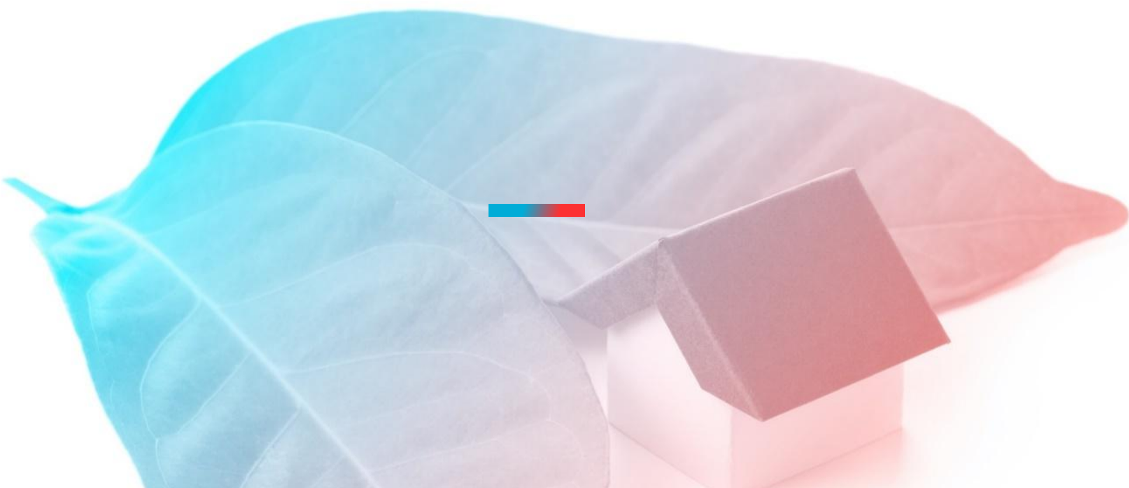
Deliverable 3.5
Installation strategies of improved PVT electrical generation system



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Note: This document includes installation strategies of improved PVT electrical generation system that can be applied to a generic location and implementation. It considers the design performed for the related demos sites (Thessaloniki, Sopron and Cork), as well as the feedback from the pre-pilot implementation completed in Thessaloniki.

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D3.5 Installation strategies of improved PVT electrical generation system.

<table>
<tr><td colspan="4">Summary</td></tr>
<tr><td colspan="4">This deliverable was prepared in the context of Task 3.3 "Engineering, installation strategies and prototyping for thermal storage system integration with conventional PVT configuration". Specifically, D3.5 is focused on the installation strategies of the PVT generation system that use an improved glazed liquid-based photovoltaic thermal (PVT) collectors that produced electrical and thermal energy in combination with solar thermal flat plate collectors (FPC) for the MiniStor System as well as for the building.

These installation strategies include the preliminary work for the location of the PVT-FPC solar field, the installation of the hydraulic system corresponding to the thermal PVT-FPC solar field and the electrical subsystem associated with the electrical PVT field. They can be applied in a generic location where the MiniStor system will be implemented. They consider the base designs conducted for the Thessaloniki pre-pilot and the related demo sites (Sopron and Cork) as well as the feedback from these demonstration sites.</td></tr>
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Abbreviations and acronyms

AC	Alternating current
DC	Direct current
DHW	Domestic hot water
ESS	Electrical storage system
FPC	Flat plate collector
HTF	Heat transfer fluid
HX	Heat exchanger
MPP	Maximum Power Point
PCM	Phase-change material
PV	Photovoltaic
PVT	Photovoltaic-thermal
RES	Renewable energy sources
STC	Standard testing conditions
TCM	Thermochemical material

1 Introduction

MiniStor[1] is a project funded by the European Union's Horizon 2020 research and innovation programme, focused on the design and production of an innovative compact integrated thermal storage system to implement sustainable energy storage for heating, cooling and electricity, adaptable to existing systems in residential buildings. MiniStor storage system is based on a thermochemical material reaction, in combination with PCM (phase-change materials) heat storage, and in parallel with an electrical storage system (ESS). The MiniStor system can use as input different Renewable Energy Sources (RES), such as hybrid Photovoltaic Thermal (PVT) collectors.

Hybrid solar collectors, also known as photovoltaic-thermal (PVT) collectors, combine, in a single collector, the ability to convert solar radiation to both electricity and thermal energy. According to the PVT collector type and the weather conditions of the location, this technology may be used for diverse applications, such as pool heating, domestic hot water production, and heat production at low temperatures for space heating and/or for industrial processes.

The MiniStor Project includes 4 demonstration facilities and one pre demo, which are rlocated in Greece, Hungary, Ireland and Spain. This deliverable was prepared in the context of T3.3, in which an improved liquid-based glazed PVT prototype[2] was developed and installed in three of the five demonstration sites, including Thessaloniki (Greece), Sopron (Hungary) and Cork (Ireland)[3]. Specifically, this deliverable is focused on the installation strategies for the PVT-FPC solar system, that combines PVT collectors and solar thermal flat plate collectors (FPC) to produce electricity and thermal energy to be used in the MiniStor system to cover the heating/cooling needs of a building.

The installation strategies include the preliminary work for the location of the PVT-FPC solar field, the installation of the hydraulic system corresponding to the PVT-FPC field, as well as the installation of the electrical subsystem associated with the PVT field, to be applied in a generic location. These strategies are based on the design process performed for the solar PVT-FPC system in the related demo sites (Sopron and Cork), as well as the feedback from the pre-pilot implementation in the Thessaloniki site. The deliverable includes feedback from the demo sites and the pre-pilot once the installation and commissioning process have been finished.

The specific details about the implementations in all related demo sites will be presented in two deliverables prepared in the context of WP6, specifically in D6.3 that presents the results from the pre-pilot implementation and stakeholder training, and D6.4 related to the Installation and commissioning report for all the MiniStor demo sites.

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[1] *Minimal Size Thermal and Electrical Energy Storage System for In-Situ Residential Installation*

[2] *The improved PVT prototype was previously developed and tested within T3.3 with the results presented in D3.4*

[3] *The demonstration sites in Kimmeria (Greece) and Santiago de Compostela (Spain) do not incorporate the PVT collectors developed in the context of Task 3.3. Kimmeria demo site already has other local RES (solar thermal energy and biomass). Santiago de Compostela demo site incorporates another PVT collector design, with a heat pump in the generation system, whose development and integration are part of Task 3.4*

2 Overview of MiniStor system

MiniStor System consists of the following components depicted in Figure 1: a) a PVT-FPC solar system coupled with a small inertia water tank, b) a TCM reactor containing ammoniated $CaCl_2$ salts, c) an ammonia refrigeration cycle and a storage tank, d) an internal small heat pump (HP) and e) PCM units. This system is combined with and Electrical Storage System (ESS), based on Li-ion batteries, where the electrical production from the PVT collectors is stored.

The solar system uses a set of PVT collectors to preheat the heat transfer fluid (HTF), and a set of FPC that completes the heat process. PVT collectors and FPC facilitate an efficient conversion of the solar energy into hot water for the TCM reactor, while at the same time providing electricity through the PVTs. To utilize solar energy, the system is equipped with an inertia or buffer tank for the smooth evolution of the collectors' outlet temperature. In addition, an electrical heater is added to increase the fluid temperature at the required levels, in cases of limited solar radiation.

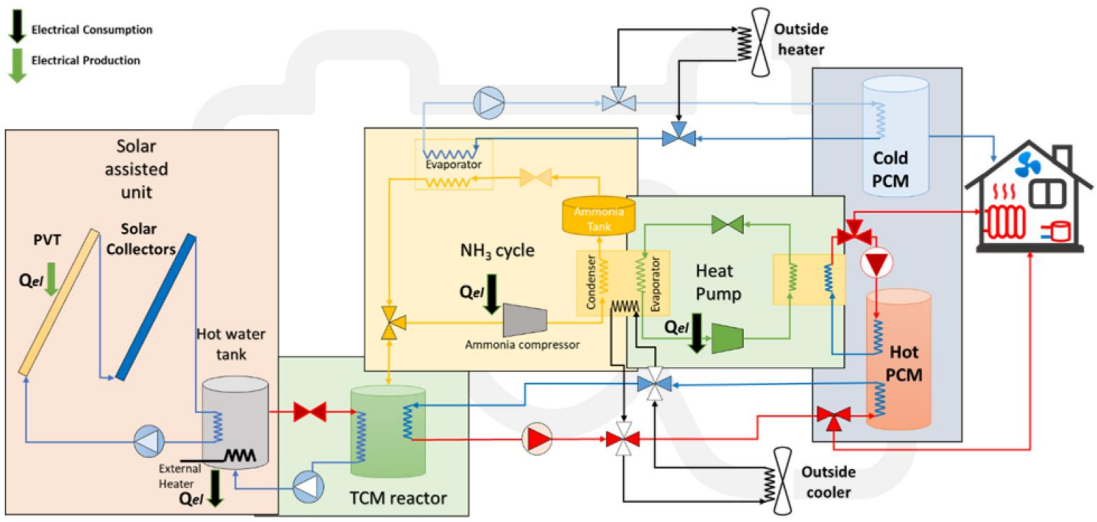

Figure 1: Overview of MiniStor system activated with a PVT-FPC generation system

The operating principle of the TCM unit is based on the thermal effect with reversible reactions using calcium chloride and ammonia. Thanks to the heat produced by the PVT-FPC system there is a charging phase to start heat into the MiniStor system. This stored thermal energy is used later to meet the thermal heating demand in the home or building. The internal small heat pump is a complementary component used to generate additional heat during the charging phase. Besides, the overall system operation incorporates a cooling effect that can be used during the summer to attend to the thermal cooling demand in the building or home. The deliverable D3.1 related to the "Initial dimensioning of the system according to general use typologies", included more thorough description of how MiniStor System works.

