



D6.4. Installation and commissioning of MiniStor system on demonstration sites



Authors:

Carlos Ochoa (IERC), Samaneh Fakouriyan (IERC), Chantal Basurto (IERC), Eszter Hajdu (EMI), Veronika Szabó (EMI), Gabor Fenyvesi (EMI), Adriana Coca (ENDEF), Yolanda Lara (ENDEF), Isabel Guedea (ENDEF), Alberto Belda González (CARTIF), Roberto Arnanz (CARTIF), Sergio Rodríguez Carro (CARTIF), George Martinopoulos (CERTH), Alexandros Tsimpoukis (CERTH), Ioannis Lampropoulos (CERTH) Paschalis A. Gkaidatzis (CERTH-ITI), Dimitrios Tzovaras (CERTH-ITI), Dimitris Papageorgiou (CERTH-ITI), Pantelis Botsaris (DUTH), Paraskevi Dimitriadou (DUTH), Kostas Lympelopoulous (DUTH), Diamantis Papatsunis (DUTH), Zoltán Kővári (WOODSPRING), Zoltán Pásztor (WOODSPRING), Juan Arias (USC), Joaquin Triñanes (USC), Michael Canny (Cork City Council), Brian Cassidy (Cork City Council).



This project has received funding from the European Union's Horizon 2020 research and innovation programme under the grant agreement No 869821

D6.4. Installation and commissioning of MiniStor system on demonstration sites

| Summary | | | |
|---|----|--|---|
| <p>This report describes the actual process and activities for the preparation, delivery, reception, installation, and commissioning of the integrated thermal and electrical energy storage system prototypes in the MiniStor project demonstration sites across Europe. The Deliverable describes the steps followed by demonstration site partners and technology providers to reach a fully functional prototype, and the requirements that were met to achieve this activity. It also details steps taken to enable system remote communication and connection to the existing heating and cooling systems. Timing of these activities is also provided in order to define a future streamlined installation procedure which is also outlined. The report details technical and non-technical aspects that delayed or hampered the installation as “lessons learnt” that need to be considered for future prototype upscaling.</p> | | | |
| Deliverable Number | | Work Package | |
| D6.4 | | WP. 6 | |
| Lead Beneficiary | | Deliverable Author(s) | |
| International Energy Research Centre - Tyndall National Institute-University College Cork (IERC) | | IERC, EMI, ENDEF, CARTIF, DUTH, WOODSPRING, USC, Cork City Council. | |
| Beneficiaries | | Deliverable contributors | |
| Psycrotherm, Sofrigam, CERTH, CNRS, HSLU | | Apostolos Gkoutas (Psycrotherm), Pantelis Bakalis (Psycrotherm), Sebastian PLUMMER (Sofrigam), Xavier Lulka (Sofrigam), Lou Cardinale (Sofrigam), David Tadiotto (Sofrigam), Driss Stitou (CNRS), Philipp Schütz (HSLU), Louis Schibli (HSLU) George Martinopoulos (CERTH), Alexandros Tsimpoukis (CERTH), Ioannis Lampropoulos (CERTH) Paschalis A. Gkaidatzis (CERTH-ITI), Dimitrios Tzovaras (CERTH-ITI), Dimitris Papageorgiou (CERTH-ITI) | |
| Beneficiaries | | Deliverable Reviewer(s) | |
| Cork City Council HSLU | | Michael Canny Louis Schibli | |
| Planned Delivery Date | | Actual Delivery Date | |
| 31/07/2024 | | 22/07/2025 | |
| Type of deliverable | R | Report | |
| Dissemination Level | C | Confidential, only for members of the consortium (including the Commission) | |
| | PU | Public | x |

Index

| | |
|---|-----------|
| Index | 3 |
| List of Tables | 4 |
| List of Figures..... | 5 |
| List of Abbreviations and Acronyms | 7 |
| 1. Brief introduction to the MiniStor system | 8 |
| 1.1. Main Components of the MiniStor system..... | 8 |
| 1.2. Physical features of the prototype enclosure | 9 |
| 1.3. MiniStor system features specific for each demo-site. | 10 |
| 2. Demonstration sites' features, system connections and prototype placement..... | 11 |
| 2.1. Pre-demo site, Thessaloniki, Greece (Partner in charge: CERTH- ITI)..... | 11 |
| 2.2. Performance testing facility, Szentendre, Hungary (Partner in charge: EMI) | 13 |
| 2.3. Kimmeria, Greece (Partner in charge: DUTH)..... | 14 |
| 2.4. Santiago de Compostela, Spain (Partner in charge: USC) | 16 |
| 2.5. Sopron, Hungary (Partner in charge: Woodspring),..... | 17 |
| 2.6. Cork, Ireland (Partner in charge: Cork City Council) | 19 |
| 3. Installation and commissioning process | 21 |
| 3.1. Examination of legal requirements and installation permissions..... | 21 |
| 3.2. Preparation and adaptation work at the sites according to technical requirements | 23 |
| 3.3. Delivery and reception of the MiniStor prototype and solar field | 25 |
| 3.4. Connection and Commissioning of the prototypes on site, including verification tests . | 34 |
| 3.4.1 Experiences obtained during connection and commissioning | 34 |
| 3.4.2 Verification and technical tests for supervised and unsupervised functioning | 39 |
| 3.4.4. Communication configuration with Control and Communication Tests..... | 43 |
| 3.5. Timing of the installation and commissioning activities..... | 48 |
| 3.5.1. General installation activities | 48 |
| 3.5.2. Meters and Sensors..... | 49 |
| 3.5.3. Piping, Cabling, and Foundation per demo site | 50 |
| 3.5.4. Major system components | 52 |
| 4. Summary of problems encountered during the installation and commissioning process, with "lessons learned" | 54 |
| 4.1. Technical issues encountered during the commissioning and operation process..... | 54 |
| 4.2. Relevant non-technical issues encountered during the process..... | 59 |
| 4.3. Key takeaways from the installation and commissioning process..... | 59 |
| 5. Streamlined method for installation of the integrated thermal and electrical storage system | 60 |
| 6. Conclusions | 62 |

List of Tables

| | |
|---|----|
| Table 1. Variations in MiniStor features according to demonstration sites | 11 |
| Table 2. List of the required permissions for the installation of the MiniStor system. | 21 |
| Table 3. Specification of solar field at Sopron demo site | 25 |
| Table 4. Specification of solar field at Thessaloniki demo site..... | 26 |
| Table 5. Specification of solar field at Cork demo site | 26 |
| Table 6. Specification of solar field at USC demo site | 26 |
| Table 7. Overview of General Installation Activities | 48 |
| Table 8. Overview of actual installation time for Meters and Sensors in each demo site..... | 49 |
| Table 9. Overview of actual installation time for Piping, Cabling, and Foundation in each demo site | 50 |
| Table 10. Overview of installation of Main Equipment in each demo site..... | 52 |



List of Figures

| | |
|--|----|
| Figure 1. Final schematic thermal layout of MiniStor (source: D3.2 “Design of peripheral thermal equipment”) with dashed line indicating schematic location of elements in separated enclosures | 9 |
| Figure 2. Three-dimensional view of machinery room for the MiniStor prototype including safety equipment. For illustration purposes the diagram does not show the opaque metal walls enclosing the system. | 10 |
| Figure 3. Interior views of the two compartments of the MiniStor system in a finished prototype. | 10 |
| Figure 4. Exterior view of Thessaloniki pre-demo site | 11 |
| Figure 5. Location of machinery room and solar field in the pre-demo site Thessaloniki, Greece. | 12 |
| Figure 6. Drawing of current HVAC infrastructure in “Control Room West” of Smart Home and proposed thermal energy supply by MiniStor | 13 |
| Figure 7. Exterior views of the standardize testing site (top and middle) and view of the test rig simulating the solar field and house demand (bottom). | 14 |
| Figure 8. (a) Bird view of the DUTH’s demo site location for the MiniStor system and (b) view of the dormitory building | 15 |
| Figure 9: Position of installation of the MiniStor system at DUTH’s demo site | 15 |
| Figure 10. (a) Overview of Burgo de las Naciones Hall and (b) apartment’s location | 16 |
| Figure 11. Proposed location of the machinery room in Santiago, Spain. | 17 |
| Figure 12. Connection the MiniStor system to current infrastructure – USC demo site | 17 |
| Figure 13. (a) Exterior view and (b) Preparation works (view to rear facade)..... | 18 |
| Figure 14. proposed location of the machinery room and solar field in Sopron, Hungary | 18 |
| Figure 15. (a) Entrance view and (b) preparation works (view to boundary wall) | 19 |
| Figure 16. Proposed location of the machinery room and solar field in the demo site of Cork, Ireland..... | 20 |
| Figure 17. A draft of the proposed connection where stored heat will transfer between the MiniStor Unit and dwelling (Cork demo site) | 20 |
| Figure 18. Installation works at Thessaloniki demo site connecting pipes to fan coil unit and on solar field (Dec 2023) | 24 |
| Figure 19. Pipe preparation, inertia tank and fan coil unit installed at Kimmeria demo site (Feb 2024) | 24 |
| Figure 20. View of preparation works for the prototype installation at Cork City demo site: electrical connection for battery, hydraulic connections to home boiler (February 2024) | 24 |
| Figure 21. Preparation works at demo site Sopron: pipes on the first stage to connect to the prototype, and their union to the existing heating system (top right) and to the electrical connections (right) February 2024 | 25 |
| Figure 22. Preparation works at Demo site Santiago de Compostela: View of district heating bypass to connect with the prototype (left) and new piping and controls connecting to apartment (right) February 2024..... | 25 |
| Figure 23. Procedure for unloading and reception of the MiniStor unit at Thessaloniki | 28 |
| Figure 24. Procedure for unloading and reception of the MiniStor unit at the Performance testing facility (EMI, HU)..... | 28 |

| | |
|--|----|
| Figure 25. Unloading of MiniStor system at DUTH's demo site | 29 |
| Figure 26 Photos of the delivery of PVT and solar field equipment by EndeF to Santiago de Compostela | 30 |
| Figure 27. Procedure for unloading and reception of the MiniStor unit at USC | 31 |
| Figure 28. Installed and commissioned MiniStor system in Sopron demo building | 32 |
| Figure 29. Images of prototype delivery to Cork demo site. | 33 |
| Figure 30. Images of installation process of MiniStor solar field at the pre-demo site Thessaloniki | 34 |
| Figure 31. Installation of solar field and electrical equipment in Cork demo site | 35 |
| Figure 32. Views of the finished hydraulic connections inside the building (left) and behind the prototype (right) at Cork demo site | 36 |
| Figure 33. Connection of the system to the existing infrastructure in the pre-demo site (left) and the installed MiniStor system (right) | 36 |
| Figure 34. Power and hydraulic connection to the MiniStor system (D.U.TH.) | 37 |
| Figure 35. Expansion tank for bypass to the MiniStor system (left) and Inertia tank at DUTH's demo site showing communication wiring and temperature set point mechanism (right) | 37 |
| Figure 36 View of the installed prototype in Santiago de Compostela (left) and inertia tank underground (right) | 38 |
| Figure 37. Views of the PVT, heat pump and electrical components at Santiago demo site. | 38 |
| Figure 38. MiniStor hydraulic and communication connection to the Sopron demo building via pipelines and cables (Left) and the installed MiniStor system (right) | 39 |
| Figure 39. Ammonia charging during testing operation at the Thessaloniki pilot site | 39 |
| Figure 40. Ammonia Alarm threshold testing at the Thessaloniki pilot site. | 40 |
| Figure 41. Pressure testing at the Thessaloniki pilot site | 40 |
| Figure 42. Solar PVTs pressure measurement during pressure testing at the Thessaloniki Pilot site | 40 |
| Figure 43. Pressure changes during parameter fine-tuning testing at the Thessaloniki Pilot site. | 41 |
| Figure 44. Operational parts of MiniStor in Sopron | 42 |
| Figure 45. Actual operational parameters of MiniStor in Sopron. | 42 |
| Figure 46. Monitoring and data storage strategy | 43 |
| Figure 47. Monitoring of a cycle visualized in Grafana | 44 |
| Figure 48. Graphical interface for system testing | 45 |
| Figure 49. BACNet communication | 46 |
| Figure 50. MiniStor TCM tank mounting solution due to overload weight during transporting for EMI testing | 55 |
| Figure 51. Water leaks in press fittings that were subsequently repaired during EMI testing | 55 |
| Figure 52. Leaks due to faulty air vent valves | 56 |
| Figure 53. Construction of a filling and emptying section in Sopron | 56 |
| Figure 54. Manual adjustment of NH ₃ level indicator against readings from the sensors | 57 |
| Figure 55. The cold environment conditions forced a special operation mode for defrosting | 58 |

List of Abbreviations and Acronyms

In the rest of the text, the following abbreviations will be frequently used:

| | |
|------|----------------------------------|
| COP | Coefficient of Performance |
| DHW | Domestic Hot Water |
| EES | Electrical Energy Storage System |
| HP | Heat Pump |
| HEMS | Home Energy Management System |
| PCM | Phase change Material |
| PLC | Programmable Logic Controller |
| PVT | Photovoltaic-Thermal Panels |
| RES | Renewable Energy Sources |
| TCM | Thermochemical Material |



1. Brief introduction to the MiniStor system

This section provides a summary of the MiniStor system, helping understand the components and technologies involved for its installation. For a more comprehensive description, please refer to D3.1.

MiniStor is an integrated thermal storage solution designed to support sustainable heating, cooling, and electricity storage in both new and existing residential buildings. Its thermal storage capabilities are based on an advanced calcium chloride/ammonia ($\text{CaCl}_2/\text{NH}_3$) thermochemical material (TCM) reaction, complemented by PCM for storing both sensible and latent heat. Electrical storage utilizes a conventional Li-Ion battery system. The system enables compact storage of renewable energy generated from PVT. Additionally, MiniStor integrates a HEMS to efficiently synchronize and manage household energy supply and demand, responding to grid constraints and price signals.

1.1. Main Components of the MiniStor system

The MiniStor system is composed of several parts that have different installation requirements. Assembly of components such as TCM reactor, ammonia circuit, heat pump, PCM, heat exchangers, fans and system controls were done in the environment of a specialized factory with delivery of finished, ready-to-use units that have been tested beforehand. For the project, the solar field that starts the thermochemical reaction was installed in situ, together with the electrical battery. In this way, demonstration sites only had to focus on preparation works, electric and hydraulic connections and internet connectivity.

Key subsystems include:

- a) TCM reactor containing a reactive medium (CaCl_2 and expanded natural graphite) and an ammonia refrigeration cycle, enabling heat storage via reversible solid/gas sorption processes, powered by an ammonia compressor and ancillary equipment. These are placed inside a dedicated enclosure.
- b) A water-to-water heat pump upgrades ammonia condensation heat to higher temperatures suitable for building heating, to upgrade the heat obtained. Placed in a separate section of the dedicated enclosure.
- c) Phase Change Material (PCM) vessels keep the thermal energy generated ready for dispatch, with specific vessels serving heating, DHW, and cold supply functions. Placed in the same section of the heat pump.
- d) PLC controller modules that enable manual and remote control of the system. Placed in the same section of the heat pump.
- e) A RES-based system utilizing PVTs and solar thermal collectors for heat input, with flexibility for integration with other RES resources. Placed on a suitable area at the demo sites to maximize solar potential. Solar field controllers are placed inside the enclosure, next to the electrical storage system controllers.
- f) The Electrical Energy Storage System (EESS) includes a Li-Ion battery and smart hybrid inverter for managing electricity flows between generation, storage, and consumption. Placed outdoors next or close to the enclosure and the solar field controllers.

Compliance with standards and safety requirements (such as Standard EN-378, with its full analysis performed in D2.3) defined system location, with the controlling parts and ammonia components placed in a dedicated enclosure with relevant safety systems and indicators, and the electrical battery located outdoors. The schematic system layout for the thermal part is shown in Figure 1, and detailed in D3.2. The dashed boundaries in the image indicate which elements are placed within the enclosures.

Moreover, EN-378 refers to a minimum distance of 2 m between exterior openings of ammonia-containing machinery rooms (the MiniStor enclosure in this case) and nearby buildings' emergency exit staircases or other openings, e.g. windows, doors, ventilation inlets. This is a very important provision taken into account when planning and implementing preparatory works in the demo sites.

Some variations exist to the basic setup, such as an additional heat pump at Santiago de Compostela to upgrade heat from the solar field (placed inside the enclosure) and the existing connections to the RES sources of demo site Kimmeria. These are detailed in Section 1.3.

