.

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EUROPEAN COMMISSION

Climate, Infrastructure and Environment Executive Agency (CINEA)

Grant agreement no. 818329

Sun coupled innovative Heat pumps

D3.11 – SunHorizon Technologies catalogue

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CO	Confidential	

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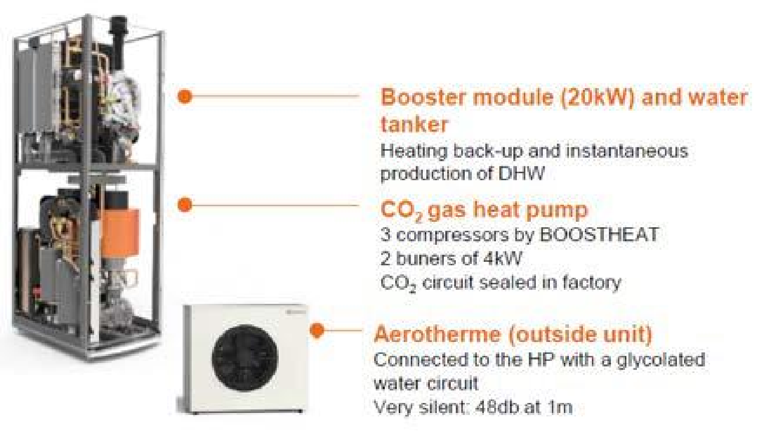
1 Executive summary

Technology provider	Application	Innovation introduced within SunHorizon project
TVP SOLAR	 **High Vacuum Flat Panels** The TVP solar panels were designed and manufactured to produce hot water/ steam at 80°C – 180°C for industrial-scale solar thermal applications exhibiting energy conversion efficiencies up to 65% and 45% respectively. Under SunHorizon project, TVP reviewed the existing MT-Power panel and the respective solar system, to define the LT-power technology, with target temperature below 100 °C, for residential and tertiary building applications. This innovative design targeted a high efficiency compared to the commercial SoA, with a reduced manufacturing cost compared to the current technology.	- Analysis and selection of materials for the LT-Power panel (absorber coating) - Product engineering and prototyping - Creation of new molds and machines - Modifications of existing production equipment - Realisation of samples for LT-Power panels - Setup and operate a test bench of 3 panels - Application checks of the above LT-Power-based test bench - Elaboration of a new, simplified layout of the solar system - Elimination of the insulated buffer tank - Selection of Balance of System (BoS) components rated at 100 °C - Safety improvements and reduction of stagnation temperature (through laminated glass cover)
	CONTACTS **Further info and TVP news on**: https://www.tvpsolar.com/ **TVP contact persons**: Guglielmo Cioni, cioni@tvpsolar.com; Dimitris Papageorgiou, papageorgiou@tvpsolar.com	

FAHRENHEIT	 The adsorption chillers from Fahrenheit utilize low-temperature heat (70-95 °C), for example from solar collectors, combined heat and power plants (CHP), district or process heat, in order to generate cold in an environmentally friendly and cost-effective way. This is also possible in the small capacity range. There are no moving parts in the process modules, since neither steam flaps nor the circulation of process water is required due to the patented dual-chamber principle. The hybridization of the adsorption with the compression technology allows to guarantee reliable operation along with an increased seasonal energy efficiency ratio (SEER) compared to the current SoA.	Adsorption part: - Adsorber heat exchangers: new vacuum brazed heat exchangers are introduced with a considerably larger surface area and new coating technique. - Evaporator/Condenser heat exchangers: in the new design, copper finned pipes are used. The horizontal arrangement ensure that the heat exchanger operates as flooded evaporator thus enhancing the heat transfer rate. - Process modules: the process modules in the latest prototypes are arranged horizontally, such layout eliminates the “false condensation” completely, since the condensate flows always to the bottom of the process module. Compression Part: - Refrigerant: The R134a has been replaced by the natural refrigerant R290 which has a global warming potential of 3 instead of 1430 for R134a. Therefore, the parts of the compression unit were redesigned. - Risk minimization: as R290 is highly explosive special attention has been paid to the prevention of explosive hazards.
	CONTACTS **Website: https://fahrenheit.cool/en/ - info@fahrenheit.cool**	

<table>
<tr>
<td rowspan="2">BOOSTHEAT</td>
<td>

The BOOSTHEAT.20 uses a new type of thermally-activated compressor. The thermally driven heat pump exploits a natural refrigerant, CO_2, to “pump” low-grade heat from the outside air into the house, achieving extremely high efficiencies compared to other gas-driven heating technologies, like gas boilers. The thermo-compressor works without oil, low wear and guarantees extremely quiet operation.</td>
<td>During the transition from the BH Origin to the BH Connect, the user interface (HMI) was redesigned to allow, among other things, easier management with solar integration.
The intuitive navigation and the integrated help assistant make it easier for the user and the heating installer service.
Furthermore, the integration of the thermostat Evohome (Honeywell) allows for simpler regulation and lower energy costs. The Evohome© thermostat facilitates individual adjustment and full access to the heating control.
With the central control unit, the user can configure customized heating profiles according to the needs.</td>
</tr>
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<td colspan="2">CONTACTS
Website: https://www.boostheat-group.com/en/</td>
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<tr>
<td rowspan="2">DUALSUN</td>
<td>

DualSun PVT solar is an advanced hybrid solar technology that produces simultaneously electricity (photovoltaic) and hot water (solar thermal).
A standard photovoltaic panel only generates 20% of electricity during operation; the remaining 80% is mostly heat. Hybrid DualSun PVT solar allows a real synergy between photovoltaic and thermal, producing up to 3 times more energy than a traditional photovoltaic panel.</td>
<td>- Simplified hydraulic connection for non-specialist installers: to reduce cost and installation time and to make technology accessible to non-specialist installers, click and flow innovative fittings adapted to standard PV mounting systems has been developed in the project.
- Redesign the heat exchanger to be compatible with more PV modules and lighter the module: a thinner heat exchanger (-10 mm in thickness) was developed, the integration with PV cells was improved (15% more efficient in electricity) and a more efficient heat exchange between fluid and panel was achieved
- Industrialization of respective manufacturing processes towards volume production</td>
</tr>
<tr>
<td colspan="2">CONTACTS
DualSun, 2 Rue Marc Donadille,13013 Marseille,France
✉ contact@dualsun.com - https://dualsun.com/en/ - for professional contact DualSun here.</td>
</tr>
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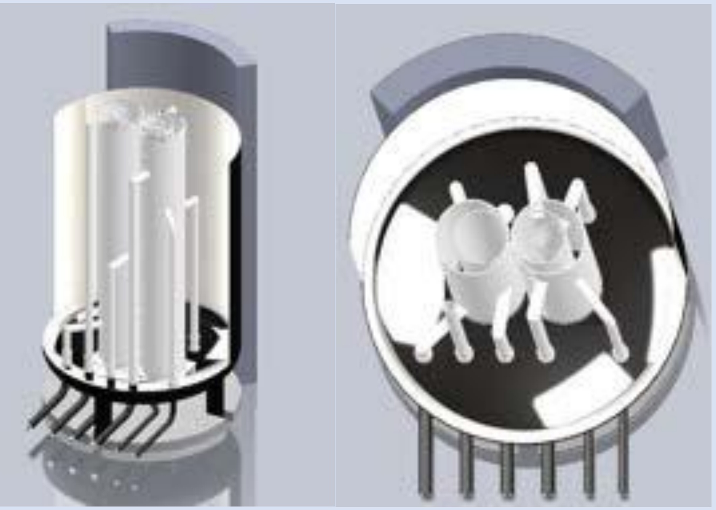
RATIOTHERM	 The main concept of the Ratiotherm thermal storage is to maintain a satisfactory stratification within the storage tank. The combination of preselected connections and the physical phenomena of stratification related to the density of the fluid allows an enhanced charging and discharging while the heat carrier is ascending and descending within the distributor, prior entering the storage. The target of the stratification device is also to guarantee a less turbulent fluctuation movement. This represents an enabling technology to properly integrate heat pumps and solar thermal technologies.	During the SunHorizon project different specialised thermal storages have been developed. The main aim was to improve the internal distributor in order to manage the different source and sinks connected to the storage and their thermal requirement. The distributor was modified from a one-chamber-system to a distributor with two circular chambers and a larger pipe diameter (DN40), thus a higher flow rate does not destroy the thermal stratification.
	CONTACTS **Website**: https://ratiotherm-systems.com/ - info@ratiotherm.de	

<table>
<tr>
<td rowspan="2">BDR THERMEA</td>
<td>The BDR Thermea group produces a wide range of heat pumps for most of the residential and tertiary requirements:
- Monobloc Water to Water
- Monobloc Air to Water
- Split Air to Water
- Split Air to Air
- Monobloc Air to DHW
- Split Air to DHW</td>
<td>The main innovation introduced within SunHorizon aimed at optimize the self-consumption of electricity produced at building scale, by optimizing the operation of the heat pump as power-to-heat converter.
The concept is based on the optimization of the overall cost, by properly selecting the best operation of the system. For instance, in an integrated hybrid configuration, using heat pumps and gas boilers, 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.
Considering also PV panels as part of the system, usually electricity generated is partly consumed by general appliances, and the rest is injected into the power grid with or without remuneration. The optimized BDR control of the heat pump is improved to use exactly the remaining electricity produced by the PV to store it as thermal energy in water tanks for heating, DHW or cooling.</td>
</tr>
<tr>
<td colspan="2">CONTACTS
The Netherlands, Kanaal Zuid 106, 7300 AL Apeldoorn.
Website: https://www.bdrthermeagroup.com/</td>
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2 Introduction

The present deliverable D3.11 – “SunHorizon technologies catalogue”, as part of the T3.7 – “Upgraded SunHorizon enabling technologies validation and final design for prototypation and commissioning”, aims to collect a full catalogue of Technical datasheets and innovations from the SunHorizon Technologies and the main features for the Technology Packages integration.

The technologies catalogue is the final resume of each single effort implemented in the Work Package 3 that aims at the optimization and adaptation of the design of the enabling technologies on which the technology packages of SunHorizon will be based. Within the WP3 the core activities are devoted to the research and development of the selected technologies with a successful result that, in this final document, shows the improvements achieved in terms of energy efficiency, user friendly design, safety, comfort and costs reduction.

Each technology provider described the general operation principle and the main concept of each technology. Furthermore, they reported the achievable performance, the potential limitations and expected applications of own manufactured technology. Then, a particular focus was dedicated to the core innovation expected within SunHorizon project and to the achieved results. Finally, the description of the integration layout of each single technology with the other ones within the technology packages was presented.

A TRL 7 is achieved for all the developed technology, these efforts will strengthen the competitiveness and growth of the involved industrial partners, enabling to mobilize significant investments by 2030 and capture a sizeable H&C market share.

Academics, scientists, designer and manufacturers can refer to the present manual as a benchmark for a set of technologies that can be integrated in a sun-coupled system.

3 TVP solar – high vacuum solar thermal panels

3.1 Description of technology

TVP’s technology and product: High-vacuum technology, initially spinned off from CERN, has been further advanced, patented, integrated, industrialised and commercialized by TVP for the design and manufacturing of innovative solar thermal High Vacuum Flat Panels (HVFP) under the brand name ‘*MT-Power*’.

Thanks to this high-vacuum technology and flat design, MT-Power panels exhibit minimal thermal losses, no degradation over time, and thus exceptional efficiency throughout their extended lifetime.

Additional engineering innovation at solar system level has further improved overall performance and cost-effectiveness. This included: standardised panel arrangements and connectors, reduced external piping, alternative system layouts, etc.

As a result, HVFP-based solar systems offer a uniquely positioned green and zero emission alternative for heat generation.

Overview of HVFP novelty: TVP has transformed solar water heaters into a high-end product that generates hot water/ steam at 80 °C – 180 °C for industrial-scale solar thermal applications exhibiting energy conversion efficiencies up to 65% and 45% respectively. No other non-concentrated solar technology can claim such performance. TVP’s super-performing flat collectors produce heat throughout the year in most climatic conditions and geographies cheaper than liquid fossil fuels. Without need of cleaning and with only minimal maintenance, TVP’s nearly 100% recyclable solar collectors can operate for 25 years to substitute fossil fuels and deliver emission-free thermal energy.

Figure 1: HVFP-based system for industrial process heat (hot water & steam) in Turin, northern Italy

The company has already built and operates a reference manufacturing plant in Italy. Solar systems driven by HVFP technology already operate in pilot/ demonstration sites and are being improved and optimised for: higher energy yields, smooth integration with existing thermal networks, modularity & scalability, easy installation and expansion, as well as for significantly lower cost in large/ mega-scale installations.

Self-assessment of the degree of innovation for HVFP-based solar thermal systems:

It is different from any existing offering and is provided by TVP only: High Vacuum Flat Panels (HVFP) are solely offered by TVP; there is no other solar technology provider to integrate high vacuum technology with flat panels. This unique combination has been realised through intensive RTD and innovation activities within a 10+ year period. TVP’s technology and know-how are protected by 10 patent families (177 patents granted) and supported by software models, blueprints, industrial secrets, etc. that create a solid barrier to enter for potential competitors.

It demonstrates innovative and distinctive outcomes: Thanks to this effort and accomplishments, HVFPs demonstrate the best energy conversion efficiency among all SolarKeyMark certified panels in the world (+30-50% better performance), even with low-to-medium sun irradiance, with no degradation over an extended lifetime.

Core innovative elements and competitive advantages:

UNIQUENESS 1 Performance and versatility: TVP’s *MT-Power* HVFP is Solar KeyMark certified as the most performant solar thermal collector in the world up to 200 °C[1]. It is designed to operate in temperatures up to 180 °C, for heat & steam (up to 4 bar) applications, in locations with yearly solar irradiance (GHI) as low as 1,000 KWh/year[2]. It captures both direct and diffuse solar irradiation and outperforms any other certified collector in terms of power production and efficiency at the low-to-medium temperature range. Such technology offering outpaces and extends operating limitations of other solar flat panel and vacuum tubes technologies by demonstrating superior performance and all year-round supply. It is a high performing panel[3] demonstrating a 65% energy conversion efficiency at 80 °C under full sun conditions (1000 W/m^2). For

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[1] HVFPs are certified to produce heat at 200C or raise the temperature of ambient water from 20C to 200C (i.e. 180C dt)

[2] GHI (Global Horizontal Irradiance) of 1000 kWh/m^2/y is available at latitudes above 50N (i.e Northern France, Germany, etc)

[3] Datong Gao, Guangtao Gao, et al; ‘Experimental and numerical analysis of an efficiently optimized evacuated flat plate solar collector under medium temperature’, Applied Energy, Volume 269, 2020

average daylight conditions (500 W/m^2) it still performs close to 60% at 80 °C. Only MT-Power is able to deliver relatively high temperature during winter weather conditions as shown in Figure 2.

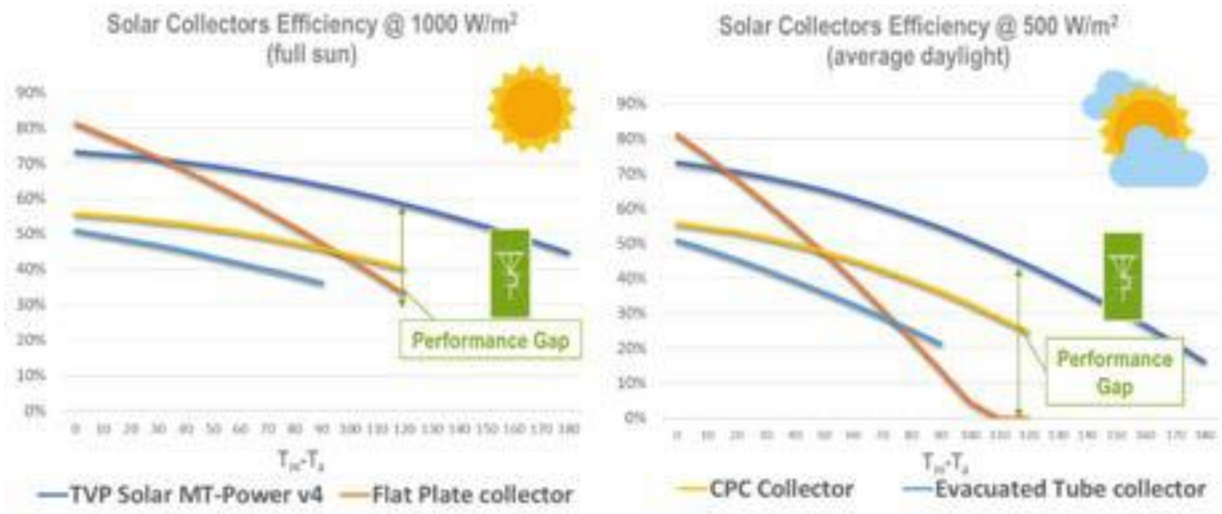


Figure 2: Certified data comparison between MT-Power and other solar thermal technologies: Best efficiency and energy output in any climate conditions, with any irradiance, at any operating temperature up to 200°C

UNIQUENESS 2 Simplicity & prolonged lifetime: By combining high-vacuum in a flat box, TVP has introduced a radical innovation to solar thermal, maximizing performance while adhering to the **construction simplicity** (static system, without concentration or tracking, no need for cleaning) and low cost of a conventional flat plate collector. This is achieved via the best transparent insulating material: a high-quality vacuum with internal pressure below 10^{-3}mbar, or "high-vacuum". High-vacuum suppresses convection losses strongly enhancing the overall conversion efficiency of solar radiation into useful thermal energy. Planar layout maximizes collector active area and allows the heat transfer fluid to remain entirely within the TVP high-vacuum collector, further improving efficiency. Assembling a panel to continually withstand 10 ton/m² atmospheric pressure caused by vacuum exhaust within its envelope becomes possible only with TVP's patented glass-metal seal. This seal introduces a bulk, perpendicular, mechanically reinforced chemical bonding between glass plate and metal frame. Highly flexible thanks to embedded ribbing in the frame, the seal remains strong and viable for long-term durability. To extending vacuum (and panel) lifetime to over 25 years, TVP has implemented a patented self-regenerating non-evaporable getter pump. In addition, the patented visual high-vacuum verification technology, Spot-Check™, aids in-field troubleshooting and reduces maintenance. The patented embedded return pipe under vacuum reduces the cost of the Balance of System (BoS) and installation while improving system performance.

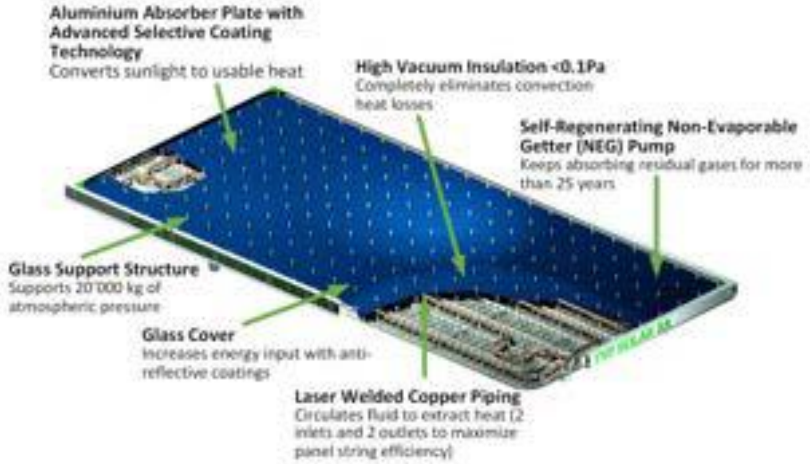
TVP's high vacuum flat panels do not show any sign of performance degradation over product's lifetime, due to the protection of high vacuum.

UNIQUENESS 3 – Low maintenance: TVP know-how related to solar field layout, custom BoS items is freely disclosed and shared to sales channel partners in order to scale-up number of installations and outsource maintenance.

UNIQUENESS 4 – Reduced heat losses at system level: In addition, TVP improvements at system level allow a high number of panels per string with no external piping at string level; panel-to-panel and end-connectors with individual insulation boxes to further reduce piping losses. Finally, an initial set of standard operating procedures for installation, and a simplified web-tool for real-time remote monitoring have been introduced.

Figure 3: Sample & schematic of TVP glass-metal sealing

UNIQUENESS 5 - Manufacturing know-how & infrastructure: TVP wholly owns and controls its **Reference Manufacturing Module (RMM)**, located in Avellino (Italy) with a 5,000 m^2 facility. It currently manufactures MT-Power panels and is ramping-up towards nominal capacity (120'000 m^2/year; 80 panel/day/shift). By design the RMM has 6 goals: (i) modularity; (ii) high yield (>92%); (iii) high throughput (40.000 m^2/shift/year; ≤5 minutes takt time); (iv) full automation (<60 line operators/shift); (v) small impact of depreciation on the product cost (≈ 15 €/m^2 with8.5 M€ equipment CAPEX); (vi) same manufacturing line for future HVFPs product development.



<u>IPR ownership</u>: TVP's IP portfolio is made of tangible and intangible assets which cover radical and incremental inventions and know-how, spanning the technology, manufacturing, as well the design, installation and operation of solar projects. This IP portfolio clearly differentiates TVP from other solar technologies, delivering high barriers to entry for high-vacuum flat panel manufacturing. It includes:

- 10 patent families, 184 patents (177 granted) for core tech, associated products & manufacturing
- Software models and meshes, FEA and CFD [4]simulations, blueprints related to products
- Industrial secrets related to materials, manufacturing processes, tools and machineries
- Blueprints/ firmware for manufacturing & testing equipment;
- Know-how in manufacturing plant operation
- Blueprints for solar field balance of system components/assemblies
- Schematic, integrated hardware platforms & tools, software & firmware for data acquisition and analysis for field applications & lab measurements;
- Simulation models, libraries, tools, calculators for solar field energetic assessments & engineering.

