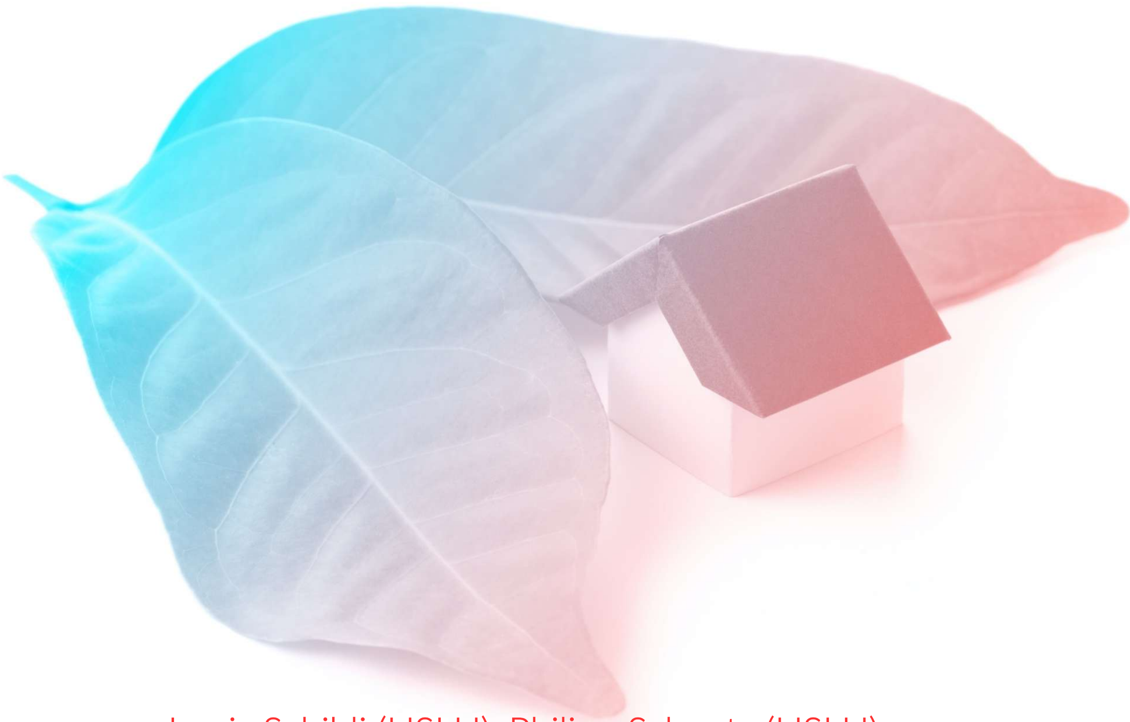
Initial report on KPI measurement and analysis



Louis Schibli (HSLU), Philipp Schuetz (HSLU),
Adriana Coca-Ortegón (END), Yolanda Lara (END),
Apostolos Gkountas (PSY), Pantelis Bakalis (PSY), Driss Stitou (CNRS)

Date: 28/02/2025

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

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

Summary
This document presents the initial calculation of the key performance indicators (KPIs) that can already be assessed before the monitoring campaign with the active MiniStor system is completed. The quality of the monitoring data is assessed, and the baseline values are calculated based on the measurement data from the monitoring systems of the individual demo sites. The baseline values for the outdoor temperature and the energy consumption of each demo site are important information for evaluating the impact of the MiniStor system on the energy balance of the demo site. These values can, for example, be used to incorporate the local climatic conditions into the calculation of the KPIs. Most KPIs can only be calculated after a sufficient monitoring period with the system commissioned. The KPIs that are accessible without an installation are presented in this document. For all other technical KPIs, the necessary measurement data are linked, which simplifies subsequent calculation.

Deliverable Number	Work Package
D6.5	WP6
Lead Beneficiary	Deliverable Author(S)
Lucerne University of Applied Sciences and Arts (HSLU)	Schibli Louis (HSLU) Schuetz Philipp (HSLU)
	Deliverable Co-Author(S)
ENDEF Psyctotherm CNRS	Adriana Coca-Ortegón (END), Yolanda Lara (END) Apostolos Gkountas (PSY), Pantelis Bakalis (PSY) Driss Stitou (CNRS)
	Deliverable Reviewer(S)
CERTH-ITI Sofrigram	Paschalis Gkaidatzis (CERTH-ITI) Xavier Lulka (Sofrigam)
Planned Delivery Date	Actual Delivery Date
31/05/2024	28/02/2025

Type of deliverable	R	Report	X
Dissemination Level	P	Public	X

Index

Index ... 3
List of Tables ... 4
List of Images ... 5
1. Introduction ... 6
2. Data acquisition and analysis ... 7
2.1. Assessment of the data quality ... 7
2.1.1. Demonstration site Thessaloniki ... 7
2.1.2. Demonstration site Sopron ... 8
2.1.3. Demonstration site Cork ... 10
2.1.4. Demonstration site Santiago de Compostela ... 11
2.1.5. Demonstration site Kimmeria ... 12
2.2. Calculation of the baseline values ... 14
2.2.1. Demonstration site Thessaloniki ... 14
2.2.2. Demonstration site Sopron ... 16
2.2.3. Demonstration site Cork ... 17
2.2.4. Demonstration site Santiago de Compostela ... 18
2.2.5. Demonstration site Kimmeria ... 19
3. Review of Key Performance Indicators (KPIs) evaluated in this report ... 21
3.1. Linking the KPIs to the measurement data ... 21
3.1.1. Demonstration site Thessaloniki ... 22
3.1.2. Demonstration site Sopron ... 23
3.1.3. Demonstration site Cork ... 25
3.1.4. Demonstration site Santiago de Compostela ... 27
3.1.5. Demonstration site Kimmeria ... 28
3.2. Initial calculation of the KPIs ... 30
3.2.1. KPI_1, System volume of thermochemical (TCM) material ... 30
3.2.2. KPI_2, System volume of hot phase change material (PCM) for heating (HW) ... 30
3.2.3. KPI_3, System volume of hot PCM (DHW) ... 30
3.2.4. KPI_4, System volume of cold PCM ... 31
3.2.5. KPI_5, System volume overall (TCM+PCM) ... 31
3.2.6. KPI_6, Permissible outdoor temperature range ... 31
3.2.7. KPI_8, TCM storage density ... 32
3.2.8. KPI_9, Required electric power for peripheral equipment (heat pump) ... 33
3.2.9. KPI_10, PVT efficiency boost ... 33
4. Conclusions ... 36

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

List of Tables

Table 1: Numerical summary of the data coverage of all existing sensors in Thessaloniki.......... 7

Table 2: Numerical summary of the data coverage of all existing sensors in Sopron. 9

Table 3: Numerical summary of the data coverage of all existing sensors in Cork. 10

Table 4: Numerical summary of the data coverage of all existing sensors in Santiago de Compostela. 11

Table 5: Numerical summary of the data coverage of all existing sensors in Kimmeria............. 13

Table 6: Overview of the technical KPIs calculated using measurement data and the link between the measurement data from Thessaloniki and the KPIs. 22

Table 7: Overview of the technical KPIs calculated using measurement data and the link between the measurement data from Sopron and the KPIs. 23

Table 8: Overview of the technical KPIs calculated using measurement data and the link between the measurement data from Cork and the KPIs. 25

Table 9: Overview of the technical KPIs calculated using measurement data and the link between the measurement data from Santiago de Compostela and the KPIs. 27

Table 10: Overview of the technical KPIs calculated using measurement data and the link between the measurement data from Kimmeria and the KPIs. 28

Table 11: Maximum and minimum outdoor temperature in the respective demo sites. 31

Table 12: Summary coefficients of thermal efficiency equation of the Glazed PVT prototype installed in Thessaloniki, Sopron and Cork demo sites 34

Table 13: Summary coefficients of thermal efficiency equation of the Unglazed PVT prototype installed in Santiago demo sites 34

Table 14: Summary of electrical parameters of the PVT prototypes used in the KPIs calculation 35

Table 15: Operation conditions of the PVT prototypes used in the KPIs calculation 35

Table 16: Summary of efficiencies of PVT prototypes before and after the MiniStor Project 35

List of Images

Figure 1: Data coverage as a heat map of all 6 installed sensors in Thessaloniki during the recording period from calendar week 36, year 2020, to calendar week 31, year 2024. 7

Figure 2: Data coverage as a heat map of all 8 installed sensors in Sopron during the recording period from calendar week 8, 2021, to calendar week 31, 2024. 8

Figure 3: Data coverage as a heat map of all 15 installed sensors in Cork during the recording period from calendar week 7, 2021, to calendar week 31, 2024. 10

Figure 4: Data coverage as a heat map of all 13 installed sensors in Santiago de Compostela during the recording period from calendar week 16, 2022, to calendar week 31, 2024. 11

Figure 5: Data coverage as a heat map of all 25 installed sensors in Kimmeria during the recording period from calendar week 01, 2021, to calendar week 31, 2024. 12

Figure 6 Monthly average outdoor temperature in Thessaloniki during the recording period from calendar week 36, 2020, to calendar week 31, 2024. 14

Figure 7 Monthly average electricity consumption in Thessaloniki during the recording period from calendar week 36, 2020, to calendar week 31, 2024. 15

Figure 8: Monthly average outdoor temperature in Sopron during the recording period from calendar week 8, 2021, to calendar week 31, 2024. 16

Figure 9: Monthly average electricity consumption in Sopron during the recording period from calendar week 8, 2021, to calendar week 31, 2024. 16

Figure 10: Monthly average outdoor temperature in Cork during the recording period from calendar week 7, 2021, to calendar week 31, 2024. 17

Figure 11: Monthly average electricity consumption in Cork during the recording period from calendar week 7, 2021, to calendar week 31, 2024. 17

Figure 12: Monthly average outdoor temperature in Santiago de Compostela during the recording period from calendar week 16, 2022, to calendar week 31, 2024. 18

Figure 13: Monthly average electricity consumption in Santiago de Compostela during the recording period from calendar week 16, 2022, to calendar week 31, 2024. 18

Figure 14: Monthly average outdoor temperature in Kimmeria during the recording period from calendar week 01, 2021, to calendar week 31, 2024. 19

Figure 15: Monthly average electricity consumption in Kimmeria during the recording period from calendar week 01, 2021, to calendar week 31, 2024. 19

1. Introduction

Minimal Size Thermal and Electrical Energy Storage System for In-Situ Residential Installation (MiniStor) is a project funded by the European Union's Horizon 2020 research and innovation program to offer a sustainable solution to harness the energy efficiency potential of the European building stock. During the development of the project, the MiniStor system is demonstrated and validated in five demonstration sites located in Ireland, Spain, Greece, and Hungary to test its effectiveness at different local climatic conditions, facilitating market replication while offering an innovative, efficient and clean thermal and electrical energy storage solution for all Europeans.

This report presents the work undertaken in WP6, Task 6.5: KPIs measurement & analysis. Deliverable 6.5 has two main objectives:

After the monitoring system developed in T6.1 had been installed in the demo sites for at least 1.5 years (in some cases even longer), the baseline values of the key performance indicators (KPIs) can now be calculated from this data. These KPI calculations are necessary to assess the MiniStor system's influence on each demo site and compare it with the KPIs defined in D6.1.

This document also assesses the monitoring system's data quality and performs an initial calculation of the KPIs that do not depend on MiniStor's operation. Each demo site shows which data is used to calculate the respective KPIs relevant to the second report on KPI measurement and analysis (D6.6) at the end of the project.

