Renovation of a Multifamily Building with Air-to-Water Heat Pumps and PCM Storage”

Integration profile “No5 UC: Comprehensive Renovation of a Multifamily Building with Air-to-Water Heat Pumps and PCM Storage” – Information exchanged

	Information exchanged				
Info exchange ID	***Name of information***	***Description of information exchanged***	***Indicative Data Types***	***Data Formats***	***Requirement, R-IDs***
1	Electricity Price	EMS needs the electricity price information from the existing electricity supplier every 15 minutes.	Float	JSON, CSV	R2, R4
2	Electricity price from competitors	EMS needs the electricity price information from electricity supplier competitors at the same interval.	Float	JSON, CSV	R2, R4
3	RES energy forecast	EMS needs the upper and lower limit of energy forecast from the Open Energy Service. EMS needs historical and real-time environmental data (e.g., temperature, humidity, weather conditions) for accurate energy forecasts.	Float (Upper Limit, Lower Limit), Timestamp	JSON, XML, CSV	R2, R4
4	Aggregation load forecast	EMS needs the aggregated load forecast (depends on the business model).	Float	JSON, XML	R2, R4
5	Disaggregation load forecast	EMS needs the disaggregated load forecast (depends on the business model).	Float	JSON, XML	R2, R4
6	Power measurement data	EMS needs actual measurements of power from and to the site.	Float, Timestamp	JSON, CSV	R2, R4, R5
7	Thermal storage data	EMS needs data on thermal storage levels and performance from the integrated systems.	Float (Storage Level, Performance)	JSON, XML	R2, R4
8	Data consumed by the services.	Implemented services need data to initialize, design and train their algorithms.	Various (based on service needs)	JSON, XML, CSV	R2, R4
9	Data produced by the services.	The services that will be provided should produce data with a specific, predefined structure.	Various (based on service output)	JSON, XML, CSV	R2, R4
10	Environmental historical and real-time data needed for the forecast.	EMS needs historical and real-time environmental data (e.g., temperature, humidity, weather conditions) to enhance the accuracy of energy consumption and generation forecasts.	Float, Timestamp	JSON, XML, CSV	R2, R4, R5

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Integration profile "No5 UC: Comprehensive Renovation of a Multifamily Building with Air-to-Water Heat Pumps and PCM Storage" – Requirements (optional)

Requirements (optional)		
Categories ID	**Category name for requirements**	**Category description**
Requirement R-ID	**Requirement name**	**Requirement description**
1	DSO regulations	Conform with the law and energy regulations.
2	Energy performance requirement	Ensure energy performance meets specified standards.
3	GDPR	Protect personal data according to GDPR.
4	Cybersecurity	Ensure service access is password protected, with regular updates every 6 months if needed.
5	Level of control	Include human decision-making in the loop for consent management.
6	Subscription	Annual subscription model for the service.

Milestones & Procurement Planning

Milestone Type		Date (DD-MM-YY)
Procurement	Starting Date	01/01/2024
	Ending Date	01/01/2026
Software Development Cycles	…	
	…	
	…	
Deployment of hardware on the field	Starting Date	01/04/2025
	Ending Date	01/01/2026
Testing		All time
Piloting Activities	Starting Date	01/01/2024
	Ending Date	01/01/2026

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Use Case 6: Spain

Scope and objectives of “No6 UC: Implementation of Dual Source/Sink Heat Pumps and PVT Systems” (Spain | TECNALIA)

SCOPE, OBJECTIVES AND RATIONALE

Scope of the UC.

Enhance energy efficiency and sustainability by integrating dual source/sink heat pumps and PVT (Photovoltaic-Thermal) systems into a new extension of TECNALIA’s headquarters, increasing the use of renewable energy sources and improving overall energy management.

Aligned with the commitment of TECNALIA, the key principles applied for the energy-installation in the extension of TECNALIA’s headquarters are energy-efficient and connected to the existing building's energy systems, and more specifically, our focus in on electrifying thermal energy demand.

With this goal on mind, the energy solution is aimed at the maximisation of the performance of the whole heating and cooling, and for that these are the key elements:

1. A **dual source/sink HP**, designed by TECNALIA, utilising storage vessels to cover a greater demand
2. tailored to heat the laboratories
3. **PVT system** improving the water-water mode performance factor of the DSHP during the heating mode
4. Thermally activated part of the foundation, achieving about 10 kW thermal exchange capacity (thermal activation of the concrete wall considered in the construction process) which also is aimed to improve the performance of the DSHP
5. **Building DT** for monitoring and smart control including features for the optimisation of the operation of the energy systems, thermal storage, indoor environmental quality, and renewable energy usage.