The 10 patent families of TVP are the following:

TVP SOLAR

Core technology	Associated products	Manufacturing process

		Case 001: "Vacuum Solar Thermal Panel With A Vacuum-Tight Glass-Metal Sealing": **EP 2283282; US 8096296; US 8161645; US 8161965**. Enhanced ability to withstand pressure.	Case 002: "Lightweight Structure Vacuum Solar Thermal Panel"; **EP 2274559; US 8578930**. Minimizing product weight and related production cost.
Case 003: "Vacuum Solar Thermal Panel with Radiative Screen"; **EP 2229561; US 8875696**. Minimizing thermal dispersion due to radiation.	Case 004: "Method for performing an exhaust cycle of a vacuum solar thermal panel"; **EP 2472194**. Long lasting quality/ reliability; Optimized outgassing reducing vacuum level loss.	Case 005: "Method for performing a frit firing cycle in the manufacturing of a vacuum solar thermal panel"; **EP 2658819; US 9546109**. Increased product safety-improved robustness	Case 006: "Vacuum solar thermal panel with pipe housing"; **EP 2474795; US 9404676**. Reduces thermal dispersion due to conduction and thus further improving panel efficiency.
Case 007: "Vacuum Solar Thermal Panel Provided with an Internal Pressure Indicator"; **EP 2530402; US 9366457**. Easier	Case 008: "Method for Manufacturing a Vacuum Solar Thermal Panel …"; **EP 2543938; US 9651278**. Simplified assembly & reduced glass/metal	Case 009: "Vacuum Solar Thermal Panel With Non-Evaporable Getter Pump Assembly"; **EP 2551609; US 9182147**. Extending getter pills'	Case 010: "Solar Thermal Panel Array Field Arrangement & Vacuum Solar Thermal Panel"; **EP 2672194; US 9683757**. Mimimised external piping,

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[4] FEA: Finite Element Analysis; CFD: Computational Fluid Dynamics

maintenance and troubleshooting.	stresses, improved yield & product robustness.	lifetime and consequently high-vacuum insulation.	insulation & thermal losses and simplified connectors

Room for improvement for HVFP-based solar thermal systems:

Further advancement for optimisation, technical adjustments and mega-scale installations: HVFP-based solar systems have been piloted and demonstrated recently at small and medium-scale (less than 1 MWpeak). Solar system optimisation at mega-scale projects (i.e. 10-100 MW peak) still needs to be proven, especially in combination with thermal storage and advanced control and management systems. Further standardisation of the Balance of System (BoS) will be required for such projects, including the expansion of the existing supply chain for the BoS.

Development of novel integration with existing thermal energy systems: HVFP-based solar thermal systems are integrated into the relevant thermal processes, as independent subsystems, and are connected with existing thermo-hydraulic systems and networks. Such distributed integration allows feeding solar heat directly into the respective processes and thus optimum matching demand and supply, while thermal storage can be used for enhancing the flexibility of the solar thermal system, enabling solar heat delivery, beyond daytime (i.e. in hours with no sun).

It combines high-tech hardware with advanced control and management: Advanced control strategies and systems are required to optimise solar heat generation and supply to meet heat demand at the lowest cost possible.

This way, low-carbon HVFP-based solar systems can massively accelerate the transition to climate neutral industrial processes at a cost-effective manner, leading ultimately to carbon-neutral operation of buildings and industrial processes.

3.2 Innovation introduced in SunHorizon project

Under SunHorizon, TVP reviews the existing MT-Power panel and the respective solar system that aim mainly at applications above 100 °C with the objective to further optimise them (in terms of cost and efficiency), and rate them at 100 °C (to further reduce costs). The new panel and respective solar thermal systems are ‘branded’ ‘**LT-Power**’. In particular, the following modifications, improvements and optimisation has been performed[5]:

- Analysis and selection of materials for the LT-Power panel (absorber coating)
- Product engineering and prototyping
- Creation of new molds and machines
- Modifications of existing production equipment
- Realisation of samples for LT-Power panels
- Setup and operate a test bench of 3 panels
- Application checks of the above LT-Power-based test bench
- Elaboration of a new, simplified layout of the solar system - Elimination of the insulated buffer tank
- Selection of BoS components rated at 100 °C (instead of 180 °C for MT-Power)
- Safety improvements and reduction of stagnation temperature (through laminated glass cover)

The following table summarises development targets versus actual achievements.

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[5] Further information on the improvements made in the HVFP technology under SunHorizon is included in the ‘D3.8 - REPORT ON UPDATED LT-POWER PANEL DESIGN AND RELATED BOS DESIGN OPTIMIZATION’ (Confidential document – available only to the consortium of SunHorizon)

Table 1: Resulting versus targeted specifications for LT-Power panels & BoS

Target	Result	Target declared	Relative Difference %	Reached up
LT-POWER panel				
Active absorption area (m^2)	1.84	1.84	0%	YES
LT-POWER panel weight (kg/m^2)	27	27	0%	YES
Cost of materials of the LT-POWER panel (€/m^2)	120	132	-10%	YES
Measurement in solar field operation of LT-POWER panels				
Average thermal efficiency	64.5% @ 87 °C	60% @ 90 °C	+7.5%	YES
Peak thermal efficiency	68.60%*	≥70%	-2%	YES[6]
Energy produced (kWh/m^2/day)	3.88@87 °C	3.60@90 °C	+ 7.7%	YES
Energy produced (kWh/m^2/year)	807 kWh/m^2/y[7]	> 550 kWh/m^2/y of heat with 1250 kWh/m^2/y of irradiation		
Improved safety standards in the case of implosion	Option for laminated glass cover	-	-	YES
Relevant BoS components	Rated at 100 °C	Rated at 100 °C	-	YES

* _Note_: The figure 68.60% refers to the average energy efficiency (not peak) measured on 17/06/2020. This means that in practice the peak performance well exceeded the 70% within this day.

3.3 Integration with the other SunHorizon technologies

TVP's solar thermal technology is integrated with the following SunHorizon technologies under three different combinations through Technology Packages:

- TP1: parallel integration with BoostHeat (BH) HP; TVP's HVFPs aim at space heating and Domestic Hot Water (DHW), while BH HP covers thermal needs at periods where solar irradiance and thus solar heat generation cannot match consumption. TP1 configuration also includes Ratiotherm's (RATIO) stratified thermal storage tank. The demonstration of TP1 is made in Berlin residential application (see diagrams below), Verviers' sports centre.
- TP3: solar-driven HP for cooling; HVFPs aim at space heating & DHW in winter. Also, the thermal compressor Fahrenheit's (FAHR) absorption chiller is activated by TVP's HVFPs. The demonstration of TP3 is made in Saint Cugat building (see diagrams below).
- TP5: mixed solar-driven/ parallel integration. HVFPs aim at space heating & DHW with BH HP to cover non-solar periods. FAHR absorption chiller is activated by BH HP or HVFPs. Only virtual demonstration (simulation) of this technology package is anticipated.

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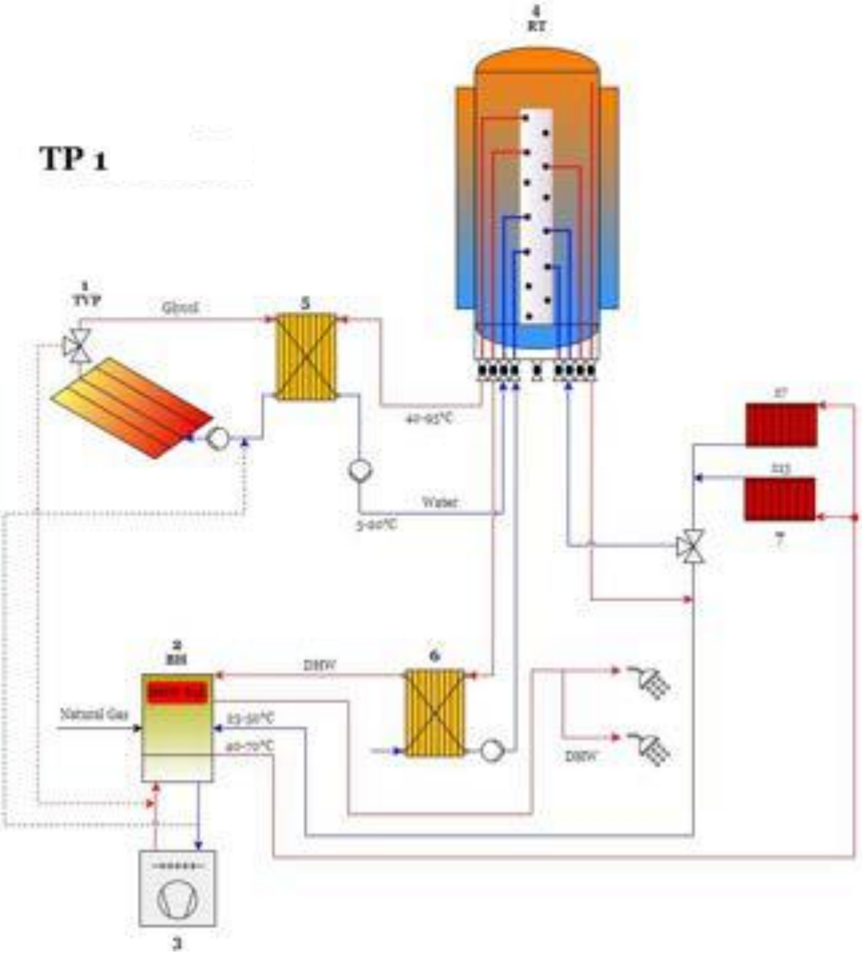
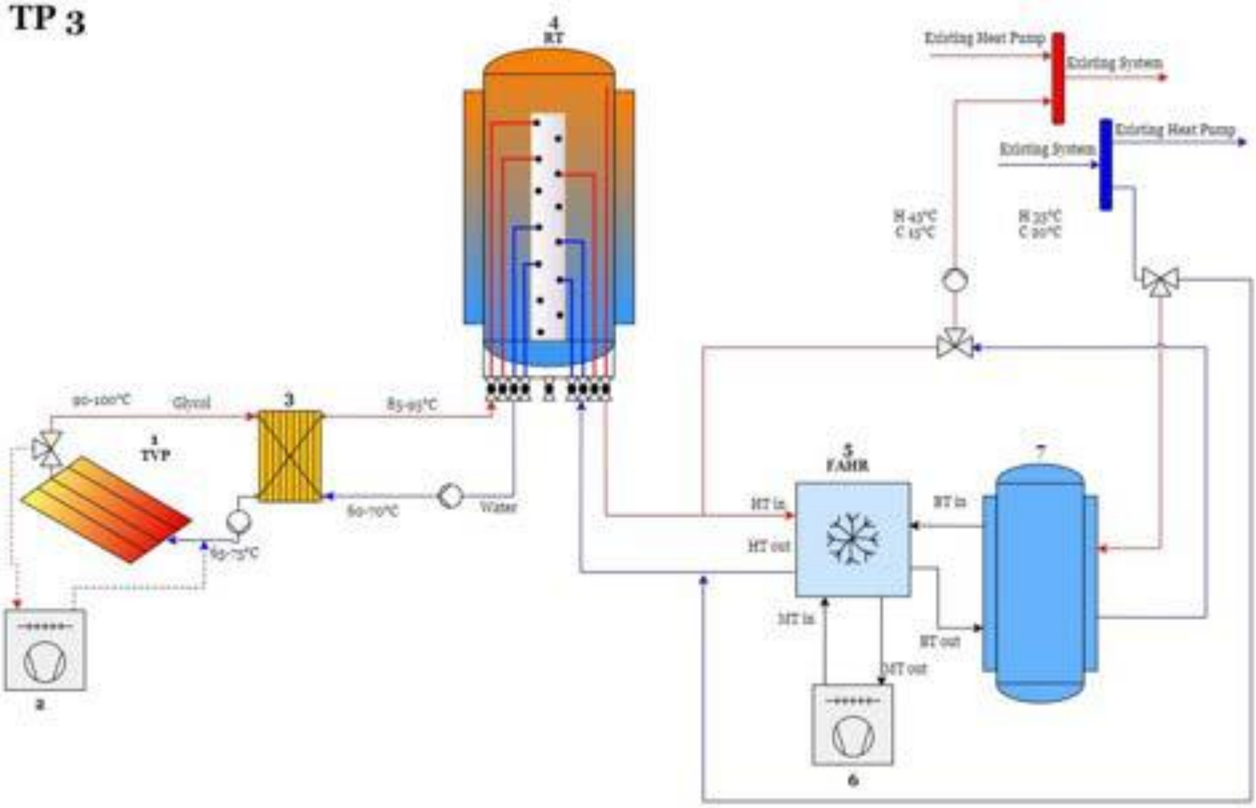
[6] Even if we consider that the average efficiency remained constant and thus is equivalent with the peak efficiency, the -2% difference is considered to be negligible in practical terms. What is matters most is the average efficiency of the real demo cases is critical and will be assessed as soon as the sites become operational.

[7] No actual measurement of this indicator exists because the operation of the test bench does not cover a full year. However, based on the measured data, the average thermal efficiency for the period covered (see Annex 4.1 of deliverable D3.8) is 64.5%. By assuming the same average efficiency throughout a year we can calculate the annual energy production based on the relevant annual irradiation (1250kWh/m^2/y in this case). That is: 64.5% x 1250kWh/m^2/y = 806kWh/m^2/y. In reality, the energy efficiency during the winter season is typically lower. Still, the overall energy production will remain well above 550kwh/m^2/y. This will also be assessed during the operation of the demo cases.

TP 1


4
RT
1
TVP
Glycol
5
40-95°C
Water
5-20°C
7
2
BH
DHW
6
Natural Gas
25-50°C
40-70°C
DHW
3

TP 3


4
RT
Existing Heat Pump
Existing System
Existing System
Existing Heat Pump
H 45°C
C 15°C
H 35°C
C 20°C
90-100°C
Glycol
3
85-95°C
1
TVP
60-70°C
Water
65-75°C
2
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FAHR
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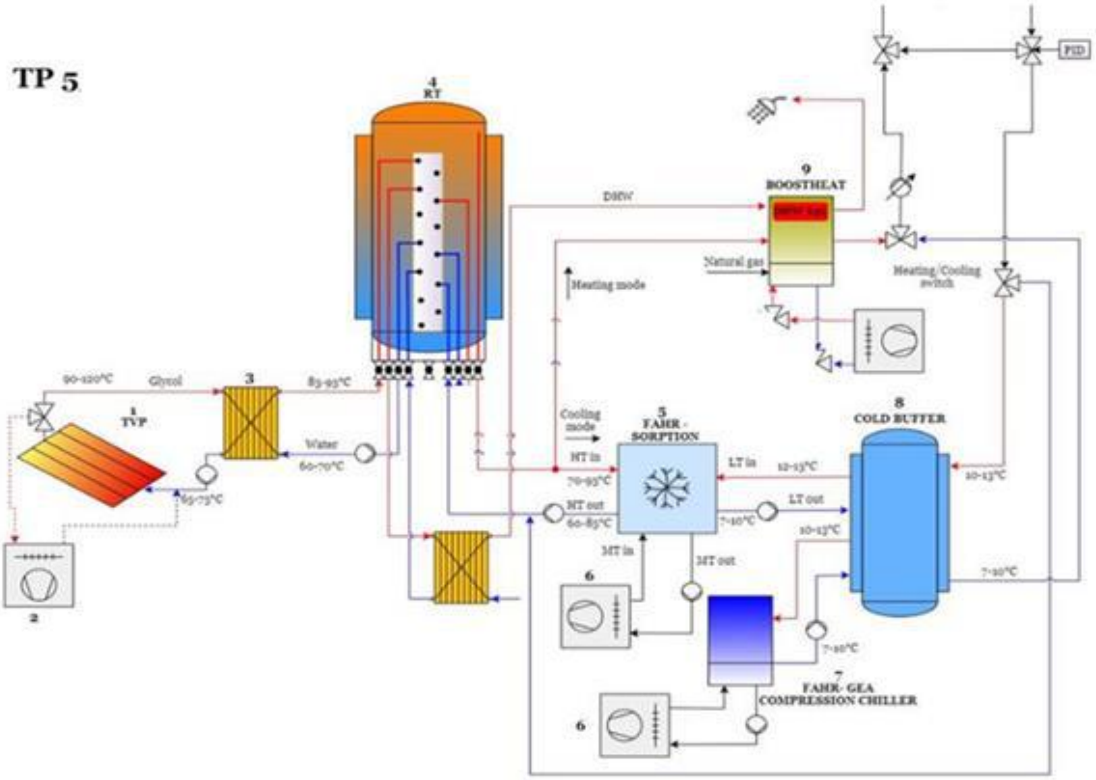
HT in
HT out
BT in
BT out
MT in
MT out
6



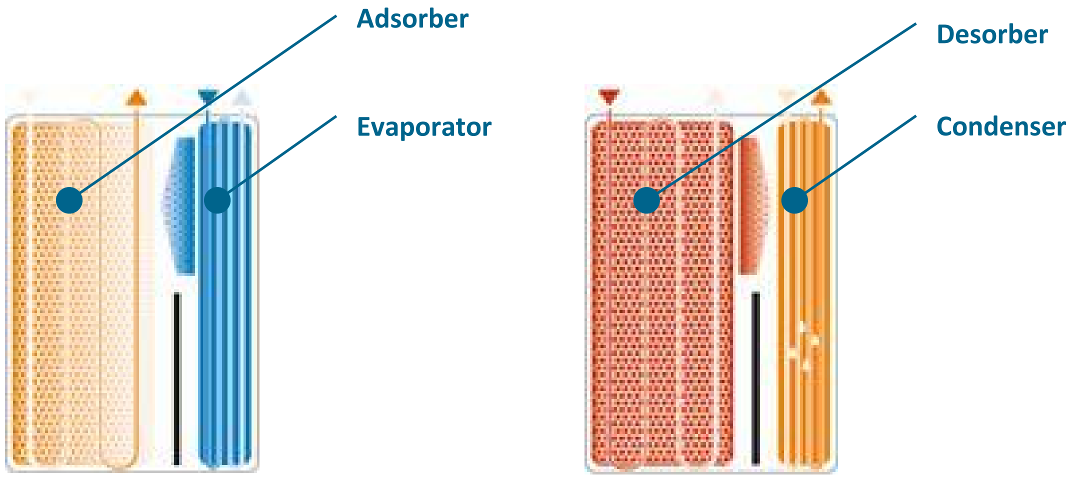
As shown in TP1, TP3 & TP5 diagrams, in all three cases the solar thermal system is integrated with the HP(s) through the stratified thermal storage tank by Ratiotherm.

4 Fahrenheit – adsorption chillers

4.1 Description of technology

The adsorption chillers from Fahrenheit utilize waste heat, for example from solar plants, combined heat and power plants (CHP), district or process heat, in order to generate cold in an environmentally friendly and cost-effective way. This is also possible in the small capacity range. There are no moving parts in the process modules, since neither steam flaps nor the circulation of process water is required due to the patented dual-chamber principle. Moreover, operation at low drive temperatures is possible

The Fahrenheit adsorption chillers are characterized by the patented dual-chamber process modules without moving parts. A process module is a vacuum-tight, welded chamber made of stainless steel. Inside the process module there are two heat exchangers which are called evaporator and adsorber or condenser and desorber depending on the operating phase. Furthermore, a precisely defined quantity of process water is contained in a process module, which carries out the heat transfer between the two heat exchangers by evaporating and condensing repeatedly. Each process module is thermally insulated.



Operation Status:
Adsorption (cooling)

Operation Status
Desorption (thermal compression)

Figure 4: Adsorption module functions (adsorption & desorption)

Heat is extracted from the space or process to be cooled by means of a heat exchanger through which chilled water flows. This cools the space or process and simultaneously heats the chilled water. Via the hydraulic group of the adsorption unit, the heated chilled water reaches the evaporator of the adsorbing process module, where it is cooled down again and can thus be fed back into the cooling circuit.

The process module contains an adsorber and an evaporator with water (R718) as the refrigerant on its surface. Due to the low pressure in the process module, the refrigerant evaporates at temperatures as low as 6 °C. Evaporation heat is supplied from outside during evaporation. This heat transfers part of the refrigerant into the vapour phase. The heat extracted from the warm chilled water and the liquid refrigerant during evaporation is now contained in the refrigerant vapour. Due to the physical characteristics of adsorption, the refrigerant vapour flows in the direction of the adsorber.

The surface of the adsorber is coated with an adsorbent (strong hygroscopic substance, e.g. silica gel or zeolite). The refrigerant vapour accumulates on this adsorbent (Figure 5), whereby the heat is released exothermically. In order to dissipate this heat, a re-cooling water circuit flow through the adsorber. The re-cooling water heats up and dissipates the heat from the adsorption unit to the environment via a re-cooler.

If the adsorbent is saturated with refrigerant vapour, the water molecules must be dissolved or expelled from the adsorbent so that adsorption can start again. The controller switches over the circuits of the integrated hydraulic group so that the hot water of the drive circuit flows through the adsorber and thus becomes the desorber. At the same time, the evaporator becomes a condenser, as water from the re-cooling circuit now flows through it.

The hot water is cooled by the heat input via the drive circuit into the desorber. The dissipated heat is added to the drive circuit outside the adsorption unit by a heat source. The bound water molecules on the adsorbent are dissolved via the desorber (Figure 6). The superheated refrigerant vapour flows to the condenser. The cooler surface of the condenser withdraws heat from the refrigerant vapour, causing it to condense and precipitate on the surface. The heat released during condensation is transferred to the re-cooling water and dissipated to the environment via an external re-cooler. The condensed and cooled refrigerant is available for the next adsorption process.

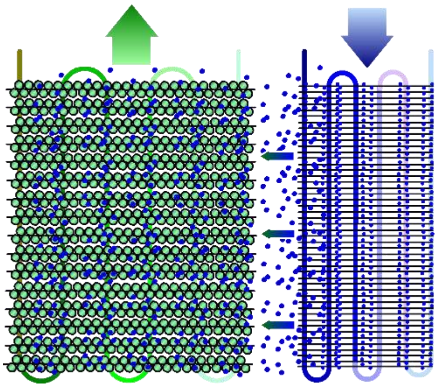


Figure 5 Operating principle of Adsorption

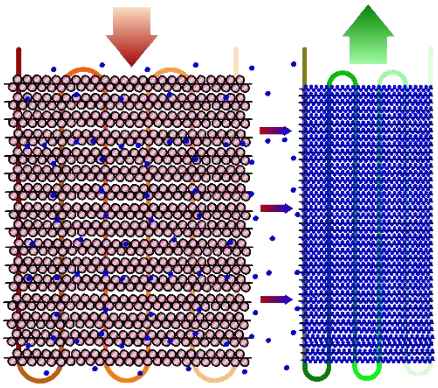


Figure 6 Operating principle of Desorption

In order to continuously extract heat from the chilled water circuit and maintain continuous cooling, two process modules are operated cyclically. While an adsorber absorbs refrigerant vapour from the evaporator (adsorption), the desorber releases refrigerant vapour to the condenser (desorption). This cyclic process causes the periodic temperature fluctuations typical for adsorption chillers, which can be smoothed out by buffer storage. The valve switching of the hydraulic group is controlled by adjustable parameters. In addition, the controller can influence the volume flows of the three circuits.

