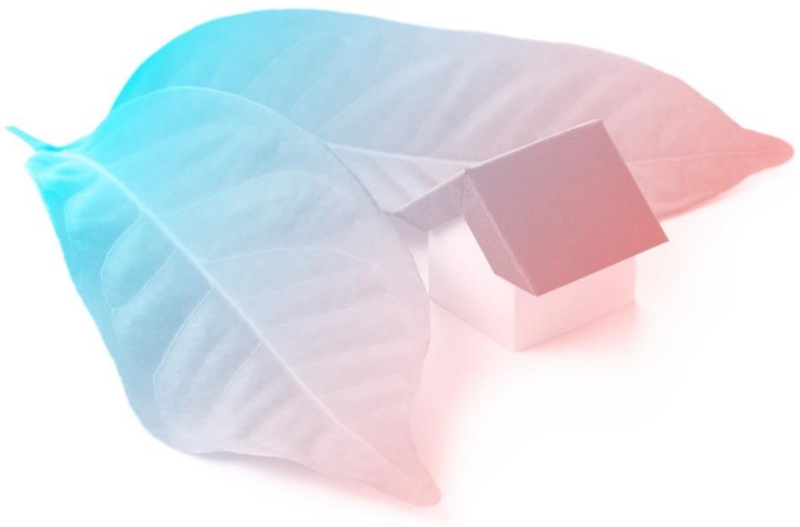
D6.1
Design of the monitoring system and KPI definition



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Summary

This deliverable presents the key performance indicators (KPI) that will be used to quantify the performance of the MiniStor system. The KPIs have been selected based on a literature review, a survey among project partners as well as indicators initially defined in the grant agreement. For each KPI, the required input (measurement) values are determined, and a calculation procedure is defined. Many of these KPIs will be measured through a monitoring system also specified in this document. This report also presents the monitoring system architecture, the selected hardware and the data flow process to collect the variables in order to aggregate, transmit and store them in a cloud-based IoT platform for data visualisation and analysis in compliance with relevant data safety measures. As each demonstration site has its site-specific features, the monitoring systems were adjusted to the requirements of each site. The respective adjustments have been described as well.

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List of Abbreviations and Acronyms

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

DHW	Domestic hot water
GHG	Green-house gas
KPI	Key performance indicator
PCM	Phase change material
PVT	Photovoltaic-thermal panels
TCM	Thermochemical storage

The source of the individual KPIs indicated in the tables are:

GA	Grant Agreement
LI	Literature review
PA	Partners' input
EU	(Potential) End-Users input

1 Introduction

Minimal Size Thermal and Electrical Energy Storage System for In-Situ Residential Installation (MiniStor) offers a sustainable solution to improve the energy efficiency potential of the European building stock. During the development of the project, the MiniStor system will be 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 6.1: Design of the monitoring, definition of KPIs and design of remote data access. The main objective of this Deliverable 6.1 is twofold: First, to define the key performance indicators used for the quantification of the performance of the MiniStor system. Second, to describe the monitoring strategy chosen to measure the required input data and to describe the calculation methodology to determine the respective key performance indicators. The key performance indicators (KPIs) are defined (cf. Sec. 2.2) to evaluate the performance of the system in terms of energy savings and its influence on the indoor environment of the household. The KPIs are categorised in technical (efficiency, smart readiness), comfort and acceptance, regulatory, economic (cost effectiveness), and environmental (eco-friendliness) aspects. The KPIs defined here have been selected according to three non-exclusive conditions: a first set of KPIs was analysed based on the grant agreement, a second set was determined from literature review and a third set was selected based on partner experience for KPIs that had not been covered in the previous two stages. For each KPI selected, a calculation procedure is defined and the required input data is determined. The set of required input parameters then form the key inputs for the specification of the monitoring system.

An advanced monitoring system for the measurement of indoor and outdoor parameters (predominately relative humidity, temperature, heat flows, and electricity consumption) is specified. To ensure a central storage of the recorded monitoring data, which will also comply with relevant data regulations, a data flow process is defined to collect the measurement data onsite, aggregate it locally and then transmit it to a cloud storage, visualisation, and monitoring system. Given site-specific requirements, the monitoring system had to be adjusted for each site individually. These monitoring systems provide the necessary data for the calculation of the current KPIs and the calculation of the KPIs after the MiniStor system has been installed in the building. The structure of this system and the definition of the handling of the data is described in this document.

The content of this document serves as a basis for the determination and analysis of the KPIs in T6.5 "KPIs measurement and analysis". In addition, the definition of the KPIs enables a feasibility study of the installation of the MiniStor system throughout Europe, which will be evaluated in T6.6 "Replication feasibility analysis". After the analysis of the KPIs and their changes before and after the installation of MiniStor (T6.5), a statement about the ideal building typologies for the system is facilitated and eventual renovation steps before the use of MiniStor can be identified.

2 Key Performance Indicators (KPI)

The key performance indicators (KPI) serve four different purposes:

a) Assess whether the MiniStor system meets the requirements defined in the grant agreement
b) Quantify the performance of the MiniStor system in the field-tests on the demonstration sites
c) Assess the performance of MiniStor against comparable thermal storage systems
d) Evaluate possible areas for MiniStor improvement

The KPIs under point a) are of fail/pass type. The KPIs type b) to d) are quantitative. Most of the KPIs have a well-defined target value (hereafter referred to as "goal"). In Sec. 2.1., the methodology how the KPIs were selected is described in detail. In Sec. 2.2., the selected KPIs are described, defined and (if applicable) numerical procedures for its computation are given. This section also lists the required input data/information for the determination of the KPI values. In Sec. 2.3., the approach chosen to determine the input values from actual monitoring data of the demonstration sites is described.

2.1 Methodology for identification of Key Performance Indicators (KPI)

This section provides an overview how the Key Performance Indicators (KPI) were selected. A first category of KPIs has been selected based on their appearance in the grant agreement (marked as "GA" source). In case target values have been set already in the grant agreement, these values have been included in the KPI definition as well. Afterwards, these KPI have been ordered according to classification schemes found in literature. Four categories can be described: economic KPI, environmental KPI, socio-cultural KPI, technical KPI, which were adopted from (Alwaer & Clements-Croome, 2010). A fifth category is created to consider the impact of legal aspects, regulatory boundary conditions and safety-related aspects. Furthermore, the selection of KPIs has been expanded based on a short literature review as described in Sec. 2.1.1. Eventually, the list of KPI has been completed based on the results of a second class of KPI which was defined based on a survey among the project partners and potential end-users. The approach is described in Sec. 2.1.2.

2.1.1 Bibliographic approach

Despite a vast literature on building monitoring studies as well as monitoring techniques (cf. for instance (Ahmad, Mourshed, Mundow, Sisinni, & Rezgui, 2016) for a recent review), only few studies on generic concepts and ontologies of building performance indicators were found (Alwaer & Clements-Croome, 2010; Mahdavi & Wolosiuk, 2019; Maslesa, Jensen, & Birkved, 2018). A key study for the selection of the KPI described here is the study (Alwaer & Clements-Croome, 2010), which categorizes the KPIs into four distinct classes:

- Environmental KPI such as energy and natural resources usage.
- Socio-cultural KPI such indoor environment quality and comfort.
- Economic KPI such as economic performance and affordability.
- Technical KPI such as controllability.

To account also for potential risks caused by the new technologies and paradigms of the MiniStor concept a fifth category has been added:

- Legal/safety related KPI such as compliance of the system to local legal and regulatory boundary conditions as well as planning requirements from local authorities. This point also includes performance requirements set by national and international standardisation bodies that guarantee safety and orderly operation.

The basic set of indicators has been selected by the review article of Maslesa et al. (Maslesa et al., 2018). The KPI selected from literature review are indicated by the source "LI" in Sec. 2.2.

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2.1.2 Review of KPIs based on partners' experience

Complementary KPIs were formulated by project partners based on their experience in similar research projects and designing storage systems.

The selected KPIs are described in Sec. 2.2. The KPIs have been organised in different categories and each category is presented individually: technological (Sec. 2.2.1), comfort and acceptance (Sec. 2.2.2), legal/ safety-related (Sec. 2.2.3), environmental (Sec. 2.2.4) and economic (Sec. 2.2.5).

2.2 Description of the Key Performance Indicators (KPI)

2.2.1 Technological related KPIs

In Table 1, the considered technologically related key performance indicators (KPI) are presented, the required input is described as well as the procedure for their calculation. In case target values (goal) are indicated, they are based on a generic dwelling typology with 80 m^2 living area. This size is chosen due to the size of the smallest demonstration site. Following is a description of the technological related KPIS's and their calculation:

Table 1: Definition of technological key performance indicators.

<table>
<tr><td>KPI_1</td><td>System volume of TCM</td><td>Source: GA</td></tr>
<tr><td colspan="2">The total volume of the uncharged, dried reactive material in the thermochemical storage that is installed in the MiniStor system.

Required Input: None</td><td>*Calculation of KPI from input:*
$KPI = Volume_{TCM}$

Goal: < 0.6 m^3 (limit defined in GA to meet expected impact of call)</td></tr>
<tr><td>KPI_2</td><td>System volume of hot PCM (HW)</td><td>Source: LI</td></tr>
<tr><td colspan="2">The total volume of solid, hot PCM material (for the residential heating demand) that is installed in the MiniStor system.

Required Input: None</td><td>*Calculation of KPI from input:*
$KPI = Volume_{PCM,Heating}$</td></tr>
<tr><td>KPI_3</td><td>System volume of hot PCM (DHW)</td><td>Source: LI</td></tr>
<tr><td colspan="2">The total volume of solid, hot PCM material (for the domestic hot water (DHW) demand) that is installed in the MiniStor system.

Required Input: None</td><td>*Calculation of KPI from input:*
$KPI = Volume_{PCM,DHW}$</td></tr>
<tr><td>KPI_4</td><td>System volume of cold PCM</td><td>Source: LI</td></tr>
<tr><td colspan="2">The total volume of solid, cold PCM material that is installed in the MiniStor system.
Required Input: None</td><td>*Calculation of KPI from input:*
$KPI = Volume_{PCM,Cold}$</td></tr>
<tr><td>KPI_5</td><td>System volume overall (TCM + PCM)</td><td>Source: GA</td></tr>
<tr><td colspan="2">The overall volume of TCM and PCMs (heating domestic hot water and cooling) installed in the MiniStor System consisting of PCM storages for cold, space heating, domestic hot water and the TCM storages.

Required Input: None</td><td>*Calculation of KPI from input:*
$KPI = Volume_{TCM+PCM} = Volume_{PCM,Cold} + Volume_{PCM,DHW} + Volume_{PCM,Heating} + Volume_{TCM}$
Goal: < 0.72 m^3 (limit defined in GA to meet expected impact of call)</td></tr>
<tr><td>KPI_6</td><td>Permissible outdoor temperature range</td><td>Source: GA</td></tr>
</table>

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<table>
<tr><td>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.
Required Input:
- Permissible outdoor temperature range for commercial-of-the-shelf sub-components</td><td>Calculation of KPI from input:
- None

Goal: -20 to +50 °C
(typical ambient temperature range rounded to next 10 °C)</td></tr>
<tr><td colspan="2">KPI_7 Overall storage density Source: GA</td></tr>
<tr><td>The overall storage density for heating/cooling is defined as the fraction of the stored heating energy per volume of the storage systems.

Required Input: None</td><td>Calculation of KPI from input:
$$KPI = \frac{Q_{TCM} + Q_{PCM,Hot} + Q_{PCM,Cold}}{Volume_{TCM+PCM}}$$
With
Q_{TCM}: The energy in TCM storage when lifting the temperature from 15 °C to 70 °C.
$Q_{PCM,Cold}$: The energy storage in the cold PCM storage from 0 °C to 70 °C.
$Q_{PCM,Hot}$ The energy storage in the hot PCM storage (DHW + heating) from 0 °C to 70 °C.

Goal: 182 kWh/m^3 (storage density achievable with selected material combination with heating capacity only)</td></tr>
<tr><td colspan="2">KPI_8 TCM storage density Source: GA</td></tr>
<tr><td>The overall storage density is defined as the fraction of the stored energy per volume of the TCM storage systems.
Required Input:
$\Delta X_1: Advancement\ rate\ of\ the\ first\ reaction$
$\Delta X_2: Advancement\ rate\ of\ the\ second\ reaction$
$N_{Salt}: Amount\ of\ salt\ in\ the\ system\ [mol]$
$Mm_{NH_3}: Molar\ mass\ of\ NH_3\ [kg/mol]$
$V_{Compound}: Volume\ of\ compound\ [m^3]$
$\overline{\Delta H}_{reaction}: Total\ exothermic\ quemical\ reaction\ [J/mol\ of\ reacting\ NH_3]$</td><td>Calculation of KPI from input:
$$KPI = m_{NH_3\_cycled} \cdot \frac{\overline{\Delta H}_{reaction}}{V_{Compound} \cdot Mm_{NH_3}}$$
$$with\ m_{NH_3\_cycled} = (4 \cdot \Delta X_1 + 2 \cdot \Delta X_2) \cdot N_{Salt} \cdot Mn_{NH_3}$$

Goal: 205 kWh/m^3
(storage density of selected TCM combination with heating capacity only)</td></tr>
<tr><td colspan="2">KPI_9 Required electric power for peripheral equipment (heat pump) Source: GA</td></tr>
<tr><td>The electric power to operate the main consumer of the peripheral equipment (heat pump) connected to the TCM. This equipment is required to ensure a proper function of the TCM and to charge and discharge the PCM vessels. It 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 heat pump start-up).</td><td>Required input: datasheet

Calculation of KPI from input:
$$KPI = Power_{heat\ pump}$$
Goal: <1 kWe</td></tr>
<tr><td colspan="2">KPI_10 PVT efficiency boost Source: GA</td></tr>
<tr><td>To improve the energy performance and to ensure a reduction of energy losses of the PVT collectors, modifications of the PVT will be developed within the MiniStor framework. This KPI concentrates on the electrical and thermal performance of the improved PVT models developed during the project against the already existing PVT models before the start of the project.</td><td>Required input:
- $\mu_{PVT,before}$: 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
Calculation of KPI from input:</td></tr>
</table>

	$$KPI = \frac{(\mu_{PVT,after} - \mu_{PVT,before})}{\mu_{PVT,before}} \cdot 100\ \%$$ *Goal:* 5 % (efficiency improvement target of PVT supplier)
KPI_11 Absolute thermal energy savings	Source: PA
Change of thermal energy consumption to satisfy the heat/cooling demand of the building normalised with respect to different climatic conditions (weather influence) and usage influence (change of the number of inhabitants). The energy consumption is calculated over 6 months or the longest possible comparable period in which the MiniStor system is running respectively not running. *Required Input:* - Q_{before} energy consumption of building's heating/cooling system gefore MiniStor is installed/operational. - Q_{after} energy consumption of heating / cooling system when MiniStor is operated (during a comparable period compared to Q_{before}).	*Required input: Thermal consumption of the demo site.* *Calculation of KPI from input:* $$KPI = (Q_{before} - Q_{after})$$ *(KPI_11 is closely related to KPI_13 as being the absolute difference compared to the relative difference)*
KPI_12 Overall coefficient of performance	Source: GA
The coefficient of performance (COP) indicates how much electrical power is required to generate the heating power and is defined as fraction of generated heat over electricity consumed. *Required input:* - $E_{el,tot}$: Overall electrical consumption of MiniStor during heating season. - $Q_{heat,tot}$: Overall provided heating energy of MiniStor during heating season.	*Calculation of KPI from input:* $$COP_{tot} = \frac{Q_{heat,tot}}{E_{el,tot}}$$ *Goal:* COP > 1.8
KPI_13 Relative change in thermal energy net consumption	Source: GA
Relative change of thermal energy consumption with respect to the final heat/cooling energy consumption to satisfy the heat/cooling demand of the building normalised with respect to different climatic conditions (weather influence) and usage influence (change of the number of inhabitants). The energy consumption is calculated over 6 months or the longest possible comparable period in which the MiniStor system is running respectively not running. *Required Input:* - Q_{before} Energy consumption of building's heating/cooling system gefore MiniStor is installed/operational.	*Calculation of KPI from input:* $$KPI = \frac{(Q_{before} - Q_{after})}{Q_{after}} \cdot 100\ \%$$ *Goal:* >= 40 % (share promised in project acquisition)

