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Deliverable D2.3

Novel Energy Generation Systems for Increasing Buildings Flexibility Potential

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VELIXIA
BUILDINGS AS ACTIVE UTILITY NODES

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Deliverable D2.3

Novel Energy Generation Systems for Increasing Buildings Flexibility Potential

Deliverable number	D2.3
Deliverable name	Novel Energy Generation Systems for Increasing Buildings Flexibility Potential
Lead beneficiary	TUCN
Description	This deliverable is directly linked to the activities foreseen in Task 2.2 and Task 2.3, consolidating all foreseen technical developments from the different renewable power generation and thermal storage systems' technology providers. This report is considered as the first version of D2.4, from Month 33.
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EXECUTIVE SUMMARY

This document highlights the critical intersection of energy innovation and smart building technologies. The deliverable encompasses the field technology developments foreseen for EVELIXIA's technological repository and focuses on the deployment of novel renewable energy-harvesting solutions, capable to extend the flexibility and self-sustainability potential of buildings. Three main innovative systems will be described and developed for the implementation at the Romania and Austria pilot sites:

1. **GeoWall** - an innovative solution of energy geostructures adapted for existing underground walls of existing buildings, leverages the existing infrastructure to create a sustainable and cost-efficient energy solutions—all while meeting the structural and functional requirements of modern buildings through retrofitting. With thousands of buildings in need of urgent retrofitting, GeoWall aims to provide a scalable and practical approach to upgrading urban environments without major disruptions or excessive costs.
2. **Circular Building-Integrated Photovoltaics (BIPVs)** including re-lamination of micro-PV panels, alongside the application of novel panel frames, junction boxes, replaced diodes, plugs and sockets. This will allow for producing new custom BIPV modules that ensure locally used PVs circularity. Performance tests for the novel BIPVs installation will be conducted prior to their installation in the laboratory, to identify best electrical configuration (on grid classical string inverter or micro inverter usage).

Both technologies are developed by the TUCN team. The following one is developed by PINK partner.

3. **Thermal flexibility through thermal storage solution** refers to the ability to efficiently store heat and release it as needed to respond to fluctuations in energy supply and demand. energy storage through thermal energy storage. This offers numerous advantages for the energy efficiency of energy supply systems or buildings. Therefore, thermal energy storage systems enable increased use of renewable energy sources in the energy system by eliminating the mismatch between renewable energy generation and the

demand load. An essential aspect of storage systems development is the possibility of charging them with different forms of energy, in the project the following charging systems are considered: a hydraulic charging system, an electric charging system, a hybrid charging system (combination of both).

EVELIXIA
BUILDINGS AS ACTIVE UTILITY NODES

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1 INTRODUCTION

1.1 Scope & Objectives

D2.3 is directly linked to the activities foreseen in Task 2.2 and Task 2.3 considering the deployment and design of the EVELIXIA's novel renewable energy generation and dynamic building envelope and thermal flexibility through thermal storage solutions.

D2.3 is the first version of D2.4, which will be delivered in Month 33.

This report focuses first, on the development of novel renewable energy-harvesting solutions, capable to extend the flexibility and self-sustainability potential of buildings. The development of three main technology elements: Geothermal Wall solution and the novel circular BIPVs, including re-lamination of micro-PV panels, foreseen by TUCN in the Romanian pilot, and a novel thermal storage system, "enerboxx" and the installation of buffer tanks, which aims to provide temporal flexibility for heating and DHW loads at the Austrian pilot site, developed by PINK under Task2.3.

1.2 Structure of the deliverable

The document is structured around each novel renewable energy. These are described as follows:

Section 2 describes the GeoWall with an overview on the energy geostructures, afterwards the focus is on the solution developed in the Romania pilot site (site investigations and preliminary numerical modelling, execution of GeoWall system and first test for the monitoring phase).

Section 3 details the deployment of the BIPVs that are going to be installed in the Romania pilot site (introduction and objectives, adaptable energy systems and some conclusions).

Section 4 is dedicated to the development of thermal storage solution which will be installed at the Austria pilot site. This section starts with the description of the thermal storage in general and then the EVELIXIA solution is presented (simulation and calculations, dimensioning of the system, timetable and next steps).

At the end of the deliverable some important conclusions and remark are drawn.

1.3 Relation to other tasks and deliverables

D2.3 collects the assessment of the three novel renewable energy-developed by TUCN and PINK. This document is directly report with the WP2 – "EVELIXIA's Intelligent Technological Repository as flexibility enablers", Task2.2 – "EVELIXIA's novel RE generation and dynamic building envelope solutions" and Task2.3 – "Thermal flexibility through thermal storage solutions".

These technologies will be implemented at the Romania and Austria pilot site at the WP5 - EVELIXIA's holistic integration, pilot demonstrations and impact assessment", Task 5.3.1: "Execution and Testing of BAUN project #1: Austrian Pilot Site" and Task 5.3.2: "Execution and Testing of BAUN project #2: Romanian Pilot Site".

2 GEOTHERMAL WALL SYSTEM

2.1 INTRODUCTION

Managing energy resources is one of the most pressing global challenges of our time. The overuse of fossil fuels has significant environmental consequences, posing numerous problems, including the impact of CO2 emissions and their contribution to climate change. Addressing these issues is essential for building a sustainable and environmentally friendly future. While renewable energy technologies are steadily gaining popularity, their overall impact and contribution remain relatively limited compared to other energy sources. According to the International Energy Agency (IEA), total primary energy demand is projected to reach approximately 23 TW by 2030—an increase of nearly 320% compared to 1970—based on current policies and political measures.

Policy changes across Europe are expected to drive a significant increase in renewable energy implementations in the coming years. However, it is crucial to emphasize that, beyond quantity, the quality of these implementations is vital to achieving sustainable and meaningful progress in renewable energy adoption and CO2 emissions reduction. This is particularly relevant for emerging thermal energy technologies like GeoWall, which, compared to other existing renewable solutions, may face unique challenges, especially in new markets with limited experience in geothermal heat pump systems.

As shown in Figure 1, the residential sector within the European Union (EU) accounts for approximately 64.1% of total energy consumption for space heating and cooling. This highlights the potential impact of advanced thermal energy solutions in addressing energy efficiency and emissions reduction within this sector.

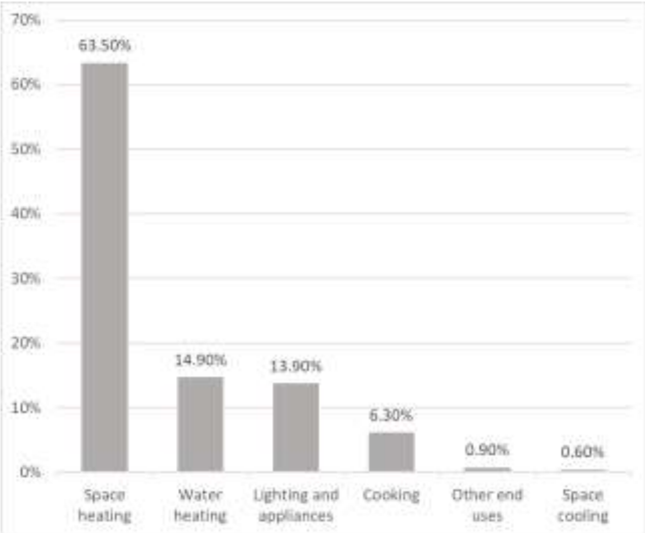


Figure 1. Final energy consumption in the residential sector by use, EU, 2022 https://ec.europa.eu/eurostat

These consumption patterns are not exclusive to EU countries. Similar statistics are observed in other nations, such as the United States (USA), where energy consumption for heating and cooling in commercial and residential buildings follows comparable trends. [1]. Based on this, it can be inferred that advancements in renewable energy technologies for heating and cooling, particularly through the development of innovative and sustainable systems, could have a significant global impact.

Geothermal energy stands out as one of the most versatile renewable energy sources, offering a wide range of applications depending on the type of geothermal system and site potential. Among these, heating and cooling are among the most common applications, delivering highly successful results in terms of operational cost efficiency and long-term performance.

Geothermal energy systems can be broadly classified into two types based on their depth: deep geothermal systems (greater than 500 m) and shallow geothermal systems (less than 500 m). The stability of ground temperature, combined with the ground's low thermal conductivity, makes the soil an ideal medium for energy exchange.

2.2 ENERGY GEOSTRUCTURES

In order to get to the idea on how GeoWall works, a short description of energy geostructures and ground source heat pump is needed.

2.2.1 Principles of a ground source heat pump

A ground source heat pump (GSHP) system, as applied in energy geostructures, is a thermal energy exchange system that utilizes the ground as a heat source in heating mode and as a heat sink in cooling mode. The system consists of a heat pump, which facilitates the transfer of thermal energy between the ground and the building, and a network of heat exchangers embedded within the geostructure. This configuration enables efficient thermal regulation by leveraging the relatively stable subsurface temperature, thereby enhancing energy efficiency and reducing reliance on conventional heating and cooling systems [2].

The operating principle of a GSHP system involves circulating a fluid through the ground, where it interacts with the stable subsurface temperature. In heating mode, a cooler fluid absorbs heat and increases in temperature, while in cooling mode, a warmer fluid releases heat and decreases in temperature.

An energy geostructure system consists of three main components:

- Primary circuit: Concrete-embedded thermal exchange elements.
- Heat pump: Facilitates heat transfer between the ground and the building.
- Secondary circuit: Pipework system that distributes heating and cooling within the building.

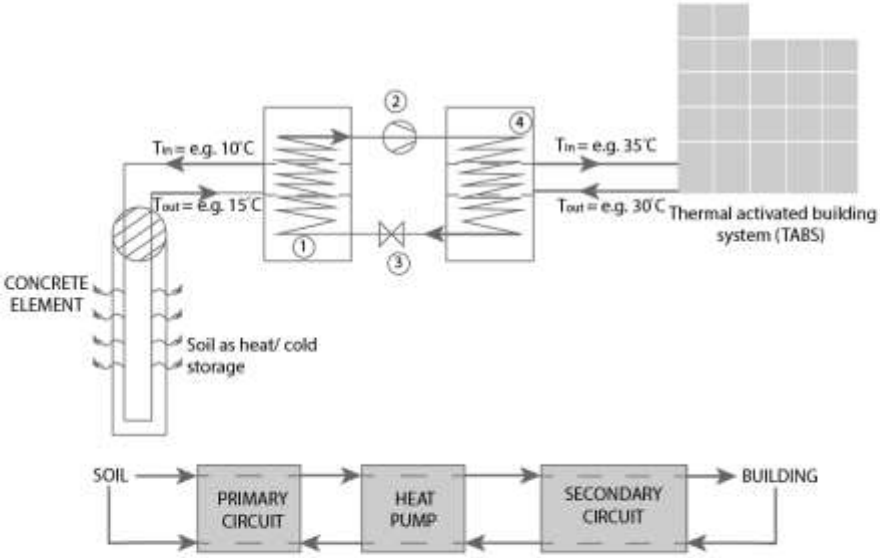


Figure 2. Scheme of a GSHP system mixed with energy geostructure [3]

2.2.2 General overview of energy geostructures

Energy geostructures represent a cutting-edge solution that provides significant contributions to environmental sustainability while delivering notable cost efficiencies. As an integral part of shallow geothermal energy systems, energy geostructures integrate principles from multiple disciplines, including geothermal energy, geotechnical and structural engineering, and building systems design. The technological innovation lies in leveraging structural concrete elements of a building to perform dual functions: structural support and energy exchange.

From a structural perspective, these elements ensure the mechanical stability, resistance, and equilibrium of the building. Simultaneously, their energy function transforms them into efficient heat exchange units. This is achieved by embedding pipes within the steel reinforcement of the concrete. A heat transfer fluid circulates through these pipes, facilitating energy exchange with the surrounding ground. During winter, the system extracts heat from the ground to warm the building, while in summer, it dissipates heat into the ground, providing cooling. This integrated approach optimizes energy performance and promotes long-term sustainability.

In comparison to conventional geothermal systems, such as borehole heat exchangers, horizontal loops, or open-loop systems, energy geostructures offer distinct advantages that enhance their sustainability. Notably, they eliminate the need for additional construction components, as the structural elements already required for the building are repurposed for energy functions. This minimizes installation costs and space requirements. Furthermore, the embedding of the energy system within the concrete ensures durability, reduced maintenance costs, and improved long-term performance. These benefits, as illustrated in **Figure 3**, position energy geostructures as a highly efficient and sustainable alternative to traditional geothermal technologies.

The primary advantage of energy geostructures lies in their ability to repurpose existing structural concrete elements for energy applications, eliminating the need for additional components dedicated solely to the renewable energy system. This integration significantly reduces initial capital costs associated with system implementation.

Moreover, unlike conventional geothermal systems, energy geostructures require no additional land or space on-site, as the energy system is embedded within the structural elements of the building. This compact integration enhances the feasibility of deployment, particularly in urban environments or areas with limited space.

By embedding the energy system within the concrete, it benefits from increased protection against external factors, ensuring enhanced durability and long-term performance. This design also minimizes maintenance requirements, further reducing operational costs. When appropriately designed and implemented, the initial investment for energy geostructures can be offset within the first few years of operation, offering a cost-effective and sustainable solution for renewable energy generation in heating and cooling applications.

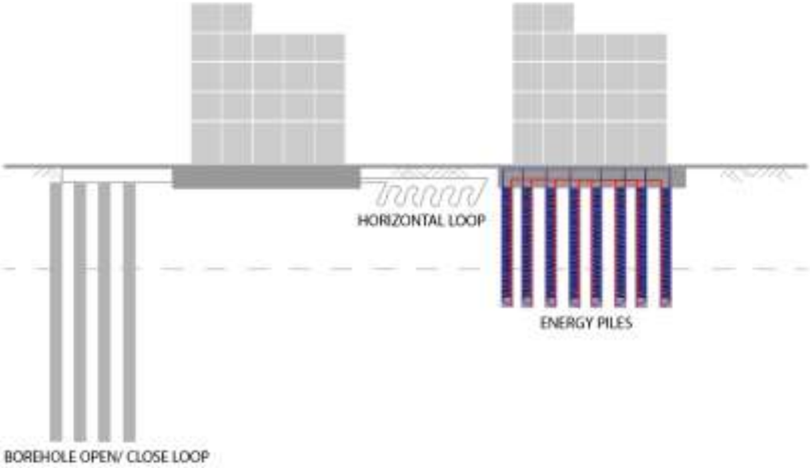


Figure 3. Conventional geothermal system vs. energy geostructures [3]

The energy geostructures system can be successfully implemented in different types of concrete structures, such as shown in **Figure 4**:

- piles, as part of deep foundation systems or as part of retaining structures;
- diaphragm walls as part of underground level of residential buildings, underground parking or metro stations infrastructure;
- tunnels.

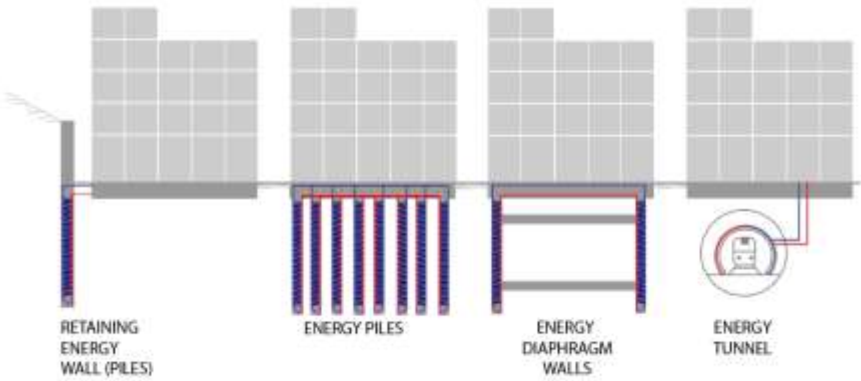


Figure 4. Energy geostructures types [3]

The primary application of ground energy utilization is the heating and cooling of commercial and residential buildings. However, the extracted thermal energy can be deployed in various additional applications. Given the high efficiency and feasibility of such systems, ground energy can be effectively used for domestic hot water supply, de-icing of exposed concrete surfaces such as parking slabs, bridge decks, and airport runways. In cooling applications, thermal regulation of bridge decks mitigates temperature-induced stresses, thereby enhancing structural longevity while reducing maintenance costs.

Among the various energy geostructure types, energy piles constitute the majority of existing installations. However, in recent years, other energy geostructures have gained increasing adoption. In particular, energy tunnels are emerging as a key component of sustainable urban infrastructure due to their significant thermal exchange potential. [4]. A key advantage of energy tunnels lies in their extensive surface area in contact with the ground, which is significantly larger than that of other energy geostructures. This increased contact area enhances heat exchange efficiency, allowing for the extraction and transfer of a greater amount of thermal energy to the supported buildings. Consequently, energy tunnels exhibit superior performance in terms of energy efficiency, sustainability, and CO_2 emission reduction, making them a highly impactful solution for geothermal energy integration in urban infrastructure.

Due to their undeniable advantages, the adoption of energy geostructures has been increasing annually. The first energy geostructures were constructed in Austria in the mid-1980s, the country where this technology originated. Globally, energy piles represent the most widely implemented type of energy geostructure, followed by energy walls and tunnels. The widespread use of energy piles can be attributed to the extensive research and development in this area, making them the most technologically advanced energy geostructure. Additionally, piles are a fundamental geotechnical element commonly employed for various structural applications, further contributing to their prevalence.

Energy tunnels, in particular, function as highly efficient heat exchangers due to their extensive surface contact with the ground, allowing for superior thermal energy capture and transfer. However, despite their clear advantages, the implementation of such structures can be challenging. This is often due to the complex decision-making processes involving multiple institutions and regulatory bodies, as well as legal uncertainties surrounding the ownership and distribution of the harvested geothermal energy.

During the pre-design phase of energy geostructures, performance estimations based on data from previous implementations can provide valuable insights, as illustrated in **Table 1**. However, site-specific factors play a crucial role in actual energy performance, and deviations—both positive and negative—from reported values are possible depending on the unique characteristics of each project.

Table 1. Energy volume that can be extracted [4], [5]

Type of element	Energy
Piles	40 to 100 W/m
Diaphragm walls and tunnels	10 to 50 W/m^2
Base slabs	10 to 30 W/m^2

Multiple case studies and applications have demonstrated that energy geostructure systems can meet up to 100% of a building's heating and cooling demands. The overall energy performance can be further optimized through precise system design, where critical influencing factors—such as geological conditions, thermal properties of the surrounding soil, structural load interactions, and operational strategies—are carefully considered during the design phase. Proper integration of these parameters ensures maximum efficiency, sustainability, and long-term reliability of the system.

2.3 GeoWall – an innovative of energy geostructures adapted for retrofitting

The existing built environment in Europe is largely composed of old buildings that many of them no longer meet current standards in terms of structural integrity, material performance, and energy efficiency. This challenge is even more critical in Eastern Europe, where many existing buildings (apartment buildings, schools, dorms, hospitals, etc.), built during the communist era, feature underground structures that require significant retrofitting efforts to ensure their long-term functionality and safety. At the same time, the demand for cost-effective solutions that not only improve the structural performance of these buildings but also enhance their sustainability is a reality. In this context GeoWall is a cutting-edge energy geostructure technology that offers a dual benefit:

- [x] It reinforces and retrofits underground walls, ensuring improved stability and durability together with thermal isolation.
- [x] It transforms these structures into local renewable energy sources, contributing to energy efficiency and decarbonization goals ensuring a local sustainable renewable energy source

By adapting energy geostructures technology for existing underground walls of existing buildings, GeoWall leverages the existing infrastructure to create a sustainable and cost-efficient energy solutions—all while meeting the structural and functional requirements of modern buildings through retrofitting.

With thousands of buildings in need of urgent retrofitting, GeoWall aims to provide a scalable and practical approach to upgrading urban environments without major disruptions or excessive costs. This innovative approach is set to redefine the way we think about structural rehabilitation, offering a smart, future-proof alternative for cities looking to build resilience and sustainability into their existing infrastructure.

2.3.1 Exterior and Interior GeoWall

The GeoWall system is a modular and scalable solution designed for retrofitting and enhancing the energy performance of existing underground structures designed to be adapted for both interior or exterior spaces depending on the location where retrofitting works are required or most suitable. It integrates thermal insulation and energy harvesting capabilities, providing a dual function that improves both the thermal efficiency of buildings and their ability to harness and repurpose waste heat from interior spaces. Given the significant share of aging buildings across Europe, particularly in Eastern Europe where underground spaces often require structural and thermal retrofitting, Interior GeoWall presents a cost-effective and innovative approach to upgrading these structures while supporting the transition towards sustainable and energy-efficient buildings.

2.4 SITE INVESTIGATIONS AND PRELIMINARY NUMERICAL MODELLING

Since the proposed GeoWall do not involve structural concrete elements, that need to be analysed the main focus is on energy harvest from soil and interior of the building.
Regarding the interior of the building the main parameter of interest is the inside temperature in the basement. Considering that at the time of installation of the heat pump there was no monitoring of the interior temperature of the basement, the temperature from below chart is the temperature in the basement from 17th of December 2024 until 16th of January 2025. A temperature around the value of 19,5°C was observed during the 1 month monitoring period, confirming the feasibility of the interior GeoWall.

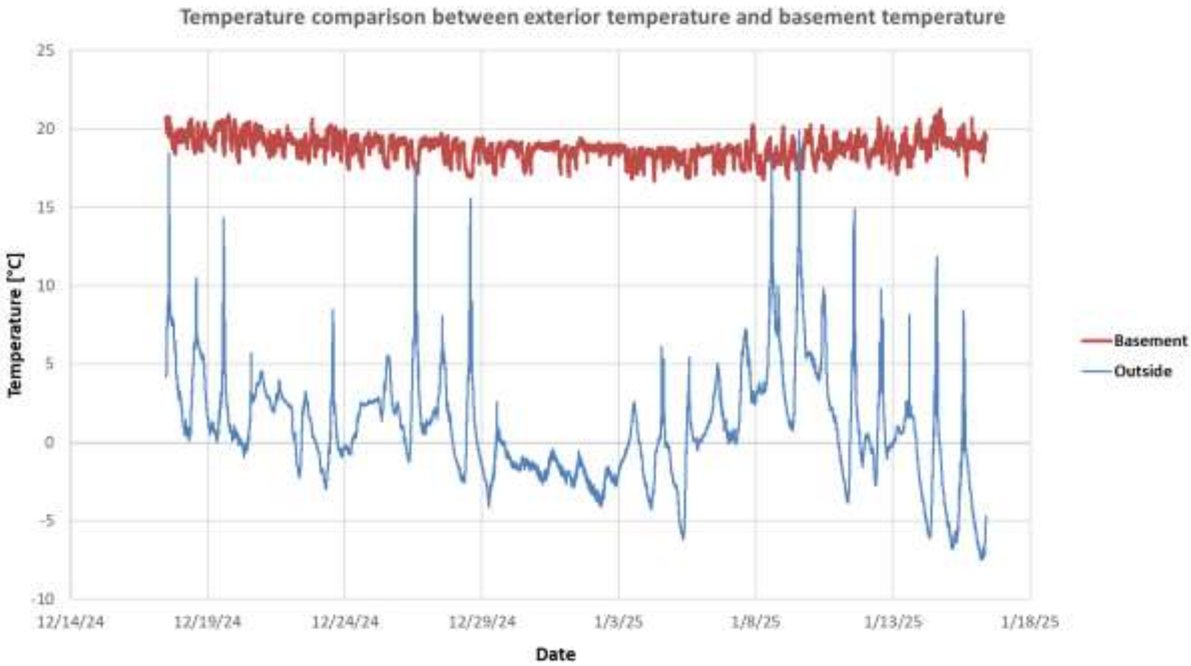


Figure 5. Temperature inside the basement compared to exterior temperature

In order to model the energy that can be extracted from the soil, various thermal and hydraulic parameters of soil are needed:

- Thermal conductivity of soil
- Volumetric heat capacity

- Thermal diffusivity
- Undisturbed soil temperature
- Groundwater flow rate

After doing a soil excavation in order to observe the dimension of the exterior wall, no groundwater flow was observed.