The two process modules with the heat exchangers and the adsorption, desorption, evaporation and condensation processes are referred to as thermal compressors.

The temperatures, flow rates and working mediums of the three circuits have a direct effect on the cooling capacity and the thermal COP. The desorption process is influenced by the drive circuit, the adsorption and condensation process by the re-cooling circuit and the evaporation process by the chilled water circuit.

For the proper use of adsorption heat pumps the following operating limits apply:

Table 2. Operating limits.

Description	Limits
Maximal operating pressure	4 bar
Drive temperature (HT)	55 … 95°C
Re-cooling temperature (MT)	< 45°C
Chilled water temperature (LT)	> 8°C
Surrounding temperature	> 5°C

As mentioned before, the adsorption chiller is integrated into its environment via three hydraulic circuits, as presented in Figure 7

- Hot water (HT),
- Cold water (LT, and
- Re-cooling (MT) circuit.

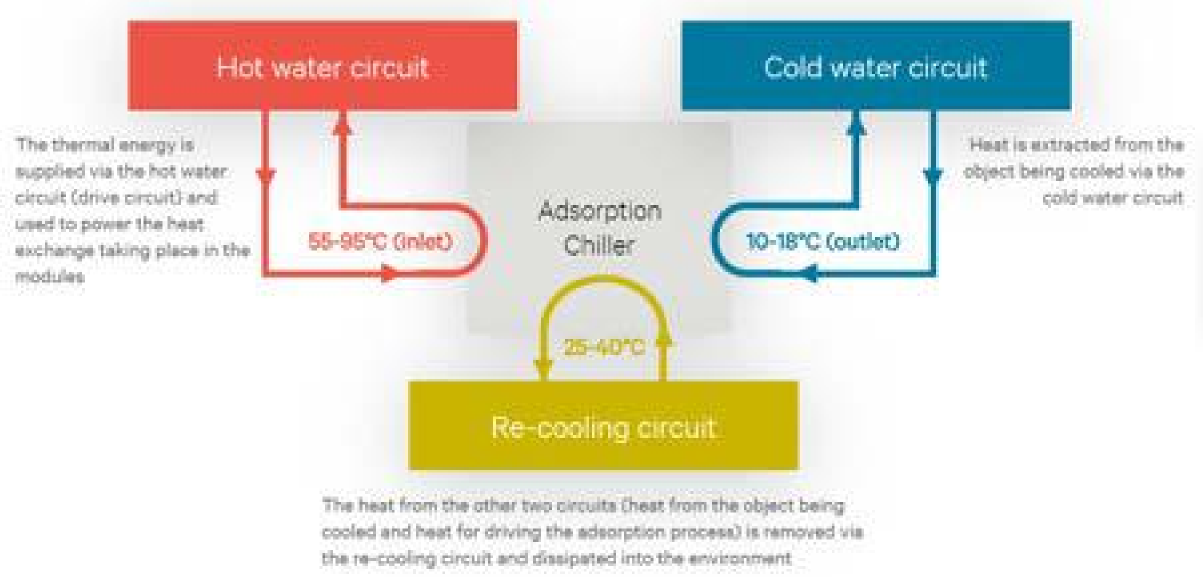


Figure 7 Energy flow during the operation of the adsorption heat pump.

As can be seen in Figure 8, the energy from hot water and cold water circuits is supplied to (flows towards) the adsorption heat pump at the high and low temperature level, respectively. This absorbed energy is dissipated to the environment at medium temperature level in the re-cooling circuit.

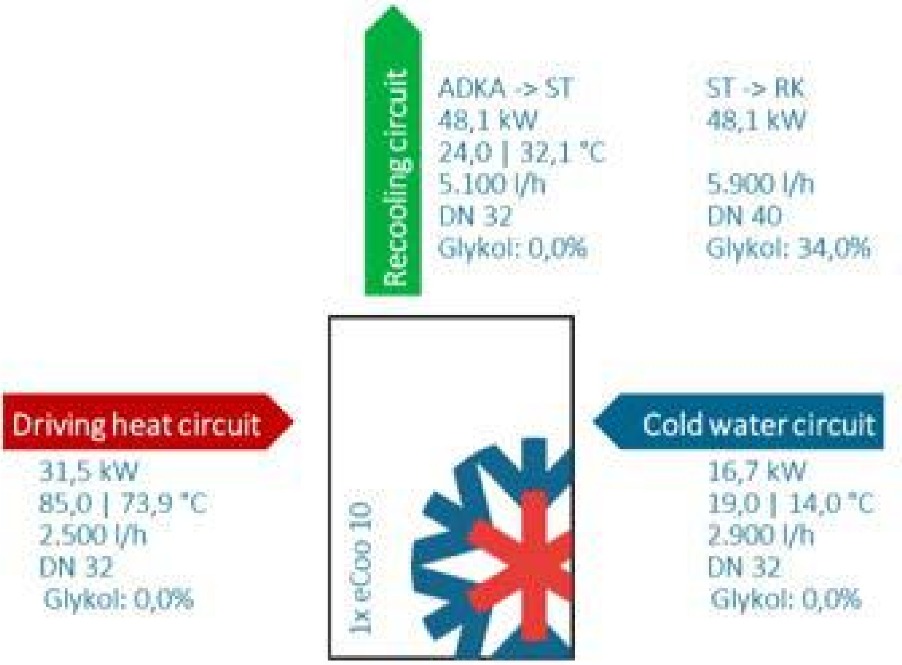


Figure 8 Example of the heat transfers within the adsorption chiller at one operating point.

The performance of the adsorption chillers depends strongly on the operating temperatures in the three circuits. Generally, in terms of cooling capacity, it is better to drive the adsorption chiller with highest possible temperature levels in hot water and cold water circuits and with lowest possible temperature levels in re-cooling circuit (of course in all cases within the operating limits).

The operating conditions for a silica gel chiller are:

- HT inlet 55-90°C,
- MT inlet 22-35°C,
- LT outlet 10-21°C.

And for a zeolite chiller are:

- HT inlet 75-95°C,
- MT inlet 22-45°C,
- LT outlet 7-21°C.

Since the adsorption chiller has no mechanical compressor like the electrical chillers, there are two parameters, which can be used to evaluate its performance. One of them is the thermal COP, which indicates how many kW of cooling energy can be generated from 1 kW of driving heat. The silica gel adsorption chiller of Fahrenheit can achieve a thermal COP of up to 0.65, and the zeolite adsorption chiller up to 0.6. The thermal COP is calculated as follows:

$$COP_{th} = \frac{Q_{LT}}{Q_{HT}}$$

The second parameter that helps to evaluate the performance of an adsorption chiller, is the EER, which is the ratio of the cooling capacity and the consumed electrical power. The main consumer of the electrical power in the adsorption chiller are the circulation pumps. Further calculations of performance could also take into account the total system, with all the auxiliary elements included, especially the dry cooler that dissipates the re-cooling heat.

$$EER_{AHP} = \frac{Q_{LT}}{W_{AHP}}$$

$$EER_{aux} = \frac{Q_{LT}}{W_{AHP} + W_{DC}}$$

Where W_{AHP} is the electrical consumption of the circulation pumps and controller of the adsorption chiller and W_{DC} is the electrical consumption of the dry cooler's fans.

The selection of the adsorbent and the refrigerant to be adsorbed (so called working pair) is crucial to the cooling capacity and the efficiency of the system. There are a lot of requirements that both the adsorbent and the refrigerant have to meet, as presented in Table 3.

Table 3: desirable features of adsorbent and refrigerant materials

The desirable features of:	
The adsorbent	**The refrigerant**
• Large adsorption capacity and large change of adsorption capacity within the temperature conditions of the application, • Efficient desorption of most refrigerant when exposed to thermal energy, • High thermal conductivity, • No deterioration with age or use, • Non-toxic, • Non-corrosive, • Low cost, • Wide availability.	• Large latent heat of vaporization per unit of volume, • Low specific volume, • Evaporation temperature below 0°C, • Saturation pressure slightly above atmospheric at normal operating temperature, • Thermally stable with the adsorbent at the cycle operating temperature ranges, • Environmentally harmless, • Non-toxic, • Non-corrosive, • Nonflammable, • Low cost, • Wide availability.

There are many possible working pairs, and actually, none of them completely satisfies the aforementioned requirements. However, there are a lot of refrigerants and adsorbents that are good enough to be commonly used in the adsorption refrigeration systems. The R&D efforts of Fahrenheit focus on the two most promising ones: zeolite-water and silica gel-water. Water is not only one of the most thermally stable adsorbates, it also has very high latent heat of vaporization. Moreover, water is non-toxic, non-flammable, widely available and relatively cheap. The most popular working pair recently is silica gel-water, because it belongs to the class of low temperature working pairs, which can be driven by low-grade waste heat. On the other hand, the zeolite-water pair has a great advantage of showing very good performance even at high re-cooling temperatures (which correspond to high outdoor temperatures typical for warm climates).

There are many similarities between silica gel and zeolite. Both materials are very good adsorbents with large adsorption capacities (water uptakes). They are also stable, non-corrosive, non-toxic and non-flammable. The differences are mainly in the operating temperatures and the coating process, which influences the heat transfer ratio.

The considered zeolite material SAPO-34 is characterized by high water uptake even at high re-cooling temperatures. Hence, the zeolite machines will show good performance for the re-cooling temperatures in the range of 20-45°C, whereas the range for silica gel is 20-35°C. This means that zeolite is a better solution for warm climates. The drawback of the zeolite SAPO-34 when compared to silica gel is that the temperature level of the driving heat should be above 75°C, and the best results are achieved with the temperatures in range of 85–95°C. This makes silica gel more suitable solution for the low-grade waste heat

The second difference between zeolite and silica gel that strongly influences the performance of an adsorber bed is the coating process. In Fahrenheit adsorbers, silica gel is glued on the surface of the heat exchanger therefore a significant heat resistance between the adsorbent granules and the heat exchanger surface is present. Additionally, the thermal conductivity of silica gel is very poor, near to that of the insulating materials. Zeolite, on the other hand, is applied to the heat exchangers in a process called PST – Partial Support Transformation as schematically shown in Figure 9. This process, via sophisticated chemistry, makes zeolite crystals grow directly out of the surface of the heat exchangers. This alleviates the need for any kind of coating or glue and optimizes heat conductivity. Because zeolite can reach even the smallest cavities of porous or fibrous material, the surface-to volume ratio and therefore power density can be maximized. Without adhesives or glue in between the crystal and the heat exchanger, heat conductivity is maximized.

Figure 9: Illustration of the Partial Support Transformation process

Adsorption chillers based on silica gel are well-known and have proven their performance in many installations is moderate and cool climates. Their big advantage is reliability and that they are suitable even for the low-grade heat sources. Zeolite adsorption modules are one of the most recent innovations in material science and design which allows a significant reduction in size of the adsorption modules, for a given cooling power. Zeolite coatings are also more suited for the applications in warm climates.

Fahrenheit also introduced the hybrid chiller that combines the energy efficiency of adsorption technology with the precision and power of compression cooling. The advantages include the ability to cover peak demands without investing in excess adsorption capacity, or to deal with fluctuations in available drive heat. The integrated controller adjusts the operating parameters of the entire system under any combination of temperatures and loads.

The hybrid chiller brings to bear the advantages of both technologies. This enables new applications, and new levels of efficiency: The efficiency is demonstrated by an ESEER value of 19.6.

Silica gel is used as an adsorbent in the current models. The available models have a total cooling capacity ranging between 45 to 90 kW. Within the scope of SunHorizon a hybrid chiller which contains zeolite as an adsorbent in the adsorption part of the hybrid chiller and propane as a refrigerant in the compression part.

4.2 Innovation introduced in SunHorizon project

Sorption part:

- Adsorber heat exchangers: New vacuum brazed heat exchangers are used with a considerably larger surface area (60 m^2 compared to 40 m^2 of the old model). The new heat exchangers have a more uniform coating and proved to be significantly more stable during the stability test. The new design of the heat exchangers offers the possibility to use various forms of turbulators in the channels, and, as a result, better heat transfer rates.
- Evaporator/Condenser heat exchangers: In the new design, finned pipes made of copper are used. The finned pipe is a standard copper pipe with thin copper fins on its external surface. A zoomed photography of the finned pipe is presented in Figure 10. The heat exchanger consists of several finned pipes brazed with two collector pipes on both sides. Contrary to the previously used heat exchanger (fin and tube), the finned pipe heat exchanger is arranged horizontally in the process module so the pipe is partially immersed in the liquid refrigerant, and the heat exchanger operates as flooded evaporator. This type of evaporation process is uniform and is characterized by high heat transfer rates. An additional advantage of finned pipe type of heat exchanger is that with similar capacity its thermal mass is about 5 times smaller than the one of fin and tube heat exchangers used in the previous design.

Figure 10 Finned pipes

- Process modules: In the previous design, each of the two process modules contains two adsorber heat exchangers and one evaporator/condenser heat exchanger in the middle (the so-called ”sandwich” module). The heat exchangers are arranged vertically with the connection pipes at the top of the process module. Due to the high vapour velocities and cold spots inside the module, such vertical arrangement can lead to ”false condensation”. This phenomenon occurs when during the desorption phase, the refrigerant vapour condenses on the module walls instead on the heat exchanger surface. Subsequently, during the adsorption phase, this part of the condensate evaporates, but does not contribute to the cooling capacity. With the use of finned pipe heat exchanger as evaporator/condenser, the process modules in the latest prototypes are arranged horizontally, with the adsorber heat exchanger located on the top. Such layout eliminates the “false condensation” completely, since the condensate flows always to the bottom of the process module.

Compression Part:

- Refrigerant: The up to now used refrigerant in the compression part of the hybrid chiller is R134a. This has been replaced by the natural refrigerant R290 which has a global warming potential of 3 instead of 1430 for R134a. Therefore, the parts of the compression unit had to be redesigned. A new evaporator and condenser had to be calculated and chosen. To reach sufficient cooling efficiencies as mentioned in the EU regulation for eco design the unit has to be equipped with an internal heat exchanger. This heat exchanger was calculated and chosen. Furthermore, will the system be equipped with a frequency inverter for higher efficiencies at part load conditions. In conclusion the overall system was assembled and optimized for the use with R290.

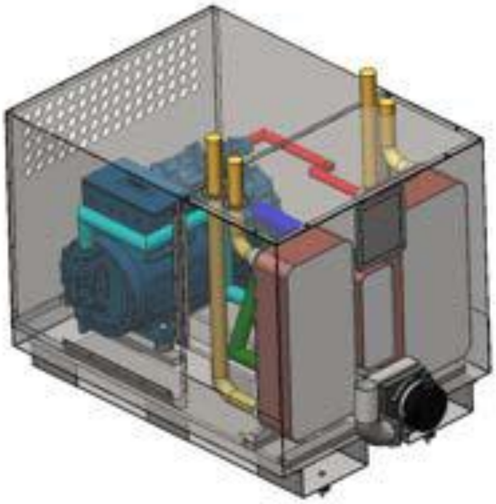


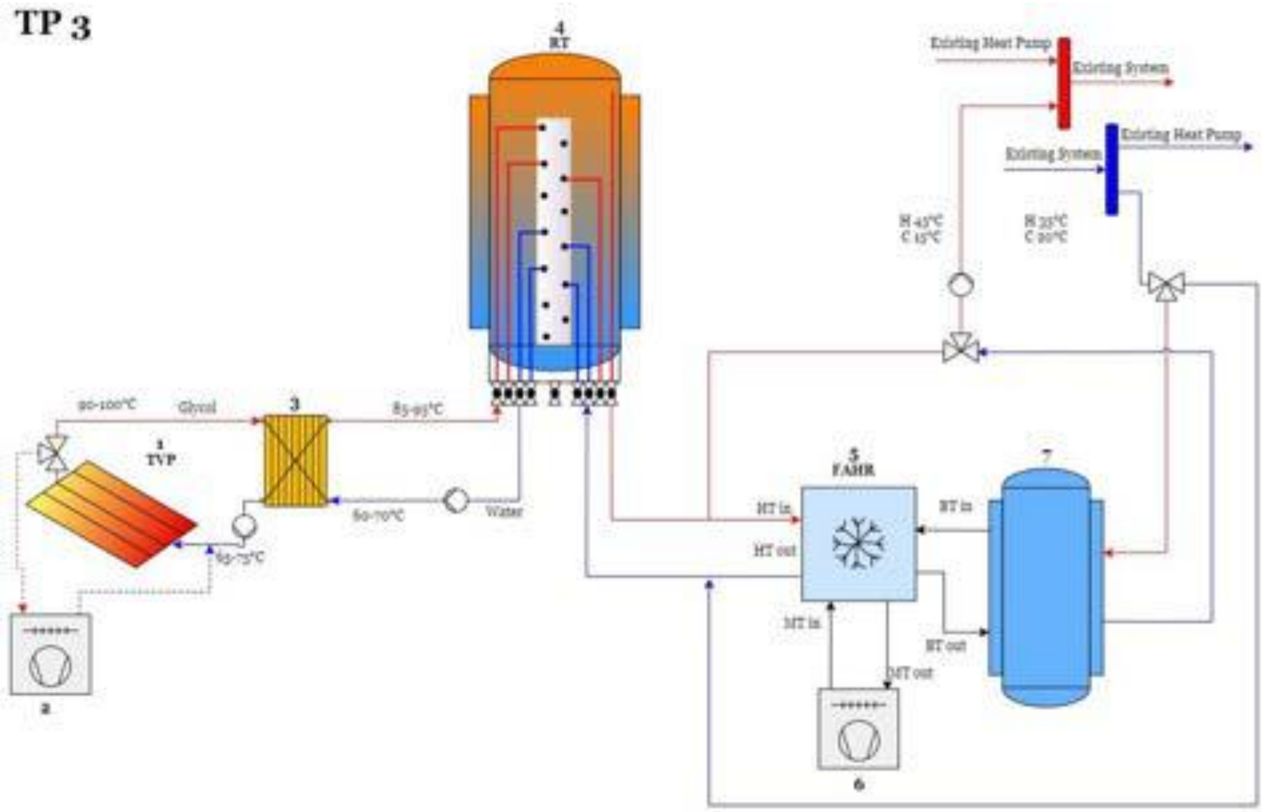
Figure 11: Design of the compression part

Risk minimization: As R290 is highly explosive special attention has been paid to the prevention of explosive hazards and the risk identification and minimization of the compression part. A housing for the compression part was designed in which the concentration of Propane can be measured and all refrigerant containing parts are located within this ventilated housing. In case of any leakage within the refrigerating system the escaping refrigerant is detected and actively ventilated to the outside. Therefore, the risk can be minimized so far, that no explosive hazardous zones need to be classified.

4.3 Integration with the other SunHorizon technologies

Fahrenheit adsorption/hybrid cooling technology is part of 2 technology packages within the scope of SunHorizon:

- TP3: solar-driven HP for cooling; Fahrenheit hybrid chiller is driven by solar thermal collectors from TVP, which are also used for heating in winter. The demonstration of TP3 is made in Saint Cugat building (see diagrams below).
- TP5: mixed solar-driven/ parallel integration. Fahrenheit adsorption chiller is driven by waste heat from TVP collectors and BH HP. Only virtual demonstration (simulation) of this technology package is anticipated.



5 Boostheat – thermal compression heat pumps

5.1 Description of technology

BOOSTHEAT is launching a new generation of CO_2 gas heat pump based on an innovative thermal compression technology.

The results are a high energy efficiency and a renewable energy production that reduces energy bills and CO_2 emissions for heating, hot water and air-conditioning applications in residential, public and commercial buildings.

The technology also benefits from using CO_2 as natural refrigerant with the lowest global warming potential.

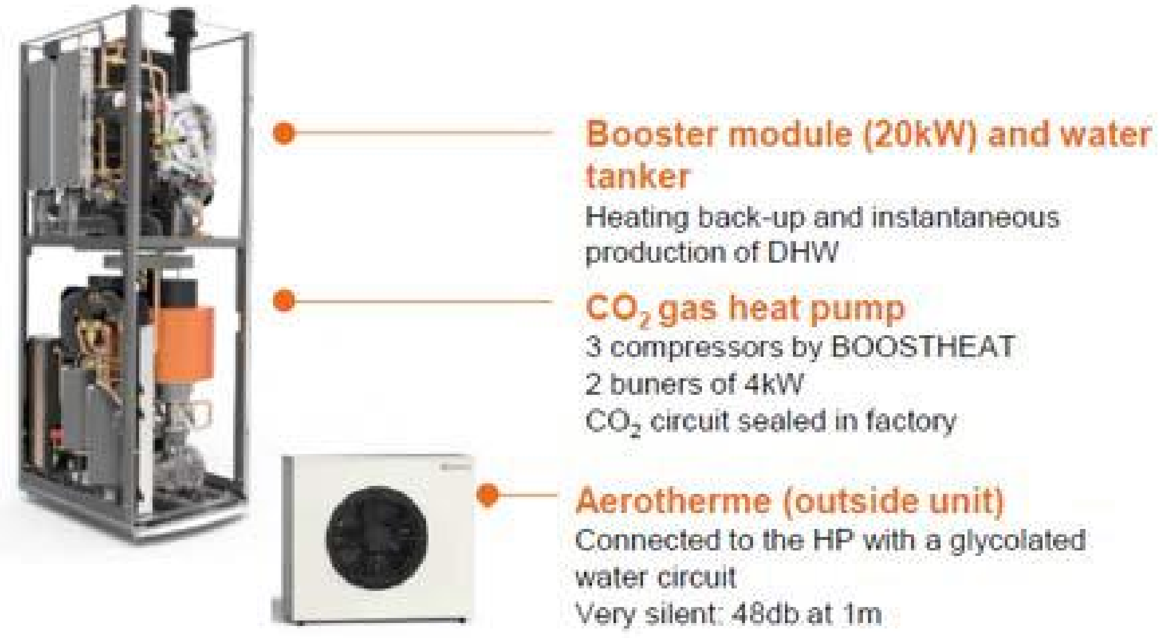


Figure 12: components of the Boostheat unit

The BOOSTHEAT.20 uses a new type of thermal compressor. The thermally driven heat pump circuit brings heat from the outside air into the house. The thermocompressor works without oil, low wear and it is extremely quiet. It therefore has a very long service life and an exceptional efficiency.