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

2. Data acquisition and analysis

The monitoring systems for data collection are designed to be consistent among the different demonstration sites to ensure comparability of the results. Due to local peculiarities of the energy system, the monitoring systems of the individual demo sites are adapted to local conditions. This adaptation ensures that all relevant data is collected specifically for the considered heating systems (gas heating, electric resistance heating, etc.). Deliverable D6.1, Sec. 3.2 presents the exact equipment for all sites.

Meanwhile, data acquisition is the same for all demo sites. The sensors are connected to a local data logger (usually a Raspberry Pi), which records a data point from the sensors at least every 15 minutes. The data logger saves the data locally and transmits it to the CERTH ITI IoT platform. A detailed description of the monitoring concept can be found in D6.1, Sec 3.3.

2.1. Assessment of the data quality

Data quality is a decisive factor in ensuring the accuracy and comparability of the calculated KPIs. When analysing data quality, the focus is on data coverage over the period to be assessed and the detection of corrupt data.

The data coverage of each sensor is analysed and displayed in a heat map. For each of the heat maps of the demonstration sites, one value corresponds to at least one data point measured every 15 minutes, which is equivalent to 100% coverage.

2.1.1. Demonstration site Thessaloniki

The monitoring system was installed in this demo site during calendar week 36 of year 2020—six sensors recorded 109 data attributes. The analysis covers until calendar week 31, year 2024. The heat map is shown in Figure 1 and data coverage in Table 1.

Figure 1: Data coverage as a heat map of all 6 installed sensors in Thessaloniki during the recording period from calendar week 36, year 2020, to calendar week 31, year 2024.

Table 1: Numerical summary of the data coverage of all existing sensors in Thessaloniki.

Sensor	**Average data coverage since installation**
Electricity Consumption (Home)	75.4 %
EnergyMeterHVAC01	75.8 %
Weather Station	74.6 %
Temperature - Humidity (Hall)	75.6 %
EnergyMeterHVAC02	76 %
Temperature - Humidity (Guest Room)	70 %

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

2.1.2. Demonstration site Sopron

The monitoring system was installed on the calendar for week 8 of 2021. The analysis covers until calendar week 31, year 2024. Overall, 26 sensors are installed, recording 304 data attributes. Due to the large amount of data generated by the 23 sensors and to enhance the clarity of the plot, the sensors are divided across two plots, shown in Figure 2. Data coverage is shown in Table 2.

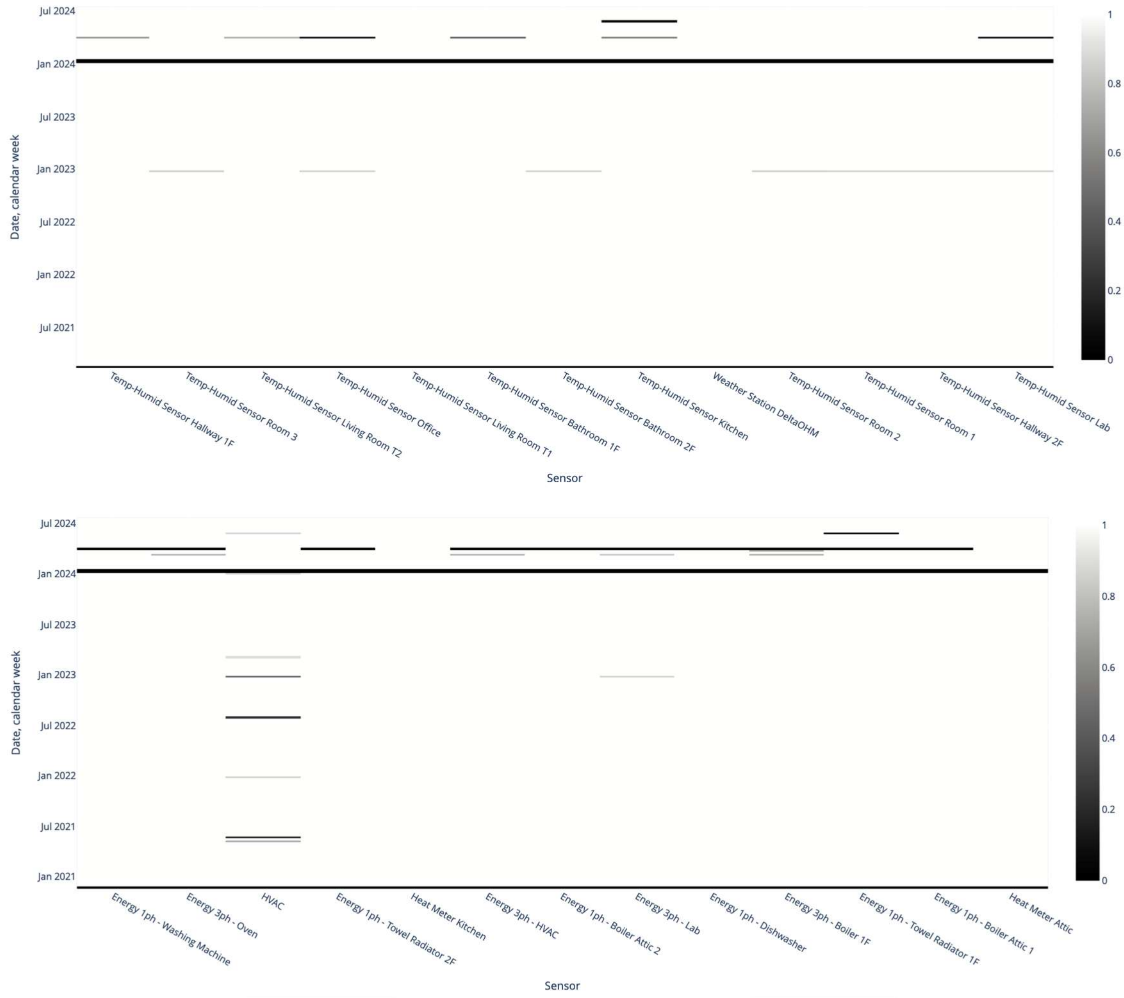


Figure 2: Data coverage as a heat map of all 8 installed sensors in Sopron during the recording period from calendar week 8, 2021, to calendar week 31, 2024.

Table 2: Numerical summary of the data coverage of all existing sensors in Sopron.

Sensor	Average data coverage since installation
Temp-Humid Sensor Hallway 1F	98.6 %
Temp-Humid Sensor Room 3	98.8 %
Temp-Humid Sensor Living Room T2	98.7 %
Temp-Humid Sensor Office	98.3 %
Temp-Humid Sensor Living Room T1	98.8 %
Temp-Humid Sensor Bathroom 1F	98.6 %
Temp-Humid Sensor Bathroom 2F	98.8 %
Temp-Humid Sensor Kitchen	98 %
Weather Station DeltaOHM	98.8 %
Temp-Humid Sensor Room 2	98.8 %
Temp-Humid Sensor Room 1	98.8 %
Temp-Humid Sensor Hallway 2F	98.8 %
Temp-Humid Sensor Lab	98.2 %
Energy 1ph - Washing Machine	98.4 %
Energy 3ph - Oven	98.3 %
HVAC	97.3 %
Energy 1ph - Towel Radiator 2F	98.4 %
Heat Meter Kitchen	98.9 %
Energy 3ph - HVAC	98.3 %
Energy 1ph - Boiler Attic 2	98.4 %
Energy 3ph - Lab	98.3 %
Energy 1ph - Dishwasher	98.4 %
Energy 3ph - Boiler 1F	98.1 %
Energy 1ph - Towel Radiator 1F	97.9 %
Energy 1ph - Boiler Attic 1	98.4 %
Heat Meter Attic	98.9 %

2.1.3. Demonstration site Cork

The monitoring system was installed on the calendar in week 7 of 2021. The analysis covers until calendar week 31, year 2024. Overall, 15 sensors record 91 data attributes. The heat map is shown in Figure 3 and data coverage in Table 3.

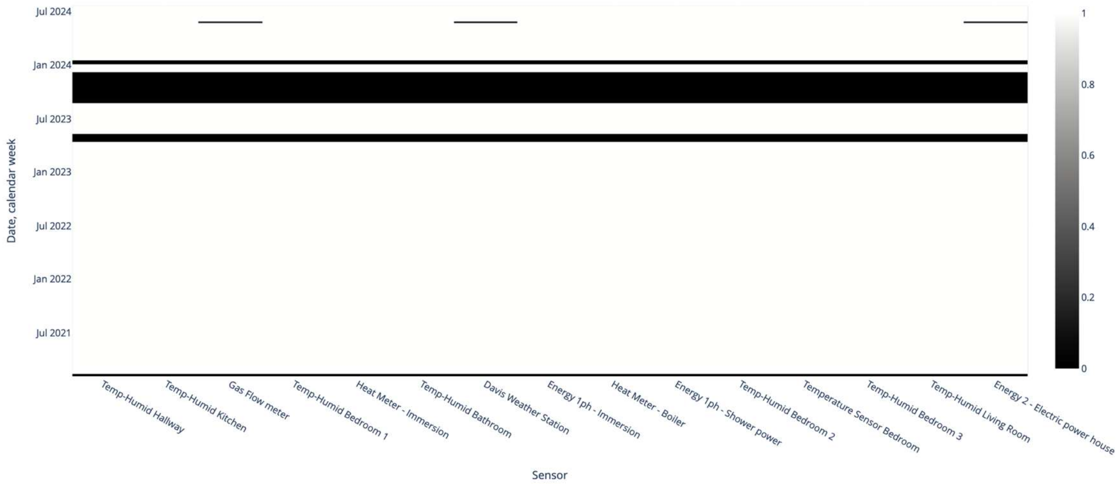


Figure 3: Data coverage as a heat map of all 15 installed sensors in Cork during the recording period from calendar week 7, 2021, to calendar week 31, 2024.

After an interruption in the connection between the monitoring system and the database at the end of 2023, the system is running reliably again.

Table 3: Numerical summary of the data coverage of all existing sensors in Cork.

Sensor	**Average data coverage since installation**
Temp-Humid Hallway	88.3 %
Temp-Humid Kitchen	88.3 %
Gas Flow meter	87.8 %
Temp-Humid Bedroom 1	88.3 %
Heat Meter - Immersion	88.3 %
Temp-Humid Bathroom	88.3 %
Davis Weather Station	87.8 %
Energy 1ph - Immersion	88.3 %
Heat Meter - Boiler	88.3 %
Energy 1ph - Shower power	88.3 %
Temp-Humid Bedroom 2	88.3 %
Temperature Sensor Bedroom	88.3 %
Temp-Humid Bedroom 3	88.3 %
Temp-Humid Living Room	88.3 %
Energy 2 - Electric power house	87.8 %

2.1.4. Demonstration site Santiago de Compostela

The monitoring system was installed in calendar week 16 of 2022. The analysis covers until calendar week 31, year 2024. Overall, 13 sensors record 30 data attributes. The heat map is shown in Figure 4 and data coverage in Table 4.