Figure 6. Execution of digging for measurements of the wall

This was confirmed when the excavations executed for the execution of the exterior GeoWall were done. Also, when the digging for the execution of GeoWall was done, soil samples were collected in order to determine the thermal conductivity test of soils around the wall.

Table 2. Collected sample for testing

Zone of sampling	Depth	Samples code
Evelixia – Section 1	1 – 2 m and 0 – 0.3 m	Sample 1 and Sample 2
Evelixia – Section 2	1 – 2 m and 0 – 0.3 m	Sample 3 and Sample 4

In terms of type of soil, all of them are gap graded sandy gravel mixed with construction materials with an average water content of 3,83%, as can be seen in the below pictures.

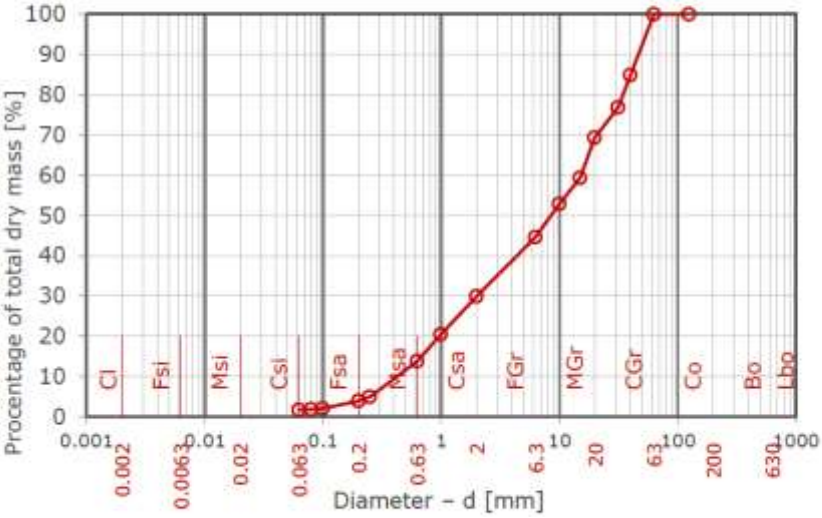


Figure 7. Granulometric curve of tested material

Figure 8. Material existing on ground

An extensive laboratory analysis was conducted on the samples to evaluate the correlation between water content variation and thermal conductivity under non-compacted conditions. The decision to exclude compaction was based on field constraints, as achieving proper backfill compaction without risking damage to the pipes would be impractical. The primary objective of the exterior GeoWall is to assess the potential energy extraction from in-situ soils when local materials are used for retrofitting, even in cases where alternative soils with superior thermal properties may be available.

The thermal conductivity was determined using needle probe method, which is a widely used technique for measuring the thermal conductivity of materials, particularly soils, polymers, and other soft or granular substances. It is based on the principle of transient heat conduction. The principle of the method is the following: A thin, cylindrical probe (needle) containing a heating element and a temperature sensor is inserted into the sample. When a constant heat flux is applied, the temperature rise in the probe over time is recorded. The thermal conductivity of the material is then determined by analysing the temperature-time response.
Based on conducted test, it can be clearly observed that the thermal conductivity varies a lot with the degree of water content:

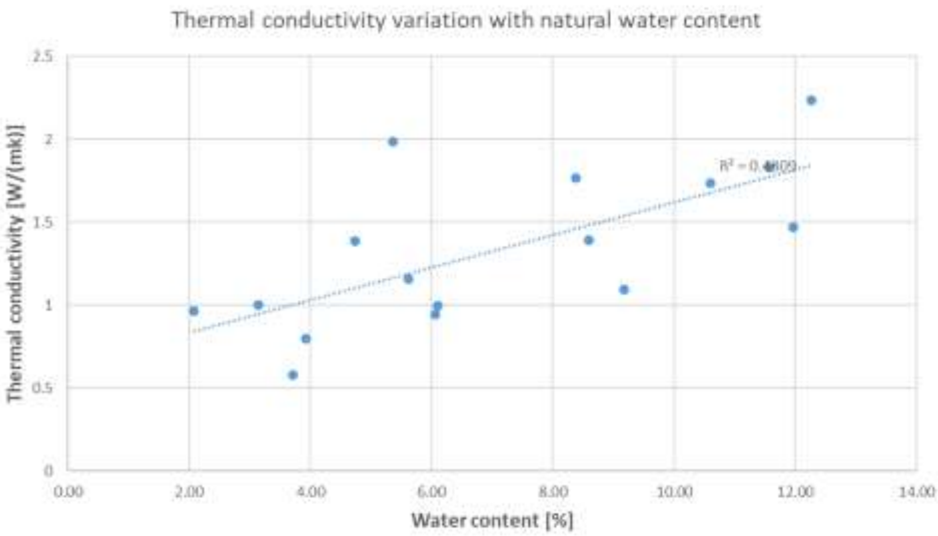


Figure 9. Thermal conductivity of samples 1-4 with water content variation

Considering that the exterior GeoWall is at the surface, with depths around 1.5 m, the water table content can vary a lot during the years, making so the numerical modelling more difficult.
In order to analyse the behaviour of the GeoWall system, installed in Cluj-Napoca pilot site, some preliminary measurement and modelling were performed. The purpose of those actions is to determine some variables that can influence the functionality and the performance of the installed system. Some initial prediction will clarify some technical details that may clarify several aspects regarding the geometry of the structure and the proprieties of the materials that will be integrated into the final implemented system.

At this point, some preliminary simulations were performed to predict the temperatures that are expected into the demo-site. The interest zone was restricted to a parallelepiped volume of soil, having the width of 8.75m, the depth of 4m and the height of 3m.

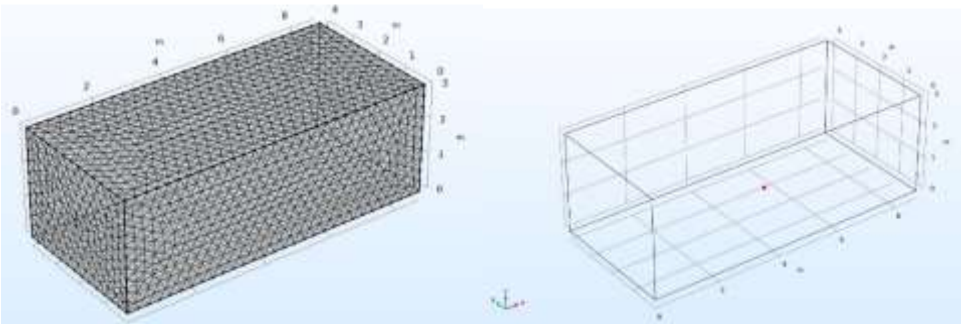


Figure 10. The analysed soil discretisation and probes point deployment

The finite element method was used for the modelling and COMSOL Multiphysics software. The soil volume was divided into 85000 elements, more than enough for the simulation of temperature variation of the soil, and three probe points were disposed in the central part of the analysed domain, at various depths in the ground: 0.5m, 1.5m and 2.5m.

The analysis of soil temperature evolution for ten years was first performed. The time for the simulation was set to 4016 days, starting from 2-nd January of 2013 and finishing with 31 of December 2023.

The daily medium external temperature Cluj-Napoca was considered as input variable. Soil properties were imposed in respect with the data provided by civil engineering authorised authorities. The values of the temperature introduced were interpolated in an analytical curve, by a piecewise cubic method, the graphical representation being represented below.

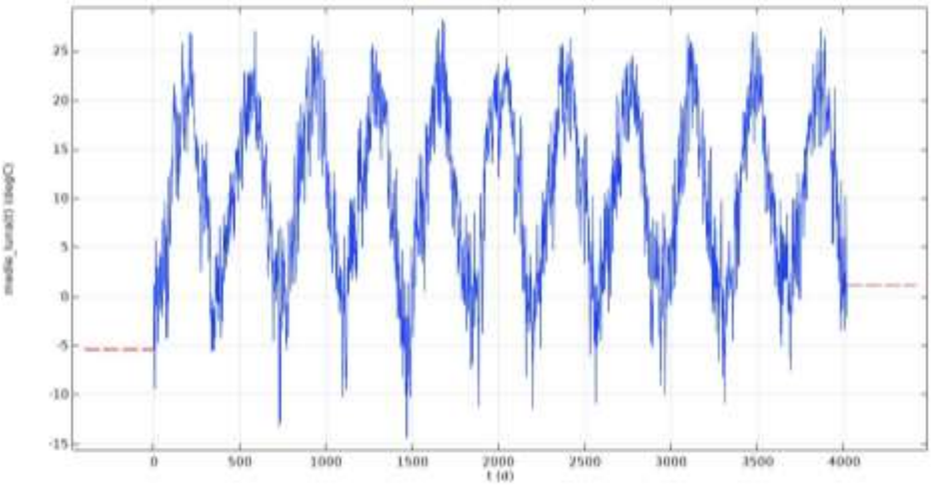


Figure 11. The daily medium external temperature, 2013-2023 interval, from Cluj-Napoca, Romania

Considering a surface emissivity of 0.97 and a heat capacity at constant pressure of 1237 [J/(kg·K], the results are presented in **Figure 12**. All the variables can be easily replaced in the modelling software in order to adapt to various soil properties or other imposed conditions.

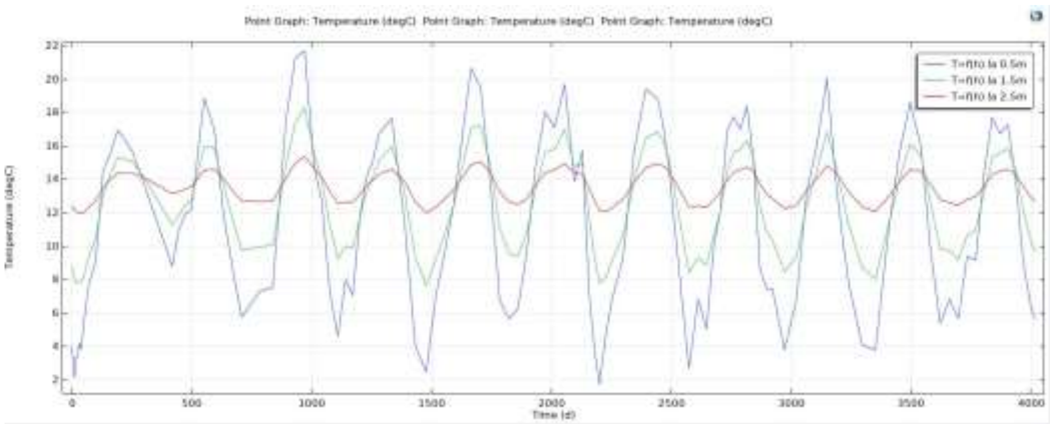


Figure 12. The variation of the temperature at three different depths in the soil

The data from simulation can be exported and used for different analytical calculus that can estimate the parameters at any time or in different points of the domain. The accuracy of the results is sustained by the convergency graph provided by the software. As it can be seen from **Figure 13,** the convergency of the results is less than 10^{-6}, a value that is more than satisfying for this kind of simulation.

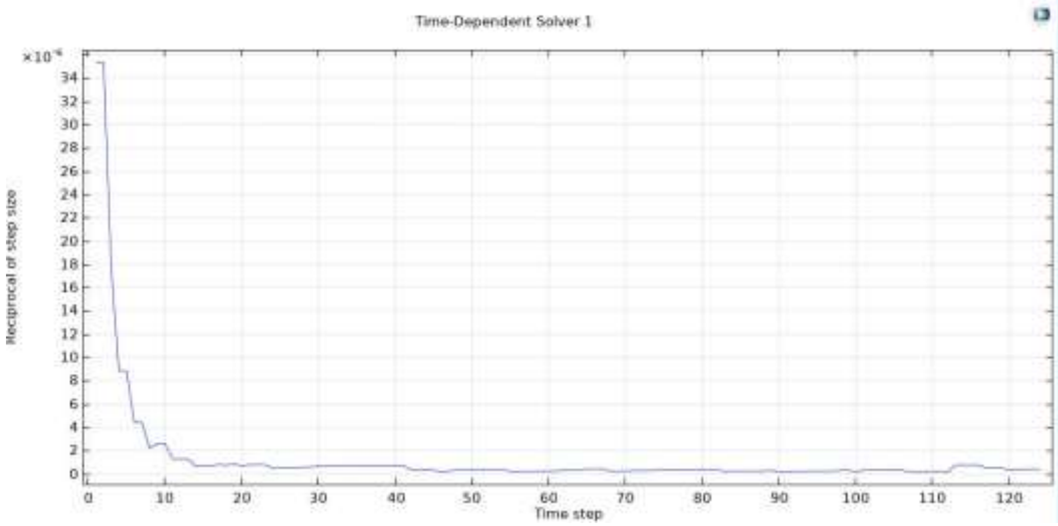


Figure 13. The convergency graph for the performed simulation

2.5 EXECUTION OF GEOWALL SYSTEM

The execution of GeoWall system was done started in October 2024, and was finished around 17th of December 2024. During that time the following execution works were done:

- Execution of radiant panels inside the dorm room
- Execution of exterior GeoWall system
- Execution of interior GeoWall system
- Connections of the systems to the heat pump system

The exterior and interior GeoWall system was connected to a general manifold, and from there to the heat pump. From the heat pump the energy is delivered to the room. A sketch of the system is described in **Figure 14**.

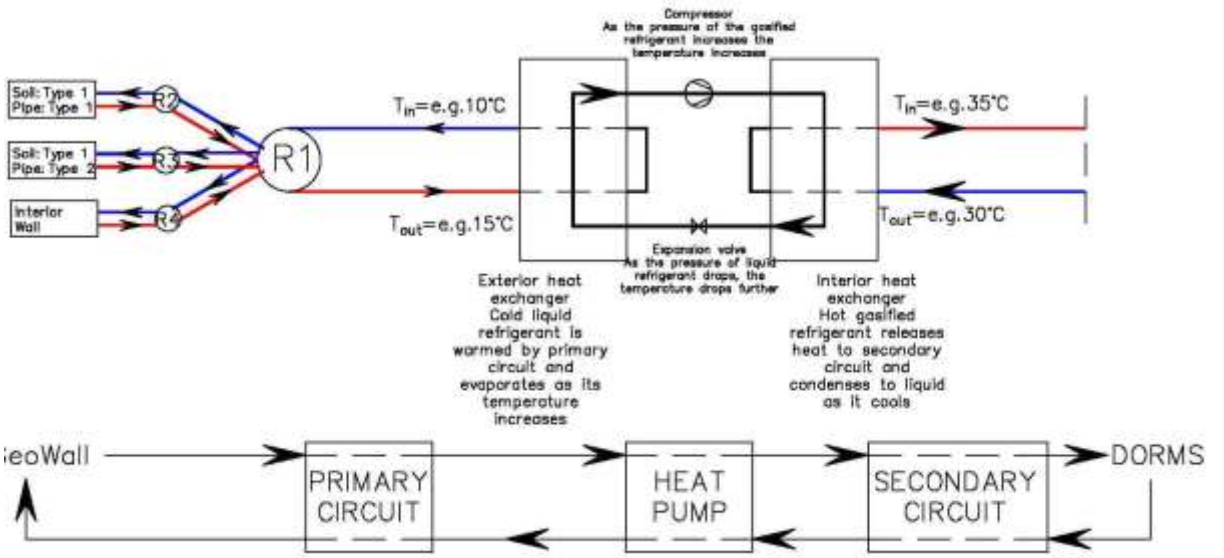


Figure 14. Sketch of the heat pump system

2.5.1 Dorm room

For the Evelixia project, 1 dorm room was renovated and radiant ceiling was installed. For each room around 250 m of Pe-xa Pipe was installed into the radiant ceiling. The total surface of radiant healing is of approx. 21.35 sqm.

Figure 15. Radiant ceiling

2.5.2 Exterior GeoWall

The exterior GeoWall was executed on the exterior of the light court of the dorms, and has a total surface of 27 m x 1,30 m = 35,10 sqm. The exterior GeoWall is spliced into 2 types where the pipe layout is different.

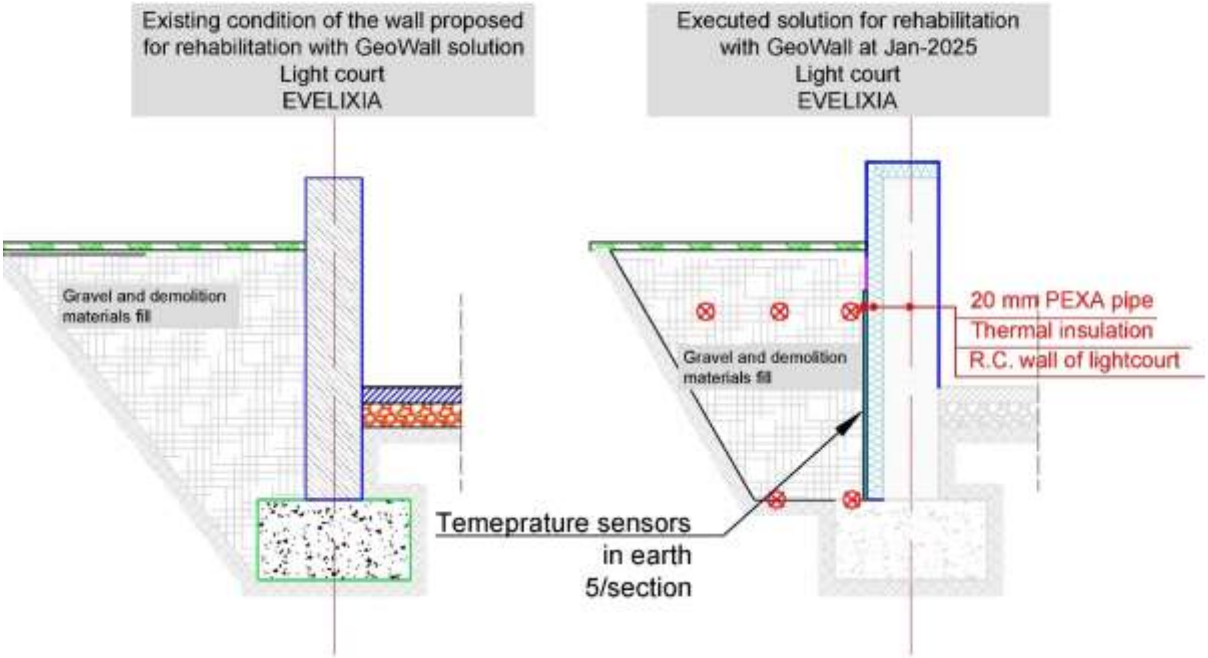


Figure 16. Exterior GeoWall system

The execution of exterior GeoWall consisted in the following execution works:

- Excavation works,

Figure 17. Excavations done for Evelixia exterior Wall

- Cleaning of the concrete wall
- Installation of GeoWall system which consist of thermal insulation plus the Pe-Xa pipes.

Figure 18. Exterior GeoWall system with Pe-Xa pipes

- Backfill

During the execution of backfill ground temperature sensors were installed into the ground.

Figure 19. Ground temperature sensors installed

2.5.3 Interior GeoWall

Concept

The Interior GeoWall system consists of prefabricated modular panels that are designed to be easily installed on the interior walls of underground spaces such as basements of existing residential apartment buildings, students' dormitories, schools, hospitals, etc. Currently these underground spaces are in conditions that prevents them to be used due to the mold, degradated materials and no thermal protection. In a society with a constant grow of urban environments non-utilisation of exiting spaces is a great loss. The GeoWall system is engineered to ensure the thermal insulation of these spaces while simultaneously capturing and repurposing waste heat that is typically lost in conventional underground environments. Therefore with implementation of GeoWall these underground spaces are given a new live and usage conditions are ensured.

Interior GeoWall system is designed as versatile panels is composed:

☑ High-performance thermal insulation layers – to minimize heat loss, improve energy efficiency, and create a more stable indoor climate in underground spaces.

☑ An embedded network of energy pipes – which act as a heat exchanger, collecting and redistributing waste heat from the surrounding environment. This energy can be repurposed for heating, pre-heating ventilation air, or supporting heat pump systems.

☑ Lightweight, modular components – designed for rapid installation and integration into existing structures with minimal disruption to building occupants.

Key Functionalities & Benefits

The Interior GeoWall solution is developed to address the specific challenges associated with retrofitting existing underground buildings, offering the following advantages:

◈ Enhanced Energy Efficiency – By combining insulation and heat recovery, the system reduces energy demand and improves thermal comfort in underground spaces.

◈ Cost-Effective Retrofitting – The modular nature of the panels accelerates the installation process, lowering labor and material costs while minimizing disruptions.

◈ Reduction of Waste Heat Loss – Underground spaces often have significant heat loss due to poor insulation and lack of optimized ventilation. In addition the temperatures found in these spaces is very similar with the undeground undistrurbed temperature that GSHPS (ground sourse heat pump systems) usually use for functioning; GeoWall captures and redirects this heat, increasing building efficiency by creating a local renewable energy source through harvesting the temperatures existig in these spaces.

◈ Improved Indoor Air Quality & Comfort – The insulation component of the panels stabilizes indoor temperatures, reduces humidity, and prevents condensation, leading to healthier indoor environments.

◈ Sustainability & CO_2 Reduction – By optimizing heat usage and reducing reliance on conventional heating sources, Interior GeoWall contributes to lower carbon emissions and supports the EU's climate neutrality goals.

Addressing Market Needs & European Energy Goals

The Interior GeoWall system aligns with the EU's Green Deal objectives, which promote energy-efficient retrofitting strategies and support innovative renewable energy technologies. With its scalable and adaptable design, Interior GeoWall offers a practical and impactful solution for modernizing underground spaces while ensuring compliance with current energy efficiency and sustainability regulations. Through the pilot project executed at UTCN students' dormitory, Interior GeoWall aims to validate its innovative approach, ensuring that it can successfully transform existing underground structures into local renewable energy sources, ultimately enhancing energy resilience and sustainability in Europe's built environment.

The main innovation that is proposed for Evelixia project is the interior GeoWall system. The system is designed to harvest the waste heat that is existent into the basement of the building.

The system is composed of different layers of materials, like insulation, pipes and support for interior finish.

For the Evelixia project, 2 basement rooms were equipped with interior GeoWall system, with a total surface of aprox. 60 sqm.

Figure 20. Interior GeoWall system

2.5.4 Heat Pump and hydraulic scheme

The exterior and interior GeoWall system was connected to the existing heat pump from site, a 7 kW brine-water heat pump.

