Ref. Ares(2023)5144717 - 25/07/2023

H2020-LC-SC3-2018-RES

EUROPEAN COMMISSION

Grant agreement no. 818329

Sun coupled innovative Heat pumps

D7.5 – E-Handbook with Guidelines for Integration of SunHorizon Solutions in Public and Private Tertiary Buildings

Due date of deliverable: **31/07/2023**

Actual submission date: 25/07/2023

Organisation name of lead contractor for this deliverable: TUCN

Contributions: All partners

Dissemination Level		
PU	Public	X
CO	Confidential	

Project Contractual Details

Project Title	Sun coupled innovative Heat pumps
Project Acronym	SunHorizon
Grant Agreement No.	818329
Project Start Date	01-10-2018
Project End Date	30-09-2023
Duration	60 months

Supplementary notes: This document will be publicly available (on CORDIS and project official websites as soon as approved by EC.

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AHU	Air Handling Unit	IRR	Internal Rate of Return
A-W	Air-to-Water	KPI	Key Performance Indicator
CAPEX	Capital Expenditure	LT	Low Temperature
CHP	Combined Heat and Power	MT	Medium Temperature
CIP	Consumer Price Index	NVP	Net Present Value
COP	Coefficient of Performance for Heat Pumps	O&M	Operation and Maintenance
DHW	Domestic Hot Water	OPEX	Operational Expenditure
DMT	Decision Making Tool	PP	Pay-back Period
DUU	Design Under Uncertainties tool	PV	Photovoltaic
ESCO	Energy Service Company	PV-T	Photovoltaic-Thermal
FMECA	Failure Modes, Effects, and Criticality Analysis	RCM	Reliability-Centered Maintenance
H&C	Heating and Cooling	RES	Reneable Energy Source
HICP	Harmonized Index of Consumer Prices	RUL	Remaining Useful Life
HP	Heat Pump	TP	Technology Package
HVFP	High Vacuum Flat Panels		

Executive summary

This document is aimed at providing general guidance on how the SunHorizon developed technologies could be replicated in other residential and tertiary buildings. An easy to understand and follow Handbook is presented for professionals, building managers and owners to identify which combination of SunHorizon technical solutions best suits their building requirements and the climate zone where is located. Insights regarding installation and maintenance actions are also provided.

The deliverable starts with a short description of the SunHorizon developed solutions and technology packages to help the reader to understand how these technologies work and why it would be beneficial to implement them in their building infrastructures.

Then the steps to identify the optimal SunHorizon technology packages configuration for any specific building are presented. Two SunHorizon developed tools are presented with the required input data that could automatically prepare a pre-feasibility sizing and design of SunHorizon solutions that could cover the analyzed building necessities.

Finally, the document offers valuable information regarding the process of integrating and installing SunHorizon solutions within a building. It delves into various aspects, including the necessary building permits, lessons learned from the implementation of SunHorizon demo-sites, and the recommended installation and maintenance actions provided by the technology providers.

1. Introduction

General description of the SunHorizon project

The main objective of SunHorizon is to demonstrate innovative and reliable Heat Pump solutions (thermal compression, adsorption, reversible) that acting properly coupled and managed with advanced solar panels (PV, Hybrid, thermal) to provide heating and cooling to residential and tertiary building with lower emissions, energy bills and fossil fuel dependency. Data Driven/KPI oriented optimized algorithms and tools were developed for predictive maintenance, optimize the management towards maximization of solar exploitation and give to the manufacturer inputs for new installation design. This monitoring platform also drives smart monitoring end user interfaces that are applied at building level to collect thermal comfort data towards a new thermal comfort driven heating control system developed within the project.

The project analyses Heat Pumps and building integrated solar solution specifics towards increasing performance, reducing cost (optimized size, installation cost reduction, etc.), increasing reliability (lifetime and reduced maintenance) as well as their integration in the building to facilitate replication and maximize self-consumption and adequate internal comfort. The project is industry driven and it is focused on three main research pillars:

- Pillar 1: *Optimized Design, Engineering and Manufacturing of SunHorizon Technologies* (under CEA and ITAE supervision)
- Pillar 2: *Smart Monitoring and Optimization Tool for H&C* (under SE supervision)
- Pillar 3: *Monitoring Data – Driven Control System for Smart Operation and Demonstration* (CARTIF/RINA-C/CEA supervision)

Furthermore, a strong replication is promoted thanks to the presence of relevant industrial stakeholders (VEO, EHPA, RINA-C, IES), analyzing business, social and environmental aspects (IVL, AJSCV, EMVS, TUCN).

Purpose of the document

To current deliverable aims at promoting the replication of the SunHorizon developed technologies outside the project consortium boundaries. The document provides professionals, building managers and/or owner with a Handbook with guidelines on how to replicate and integrate the SunHorizon solutions in public and/or private residential and/or tertiary Buildings.

Structure of the document

Section 2 of the document makes a brief description of the SunHorizon developed technical solutions and technology packages, and how they could be used in residential and tertiary building to reduce the building conditioning (heating and cooling) related cost promoting, at the same time, the large-scale adoption of energy efficiency and renewable energy solutions.

Section 3 provides guidelines for professionals and building managers on how to identify which is the best combination of the SunHorizon developed technical solutions that suits the requirements and exploitation mode of their building, what are the required input data and what SunHorizon developed tools could be used for the proper technical solution sizing and pre-feasibility design.

Section 4 provides some insights into the integration / installation process of SunHorizon solutions within a building. Which are the required building permits, what lesson has been learned during the SunHorizon demo-sites implementation, what installation and maintenance actions are recommended from the technology providers, etc.

2. Summary of SunHorizon project solutions

In order to help the reader, who wants to increase the thermal comfort level of its own building and in the same time to reduce the correlated energy consumption, the following paragraphs present a short description of the technology solutions developed within the SunHorizon project [1]. This will allow the reader to better understand how these technologies work and how they could be combined in technologies packages that would best fit the specific requirements of the building. This way, replicating the technology solutions developed within the SunHorizon project, high efficiency building heating and cooling system could be implemented by any professional, harnessing at maximum the available renewable solar energy and the capabilities of high-performance heat pumps.

2.1.SunHorizon Technology Solutions

TVP "LT-Power" – High Vacuum Solar Thermal Panels

The "LT-Power" high vacuum solar thermal panels were developed within the SunHorizon project by the TVP Solar partner [2]. They were developed based on TVP's "MT-Power" panels that were previously designed for applications that operate at medium temperature levels (mostly around 180 °C). The new "LT-Power" panels (see Figure 1) are designed to operate at 100 °C, to optimize the efficiency of producing thermal agent at low temperature levels and to reduce installation and operation costs.

Figure 1:"LT-Power" solar thermal panels by TVP.

The new "LT-Power" panels use cutting-edge technology based on High Vacuum Flat Panels (HVFP) developed and patented by the TVP partner. TVP is the sole provider of high vacuum technology integrated with flat panels in the market.

The "LT-Power" panels, thanks to their high-vacuum technology and flat design, exhibit minimal thermal losses and maintain exceptional efficiency throughout their extended lifetime. With energy conversion efficiencies of up to 65% for hot water these solar thermal panels outperform any other non-concentrated solar technology available. Their superior performance remains consistent even in low-to-medium sun irradiance conditions, making them a cost-effective and eco-friendly alternative to liquid fossil fuels in heating applications.

TVP has not only focused on advancing the HVFP technology but has also incorporated additional engineering innovations at the solar system level. These include standardized panel arrangements and connectors, reduced external piping, and alternative system layouts. These enhancements have further improved the overall performance and cost-effectiveness of HVFP-based solar systems, enabling smooth integration with existing thermal networks, modularity, scalability, easy installation, and expansion. Moreover, these innovations have significantly reduced costs, making HVFP-based solar systems viable both for large-scale (industrial applications using "MT-Power" panels) and small-scale (residential or tertiary building applications using "LT-Power" panels) installations.

The applied HVFP technology outperforms all other certified collectors in terms of power production and efficiency at low-to-medium temperature ranges, making the “LT-Power” panels highly suitable for year-round operation in diverse climate zones.

By combining high-vacuum technology with a flat plate collector design, TVP has achieved a breakthrough in solar thermal innovation. The high-vacuum environment minimizes convection losses and enhances overall conversion efficiency. The panel's planar layout maximizes the active collector area, and the robust glass-metal seal allows the panel to withstand high atmospheric pressure caused by the vacuum exhaust. TVP's system-level improvements, such as panel-to-panel and end-connector insulation boxes, reduction of stagnation temperature (through laminated glass cover), new simplified layout of the low temperature solar system; reduce heat losses and the need for external piping, enhancing overall system efficiency. This design simplicity and durability contribute to a prolonged panel lifetime of over 25 years without performance degradation.

DualSun “Spring” – Hybrid PV-T Panels

The “DualSun Spring” is an innovative solar panel developed by DualSun project partner that simultaneously produces electricity and low temperature thermal (hot water) agent [3]. It is a Hybrid Photovoltaic-Thermal (PV-T) panel that combines photovoltaic (PV) cells for electricity generation with a solar thermal collector to harness the waste heat of PV cells.

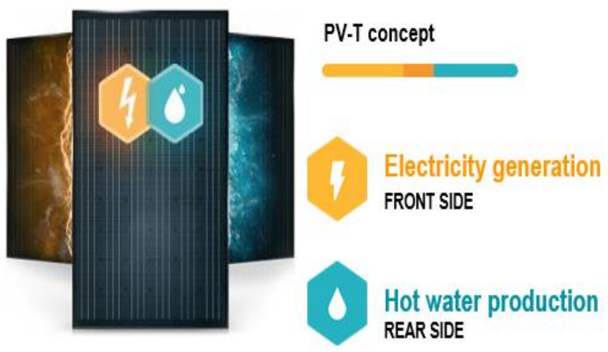

Figure 2: PV-T concept illustration.

Unlike standard photovoltaic panels that primarily convert solar radiation into electricity, Hybrid PV-T panels harness the wasted heat produced by PV modules. By utilizing a heat transfer fluid, the solar thermal collector captures and transfers this heat, enabling the panel to produce both electricity and hot water. The combination of photovoltaic and thermal technologies in a single panel offers a real synergy, resulting in up to three times more energy production compared to traditional photovoltaic panels.

Therefore, hybrid PV-T panels fulfill thermal regulations by reducing the demand for heat while simultaneously generating self-consumed electricity that can be used on-site or sold back to the grid. These panels are designed to cover a significant portion of a building's energy needs, optimizing energy utilization while minimizing the required roof area for installation.

The DualSun SPRING 315 Black hybrid solar panel, developed and improved within the SunHorizon project, represents the main concept of the Hybrid PV-T system. It features the following key components:

Table 1: Hybrid PV-T key components.

PHOTOVOLTAIC FRONT FACE		THERMAL REAR FACE	
	• High performance monocrystalline cells cooled by water circulation • Positive classification -0/+5 Wp • Anti-reflective glass ensuring high performance even in diffused light		• Hot water production thanks to an ultra-thin patented heat exchanger completely integrated into the panel **DualBoost** : Photovoltaic efficiencyboost by the cooling cells

Table 2: Dualsun Spring 315 Black technical characteristics

Photovoltaic (PV) characteristics		Thermal characteristics	
Nominal PV power	315 W	Thermal power	629 Wth / m^2
Output power tolerance	0 / +5W	Heat exchanger area	1,635 m^2
Module PV efficiency	19,08 %	Max operating pressure	1,5 bar
Power temperature coef.	-0,36 % / °C	Optical efficiency a_0	58,9 %
Application class	Class II	Coefficient a_1 *(1m/s wind)*	16,0 W/ K/ m^2

While the DualSun Spring panel delivers heat based on sun irradiation and ambient temperature, it is not recommended for systems operating above 70°C. The maximum operating pressure is 1.5 bar, which can be increased to 2 bar during the filling phase only. As a result, the most suitable low temperature heating applications of the hybrid PV-T panels are:

- Heat pump systems;
- Heating swimming pools or spas up to 50°C;
- Space heating and water heating in buildings, with temperature ranges from 20°C to 80°C;
- Solar process heat for various industrial or agricultural applications with temperature requirements below 70°C.

During the SunHorizon project the following improvements have been implemented to the DualSun Hybrid PV-T technology:

- Thinner heat exchanger: Reduced thickness by 10mm to fit within a 35mm photovoltaic frame.
- Compatibility: Compatible with a wider range of PV modules and mounting systems, improving panel performance and reducing costs.
- Improved PV cell integration: Integration of up-to-date PV cells, providing a 15% increase in electricity generation efficiency.
- Enhanced fluid exchange: A more efficient heat exchange mechanism, resulting in a 24% improvement in heat production.
- Lower stagnation temperature: The new PV-T technology allows the panel to operate below 80°C, reducing costs associated with piping and maintenance.

Ratiotherm Stratified Thermal Storage

The thermal storage system developed by the Ratiotherm project partner [4] is designed to maintain an optimal stratification of the thermal agent (mostly hot water) temperatures within the storage tank. This is achieved using an insert component made of polyphenylene ether, which has a permanent temperature resistance of 105°C or a short-term resistance of 130°C. Inside the distributor, multiple chambers are connected to the exterior of the tank. The height of the connections is determined based on expected temperatures, allowing different heat generators and consumers to charge and discharge without disrupting the thermal stratification (see Figure 3).

The combination of preselected connections and the physical phenomena of stratification, which is influenced by the density of the fluid corresponding to the temperature, enables improved charging and discharging as the heat carrier ascends and descends within the distributor before entering the storage. The stratification device also aims to minimize turbulent movements and irregular recirculation. This is achieved by ensuring a hydraulically smooth surface and promoting volumetric expansion of the heat carrier within the circular chambers, resulting in a reduced flow rate. However, it is necessary to limit the maximum flow rate of the distributor to a maximum of 1,500 liters per hour to maintain the desired stratification.