The system is connected to the existing heating, cooling and DHW loops through insulated pipes coming from the building up to the location of the MiniStor enclosure, which are then attached to dedicated inlets and outlets located at the rear of the prototype. Each site has been responsible to ensure that the correct flows and pressures are maintained to reach the system and to complete the necessary loop bypass.

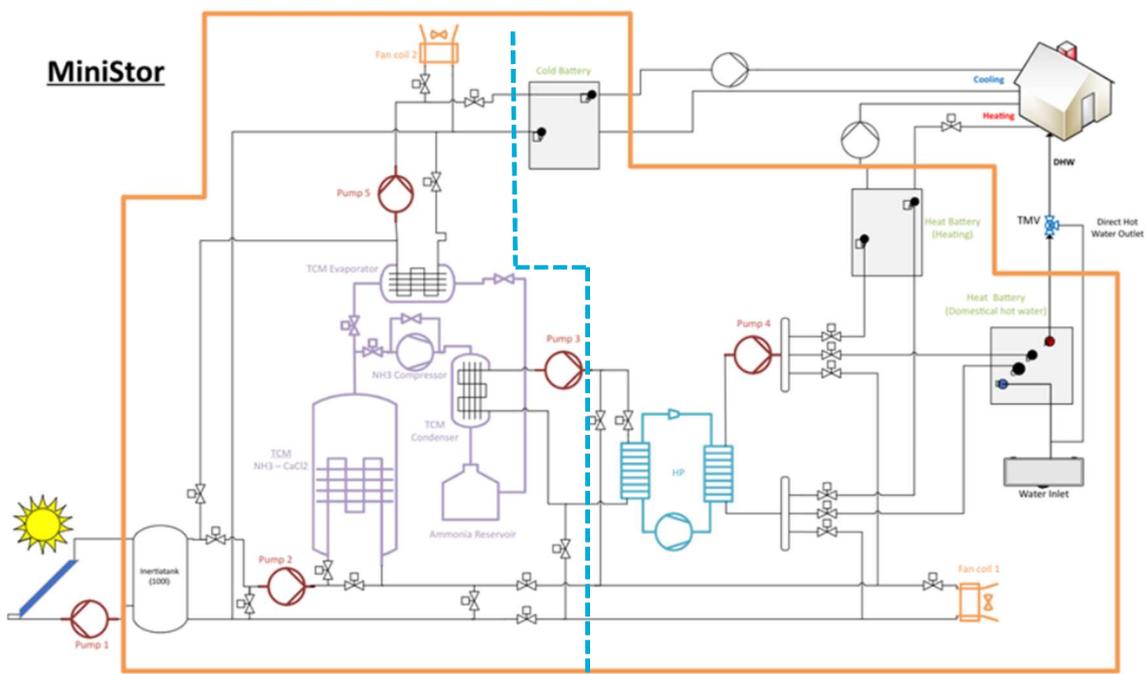


Figure 1. Final schematic thermal layout of MiniStor (source: D3.2 "Design of peripheral thermal equipment") with dashed line indicating schematic location of elements in separated enclosures

1.2. Physical features of the prototype enclosure

The components of the system are incorporated in a prototype enclosure of dimensions 3m*2m*2.5m (W*D*H) which was assembled by partner Psycrotherm (Greece) and delivered as a finished unit to the different demo sites. The estimated weight of the enclosure and components is about 1.7 tons. The prototype enclosure ("the container") complies with the provisions of EN-378 for ammonia-containing machinery rooms and is made of metal panels with insulating material, see Figure 2. The images show the structure for clarity purposes only.

The container has two compartments: the first houses the ammonia loop (including the TCM reactor manufactured by partner Sofrigam, located in France), while the second contains the control systems, heat pump and PCM batteries. Both are accessible separately through separate locked doors that open directly to the outside, clearly marked with relevant safety placards. Access is restricted to the compartments to authorized personnel only. Inhabitants are excluded from

access. This container is located outdoors of the demonstration buildings and connects to the solar field (PVT panels and solar collectors). The exact placement and distance of the container from the buildings at all demonstration sites are mentioned in the following sections.

Container with two compartments: - 1 for NH₃ circuit
3m x 2m x 2.5m (WxDxH) - 1 for the rest equipment and control

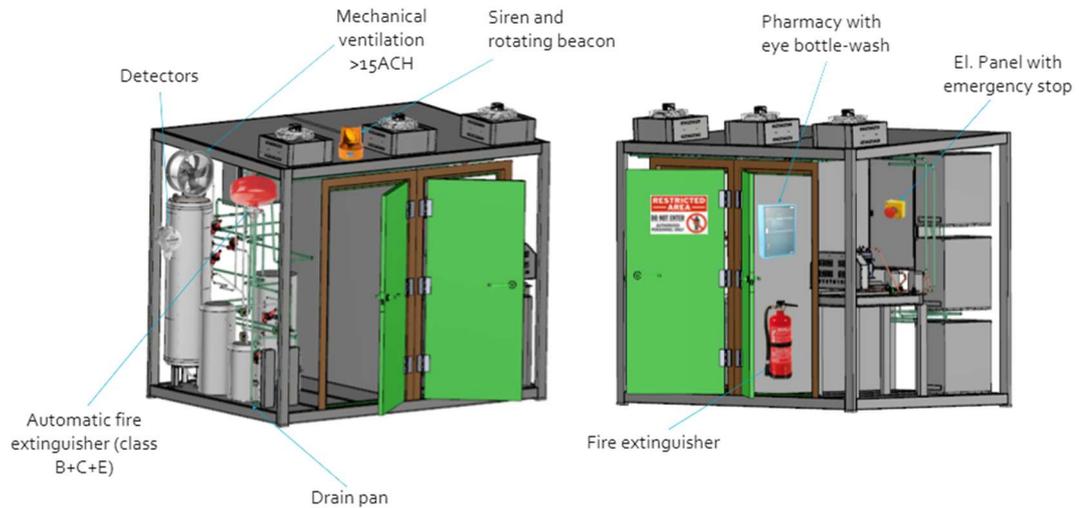
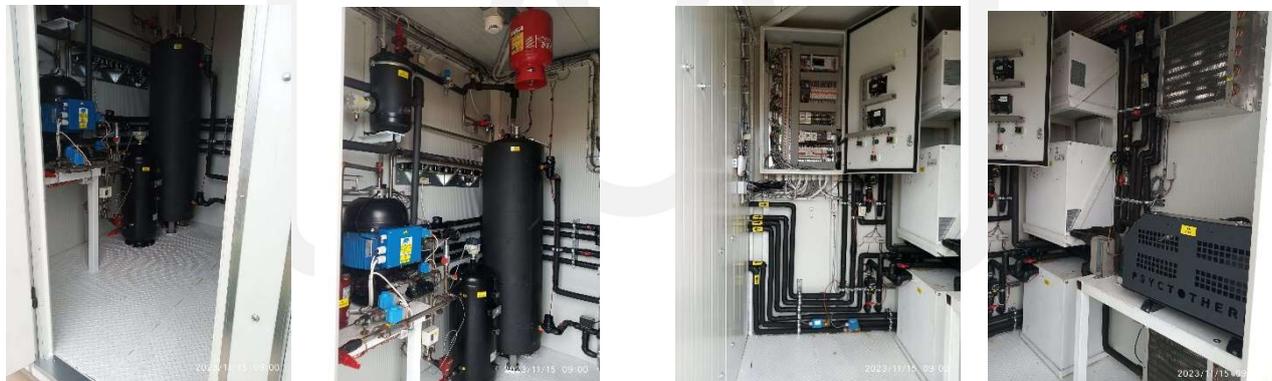


Figure 2. Three-dimensional view of machinery room for the MiniStor prototype including safety equipment. For illustration purposes the diagram does not show the opaque metal walls enclosing the system.



Ammonia tank compartment (left side)

Controllers compartment (right side).

Figure 3. Interior views of the two compartments of the MiniStor system in a finished prototype.

1.3. MiniStor system features specific for each demo-site.

Certain variations to the main prototype or solar field were produced, to test alternatives (e.g. variations in the PVT panel) or adapt to local conditions (e.g. 2-phase electrical supply in Cork and enclosure size that fits inside shipping containers). The variations are summarized in the following table:

Table 1. Variations in MiniStor features according to demonstration sites

| Demo site | New Solar field | Additional Heat pump | PVT type | Electrical storage | Electricity feed | Enclosure type |
|---------------------------------|------------------|----------------------|----------|--------------------|------------------|----------------------|
| Thessaloniki, Greece (pre-demo) | Y | N | Glazed | Y | Tri-phasic | Same size |
| Kimmeria, Greece | N (use existing) | N | n/a | N | Tri-phasic | Same size |
| Santiago de Compostela, Spain | Y | Y | Unglazed | Y | Tri-phasic | Same size |
| Sopron, Hungary | Y | N | Glazed | Y | Tri-phasic | Same size |
| Cork, Ireland | Y | N | Glazed | Y | Bi-phasic | Smaller for shipping |

2. Demonstration sites' features, system connections and prototype placement

This section summarizes the main technical characteristics that were considered for system installation in the sites. A more detailed account can be found in D6.3. Due to the lessons learned during the performance testing, this section also gives an overview of the test facility at EMI in Hungary, which is described in more detail in D6.2.

2.1. Pre-demo site, Thessaloniki, Greece (Partner in charge: CERTH- ITI).

MiniStor was first launched for installation and operation in the premises of CERTH in Thessaloniki, Greece and more specifically in the Smart Home of CERTH / ITI (Latitude 40.57° N, Longitude 22.99° E). The Smart Home is a demonstration testbed with a high concentration of sensors and automated systems where new automation systems are tested. It has a total habitable area of 317.7 m², of which 182.7 m² are on ground floor and 135 m² are on first floor built in 2017. A machinery room (area 9.9 m²) is attached to the western side of Smart Home, housing hydraulic and electrical connections.

The building is currently used as offices for CERTH's personnel, thereby its occupancy is limited to usual working hours of the week. Figure 4 shows the front view of CERTH/ITI smart home as well as the location of the machinery room and solar field. The site is accessible by internal paved roads. All surrounding areas belong to CERTH.



Figure 4. Exterior view of Thessaloniki pre-demo site

The building's heating and cooling needs are currently met by two HVAC systems with total nominal thermal capacities of 56.7 kW for heating and 50.4 kW for cooling. Each system features an external unit (with compressors) and multiple indoor ceiling cassette units, with a total capacity matching the outdoor units (58.8 kW for heating and 52.4 kW for cooling). The connection between external and indoor units utilizes a variable refrigerant flow (VRF) system with R-410A refrigerant. In the demonstration room, two indoor units with a cumulative capacity of 8 kW for heating and 7.2 kW for cooling will cover the room's climate needs.

The building's electricity demand is partially met by thin film CIS PV panels on the roof, with a total capacity of 9.57 kWp. In the Thessaloniki pre-pilot, excess electricity from MiniStor will be used for lighting purposes. An external light has been installed, outside the MiniStor container, for security purposes.

System placement

Due to the construction of new buildings behind the Smart Home, the solar field was moved to its final location above the existing machinery room, which is to the north-west of the Smart Home. The location of the MiniStor container remains the same, and in any case, more than 2m from all buildings. MiniStor testing took place in a large room ("Control Room West"), covering around 49 m² on the western side of the ground floor. This room's peak heating and cooling needs are approximately 3.6 kW and 8.1 kW, respectively.

A detailed description of the pre-demo site preparation and installation of the MiniStor system can be found in D6.3 Section 4.1.3. The solar field installed comprises 10 PVTs and 5 Flat Plate Collectors (FPCs) with gross collectors' area of 16.10 and 12.55 m² respectively. This results in a total gross area of 28.65 m² for the whole solar field leads to an even larger required open area for the collector's installation. The location of the MiniStor container is 4.71m far from the CERTH/ITI smart home (Figure 5).

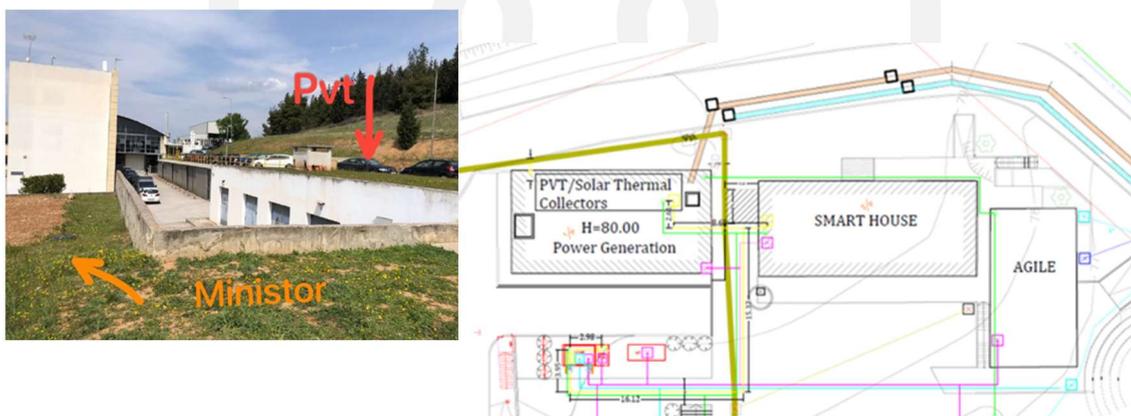


Figure 5. Location of machinery room and solar field in the pre-demo site Thessaloniki, Greece.

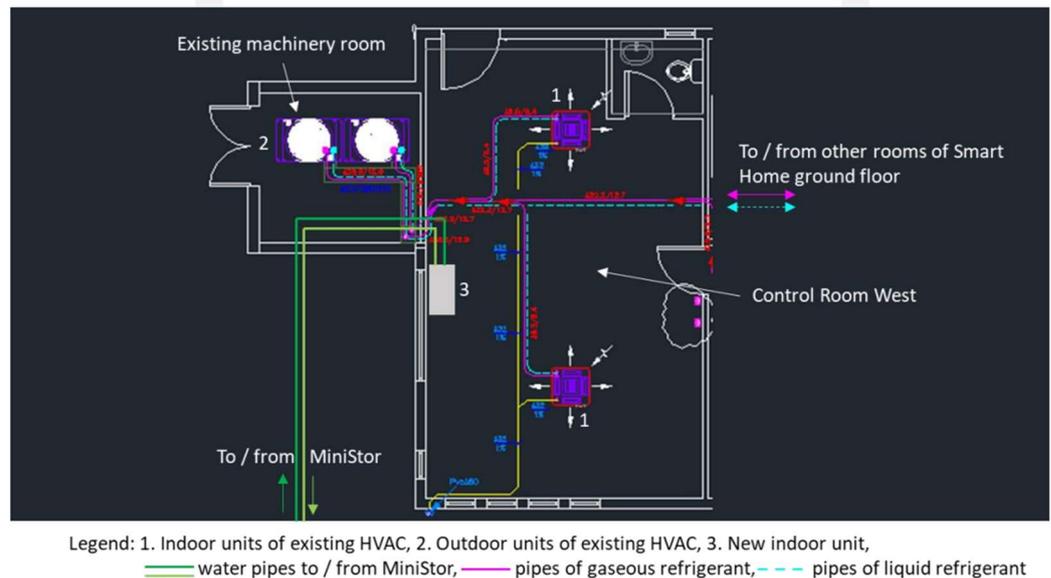
Connections to infrastructure

The heating and cooling systems integration of MiniStor with the Smart Home's existing system posed challenges due to different heat transfer media: MiniStor uses a water-propylene glycol mixture, while the existing system uses refrigerant. A parallel operation was chosen as seen in Figure 6, involving a new indoor unit in the "Control Room West" connected directly to MiniStor's hot and cold PCM vessels. A recirculating pump (Wilo Varios PICO-STG 15/1-13) was installed to meet the system's specifications. Details of this integration are explained in D6.3.

The electrical components (battery, inverter, electrical panel) were installed outside the thermal storage. The system cannot operate in islanded mode, so it requires a grid connection. A smart meter from HEDNO was installed after the inverter to comply with Greek regulations, allowing

network operators to monitor system operation. This installation is managed by specialized personnel assigned by CERTH.

