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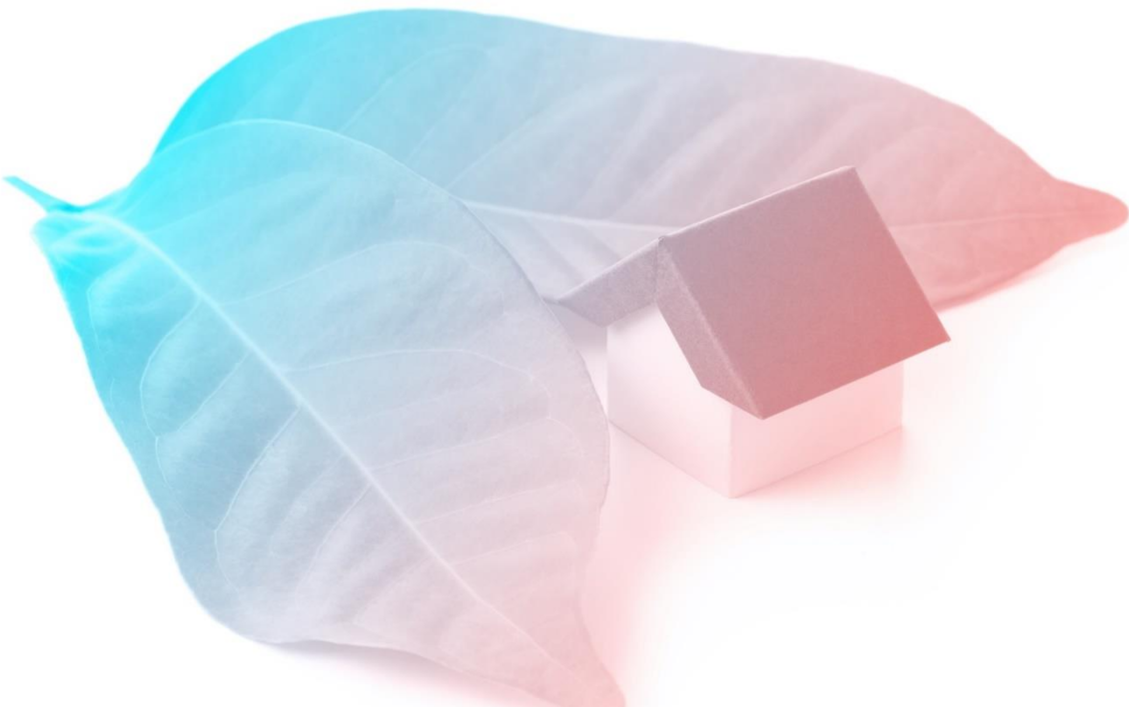
D2.5 Safety and maintenance requirements



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D2.5 Safety and maintenance requirements

Summary

This deliverable presents basic safety and maintenance requirements of the MiniStor project. A particular focus is put on the requirements for a safe system operation including a hazard and risk analysis, safe operation principles as well as maintenance procedures based on recognized standards. A risk analysis and mitigation measure list is produced for both established and novel elements of the MiniStor system. Tests that will result in certification of safe operation are described. A first analysis of shipping requirements is presented.

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D2.5	WP 2
Lead Beneficiary	**Deliverable Author(S)**
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	PU	Public	X

Index

List of Tables

List of Figures

List of abbreviations

ATEX	Regulations for potentially explosive atmospheres
CE	Conformity marking of European health, safety, and environmental protection standards for products sold within the EEA
EN	European Norm
EU	European Union
HTF	Heat Transfer Fluid
ISO	International Standards Organization
PCM	Phase-change material
PVT	Photovoltaic thermal panels
TCM	Thermochemical material
TRL	Technology Readiness Level

1 Introduction

Minimal Size Thermal and Electrical Energy Storage System for In-Situ Residential Installation (MiniStor) offers a practical answer to improve the energy efficiency potential of the European building market. The MiniStor system will be demonstrated and validated in five demonstration sites located in Ireland, Spain, Greece, and Hungary to proof its effectiveness at different local climatic conditions, facilitating market replication. In this report, the results of Task 2.5 in work package 2 of this project will be reported focussing on requirements for safe operation, maintenance and safe transportation of the Ministor system.

The Ministor system combines a thermochemical storage (TCM), up to three phase change material based stores (PCM) and 1 – 2 heat pumps (depending on the demonstration site). The heat pumps and 2 out of 3 PCM based stores are commercial products provided with the required documentation for safe operation and transport. The TCM based storage uses a reversible reaction of calcium chloride with ammonia. Due to the use of ammonia as a reactive agent and as a heat transfer fluid (HTF, or refrigerant), this document contains an assessment of how to handle this medium safely due to its flammability and toxicity. Furthermore, this document contains also inputs about maintenance and hazard analysis of all relevant subcomponents of the MiniStor system such as proposed actions, maintenance works and shipping guidelines. On a wider regulatory context, they become relevant for the implementation of Directive (EU) No 517/2014 on the elimination of fluorocarbons and their replacement with "natural refrigerants" (which include ammonia).

A summary analysis of the relevant legal framework as presented in deliverable D2.3 is given. Thereby, the legal constraints of the EU are specifically discussed. This is followed by the requirements for a safe system operation.

The hazard analysis is performed considering the following hazard types: mechanical, electrical, thermal, noise, vibration, radiation, material/substances, ergonomics and those associated with the environment. The different subcomponents of the MiniStor system with the hazard types are examined and possible protection measures are defined.

The maintenance requirements are firstly described by parsing the components of MiniStor system individually. For each of them an overview is given of when such component should be checked. Inputs about regulations and information from the respective manufacturers are summarised.

In the shipping guidelines, information about shipping regulations is collected from various sources (e.g. manufacturers) and placed in a single chapter. It should be noted that these are only guidelines and the consortium will follow the rules and recommendations of the shipping companies.

The contents of this deliverable have been agreed by the Consortium based on the Consortium Agreement rules.

2 Summary of relevant EU standards

Deliverable D2.3 presents the main EU standards and legislation related to system design and operation, which must be respected irrespective of location. Standards related to refrigeration systems have been used as the main guide for the thermal part of MiniStor, since there are no specific directives for thermal energy storage systems. Since MiniStor is a composite product for hybrid storage (thermal and electrical energy), existing standards were also consulted for the electrical energy storage.

It has been found that the standards define, based on type of refrigerant and not on final use of the building, where they can be placed and the maximum amounts of refrigerant allowed. From the standards, it was decided that the best location for the *ammonia-related* MiniStor components is in an outdoor area that meets specific requirements, or inside a machinery room that complies with the conditions required for ammonia based refrigeration systems. Layout configurations must be studied in order to see if only the ammonia-related parts or the entire thermal storage system should be placed in the regulated area. An essential part of the regulations on the installation location of the ammonia-containing system is the installation of suitable safety and alarm equipment. Together with the necessary safety equipment needed, these decisions will have an impact on market price and future commercialization, for which measures should also be studied to be a competitive technology. *These safety measures should be contrasted with existing technologies to handle hazardous flammable materials already present in the household, such as natural gas, propane, etc.*

On the other hand, it is acknowledged that ammonia can be safely used as a refrigerant provided the system is properly designed, constructed, operated, and maintained. It is important to note, however, that ammonia is toxic and careless management can be hazardous to human health. For this reason, D2.3 has examined relevant manufacturing standards, legislation and safety measures that must be met to reduce potential hazards.

At the European level, the most influential standard for the design of MiniStor is Standard EN-378 "Refrigerating systems and heat pumps - Safety and environmental requirements". However, although it has been approved and is valid for all the European Union, transposition has been done by some but not all Member States. Transposition will facilitate the development of future systems by the industry. EN-378 takes into account aspects for system of different degrees of magnitude according to ammonia storage. D2.3 has also taken into account aspects that are applied to systems of much larger magnitude. D2.3 has also examined all standards that apply to the components of MiniStor such as pressure vessels and heat exchangers.

Another directive that is applicable to MiniStor is Directive 2014/34/EU, on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres (recast). This is the so-called explosive atmospheres (ATEX) directive. Declarations of conformity that are part of this directive need assessment procedures that have to be carried out by notified bodies. There is also an obligation to classify areas where flammable atmospheres may exist, that in the case of Ministor would be the machinery room (Directive 1999/92/EC; IN 60079-10-1; IN 60079-10-2). These zones can be classified into different levels. This level depends on the degree of possibility of an explosive atmosphere (always, occasionally or only in case of leaks or ruptures).

Furthermore, the extent of the hazardous area needs to be defined. This can be all the room, a specific sector, or just a few centimetres around valves, tanks or other, depending on different parameters. All equipment (motors, pumps, lighting...) that are installed within the area of the hazardous area must have ATEX marking. This marking must be more or less restrictive depending on different parameters such as:

- Type of fuel and its characteristics of flammability and ignition temperature
- The level of risk in which the area has been classified.

The degree and extent of this safety zone should be evaluated by a competent professional.

The main gaps identified through this deliverable relate to the lack of standards and directives for thermal energy storage systems specifically. From the point of view of refrigeration systems, the closed loop thermal storage elements are not changing the temperature of a heat transfer fluid (gas, liquid) for immediate use, but for release at a future time at the convenience of the end-user. An additional gap identified is that standards and risk mitigation measures have in mind primarily industrial applications. Specific safety measures and standards that assure the same level of quality of industrial levels and promote zero-leak manufacture must be developed for smaller amounts of ammonia such as those that could be used in residential settings. Another identified gap is the influence that state-of-the-art manufacturing and operation measures for these storage systems can have towards the design and application of novel systems, as reflected in standards for use of thermal storage systems in domestic settings.

3 Hazard analysis and proposed actions

In the following subchapter, a hazard analysis of the individual components is carried out, which provides an overview of the hazard potential of the overall system. Table 1 contains an overview of the potential hazards and the associated sub-components. The following hazard types are considered: mechanical, electrical, thermal, noise, vibration, radiation, material/substances, ergonomics and those associated with the environment. The detailed analysis of the individual components can be found in sections 3.1.1 - 3.1.7.