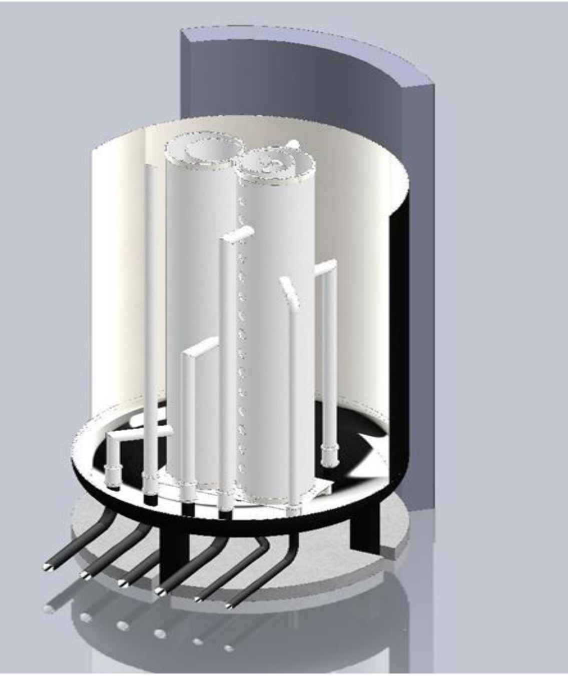

Figure 3: 3D-CAD model of a stratified thermal storage

Figure 4: Ratiotherm thermal storage tank installed at SunHorizon demo site in Madrid.

Within the SunHorizon project, dedicated thermal storage systems have been developed, such as the customized heating and cooling reservoir used in the Madrid demo site (see Figure 4). This reservoir has a volumetric capacity of 1000 liters and is connected to the heat pumps via connections 5 and 6. To accommodate a higher flow rate for charging the storage, the distributor was modified from a one-chamber system to a distributor with two circular chambers and a larger pipe diameter (DN40). This modification ensures that a higher flow rate does not disrupt the thermal stratification.

The temperature stratification within the Ratiotherm developed thermal storage tanks enables various energy efficient applications in heating systems for residential or tertiary buildings. Heat pumps, in combination with other heat producers, benefit from charging the thermal storage at different levels. By regulating the outlet temperature of the condenser based on the inlet temperature, the heat pump enables a small temperature difference. Conventional boilers, on the other hand, recirculate the fluid, which raises its temperature before entering the storage. In terms of energy efficiency, heat production should be aligned with consumption. For example, domestic hot water applications require higher temperature levels compared to heating circuits. By using control valves, it is possible to decide whether to charge the upper or lower area of the tank, allowing for effective thermal energy buffering for domestic hot water while avoiding complete charging of the entire thermal storage.

Fahrenheit Adsorption Chillers

Fahrenheit Adsorption Chillers [5] are innovative systems that utilize waste heat, such as that generated by solar plants, combined heat and power plants (CHP), district heating, or industrial processes, to produce cooling in an environmentally friendly and cost-effective manner. These chillers can operate even in small capacity ranges and offer several advantages due to their unique design.

One of the key features of Fahrenheit adsorption chillers is their patented dual-chamber process modules, which eliminate the need for moving parts. These process modules are vacuum-tight, welded chambers made of stainless steel and are thermally insulated. Inside each module, there are two heat exchangers: an evaporator/adsorber and a condenser/desorber, depending on the phase of operation (see Figure 5).

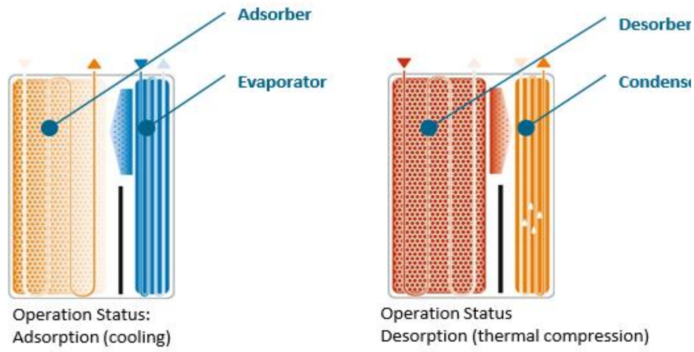

Figure 5: Adsorption module functions (adsorption & desorption).

The process begins by extracting heat from the space or process that needs to be cooled. A heat exchanger facilitates the transfer of heat to chilled water, simultaneously cooling the space and heating the water. The heated chilled water then flows through the hydraulic group of the adsorption unit and reaches the evaporator of the adsorbing process module. Here, the water is cooled down again, allowing it to be fed back into the cooling circuit.

The adsorbent-coated surface of the adsorber allows the refrigerant vapor to accumulate and release heat exothermically. To dissipate this heat, a re-cooling water circuit flows through the adsorber, which absorbs the heat and carries it away to the environment via a re-cooler. This ensures efficient cooling and prevents the adsorber from becoming saturated with refrigerant vapor.

In the condenser, the cooler surface withdraws heat from the refrigerant vapor, causing it to condense and precipitate on the surface. The heat released during condensation is transferred to the re-cooling water, which dissipates it to the environment through an external re-cooler. The condensed and cooled refrigerant is then ready for the next adsorption process.

To maintain continuous cooling and extract heat from the chilled water circuit, two process modules are operated cyclically. While one module absorbs refrigerant vapor (adsorption), the other module releases vapor to the condenser (desorption). This cyclic process introduces periodic temperature fluctuations, which can be smoothed out by using buffer storage. The valve switching of the hydraulic group is controlled by adjustable parameters, and the controller can influence the volume flows of the three circuits, optimizing performance.

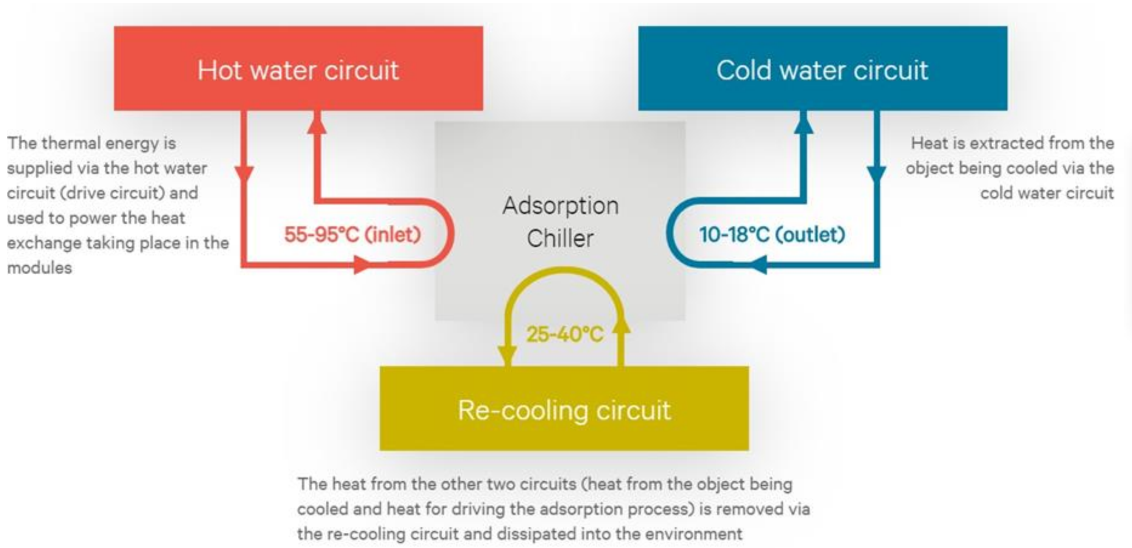

Figure 6: Energy flow during the operation of the adsorption chiller.

The combination of the dual-chamber process modules, the efficient adsorption and desorption processes, and the utilization of waste heat make Fahrenheit adsorption chillers highly effective and environmentally friendly cooling solutions. By harnessing otherwise wasted heat, these systems offer a sustainable alternative for meeting cooling demands in various applications.

In the SunHorizon project, several innovations have been introduced in the sorption and compression parts of the Fahrenheit Adsorption Chiller:

- *Adsorber heat exchangers:* The new design incorporates vacuum brazed heat exchangers with a larger surface area compared to the previous model. These heat exchangers have a more uniform coating and demonstrate greater stability during testing. The new design also allows for the use of various forms of turbulators in the channels, resulting in improved heat transfer rates.
- *Evaporator/Condenser heat exchangers*: The new design utilizes finned pipes made of copper. These pipes have thin copper fins on their external surface and are arranged horizontally in the process module, partially immersed in the liquid refrigerant. This arrangement enables uniform evaporation and high heat transfer rates. The thermal mass of the finned pipe heat exchangers is approximately five times smaller than that of the previous fin and tube heat exchangers.
- *Process modules:* In the latest prototypes, the process modules have been redesigned. Each module now contains two adsorber heat exchangers and one evaporator/condenser heat exchanger, arranged horizontally. This layout eliminates the issue of "false condensation," where refrigerant vapor condenses on the module walls instead of the heat exchanger surface. With the new design, the condensate always flows to the bottom of the process module.
- *Refrigerant:* The previous refrigerant, R134a, has been replaced with the natural refrigerant R290, which has a significantly lower global warming potential. This change required the redesign of the compression unit, including the calculation and selection of a new evaporator and condenser. To meet the cooling efficiency standards set by EU regulations, an internal heat exchanger was incorporated into the unit. Additionally, a frequency inverter was added to improve efficiencies at part load conditions. The overall system was assembled and optimized for use with R290.

BDR Innovative Heat Pumps

The BDR Thermea project partner is specialized in the production and delivery of intelligent thermal comfort solutions that have an incredibly low carbon footprint, benefiting both building owners and occupants. A key element in the technological package solutions proposed, developed, and tested by the SunHorizon project are the Heat Pumps systems developed by the BDR partner . Main focus of the project is to optimize the integration of heat pumps with solar systems and variable loads by utilizing stratified tanks. This approach aims at enhancing efficiency and maximizing energy savings. The table below provides a description of the different product types that were extensively studied for research and development purposes and subsequently installed in the demonstration sites:

Table 3: Heat Pump solutions provided by BDR Thermea partner

Type	Description	Ppower Efficiency	Illustration
Monobloc Water-to-Water	All the components of the heat pump, compressor, condenser, evaporator, water pump, controllers, are in one appliance,placed inside the building. Supply heating, cooling, and Domestic Hot Water (DHW). The cold source is water. The water can come from a well, a river or a grey energy recover system, but must be over 7°C to prevent frost. If the cold source temperature can be lower than 7°C, the water must be added with an anti-frost fluid. The cold source can be a ground collector, solar collector,	6kW to 28kW 175% - 193%	
Monobloc Air-to-Water	The compressor, evaporator condenser and the controller of the refrigerant circuit are inside the outdoor unit. A water link, with or without an anti-frost fluid, transfers the energy to the indoor unit. The indoor unit includes the pumps, valves and the controller for the distribution of the energy distribution inside the building. Supply heating, cooling, and Domestic Hot Water (DHW). The cold source is outside air. The hotsource is the water from the heating circuit.	6kW to 11kW 169% - 184%	
Split Air-to-Water	The compressor and the evaporator areinside the outdoor unit. A refrigerant pipe links it to the condenser placed inside the indoor unit. The indoor unit includes the condenser, the pumps, valves, and the controller for the energy distribution inside the building. Supply heating, cooling, and Domestic Hot Water (DHW). The cold source is outside air. The hotsource is the water from the heating circuit.	4kW to 24kW 151% to 189%	

Through innovation actions supported by the SunHorizon project the control sequence of the above presented BDR Heat Pumps has been improved as follows:

- If another source of energy is connected to the system, the heat pump can choose the best cost of energy. For example, with a gas boiler as a backup for the heat pump, if the COP is below the cost ratio between electricity and gas the heat pump will work only with the gas boiler to minimize the working cost.
- If a PV system adds electricity production to the building, a part of it will be consumed by general appliances, and the rest is injected into the power grid with or without remuneration. The BDR heat pumps have the capability to multiply the electric energy into heat or cold by the coefficient of performance (COP). If a part of the electricity comes from a renewable source on site, this part is free of cost and energy, so the real COP of the heat pump is bigger. With half of the electricity produced by PV the COP is multiplied by two.
- To use exactly the remaining electricity produced by the PV to store it as thermal energy in water tanks for heating, DHW or cooling. The stored thermal energy will be used when PV electricity is not available.

BoostHeat – Thermal Compression Heat Pumps

The BoostHeat project partner has developed a new generation of CO2 gas heat pump based on innovative thermal compression technology. The thermally driven heat pump circuit brings heat from the outside air. The thermocompressor works without oil, low wear, and it is extremely quiet (33 dB at a 3 m distance). Therefore, it has a very long service life and exceptional efficiency.

To surpass the limitations and drawbacks of traditional boilers and heat pumps, the new BoostHeat solution (see Figure 7) uses Stirling engines and absorption systems for compressing gas from a heat source. The developed thermal compression heat pump uses CO2 gas as refrigerant agent. This is in line with the future of heat pumps due to the lowest global warming potential cooler on the market (thousands of times less harmful to the climate than HFC) and zero ozone-depleting potential, being also in line with the Montreal Protocol, which will bring about a global phasedown of hydrofluorocarbons (HFCs) - powerful greenhouse gases.