Figure 6. Drawing of current HVAC infrastructure in "Control Room West" of Smart Home and proposed thermal energy supply by MiniStor



2.2. Performance testing facility, Szentendre, Hungary (Partner in charge: EMI)

The prototype (without solar field) was tested under controlled conditions at the facilities of EMI, located in Szentendre, Hungary as part of Task 6.2. This is not a demonstration site but was used to characterize the system under different controlled input temperatures and cycles. However, due to the timing of its installation, useful experiences were obtained for the rest of demonstration sites. After testing, the prototype was transported for installation at Sopron, Hungary.

EMI has several areas for different types of tests. The MiniStor prototype was tested outdoors next to the main laboratory (Hall E). Specific connections to simulate heating and cooling input and output were built, with a cabinet for control and measurement (Figure 7). Further details of the testing can be found in D6.2.

total (3 rooms on the ground and 2 rooms on the first floor), covering a heated volume of 226.95 m³ and a total area of 75.65 m². These rooms have different orientations to test the system's response to both southern and northern exposures.

Thermal energy demand at DUTH's demo site is currently met by a district heating system connected to the campus's Energy Center, which produces thermal energy for the entire community. The Energy Center includes a 1.18 MWth solar collector installation, a 1.15 MWth biomass boiler, and two backup oil boilers used during biomass boiler maintenance. Electrical infrastructure at the Energy Center includes transformers connected to the main medium voltage grid, providing electricity to all eight campus buildings. A 51 kWp PV array on top of the G2 building supplies power to common areas and the 9-kW electrical resistance load of the DHW tank.

The current HVAC system features extensive pipework originating from the Energy Center's hot water collector, distributing hot water to all buildings' collectors via a two-pipe hydraulic system that transfers hot water to room radiators. There is no existing cooling connection, so the MiniStor system will also address the cooling needs of the DUTH rooms during summer, in addition to providing heating in winter.

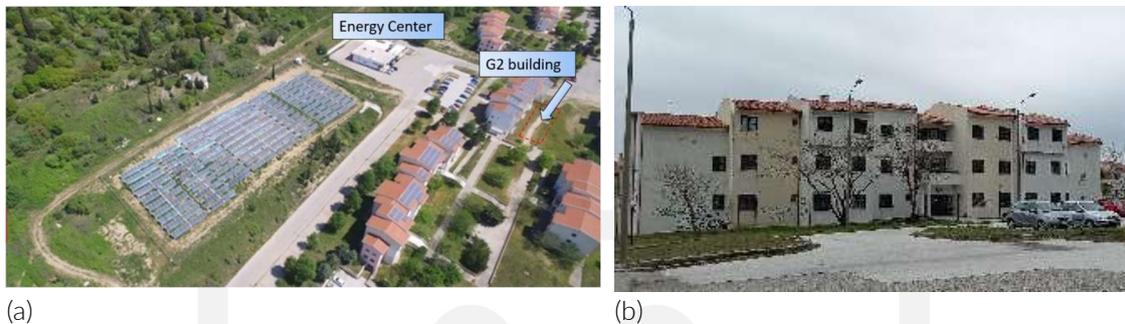


Figure 8. (a) Bird view of the DUTH's demo site location for the MiniStor system and (b) view of the dormitory building

System placement

The system was placed >12m from the South side of the G2 building, as shown in Figure 9.

Connections to infrastructure

The MiniStor system at the DUTH demo site connects to the building's hot water collector for thermal energy. Plumbing uses a suspended pipework routed through a window on the building's southern side. Fan coil units, connected to MiniStor's hot and cold PCM, were installed in the student rooms.

Electrically, the DUTH campus in Kimmeria, Xanthi, connects to the MV Grid through a transformer in the Energy Centre. The G2 building has a dedicated three-phase cable and main electrical board. MiniStor was connected directly to this board with a dedicated line, ensuring adequate power supply.

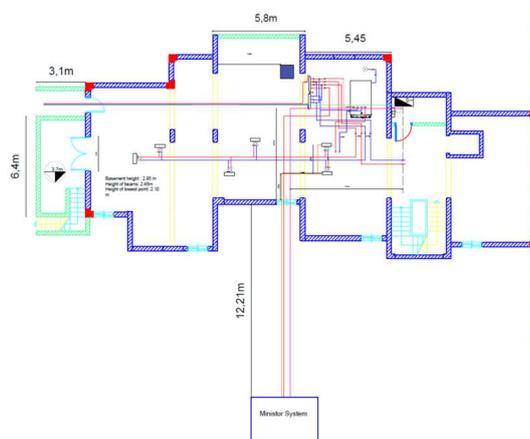


Figure 9: Position of installation of the MiniStor system at DUTH's demo site

2.4. Santiago de Compostela, Spain (Partner in charge: USC)

Santiago de Compostela has a temperate oceanic climate (Cfb - Köppen classification). For the demonstration, USC selected the "Burgo de las Naciones" Hall (Figure 10a), a U-shaped building with a large interior patio. The building serves as a university residence for students and visiting faculty, featuring 400 individual rooms and 9 apartments. One apartment ("Apartment B") is inhabited by a family and was chosen for the demonstration due to its continuous occupancy. This apartment, located in the southwest wing, has a single level with 80.47 m² of living space, including 3 bedrooms, a kitchen, a living room, a bathroom, and a hall (Figure 10b).

The Burgo de las Naciones Hall has a centralized heating and DHW system powered by gas boilers. These boilers distribute hot water through central buffer tanks and vertical hydraulic circuits. Each room in the selected apartment has a radiator connected to these circuits, ensuring an even distribution of heat and hot water.

The building, constructed in phases starting in the 1990s, houses two boiler rooms. One of these, "Room BC", is adjacent to the apartments in the southwestern wing. In September 2020, the heating and hot water systems were renovated, adding four gas condensing boilers with a total capacity of 1899 kW and five buffer tanks with a combined capacity of 16,000 litres. The distribution networks remained unchanged.

The heating and DHW circuits from Room BC supply the apartments through multiple pipe branches that run vertically throughout the building. For the MiniStor Project, Apartment B was isolated with an individual hydraulic circuit for heating and hot water, while still receiving heat from the inertia tanks for reliability. The MiniStor system provided electricity, supplementary heating, and DHW to the apartment.



(a)



(b)

Figure 10. (a) Overview of Burgo de las Naciones Hall and (b) apartment's location

System placement

The MiniStor enclosure and solar field was placed in the courtyard area, while the electrical storage components was placed in the machinery room. A total of 20 PVT panels of the unglazed model were installed on a nearby embankment.



Figure 11. Proposed location of the machinery room in Santiago, Spain.

Connections to infrastructure

At the USC demo site, MiniStor elements connect to the existing infrastructure in the basement of Burgo de las Naciones Hall, accessed through the BC boiler room. This basement houses the new facilities for apartment B (Figure 12). A canalization links the PVT solar collectors to the MiniStor container and then to the building's basement.

Burgo de las Naciones Hall, located on USC's North campus, is part of an electrical microgrid with a connection to the public network. Therefore, the MiniStor system, along with the photovoltaic and thermal collectors, connect internally to the USC Network. An engineering company helped prepare the necessary technical documentation and permits for this setup.

Figure 12. Connection the MiniStor system to current infrastructure – USC demo site



2.5. Sopron, Hungary (Partner in charge: Woodspring),

The city is in western Hungary, has a sub-Alpine climate with a heating demand for five months and cooling needed for about one-and-a-half months. The demonstration site has a dual function: a family house on the upper floor and the Woodspring research division office downstairs (Figure 13). The family's energy consumption peaks on weekends, while the office's consumption is high on weekdays, balancing the overall energy use throughout the week.

The building, planned and built as a nearly zero energy structure with high thermal resistance, has a heating energy demand of slightly above 2 kW for the family area (118 m²) and about 2 kW for the office area (58 m²), reaching up to 5 kW in very cold weather. The building's planning phase coincided with the MiniStor project, allowing for optimization of the heating and domestic hot water systems to integrate MiniStor's capabilities.

The HVAC system is integrated for heating, cooling, and ventilation. Fresh air is conditioned through a 3-kW heat exchanger driven by a soil collector, which preheats air in winter and cools it in summer. The soil collector, buried about 4 meters deep, provides preheated air in winter and 12–18°C liquid for cooling in summer. Additionally, a heat recovery unit exchanges heat between fresh and exhaust air streams, and 3 kW electric heating filaments are built into the ventilation inlet pipe. Bathrooms have 500 W towel dryers for higher temperatures. An additional 3 kW liquid-air heat exchanger connected to the MiniStor system provides thermal energy for heating and cooling.

Domestic hot water is supplied by two 2.4 kW electric boilers and a 6-kW instantaneous water heater in the kitchen. The first boiler, equipped with an extra heat exchanger for use with the MiniStor prototype, heats water through this exchanger. The second boiler is supplied by the first, only using electricity if MiniStor cannot provide sufficient energy.

The building features a 3-phase electrical system and a 7.9 kW solar panel array that partially meets its electricity needs. This solar system connects to the grid and an electric meter, billing only the net difference between energy used and generated. The MiniStor system has its own PVT panels for electricity production, connected to the grid and charging a battery installed next to the building's electric box.



(a)



(b)

Figure 13. (a) Exterior view and (b) Preparation works (view to rear facade)

Solar field characteristics

The solar field for feeding MiniStor system includes both PVTs (8 panels with total gross area of 12.88 m²) and solar thermal collectors (initially 4 collectors with total gross area of 10.04 m²). They were installed next to the MiniStor box, on the ground. In this way, the solar field has the same efficiency as it would have if installed on the roof, but the energy transport heat losses will be significantly lower.

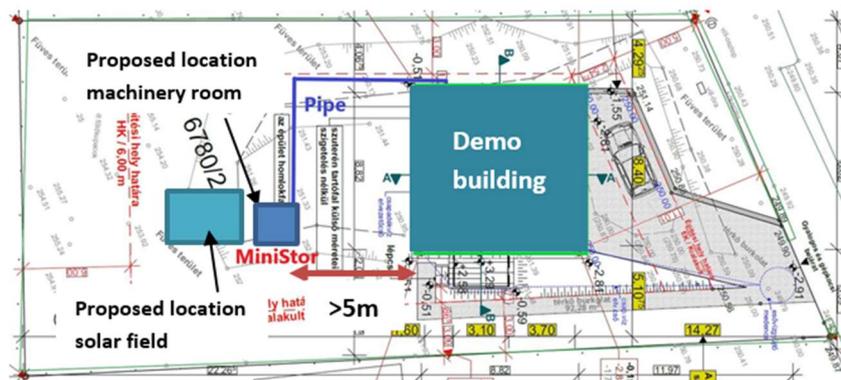


Figure 14. proposed location of the machinery room and solar field in Sopron, Hungary

Connections to infrastructure

At this demo site, connections are made to the existing HVAC system, which has been designed to accommodate additional inputs from the thermal storage, since the building was being finalized close to project start.

2.6. Cork, Ireland (Partner in charge: Cork City Council)

The Cork demo site is located in the Bishopstown area of Cork, Munster region, at the southwestern edge of Cork city's urban area, about 24 meters above sea level. Cork has a temperate oceanic climate (Cfb according to the Köppen climate classification).

The demo building is a semi-detached, two-storey, three-bedroom property owned by the city council and constructed in the 1980s, with a habitable area of approximately 75.286 m² and a volume of 376.431 m³, housing five occupants (Figure 15). A Building Energy Rating (BER) assessment conducted in 2015 rated the property at C1, with an energy consumption of 165.59 kWh/m²/yr and CO₂ emissions of 35.18 kgCO₂/m²/yr. The property uses a 27kW gas boiler system for heating and DHW, which is controlled by time and temperature settings.

The system is divided into three zones, each with independent thermostats, allowing for manual temperature adjustments based on the season. The MiniStor system was implemented to provide electricity, heating, and DHW, partially meeting the energy needs of the Cork demo site.

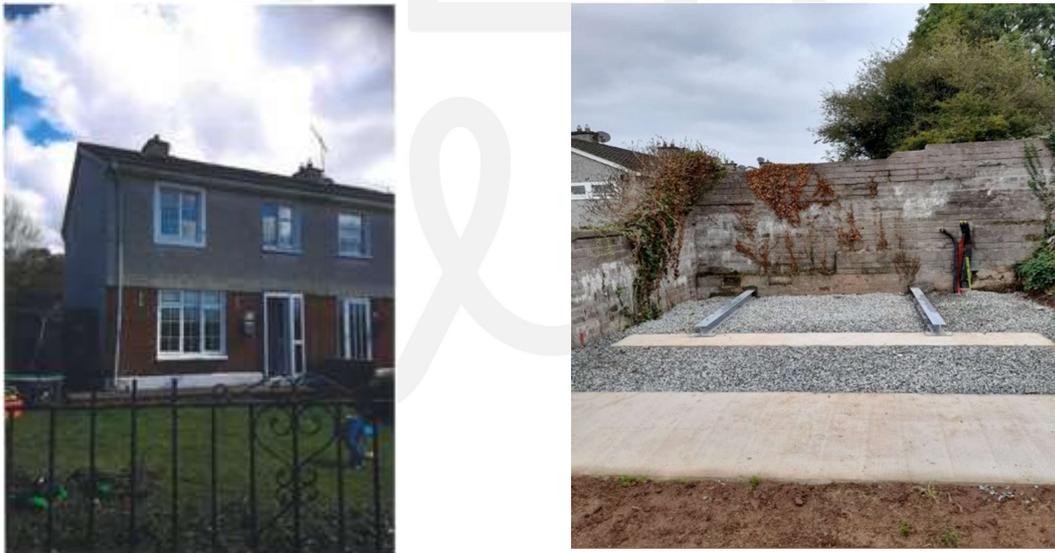


Figure 15. (a) Entrance view and (b) preparation works (view to boundary wall)

Solar field characteristics

The solar field in Cork City Council (CCC) comprises 4 PVT panels with total gross area of 6.44 m², 4 FPC panels with total gross area of 8 m² and the solar frame. Figure 16 shows location of the machinery room and solar field, which is at the back of the garden area.



Figure 16. Proposed location of the machinery room and solar field in the demo site of Cork, Ireland.

Connections to infrastructure

At the Cork demo site, the MiniStor unit connects to the existing heating system via a heat exchanger unit on the eastern external wall of the house. Pipes supplying heat are partially underground and partially mounted on the boundary fence and external wall, insulated to minimize heat loss and accident risk. The heat exchanger, located near the domestic boiler, operates in parallel to provide heat on demand (Figure 17).

When conditions are optimal, signals are sent from the boiler to MiniStor, transferring stored heat to the house's heat exchanger. This will also reduce the load on the existing boiler.

The electrical battery and inverter were installed in an existing concrete shed, with cables connecting them to the PVT solar array, mains power, and domestic distribution system.

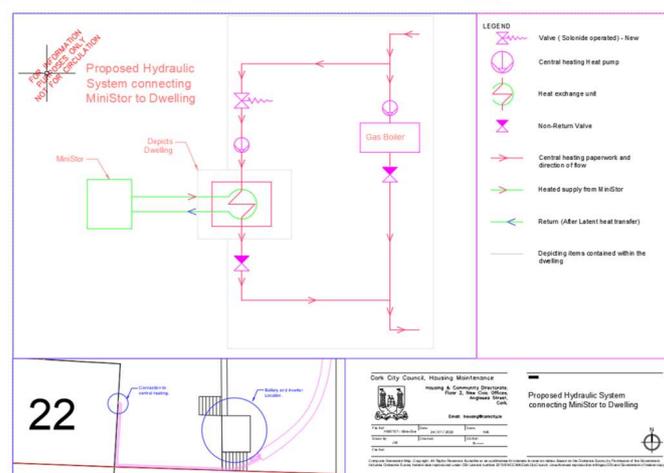


Figure 17. A draft of the proposed connection where stored heat will transfer between the MiniStor Unit and dwelling (Cork demo site)

3. Installation and commissioning process

The main steps listed below were followed for the demonstration activity, meeting relevant requisites at all sites:

- 1) Examination of legal requirements and installation permissions at different levels (EU, national, local) for each of the demo site countries.
- 2) Preparation and adaptation work at the sites according to technical requirements, including construction of supporting structures and connection pipes.
- 3) Delivery of the prototype by the integrating partner (Psyctotherm) and of the solar field by EndeF, with reception by demo site responsible.
- 4) Installation and configuration of the prototypes on site, including verification tests.
- 5) Full testing and running phase with supervised and unsupervised operation.

These steps were carried out at different stages of the project lifetime. Time and activities performed for each of the steps were recorded. As a research project, the time taken for each stage reflects the challenges faced when installing a completely new system, with the experience gained helping to develop a future streamlined installation procedure for upscaling the system.