The Innovation behind BOOSTHEAT

After 6 years of R&D, supported by renowned laboratories (*ENGIE Crigen, LaTep,* and *Mines ParisTech*), BOOSTHEAT has created a leading-edge thermal compressor (in Figure 13) to surpass the limitations and drawbacks of traditional boilers, heat pumps, Stirling engines or absorption systems for compressing a gas from a heat source.

BOOSTHEAT's key innovation is the development of a novel thermal compressor designed as a four-stage compression system. With our patented compressor, efficiency increases allowing the highest yields in all existing market products, up to 200% GUE (see Figure 14: 60+25+(25-2)-1+100), low noise (<40dB), and high reliability (can operate 50,000h without any oil or maintenance) using environmentally friendly refrigerants (CO2).

Figure 13: Thermal compressor

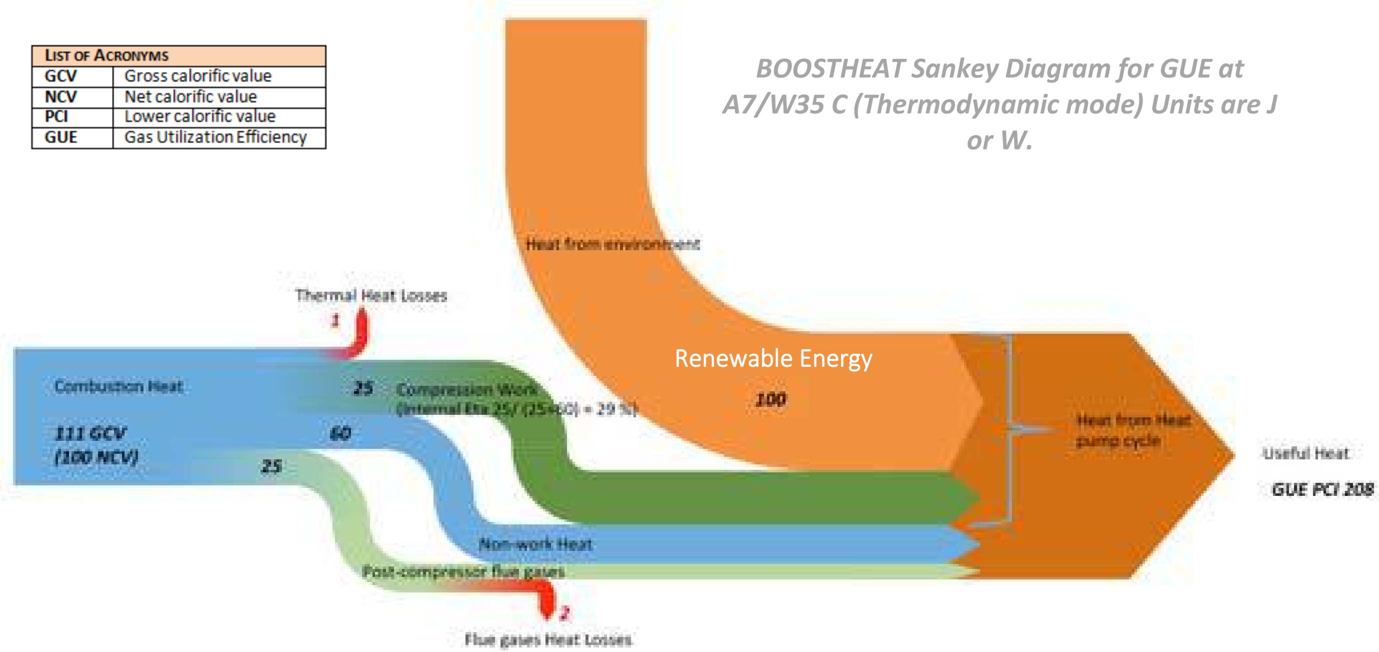
The use of this refrigerant is directly in line with the future of heat pumps due to the lowest global warming potential cooler on the market (thousands of time less harmful to the climate than HFC) and zero ozone-depleting potential. This is also in line with the objectives of Europe which ratified in September 2018 the Kigali Amendment[8] to the Montreal Protocol, which will bring about a global phasedown of hydrofluorocarbons (HFCs) - powerful greenhouse gases.

This novel four stage compression system uses the natural gas to activate a thermal compression cycle at a high temperature without mechanical power transmission rather than directly power the heaters. As Figure 14 shows, the thermal compressor powers a heat pump cycle at 700 °C, drastically increasing the efficiency of the heat pump cycle. This is easily explained by the principle of the Carnot cycle (a fundament principle of thermodynamics): higher temperature difference translates into increased efficiency.

The thermodynamic cycle takes place in 4 steps (illustrated in Figure 15): 1) **compression**, 2) **discharge**, 3) **expansion**, and 4) **intake**. Unlike a volume compressor where power is transmitted by mechanical, our thermal compressor does not have a working piston but a displacer piston. The innovative **thermal compressor** uses directly the heat of a burner for the direct and of very high efficiency compression of CO_2 (R-744) working at pressure levels between 40 and 100 bars, higher than with HFC refrigerants (ozone depleting substances).

By using this thermodynamic cycle, BOOSTHEAT maximises, 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.

Its hermetic design, fully sealed refrigeration circuit, and absence of mechanical power transmission ensure absolute reliability of the system with very little wear and standard maintenance (cleaning burners at a maximum once per year, depending national regulations).



LIST OF ACRONYMS	
GCV	Gross calorific value
NCV	Net calorific value
PCI	Lower calorific value
GUE	Gas Utilization Efficiency

Figure 14: Sankey Diagram for GUE: burner efficiency (blue), compression work efficiency (green), heat pump cycle efficiency (orange)

OPTIMIZATION

Gas combustion activates the thermal compression to power a heap pump cycle.

ADVANTAGES

PERFORMANCE
Engine and compressor in one product

RELIABILITY
No oil,
Very low wear,
No maintenance

ENV. IMPACT
Natural coolant
R744 (CO_2)
GWP = 1

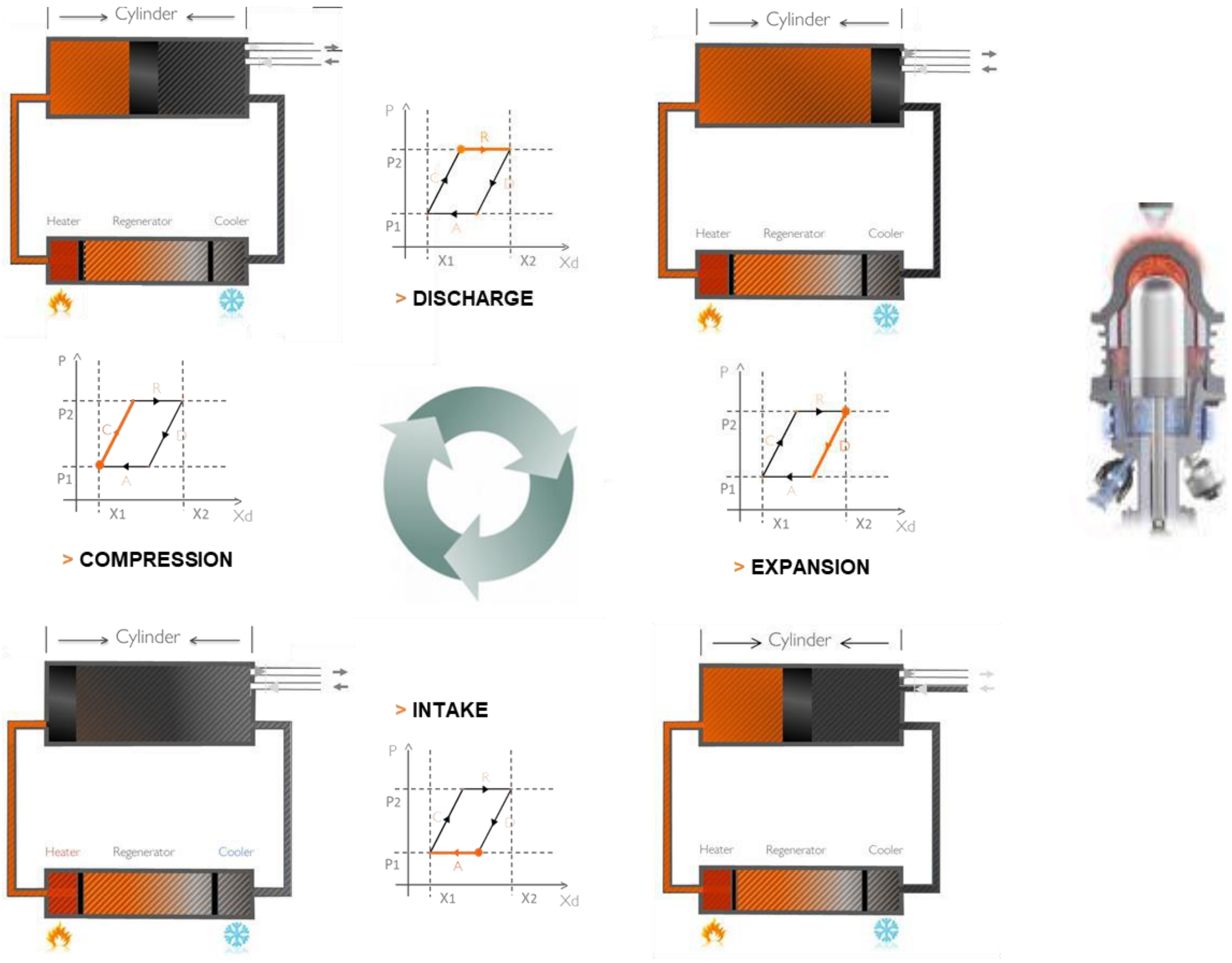


Figure 15: diagram showing the different stages in the BOOSTHEAT compressor cycle

Since the first version of the BH Origin, Boostheat has continuously improved the machine (new software, new touch screen, new Evohome thermostat) to create the current BH Connect version.

BH.20 Connect: Technical data

Figure 16: BH.20 Connect

Thermal power: **4 – 20 kW**
Energy efficiency class (Heating): **A++**
Combustible: **Natural gas or liquid gas**
Refrigerant: **R744 (CO2)**
Outdoor unit: **Bind with water/glycol**
Seasonal gas utilization efficiency according to DIN 4650-2:2013: **35/28°C: 195% - 55/45°C: 165%**
Gas utilization efficiency (GUE): **W10/W35: 229%**
Hot water: **Integrated 65 litre stainless steel hot water tank**
Indoor unit dimensions: 187 x 60 x 89 cm (H x W x D)
Outdoor unit dimensions: 101 x 113 x 62 cm (H x W x D)
Sound level: **33 dB(A) at 3 metres distance**
Convector's compatibility: **Heating surfaces with up to 70°C flow temperature**
Connectivity: **Remote data monitoring**
Installation: **possible without cold certificate**
Area of application: **One- and two-family house**
Production: **France**
Certifications: **according to European standards**
Funding: **KfW, BAFA, municipal utilities**

5.2 Innovation introduced in SunHorizon project

During the transition from the BH Origin to the BH Connect, **the user interface (HMI)** was redesigned to allow, among other things, easier management with solar integration.

Figure 17: new user interface of the BH Connect

New user interface for more efficiency and less energy consumption.
With its new user interface, the BOOSTHEAT.20 Connect 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.

Furthermore, the integration of the thermostat **Evohome (Honeywell)** allows for simpler regulation and lower energy costs.

Figure 18: Evohome Thermostat

More connectivity for more flexibility.
The evohome © thermostat facilitates individual adjustment and full access to the heating control.
With the central control unit, the user can configure needs-based heating profiles.
Thanks to the freely available evohome app for mobile devices, the system can be also easily manged remotely.

5.3 Integration with the other SunHorizon technologies

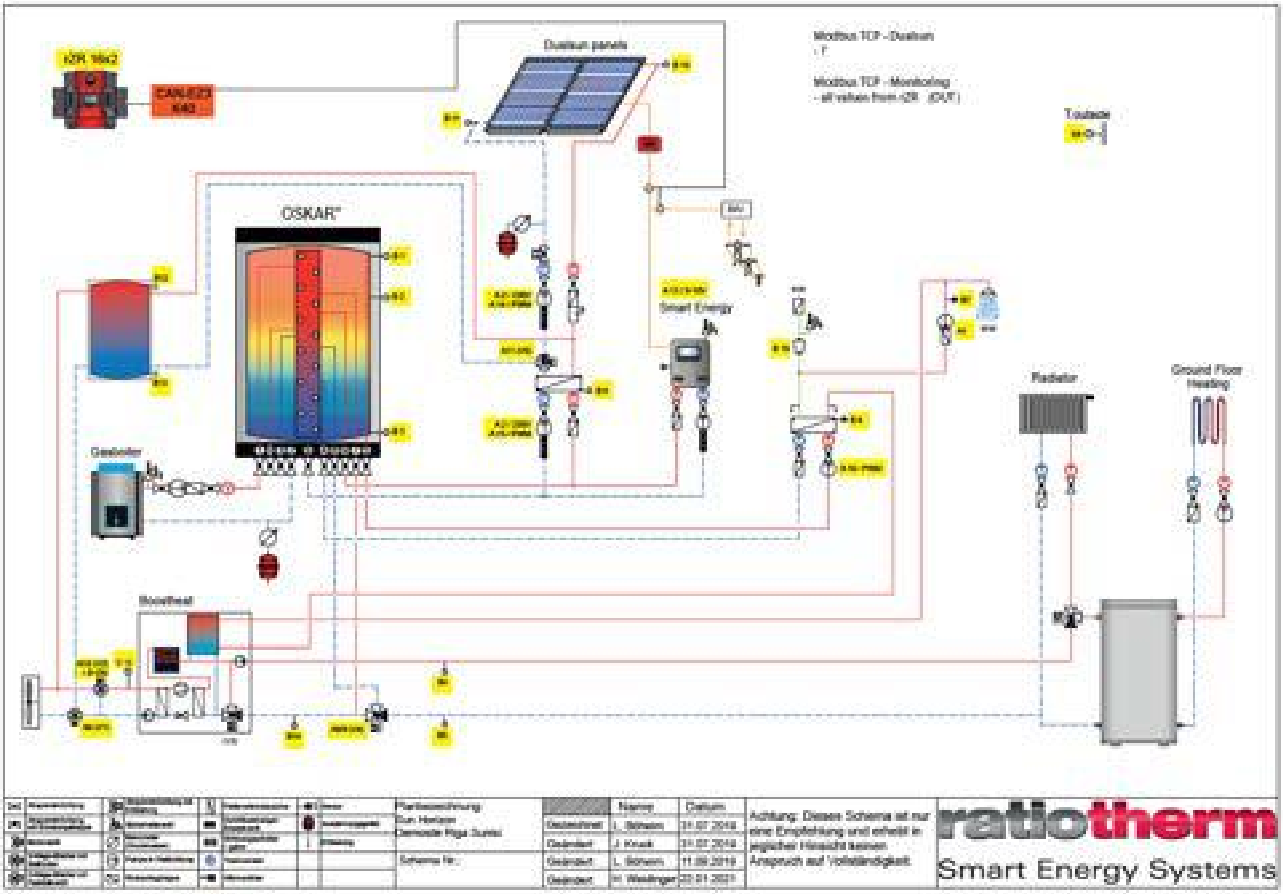
<u>TP2:</u> (mixed solar assisted / parallel integration).

BH for space heating + DHW support; DS PV-T thermal output to cover as much heat demand as possible + excess electricity production for appliances.

In TP2, the external heat input is made either by the glycol storage tank (heating energy from solar panels), or by the fan of the Boostheat (heating energy from outside air). The v1 valve allows switching either to one or the other (It is controlled by the regulation).

On the DHW loop, the fresh water is preheated via an exchanger integrated on the solar panel circuit, before reaching the Boostheat circuit for DHW.

Regarding the heating circuit, the V4 valve allows preheating of the heating returns via the Ratiotherm water tank, before returning to the Boostheat heating circuit.



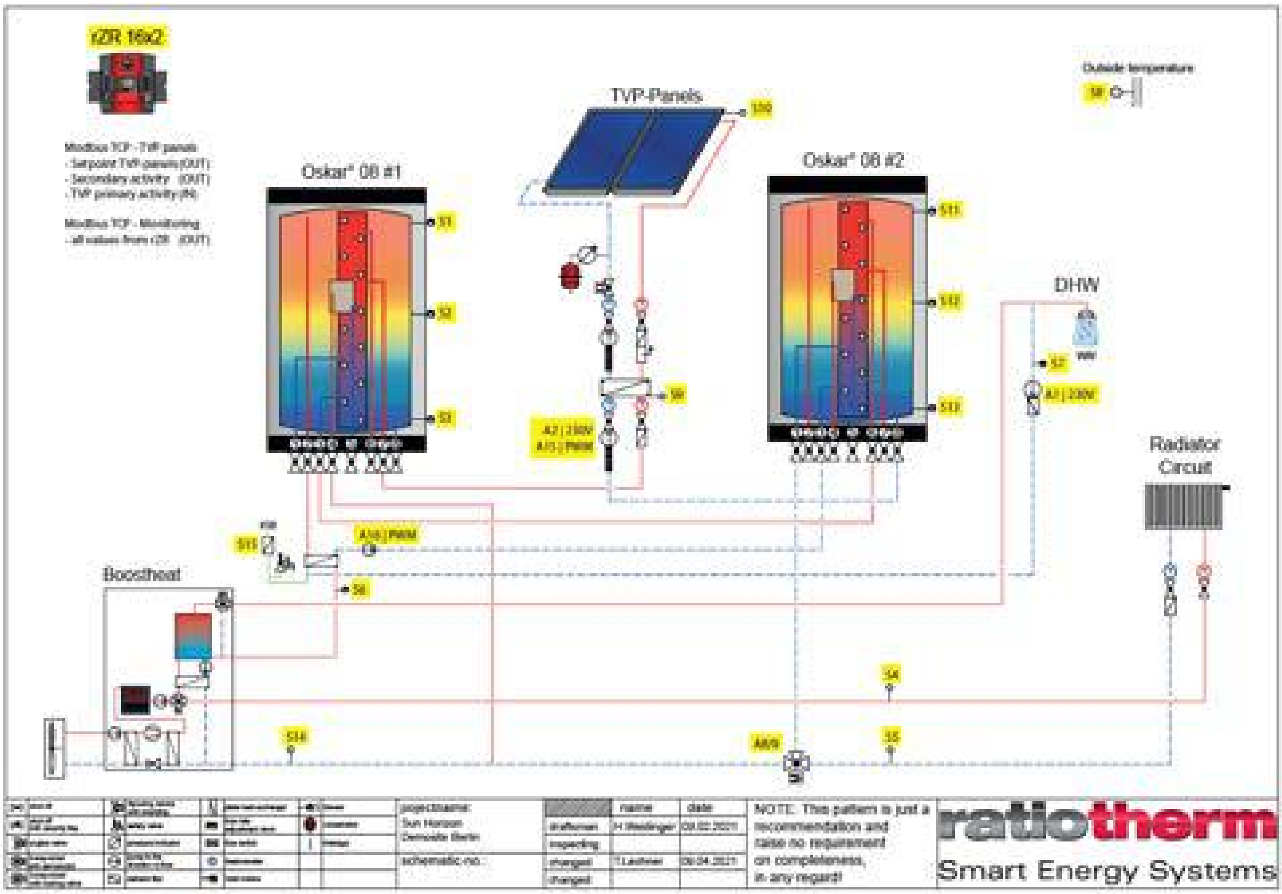
<u>TP1:</u> (parallel integration).

Solar panels for space heating + DHW; BH to cover non-solar periods.

In TP1, the external energy is supplied exclusively by the fan of the Boostheat via the ambient air.

DHW: The fresh water is preheated by means of a heat exchanger connected to the Ratiotherm hot tank. External energy is supplied via solar panels.

For the heating circuit, the heating returns can be preheated via the Ratiotherm tanks before returning to the Boostheat.



6 Dualsun – hybrid PV-T panels

6.1 Description of technology

Zero emission electricity and heat for building

Photovoltaic (PV) energy is growing exponentially worldwide. The fact that the price of PV is becoming more competitive than traditional energy prices has made it a key solution for covering electricity needs. But alone, PV is it not enough to meet the energy needs of our buildings. In addition to electricity, buildings require heat: for space heating and also for hot water needs.

Heating is a major challenge for the 21st century.

The capacity to provide solutions that produce both electricity and hot water to render our buildings energy-positive, all while being aware that rooftop space is not infinite drives the market towards new solar technology like PVT.

Solar electricity and heat in a unique panel

PVT solar is an advanced hybrid solar technology that produces simultaneously electricity (photovoltaic) and hot water (solar thermal). These collectors combine photovoltaic cells that convert solar radiation into electricity with a solar thermal collector that exploits the waste heat from the PV module by transferring it to a heat transfer fluid.

A standard photovoltaic panel only generates 20% of electricity during operation; the remaining 80% is mostly heat. Hybrid PVT solar allows a real synergy between photovoltaic and thermal, it produces up to 3 times more energy than a traditional photovoltaic panel.

Figure 19: PVT concept illustration

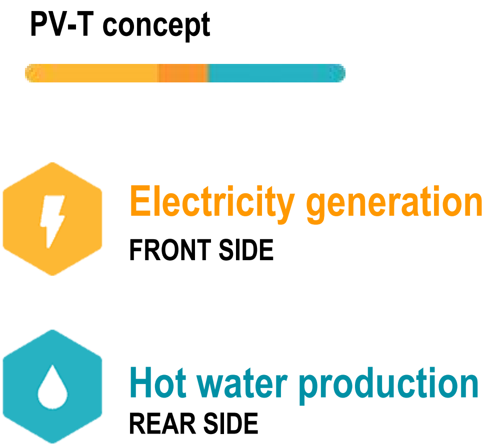


Figure 20: PVT concept illustration

All building energy needs

PV-T meets the requirements of thermal regulations by reducing the need for heat while regaining profitability through the production of self-consumed electricity (or electricity selling). PVT products are capable of covering a major part of the building's energetic needs while minimizing the occupied roof area.