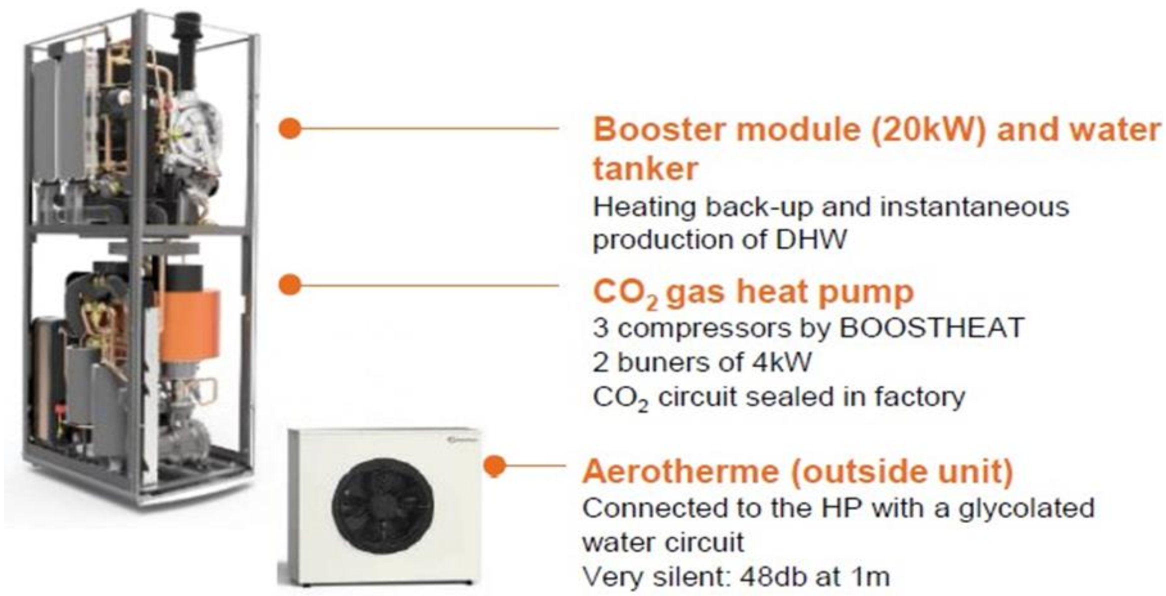

Figure 7: Components of the BoostHeat unit

The thermodynamic cycle of the developed thermal compression system takes place in 4 steps: *1) compression*, *2) discharge*, *3) expansion*, and *4) intake*. Unlike volume compressors where power is transmitted mechanically, the BoostHeat solution does not have a working piston but a displacer piston. This new technology harnesses the heat from a burner to achieve direct and remarkably efficient compression of CO2 (R-744) at pressure levels ranging from 40 to 100 bars. These pressure levels are higher than those achieved with HFC refrigerants (ozone-depleting substances).

By using this four-stage thermodynamic cycle, BoostHeat maximizes, in the best possible way, the full capacity of the high energy available at high temperature provided by a burner (700°C) instead of producing hot water at 35°C. This is drastically increasing the efficiency of the heat pump cycle, that is easily explained by the principle of the Carnot cycle: higher temperature difference translates into increased efficiency.

Figure 8: New user interface of the BoostHeat Connect

During the SunHorizon project the BoostHeat project partner has also developed a new user interface (see Figure 8) for easier management and interconnection with solar technologies. The new user interface was designed for more efficiency and less energy consumption. With this interface the BOOSTHEAT.20 Connect (see Figure 7) is very easy to set up and adapt to the needs. The intuitive navigation and the integrated help assistant make it easier for the user and the heating installer service. With the central control unit, the user can configure needs-based heating profiles. Furthermore, the integration of the thermostat Evohome (Honeywell) allows for simpler regulation and lower energy costs. Thanks to the freely available Evohome App for mobile devices, the system can be also easily managed remotely.

BoostHeat left the consortium with an Amendment in July 2023.

Data Monitoring System

To interconnect the above presented technologies and to be able to work together in optimal conditions to simultaneously maximize the capabilities and outputs of each particular technical solution, at least a data collection and monitoring system should be installed if not a full-scale Building Management System (BMS) or Building Energy Management System (BEMS). The EcoStruxure platform provided by Schneider Electric could properly handle this task and organize data flows between technologies from the raw collected data to the final processed data that should be presented to building managers [8].

The aim of the EcoStruxture platform [9] is to connect four main domains: Buildings, Data Centers, Industries, and Infrastructures through three interconnected levels (see Figure 9):

- *Connected Products*: These are smart devices with IP connectivity.
- *Edge Control*: This level involves peripheral control, where control devices and local management software are located as close as possible to the data at the field level.
- *Analytics, Apps & Service*: This level encompasses analytics tools, applications, and various types of services that can be offered across all three levels.

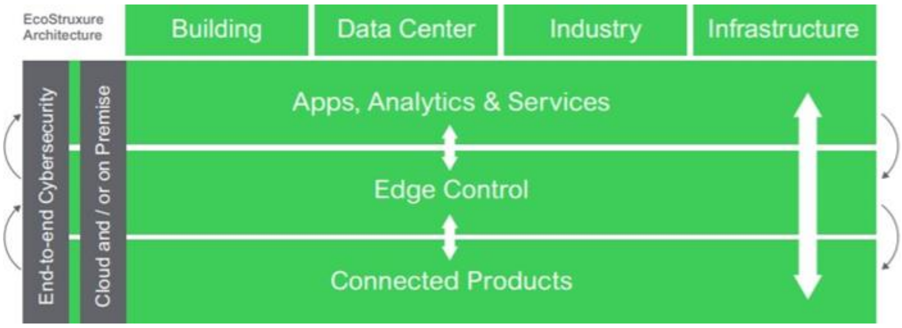

Figure 9: EcoStruxure Architecture

The EcoStruxture platform could be installed either locally (OnPremise) or remotely (OnCloud), with a strong emphasis on information-cyber security, an important aspect that accompanies technological advancements. The above mentioned three layers/levels of the EcoStruxture platform can exchange information and data bidirectionally using well-known standard and open communication protocols. The choice of protocols is based on their specific characteristics and suitability for each field of application.

The strength of this platform lies in its ability to facilitate the exchange of information and services among the different levels, enabling maximum results in terms of efficiency, reliability, safety, and sustainability within each specific domain. For the data collection process from SunHorizon developed technologies and to monitor the comfort level of the occupants within the building the following field level components should be connected to the EcoStruxure platform:

- Smartx Automation Serve is the core of an EcoStruxure BMS, it performs key functionality, such as control logic, trend logging, and alarm supervision, and supports communication and connectivity to the I/O and field buses.
- CO2, room Temperature and Humidity sensors to monitor building occupants comfort level.
- Motion, Window and Door sensor to monitor the building exploitation as occupants' behavior.
- Weather Station to monitor the building exploitation conditions.
- Power and Thermal Energy meters monitor the energy production of the SunHorizon developed technologies and energy consumption patterns and energy flow within the building.
- Communication ports of the SunHorizon developed technologies, for the optimal control and exploitation.

To visualize the collected data the customized user interface of the EcoStruxure Building Operation software (by Schneider Electric) could be used via any web browser [10]. It allows us to visualize any monitored data in a way that is easy to understand and consult. Data are displayed in graphic pages called "dashboards" that are composed by different types of widgets (see Figure 10):

- *Real-time visualization widget*: a dashboard component that shows a precise value that is needed for continuous monitoring, i.e., actual room temperature.
- *Chart widget*: a dashboard component that shows how a precise value changes over time, i.e., energy consumption.

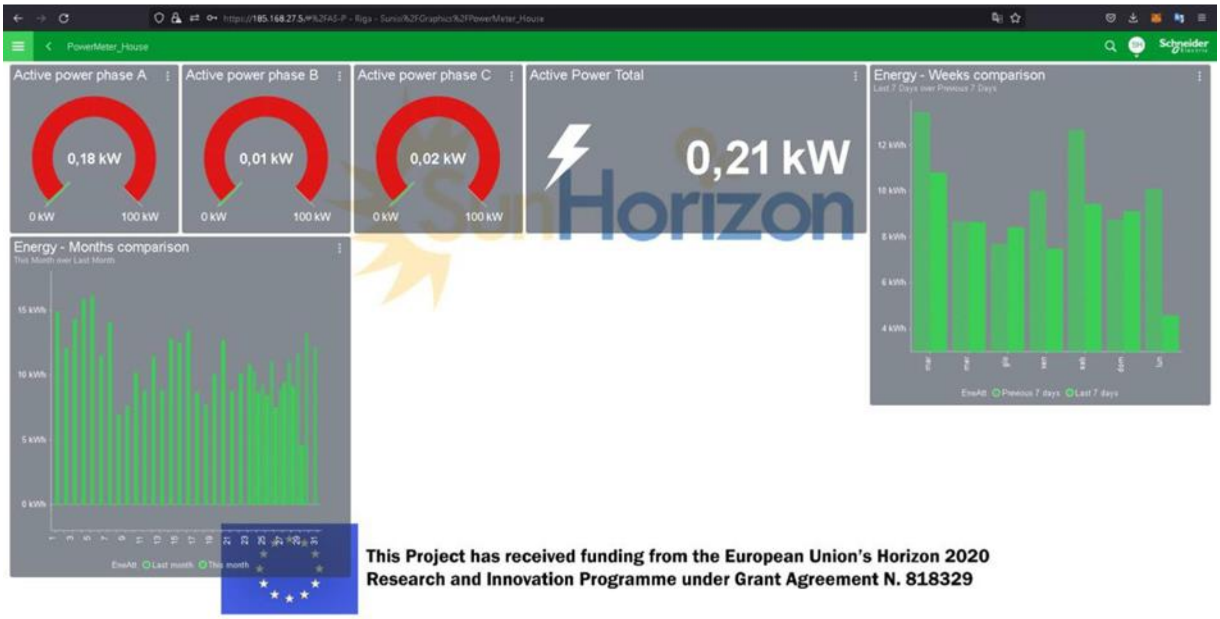

Figure 10: Energy meter Dashboard customized the SunHorizon project.

Another option to visualize the collected data and energy flows within is the iDashboards [10] a web-based platform developed by IES Ltd project partner [11], extension of iSCAN software User Interface designed for the Sunhorizon developed technologies. It allows non-energy experts to interact with energy data. iDashboards provides a customizable end-user interface in order to share insights from various types of time-series operational data in a centralized location. Its main purpose is to present near real-time visualizations and key performance indicators (KPIs) to end users. The dashboards can be tailored to present data in a concise and easily navigable manner, catering to specific audiences such as decision-makers within an organization or the general public. iSCAN serves as the source of the time-series data that is displayed in iDashboards. By utilizing data visualizations, including charts, KPI cards, and custom images or floor plans with dynamic values.

iDashboards is composed of multiple widgets that can be customized and combined to create user-specific dashboards. For example, a relevant widget for the SunHorizon project is a KPI card, which provides quick overviews of performance indicators. These KPI cards can be easily customized to display different colors or icons based on the value of the data being presented (see Figure 11). The dynamic formatting feature allows users to identify areas that require attention and focus. Furthermore, iDashboards offers the capability to display real-time data over an image of a building floor plan or specific equipment, offering valuable contextual insights into the data. For instance, visualizing the space temperatures of different areas in a building or the current electrical load of power meters serving various sections allows users to easily comprehend vast amounts of data.

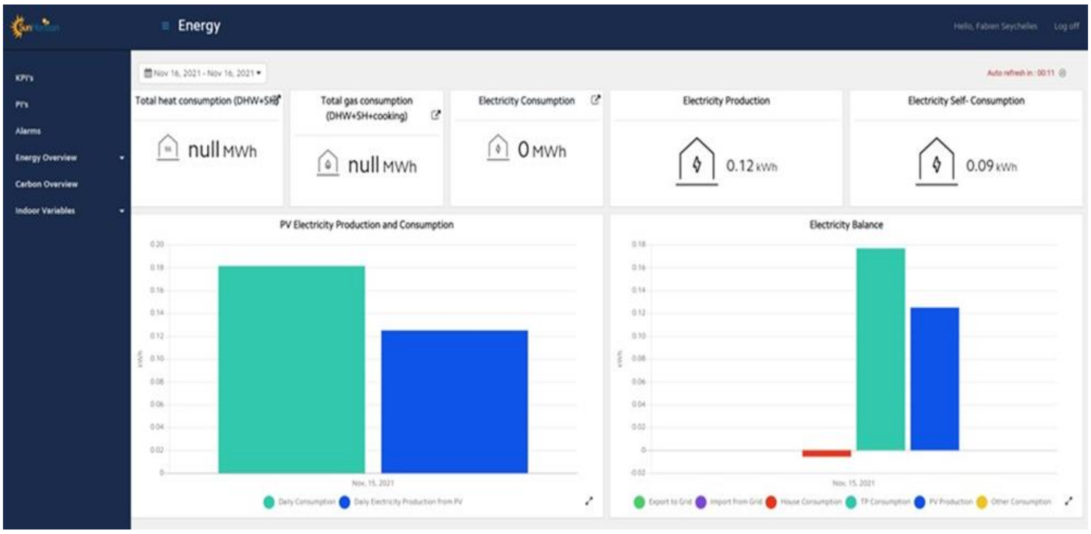

Figure 11: SunHorizon iDashboards tool – Riga Sunisi house Example

Additionally, iDashboards includes highly customizable chart visualizations specifically designed for time-series data. The charts are interactive, allowing users to select specific dates to display at the widget level and hover over values to view corresponding timestamps.