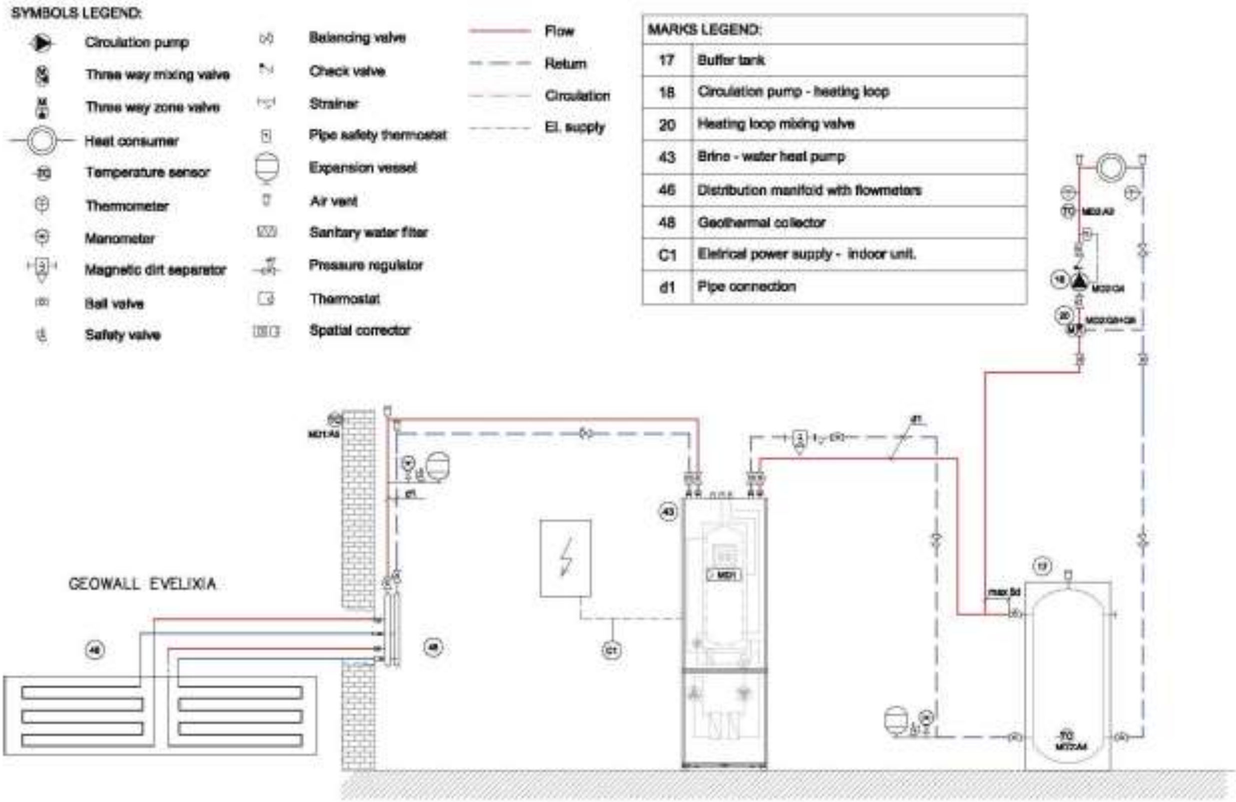


Figure 21. Hydraulic scheme

When reading the hydraulic scheme, it should be considered that the geothermal collector is not only from Evelixia, and there are other geothermal collectors connected to the heat pump. But all circuits that are connected to the heat pump can be closed, so, only specific circuits to be tested at a time. This will be decided based on what specific parameters are needed to be read.

A view of the room where the heat pump was installed can be observed in **Figure 22.**

Figure 22. Heat pump technical room

2.6 MONITORING OF GEOWALL SYSTEM

For the exterior GeoWall system we installed the following sensors, that are connected to the data logger:

- Temperature sensors. There were installed 6 sensors/section, are different depth and distance from the GeoWall. Sensor's type is NTC with 10.000-ohm resistance.
- Flow sensor for each circuit corresponding to each type of exterior GeoWall. Sensors are vortex type, 4-20 mA, able to read both water and water-glycol mixture.
- T_{in} and T_{out} of each circuit corresponding to each type of exterior GeoWall. For the T_{out}, PT1000 sensors are used and for the T_{in}, NTC with 10.000-ohm resistance are used.

For the interior GeoWall system the sensors installed are the following:

- Temperature sensors. Both rooms with interior GeoWall have their temperature monitored. Another 2 temperature sensors are installed at different distances from rooms where interior GeoWall are installed. The sensors installed are NTC with 10.000-ohm resistance.
- Flow sensor for each circuit corresponding to each room where interior GeoWall was installed
- T_{in} and T_{out} of each circuit corresponding to each room where interior GeoWall was installed

In future there is planned to be installed surface VW sensors in order to monitor the thermal effect on the structural elements of the basement, where the interior GeoWall is installed.

The heat pump is also monitored in terms of energy consumption in order to provide real COP, EER and seasonal ones.

The room where energy provided by the heat pump is being delivered is monitored in terms of temperature and energy consumption.

2.7 FUTURE DEVELOPMENT & PILOT TESTING

GeoWall technology is currently under development and testing to assess its performance, scalability, and integration potential in real-world applications. The pilot testing phase will evaluate:

- Thermal insulation effectiveness and energy savings potential
- Heat harvesting capacity and integration with existing HVAC systems
- Feasibility of large-scale implementation across different underground environments

Through the pilot project executed at UTCN students' dormitory, Interior GeoWall aims to validate its innovative approach, ensuring that it can successfully transform existing underground structures into local renewable energy sources, ultimately enhancing energy resilience and sustainability in Europe's built environment.

3 WINDOW SOLAR SHADING CONTROL USING RECYCLED PV CELL

3.1 INTRODUCTION AND OBJECTIVES

3.1.1 Scope and objectives

In this chapter we will highlight the critical intersection of energy innovation and smart building technologies. The need for enhancing building flexibility in energy systems, emphasizing how novel building integrated generation technologies (in particular photovoltaic PV) address major hurdles in grid stability, energy efficiency, and decarbonization goals. We will discuss the increasing demand for adaptable energy systems in response to grid fluctuations, the rise of renewable energy integration and stricter regulations on carbon emissions.

Main task objectives encompass raw materials identification (in form of repairable PV modules and their refurbishment); repair methods and technologies, new integrated PV generator system design and proposed performance testing.

3.1.2 Structure

Integrating the development of circular Building-Integrated Photovoltaics (BIPVs) into the context of novel energy generation systems and building flexibility encompasses three major stages: development and features, customization and local circularity and pre-installation performance testing. The work conducted in this task can be described in three distinct steps/stages.

The first stage "re-lamination/refurbishment of PV panels" consists in reprocessing existing PV modules electrically damaged into functional ones, ensuring the circularity of resources and reducing waste. These repairs can be done over: PV sandwich, panel frames , junction boxes, replaced diodes, modernized plugs and sockets to improve functionality and durability in BIPV installations.

The second stage "customization and local circularity" consists in local refurbishment techniques for BIPV modules tailored to building-specific designs with a focus on regional material usage and supply chain optimization to enhance sustainability.

Third stage "pre-installation performance calibration" consists of laboratory tests, simulations and controlled experiments to determine optimal electrical configurations for disjunct electrical parameters PV modules interconnection. System configuration modelling, simulations and real-life testing for: classical string inverters for centralized energy conversion, and micro-inverters for decentralized, module-level control, enabling better fault tolerance and shading resilience.

3.1.3 Challenges and Solutions

Technical hurdles can be identified in the field of development of durable yet recyclable BIPV components and the calibration of electrical configurations for maximum performance.

The integration of Photovoltaic (PV) systems into the circular economy requires technical and systemic innovations to maximize sustainability, resource efficiency, and performance.

In terms of the economic feasibility, we can identify two aspects: the need for policy incentives to support circular technology adoption and investments in local recycling and re-manufacturing facilities.

Processing PV modules with electrical damage (such are delamination, hot-spots) within the framework of the circular economy involves repair, reuse, and recycling to maximize resource efficiency and minimize waste. The first step is assessing the module's condition to determine if it can be refurbished or if material recovery is required. This involves inspecting electrical performance, such as current-voltage characteristics, and identifying physical damage like cracks, degraded encapsulants, or malfunctioning interconnects. Modules with minor delamination or localized issues can often be repaired, while severely damaged units are sorted for recycling.

Addressing electrically damaged photovoltaic (PV) modules within PV generators is essential from both technical and economic perspectives. Technically, damaged modules can lead to significant performance degradation. Issues such as microcracks, delamination, or faulty wiring can cause reductions in power output, potentially creating hotspots that may escalate into safety hazards. Infrared

thermography is commonly employed to detect these hotspots, enabling timely identification of compromised modules. [6]
Economically, the decision to repair or replace damaged PV modules hinges on a cost-benefit analysis. Repairing modules can be cost-effective, especially when addressing minor defects that do not severely impact performance. However, certain damages, such as shattered or cracked panels, are irreparable, necessitating replacement. [7]
Moreover, the presence of damaged modules can affect the overall efficiency of the PV system, leading to reduced energy production and financial returns. In some cases, upgrading to newer, more efficient panels during replacement can enhance system performance and economic viability. [8]
The main benefits of circular BIPVs in building flexibility towards increased energy independence point to custom BIPV systems aligned with building-specific energy needs, improved efficiency and reduced reliance on centralized grids. Additional benefits based on area of intervention:
Enhanced Integration with Multi-Vector Systems

- Synergy with HVAC systems and other thermal energy solutions.
- Storage integration to manage intermittent energy supply.

Sustainability and Cost-Effectiveness

- Extending the lifecycle of PV materials through re-lamination.
- Lower carbon footprint of production due to circular design principles.

Scalability and Modularity

- Adaptation for varying building scales and energy requirements.
- Modular systems ensure easy upgrades and maintenance.

3.2 Adaptable energy systems

The increasing integration of renewable energy sources, such as wind and solar power, into the electricity grid introduces variability due to their dependence on weather conditions. This variability can lead to significant fluctuations in energy supply, necessitating adaptable energy systems to maintain grid stability and reliability.

One approach to enhancing grid flexibility is the development of Virtual Power Plants (VPPs). VPPs aggregate distributed energy resources, including smart appliances and electric vehicles, to balance supply and demand dynamically. By incentivizing consumers to adjust their energy usage in response to real-time supply conditions, VPPs help mitigate the impact of supply fluctuations. For instance, during periods of high renewable output, consumers might be encouraged to increase usage, while during low production, they might reduce consumption. This demand-side management is crucial for integrating higher shares of renewable energy without compromising grid stability. [9]

Energy storage systems, particularly long-duration storage solutions, are also vital in addressing supply variability. These systems store excess energy generated during periods of high renewable output and release it during low production periods, effectively smoothing out supply fluctuations. The UK's experience with a "dunkelflaute"—a period characterized by low wind and solar output—highlighted the need for substantial investment in energy storage to reduce reliance on fossil fuels and enhance grid resilience. [10]

Moreover, the transition to flexible grids supports energy equity by enabling decentralized energy systems. In emerging markets, microgrids and distributed storage can provide reliable energy supply, and energy security.

The TUCN pilot site operates a Building Energy Management System (BEMS) which during the Evelixia project development is intended to be extended to cover some of the above use cases. The current task deals with the development of a PV generator constructed from refurbished photovoltaic modules to provide BIPV renewable energy power to the local grid. In the following chapters we will describe work done towards identifying and refurbishing PV modules to be used in the newly designed PV generator for the pilot site.

3.2.1 Electrical and optical methods for identifying repairable PV modules

Identifying repairable PV modules with electrical damage or physical defects requires precise diagnostic techniques. These methods help pinpoint faults, assess their severity, and determine whether repair is feasible. Up to the present moment, studies have been conducted in a pilot research infrastructure (ICSTM) from a partner university UVTgv. [11]

Inspection parameters:

- Electrical performance: measurement of the current-voltage (I-V) characteristics to identify power loss. Detection of faults like open circuits, hotspots, or reduced efficiency.
- Physical damage: Checking for delamination, cracked glass, or degraded encapsulants. Inspection of interconnects, busbars, and junction boxes for visible damage.
- Sorting criteria: Repairable Modules (minor delamination, localized cell or interconnect damage) and Recyclable Modules (extensive delamination or irreversible performance loss).

Figure 23. The experimental platform used for analysis and defectoscopy

The fastest way to identify damaged PV modules is by using a drone equipped with FLIR imaging followed by visual and electrical inspection for confirmation of the infrared artifacts identified. An overview of the diagnostic techniques is presented in **Figure 24**.

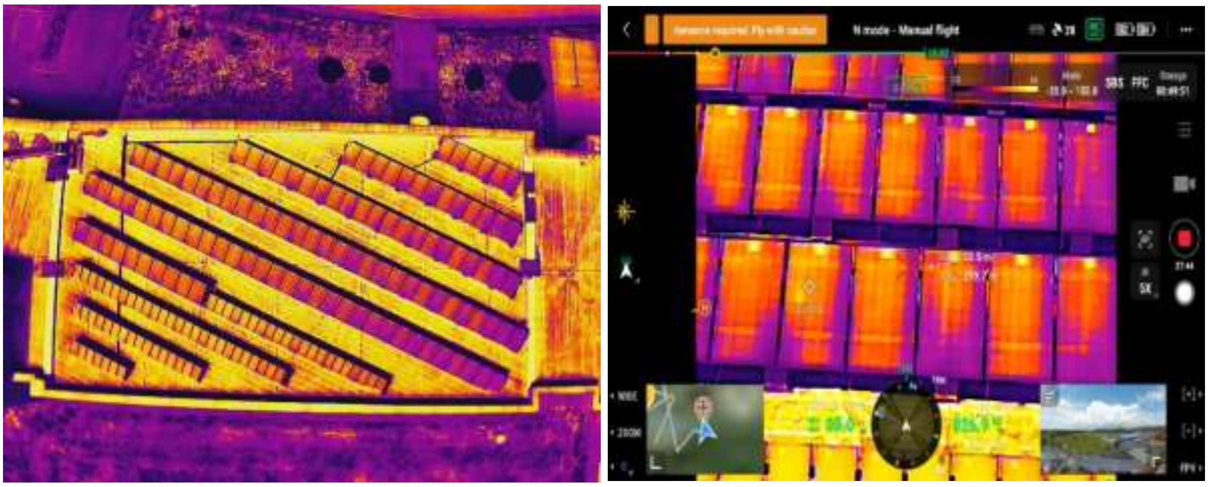


Figure 24. Drone FLIR imaging

3.2.1.1.1 Electrical diagnostic methods

Current-Voltage (I-V) Curve Tracing

Purpose: Measuring electrical performance to identify deviations from expected behaviour (tailored to STC conditions).

Method: Record the module's output current against voltage under standard test conditions (STC). Compare the I-V curve with manufacturer specifications. Deformities in the curve, such as reduced short-circuit current (I_{sc}) or open-circuit voltage (V_{oc}), indicate potential issues like cell mismatch, shading, or circuit interruptions.

Use Case: Determines power loss and identifies whether damage is repairable.

Equipment used: https://www.ht-instruments.com/en/products/photovoltaic-testers/performance-check/solar-i-ve

Figure 25: HT SOLAR I-Ve

<u>**Electroluminescence (EL) Imaging**</u>

Purpose: Detects microcracks, interconnect issues, and cell degradation.

Method: Apply an external forward bias to the PV module. Capture infrared emissions using a sensitive camera under dark conditions. Non-uniform or dark regions in the EL image indicate cracks, inactive areas, or shunted cells.

Use Case: Locates localized defects suitable for cell or interconnect repair.

Equipment: Proprietary developed test stand in dark room which uses IMX571 APS-C camera

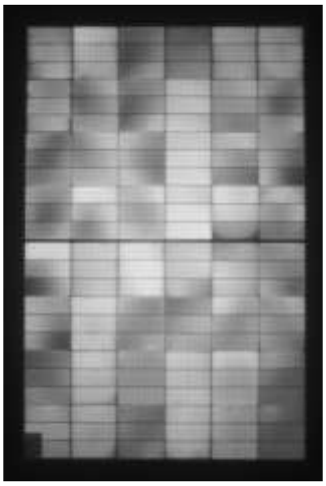


Figure 26: Test stand in dark room

Thermography (infrared imaging)

Purpose: Identifies hotspots caused by defective cells, interconnects, or bypass diodes.

Method: Use an infrared (IR) camera to capture the temperature profile of the module during operation. Hotspots appear as thermal anomalies and indicate potential failures like delamination, poor solder joints, or electrical resistance increases.

Use Case: Diagnoses thermal issues that can often be addressed through repair.

Equipment: DJI Matrice 30T Series with thermal imaging camera (Uncooled VOx Microbolometer Accuracy ±2°C)

Figure 27: DJI Matrice 30T Series with thermal imaging camera

Isolation Resistance Testing

Purpose: Ensures electrical safety and detects insulation breakdown.

Method: Measure the resistance between live electrical components (e.g., interconnects) and the grounded frame. Low resistance values indicate potential insulation damage or moisture ingress.

Use Case: Helps assess the need for encapsulant replacement or insulation repair.

Equipment: https://www.ht-instruments.com/en/products/photovoltaic-testers/commissioning-and-maintenance/pv-isotest

Bypass Diode Testing

Purpose: Verifies the functionality of bypass diodes, which protect cells from overheating.

Method: Use a multimeter to test diode continuity and forward/reverse voltage characteristics. Faulty diodes can cause power losses or excessive heating.

Use Case: Identifies diodes that require replacement during refurbishment.

3.2.1.1.2 Optical diagnostic methods

Visual inspection

Purpose: Identifies visible defects that impact performance.

Method: Inspect the module for signs of delamination, discoloration, cracked glass, or corrosion. Check the condition of interconnects, solder joints, and junction boxes.

Use Case: Provides a preliminary assessment to determine repair feasibility.

Equipment used: Canon Eos 800D with Tamron 18-400mm F/3.5-6.3 objective

Figure 28: Visual Inspection

Photoluminescence (PL) Imaging

Purpose: Evaluates material quality and detects recombination defects.

Method: Illuminate the module with a laser or LED source at specific wavelengths. Capture the emitted photoluminescence using a sensitive camera. Low-emission regions indicate defective cells or degraded materials.

Use Case: Useful for assessing material-level issues that may require cell replacement.

Light-Induced Degradation (LID) Testing

Purpose: Detects performance degradation due to prolonged exposure to light.

Method: Subject the module to controlled illumination and monitor performance over time. Observe reductions in efficiency or changes in electrical parameters.

Use Case: Determines whether degradation is reversible, or repair is required.

UV Fluorescence Imaging

Purpose: Highlights encapsulant and backsheet degradation caused by UV exposure.

Method: Illuminate the module with UV light. Observe fluorescence patterns indicating delamination or backsheet failure.

Use Case: Guides decisions on encapsulant or backsheet replacement.

Spectral Response Testing

Purpose: Measures the module's ability to convert light into electrical energy across different wavelengths.

Method: Use a monochromatic light source to illuminate the module and record current output. Decreased response in specific spectral regions indicates defective cells or encapsulant degradation.

Use Case: Identifies cell-level performance issues suitable for repair.

Combined electrical and optical analysis

Integration of multiple methods, such as EL imaging and thermography, enhances diagnostic accuracy. For example, hotspots detected via thermography can be cross verified with EL images to locate and repair specific cell or interconnect issues.

3.2.1.1.3 Decision criteria for repair

Modules are deemed repairable if:

- Defects are localized (e.g., specific cells or interconnects).
- Power loss is within a recoverable range (e.g., <20%).
- Structural damage (e.g., delamination or cracked glass) is minor and addressable.

Modules with extensive defects, such as widespread cell degradation or irreparable encapsulant damage, are redirected to recycling processes.

3.2.1.2 Refurbishment of repairable PV modules

Refurbishment focuses on restoring the functionality of repairable modules. Delamination can be reversed using controlled heating to soften encapsulants and applying vacuum pressure to rebind layers. Damaged solar cells are replaced while functional cells are retained, and new encapsulants, such as thermoplastic polyolefins (TPOs), are applied to ensure durability. Frames and junction boxes can be repaired or replaced with modular, recycled components, and the reassembled module can be re-laminated under heat and vacuum to restore the weather sealing. This approach prolongs the lifespan of PV modules, reduces material demand, and provides functional units for secondary applications, such as off-grid systems.

For modules that cannot be repaired, recycling focuses on material recovery. Disassembly separates frames, glass, and junction boxes, followed by the removal of encapsulants to access cells and backsheets. Glass is cleaned, crushed, and reused in new PV modules or construction materials, while silicon undergoes chemical or thermal etching to remove impurities and prepare for re-wafering. [12] Reclaimed silicon can then be melted and cast into new wafers. Metals like copper, silver, and aluminium are extracted through hydrometallurgical or pyrometallurgical methods, while encapsulants may be reprocessed if recyclable or incinerated for energy recovery. Advanced techniques, such as cryogenic separation and laser ablation, enhance the efficiency and cleanliness of material recovery, ensuring minimal resource loss. [13]

These processes align with circular economy principles by reintegrating recovered materials into new PV manufacturing and supporting the lifecycle management of modules. Circular business models, such as product lifecycle tracking and take-back schemes, promote refurbishment and recycling, while refurbished modules can be sold for low-demand applications. [14] Extended producer responsibility (EPR) policies incentivize manufacturers to manage end-of-life panels, ensuring sustainable collection and processing. By implementing these strategies, the

environmental footprint of PV systems is reduced, waste is minimized, and valuable materials are conserved, creating a closed-loop system that supports global sustainability goals. [15]
Policy and incentives that can be suggested including regulatory support: like policies promoting take-back schemes and subsidies for recycling infrastructure; and financial incentives: in the form of tax benefits for companies adopting circular PV practices. [16]

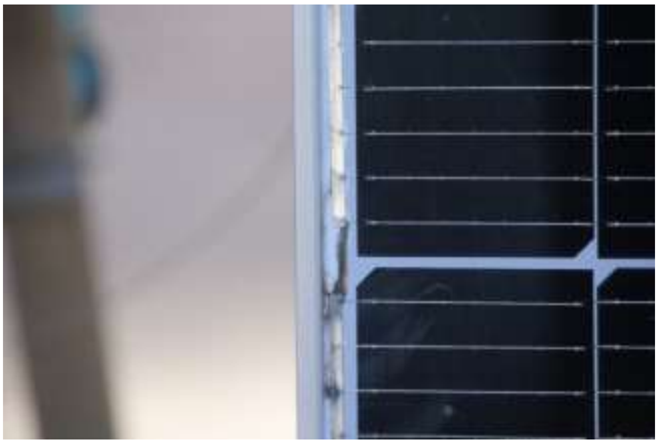
Refurbishment focuses on restoring the functionality of PV modules with minor delamination.