Figure 21: PVT meeting building needs

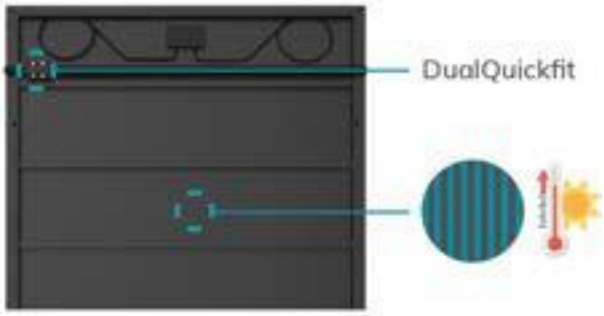
Description of technology

Solar Hybrid PVT: main concept

DualSun SPRING 315 Black hybrid solar panel (PVT) produces both electricity and hot water.

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 efficiency boost by the cooling cells

DUALQUICKFIT	
	Patented Plug & Play hydraulic connection system for faster and more reliable installation of the SPRING® panel



← DualSun Spring 315 Black: front and rear

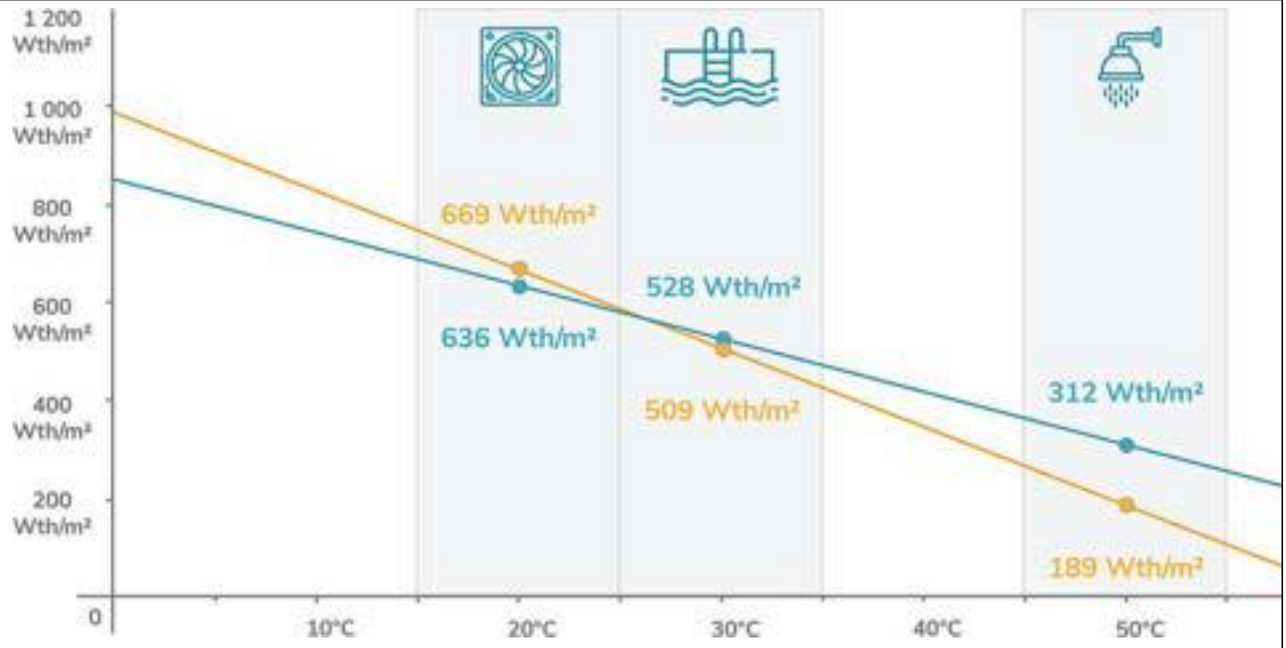
Physical characteristics		Quality & Safety	
Length	1658 mm	CE marking	
Width	996 mm	IEC 61215 & 61730	n°16429 Rev.2
Thickness	35 mm	SOLAR KEYMARK	n°16458
Empty / full weight	25,3 / 30,3 kg	CEC	listed
Maximum load	5400 Pa (snow)	UL 1703	n°702139
	2400 Pa (wind)	ICC-SRCC	n°10002099

Performance

Photovoltaic (PV) characteristics		Thermal characteristics	
Nominal PV power	315 W	Thermal power	629 Wth / m²
Output power tolerance	0 / +5W	Heat exchanger area	1,635 m²
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/ m²

Thermal power output as a function of the temperature of the water in the panel and by application[9]

Performance from values a_0, a_1 (wind u=1m/s) in STC conditions (Tair = 25°C, G = 1000 W/m²)



Orange curve = *SPRING non-insulated* **Blue curve** = *SPRING insulated*

DHW : Domestic Hot Water
HP : "Solar" Ground *water-water* Heat pump
POOL : Swimming Pools

Limitations

DualSun Spring delivers heat depending on the sun irradiation and the ambient temperature but in any case, is **not recommended for systems functioning at > 70°C**.

The maximum operating pressure of the hybrid DualSun Spring panel is **1.5 bar**. It can be increased up to 2 bar during the filling phase only.

No flammable object must be near the device.

The entire solar installation must be installed and operated in accordance with recognized technical rules, the complete installation must be carried out **by trained and qualified personnel**. The control, commissioning, maintenance and repair of the installation also must only be carried out by qualified personnel.

Notes :

- To ensure correct filling of the panels during commissioning, the maximum **recommended number of modules in the same branch is 6** portrait or landscape. The fluid must flow from bottom to top in the panels.
- Consider the glycol content (%) in the fluid mix depending on the local weather.

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[9] https://academy.dualsun.com/hc/en-us/articles/360005303879-What-is-the-thermal-performance-of-the-DualSun-SPRING-panel-

- The installation must be commissioned cold, ideally in a range of panel temperature between 10 and 45 °C.
- Be careful properly bleed the air from the hydraulic circuit.

Applications

DualSun Spring is a low temperature concept, also called uncovered PVT collector (WISC).

Low temperature applications include:

- heat pump systems
- heating swimming pools or spas up to 50 °C
- space heating and water heating are found in buildings, with temperatures from 20 °C to 80 °C
- solar process heat (diverse range of industrial or agricultural applications – <70°C temperature requirements only)

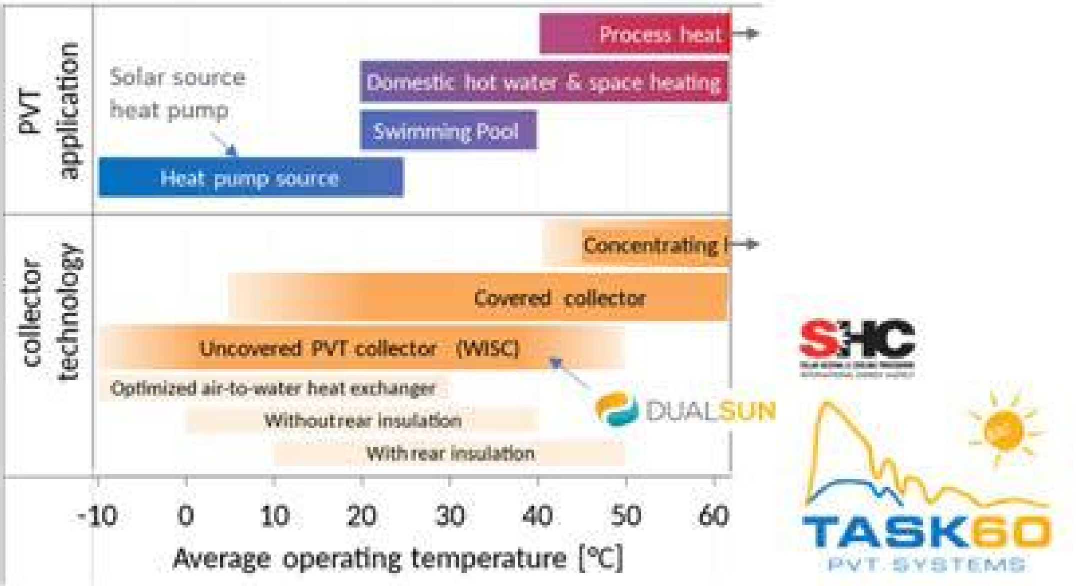
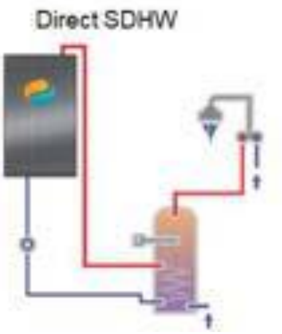
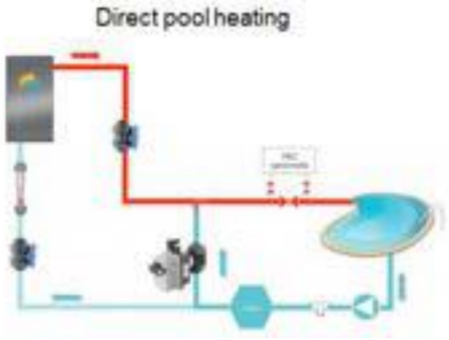


Figure 22: definition of different solar technologies according to the operating temperature

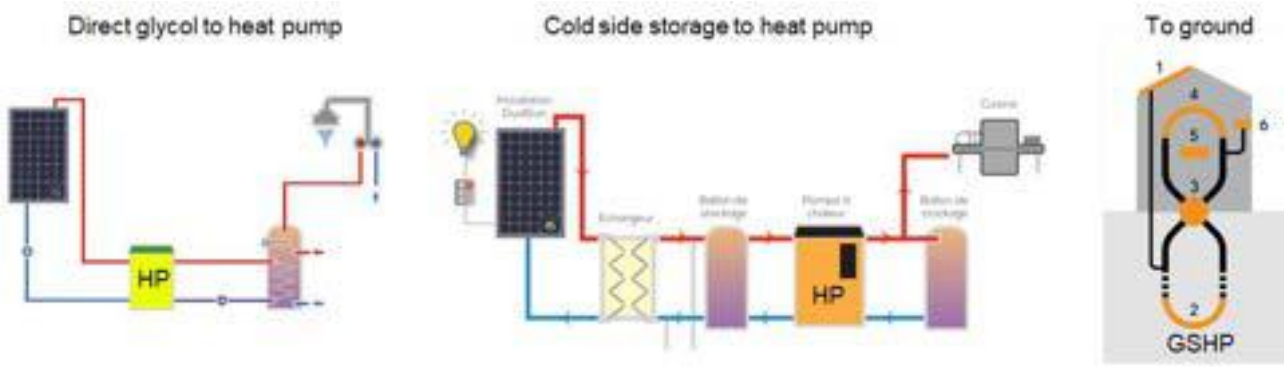
Many systems are possible with solar hybrid PVT:

- Direct heating





- Indirect heating

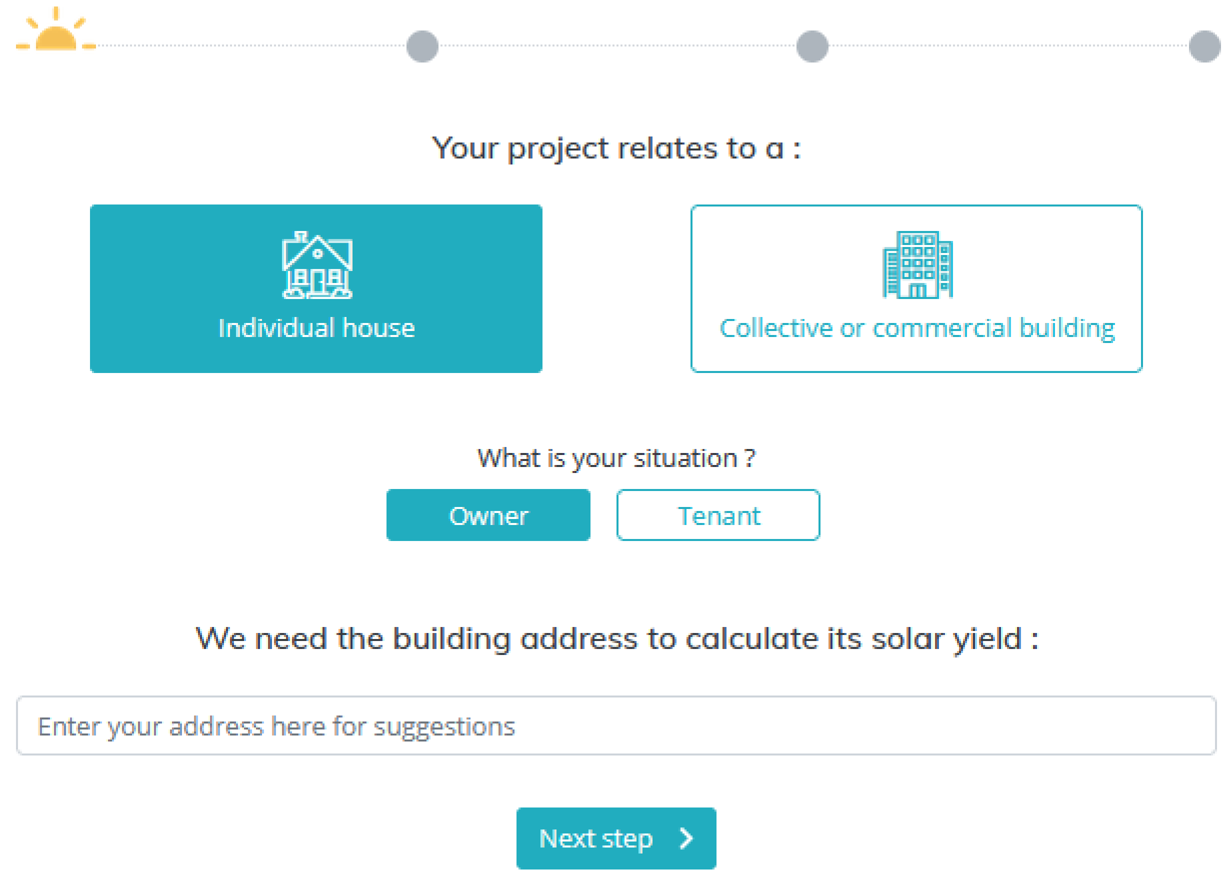


And a wide typology of clients :

Online tools

For performance at different weather conditions (wind, irradiation and ambient temperature) see : https://academy.dualsun.com/hc/en-us/articles/360019076100-How-does-the-thermal-power-output-of-the-SPRING-panel-change-according-to-outdoor-conditions-

➔ In the DualSun solar simulator statistical local weather conditions are considered hour by hour. An estimation of the yield for your project could be simulated here: https://my.dualsun.com/en/get-dualsun/



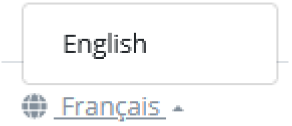
Your project relates to a :

What is your situation ?

We need the building address to calculate its solar yield :

Enter your address here for suggestions

NB : you can choose French or English language in the bottom left of your screen :



If **you are a homeowner** and interested in installing DualSun panels for your home, please visit MyDualSun to perform a free simulation of your project.

6.2 Innovation introduced in SunHorizon project

To address the innovation potential in PVT, two main challenges have been addressed in the scope of the SunHorizon project.

Simplified hydraulic connection for non-specialist installers

To reduce cost and installation time and make technology accessible to non-specialist installers, click and flow innovative fittings adapted to standard PV mounting systems has been developed in the project.

This improvement allows a simplified panel mounting and a better compatibility of hybrid panels to different types of roofs.[10]

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[10] https://academy.dualsun.com/hc/en-us/articles/360005304199-How-do-DualQuickFit-interpanel-connectors-work-

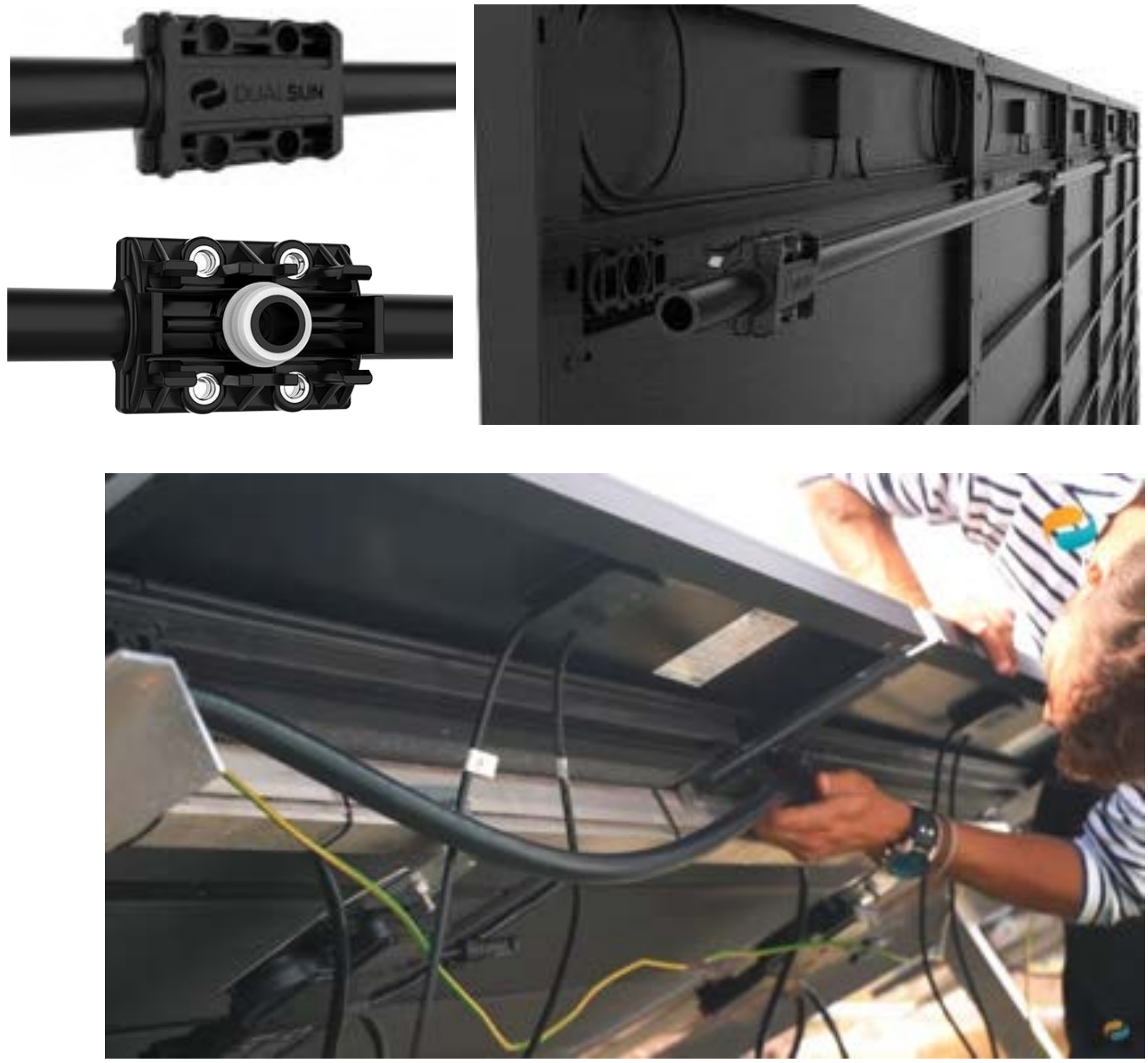


Figure 23: DualQuickfit coupling simply need to be clipped on to be leaktight

Redesign the heat exchanger to be compatible with more PV modules and lighter the module

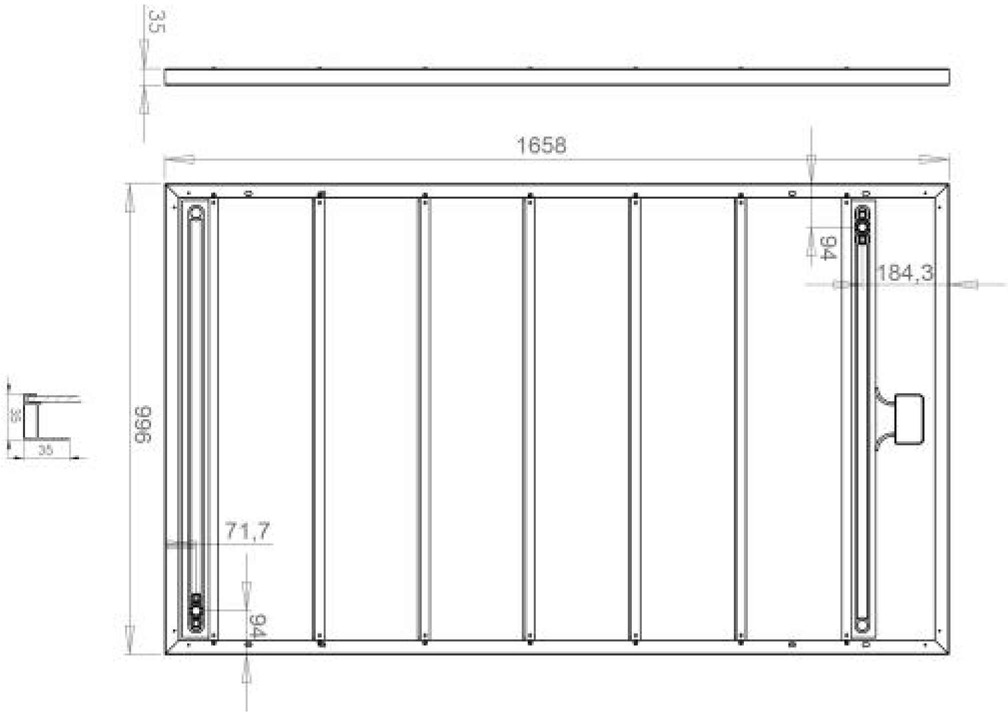
To follow better the PV quick trend the heat exchanger has been redesigned to be compatible with more PV modules, improving panel performances and in same time reducing costs.

➔ Thinner heat exchanger (-10 mm in thickness!)
- Fit in 35mm photovoltaic frame
- Compatible with many photovoltaic mounting systems
- Less fluid = lighter!