3 PVT-FPC solar field designed for the MiniStor System

This section includes a summary of the basic configuration designed for the solar field, which combines hybrid photovoltaic thermal collectors (PVT) and solar thermal flat plate collectors (FPC). Additionally, the general construction details, for both types of collectors (PVT and FPC), are also shown, since these characteristics determine the strategies to perform the connections between collectors.

3.1 Solar field general configuration

To activate the MiniStor system, a PVT-FPC solar field was designed, which consists of a set of glazed PVT collectors and a set of flat plate solar thermal collectors. The PVT collectors correspond to prototypes developed by ENDEF within the MiniStor project research activity, in the context of T3.5 and D3.4[4], with an individual gross area of 1.61 m^2; while the FPC correspond to a model available on the market, manufactured by the Greek company Papaemmanouel SA, using two models of individual gross surfaces of 2.0 and 2.37 m^2.

Figure 2 shows the basic configuration used for the connection of the PVT collectors and FPC. The heat transfer fluid (HTF) is pumped by a circulation pump incorporated in the MiniStor system to the group of PVT collectors, responsible for preheating the fluid. After passing through the PVT collectors, the fluid passes through a group of FPC, where the heating process continues and is completed. Finally, the heated fluid returns to the MiniStor system, where it is used either to activate the TCM reactor or for direct use in the demand system or building or home. Besides, to dissipate the heat excess, particularly during the summertime, a solar air cooler is included in the hydraulic solar circuit.

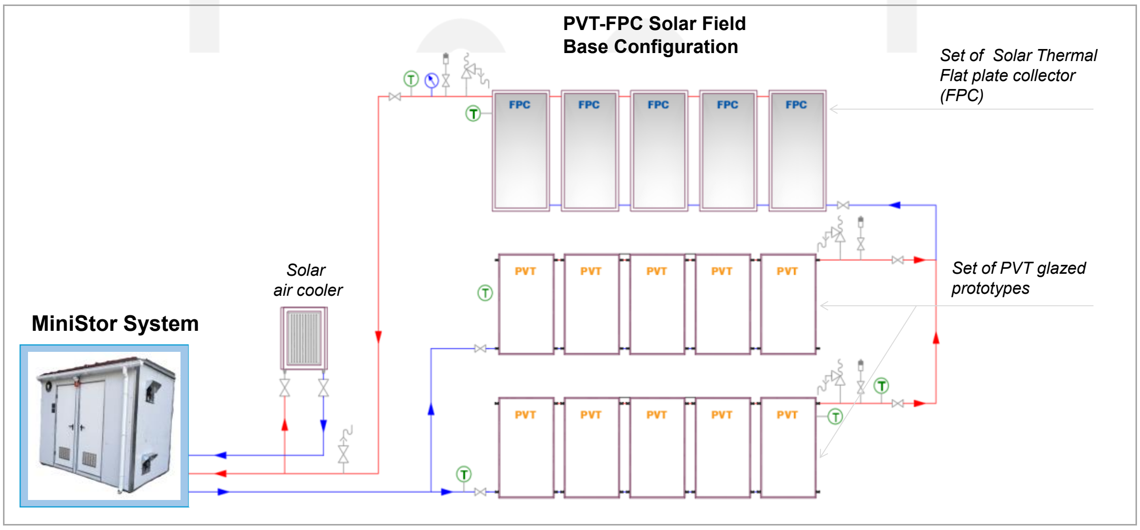

Figure 2: PVT-FPC solar thermal field base configuration

The specific layout shown has two groups of 5 PVT collectors connected in parallel to each other, while the overall PVT collectors are connected in series with a group of 5 FPC. The purpose of this is to preheat the HTF using the PVT collectors and complete the heat process with the FPC, as it was indicated previously. The number of solar collectors by group is defined by the collector's manufacturer, considering the maximum mass flow rate and pressure drop desired by collectors' group.

[4] *D3.4: Design and integration of improved PVT electrical generation system: Description and specification of the improved conventional PVT collector for thermal and electrical generation*

The final size of the solar field depends on several factors, such as the physical availability of space for the installation of the solar field in the home or building, the orientation of the solar field and the availability of solar resources. For the implementation of the MiniStor system, it is highly recommended to use a southern orientation and avoid east-west orientations, to improve the thermal performance of the solar system. In areas with low availability of solar resources, it is advisable to use other renewable energy technologies, such as biomass boilers and solar concentration thermal collectors, among others.

3.2 Developed PVT-liquid prototype.

The PVT collector used in the PVT-FPC field was a prototype developed in the context of Task 3.3, with the corresponding results presented in D3.4. This developing process considered the re-design of the absorber with different types of PV-laminates; three PVT prototypes were developed and tested in ENDEF facilities according to the European Norm EN ISO-9806:2014 [5]. Table 1 summarizes the main general characteristics of these prototypes.

Table 1: List of PVT prototypes developed in the MiniStor project.

PVT prototype	Main technical characteristics
Prototype 1	✓ Unglazed PVT type, 1.61 m^2. ✓ PV laminate of 320 Wp STC, electrical efficiency 18.80 %, cells monocrystalline silicon type, module type with half-cut cells. ✓ Sheet & tube absorber type, sheet made of aluminum, tubes made of copper.
Prototype 2	✓ Glazed PVT type with a transparent Insulating Cover (CTA), 1.61 m^2. ✓ PV laminate of 270 Wp STC, electrical efficiency 16.60%, cells monocrystalline silicon type. ✓ Sheet & tube absorber type, sheet made of copper, tubes made of copper. ✓ Model based on a previous ENDEF PVT model. The manufacturing process was adjusted to reduce energy consumption.
Prototype 3	✓ Unglazed PVT type, 1.62 m^2. ✓ Semi-transparent PV laminate, 160 Wp STC, 46% of transparent surface, cells polycrystalline silicon type. ✓ Sheet & tube absorber type, sheet made of copper, tubes made of copper.
Prototype 4	✓ Glazed PVT type, with a transparent Insulating Cover (CTA), 1.62 m^2 ✓ Semi-transparent PV laminate, 160 Wp STC, 46% of transparent surface, cells polycrystalline silicon type. ✓ Sheet & tub absorber type, sheet made of copper, tubes made of copper.

STC: Standard Testing Conditions.

After the energy test process, Prototype 2 (glazed PVT) was selected for the MiniStor implementations, considering the energy efficiency under the production conditions required by the MiniStor system. All the technical details about the PVT prototypes are included in D3.4 related to the Design and integration of improved PVT electrical generation system.

The selected PVT prototype has a gross area of 1.61 m^2, with a nominal electrical and thermal power of 270 and 742 W respectively, and a stagnation temperature of 148 °C. It also has four lateral fittings, with a diameter of 22 mm for hydraulic connection, and a rear connection box with electrical cables provided with standard connectors MC4 type. Figure 3 shows details

[5] *This standard was prepared by the European Committee for Standardization (CEN), Technical Committee CEN / TC 312 - Thermal solar systems and their components, in collaboration with Technical Committee ISO / TC 180, Solar Energy.*

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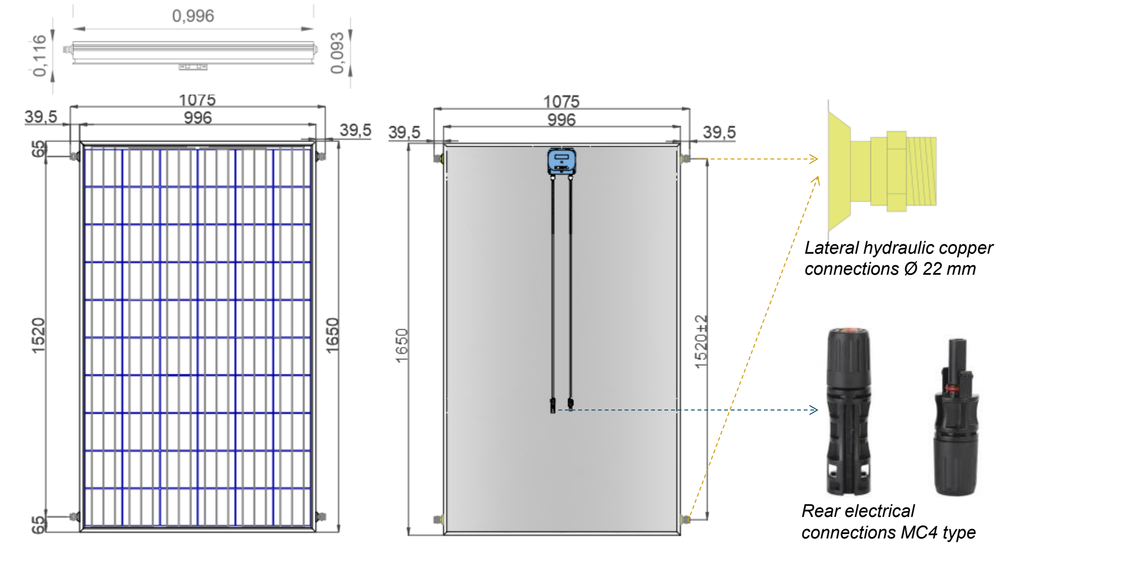
for this PVT collector including the frontal view, the back view and details for the hydraulic and the electrical connections.