3.1. Examination of legal requirements and installation permissions

This Section summarizes the examination, done at an early stage, of requirements and permissions that needed to be fulfilled before installation of the system. From all these, it was found that the most influential requirements had to do with compliance with EU and local standards for both thermal and electrical storage. These are discussed in detail in D2.3 and D6.3.

The following table presents the results of the analysis done by demo site owners for obtention of specific permits or authorizations required by other stakeholders (e.g. electricity distribution operators, municipal bodies, etc). For the case of Cork, many procedures are covered by statutory exemption, as the work is carried out by a municipal body on its own properties. For the pre-demo in Thessaloniki and demo sites Kimmeria and Santiago de Compostela, their prototypes' locations are within managed campuses with facility services and IT departments which require institutional approval procedures in addition to those listed in Table 2.

Table 2. List of the required permissions for the installation of the MiniStor system.

| | Category | Thessaloniki, GR | Kimmeria, GR | Santiago, ES | Sopron, HU | Cork, IR |
|---------------------------------|--|------------------|----------------|----------------|----------------|----------------|
| Permits before the installation | | | | | | |
| 1 | Permit from city authority to build a "small construction/shed" | Not Applicable | Not Applicable | Not Applicable | Not Applicable | Not Applicable |
| 2 | Permit from city authority for PVT panel installation (irrespective of final location) | Not Applicable | Not Applicable | Not Applicable | Yes | Not Applicable |
| 3 | Permit from city authority to dig trenches or place tube covers inside property | Not Applicable | Not Applicable | Not Applicable | Not Applicable | Not Applicable |
| 3 | Permit from electrical supply authority for PVT | Not Applicable | Not Applicable | Not Applicable | Yes | Not Applicable |

| | | | | | | |
|------------------|--|-------------------------------------|-------------------------------------|------------------------------------|---------------------------------|---|
| | panels (irrespective of final location) | | | | | |
| 4 | Permit from electrical supply authority to connect system to house | Yes | Yes | Not applicable | Yes | Bi-phase used due to time to obtain triphasic permit |
| 5 | Permit from electrical supply authority to sell to the grid (if allowed) | Not Applicable (internal grid only) | Not Applicable (internal grid only) | Not Applicable | Yes | No grid selling allowed, small production |
| 6 | Permit from water supply authority for supply to system | Not Applicable | Not Applicable | Not applicable | Not Applicable | Not Applicable |
| 7 | Provide plans for all the permits –system location in property, piping, wiring | Not Applicable | Not Applicable | Yes | Not Applicable | Not Applicable |
| Customs | | | | | | |
| 8 | Advance notification to authority (ies) on container arrival to customs, its contents and non-commercial nature. To be liaised with shipping company | Not Applicable | Not Applicable | Not Applicable | Not Applicable | Shipping company rules apply regarding NH ₃ transport and container size |
| 9 | Designate authorized contact person to be in touch with shipping company in case they need info and reception sign-off (to be done by all sites) | Yes | Yes | Yes | Yes | Yes |
| Delivery to site | | | | | | |
| 10 | Permit from city/traffic/police authorities for closing streets if site access is too narrow and that vehicle has sufficient height clearance on the way | Standard articulated lorry used | Standard articulated lorry used | 3-axle rigid body crane lorry used | Standard articulated lorry used | Not Applicable |
| 11 | Permit to use a large crane (to hold +2 tons) and/or other equipment if needed to place it (e.g. forklift) | Not Applicable | Not Applicable | Not Applicable | Not Applicable | Not Applicable |
| Commissioning | | | | | | |
| 12 | System approval by ammonia HVAC specialist (Note: all NH ₃ loading done by authorized | Not Applicable (loaded system) | Not Applicable (loaded system) | It has not been necessary | Not Applicable (loaded system) | Licence to transport NH ₃ to site if |

| | HVAC specialist even if not legally required) | | | (loaded system) | | TCM vessel empty |
|----|--|----------------|----------------|-----------------|----------------|------------------|
| 13 | Verification of overall system construction by city authorities | Yes | Yes | Yes | Yes | Yes |
| 14 | Verification of electrical connection (including PVT, sell to grid) by supply authorities or authorized person for operation | Yes | Yes | Yes (USC) | Yes | Yes |
| 15 | Verification of water connection by supply authorities or authorized person for operation | Not Applicable | Not Applicable | Yes (USC) | Not Applicable | Not Applicable |

To speed up installation and commissioning, partner Psycotherm provided the systems pre-loaded with ammonia, except for Cork, as regulations for sea transport forbid it when inside a transport container. For the same purpose of reducing installation time, there are dedicated connections at the back of the enclosure. In this way, demo sites had only to provide connectivity to the pipes and wires leading to the enclosure.

3.2. Preparation and adaptation work at the sites according to technical requirements

This activity encompassed most of the actions for WP6. Regular meetings were held between technical partners and demo site responsible to define concrete actions, monitor progress, and to answer any queries from both sides.

For the pre-demo in Thessaloniki, demonstration sites Sopron, Santiago and Cork, the preparation works included several activities listed below. Some of these were not sequential, as this would depend on the specific location and the time the prototype would arrive to site:

- a) If required, clearing and levelling of the surfaces where the prototype and solar field would be placed.
- b) Preparation of foundations for both items using the estimated weight of ≥ 3 tons.
- c) Digging of trenches to conduct pipework both from the building and from the solar field.
- d) Layout of the insulated pipework.
- e) Extension of water supply if needed, for the PVT loop.
- f) Digging of trenches or laying of conduit for electrical and network connections.
- g) Layout of the electrical and network connections.
- h) Preparation of hydraulic bypass for the heating and DHW loops.
- i) Installation of sensors and meters in the target building and spaces, including weather station.
- j) Connectivity of the building sensors and meters to the CERTH IoT platform for Cork, and Santiago via Woodspring gateway, and for Kimmeria via DUTH gateway.
- k) Preparation and installation of structures for the solar field, assembled and finished according to design by EndeF (except at DUTH).
- l) Setup of solar collectors and PVT panels on the solar field structure, including hydraulic and electrical connection to prototype. This activity is done closer to the arrival of the prototype to avoid overheating in the empty panels that could damage them (except at DUTH where the solar field is pre-existing).

For DUTH, the preparation works included the same steps except that the RES connection was done to the existing solar and hot water field. The following are photos from different stages of the preparation work at the demonstration sites:



Figure 18. Installation works at Thessaloniki demo site connecting pipes to fan coil unit and on solar field (Dec 2023)

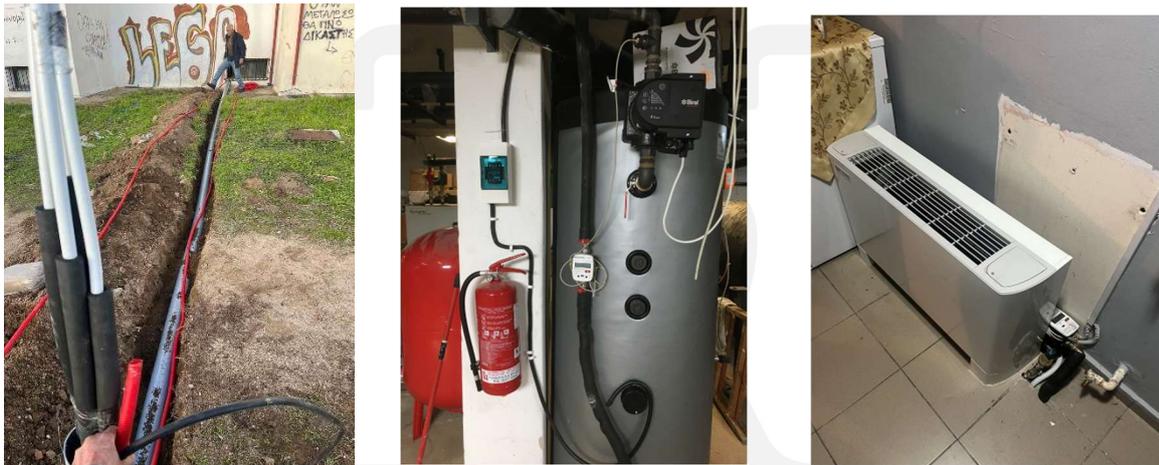


Figure 19. Pipe preparation, inertia tank and fan coil unit installed at Kimmeria demo site (Feb 2024)



Figure 20. View of preparation works for the prototype installation at Cork City demo site: electrical connection for battery, hydraulic connections to home boiler (February 2024)



Figure 21. Preparation works at demo site Sopron: pipes on the first stage to connect to the prototype, and their union to the existing heating system (top right) and to the electrical connections (right) February 2024

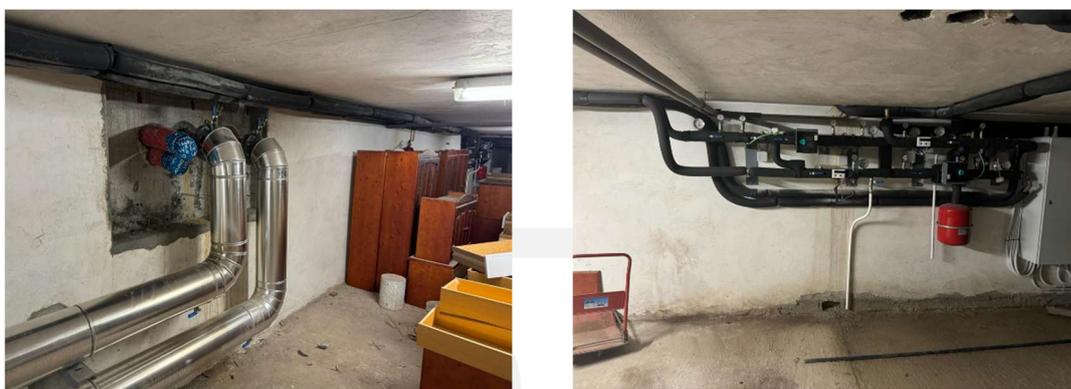


Figure 22. Preparation works at Demo site Santiago de Compostela: View of district heating bypass to connect with the prototype (left) and new piping and controls connecting to apartment (right) February 2024

3.3. Delivery and reception of the MiniStor prototype and solar field

Delivery of the components for setup at the demonstration sites was done as follows: Earlier in the project, glazed PVT panels were delivered to demonstration sites Thessaloniki, Cork and Sopron in 2021, the FPC panels were delivered in 2023, and the unglazed PVT panels were delivered to Santiago de Compostela in 2024. The supporting components for all demo sites were sent during 2024. The following table shows the delivery sequence:

Table 3. Specification of solar field at Sopron demo site

| Nr. | Description | Type | Pieces | Delivery |
|-----|---|-----------------|--------|----------|
| 1 | PVT hybrid solar collector | PVT glazed | 9 | 2021 |
| 2 | Aluminium structures set, for eight hybrid solar collectors, with accessories | for PVT glazed | 1 | 2021 |
| 3 | Solar thermal collectors 2.4 m2 with fittings | ESCOSOL FMAX | 6 | 2023 |
| 4 | Air cooler | Inditer ATS 391 | 1 | 2023 |
| 5 | Temperature, pressure and flow sensors | Various | 12 | 2023 |

| | | | | |
|---|--|---------------|---|------|
| 6 | Steel structures, for solar thermal collectors, with accessories | Custom | 6 | 2023 |
| 7 | Battery 5 kW unit | Luna 2000 | 2 | 2023 |
| 8 | Battery controller | for Luna 2000 | 1 | 2023 |

Table 4. Specification of solar field at Thessaloniki demo site

| Nr. | Description | Type | Pieces | Delivery |
|-----|---|---------------------|--------|----------|
| 1 | PVT hybrid solar collector | PVT glazed | 10 | 2021 |
| 2 | Aluminium structures set, for ten hybrid solar collectors, with accessories | for PVT glazed | 1 | 2021 |
| 3 | Solar thermal collectors 2.4 m2 with fittings | ESCOSOL FMAX | 5 | 2023 |
| 4 | Air cooler | Inditer ATS 391 | 1 | 2023 |
| 5 | Temperature, pressure and flow sensors | Various | 12 | 2023 |
| 6 | Steel structures, for solar thermal collectors, with accessories | Custom | 5 | 2023 |
| 7 | Battery 7.7 kWh unit | BYD HVS | 1 | 2023 |
| 8 | Smart meter | Fronius | 1 | 2023 |
| 8 | Inverter | Fronius Symo Gen 24 | 1 | 2023 |

Table 5. Specification of solar field at Cork demo site

| Nr. | Description | Type | Pieces | Delivery |
|-----|--|----------------------|--------|------------|
| 1 | PVT hybrid solar collector | PVT glazed | 4 | 2021 |
| 2 | Custom made solar frame structure for four hybrid solar collectors and four FPC collectors, with accessories | Custom | 1 | 2021,2024 |
| 3 | Solar thermal collectors 2.4 m2 with fittings | ESCOSOL FMAX | 4 | 2023 |
| 4 | Air cooler | Inditer ATS 391 | 1 | 2023, 2025 |
| 5 | Temperature, pressure and flow sensors | Various | 12 | 2023 |
| 6 | Battery 5.12 kWh unit | BYD HVS | 1 | 2023 |
| 7 | Smart meter | Fronius | 1 | 2023 |
| 8 | Inverter | Fronius Primo Gen 24 | 1 | 2023 |

Table 6. Specification of solar field at USC demo site

| Nr. | Description | Type | Pieces | Delivery |
|-----|--|---------------------|--------|----------|
| 1 | PVT hybrid solar collector | PVT unglazed | 20 | 2024 |
| 2 | Aluminium structures set, for twenty hybrid solar collectors, with accessories | for PVT unglazed | 1 | 2024 |
| 3 | Heat pump | Hiltachi Yutaki S80 | 1 | 2024 |
| 4 | Air cooler | Inditer ATS 391 | 1 | 2024 |
| 5 | Temperature, pressure and flow sensors | Various | 10 | 2024 |

| | | | | |
|---|---------------------|---------------------|---|------|
| 6 | Battery 16 kWh unit | BYD HVS | 2 | 2024 |
| 7 | Smart meter | Fronius | 1 | 2024 |
| 8 | Inverter | Fronius Symo Gen 24 | 1 | 2024 |

Delivery dates to demo sites

The prototypes with the TCM, PCM, heat pump, accessories and control components were assembled by Psycrotherm at their facilities, which were dispatched after completion and preliminary testing. The assembly and delivery sequence were as follows:

- 1- Thessaloniki (pre-demo site). Received: 15 November 2023.
- 2- Sopron (delivered first to Szentendre for performance testing at EMI's facilities in February 2024). Received: 17th September 2024.
- 3- Kimmeria. Received: 10th April 2024.
- 4- Santiago de Compostela. Received: 20th June 2024.
- 5- Cork. Received: 12th February 2025

For sites within mainland Europe, the prototype was safely carried on the bed of a lorry, which in some cases had sandbags to prevent its movement. These prototypes had the necessary NH₃ load within them from the factory. Delivery was carried out using freight companies, with the prototype for Cork having a sea crossing. For the Cork demo site, the prototype was placed inside a shipping container from the factory until reception at port. This necessitated to reduce slightly the enclosure dimensions. In this case, due to shipping regulations, there was no full load of NH₃, except residual amounts used for testing.

Unloading and reception procedure

Due to the dimensions and weight of the prototype and its enclosure, the unloading procedure needed to be planned beforehand and in cooperation with the delivery company. In some cases, the prototype was changed from an 18-wheel lorry to a shorter one with an articulated crane. If not available, a separate crane of sufficient capacity and extension had to be hired and used to move the prototype from the lorry to the designated place. Where there is difficulty to achieve this, a forklift can be used to move the prototype from the unloading area to the designated location. The forklift operator must be careful not to damage the panels and use the base only to move the prototype. The prototype can be supplied with hoisting points on its roof to facilitate unloading.

After unloading, the system is required to be left standing for 24 hours, for the refrigerant to settle down, which is a common procedure. Only after this period it is allowed to perform tests, commissioning and to connect the system to the existing infrastructure. In the meanwhile, inspections can be made to ensure the structural integrity of the system and that there are no leaks or misplaced wires due to the reception procedure.

Pre-demo site: Thessaloniki, Greece

The prototype for the pre-demo was received on 15 November 2023. It was the first prototype delivered to a site, with the experiences recorded and used for other demo sites. The location was accessed by the delivery truck into a cul de sac. The procedures are described in detail in D6.3, with a photographic summary presented below.