- Q_{after} energy consumption of heating / cooling system when MiniStor is operated (during a comparable period compared to Q_{before}).		
KPI_14	Energy losses	Source: LI
The energy losses are determined as the difference between 1) the energy collected by the solar panels or supplied by the electrical grid and 2) the energy consumed to provide electricity, heating, and cooling to the building. *Required Input:* - E_{solar} electrical energy collected by PVT panels. - Q_{solar} heat collected by PVT panels and solar thermal collectors. - E_{grid} electrical energy extracted from the grid. - Q_{gas} heat injected into energy system from gas boiler. - $Q_{demand,heating/cooling}$ heating /cooling energy demand of the demonstration site. - $E_{demand,residential}$ electrical energy demand of the demonstration site.	*Calculation of KPI from input:* $E_{demand} = Q_{demand,heating/cooling} \mp E_{demand,residential}$ $E_{supply} = E_{grid} + E_{solar} + Q_{solar} + Q_{gas}$ $KPI = \frac{E_{supply} - E_{demand}}{E_{supply}} \cdot 100\%$	
KPI_15	RES on-site average use	Source: GA
The KPI is the fraction of the time the renewable energy systems (RES) is used, based on the heating and cooling demand. The final value highly depends on building characteristics and available space for RES generation. *Required Input:* - T_{RES} time of activity of renewable energy system. - T_{NES} time of activity of non-renewable energy system.	*Calculation of KPI from input:* $KPI = \frac{T_{RES}}{T_{RES} + T_{NES}} \cdot 100\ \%$ *Goal:* 50 %	
KPI_16	Better visualization of design options for retrofit of existing heating/ cooling system	Source: GA
This KPI assess the feedback of end-users, and suppliers to the new visualization to the new design and retrofitting options.	Goal: measured in Likert Scale[1]= "Strongly Agree" (4.5/5), easy and fast access.	
KPI_17	Electrical energy savings	Source: LI
The relative change in electrical consumption between the situations with and without MiniStor system relative to the final electrical energy consumption. The energy consumption is calculated over 6 months or the longest possible comparable period in which the MiniStor system is running respectively not running. *Required Input:*	*Calculation of KPI from input:* $KPI = \frac{(E_{after} - E_{before})}{E_{after}} \cdot 100\ \%$	

[1] Cf. (Likert, 1932)

<table>
<tr><td>- E_{before} electrical energy consumption from the grid while MiniStor is not running.
- E_{after} electrical energy consumption from the grid while MiniStor is running (over a period comparable to E_{before}).
The respective values will be corrected for changes in different usage patterns.</td><td>Goal: < 0 %

(the overall aim is to reduce the grid's electricity consumption while reducing the green house gas emissions)</td></tr>
<tr><td colspan="2">KPI_18 — Change in electrical consumption from grid (kWh) — Source: GA</td></tr>
<tr><td>This KPI measures how much the electrical energy is taken from the grid. This KPI will serve to compare by how much the energy import from the grid could be reduced by the installation of the MiniStor system.

Required Input:
- E_{before} electrical energy consumption from the grid while MiniStor is not running.
- E_{after} electrical energy consumption from the grid while MiniStor is running (over a period comparable to the one used to calculate E_{before}).</td><td>Required Input:
E_{grid} electrical consumption from the grid.

Calculation of KPI from input:

$$KPI = E_{after} - E_{before}$$</td></tr>
<tr><td colspan="2">KPI_19 — Share of renewables — Source: LI</td></tr>
<tr><td>Fraction of renewable energy sources used to operate the MiniStor system.

Required Input:
- $E_{renewables}$ electrical and thermal demand of the MiniStor system.
- E_{grid} electrical energy extracted from the grid by the MiniStor system.</td><td>Calculation of KPI from input:

$$KPI = \frac{E_{renewables}}{E_{renewables} + E_{grid}} \cdot 100\ \%$$
(the aim is to maximise this KPI. As its value depends strongly on the location and the weather conditions, no target is indicated)</td></tr>
<tr><td colspan="2">KPI_20 — Self-electricity production/ self-sufficiency ratio — Source: PA</td></tr>
<tr><td>Percentage of electricity consumption consumed electrical energy that is produced by the PVT panels.

Required Input:
- $E_{renewables}$ electrical production of the PVTs.
- E_{grid} electrical energy extracted from the grid not consumed by the MiniStor system.</td><td>Calculation of KPI from input:

$$KPI = \frac{E_{renewables}}{E_{renewables} + E_{grid}} \cdot 100\ \%$$</td></tr>
<tr><td colspan="2">KPI_21 — Maximum hourly energy surplus/ deficit (kWh) — Source: PA</td></tr>
<tr><td>Maximum hourly surplus or deficit of energy stored by the MiniStor system compared to demand in the respective moment.
Required Input:
- E_{demand} electrical and thermal demand of the building at the considered moment.
- $E_{MiniStor}$ energy stored/produced by MiniStor.</td><td>Calculation of KPI from input:

$$KPI = E_{MiniStor} - E_{demand}$$</td></tr>
<tr><td colspan="2">KPI_22 — Expected lifetime — Source: GA</td></tr>
<tr><td>The expected lifetime of the system based on estimations of the individual components.

Required Input:</td><td>Calculation of KPI from input: None

Goal: > 20 years</td></tr>
</table>

- Component manufacturers' details on life expectancy.	(typical lifetime expectation for HVAC systems)
KPI_23 System reliability	Source: PA
This KPI quantifies the system's reliability by calculating the share of the time the system is performing its intended tasks compared to the time the system is operated. *Required input:* - $T_{operational}$ time the MiniStor system was operational (storing or ready to store energy). - $T_{installed}$ time the MiniStor system was installed.	*Calculation of KPI from input:* $$KPI = \frac{T_{operational}}{T_{installed}}$$

2.2.2 Comfort and acceptance KPIs

In Table 2, the comfort and acceptance key performance indicators (KPI) will be defined, and their assessment/calculation method will be defined. These KPIs encompass on side KPIs that will be calculated specific for the individual demonstration sites (KPI_24 – KPI_26) as well as KPIs that will be determined based on dissemination activities of the project (KPI_27).

Table 2: Definition of comfort and acceptance key performance indicators.

KPI_24 User acceptance of MiniStor (inhabitants)	Source: GA
The degree of acceptance of MiniStor energy storage system by its users. *Required input:* - acc_i answer of the i inhabitant regarding the system acceptance, expressed on a scale of 1 (very low acceptance) to 10 (very high acceptance). - $N_{users,q}$ number of inhabitants providing feedback.	*Calculation of KPI from input:* $$KPI = \frac{\sum_{i=1}^{N_{users,q}} acc_i}{N_{users,q} \cdot 10}$$ *Goal:* exceeding 95 % (only 1 out of 20 persons rejects the MiniStor system)
KPI_25 Thermal comfort preservation as reported by active users after demonstration activities	Source: GA
Assessment of the thermal comfort preservation achieved by MiniStor, as reported by its users. *Required input:* - $TC_{i,x}$ answer of the i inhabitant regarding the thermal comfort preservation, expressed on a scale of 1 (very low thermal comfort) to 10 (very high thermal comfort) under situation x (before, after). - $N_{users,q}$ number of inhabitants providing feedback.	*Calculation of KPI from input:* $$TC_x = \frac{\sum_{i=1}^{N_{users,q}} TC_{i,x}}{N_{users,q} \cdot 10}$$ $$KPI_{thermal\ comfort} = \frac{TC_{after}}{TC_{before}}$$ *Goal:* above 95 % (only 1 out of 20 persons notices a difference in the thermal comfort)
KPI_26 Change in perceived thermal comfort, indoor temperature and humidity variability	Source: LI
Evaluation of the change of the perceived thermal comfort, variability of the indoor room temperature and humidity achieved with the MiniStor system. Due to the limited number of inhabitants only the change	*Calculation of KPI from input:*

<table>
<tr><td>in the qualitative feedback will be considered instead of standardised procedures such as Fanger's method[2].

Required input:
- Assessment of indoor temperature and humidity variability by the demonstration site inhabitants.
- Temperature values measured in the rooms of each demo site.
- Relative humidity values measured in the rooms of each demo site.</td><td>The change in the qualitative feedback from the demo site inhabitants as provided in the questionnaire will be the key input for this KPI. In case the quality and quantity of the measurements of temperature and humidity is sufficient, the change in the variability will provide a second contribution to this the KPI.</td></tr>
<tr><td colspan="2">KPI_27 Number of users involved in demonstration activities Source: GA</td></tr>
<tr><td>The number of participants that will be involved in demonstration and/or dissemination activities such as homepage visitors, webinars, trade shows, conferences etc.

Required input:
- N_d number of participants (input from WP8).</td><td>Calculation of KPI from input:

$KPI = N_d$

Goal: at least 1000 participants.
(at least 20 dissemination events (conferences, webinars, workshops) with on average 50 participants.</td></tr>
</table>

2.2.3 Compliance with KPIs related to standards and regulations

To guarantee a safe operation of MiniStor, there are multiple standards and regulations that the system must comply with. These are KPIs with a pass/fail criterion, which indicates fulfilment of the requirements stated in relevant local, national and European regulations. While standards are not of mandatory compliance, they nevertheless ensure that quality is kept to a high level. In addition, the compliance with national regulations is assessed. This work will be dealt in more detail in tasks T2.5 "Safety and maintenance requirements" and T4.5 "Safety assessment for NH3 handling". The compliance of the machinery room is also included here as a KPI and further explored in T2.3. "Highlights for designing of a machinery room in a container-based in European Standard 378".

Table 3: Definition of legal key performance indicators.

<table>
<tr><td colspan="2">KPI_28 Compliance with safety standards for NH3 usage and storage Source: GA</td></tr>
<tr><td>Pass/Fail criterion whether the MiniStor system complies with the local legal/safety regulations as well as national compulsory regulations. In addition, also the overlap with national standards will be investigated.</td><td>Compliance with European standard EN 378:2016 for relevant refrigerant requirement</td></tr>
<tr><td colspan="2">KPI_29 Compliance with safety standards for use a container as a machinery room Source: GA</td></tr>
<tr><td>Pass/Fail criterion whether the MiniStor system complies with the sections of the European standard EN 378-3 considered relevant to use the TCM container in a machinery room due to the use of ammonia as a refrigerant.</td><td>Compliance with European standard EN 378-3 for relevant refrigerant requirement</td></tr>
<tr><td colspan="2">KPI_30 Compliant to building and planning regulations to the installation of the system Source: GA</td></tr>
<tr><td>Pass/Fail criterion whether the MiniStor system complies with the planning regulations that apply for renewable systems and for the installation regional or/and local level as well as national compulsory</td><td>- Compliance with the national building and/or energy regulations to get approved installation in the demonstration site from the correspondent authority.</td></tr>
</table>

[2] Fanger, P Ole (1970). Thermal Comfort: Analysis and applications in environmental engineering. McGraw-Hill.

regulations. In addition, also the overlap with national standards will be investigated.	- Compliance with the regional and/or local energy and building regulations to be approved for installation in the demonstration site from the municipality or any other authority.

2.2.4 Environmental KPIs

The environmental KPIs refer to the reduction in the generation of Greenhouse gases and usage of fossil fuels for heating and for electrical consumption. A direct one-to-one comparison of these indicators before and after the installation of the MiniStor system is not possible because the environmental conditions (weather, usage, etc.) will be different. Therefore, the KPIs for the period after the MiniStor system installation will be calculated from the actual measurement values. As the environmental conditions during the assessment period without the MiniStor system will be different compared to the period before the MiniStor installation, the consumption values will be corrected for the influence of different weather and usage. The KPI values will then be calculated between the uncorrected input values of the period after the MiniStor system installation and the corrected values before the MiniStor installation.

Table 4: Definition of environmental key performance indicators.

KPI_31	Reduced fossil fuel consumption (kg/ year) Source: GA
This KPI quantifies the relative change of the fossil fuel consumption per year before and after the installation of the MiniStor system with respect to the final fuel consumption. *Required input:* - m_{before} mass of oil-equivalent fossil fuel consumed per year before the installation of the MiniStor corrected for environmental difference - m_{after} mass of oil-equivalent fossil fuel consumed per year after the installation of the MiniStor	*Calculation of KPI from input:* $KPI = \frac{m_{before} - m_{after}}{m_{after}} \cdot 100\ \%$ Goal: Expected reduction of up to 25% energy consumption assuming an average of 75% of energy coming from fossil fuels. (estimated improvement based on theoretical calculations for MiniStor system)
KPI_32	**Reduction of GHG emissions Source: GA**
This KPI quantifies the reduction of the greenhouse gas (GHG) emissions per year before and after the installation of the MiniStor system. *Required input:* - n_{before} mass of CO2-equivalent emissions of GHG per square meter area and demonstration site per year before the installation of the MiniStor corrected for environmental difference - n_{after} mass of CO2-equivalent emissions of GHG per square meter area and demonstration site per year after the installation of the MiniStor	*Calculation of KPI from input:* $KPI = n_{before} - n_{after}$ *Goal*: 31.87 kg CO_2 eq/m^2/year on average for all demonstration sites (calculated impact from exchange of conventional fossil-based burner to MiniStor solution)

2.2.5 Economic KPIs

The calculation of the economic KPIs require both the analysis of monitoring data as well as the integration of installation and operation costs for the individual demonstration sites. As the costs are strongly dependent on the demonstration site, a careful analysis of the impact of the geographical location of the demonstration site will be required.

Table 5: Definition of economic key performance indicators.

<table>
<tr><td>KPI_33</td><td>Total capital cost per kW installed</td><td>Source: PA</td></tr>
<tr><td colspan="2">Expected total cost of the system evaluated in relation to the maximum power in kW.

Required input:
- $C_{capital}$ Capital cost (includes delivery and installation costs) [€]
- P_{kW} Power of the system [kW]</td><td>Calculation of KPI from input:
$$KPI = \frac{C_{capital}}{P_{kW}}$$</td></tr>
<tr><td>KPI_34</td><td>Reduction in construction costs</td><td>Source: GA</td></tr>
<tr><td colspan="2">This KPI measures the relative reduction in the construction cost of the MiniStor system relative to the MiniStor installation costs due to MiniStor solutions: pre-assembled components, AR/VR mounting support and prefabricated system modules. A major challenge in the calculation of this KPI is the estimation of the installation costs without the MiniStor solution because multiple concurrent solutions exist. Here, the costs are estimated based on the installation costs of a comparable system that is supported / exchanged by MiniStor.