Table 1: Hazard types or groups for each sub-component

	Mechanical	Electrical	Thermal	Noise	Vibration	Radiation	Material/ Substances	Ergonomics	Associated with environment
Compressor	X	X	X	X	X	X	X		
Evaporator / condenser	X				X		X		
Heat pump	X	X	X			X			X
Pumps	X	X	X	X	X	X	X		
PCM (hot and cold)	X		X				X		
TCM reactor	X		X				X		
PVT	X	X	X			X			X
Electrical batteries	X	X	X				X		X

It must be noted that Table 1 presents an analysis of elements available in the market. Other elements that have a lower TRL level such as the thermochemical reactor will be analysed in detail in D4.6. The risk assessment is based on Standard EN 12100 Safety of machinery - General principles for design - Risk assessment and risk reduction (ISO, 2010). For the specific element of PVT panels, partner EndeF was consulted.

The purpose of the standard is to provide guidelines about how to obtain a safe machine or equipment, through a Risk Assessment process. This process will reveal if there are measures to take or adopt for risk reduction (GT-Engineering, 2021). Risk reduction is achieved when all operating conditions have been considered, hazards eliminated or risk is at its lowest possible level, users are informed and warned, protective measures are compatible with each other, protective measures do not affect normal working conditions for operators.

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The scheme to be followed is represented in the following figure:

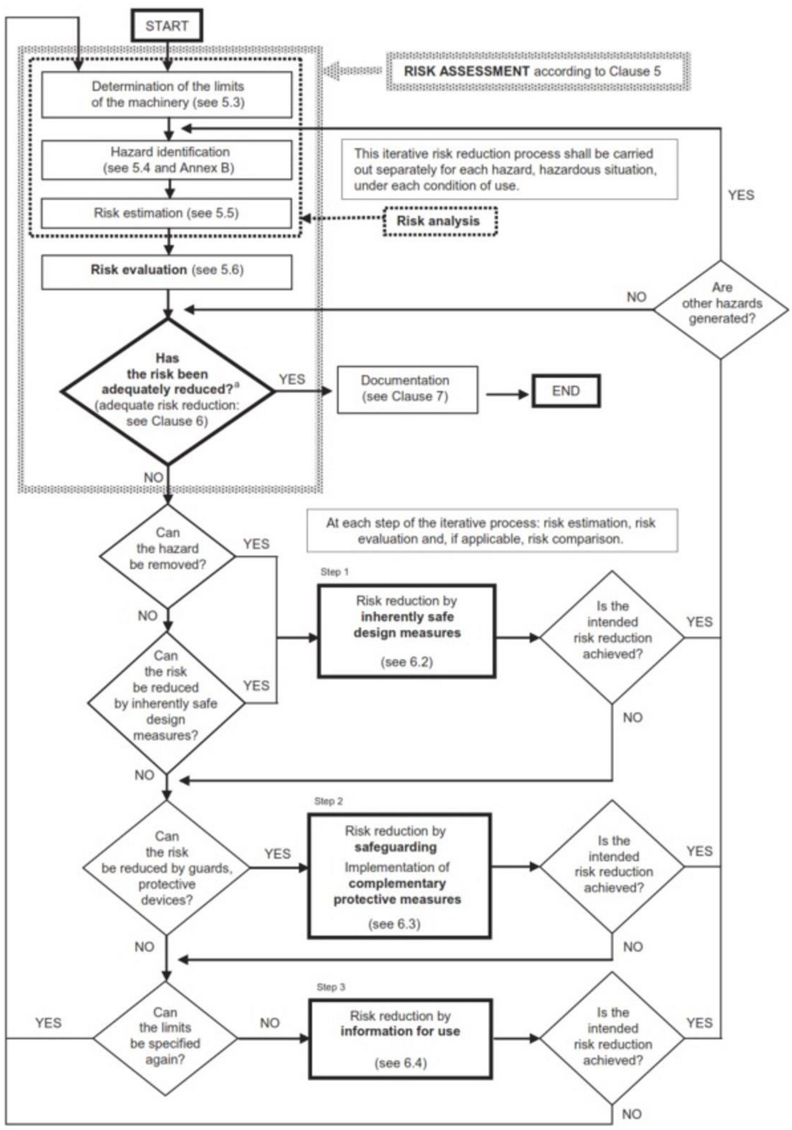

Figure 1 diagram of the Risk Assessment and Reduction process according to EN 12100.

Hazards must be identified during all phases of machinery life, such as transport, assembly and installation; commissioning; use; dismantling, disabling and scrapping (GT-Engineering, 2021). The risk associated with a particular hazardous situation depends on the severity of harm and the probability of occurrence of that harm. Harm can be minor, elevated or even death. This can occur to one or more persons. It can occur in a specific area (zone) or become residual after its occurrence (ISO, 2010)

Risk evaluation is given on the basis of probability of harm occurring, the type of damage done or disability caused, and if it is permanent or not. Risk evaluation will also indicate if the risk is acceptable or not. In this deliverable, the risk evaluation will be limited to possible consequences. Risk will be managed at this stage through the suggestion of possible protection measures. Therefore, risk and consequences will be limited in this deliverable to off-the-shelf or close to off-the shelf products.

For reference, the main components of the system are shown in the figure below. Pumps within the system are indicated as well:

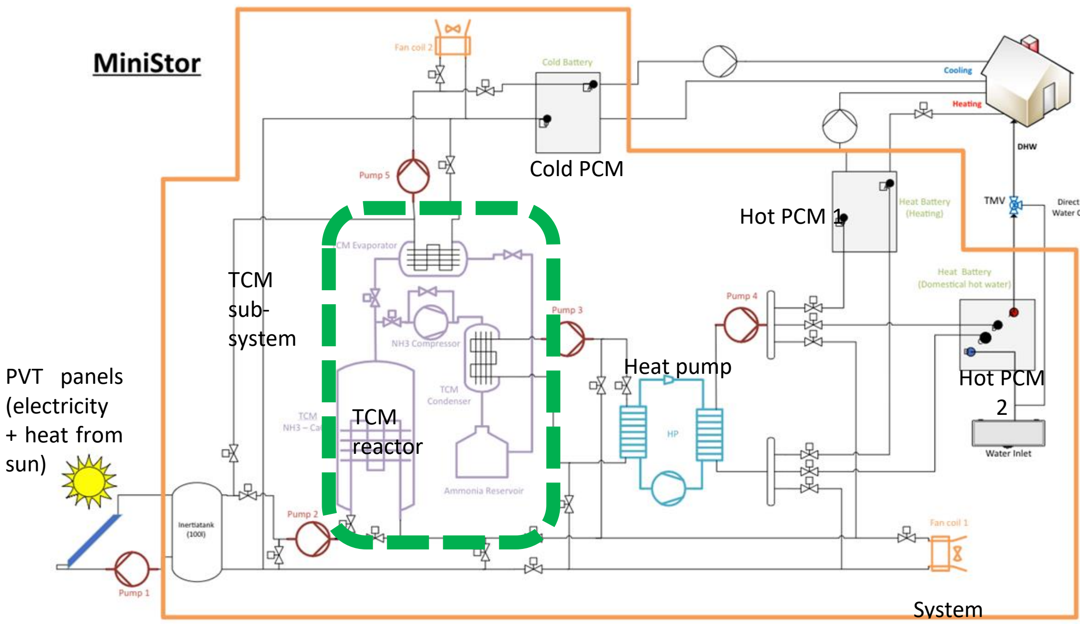

Figure 2 MiniStor system layout with main thermal components. Green denotes the section using ammonia directly, orange the system boundary of thermal system components

3.1.1 TCM System

3.1.1.1 Thermochemical reactor

The thermochemical reactor TCM is the only element in the MiniStor system that is not established on the market and is accordingly newly developed and manufactured for this project. The exact description of the safe system operation of this element is elaborated in WP 4 and presented in deliverable D4.6. Since it is a custom-made product, practical demonstration activities will help to complete the risk evaluation. To avoid the risk of ammonia leakage, the TCM reactor will be manufactured in compliance with all standards and taking all risks into account. In normal use, the TCM reactor can be heated up to a maximum temperature of 80°C (from the solar loop temperature) and for this temperature, if the reactor is operated closed, the pressure will only reach 10 bar. The manufacturer will guarantee an operating pressure of 18 bar with an operating temperature of 100°C and will test the reactor at a pressure of 30 bar. The TCM reactor will also be equipped with all necessary safety devices (safety valve, temperature control).

3.1.1.2 Ammonia Compressor

The compressor is used to cycle ammonia in the TCM reactor and produce a reaction with the calcium chloride. It forms part of the closed loop.

Table 2: Hazard analysis of the compressor and possible protective measures to reduce the risks.

	Origin – EN 12100	Consequences	Possible protection measures
Mechanical hazards	Cutting parts / Angular parts	Cutting, Severing, Stabbing, Puncture	- The element should be filed to avoid cutting or angular parts - Compressor must be embedded into a structure, which works like a safeguard, for prevent fromcoming into contact with its structure.
	High pressure	Impact	- A strong grid should be installed around the elements that can be broken in case of a sudden increase of pressure. - Pneumatic elements must carry CE mark.
	Approach of a moving element to a fixed part / Kinetic energy / Moving elements / Rotating elements	Drawing-in, Trapping, Cutting, Severing	- A strong protection grid should be installed around the elements that can be touched by users. - Pneumatic elements must carry CE mark.
Electrical hazards	Arc / Electromagnetic phenomena / Electrostatic phenomena / live parts /overload / Parts which have become live under fault conditions / Short-circuit	Burn, Chemical effects, Effects on medical implants, Electrocution Falling, being thrown, Fire Shock	- Electrical cables throughout the installation must have the CE mark and be protected by housings that reduce deterioration due to external agents. - The electrical conductors will be inside a box with fixed protectors, which will prevent access, except to specialized maintenance technicians. - The machine must be protected against direct and indirect contacts (overload and short circuits respectively) - Electrical hazard signage must be easy to see. - Grounding of all electrical equipment according to EN 60204. - The machine must have a switch or disconnecting element.
Thermal hazards	Explosion / Flame / Objects or materials with a high or low temperature	Burn, Scald	- Correct design of the electrical installations and periodic maintenance to avoid the increase in the temperature of the compressor body due to contact with the electrical installation. - Compliance with fire and ATEX regulations if necessary. - Order and cleanliness at the equipment location is necessary to avoid contact with products or materials that are combustible or spread fire.