Objectives and Rationale of the Use Case (UC).

This use case aims to minimize energy costs and carbon emissions by maximising the ratio of locally produced renewable energy, primarily through advanced dual source/sink heat pump technologies and PVT systems, to meet the thermal energy demand of the TECNALIA headquarters extension. The goal is to reduce dependency on traditional energy sources and enhance energy self-sufficiency.

As mentioned above. the energy solution is aimed at the maximisation of the performance of the whole heating and cooling. This ambitious objective results in the minimisation of energy costs and carbon emissions by maximising the ratio of locally produced renewable energy, primarily through advanced dual source/sink HP technologies and PVT systems. The goal is to reduce dependency on traditional energy sources and enhance energy self-sufficiency.

Features under study:

1. Dual Source/sink heat pump (DSHP) TE-6
2. Hybrid photovoltaic-thermal systems (thermally activated foundation) TE-7
3. Storage systems including second life batteries TE-9
4. Semantic interoperability enablers TE-10
5. Operation, control, and proactive maintenance TE-15
6. Building Digital Twins TE-16
7. Decarbonisation as a service TE-17
8. Artelys Crystal Super Grid TE-18

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Assets: 1. Office and laboratory facilities 2. Renewable Energy Sources (RES) 3. Energy Management Systems (EMS) 4. Thermal activation of concrete structures 5. Digital Twin (DT) **Networks/Markets under study:** 6. Electricity retail market **Dependence on other BUCs:** 7. Integration with existing biomass boiler system 8. Coordination with smart building management systems
BUSINESS OBJECTIVES (discrete objectives narrow scope): • Electrification of thermal energy demand • Minimize mismatches between supply and demand in terms of energy • Create optimal schedules for energy usage and production • Minimize CO_2 emissions • Increase resilience to energy price fluctuations and minimize risk exposure • Ensure reliable and cost-effective outsourcing of required services • Improve overall building performance and indoor environmental quality via digitalisation tools • Ensure interoperability between energy usage and production systems

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Overview of integration profile "No6 UC: Implementation of Dual Source/Sink Heat Pumps and PVT Systems"

Description of the action of the UC (from a business point of view), and the actors that participate in this action.

ACTORS & ROLES, NAMES AND TYPES
Indicate which actors contribute to the use case in the sense of providing inputs/outputs, processing or aggregation. In case the writer of the use case defines an own actor, the actor shall be classified and shortly described.
• **ESCO (Building operator/Energy planner):** Manages building operations and ensures systems are functioning efficiently. Oversees planning and strategic decisions for energy systems i.e., the facility's infrastructure, maintenance, and services. • **Building owner/ Demo operator (TECNALIA):** Coordinates demonstration activities and collects data for analysis. • **Tenants/Occupants (Office and laboratory users):** Occupants of the building who use the energy systems. • **IT service/ Digital solutions providers:** Manages data platforms and ensures seamless integration of various systems. • **Technology suppliers / technology specialists (TECNALIA):** Provide the dual source/sink heat pumps, PVT systems, RES, Digital Twin and other technological components. • **Energy providers (Grid Operators):** Supply electricity and other energy forms to the building. Ensure the distribution and stability of the electricity grid, facilitating the connection and integration of RES. • **Retailer (OMIE):** the nominated electricity market operator (NEMO) for managing the Iberian Peninsula day-ahead and intraday electricity markets. Provides energy pricing and market data. • **Construction Contractors:** Responsible for the construction process, including the thermal activation of the concrete wall and installation of energy-efficient systems.

SHORT DESCRIPTION
A short narrative focusing on the question «what», not «why». Intended only to get a brief overview.
Step wise approach: (Interactions between Actors and in certain cases with the systems/components) 1. The Building owner/Demo operator gives the Constructor contractors the information regarding the building construction needs for the HP, PVT, thermally activated concrete walls and monitoring/control parameters. 2. The Building owner/Demo operator/Technology provider gives the IT services and ESCO the building management strategies and the monitoring/control/strategy validation predefined needs. 3. The Building Energy Management System (BEMS): The ESCO together with the IT service program the energy operation schemes. Manages data platforms and ensures seamless integration of various systems including the operational Digital Twin including predictive models. 4. The BEMS from the ESCO collects energy consumption and production data from the building via an API every timestep selected, storing it in an online/local database of the Digital Twin. 5. The Digital Twin from the demo owner communicates with the BEMS, uses the stored data to calculate the net energy output, building optimised operation (energy generation and consumption, comfort, EIQ parameters) and preventive maintenance and decision making. 6. The DIGITAL TWIN retrieves combined signals for retail prices and grid tariffs for the day/week-ahead from the Retailer.