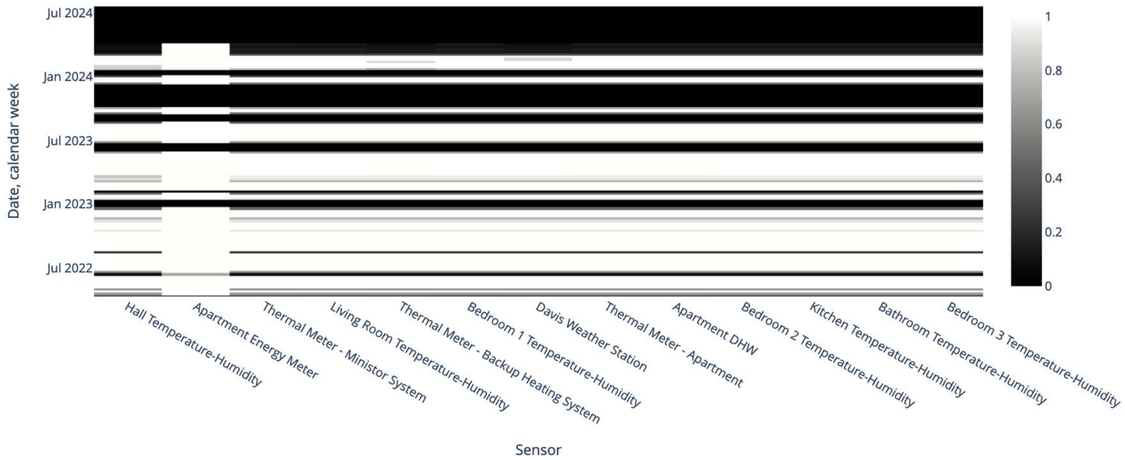


Figure 4: Data coverage as a heat map of all 13 installed sensors in Santiago de Compostela during the recording period from calendar week 16, 2022, to calendar week 31, 2024.

Figure 4 shows that the connection between the monitoring system and the database is repeatedly faulty. The sensors function reliably, which becomes apparent as soon as they are connected to the database (100 % coverage). However, the connection problems must be improved to ensure good data quality.

Table 4: Numerical summary of the data coverage of all existing sensors in Santiago de Compostela.

Sensor	**Average data coverage since installation**
Hall Temperature-Humidity	58.3 %
Apartment Energy Meter	68.6 %
Thermal Meter - Minister System	58.7 %
Living Room Temperature-Humidity	58.4 %
Thermal Meter - Backup Heating System	58.6 %
Bedroom 1 Temperature-Humidity	58.4 %
Davis Weather Station	58.5 %
Thermal Meter - Apartment	58.7 %
Apartment DHW	58.7 %
Bedroom 2 Temperature-Humidity	58.7 %
Kitchen Temperature-Humidity	58.7 %
Bathroom Temperature-Humidity	58.7 %
Bedroom 3 Temperature-Humidity	58.7 %

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

2.1.5. Demonstration site Kimmeria

The monitoring system was installed on the calendar for week 1 of 2021. The analysis covers until calendar week 31, year 2024. Overall, 25 sensors record 25 data attributes. The heat map is shown in Figure 5 and data coverage in Table 5.

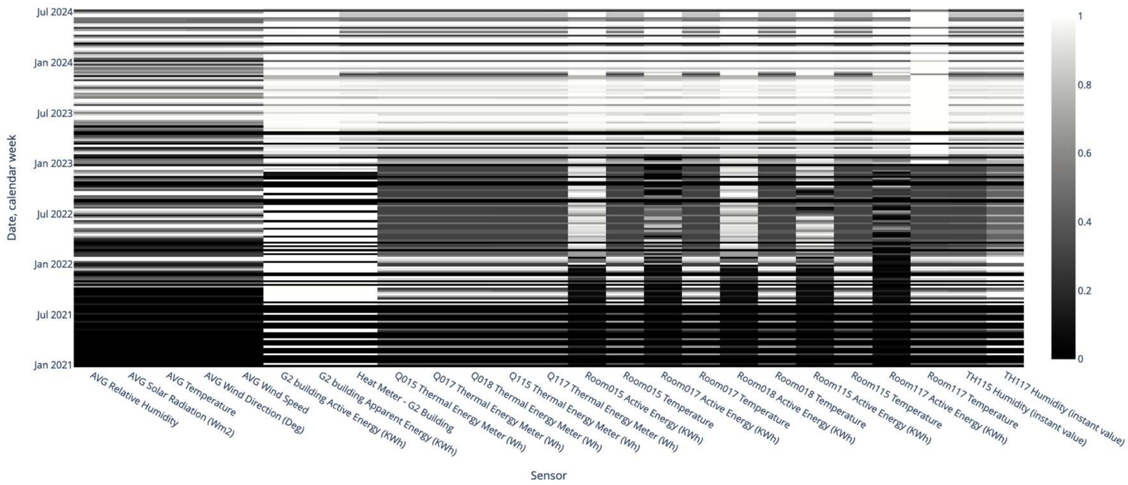


Figure 5: Data coverage as a heat map of all 25 installed sensors in Kimmeria during the recording period from calendar week 01, 2021, to calendar week 31, 2024.

The demo site in Kimmeria already had a monitoring system installed before the MiniStor project was launched. However, this monitoring system is designed to record values only every 15 minutes. As a minimum sampling rate of 15 minutes was set for analysing the data quality, even the absence of a few entries can significantly reduce the analysis result. These few misses may lead to comparatively low data coverage values compared to the other demo sites.

Table 5: Numerical summary of the data coverage of all existing sensors in Kimmeria.

Sensor	Average data coverage since installation
AVG Relative Humidity	43.9 %
AVG Solar Radiation (Wm2)	43.9 %
AVG Temperature	43.9 %
AVG Wind Direction (Deg)	43.9 %
AVG Wind Speed	43.9 %
G2 building Active Energy (KWh)	67.2 %
G2 building Apparent Energy (KWh)	67.2 %
Heat Meter - G2 Building	65.1 %
Q015 Thermal Energy Meter (Wh)	52.2 %
Q017 Thermal Energy Meter (Wh)	52.2 %
Q018 Thermal Energy Meter (Wh)	52.2 %
Q115 Thermal Energy Meter (Wh)	52.2 %
Q117 Thermal Energy Meter (Wh)	52.2 %
Room015 Active Energy (KWh)	58.7 %
Room015 Temperature	52.2 %
Room017 Active Energy (KWh)	46.7 %
Room017 Temperature	52.2 %
Room018 Active Energy (KWh)	58.6 %
Room018 Temperature	52.2 %
Room115 Active Energy (KWh)	53.5 %
Room115 Temperature	52.2 %
Room117 Active Energy (KWh)	43.6 %
Room117 Temperatur	57.6 %
TH115 Humidity (instant value)	52.2 %
TH117 Humidity (instant value)	58.6 %

2.2. Calculation of the baseline values

The baseline values for outdoor temperature and electrical energy consumption are essential for assessing MiniStor's impact on the demo sites. The outside temperature influences the consumption of thermal or electrical energy needed to heat the respective demo site. Once MiniStor is installed, this temperature profiles can be used to integrate the climatic conditions into assessing its influence. This section shows the average monthly values for electrical energy consumption and outdoor temperature.

2.2.1. Demonstration site Thessaloniki

2.2.1.1. Outdoor temperature

The ambient temperature impacts the demo site's energy consumption. The average monthly temperature provides an overview of the local climatic conditions. Additionally, extreme values are reported, each presented as a six-hour moving average. These are shown in Figure 6.

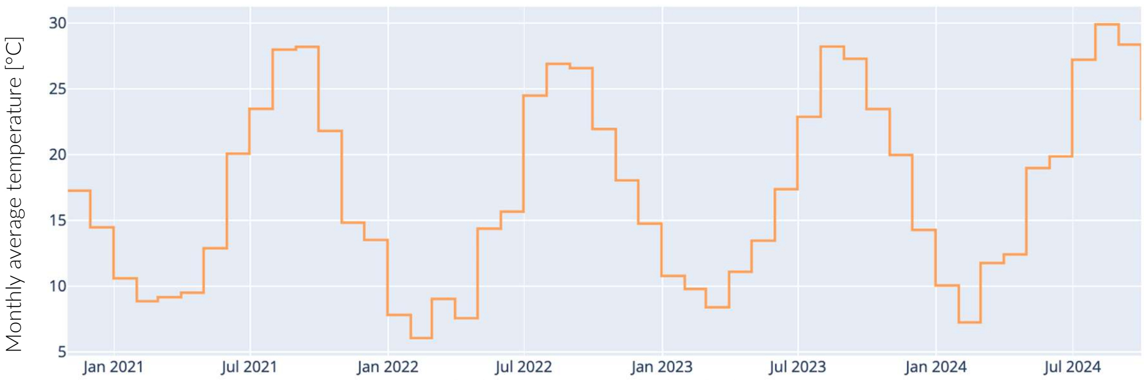


Figure 6 Monthly average outdoor temperature in Thessaloniki during the recording period from calendar week 36, 2020, to calendar week 31, 2024.

On 14.02.2021, the lowest temperature value averaged over six hours was recorded, while on 03.08.2021, the highest temperature value averaged over six hours was observed. The maximum temperature recorded as a six-hour average was 38.8 °C, while the minimum recorded temperature was -3.6 °C.

2.2.1.2. Electrical energy consumption

The electrical energy consumed by the entire building is presented as a monthly aggregate. Additionally, the average, maximum, and minimum daily consumption are calculated. This is shown in Figure 7.

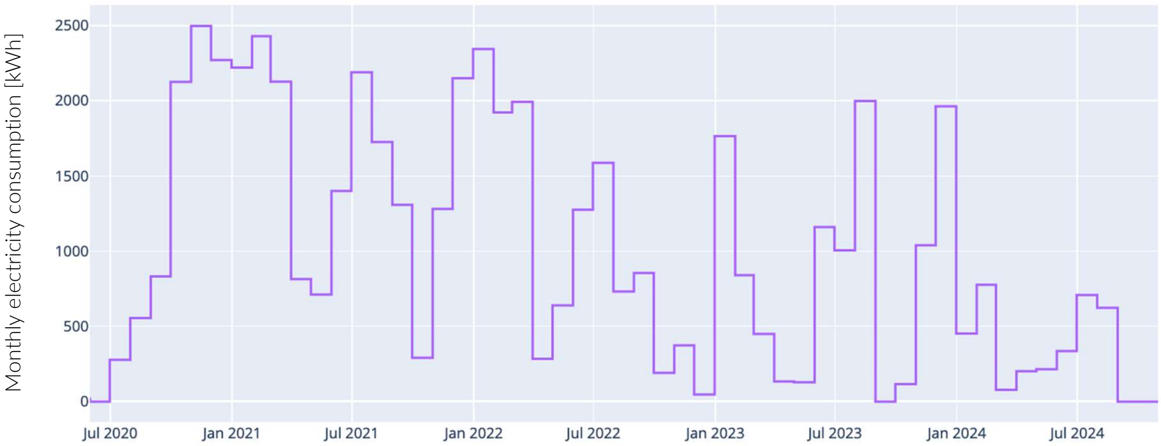


Figure 7 Monthly average electricity consumption in Thessaloniki during the recording period from calendar week 36, 2020, to calendar week 31, 2024.

Above, a plot of the monthly aggregated electricity consumption is displayed. The average daily consumption is 95 kWh, the highest recorded daily consumption is 1'870 kWh (03.10.2023), and the lowest is 0 kWh.

2.2.2. Demonstration site Sopron

2.2.2.1. Outdoor temperature

The ambient temperature impacts the demo site's energy consumption. The average monthly temperature provides an overview of the local climatic conditions. Additionally, extreme values are reported, each presented as a six-hour moving average, as summarized in Figure 8.