Noise	Cavitation phenomena / Exhausting system / Gas leaking at high speed / Moving parts / Scraping surfaces / Unbalanced rotating parts / Whistlingpneumatics / Worn parts	Discomfort, Loss of awareness, Loss of balance, Permanent hearing loss, Stress, Tinnitus, Tiredness.	- A study must be carried out to analyse the noise during the installation of the machinery and take the appropriate protection measures to reduce it as much as possible. - A correct maintenance plan prevents breakage and wear of the internal components of themachine that can produce noise. - The user must be informed that if any unusual noise is detected, the technical service must benotified.
Vibration	Cavitation phenomena / Misalignment of moving parts / Unbalanced rotating parts	Discomfort, Neurological disorder	- Proper installation to reduce the transmission of vibrations to the building structure. - A correct maintenance plan avoids breakages and wear in the internal components of the machinethat can produce vibrations. - The user must be informed that if any vibration is detected, the technical service must be notified. - Sensors in the equipment can also be part of predictive maintenance cycles
Radiation	Electromagnetic radiation	Health consequences, Interference with implants and electronic medical devices	- The equipment must incorporate the CE marking. - The equipment must comply with EU Directive 2004/108 / CE relating to electromagnetic compatibility and other applicable standards.
Material/ substance	Fluid / Mist / Flammable	Breathing difficulties, poisoning, explosion, fire.	- Compressor must be installed in areas with access to specialized workers only. - Proper maintenance must be carried out to prevent leaks. - Compliance with fire and ATEX regulations if necessary.
Ergo-nomics	n/a	n/a	- n/a
Environ-mental	n/a	n/a	- n/a

3.1.1.3 Evaporator/ Condenser

These elements are used to regulate pressure in the closed TCM loop, changing its state from vapour to liquid and vice versa.

Table 3: Hazard analysis of the evaporator/ condenser and possible protective measures to reduce the risks.

	Origin – EN 12100	Consequences	Possible protection measures
Mechanical hazards	Cutting parts / Angular parts	Cutting, Severing, Stabbing, Puncture	- The element should be filed to avoid cutting or angular parts.
	High pressure	Impact	- Periodic checks should verify that the elements and conduits under pressure are adequately supported and in good operating condition. - A grid strong enough should be installed around the elements that can be break in case of a sudden increase of pressure. - All elements must carry CE mark.
	Falling objects (For hanging outdoor units only)	Impact	- Install far enough away to avoid being hit and avoid placing objects above the unit. - Install security cables.
Electrical	n/a	n/a	- n/a
Thermal	n/a	n/a	- n/a
Noise	n/a	n/a	- n/a
Vibration	Cavitation phenomena / Misalignment of moving parts / Unbalanced rotating parts	Discomfort, Neurological disorder	- Proper installation to reduce the transmission of vibrations to the building structure. - A correct maintenance plan avoids breakages and wear in the internal components of the machine that can produce vibrations. - The user must be informed that if any vibration is detected, the technical service must be notified.
Radiation	n/a	n/a	- n/a

Material/ substance	Fluid / Mist / Flammable	Breathing difficulties, poisoning, explosion, fire.	- Machinery must be installed in machine rooms, with access only for specialized workers. - Proper maintenance must be carried out to prevent leaks. - Compliance with fire and ATEX regulations if necessary.
Ergo-nomics	n/a	n/a	- n/a
Environ-mental	n/a	n/a	- n/a

3.1.2 Heat pump

The heat pump is used to upgrade the heat produced by the TCM loop and then send it to the hot PCM batteries (domestic hot water or heating)

Table 4: Hazard analysis of the heat pump and possible protective measures to reduce the risks.

	Origin – EN 12100	Consequences	Possible protection measures
Mechanical hazards	Cutting parts / Angular parts	Cutting, Severing	- When there is a risk of contact with moving parts, adequate safety measures must be available
	High pressure	Impact	- Components and pipes must have CE marking and have passed a tightness and pressure test and other requirements and tests according to EN 378-2 (only if in contact with ammonia which is not the case). - Pipe joints will be made according to the requirements of EN 378-2 (only if in contact with ammonia which is not the case). - Signage in pipe installation to avoid its misuse (climbing, hanging tools ...).
Electrical hazards	Arc / Electromagnetic phenomena / Electrostatic phenomena / live parts / overload / Parts which have become live under fault conditions / Short-circuit	Burn, Chemical effects, Effects on medical implants, Electrocution, Falling, being thrown, Fire Shock	- Electrical cables throughout the installation must have the CE mark and be protected by housings that reduce deterioration due to external agents. - The electrical conductors will be inside a box with fixed protectors, which will prevent access, except to specialized maintenance technicians. - The machine must be protected against direct and indirect contacts (overload and short circuits respectively) - Electrical hazard signage must be easy to see.

			- Grounding of all electrical equipment (equipotential) according to EN 60204. - The machine must have a switch or disconnecting element.
Thermal hazards	Explosion / Flame / Objects or materials with a high or low temperature / Radiation from heat surfaces	Burn, Scald, Injuries	- Mark and protect from contact adequately at the achievable temperature. - Correct design of the electrical installations and periodic maintenance to avoid the increase in the temperature of the heat pump body due to contact with the electrical installation. - In case of use of flammable refrigerants, the system must be constructed so that the refrigerant cannot flow or stagnate and cause a risk of fire or explosion (EN 60335) - Pressure protection devices, relief valves, limiters and others according to EN-378-2 - Compliance with fire and ATEX regulations if necessary. - Order and cleanliness at the equipment location is necessary to avoid contact with products or materials that are combustible or spread fire.
Noise	n/a	n/a	- n/a
Vibration	n/a	n/a	- n/a
Radiation	Electromagnetic radiation	health consequences, Interference with implants and electronic medical devices	- The equipment must incorporate the CE marking. - The equipment must comply with DIRECTIVE 2004/108 / CE relating to electromagnetic compatibility and other applicable standards.
Material/ substance	Fluid / Gas / Fume / Mist / Dust	Breathing difficulties, poisoning, explosion, fire.	- The deliberate discharge of refrigerant should only be allowed in a way that is not harmful to people, property and the environment and in accordance with national laws. - The closing devices or stopcocks of drains must be protected from unauthorized manipulations, for example, by their installation in the machine room and their characteristics and location will comply with EN 378-2. The operations must be explained in the instruction manual.

			- Sufficient isolation valves must be provided to minimize the risk of refrigerant loss, especially during maintenance and repairs. - The characteristics and location of the system valves (isolation, oil drain ...) will comply with EN378-2 - In case of use of flammable refrigerants, the system must be constructed so that the refrigerant cannot flow or stagnate and cause a risk of fire or explosion (EN 60335) - Pressure relief and pressure limiting safety devices must meet the requirements of EN 378-2
Ergo-nomics	n/a	n/a	- n/a
Environmental hazards	Pollution / Lack of oxygen	Disease, suffocation.	- The materials used in the equipment, as well as gaskets and cladding materials will be those indicated in standard EN 378-2. Asbestos should not be used. - Sufficient isolation valves must be provided to minimize the risk of refrigerant loss, especially during maintenance and repairs. - The characteristics and location of the system valves (isolation, oil drain ...) will comply with EN378-2. - The deliberate discharge of refrigerant should only be allowed in a way that is not harmful topeople, property and the environment and in accordance with national laws.

3.1.3 Pumps

The pumps used in the system are used to circulate fluid (water, water-glycol mixture) in order to transport it to different areas of the system or allow it to collect heat from the heat exchangers.

Table 5: Hazard analysis of the pumps and possible protective measures to reduce the risks.

	Origin – EN 12100	Consequences	Possible protection measures
Mechanical hazards	Cutting parts / Angular parts	Cutting, Severing, Stabbing, Puncture	- The element should be filed to avoid cutting or angular parts.
	High pressure	Impact	- Periodic checks should verify that the elements and conduits under pressure are adequately supported and in good operating condition.

			- Hydraulic elements must carry CE mark.
Electrical hazards	Thermal radiation	Burn	- Only trained workers should be able to access the device, which must be protected or located in a restricted access area. - The thermal danger must be marked, as well as the mandatory use of thermal protection gloves.
	Arc / Electromagnetic phenomena / Electrostatic phenomena / live parts / overload / Parts which have become live under fault conditions / Short-circuit	Burn, Chemical effects, Effects on medical implants, Electrocution, Falling, being thrown, Fire Shock	- Electrical cables throughout the installation must have the CE mark and be protected by housings that reduce deterioration due to external agents. - The electrical conductors will be inside a box with fixed protectors, which will prevent access, except to specialized maintenance technicians. - The machine must be protected against direct and indirect contacts (overload and short circuits respectively) - Electrical hazard signage must be easy to see. - Grounding of all electrical equipment (equipotential) according to EN 60204. - The machine must have a switch or disconnector.
Thermal hazards	Explosion / Flame / Objects or materials with a high or low temperature	Burn, Scald	- Correct design of the electrical installations and periodic maintenance to avoid the increase in the temperature of the machinery body due to contact with the electrical installation. - Compliance with fire and ATEX regulations if necessary. - Order and cleanliness at the equipment location is necessary to avoid contact with products or materials that are combustible or spread fire.
Noise	Cavitation phenomena / Exhausting system / Gas leaking at high speed / Moving parts / Scraping surfaces / Unbalanced rotating parts / Whistling pneumatics / Worn parts	Discomfort, Loss of awareness, Loss of balance, Permanent hearing loss, Stress, Tinnitus, Tiredness.	- A study must be carried out to analyse the noise during the installation of the machinery and take theappropriate protection measures to reduce it as much as possible. - A correct maintenance plan prevents breakage and wear of the internal components of the machine that can produce noise. - The user must be informed that if any unusual noise is detected, the technical service must benotified.