Required input:
- $C_{conventional}$ Estimated installation costs of the components according to suppliers' estimation to an equivalent power output system.
- $C_{MiniStor}$ Installation costs of MiniStor system averaged for each different demonstration sites.</td><td>Calculation of KPI from input:
$$KPI = \frac{C_{conventional} - C_{MiniStor}}{C_{MiniStor}} \cdot 100\,\%$$
Goal: 20 %
(typical cost reduction in other solutions where the suggested technologies have been employed)</td></tr>
<tr><td>KPI_35</td><td>Operational cost (Euros/kWh)</td><td>Source: LI/PA</td></tr>
<tr><td colspan="2">The operational cost is the sum of the costs (O&M, energy consumed, spare parts, etc.) necessary to maintain the system operative.
Required input:
- $C_{operation}$ Total operational cost during 1 year [€]
- E_{kWh} Energy provided by the system during 1 year[kWh]</td><td>Calculation of KPI from input:
$$KPI = \frac{C_{operation}}{E_{kWh}}$$</td></tr>
<tr><td>KPI_36</td><td>Payback period (in years)</td><td>Source: GA/PA</td></tr>
<tr><td colspan="2">The payback period or Pay Back Time (PBT) is the amount or time necessary to recover the initial investment compared to the generated cash flow. It measures the length of time to reach the break-even point.

Required input:
- $C_{capital}$ Capital cost [€]
- CF_y Annual cash flow [€]</td><td>Calculation of KPI from input:
$$PBT = \frac{C_{captial}}{CF_y}\ [y]$$
Goal: 6.7 a
(estimated payback period based on estimated energy and cost savings)</td></tr>
<tr><td>KPI_37</td><td>Reduction of energy cost (Euros)</td><td>Source: GA</td></tr>
<tr><td colspan="2">The reduction of energy cost defines the difference of cost for 1 kWh of energy obtained with MiniStor (improved scenario) compared to 1kWh without the MiniStor system (baseline scenario).</td><td>Calculation of KPI from input:
$$KPI = C_{kWh\_baseline} - C_{kWh_{MiniStor}} \left[\frac{€}{kWh}\right]$$
In percentage of the baseline cost:</td></tr>
</table>

Required input: - $C_{kWh\_baseline}$ Baseline cost for 1 kWh - $C_{kWh\_MiniStor}$ MiniStor cost for 1 kWh	$$KPI = \frac{C_{kWh\_baseline} - C_{kWh\_MiniStor}}{C_{kWh\_baseline}} \cdot 100$$ *Goal: 30 %* (estimation of efficiency improvement and integration of renewable energies)
KPI_38 Internal Rate of return (IRR)	Source: PA
The IRR estimates the profitability of the investment. It represents the discount rate that makes the net present value (NPV) of the cash flows equal to zero. The Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. *Required input:* - NPV Net present value - NCF_t Net cash flow during year t - C_c Capital cost [€] - T Number of years - IRR Internal rate of return	*Calculation of KPI from input:* $$KPI = IRR, \text{such that}$$ $$NPV = \sum_{t=1}^{T} \frac{NCF_t}{(1+IRR)^t} - C_c = 0$$ The analytical calculation of the IRR is not an easy task. To calculate IRR, it is common to use the NPV formula setting NPV equal to zero and solving the IRR in iterative way by the support of a calculator sheet.
KPI_39 Return of Investment (ROI)	Source: PA
It is the economic performance indicator used to evaluate the investment (€) for the MiniStor system, compared to the economic efficiency of an alternative investment. Here, ROI is expressed in percentage of the sum of the net profit generated during its operation, in relation to the total capital investment. *Required input:* - NCF_t Net cash flow during the year t - C_c Capital cost [€]	*Calculation of KPI from input:* $$ROI = \frac{\sum NCF_t}{C_{captial}} \cdot 100\ \%$$
KPI_40 Maintenance cost reduction	Source: GA
It represents the percentage of reduction of maintenance cost calculated by the comparative analysis of the baseline with an alternative system and the scenario with MiniStor. It can be expressed in absolute value or in percentage. *Required input:* - $C_{maint,Base}$ Cost for maintenance in the baseline scenario. - $C_{maint,MiniStor}$ Cost for maintenance in the MiniStor scenario.	*Calculation of KPI from input:* $$KPI = C_{maint,Base} - C_{maint,MiniStor}$$ *In percentage:* $$KPI = \frac{C_{maint,Base} - C_{maint,MiniStor}}{C_{maint,Base}} \cdot 100\ \%$$ *Goal:* > 25 % relative change of maintenance costs (typical reduction of maintenance costs from integration of the chosen technologies)
KPI_41 Maintenance frequency reduction	Source: GA
This KPI expresses the reduction in the frequency of maintenance interventions respect to a common system. *Required input:* - f_{before} Frequency of maintenance before MiniStor installation - f_{after} Frequency of maintenance after MiniStor installation	*Calculation of KPI from input:* $$KPI = \frac{(f_{before} - f_{after})}{f_{after}} \cdot 100\ \%$$ *Goal:* > 20 % (typical frequency reduction due the integration of the chosen technologies)

<table>
<tr><td>KPI_42</td><td>Energy cost savings in pilot demonstration sites Source: PA</td></tr>
<tr><td>The reduction of energy cost defines the difference of cost for the annual energy consumption calculated in the pilot site, by the difference between the baseline and the scenario with MiniStor system. It can be expressed in absolute value or in percentage of the baseline cost.

Required input:
- C_{en_base} Baseline annual energy cost
- $C_{en\_MiniStor}$ Energy cost in the MiniStor</td><td>Calculation of KPI from input:
$$KPI = C_{en\_base} - C_{en\_MiniStor}$$
In percentage of the baseline cost:
$$KPI = \frac{C_{en\_base} - C_{en\_MiniStor}}{C_{en\_base}} \cdot 100\ \%$$
Goal: 30 %
(estimated cost savings based on theoretical calculations of system improvements due to MiniStor installation)</td></tr>
<tr><td>KPI_43</td><td>Reduction of energy consumption Source: PA</td></tr>
<tr><td>The KPI is defined as the percentual change of the energy consumption after the installation of the MiniStor system compared to the baseline system behaviour. It can be expressed in absolute value or in percentage of the baseline cost

Required input:
- E_{base} Baseline annual energy consumption
- $E_{MiniStor}$ MiniStor scenario annual energy consumption</td><td>Calculation of KPI from input:
$$KPI = E_{base} - E_{MiniStor}$$
In percentage of the baseline cost:
$$KPI_{relative} = \frac{E_{base} - E_{MiniStor}}{E_{base}} \cdot 100\%$$
Goal: > 25 %
(estimated energy savings based on theoretical calculations of system improvements due to MiniStor installation)</td></tr>
<tr><td>KPI_44</td><td>Energy storage costs (Euros/ kWh) Source: PA</td></tr>
<tr><td>This KPI represents the cost to store 1 kWh of energy with the MiniStor system calculated by the sum of the operative costs (O&M, energy input cost, etc.).

Required input:
- $C_{operation}$ Operational cost in considered period.
- C_{maint} Maintenance cost in considered period.
- C_{energy} Cost of energy for the system in considered period.
- E_{stored} Sum of the energy stored in the considered period.</td><td>Calculation of KPI from input:
$$KPI = \frac{C_{operation} + C_{maint} + C_{energy}}{E_{stored}}$$</td></tr>
<tr><td>KPI_45</td><td>Energy Return of Investment (EROI) Source: PA</td></tr>
<tr><td>EROI is the amount of energy expended to produce a certain amount of energy. EROI is central in determining the price of energy.

Required input:
- E_{In} Energy input to MiniStor.
- E_{Out} Energy output to MiniStor.</td><td>Calculation of KPI from input:
$$EROI = \frac{E_{Out}}{E_{In}}$$</td></tr>
<tr><td>KPI_46</td><td>Cost of downtimes Source: PA</td></tr>
<tr><td>This KPI measures the financial costs generated by a downtime of the MiniStor system. These costs will be measured based on additional energy costs for operation of the (backup) heating system, maintenance, and repair costs.</td><td>Calculation of KPI from input:
$$KPI = C_{energy,paid} - C_{energy,Ministor} + C_{maint} + C_{repair} + C_{backup}$$</td></tr>
</table>

Required input: - $C_{energy,paid}$ Cost for energy of backup system during MiniStor outage. - $C_{energy,Ministor}$ Estimated costs of energy for MiniStor system operation if system was not broken. - C_{maint} Cost for maintenance of system during down time. - C_{repair} Cost for repair of MiniStor system. - C_{backup} Cost for temporary installation of a backup system.	
KPI_47 — Life-cycle cost of energy storage	**Source: PA**
Life cycle cost (LCC) is a KPI that estimates how much money you will spend on an asset over the course of its useful life. Whole-life costing covers an asset's costs from the time you purchase it to the time you get rid of it. *Required input:* - C_c Capital cost, include delivery and installation - C_{op} Operational cost - C_m Maintenance cost (include repair costs) - C_{en_in} Cost for energy in system input - C_{down} Downtime costs - C_d Decommissioning cost - C_{di} Costs for disposal	*Calculation of KPI from input:* $LCC = C_c + C_{op} + C_m + C_{en\_in} + C_{down} + C_d + C_{di}$
KPI_48 — Total annual costs	**Source: PA**
It is sum of the annual costs to sustain for the MiniStor system operation (O&M, energy input cost, etc.). *Required input:* - $C_{operation}$ Operational cost in considered period. - C_{maint} Maintenance cost in considered period. - C_{energy} Cost for system input energy in considered period.	*Calculation of KPI from input:* $KPI = C_{operation} + C_{maint} + C_{energy}$
KPI_49 — Annuity Gain	**Source: PA/LI**
Annuity (AN) is the incoming or the economic benefits made at the same interval at the beginning of each period (month, year etc.). *Required input:* - AN Annuity gain - B annual benefits - C annual costs - C_{cost} Capital costs at the year zero - $CR(i,T)$ Capital recovery factor. It considers an assumed discount rate (i) and the time for the amortization of the investment (T)	*Calculation of KPI from input:* $KPI = AN = B - C - C_{cost} \cdot CR(i,T)$

2.3 Assessment methodology

The following section summarises the required quantities to determine according to the description of the KPIs in the last sections. This overview is required to identify the required input measurements (observables) as well as to identify a suitable plant monitoring strategy to access the observables. The measurement strategy and sensors to determine the latter is described in Sec. 3. In Section 2.3.1. the overall approach for the plant monitoring is described, i.e., which quantities are measured. In Section 2.3.2., the approach to calculate the technological KPI based on the measurement signals described in Section 2.3.1 is described. In the Sections 2.3.3. to 2.3.6., this procedure is repeated for the comfort and acceptance KPIs (2.3.3.), the legal/safety-related KPI (2.3.4.), the environmental KPIs (2.3.5.), and the economic KPI (2.3.6.).

2.3.1 Overall plant monitoring approach

The calculation of the KPIs necessitates the following properties to be monitored:

Heat-related measurements:

The sensors of the demonstration sites measured for each room if possible (cf. Sections 3.3 for details), at least each floor every 15 minutes:

- Inlet/Outlet temperatures of the heating system in degree Celsius.
- Energy flow into/out of heating/cooling circuit in kWh.

Electricity-related measurements:

On the demonstration sites, the sensors measure for each room every minute:

- Average power in W
- Active power in W
- Reactive power in VAr
- Consumed energy in kWh

Consumed by:

- Each room.
- Each electricity-based heat/cooling source (e.g., hot water preparation systems, cooling systems, direct resistance heaters).

A higher granularity for the electricity-related measurements is chosen for two reasons:

- Due to the high thermal inertia of the building/apartment/room walls, changes of the respective quantities are slow compared to the change in electrical consumption.
- A measurement of the electrical consumption with higher frequency enables (at least partially) the disaggregation of different (major) consumers by non-intrusive load monitoring approaches. This splitting enables the correction of the effects of additionally installed large consumers (tea water kettles, entertainment electronics, etc.).

Fuel consumption related quantities:

Measured every 15 minutes:

- Gas (in m^3/h) / oil (in l/h) consumption

Consumed by:

- Boilers connected to heating/cooling system of the considered demo site (part).

Environmental quantities:

Measured every 15 minutes:

- Ambient temperature in degree Celsius.
- Relative humidity in percent.
- Integrated precipitation.
- Average solar radiation in W/m^2.
- Wind speed in m/s and direction in degree.
- Atmospheric air pressure in hPa.

Comfort indicators:
Measured every 15 minute:

- Temperature in degree Celsius in each room (or at multiple locations in the same room for the Thessaloniki site).
- Relative humidity in percent in each room (or at multiple locations in the same room for the Thessaloniki site).

2.3.2 Measurement approach for technological related KPIs

The KPIs:

- KPI_1: System volume of TCM.
- KPI_2: System volume of hot PCM (HW).
- KPI_3: System volume of hot PCM (DHW).
- KPI_4: System volume of cold PCM.
- KPI_5: System volume overall (TCM + PCM).
- KPI_6: Operational range ambient temperature.
- KPI_7: Overall storage density.
- KPI_8: TCM storage density.
- KPI_9: Electric consumption of peripheral equipment

can be calculated based on the design parameters of the MiniStor system.

The KPIs:

- KPI_12: Overall coefficient of performance.
- KPI_13: Energy net consumption.
- KPI_14: Energy losses.
- KPI_15: RES on-site average use.
- KPI_16: Better visualization of design options for retrofit of existing heating/ cooling system.
- KPI_18: Electrical consumption form grid (kWh).
- KPI_19: Share of renewables.
- KPI_20: Self-production/ self-sufficiency ratio.
- KPI_21: Maximum hourly energy surplus/ deficit (kWh).
- KPI_23: System reliability

will be calculated based on the monitoring data of the demonstration sites after the installation of the MiniStor system using the input data as defined in section 2.2.1.

The KPIs:

- KPI_11: Thermal energy savings.
- KPI_17: Electrical energy savings.

will be calculated based on a comparison of the thermal/electrical energy measurement results as acquired prior and after the installation of the MiniStor system. A major challenge in this step here will be the normalisation of the climatic influence in the monitoring periods. For this challenge, methods from the literature (Li, Hong, Lee, & Sofos, 2020; Wang, Yan, & Xiao, 2012) will be adopted to render the consumption values of the two non-overlapping measurement periods comparable.

The KPIs:
- KPI_10: PVT efficiency boost.
- KPI_22: Expected lifetime.

will be determined by the partners supplying the technical systems. Endef will assess the change of the PVT performance based on standardised performance measurements of PVT as currently manufactured by Endef and compare their efficiency with identical measurements performed on the PVT developed within the framework of the MiniStor project.

2.3.3 Measurement approach for comfort and acceptance KPIs

The KPIs "*KPI_24: User acceptance of MiniStor*" and "*KPI_25: Visual/ thermal comfort preservation as reported by active users after demonstration activities*" will be calculated based on the analysis of a questionnaire answers provided by the inhabitants. The inquiry is done prior the installation of the MiniStor system and after the completion of the monitoring study.

The KPI "*KPI_26: Indoor temperature and relative humidity*" will be calculated based on the variation of the measured values of temperature and humidity in the respective rooms (Li et al., 2020; Wang et al., 2012).