Figure 12: iDashboards - Line Chart

2.2.Developed Technology Packages

As mentioned in the Introduction section main objective of SunHorizon project is to demonstrate up to TRL 7 innovative and reliable Heat Pump solutions (thermal compression, adsorption, reversible) that acting properly coupled and managed with advanced solar panels (PV, Hybrid, thermal) can provide heating and cooling to residential and tertiary building with lower emissions, and lower energy bills and fossil fuel dependency. Therefore, to test and validate the interoperability of the above presented technologies (section 2.1) in various exploitation conditions four technology packages were defined within the SunHorizon project (see Table 4):

Table 4: Technology Packages proposed within the SunHorizon project.

Technology Packages	Supply	Technology	Description
TP1	Heating + DHW	Heat Pump (HP) Ratiotherm Tank TVP Solar Thermal Panels	Solar thermal for space heating based on High Vacuum Flat Panel (HVFP) technology provided by TVP + Domestic Hot Water (DHW) + Heat Pump to cover non solar periods
TP2	Heating + DHW	Heat Pump (HP) Ratiotherm Tank DualSun hybrid PV-T panels	Hybrid PV-T panels (provided by DS) thermal output to cover as much heat demand as possible + excess electricity production for appliances + Heat Pump for spaceheating & DHW support
TP3	Cooling + Heating/DHW contribution thanks to solar panels	Fahrenheit Adsorption Chiller Compression Chiller Ratiotherm Tank TVP Solar Thermal Panels	Solar thermal for space heating based on HighVacuum Flat Panel (HVFP) technology, provided by TVP + DHW in winter + activation of the thermal compressor of the adsorption chiller Heat Pump for cooling, provided by FAHR
TP4	Heating/Cooling + DHW	BDR A-W Heat Pump Heating/Cooling Tank DHW tank PV panels Thermal panels	Combined PV and solar thermal panels to cover part of space heating and DHW heat demand + electricity production to cover reversible HP (provided by BDR) electricity consumption

Among the technology packages considered:

- **TP1** (Heat Pump; Ratiotherm Tank; TVP Solar Panels) and **TP2** (Heat Pump; Ratiotherm Tank; Dual Sun PV-T panels) are meant for DHW and heating supply, while:
- **TP3** (Fahrenheit Sorption Chiller; Compression Chiller; Ratiotherm Tank; TVP Solar Panels) and **TP4** (BDR Air-to-Water Heat Pump; Heating/Cooling Tank; DHW/RATIO tank; Dual Sun PV-T panels) are meant for cooling, heating and DHW supply.

Initially the **TP1** and **TP2** technology packages were meant to operate with BoostHeat thermal compression heat pumps. However, due to unforeseen events (COVID-19 & Ukrainian war situation) that lead to a financial crisis at the level of the BoostHeat project partner and its withdraw from the SunHorizon project in summer 2023, the Heat Pumps in **TP2** technology packages were replaced with BDR Air-to-Water heat pumps with similar capabilities.

3. Identification of the proper SunHorizon solution

For a residential or tertiary building that wants to increase the comfort of its occupants and in the meantime to reduce its energy consumption and corresponding CO_2 emissions one or more of the above presented SunHorizon technologies could be implemented. To identify the technologies and/or technology packages that best suit the requirements of building that want to replicate the technology solutions implemented and tested within the SunHorizon project the Design Under Uncertainties (DUU) [12] web tool could be used. Additionally the Decision Making Tool (DMT) [13] could be used to obtain a preliminary recommendation regarding which of the four SunHorizon proposed technology packages (see section 2.2) would suit the selected application and country.

The DUU Tool has been developed within tasks T4.3 "*Formulation and methods for optimal design under uncertainty of H&C components*" and T4.4 "*SunHorizon integrated tool for optimized H&C technologies*" [14], tested and validated within task T4.5 "*SunHorizon integrated tool Validation and fine-tuning*" respectively [10]. Its scope is to help building service engineers and professionals to identify the optimal SunHorizon technology package configuration required the meet the building comfort and energy consumption necessities under multiple uncertainties factors due to various weather and building exploitation conditions.

3.1. Required Input Data

For a building that wants to replicate and implement the SunHorizon developed technology solutions, firstly the heating and cooling demand of the building have to be evaluated over an entire year. Therefore, the bellow presented input data describing the building envelope and building exploitation should be collected:

Table 5: Required data for building heating and cooling demand evaluation.

BUILDING DESCRIPTION PARAMETERS			
Building location parameters			**Units**
Location Coordinate		Country	---
		City	---
		Latitude	DD
		Longitude	DD
Building exploitation parameters			**Units**
Ambient data	Tset,h	Heating set point	°C
	Tset,h	Cooling set point	°C
	n	Infiltration Rate	1/h
Building data	Ac	Ac - Conditioned Building area	m^2
	Vc	Heated/Conditioned Building Volume	m^3
	Nap	N° of apartment (in case of residential)	N°
	Ac,ap	Average Conditioned area per apartment (in case of residential)	m^2
	Nbath	N° of Bathroom Sink (in case of non residential)	N°
	Noc	N° of occupants	N°
	Amax,sp	Max m^2 of PV or ST Panels to be considered	m^2

BUILDING DESCRIPTION PARAMETERS			
Building envelope characterization			Units
Walls	Uwall	External wall(s) Transmittance (U_{value})	W/m²K
	Awall	External wall(s) Area	m²
	Uwall	External wall(s) Transmittance (U_{value})	W/m²K
	Awall	External wall(s) Area	m³
Floor	Ufloor	Ground floor slab(s) Transmittance (U_{value})	W/m²K
	Afloor	Ground floor slab(s) Area	m²
Roof	Uroof	Roof(s) Transmittance (U_{value})	W/m²K
	Aroof	Roof(s) Area	m²
Windows	Uw,N/S	Window(s) N/S oriented Transmittance (U_{value})	W/m²K
	Aw,N/S	Window N/S oriented Area	m²
	Uw,W	Window(s) West oriented Transmittance (U_{value})	W/m²K
	Aw,W	Window West oriented Area	m²
Doors	Ud	Door	W/m²K
	Ad	Door Area	m²

3.2.How to Use the DUU (Design Under Uncertainties) Tool

The Design Under Uncertainties (DUU) [12] web tool could be used by building service engineers or professionals during the pre-design phase, to explore the optimal design of the SunHorizon Technology Packages. The DUU tool has been developed to be online freely accessible and easy to use by larger variety of building professionals, to provide accurate evaluations and pre-design phase sizing estimation of the required technology solution with a minimum required input data. Therefore, the design evaluation takes place "under uncertainties" by incorporating input parameters provided by the user of the tool, considering statistical variation to account for uncertainties, and employing the Monte Carlo method to calculate a peak load distribution. Subsequently, the tool conducts a multi-criteria system design, considering thermal comfort and costs. As a result, the tool identifies the optimal configuration for each technology package, providing estimations of size, capital cost, and operational (energy-related) costs.

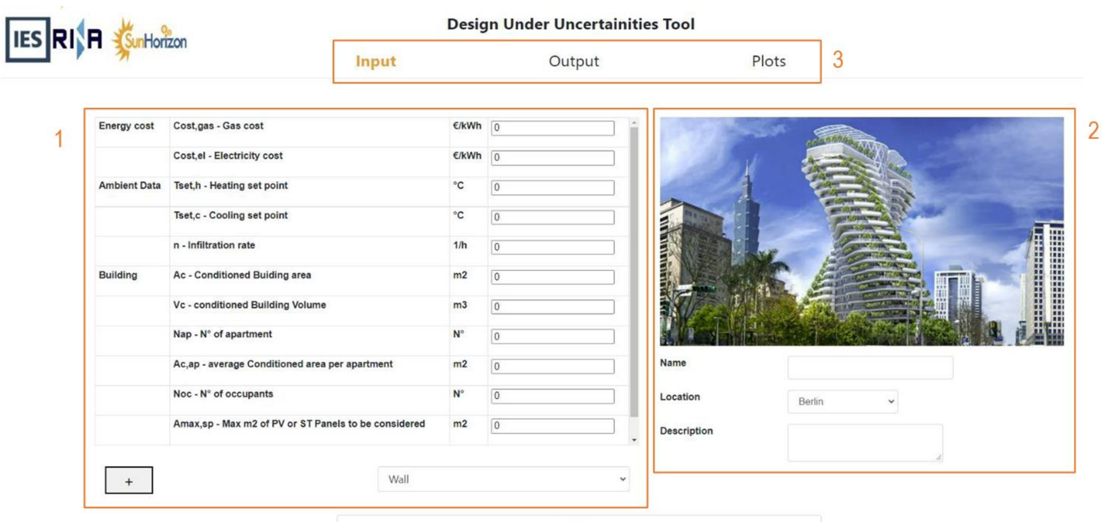

Figure 13: DUU tool - Input page section

The initial step involves the user providing a set of input data as presented in the previous section 3.1 to characterize the building. These data, along with the weather data stored within the tool (obtained as statistical data tool from international meteorological database) are used to determine the building's heating and cooling demand profile over a year. Figure 13 shows the DUU webtool tool landing page, which is divided into three main sections as highlighted below.

In the first section the user of the tool (construction or building service professional) should specify the building construction and/or exploitation related data required by the DUU tool to evaluate the building heating and cooling demand regarding various analyzed uncertainties factors and weather conditions. The heat transfer widgets related to building envelopes are dynamic, allowing the user to add as many building construction elements as necessary to accurately represent the building's thermal dissipation. The dropdown list enables the selection of elements such as walls, roof, floor, and windows for each orientation. After selecting an element, the user can click the add button (see Figure 14) to include it. The use of input parameters such as Number of Apartments or Number of Occupants allows the user to indirectly specify the type of building which is analyzed (Number of Apartments for multi-family residential buildings and Number of Occupants for tertiary buildings).

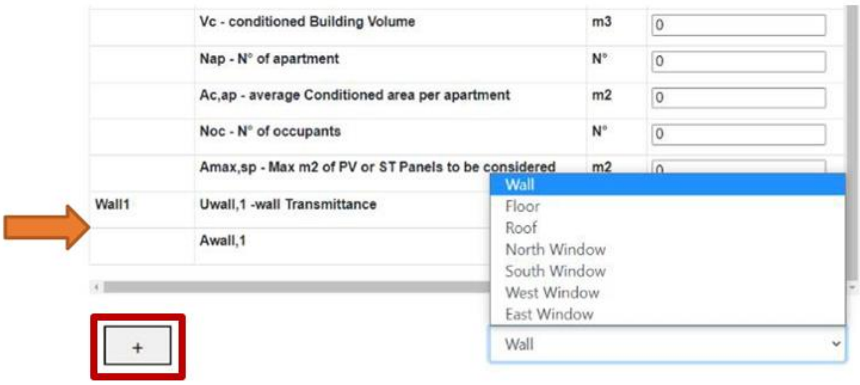

Figure 14: DUU tool - Heat transfer widget selection.

Section 2 of the DUU tool landing page (see Figure 13) presents a summary of the building metadata, including its name, location, and a general description of the facility. An image upload feature allows the user to showcase the building under analysis.

Once all the input data has been submitted the user can initiate the simulation and calculation process by clicking the "Submit" button located at the bottom of the page (see Figure 13). The DUU tool evaluates the heating and cooling demand of the building based on the introduced building envelope, building exploitation and statistical weather data associated to building location. A detailed description of the calculation and simulation process behind the DUU tool has been presented in deliverable D4.3 *Implementation of design under uncertainty optimization tools* [14].

The evaluate peak load distribution, through the implemented Monte Carlo method to assess various uncertainty factors, helps to select seven design capacities associated with different levels of risk, ranging from 50% to less than 1%, while considering a certain degree of thermal discomfort to identify optimal building energy usage and maximum exploitation levels for the analyzed SunHorizon technology packages as minimum implementation and exploitation costs. Correspondingly, seven energy demands are calculated proportionally based on the selected peak loads. Figure 15 shows cases the evaluated heating (Figure 15.a) and cooling (Figure 15.b) demand variation of a small residential building from Berlin (SunHorizon demo site #1 [15],[16]) over an entire year.

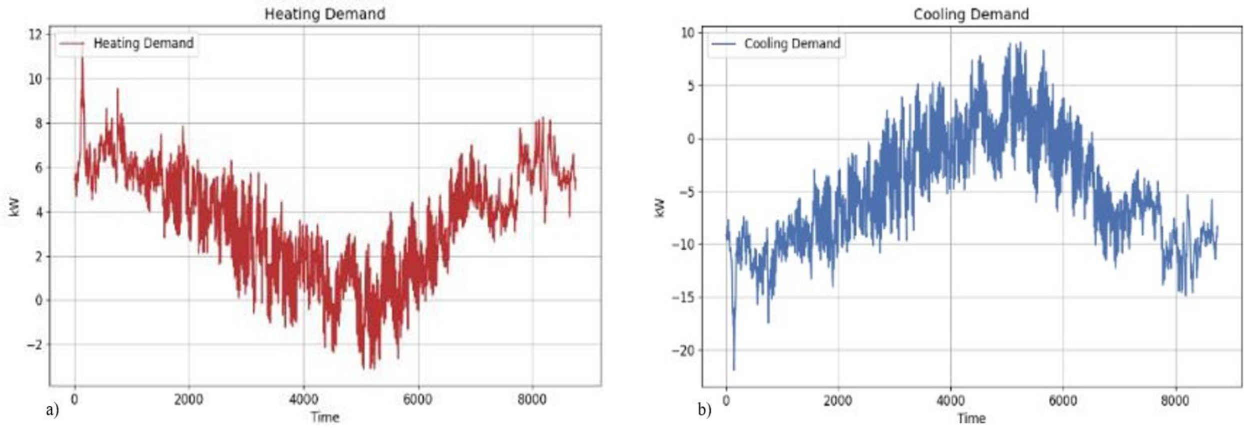

Figure 15: DUU tool – Evaluated heating and cooling demand over an entire year: a) Heating Demand, b) Cooling Demand.