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7. This information (net load, prices) and occupation schedule (room reservation provided by occupants, monitoring and prediction) is combined with forecasted energy demand/generation models and guarantees of origin from the electricity supplier to derive a consumption schedule. The DIGITAL TWIN communicates with the BEMS/controller to activate or deactivate devices based on this schedule and predictive operation schemes. Data will be stored on a data platform provided by the IT service.

Additional flows:

1. **Energy Consumption Analysis:** The system continuously monitors and records real-time energy usage data from all building systems.
2. **Renewable Energy Tracking:** Accurately measures the building's renewable energy generation from dual source/sink heat pumps and PVT systems.
3. **Advanced Energy Forecasting:** Predictive models forecast future energy needs using historical, environmental and occupation data.
4. **Sustainable Energy Verification:** The platform verifies real-time sustainability and the origin of electricity.
5. **Intelligent Load Management:** The system controls flexible loads based on the consumption schedule for efficiency.
6. **Integrated Data Management:** The DIGITAL TWIN manages and analyses all energy-related data based on decision support systems (DSS).
7. **Testing and Validation:** The Building Owner/ Demo Operator conducts testing and provides validation results.

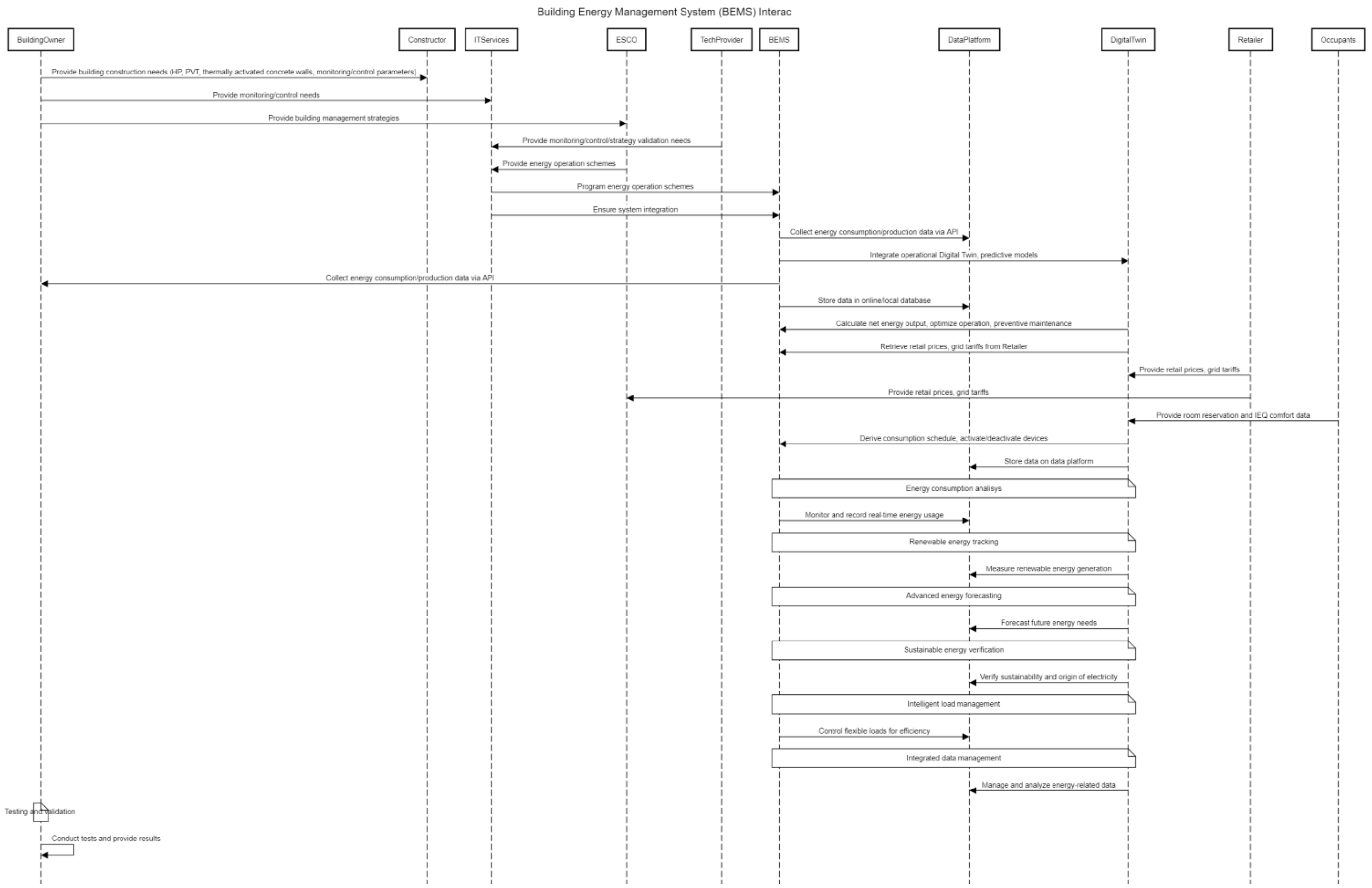

Figure 41 – FR 6 BEMS interaction

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Overview of integration profiles and transactions “No6 UC: Implementation of Dual Source/Sink Heat Pumps and PVT Systems”

Integration profile “No6 UC: Implementation of Dual Source/Sink Heat Pumps and PVT Systems” – Information exchanged

	Information exchanged				
Info exchange ID	**Name of information**	**Description of information exchanged**	**Indicative Data Types**	**Data Formats**	**Requirement, R-IDs**
1	Electricity Price	EMS needs the electricity price information from the existing electricity supplier every 15 minutes.	Float	JSON, CSV	R2, R4
2	Electricity price from competitors	EMS needs the electricity price information from electricity supplier competitors at the same interval.	Float	JSON, CSV	R2, R4
3	RES energy forecast	EMS needs the upper and lower limit of energy forecast from the Open Energy Service. EMS needs historical and real-time environmental data (e.g., temperature, humidity, weather conditions) for accurate energy forecasts.	Float (Upper Limit, Lower Limit), Timestamp	JSON, XML, CSV	R2, R4