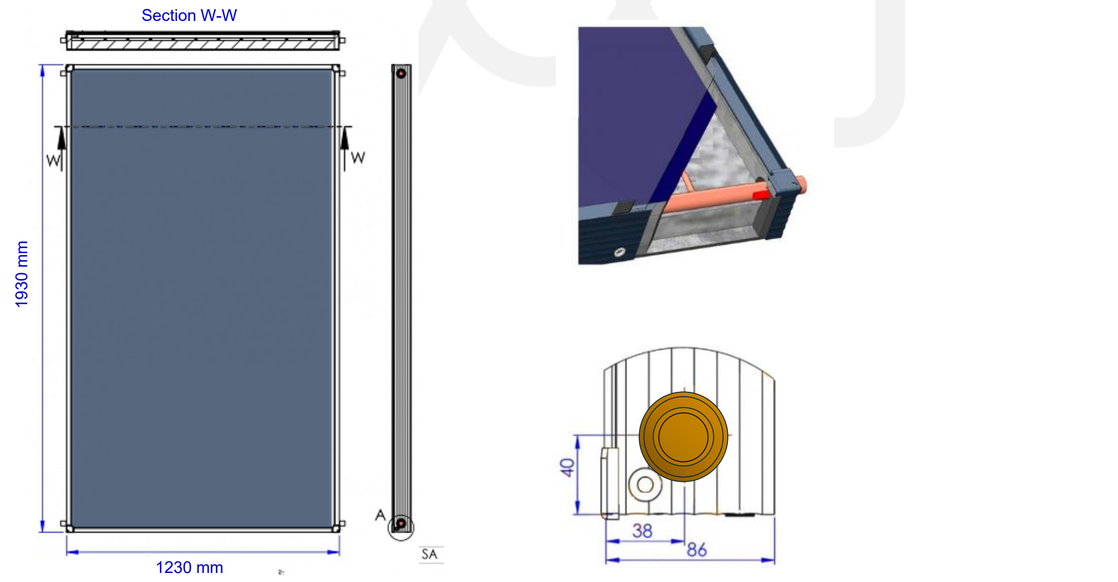


(a) Frontal view (b) back view (c) Hydraulic and electrical connections

Figure 3: Glazed PVT prototype details

3.3 Commercial FPC collector

The solar collectors used in the PVT-FPC solar field correspond to a flat plate commercial model manufactured by Papaemmanouel SA, a European company located in Greece. The base models selected in the context of MiniStor system are the FMAX 2.0 and FMAX 2.4, with a gross area of 2.0 and 2.4 m^2 and nominal thermal power of 1421 and 1694 W respectively, with a stagnation temperature of 190 °C.



(a) Collector dimensions (b) Collector details

Figure 4: Glazed PVT prototype details Source: Papaemmanouel SA

Figure 4 shows constructive details of this FPC model; it has a high transparency glass cover made of low iron tempered glass, a sheet & tubes absorber type, covered with a selective absorbing surface, an aluminum frame, lateral and back rock wool insulation, and an aluminum back closing sheet. This FPC collector model incorporated lateral copper fittings, diameter 22 mm to perform the corresponding hydraulic connections.

4 Solar field previous and initial works

This section presents the initial considerations and strategies regarding to the location of the solar field, that comprise the definition of the solar field layout, and the paths for the electrical and the hydraulic canalizations. The general types of structures to support the PVT and collectors are also presented, which must be selected according to the final location defined for the solar field.

4.1 Previous works: layout definition and canalizations

The work starts by defining the location for the PVT-PFC solar field as close as possible to the MiniStor system, which is packaged in a container-room and uses ammonia as refrigerant in an internal thermodynamic circuit, so the suitable location for the system is outdoors. According to this, the PVT-FPC solar field location could adopt one of these strategies:

Table 2: Solar field location strategies

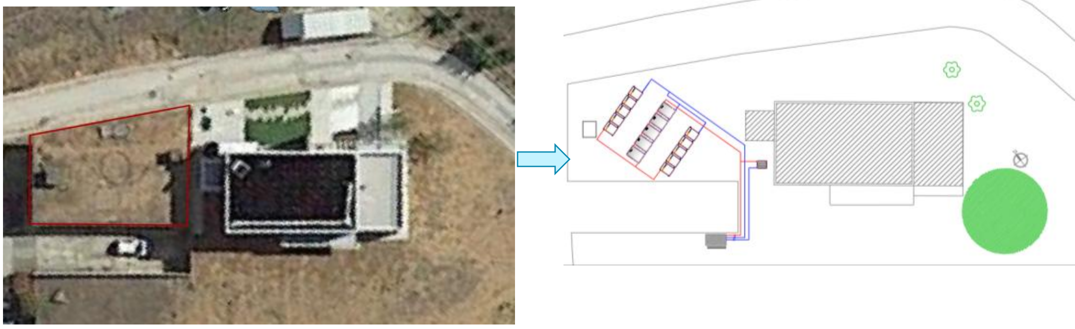
Case	PVT solar field location strategy	MiniStor system location
1. Individual home	1.1 Outdoors in the garden area if there is available space	Outdoors in an individual home, in a garden area
	1.2 Outdoors in the roof home	
2. Multifamily building	2.1 Outdoors in the garden area if there is available space	Outdoors in a garden area
	2.2 Outdoors on the building roof	Outdoors on the building roof

The implemented demonstration sites, related to this deliverable (Thessaloniki, Sopron and Cork) correspond to individual homes that have adopted the location strategy 1.1, in the garden area.

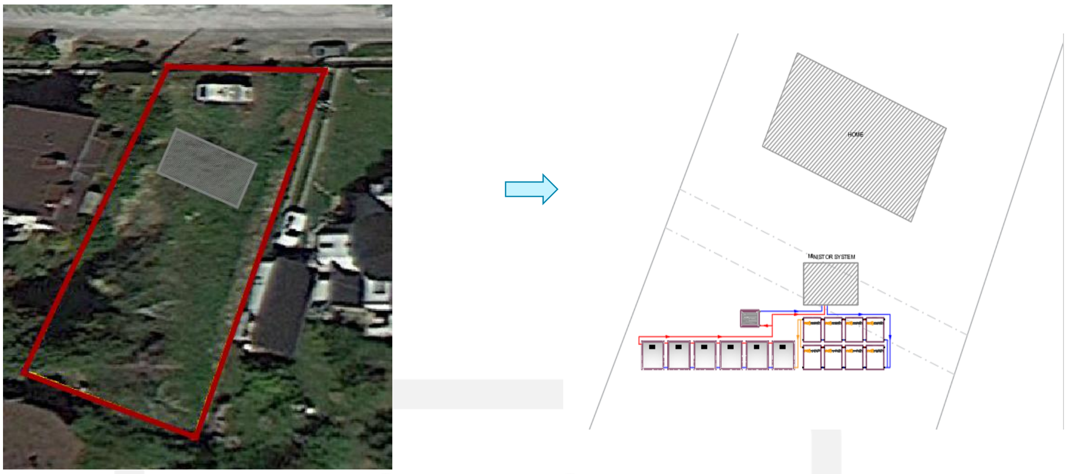
The specific layout and location of the solar field must follow the usual recommendations applied to the solar thermal collectors and PV solar panels:

- The solar field should be located as near as possible to the MiniStor system, in order to limit the thermal losses, which is a key point in the system performance.
- The solar field also must be in a zone free of shadows. Shadows are more critical for the PV laminate, because a partial shadow over it impacts the overall PVT electrical performance.
- It is strongly recommended that the solar field, including PVT and FPC collectors is installed with south orientation (in the north latitudes), using slopes equal or bigger than to the corresponding latitude. This orientation incidents directly in the thermal production, especially for the MiniStor system, in which the minimal required production temperature is 44 °C.
- The previous point implies that location on the roofs with east-west orientations must be avoided, for the PVT-FPC thermal applications.

Figure 4 illustrates the location adopted in the different demo sites. In all cases both the MiniStor System as well as the solar field are located outdoors using garden areas.



(a) PVT-FPC solar field base layout designed in Thessaloniki demo site



(b) PVT-FPC solar field base layout designed in Sopron demo site

(c) PVT-FPC solar field base layout designed in Cork demo site

Figure 4: PVT-FPC solar field location examples

The specific layout can consider two main options as follows:

a) Distribution of the solar collectors (PVT and FPC) on various arrays located among the garden area. This option was chosen in the Thessaloniki and Sopron demo sites, as it is illustrated in Figure 4 (a) and (b) respectively.
b) Distribution of the solar collectors (PVT and FPC) in a common bench that integrates the two collector types. It was the option proposed in the Cork demo site as it is illustrated in Figure 4 (c).

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The main advantage of option (a) is that commercial standard structures can be used to install the panels with overall lower cost; however, this type of layout requires a larger available area to install the solar field. The main advantage of option (b) is the optimization of the space available to install the solar collectors but implies higher costs of structures and civil works.

The final layout location must be validated during installation tasks considering different points, among which are the state of the area where the panels will be located, the route of the hydraulic pipelines, the electrical and communications pipelines, as well as possible intersections with other existing pipelines.

4.2 Structures solution types

Before installing the PVT and FPC solar collectors, it is necessary to prepare and install the support structures. This work includes the following main steps:

1. Leveling the surface where the solar field will be located.
2. Sizing and installing counterweights.
3. Installing sub-structures if they are required.
4. Installing the structure set by collectors' bench and finally fixing the solar collectors (PVT and FPC) to the support structures.

According to the characteristics of the zone where the solar collectors will be installed, the type of structure will be chosen. Table 3 summarizes the indicative and generic structure types that can be used in accordance with the location adopted for the solar field. The type of structure selected in the MiniStor demonstration sites linked to this deliverable are type 3 for Thessaloniki, type 4 for Cork, and a combination of type 2 and type 4 for Sopron.

Table 3: Indicative structure types according to the solar field location

PVT solar field location	Type of zone
On the building roof	Tilt roof
	Flat roof
	Mixed roof
Outdoors in the garden	Smooth terrain
	Uneven terrain

Indicative structure strategic solution	
1.	Structure set for tilt roofs One structure set by collector's bench
2.	Structure set for flat zones, closed type, One structure set by collector's bench Counterweights set by collector's bench
3.	Structure set for flat zones, open type, One structure set by collector's bench, with special sub-structure for the overall solar field
4.	Structure set for flat zones, open type One structure set by collector's bench with special foundation

Each manufacturer designs and specifies the most suitable structures for its solar collectors, considering, among other factors, their size, weight, load regime and wind at the location of the installation. In the case of the PVT prototypes used in MiniStor, the specified structures include two models, one available in the market, the other custom-designed for the project.