In the meantime, Figure 16 depict the evaluated peak power load distribution computed by the DUU tool for a multi-family residential building from Nuremberg (SunHorizon demo site #2 [15],[16]) small public administration office in Berlin. It is important to note that the tool may require several minutes to complete the calculations. Additionally, due to the application of uncertainties using the Monte Carlo method, which utilizes a random function to generate the peak load distribution, each simulation cannot be replicated with identical values of the statistically calculated peak loads.

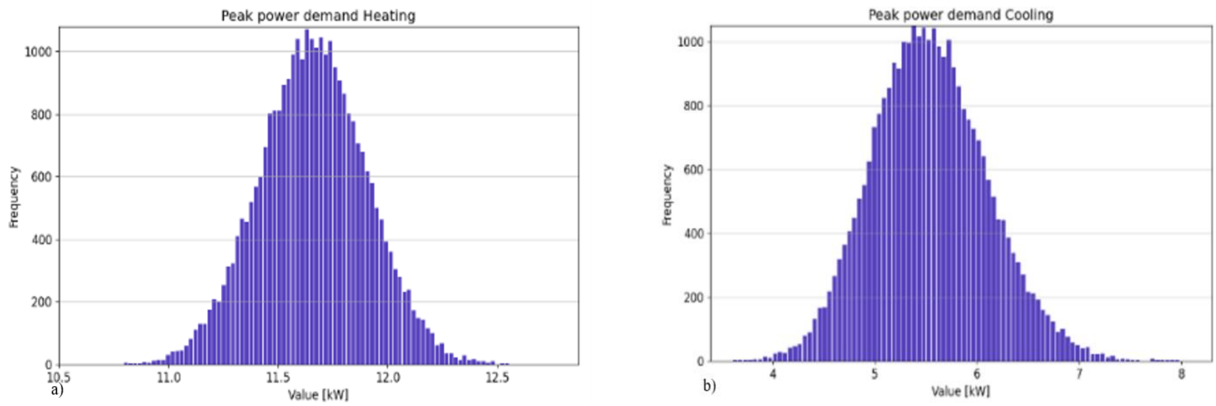

Figure 16: DUU tool – Evaluated peak power distribution: a) Heating, b) Cooling.

Once the peak loads and energy demands are defined, the tool performs a multi-criteria analysis that takes into account the Thermal Comfort score ($\Gamma_{comfort}$) and the cost score (Γ_{cost}). The $\Gamma_{comfort}$ reflects the number of hours the hourly demand exceeds the considered peak load. The Γ_{cost} is linked to the evaluated technology packages and depends on the capital and energy costs, which are determined by the sizes and energy performance calculated by the tool.

Section 3, which positioned at the top of DUU landing page (see Figure 13), allows the user to navigate between the input and output interface windows of the web toll. Once all the input data has been submitted and the simulation executed, the user can utilize the "Next" and "Previous" buttons, which appear at the bottom of the page, to navigate through the Input, Output, and Plot pages.

The output page consists of two primary sections. A top section that contains a summary of the building metadata followed by foldable table widgets used to display the calculation results and organize the visualization, as illustrated in Figure 17.

Figure 17: DUU tool – Output page example.

For each SunHorizon technology package (as described in section 2.2), five different configurations are assessed by varying the size of the Solar Thermal or PV panel based on the available space specified by the user. Configuration 1 considers 100% of the available space, while configuration 5 assumes 0%. The goal is to calculate the capital costs and operational costs for each selected design capacity and configuration. The tool determines the final performance score, J, by equally combining the Γ_{cost} and $\Gamma_{comfrot}$ [14].

Based on the evaluated final performance score, J, the best fitting combination of the SunHorizon technology solutions is determined for each of the four technology packages developed and analyzed within the SunHorizon project. Figure 18 depicts the foldable table widget for the best TP1 combination identified for a small residential building from Berlin (SunHorizon demo site #1).

Output

TP1 Best Ranking

lambda6 Conf1	BH HP		RATIO TANK		TVP SP	
Size	20.00	kW	881.25	liters	18.75	m2
Energy produced	33082.24	kWh/y	0.00	kWh/y	11711.29	kWh/y
YEOH	1654.11	YEOH	0.00	YEOH	0.00	YEOH
Capital costs	20000.00	€	3546.53	€	12500.00	€
Operative costs	46198.38	€/y	0.00	€/y	0.00	€/y

TP2 Best Ranking

TP3 Best Ranking

Figure 18: DUU tool – Technology package result table example

Based on the optimal combination of SunHorizon technology solutions identified by the DUU tool for each of the four technology packages prosed and tested by the SunHorizon project one could identify and elaborate on the best technology package that would suit the analyzed building. In our case, the optimal combination of technology solutions identified by the DUU tool and presented as an TP1 example in Figure 18 has been further detailed and started to be implemented at the SunHorizon demo site #1 in Berlin.

3.3. General recommendations regarding suitable SunHorizon solutions for different building type and climate zones

During task T7.3 "*Pre-feasibility studies in six virtual demonstrators all around Europe via SunHorizon Design Optimized Tool*" an analysis was carried out to identify which SunHorizon technology package build best suit in different climate zones considering both residential and tertiary type buildings [17]. Three major climate zones across Europe were investigated: a warm temperature climate zone (Italy), a moderate temperature climate zone (Netherlands) and a cold temperature climate zone (Sweden). In each case the DUU tool [12] has been used to evaluate in detail the four SunHorizon proposed technology packages for a multi-family residential and a tertiary building.

Warm Temperature Climate Zones

Multi-Family Residential Building (Italy)

Building Description: An average building with about 10 apartments, 90 m^2 each in Rome. The investigated building had a total net lettable area of 952 m^2 and 2,380 m^3 heated/conditioned volume with a heating set point at 20 °C and cooling set point at 26 °C (for more details of the building check [17]).

DUU tool Results: The pre-feasibility study carried out in task T7.3 with the DUU tool and presented in detail in the SunHorizon deliverable D7.4 [17] showed that for multi-family residential buildings in warm temperature climate zones TP2 SunHorizon technology package could be more appropriate. In this configuration 150 m2 of both photovoltaic and thermal solar modules are installed. Approximately 7,000 l storage tank must be coupled with solar technology. The heat pump capacity of 40 kW, required to overcome 39.34 kW peak load, in the analyzed building is needed to fulfil the gap between the required heating demand (88,673.84 kWh/year) plus the DHW demand (13,754.29 kWh/year) and the energy produced by solar technology (52,157kWh/year). The electric energy produced by the PV technology can be used by the system or sold to the grid resulting in a negative operative cost (it is a cost saving for this configuration).

Average Tertiary Building (Italy)

Building Description: An office destination building in Rome with 250 occupants, a 3,584 m^2 net lettable area and 10,752 m^3 heated/conditioned volume. The heating set point was considered at 20 °C while the cooling set point was considered at 26 °C.

DUU tool Results: The pre-feasibility study carried out in task T7.3 [17] showed that for tertiary office buildings in warm temperature climate zones TP3 SunHorizon technology package could be more appropriate. This technology package primarily focuses on providing space cooling during the summer season. To achieve this, the sorption chiller needs to be connected to a solar thermal source, with a specific emphasis on summer production. All the heat generated during the winter period is considered as energy savings. For the analyzed building the DUU tool suggested TP3 configuration, consists in thermal solar module area of 358 m^2. Furthermore, the integration of a storage tank with a capacity of approximately 16,800 liters is required for the solar technology. The annual cooling energy demand for the building, taking uncertainties into account was calculated by dividing the cooling energy demand without uncertainties (95,932.04 kWh/year) by the cooling peak load (196.33 kW). This division provides the yearly operating hours (489 hours/year). By multiplying the operating hours by the cooling peak load with uncertainties (207.241 kW), the annual cooling energy demand value of 101,262.96 kWh/year was obtained. This cooling demand could be met by the energy produced by the Farhenehit sorption chiller, which amounts to 101,264 kWh/year.

Moderate Temperature Climate Zones

Multi-Family Residential Building (The Netherlands)

Building Description: An average building with about 18 apartments 100 m^2 each in Rotterdam. The investigated building had a total net lettable area of 1,804 m^2 and 4,510 m^3 heated/conditioned volume with a heating set point at 18 °C and cooling set point at 26 °C.

DUU tool Results: The pre-feasibility study carried out in task T7.3 [17] showed that for multi-family residential buildings in moderate temperature climate zones TP1 SunHorizon technology package could be more appropriate. In this configuration, a thermal solar module area of 141 m^2 is unable to meet the entire heating demand, which amounts to 117,671.35 kWh/year. To support the solar technology, a storage tank with a capacity of approximately 6,600 liters needs to be integrated. A 60 kW heat pump is appropriately sized to overcome a peak load of 42.12 kW and fulfill the entire heating demand. The total heating demand encompasses the sum of the annual heating energy demand and the domestic hot water (DHW) demand (31,650.34 kWh/year), totaling 149,321.69 kWh/year. Consequently, the combined energy produced by the BH HP and TVP solar (149,322 kWh/year) sufficiently covers the entire heating demand (149,321.69 kWh/year).

Small Tertiary Building (The Netherlands)

Building Description: A small office destination building in Rotterdam with 50 occupants, a 764 m^2 net lettable area and 2,292 m^3 heated/conditioned volume. The heating set point was considered at 18 °C while the cooling set point was considered at 26 °C.

DUU tool Results: The pre-feasibility study carried out in task T7.3 [17] showed that for small office buildings in moderate temperature climate zones TP2 SunHorizon technology package could be more appropriate. In this configuration 76 m^2 of hybrid PV-T panels should be installed for the analyzed office building. To support the solar technology, a storage tank with a capacity of approximately 3,600 liters needs to be integrated. A heat pump with a capacity of 40 kW is required to overcome a peak load of 27.83 kW and bridge the gap between the required heating demand (76,782.97 kWh/year) plus the DHW demand (1,873.87 kWh/year) and the energy produced by the solar technology (6,449 kWh/year). It's worth noting that the electric energy generated by the photovoltaic technology in this case can be utilized within the system or sold back to the grid, resulting in a negative operative cost and cost savings for this configuration.

Cold Temperature Climate Zones

Multi-Family Residential Building (Sweden)

Building Description: An average building with about 12 apartments 100 m2 each in Goteborg. The investigated building had a total net lettable area of 1 207 m^2 and 3 018 m^3 heated/conditioned volume with a heating set point at 21 °C and cooling set point at 24 °C.

***DUU tool Results*:** The pre-feasibility study carried out in task T7.3 [17] showed that for multi-family residential buildings in cold temperature climate zones TP4 SunHorizon technology package could be more appropriate. In this configuration. This configuration comprises a total of 188 m^2 of solar panels, consisting of 47 m^2 for thermal purposes and 141 m^2 for photovoltaic applications. These solar panels serve the dual function of providing hot water and generating electricity. Two separate tanks are being considered, one for domestic hot water (DHW) and the other for space heating (SH). To bridge the gap between the required heating demand (148,415.63 kWh/year) plus the DHW demand (22,871.32 kWh/year) and the energy produced by the solar technology (7,931 kWh/year), a heat pump with a capacity of 47 kW is necessary. This heat pump is designed to overcome a peak load of 42.24 kW. It's worth noting that the electric energy generated by the photovoltaic (PV) technology in this demonstrator building can be utilized within the system or sold back to the grid, resulting in a negative operative cost and cost savings for this configuration.

Tertiary Building (Sweden)

Building Description: An office destination building in Goteborg with 120 occupants, a 1 801 m^2 net lettable area and 5 403 m^3 heated/conditioned volume. The heating set point was considered at 21 °C while the cooling set point was considered at 25 °C.

***DUU tool Results*:** The pre-feasibility study carried out in task T7.3 [17] showed that for tertiary office buildings in cold temperature climate zones TP1 SunHorizon technology package could be more appropriate. For the analyzed building the annual heating energy demand required by the building is equal to 116,042.80 kWh/y. This is the energy demand affected by uncertainties. It has been calculated dividing the heating energy demand without uncertainties (111,538.36 kWh) by the heating peak load (31.74 kW), thus obtaining the yearly operating hours (3,514 h/y). Multiplying the operating hours by the peak load λ7 (33.026 kW), the annual heating energy demand value of 116,042.80 kWh/y is obtained. This heating demand can be covered by 180 m^2 thermal solar modules connected to an 8,450-liter storage tank and a 40 kW heat pump capable of overcoming a peak load of 33.026 kW.

Use of the Decision Making Tool (DMT)

Additionally the DMT tool [13] could be used to obtain a more specific recommendation regarding which of the four SunHorizon proposed technology packages (see section 2.2) would suit a particular application from a given country. The DMT tool is an efficient and rapid digital web platform designed for assessing the most suitable SunHorizon technology package based on specific conditions. It provides a preliminary estimation of performance, taking into account factors such as location, system type, and outcomes from energy modeling activities. By utilizing this tool, users can receive recommendations on the optimal combination of technologies for their chosen application and country. Anyone could use this tool, the user do not need to be a professional or do not need to have any specific knowledge.

The selection process proposed by the DMT is user-friendly and easily accessible. It involves a few simple steps that lead to the final result. Each step involves a question directed towards the end-user. Through the selection engine, it becomes possible to preliminarily identify the technologies that are well-suited for the specified application.