➔ Integration of the up-to-date PV cells
- 15% more efficient in electricity

➔ A better fluid exchange
- 24% more efficient in heat

- the new PVT stagnates below 80°C, reducing costs in piping and maintenance



Industrializing respective manufacturing processes towards volume production

Both innovations have been integrated in DualSun manufacturing lines and certified by KIWA[11]. DualSun has implemented the innovations in its factory based in Jujurieux in the department of Ain (France). The integration has to respect ISO 9001 certification of the factory so as to guarantee the quality of the new version of products.

6.3 Integration with the other SunHorizon technologies

One of the ways in which DualSun SPRING hybrid panels can be used is to generate the heat and electricity required by water-to-water heat pumps. The heat exchanger located on the rear side of the DualSun SPRING hybrid panels heats up the water which is then transferred to the cold source of the heat pump. Meanwhile, the front side of the panel contributes to the energetic output by producing photovoltaic electricity.

This system is optimally designed to cover heating needs and works very well at low temperatures, meaning that it resists well to chilly winter temperatures and in cold climates!

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[11] https://my.dualsun.com/wp-content/uploads/sites/2/DualSun-EN-Spring-IEC-Certificate.pdf
https://my.dualsun.com/wp-content/uploads/sites/2/DualSun-EN-Spring-non-insulated-Solar-Keymark-certificate.pdf

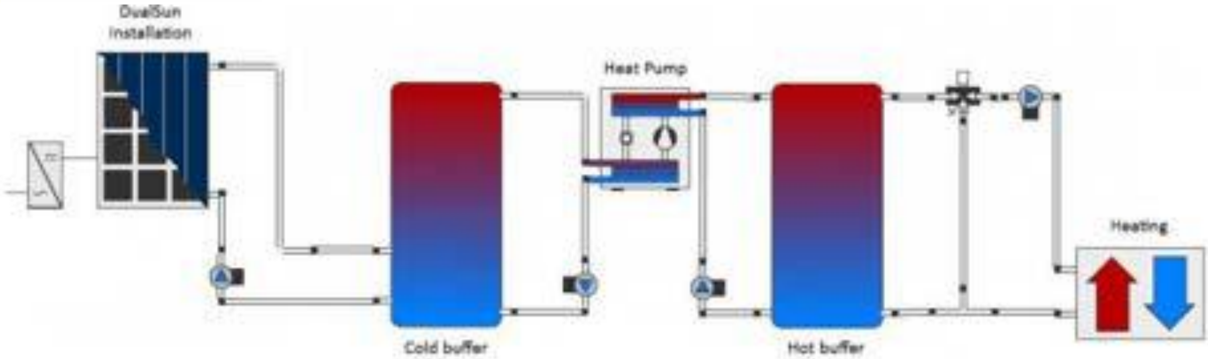


Figure 24: Simplified schematic of PVT solar - heat pump coupling

The DualSun SPRING exchanger collects heat from the photovoltaic cells and heats a storage tank located on the heat pump's primary circuit. This coupling works equally well on sunny days, at night or during spells of bad weather.

This coupling is set in motion whenever there is a difference in temperature between the external air and the water inside the panels, meaning that it functions both on sunny days and during the night or in poor weather conditions.

On sunny days, the sun heats the panels and the fluid circulating inside. When there is no sunshine, the solar panels' heat exchanger collects energy through an exchange with the external air.

This characteristic allows the system to operate at very regular performance levels throughout the year and exceed the performance of a classic thermal solar system.

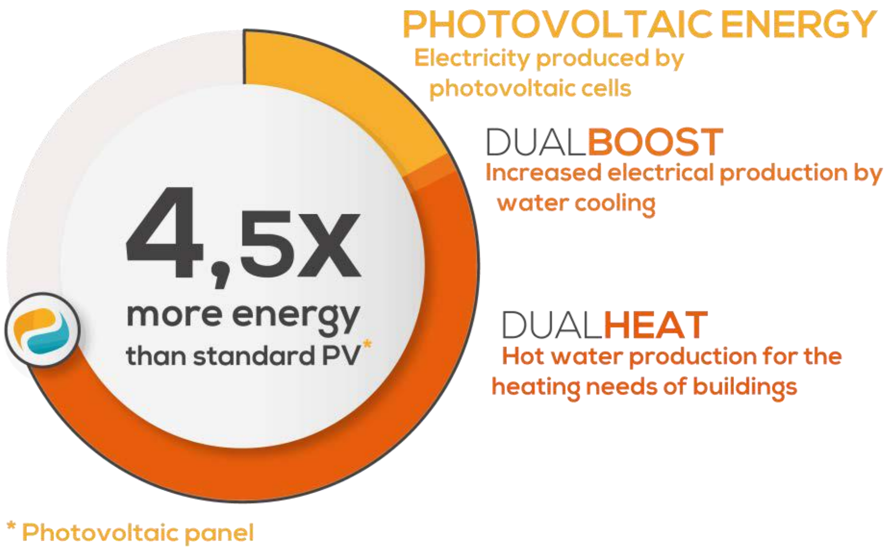


Figure 25: Main outcomes achieved by DS PVT panels

The excellent heat exchange between the photovoltaic cells and the SPRING® solar panel's heat exchanger allows the cells to operate at a lower temperature than classic photovoltaic panels, which makes them more efficient. This coupling provides a 10 to 15% improvement in energy production!

Therefore, the heat transfer performed by the system not only supplies the building with solar heating and hot water, but it also considerably cools down the panel cells and thus increases their overall efficiency.

On average, our hybrid solar panels produce 4.5 times more energy than a classic photovoltaic panel.

7 Ratiotherm – stratified thermal storage

7.1 Description of technology

The main concept of the thermal storage is to maintain a satisfactory stratification. It is achieved by an insert component which consists of polyphenylene ether with a permanent temperature resistance of 105°C or a short-term temperature resistance of 130°C. Inside the distributor there are multiple chambers that are connected to the outside of the tank. A preselection of the connections according to expected temperatures determines the height, so different heat generators as well as heat consumers can charge and discharge without destroying the thermal stratification. The combination of preselected connections and the physical phenomena of stratification related to the density of the fluid which correlates with the temperature allows an enhanced charging and discharging while the heat carrier is ascending and descending within the distributor, prior entering the storage. The target of the stratification device is also to guarantee a less turbulent fluctuation movement. Less turbulence and less irregular recirculation are accomplished by a hydraulically smooth surface and a volumetric expansion of the heat carrier within the circular chambers, thus the flow rate is reduced. Nonetheless it is unavoidable to limit the maximum flow rate of the distributor, since it tolerates a maximum flow of 1.500 litre per hour so that the stratification can be obtained. A 3D-CAD Model of the standard stratified thermal storage is shown in Figure 26.

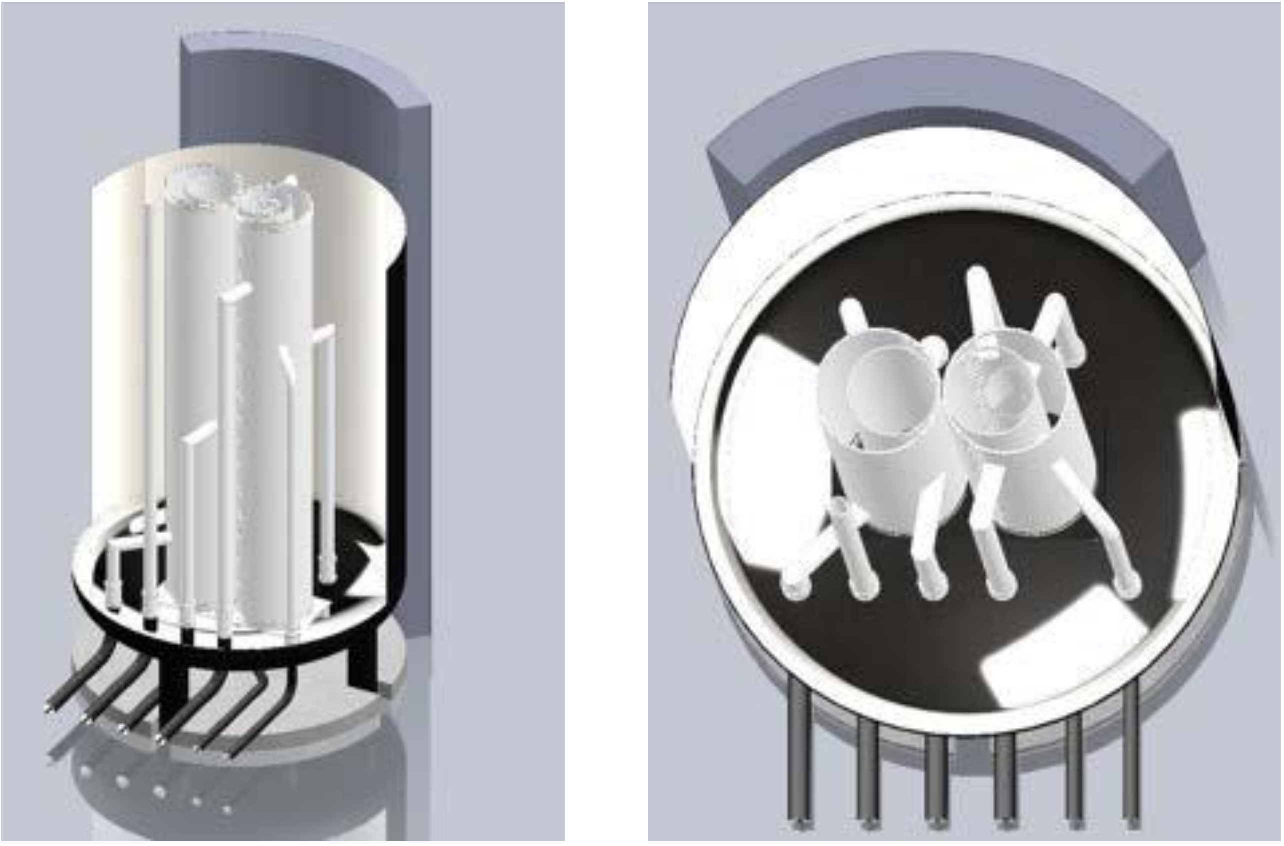


Figure 26: 3D-CAD model of a stratified thermal storage with a distributor inside of the steel tank.

Applications for the use of the tank are heating networks for homes. Especially heat pumps in combination with other heat producers benefit from charging the thermal storage in different heights. The heat pump regulates the outlet temperature of the condenser according to the inlet temperature and enables a temperature difference of a few Kelvin. Whereas conventional boiler recirculates the fluid in return raises before entering the storage. In the view of energy efficiency, the heat shall be produced in relation to the consumption. Domestic hot water applications for example need temperature on a higher level of temperature compared to heating circuits. Due to control valves it is possible decide whether to charge in the upper area or the lower area of the tank. Therefore, it is possible to buffer thermal energy especially for domestic hot water within the upper area, while avoiding charging the whole thermal storage.

7.2 Innovation introduced in SunHorizon project

In the course of the SunHorizon project different specialised thermal storages have been developed. For example, according to the demosite Madrid. The heating and cooling reservoir is a customized thermal storage with a volumetric capacity of 1000 litres. The heat pumps are connected to the storage at the connections 5 and 6. On the basis of a higher flow rate for charging the storage it has been necessary to change the distributor from a one-chamber-system to a distributor with two circular chambers and a larger pipe diameter (DN40), thus a higher flow rate does not destroy the thermal stratification. The technical drawing of the heating and cooling reservoir is shown in Figure 27.

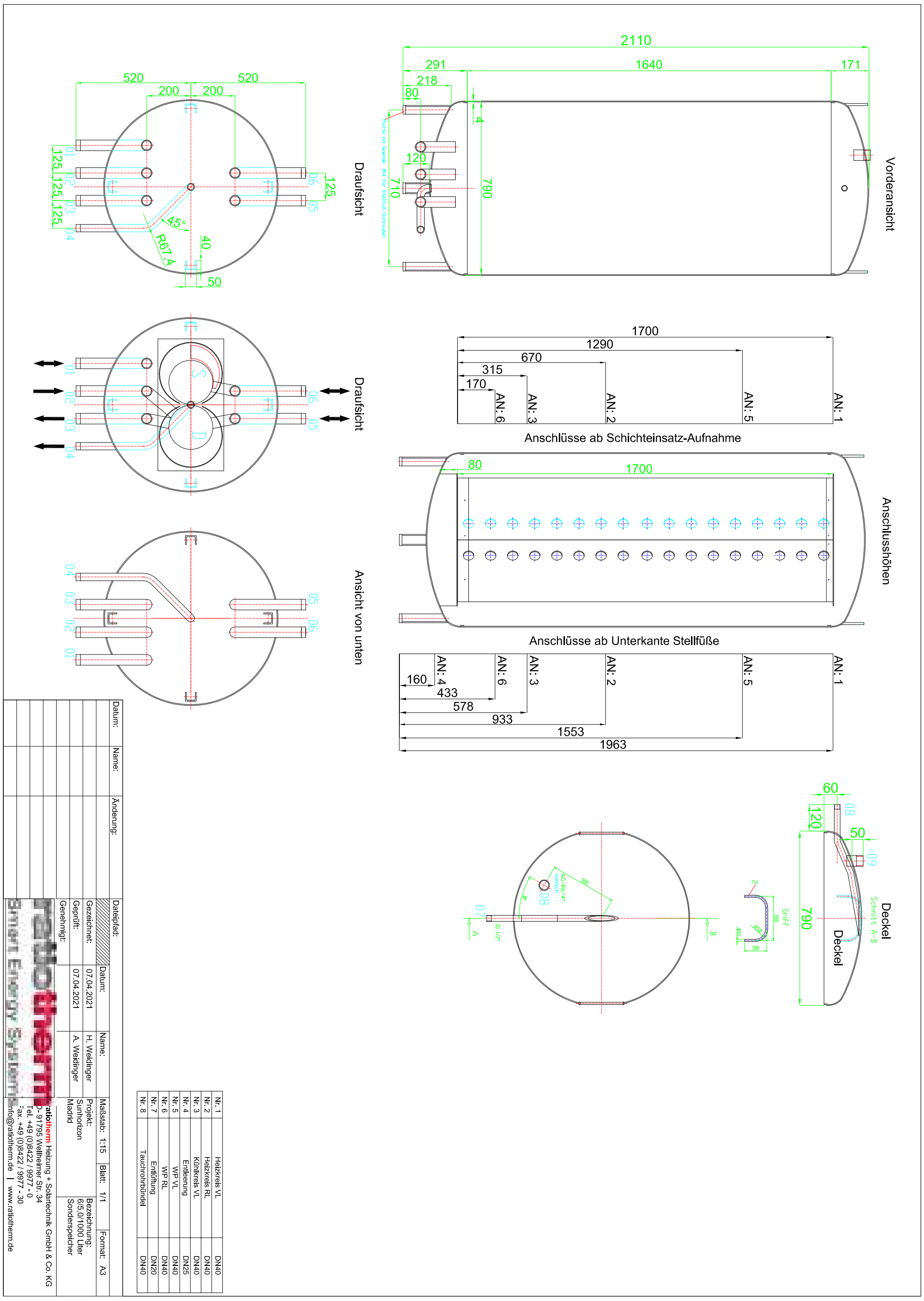


Figure 27: technical drawing of the heating and cooling reservoir (1000 litre)

Besides, the thermal storage has three connections for the heating circuit. It is possible to use the higher temperature (connection 1) or the connection 3 for the cooling application. The return flow is connected to connection no. 2. Furthermore, a thermal storage for the domestic hot water application has been developed. The domestic hot water reservoir has a volumetric capacity of 1300 litres. The connections are similar to the heating and cooling reservoir aside from an adaption of height according to the connections. A technical drawing of the domestic hot water reservoir is shown

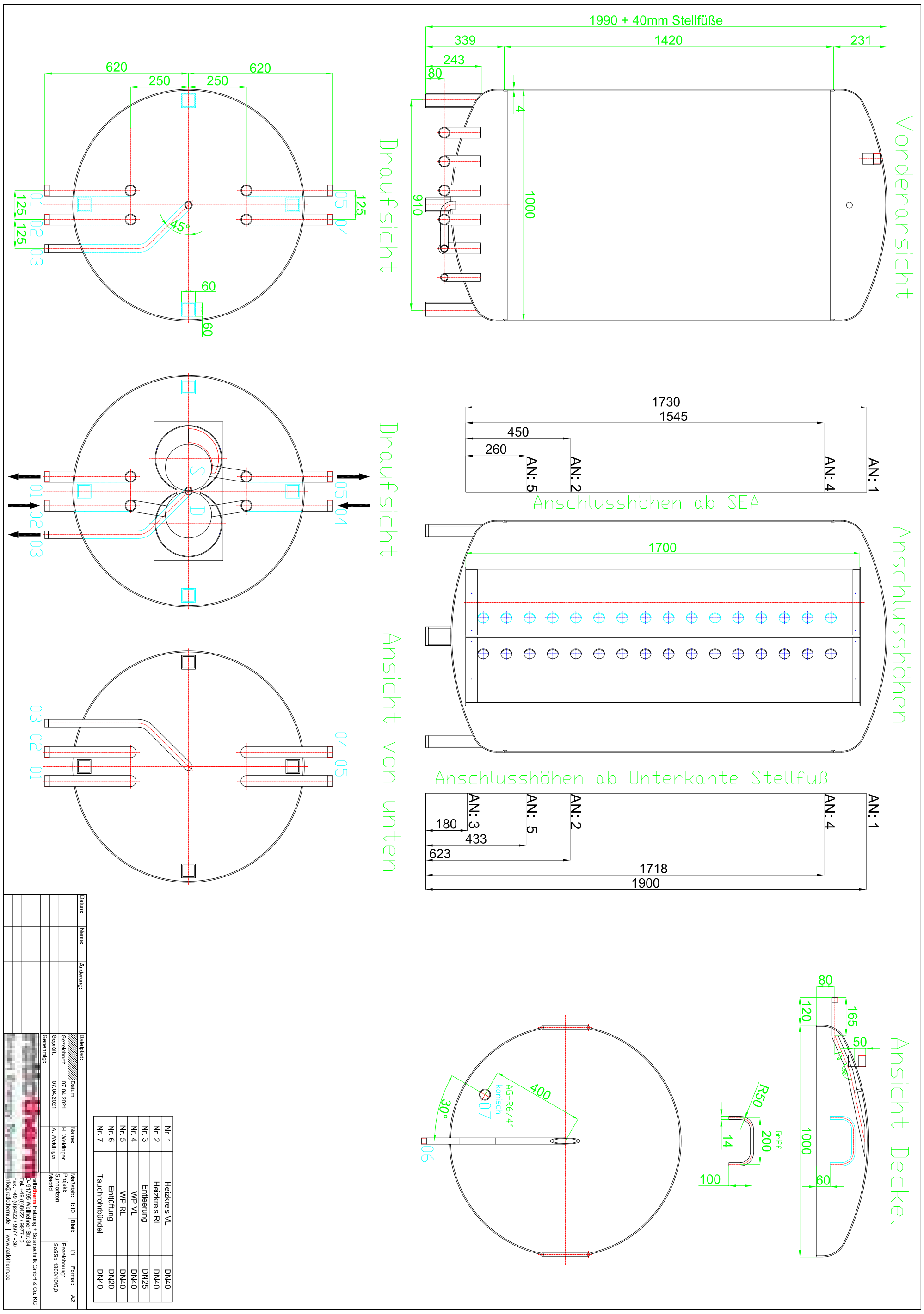
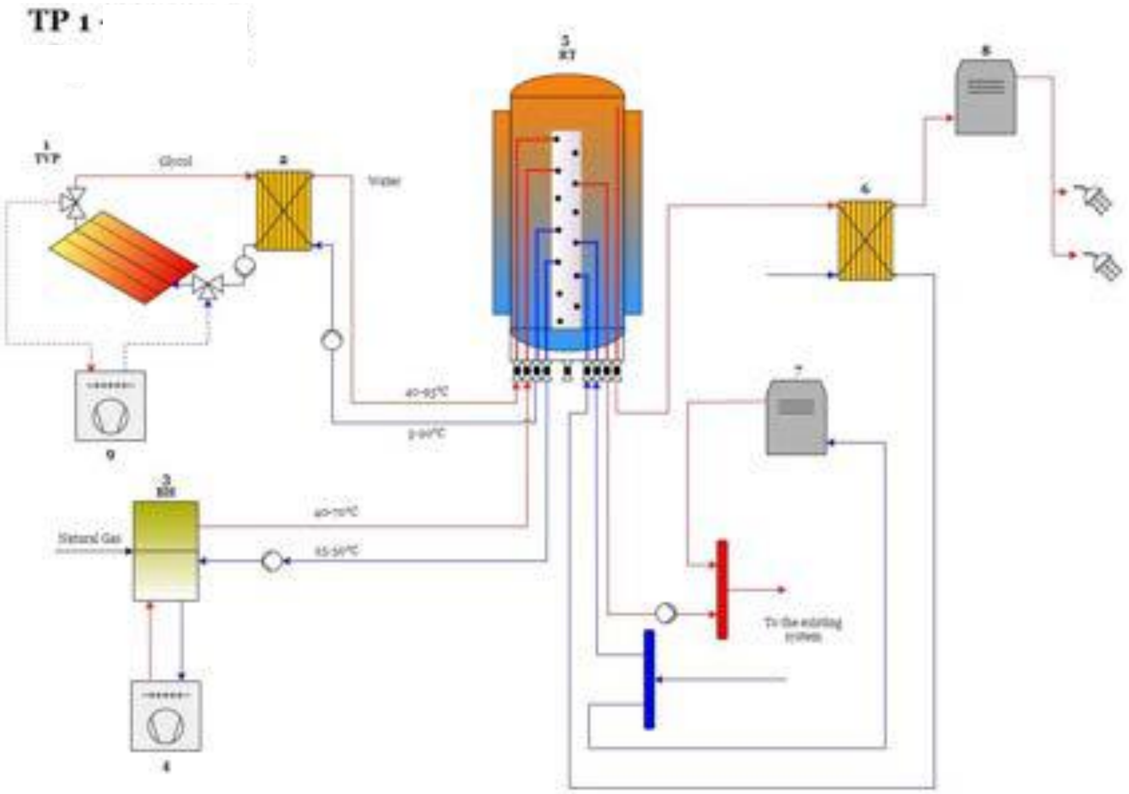