The proposed refurbishment steps:

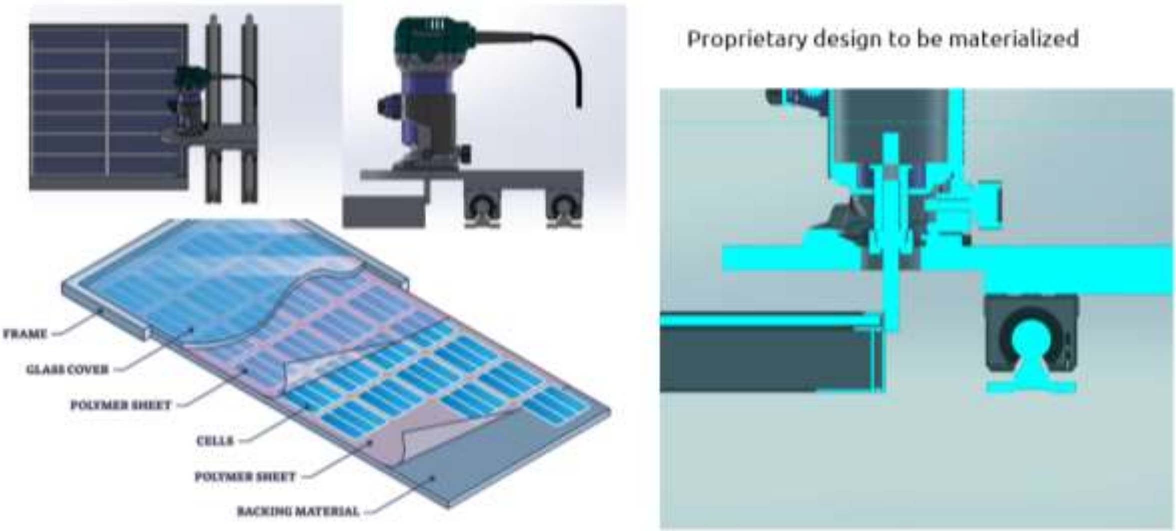
- Delamination reversal by heat treatment which consists in controlled heating (~80–100°C) to soften encapsulants (e.g., EVA) and re-laminate using pressure. Requires clean vacuum press systems for precise application. This would be followed by vacuum sealing, a process that rebinds the layers under vacuum to eliminate air pockets that degrade performance.
- Cell repair involves replacing damaged solar cells while preserving functioning ones. Uses soldering techniques to re-establish electrical connections across busbars and interconnects.
- Encapsulant replacement consists in removal of the degraded encapsulant and replace it with a durable, recyclable material like thermoplastic polyolefins (TPOs). Ensure compatibility with the module's thermal and mechanical properties.
- Frame and junction box repairs mean to reuse or replace damaged frames with modular or recycled aluminium and to install new junction boxes, plugs, and diodes for electrical safety in place of electrically or mechanically damaged ones.
- Re-lamination. Apply fresh layers of encapsulant and reassemble the module under vacuum and heat.

The main advantages of the proposed PV module refurbishment are the techniques prolong the lifespan of modules, reduce material demand for new panels and maintains performance efficiency for secondary applications.

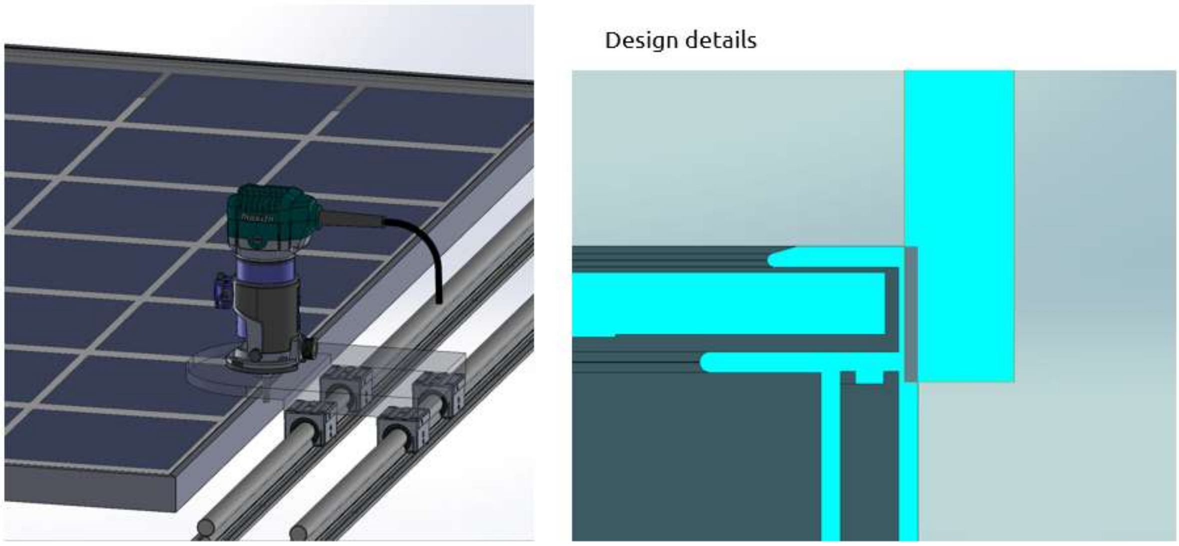
Table 3: Identified PV modules to be repaired

Method	Sample
Bi-component polymer or TPOs localized injection	 Location: ICSTM microgrid installation, BIPV array
Reframing and re-sealing the sandwich	 Location: Storage, donated module
Reframing, resoldering and re-sealing the module	 Location: Storage, donated module

The frame removal prototype that's proposed to be developed (subject of IPR rights, no further information will be disclosed) will be used in the refurbishment of the PV modules deemed to be repairable. Some design details are presented in **Figure 29** .



(a)



(b)

Figure 29. Frame Removal -CAD/CAM SolidWorks design of the frame removal prototype device

3.2.1.3 Customization and local circularity

Custom Building-Integrated Photovoltaic (BIPV) installations represent a harmonious fusion of renewable energy technology with architectural design, enabling structures to generate electricity while maintaining or enhancing their aesthetic appeal. These bespoke systems are tailored to the specific dimensions, styles, and functional requirements of individual buildings, ensuring seamless integration into various architectural elements such as facades, roofs, skylights, and canopies. The customization process involves selecting appropriate photovoltaic materials, adjusting transparency levels, and choosing colours that align with the building's design ethos. For instance, companies like WEUP offer BIPV glass panel customization options, providing architects with the freedom to design and implement visually unique, energy-efficient solar facades. [17]

The implementation of custom BIPV systems requires a collaborative approach, engaging architects, engineers, and manufacturers from the project's inception to ensure that the photovoltaic components meet both aesthetic and performance criteria. This collaboration facilitates the development of solutions that not only contribute to a building's energy efficiency but also enhance its visual and functional attributes. For example, the EnergyX DY-Building in South Korea exemplifies the successful integration of BIPV technology, achieving an energy self-sufficiency rate of 121.7% while maintaining architectural integrity. [18]

Figure 30. Sample of facade and wall/ceiling BIPV custom integrations

Producing building-specific BIPV modules with a focus on regional material usage and supply chain optimization enhances sustainability by aligning manufacturing with circular economy principles. Customization is key, enabling the tailoring of module shapes, sizes, and materials to meet architectural and climatic requirements. Local facilities equipped with flexible production lines, CNC cutters, and lamination units can efficiently create unique modules that integrate seamlessly into facades, roofs, or windows. These facilities leverage regionally sourced materials, such as float glass and recycled aluminium, to reduce transportation emissions and promote circularity. Encapsulants like thermoplastic polyolefins or bio-based adhesives derived from agricultural by-products further enhance the sustainability of the modules. [19, 20, 21]

3.2.2 TUCN pilot site PV generator design

In order to accommodate a PV generator on the TUCN pilot location, a site survey was conducted for proper orientation and management agreed mounting surface.

(a)

(b)

(c)

Figure 31. UTCN Pilot site design (a- cafeteria south facade photo, b- proposed PV array, c- 3D modelling of the site)

Figure 31 presents the south façade of the cafeteria situated on the pilot site. This location was chosen due to recent energy efficiency improvement works done to the dormitory's façades over which if PV modules would be installed will void the works warranty. **Figure 31.b** illustrates a photographic overlay of the proposed PV arrays, this represents the total amount of modules that could be installed, full solar potential. In **Figure 31.c** one can observe a 3D rendering of the other surrounding buildings at scale. The system modeling was executed in the PV*SOL 2022 (R4) software. Based on the model the software calculated the yearly shading over the PV array which is presented in **Figure 32.**

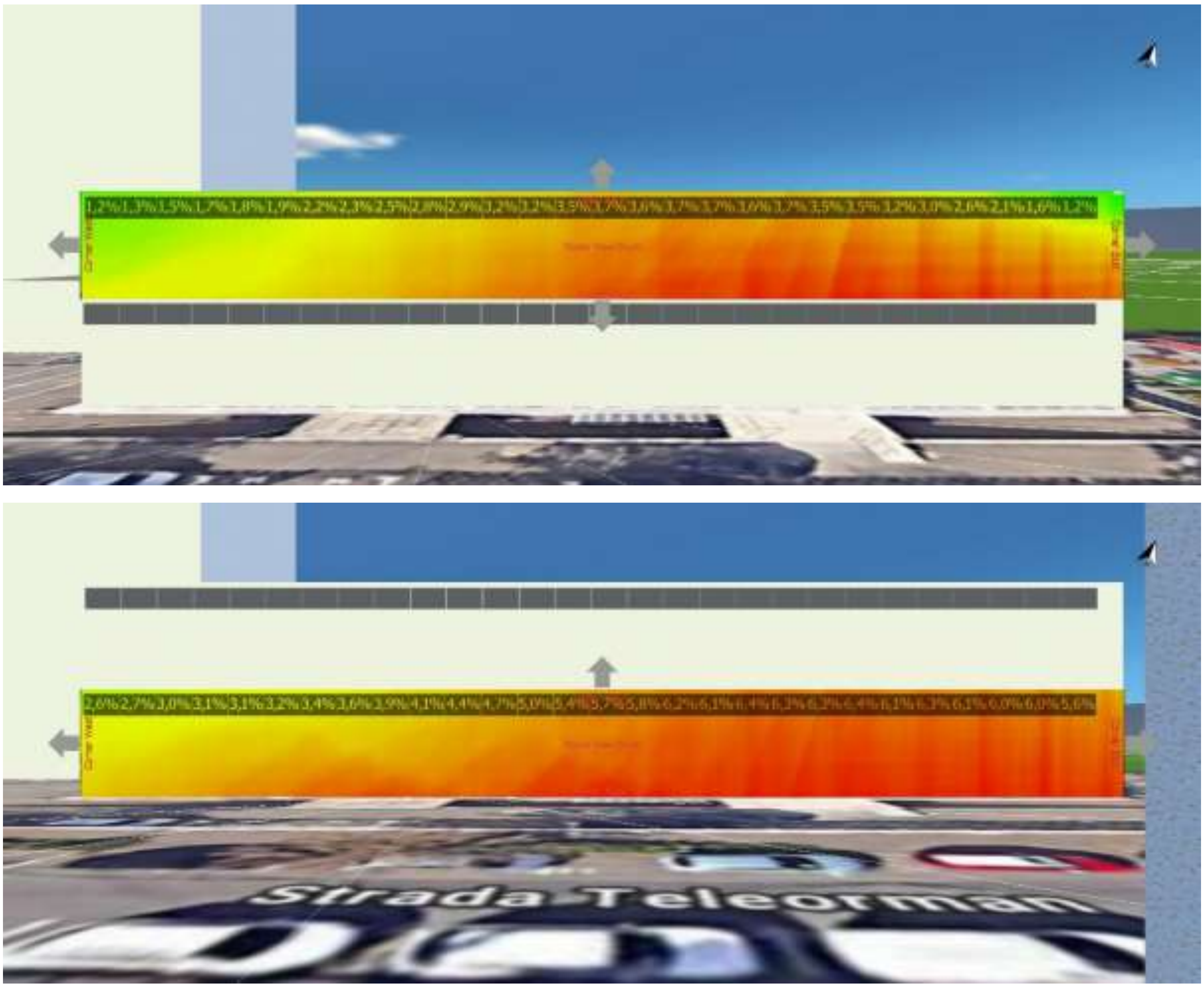


Figure 32. 3D Shading simulation results

The PV generator model took into account the installation of refurbished modules and in that sense an averaged "value" was used in place of actual ones for the PV module model. This process was conducted based on a survey made between partner installer companies and taking into account the availability of PV modules with electrical faults. These companies provide service to PV generators at national level and have some understanding over the specific type of PV module that the researchers are interested into. The actual parameters used for the model are presented in **Figure 33** , the I-V characteristic was automatically calculated.

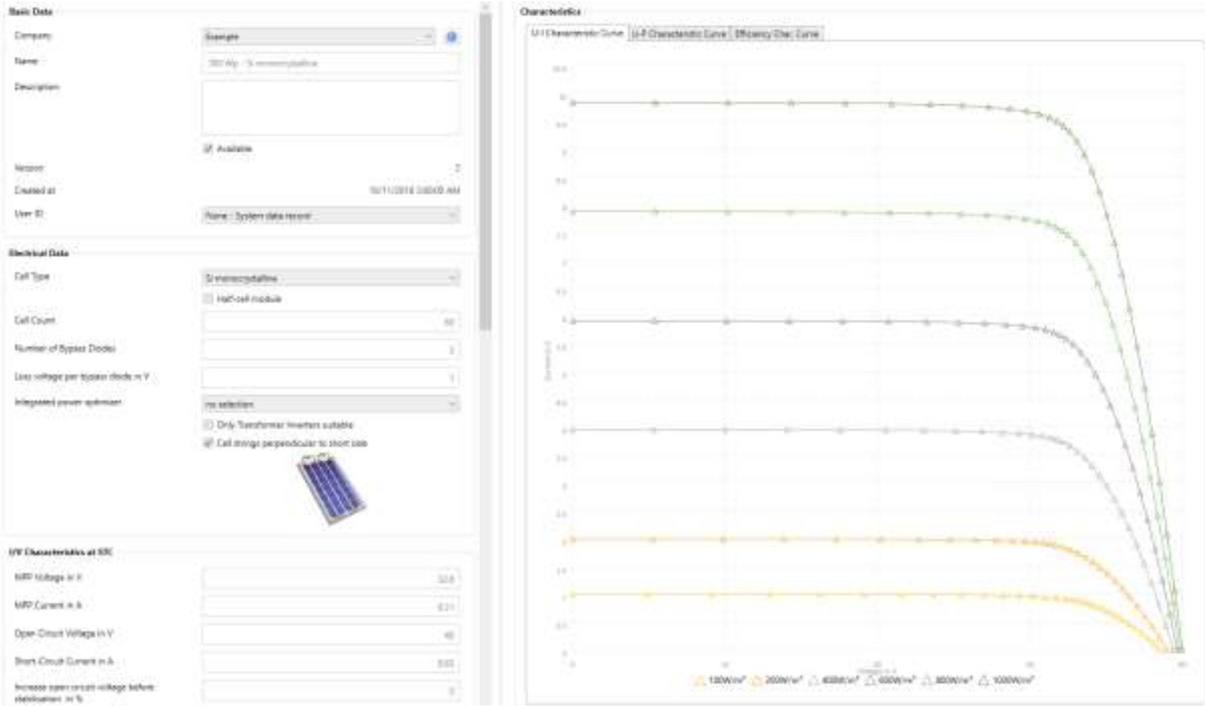


Figure 33. PV modules parameters used for the system modelling

The simulation was conducted based on environmental data specific to the pilot site coordinates (data source: Meteonorm 7.2c3).

Simulation models used:

- Diffuse Irradiation onto Horizontal Plane Hofmann
- Irradiance onto tilted surface Hay & Davies

Main simulation results:

The total PV Generator available surface was measured at: 46,9 m² considering inclination of 90 ° and South orientation azimuth 160 ° for a maximum amount of 56 PV modules of averaged 300 Wp (16.8 kWp).

The calculated PV Generator specific annual yield is: 835,14 kWh/kWp with a Performance Ratio (PR) of 83,17 % and an Yield Reduction due to Shading of 6,6 %/Year. More details in **Figure 34**.

Evelixia

Project Designer: ICSTM - UVTgv **Client: Technical Univ. of Cluj-Napoca UTCN**

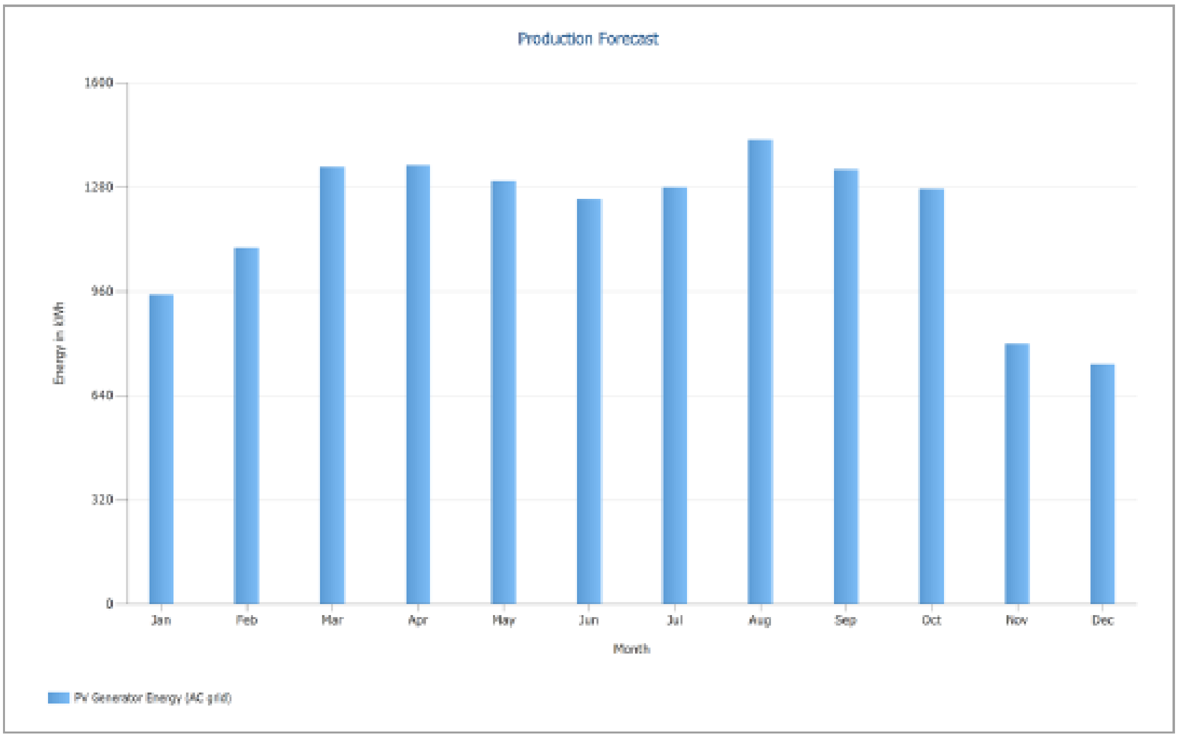


Figure: Production Forecast

Results per Module Area

Cantina-Storey2-Facade South

PV Generator Output	8,40 kWp
PV Generator Surface	46,95 m²
Global Radiation at the Module	951,50 kWh/m²
Global Radiation on Module without reflection	992,57 kWh/m²
Performance Ratio (PR)	84,88 %
PV Generator Energy (AC grid)	7159,98 kWh/Year
Spec. Annual Yield	852,38 kWh/kWp

Cantina-Storey1-Facade South

PV Generator Output	8,40 kWp
PV Generator Surface	46,95 m²
Global Radiation at the Module	951,50 kWh/m²
Global Radiation on Module without reflection	992,57 kWh/m²
Performance Ratio (PR)	82,54 %
PV Generator Energy (AC grid)	6962,62 kWh/Year
Spec. Annual Yield	828,88 kWh/kWp

Figure 34. Energy simulation results

Evelixia

Project Designer: ICSTM - UVTgv | Client: Technical Univ. of Cluj-Napoca UTCN

PV System Energy Balance

PV System Energy Balance

Global radiation - horizontal	**1.269,25**	**kWh/m²**	
Deviation from standard spectrum	-12,69	kWh/m²	-1,00 %
Ground Reflection (Albedo)	125,66	kWh/m²	10,00 %
Orientation and inclination of the module surface	-378,79	kWh/m²	-27,40 %
Module-independent shading	-10,85	kWh/m²	-1,08 %
Reflection on the Module Interface	-41,07	kWh/m²	-4,14 %
Global Radiation at the Module	**951,50**	**kWh/m²**	
	951,50	kWh/m²	
	x 93,894	m²	
	= 89.339,59	kWh	
Global PV Radiation	**89.339,59**	**kWh**	
Soiling	0,00	kWh	0,00 %
STC Conversion (Rated Efficiency of Module 18,1 %)	-73.167,64	kWh	-81,90 %
Rated PV Energy	**16.171,95**	**kWh**	
Module-specific Partial Shading	-628,22	kWh	-3,88 %
Low-light performance	-228,43	kWh	-1,47 %
Deviation from the nominal module temperature	-63,74	kWh	-0,42 %
Diodes	-14,61	kWh	-0,10 %
Mismatch (Manufacturer Information)	-304,74	kWh	-2,00 %
Mismatch (Configuration/Shading)	-32,99	kWh	-0,22 %
PV Energy (DC) without inverter down-regulation	**14.899,22**	**kWh**	
Failing to reach the DC start output	-52,34	kWh	-0,35 %
Down-regulation on account of the MPP Voltage Range	-120,30	kWh	-0,81 %
Down-regulation on account of the max. DC Current	0,00	kWh	0,00 %
Down-regulation on account of the max. DC Power	0,00	kWh	0,00 %
Down-regulation on account of the max. AC Power/cos phi	-0,69	kWh	0,00 %
MPP Matching	-2,18	kWh	-0,01 %
PV energy (DC)	**14.723,71**	**kWh**	
Energy at the Inverter Input	**14.723,71**	**kWh**	
Input voltage deviates from rated voltage	-111,08	kWh	-0,75 %
DC/AC Conversion	-490,03	kWh	-3,35 %
Standby Consumption (Inverter)	-92,19	kWh	-0,65 %
Total Cable Losses	0,00	kWh	0,00 %
PV energy (AC) minus standby use	**14.030,41**	**kWh**	
PV Generator Energy (AC grid)	**14.122,60**	**kWh**	

Based on the proposed PV generator system design a single wire diagram is presented in **Figure 35.** This reference design can be used by the installer during the pilot development.