Figure 23. Procedure for unloading and reception of the MiniStor unit at Thessaloniki

Procedures at the performance testing facility (Hungary)

The Hungarian prototype arrived from Greece on the evening of the 30th of January 2024 to EMI's premises in Szentendre, Hungary. Due to the uneven grassed area, it was not possible to use a forklift to place it at its final location; therefore, a crane was hired for this procedure on the 2nd of February 2024. See the following figures.



Figure 24. Procedure for unloading and reception of the MiniStor unit at the Performance testing facility (EMI, HU)

Kimmeria, Greece.

Delivery of the system was made on 10 April 2024. This demo site does not require PVT panels provided by EndeF but has been connected to its existing energy centre. In this case, the prototype was transferred to a smaller truck in order to access the site.



Figure 25. Unloading of MiniStor system at DUTH's demo site

Santiago de Compostela, Spain.

This site tested the new model of unglazed PVT panels, which required slight changes to the shipment logistics. The PVT material was sent to the demonstration site in two shipments. One was received on 18 March 2024 (novel PVT panels and complementary material) and the other on 18 April 2024 (batteries and inverter). They were sent by medium-sized truck and unloaded with a pallet truck. They were stored in the boiler room of the building.

The container with the MiniStor system was received on 19 June 2024 at the facilities of the Station Crane Service in Padrón. This decision was made because the container was sent on a truck with a trailer that would possibly have difficulty entering the demonstration site due to some trees. It was unloaded with a gantry crane.

The following day in the afternoon, 20 June 2024, it was transferred to Santiago de Compostela, to the demonstration centre, by truck crane (3-axle truck and Palfinger 27000 crane). During the loading process at the crane service facilities in Padrón, the container was accidentally released and suffered damage to its exterior and interior. This consisted of panels being slightly bent, and some

parts inside the prototype such as the alarm and compressor seat became loose. However, there was no ammonia leak. The project partners were informed, and preliminary tests were carried out to assess the damage. This damage was repaired afterwards but affected running the compressor in the early tests.



Figure 26 Photos of the delivery of PVT and solar field equipment by EndeF to Santiago de Compostela



Delivery lorry at crane service company headquarters



Reception of MiniStor system at crane service facilities



Reception of MiniStor system at USC demo site (photo taken after the incident, left, and the prototype after final positioning, right)

Figure 27. Procedure for unloading and reception of the MiniStor unit at USC

Sopron, Hungary.

The system was transported from EMI's facilities in Szentendre, Hungary to Sopron after finishing the performance testing. The prototype was delivered to the site on 17 September 2024. After unloading of MiniStor to the designated place, the solar field was built to the foundation of a soil screw structure. The unit was placed at a planned distance from the building to maintain safety, but as close as possible to the solar field. The connecting pipe was dug to the ground with its connection behind the MiniStor unit. The foundation of the MiniStor unit was made of concrete slabs in more layers to share the load to the ground. This method facilitates installation without significant damage to the surroundings.

After unloading the MiniStor container, the precise places of soil screws were pointed out and the soil screws were drilled to the ground. These soil screws were part of the foundation of the solar field. To the top of the soil screw the PVT and Solar thermal collectors were built close to each other. As the building heating energy demand was lower than expected, as mentioned in previous sections due to the energy performance of the building, a total of 8 PVTs were installed instead of

the planned 9 PVT. The number of FPCs installed was 4 as they provided enough energy for the building. The experience showed that these four solar thermal collectors could provide enough heat for heating and domestic hot water. In addition, in a normal solar load, the forced cooler had to be turned on more times in an hour to release the surplus energy. The angle of the solar panels including the PVT and thermal collector was 50° for optimizing to the heating period when the sun incidence is lower. Consequently, the efficiency of steeper panels is higher in wintertime.



Figure 28. Installed and commissioned MiniStor system in Sopron demo building

Cork, Ireland.

The MiniStor container was delivered by ship to Dublin port, Ireland, on the 5th of February 2025. There were delays in the planned arrival date due to rough seas. It was transferred from Dublin to County Cork using an articulated truck on the 7th of February where it was unloaded by forklift to a storage site. It was delivered to the demonstration site using a rigid truck, where it was installed using a HIAB crane which was mounted on the truck body on the 12th of February 2025. The size of truck used to deliver container to demo site had to be given careful consideration due to the location of the demo site which offered limited space for unloading and installing, on a cul de sac with a slope. This meant unloading the prototype from the street into the back side of the demo site. The process is illustrated in the following photos.



Prototype arrival to contractor premises in Cork via articulated truck



Unloading MiniStor Prototype in Cork using forklift before transfer to rigid truck



MiniStor prototype arrival on Rigid truck to Cork Demo site



MiniStor prototype installation at Cork demo site using HIAB Crane.



MiniStor prototype installed successfully at Cork Demo Site.

Figure 29. Images of prototype delivery to Cork demo site.

3.4. Connection and Commissioning of the prototypes on site, including verification tests

After the preparation works and arrival of the unit, prototype connection and commissioning comprised the following activities, which in most cases were carried out simultaneously:

- a) Connection of the prototype with the existing heating, cooling and DHW piping with verification of pressure in the pipes.
- b) Filling of the solar field with the glycol mixture.
- c) Connection of the prototype with the solar field.
- d) Finalising electrical connections between prototype, PV, and electrical battery.
- e) Initial operation and configuration of solar controller.
- f) Connection of the prototype with the existing internet network and with the control cloud via the PLC.
- g) For the case of Cork, filling the system with ammonia and performing leak tests.
- h) Verification tests (leaks, pressure, mechanical, electrical and controls).
- i) First charging and discharging procedure of the TCM reactor to verify complete functioning.

Local technicians oversaw the installation, with Psycrotherm and EndeF assisting remotely in the process, and onsite during the final commissioning steps. Psycrotherm representatives were available for steps f) to i). Some representatives from the demo sites were able to travel to the pre-demo in Thessaloniki to examine and learn about the connections and functioning of the system. The pre-demo site also provided to all partners, via online meetings and emails, with insights into their experiences performing the very first runs of the system.

3.4.1 Experiences obtained during connection and commissioning

A challenge that has been found for the connection is that the solar field must be installed close to the date of the arrival of the prototype to each demonstration site. This has the purpose to reduce overheating in the PVT panels due to empty channels. The PVT support structure and electrical components can be installed at almost any time before arrival of the prototype. Figure 30 show an example of the installation process of the MiniStor solar field at the pre-demo site. Other specific issues encountered during installation of the solar field were the configuration of batteries and inverters.



Figure 30. Images of installation process of MiniStor solar field at the pre-demo site Thessaloniki

It is worth mentioning that for Cork demo site, a custom-made solar frame was developed for the installation of 4 PVT panels and 4 FPCs. For the electrical component, a Fronius Inverter and 2 BYD batteries were installed in a concrete shed located adjacent to the solar field. To connect the MiniStor to the gas boiler located on the first floor of the dwelling house, a 5kW heat exchanger was installed, together with a circulating pump and a motorised solenoid valve connected in parallel underneath the boiler. The heat exchanger will act as a pre-heater for the boiler. Electrical and communication cables had to be routed between the house, concrete shed and the MiniStor enclosure. The heat exchanger was connected hydraulically to the MiniStor container via two ¾" pipes, some of which is routed underground in the garden.

Commissioning of the Cork system took place on 31st March – 2nd April 2025 by representatives from EndeF and Psycotherm. During commissioning, the ammonia compressor failed and required new rubber seals on the drive shaft. These were sourced locally in Cork and the compressor was fixed by Psycotherm and completed full operational testing successfully.



Installation of solar mounting frame at Cork demo site Ireland



Solar frame with 4 PVT panels mounted on lower section and 4 FPCs mounted above PVTs



Batteries and Inverter located in concrete shed located adjacent to solar field



Cable ducting being laid underground from site to dwelling house.

Figure 31. Installation of solar field and electrical equipment in Cork demo site



Figure 32. Views of the finished hydraulic connections inside the building (left) and behind the prototype (right) at Cork demo site

The following pictures illustrate the finished installation and the connections made at the other demonstration sites:

Pre-demo site: Thessaloniki, Greece.



Figure 33. Connection of the system to the existing infrastructure in the pre-demo site (left) and the installed MiniStor system (right)

Kimmeria, Greece.



Figure 34. Power and hydraulic connection to the MiniStor system (D.U.TH.)



Figure 35. Expansion tank for bypass to the MiniStor system (left) and Inertia tank at DUTH's demo site showing communication wiring and temperature set point mechanism (right)

Santiago de Compostela, Spain



Figure 36 View of the installed prototype in Santiago de Compostela (left) and inertia tank underground (right)



Solar field with unglazed PVTs as seen from behind



Heat pump (exterior unit).



Heat pump (interior unit)



Fronius inverter and batteries (machinery room)

Figure 37. Views of the PVT, heat pump and electrical components at Santiago demo site.

Sopron, Hungary



Figure 38. MiniStor hydraulic and communication connection to the Sopron demo building via pipelines and cables (Left) and the installed MiniStor system (right)

3.4.2 Verification and technical tests for supervised and unsupervised functioning

The verification tests ensured that the prototype was delivered without damage and in good working order before its first run for complete cycles. These included gas leak detection (primarily by smell), water pressure test, visual inspection of components and corroboration that the components were bolted and secured. There was also initial verification after connection to the electrical supply and first starting of the PLC to detect any errors during startup. After passing of these tests, the system was ready for the next stage.

The technical tests were the first supervised runs of the system for charging and discharging, making sure that the system was operated as intended first under manual operation, and then with remote operation with human supervision. The following outcomes were obtained:

Pre-demo site: Thessaloniki, Greece.

After the installation process, a few tests were conducted to validate if performance of the MiniStor system was according to the planned parameters. The first tests were in cooling mode, as they took place mostly in spring and summer. In the figure below shows a test of charging the ammonia tank, using the solar fan coil as well, along with the solar PVTs.



Figure 39. Ammonia charging during testing operation at the Thessaloniki pilot site.

The next figure presents another test for validating the ammonia safety alarm thresholds. A series of tests were conducted, under real-life conditions onsite, to fine-tune parameters such as pressure in the ammonia tank etc. that trigger the ammonia alarm.

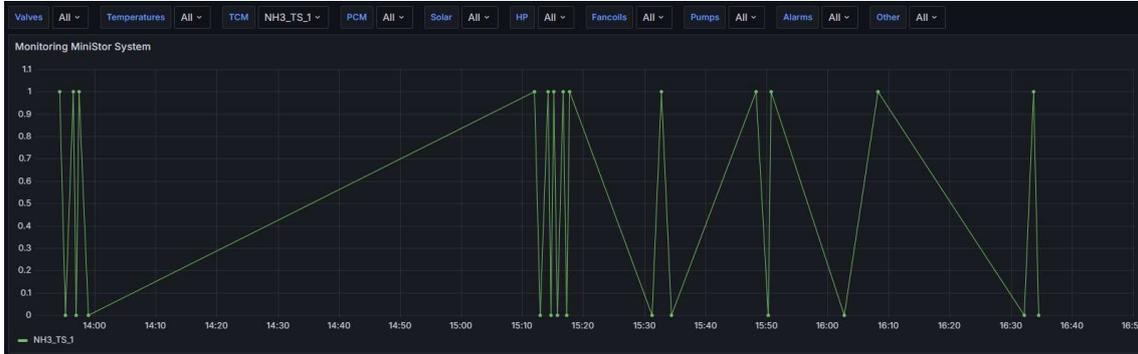


Figure 40. Ammonia Alarm threshold testing at the Thessaloniki pilot site.

In the next figure, pressure testing is conducted, after which it was determined that the pressure should be increased by 1 bar, in order for the MiniStor system to operate optimally.

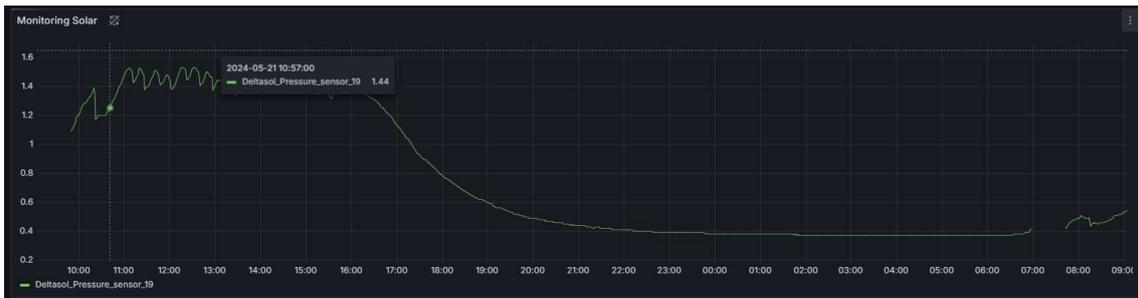


Figure 41. Pressure testing at the Thessaloniki pilot site.



This was also advised by the pressure in the manometers at the solar panels in the field, as seen in the figure below.

Figure 42. Solar PVTs pressure measurement during pressure testing at the Thessaloniki Pilot site.

In the next figure, it is shown the pressure of the PCM, during a fine-tuning of the parameters for the charging mode process.



Figure 43. Pressure changes during parameter fine-tuning testing at the Thessaloniki Pilot site.

Performance testing facility, Hungary.

For this prototype, the same tests were followed as in Thessaloniki. As mentioned before, the particularity of this test was that no solar collectors were present. Therefore, the tests were limited to the thermal storage unit itself.

Kimmeria, Greece.

During testing, the supply temperature of MiniStor buffer tank was initially set at 75 degrees Celsius, taking into account some minor thermal losses through piping. This threshold was lowered to 70 degrees Celsius later because high water temperatures were recorded in the solar inlet of MiniStor. Upon the delivery of the container, the ammonia level sensor was calibrated and functioning correctly for a few months. However, it soon began to lose its calibration, resulting in noticeable deviations in its readings. A visit was conducted by the supplier company to address the issue. A temporary fix was applied for the calibration but which needs to be revisited every few months.

Additionally, the compressor of the unit has also malfunctioned. It was removed for repairs and replaced towards the end of the project.

Santiago de Compostela, Spain.

Due to the accident during unloading, the unit went careful verification before integrating all the elements of the Ministor system. Visible damage to the enclosure walls and loose siren were inspected and repaired. The TCM reactor anchors were tightened, the anti-vibration mounts on the internal heat pump compressor were replaced. The emergency light and a visor were re-installed to prevent water ingress. Some openings were sealed.

During the installation and commissioning of the various parts of the Ministor system, other equipment failures or malfunctions occurred, requiring repair, replacement, or configuration modification.

During pressure testing of the hydraulic component of the PVT panels, a fluid leak was detected and repaired as result of defective installation. During commissioning of the Hitachi heat pump, a faulty weld was detected on the indoor unit, which required repair.

A level probe, a three-way valve and a pressure gauge were replaced in the PVT cooling circuit. During installation, the Hitachi heat pump was integrated into the container incorrectly due to an

overly simplified scheme and had to be redone. Pump 1 was removed from the enclosure's heating circuit, as it interfered with the existing pump in the apartment circuit.

After a period of normal operation, a fault was detected in the ammonia compressor, which was not reaching the normal rpm. The compressor's inverter was replaced, and operational tests were performed with negative results. It was decided to replace the compressor with a new one for further testing. The compressor reinstallation was done during June 2025, with the compressor working properly.

Sopron, Hungary.

Local tests were done during February 2025 when the representatives of EndeF installed the control system of the solar circuit including the PVT and FPC solar panels.

Psycrotherm replaced the inverter and that made the system viable. After this change, there were several smaller modifications such as a 50-liter expansion vessel installed to the glycol circuit. During the third day of commissioning, the MiniStor started to charge the ammonia tank and produced heat as it was expected in a regular operation.



Figure 44. Operational parts of MiniStor in Sopron.



Figure 45. Actual operational parameters of MiniStor in Sopron.

Immediately after the MiniStor started to operate in charging mode, the ammonia reservoir was filled and reached the basic level and after several hours of operation the second half of the reservoir was filled.

Cork, Ireland.