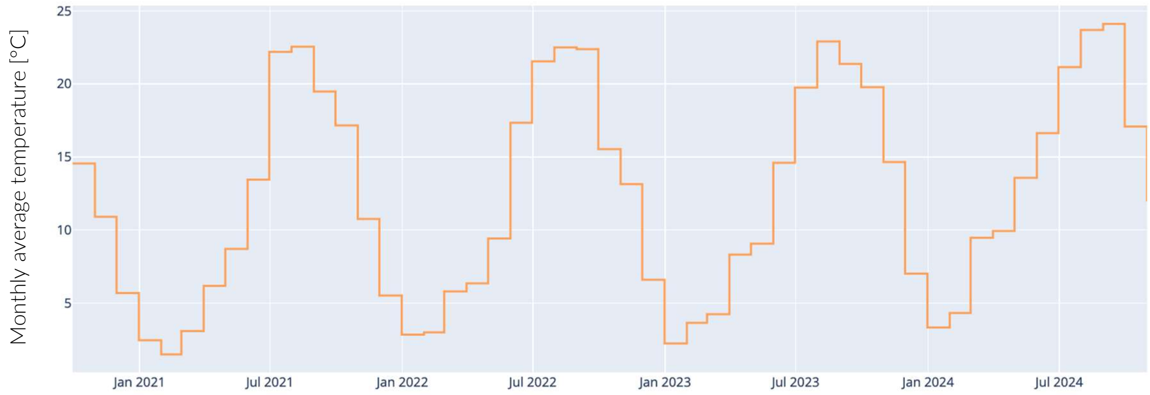


Figure 8: Monthly average outdoor temperature in Sopron during the recording period from calendar week 8, 2021, to calendar week 31, 2024.

The lowest temperature averaged over six hours was recorded on 13.02.2021, while the highest was observed on 17.07.2022. The maximum recorded six-hour average was 33.7 °C, while the minimum recorded temperature was -8 °C.

2.2.2.2. Electrical energy consumption

The electrical energy consumed by the entire building is presented as a monthly aggregate. Additionally, the average, maximum, and minimum daily consumption are calculated.

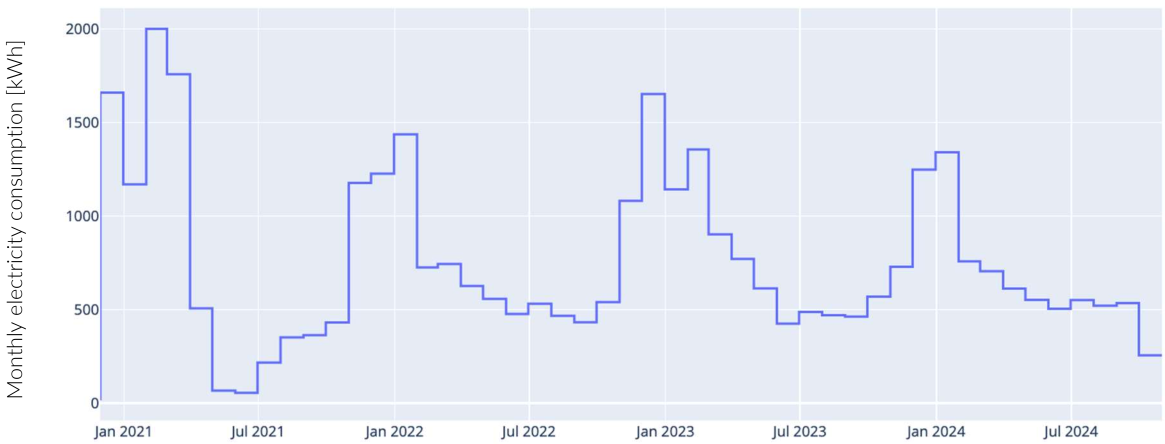


Figure 9: Monthly average electricity consumption in Sopron during the recording period from calendar week 8, 2021, to calendar week 31, 2024.

Figure 9 shows a plot of the monthly aggregated electricity consumption is displayed. The average daily consumption is 24.4 kWh, the highest recorded daily consumption is 165.2 kWh (27.02.2023), and the lowest is 0.175 kWh (10.04.2024).

2.2.3. Demonstration site Cork

2.2.3.1. Outdoor temperature

The ambient temperature impacts the demo site's energy consumption. The average monthly temperature provides an overview of the local climatic conditions. Additionally, extreme values are reported, each presented as a six-hour moving average.

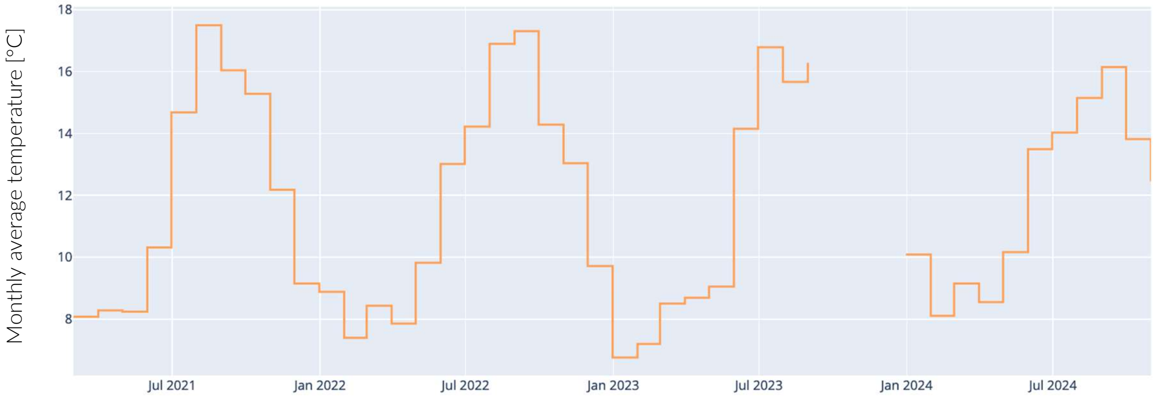


Figure 10: Monthly average outdoor temperature in Cork during the recording period from calendar week 7, 2021, to calendar week 31, 2024.

As shown in Figure 10, on 13.02.2021, the lowest temperature value averaged over six hours was recorded, while on 17.07.2022, the highest temperature value averaged over six hours was observed. The maximum temperature recorded as a six-hour average was 27.9 °C, while the minimum recorded temperature was 0 °C.

2.2.3.2. Electrical energy consumption

The electrical energy consumed by the entire building is presented as a monthly aggregate. Additionally, the average, maximum, and minimum daily consumption are calculated.

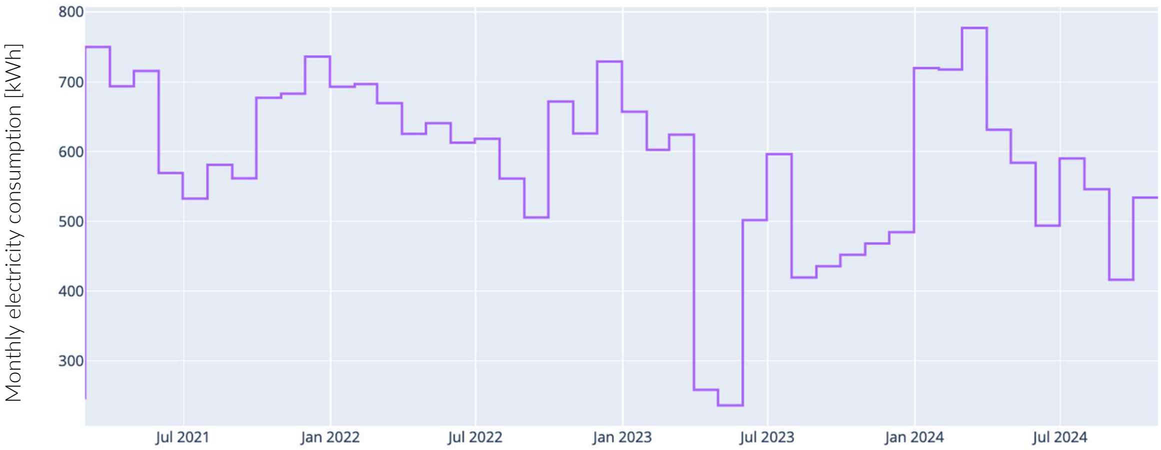


Figure 11: Monthly average electricity consumption in Cork during the recording period from calendar week 7, 2021, to calendar week 31, 2024.

Figure 11 displays a plot of the monthly aggregated electricity consumption. The average daily electrical energy consumption is 19.2 kWh, the highest recorded daily consumption is 47.5 kWh (24.12.2022), and the lowest is 0.629 kWh (22.05.2023).

Energy consumption in Cork is relatively constant. The drop in consumption in April and May 2023 is due to missing data. This area is interpolated for the subsequent analysis. The data at the end of 2024 is also analysed using the previous year's data.

2.2.4. Demonstration site Santiago de Compostela

2.2.4.1. Outdoor temperature

The ambient temperature impacts the demo site's energy consumption. The average monthly temperature provides an overview of the local climatic conditions. Additionally, extreme values are reported, each presented as a six-hour moving average.

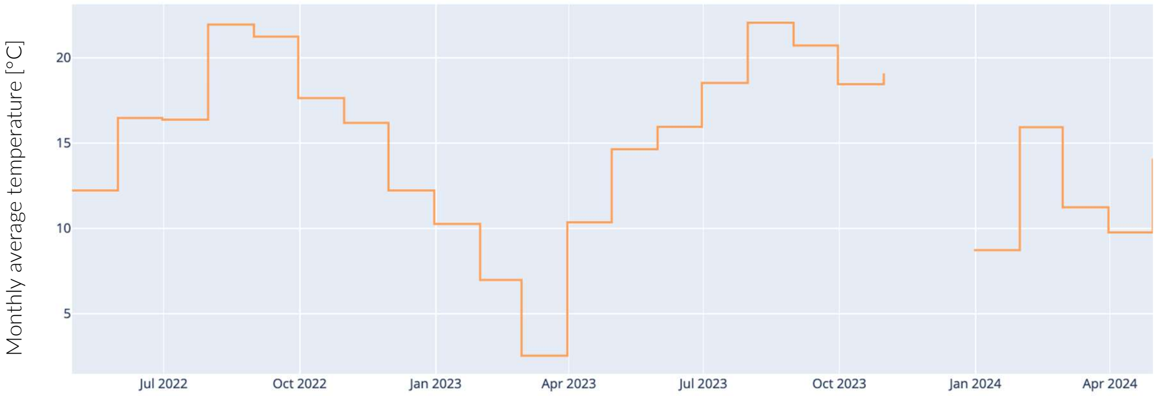


Figure 12: Monthly average outdoor temperature in Santiago de Compostela during the recording period from calendar week 16, 2022, to calendar week 31, 2024.

The lowest temperature value averaged over six hours was recorded on 17.12.2023, while the highest temperature value averaged over six hours was observed on 12.07.2022. The maximum temperature recorded as a six-hour average was 34.5 °C, while the minimum recorded temperature was 0.8 °C.

2.2.4.2. Electrical energy consumption

The electrical energy consumed by the entire building is presented as a monthly aggregate. Additionally, the average, maximum, and minimum daily consumption are calculated.