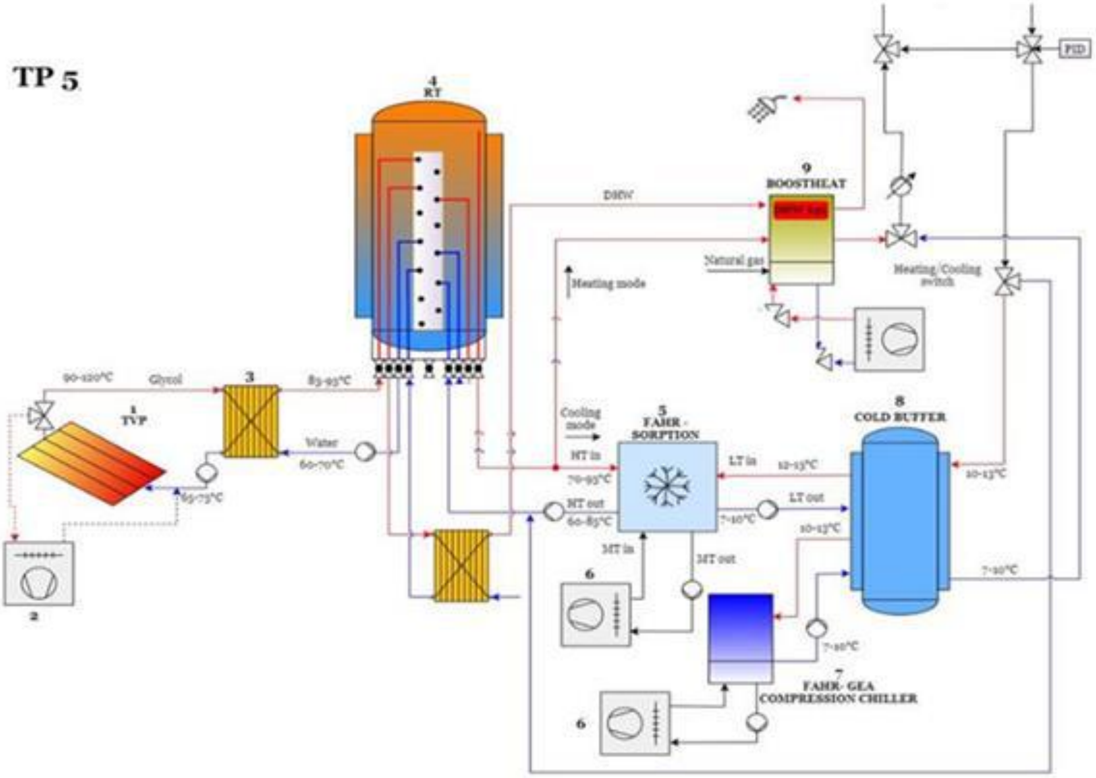
Figure 28: technical drawing of the domestic hot water reservoir

7.3 Integration with the other SunHorizon technologies

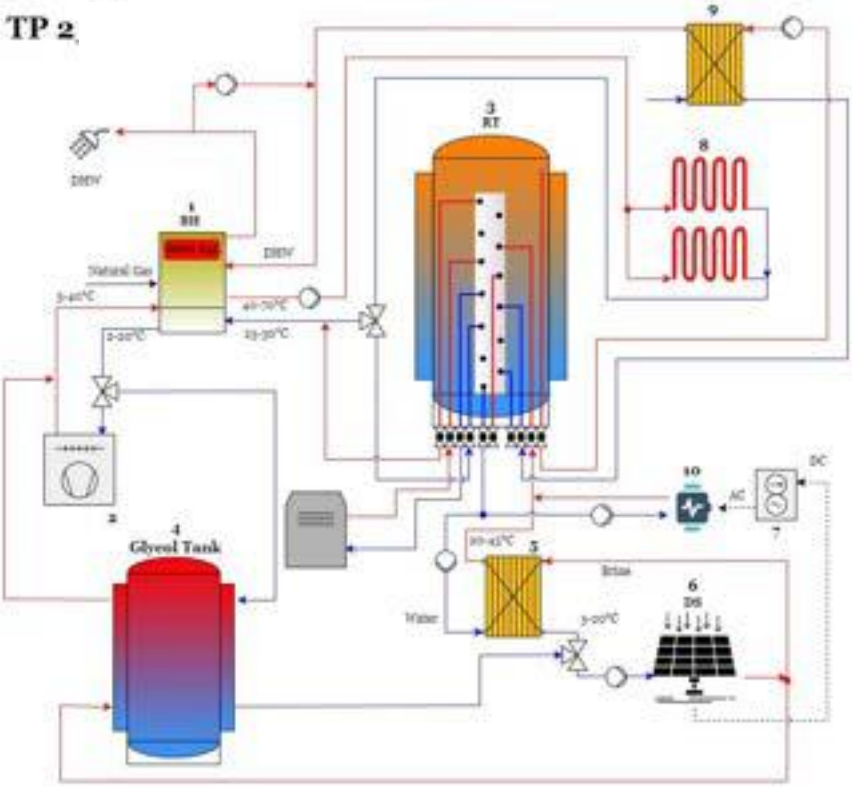
Since the home heating network is characterised by various heat generators as well as heat consumers and therefore the thermal storage is charged and discharged with different levels of temperature it is necessary to provide the stratification considering a more efficient energy concept. According to the integration of the stratified thermal storage with the other SunHorizon technologies, the level of temperature of the thermal energy gained from the hybrid PV-T panels or the high vacuum solar thermal panels is dependent on some factors like intensity of solar radiation or the regulation of the rotation speed of solar pumps for example. The temperature of the heat carrier in solar thermal energy processes is characterised by fluctuation. Consequently, a stratification related to temperature is sought in order to obtain the stratification. RATIO stratified thermal storage integration is foreseen in all the technology packages, TP1 and TP5 integration with TVP high vacuum solar thermal and TP2 integration with DS PVT panels are showed.



TP 5


4
RT
DHW
9
BOOSTHEAT
Natural gas
Heating mode
Heating/Cooling switch
PID
90-120°C
Glycol
3
83-93°C
1
TVP
Water
60-70°C
65-75°C
2
Cooling mode
5
FAHR - SORPTION
HT in
70-93°C
MT out
60-85°C
MT in
MT out
LT in
12-15°C
LT out
7-10°C
8
COLD BUFFER
10-13°C
10-15°C
7-10°C
6
6
7
FAHR- GEA
COMPRESSION CHILLER

TP 2


9
DHW
3
RT
8
1
BH
DHW
Natural Gas
5-40°C
40-70°C
2-20°C
25-30°C
2
4
Glycol Tank
10
AC
DC
7
10-45°C
5
Brine
6
DS
Water
5-20°C

8 BDR Thermea – innovative heat pumps

8.1 Description of technology

BDR Thermea group manufacture and distribute smart thermal comfort solutions with a near-zero carbon footprint to building owners and users. The heat pump technology was chosen, among the other commercialised technologies, to be proposed in the SunHorizon project. One of the main objectives is to optimize the heat pump integration with solar systems and variable loads by exploiting stratified tanks, thus enhancing the efficiency and energy saving. The product types that were studied for R&D development and then installed in the demo sites are described in the following table.

Product types

Type	Description	Heating power 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, transfer the energy to the indoor unit. The indoor unit include 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 hot source is the water from the heating circuit.	6kW to 11kW 169% to 184%	

Split Air to Water	The compressor and the evaporator are inside the outdoor unit. A refrigerant pipe link it to the condenser placed inside the indoor unit. The indoor unit include 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 hot source is the water from the heating circuit.	4kW to 24kW 151% to 189%	

Certification

All heat pumps sold by the companies of BDR Thermea Group are compliant with the EC requirements. The EC is about the security of electrical appliances and is mandatory in the EEA (European Economic Area). The ErP (Energy related Product) labelling is mandatory too in the EEA.

Depending of countries, performances and quality labels are required to be eligible to subsidies and to be compliant with the energy regulations.

The performance of heat pump is measured by following European standards.

European requirements

EC

The EC marking, CE in French, is a mark of compliance with security standards to the customers. Concerning the electrical, mechanical and electromagnetical security.

ErP

The Energy related Product is a mark to inform the customer about the energy performance of the product.

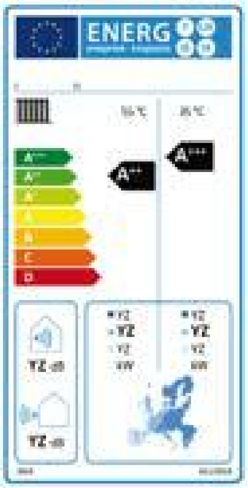


Figure 29 - ErP label

Labels

The heat pumps from BDR Thermea complies to labels of quality and performances, depending on models, some example below.

NF PAC

The label ''NF Pompe à chaleur Chauffage'' certify the performance and quality of heating heat pumps in France.

NF Electricité Performance

The label ''NF Electricité Performance'' certify the performance and quality of domestic hot water heat pumps in France.

HP Keymark

The label ''HP Keymark'' certify the performance and quality of heating and domestic hot water heat pump in Europe.

Performance standards

EN 14511

Rated performance.

The power and efficiency are measured in normal conditions of cold source and hot source.

Used for the NF PAC and HP Keymark

EN 14825

Seasonal efficiency.

The power and efficiency are measured at different conditions to calculate the seasonal efficiency of the heat pump in a chosen application. The application is the temperature of supply at the design temperature. The design temperature in average climate is -10°C. The application temperature is between 35°C in low temperature application to 65°C in high temperature application.

The seasonal efficiency is calculated with the results of measurement.

Used for the ErP

EN 16147

Performances for domestic hot water production. Mainly for domestic hot water heat pump, but also for heating heat pump with domestic hot water production.

The performance is measured at 7°C outside air and a typical water tapping is applied to the appliance.

Used for the ErP and the NF Electricité Perormance.

Application schematics

Example of schematic of system with an air to water heat pump. The schematics are the same with a water to water heat pump.

Heating and cooling on a single circuit

This is the simplest schematic; the heat pump provides heating and cooling to a single heating circuit. The backup is by an electrical heater included in the heat pump.

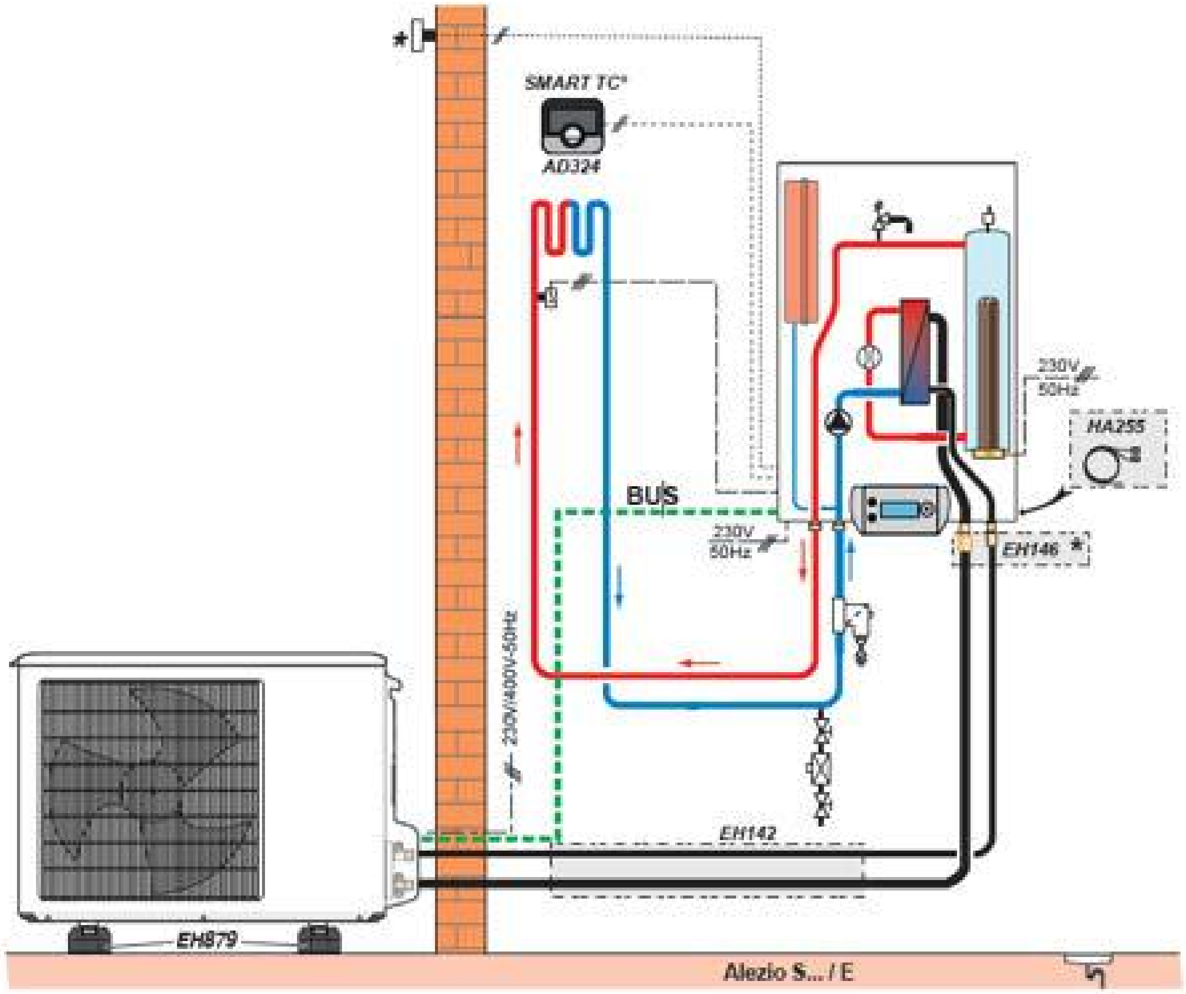


Figure 30 - Single circuit

Heating and cooling on a single circuit and domestic hot water on a water tank

The heat pump provides domestic hot water (DHW) stored in a water tank in addition of the heating circuit. The backup is by an electrical heater included in the heat pump.

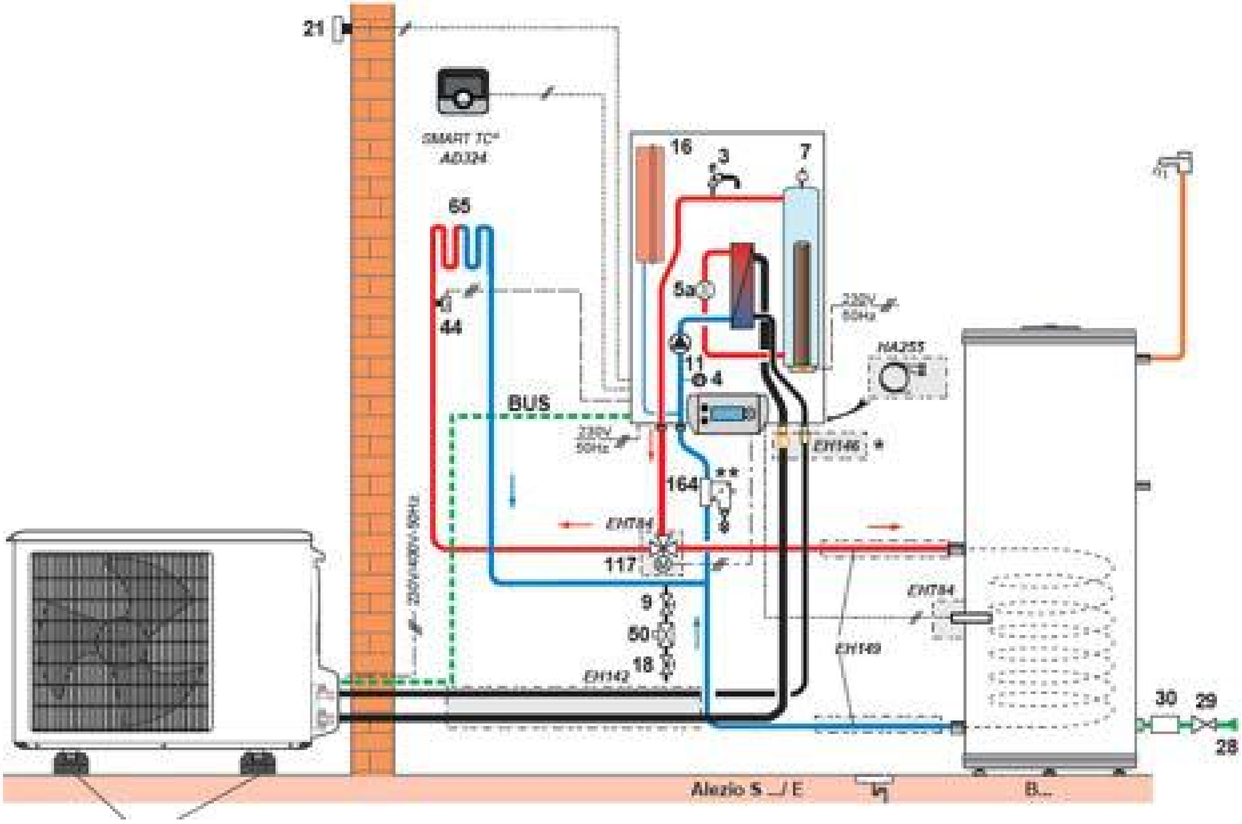


Figure 31 - One circuit and DHW

Heating and cooling on two circuits, one direct and one mixed, and domestic hot water

Addition of a second heating circuit after a mixing valve. So, the second circuit can deliver lower temperature than the first circuit. Usually, the first direct circuit is on radiators and the second mixed circuit is on floor heating.

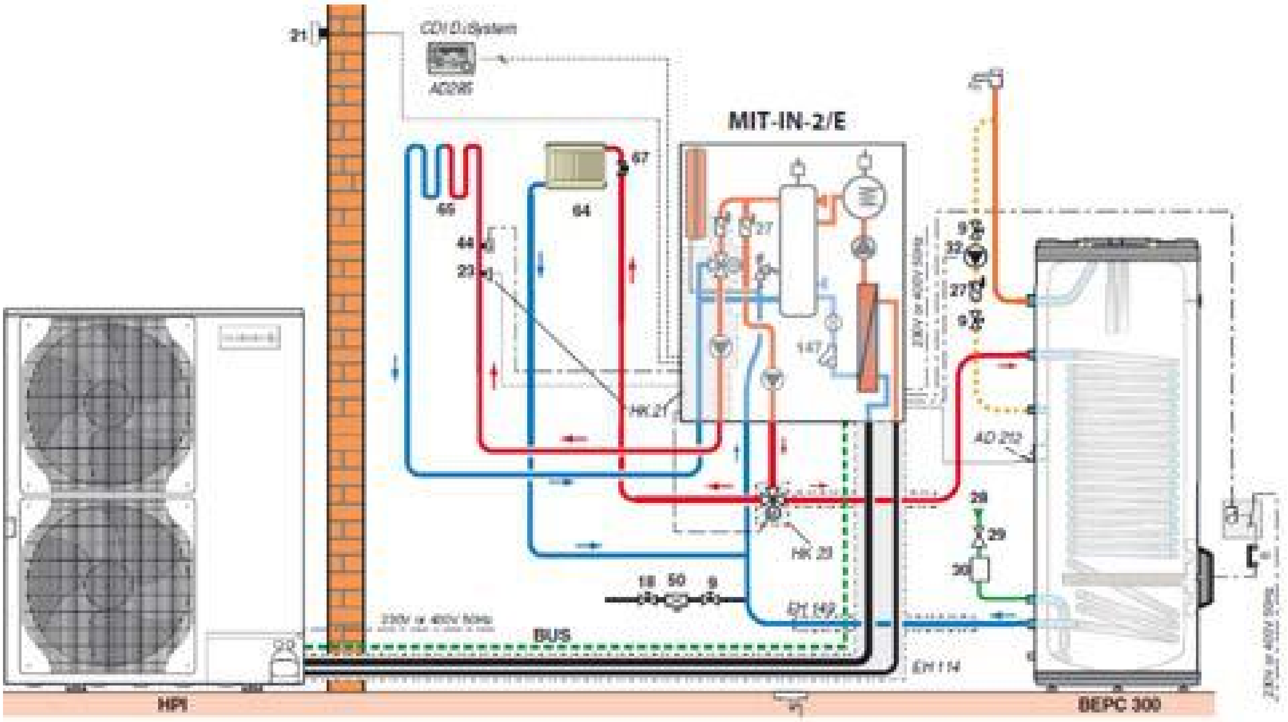


Figure 32 - Two circuits and DHW

Heading and cooling on two circuits, one direct and one mixed, and backup on domestic hot water by solar collectors

On this schematic the DHW is made mainly by solar collectors. The backup of the DHW tank is made by the heat pump.