The KPI "*KPI_27: Number of users involved in demonstration activities*" will be determined based on the feedback of the dissemination activities in WP8.

2.3.4 Assessment of legal/safety related KPIs

The KPIs "*KPI_28: Compliant to safety regulations for NH3 usage and storage*", "*KPI_29: Compliance with safety standards for use a container as a machinery room*" and "*KPI_30: Compliant to building and planning regulations to the installation of the system*" are pass/fail criteria that will be assessed based on a desk research of the valid national codes and regulations as well as interviews with local safety authorities (fire brigade, chief of construction authorities). The relevant codes are identified as a part of the work in T2.5 and T4.5 and the results of the analysis will be documented in the deliverables D2.5 due in M18 and D4.6 due in M30. Furthermore, document D6.3 describes which local authority standards must be met in each demo site and what preparations the demo sites must be performed before installing the system. As part of this process of obtaining the building permit, the compliance of KPI 28 and KPI 29 is assessed.

The positioning of the MiniStor system in the individual demo sites, which is an important part of compliance with the standards, is described in section 3.4. To comply with the standard EN 378 Part 3, it is essential that the system is placed at least 2 metres from the nearest opening of surrounding buildings.

The MiniStor system is manufactured as a unit in a self-enclosed unit and delivered to the demo sites. The container serves as a machinery room according to EN 378 and the manufacturer is responsible for compliance with the standard after manufacture. The operation in the Demo Sites will be initiated in cooperation with a local and approved installer. The certified installer is responsible for the maintenance and functioning of the container as a machinery room. The maintenance programme, to be determined with the manufacturer and the installer, will be ensured in compliance with the regulations.

Since MiniStor is a system that can be adapted to changing or future heating and cooling demands (cf. D2.2, Sec. 2.3.2) with little effort, the KPIs 28 and 29 should also remain fulfilled in the event of any adjustments to the system. Since the adjustments to the system are largely based on the expansion of the TCM reactor and therefore a larger quantity of ammonia, it must be ensured that the maximum permissible quantity of ammonia (cf. D2.3, D4.5) is not exceeded. Furthermore, the compliance of KPI 28 and 29 as well as the necessity to renew the building permit is assessed.

2.3.5 Measurement approach for environmental KPIs

The KPIs:

- KPI_31: Reduced fossil fuel consumption (kg/ year).
- KPI_32: Reduction of GHG emissions.

will be determined based on the consumption values determined in the monitoring study based on the formulae as indicated in the definition of the KPIs.

2.3.6 Measurement approach for economic KPIs

The following KPIs:

- KPI_33: Total capital cost per kW installed.
- KPI_34: Reduction in construction costs.
- KPI_44: Energy storage costs (Euros/ kWh).

can be calculated based on a desk research combined with the design parameters of the MiniStor system at the respective demo site as well as the results of the market overview performed in T7.5 "Market analysis, cost benefit and cost effectiveness assessment".

The KPIs:

- KPI_35: Operational cost (Euros/kW).
- KPI_40: Maintenance cost reduction.
- KPI_41: Maintenance frequency reduction.
- KPI_42: Energy cost savings in pilot demonstration sites.
- KPI_43: Reduction of energy consumption.
- KPI_45: Energy Return of Investment (EROI).
- KPI_46: Cost of downtimes.
- KPI_49: Annuity Gain (Euro/ kWh).

can be calculated based on the data collected in the monitoring study.

The KPIs:

- KPI_34: Payback period (in years).
- KPI_35: Reduction of energy cost (Euros).
- KPI_36: Internal Rate of return (IRR).
- KPI_37: Return of Investment (ROI).
- KPI_45: Life-cycle cost of energy storage.
- KPI_46: Total annual costs.

can be calculated based on the results of the completed monitoring study based on the formulae mentioned in the definition of the KPIs.

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3 Monitoring of the system

In this section, the monitoring system (hardware, Sec. 3.1, 3.2) as well as its software components (cf. Sec. 3.3) will be described. The overall data flow is described in Sec. 3.3. To account for site-specific features, the monitoring system has been adjusted for each site. The respective adjustments in hard- and software are described in Sec. 3.4.

3.1 Measurement hardware

In the MiniStor project, the following measurement hardware has been integrated. The devices are described in groups of the measured quantities. The devices were connected to the pipe or grid or any energy flow line according to the description of the given device. For example, the thermal heat meter had to connect to the cold line of the water and the hot and cold temperature sensors were installed by means of the additionally added adapter to the water flow. There are devices such as air flow or water flow meters needed additional electric supplement, but the electric meters could supply itself by the line they measure. The smart meters were able to supply via the Modbus system, which makes the connection easier. Other sensors (predominately heat meters, temperature and humidity sensors) were connected via M-Bus via a logging device. The individual data sources were collected by a raspberry Pi microcontroller and subsequently transmitted to the IoT platform. The monitoring concept is described in Sec. 3.2 f.

3.1.1 Heat meter

The types of heat meters displayed in Table 6 have been installed on the demonstration sites. The measured quantities are taken from the datasheets of the sensors and the prices indicated are the costs for the component paid by the demonstration partners.

Table 6: Heat-monitoring hardware in MiniStor monitoring systems.

Integral-MK UltraMaxx [3]	Ultrasonic heat meter			Price
	Measured quantities			€222,64
	Quantity	Range	Accuracy class	
	Volume flow	0 – 3 m3/h	EN1434 Cl. 2	
	Temperatures	0 – 150 °C	EN60751 Class B	
	Energy	n/a kWh	No data for this, but it can be derived from the two above.	
B Meters Hydrosplit-M3 [4]	Heat calculator			Price
	Measured quantities			€750.00
	Quantity	Range	Accuracy class	
	Volume flow	0 – 31 m3/h	6 – 20 l/h	
	Temperatures	0 – 90 °C		
	Energy	kWh		

[3] Image source: https://dokumente.meiertobler.ch/files/doc-portal/51550.2xx_td_de_Integral-MK-UltraMaXX.pdf?content-disposition=inline

[4] Image source: https://www.bmeters.com/wp-content/uploads/2017/04/Hydrosplit-M3_2018.png

GMDM-I with IWM-PL3 [5] **Water flow meter** **Price:**

Measured quantities

Quantity	Range	Accuracy class
Volume flow	0 – 25 m3/h	6 – 20 l/h
Temperatures	0.1 – 90 °C	
Energy	kWh	

€372.00

Additional features

IWM-PL3 static pulse generator module for multi-beam counting.

Hydrocal M3 [6] **Compact heat meter** **Price:**

Measured quantities

Quantity	Range	Accuracy class
Volume flow	0 –2.5 m3/h	2
Temperatures	0 – 150 °C	2
Energy	kWh	2

€180.00

Additional features

Cooling applications temp. Range 0.2-24 °C

GSD8-R+REED pulse [7] **Flow meter** **Price:**

Measured quantities

Quantity	Range	Accuracy class
Volume flow	0 –2.0 m3/h	2

€273.00

B-Meters Ultrasonis ULC DN20 [8] **Heat meter** **Price:**

Measured quantities

Quantity	Range	Accuracy
Volume Flow	0.025-5 m3/h	Class 2-3 (EN1434)
Temperature	0 - 105 °C	
Energy	kWh	

€380.00

5 Image source: https://www.bmeters.com/wp-content/uploads/2017/04/GMDM-I_AFAC_2018.png

6 Image source: https://shop.gestical.ch/wp-content/uploads/2019/04/Hydrocal-M3.png

7 Image source: https://www.bmeters.com/en/bm_product/gsd8-rfm/

8 Image source: https://koka.fi/wp-content/uploads/2019/08/Hydrosonis-ULC_WEB-768x769.jpg

B-Meters Ultrasonis – ULC DN15 [9]	Heat meter	Price:

Measured quantities

Quantity	Range	Accuracy
Volume flow DN15	0.015 – 3 m3/h	2-3 (EN1434)
Temperatures	0-105 °C	
Energy	kWh	

€380.00

NEOVAC SUPERCAL 531 [10]	Ultrasonic heat meter	Price:

Measured quantities

Quantity	Range	Accuracy
flow	1 – 10 m3/h	
Temperatures	0 – 200 °C	EN 1434-1
Energy	kWh, MWh,m^3,°C,°K,°F	
Pressure	16 – 25 bar	
Volume per pulse	1-1000 l/p 2.5-2,500 l/p	

€1022.00

Additional features
Temperature: 5-55 °C
Temp. probes PT 500, PT 100 (2,4 wires)

3.1.2 Gas and air flow meters

The types of gas and air flow meters installed on the demonstration sites are displayed in Table 7. The indicated measured quantities are taken from the datasheets of the sensors and the prices are prices paid by the demonstration partners.

Table 7: Gas, Air flow and diesel consumption meters used in MiniStor monitoring system.

Air Vent Microplex	Energy meter for air streams	Price:

One of the demo site building (Sopron) was heated by air system which provides the fresh air and heating energy in a same time. It was measured the blown and sucked air amount and temperature.

Measured quantities

Quantity	Range	Accuracy
Air stream	0 – 150 m^3	<5%
	150 – 450 m^3	<3%
	450 – 650 m^3	<5%

€2238.54

[9] Image source: https://koka.fi/wp-content/uploads/2019/08/Hydrosonis-ULC_WEB-768x769.jpg

[10] Image source: https://www.neovac.ch/assets/images/e/1511-F-Supercal-531-23e13490.png

Honeywell BK-G4 c/w Honeywell IZ-61 low frequency pulse transmitter [11] | Energy meter for gas meter | Price:

Measured quantities

Quantity	Range	Accuracy
Gas flow	0.04 m^3/h – 6 m^3/h	>99% over the range

€210.00

Aquametro, CONTOIL VZO 8RE | Diesel consumption meter | Price:

Measured quantities

Quantity	Range	Accuracy
D n	8 mm	
Q max.	200 l/h	+- 1%
Q min	4 l/h	+- 1%
Q nom	135 l/h	+- 1%
P n	25 bar	
Volume per pulse	1 l/p	

€472.00

3.1.3 Electrical energy meters

Table 8 shows the types of electrical energy meter installed on the demonstration sites. The indicated measured quantities are taken from the datasheets of the sensors and the prices are prices paid by the demonstration partners.

Table 8: Electrical energy meters used in MiniStor monitoring system

Carlo Gavazzi energy meter 1-phase EM112 [12] | Smart meter for electricity measurements | Price:

Measured quantities

Quantity	Range	Accuracy
Voltage	120V, 230V	0.1 V
Current	0 – 100 A	0.001 A
Frequency	45 – 65 Hz	0.1 Hz
Active energy		Class 1
Reactive energy		Class 2
Max. sampling rate	4096 samples @ 50Hz	

Class: EN62053-21 and MID Annex MI-003 Class B

*Special prices may have been applied for R&D purposes.

€180.00*

[11] Image source: https://cdn.shopify.com/s/files/1/0435/3399/2089/products/IN-Z61_373x.jpg?v=1600764865

[12] Image source: https://il.farnell.com/productimages/large/en_GB/2672857-40.jpg

Carlo Gavazzi EM111 [13] | Alternative meter to EM112 | Price:

Measured quantities

Quantity	Range	Accuracy
Voltage	230 VAC	0.1 V
Current	0 – 45 A	0.001 A
Active energy	Class 1	

€130.00

Carlo Gavazzi energy meter 3-phase EM340 [14] | Smart meter for electricity measurements | Price:

Measured quantities

Quantity	Range	Accuracy
Voltage	208-400 V	0.1 V
Current	0 – 65 A	0.001 A
Frequency	45 – 65 Hz	0.1 Hz
Power	2-26000 W	0.1 W
Active energy	Class 1	10 Wh
Reactive energy	Class 2 (20 mA)	10 Wh

€147.00

Circutor-CEM-C6, 1-phase, 40A [15] | Additional features to EM340 | Price:

Measured quantities

Quantity	Range	Accuracy
Voltage	230 V	0.1 V
Current	0 – 100 A	0.001 A
Frequency	45 – 65 Hz	0.1 Hz
Power		0.1 W

Additional Features: RS-485/Modbus RTU

€50.00

Circutor, CVM-C10-MC-485-ICT12 with transformer MC3 [16] | Smart meter for electricity measurements | Price:

Measured quantities

Quantity	Range	Accuracy
Voltage	380 Vac	0.5 %
Current	63 – 250 A	0.5 %
Frequency	50 – 60 Hz	0.5 %
Power		0.1 W
Active energy		Class 0.5S
Reactive energy		Class 2

Additional features: RS-485/Modbus RTU

€180.00

13 Image source: http://www.gavazzi.de/images/gavazzifiles/control/BRO_EM100_EM300_GER.pdf
14 Image source: https://cdn.competec.ch/images2/6/9/5/58029596/58029596_xxl.jpg
15 Image source: http://circutor.com/images/stories/virtuemart/product/FO_CEM-C6_250x250.jpg
16 Image source: https://shop-api.readyplanet.com/v1/image/500x0/da75185cb25240e495cd08660956762e

Schneider A9MEM2135, 230VAC [17]	Energy Meter single phase up to 63 A	Price:
	Range: 0-999999 kWh Approved to the following standards: CE,EN50470-3, IEC 60529, IEC62052-11, IEC 62053-21, IEC 62053-31, MID conforming to EN 50470-1, MID connecting to EN50470-3, UL94	€277.00

EMU professional 3/5 LON, M15 3 phase energy meter, 10 imp/Wh [18]	Smart meter for electricity measurements	Price:
	See measured quantities below	€405.00

Measured quantities

Quantity	Range	Accuracy
Voltage	3*230/400	CL. B
Current	0.01 – 1(6) A	CL. B
Frequency	50 – 60 Hz	CL. B
Power		CL. B
Active energy		CL. B
Reactive energy		CL. B

Accuracy according to EN 50470-1.
Additional features:
Temperature: -25/+55° C ; Relat. humidity <95%

3.1.4 Room sensors (temperature, relative humidity)

In Table 9, the sensor types for temperature and relative humidity measurements are shown. The indicated measured quantities are taken from the datasheets of the sensors and the prices are prices paid by the demonstration partners.

Table 9: Room temperature and humidity sensors used in MiniStor monitoring system

Elvaco CMa10 [19]	Indoor wired M-Bus temperature and humidity meter	Price:
	See measured quantities below	€70.63

Measured quantities

Quantity	Range	Accuracy
Temperature	0 – 50 °C	< 0.4 °C < 0.2 °C (10 – 30 °C)
Humidity	0 – 100 %rH	<4 % rH < 2 % rH for 10 – 90 %rH

[17] Image source: https://download.schneider-electric.com/files?p_Doc_Ref=PB115424&p_File_Type=rendition_1500_jpg
[18] Image source: https://www.emu-metering.de/data/media/images/shop/EMU%20Professinal%203-5%20d.jpg
[19] Image source: https://www.elvaco.se/de/image/getthumbnail/1563?width=600&height=600&version=1&s=001

Elvaco CMa11 [20]	Indoor wireless M-Bus temperature and humidity meter	Price:

Measured quantities

Quantity	Range	Accuracy
Temperature	-200 – +55 °C	(±0.2 °C)
Humidity	0 – 100 %rH	<2%RH (10 – 90 % rH) < 4 %rH (full range)

Price: €105.00

S+S Regeltechnik THERMASGARD RTF1 [21]	Indoor temperature and humidity meter	Price:

Measured quantities

Quantity	Range	Accuracy
Temperature	-30 – +70 °C	0.2 K

Price: €60.00

Plugwise Sense [22]	Indoor temperature and humidity meter	Price:

Measured quantities

Quantity	Range	Accuracy
Temperature	0 – 60 °C	0.3°C - 0.8 °C (within 0 °C - 60 °C
Humidity	0 – 95% rH	3.5% rH – 2% rH (for 5% rH – 95% rH)

Price: €59.00 *

*Special prices may have been applied for R&D purposes

3.1.5 Logging Hardware

Table 10 displays the different logging hardware types installed on the demonstration sites. The indicated logging properties are taken from the datasheets of the sensors and the prices are prices paid by the demonstration partners.