4	Aggregation load forecast	EMS needs the aggregated load forecast (depends on the business model).	Float	JSON, XML	R2, R4
5	Disaggregation load forecast	EMS needs the disaggregated load forecast (depends on the business model).	Float	JSON, XML	R2, R4
6	Power measurement data	EMS needs actual measurements of power from and to the site.	Float, Timestamp	JSON, CSV	R2, R4, R5
7	Thermal storage data	EMS needs data on thermal storage levels and performance from the integrated systems.	Float (Storage Level, Performance)	JSON, XML	R2, R4
8	Data consumed from the Digital Twin	The Digital Twin implementation needs data both before and after its integration.	Float, Integer, Timestamp	JSON, XML, CSV	R2, R4, R5
9	Data consumed and produced from the Digital Twin	The Digital twin implementation produces information that needs to have a specific, predefined structure.	Float, Integer, Timestamp	JSON, XML, CSV	R2, R4, R5

Integration profile “No6 UC: Implementation of Dual Source/Sink Heat Pumps and PVT Systems” – Requirements (optional)

Requirements (optional)		
Categories ID	**Category name for requirements**	**Category description**
Requirement R-ID	**Requirement name**	**Requirement description**
1	DSO regulations	Conform with the law and energy regulations.
2	Energy performance requirement	Ensure energy performance meets specified standards.
3	GDPR	Protect personal data according to GDPR.
4	Cybersecurity	Ensure service access is password protected, with regular updates every 6 months if needed.

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5	Level of control	Include human decision-making in the loop for consent management.
6	Subscription	Annual subscription model for the service.

Milestones & Procurement Planning

Milestone Type		Date (DD-MM-YY)
Procurement	Starting Date	01/01/2024
	Ending Date MS10	28/02/2027 MS10
Software Development Cycles	1st technology development cycle completion MS5	28/02/2025
	2nd technology development cycle completion MS8	31/01/2026
	Final technology development cycle completion MS10	31/03/2027
Deployment of hardware on the field	Starting Date	01/06/2024
	Ending Date MS10	28/02/2027
Testing	Starting Date	01/03/2025
	Ending Date MS10	28/02/2027
Piloting Activities	Starting Date	01/01/2024
	Ending Date MS11	31/10/2027

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