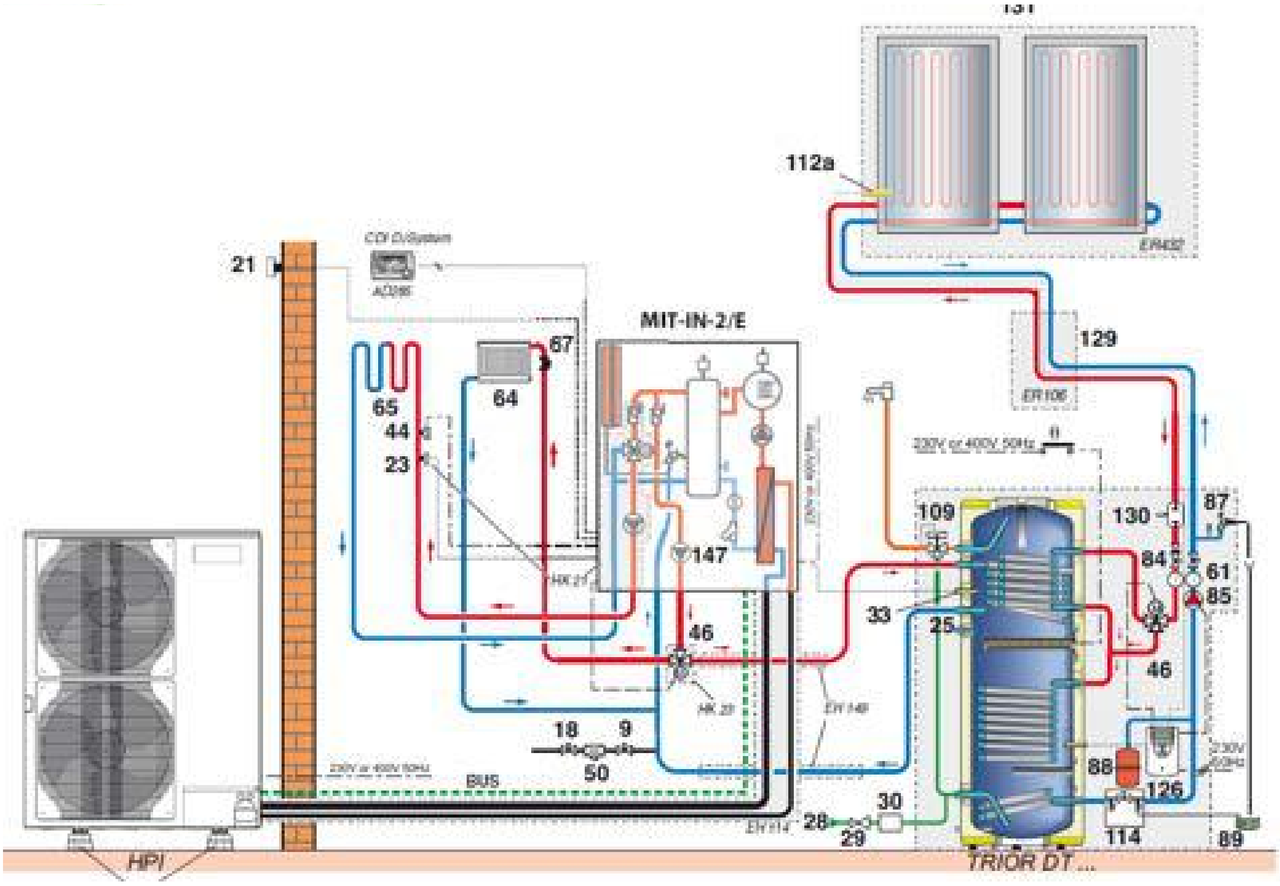


Figure 33 - Two circuits and solar DHW

Hybrid heat pump for heating and cooling on a single circuit with a hydraulic backup

The heat pump can be in hydraulic backup configuration. In this case there is no electrical backup, the hydraulic backup is connected inside the heat pump and the heat pump will choose which generator will be used depending on outdoor temperature, the supply temperature and the energies prices. The hydraulic backup can be a gas boiler, an oil boiler or a wood boiler, or other.

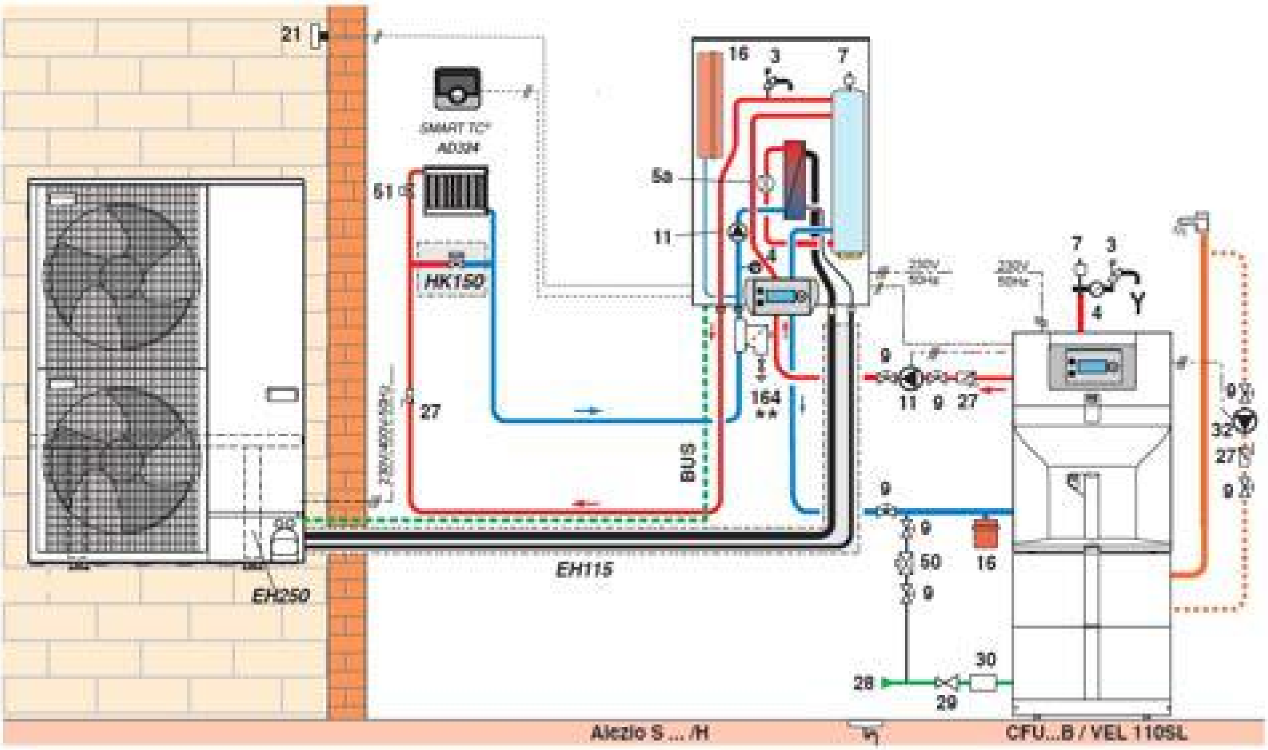


Figure 34 - Hydraulic backup

Cascade with two heat pumps and a gas/oil boiler as backup for heating and domestic hot water

Two or more heat pumps can be added in the system to increase the power.

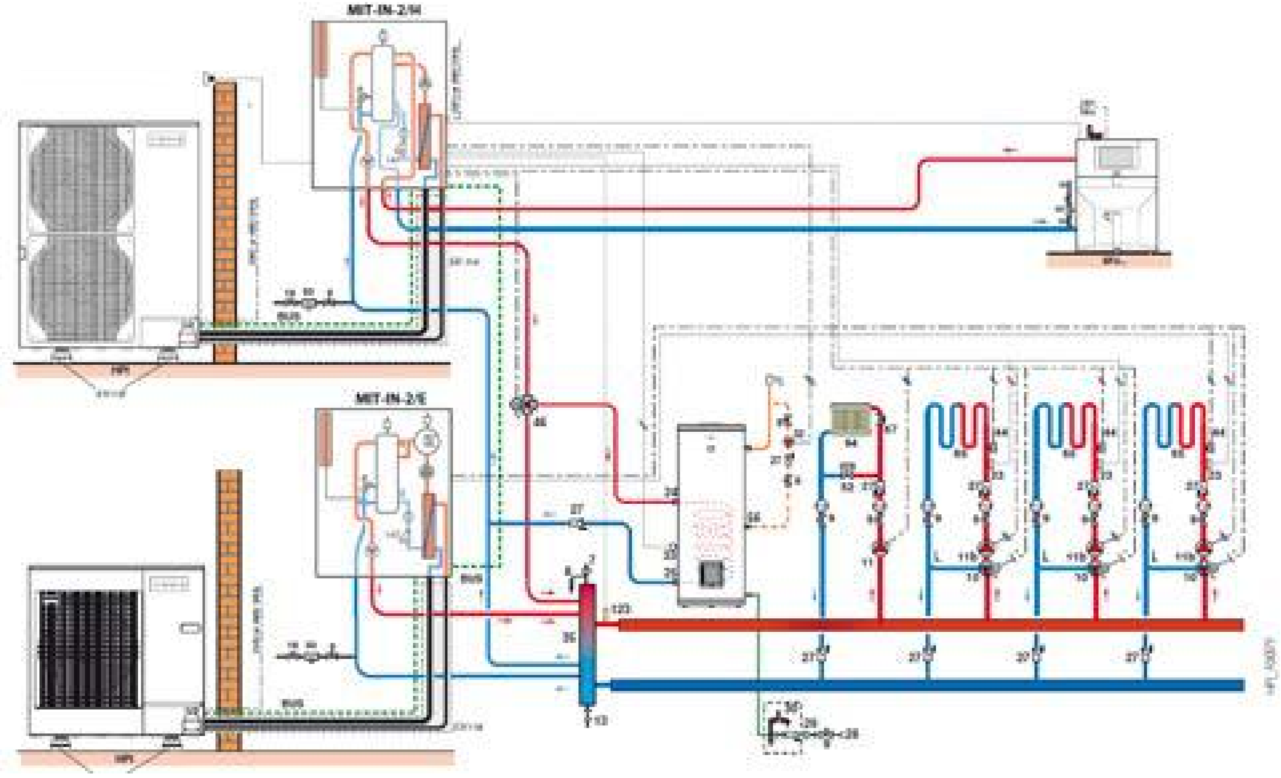


Figure 35 - Cascade

8.2 Innovation introduced in SunHorizon project

The current heat pumps supply heating, cooling or DHW regardless the electricity availability. 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.

A system with PV panels will add electricity production to the house. A part will be consumed by general appliances, and the rest is injected into the power grid with or without remuneration.

The heat pump has the capability to multiply the electric energy into heat or cold by the coefficient of performance (COP). If a part of the electricity come from a renewable source on site, this part is free of cost and energy, so the real COP of the heat pump is bigger as show in Figure 36. With a half of the electricity produced by PV the COP is multiplied by two.

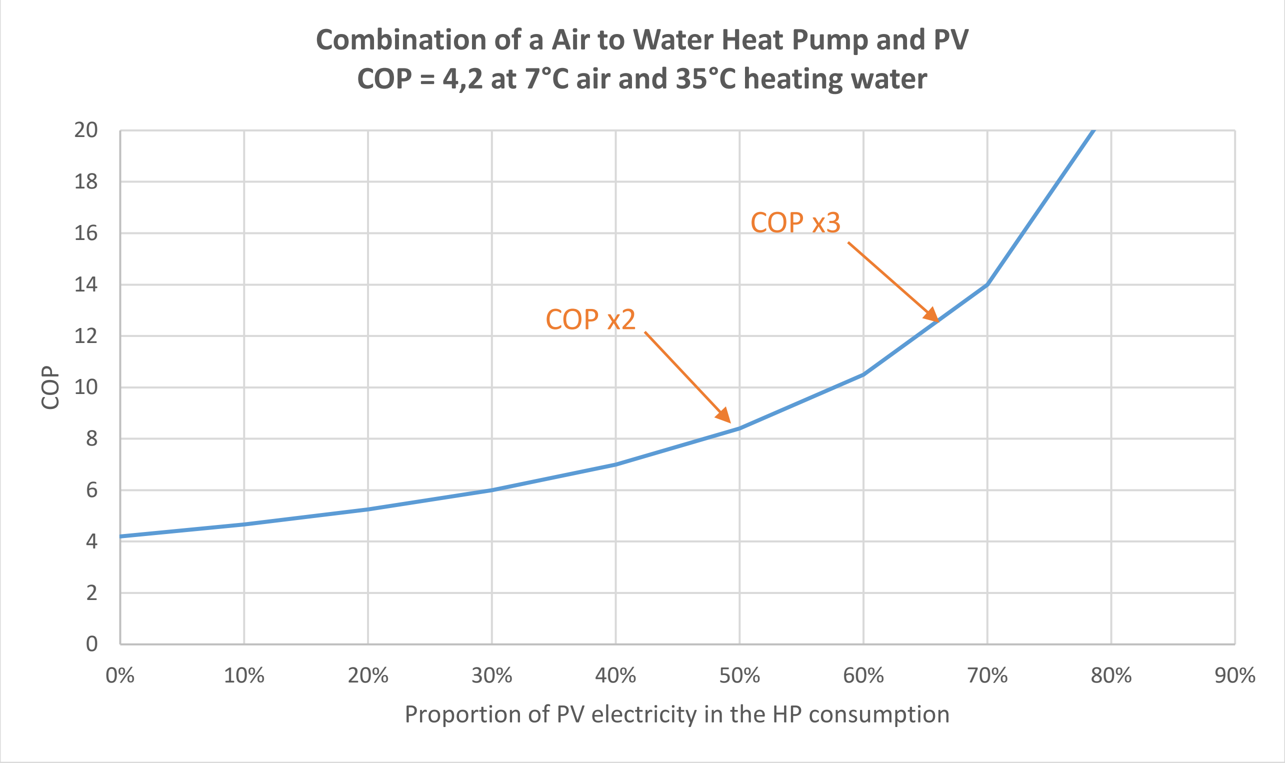


Figure 36 - COP with PV self-consumption

The control of the heat pump is improved 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.

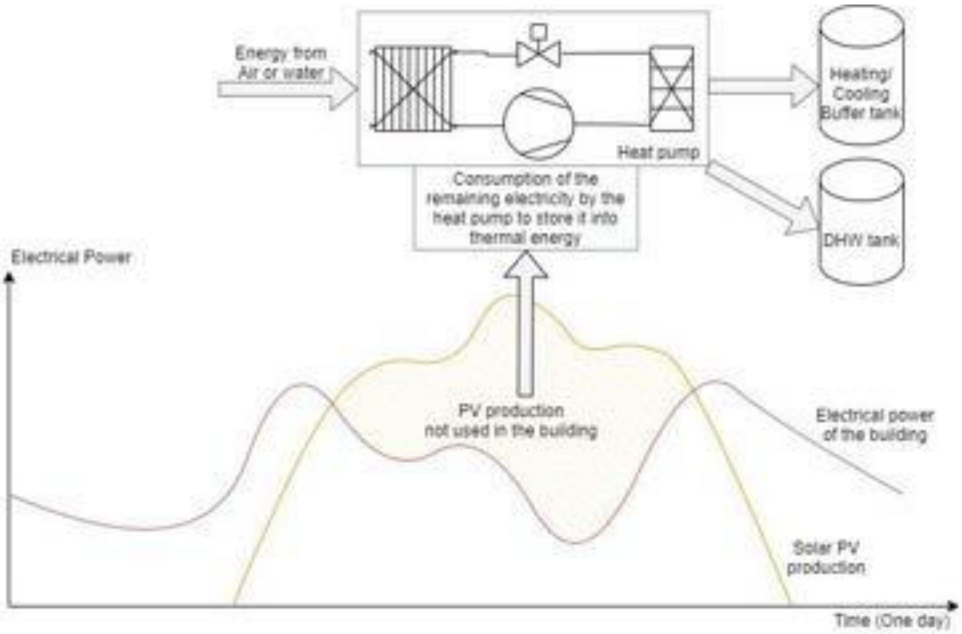


Figure 37 - Energies in the system with PV and heat pump

The demo-site of Piera will demonstrate the combination of an air to water heat pump with solar PV panels in self-consumption and solar collectors for domestic hot water as show in Figure 38. In addition, the current oil boiler of the house is kept on place and will serve as a backup for the heat pump.

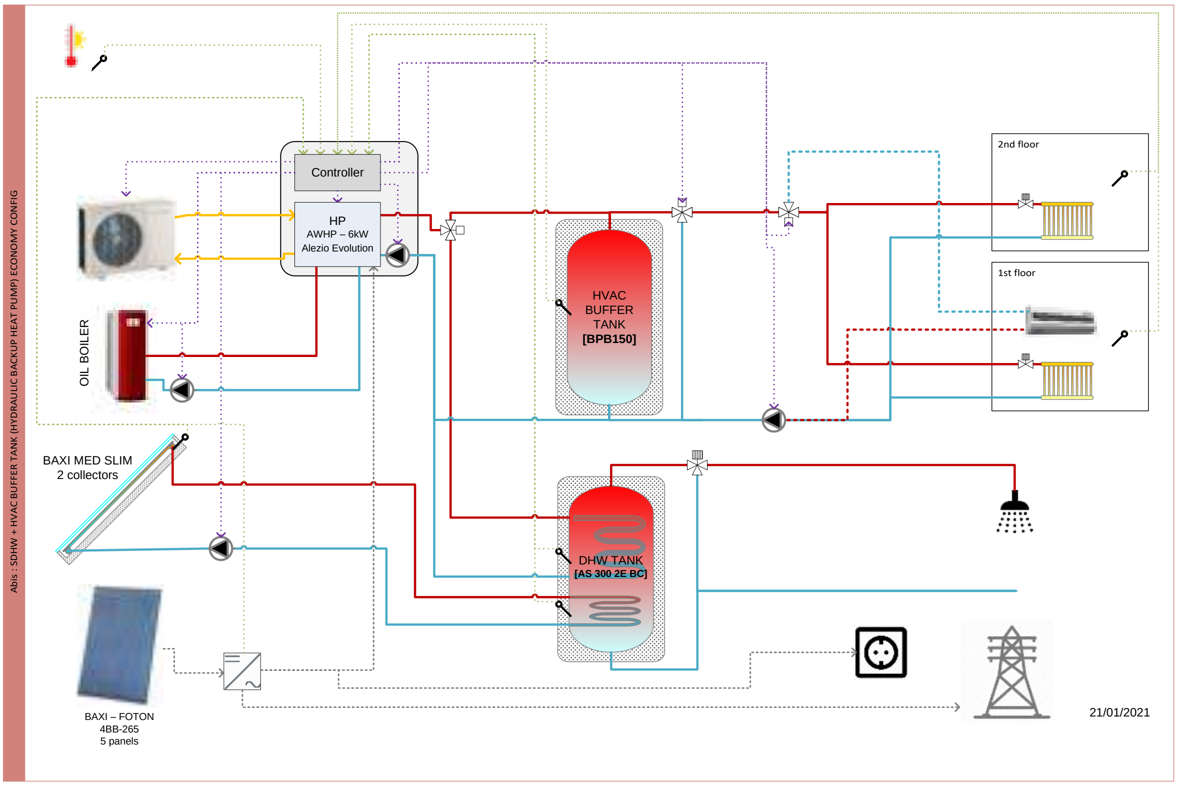


Figure 38 - Piera schematic

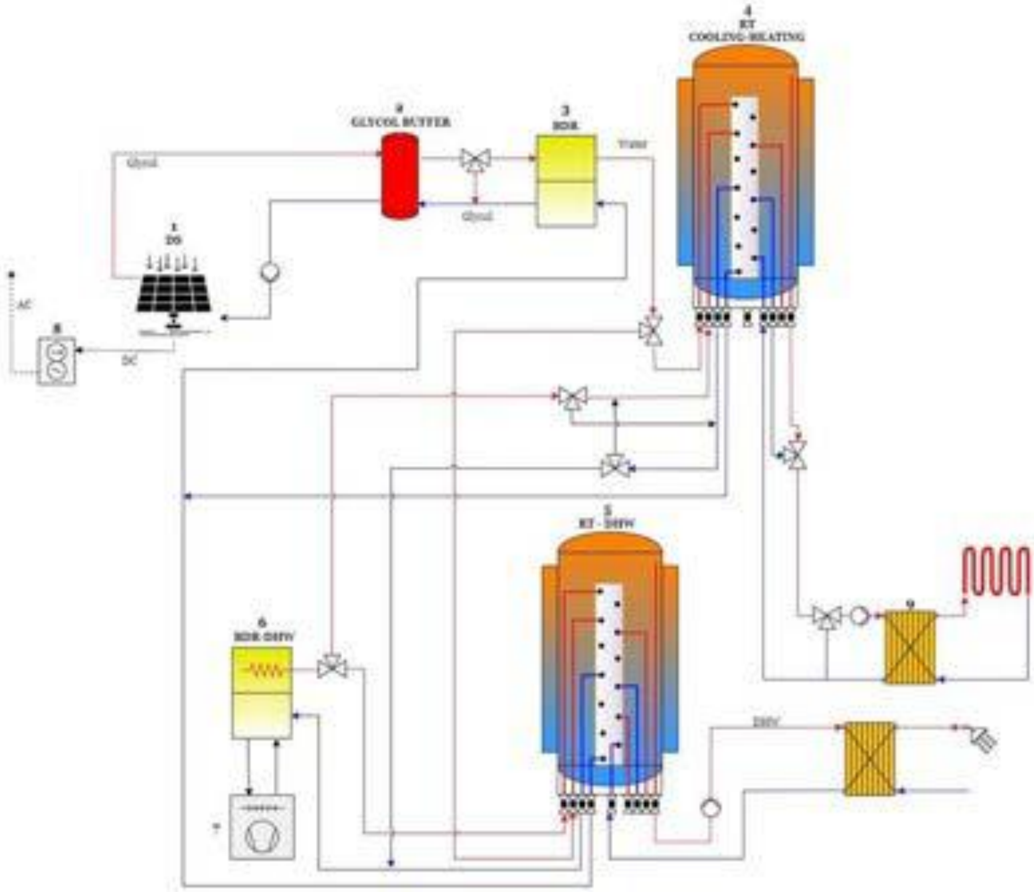
8.3 Integration with the other SunHorizon technologies

The improved heat pump can work on all system with an overproduction of renewable electricity.

In SunHorizon, the hybrid PV thermal panels from DualSun are compatible, as well as the PV panels from BDR Thermea.

The stratified heat storage from Ratiotherm is compatible and is the best efficient solution but need a specific controller to manage the stratification. Heat storage tanks from BDR Thermea are compatible and don't need a specific controller to work.

The demosite of Madrid is the system in which a water to water heat pump work on the collector side of the DualSun hybrid panels. An air to water heat pump adds capacity to the system. Both heat pumps feed two stratified heat storage from Ratiotherm. A controller manages the heat and cool production, according to the needs and the PV production.


4
RT
COOLING-HEATING
2
GLYCOL BUFFER
3
BDR
Water
Glycol
Glycol
1
DS
AC
8
DC
5
RT - DHW
6
BDR-DHW
7
9
DHW

9 Conclusion

The activities performed during the first 3 years of the SunHorizon project, belonging to the WP3, allowed to further develop and optimize innovative enabling technologies for coupling solar thermal and heat pumps in buildings.

The main features of each technology along with the innovations introduced during the project were reported in the present deliverable and can be used as reference for understanding how these technologies will be integrated in the SunHorizon technology packages.

The expected techno-economic performance will be further validated in the final phase of the project in the different demo sites. The results will be publicly available and constantly updated at the SunHorizon project' website (www.sunhorizon-project.eu).