Table 10: Logging systems used in MiniStor monitoring system

CMe3100 M-Bus data logger [23]	M-Bus Metering Gateway for Fixed Network	Price:

[20] Image source: https://www.elvaco.se/en/image/getthumbnail/1563?version=1&s=001
[21] Image source: https://spluss.de/de/produkte/temperatur/temperatur-passiv/raumtemperaturfuehler/rtf1/
[22] Image source: https://de.elv.com/plugwise-sense-funk-temperatur-und-luftfeuchtigkeitssensor-fuer-plugwise-home-start-106128
[23] Image source: https://www.elvaco.se/en/image/getthumbnail/1119?width=600&height=600&version=2&s=001

Logging properties

Quantity	Range
Sampling rate	1/min
Number of monitored devices	32
Communication standards	RESTFUL API
Logging duration	4 years (15 min values)

€418.00 – 646.00

DEOS OPEN 810/0 EMS+M-Bus [24]	M-Bus Metering Gateway for Fixed Network	Price:

Quantity	Range
Sampling rate	1/min
Number of monitored devices	74
Communication standards	RESTFUL API
Logging duration	*unlimited

*DEOS openweb 10+SQL software, stored in local server and SQL server

€2,200.00 (controller)

€2,900.00 (software)

3.1.6 Environmental sensors

The types of weather stations installed on the demonstration sites are shown in Table 11. The indicated measured quantities are taken from the datasheets of the sensors and the prices are prices paid by the demonstration partners.

Table 11: Weather stations used in MiniStor monitoring system

Delta-OHM HD52.3DP17R [25]	Weather station	Price:

Weather station with ultrasonic anemometer, pyranometer and humidity measurement.

Measured quantities

Quantity	Range	Accuracy
Wind speed	0 – 60 m/s	0.2 m/s
Wind direction	0 – 360 °	2 °
Magnetic direction	0 – 360 °	1 °
Air temperature	-40 – 60 °C	0.15 °C
Humidity	0 – 100 % rH	< 1.5 % rH
Air pressure	300 – 1100 hPa	0.5 hPa
Solar radiation	0 – 2000 W/m2	1 W/m2

€2,800.00

[24] Image source: https://www.deos-ag.com/de/produkte/gebaeudeautomation/ddc-controller/open810710/

[25] Image source: https://www.messbar.de/media/image/product/16349/md/delta-ohm-hd52-3dp17r-ultraschall-anemometer.jpg

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Delta-OHM HD52.3DP17 [26] **Weather station** **Price:**

Weather station with ultrasonic anemometer, pyranometer and humidity measurement

Measured quantities

Quantity	Range	Accuracy
Wind speed	0 – 60 m/s	0.2 m/s
Wind direction	0 – 360 °	2 °
Air temperature	-40 – 60 °C	0.15 °C
Humidity	0 – 100 % rH	< 1.5 % rH
Solar radiation	0 – 2000 W/m2	1 W/m2

Price: €1,970.00

Vantage Pro 2plus [27] **Weather Station** **Price:**

Davis Weather Station Vantage Pro 2plus c/w Davis data logger 6510SER and Ocean Controls KTA282 Modbus Gateway

Measured quantities

Quantity	Range	Accuracy
Wind speed	0 – 60 m/s	0.2 m/s
Wind direction	0 – 360 °	2 °
Ext. Air Temperature	-40C – +65 °C	±0.3 °C
Humidity	0 – 100 % rH	2 % rH
Air pressure	540 – 1100 hPa	1 hPa
Solar radiation	0 – 1800 W/m2	5% of full scale
Wind Chill	-79C – +57°C	1 °C

Price: €1,615.00

FINoT Agri Weather Station [28] **Weather station** **Price:**

Weather station with ultrasonic anemometer, pyranometer and humidity measurement

Measured quantities

Quantity	Range	Accuracy
Wind speed	0 – 80 m/s	0.3 m/s
Wind direction	0 – 360 °	2 °
Magnetic direction	0 – 360 °	1 °
Air temperature	-25 – 50 °C	<0.4 °C
Humidity	0 – 99.9% rH	2% rH
Solar radiation	0 – 2000 W/m2	1 W/m2

Price: €2,500.00*

*Special prices may have been applied for R&D purposes

[26] Image source: https://www.messbar.de/media/image/product/16349/md/delta-ohm-hd52-3dp17-ultraschall-anemometer.jpg

[27] Image source: https://www.davisinstruments.com/product/cabled-vantage-pro2-plus-with-standard-radiation-shield/

[28] Image source: https://www.f-in.gr/products/finot-agri-objects/

3.2 Overview monitoring hardware at each demonstration site

In Table 12, the types and the number of the sensors installed at the individual demonstration sites is displayed. A detailed description of the individual demonstration sites is given in section 3.4. The number of chosen sensors typically refers to the number of considered rooms for the temperature and humidity sensors and the number of energy streams (heating system and domestic hot water) for the other sensor types. In the Kimmeria demonstration site, electrical and thermal energy consumption are measured on a per apartment level. The selection of the monitoring hardware used in Santiago de Compostela is not yet completed due to the later accession of this demonstration site (M12) and will be carried out in the deliverable D6.5.

Table 12: Overview of employed sensors per demonstration site.

	Cork	Kimmeria	Sopron	Thessaloniki
Heat meters:				
Ultra maxx integral			2	
GMDM-I with IWM-PL3 and HYDROSPLIT-M3		2		
Hydrocal M3		10		
Bmeters Ultrasonis ULC 15DN	1			
Bmeters Ultrasonis ULC 20DN	1			
Gas and air flow meters:				
Air vent Microplex integrated			1	
Honeywell BK-G4	1			
Electrical energy meters:				
Carlo Gavazzi EM112				2
Carlo Gavazzi EM340			4	3
Circutor-C6		10		
Circutor, CVM-E3-MINI-ITF-485-IC		20		
Carlo Gavazzi EM111, 45Amp, 220VAC	2		8	
Schneider A9MEM2135, 63Amp, 220VAC	1			
Room sensors:				
CMa10			12	
CMa11	7	10		
S+S, RTF1-NTC10k		10		
Plugwise Sense				2
Environmental sensors:				
Delta-OHM HD52.3DP17		1	1	
Davis Vantage Pro 2 plus	1			
FINoT Agri Weather Station				1
Logging hardware:				
CMe3100	1		1	
DEOS OPEN 810/0 EMS+M-Bus		2		
Raspberry Pi	1		1	
DEOS Openweb 10 + SQL		1		

3.3 Monitoring data collection

3.3.1 Overview of the monitoring concept

The monitoring concept is designed to measure all quantities required to calculate the key performance indicators (KPI) as defined in Section 2. To prevent costly hardware installations and software developments, the monitoring concept is organized in a strictly hierarchical manner. The sensors measure the desired quantity and forward it to an aggregator. The aggregator then collects all monitoring values and forwards the information to the CERT IoT platform described in detail in Section 0. The generic concept for the monitoring system is visualized below:

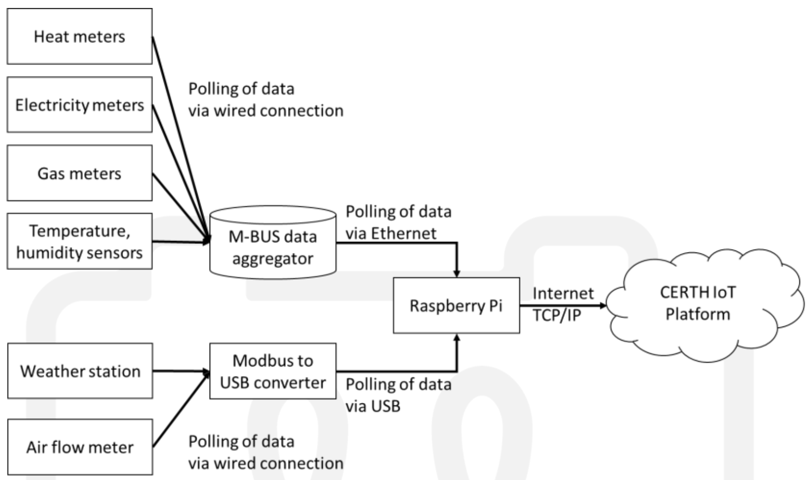


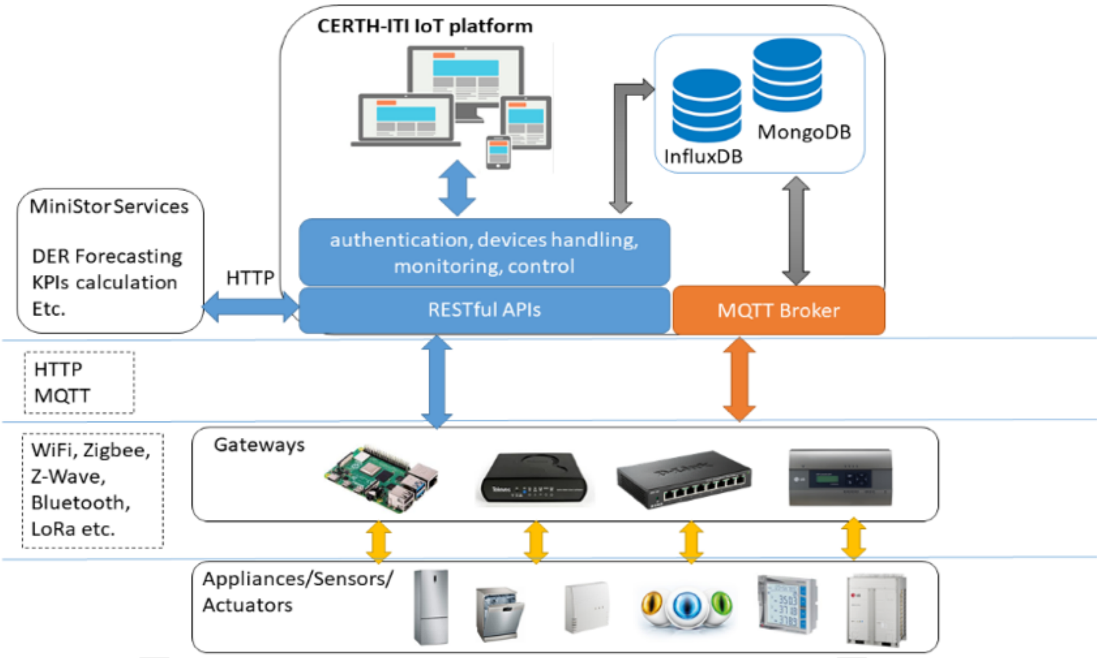
Figure 1: Overview over monitoring strategy from sensor measurements (left) to the IoT platform ecosystem (cf. Section 3.3.2. for details).

The M-Bus capable meter are connected via wires (except for the CMa10w temperature sensors) to the M-Bus data aggregator. The temperature/humidity sensors CMa10w are connected via wireless M-Bus to the M-Bus data aggregator. The latter polls every 15 minutes the current measurement values from the meters and stores them in an internal database. The Modbus compatible devices are connected via a Modbus-to-USB connector directly to the Raspberry Pi. The microcontroller regularly (every 5 minutes) polls the latest measurement values from the M-Bus data aggregator and reads the current sensor values from the modbus devices. The measurement values are then stored locally in a csv file for safety reasons and transmitted via API call to the CERTH IoT platform.

3.3.2 Data handling and storage at CERTH IoT platform

The process of recording the monitoring data utilizes a data flow procedure that collects the measurement data onsite, aggregates it locally and then transmits it to cloud storage. Figure 2 describes this process. The IoT platform has access to the cloud storage that allows for the creation of insightful schemas and optimisation of the system’s usage. Generally, the platform provides the ability for registering multiple users, where each one can manage one or more owned pilot sites with multiple devices/sensors installed in each individual site.

Figure 2: IoT platform ecosystem



In more detail, the platform is connected to a central storage, which is composed of two different databases. The first (MongoDB) stores user, site, and device information, while the second (InfluxDB) stores device monitoring data. The data can be accessed both by computer programs and through a user interface (IoT platform) in two different ways. The first method is direct access to the databases, but it is not publicly available as it suffers from security issues. Specifically, it allows the end user to access all available data and possibly make operations that may jeopardize the integrity of them and of the database as a whole. For example, a malicious user could potentially access third party data and even delete the whole database. The second method solves those issues by providing controlled access to the data through specified endpoints and a user authentication mechanism, granted by a RESTful API. This is the method used by the IoT platform. The API allows for posting (POST) and retrieving (GET) monitoring data, while for the user, site, and device information, specifically, it further offers the ability to alter (PUT) or delete them (DELETE). Due to the differences between each site's components and the requirements set by the geopolitical conditions that prevail in each individual pilot site, adjustments had to take place that yield a personalized experience. Specifically, the system follows a multi-layer approach that empowers the versatility for each site to have their own separate central storage.

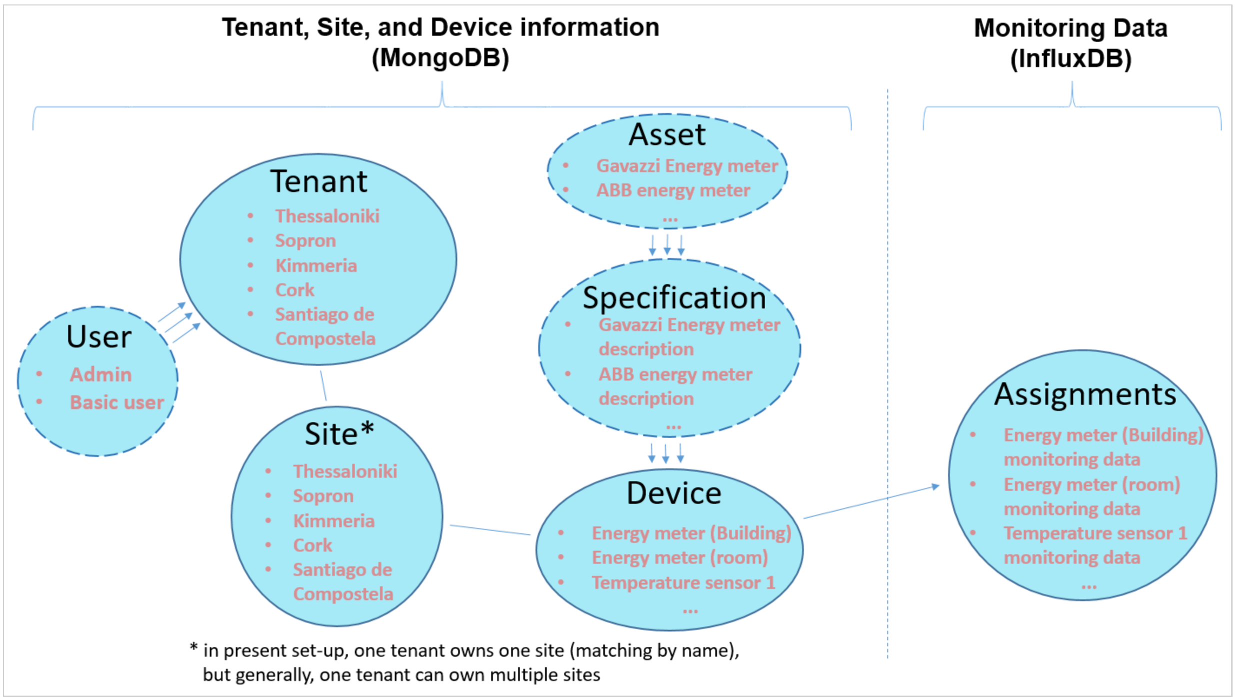


Figure 3: Core Framework of central database - RESTful API

There are seven main endpoints in the RESTful API, which are user, tenant, site, asset, specification, device, and assignments. The core fare depicted in figure 3. The user endpoint defines the type of the user and can be either an admin or a basic user. The site refers to location information about the pilot installation site and the tenant is the owner of a site or a set of sites. The asset defines the devices' names, while the specification describes a device and defines its monitoring values. A device correlates an actual device with a unique id, that is used to send and retrieve data. Lastly, the assignments endpoint allows for recording and retrieving monitoring data.