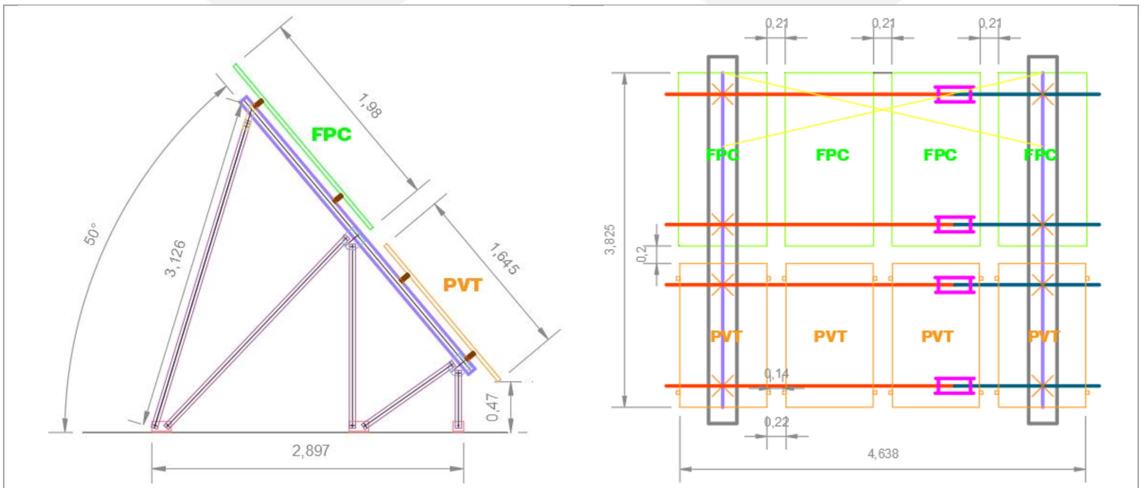
The first structure corresponds to a model suitable for the installation of PVT collectors on a flat area, manufactured by Sunfer Energy S.A. This structure is made of aluminum, with an open triangle configuration that allows the PVT slope to adjust between 20 and 50° (Figure 5). The installation must be conducted with counterweights by bench (structure type 2) or with a special substructure (structure type 3), which must be designed according to local requirements and regulations. For fixing the PVT collectors to the structures, the specific staple, “S51” also manufactured by Sunfer, is used (Figure 5.d).

(a) Overall structure view 14.1V (b) Slope regulation 20 to 50° (c) Lateral view (d) Longitudinal rail (e) Staple S51 for fixing panels to the structures

Figure 5: Support structures details for the PVT prototypes installed on a flat zone

Source: Sunfer Energy S.A, model 14.1V

The second structure used in the MiniStor project was designed ad hoc for the project by CSolar, that corresponds to structure Type 4, in which a special foundation is required instead of simple counterweights by bench. The structure design allows installing in the same structure a first row of PVT collectors at the bottom zone and a second row of FPCs at the top zone, as Figure 6 shows. To fix the PVT collectors to the structure is specified the same accessory showed in Figure 5.d; for fixing the FPC, CSolar designed a fixing clip, considering the specific characteristics of the FPC.



(a) Lateral View (b) Plant view

Figure 6: Support structures details for PVT prototypes together with FPC installed on a flat zone Source: CSolar, design did a custom implementation for the MiniStor project

Using this collector's arrangement, with PVT and FPCs on a common structure, the use of space is optimized. In addition, the structure was designed with a high slope (50°) to increase the incident solar radiation on the collectors during the winter period and thus increase the thermal energy produced.

5 Hydraulic subsystem installation

This section focuses on the hydraulic connection strategies for the PVT-FPC system, which includes the general connection strategies that can be applied in the PVT-FPC system, the connection strategies for the hydraulic connection between the solar field and the MiniStor system, as well as the detailed hydraulic connection between collectors in a PVT array. Besides, the main safety elements and the control strategy applied are also presented which guarantees the right and safe operation of the hydraulic subsystem.

5.1 General PVT-FPC hydraulic system connections strategies

The connection between the PVT-FPC system and the MiniStor system is performed through a hydraulic circuit from the solar field to an inertia tank, which is installed inside the MiniStor system, next to the TCM reactor.

The purpose of this tank is to heat a minimum volume of HTF, before charging operations for the TCM reactor. The hydraulic connection of these two systems (PVT-FPC and MiniStor) can adopt two basic connection strategies; a direct one, without using a heat exchanger (HX) inside the inertia tank, and an indirect one with a HX. Table 4 shows the main advantages and disadvantages of each of these connection strategies.

The strategy selected in the MiniStor project was the second one: direct connection without a HX. The following sections illustrate the details of the hydraulic connection conducted at a general level, as well as details relating to the safety elements and thermal control strategy

Table 4: Hydraulic connection strategies between FPC-PVT system and MiniStor system

Hydraulic connection strategy	Main advantages	Main disadvantages
1. Indirect connection	- Easier maintenance operations thanks to the hydraulic independence of the circuits (PVT-FPC and the charging TCM circuit) - Possibility of using different pressure for both circuits and easier operation of solar thermal system	- Lower temperature obtained from the solar field due to the influence of the heat exchanger (HX). - Lower overall system efficiency - Longer charging TCM process
2. Direct connection	- Higher temperature obtained from the solar field. - Lower inertia tank cost - Better overall system efficiency	- Need of using propylene glycol-water mixture in the overall system, including the internal MiniStor circuits in order to effective protection of freezing risks in the PVT-FPC circuit. - Pressure up to 3 bars is required, even though in the PVT-FPC system, that implies a higher expansion vessel volume.

5.2 PVT-FPC system general hydraulic connection

The general hydraulic connection between the PVT-FPC solar field and the TCM reactor of the MiniStor system is performed directly, using as an intermediate connection element a small-sized inertia tank (57 l) installed within the MiniStor system. The purpose of this buffer tank is to provide a small volume of water or heat transfer fluid, which is gradually heated by the solar field until it reaches the temperature range required by the TCM. The tank's size is based on simulations performed in the context of Task 3.1, to minimize the inertia tank volume and thus the overall volume of the MiniStor System.

Figure 7 shows the concept of this general hydraulic circuit with the main elements, including:

i) the inertia tank,
ii) the supply and return pipes up to the PVT-FPC solar field,
iii) the solar station, which incorporates a high-efficiency circulation pump, iv) the solar air cooler for heat dissipation, and v) the solar controller.

All the hydraulic pipes in the solar field as well as in the general hydraulic circuit are made of copper, a material suitable for the stagnation temperature specified for the PVT glazed prototypes and the solar thermal FPC, which are 148 °C and 190 °C respectively. This material is also suitable for the required operation range pressure in the system (1.5 to 2 bar).

As design and installation strategy, the MiniStor system has pre-assembled the most relevant components of this hydraulic circuit, including the inertia tank, the solar station, and the solar controller. Besides, the system is also already pre-assembled with most of the sensors and actuators including, a temperature sensor in the bottom zone of the inertia tank, used in the solar controller, a pressure sensor to monitor the pressure in the solar system and the complementary sensors to measure the energy that comes from the solar field. Figure 8.a shows the components that are pre-installed inside the MiniStor system.