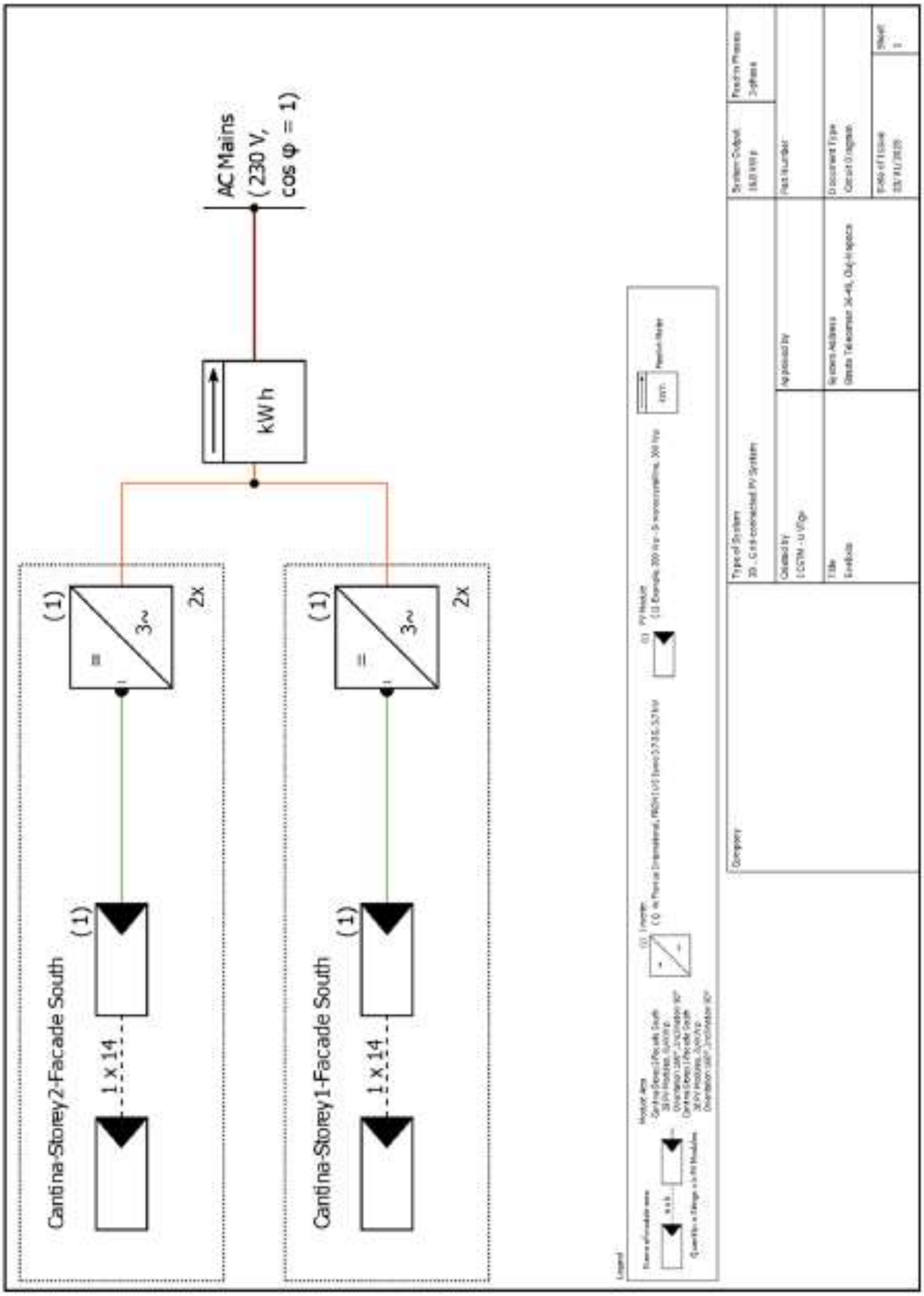


Figure 35. Electrical design of the PV generator

3.2.2.1 Local circular economy model

Energy self-sufficiency in facilities, powered by renewable sources or integrated PV systems, minimizes the carbon footprint. [22] Waste reduction strategies, including the reuse of glass cuttings and polymer trimmings, align with circular principles. [18] Life Cycle Assessments (LCA) quantify environmental impacts and guide improvements to reduce embodied carbon. [23]

Advanced manufacturing techniques, including 3D printing and modular designs, allow for on-demand production, facilitating rapid customization while minimizing waste. Circular production practices, such as incorporating re-laminated cells and recycled materials, extend the lifecycle of BIPV modules. By optimizing regional supply chains, partnerships with local suppliers and stakeholders reduce logistical costs and emissions, while ensuring alignment with regional building codes and user needs. Just-in-time inventory management and low-emission transportation further enhance supply chain efficiency.

In addition to environmental benefits, local production techniques create economic and social value. They generate employment opportunities, promote skills development in renewable energy and advanced manufacturing, and reduce costs by minimizing dependence on international supply chains. [24] Community engagement fosters awareness of sustainable energy practices, while regional take-back programs ensure damaged BIPV modules are repurposed or recycled. This holistic approach supports cost-competitive, sustainable construction practices while strengthening regional economies and contributing to global sustainability goals. [25]

3.2.2.2 Pre-installation performance testing

Pre-installation performance testing is a critical step in ensuring the reliability, efficiency, and durability of BIPV modules before their integration into buildings. This process begins with a thorough assessment of the module's electrical performance under controlled conditions. Current-voltage (I-V) curve testing is conducted to measure parameters such as open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), and maximum power output (P_{max}). These measurements are compared against manufacturer specifications to identify any deviations that may indicate defects or inconsistencies. Electroluminescence (EL) imaging is another essential test, performed in a dark environment with an external bias applied to the module. This method detects microcracks, inactive areas, and interconnect failures that are invisible to the naked eye. Infrared thermography complements EL imaging by identifying hotspots that may arise from cell mismatches, bypass diode failures, or solder joint defects, which could compromise module performance.

Optical tests, such as spectral response and light-induced degradation (LID) assessments, are also employed to evaluate the module's ability to convert light into electrical energy across various wavelengths and its resistance to efficiency losses over time. For modules intended for semi-transparent applications, tests to measure optical properties, including transmittance and haze, ensure the balance between energy generation and aesthetic integration. Mechanical testing, including load-bearing capacity and impact resistance, is conducted to simulate environmental stresses such as wind, snow, or hail impacts, ensuring the modules can withstand site-specific conditions.

These tests are followed by the evaluation of system-level compatibility, particularly the selection of the appropriate electrical configuration. For example, testing the performance of modules with classical string inverters versus microinverters helps determine the optimal setup for maximizing energy output while maintaining system reliability. Modules that pass these rigorous pre-installation tests are deemed fit for integration, ensuring their performance aligns with design expectations and their durability meets long-term operational requirements. This comprehensive testing process minimizes installation risks, reduces potential maintenance costs, and guarantees the efficiency and longevity of the BIPV system.

3.3 Conclusion

In conclusion, our discussions have underscored the critical importance of integrating circular economy principles within the photovoltaic (PV) industry to enhance sustainability and economic viability. Implementing innovative recycling methods, such as the Hot Knife technique, facilitates efficient delamination of PV modules, thereby improving material recovery and reducing environmental impact. [26]

Additionally, the development of PV module design guidelines that emphasize recyclability—through the use of reversible encapsulants and durable material identification—further supports sustainable end-of-life management. [27]

The advancement of Building-Integrated Photovoltaics (BIPV) has been highlighted as a multifaceted solution that merges energy generation with architectural aesthetics. Custom-colored modules, for instance, have been shown to increase public acceptance of PV systems, particularly in historically significant buildings. [28]

However, challenges remain in supply chain reliability and the integration of BIPV products into established building material distribution networks. Addressing these issues is essential to lower perceived risks and improve customer perception, thereby fostering broader adoption of BIPV technologies. [29]

Furthermore, the necessity of repairing or replacing electrically damaged PV modules has been emphasized from both technical and economic perspectives. Timely interventions are crucial to maintain optimal system performance, ensure safety, and maximize economic returns. Implementing comprehensive pre-installation performance testing, including current-voltage (I-V) curve assessments, electroluminescence imaging, and infrared thermography, is vital to identify and address potential issues before deployment.

Collectively, these insights highlight the imperative for ongoing innovation and collaboration among stakeholders in the PV industry. By embracing sustainable practices, optimizing supply chains, and ensuring the reliability of PV systems, we can contribute significantly to a more sustainable and resilient energy future.

4 THERMAL FLEXIBILITY THROUGH THERMAL STORAGE SOLUTIONS

Thermal flexibility through thermal storage solutions refers to the ability to efficiently store heat and release it as needed to respond to fluctuations in energy supply and demand.

4.1 Thermal Storage - General

In principle, energy storage through thermal energy storage (TES) offers numerous advantages for the energy efficiency of energy supply systems or buildings. Therefore, thermal energy storage systems enable increased use of renewable energy sources in the energy system by eliminating the mismatch between renewable energy generation and the demand load. When combined with electrical systems, thermal energy storage also offers advantages for heating and hot water production by shifting demand and covering the electrical load through the use of electricity during off-peak hours, which can result in a substantial decrease in household energy expenses. 0

According to the mechanisms involved in the storage process, thermal energy storage can be divided into four main categories: sensitive thermal storage, latent thermal storage, thermochemical thermal storage, and mechanical-thermal storage [0. However, if one adds the commercial availability of the storage technologies listed, it becomes clear that only the water tank thermal storage systems (WTTES) and the "solid-state" technologies are currently marketable for the storage of thermal energy (see **Figure 36**).

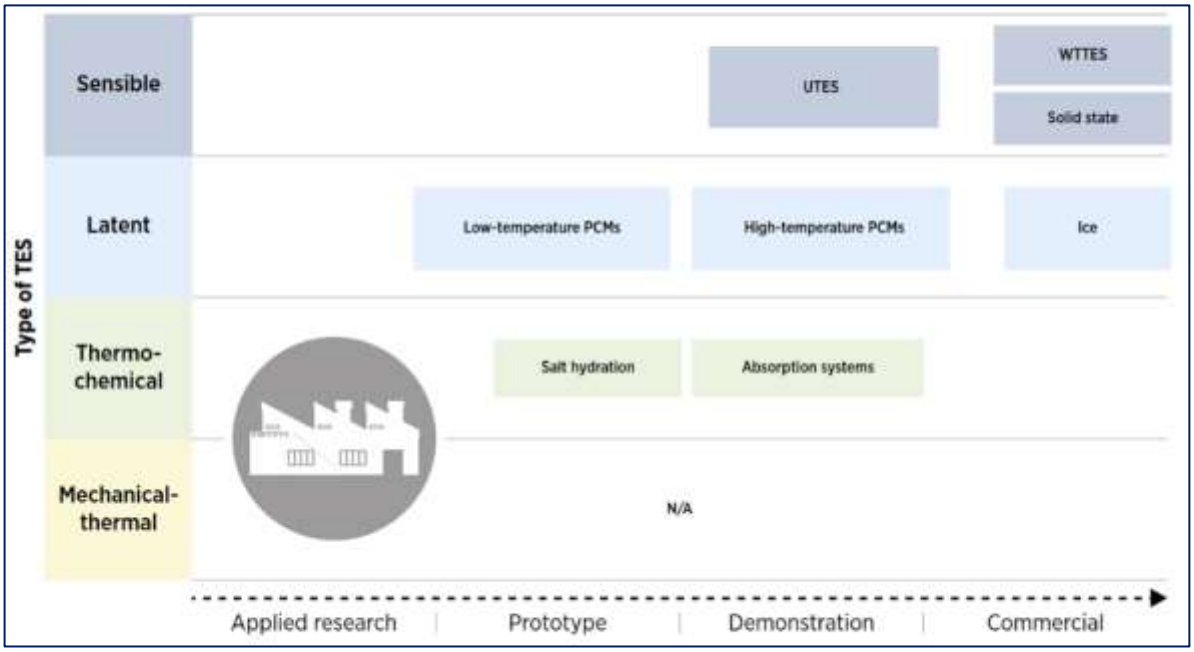


Figure 36. Commercial readiness of TES 0

Therefore, the conventional water-filled thermal storage system is still of great importance for use in energy systems and buildings, and its dominance can be justified by the following advantages, among others: 0

- **Excellent properties**

Water possesses a significant heat capacity, thereby enabling it to store a substantial amount of energy in relation to its temperature variation. It is therefore an effective medium for thermal energy storage.

- **Cheap**

Water is available in large quantities almost everywhere, it is environmentally friendly, and it is extremely cost-effective. The use of steel and stainless steel creates only moderate investment costs for containers.

- **Scalability**

Water tank systems can be easily scaled according to storage needs, whether for a small household or a large industrial facility. This flexibility makes it an ideal solution for different applications.

- **Short-term and long-term storage**

Water reservoirs can store thermal energy for longer periods of time, depending on insulation and conditions. This makes them suitable for both short- and long-term storage of heat or cold.

4.2 Thermal Storage - EVELIXIA

As the central point within task 2.3 of the EVELIXIA project can now be the provision of thermal flexibility through the use of the thermal storage tanks (WTTES) described above, whereby both the use of domestic hot water storage tanks and the use of buffer storage tanks should be investigated. An essential aspect of storage systems development is the possibility of charging them with different forms of energy, whereby the following charging systems are considered:

- a hydraulic charging system
- an electric charging system
- a hybrid charging system (combination of both)

Besides the actual storage systems, all variants have to be equipped with a control system. The control and the associated optimization algorithms, which are embedded in the storage system, are configured in such a way that they are seamlessly and interoperable connected to the higher-level framework from EVELIXIA. Exemplary control variables could be the regulation of water volume flows, temperature levels, and programmable charge/discharge rates according to the predicted availability of the heat capacity of the district heating operator. These variables also include the offer of flexibility through load shifting and shedding strategies. The following essential operating parameters should be positively impacted by this.

- low operating temperatures,
- Low maximum load
- high self-consumption shares of PV energy is optimized.

Another requirement of the project is to integrate the thermal storage systems into a district heating network, as they are often operated with a high proportion of fossil fuels (oil and gas boilers). Due to the ongoing energy transition, DH operators are increasingly forced to increase the share of renewable energies for space heating and hot water preparation, whereby such systems (e.g. solar thermal energy, biomass) often cannot be used flexibly due to longer start-up and shut-down times or volatile availability.

Specifically, the project will subject the Austrian pilot's "Strem" district heating network to a comprehensive analysis and, based on this, develop a suitable storage solution for the operational optimization of the district heating system. Again, the aim is to ensure that heating and hot water loads are flexible in terms of time and while heat losses and peak demand are minimized, whereby load balancing services can be offered to the Austrian district heating operator.

4.2.1 Position, type and volume

As already mentioned, thermal storage systems can be implemented in different types, whereby the following designs are being investigated as part of the project:

- Domestic hot water tank

The domestic hot water tank heats and stores the drinking water directly, which is later used for daily needs (e.g. showering, cooking, washing). The warming can be done through different heat sources (district heating, gas, electricity, solar thermal energy, etc.). In the case of decentralized domestic hot water storage tanks, such as those being investigated in the project, only the daily requirement of hot water is usually stored, which means that the volume of these storage tanks is often between 100 and 200 litres. In any case, due to the direct contact with drinking water, hygienic aspects must be considered in the charging system and also the storage tank material.

- Buffer tank

The buffer tank stores heat in the form of technical water from the heating system or a district heating system, which is heated by a heat source (district heating, boiler system, solar system, Power2Heat system, etc.). This heat can be used later if the heating source produces less or if the heat demand is higher than the current output. The integration of buffer storage tanks into a district heating system can take place at different levels. Installation is often carried out directly in the boiler house, and secondary use in the building's heating system is also common. As an interim solution, however, the decentralized integration of a buffer storage tank directly into the district heating network can also be implemented. In terms of volumes, there is an expansive range, as it can range from less than 1 to over 100 m^3 (and larger).

The **Figure 37** shows the position and different types of thermal storage systems that are being investigated in the project. This shows a central and a decentralized buffer storage tank, both are directly integrated into the district heating system. A third buffer storage tank was installed in the heating system of a building, but this is hydraulically separated from the district heating system by a transfer station. Finally, the integration of a domestic hot water storage tank into a building was shown, where the heat is also fed via a transfer station and an additional heat exchanger.

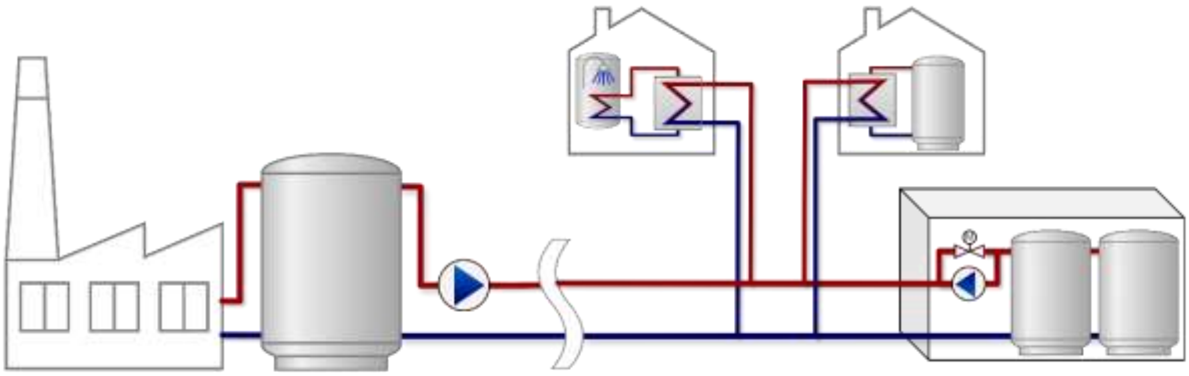


Figure 37. Integration variants of thermal storage tanks into a district heating system

4.2.2 Charging system

The thermal storage tanks can be charged with different forms of energy, depending on the type of energy supply that is provided or available. As shown in **Figure 38**, the variants "hydraulic" or "electric" are available, but also the combination of these variants to a third variant "hybrid" is feasible. Thereby, the alternates for both the domestic hot water tank and a buffer tank were shown.

It is worth mentioning here that in the hydraulic version, the heat input in a domestic hot water tank must take place via a heat exchanger, while in a buffer tank, the medium can be transported due to the use of the heating water. There are also differences in the electrical charging because while the domestic hot water tank is generally charged via an electric heating element, the buffer tank often uses its own charging module or a power-to-heat module due to the greater electrical power.

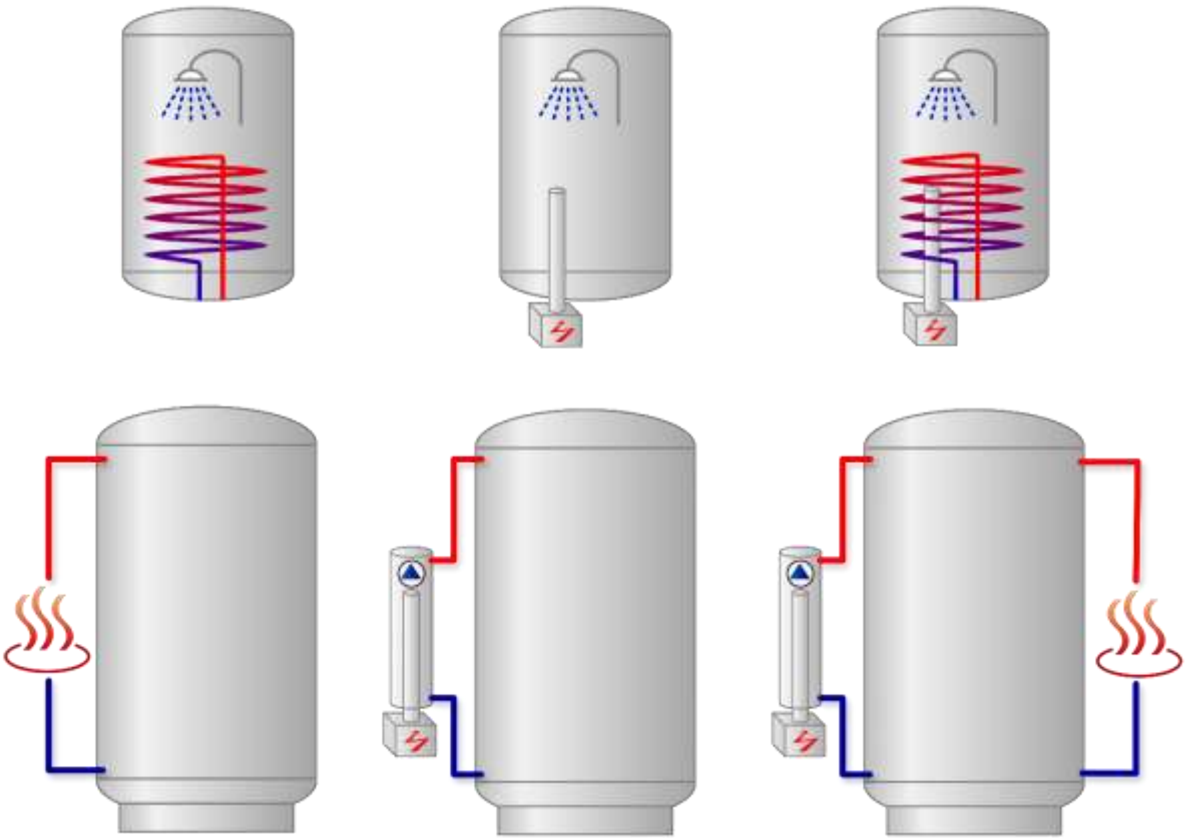


Figure 38. Thermal, electrical and hybrid charging system

4.2.3 Control and optimized operation

To be able to implement the aspects of optimized operation of the thermal storage systems already listed in the previous chapter, the individual variants of the thermal storage systems and the different charging options must also be equipped with an optimized control strategy.

For this, a programmable logic controller (PLC) from the Austrian manufacturer "Technische Alternative", which has been used by PINK for years in combination with storage solutions, is ideal. The PLC is a freely programmable universal controller that has numerous inputs and outputs and is equipped with a 4.3" touch display (see **Figure 39**). In addition to the standard "CAN-Bus" bus system, the system also offers interfaces to other bus systems such as "LAN", "KNX", "Modbus" or "M-Bus".

Figure 39. PLC and C.M.I. interface of the storage system

This controller can be used to implement a wide range of regulation and control tasks in building automation and energy management, such as listed below:

- control of heating and cooling circuits
- control of solar thermal systems
- capacity control and cascading of heat generators
- control of hygienic domestic hot water preparation
- control of Ventilation systems

As part of the project, the PLC will be extended by an additional component of TA, namely the Control and Monitoring Interface (CMI), which is shown on the right side of **Figure 40.** With this component, the listed functions can be enabled:

- system monitoring
- remote control
- data logging
- visualization of all controllers
- Modbus TCP/IP
- and devices with CAN bus network.

As has already been proven based on tests within Task 2.4, the defined solution also makes it possible to integrate the storage system / the associated control system into the higher-level EVELIXIA platform. As the illustration in Figure 36 shows, a test environment was set up to check the functionality, whereby the first results showed no problems with the communication and the data logging, also the reading (get) and writing (set) of individual values also worked entirely.

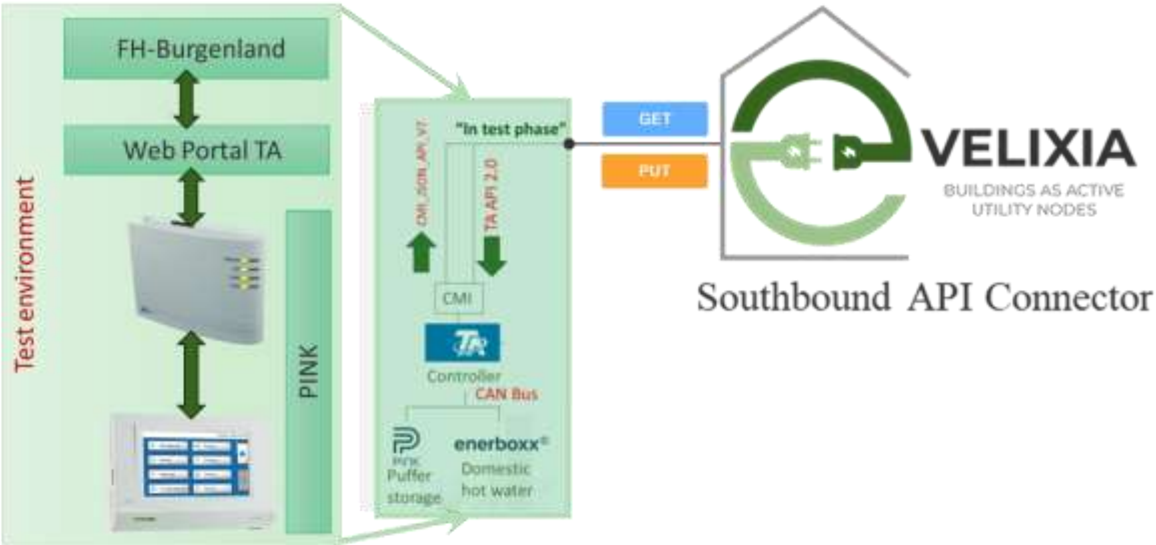


Figure 40. Test environment for the control system

4.3 Simulation calculations

4.3.1 District heating system

The district heating system analysed in the project is located in the south of Burgenland, which in turn is a province of Austria. It is operated in the form of a cooperative, namely Öko Energie Strem, whereby about 60% of the heat consumers are also members of the cooperative. The heat for the district heating network comes from the local biomass district heating plant (based on forest biomass) and from the waste heat from the local biogas co-generation plant (based on agricultural biomass). About 2/3 of the heat comes from the biogas CHP plant.