3.4 Specific solution for each demo site

Each demonstration site has its particularities such as different existing heating systems, size of the property, preinstalled monitoring system and installed infrastructure. To account for this variability, the monitoring system has been adjusted to accommodate for these differences. In this section, the particularities of the demonstration sites are discussed and the specific adjustments for each demonstration site are discussed.

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3.4.1 Cork demo site

The demonstration site in Cork is a residential house with currently five inhabitants in a residential area.

3.4.1.1 Hardware and system scheme

Figure 4: Google Streetview image on the demonstration site (end house on the left).

Table 13: Basic properties of Cork demonstration site

General Information:

City, Country	Cork, Ireland
Type of building and usage	3 Bedroomed Semi-detached two storey house
Number of floors	2
Total area heated by MiniStor system	75.286m^2
Number of occupants	5 (est.)
Type of energy demand to be covered by MiniStor system	Electricity, DHW, Heating

Architectural characteristics:

Total	
Total surface (habitable)	75.286m^2
Heated surface	75.286
Volume	376.431m^3
Height	5m (heated area)
Orientation	East-West
Ground floor	
Surface	37.64 m^2
Height	2.48 m
First floor	
Surface	37.64 m^2
Height	2.52 m
Roof	
Surface	37.64m2
Tilt	30°
Type	Apex Roof

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Existing HVAC:

System	Type	Volume	Output	Description
Heating system	Boiler	90 l	27 kW	For heating and DHW

Positioning of the MiniStor system

The MiniStor system is positioned within the back garden of the demo site at the North most area within the boundary of the property. This is at the highest most elevation with a clear line of sight directly south. The minimum distance from the southwest corner of the MiniStor container to the dwelling is 12.2 metres. The outline around the word "dwelling" represents the structure of the two-story dwelling to which MiniStor will be connected. The pink lines to the east boundary depict the path of the buried utility pipework from the MiniStor unit to the dwelling. For more information on the positioning and preparation work that will be done in the demo site, see D6.3.

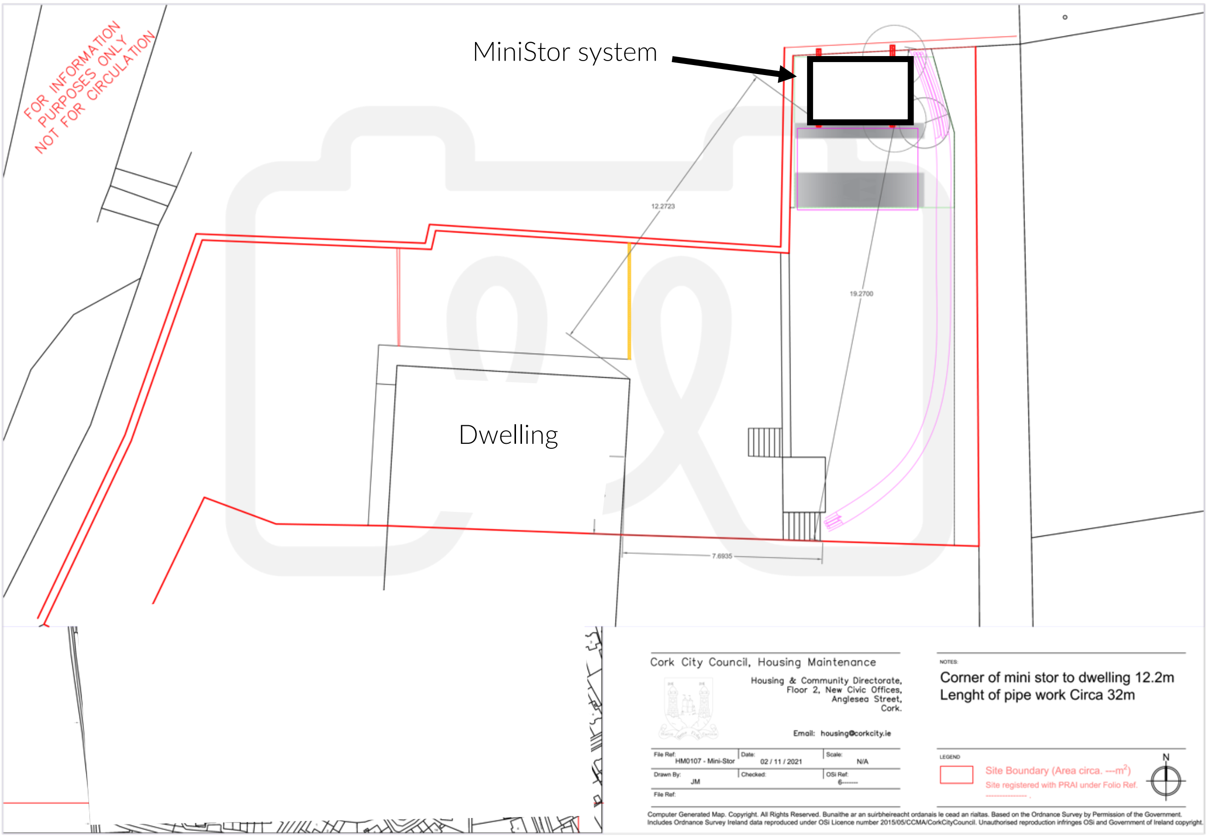

Figure 5: Construction plan of the demo site in Cork including the positioning of the MiniStor system and its distances from the site.

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3.4.1.2 Hardware and system scheme

The monitoring system at Cork has the following sensors and interconnections with the MiniStor monitoring system:

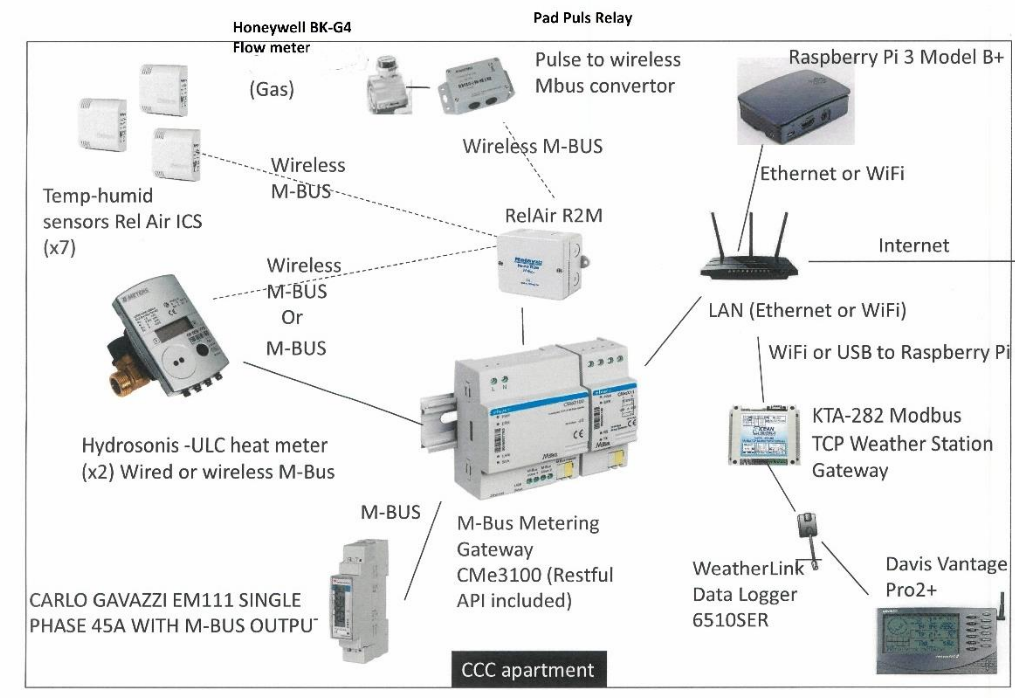

Figure 6: Overview over installed sensors and their interconnection in the demonstration site in Cork.

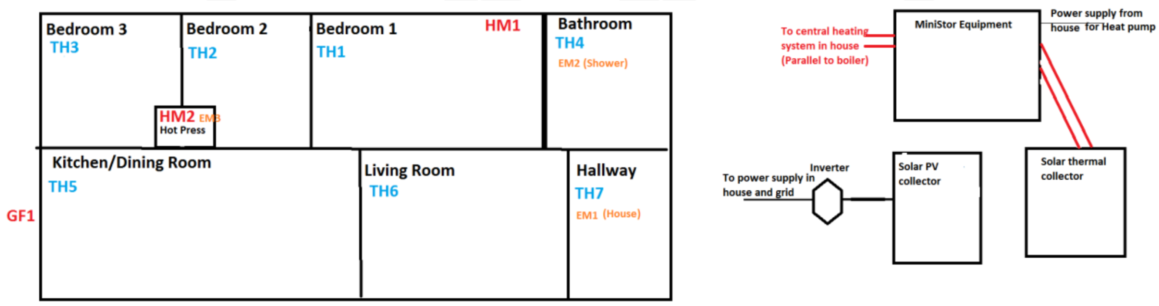

Figure 7: Location of the installed thermal, electrical, gas flow and heat sensors in the demonstration site in Cork.

3.4.2 Kimmeria demo site

The demonstration site in Kimmeria are student apartments in a dormitory on the campus of DUTH.

3.4.2.1 Hardware and system scheme

Figure 8: Satellite image of demonstration site in Kimmeria.

Table 14: Basic properties of Kimmeria demonstration site

General information:

City, Country	Kimmeria, Greece
Type of building	Student residencies (The buildings host DUTH's students)
Number of floors	2 (basement and ground floor are not included)
Total area heated by MiniStor system	75.65 m^2 (5 rooms)
Estimated number of occupants	5
Type of energy demand to be covered by MiniStor system	Heating, Cooling

Architectural characteristics

G2 Building – MiniStor system	
Total surface (habitable)	1188.01 m^2 (total heated area of the building)
Heated surface by MiniStor	75.65 m^2
Height	9 m (total hight of the building)
Total Volume	4079.3 m^3 (total heated volume of the building)
Heated volume by MiniStor	226.95 m^3
Orientation	From North to South, Tilt of the roof: ~14.5°
Ground floor	
Surface	449.9 m^2 (total heated area of the ground floor)
Height	3m

First floor	
Surface	449.9 m^2 (total heated area of the first floor)
Height	3m

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Second Floor	
Surface	288.2 m^2 (total heated area of the second floor)
Height	3m
Machinery room	
Surface	300 m^2

Existing HVAC

System	Type	Power	Description
Heating system	Hybrid Solar/Biomass boiler	1150kWth	Providing both DHW and heating (covers the whole campus)

Positioning of the MiniStor system

The MiniStor system will be installed in Kimmeria in the garden behind the demo site with a distance of 12.21 metres to the closest window of the demo site. The system will be positioned on rocky soil. The connection between the demo site and the MiniStor system is marked in red on the plan (cf. Figure 9). For more information on positioning, preparation work at the demo site and connections between the demo site and the system, see D6.3.

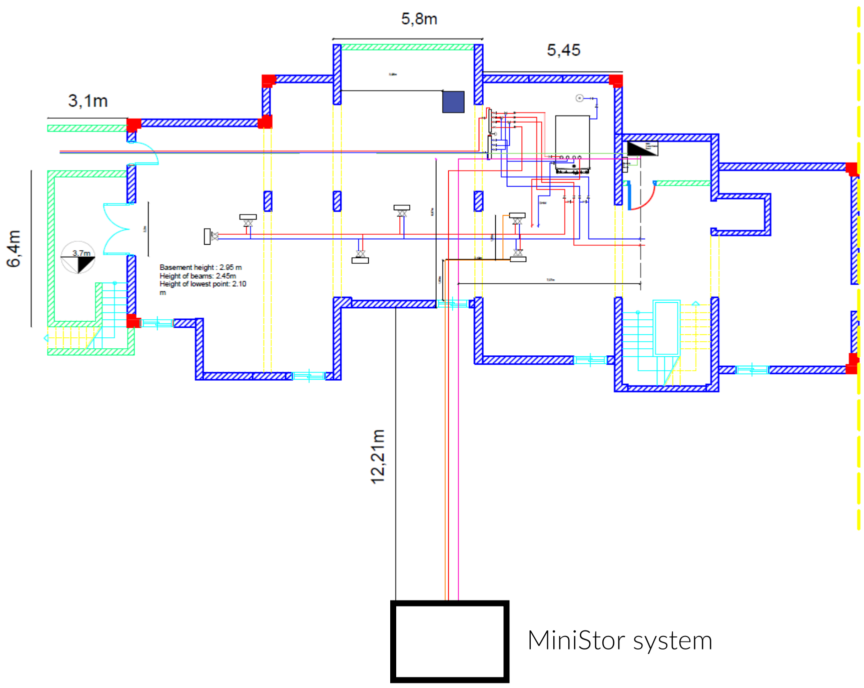

Figure 9: Construction plan of the demo site in Kimmeria including the positioning of the MiniStor system and its distances from the site.

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

The monitoring system at Kimmeria has the following sensors and interconnections with the MiniStor monitoring system:

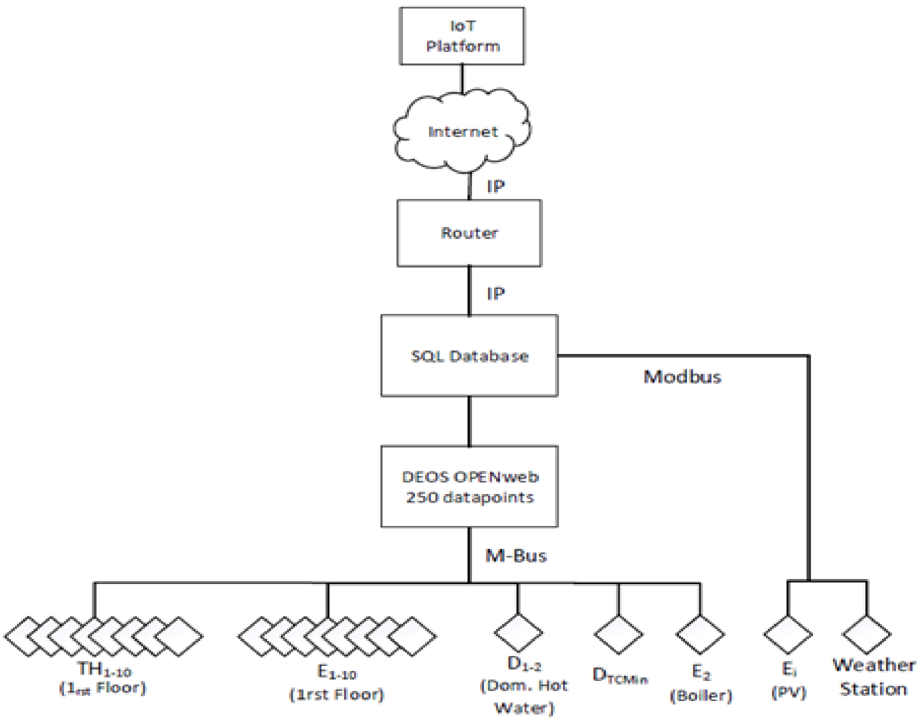

Figure 10: Overview of logical connection between sensors at demonstration site in Kimmeria.