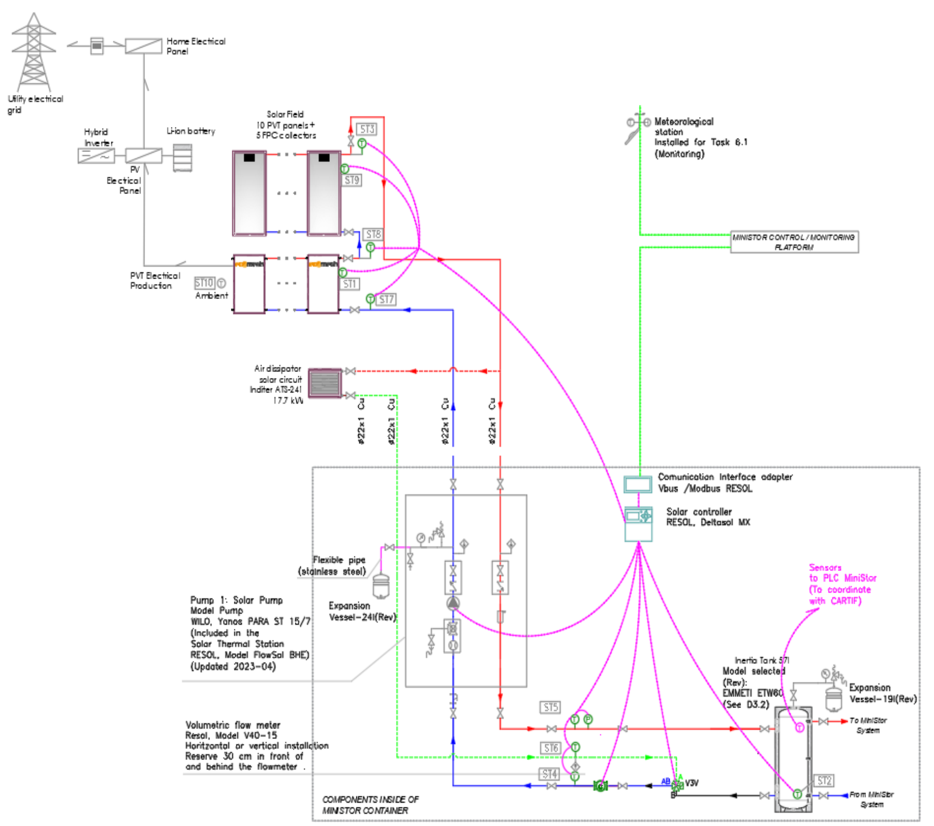


Figure 7: General concept for the solar thermal hydraulic PVT-FPC system

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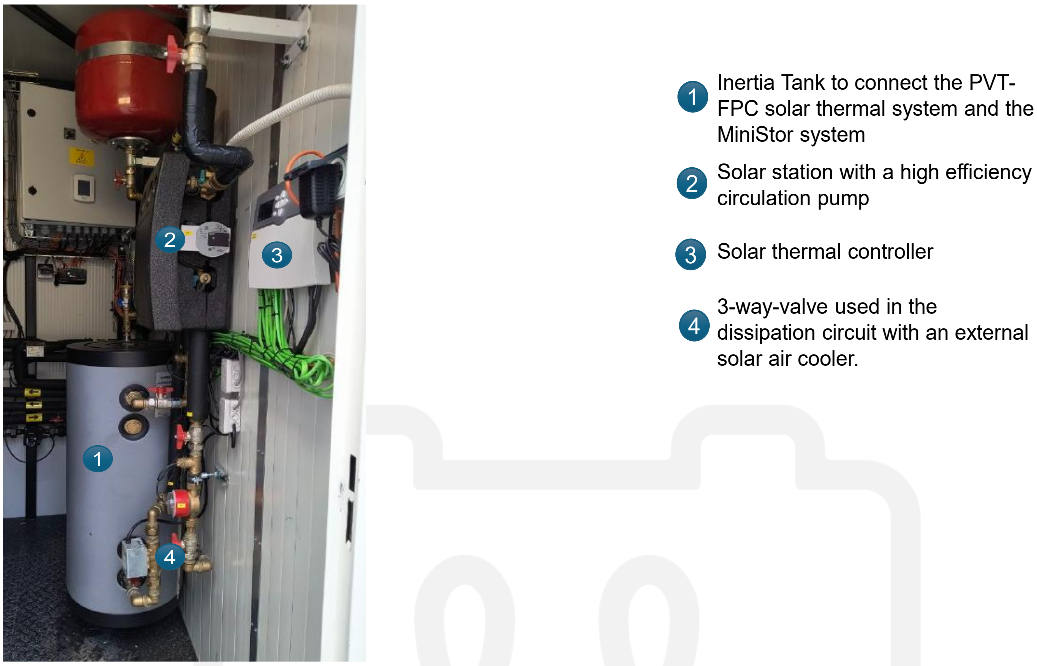
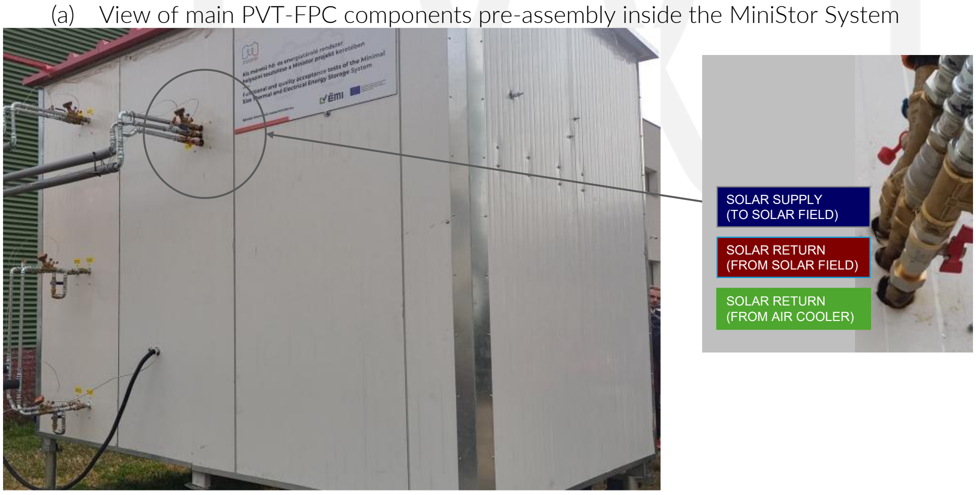
Thanks to this pre-assembly strategy the connection process between the MiniStor system and the PVT-FPC solar field is simplified, providing three external points for the hydraulic connections, as shown in the Figure 8.b:

i) the first point used to connect the supply pipe up to the solar field,
ii) the second point is dedicated to the return pipe from the solar field and,
iii) the third point is destinated to connect the return pipe from the solar air cooler.



(a) View of main PVT-FPC components pre-assembly inside the MiniStor System



(b) External hydraulic connection points in the MiniStor System to connect the PVT-FPC circuit

Figure 8: View of main PVT-FPC system components pre-assembly inside the MiniStor system

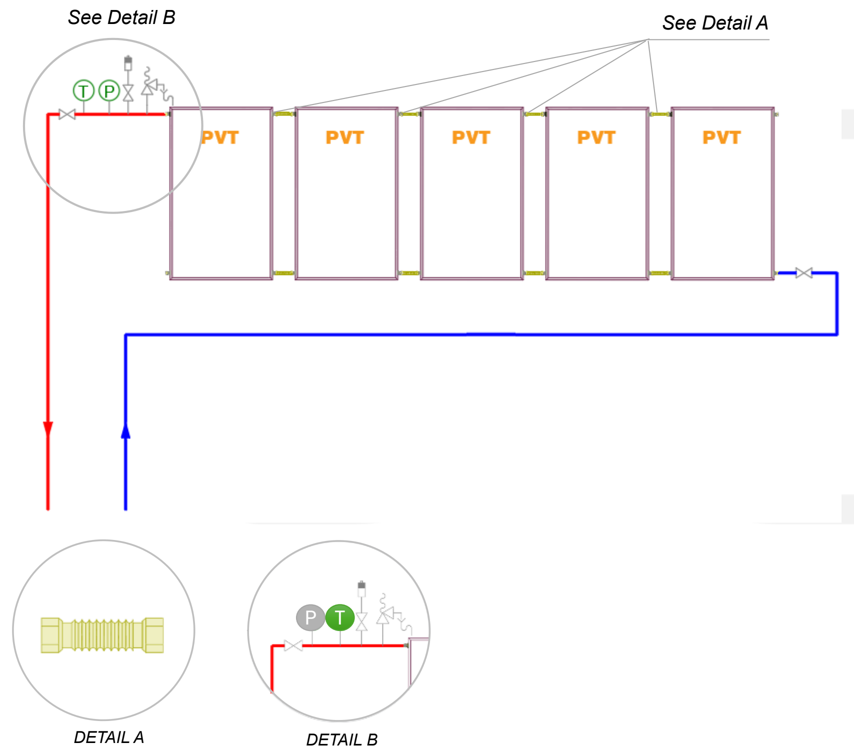
The MiniStor system as well as the PVT-FPC solar field must be filled with a HTF such as propylene glycol-water mixtures. The MiniStor system requires internally 185 liters, which consider the TCM volume, the PCM units, the inertia tank and the internal pipes. The PVT-FPC solar field has a variable volume that depends on the solar field size and the piping length; this volume must consider the PVT collectors, the FPC, the solar air cooler and the piping. In the MiniStor implementations linked to the present deliverable (Thessaloniki, Sopron and Cork), the PVT-FPC solar field volume varies between 30 and 60 liters,

Considering both volumes: the volume inside the MiniStor System and the volume in the PVT-FPC solar field, the total HTF volume in the mentioned implementations is between 215 and 245 liters, **The corresponding filling operation should be conducted using external filling pump equipment, suitable for solar installations**. In order to avoid damage, maintain pressure in the circuit and reduce refilling instances, protective covers should be placed on the solar collectors.

In general, thanks to the pre-assembly strategy, the main components of the PVT-FPC hydraulic circuit as a package together to MiniStor system, the quality of the installation is improved and the installation time of the entire PVT-FPC system is reduced.

5.3 Connection of an array of PVT collectors

This section presents the installation strategy defined for connecting a PVT collector bench, which can consist of a set of PVT glazed collectors. Figure 9, shows a PVT bench with 5 PVT collectors connected in parallel to each other, however the number of PVT collectors can vary between 2 and 6 units, to adapt to the specific conditions in the site.



SYMBOL	DESCRIPTION
	Ball valve in the inlet and the outlet of PVT collector bench
	Safety valve in the outlet of the PVT collector Bench
	Automatic air drain valve In the outlet of the PVT collector bench
T	Temperature sensor in the outlet of PVT bench (mandatory)
P	Pressure sensor in the outlet of PVT bench (optional)
	Sleeves for connection between PVT collectors
	Inlet pipe made of copper, insulated
	Outlet pipe made of copper, insulated

Figure 9: Hydraulic connection for a typical PVT bench

The connection between the PVT collectors is performed by joining their side fittings, using the flexible sleeves shown in the "Detail A" of Figure 9. Thanks to these sleeves, the pressure loss in the hydraulic circuit is minimized, by reducing the number of accessories between collectors, and the connection process time is also faster.

Each PVT collectors' bench must incorporate a ball valve in the inlet as well as in the outlet, in order to allow the closing and opening operations in the hydraulic circuits for maintenance purposes. Additionally, a set of valves and safety elements must be installed in the outlet, at the highest bench point, including a safety valve, an automatic drain air valve, a temperature

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sensor and optionally a pressure sensor (see "Detail B" in Figure 9). The temperature sensor included in Detail B is used in the solar controller to activate the circulation pump in the solar circuit, so this sensor must connect up to this controller, located inside the MiniStor system.

5.4 Safety elements in the hydraulic connection

The solar hydraulic circuit incorporates different protection elements as follows:

- For overheating protection, the hydraulic solar circuit includes an air-cooler, which is activated when the solar field outlet temperature exceeds the design temperature of PVT and FPC collectors. The solar air cooler is activated through the solar controller in order to dissipate the excess of thermal energy to the outside environment, particularly during the summer season. Figure 10.a shows a solar cooler model used in the MiniStor implementations, suitable for outdoors installation; this equipment needs hydraulic connections according to the manufacturer's requirements, as well as electrical wiring at 230V, 50 Hz.