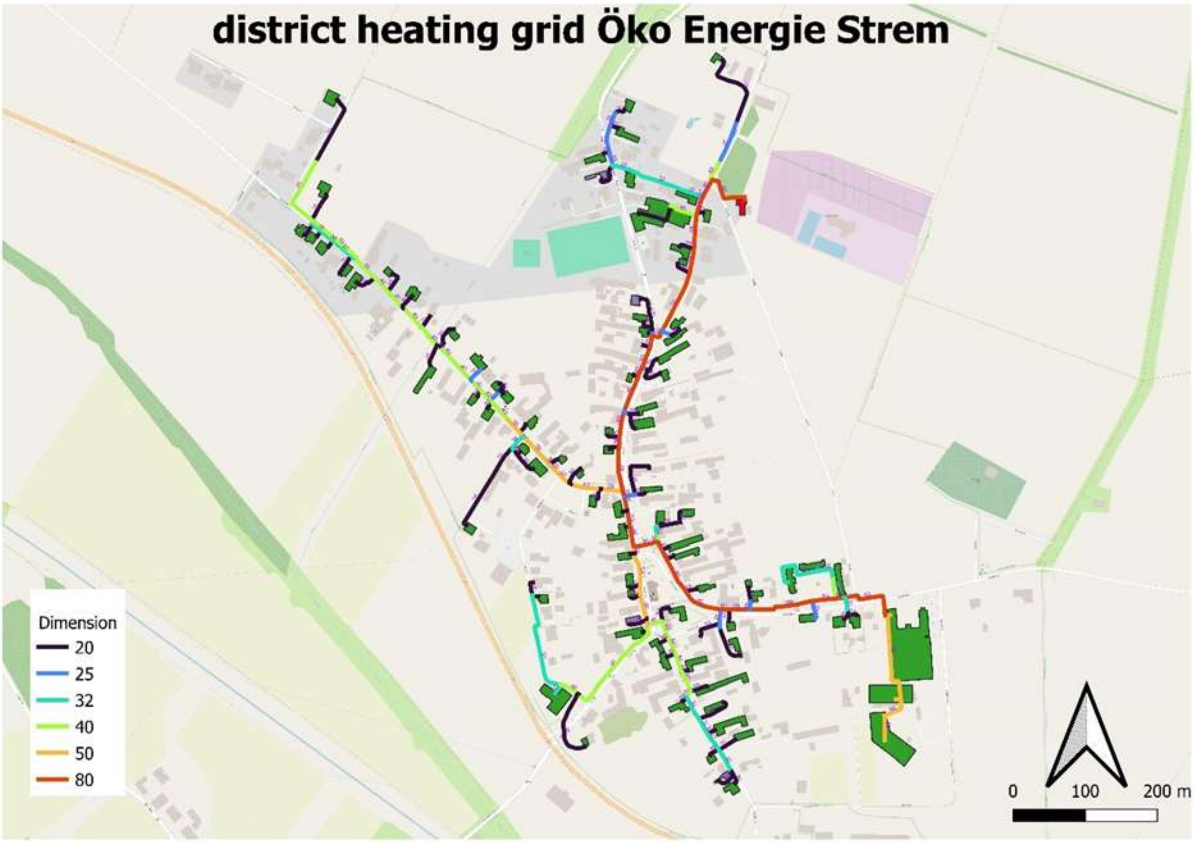


Figure 41. General plan of district heating network “Strem”

For the district heating network, a simulation model for the comprehensive analysis of district heating networks was created using the "simplex" software, which has already been used in many research and customer projects. Based on this, the piping network system can be evaluated regarding a wide variety of aspects, such as the pressure and temperature conditions in the network, the feed-in capacity and the heat load consumed for each individual customer.

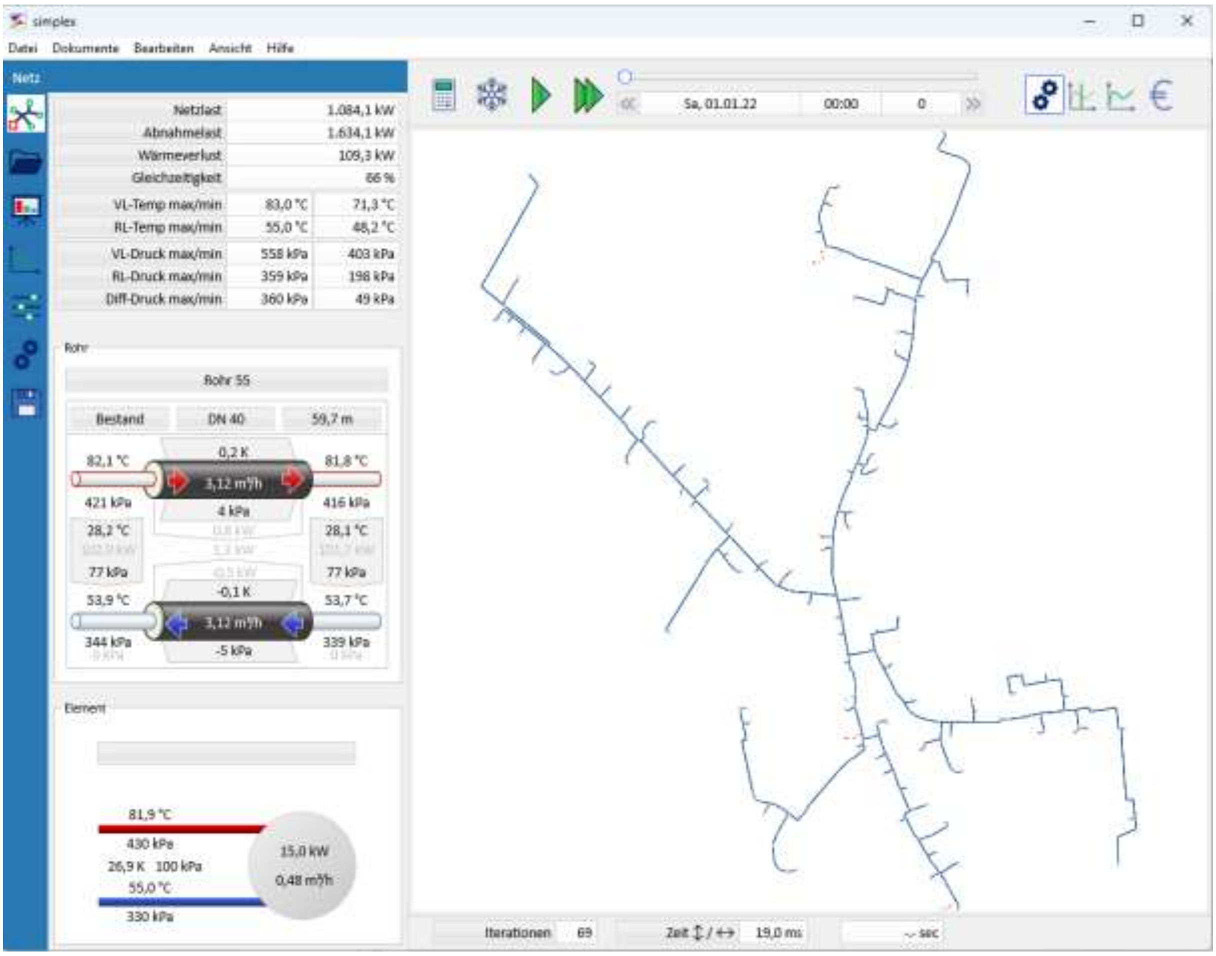


Figure 42. Model of the "Strem" district heating network

In addition to the overview of the DH model, **Figure 43** shows the pressure situation of the district heating system as well as the temperature and pressure profile as well as the load profile for the feed-in capacity. Among other things, it shows the possibilities for detailed evaluation for the entire system, a single pipeline and a single customer.

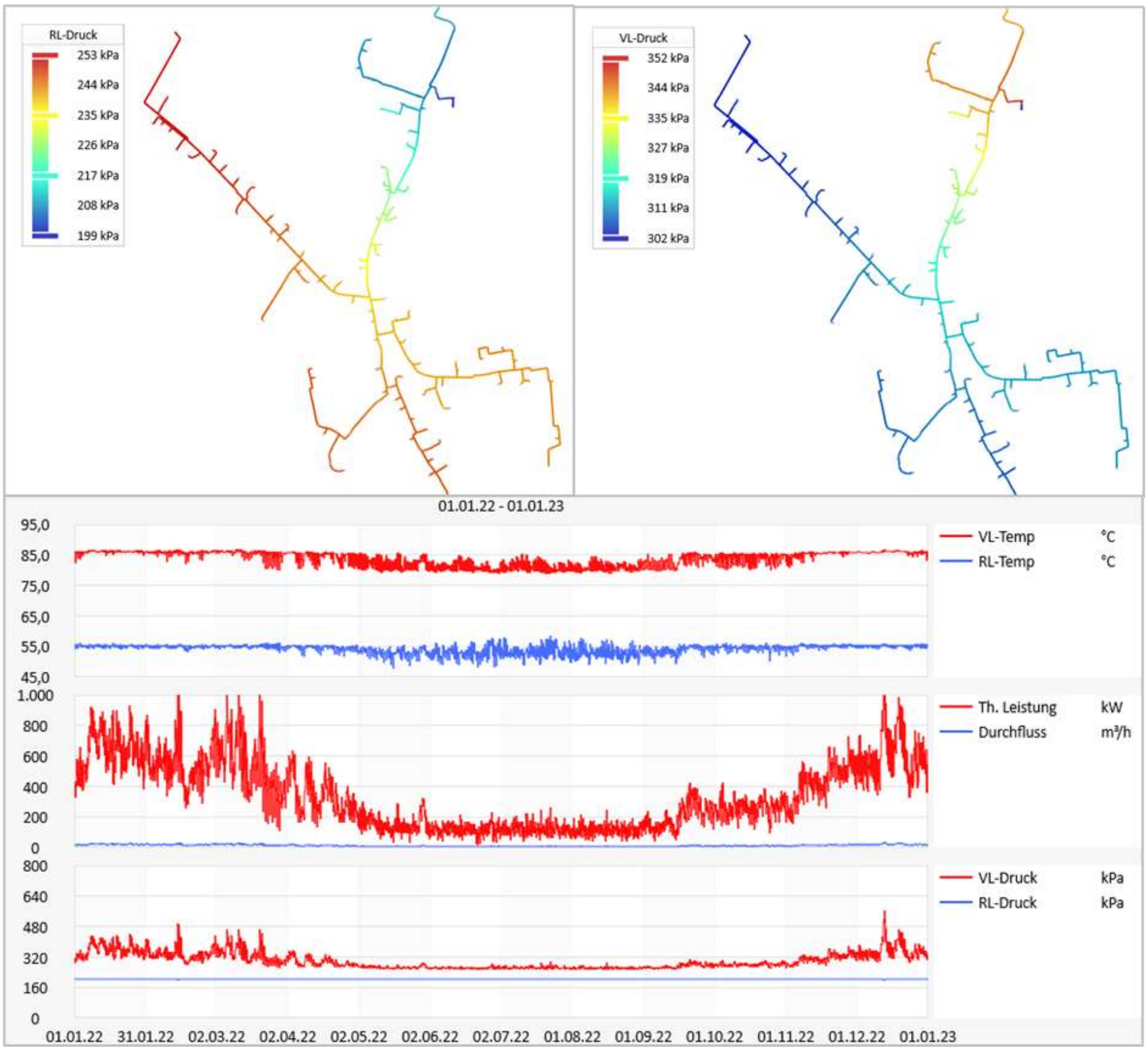


Figure 43. Simulation results of the district heating network

A central consideration dealt with the identification of those network areas in which there may be temporarily low differential pressures during operation and thus undersupply in the district heating system. This was particularly necessary for the positioning of the thermal storage systems to be installed as part of the project, which can solve these problems by creating thermal flexibility. **Figure 44** gives an overview of these actual network areas.

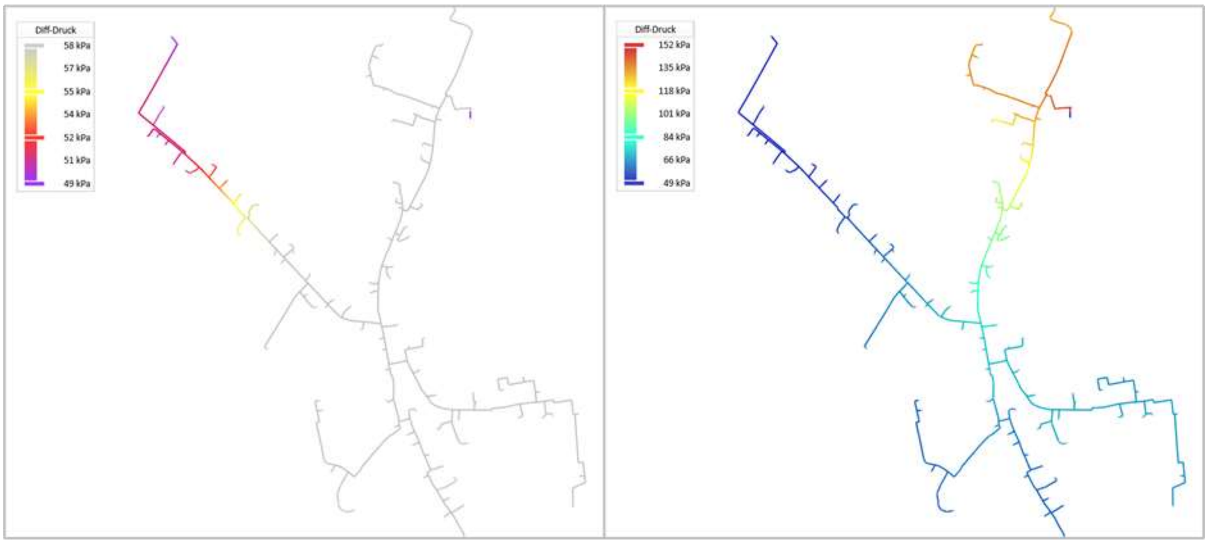


Figure 44. Network areas with undersupply or low differential pressure

Based on these analyses in combination with practicable locations for the integration of thermal storage systems, which were developed together with the district heating operator, the geographical area for the integration of the two variants (buffer tank / hot water tank) could be determined. **Figure 45** gives an overview of these actual network areas.

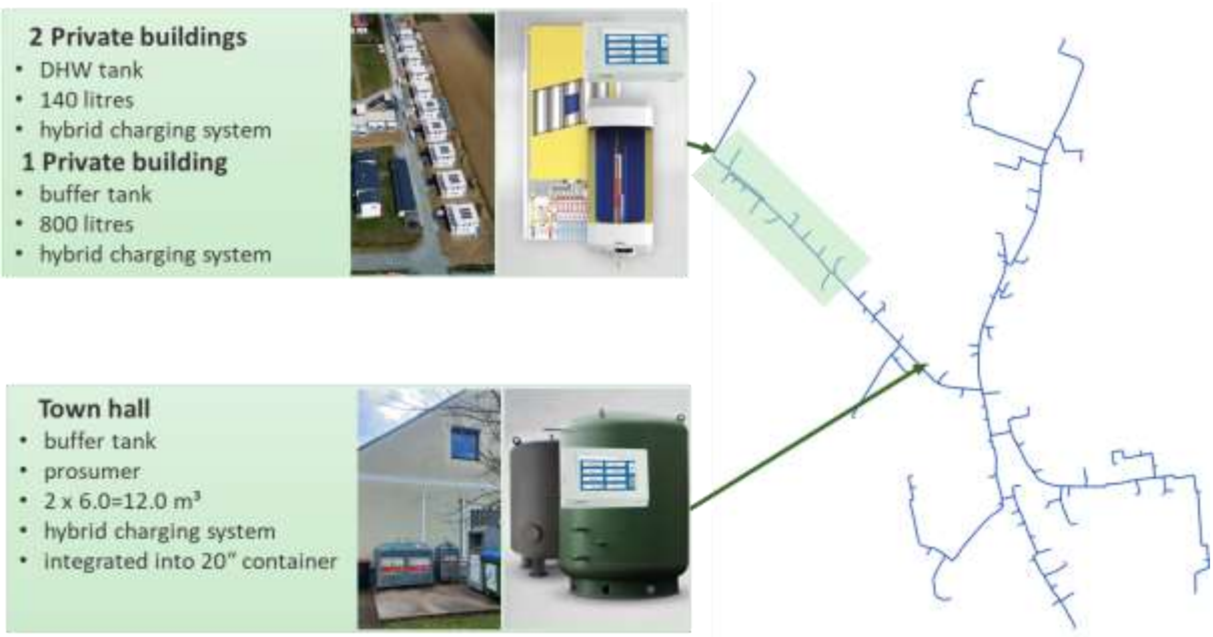


Figure 45. DH network position for the thermal storage tanks

4.4 Dimensioning of storage solutions

According to the definition in the proposal, the EVELIXIA project uses and develops an innovative concept for storing energy, with the main element of this solution being a decentralized hot water storage tank in which hot water is stored. The wide range of options for customizing the storage tank, as well as the extended sphere of influence, which also includes components outside the actual water tank, make it possible to find the most suitable solutions for optimizing the operation of the district heating system. In the following, a detailed overview of all aspects that are important in this context will be given.

4.4.1 Buffer storage tank in the district heating network

This thermal storage tank consists of two buffer storage tanks installed in a 20"container with a special height of 2.9 m (see **Figure 46** and **Figure 47**), whereby the total volume is 12,0 m^3 (2 x 6.0m^3). The storage tanks are insulated with cellulose insulation, which can be used to adequately fill the complex structure of the gaps. **Figure 48** furthermore shows the hydraulic components, the Power2Heat module and the connection to the district heating lines.

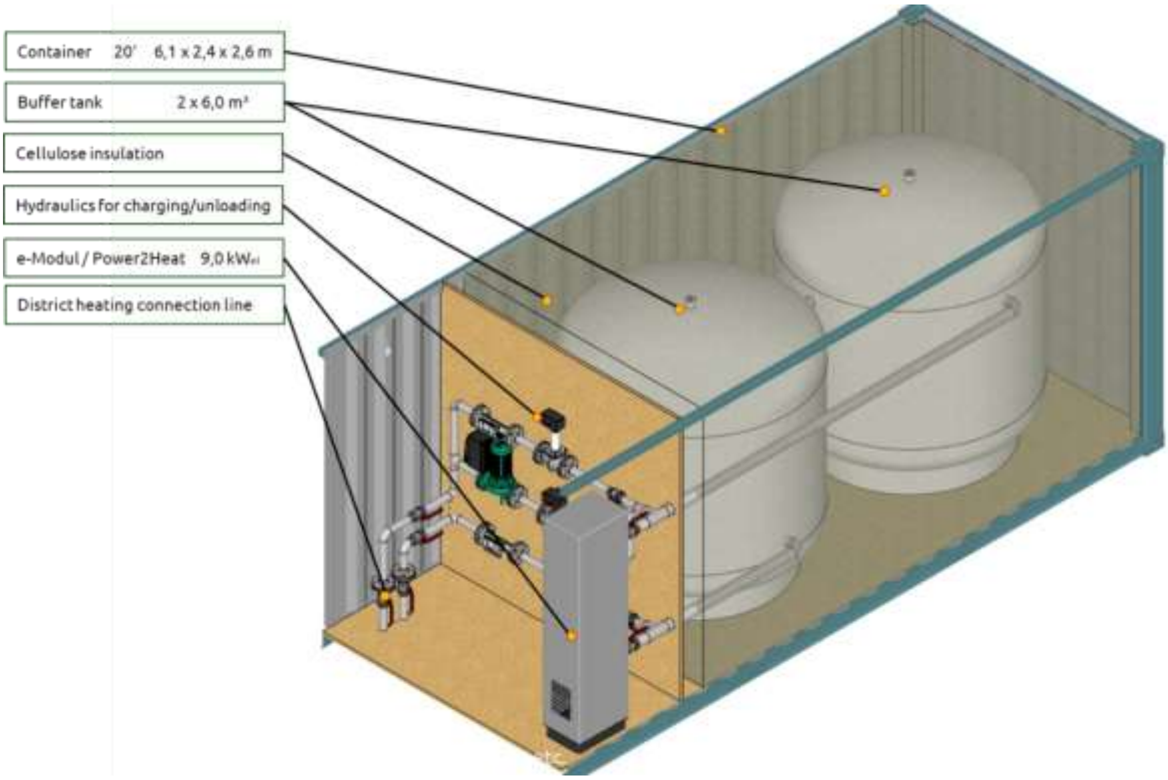


Figure 46. Model of the DH - buffer tank

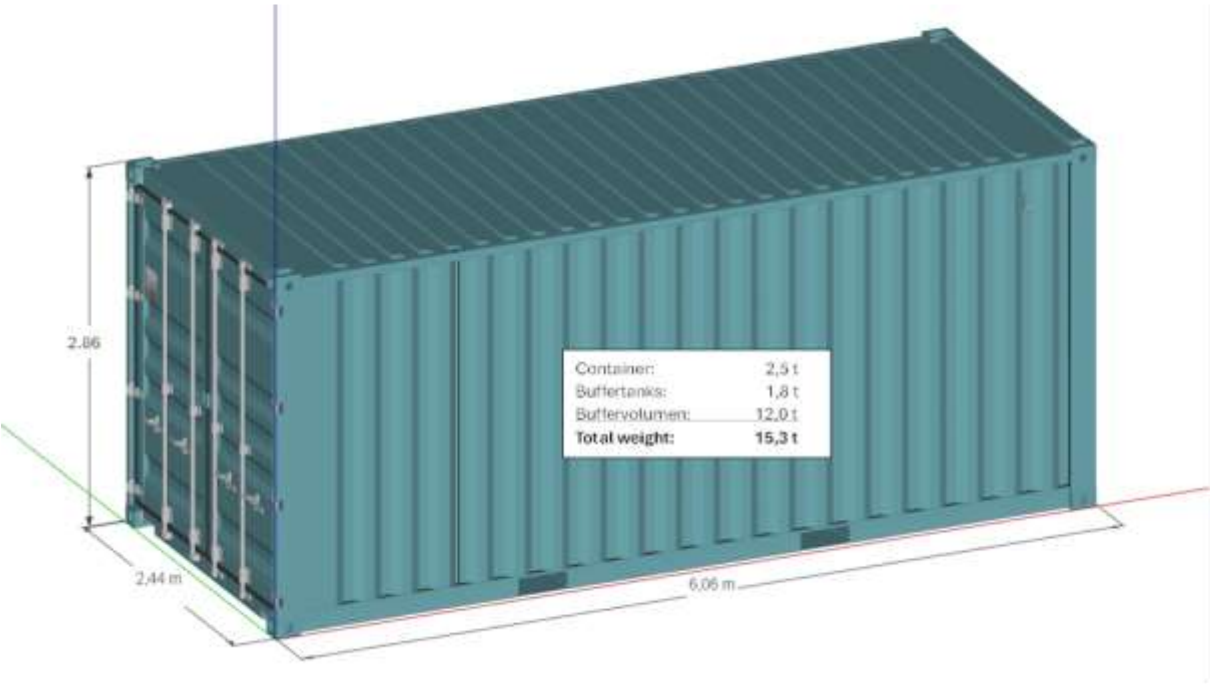


Figure 47. Dimension and weight of DH - buffer tank

The hydraulic diagram of the storage system outlines all the components required to operate the system. This includes the charging valve, which can be used to feed the storage system via the supply lines of the district heating network. In contrast, the storage tank is discharged via the feed pump, which pumps the hot water into the supply network and thus takes over part of the heat requirement. All of these activities are controlled by a PLC that also integrates all the components for monitoring, such as temperature/pressure sensors and heat meters.