The position of the individual monitoring sensors is shown in the schematic diagram below:

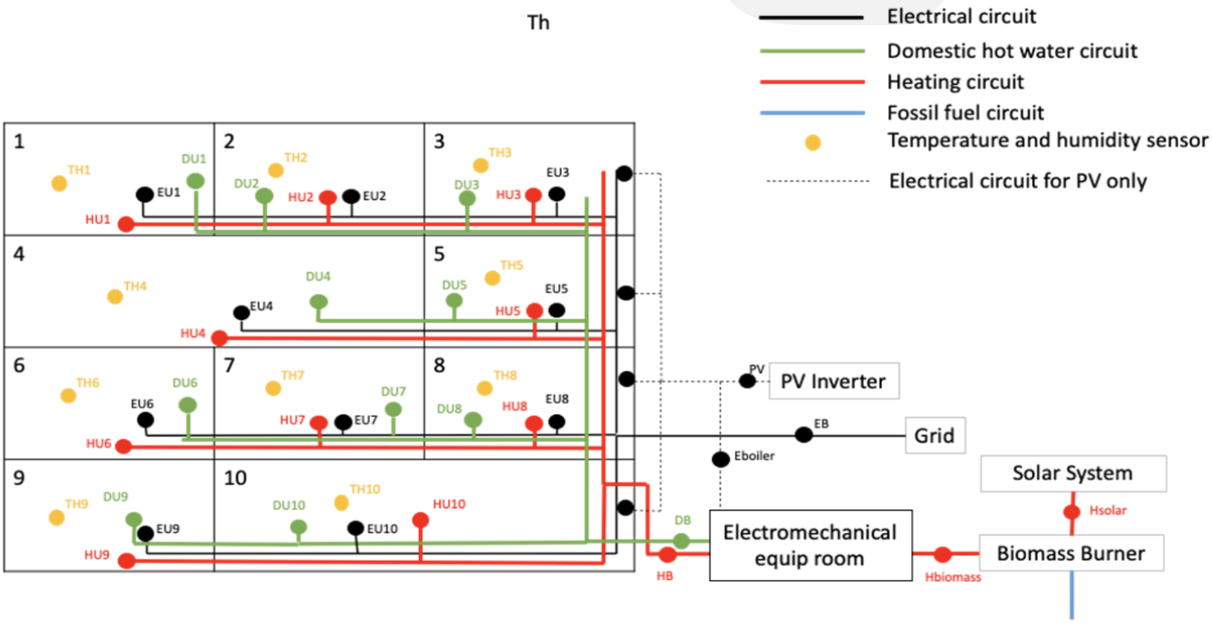

Figure 11: Location of the installed thermal, electrical, gas flow and heat sensors in the demonstration site in Kimmeria.

3.4.2.2 Specific adjustment of software

The electromechanical equipment of the demonstration site in Kimmeria is controlled and monitored by a BMS system provided by DEOS AG. The system utilizes DEOS OPEN 810/0 EMS + M-Bus BACnet controllers which are used as data logger. The BACnet controllers are being managed by DEOS openweb 10. The software is used to collect and store the available measuring data. The software is expanded with a SQL module that is used for bi-directional data exchange with other systems via a SQL database. CERTH introduced a novel approach to connect the SQL database of the DEOS system with the IoT platform of MiniStor. Particularly, the data is transmitted to the central storage of the IoT platform by utilizing a binary executable file. This executable retrieves sensor/device and weather data directly from the SQL database and the weather station's cloud database, respectively, and then it propagates them to central storage.

3.4.3 Santiago de Compostela site

The demonstration site in Santiago de Compostela joined in M12 to replace the demonstration site in St. Etienne. It consists of an apartment in the Burgo das Nacións university residence and is occupied by a family. Due to the late joining of this partner, monitoring data was sent at a much later date to the CERTH IoT platform. The final configuration is reported in deliverable D6.5.

3.4.3.1 Hardware and system scheme

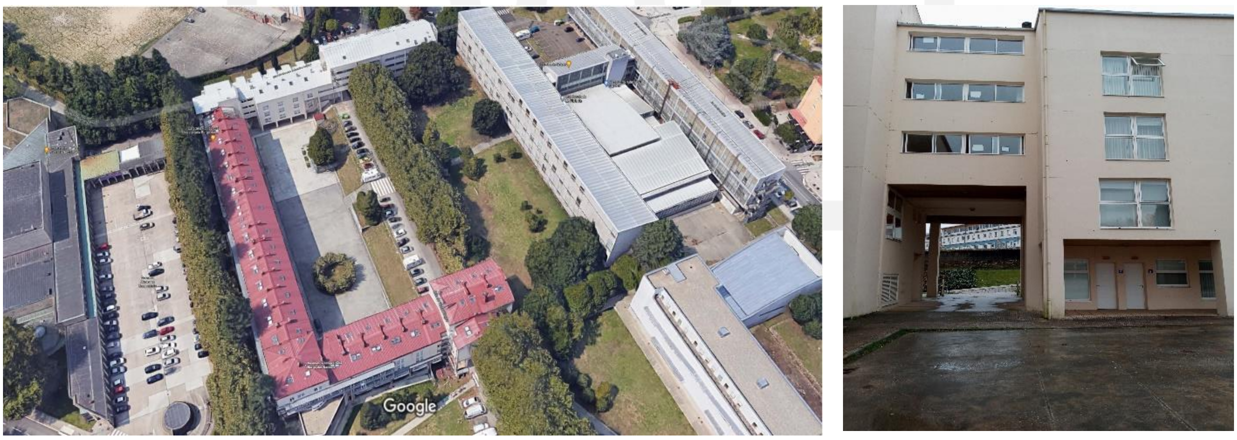

Figure 12: Satellite image of demonstration site in Santiago de Compostela.

Table 15: Basic properties of Santiago de Compostela demonstration site

General Information:

City, Country	Santiago de Compostela, Spain
Type of building	University apartment (apart.# B)
Number of floors	1
Total area heated by MiniStor system (habitable)	80,47 m^2
Estimated number of occupants	3
Type of energy demand to be covered by MiniStor system	Heating, DHW, Electricity

Architectural characteristics

Total	
Total surface (habitable)	n.a.
Constructed surface	80,47 m2
Height	2,5 m (est.)
Orientation	Approx. 255° W ("Almost W")

Entrance	
Surface	4,68 m^2
Staircase	
Surface	2,42 m^2
Hall	
Surface	4,94 m^2
Kitchen	
Surface	13,32 m^2
Bathroom	
Surface	2,82 m^2
Room#1	
Surface	10,50 m^2
Room#2	
Surface	10,71 m^2
Room#3	
Surface	9,46 m^2
Living room	
Surface	21,62 m^2

Existing HVAC:

System	Type	Power	Description (if necessary)
Heating system	4 gas boilers	1899 kW	Heating, covers the hole campus
	5 inertia tanks	16'000 l	DHW, covers the hole campus

At this time, the apartment, as part of the university residence, has its heating and domestic hot water system connected to those of the building. To serve as a demonstration site, its heating and domestic hot water systems will be hydraulically independent from the building.

Positioning of the MiniStor system

Figure 13 shows the demo site and the positions of the individual components (MiniStor container, solar system and boiler room). The demo site is located in the southwest wing of the U-shaped building complex. The distance from the MiniStor container to the nearest building is at least 17 metres. The solar system (marked red) is located directly next to the MiniStor container. For more information on positioning and preparation work at the demo site, see D6.3.

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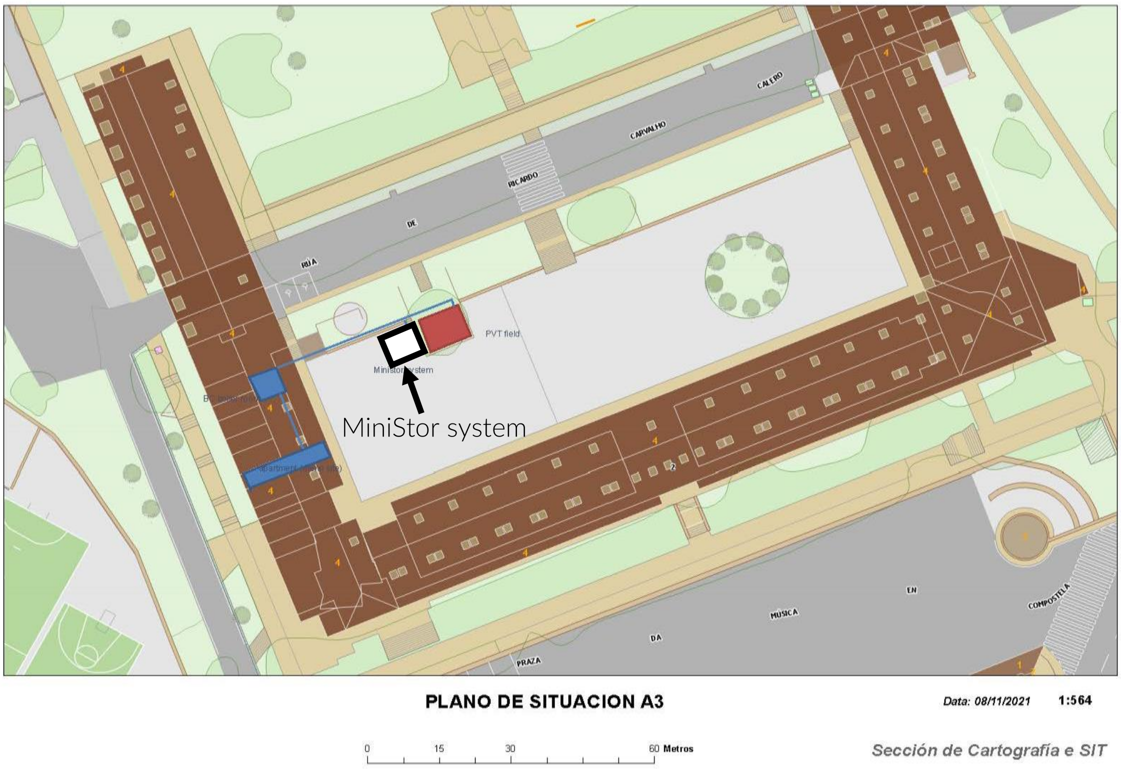

Figure 13: Designation of the possible positions and buildings for the installation of the MiniStor system in the demo site in Santiago de Compostela.

The pilot apartment does not have any element for monitoring environmental conditions or electrical or thermal consumption. All of them will be installed in the framework of the MiniStor project that will allow separating the apartment from the building and integrating the MiniStor system. In a preliminary design, the monitoring system in Santiago de Compostela could have the following sensors and interconnections with the MiniStor monitoring system:

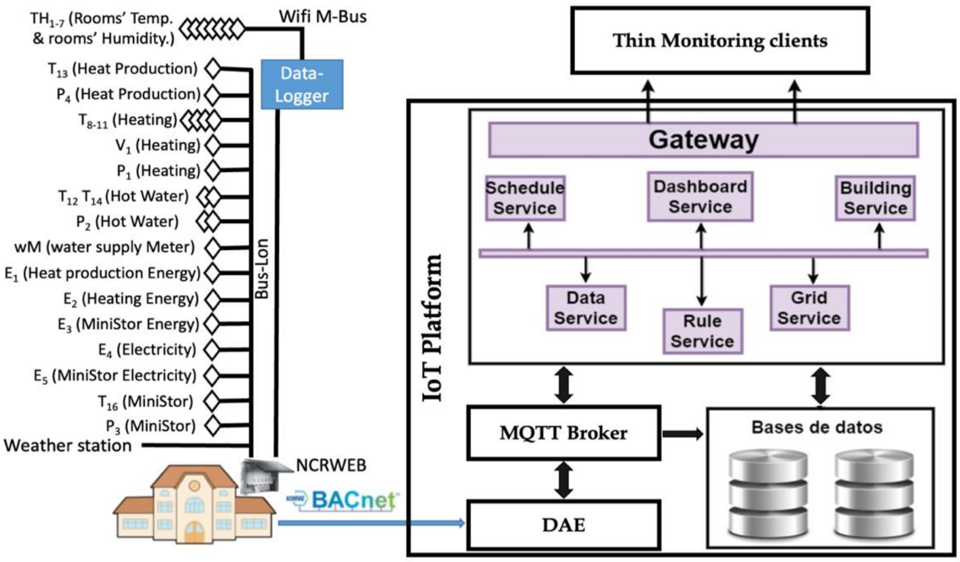

Figure 14: Overview of logical connection between sensors at demonstration site in Santiago de Compostela.

Figure 15: Floor plan of the apartment and its connection to the hydraulic system.

3.4.4 Sopron demo site

The demonstration site in Sopron is a newly erected building, with near zero energy requirements. A combined residential and commercial usage is foreseen.

Figure 16: Picture of the demonstration site in Sopron.

3.4.4.1 Hardware and system scheme

Table 16: Basic properties of Sopron demonstration site

General information:

City, Country	Sopron, Hungary
Type of building and usage	Single-family house, used as an apartment and office
Number of floors	2 + cellar (Ground floor, first floor, cellar)
Total area heated by MiniStor system	176.57 m^2 (total useful area)
Number of occupants	5 (est.)
Type of energy demand to be covered by MiniStor system	Electricity, DHW, Heating, Cooling

Architectural characteristics:

Total	
Total surface (habitable)	176.57 m^2
Heated surface	176.57 m^2
Volume	435.59 m^3
Height	9.07 m (est.)
Orientation	15°SW ("Almost south")
Ground floor	
Surface	59.52 m^2
Height	2.48 m
First floor	
Surface	58.45 m^2
Height	2.52 m
Cellar	
Surface	58.6 m^2
Height	2.4 m
Roof	
Surface	2x 45 m^2 = 90 m^2 (est.)
Tilt	35° one side is oriented to the south
Type	Gable roof

Existing HVAC:

System	Type	Power	Description
Heating system	Heat exchanger	3 kW	Soil collector preheater
	Heat exchanger	3 kW	For MiniStor,
	Heating filaments	3 kW$_{el.}$	Integrated into the ventilation system.
	Boiler 1	2* 2,4 kW (2*70 l)	for DHW
	Boiler 2	0.3 kW (10 l)	for DHW
	Bathroom heating device towel drier	2* 0.5 kW$_{el.}$	for heating

Positioning of the MiniStor system

The demo site in Sopron is located in a suburb of Sopron where the buildable area is only 10%. This means that the building may not exceed 10 % of the plot. Consequently, the area is loosely built-up and there is a lot of free space between the buildings. The MiniStor container is placed outside the building facing south. The distance between the building and the MiniStor system is at least 5 metres (cf. Figure 17). The prevailing wind direction in the city is north, so the wind blows from the building towards the MiniStor container, which is much more advantageous. The building has a ventilation system and the intake pipe is

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on the opposite side of the building. For more information on positioning, preparation work at the demo site and connections between the demo site and the system, see D6.3.