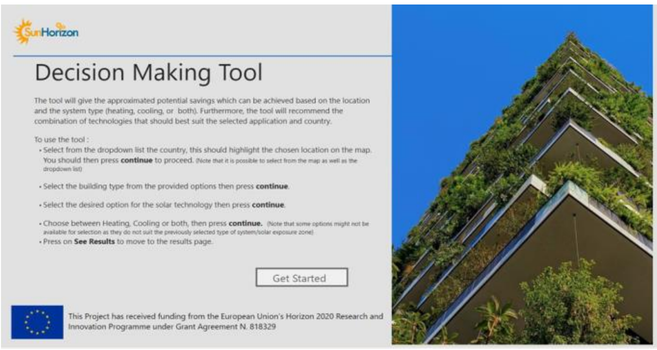

Figure 19. DMT tool – Landing page

The landing page of the DMT tool (see Figure 19) provides instructions on how to use the tool effectively. To initiate the process, users are required to click on the "Get Started" button, which leads them to the subsequent page which refers to as the "Map page" (Figure 20).

On the “Map page” users can select the country where the analyzed building is located. This selection can be made either by directly clicking on the country on the map or by checking the corresponding box in the list provided on the right-hand side. Based on the user’s choice the tool will identify the corresponding climate zone where the building is located.

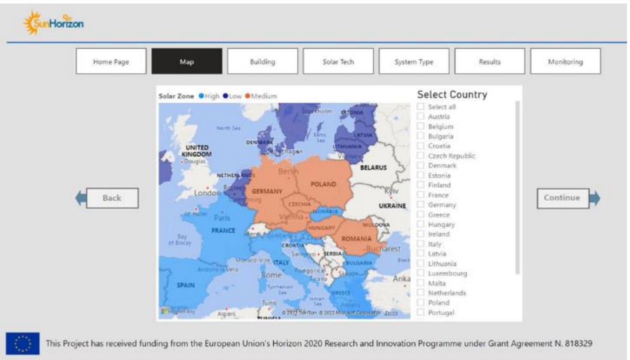

Figure 20: DMT tool – Map page

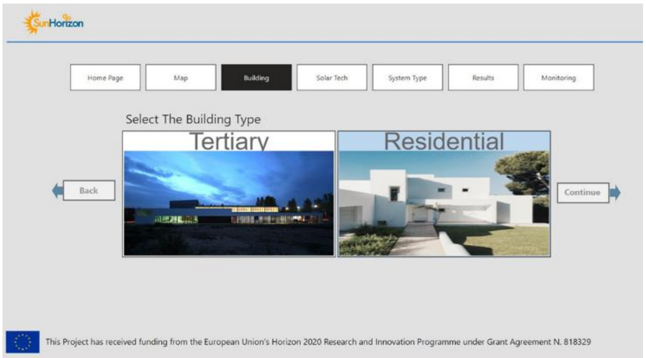

Figure 21: DMT tool – Building page

Throughout all the pages, there are buttons for "Continue" and "Back," along with a navigation toolbar positioned at the top. After making the country selection, the user can proceed to the next page by either clicking "Continue" or navigating to the "Building" tab (Figure 21). On the “Building page” the users could select the type of building where they want to replicate the SunHorizon proposed technology solutions.

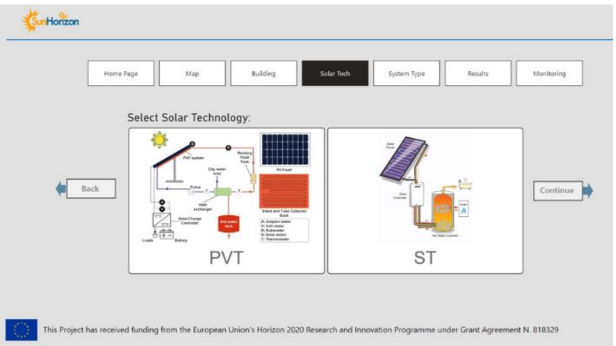

Figure 22: DMT tool – Solar Technology page.

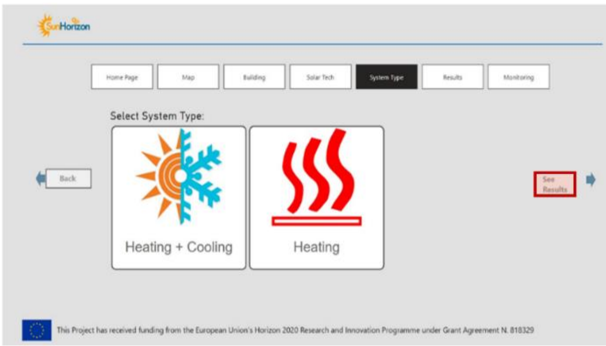

Figure 23: DMT tool – Building Conditioning System page.

After clicking on the "Continue" button, the tool progresses to the subsequent “Solar Technology page” (Figure 22) where users can choose what kind of solar technology they would prefer to be installed. The user can select between hybrid PV-T and solar thermal panels. A schematic representation of both solutions is presented as selectable buttons.

Finally, through the “Building Conditioning System page” (Figure 23) the user could specify what kind building conditioning system is or is planned to be installed. There are two possible options: both heating and cooling or only heating system.

The button “See Results” button (highlighted with red in Figure 23) allows to display the “Results page” (Figure 24). The following information will be presented:

- Which technology package suits the selections made by the user.
- An estimation of the savings that could be achieved based on standard systems simulated (in the green box on the top right corner, see Figure 24).
- Button to check the monitoring solution that could be applied.
- Return button to go back to Homepage and start over.

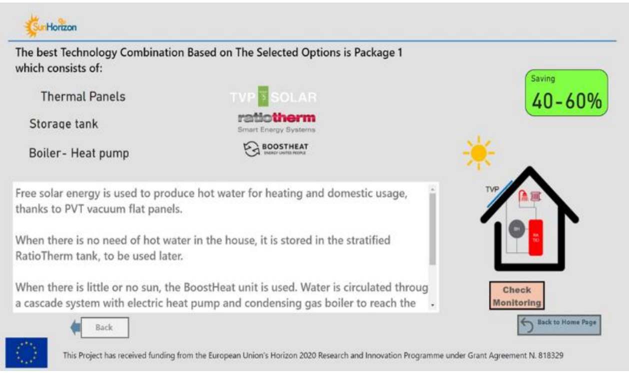

Figure 24: DMT tool – Results page.

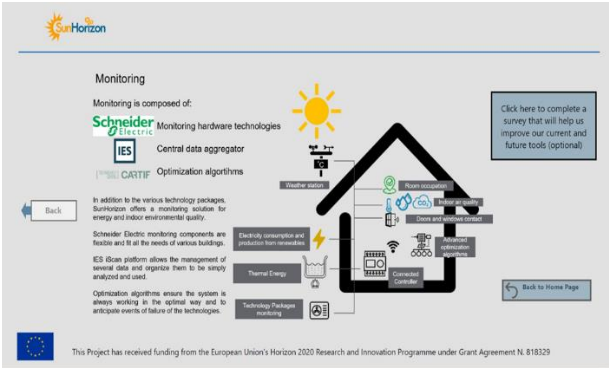

Figure 25: DMT tool – Monitoring Options page.

If the “Check Monitoring” button is selected, then a new page opens (see Figure 25) where the monitoring solution proposed by SunHorizon could be briefly explored.

3.4. How to evaluate the Financial Feasibility of the possible SunHorizon solutions

Although the two tools developed within the SunHorizon project, DMT and DUU, provide useful technical insights with regard to the pre-feasibility sizing of the SunHorizon technical solutions that could be applied and the corresponding equipment costs, the final decision of which of the suitable technical packages should be implemented comes to the financial feasibility of these solutions in the framework of the analyzed building.

Therefore, implementation Business Models should be constructed for each of the technical solutions provided by the DUU tool as optimal technology package configurations. These TP implementation Business Models should be then compared to each other from a point of view of the following financial parameters:

- Savings;
- Cash Flow;
- Internal Rate of Return;
- Net Present Value;
- Pay-back Period;

To evaluate *Savings* and *Cash Flows* heating, cooling and domestic hot water demand with the corresponding natural gas and electricity consumption should be known for a “Baseline” scenario with no SunHorizon solutions implemented and for the optimal technology package configurations identified by the DUU tool. The “Baseline” demand and consumption data could be obtained from the building historical exploitation data or based on estimation of actual technology providers’ technical specifications of heating/cooling generation units (pressurized/atmospheric/condensing/electrical boilers, chillers, AHU/fan-coil/split units, etc.) considering that their lifespans stand between 10 and 25 years. The DUU tool provides a preliminary evaluation of the energy produced and energy savings generated by the optimal technology package configurations identified, that can be used to compute the corelated monetary *Savings* and *Cash Flows.* In the meantime, for the *Internal Rate of Return (IRR)*, the *Net Present Value (NVP)* and the *Pay-back Period (PP)* the cost of the equipment (CAPEX) calculated by the DUU tool and the Operation and Maintenance (O&M) costs, mainly related to spare parts and working days of specialized technicians, should be considered.

A first assumption in the implementation of Business Models development should be the project duration, the exploitation period that should be considered for the technical solutions that are planned to be installed. All the small equipment, accessories and/or components of the installations have high lifespans such as valves (25 years), pipelines and traps (35 years), expansion vessels (25 years), electrical wiring and accessories (20 to 25 years), boilers and chillers (between 15 and 20 years), etc., while some other equipment lifespan is significantly lower (as it is the case of photovoltaic system inverters, whose maximum lifespan is usually no more than 10 years). The lifespan of the overall PV installation is 25 years, approximately the same lifespan in terms of overall solar thermal plus thermal energy storage systems (which in some cases can even last longer as different literature and case studies have shown). Therefore, an average life span / project duration of the analyzed technology package solutions could be set to 20 - 25 years.

Another key element in defining the proper Business Models for the implementation of the DUU tool provided technology package configurations in identifying if the client will have to rely on its own financial strength or third-party financing solutions or founding schemes could be considered for the initial investment costs. In the same framework the O&M could be undertaken either by an ESCO or another small maintenance operator.

In this context some remarks that should be accounted in the development of the implementation Business Models are noted below:

- Investment costs can be curtailed by up to 10 – 15% through a public or private tender and procurement process for the selection of the contractor/tenderer that will be responsible for the installation. That’s one of the main issues that the SunHorizon project has faced during the deployment phase, mainly due to construction and/or civil works that were required to adapt the system to each pilot building typology.
- As to the experience of ESCOs, technology suppliers and research technology organizations, the degradation of PV panels and therefore the reduction of the electricity produced by PV panels is about 0.5 – 1% per year. Therefore, an average of 0.8% annual decay of the PV production should be applied.
- With regards to the maintenance provision, it is meant to consider the following aspects:
    - Personnel costs, including operational staff, operator/workman.
    - Tools, clothing, and other material costs including uniforms, protective and safety equipment.
    - Vehicle and transportation costs.
    - Communication and management systems (Personal Digital Assistant/handheld devices, monitoring devices, etc.).

- Subcontracting costs for specific work.
- Additional specific contracting works not included before (such as legionella prevention tasks, sanitation, etc.).

Therefore, different O&M costs should be accounted for according to the optimal technology package solutions identified by the DUU tool. When considering standard assets like natural gas boilers for meeting heating and DHW demand, along with fan coils/splits for fulfilling cooling demand, it is recommended to allocate approximately 3% of the CAPEX as an achievable annual O&M (Operations and Maintenance) quota. In the case of the new TP (Technology Package) deployments, the O&M annual cost (OPEX) ranges between 0.25% and 0.50% of the CAPEX, depending on the specific TP's small equipment, accessories, and components.

It is important to note that PV-T (Photovoltaic-Thermal) panels require more intricate maintenance and repair compared to regular PV panels. Therefore, TP2, which includes both PV-T RES (Renewable Energy System) generation and HPs (Heat Pumps), shares a common OPEX of 0.35% of the CAPEX with TP2 due to their similar features. On the other hand, TP1 involves ST (Solar Thermal) panels and BH's (Borehole Heat) gas-driven HP, resulting in the lowest OPEX among all TP's, set at 0.25% of the CAPEX.

In the case of TP3, which encompasses PV-T RES generation as well as FAHR's (Fahrenheit Heat) adsorption chiller and a compression chiller, the equipment involved requires more comprehensive maintenance. As a result, TP3 has the highest OPEX among all TP's, amounting to 0.50% of the CAPEX.

As a result, the profitability / financial feasibility of implementation Business Models correlated to the optimal technology package configuration identified by the DUU tool should be compared and evaluated based on the following 3 financial indicators:

- The *Net Present Value (NVP)* is one of the best financial profitability indicators; to determine whether a project or investment will result in a net profit or a loss. It evaluates the current value of future cash flows generated by the investment, considering the time value of money. If the resulting NPV is positive, the investment is expected to generate a return greater than the required rate of return and is considered financially attractive. Conversely, a negative NPV indicates that the investment is expected to generate a return below the required rate of return and is therefore not financially viable.

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t} - I$$

where: T is the number of time periods (project lifespan/duration), CF is the expected net cash flow, r is the discount rate, t is a certain period of investment (usually a 1 year long period) and I is the initial investment.

- The *Internal Rate of Return (IRR)* is another key financial profitability indicator. It is defined as the rate of return that sets the NPV of all cash flows for the investment equal to zero, meaning that it is the discount rate at which the NPV of the future cash flows is equal to the initial investment. Whenever the IRR is positive, the project is profitable. The IRR is a relative profitability indicator of the project, but not an absolute profitability indicator. When comparing different internal rates of return of two projects (of two technology package configurations in our case), the possible difference over their size is not considered (neither do other external factors as inflation, cost of capital or various financial risks). A project with a huge investment and a low IRR can have a bigger NPV than a lower investment project with a higher IRR; in conclusion, IRR cannot be considered as an alternative to NPV but as complementary information while comparing different project's profitability.