Vibration	Cavitation phenomena / Misalignment of moving parts / Unbalanced rotating parts	Discomfort, Neurological disorder	- Proper installation to reduce the transmission of vibrations to the building structure. - A correct maintenance plan avoids breakages and wear in the internal components of the machine that can produce vibrations. - The user must be informed that if any vibration is detected, the technical service must be notified.
Radiation	Electromagnetic radiation	health consequences, Interference with implants and electronic medical devices	- The equipment must incorporate the CE marking. - The equipment must comply with DIRECTIVE 2004/108 / CE relating to electromagnetic compatibility and other applicable standards.
Material/ substance	n/a	n/a	- n/a
Ergo-nomics	n/a	n/a	- n/a
Environ-mental	n/a	n/a	- n/a

3.1.4 Hot and cold phase change materials (PCM) vessels

The hot and cold PCM materials are used for flexibility to dispatch heat and cold when needed by the user, as they are in direct contact with heat exchangers connected to the heating or cooling system.

Table 6: Hazard analysis of the hot PCM vessels and possible protective measures to reduce the risks.

	Origin – EN 12100	Consequences	Possible protection measures
Mechanical hazards	Cutting parts / Angular parts	Cutting, Severing, Stabbing, Puncture	- The element should be filed to avoid cutting or angular parts.
	Height from the ground (Only in the case of large tanks)	Impact, slipping, tripping and falling	- Access should only be possible to qualified workers provided with adequate security measures. - The design of walkways (if necessary) must be done according to EN ISO 14122.
Electrical hazards	n/a	n/a	- n/a

Thermal hazards	Objects or materials with a high or low temperature / Radiation from heat surfaces	Burn, Scald, injuries by the radiation of heat surfaces	- Contact with the equipment is possible if the equipment is installed in common areas such as roofs. It is recommended to install into machinery room to avoid proximity and contact. - Adequate ventilation must be installed in rooms with possible high temperatures. - A correct maintenance plan prevents leaks that can cause thermal risks, such as burns or scalds.
Noise	n/a	n/a	- n/a
Vibration	n/a	n/a	- n/a
Radiation	n/a	n/a	- n/a
Material/ substance	Fluid	Sensitization	- Machinery must be installed in special areas, with access only for trained workers. - Proper maintenance must be carried out to prevent leaks.
Ergo-nomics	n/a	n/a	- n/a
Environ-mental	n/a	n/a	- n/a

3.1.5 Photovoltaic thermal collectors

Photovoltaic thermal (PVT) collectors are the main type of components included in the solar-heat generation system for the MiniStor system. The relevant risk linked to this component, are presented in Table 8, classified as mechanical, electrical, thermal, environmental and others. Possible protection measures are also indicated taking into account the manufacturer's specifications, the European Standard EN12100 and other complementary regulation.

Table 7: Hazard analysis of the photovoltaic thermal collectors and possible protective measures to reduce the risks.

	Origin – EN 12100	Consequences	Possible protection measures
Mechanical hazards	Cutting parts / Angular parts	Cutting, Severing, Stabbing, Puncture, impact	- The elements should be filed to avoid cutting or angular parts. - The impact with the equipment or

			with its support structure is possible if the equipment is installed in common areas such as roofs. It is recommended to install a perimeter fence or other prevention measures to avoid contact.
	Falling objects (For hanging outdoor units only)	Impact	- Install far enough away to avoid being hit and avoid placing objects on the unit. Install security cables.
Electrical hazards	Arc / Electromagnetic phenomena / Electrostatic phenomena / live parts / overload / Parts which have become live under fault conditions / Short-circuit	Burn, Chemical effects, Effects on medical implants, Electrocution, Falling, being thrown, Fire Shock	- Electrical cables throughout the installation must have the CE mark and be protected by housings that reduce deterioration due to external agents. - The electrical conductors will be inside a protective box, which will prevent access, except to specialized maintenance technicians (IEC-61730). - The machine must be protected against direct and indirect contacts (overload and short circuits respectively) - Electrical hazard signage must be easy to see. - Grounding of all electrical equipment (equipotential) according to EN 60204. - The electrical PVT DC and AC circuits must have electrical protections against overloads, indirect contacts, transient over-voltages and other complementary protection elements according to local regulations.
Thermal hazards	Objects or materials with a high or low temperature / Radiation from heat surfaces	Burn, Scald, injuries by the radiation of heat surfaces	- Contact with the equipment is possible if the equipment is installed in common areas such as roofs. It is recommended to install a perimeter fence or other prevention measures to avoid proximity and contact. In addition, all the pipes that transport the HTF in the solar thermal loop must have thermal insulation and mechanical protection, suitable for installation in an outdoor environment. - A correct maintenance plan prevents leaks that can cause thermal risks, such as burns or scalds.
Noise	n/a	n/a	- n/a

Vibration	n/a	n/a	- n/a
Radiation	Electromagnetic radiation	Health consequences, Interference with implants and electronic medical devices	- The equipment must incorporate the CE marking. - The equipment must comply with Directive 2004/108 / CE relating to electromagnetic compatibility and other applicable standards.
	Optical radiation	Damage to eyes	- Close enough proximity for sunlight reflections on solar collectors to affect the eyes is possible if the collectors are located in common areas such as terraces. Proper building integration.
Material/ substance	n/a	n/a	- n/a
Ergo-nomics	n/a	n/a	- n/a
Environmental hazards	Wind	Impact, cutting, crushing, electrocution, fire, shock	- The action of the wind on the collectors can detach parts of them, as well as affect the electrical installation. A study of the wind in the area should be made to make the proper anchoring structure.

At the solar thermal system level, there are other risks that can affect the normal operation of the solar thermal loop. In this sense, Table 8 summarizes the extended risks identified and possible protection measures, taking into account the European Standard EN 12975-1 (ISO, 2006) and the installation manual of the PVT manufacturer (EndeF).

Table 8: Extended hazard analysis of the slar thermal loop and possible protective measures to reduce the risks according to PVT manufacturer specifications, carried out by the manufacturer.

	Description	Possible protection measures
Overheating	The PVT glazed and unglazed panels, manufactured by EndeF can support up to 85°C and 70°C respectively.	- Activate the air-cooler, included in the solar thermal loop when the output temperature is 5°C below the maximum temperature that PVT collectors are designed for. - Install correctly air the air-cooler in the solar-loop according to manufacturer specifications. - Install the safety element: safety valves, expansion vessel, automatic drain elements, etc. - Qualified technical personnel must carry out a regular general inspection of the installation
Freezing of the solar loop outside the container	Failures in the components (solar collectors, pipes, pumps, etc.) due to the freezing of the heat transfer fluid (HTF), when the ambient temperature is very low.	- To use as HTF propylene glycol mixture in the system, according to the minim expected ambient temperature. - To activate the pump in the solar loop when the ambient temperature arrives to freezing temperature of the HTF + 4°C. - To establish a minimal temperature in the inertia tank, and use the backup heater in case it is necessary. - Periodically check the density and PH of the propylene glycol mixture. - To install thermal insulation in all pipes and components - Qualified technical personnel must carry out a regular general inspection of the installation
Freezing inside of container	Different components cannot support the extremely low temperatures (pumps, electronic components, etc.).	- All components inside the container must to be insulated (pipes, pumps, inertia tank, others). - Set a minimum temperature in the inertia tank and use the auxiliary heater if necessary. - Pumps should be vented and defrosted at least monthly. - Use of electrical tracing in pumps and sensitive elements.
Overpressure	The operating pressure in the solar loop must be below 4,0 bar.	- Select components with maximum operating pressure above 4.0 bar - Install the expansion vessel in the solar loop to absorb thermal expansion of the HTF; and check the pressure of the expansion vessel regularly. - Install the safety valve, automatic drain element and complementary safety elements correctly. - Monitoring the pressure and set an alarm for the maintenance service - Qualified technical personnel must carry out a regular general inspection of the installation
Loss of HTF	Loss of Heat Transfer Fluid (HTF)in the installation due to leaks, overpressure or other causes. (Minimal Pressure 1,5 bar)	- Carry out pressure tests correctly during commissioning - Monitoring the pressure and set an alarm for the maintenance service - Install auto fill group for Ministor system - Periodically check for the absence of moisture in the insulation of pipes and components. - Qualified technical personnel must carry out a regular general inspection of the installation
Air accum ulation	Air accumulation in the installation	- Install drain elements at the highest points of the installation with a slope to ensure the discharge of the air present. - Clean regularly the drain elements. - Qualified technical personnel must carry out a regular general inspection of the installation

Reverse flow	Reverse flow must be avoid in the solar loop	- The correct direction of rotation of the pump must be checked during installation. - Install check valve in the solar circuit - Install the corresponding components by skilled personnel. - Qualified technical personnel must carry out a regular general inspection of the installation

3.1.6 Electrical batteries

Li-Ion batteries are used by the electrical component of MiniStor to store surplus electrical energy. These batteries can be charged either from RES sources such as the PVT panels, and then electrical energy be used either for internal consumption at a later time or sold to the grid.

Table 9: Hazard analysis of the electrical batteries and possible protective measures to reduce the risks.