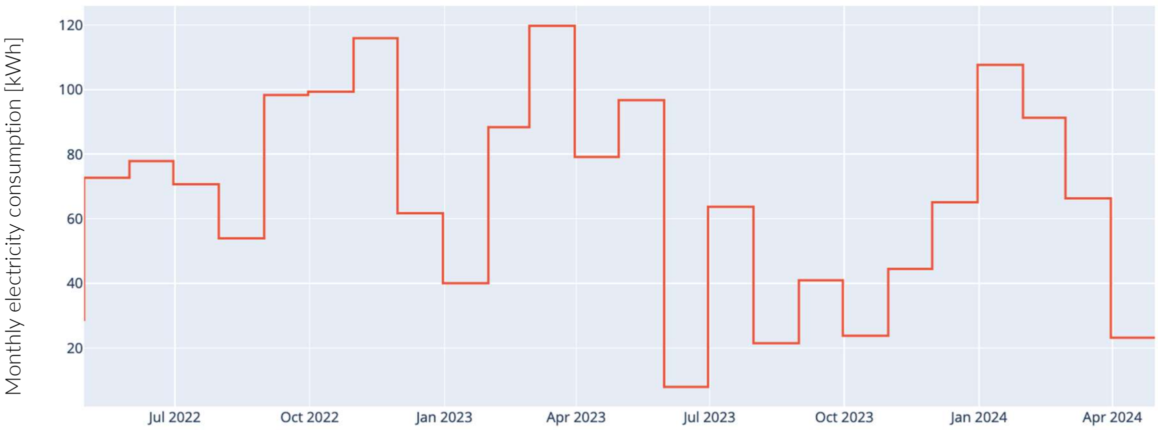


Figure 13: Monthly average electricity consumption in Santiago de Compostela during the recording period from calendar week 16, 2022, to calendar week 31, 2024.

Above, a plot of the monthly aggregated electricity consumption is displayed. The average daily consumption is 2.36 kWh, the highest recorded daily consumption is 7.1 kWh (11.12.2022), and the lowest is 0 kWh.

2.2.5. Demonstration site Kimmeria

2.2.5.1. Outdoor temperature

The ambient temperature impacts the demo site's energy consumption. The average monthly temperature provides an overview of the local climatic conditions. Additionally, extreme values are reported, each presented as a six-hour moving average.

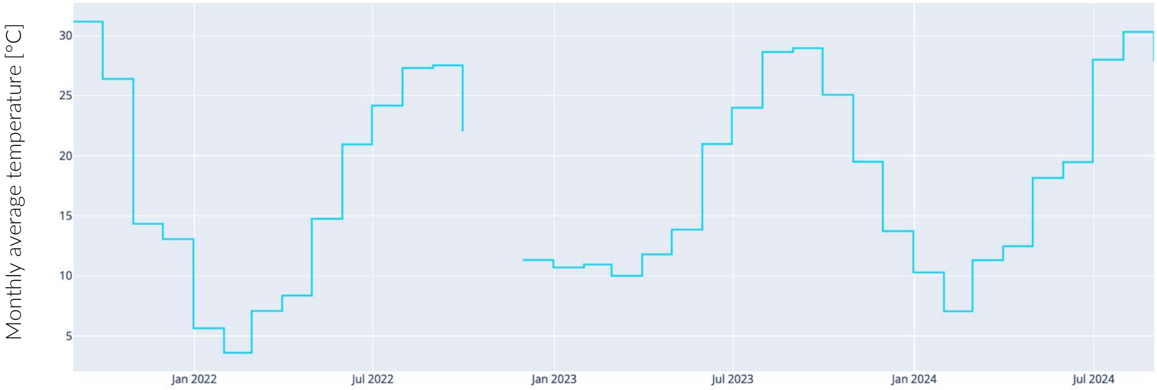


Figure 14: Monthly average outdoor temperature in Kimmeria during the recording period from calendar week 01, 2021, to calendar week 31, 2024.

The lowest temperature value averaged over six hours was recorded on 26.01.2022, while the highest temperature value averaged over six hours was observed on 18.07.2024. The maximum temperature recorded as a six-hour average was 39.8 °C, while the minimum recorded temperature was -2.6 °C.

2.2.5.2. Electrical energy consumption

The electrical energy consumed by the entire building is presented as a monthly aggregate. Additionally, the average, maximum, and minimum daily consumption are calculated.

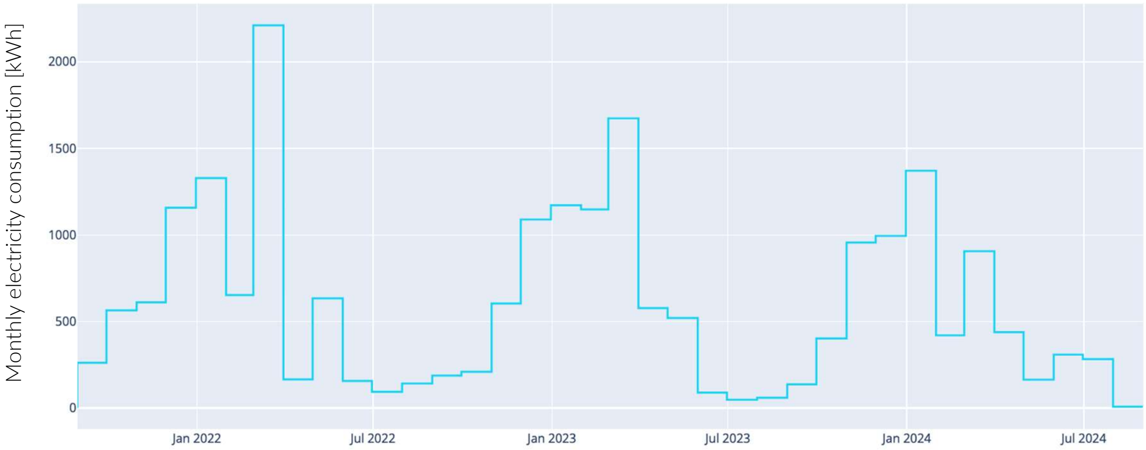


Figure 15: Monthly average electricity consumption in Kimmeria during the recording period from calendar week 01, 2021, to calendar week 31, 2024.

Above, a plot of the monthly aggregated electricity consumption is displayed. The average daily electrical energy consumption is 19.91 kWh. The maximum and minimum values cannot be reliably determined. This issue is caused by the large share of missing data caused by the method used to store the measurement data and how to handle errors in the transmission of measurement data.

The related energy is added to the next entry if an error occurs when transmitting the measured values. As soon as the transmission is stabilised again, the total is transmitted. It is, therefore, only possible to make a limited statement about the time the energy was obtained. Nevertheless, the total energy consumed is correct, and the average value can also be determined.

The rooms are not occupied during the university's semester holidays, which is the reason for the significant drop in energy consumption, along with the seasonal effect and warmer outside temperatures.

3. Review of Key Performance Indicators (KPIs) evaluated in this report

This section provides an overview of how the technologically related key performance indicators (KPIs) are calculated and provides an initial report on the KPIs, which are already available. Many KPIs require comparing the situation before and after the installation of MiniStor at the respective demo sites. However, since the MiniStor systems have only been installed in summer 2024 or later, many KPIs cannot yet be calculated. For these KPIs, the parameters associated with each demo site are listed. Due to the dependence on data during the operation of MiniStor, the remaining categories of KPIs (comfort and acceptance, economic, legal/safety-related and environmental) are not presented in this report. The respective calculation methods are listed in Deliverable 6.1. This presentation of the methodology will facilitate the calculations in the final KPI report (Deliverable 6.6). The KPIs' list and calculations can be found in Deliverable 6.1, Section 2.1.

3.1. Linking the KPIs to the measurement data

The technological KPIs listed in the following section are calculated based on operational data from MiniStor. Since each demo site has different existing heating systems and sensor data, the respective data source (sensor) for each demo site is listed and assigned to the corresponding KPIs. All KPIs not covered in this section can be found in Chapter 3.2. Their calculation is not linked to operational data and, therefore, does not require specification.

3.1.1. Demonstration site Thessaloniki

Table 6: Overview of the technical KPIs calculated using measurement data and the link between the measurement data from Thessaloniki and the KPIs.

KPI No.	6	Name:	Permissible outdoor temperature range
Sensor:	Weather Station.csv	Parameter:	airTemperature

KPI No.	11	Name:	Absolute thermal energy savings
Sensor:	EnergyMeterHVAC01.csv	Parameter:	Energy
Sensor:	EnergyMeterHVAC02.csv	Parameter:	Energy

KPI No.	12	Name:	Overall coefficient of performance
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el,\,tot}$
Sensor:	*MiniStor_PVT_output*	Parameter:	$Q_{el,\,tot}$
Sensor:	*MiniStor_th_output*	Parameter:	$Q_{th,\,tot}$

KPI No.	13	Name:	Relative change in thermal energy net consumption
Sensor:	EnergyMeterHVAC01.csv	Parameter:	Energy
Sensor:	EnergyMeterHVAC02.csv	Parameter:	Energy

KPI No.	14	Name:	Energy losses
Sensor:	*MiniStor_PVT_output*	Parameter:	$Q_{el,\,tot}$
Sensor:	*MiniStor_FPC_output*	Parameter:	$Q_{th,\,tot}$
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el,\,tot}$
Sensor:	EnergyMeterHVAC01.csv	Parameter:	Energy
Sensor:	EnergyMeterHVAC02.csv	Parameter:	Energy
Sensor:	Electricity Consumption (Home).csv	Parameter:	Energy

KPI No.	15	Name:	RES on-site average use
Sensor:	*MiniStor_th_output*	Parameter:	$Q_{th,\,tot}$
Sensor:	*MiniStor_PVT_output*	Parameter:	P_{el}
Sensor:	*MiniStor_FPC_output*	Parameter:	P_{th}

KPI No.	17	Name:	Electrical energy savings
Sensor:	Electricity Consumption (Home).csv	Parameter:	Energy
Sensor:	*MiniStor_th_output*	Parameter:	P_{th}

KPI No.	18	Name:	Change in electrical consumption from grid (kWh)
Sensor:	Electricity Consumption (Home).csv	Parameter:	Energy
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el,\,tot}$

KPI No.	19	Name:	Share of renewables
Sensor:	*MiniStor_PVT_output*	Parameter:	$E_{el,\,tot}$
Sensor:	*MiniStor_FPC_output*	Parameter:	$Q_{th,\,tot}$
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el,\,tot}$

KPI No.	20	Name:	Self-electricity production/ self-sufficiency ratio
Sensor:	*MiniStor_PVT_output*	Parameter:	P_{el}
Sensor:	Electricity Consumption (Home).csv	Parameter:	Energy

KPI No.	21	Name:	Maximum hourly energy surplus/ deficit (kWh)
Sensor:	Electricity Consumption (Home).csv	Parameter:	Energy

Sensor:	EnergyMeterHVAC01.csv	Parameter:	Energy
Sensor:	EnergyMeterHVAC02.csv	Parameter:	Energy
Sensor:	*MiniStor_PVT_output*	Parameter:	P_{el}
Sensor:	*MiniStor_th_output*	Parameter:	P_{th}
Sensor:	*MiniStor_FPC_output*	Parameter:	$Q_{th, tot}$
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el, tot}$
		Parameter:	*COP (KPI_12)*

KPI No.	23	Name:	System reliability	
Sensor:	*MiniStor_status*		Parameter:	*connection*

3.1.2. Demonstration site Sopron

Table 7: Overview of the technical KPIs calculated using measurement data and the link between the measurement data from Sopron and the KPIs.