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+IRR)^t} - I = 0$$

❖ The *Pay-back Period (PP)* represents the duration required to recover the initial investment cost. It signifies the time it takes to reach a breakeven point and is determined by dividing the investment amount by the annual cash inflow. A shorter payback period indicates a more appealing investment. However, one drawback of this metric is that it does not account for the time value of money.

$$PP = \frac{Initial\ Investment}{Inflows}$$

Unfortunately, the last years (the COVID-19 pandemic and the Ukrainian war) highlight the influence of unpredictable events and importance of a proper assessment of consumer price index (CPI) in the accuracy of long-term Business Models evaluations. Note that on May 2023 the harmonized index of consumer prices (HICP) at EU-27 level was 7.1%, in November 2022 it was 11.1%, in June 2022 it was 8.6% while in June 2021 it was only 1.9%.

4. Integration of a SunHorizon solution

4.1. Required Building Permits

In accordance with the experience gained through the implementation of the SunHorizon demo sites, Table 6 presents a list of building permits that are required for the installation of the SunHorizon proposed technology solutions. Due to the fact that the European legislation is uniformized over the entire EU the required building permits are similar in all the EU-27 states.

Table 6: Required Building Permits

Permit Name	Type	Short Description	Issuing Agency	Duration to Obtain
Roof Static Study	Study	Static Investigation of the Building Roof in order to identify if the roof could support the solar panels installation or what kind of reinforcement works should be carried out. Required for: PV panels, solar thermal panels and/or hybrid PV-T panels installation.	Specialized Construction Company	1 month
Structural Study	Study	Structural Investigation to identify if the building could support the thermal tank installation or what kind of reinforcement works has to be done for the installation works. Required for: medium-to-large scale storage tank installations and/or heat pump installation in special spaces.	Specialized Construction Company	1 month
Installation License	Permit	Present project to local public administration that approve the project and allow the beginning of the works. In some cities there could be some local limitations with regards to rooftop or building facade works from an architectural point of view and general town development strategies. Required for: solar panels, heat pump installation or any action that would affect the rooftop or the facade of the building.	Local Public Administration	2 months
PV Electric Connection	Permit and energy contract	Legalization of the PV system and contracting self-consumption and/or surplus energy selling to the grid. Achieve Prosumer status. Required for: PV panels, hybrid PV-T panels, invertors installations and connection to the grid.	Local Electrical DSO and/or National Energy Regulatory Authority	2 months
General Electric Connection	Permit. and energy contract	Administrative, Installation, legalization, and contracting process with the electric company to modify the existing electric connection from single phase to three phase connection or to change connection power level. Required for: electricity-based Heat Pumps and/or high-capacity PV or hybrid PV-T panels.	Local Electrical DSO	12 months

Permit Name	Type	Short Description	Issuing Agency	Duration to Obtain
Gas Connection License	Permit	Legalization process with the gas company to modify the existing gas connections and pipelines. Required for: gas-based Heat Pumps installation and/or conventional gas-based boilers replacement.	Local Gas DSO	2 months
Health and Safety Study	Study	Investigation on the effects of the installation works and the exploitation actions of the technologies that are planned to be implemented, on health and safety of occupants, installation, and maintenance personnel. Required for all the technologies planned to be installed to define proper safety measures to be applied during installation and exploitation actions.	Competent Technician	1 month

4.2. Installation Recommendations

Based on some specific questions that were addressed to the SunHorizon technology provider partners, in the following some of their recommendations regarding the installation process and the required skills for the installation professionals are presented:

TVP "LP-Power" – High Vacuum Solar Thermal Panels

Should the technology be installed only by the technology provider staff? **Not necessarily**, but TVP could provide appropriate training and guidance for installation personnel.

Required staff skills for installation/commissioning:

- Proficiency in plumbing techniques and pipefitting, including proper sizing, cutting, and joining of pipes, as well as installation of valves and fittings.
- Familiarity with electrical wiring and connections involved in solar thermal systems, such as connecting pumps, controllers, and sensors.
- Expertise in working with roofing materials and installation techniques to ensure proper integration of solar thermal panels into the building structure.
- A deep understanding of solar thermal technology, including the principles of heat transfer, fluid dynamics, and thermal storage.

Installation Recommendations:

Before receiving the goods: Ensure availability of space for temporary storage and of forklifts/ small cranes to place the crates that contain the panels and the Balance of System

Before the start of the installation: Ensure that all necessary civil works have been completed and an insurance contract against natural disasters and other unforeseen events has been signed.

During installation: Check the panels for potential damage (as soon as they are unpacked) and use replacements in case of lost vacuum. Follow the instructions provided by TVP personnel and/or installation guide. Pay attention to the quality of connections to avoid leakages and minimize troubleshooting.

The following main activities should be performed for the installation of the HVFP solar thermal systems:

- **STEP 0**: Preparatory (civil) works: preparation of the ground/roof space | Performed by local contractor; Required skills vary depending on each case.
- **STEP 1**: Pipe array support and panel support installation | Can be performed by construction workers after receiving a short training by TVP staff.
- **STEP 2**: Thermal cabinet, application machine / heat exchanger and control cabinets positioning |Can be performed by plumbers (thermal cabinet) and electricians following (remote) guidance by TVP.
- **STEP 3**: HVTF filling and thermal expansion management system and dry cooler positioning, pipes mounting, cable routing | Can be performed by local contractor: its workers, plumbers and electricians may receive (remote) guidance by TVP.
- **STEP 4**: Mounting panels and connectors installation | Can be performed by local contractors: its workers, plumbers and electricians may receive (remote) guidance by TVP.
- **STEP 5**: System commissioning, insulation completion and performance assessment.

Guidance for the above steps is included in the Installation Guide developed within deliverable D3.7 [18].

During commissioning: Follow the instructions provided by TVP personnel and/or installation guide.

DualSun "Spring" – Hybrid PV-T Panels

Should the technology be installed only by the technology provider staff? **No**, but DualSun could provide technical guidelines and remote training lessons for professional staff.

Required staff skills for installation/commissioning:

- Previous experience setting up photovoltaic installations under similar conditions.
- Previous experience setting up solar thermal installations under similar conditions.
- Electrical clearance for working on PV installations.
- HVAC clearance for working on Solar Thermal installations, being also skilled with the installation of common sanitary or heating equipment.
- To have training in grid-connected PV, particularly in terms of protection of persons and property.
- To be trained in PV-T specificities through technical guidelines or during DualSun (remote) lessons.

Installation Recommendations:

For the hybrid PV-T panels installation the steps presented in the "Installation, use, maintenance manual DualSun SPRING" [19] and in "Installation, use, maintenance manual - DualSun pressurized systems" respectively should be followed considering also the schematics presented in [21]. During installation works a special focus should be given to the following aspects:

- Respect hydraulic recommendations: connection bottom left (cold side) to top right (hot side) up to 6 panels.
- A kit of brass inlet / outlet fittings is used to connect the inter-panel links to the transfer circuit; these fittings are installed at the inlet and outlet of each line of sensors.

- In case of micro-inverter, let space up to down the box.
- Insert thermal probe in the last panel.
- When interconnect PV-T modules with specific inter-panels connectors, be carefully to clip straightly (without any angle).
- Connect the cold / hot hydraulic side correctly with the solar station.
- Connect the wires correctly to the controller, follow the parametrization accordingly to your application.
- Be careful not to overpass the maximum pressure in the hybrid PV-T module when filling with the good rate of glycol water. Use demineralized water.
- Size and install with the accurate pre-charge pressure (bar) the expansion vase when needed (more than 12 panels).
- Fill in the installation minutes to activate the warranties.

Ratiotherm Stratified Thermal Storage

Should the technology be installed only by the technology provider staff? **Not necessarily**

Required staff skills for installation/commissioning:

The following technical skills and qualifications are essential for installers to ensure the proper installation, operation, and maintenance of thermal storage tanks, contributing to the efficient and reliable functioning of the entire heating or cooling systems:

- Proficiency in plumbing techniques and pipefitting, including proper sizing, cutting, and joining of pipes, as well as installation of valves and fittings.
- Know-how on proper anchoring, sealing, and connection methods.
- Familiarity with safety protocols and regulations related to the installation of thermal storage tanks, including proper venting, pressure relief mechanisms, and adherence to building codes.
- Knowledge of insulation materials and techniques to effectively insulate the thermal storage tank and minimize heat loss, ensuring optimal energy storage and efficiency.
- Competence in regular maintenance tasks such as cleaning, inspecting, and repairing thermal storage tanks, as well as troubleshooting common issues like leaks, temperature fluctuations, and system malfunctions.
- Ability to integrate the thermal storage tank with the control system of the overall heating or cooling system, including wiring, sensor placement, and programming.

Installation Recommendations:

- The tank should be positioned securely on a stable foundation or support structure, ensuring that it is level and properly aligned. Attention should be given to the location of the tank to facilitate easy access for maintenance and ensure proper connectivity with the heating and cooling system components.
- Once the thermal storage tank is installed, it is important to conduct a full testing of the system to ensure all components are functioning correctly and integrated properly with the building's heating and cooling system. The tank's sensors, valves, pumps, and controls should be tested for accuracy and responsiveness. Flow rates, temperature differentials, and pressure levels should be verified to confirm proper operation and optimal performance.

Fahrenheit Adsorption Chillers

Should the technology be installed only by the technology provider staff? **No, but installers should be certified by Fahrenheit for installation works.**

Required staff skills for installation/commissioning:

- Work on the transport and connection of Fahrenheit Adsorption Chillers may only be carried out by expert personnel.
- Service training from Fahrenheit GmbH with certification is required for installation and commissioning of Fahrenheit Adsorption Chillers.

Installation Recommendations:

For the installation of a Fahrenheit Adsorption Chillers should consult deliverable D3.4 "Manual with the Guidelines for the Hybrid Chiller Installation" [22]. A special focus should be given to the following aspects:

- Check the connection nozzle for impurities before connecting a pipeline.
- The hydraulic connection must be free of tensile, torsional, and compressive forces.
- During work on the control cabinet, it must be kept voltage-free via the main switch. Protect it against unintentional switching on.
- Insert cables into the control cabinet only via the cable glands provided.
- Observe and check the current and voltage of the respective connections before clamping them.

BDR Innovative Heat Pumps

Should the technology be installed only by the technology provider staff? **No**.

Required staff skills for installation/commissioning:

- Technical knowledge in heating systems and thermodynamics. Need to understand the principles and the components of heat pumps, electrical systems, and water circulation.
- Plumbing skills. Need to know how they connect the heat pump to the emitters with water pipes in accordance with the local regulations and the state of the art. Need to know how to properly install the indoor unit and the outdoor unit on the floor and the wall.
- Electrical skills. Need to know how to connect the heat pump to the electrical grid in accordance with the local regulations and the state of the art.
- For some cases, the empowerment for fluorinated gases handling.

Installation Recommendations:

- The installation of the heat pumps should be done in accordance with the installation manuals that come with equipment, see also deliverable D3.5 [6] for general installation schematics.
- The connections to the heating/cooling buffer tank will be done with the standard fittings. A first water loop between the heat pump and the buffer tank is to separate the water flow from the heat pump and the water flow from the heating circuit. So, the heat pump can load the buffer tank, and the heating circuits will pump energy according to the needs.

- In case that DHW is made by solar collectors, the heat pump will work as a backup and is connected to the DHW tank on the top coil, the solar circuit is connected to the bottom coil.
- For the Water-to-Water heat pump on hybrid solar panels, a decoupling tank needs to be installed on the cold side. If an external pump is required on the hot side, a decoupling tank will be necessary too.

Data Monitoring System

Should the technology be installed only by the technology provider staff? **No**.

Required staff skills for installation/commissioning:

- For the installation of the hardware that characterizes the data monitoring system or any BMS no particular skills are required for the installers. They should be able to install technologies such as heat and electricity meters, window contacts, presence, and ambient sensors.
- However, for the commissioning of the system (to set up variables, collection of data, etc.) are required Schneider Electric EcoXpert, trained and certified staff.

Installation Recommendations:

- During the installation of the field devices, it is very important to be careful while connecting the power and bus cables. A polarity reversal of both wiring can cause many problems during commissioning and, subsequently, with data reading and communication between devices.
- Another recommendation is to have a stable internet connection during commissioning.

4.3. Lessons Learned from SunHorizon demo-site implementations

The main lesson learned from the implementation of the SunHorizon demo-site, was to always ask the local partners present on-site to have a stable and cabled internet connection. After the installation and during the monitoring phase of the project we realized we had communication problems related to the internet connection which were solved by installing Wi-Fi repeaters. It's also important to have an ethernet cable running from the main router to the monitored building to avoid communication issues.

For the onsite implementation of any SunHorizon proposed technology package solution it is important to pre-schedule the installation works with technology providers and local craftsmen and installers. A local contractor should better be made responsible for the integration of the different technologies and their interconnection with the heating & cooling system of the beneficiary. The main contractor must be skilled and have wide experience in executing similar projects, especially regarding high complexity control systems. Technology providers must be fully involved in the local design phase. They also must validate the final solution and assure the proper integration and operation of their technology within the system as a whole. They should provide guidance and remote support for local installers during the installation phase and should be onsite supporting the commissioning phase of their equipment.

The dimensioning of the water-to-water heat pumps according to the hybrid panels field size is dependent on the working logic of the heat pump and the other heating appliance is in the system. Air-to-water heat pump could be installed in the system and to work during the night when the water-to-water heat pump is off, so the water-to-water heat pump could be dimensioned on a working point during the day, when thermal agent is available from solar panels, instead of the night.