	Origin – EN 12100	Consequences	Possible protection measures
Mechanical hazards	Cutting parts / Angular parts	Cutting, Severing, Stabbing, Puncture, impact	- The equipment should be filed to avoid cutting or angular parts. - The impact with the equipment if the equipment is installed in common areas such as roofs. It is recommended to install safeguards to avoid contact.
Electrical hazards	Arc / Electrostatic phenomena / live parts / overload / Parts which have become live under fault conditions / Short-circuit	Burn, Chemical effects, Effects on medical implants, Electrocution, Falling, being thrown, Fire Shock	- Electrical cables throughout the installation must have the CE mark and be protected by housings that reduce deterioration due to external agents. - The electrical conductors will be inside a box with fixed protectors, which will prevent access, except to specialized maintenance technicians. - The machine must be protected against direct and indirect contacts (overload and short circuits respectively) - Electrical hazard signage must be easy to see. - Grounding of all electrical equipment (equipotential). - The machine must have a switch or disconnector.
Thermal hazards	Explosion / Flame / Objects or materials with a high or low temperature	Burn, injuries by the radiation of heat surfaces	- Use only of CE certified batteries. - The batteries must be installed in a place protected from shocks or mechanical damage of any kind. - The batteries must be installed in a place protected from high temperatures (danger of explosion) or from very low temperatures to

			avoid a high degree of discharge of the batteries (risk of fire during recharging). - The battery installation site must have adequate fire resistance and must not contain combustibleor fire-propagating products or materials. - The battery installation site must have adequate ventilation. - Depending on the number of batteries and their power, it may be necessary to install them in battery safety cabinets. - Depending on the number of batteries and their power, it may be necessary to install detectionor extinguishing systems. - Performing periodic reviews by qualified personnel to assess the condition of the batteries and removal of those that present blows, breaks or spills. - Compliance with fire and ATEX regulations if necessary.
Noise	n/a	n/a	- n/a
Vibration	n/a	n/a	- n/a
Radiation	n/a	n/a	- n/a
Material/ substance	Fluid / Mist / Flammable / Explosive	Breathing difficulties, poisoning, explosion, fire.	- Use only of CE certified batteries. - The batteries must be installed in a place protected from shocks or mechanical damage of any kind. - The batteries must be installed in a place protected from high temperatures (danger of explosion) or from very low temperatures to avoid a high degree of discharge of the batteries (risk of fire during recharging). - The battery installation site must have adequate fire resistance and must not contain combustibleor fire-propagating products or materials. - The battery installation site must have adequate ventilation. - Depending on the number of

			batteries and their power, it may be necessary to install them in battery safety cabinets. - Depending on the number of batteries and their power, it may be necessary to install detectionor extinguishing systems. - Performing periodic reviews by qualified personnel to assess the condition of the batteries and removal of those that present blows, breaks or spills. - Compliance with fire and ATEX regulations if necessary.
Ergo-nomics	n/a	n/a	- n/a
Environmental hazards	Sun / temperature / humidity / water	Breathing difficulties, poisoning, explosion, fire	- Install and store following the manufacturer's instructions. Environmental conditions can damage batteries causing leakage, fire and explosion. - The batteries must be installed in a place protected from high temperatures (danger of explosion) or from very low temperatures to avoid a high degree of discharge of the batteries (risk of fire during recharging). - The battery installation site must have adequate fire resistance and must not contain combustibleor fire-propagating products or materials. - The battery installation site must have adequate ventilation. - Depending on the number of batteries and their power, it may be necessary to install them in battery safety cabinets. - Depending on the number of batteries and their power, it may be necessary to install detection or extinguishing systems. - Performing periodic reviews by qualified personnel to assess the condition of the batteries and removal of those that present blows, breaks or spills. - Compliance with fire and ATEX regulations if necessary.

4 Safe system operations

This chapter describes the requirements for safe system operation based on the findings from the study of the applicable standards and regulations (see chapter 2) and a hazard analysis of the system (see chapter 3). To achieve a secure system operation, three important steps are described in the following chapter. Section 4.1 describes system testing under real conditions in a protected environment and performed by qualified personnel. Section 4.2 describes the maintenance requirements of the system and the associated components and lists the corresponding measures. Finally, the last section, 4.3, defines the basic requirements for safe transport and indicates the transport routes to be followed.

4.1 Tests and measurements of the system before installation

The purpose of the measurements and tests is to control the main design performance values published by the manufacturer. The main design performance values are approached from the customer side. These performance values are the electrical power used by the MiniStor, and the heating and cooling (storage) performance extracted from it. Furthermore, during these tests, the MiniStor system is tested for the first time in a protected and controlled setting. The tests are carried out by qualified personnel from the respective partner EMI. This chapter describes the most important information about the test procedure, the environment and the test criteria. The test requirements are described by the standards MSZ EN 12599:2013 and EN 14240 and are carried out according to these specifications. A detailed description of the tests and their results follow in the designated document deliverable D6.2.

4.1.1 Description of the tests

The performance values are measured with different, normal and extreme operating conditions. The parameters for the extreme operating conditions are also set based on the data provided by the manufacturer. The tests are performed by simulating winter, transient (normal) and summer operating conditions. During the tests, a change of temperature around the MiniStor unit and the heat requirements in the residential building supplied by the MiniStor will be performed.

4.1.2 Description of the environmental modelling of the MiniStor

The test environment is a separate room as shown in the Figure 3, where several types of environmental conditions can be produced to a limited extent. In the produced comfort conditions, the temperature of the boundary walls, of the supply air and of the room air can be modified. MiniStor will be placed into this room and by modifying the environmental parameters the outdoor temperature conditions can be created corresponding to several seasons. Thermodynamically, this model may affect the heat storage capacity of the MiniStor.

Figure 3: EMI room for real simulation of different comfort types.

4.1.3 Description of modelling of a residential building supplied by MiniStor

A liquid-liquid heat exchanger will be connected to the cooling, heating, and domestic hot water systems of MiniStor. The primary side of the heat exchangers is supplied with positive heat output by MiniStor, the secondary side is set to a negative value of the heat quantities declared by the manufacturer as a deficiency. Thermodynamically, in this model MiniStor must be able to produce the amount of heat declared by the manufacturer. On the secondary side of the heat exchanger, positive or negative heat quantities according to the given winter, transient and summer operating conditions can be produced. Figure 3 shows the mechanical circuits that supply the room. These circuits are used to set the negative value of the heat quantities declared by the manufacturer.

4.1.4 The measurements/tests process

In winter mode, the negative value of the heating output declared by the manufacturer to the secondary side of the heat exchanger in the heating circuit will be set. A negative heat output value is also set for the secondary side of the domestic hot water extraction modelling heat exchanger, based on the manufacturers' data. The cooling output does not operate in winter mode; no heat output value will be set here. The ambient air temperature of the MiniStor corresponding to the winter condition is also set according to the manufacturer's data. In the event of a steady state the electrical power used by the MiniStor, the heat output of the delivered heating and domestic hot water at an ambient temperature corresponding to the winter state will be measured.

In summer mode, the positive value of the cooling heat output declared by the manufacturer to the secondary side of the heat exchanger in the cooling circuit will be set.
A negative heat output value is also set for the secondary side of the domestic hot water extraction modelling heat exchanger based on the manufacturer's data. The heating heat output

does not operate in summer mode; therefore no heat output values will be set. The ambient air temperature of the MiniStor system corresponding to the summer condition is also set according to the manufacturer's data. In the event of a steady state the electrical power used by the MiniStor, the heat output of the cooling and domestic hot water delivered at an ambient temperature corresponding to the summer state will be measured.

In the case of the transient operating mode, the negative value of the heating-cooling heat output declared by the manufacturer to the secondary side of the heat exchanger in the heating-cooling circuit will be set. In this case, assuming an extreme state, the cooling and heating demand are modelled alternately. The practical extreme case where the heat minimum in the evening and cool minimum during the day will be considered. A negative heat output value is set for the secondary side of the domestic hot water extraction modelling heat exchanger based on the manufacturer's data. The ambient temperature of the MiniStor is also set according to the manufacturer's data. In the event of a steady state, the electrical power used by the MiniStor, the heat output of the heating-cooling and domestic hot water delivered at an ambient temperature corresponding to a transient state will be measure.

4.1.5 Data measurement

Each main manufacturers' data are measured with two instruments operating on different methods. The electrical power used by the MiniStor is measured by a hand instrument and by a built-in electric meter. The heating, cooling and domestic hot water heat outputs delivered by the MiniStor are measured by a sealed heat meter and by an IMI TA measuring device integrated into the primary circuits of each system. The ambient temperature of the MiniStor will be measured by a mercury laboratory thermometer and a digital thermocouple thermometer.

4.2 Maintenance works

Maintenance is an important measure to be able to operate the MiniStor system in a risk-minimised manner. In the following chapter, the applicable regulations or the measures prescribed by the manufacturer regarding the maintenance of the individual components are listed, as well as the maintenance interval and the maintenance work to be carried out.

Many components installed in the MiniStor system require very little maintenance. The manufacturers recommend periodic visual inspections and removal of dirt, but these periods are longer than the intended service life of the MiniStor system. Therefore, additional visual inspections are provided for these components during the period of use, which are coupled to the specifications of the components that require more frequent maintenance. Table 10 shows an overview of the components in which the maintenance intervals and the responsible party are defined.

Table 10: Overview of the maintenance intervals of the individual components as well as definition of the specialists to execute this maintenance.

Component	Interval	Maintenance	Executing
Compressor	monthly	Clean air filter.	Instructed person
	500 h	Change air filter.	
	yearly	Visual inspection of the grid around the pressurized elements.	
	yearly	Visual inspection of all hazard signs (electrical)	
	yearly	Interview the demo site owners on: unusual noise or unusual vibrations during operation.	
Evaporator/ condenser	yearly	Visual inspection, remove dirt.	Specialist
	yearly	Visual inspection of the grid around the pressurized elements.	
	yearly	Interview the demo site owners on: unusual noise or unusual vibrations during operation.	
Heat pump	yearly	Visual inspection, remove dirt.	Costumer service or instructed person
	yearly	Visual inspection of all hazard signs (electrical, misuse of pipe installation, heat)	
	yearly	Visual inspection of all stopcocks.	
Pumps	yearly	Visual inspection, remove dirt.	Costumer service or instructed person
	yearly	Visual inspection of all hazard signs (heat, electrical)	
	yearly	Interview the demo site owners on: unusual noise or unusual vibrations during operation.	