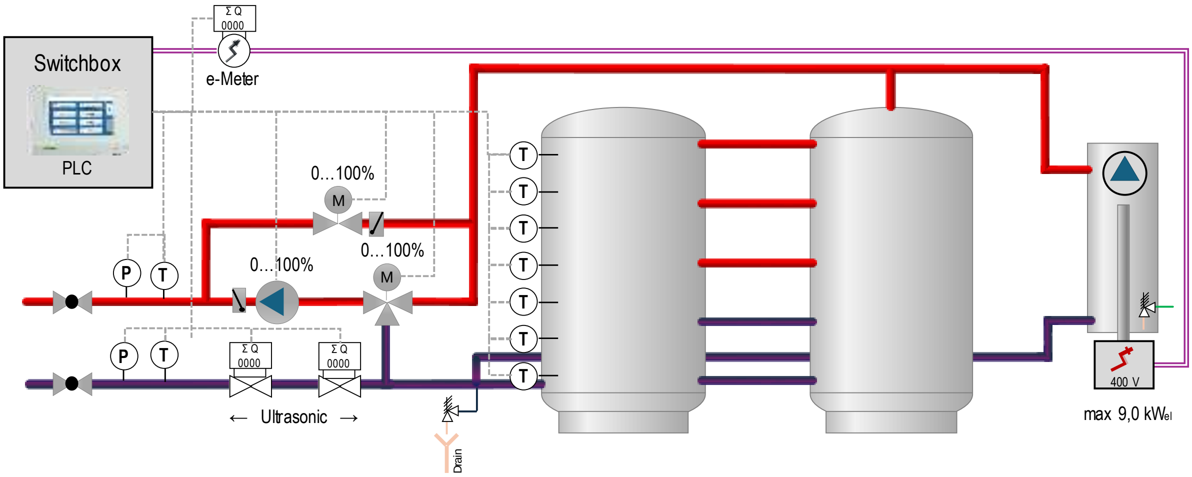


Figure 48. Hydraulic diagram of the DH - buffer tank

The most important components used in the solution, including essential product data, have been summarized in **Table 4**.

Table 4 – Main components of the DH-buffer tank

Component	Image
Feeding Pump Manufacturer: Wilo Type: Stratos GIGA2.0-I 40/1-23/1,5-S1 Power: 1,50 kW Volume flow: 10,0 m³/h Head: 20,0 m Weblink: https://wilo.com	

Charging Valve Manufacturer: Danfoss Type: AVQM DN 40 Size: DN 40 Qmax: 12,0 m³/h kVs-Value: 20,0 m³/h Weblink: https://store.danfoss.com	
Power2Heat modul Manufacturer: Tuxhorn Type: tubra-eTherm C9 Heating power: 9 kW (3 x 3 kW) Size: 605 x 400 x 240 mm Tmax: 80 °C Weblink: tubra-eTherm C	
Ultrasonic counter Manufacturer: Kamstrup Type: MULTICAL 403 Size: DN 50 Qmax: 15,0 m³/h Weblink: https://www.kamstrup.com/	

The detailed design drawing of the buffer tank, which is shown in **Figure 49**, is an exemplary result of the detailed planning process that has already been completed. This was used to purchase the necessary materials and finally manufacture the storage tank.

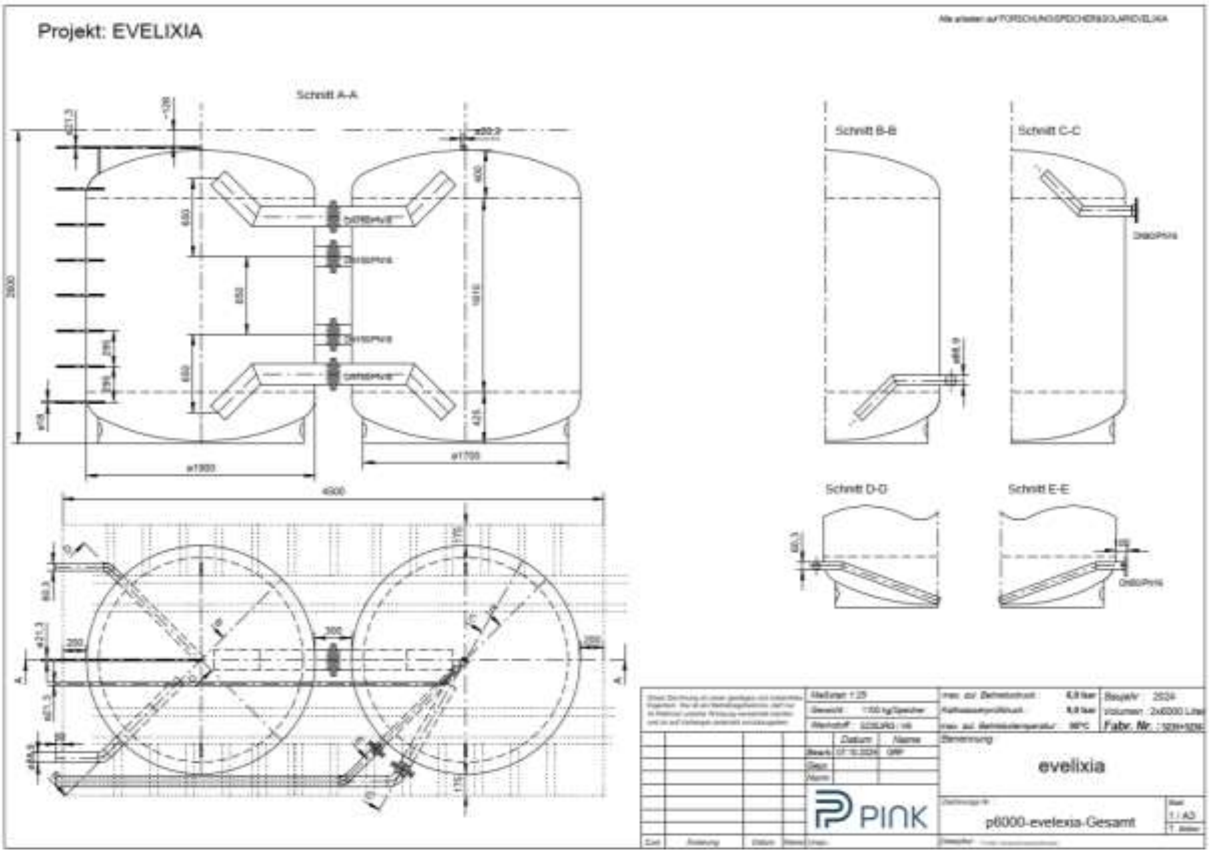


Figure 49. Detailed design drawing

The P&ID diagram in **Figure 50** was also created as part of the detailed planning process, whereby the purchase of the components and their integration into the hydraulic and the control system were determined here. Among other things, the definition of the individual sensors of the monitoring system as well as the assignment to the individual Inputs of the PLC can be seen.

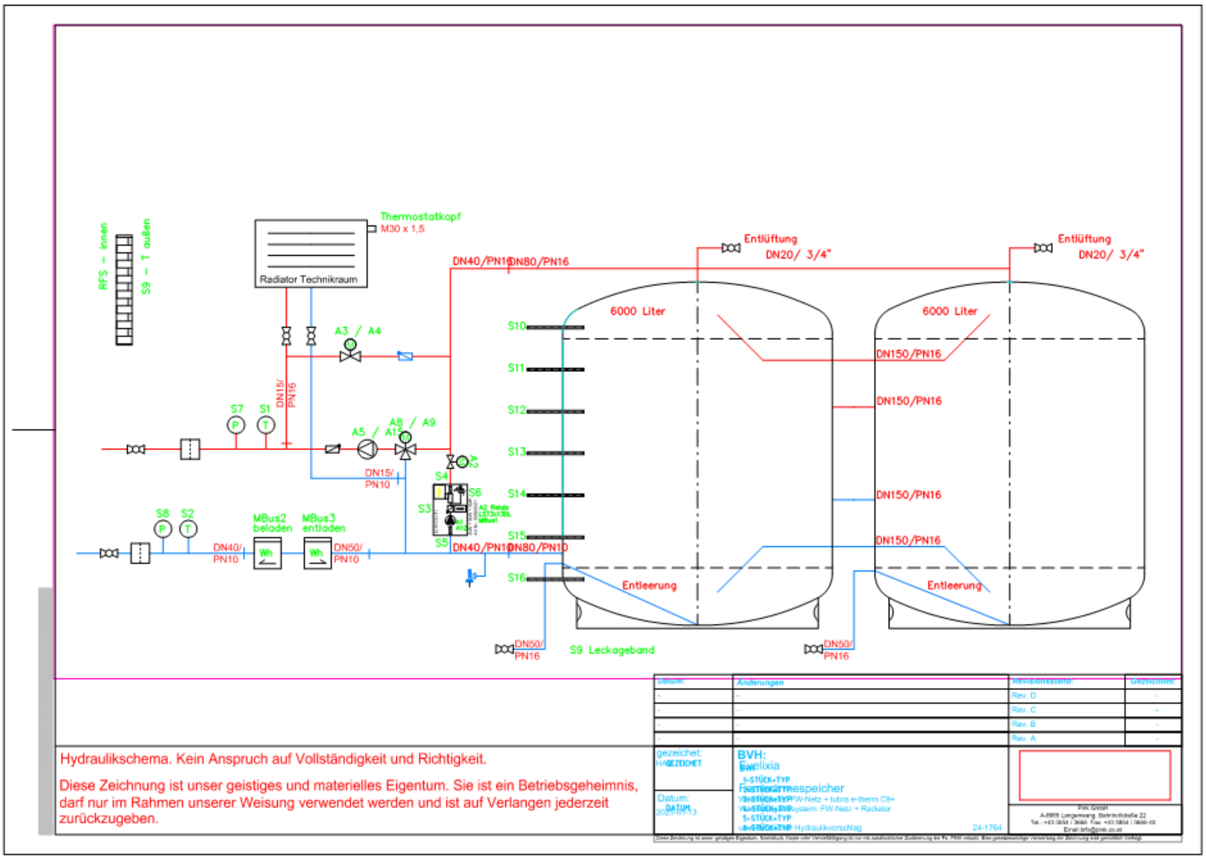


Figure 50. P&ID diagram of DH-buffer tank

As can be seen in the following photos, the manufacturing of the buffer tank is almost complete in accordance with the specific actions. **Figure 51** shows one of the two buffer storage tanks outside the container and the storage tanks already installed into the container, the second photo furthermore shows the insulation process with cellulose insulation.

Figure 51. Buffer tank and insulation process of the DH-buffer tank

The insulation was then separated from the front area of the container. In this "technical room", the piping could then be carried out and the charging and discharging components could be installed. Also, components of the electrical installation as well as the control and monitoring system are installed already.

Figure 52. Cladding and piping and container of the DH-buffer tank

4.4.2 Private Building 1

Figure 53 shows the hydraulic diagram of the thermal storage solution, which was designed for the first of the three private buildings, where thermal storage systems are to be installed as part of the project. Due to the existing integration of the private building 1 into the district heating network (as well as the other two buildings 2 and 3), a district heating transfer station is already installed and functional. In addition, a wood boiler and a solar thermal system are integrated into the heating system as additional heat sources, whereby the wood boiler in particular only serves as a backup reserve and is therefore only used sporadically. In addition to the thermal heat sources, a PV system is also installed, but system integration is only possible via the Power2Heat module, which is also provided.

As already mentioned, a buffer tank with a volume of 800 litres is used as a thermal storage tank in this solution, which is integrated directly into the heating system, so a fresh water module must be used for domestic hot water preparation.

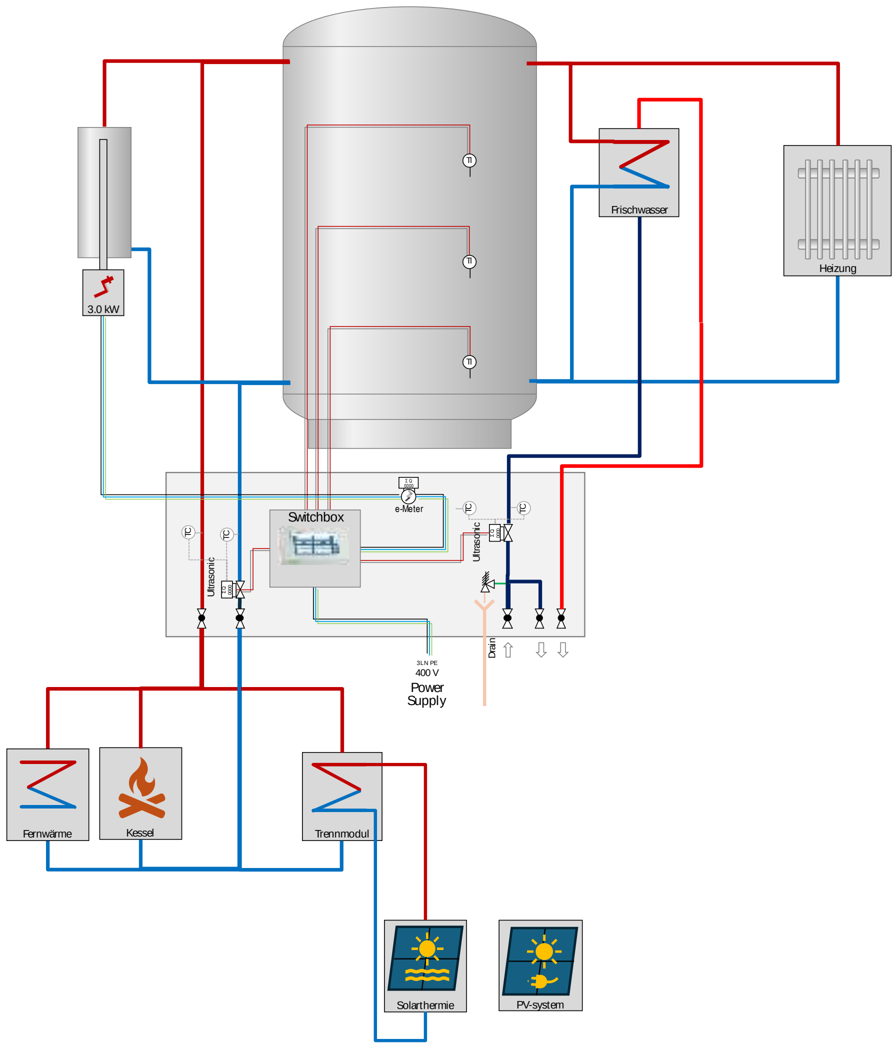


Figure 53. Hydraulic scheme of the Private building 1

The list of relevant components that will be integrated into the storage solution is again presented in the form of the **Table 5**.

Table 5 – Main components of the Private building 1

Component	Image
Power2Heat modul Manufacturer: Tuxhorn Type: tubra-eTherm C9 Heating power: 9 kW (3 x 3 kW) Size: 605 x 400 x 240 mm Tmax: 80 °C Weblink: tubra-eTherm C	
Fresh water station Manufacturer: Technische Alternative Performance: max. 30 l/min Size: 366 x 573 x 160 mm Kv-Value: 2,60 m^3/h Weblink: Fresh water station 3	
Pre-mixing set Manufacturer: Technische Alternative Setting range: 30°C bis 70°C Tmin-op: 70 °C Weblink: Pre-mixing set	

Pump-mixer-group	
Manufacturer: Technische Alternative	
Weblink: Pump-mixer-group 1	

A P&I diagram was also created for this building, which accurately depicts the storage system regarding all aspects such as heating, domestic hot water preparation, control and monitoring. (**Figure 54**).

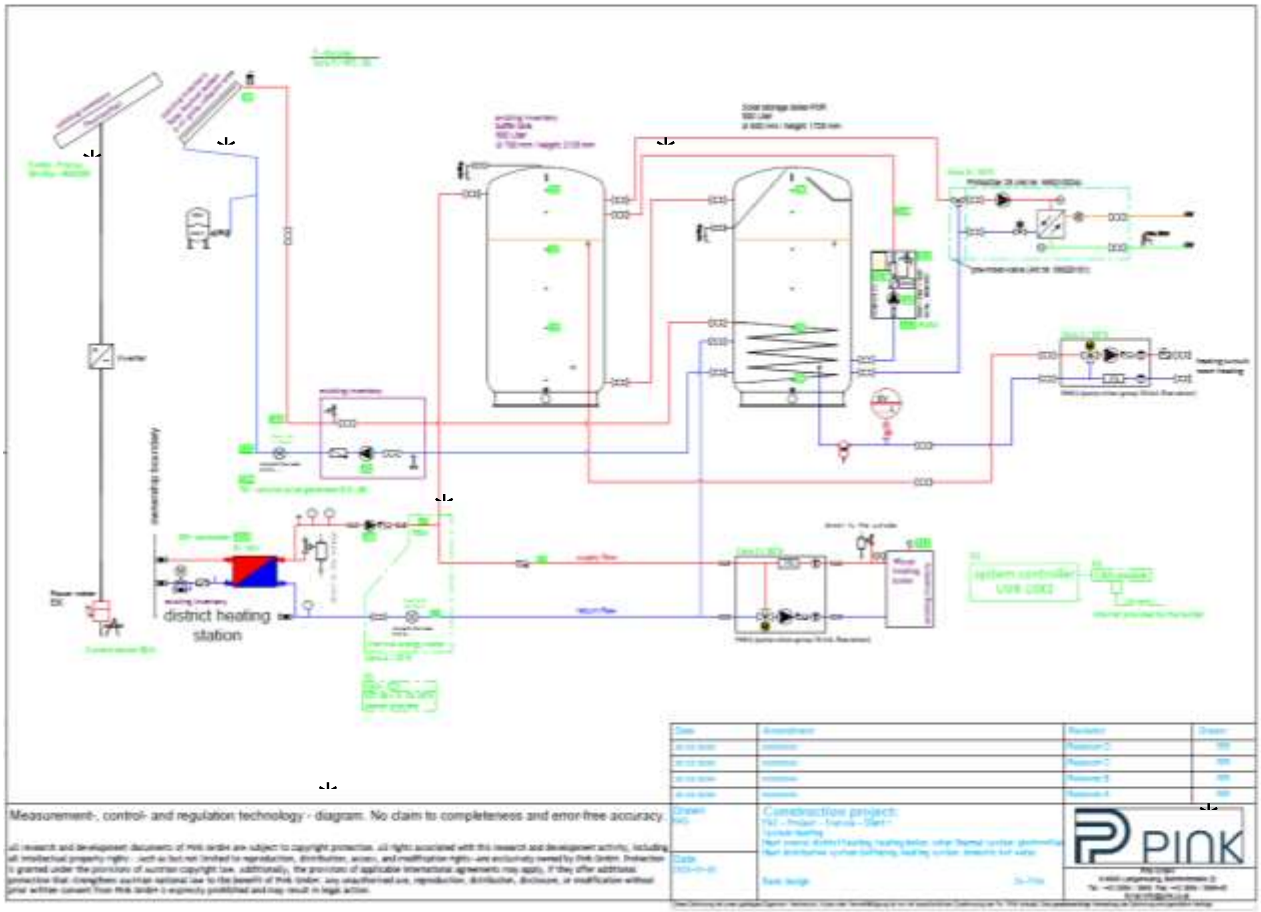


Figure 54. P&ID diagram of the Private building 1

4.4.3 Private Building 2

In contrast to the previous solutions, this heating system does not use a buffer tank, but a domestic hot water tank with 140 litres will be installed. In addition to the district heating station, a wood-fired boiler is again available as a heat source, but little is known about its service life. On the electrical side, a PV system is again available, which can be integrated into the thermal storage system via the e-rod of the hot water system if necessary.