A decoupling tank could be installed between the solar panels and the water-to-water heat pump, but not on the hot side. If the system requires an external pump due to long piping, a decoupling tank on the hot side will be good for the proper working of the heat pump. The decoupling tank between the solar panels and the water-to-water heat pump can be used as a thermal storage to be used when the sun is unavailable, the size could be bigger, and the control could be optimized for that.

Regarding the data monitoring and control system, a reliable solution should be applied to ensure that potential deviations and alarms are spotted immediately, and remote or onsite troubleshooting is performed.

4.4. Maintenance of SunHorizon solutions

TVP "LP-Power" – High Vacuum Solar Thermal Panels

Maintenance Periodicity: Annually or .on request (when the pressure of the system drops).

Maintenance Focus:

Visual inspection of the panels for breaks and vacuum integrity (spot check) and check of gaskets according to the installation guide [18] (the document also provides guidance for maintenance activities). Leakage inspection of the thermal agent piping system.

Required Maintenance Personal Skills:

The local system operator can perform the inspection. If a leakage is detected and depending on the severity of the situation maintenance personnel or a local contractor may be required. TVP personnel may also be consulted to provide further guidance.

DualSun "Spring" – Hybrid PV-T Panels

Maintenance Periodicity: Ideally each year

Maintenance Focus: Maintenance of the Thermal part

The maintenance of the DualSun panel on a solar installation is no more difficult than the maintenance of the panel of a thermal solar installation. Ensure that the installation is perfectly sealed and waterproof. Confirms the absence of fluid leaks on the accessible portions of the system.

The heat transfer medium (glycol water) should be checked once every 5 years. Its acidity should be checked with a Ph tester and its frost protection rate should be checked with a refractometer [20].

A maintenance contract for the solar panels can be set up with the installer, to plan one visit per year to the installation. Monitors the operation of the installation's safety devices, such as the mixing valve at the outlet to the domestic hot water tank or the solar safety valve. Verifies the pump, the expansion tank, and the electrical connections.

In addition, an energy production follow-up (monitoring) could be set up to monitor daily the DualSun solar installation, without the need for a technical visit. Thanks to the performance monitoring, if any problem is noticed, then consider the maintenance of the solar panel and the solar installation in general by contacting the installer or the maintenance company.

Maintenance of the Photovoltaic part

In general, the panels could be cleaned at least once a year and more often depending on exposure to dust and pollen. In France, there is sufficient wind and rain to adequately clean and rinse off photovoltaic solar installations, but you may also wipe down the panels with a sponge if you wish.

The electrical connections of the roof panels and the condition of the protective sheaths should also be visually checked. Finally, it must be ensured that all the protective devices in the AC box are working correctly: use the "Test" button on the Differential Circuit Breaker and the Q-Relay if there is one [19].

Required Maintenance Personal Skills:

- PV and solar thermal maintainers (or equivalent).

Ratiotherm Stratified Thermal Storage

Maintenance Periodicity: Annually with the heating and DHW system or on request when leakage is detected

Maintenance Focus: Visual inspection for leakage at the storage tank or connection pipes level.

Required Maintenance Personal Skills:

- Plumbing techniques and pipefitting, cutting, and joining of pipes, as well as installation of valves and fittings.
- Knowledge of insulation materials and techniques to effectively insulate the thermal storage tank and minimize heat loss, ensuring optimal energy storage and efficiency.

Fahrenheit Adsorption Chillers

Maintenance Periodicity: Annually or on request (when the pressure of the system drops).

Maintenance Focus:

- Visual inspection of the system for damaged insulation, leaks and defects in the electrical wiring.
- Checking the operating pressure of all hydraulic circuits; if necessary, a permitted working medium must be refilled.
- Inspection of the fans of the re-cooler and cleaning of the heat exchanger block, especially on the suction side.
- Leakage and functional testing of all the valves and pumps of HCH and the circuit separation.
- When a mixture of water and mono ethylene glycols is used, its concentration is checked with a refractometer and if necessary, further measures are taken to exclude damage caused by frost.
- Checking the vacuum stability of all process modules and restoring the vacuum if necessary.
- For systems with more than 3 kg of refrigerant, a maintenance log of the work performed on the system must be kept, which is not the case for this project, as the refrigerant amount is 2.7 kg.
- If flammable refrigerants are used, the suction hose must also be checked for damage and an unhindered discharge of the extraction volume flow into the open air must be checked regularly.
- Function test of the pumps.

Required Maintenance Personal Skills:

- Service training from Fahrenheit GmbH with certification is required for installation and commissioning of Fahrenheit Adsorption Chillers.

BDR Innovative Heat Pumps

Maintenance Periodicity: Annually

Maintenance Focus:

- Refrigerant leaks search and repair.
- Water leaks search and repair.
- Water filters cleaning.
- Water pressure check and refill.
- Air heat exchanger cleaning.

Required Maintenance Personal Skills:

The maintenance of a heat pump requires several personal skills:

- Plumbing skills are required to ensure proper connection of the heat pump to the emitters using water pipes, the correct installation and repair of indoor and outdoor units on various surfaces such as floors and walls.
- Competence in electrical work following local regulations and industry standards to ensure safety and efficiency.
- Need the necessary certification and training for handling fluorinated gases, which are commonly used in heat pump systems.

Data Monitoring System

Maintenance Periodicity: On Alarm

Maintenance Focus:

It is important to check that the devices are switched on, working properly and that there is no external damage. The correct installation of power supply and bus cables should be verified, moreover, if the devices are equipped with batteries, the battery power should be checked (if low or dead, replace them). It's also important to check that the field devices are communicating correctly with the data monitoring platform and that it is receiving the data.

For the maintenance of software, it is important to check that it is online, the license is valid and possibly renew it. The maintenance of the ZigBee sensors should focus on batteries status: an incorrect behavior can depend on batteries fault or communication interferences.

Required Maintenance Personal Skills:

There are not particularly required skills for the maintenance staff. They should be experts to install and control the correct functioning of the technologies installed. However, to verify the correct communication of the field devices with the Automation Server and of the Automation Server with the Enterprise Server they are required to be trained and certified partners for the Schneider Electric EcoXpert.

SunHorizon Pro-Active Maintenance Tool

To reduce maintenance costs by optimizing the maintenance actions and by minimizing repair costs related to unexpected equipment failures, the Pro-Active Maintenance Tool developed [10] within the SunHorizon project could be incorporated in the data monitoring system.

The Pro-Active Maintenance tool was developed based on a Reliability-Centered Maintenance (RCM) strategy [11], which is used to achieve the best exploitation strategy for a process or an equipment by maintenance monitoring activities and pre-detecting possible failures events. RCM involves analyzing various maintenance scenarios to determine and implement the most effective strategy, considering the consequences and costs of failures on a preventive, corrective, and predictive basis. The goal is to enhance reliability and maintenance throughout the entire life cycle of the system.

To achieve this objective and identify failures, a set of Key Performance Indicators (KPIs) has been established. These KPIs are calculated in real-time operations and compared to the baseline simulation data. When an alarm is triggered, the relevant KPI is utilized to detect the failure, prompting the execution of maintenance actions defined in the Failure Modes, Effects, and Criticality Analysis (FMECA) [11]. Additionally, the remaining useful life (RUL) is estimated to predict potential future failures.

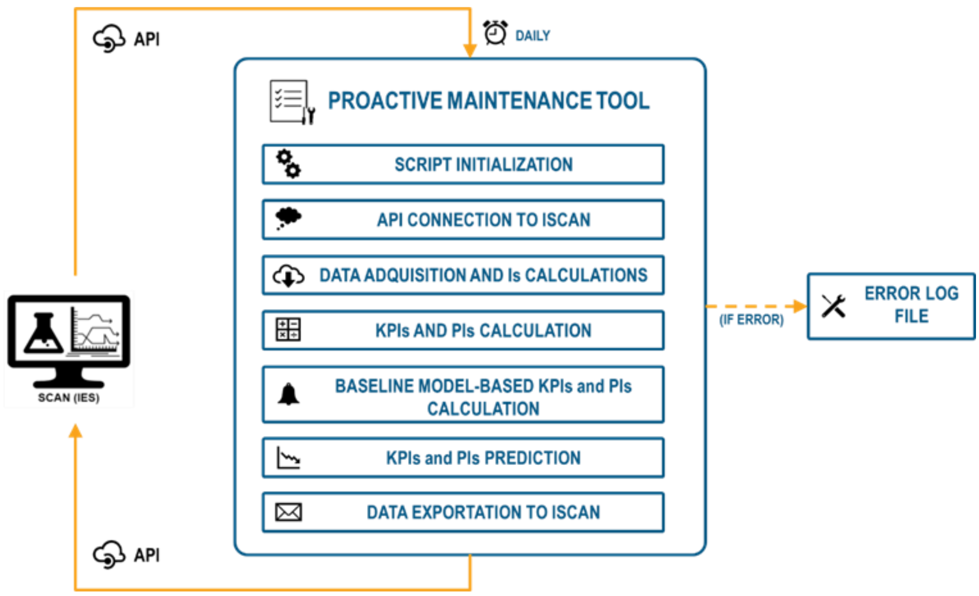

Figure 26: Pro-Active Maintenance Tool Workflow.

Figure 26 presents the operational workflow of the Pro-Active Maintenance tool. The process involves several steps that are executed daily. Initially, monitoring data from the iDashboards [10], iSCAN cloud platform is collected using an API. Subsequently, both overall KPIs and performance indicators (PIs) specific to each installed SunHorizon technology within the system are calculated. The formulas for these KPIs and PIs incorporate a predefined resolution time, such as 15 minutes, hourly, daily, or yearly. If any alarm is triggered, a notification is sent via email to the worker for the scheduling of maintenance tasks.

To identify the alarm level in a building where the Pro-Active Maintenance tool is used, a customized alarm library will be incorporated where the stakeholder (building owner or building manager) can define the alarm expressions to be shown. In relation to the Pro-Active Maintenance Tool, the alarm levels have been defined according to Table 7 , based on the percentage ratio value obtained from the indicator actual and the indicator estimated.

Table 7: Procative Maintenance tool - Alarms levels

Alarm level	Formula
Warning	$50\% \leq \left\lvert \frac{Indicator_{actual} - Indicator_{estimated}}{Indicator_{estimated}} \right\rvert < 80\%$
Danger	$\left\lvert \frac{Indicator_{actual} - Indicator_{estimated}}{Indicator_{estimated}} \right\rvert \geq 80\%$

When an alarm associated with the main one necessary to perform the Failure Modes, Effects and Criticality Analysis (FMECA) is triggered the actions indicated in the demo tables of deliverable D4.2 need to be followed:

1. Check the table of alarms and troubleshooting.
2. Follow the instructions indicated in the table.
3. Calculate the FMECA.

An example is given below in relation to the DualSun hybrid PV-T dual outlet temperature, from the SunHorizon Riga Sunishi demo-site:

- The DualSun outlet temperature has reached a value above the threshold (i.e. 80 °C). Alarm “A.I.S.DST01-9- Tmax" is activated and the operator receives an email:

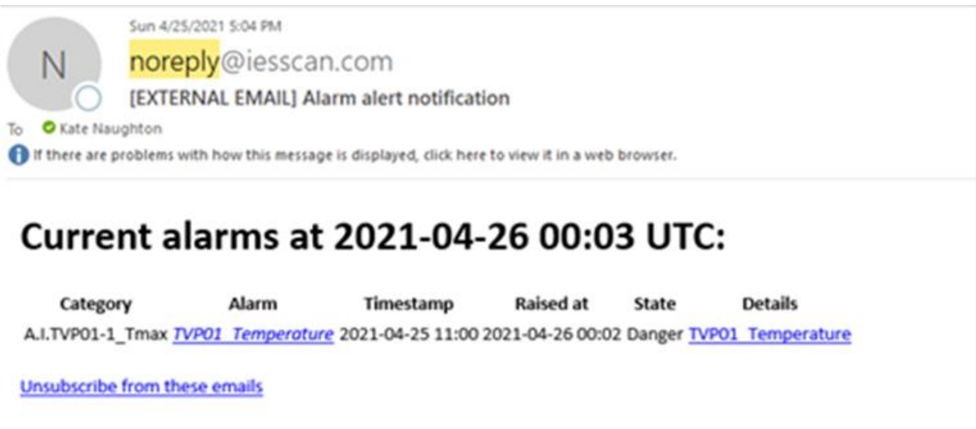

Figure 27: *Appearance of the e-mail received by the user.*

- The FMECA Table of Riga Sunisi demo site is checked, looking for the alarm code “A.I.S.DST01-9-Tmax”.

5. Conclusions

The primary goal of the SunHorizon project is to showcase cutting-edge Heat Pump solutions (including thermal compression, adsorption, and reversible technologies) that, when properly integrated and controlled alongside advanced solar panels (such as PV, Hybrid, and thermal panels), can deliver efficient heating and cooling to residential and commercial buildings. This integration aims to achieve significant reductions in emissions, energy costs, and reliance on fossil fuels.

The purpose of this document is to offer comprehensive guidance on replicating the SunHorizon developed technologies in various residential and tertiary buildings. It presents an easy-to-understand Handbook, specifically designed for professionals, building managers, and owners, to assist them in selecting the most suitable combination of SunHorizon technical solutions based on their building requirements and the specific climate zone.

The Handbook not only aids in identifying the appropriate SunHorizon solutions but also provides valuable insights regarding installation and maintenance procedures. By offering this guidance, the document aims at facilitating the replication of SunHorizon technologies beyond the project consortium. It serves as a valuable resource for professionals, building managers, and owners, equipping them with the necessary guidelines to successfully integrate and replicate SunHorizon solutions in both public and private residential and commercial buildings.

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