PCM vessels	yearly	Visual inspection, remove dirt.	Costumer service or instructed person
PVT system	yearly	Cleaning of the surface and visual inspection.	Specialist or instructed person
	yearly	Inspection of the PVT loop (min. pressure HTF: 1.5 bar, max. pressure loop: 4 bar)	Specialist
	yearly	Visual inspection of all hazard signs (electrical, heat)	Specialist or instructed person
	yearly	Density and pH check of the propylene glycol mixture.	
	monthly	Venting and defrosting of the pumps.	
	yearly	Inspection and cleaning of drain elements.	
Electrical batteries	yearly	Visual inspection, remove dirt.	Specialist
	yearly	Visual inspection of all hazard signs (electrical)	Specialist of instructed person
Valves and safety equipment	n/a	According to the manufacturer's recommendation	According to the manufacturer's recommendation
Pipes and cables	yearly	Visual inspection, remove dirt.	Specialist
TCM system	quarterly	Visual inspection of all junctions and the insulation jacket, check for leaks	Specialist
	twice a year	Check the electrical connections for power and control for excessive temperatures and corrosion.	
	quarterly	Check the presence of non-condensable gas by checking the correct condensing pressure of the liquid ammonia at the condenser outlet.	
	monthly	Check: nominal flow rate and temperature of the HTF	Specialist or trained person
	monthly	Check: Operating pressure, safety and temperature controls.	
	monthly	Check the function of pressure switches by lowering the set values temporarily or throttling the condenser or suction line.	
	weekly	Check the level of ammonia oil in the compressor.	Trained person
General	After every inspection	The container must be cleaned after each inspection or maintenance and unnecessary utensils must be removed (access and minimisation of fire load).	Person involved

All maintenance work carried out on the system, whether as part of scheduled maintenance or extraordinary maintenance, must be carried out and documented by an inspection body certified to ISO 17020:2012 (ISO, 2012). The work that has been carried out must be described in the log, and the entry must be dated and signed by the person carrying out the work. In addition, it must be evident whether it is a matter of regular or extraordinary maintenance. The log shall be kept digitally and an up-to-date version shall be available at the system (whether digitally or in printed form). The log must consists of a protocol with date, time, name of the maintenance person, ticked checklist and result of each work step, measures taken in case of adjustments, list of installed spare parts, signature of the maintenance person and photos for visualisation if necessary.

4.2.1 TCM System

During the first full operating cycle, check at the beginning of each day for ammonia leaks from valves and other pipe connections, compressors, sensors, heat exchanger or liquid ammonia tank.

In general, the EN 378-4 standard applies to the maintenance of systems that work with ammonia, with Annex C.4 describing the special provisions for the handling of ammonia during maintenance. The following specifications therefore apply equally to all components that come into contact with ammonia (liquid or gaseous).
"*Where subsections of an ammonia system are to be opened for maintenance the ammonia must be removed from the system safely. Small quantities of vapour (up to 10 kg) can be vented to the atmosphere, subject to local regulations. This must be done safely and in a manner which does not damage the local environment. It is also possible to absorb the residual ammonia vapour in water to reduce the loss of ammonia to atmosphere. However, this creates a solution of aqueous ammonia, which must be handled with care and removed from site safely*" (EN 378-4 Annex C).
The standard EN 378-4 provides for a distinction between the discharge of small quantities and large quantities of steam (< 10 kg). According to the analysis of local regulations in the demo site countries, this distinction is adopted or no additional specifications are given for this point. An extended analysis of the requirements for the individual demo sites can be found in document D6.3.

Figure 4 shows the schematic setup to release the complete amount of ammonia.

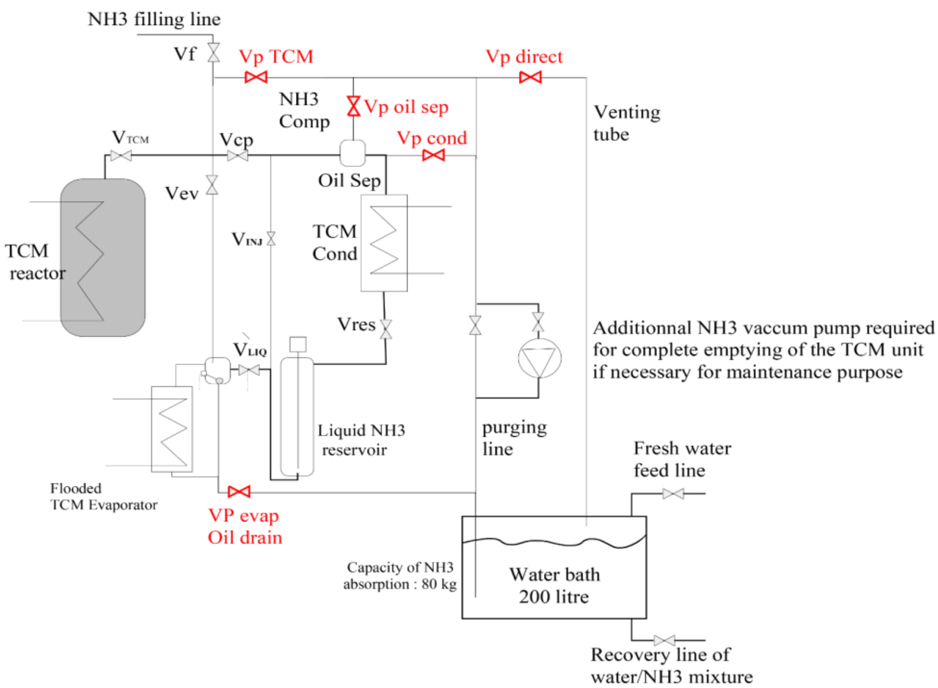

Figure 4: Schematic setup for the complete emptying of the TCM system.

- *Vp_TCM:* outlet of the TCM reactor, suction of the compressor, outlet of the flooded evaporator.
- *Vp_oil_sep:* drained oil of the separator
- *Vp_cond:* for draining non-condensable gas
- *Vp_direct:* connects the purging line directly to the venting line for small amounts of ammonia that may be released (e.g. relief valve checking or vacuuming the pipes for maintenance operation)
- *Vp_evap:* for draining of the oil that may accumulate at the flooded evaporator

All the purging valves are connected to a water bath to absorb the released ammonia. The water bath is equipped with a venting tube to bring it to atmospheric pressure and evacuate excess ammonia gas in case of ammonia saturation of water. The complete emptying of the installation has to be carried out, when the pressure becomes closed to the atmospheric pressure by an additional ammonia compressor for a complete vacuuming of the installation. Water is a very good ammonia absorber. In 1L of water (at room temperature) 0.4 kg of ammonia can be absorbed. The 200L water tank can therefore absorb 80 kg of ammonia.

According to the UK Institute of Refrigeration (UK Institute of Refrigeration, 2016), in the context of ammonia refrigeration plants for food and drinks, a suggested schedule for checking components goes from annual for the whole system, down to weekly for different fluid levels. Within MiniStor, it is suggested this type of inspection could be carried out through specialized sensors, due to the amounts of refrigerant involved.

The inspection of elements in this sub-system is aided by current system diagrams and up-to-date logs and certificates. Ignition sources for compressors should be completely eliminated (e.g. no welding work in the vicinity of a live ammonia system). Valves which are required for safe operation and maintenance of the system should be periodically checked for effective closure and early signs of defect.

Inspection of seals, glands and gaskets must be done regularly but without dismantling. Draining of oil and all inspections must be done by qualified personnel accredited to work in the country where the system has been installed.

4.2.1.1 Thermochemical reactor

The TCM reactor is being developed and built specifically for this project. Therefore, there are currently no empirical values or requirements for the maintenance of the reactor from the manufacturer. The exact maintenance measures for the reactor are defined and listed in deliverable D4.6.

4.2.1.2 Compressor

Since the specialized ammonia compressor also comes into contact with ammonia, the following additions to standard EN 378-4 apply:
"It should be equipped with oil collectors with draining valves in order to remove the entrained and accumulated oil from the system. The oil draining apertures shall be equipped with advanced scroll temperature protection (astp) valve and a self-closing valve downstream, or a catch pot oil collecting system, which enables isolation from a part of the refrigerating system containing liquid refrigerant safe venting of oil containing refrigerant and isolation of the vapour line before the oil is drained off. During the draining procedure, the pressure of the section from which the

oil is drained shall be above atmospheric pressure. If the draining aperture is blocked, additional care is necessary. Two valves are provided on the oil drain, one manually operated valve and one self-closing valve. If the self-closing valve is partly opened and no oil or refrigerant is emitted it shall be disassembled, cleaned and reinstalled. Ensure that the manually operated valve remains close during this operation. It is recommended that oil drained regularly in order to avoid interference with liquid level control, which could lead to compressor or pump damage." (EN 378-4 Annex A)

"With the system in normal operation, the refrigerant suction and discharge pressures and temperatures, the interstage pressure and temperature (where applicable) and the oil pressure should be compared with the permissible and normal operating conditions. Oil level should be observed and oil added (or removed) if required; it is potentially dangerous to have an oil level either above or below the level recommended by the supplier. The type of oil available shall be of a suitable grade. Where oil separators are installed, it should be verified that oil does return and is supplied to each compressor in suitable quantities. The log should be examined to ensure that the rate of oil added to compressors is not excessive and is matched by oil drained from the system after sufficient time has elapsed for stable conditions to be established. The compressor and associated piping and equipment shall be examined for abnormal vibration. Excessive vibration can cause piping to fail and can also cause failure of the internal moving parts of the compressor, with dangerous consequences. For example, the cause of any excessive vibration, drive misalignment or failure of supports or foundations shall be identified and the fault(s) corrected. Any pipes which have been subjected to excessive vibration should be tested for crack formation. Rotating equipment, particularly compressors, should be monitored separately for vibration at start-up. A vibration reference level, within satisfactory levels established by the equipment manufacturer, should be recorded. These levels establish the reference point upon which future measurements will be based."[1]

The compressor chosen for use in conjunction with the TCM reactor is based on Frigopol's 7-DLRC established compressor. This has a declaration of conformity according to EC Machine Directive 98/37/EC. The manufacturer does not give any specific information on the maintenance of the product, but advises a periodic check (no more precise information) and revision by the customer service.

Usually compressors are not serviced at periodic intervals but after a certain operating time. The following work must be carried out:

- Clean air filter → monthly
- Replace air filter → after 500 operating hours

The monthly checks and the work on the air filter can be carried out by an specialized person.