KPI No.	6	Name:	Permissible outdoor temperature range	
Sensor:	Weather Station.csv		Parameter:	airTemperature

KPI No.	11	Name:	Absolute thermal energy savings	
Sensor:	Heat Meter Attic.csv		Parameter:	Q
Sensor:	Heat Meter Kitchen.csv		Parameter:	Q
Sensor:	HVAC.csv		Parameter:	Q_Sup, Q_Exh

KPI No.	12	Name:	Overall coefficient of performance	
Sensor:	*MiniStor_el_consumption*		Parameter:	$E_{el, tot}$
Sensor:	*MiniStor_th_output*		Parameter:	$Q_{th, tot}$

KPI No.	13	Name:	Relative change in thermal energy net consumption	
Sensor:	Heat Meter Attic.csv		Parameter:	Q
Sensor:	Heat Meter Kitchen.csv		Parameter:	Q
Sensor:	HVAC.csv		Parameter:	Q_Sup, Q_Exh

KPI No.	14	Name:	Energy losses	
Sensor:	*MiniStor_PVT_output*		Parameter:	$Q_{el, tot}$
Sensor:	*MiniStor_FPC_output*		Parameter:	$Q_{th, tot}$
Sensor:	*MiniStor_el_grid*		Parameter:	$E_{el, tot}$
Sensor:	Heat Meter Attic.csv		Parameter:	Q
Sensor:	Heat Meter Kitchen.csv		Parameter:	Q
Sensor:	HVAC.csv		Parameter:	Q_Sup, Q_Exh
Sensor:	Energy 1ph - Boiler Attic 1.csv		Parameter:	KWh_Tot
Sensor:	Energy 1ph - Boiler Attic 2.csv		Parameter:	KWh_Tot
Sensor:	Energy 1ph - Dishwasher.csv		Parameter:	KWh_Tot
Sensor:	Energy 1ph - Towel Radiator 1F.csv		Parameter:	KWh_Tot
Sensor:	Energy 1ph - Towel Radiator 2F.csv		Parameter:	KWh_Tot
Sensor:	Energy 1ph - Washing Machine.csv		Parameter:	KWh_Tot
Sensor:	Energy 3ph - Boiler 1F.csv		Parameter:	KWh_Tot
Sensor:	Energy 3ph - HVAC.csv		Parameter:	KWh_Tot
Sensor:	Energy 3ph - Lab.csv		Parameter:	KWh_Tot
Sensor:	Energy 3ph - Oven.csv		Parameter:	KWh_Tot

KPI No.	15	Name:	RES on-site average use
Sensor:	*MiniStor_th_output*	Parameter:	P_{th}
Sensor:	*MiniStor_PVT_output*	Parameter:	P_{el}
Sensor:	*MiniStor_FPC_output*	Parameter:	P_{th}

KPI No.	17	Name:	Electrical energy savings
Sensor:	Energy 1ph - Boiler Attic 1.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Boiler Attic 2.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Dishwasher.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Towel Radiator 1F.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Towel Radiator 2F.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Washing Machine.csv	Parameter:	KWh_Tot
Sensor:	Energy 3ph - Boiler 1F.csv	Parameter:	KWh_Tot
Sensor:	Energy 3ph - HVAC.csv	Parameter:	KWh_Tot
Sensor:	Energy 3ph - Lab.csv	Parameter:	KWh_Tot
Sensor:	Energy 3ph - Oven.csv	Parameter:	KWh_Tot
Sensor:	*MiniStor_th_output*	Parameter:	P_{th}

KPI No.	18	Name:	Change in electrical consumption from grid (kWh)
Sensor:	Energy 1ph - Boiler Attic 1.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Boiler Attic 2.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Dishwasher.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Towel Radiator 1F.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Towel Radiator 2F.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Washing Machine.csv	Parameter:	KWh_Tot
Sensor:	Energy 3ph - Boiler 1F.csv	Parameter:	KWh_Tot
Sensor:	Energy 3ph - HVAC.csv	Parameter:	KWh_Tot
Sensor:	Energy 3ph - Lab.csv	Parameter:	KWh_Tot
Sensor:	Energy 3ph - Oven.csv	Parameter:	KWh_Tot
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el, tot}$

KPI No.	19	Name:	Share of renewables
Sensor:	*MiniStor_PVT_output*	Parameter:	$E_{el, tot}$
Sensor:	*MiniStor_FPC_output*	Parameter:	$Q_{th, tot}$
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el, tot}$

KPI No.	20	Name:	Self-electricity production/ self-sufficiency ratio
Sensor:	*MiniStor_PVT_output*	Parameter:	P_{el}
Sensor:	Energy 1ph - Boiler Attic 1.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Boiler Attic 2.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Dishwasher.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Towel Radiator 1F.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Towel Radiator 2F.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Washing Machine.csv	Parameter:	KWh_Tot
Sensor:	Energy 3ph - Boiler 1F.csv	Parameter:	KWh_Tot
Sensor:	Energy 3ph - HVAC.csv	Parameter:	KWh_Tot
Sensor:	Energy 3ph - Lab.csv	Parameter:	KWh_Tot
Sensor:	Energy 3ph - Oven.csv	Parameter:	KWh_Tot

KPI No.	21	Name:	Maximum hourly energy surplus/ deficit (kWh)
Sensor:	Energy 1ph - Boiler Attic 1.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Boiler Attic 2.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Dishwasher.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Towel Radiator 1F.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Towel Radiator 2F.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Washing Machine.csv	Parameter:	KWh_Tot
Sensor:	Energy 3ph - Boiler 1F.csv	Parameter:	KWh_Tot
Sensor:	Energy 3ph - HVAC.csv	Parameter:	KWh_Tot
Sensor:	Energy 3ph - Lab.csv	Parameter:	KWh_Tot
Sensor:	Energy 3ph - Oven.csv	Parameter:	KWh_Tot
Sensor:	Heat Meter Attic.csv	Parameter:	Q
Sensor:	Heat Meter Kitchen.csv	Parameter:	Q
Sensor:	HVAC.csv	Parameter:	Q_Sup, Q_Exh
Sensor:	*MiniStor_PVT_output*	Parameter:	P_{el}
Sensor:	*MiniStor_th_output*	Parameter:	P_{th}
Sensor:	*MiniStor_FPC_output*	Parameter:	$Q_{th,\ tot}$
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el,\ tot}$
		Parameter:	*COP (KPI_12)*

KPI No.	23	Name:	System reliability
Sensor:	*MiniStor_status*	Parameter:	*connection*

3.1.3. Demonstration site Cork

Table 8: Overview of the technical KPIs calculated using measurement data and the link between the measurement data from Cork and the KPIs.

KPI No.	6	Name:	Permissible outdoor temperature range
Sensor:	Weather Station.csv	Parameter:	airTemperature

KPI No.	11	Name:	Absolute thermal energy savings
Sensor:	Gas Flow Meter.csv	Parameter:	V
Sensor:	Heat Meter – Boiler.csv	Parameter:	Q
Sensor:	Heat Meter – Immersion.csv	Parameter:	Q

KPI No.	12	Name:	Overall coefficient of performance
Sensor:	*MiniStor_el_consumption*	Parameter:	$E_{el,\ tot}$
Sensor:	*MiniStor_th_output*	Parameter:	$Q_{th,\ tot}$

KPI No.	13	Name:	Relative change in thermal energy net consumption
Sensor:	Gas Flow Meter.csv	Parameter:	V
Sensor:	Heat Meter – Boiler.csv	Parameter:	Q
Sensor:	Heat Meter – Immersion.csv	Parameter:	Q

KPI No.	14	Name:	Energy losses
Sensor:	*MiniStor_PVT_output*	Parameter:	$Q_{el,\ tot}$
Sensor:	*MiniStor_FPC_output*	Parameter:	$Q_{th,\ tot}$
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el,\ tot}$

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

Sensor:	Gas Flow Meter.csv	Parameter:	V
Sensor:	Heat Meter – Boiler.csv	Parameter:	Q
Sensor:	Heat Meter – Immersion.csv	Parameter:	Q
Sensor:	Energy 1ph - Immersion.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Shower power.csv	Parameter:	KWh_Tot
Sensor:	Energy 2 - Electric power house.csv	Parameter:	KWh_Tot

KPI No.	15	Name:	RES on-site average use
Sensor:	*MiniStor_th_output*	Parameter:	$Q_{th, tot}$
Sensor:	*MiniStor_PVT_output*	Parameter:	P_{el}
Sensor:	*MiniStor_FPC_output*	Parameter:	P_{th}

KPI No.	17	Name:	Electrical energy savings
Sensor:	Energy 1ph - Immersion.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Shower power.csv	Parameter:	KWh_Tot
Sensor:	Energy 2 - Electric power house.csv	Parameter:	KWh_Tot
Sensor:	*MiniStor_th_output*	Parameter:	P_{th}

KPI No.	18	Name:	Change in electrical consumption from grid (kWh)
Sensor:	Energy 1ph - Immersion.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Shower power.csv	Parameter:	KWh_Tot
Sensor:	Energy 2 - Electric power house.csv	Parameter:	KWh_Tot
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el, tot}$

KPI No.	19	Name:	Share of renewables
Sensor:	*MiniStor_PVT_output*	Parameter:	$E_{el, tot}$
Sensor:	*MiniStor_FPC_output*	Parameter:	$Q_{th, tot}$
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el, tot}$

KPI No.	20	Name:	Self-electricity production/ self-sufficiency ratio
Sensor:	*MiniStor_PVT_output*	Parameter:	P_{el}
Sensor:	Energy 1ph - Immersion.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Shower power.csv	Parameter:	KWh_Tot
Sensor:	Energy 2 - Electric power house.csv	Parameter:	KWh_Tot

KPI No.	21	Name:	Maximum hourly energy surplus/ deficit (kWh)
Sensor:	Energy 1ph - Immersion.csv	Parameter:	KWh_Tot
Sensor:	Energy 1ph - Shower power.csv	Parameter:	KWh_Tot
Sensor:	Energy 2 - Electric power house.csv	Parameter:	KWh_Tot
Sensor:	Gas Flow Meter.csv	Parameter:	V
Sensor:	Heat Meter – Boiler.csv	Parameter:	Q
Sensor:	Heat Meter – Immersion.csv	Parameter:	Q
Sensor:	*MiniStor_PVT_output*	Parameter:	P_{el}
Sensor:	*MiniStor_th_output*	Parameter:	P_{th}
Sensor:	*MiniStor_FPC_output*	Parameter:	$Q_{th, tot}$
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el, tot}$
		Parameter:	*COP (KPI_12)*

KPI No.	23	Name:	System reliability
Sensor:	*MiniStor_status*	Parameter:	*connection*

3.1.4. Demonstration site Santiago de Compostela

Table 9: Overview of the technical KPIs calculated using measurement data and the link between the measurement data from Santiago de Compostela and the KPIs.