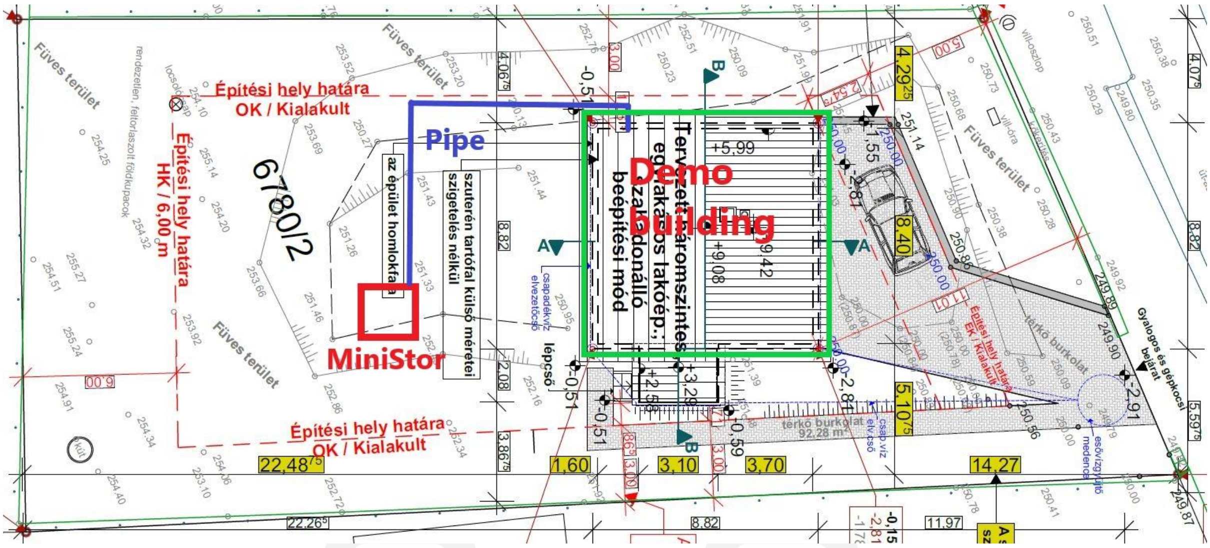

Figure 17: Map section of the demo site in Sopron showing the position of the MiniStor system on the southern side of the building.

The monitoring system at Sopron has the following sensors and interconnections with the MiniStor monitoring system:

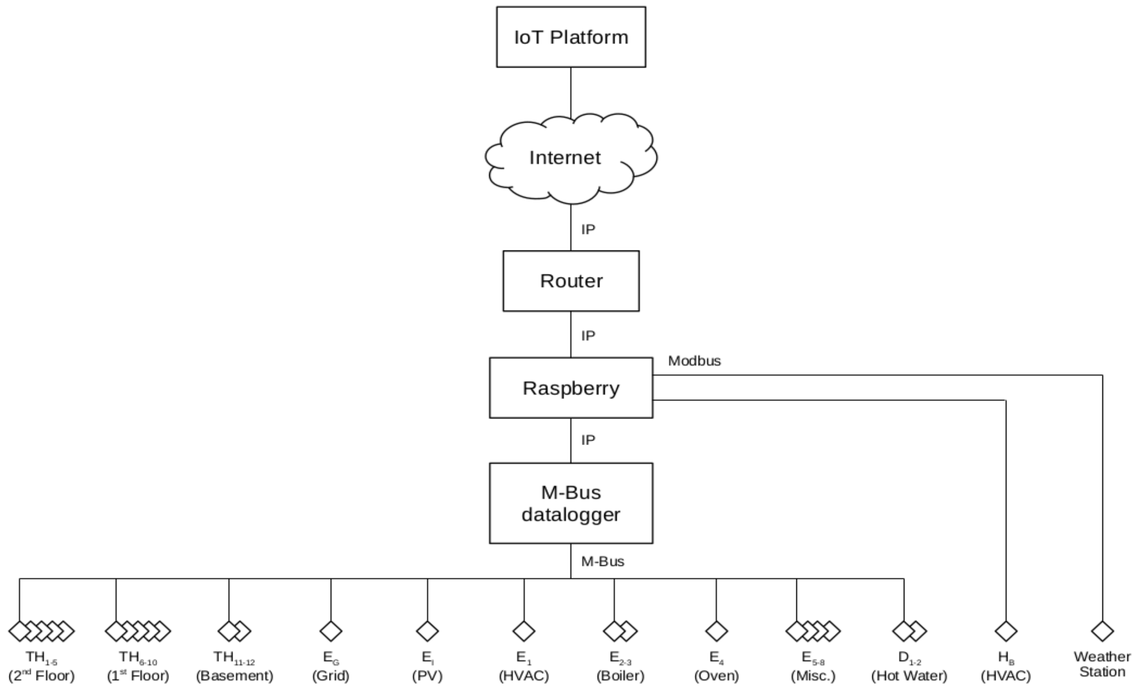

Figure 18: Overview of logical connection between sensors at demonstration site in Sopron.

The position of the individual monitoring sensors is shown in the schematic diagram below:

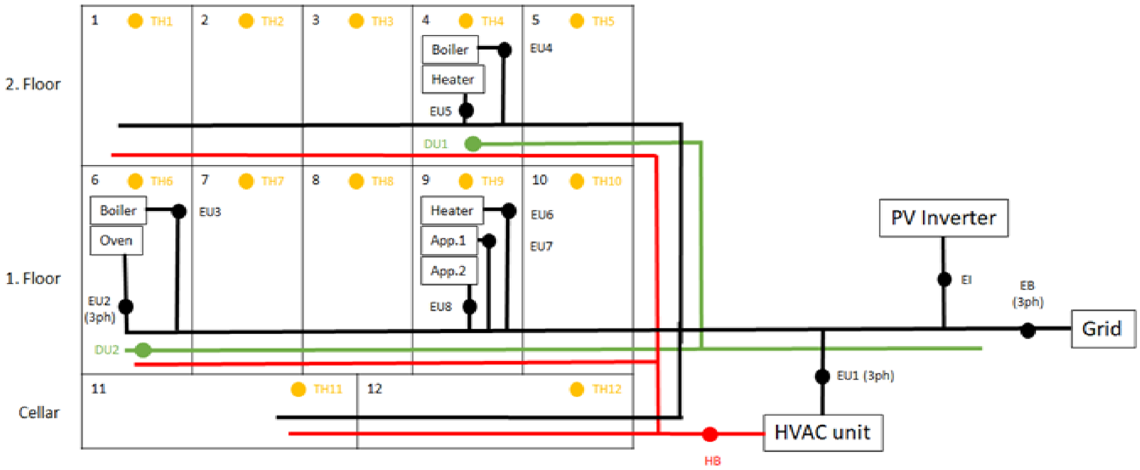

Figure 19: Location of the installed thermal, electrical, air flow and heat sensors in the demonstration site in Sopron.

3.4.5 Thessaloniki demo site

The demonstration site in Thessaloniki is a demonstration platform that tests technologies for residential buildings and offices and is shaped as a home.

3.4.5.1 Hardware and system scheme

Figure 20: Picture of the demonstration site in Thessaloniki.

Table 17: Basic properties of Thessaloniki demonstration site

General information:

City, Country	Thessaloniki, Greece
Type of building and usage	Demonstration platform shaped like real house, offices
Number of floors	2 (Ground floor, first floor)
Total area heated by MiniStor system	~49 m² (gross area)
Number of occupants	Varying
Type of energy demand to be covered by MiniStor system	Electricity, Heating, Cooling

Architectural characteristics:

Total	
Total surface (habitable)	317.7 m²
Heated surface	317.7 m²
Volume	1075.8 m³
Height	6.75 m
Orientation	Longest dimension facing SW-NE (+37º / -143º)
Ground floor	
Surface	182.7 m² (gross area)
Height	3.45 m
First floor	
Surface	135.0 m² (gross area)
Height	3.30 m
Roof	
Surface	135 + 47.7 = 182.7 m²
Tilt	0º
Type	Flat roof

Existing HVAC & electricity production system:

System	Type	Power
Heating & cooling system	LG ARUN100 LTE4 VRF Unit	31.5 kW (heating) 28.0 kW (cooling)
	LG ARUN080 LTE4 VRF Unit	25.2 kW (heating) 22.4 kW (cooling)
Electricity production system	Thin Film CIS PV Panels (installed in the building roof)	9.57 kWp

Positioning of the MiniStor system

There are two possible locations for positioning the MiniStor system in Thessaloniki (cf. Figure 21). Due to the short distance of location 2 to the demo site and the ability to accommodate a system of rather small dimensions in this position, location 1 is selected for the installation of the prototype. The prototype therefore has a distance of at least 4.71 metres to the demo site. Placing the container at a longer distance from the building is hindered by the high-slope terrain. The white shaded area shows a part of the solar system that is installed at the back of the Smart Home. For more information on positioning, preparation work at the demo site and connections between the demo site and the system, see D6.3.

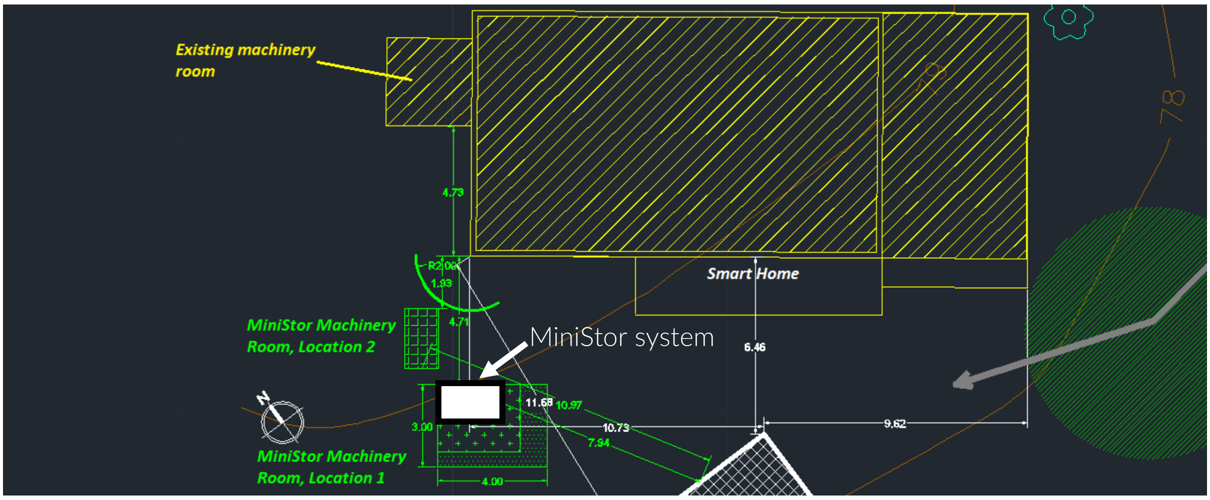

Figure 21: The MiniStor system in the pre-pilot site in Thessaloniki is installed at location 1 in the backyard of the Smart Home.

The position of the monitoring sensors in Thessaloniki pre-pilot is displayed in the following figure. A simplified layout of the existing heating and cooling system is also depicted.

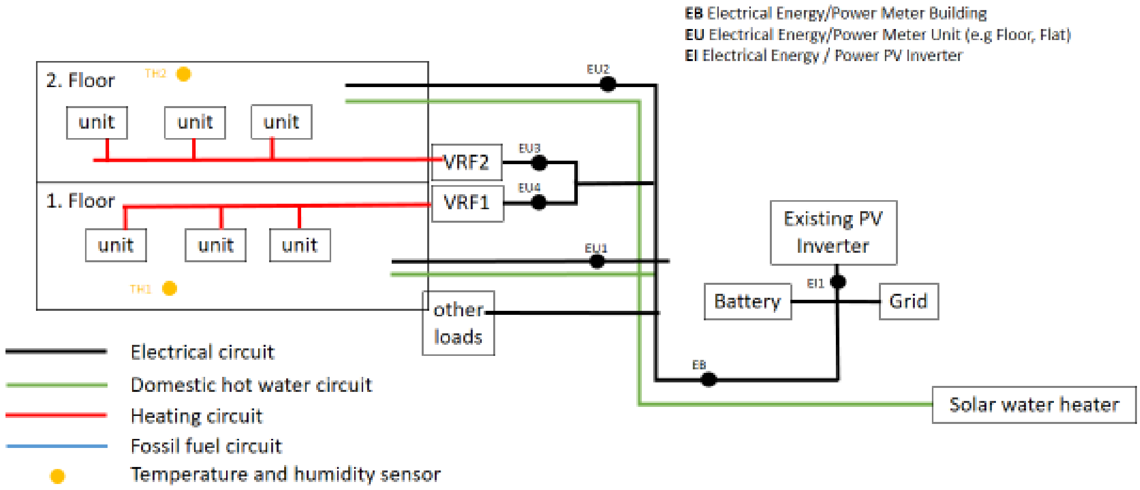

Figure 22: Location of the installed thermal, electrical, gas flow and heat sensors in the demonstration site in Thessaloniki.

3.4.5.2 Specific adjustment for software

Software has been fabricated to transmit monitoring data from devices/sensors to the main storage with the specified frequency defined for each device in the section 2.3.1. For the weather station unit, the data is retrieved by the provider's cloud database, while for the rest of the sensors, the data is extracted from available gateways connected to the IoT platform.

Conclusions

This deliverable discusses the key performance indicators (KPI) of the MiniStor project, their selection methodology, the measurement concept to determine the required input parameters from monitoring studies and the configuration of the monitoring system at each demonstration site of the MiniStor project.

Determining the KPIs is a first step to determine, appropriate monitoring hardware. The hardware has been selected according to the required input data, its frequency and connectivity. Therefore, different commercial off-the-shelf components have been compared and decisions have been taken based on prior experiences of the demo site owners, economical suitability, and technical excellence.

Secondly, a monitoring concept has been developed and the collection and handling of data has been specified and revised by the experts in the consortium.

Thirdly, a scheme of each demo sites regarding the hydraulic connections has been made to get an overview. In addition, important architectonic data has been collected to have all this information in one document.

Finally, specific solutions for each demo site have been compiled to integrate the selected components and to facilitate the designed monitoring concept on the demonstration sites of Cork, Kimmeria, Sopron, Santiago de Compostela and Thessaloniki.

The outcomes of this deliverable will lead to the evaluation of the system. This evaluation will be driven by the monitoring of the KPIs and the data from the measurement devices mentioned in this deliverable. This evaluation will be performed in T6.5. The goal is to acquire data during two periods: the first one before the installation of the MiniStor system, the second one after the installation of the MiniStor system. After correcting the effects of different climatic conditions and usage pattern, the KPIs will be calculated and evaluated in perform a final evaluation of the MiniStor system and project.

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