4.2.1.3 Evaporator/ condenser

The suggested heat exchanging components (EC.07.48) used in the MiniStor system are corrosion resistant, durable and low maintenance. Due to the use of ammonia, they must comply with the general maintenance requirements from the EN-378 standard (cf. section 4.2.1). The components should be inspected annually and visually checked for leaks. They should also be vented annually to ensure efficient operation. In addition, they are to be freed from dust and impurities. The inspection is to be carried out by a specialist.

[1] *(International Institute of Ammonia Refrigeration - Guidelines for: Start-up, Inspection and Maintenance of Ammonia Mechanical Refrigerating Systems)*

4.2.2 Heat pump

The suggested Hautec heat pump (HWBW-S19) is a hot water heat pump and has no contact with the ammonia circuit in the MiniStor system. The conformity of the heat pump is guaranteed by conformity and compliance with the following standards:

- 73/23/EWG
- EN 60335 1 and EN 60335 2/40
- 89/336/EWG
- EN 5501 4, part 1 and 2
- EU Regulations 811/2013 and 813/2013

The CE marking was issued after testing and compliance with the following directives and standards:

- 89/336/EWG (electromagnetic compatibility)
- 73/23/EWG (Low Voltage Directive)
- DIN EN 1 4511 (Air conditioners, liquid chillers and heat pumps with electrically driven compressors for space heating and cooling)
- EN 378 (Safety and environmental requirements for refrigeration systems and heat pumps)

Due to the low risk posed by this component, maintenance is to be carried out as follows according to the manufacturer (Hautec GmbH):
"An annual visual inspection by the customer service or a trained person is advisable. In this way, any possible contamination or faults can be detected at an early stage."

4.2.3 Pumps

None of the pumps 1-5 (in reference to deliverable D3.2) used in the MiniStor system are in contact with the ammonia circuit. Their use is limited to distributing the heat transfer fluid to or from the TCM system to other components. Three different types of pumps are used. Two of them are suggested to be those manufactured by Wilo SE and the remaining three (all the same model) by Hautec GmbH.

Pump 1 (Varios PICO-STG 25/1-7 by Wilo SE)
The suggested pump Varios PICO-STG 25/1-7 from Wilo SE is CE certified and complies with the following regulations:

- Low Voltage 2014/35/EU
- Electromagnetic compatibility 2014/30/EU
- Energy-related products 2009/125/EC
- Restriction of the use of certain hazardous substances 2011/65/EU + 2015/863

In addition, it complies with the following standardised European standards:

- EN 60335-2-51
- EN IEC 63000
- EN 16297-1 and EN 16297-3
- EN 61000-6-(1-4)

The following maintenance note is advertised by the manufacturer:
"Carefully remove dirt from the pump regularly with a dry duster. Never use liquids or aggressive cleaning agents."

Since no routine maintenance of the component is scheduled, the maintenance of pump 1 is coupled with the maintenance of the heat pump, which should happen once a year. In addition to removing contamination, a visual inspection should also be carried out.

Pump 2 (Stratos MAXO 25/0.5-8 PN10 by Wilo)

The suggested pump MAXO 25/0.5-8 PN10 from Wilo SE is CE certified and complies with the following regulations:

- Machinery 2006/42/EC
- Energy-related products 2009/125/EC
- Radio Equipment – directive 2014/53/EU
- Low Voltage 2014/35/EU
- Electromagnetic compatibility 2014/30/EU

In addition, it complies with the following standardised European standards:

- EN 60335-2-51
- EN 62479
- EN 16297-1 and EN 16297-2
- EN 300328 V2.1.1
- EN 301489-1 V2.1.1
- EN 301489-17 V3.2.0
- EN 61800-3 + A1:2012

The following maintenance note is advertised by the manufacturer: *"Carefully remove dirt from the pump regularly with a dry duster. Never use liquids or aggressive cleaning agents. Maintenance should only be carried out by customer service or trained personnel. For all maintenance work, the pump must be taken out of operation."*

Since no routine maintenance of the component is scheduled, the maintenance of pump 2 is coupled with the maintenance of the heat pump, which should happen once a year. In addition to removing contamination, a visual inspection should also be carried out.

Hautec GmbH

The suggested pump from Hautec GmbH is CE certified and complies with the following regulations:

- Low Voltage 2014/35/EU
- Electromagnetic compatibility 2014/30/EU
- Energy-related products 2009/125/EC

In addition, it complies with the following standardised European standards:

- EN 60335-2-51
- EN IEC 63000
- EN 16297-1 and EN 16297-3

The manufacturer does not maintain a specific maintenance manual for this product. As the pumps are used in conjunction with the heat pump, the maintenance of the pumps is linked to that of the heat pump. According to the manufacturer, the following applies:
"The circulation pumps or their function are checked as part of the maintenance of the heat pump, for example when checking the running behaviour of the heat pump. If the circulation

pumps do not function properly, the heat pump will malfunction and switch off." (Hautec GmbH, Thomas Niemann, written correspondence on 18.05.2021)

4.2.4 Phase change material vessels

The maintenance of the PCM vessels is independent of whether they are hot or cold PCM storage units. The current PCM Vessels designed for use in the MiniStor system are CE certified.

The maintenance requirements of the product are described by the manufacturer as follows: *«Where undertaking maintenance, repairs or removals, and where necessary, ensure that the system is first disconnected from the electrical and/or water supply.*

- *The product does not require any regular maintenance.*
- *In areas, where the mains water hardness can exceed 150 ppm Total Hardness and a scale-reducing device has been fitted, the service and maintenance requirements of this device (especially re-fill requirements) need to be adhered to.*
- *The air pressure in the expansion vessel should be checked every 2-3 years and topped up if necessary.*
- *If the supply cord is damaged, it must be replaced by the manufacturer, its service agent or similarly qualified persons in order to avoid a hazard, please refer to the Electrical wiring sections.»*

In addition, the manufacturer gives a recommendation for cleaning the components:

- *"The product does not require any regular cleaning.*
- *Should the product exterior have become dirty it can be wiped down with a damp cloth and a mild detergent (such as soap) after having been isolated from the electricity supply. Let the appliance dry before reconnecting the electricity supply."*

4.2.5 Photovoltaic thermal collectors

The selected PVT panels ECOMESH from EndeF are certified according to EN 12975. The collectors are designed to be low-maintenance. To ensure safe and efficient operation, the surfaces must be cleaned at least annually. Cleaning must be carried out with a suitable and non-aggressive cleaning agent and low-lime water. Under no circumstances should a high-pressure cleaner be used. If efficient cleaning of the collectors is only possible by climbing on a roof or frame, this cleaning must be carried out by specialists. If cleaning is possible without climbing, it can be carried out by an instructed person. After cleaning, the surfaces must be inspected for damage and cracks.

The complete solar loop is to be checked as part of an annual inspection. This work must be carried out by a specialist or the customer service. The checks to be carried out during this inspection are described in the extended hazard analyses (Table 8).

4.2.6 Electrical batteries

The selected electric batteries from BYD Battery-Box used in conjunction with the PVT system are CE certified, and have thus been tested according to the following standards:

- EN 300328 V 2.2.2:2019
- EN 301489-1 V 2.2.3:2019
- EN 301489-17 V 3.2.0:2017
- EN 61000-6-1:2007

- EN 61000-6-3:2007 + A1
- EN 62311:2008
- EN 62477-1_2012 + A11 + A1

Furthermore, they are provided with the certificate for the following standards:

- IEC 62040-1:2017
- IEC 62619:2017
- VDE-AR-E 2510-50:2017

The batteries are delivered with a material and test certificate.

For the maintenance of the products, the manufacturer writes:
"The battery module should be stored in an environment with a temperature between -10°C – +50°C, and charged regularly according to the table below with no more than 0.5 C (A C-rate is a measure of the rate at which a battery is discharged relative to its maximum capacity.) to the SOC of 40% after a long time of storage."

Table 11: Storage time in relation to environment temperature, humidity and SOC.

Storage environment temperature	Relative humidity of the storage environment	Storage time	SOC
Below -10 °C	-	Not allowed	-
-10 – +25 °C	5% – 70%	≤ 12 months	30% ≤ SOC ≤ 60%
25 – 35 °C	5% – 70%	≤ 6 months	30% ≤ SOC ≤ 60%
35 – 50 °C	5% – 70%	≤ 3 months	30% ≤ SOC ≤ 60%
Above 50 °C	-	Not allowed	-

For cleaning the products, the manufacturer states: *"It is recommended that the battery system be cleaned periodically. If the enclosure is dirty, please use a soft, dry brush or a dust collector to remove the dust. Liquids such as solvents, abrasives, or corrosive liquids should not be used to clean the enclosure."*

As the described maintenance work is not actual maintenance work, a periodic inspection of the batteries and a visual check as well as cleaning by a specialist is set. The inspection should take place annually and together with the inspection of the PVT loop.

4.2.1 Valves and safety devices

Safety devices such as fire alarms, gas alarms, eye showers or storm vents must be checked regularly for functionality. They must be tested at least annually (according to EN 378 and (UK Institute of Refrigeration, 2016)). These products are to be selected so that they are certified, easy to handle, as low-maintenance as possible and durable. The maintenance of the individual installations is described in detail in the corresponding manuals provided by the manufacturers. In addition, the testing procedure is explained.

The same applies to safety valves in all parts of the system. These must be inspected regularly (at the intervals defined by the manufacturers) and tested if necessary. They must be cleaned regularly to ensure that dirt does not cause them to malfunction. The corresponding procedure is defined by the manufacturers.

4.2.1 Pipes and cables

The pipes of the thermal circuit must be visually inspected annually for leaks. This applies specially to transitions and connections to components. In addition, they should be cleaned of coarse dirt annually to prevent corrosion. The cables must be visually inspected annually for damage and weak points. In addition, they should be cleaned of coarse dirt annually. The work is to be carried out by a specialist.

4.3 Shipping guidelines

This chapter will explain the shipping boundaries of the different components of the MiniStor system, together with an overview about the logistic path that the components will make during the shipping process. This document describes the basic shipping guidelines of the components, specifically in relation to the handling of ammonia. However, shipping is outsourced to a third party company that specializes in the transport of specialized goods, even if they contain hazardous materials. The final provisions for the transport are to be defined by the company to be selected.