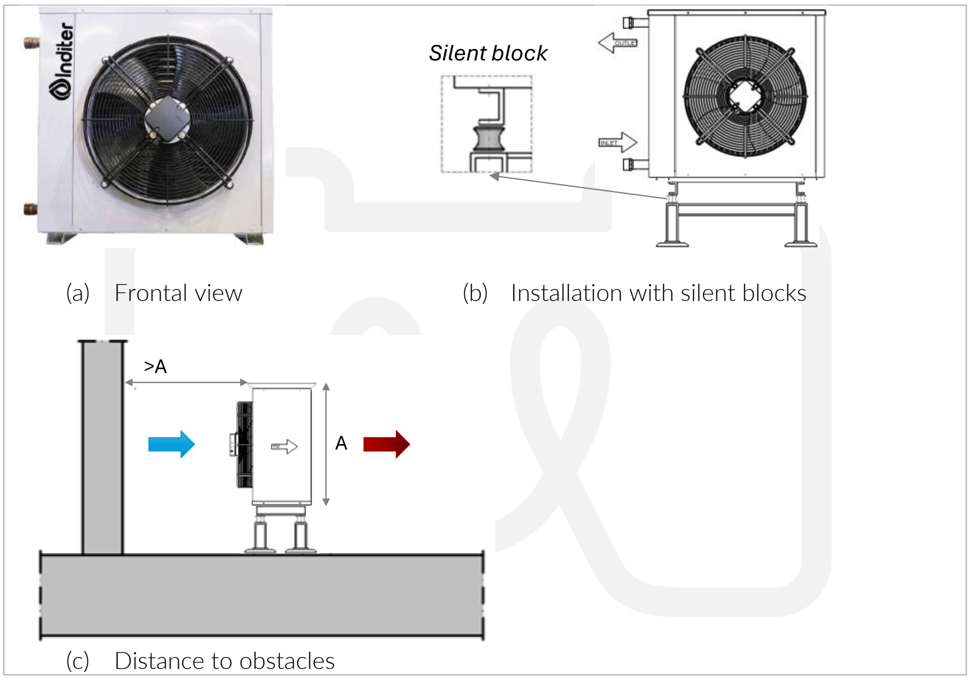


Figure 10: Solar air cooler for overheating protection.

Source: adapted from inditer.com

The solar air cooler selected must be anchored using metal profiles and incorporate anti-vibration elements such as silent blocks, as shown in Figure 10.b. For proper operation, it is recommended to maintain a minimum separation between the equipment and adjacent physical obstacles, as the Figure 10.c illustrates.

As an additional overheating protection measure, the MiniStor system incorporates an additional air-cooler (fan coil) inside the MiniStor machinery room, which is activated in case the inertia tank temperature exceeds the desired maximum value.

- For freezing protection, the solar circuit uses as HTF a water-propylene glycol mixture, which has a lower freezing temperature compared to water. Besides, the solar controller can activate the circulation pump in case that the ambient temperature is lower than the minimal desired temperature.

- For high pressure protection: the circuit incorporates an expansion vessel to absorb the volume increment due to changes in the fluid temperature. In addition, there is a safety valve for each solar bench as well as in the solar station, which acts when the circuit pressure exceeds the maximum allowed value (3 bar). Air vent valves are also installed in each solar bench as well as at the higher points of the system to drain the air inside the circuit to avoid punctual overpressures due to the air.
- Additional alarms: Besides the previous elements, the MiniStor system incorporates a PLC which reads the key variables from the solar controller using Modbus protocol. Using the information read, the PLC is programed with additional alarms as complementary safety measures, including an alarm for high-temperature in the inertia tank, and alarms for low and high pressure in the solar circuit.

5.5 Control strategy for the PVT-HP hydraulic system.

To control the solar circuit the overall system includes a commercial solar controller, which has already been programmed with a set of functionalities for a suitable operation of the PVT-FPC solar system. This solar controller communicates with the MiniStor system PLC, using Modbus protocol, through which relevant variables can be read to have an integrated monitoring system.

These strategies have been adapted during the different commissioning stages in order to adjust the final control strategy.

To control the PVT-FPC solar system, the minimum sensors required are a first temperature sensor installed in the outlet of the FPC solar bench and a second temperature sensor installed in the bottom zone of the inertia tank. With this information the solar controller evaluates the temperature difference between both sensors in order to activate the solar circulation pump when the temperature outlet in the solar system is higher than the temperature measured in the inertia tank.

The solar controller is programed with a dissipation functionality that activates the solar air cooler in case the temperature in the solar bench exceeds the desired temperature in these collectors. To do this, the solar controller activates first a relay output, which gives a signal to the corresponding contactor in the electrical circuit that feeds the solar air cooler and a 3-way valve, in order to dissipate the heat to the environment.

Besides the previous basic control functions, performed by the solar controller, to get an effective charging operation of the TCM in the MiniStor system the implemented control strategy includes the set temperatures presented in Table 5.

Table 5: Set temperatures used in the PVT-FPC control strategy

Operation	Description	Value [°C]
Charging TCM	Set temperature - Start - Stop	70 70 65
Inertia Tank (Solar Circuit)	Set temperature Maxim temperature - Start - Stop	72 75 ΔT FPC -Tank > 6 ΔT FPC -Tank < 4
Solar air cooler	Set temperature PVT Set temperature FPC - ΔT Valve (temperature difference valve open) - Start	76 83 2 79

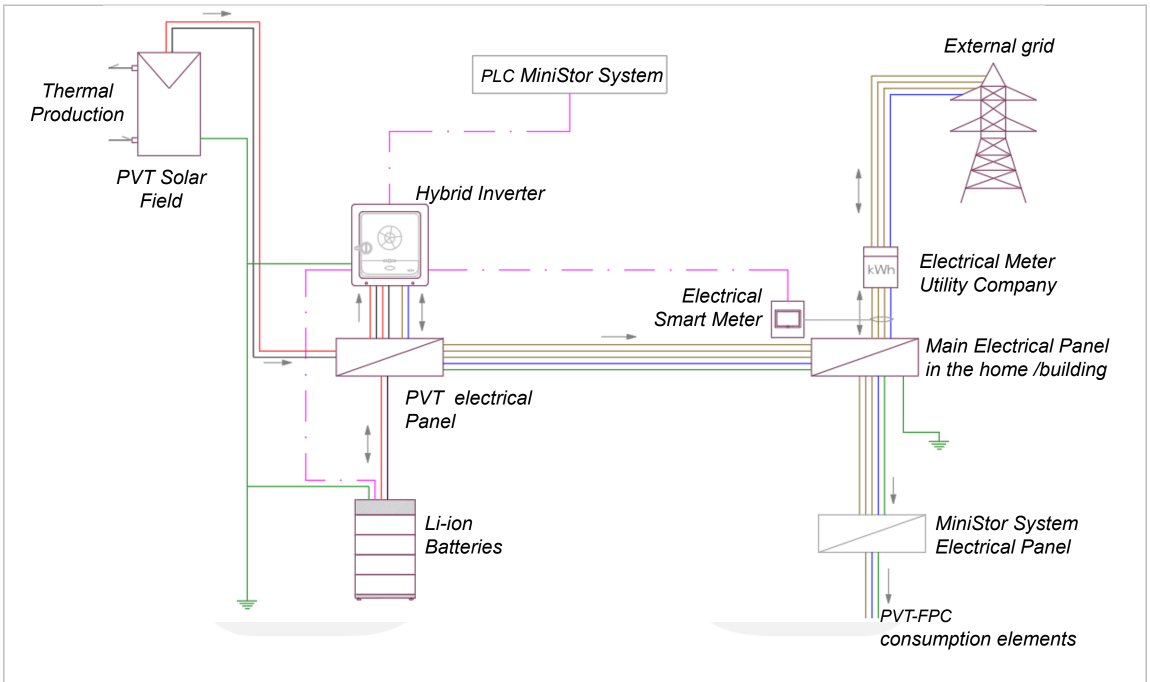
	- Stop	76
Restriction (FPC)	Maximum temperature in FPC Maximum temperature in PVT Conservative value adopted	< 150 < 85 < 130

6 Electrical subsystem installation

This section focuses on the electrical connection strategies of the PVT-FPC system; to do this, firstly the concept developed for the electrical PVT system is summarized, to understand the elements that compose it. Subsequently, the electrical strategies are presented including the connection strategies for the General PVT electrical system, the connection strategies between PVT collectors (string), the connection strategies to feed electricity to the consumption elements in the solar thermal system and finally the base strategy to control the electrical PVT system.

6.1 Electrical PVT system concept developed in the MiniStor project

The general scheme of the PVT electrical system is presented in Figure 11. The main components in the PVT electrical production system are the PVT solar field, the hybrid inverter and the electrical batteries based on Li-ion technology, which are directly connected to the inverter.



(red line)	DC line - positive	(orange line)	AC line - phase	(green line)	Grounding line
(grey line)	DC line - negative	(blue line)	AC line - neutral	(magenta dash-dot line)	Communication line

Figure 11: Base concept electrical PVT system

The hybrid inverter fulfils a dual function. First, direct current electricity (DC) is converted into alternating current electricity (AC) to be used in the electrical receptors, and second, charging and discharging processes in the ESS are controlled. The hybrid inverter is the *smart* element in the electrical production subsystem, since it decides when the surplus in the PVT electrical production is stored in the ESS for a later use.

Once the inverter converts DC electricity produced by the PVT field into AC, this energy is sent to the main electrical panel in the building or home, through a dedicated AC electrical line. The connection to the external electrical grid (main grid) must be performed following local norms and regulation.