After the reception of the unit its and integration with the solar field, verification tests showed all components had been well installed. Small leaks in the interface between PCM and hydraulic to the home were fixed by a plumber. Ammonia filling was done by an authorized local HVAC technician without incidents. The ammonia compressor failed during the first test and had to be repaired on site using local parts. The tests were done initially with manual running, as the remote communication was established later on due to protocol differences with the local internet router. The unit worked well for a while under remote control but had to be stopped as the compressor failed again. A replacement compressor which was shipped to Cork by Psycrotherm was installed by local technicians and has been operating successfully since installation.

3.4.4. Communication configuration with Control and Communication Tests.

This section describes the setup and testing phase during which the communication protocols and the functionality of the Home Energy Management System (HEMS) were evaluated. It also covers the tests conducted to assess the predictive control system, aiming to optimize performance based on both occupants' needs and climatic conditions. Additionally, tests were carried out to verify data collection processes for the CERTH platform (repository) and to evaluate the IoT platform's ability to control components developed by CARTIF and EndeF. This section also explains the involvement of partners such as CARTIF, outlining their contributions in system integration, testing, and the refinement of control functionalities.

For the data monitoring strategy in all demonstrators, a Mosquitto (MQTT) broker was used, from which all PLCs publish data, and it acts as a buffer. These data are collected by Telegraf, which transforms them into Flux queries and inserts them into the InfluxDB database. This approach prevents potential InfluxDB crashes caused by excessive direct data insertions. Finally, Grafana is used to visualize the data. Grafana is the tool employed by CARTIF, Psycrotherm, EndeF and CERTH to monitor the system during its commissioning.



Figure 46. Monitoring and data storage strategy

This control strategy is consistently applied across all demonstrators. In addition to managing thermal energy delivery, the PLC also publishes the system's operational data on the platform developed by CERTH. This mechanism not only provides real-time information to the demonstrators but also ensures access to monitoring data for other users interested in the system's performance.

The previously described strategy is specifically implemented during the commissioning phases to ensure continuous system monitoring and minimize potential data losses. During this process, key operational parameters are established, optimizing data collection to evaluate system performance and ensure its proper integration with the demonstrators.

Pre-demo site: Thessaloniki, Greece.

The communication procedure was developed by CARTIF and CERTH. The PLC responsible for controlling the plant was configured to allow external access and ensure communication within the local subnet. A public IP address was assigned to enable remote access to the system.

Within the internal subnet, static IP addresses were configured for the various devices involved in the operation. These addresses were then integrated into the PLC configuration, allowing it to establish communication with each device for real-time data acquisition and control.

The first testing of the functioning of the system were performed in the month of October in 2023 in Psycotherm laboratory, and lasted 3 hours, in which the connections with the system was tested first. Then the performance of the system in charging mode was tested for 2 days. This test was performed manually by CARTIF with the support and feedback from Psycotherm.

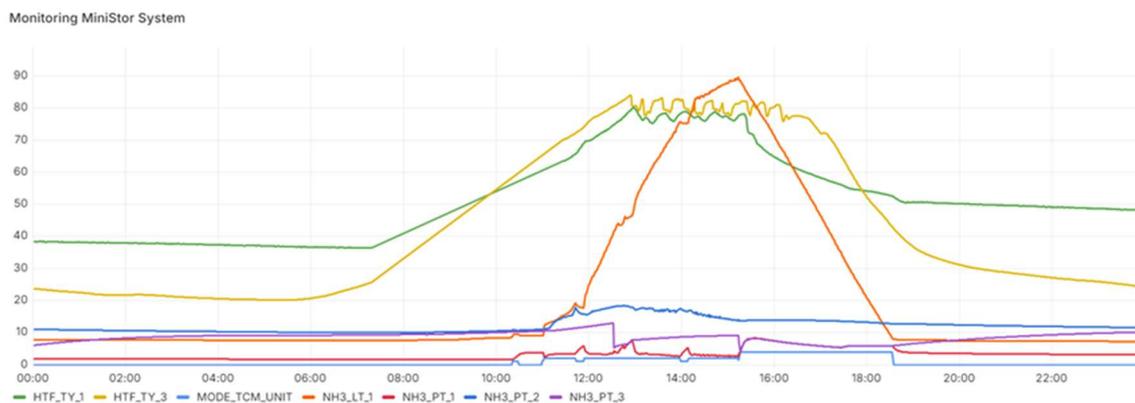


Figure 47. Monitoring of a cycle visualized in Grafana

In March, in parallel with the performance testing facility from Hungary many tests of the operation were performed by CARTIF with the target of gradually leave the system in automatic mode and monitoring it diary.

Once the system was validated, it was set to automatic mode, continuously evaluating how it interacted with the solar plant with the support from EndeF. Due to the connectivity scheme (through a switch in the MiniStor container), the communication with the solar datalogger controller was set to Modbus instead of the usual configuration through VBUS or BACNet to communicate with the PLC. This strategy was the one used through the rest of the sites. This configuration needed to be enabled in the local network.

It was necessary to conduct a series of exhaustive tests to evaluate how the control system of the solar plant behaved, with the aim of ensuring its efficiency in providing a stable and continuous energy source to the system. These tests were crucial to ensure that the solar plant could meet the energy demands of the reactor under different operating conditions. Regarding the electrical part, Modbus TCP control was enabled in the inverter for the PLC to be able to control it.

The evaluation of this process was monitored by CARTIF, with technical support from CERTH and Psycotherm, allowing for detailed supervision and precise analysis of the results. During the process, it was observed that some control parameters, specifically the temperature signals, required adjustments to adapt to the optimal operating conditions of the reactor.

Regarding the system's energy delivery to the demonstrator, a control strategy was established. In this case, the system operates with a single signal that defines the seasonal control mode, distinguishing between winter and summer operation.

For thermal demand management, a schedule-based scheme was implemented. During the predefined time intervals, the pumps located at the phase change material (PCM) outlet are activated only if the thermal storage units are sufficiently charged.

Performance testing facility, Hungary.

The communication procedure was developed by CARTIF and EMI. The PLC responsible for controlling the plant was configured to allow external access and ensure communication within the local subnet. A multi-factor VPN was deployed to enable CARTIF's access to the subnet.

Within the internal subnet, static IP addresses were configured for the various devices involved in the operation. These addresses were then integrated into the PLC configuration, allowing it to establish communication with each device for real-time data acquisition and control.

The first testing of the functioning of the system were performed in the month of February, in which the connections with the system systems was tested first.

In this demonstrator, testing of the system functionality that EMI wanted to evaluate was initiated. Initially, the tests were carried out by CARTIF, while EMI was responsible for monitoring the results and measuring the system's performance. As the tests progressed, CARTIF adapted the control interface so that EMI could continue conducting its evaluations independently. To achieve this, EMI acquired the necessary knowledge through the monitoring of previous tests, as well as through a user manual for the control interface, allowing them to fully understand all modes of operation and how to implement them correctly.

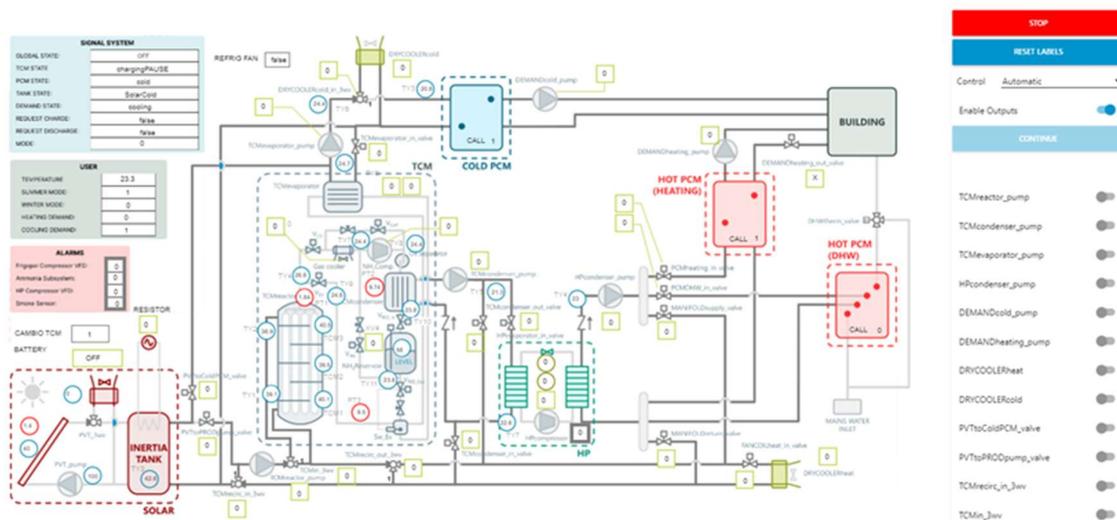


Figure 48. Graphical interface for system testing

Between March and July, all possible system combinations were tested, not only those corresponding to the summer period but also those related to winter conditions. This comprehensive approach allowed for the evaluation of the system's behaviour in various scenarios, ensuring optimal operability throughout the year.

Kimmeria, Greece.

The procedure followed for configuring the PLC in charge of control is the same as the one carried out in Thessaloniki, this time in collaboration with DUTH to access its cloud service.

The first testing of the functioning of the system were performed in the month of July and it lasted 2 hours, in which the connections with the system was tested first. Since we had already validated the system in a real environment, such as Thessaloniki in summer mode, and the laboratory tests with EMI had also been completed, the implementation of the control in this demonstrator was

carried out directly in automatic mode. The initial functional tests yielded positive results, which led to the decision to continue monitoring the system without directly intervening in its operation. This allowed us to observe the system's behaviour in real conditions, just like in Thessaloniki, and continue improving the system control by adjusting parameters such as the operating limits of the HP.

In this particular case, the solar plant did not have an autonomous controller, so it was decided to fix its operation only during daylight hours, adapting its functionality to the natural cycles of energy generation.

Regarding the system's energy delivery to the demonstrator, a control strategy was established based on schedules for both energy transfer and the definition of the system's operating mode, distinguishing between winter and summer regimes.

These schedules were defined according to the demonstrator's requirements to ensure the supply of heating or cooling to the residents during specific periods of the day.

Santiago de Compostela, Spain.

The procedure followed for configuring the PLC in charge of control also followed a multifactor VPN, to ensure communication with the local network, this time in collaboration between CARTIF and USC. There were some initial problems achieving Modbus communication, but these were solved.

In this demonstrator, the initial connection and operation tests were carried out in September. As in the other demonstrators, control was deployed on the PLC, incorporating all the improvements and updates implemented in the other systems. No further tests were necessary, only monitoring the automatic control.

A distinctive feature of this demonstrator is the use of the BACNet protocol for communication. Through BACNet, the control system has been integrated with the demand from the university's home automation network, allowing smooth interaction between devices and the existing infrastructure.

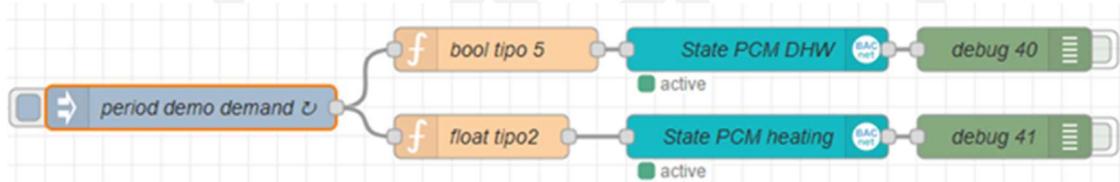


Figure 49. BACNet communication

Additionally, a new communication configuration was introduced to the system, highlighting the deployment of an additional Modbus-based device: a heat pump installed in the solar section of the plant. The operational strategy of the heat pump (HP) was established in collaboration with EndeF, defining its use based on the thermal conditions of the system. This equipment is designed to be activated during the hours of the day when the solar system temperature exceeds a predefined threshold, allowing for the preheating of the inertia tank.

However, the activation of the heat pump has been made to be conditional on the demand of the phase change thermal storage system (TCM). Its operation is only allowed if the TCM requires charging; otherwise, the generated thermal energy would not be efficiently utilized within the system.

For the thermal energy delivery to the demonstrator, an operational strategy was established considering the specific requirements of its system. It is important to note that the demonstrator only demands heat and has its own pumps to extract thermal energy from the system.

As a first measure, the pump located at the outlet of the phase change material (PCM) heat storage was removed to prevent interference with the demonstrator's pump operation, which is solely responsible for heat extraction.

The energy delivery control is managed through BACnet communication between the demonstrator's PLC and the thermal storage system. If the demonstrator's PLC indicates a heat demand and the PCM is fully charged, a signal is sent authorizing the extraction of thermal energy from the system.

In this demonstrator, temperature control is a critical factor, as the system must ensure a minimum threshold of approximately 60°C. In other demonstrators, this requirement is not as strict, so heat delivery remains active until a discharge signal is received, indicating that the thermal storage has been depleted.

Sopron, Hungary.

In the beginning of February 2025, the system was restarted in Sopron after the tests conducted at EMI. During the commissioning phase, connection tests were carried out, allowing real-time data monitoring to begin. Once this stage was completed, the system started operating in automatic mode. No further tests were necessary, only monitoring the automatic control.

For energy delivery to the demonstrator, a strategy was defined based on three control signals. One of them indicates the system's operating mode, distinguishing between winter and summer operation. The other two reflect the demonstrator's thermal demand, specifying whether heating or cooling is required. Based on these signals, the pumps in the container at the PCM outlet are activated only when the thermal storage units are sufficiently charged. This control scheme ensures efficient thermal energy management, optimizing supply according to the system's operational needs.

Cork, Ireland.

In the case of the installation in Cork, initial communication issues were identified due to the residence being connected to the internet through a commercial provider. This provider blocks incoming port forwarding to internal ports 443 (HTTPS) and 80 (HTTP), which are essential for remote access to the PLC's web interface and for deploying and monitoring the control system via web services.

The issue was jointly diagnosed and resolved by CARTIF and Cork City Council. The adopted solution involved installing an additional Raspberry Pi connected to the same local network within the residence. This Raspberry Pi was configured with AnyDesk software, enabling secure remote access through outgoing connections without requiring port forwarding, thus bypassing the restrictions imposed by the internet service provider.

This alternative access infrastructure enabled the successful configuration of the solar subsystem, which required access to the web interfaces of both the Fronius inverter and the Resol controller. Through these interfaces, the necessary Modbus communication settings were adjusted to ensure correct integration and remote supervision of the system.

3.5. Timing of the installation and commissioning activities

The installation and commissioning activities of the MiniStor system at the demonstration sites were carried out in multiple stages, involving different components, infrastructure, and measurement devices. The timing of these activities varied depending on the complexity of the components, demo site conditions, and workforce availability.

The following tables provide a structured overview of the installation timeline, specifying the required manpower and estimated working hours. The details are categorized into general installation activities, meters and sensors, piping and cabling, and the main system equipment.

This information can be used to formulate a streamlined method for system installation in a future commercialization stage.

3.5.1. General installation activities

Table 7 provides an overview of time taken to install several components from all demo sites, and the number of people involved in the process of installation and commissioning. Additionally, it includes an estimate of the working hours required for each component, categorized by unit, length, area, or volume.

Table 7. Overview of General Installation Activities

| Stage | Number | Name | Average | |
|---------|--------|--|---------------------------|--|
| | | | Number of people involved | Working hours per device/length/area/volume |
| [-] | [-] | [-] | [-] | [h/unit]/[h/m]/[h/m ²]/[h/m ³] |
| I | 1 | Heat meter | 2.00 | 3.00 |
| | 2 | Electricity meter | 2.00 | 2.03 |
| | 3 | Gas and air flow meter | 1.50 | 5.00 |
| | 4 | Rooms sensor | 2.00 | 2.24 |
| | 5 | Logging equipment meter | 1.75 | 6.10 |
| | 6 | Weather station | 2.50 | 15.00 |
| II | 1 | Piping from system to house | 2.75 | 2.19 |
| | 2 | Piping from system to solar field | 6.00 | 6.00 |
| | 3 | Electrical cable | 2.00 | 11.00 |
| | 4 | Electrical connection | 1.75 | 13.00 |
| | 5 | Foundations | 4.00 | 4.41 |
| III | 1 | PV/PVT | 2.33 | 2.78 |
| | 2 | Solar collectors | 2.25 | 3.29 |
| | 3 | Inverter & EES | 2.00 | 13.33 |
| | 4 | MiniStor system | 3.00 | 22.67 |
| | 5 | MiniStor connection - sensors and piping and electrical connection | 2.00 | 24.00 |
| | 6 | System running (boot) | 4.00 | 30.67 |
| Summary | | | | 166.71 |

3.5.2. Meters and Sensors

Table 8 details the time taken for installation of measurement devices such as heat and electricity meters at demonstration sites. It specifies whether each device was installed at a particular location, the time required for installation, and the number of personnel involved. Regarding DUTH's demo-site, most of the meters and sensors were already pre-installed as part of their own monitoring efforts. The pre-installed equipment consists of heat/cool energy meters, electrical energy consumption, indoor temperature and the outside weather station. The only sensors installed during the project at the Kimmeria pilot were a flow meter, an electricity consumption meter and the pressure and temperature sensors for the device's inertial tank.