4.3.1 Shipping overview

This chapter aims at describing the logistic process that the different components of the MiniStor system will experience. Firstly, the different places are listed:

- Manufacturer of the TCM unit
- Assembly of the MiniStor system (which might be the same of the above)
- Manufacturer and provider of the solar and electrical loop (EndeF)
- All demo sites:
  - Santiago de Compostela
  - Sopron
  - Thessaloniki
  - Cork
  - Kimmeria

According to the scheduled tasks, partner CNRS will also perform testing of a TCM unit to ensure good functioning and work. Partner EMI will perform a whole-system test.

It should be mentioned that the thermal subcomponents (e.g. heat pump, pump, fan coil units, etc.) are all supplied by their producers as off-the-shelf products to the MiniStor system manufacturer.

Thirdly, it has to be mentioned that the electrical components (e.g. Li-ion-battery, converter, etc) and the components of the solar loop (e.g. PVT, FPC, solar pump, etc) will be delivered from the manufacturer and provider (EndeF) of the solar and electrical loop directly to the respective demo sites. Just as a reminder at this point, the demo site in Kimmeria will use a different RES source.

4.3.2 Ammonia related components

To reduce the risks posed by ammonia during transport, it is suggested to ship the TCM units with only a residual amount that is needed to prevent the salts from coagulating with ambient humidity. At that stage, the TCM unit has no pressure and the ammonia amount is minimal. The system would be pressurised on site by a certified specialist, who will also be in charge of commissioning. This procedure will be revised at the moment of manufacture. Despite this, shipping should still be considered as in a pressurised transport vessel with suitable packaging and isolation. It should be protected against direct sunshine, electric sparks and from the magnetic environment. The use of a PPM gas detector during transport is mandatory. Few measurements on ease to ignite showed that the most explosive mixture of ammonia and air was much more difficult to ignite than corresponding pentane/air mixture.

4.3.2.1 Ammonia Compressor

Before shipping, the components should have passed a vibration and drop test.

EN 378-2 6.2.12.
"*Factory sealed single package units (i.e. one functional unit in one enclosure) which are not fixed appliances, shall withstand the effects of dropping and vibration during the transport and intended use without leaking refrigerant. A sample shall be subjected to the test of 6.2.12.2. to 6.2.12.6. There shall be no refrigerant leakage. During the test damage of parts other than refrigerating circuit is allowed.*"

EN 378-2-6.2.13.
"*To ensure safety during transport the following requirements should apply: Based on the fact that repetitive pressure peaks seldom occur during the transport, that all system are strength pressure tested beforehand and taking into account the characteristic of the refrigerant, there are additional pressure requirements related to transport of equipment without pressure relief devices.*"

EN 378-2 6.2.14.
"*For systems using flammable refrigerants, refrigerating systems shall be constructed so that any leaked refrigerant will not flow or stagnate so as to cause a fire or explosion hazard in areas within the equipment where components and apparatus which could be a source of ignition and which could function under normal conditions or in the event of a leak, are fitted.*"

Compressors should be shipped as fragile goods. Moving parts should be temporary fixed/locked.

4.3.2.2 Evaporator/ condenser

The evaporator and condenser shipping preparation should start with a temporary fixing of the moving part to the equipment. The equipment should be protected against the impact, destructive attack or load. The equipment should be properly fixed to the temporary substrate panel. For manipulation loadbearing hooks should be integrated temporary or in a permanent mode.

4.3.3 Heat pump

Heat pumps shipping preparation should start with a temporary fixing of the moving part of the equipment. The transported good should be protected against the impact, destructive attack or load. The equipment should be properly fixed to the temporary substrate panel. For manipulation loadbearing hooks should be integrated temporary or in a permanent mode.

4.3.4 Pumps

Shipping as fragile goods. Moving parts should be temporary fixed/locked.

4.3.5 Phase change material vessels

The phase change material thermal stores, both for heating and cooling, are to be shipped at ambient conditions (~5-30 °C). The hot thermal store with the PCM at 58 °C will be discharged at the end of their manufacture and hence be shipped solid. There may be residual water in the heat exchanger from this process; hence extended periods of time at below zero are undesirable as may lead to ice formation within the heat exchanger, which could cause damage. The cold material thermal stores are to be shipped as is, and as such, the PCM will most probably be in the liquid form. This introduces two potential risks.

- A leakage potential.

Since the thermal stores are designed to contain their PCM as a primary aim, and as such it is their intended purpose to contain liquid PCM. Therefore, this risk is to be classified as very low. In the case of spillage, the safety datasheets of the manufacturer detail the procedure to be adhered.

- Sloshing leading to instability when in transport.

The heat exchanger acts as a baffle for the majority of the liquid PCM, and thus increase the stability of the unit when in transport compared to a vessel with no internal baffles. The tanks must be secured for transport to prevent them from tipping over or moving in any other way.

In the case of extraordinary events, such as a vehicle collisions or warehouse accident, where the thermal stores may be very significantly damaged or inverted, safety datasheets detailing the procedure to be adhered will be included in the packaging slip for the cooling thermal stores, as well as being available in the digital format for the end receiver and the transport companies.

4.3.6 Photovoltaic thermal collectors

PVT collectors are not extremely fragile, but could be damaged easily, therefore careful preparation is needed. The equipment should be shipped without the fluent part; it should be filled on site. The PV part should be protected against scratches. Direct sunlight and extreme temperature changes should be avoided. The manufacturer decides if it should be shipped horizontally or vertically. No more than ten collectors should be put on top of each other. Each three elements should be divided distribution battens supported by the frames. Protection layer should be installed between the elements. The elements should be wrapped by adjustable tape against slipping in different directions. No shipping allowed facing two element toward each other. Elements should be shipped with the glazing top side up.

4.3.7 Electrical batteries

The shipment of lithium-ion batteries has different transportation modes, shipment vehicles (rail, truck, sea fright or air fright) and different packaging instructions. For the following statements it is assumed that the chosen lithium-ion battery has more than 100 Wh capacity, will be shipped by truck, has passed the transportation test section 38.3 of the UN Manual of Test and Criteria (United Nations, 2009) and the batteries are being shipped without equipment. In this case, the batteries must be placed in other packages (UN approved package) that completely enclose those batteries, they have to be protected to prevent short circuits and secured against undesired movement within the outer package. The manufacturer of the chosen lithium ion batteries (BYD Electronic Co., Ltd) has specially certified packaging for shipping that meets the requirements for safe transport of goods (till class 9).

4.4 Residential usage conditions

Safe system operation is enabled if the safety and maintenance measures described in sections 4.1-4.3 are fulfilled. Another important aspect is that the residential usage conditions are considered and are in accordance with the environmental conditions allowed by the manufacturers of the individual components. Table 12 lists specific information on the individual components as defined by the manufacturers.

Table 12: Summary of available manufacturer information on specific requirements regarding residential conditions.

	Parameter	Min. value	Max. value
Compressor	n/a	n/a	n/a
Evaporator	Temperature [°C]	-10	+70
Condenser	Temperature [°C]	-10	+70
TCM system	n/a	n/a	n/a
Heat pump	Temperature [°C]	-20	+70
	Humidity	n/a	90 %
Pumps	Temperature [°C]	-10	+65
PCM vessels	n/a	n/a	n/a
PVT system	Temperature [°C]	-40	+85
	Maximum wind load [Pa]	n/a	2400
	Maximum snow load [Pa]	n/a	5400
Electrical batteries	Temperature [°C]	-10	+50

For components where several different types are installed in the system, such as pumps, only the most restrictive values are listed. No specifications are defined by the manufacturers for the PCM vessel and compressor. Since the TCM system is a custom-made product for the MiniStor project, the manufacturer will update the above list after completing the safety/operation tests for the system. This can be seen as an advantage, as it means that the most restrictive boundary conditions from Table 12 can be used as a default.

As MiniStor is a complex system of different components and only functions in this compound, the strictest conditions from Table 12 must apply to the entire system. Since the batteries are not in the container for safety reasons, the maximum outside temperature of the pumps is specified as the maximum value for the MiniStor container. Therefore, the MiniStor container is only safe for use at outdoor temperatures of -10 °C to +65°C. The maximum outside temperature of the batteries must be taken into account when placing them. In addition, the maximum humidity is set by the heat pump and must not exceed 90%. These limits must be guaranteed at every stage from shipping to active operation of the MiniStor system. In addition, the information from 4.1 - 4.3 must be taken into account for safe system operation at the appropriate stages.

Conclusions

This deliverable discusses relevant requirements for the safe operation, maintenance and shipping of the MiniStor system, since the MiniStor system is composed of commercial components and novel components. The identification of the requirements is performed based on a hazard analysis that takes into account EN 12100 and a summarized review of the relevant European standards. The chapter Hazard analysis and proposed actions should be considered as a first analysis of the whole system. Although many issues have been addressed, it should not be neglected that additional hazards may be identified during the progress of the project and, through the methodology suggested by EN 12100, supplement it with mitigation measures and risk evaluation.

In addition, also a review of the maintenance requirements as indicated by the components' manufacturers has been performed. The analysis indicates that the maintenance works are not time consuming but need to be performed regularly. New automated supervision methods such as continuous system monitoring through sensors, and predictive maintenance, should be implemented. These can help to bring down the costs of traditional maintenance, where traditional human inspection might miss some potential issues that might start to develop. This should also be part of any business model towards system commercialization while keeping optimum performance.

A cursory review of the requirements for the shipping requirements of the MiniStor system has been performed on the main system elements. The identified relevant guidelines show that most of the subcomponents can be shipped without major problems. Certain components still need care when handling them during transport:

- TCM unit: due to residual amounts of ammonia, to be transported not under pressure.
- PVT: Even if they are robust, they can be damaged easily
- Lithium-ion battery: Certified packages for shipping should be used.

The remaining components (e.g. pumps, heat pump, phase change vessels, etc.) can be shipped with a temporary fixation.

In conclusion, it has to be mentioned that this document is the basis for the handling of safety aspects operation and maintenance and shipping assessment, which is of utmost importance. Further tasks will be performed and relevant regulations will be identified beyond this document.

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