KPI No.	6	Name:	Permissible outdoor temperature range
Sensor:	Weather Station.csv	Parameter:	airTemperature

KPI No.	11	Name:	Absolute thermal energy savings
Sensor:	Apartment DHW.csv	Parameter:	thermalEnergy
Sensor:	Thermal Meter – Apartment.csv	Parameter:	thermalEnergy
Sensor:	Thermal Meter - Backup Heating System.csv	Parameter:	thermalEnergy
Sensor:	Thermal Meter - Ministor System.csv	Parameter:	thermalEnergy

KPI No.	12	Name:	Overall coefficient of performance
Sensor:	*MiniStor_el_consumption*	Parameter:	$E_{el, tot}$
Sensor:	*MiniStor_th_output*	Parameter:	$Q_{th, tot}$

KPI No.	13	Name:	Relative change in thermal energy net consumption
Sensor:	Apartment DHW.csv	Parameter:	thermalEnergy
Sensor:	Thermal Meter – Apartment.csv	Parameter:	thermalEnergy
Sensor:	Thermal Meter - Backup Heating System.csv	Parameter:	thermalEnergy
Sensor:	Thermal Meter - Ministor System.csv	Parameter:	thermalEnergy

KPI No.	14	Name:	Energy losses
Sensor:	Apartment Energy Meter.csv	Parameter:	KWh_Tot
Sensor:	Thermal Meter – Apartment.csv	Parameter:	thermalEnergy
Sensor:	Thermal Meter - Backup Heating System.csv	Parameter:	thermalEnergy
Sensor:	Thermal Meter - Ministor System.csv	Parameter:	thermalEnergy
Sensor:	*MiniStor_PVT_output*	Parameter:	$Q_{el, tot}$
Sensor:	*MiniStor_FPC_output*	Parameter:	$Q_{th, tot}$
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el, tot}$

KPI No.	15	Name:	RES on-site average use
Sensor:	Thermal Meter - Ministor System.csv	Parameter:	thermalEnergy
Sensor:	*MiniStor_PVT_output*	Parameter:	P_{el}
Sensor:	*MiniStor_FPC_output*	Parameter:	P_{th}

KPI No.	17	Name:	Electrical energy savings
Sensor:	Apartment Energy Meter.csv	Parameter:	KWh_Tot
Sensor:	Thermal Meter - Ministor System.csv	Parameter:	thermalEnergy

KPI No.	18	Name:	Change in electrical consumption from grid (kWh)
Sensor:	Apartment Energy Meter.csv	Parameter:	KWh_Tot
Sensor:	Thermal Meter - Ministor System.csv	Parameter:	thermalEnergy

KPI No.	19	Name:	Share of renewables
Sensor:	*MiniStor_PVT_output*	Parameter:	$E_{el, tot}$
Sensor:	*MiniStor_FPC_output*	Parameter:	$Q_{th, tot}$
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el, tot}$

KPI No.	20	Name:	Self-electricity production/ self-sufficiency ratio		
Sensor:	*MiniStor_PVT_output*			Parameter:	$E_{el,\ tot}$
Sensor:	Apartment Energy Meter.csv			Parameter:	KWh_Tot

KPI No.	21	Name:	Maximum hourly energy surplus/ deficit (kWh)		
Sensor:	Apartment Energy Meter.csv			Parameter:	KWh_Tot
Sensor:	Thermal Meter – Apartment.csv			Parameter:	thermalEnergy
Sensor:	Thermal Meter - Backup Heating System.csv			Parameter:	thermalEnergy
Sensor:	Thermal Meter - Ministor System.csv			Parameter:	thermalEnergy
Sensor:	*MiniStor_PVT_output*			Parameter:	P_{el}
Sensor:	*MiniStor_th_output*			Parameter:	P_{th}
Sensor:	*MiniStor_FPC_output*			Parameter:	$Q_{th,\ tot}$
Sensor:	*MiniStor_el_grid*			Parameter:	$E_{el,\ tot}$
				Parameter:	*COP (KPI_12)*

KPI No.	23	Name:	System reliability		
Sensor:	*MiniStor_status*			Parameter:	*connection*

3.1.5. Demonstration site Kimmeria

Table 10: Overview of the technical KPIs calculated using measurement data and the link between the measurement data from Kimmeria and the KPIs.

KPI No.	6	Name:	Permissible outdoor temperature range		
Sensor:	AVG Temperature.csv			Parameter:	ABSOLUTE VALUE

KPI No.	11	Name:	Absolute thermal energy savings		
Sensor:	Q015 Thermal Energy Meter (Wh)			Parameter:	ABSOLUTE VALUE
Sensor:	Q017 Thermal Energy Meter (Wh)			Parameter:	ABSOLUTE VALUE
Sensor:	Q018 Thermal Energy Meter (Wh)			Parameter:	ABSOLUTE VALUE
Sensor:	Q115 Thermal Energy Meter (Wh)			Parameter:	ABSOLUTE VALUE
Sensor:	Q117 Thermal Energy Meter (Wh)			Parameter:	ABSOLUTE VALUE

KPI No.	12	Name:	Overall coefficient of performance		
Sensor:	*MiniStor_el_consumption*			Parameter:	$E_{el,\ tot}$
Sensor:	*MiniStor_th_output*			Parameter:	$Q_{th,\ tot}$

KPI No.	13	Name:	Relative change in thermal energy net consumption		
Sensor:	Q015 Thermal Energy Meter (Wh)			Parameter:	ABSOLUTE VALUE
Sensor:	Q017 Thermal Energy Meter (Wh)			Parameter:	ABSOLUTE VALUE
Sensor:	Q018 Thermal Energy Meter (Wh)			Parameter:	ABSOLUTE VALUE
Sensor:	Q115 Thermal Energy Meter (Wh)			Parameter:	ABSOLUTE VALUE
Sensor:	Q117 Thermal Energy Meter (Wh)			Parameter:	ABSOLUTE VALUE

KPI No.	14	Name:	Energy losses		
Sensor:	*MiniStor_PVT_output*			Parameter:	$E_{el,\ tot}$
Sensor:	*MiniStor_FPC_output*			Parameter:	$Q_{th,\ tot}$
Sensor:	*MiniStor_el_grid*			Parameter:	$E_{el,\ tot}$
Sensor:	Q015 Thermal Energy Meter (Wh)			Parameter:	ABSOLUTE VALUE
Sensor:	Q017 Thermal Energy Meter (Wh)			Parameter:	ABSOLUTE VALUE
Sensor:	Q018 Thermal Energy Meter (Wh)			Parameter:	ABSOLUTE VALUE

Sensor:	Q115 Thermal Energy Meter (Wh)	Parameter:	ABSOLUTE VALUE
Sensor:	Q117 Thermal Energy Meter (Wh)	Parameter:	ABSOLUTE VALUE
Sensor:	G2 building Apparent Energy (KWh)	Parameter:	ABSOLUTE VALUE
Sensor:	G2 building Active Energy (KWh)	Parameter:	ABSOLUTE VALUE

KPI No.	15	Name:	RES on-sit average use
Sensor:	*MiniStor_th_output*	Parameter:	$Q_{th,\ tot}$
Sensor:	*MiniStor_PVT_output*	Parameter:	P_{el}
Sensor:	*MiniStor_FPC_output*	Parameter:	P_{th}

KPI No.	17	Name:	Electrical energy savings
Sensor:	G2 building Apparent Energy (KWh)	Parameter:	ABSOLUTE VALUE
Sensor:	G2 building Active Energy (KWh)	Parameter:	ABSOLUTE VALUE

KPI No.	18	Name:	Change in electrical consumption from grid (kWh)
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el,\ tot}$
Sensor:	G2 building Apparent Energy (KWh)	Parameter:	ABSOLUTE VALUE
Sensor:	G2 building Active Energy (KWh)	Parameter:	ABSOLUTE VALUE

KPI No.	19	Name:	Share of renewables
Sensor:	*MiniStor_PVT_output*	Parameter:	$E_{el,\ tot}$
Sensor:	*MiniStor_FPC_output*	Parameter:	$Q_{th,\ tot}$
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el,\ tot}$

KPI No.	20	Name:	Self-electricity production/ self-sufficiency ratio
Sensor:	*MiniStor_PVT_output*	Parameter:	P_{el}
Sensor:	G2 building Apparent Energy (KWh)	Parameter:	ABSOLUTE VALUE
Sensor:	G2 building Active Energy (KWh)	Parameter:	ABSOLUTE VALUE

KPI No.	21	Name:	Maximum hourly energy surplus/ deficit (kWh)
Sensor:	Q015 Thermal Energy Meter (Wh)	Parameter:	ABSOLUTE VALUE
Sensor:	Q017 Thermal Energy Meter (Wh)	Parameter:	ABSOLUTE VALUE
Sensor:	Q018 Thermal Energy Meter (Wh)	Parameter:	ABSOLUTE VALUE
Sensor:	Q115 Thermal Energy Meter (Wh)	Parameter:	ABSOLUTE VALUE
Sensor:	Q117 Thermal Energy Meter (Wh)	Parameter:	ABSOLUTE VALUE
Sensor:	G2 building Apparent Energy (KWh)	Parameter:	ABSOLUTE VALUE
Sensor:	G2 building Active Energy (KWh)	Parameter:	ABSOLUTE VALUE
Sensor:	*MiniStor_PVT_output*	Parameter:	P_{el}
Sensor:	*MiniStor_th_output*	Parameter:	P_{th}
Sensor:	*MiniStor_FPC_output*	Parameter:	$Q_{th,\ tot}$
Sensor:	*MiniStor_el_grid*	Parameter:	$E_{el,\ tot}$
		Parameter:	*COP (KPI_12)*

KPI No.	23	Name:	System reliability
Sensor:	*MiniStor_status*	Parameter:	*connection*

3.2. Initial calculation of the KPIs

3.2.1. KPI_1, System volume of thermochemical (TCM) material

1. KPI description

The total volume of the uncharged, dried reactive material in the thermochemical storage installed in the MiniStor system.

2. Formula for calculation

$KPI = Volume_{TCM}$

Goal: < 0.6 m^3 (limit defined in GA to meet the expected impact of call)

3. Calculation

The system volume of the TCM is consistent across all demo sites and is 82 litres (0.082 m^3).

4. Discussion

The TCM's system volume, at 0.082 m^3, represents 13.6% of the maximum volume defined by KPI_1. Thus, this KPI_1 can be considered met.

3.2.2. KPI_2, System volume of hot phase change material (PCM) for heating (HW)

1. KPI description

The total volume of solid, hot PCM material (for the residential heating demand) is installed in the MiniStor system.

2. Formula for calculation

$KPI = Volume_{PCM,Heating}$

3. Calculation

The PCM storage units given by provider. have a volume of 185 litres.

4. Discussion

The installed storage units' volume, 185 litres, is significantly smaller than typical thermal storage tanks used in residential environments.

3.2.3. KPI_3, System volume of hot PCM (DHW)

1. KPI description

The total volume of solid, hot PCM material (for the domestic hot water (DHW) demand) that is installed in the MiniStor system.

2. Formula for calculation

$KPI = Volume_{PCM,DHW}$

3. Calculation

The PCM storage units given by the provider hold a volume of 85 litres.

4. Discussion

The installed storage units' volume, 85 litres, is significantly smaller than typical thermal storage tanks used in residential environments.

3.2.4. KPI_4, System volume of cold PCM

1. KPI description

The total volume of solid, cold PCM material installed in the MiniStor system.

2. Formula for calculation

$KPI = Volume_{PCM,Cold}$

3. Calculation

The PCM storage units given by the provider hold a volume of 185 litres.

4. Discussion

–

3.2.5. KPI_5, System volume overall (TCM+PCM)

1. KPI description

The overall volume of TCM and PCMs (heating, domestic hot water, and cooling) installed in the MiniStor System consists of PCM storages for cold, space heating, domestic hot water, and TCM storages.

2. Formula for calculation

$$KPI = Volume_{TCM+PCM} = Volume_{PCM,Cold} + Volume_{PCM,DHW} + Volume_{PCM,Heating} + Volume_{TCM}$$

Goal: < 0.72 m^3 (limit defined in GA to meet the expected impact of call)

3. Calculation

$$KPI = 0.185\ m^3 + 0.085\ m^3 + 0.185\ m^3 + 0.082\ m^3 = 0.537\ m^3$$

4. Discussion

The total volume of the TCM and PCM material, 0.537 m^3, represents 74.6% of the maximum allowed volume, so the KPI is met.