Table 8. Overview of actual installation time for Meters and Sensors in each demo site

| <u>Heat meter</u> | | | | | |
|-------------------------------|----------------|-----------------------|---------------------------|----------|--------------------------|
| Demo site | Data available | Time for installation | Number of people involved | Quantity | Working hours per device |
| | [-] | [h] | [-] | [-] | [h/unit] |
| Cork | Yes | 3.0 | 2.0 | 2.0 | 3.0 |
| Kimmeria | No | | | | 0.0 |
| Santiago | Yes | 8.0 | 2.0 | 4.0 | 4.0 |
| Sopron | Yes | 4.0 | 2.0 | 4.0 | 2.0 |
| Average | | | | | 3 |
| <u>Electricity meter</u> | | | | | |
| Demo site | Data available | Time for installation | Number of people involved | Quantity | Working hours per device |
| | [-] | [h] | [-] | [-] | [h/unit] |
| Cork | Yes | 3.0 | 2.0 | 2.0 | 3.0 |
| Kimmeria | No | | | | 0.0 |
| Santiago | Yes | 4.0 | 2.0 | 4.0 | 2.0 |
| Sopron | Yes | 6.0 | 2.0 | 11.0 | 1.1 |
| Average | | | | | 2.0 |
| <u>Gas and air flow meter</u> | | | | | |
| Demo site | Data available | Time for installation | Number of people involved | Quantity | Working hours per device |
| | [-] | [h] | [-] | [-] | [h/unit] |
| Cork | Yes | 3.0 | 2.0 | 1.0 | 6.0 |
| Kimmeria | No | | | | 0.0 |
| Santiago | No | | | | 0.0 |
| Sopron | Yes | 4.0 | 1.0 | 1.0 | 4.0 |
| Average | | | | | 5.0 |
| <u>Rooms sensor</u> | | | | | |
| Demo site | Data available | Time for installation | Number of people involved | Quantity | Working hours per device |
| | [-] | [h] | [-] | [-] | [h/unit] |
| Cork | Yes | 3.0 | 2.0 | 7.0 | 0.9 |
| Kimmeria | Yes | 6.0 | 2.0 | 5.0 | 2.4 |
| Santiago | Yes | 4.0 | 2.0 | 7.0 | 1.1 |
| Sopron | Yes | 25.0 | 2.0 | 11.0 | 4.5 |

| Average | | | | | 2.2 |
|--------------------------------|----------------|-----------------------|---------------------------|----------|--------------------------|
| <u>Logging equipment meter</u> | | | | | |
| Demo site | Data available | Time for installation | Number of people involved | Quantity | Working hours per device |
| | [-] | [h] | [-] | [-] | [h/unit] |
| Cork | Yes | 3.0 | 2.0 | 3.0 | 2.0 |
| Kimmeria | Yes | 6.0 | 2.0 | 5.0 | 2.4 |
| Santiago | Yes | 8.0 | 2.0 | 1.0 | 16.0 |
| Sopron | Yes | 4.0 | 1.0 | 1.0 | 4.0 |
| Average | | | | | 6.1 |
| <u>Weather station</u> | | | | | |
| Demo site | Data available | Time for installation | Number of people involved | Quantity | Working hours per device |
| | [-] | [h] | [-] | [-] | [h/unit] |
| Cork | Yes | 8.0 | 4.0 | 1.0 | 32.0 |
| Kimmeria | Yes | 2.0 | 2.0 | 1.0 | 4.0 |
| Santiago | Yes | 8.0 | 2.0 | 1.0 | 16.0 |
| Sopron | Yes | 4.0 | 2.0 | 1.0 | 8.0 |
| Average | | | | | 15.0 |

3.5.3. Piping, Cabling, and Foundation per demo site

Table 9 outlines the specific installation time per demo site to install infrastructure elements such as piping from the system to the target building. It provides details on installation data availability, estimated installation time, the number of personnel involved, and the length of installed piping. In the case of Santiago de Compostela, no foundation was required as the system was placed on a stable concrete pavement.

Table 9. Overview of actual installation time for Piping, Cabling, and Foundation in each demo site

| <u>Piping from system to house</u> | | | | | |
|--|----------------|-----------------------|---------------------------|--------|-------------------------|
| Demo site | Data available | Time for installation | Number of people involved | Length | Working hours per meter |
| | [-] | [h] | [-] | [m] | [h/m] |
| Cork | Yes | 24.0 | 6.0 | 32.0 | 4.5 |
| Kimmeria | Yes | 12.0 | 2.0 | 80.0 | 0.3 |
| Santiago | Yes | 240.0 | 2.0 | 332.0 | 1.4 |
| Sopron | Yes | 30.0 | 1.0 | 12.0 | 2.5 |
| Average | | | | | 2.2 |
| <u>Piping from system to solar field</u> | | | | | |
| Demo site | Data available | Time for installation | Number of people involved | Length | Working hours per meter |
| | [-] | [h] | [-] | [m] | [h/m] |

| Cork | Yes | 4.0 | 6.0 | 4.0 | 6.0 |
|-------------------------------|----------------|-----------------------|---------------------------|-------------------|--------------------------|
| Kimmeria | No | - | - | - | 0.0 |
| Santiago | No | - | - | - | 0.0 |
| Sopron | Yes | - | - | 2.0 | 0.0 |
| Average | | | | | 6.0 |
| <u>Electrical cable</u> | | | | | |
| Demo site | Data available | Time for installation | Number of people involved | Quantity | Working hours per device |
| | [-] | [h] | [-] | [-] | [h/unit] |
| Cork | Yes | 4.0 | 2.0 | 1.0 | 8.0 |
| Kimmeria | Yes | 2.0 | 2.0 | 1.0 | 4.0 |
| Santiago | Yes | 10.0 | 2.0 | 1.0 | 20.0 |
| Sopron | Yes | 6.0 | 2.0 | 1.0 | 12.0 |
| Average | | | | | 11.0 |
| <u>Electrical connections</u> | | | | | |
| Demo site | Data available | Time for installation | Number of people involved | Quantity | Working hours per device |
| | [-] | [h] | [-] | [-] | [h/unit] |
| Cork | Yes | 4.0 | 2.0 | 1.0 | 8.0 |
| Kimmeria | Yes | 2.0 | 2.0 | 1.0 | 4.0 |
| Santiago | Yes | 16.0 | 2.0 | 1.0 | 32.0 |
| Sopron | Yes | 8.0 | 1.0 | 1.0 | 8.0 |
| Average | | | | | 13.0 |
| <u>Foundations</u> | | | | | |
| Demo site | Data available | Time for installation | Number of people involved | Volume | Working hours per volume |
| | [-] | [h] | [-] | [m ³] | [h/m ³] |
| Cork | Yes | 6.0 | 6.0 | 5.9 | 6.2 |
| Kimmeria | Yes | 4.0 | 2.0 | 3.0 | 2.7 |
| Santiago | Not req. | | | | 0.0 |
| Sopron | No | | | | 0.0 |
| Average | | | | | 4.4 |

3.5.4. Major system components

Table 10 shows on the installation time taken for major system components, such as PVT/FPC panels. It specifies installation data availability, required installation time, and number of people involved. It also includes data on the surface area covered and the corresponding working hours per square meter. As a reminder, the site in Kimmeria did not require the installation of PVT or FPC panels. For Santiago de Compostela, some items are not reported as repair activities were done due to the unloading incident.

Table 10. Overview of installation of Main Equipment in each demo site

| PVT panels | | | | | |
|--------------------------------------|----------------|-----------------------|---------------------------|-------------------|--------------------------|
| Demo site | Data available | Time for installation | Number of people involved | Area | Working hours per area |
| | [-] | [h] | [-] | [m ²] | [h/m ²] |
| Cork | Yes | 4.0 | 3.0 | 8.0 | 1.5 |
| Kimmeria | Not req. | | | | 0.0 |
| Santiago | Yes | 25.0 | 2.0 | 20.0 | 2.5 |
| Sopron | Yes | 28 | 2 | 12.88 | 4.34 |
| Average | | | | | 2.8 |
| Flat-plate solar collectors | | | | | |
| Demo site | Data available | Time for installation | Number of people involved | Quantity | Working hours per device |
| | [-] | [h] | [-] | [-] | [h/unit] |
| Cork | Yes | 4.0 | 3.0 | 4.0 | 3.0 |
| Kimmeria | Not req. | | | | 0.0 |
| Santiago | No | | | | 0.0 |
| Sopron | Yes | 24 | 1.5 | 10.04 | 3.58 |
| Average | | | | | 3.3 |
| Inverter & ESS | | | | | |
| Demo site | Data available | Time for installation | Number of people involved | Quantity | Working hours per device |
| | [-] | [h] | [-] | [-] | [h/unit] |
| Cork | Yes | 4.0 | 2.0 | 1.0 | 8.0 |
| Kimmeria | Not req. | | | | 0.0 |
| Santiago | Yes | 10.00 | 2.00 | 1.00 | 20.0 |
| Sopron | Yes (only ESS) | 6.00 | 2.00 | 1.00 | 12.0 |
| Average | | | | | 13.3 |
| MiniStor system thermal storage unit | | | | | |
| Demo site | Data available | Time for installation | Number of people involved | Quantity | Working hours per device |
| | [-] | [h] | [-] | [-] | [h/unit] |
| Cork | Yes | 8.0 | 4.0 | 1.0 | 32.0 |
| Kimmeria | Yes | 10.0 | 3.0 | 1.0 | 30.0 |
| Santiago | No | | | | 0.0 |
| Sopron | Yes | 3.0 | 2.0 | 1.0 | 6.0 |
| Average | | | | | 22.7 |

| MiniStor connection – sensors, piping and electrical connection | | | | | |
|---|----------------|-----------------------|---------------------------|----------|--------------------------|
| Demo site | Data available | Time for installation | Number of people involved | Quantity | Working hours per device |
| | [-] | [h] | [-] | [-] | [h/unit] |
| Cork | Yes | 16.0 | 2.0 | 1.0 | 32.0 |
| Kimmeria | Yes | 12.00 | 2.0 | 1.0 | 24.0 |
| Santiago | No | | | | 0.0 |
| Sopron | Yes | 8.0 | 2.0 | 1.0 | 16.0 |
| Average | | | | | 24.0 |
| System running (boot) | | | | | |
| Demo site | Installed | Time for installation | Number of people involved | Quantity | Working hours per device |
| | [-] | [h] | [-] | [-] | [h/unit] |
| Cork | No | 5.0 | 4.0 | 1.0 | 20.0 |
| Kimeria | Yes | 6.0 | 4.0 | 1.0 | 24.0 |
| Santiago | No | | | | 0.0 |
| Sopron | Yes | 12.0 | 4.0 | 1.0 | 48.0 |
| Average | | | | | 30.7 |



4. Summary of problems encountered during the installation and commissioning process, with “lessons learned”

This section details specific technical and non-technical issues that were encountered by the demo sites during the installation and commissioning process, and which can serve as a guide for future installation of novel thermal storage systems. Some of these issues had been formulated as part of the risk assessment for the overall project, with a mitigation plan in place. This section also details the actual mitigation actions taken.

4.1. Technical issues encountered during the commissioning and operation process

This section will describe problems of technical nature that were found during the installation and commissioning: for example, issues with sensors, with the instructions for operation, etc and how they were solved.

Pre-demo site: Thessaloniki, Greece

During the tests conducted on this demonstrator, CARTIF observed that the built-in controllers of the heating PCM had a setpoint significantly higher than the phase change temperature, preventing these thermal batteries from discharging. The manual was reviewed, and the setpoint was adjusted with the support of Psycrotherm. Additionally, Psycrotherm added a temperature sensor in the heating PCM.

During the system's operation, it was identified that the solar controller experienced sporadic resets due to power losses, resulting in the loss of its configuration. This situation led to unregulated operation of the solar plant, generating excessively high temperatures that could compromise the integrity of the equipment.

To address this issue, EndeF conducted a review of the controller to diagnose the cause of the resets, while CARTIF implemented rules in the control system to efficiently manage excess thermal energy. These rules allowed for the evacuation of accumulated heat in the solar plant through the use of the unit's fan coils, in addition to activating notification mechanisms to alert about the situation and facilitate its resolution. Also, as part of the commissioning procedure, the solar controller's configuration was stored in a SD card in order to be able to reset again and restore the values if there were any future problems.

The expansion vessels volumes were reviewed, and an additional one was included in the system.

The implementation of these measures was carried out in collaboration with CERTH and under the supervision of Psycrotherm. These measures were also communicated to other demo sites for their consideration during the reception of the prototype and the setup.

Performance testing facility, Hungary

During transport to the EMI site, the TCM tank's mounting structure broke through the sidewall panel. It was assumed that when the transport truck braked suddenly, the weight of the tank produced an overload of the side external panel, becoming torn but not affecting performance or any other component. Bolting and securing the support with a plate proved to be adequate for the transport later to Sopron (see next figures).



Figure 50. MiniStor TCM tank mounting solution due to overload weight during transporting for EMI testing

During filling of the MiniStor and the charging and operational test at the EMI site, an air plug was created inside the MiniStor system. The air plug caused the pump to stop with a fault signal. This fault was resolved by disconnecting the connecting pipework. The solution to this phenomenon has already been successfully applied in Sopron. It consists of when the ball valve is closed, and the filling-emptying stubs are opened; the liquid can be circulated through the system by means of a pressure test pump suitable for this purpose. See Figure 53.

Several water leaks were experienced while operating the unit system, and successfully repaired. One third of the leaks were caused by the built-in venting devices. Unfortunately, in some places the space is so small that it is not always possible to install a venting device (special venting equipment is needed). Most leaks were caused by press fittings in five-layer pipes, not by the threaded connection, but the press connection. A pressed connection can leak for several reasons, unfortunately it is not possible to determine the cause clearly afterwards. See the figures below.

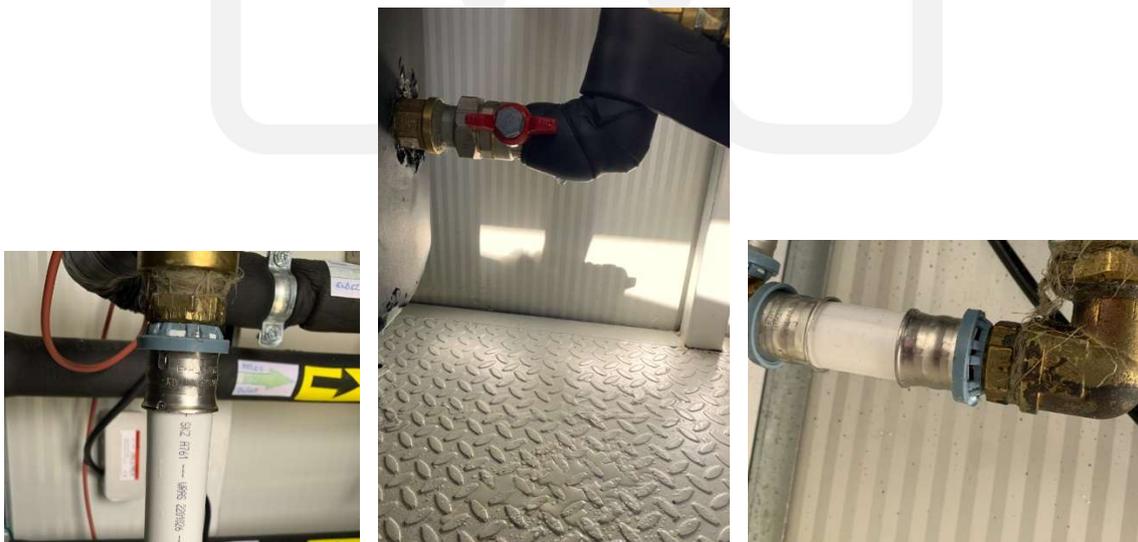


Figure 51. Water leaks in press fittings that were subsequently repaired during EMI testing

Another suspected cause of leaks may be caused by the position of solenoid valves during normal operation of the system but requires further testing to confirm if they are not constricting flow. See the figures below.