Besides the PVT electrical production subsystem, there are also elements in the solar thermal subsystem that require AC connection at 230 V, including the solar circulation pump, the solar air-cooler and control elements. These elements integrate a PVT-FPC electrical consumption subsystem.

All DC and AC lines in the PVT electrical production system require electrical protections which are installed in a PVT electrical panel. Similarly, the electrical lines that feed the consumption elements, in the PVT-FPC thermal system, require electrical protections, which are pre-assembled inside the MiniStor System Electrical panel.

6.2 General PVT electrical system general connection strategies

As was stated in the previous section, the electrical installation of the PVT-FPC system comprises, on the one hand, the installation associated with the electrical production the PVT system, and, on the other hand, the installation associated with the electrical consumption of the PVT-FPC solar thermal system. The connection strategies of both subsystems (production and consumption) can use different options which are summarized in Table 6. Particularly the connection options for the PVT electrical production system are strongly dependent on the local legislation.

Table 6: Electrical connection strategies for the PVT electrical system

Electrical Subsystem	Strategy #	Connection strategy
1. PVT-electrical production system	1.1	PVT electrical panel with the DC and AC electrical located close to the PVT solar field, with shorter DC electrical line from the PVT and a longer AC electrical line to feed the electricity into the home/building electrical panel.
	1.2	PVT electrical panel with the DC and AC electrical located close to home /building electrical panel, with longer DC electrical lines from the PVT and a shorter AC electrical line to feed the electricity into the home/building electrical panel.
2. PVT-FPC electrical consumption system	2.1	The elements in the PVT-FPC solar thermal system, that need electricity for the operation, are fed <u>from the main electrical panel in the building</u>.
	2.2	The elements in the PVT-FPC solar thermal system that need electricity for the operation are <u>fed from an additional electrical panel</u> located next to the MiniStor system.
	2.3	The elements in the PVT-FPC solar thermal system, that need electricity for the operation, are <u>feed directly from the MiniStor system electrical</u>, in which the required electrical protections are pre-assembly.

For the PVT electrical production system, different demo sites in the MiniStor project (Thessaloniki, Sopron and Cork) use strategy 1.2, in which the PVT electrical panel, with the DC and AC protections were located next to the MiniStor System, close to the PVT solar field. The purpose of this strategy is to centralize all the equipment together with the MiniStor system to facilitate the installation process and the maintenance operations.

Following similar criteria, the PVT-FPC electrical consumption system uses the connection strategy 2.3, in which the electrical circuits that feed the electrical receptors in the solar thermal system are pre-assembled inside the MiniStor Electrical panel.

The following section presents the base concept applied for the overall PVT electrical system with the previously indicated connection strategies.

6.3 Electrical connection of a PVT electrical string

To collect the DC electrical production from the PVT solar system, the PVT collectors must be organized in groups to form strings and connect them in a series configuration as Figure 12 illustrates. The number of the PVT collectors by string is defined taking into account the inverter characteristics and restrictions including the maximum DC power input by string, the minimum required starting voltage, the MPP voltage range, and the short circuit support by the inverters. The DC electrical wiring must be performed using suitable electrical cables, with a rated voltage of 1 kV, suitable for outdoor installation, with insulation materials that are halogen free, H1Z2Z2-K type, following the EN50618 standard as well as the local regulation and requirements.

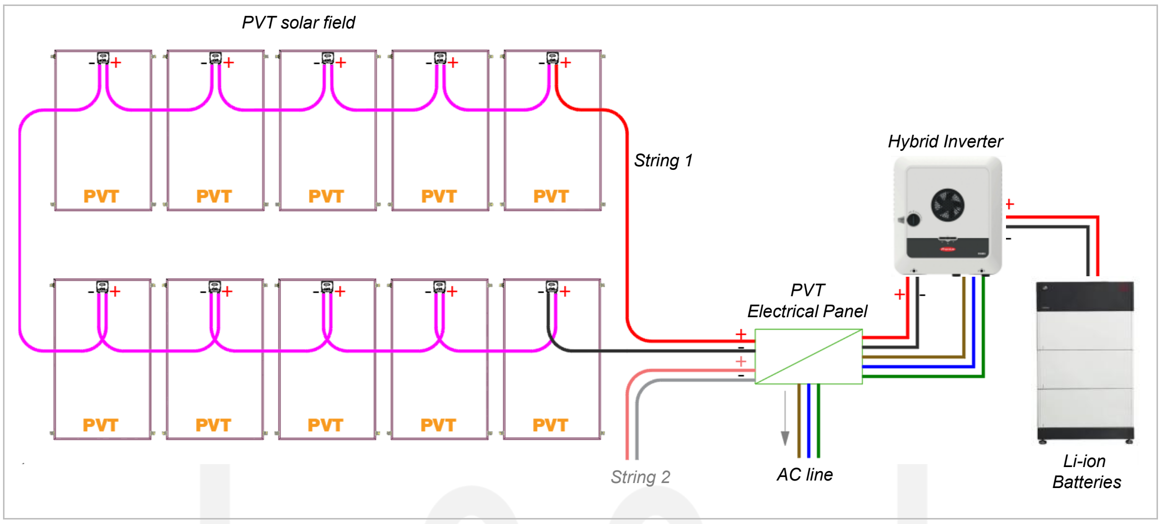


Figure 12: Electrical connection wiring in the PVT electrical production subsystem

The inverters usually admit more than one string, so their technical characteristics must be revised carefully before selecting the model to be installed. In the context of the MiniStor project, the inverter selected is a hybrid type to incorporate high voltage electrical batteries based on Li-ion technology. Figure 12 includes the base models used in the MiniStor implementation, which correspond to the Inverters Gen24 model, manufactured by Fronius International GmbH.

Once the hybrid inverter has converted the DC into AC electricity, the AC is sent to the main electrical panel in the home or building, where it is used for self-consumption. The connection between the hybrid inverter and the Li-ion batteries is performed at high voltage. Any excess in the electrical production is stored in the Li-ion batteries or sent to the external grid, depending on the local regulation; more details in this regard are presented in D3.9 related to the installation strategies for the ESS.

Both the DC and AC electrical lines must include electrical protections, which are installed inside the PVT electrical panel. As it was stated in the section 6.2, in the MiniStor project, the connection strategy applied for the implementations for the "PVT electrical production system" was to centralize the AC and DC protections in a common electrical panel, to be located close to the PVT solar field and the MiniStor system (connection strategy 1.2, Table 6). The types of protections that should be included are: (i) Overloads, (ii) short circuit DC, (iii) transient overvoltage, (iv) differential protections in AC lines. Figure 13 shows an example of these electrical protections included in a PV or PVT electrical panel, integrated in a commercial solution available in the Spanish market. The final implementation must adopt the local regulation and requirements.

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1. DC protection against overloads and short circuits (fuse) / input from PVT collectors +
2. DC protection against overloads and short circuits (fuse) / input from PVT collectors -
3. DC Switch ON-OFF
4. DC protection against transient over voltages
5. AC protection against overloads and short circuits
6. AC differential protection type A
7. AC protection against transient over voltages

Figure 13: Electrical protections in the PVT electrical panel

Source: Adapted from Saltoki S.A

6.4 Electrical connection of the elements in the solar thermal system

The PVT-FPC thermal system has electrical equipment including the hydraulic circulation pump, which is incorporated in the solar station, the solar air cooler or fan coil to dissipate the excess of heat in the solar hydraulic circuit, the solar controller, and most of the sensors and actuators.

The connection strategy used to feed these equipment was to pre-assembly three electrical circuits and protections inside the Electrical MiniStor system panel (connection strategy 2.3, Table 6); in this way, the installation procedure in the site only needs to connect the solar air-cooler; meanwhile, the other equipment is already connected within the MiniStor system, to optimize the overall connection time of the system.

Figure 14 shows the corresponding electrical protections pre-assembly in the electrical MiniStor system panel.

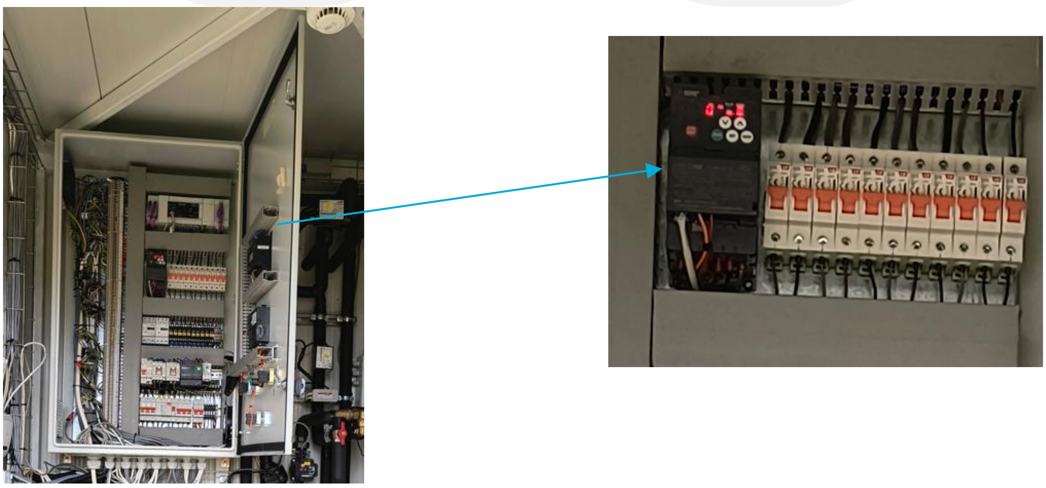

Figure 14: Electrical protections pre-assembly in the electrical MiniStor Panel to feed elements in the PVT-FPC solar thermal system

6.5 Control strategy for the PVT electrical system.

The control strategy for the electrical PVT production system is performed by the hybrid inverter. This equipment is the smart element in system, since it is responsible for managing the different operating modes, mainly including:

(1) direct use of the electricity produced by the electrical receptors in the home or building and also in the MiniStor system,
(2) charging the ESS using the surplus of electrical production or, when allowed, using grid electricity during low-price periods,
(3) discharging the ESS to meet the electricity demand, or
(4) feeding the surplus of electrical production into the grid according to the existing regulatory conditions in the demo site (e.g. compensation prices, net balance).