3.2.6. KPI_6, Permissible outdoor temperature range

1. KPI description

The allowed outdoor temperature range for the MiniStor system to operate. The different sub-components are commercial-of-the-shelf and will be chosen to meet this goal.

2. Formula for calculation

Data presented in Sec. 0.
Goal: -20 to +50 °C (typical ambient temperature range rounded to next 10 °C)

3. Calculation

Table 11: Maximum and minimum outdoor temperature in the respective demo sites.

Demo site	Max. temperature [°C]	Min. temperature [°C]
Thessaloniki	38.8	-3.6
Sopron	33.7	-8
Kimmeria	39.8	-2.6
Cork	27.9	0
Santiago de Compostela	34.5	0.8

4. Discussion

Over the past two to three years, the permissible outdoor temperature range has not been exceeded or underrun in any demo site, and the temperatures were monitored on-site. Therefore, this KPI can be considered met.

3.2.7. KPI_8, TCM storage density

1. KPI description

The overall storage density is the fraction of the stored energy per volume of the TCM storage systems.

2. Formula for calculation

$$KPI = m_{NH_3\_cycled} \cdot \frac{\overline{\Delta H}_{reaction}}{V_{Compound} \cdot Mm_{NH_3}}$$

$$with: m_{NH_3\_cycled} = (4 \cdot \Delta X_1 + 2 \cdot \Delta X_2) \cdot N_{Salt} \cdot Mn_{NH_3}$$

$$with:$$

$$\Delta X1 : Advancement\ rate\ of\ the\ first\ reaction$$

$$\Delta X2 : Advancement\ rate\ of\ the\ second\ reaction$$

$$N_{Salt}: Amount\ of\ salt\ in\ the\ system\ [mol]$$

$$Mn_{NH_3}: Molar\ mass\ of\ NH3\ \left[\frac{kg}{mol}\right]$$

$$V_{Compound}: Volume\ of\ compound\ [m^3]$$

$$\overline{\Delta H}_{reaction} : Total\ exothermic\ chemical\ reaction\ \left[\frac{J}{mol}\right] of\ reacting\ NH_3$$

Goal: 205 kWh/m³ (storage density of selected TCM combination with heating capacity only)

3. Calculation

$$m_{NH_3\_cycled} = (4 \cdot 0.95 + 2 \cdot 0.46) \cdot 314\ mol \cdot 0.045 \frac{kg}{mol} = 66.6936\ kg$$

$$KPI = 66.6936\ kg \cdot \frac{42300 \frac{J}{mol}}{0.082\ m^3 \cdot 0.045 \frac{kg}{mol}} = 764'536.39 \frac{kJ}{m^3} = 212.3 \frac{kWh}{m^3}$$

4. Discussion

With a storage density of 212.3 kWh/m³, the density of the TCM exceeds the required value. Therefore, the KPI is met.

3.2.8. KPI_9, Required electric power for peripheral equipment (heat pump)

1. KPI description

The electric power to operate the peripheral equipment's leading consumer (heat pump) connected to the TCM is required to ensure the proper function of the TCM and charge and discharge the PCM vessels. This equipment will be designed to be as efficient as possible. The grant agreement states an indicative value of less than 1 kWe for the heat pump (neglecting power peaks during start-up).

2. Formula for calculation

$$KPI = Power_{heat\ pump}$$

Goal: <1 kWe

3. Calculation

According to the datasheet of the chosen compressor, Dorin 2Q3, the power rating is < 1 kWe.

4. Discussion

With the power rating smaller than 1 kW, i.e. the KPI condition has been met.

3.2.9. KPI_10, PVT efficiency boost

1. KPI description

Modifications of the PVT were developed within the MiniStor framework to improve the energy performance and reduce energy losses of the PVT collectors. This KPI concentrates on the electrical and thermal performance of the improved PVT models developed during the project compared to the existing PVT models before the start of the project.

2. Formula for calculation

$$KPI = \frac{(\mu_{PVT,after} - \mu_{PVT,before})}{\mu_{PVT,before}} \cdot 100\ \%$$

$$with:$$

$\mu_{PVT,before}$: PVT efficiency (sum of electric and thermal efficiency) before the start of the MiniStor project

$\mu_{PVT,after}$: PVT efficiency (sum of electric and thermal efficiency) after the optimisations within the MiniStor project

Goal: 5 % (efficiency improvement target of PVT supplier)

3. Calculation

The total efficiency of PVT c (η_{PVT}) is calculated by adding the thermal and electrical efficiency ($\eta_{PVT,el}$). These values are calculated according to the characterisation and performance equations obtained in T3.3 and T3.4 for the Glazed and Unglazed PVT prototypes, respectively. The corresponding measurements were carried out in a test bench in Endef's facilities following ISO 9806:2014.

The Glazed PVT prototype has been installed in the Thessaloniki, Sopron, and Cork demo sites. The corresponding thermal performance equation was included in D3.4, and it has the following functional form:

$$\eta_{hem} = \eta_0 - a_1\left(\frac{T_m - T_a}{G}\right) - a_2 G\left(\frac{T_m - T_a}{G}\right)^2$$

Where η_{hem} represents the thermal efficiency, η_0 corresponds to the optical efficiency, a_1 and a_2 are the first and second-order thermal loss coefficients, T_m and represents the mean fluid temperature, T_a the ambient temperature and G the global radiation incident on the collector surface. The coefficients obtained are summarised in the following table.

Table 12: Summary coefficients of thermal efficiency equation of the Glazed PVT prototype installed in Thessaloniki, Sopron and Cork demo sites

Description	Value
Type of PVT	Glazed
Optical efficient (η_0)	0.461
Coefficient a1	3.22 W / m^2 / K

The unglazed PVT prototype has been installed at the Santiago (USC) demo site. The corresponding thermal efficiency equation was included in D3.6, and it is shown in the following:

$$\eta_{hem} = \eta_0(1 - b_u u) - (b_1 + b_2 u)\left(\frac{T_m - T_a}{G"}\right)$$

Where u represents the wind speed, η_0 corresponds to the optical efficiency of the PVT collector, b_1 is a first-order thermal loss coefficient, b_2 is a second thermal loss coefficient dependent on wind speed and y b_u is a dimensionless coefficient. It also depends on wind speed, which affects the optical efficiency of the PVT collector. Like the glazed PVT collector, T_m represents the mean fluid temperature, and T_a is the ambient temperature $G"$, which is the net irradiance, estimated at 85 W / m^2 below the incident solar irradiance G. The coefficients obtained in this case are summarised in the following table.

Table 13: Summary coefficients of thermal efficiency equation of the Unglazed PVT prototype installed in Santiago demo sites

Description	Value
Type of PVT	Unglazed
Optical efficient (η0)	0.593
Coefficient b1	8.44 W / m^2 ·K
Coefficient b2	0.66 W·s / m^3 ·K
Coefficient bu	0.0138 s / m

For both prototypes (Glazed and Unglazed), the electrical efficiency (η_{el}) is obtained by the following equations, also included in D3.4 and D3.6.

$$\eta_{el} = {}^{P}/_{(A_G \cdot G)}$$

$$P = P_{MPP}\cdot\left(1 - \beta\,(T_{CELL} - 25)\right)\cdot(G/1000)$$

$$T_{cell} = T_{a,cell} + G\,\frac{NOTC\ - 20}{800}$$

The power produced by the PVT prototype A_G is the gross area of PVT, G the incident irradiance, P_{MPP} and corresponds to the power at the maximum power point. Under standard testing conditions (STC), β the power temperature coefficient specified by the PV laminate manufacturer T_{cell} is the PV cell temperature under operation conditions. The cell temperature is obtained through the ambient cell temperature ($T_{a,cell}$), the normal operation temperature cell ($NOTC$) and the solar incident irradiance. The ambient cell temperature is estimated as the fluid temperature for the glazed PVTs and the average between the ambient temperature and the fluid temperature for the unglazed PVTs. The following table summarizes electrical parameters used to calculate electrical efficiency for each PVT prototype.

Table 14: Summary of electrical parameters of the PVT prototypes used in the KPIs calculation

Description	Unit	Glazed PVT prototype	Unglazed PVT prototype
Gross area	m2	1.61	1.65
Power MPP ($\boldsymbol{P_{MPP}}$)	W	270	390
Temperature coefficient of P_{MPP} ($\boldsymbol{\beta}$)	% / K	-0.40	-0.34%
Temperature NOTC	°C	42±2	42.3±2

To compare the PVT efficiency values before and after the MiniStor project, a reference operation condition is selected, considering the standard operation conditions of the PVTs. The following table summarises that these operation conditions are specified according to the difference between fluid and ambient temperature (ΔT), solar incident irradiance (G), wind velocity (u), mass flow rate $(\dot{m})$, and the PVT collector type.

Table 15: Operation conditions of the PVT prototypes used in the KPIs calculation

PVT Prototype	Operation conditions	Related Pilots
Glazed PVT	$T_m = 60°C$ $\Delta T = 35°C$ $G = 1000\,W/m^2$ $\dot{m} = 120\,kg/h$	Thessaloniki, Sopron, Cork
Unglazed PVT	$T_m = 50°C$ $\Delta\theta = 25°C$ $G = 1000\,W/m^2$ $u = 1\,m/s$ $\dot{m} = 100\,kg/h$	Santiago

The following table presents the efficiency calculations for both prototypes developed in the MiniStor project and installed in the demo sites, according to the previous calculation method and the operation conditions.

Table 16: Summary of efficiencies of PVT prototypes before and after the MiniStor Project

PVT collector type	Efficiency PVT before			Efficiency PVT after			Efficiency variation [%]
	$\eta_{PVT,th}$	$\eta_{PVT,el}$	$\eta_{PVT,before}$	$\eta_{PVT,th}$	$\eta_{PVT,el}$	$\eta_{PVT,after}$	
Glazed PVT	0.262	0.131	0.393	0.244	0.139	0.383	-2.5%
Unglazed PVT	0.084	0.175	0.259	0.090	0.191	0.281	8.5%

4. Discussion

Under operating conditions, the electrical efficiency of the glazed PVT increases by 6.15%, while the thermal efficiency drops by 6.9% due to variations in the manufacturing process, which reduces energy consumption and improves the collector's useful lifespan. Overall efficiency decreases by 2.5%. However, the modified manufacturing process enhances the PVT collector's durability and reliability.

Regarding the unglazed PVT prototype implemented at the Santiago demo site, the thermal and electrical efficiency increased by 8.2 and 8.6%, respectively, under the system operating conditions. The overall efficiency of the PVT increases by 8.5%, mainly due to the improvement of the thermal absorber as well as the new PV laminate used in the developed PVT prototype.

4. Conclusions

In conclusion, this document highlights the preliminary assessment of KPIs before installing the MiniStor system. The baseline data collected from the demo sites provides crucial information on energy consumption and outdoor temperature, laying a foundation for future comparisons. The monitoring data quality was generally consistent, though some variations in data coverage were observed across sites due to local conditions and technical challenges.

The initial KPIs were calculated to confirm that the MiniStor system is on track to meet its objectives, particularly regarding system volume and permissible temperature range. These early results provide confidence that the MiniStor system will perform effectively once installed and operational. For KPIs that require the system's active operation, the document establishes a clear linkage between the necessary data and the specific KPIs, ensuring that future evaluations will be comprehensive and reliable.

This initial assessment underscores the importance of precise data monitoring and establishes a solid framework for evaluating the MiniStor system's impact on energy efficiency and sustainability in diverse climatic settings. Future reports will build on this groundwork to provide a more detailed analysis of the system's effectiveness.