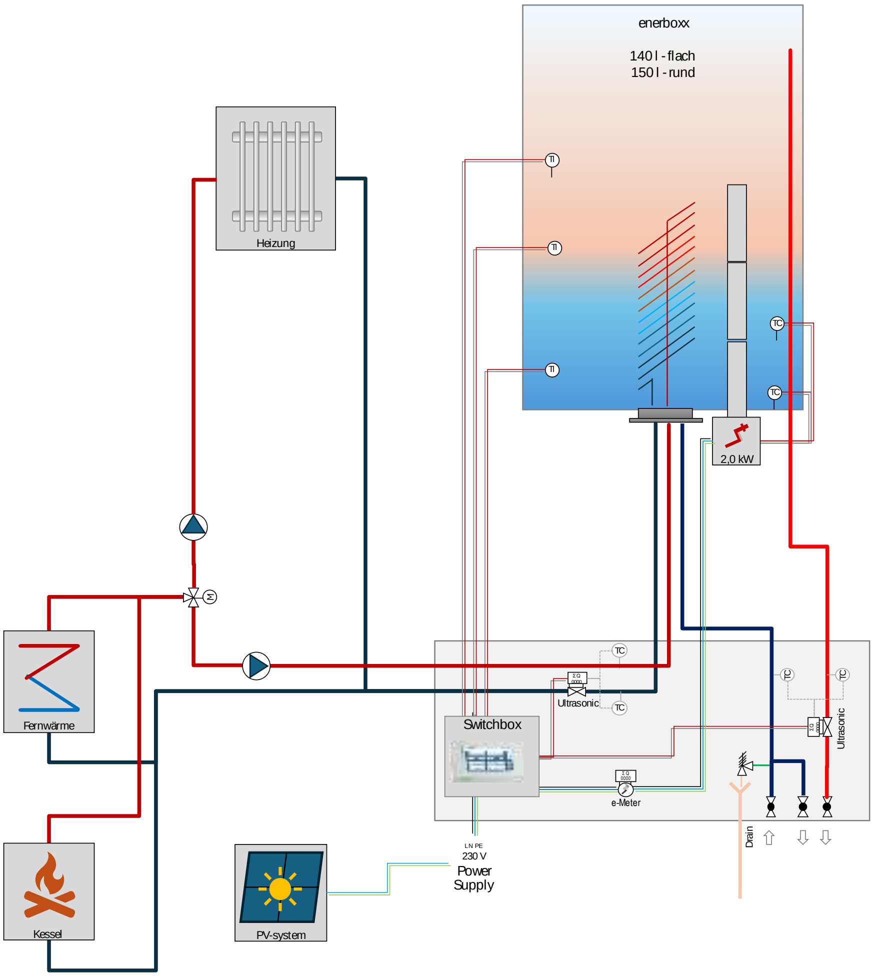


Figure 55. Hydraulic scheme of the Private building 3

The central component of this solution is a domestic hot water tank with a very flat design and a volume of 140 litres, namely the “enerboxx premium”, which was developed by the PINK company in recent years. This unique design of the storage tank allows a direct integration into walls, or at least tightly mounted to walls. It was precisely this potential for space-saving integration that brought significant advantages in the implementation planning. The main technical data of the tank is listed in**Table 6.**

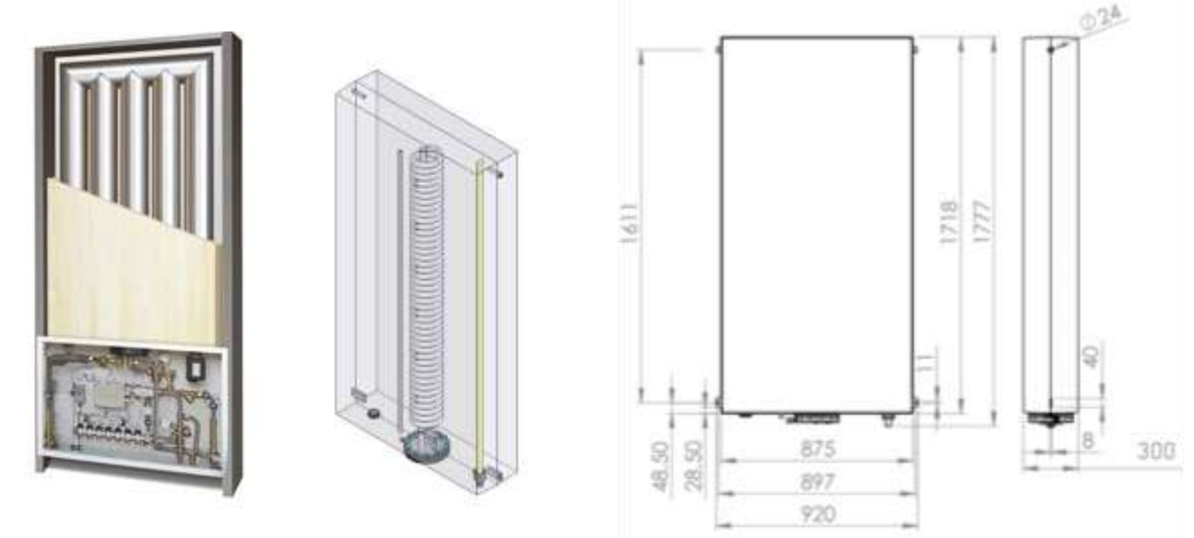
In addition to the flat design, it can be positively pointed out that this storage tank has the option of charging via a thermal heat exchanger, an electric heating element and a combination of both components, which in turn can ideally cover the requirements of the project.

Table 7 lists additional essential system components. From the P&ID diagram of the system in **Figure 56** , it can be seen that the system is much simpler compared to the previous variants. This is because, apart from the pump groups for heating and hot water preparation, hardly any components are required.

Table 6: Datasheet of “enerboxx premium”

enerboxx® - wall integrated DHW storage tank

Stainless steel - Type W+



... for the installation into a steel frame or a mounting set, which is available separate

Technical data:	
Material of the storage tank:	stainless steel -1.4571 (V4A)
Volume of the storage tank:	140 litres
Dimension (H/W/D):	~1750 mm / 920 mm / 300 mm
Max. allowable operating pressure:	6.0 bars
Testing pressure:	9.0 bars
Max. operating temperature:	95.0 °C
Weight (empty):	75.0 kg
Insulation:	PU rigid foam, CFC-free
Stand-by consumption loss:	ca. 1.05 kWh / 24 h, energy label B
Installation parts:	
Inspection flange:	Stainless steel, inner diameter 150 mm (insulated with a flange cover with a fleece inlay)
Heat exchanger for DHW charging:	Stainless steel corrugated pipe heat exchanger (transfer area = 2.0 m²) - recommended volume flow: 150 - 300 l/h - kv-Wert:1,22 / pressure loss: 15 – 60 mbar - volume: ~ 7 litres
Sensor tube:	Inner diameter 12 mm (for max. 3 temperature sensor each ø 6 mm) - the tube reaches the entire storage height
Connections:	
Cold water (drainage):	DN20 - 3/4“ external thread / flat sealing
Hot water:	3/4“ external thread / flat sealing (the hot water is discharged at the very top of the storage tank via an internal plastic pipe) ent
Electrical heater:	6/4" internal thread (closed with a brass cap on delivery)
Potential equalisation:	Ring cable plug for ground lead wires up to 25 mm²

Table 7: Main components of the private building 2

Component	Image
Pre-mixing set Manufacturer: Technische Alternative Setting range: 30°C bis 70°C Tmin-op: 70 °C Weblink: Pre-mixing set	
Pump-mixer-group Manufacturer: Technische Alternative Weblink: Pump-mixer-group 1	

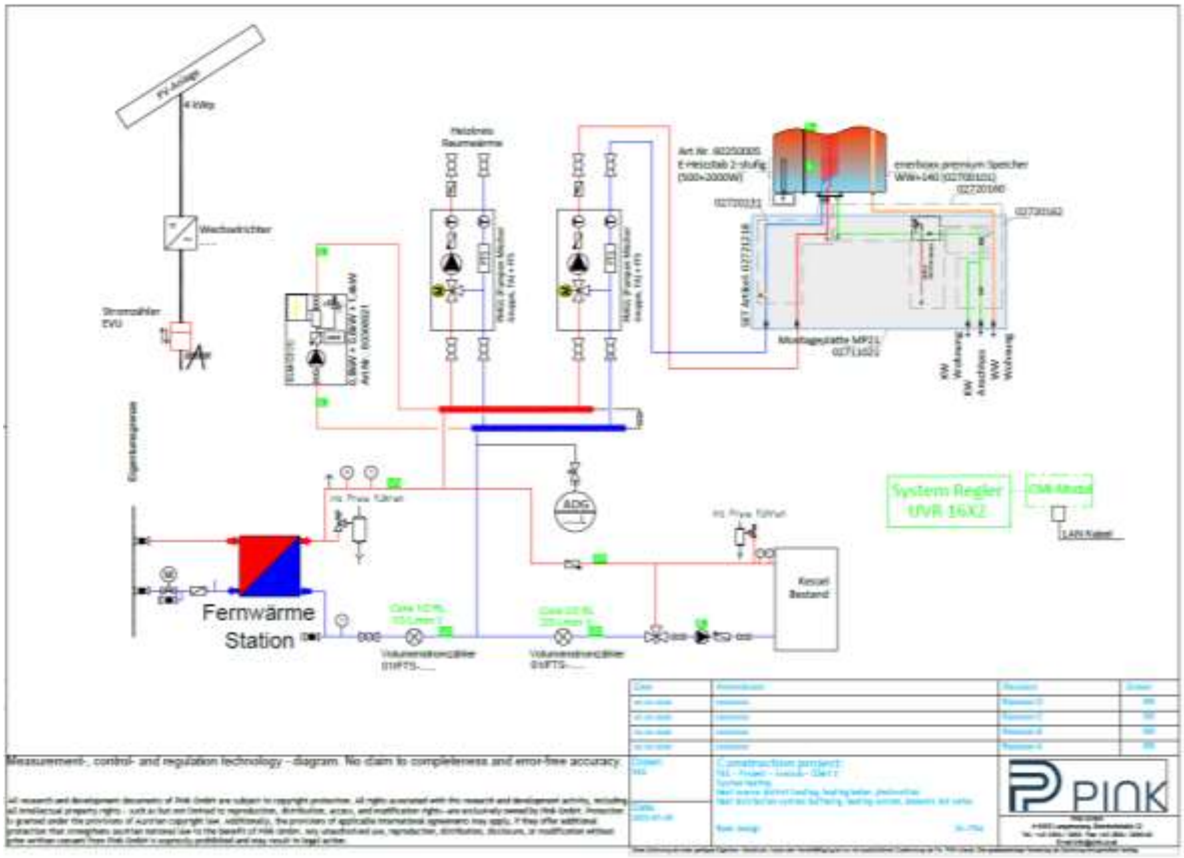


Figure 56. P&ID diagram of the Private building 2

4.4.4 Private Building 3

The heating system of the third private building is very similar to that of the second building. As can be seen in **Figure 57**, a domestic hot water tank is used again, and a wood boiler and a PV system are also integrated into the system again.

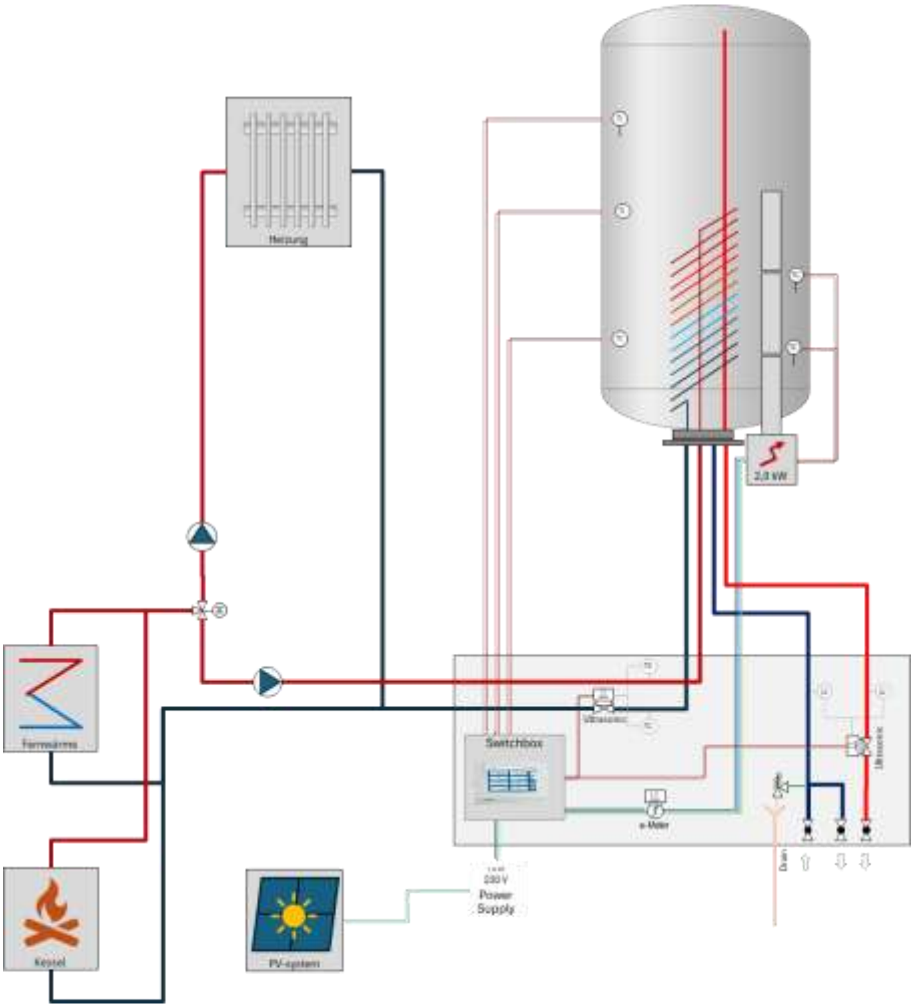


Figure 57. Hydraulic scheme of the Private building 3

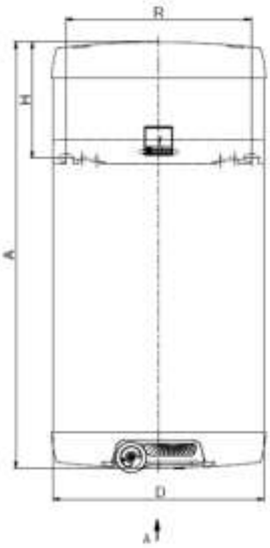
In contrast to the previous solution, however, the flat tank will not be used, but a conventional hot water tank with a cylindrical design, which has a volume of 150 litres, should be installed here (see **Table 8**).

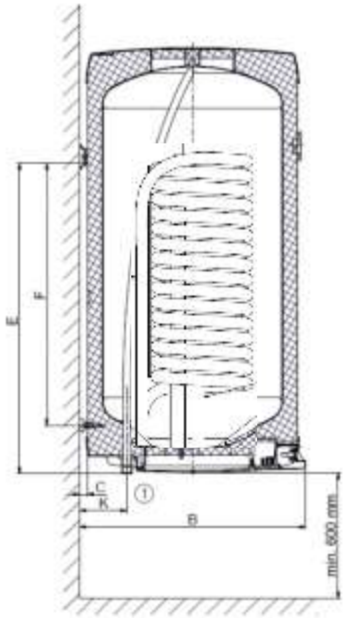
However, the possibility of realization the charging process via thermal, electrical and hybrid charging remains the same as well for this type of tank, which in turn is a key advantage compared to conventional domestic water storage tanks.

Table 8 – Datasheet of "enerboxx basic"

HW160 - wall mounted DHW storage tank

enamelled steel





...zur Wandmontage auf tragfähigem Untergrund.

Technical data:

Material of the storage tank:	steel enamelled, with an sacrificial anode
Volume of the storage tank:	150 litres
Dimension (H/W/D):	~1235 mm / 520 mm / 550 mm
Further Dimensions [mm]:	A: 1235 / B: 550 / C: 19 / D: 520 / F: 880 / H: 235 / K: 88
Max. allowable operating pressure:	6.0 bars
Testing pressure:	9.0 bars
Max. operating temperature:	90 °C
Weight (empty):	~57 kg
Insulation:	PU rigid foam, CFC-free
Outer Jacket:	white powder-coated sheet steel
Stand-by consumption loss:	ca 1.26 kWh / 24 h, energy label B

Installation parts:

Inspection flange:	inner diameter 150 mm
Heat exchanger for DHW charging:	tube bundle heat exchanger (transfer area = 1.45 m²)
Electrical heater:	none (but already prepared for the retrofitting with the electrical stratification charging system "DynaStrat")
Displays:	temperature display (analog temperature indicator)

The list of the main used components in **Table 9** and the P&ID diagram of the solution in **Figure 54** are also almost the same as those of the previous variant due to the very similar system design.

Table 9 – Main components of the private building 3

Component	Image
Pre-mixing set Manufacturer: Technische Alternative Setting range: 30°C bis 70°C Tmin-op: 70 °C Weblink: Pre-mixing set	
Pump-mixer-group Manufacturer: Technische Alternative Weblink: Pump-mixer-group 1	

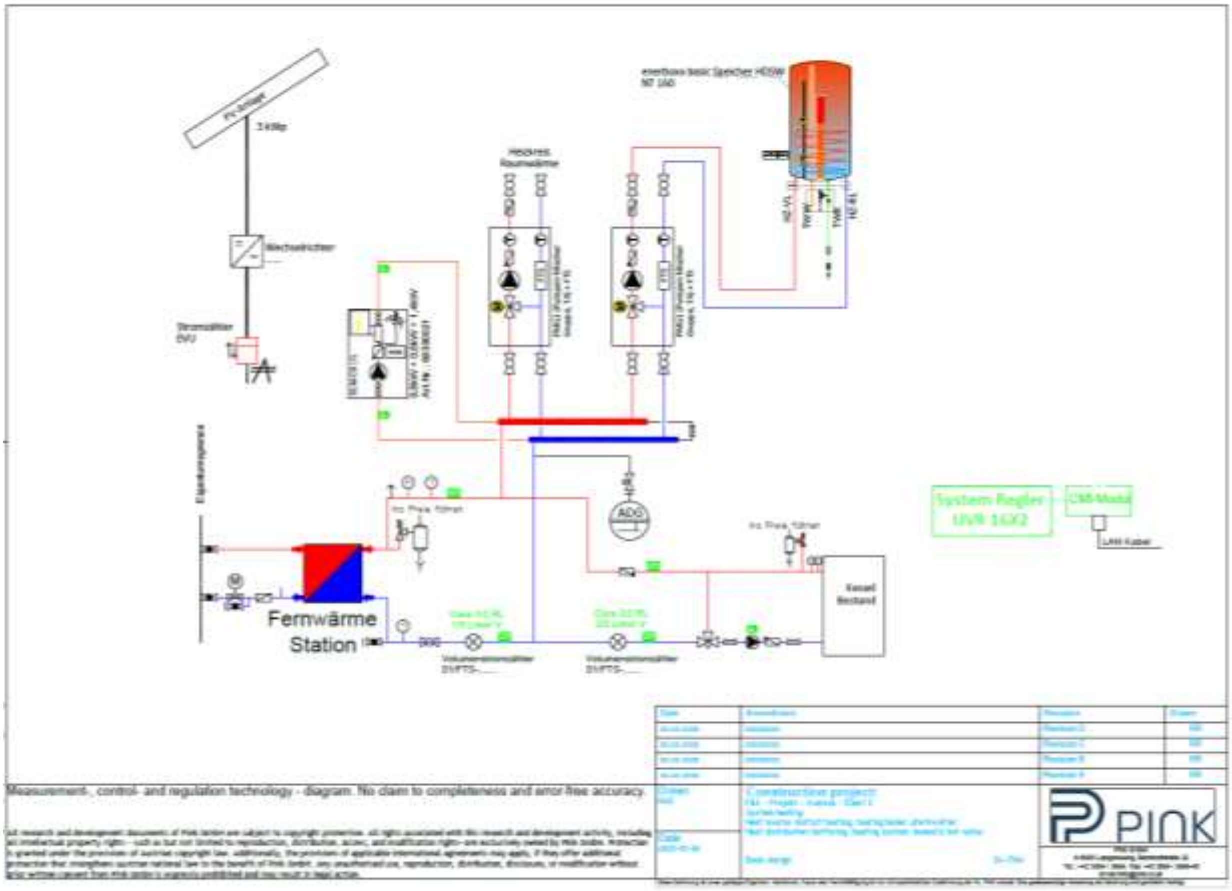


Figure 58. P&ID diagram of the Private building 3

4.5 Timetable and next steps

As can be seen from the schedule with the listed subtasks of Task 2.3 and as can be proven by the job description in the previous chapters, numerous of the planned tasks have already been completed. This includes the initial design of the thermal storage systems in terms of type, size and function, the definition of the equipment and the determination of the technical specifications, and finally the detailed planning of the storage solutions.

The longest delay occurred in the issuance of the assembly permit for the DH buffer tank, but this was also granted in September 2024, which allowed the ordering processes for the components to be started. The installation work can be carried out with a slight delay.

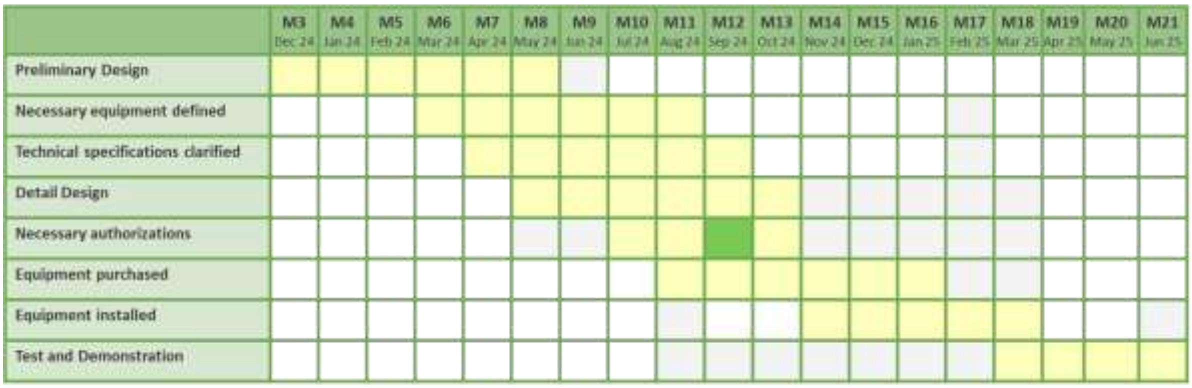


Figure 59. Schedule for the implementation of the thermal storage systems

February 2025 has already been defined as the date for the installation of the DH buffer storage tank, and the delivery of the container and the connection to the district heating system have already been organized. After that, test operation of the storage system can begin immediately.

Several on-site visits have also already been held for private buildings, and detailed storage solutions have already elaborated based on this. There has also already been a meeting with the executing companies regarding the actual implementation, although details of the placing of the order or the processing of the order still have to be clarified. Once this is seen, the further procedure for installing the three storage solutions can be determined.

4.6 CONCLUSIONS

This document underscores the important role of energy innovation in advancing smart building technologies, focusing on the integration of cutting-edge solutions that enhance the sustainability, flexibility, and self-sufficiency of buildings. Through the implementation of three innovative systems—GeoWall, Circular Building-Integrated Photovoltaics (BIPVs), and thermal flexibility solution in Romania and Austria pilot sites, this initiative not only demonstrates their real-world applicability but also paves the way for broader adoption in the built environment.

- **GeoWall system** is designed as a modular and scalable solution for retrofitting and enhancing the energy performance of existing underground structures. It is deployed to be adapted for both interior and exterior spaces. The main innovation that is proposed for Evelixia project is the interior GeoWall system. The system is designed to harvest the waste heat that is existent into the basement of the building.

Through the pilot project executed at UTCN student's dormitory, Interior GeoWall aims to validate its innovative approach, ensuring that it can successfully transform existing underground structures into local renewable energy sources, ultimately enhancing energy resilience and sustainability in Europe's built environment.

- In the second section of this deliverable, the critical importance of integrating circular economy principles within the photovoltaic (PV) industry to enhance sustainability and economic viability is presented Implementing innovative recycling methods, facilitates efficient delamination of **PV modules**, thereby improving material recovery and reducing environmental impact. Furthermore, the necessity of repairing or replacing electrically damaged PV modules has been emphasized from both technical and economic perspectives. Timely interventions are crucial to maintain optimal system performance, ensure safety, and maximize economic returns.
- The integration of **thermal flexibility solutions** within the EVELIXIA project plays a crucial role in optimizing energy storage and distribution in district heating networks. By investigating the use of domestic hot water storage tanks and buffer storage tanks, this initiative aims to enhance energy efficiency while ensuring seamless interoperability with the overarching EVELIXIA framework.

The implementation of hydraulic, electric, and hybrid charging systems enables greater adaptability in energy storage, allowing the system to be charged with different energy sources. A key component of this development is the advanced control system, which regulates water volume flows, temperature levels, and charge/discharge rates based on heat capacity forecasts. These controls not only facilitate load shifting and shedding strategies but also contribute to key performance improvements, including lower operating temperatures, reduced peak loads, and increased self-consumption of photovoltaic energy.

A critical aspect of this project is the integration of thermal storage systems into district heating networks, traditionally reliant on fossil fuels. The Austrian pilot project in "Strem" serves as a testbed for optimizing district heating operations, minimizing heat losses, and reducing peak demand. By offering load-balancing services to district heating operators, this project contributes to the broader transition towards sustainable, efficient, and resilient heating infrastructure.

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