Figure 52. Leaks due to faulty air vent valves

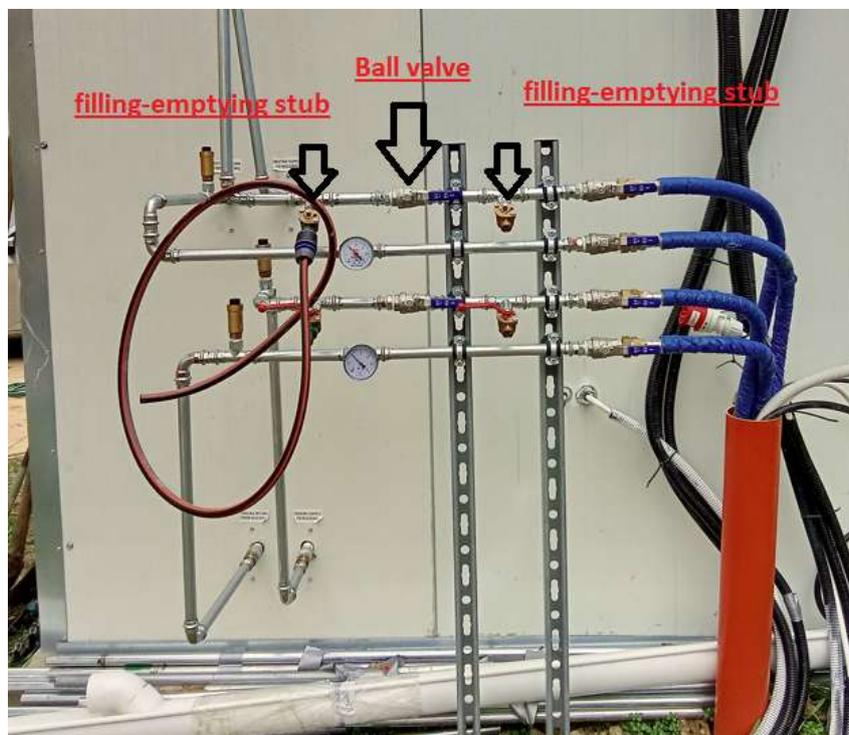


Figure 53. Construction of a filling and emptying section in Sopron

Issues developed with the ammonia compressor and an ammonia level indicator during the performance testing. The faulty level indicators were providing false readings indicating overheating that was not occurring. The system reacted by continuous operation of the fan coils to dissipate heat. This increased total energy consumption.

Troubleshooting was made of the compressor, with the level indicator being replaced and manually adjusted. However, the compressor became unstable again and stopped the testing. Further inspections and on site repairs were carried out after transportation of the unit to Sopron, which proved successful. See the figures below.

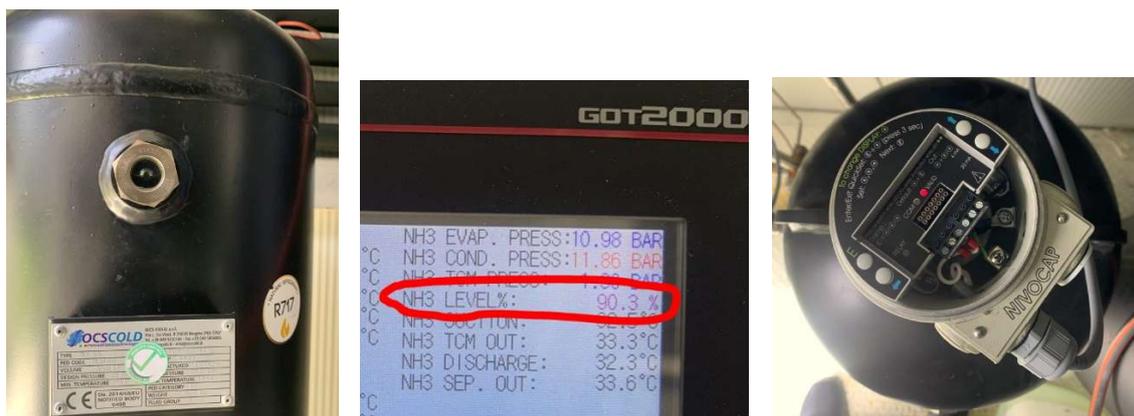


Figure 54. Manual adjustment of NH₃ level indicator against readings from the sensors

Kimmeria, Greece

- a) The MiniStor system is connected to the internet via a NAT router and firewall to avoid unauthorised access to the system. Due to various misconfigurations, there were connection errors, that were resolved with the help of the DUTH IT department.
- b) On 18/7/2024 there was a small ammonia leakage. During midday the air temperature inside the MiniStor system was nearly 50°C. Very hot water entered the evaporator and condenser of the ammonia heat pump, and the water reached rapidly 55°C on the condenser and 75°C on the evaporator of the heat pump. Safety valves opened and discharged a small amount of ammonia. Shutoff procedures were implemented to avoid this from happening again.
- c) On 18/7/2024 there was a water leak which was due to a bad fitting of a pipe.
- d) There was a calibration problem with the ammonia level sensor. All necessary steps for correction were taken according to the sensor manufacturer.
- e) In August 2024, a pump started to leak water and was shipped by DUTH's team back to Psycrotherm. The pump was replaced by Psycrotherm during the next weeks of the leak detection.
- f) During February 2025 the efficiency of MiniStor dropped significantly. The investigation concluded that the NH₃ compressor was malfunctioning. Psycrotherm gave further insights after the scheduled meeting with DUTH's team on 11/03/2025.
- g) Power outages occur sometimes in the demo site campus due to grid faults or electrical suppliers and distributor maintenance. When the duration is long, the MiniStor system loses network connection temporarily.

Santiago de Compostela, Spain

During the commissioning phase, several tests were conducted on the Hitachi heat pump, requiring multiple meetings and additional consultations between EndeF and CARTIF to address an issue with the equipment's remote communication.

After these discussions and using EndeF's prior experience with a similar device, it was determined that the issue stemmed from a discrepancy in the Modbus map version. This version mismatch affected the interpretation of registers, preventing proper communication with the system. Once identified, the necessary adjustments were made to ensure compatibility and establish effective remote communication with the support of USC.

Sopron, Hungary

When the solar field system was charged in Sopron, we found that the pressure in the system dropped significantly in a day or two, but without leakage. The explanation for this phenomenon is that after the system was filled, the solar panels heated the liquid so much that its pressure increased and it "vaporized" on the automatic vents, requiring refilling until reaching the desired pressure. A suggested solution is to cover the collectors during installation and filling.

During the commissioning phase, unforeseen requirements were identified for the operation of the heat pump in extreme cold conditions. Following Psycrotherm recommendations, CARTIF implemented a preheating strategy at the inlet and outlet of the heat pump to prevent operational issues and ensure its proper performance.



Figure 55. The cold environment conditions forced a special operation mode for defrosting

There was a problem caused due to loss of calibration from the ammonia level sensor, which might have been caused during transportation. This sensor had to be recalibrated. The representative of the sensor manufacturer visited the Sopron demo site and suggested a solution for the problem. In addition, there were no small screens installed for the sensor and the representative offered to buy a screen fit for this ammonia sensor.

During commissioning, a leakage of the solar glycol system was detected, which was fixed locally.

Cork, Ireland

During commissioning, it was found that some pipework located under the PCM tanks was leaking water, this was fixed by local plumbers on site. More leaks were located in the solar circuit outside of the container, these were also fixed. The leaks might have been caused by the fittings becoming loose during the transportation process.

During testing of the system, the ammonia compressor failed. It was fixed on site by Psycrotherm, who replaced defective seals on the drive shaft of the compressor, it worked successfully after these were replaced. However, after a few hours of operation, the compressor failed again and had to be replaced by the compressor manufacturer with a model that had been proven to work. No other faults were reported afterwards.

4.2. Relevant non-technical issues encountered during the process.

This section describes problems of non-technical nature that were found during the installation and commissioning.

Kimmeria, Greece

During the initial commissioning, there were some delays due to network issues regarding online control of the MiniStor components. It took some time to configure the IP addresses and other IT parameters to ensure the integrity of network connections.

Sopron, Hungary

In the case of commissioning for this site, there was an unexpected delay caused by the selected company who cancelled their commitment to piping work on the last days of 2024. The company promised they would connect the solar field to the MiniStor unit and by so the operation could be started about two-three weeks earlier. Unfortunately, the company cancelled this offer also, and another company was selected in January 2025, with the connection and the commissioning fulfilled in February 2025.

Santiago de Compostela

Communications had to be made with the delivery company due to the accident when the unit was dropped. This delayed the installation as the unit had to be carefully inspected to define damages, while at the same time the delivery company contacted their insurers.

Cork, Ireland

The container arrived in Cork without ammonia, as safety and regulatory restrictions related to sea transport prevented it from the TCM reactor being shipped with the required charge. The sourcing of ammonia in Ireland proved to be difficult because of safety regulations associated with the gas, despite the small amount required, increasing installation time. The ammonia was supplied by a registered installer who required a special HAZChem licence to transport it and other professional certificates to administer it to the TCM sub-system in the MiniStor unit. When shipping empty units, adequate time should be allowed for delivery of ammonia gas if this is required for the TCM unit.

4.3. Key takeaways from the installation and commissioning process

Based on the manufacture, shipment and installation of the five prototypes that was followed during the project, and the effectiveness of the measures, the following are some important points that need to be considered for the installation of future and improved thermal and electrical energy storage systems:

- a) Application of improved bolt and plate connectors for large elements such as the TCM reactor and heat pump, to ensure complete immobilisation during transportation and avoid “ripping” of the enclosure panels by the screws due to heavy elements pushing into lighter ones.
- b) Modularity of the components proved useful when replacing specific components (e.g. ammonia compressors) without major requirements for isolation of the prototype, providing a safe environment for technicians carrying out the repairs.
- c) Improved packaging to protect and immobilise components within the thermal storage unit, e.g. recyclable wrapper to avoid cosmetic scratches to the enclosure panels, use of biodegradable foam or carton blocks to reduce component movement inside the unit, etc.

- d) Improved connective valves in the water circuits that allow some movement during transportation, to reduce water and glycol leaks as most leaks were produced in those points.
- e) Protective covers for the solar collectors to be placed during their installation and up to their connection to the unit, to protect the PVT surfaces, avoid damage and maintain pressure, reducing the instances of refilling.
- f) Ensure continued power supply to the solar controllers in order not to lose configuration, which can be in the form of local batteries or uninterruptible power supply. Store the configuration in an SD card to ease the reload.
- g) Ensure a stable internet connection that supports the remote access required for system monitoring and operation. It is important to verify that the internet provider does not impose restrictions that could hinder access to device interfaces.
- h) Expand the monitoring of key variables such as flow rates and temperatures at additional points in the system, to improve the accuracy of thermal modelling and the analysis of the dynamic behaviour of subsystems. This data is essential for model validation and the optimization of control strategies.

5. Streamlined method for installation of the integrated thermal and electrical storage system

This section proposes a general and improved procedure for the installation and commissioning of the MiniStor prototype with reduced timing. Shorter installation and commissioning of the integrated system would be able to give a competitive advantage over the installation of separate components, together with the optimisation made for the unit to the local condition. Given the diversity of sites, some steps should be tailored to specific country conditions, but the overall workflow should remain consistent. From initial site assessment and stakeholder coordination to system installation, testing, and reporting, these steps are essential to ensure proper integration of the system with each site's existing infrastructure, enabling effective operation, monitoring, and evaluation in real-life conditions. The steps are enumerated under the assumption that a single commercialization entity will supervise them, according to business models developed in WP7.

- **Site assessment and preparation:** Initial evaluation and site survey of the physical, and environmental conditions of the site, including available installation space, space for the solar field, the need for surface levelling, provision of suitable foundation (considering the system's weight), and inventory of access to existing infrastructure such as water, electricity, and internet network connections.
 - Consider the distance between prototype and building to minimize heat losses but comply with requirements of EN-378. Study of the space available to install the solar field (including roofs), or if this can be placed close to the prototype.
 - Careful study of the access routes to see if there is sufficient space for a truck with crane to access. If not, study of access routes to arrange for forklift access and lifting.
 - Define site for secure storage of components while they are not installed (e.g. PVT panels).
 - Define location of the electrical batteries if they cannot be installed close to the unit.
- **Coordination with local stakeholders:** Engagement with the site owners or manager to obtain necessary permissions, agree on a detailed installation timeline, and ensure operational and safety coordination. Engagement with inhabitants in case they are not the owners.
- **Obtention of permits:** After obtaining green light for the installation, obtain all necessary permits, including transportation of ammonia gas in case the TCM reactor is shipped empty,

and permits to install energy trading from excess solar electricity when allowed. Timing and documentation required varies according to each EU country, so this step will be tailored to different situations.

- **Installation of mechanical and electrical infrastructure:** Preparation of ground foundations for the unit and the solar field structure.
 - Trench excavation for insulated piping and cabling, connection to the site's water and electricity supply, and preparation of hydraulic bypass for heating and domestic hot water.
 - Preparation of sensors within the residence to facilitate energy management. Installation of safety systems to avoid accidents within the site.
 - Preparation of internet connectivity to have a defined and working IP address.
- **Transport and delivery of system components for installation:** Organize transportation of the thermal storage unit and solar field with corresponding accessories to the demonstration site, considering the appropriate transportation routes (by sea or land) and inspecting the delivered items to ensure completeness and integrity. This requires coordination between unit manufacturer and the transportation company.

Currently, the solar field, thermal and electrical storage were shipped separately from different locations in Europe. It is envisaged that for future commercialization of the system, all parts would be sent in a single large shipment, or several smaller shipments with close delivery dates.

- **Physical installation of system on site:** After reception, the installation of various modules, including the MiniStor thermal storage unit, control system, solar field, supporting structures, and other main components, according to the system design. This phase will include:
 - Placement of the thermal storage unit in the designated area with visual verification of integrity both inside and outside the unit. Reporting of any damages for repair.
 - Installation of solar structures and collectors: Assembly and placement of support structures.
 - Installation of solar collectors: Assembly and connection of PVTs and solar collectors including their internal piping and cabling and overall connection to the MiniStor system.
 - Connection of the thermal unit to hydraulic networks: Establishing thermal and electrical connections to the site's existing infrastructure
 - Connection of batteries and electrical system to electrical networks: Establishing thermal and electrical connections to the site's existing infrastructure.
- **Integration with IoT platform:** Connectivity tests for manual and remote control via IoT platform. Diagnostic and setting up of initial values at the controllers.
- **Commissioning with calibration and testing:** Verifying the performance of individual components, troubleshooting issues, and ensuring stable operation of the system. First supervised run of the entire system for a charge and discharge cycle, checking if pressures are kept as intended. Verification of the solar field and the solar controller, checking pressures and electrical output. Verification of connective valves with detection and correction of any leaks if they occur.
- **Training of local users:** Provide training for responsible personnel on system operation, safety measures, and when to contact technical support.
- **Technical documentation:** Preparing and providing users with technical documents including operation instructions, system layout diagrams, configuration details, installation

steps, completed checklists and technical support numbers (in a future stage of commercialization).

6. Conclusions

This Deliverable describes the process of installation and commissioning of the MiniStor prototypes that was followed in the five demonstration sites across Europe. It presents a comparison of the conditions in each demo site, including site-specific infrastructure, regulatory requirements, and technical configurations. It describes the sequence of actions taken to ensure deployment of the unit and its commissioning, both as an actual activity and future streamlined one.

The report highlights the collaborative work that was done between technology providers and demonstration site partners, detailing the procedures for preparing the sites, delivering the components, configuring the system, and conducting verification and performance tests. Due to the research nature of the project and the expected technology readiness level, several alternatives had to be considered previous to installation, and different solutions were formulated to problems that arose while performing the demonstration activity. The installation and commissioning were completed under a wide range of environmental and operational conditions, which also served to provide corrective actions for system operation. The demonstration provided valuable insights into the flexibility and robustness of the MiniStor system and helped to show in practice how the system behaves and how it can be improved.

These improvements can be formulated after solving the main challenges that were encountered at each site such as technical and non-technical delays, transport limitations, integration with existing systems, or component malfunctions which are documented alongside the practical solutions that were adopted. Based on these experiences, a streamlined method for installation by a future commercialization entity is proposed, helping to scale up system deployment in different residential and climatic contexts.