This equipment allows measuring the electrical production of the PVT field using sensors incorporated in the inverter itself, as well as the electrical consumption of the demand subsystem using a bidirectional electrical power meter (smart meter), compatible with the inverter. The demand subsystem includes consumption in the house or building, as well as the demand of the MiniStor electrical system.

These control strategies will be presented in detail in D3.9[6] related to the installation strategies of the ESS as well as in deliverables related to WP5 which is focused on the overall control subsystems including the Modbus integration components.

[6] *D3.9: Installation strategies of the electrical storage system*

7 Summary of installations strategies applied in the pilot implementations.

The PVT-FPC system deployments were performed at three of the five MiniStor project demonstration sites (Thessaloniki, Sopron and Cork). Table 7 presents a summary of the installation strategies applied to the PVT-FPC system at each demo site.

The feedback received from the installation and commissioning phases, which has been used to fine-tune the installation strategies described in this document is also included in the table below.

Slides presenting the commissioning process were prepared for all the demo sites. The commissioning slides were intended to summarize and explain the procedure before and during the commissioning itself. Those slides were reviewed and updated according to the feedback received from the demos, and have been a cornerstone of the installation procedures followed.

Full information and details about implementations will be presented in various deliverables, prepared in the context of WP6, specifically in D6.3, linked to the results from pre-pilot implementation and stakeholder training, and D6.4, related to the Installation and commissioning report for all the MiniStor demo sites.

Table 7: Summary of main installation strategies applied to the PVT-FPC system in the MiniStor project.

<table>
<tr><th colspan="2">Thessaloniki pre-demo site</th></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Number of collector's bench in the solar field:</td><td>• PVT benches: 2 arrays with 5 glazed PVT collectors each (PVT model 1.61 m²)
• FPC arrays: 1 bench with 5 solar thermal FPC (FPC model 2.37 m²)</td></tr>
<tr><td colspan="2">Solar field and structures</td></tr>
<tr><td colspan="2">Main installation strategies applied to the PVT-FPC system</td></tr>
<tr><td colspan="2">• Solar field location strategy: in outdoors in a garden area</td></tr>
<tr><td colspan="2">• Structures type 3: Structure set for flat zones, open type, one structure set by collector's bench, with special sub-structure for the overall solar field.</td></tr>
<tr><td>Feedback received</td><td>Actions taken</td></tr>
<tr><td>Lack of fixing elements to the structures[7]</td><td>To prepare a detailed material checklist, including also all small material, to have an effective control in the delivery, reception and storage processes.</td></tr>
</table>

<table>
<tr><td>Hydraulics connection</td></tr>
<tr><td>Main installation strategies applied to the PVT-FPC system</td></tr>
</table>

[7] *Note: These elements were sent to the site in 2021, and the installation process was performed in 2023. It suggests that the pieces were lost during the sent/storage process*

• General hydraulic connection strategy between solar field and MiniStor system: direct connection trough an inertia tank pre-assembly in the MiniStor system and using insulated copper pipes.	
• Connection between PVT collectors in each bench	
Feedback received	Actions taken
Addressing connections using alternative fittings.	To implement a detailed material checklist, including also all small material, to have an effective control in the delivery, reception and storage processes, was included in the commissioning procedure
Some difficulties encountered in the filling process	The filling procedure was revised and improved for the demo sites.
Need to review the expansion vessel volumes according to the as-built drawings.	Revision of expansion vessel volume in the solar circuit according to the final circuit layouts including in the installation strategy, including the addition of expansion vessel linked to the TCM tank and internal circuit (see subsection 5.2)
Need of protection of the over temperature in the solar field during longer power outages and holiday period	A specific period for covering the solar field during holiday period if the system not to be used was included in the commissioning and operation recommendations. Implementation of alarm in the PLC in case of long power outages
Electrical connections	
Main installation strategies applied to the PVT-FPC system	
• General PVT electrical system general connection strategy: PVT electrical panel with DC and AC centralized, next to the MiniStor system, together with the ESS (Inverter and Li-Ion batteries)	
• Electrical connection using the MC4 connectors incorporated in the PVT collectors.	
Feedback received	Actions taken
N/A	N/A
Control and connectivity elements	
Main installation strategies applied to the PVT-FPC system	
• Control strategy for the solar pump based on the temperature difference between PVT benches and inertia tank.	
• Dissipation control based on the PVT solar bench temperature	
Feedback received	Actions taken
Configuration of the solar controller can be lost when there is long power outages	Saving the solar controller configuration in a SD card to retrieve it was included in the commissioning procedure.

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Sopron-demo site	
	
Number of collector's bench in the solar field:	• PVT arrays: 1 bench, double height with 8 glazed PVT collectors each (PVT model 1.61 m^2) • FPC arrays: 1 bench, double height with 4 solar thermal FPC (FPC model 2.37 m^2)
Solar field and structures	
Main installation strategies applied to the PVT-FPC system	
• Existing PV solar field on the building's roof	
• Solar field location strategy: in outdoors in a garden area	
• Structure type 4: Structure set for flat zones, open type. one structure set by collector's bench. with special foundation.	
Feedback received	Actions taken
N/A	N/A
Hydraulics connection	
Main installation strategies applied to the PVT-FPC system	
• General hydraulic connection strategy between solar field and MiniStor system: direct connection through an inertia tank pre-assembly in the MiniStor system and using insulated copper pipes	
• Connection between PVT collectors in each bench using standard hydraulic fittings	
Feedback received	Actions taken
Review of the expansion vessel volumes according to the as-built drawings.	Addition of expansion vessel linked to the TCM tank and internal circuit (see subsection 5.2)
Pressure reduction in the system and refilling requirements	Placement of protective covers on the solar collectors tor avoid damages, maintain pressure and reduce refilling instances.
Electrical connections	
Main installation strategies applied to the PVT-FPC system	
• General PVT electrical system general connection strategy: PVT electrical panel with DC and AC centralized, next to the MiniStor system, together with the ESS (Inverter and Li-Ion batteries)	
• Electrical connection using the MC4 connectors incorporated in the PVT collectors.	
Feedback received	Actions taken
Adaptation of the connection strategy to the current PV installation in the building.	The building had a previous PV installation. The electrical system has been connected to a string of the current inverter. The ESS system has been chosen according to the inverter compatibility.
Control and connectivity elements	
Main installation strategies applied to the PVT-FPC system	
• Control strategy for the solar pump based on the temperature difference between Solar system outlet and inertia tank. a	
• Dissipation control based on the PVT solar bench temperature	
Feedback received	Actions taken
Configuration of the control strategy according to the main outlet of the solar system	Control strategy was modified from previously using PVT outlet to use FPC outlet for controlling the system. This temperature setting is applied to the solar pump start as well as to the dissipation strategies.

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<table>
<tr><th colspan="2">Cork-demo site</th></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Number of collector's bench in the solar field:</td><td>● Common bench for PVT collectors and FPC designed ad hoc for the MiniStor project, double height with 4 glazed PVT collectors each (PVT model 1.61 m^2) and 4 solar thermal FPC (FPC model 2 m^2)</td></tr>
<tr><td colspan="2">Solar field and structures</td></tr>
<tr><td colspan="2">Main installation strategies applied to the PVT-FPC system</td></tr>
<tr><td colspan="2">● Solar field location strategy: in outdoors in a garden area</td></tr>
<tr><td colspan="2">● Structure type 4: Structure set for flat zones, open type. one structure set by collector's bench with special foundation. Desing ad hoc for the MiniStor project to install in the same structure PVT collectors and FPC.</td></tr>
<tr><td>Feedback received</td><td>Actions taken</td></tr>
<tr><td>N/A</td><td>N/A</td></tr>
<tr><td colspan="2">Hydraulics connection</td></tr>
<tr><td colspan="2">Main installation strategies applied to the PVT-FPC system</td></tr>
<tr><td colspan="2">● General hydraulic connection strategy between solar field and MiniStor system: direct connection through an inertia tank pre-assembly in the MiniStor system and using insulated copper pipes</td></tr>
<tr><td colspan="2">● Connection between PVT collectors in each bench using standard hydraulic fittings</td></tr>
<tr><td>Feedback received</td><td>Actions taken</td></tr>
<tr><td>N/A</td><td>N/A</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Electrical connections</td></tr>
<tr><td colspan="2">Main installation strategies applied to the PVT-FPC system</td></tr>
<tr><td colspan="2">● General PVT electrical system general connection strategy: PVT electrical panel with DC and AC centralized, next to the MiniStor system, together with the ESS (Inverter and Li-Ion batteries)</td></tr>
<tr><td colspan="2">● Electrical connection using the MC4 connectors incorporated in the PVT collectors.</td></tr>
<tr><td>Feedback received</td><td>Actions taken</td></tr>
<tr><td>N/A</td><td>N/A</td></tr>
<tr><td colspan="2">Control and connectivity elements</td></tr>
<tr><td colspan="2">Main installation strategies applied to the PVT-FPC system</td></tr>
<tr><td colspan="2">● Control strategy for the solar pump based on the temperature difference between Solar system outlet and inertia tank. a</td></tr>
<tr><td colspan="2">● Dissipation control based on the Solar system outlet temperature</td></tr>
<tr><td>Feedback received</td><td>Actions taken</td></tr>
<tr><td>Connectivity through an Anydesk application</td><td>Configuration of connectivity by remote local access through an AnyDesk application included in the connectivity aspects on the commissioning procedure</td></tr>
</table>