H2020 - EEB - 2017 - 766464 – SCORES

Self Consumption Of Renewable Energy by hybrid Storage systems

D 8.7 Report on the technic, economic and environmental performance of DEMO B

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1 Background

The objectives of the SCORES project are to develop and demonstrate in the field the performance of new storage technologies to support self-consumption in residential buildings. Combination and optimization of multi-energy generation, storage and consumption of local renewable energy (electricity and heat) bring new sources of flexibility to the grid and giving options for tradability and economic benefits, enabling reliable operation with a positive business case in Europe's building stock. SCORES optimizes self-consumption of renewable energy and defers investments in the energy grid.

Evaluating the technic-economic potential of thermal and electrical energy storage, such as greenhouse emissions reduction, in residential buildings is important to optimize future investments in the framework of energy transition and prepare new European buildings to become "zero-energy building".

Work Package 8 focuses mainly on answering these techno-economic aspects and has three objectives:

- Reporting the results of measurements made in the field
- Demonstrate the feasibility of the project through the on-site operation of the different systems of the project
- Provide feedback on what worked well and areas for improvement in relation to what did not work

The present report (D8.7) describes the technic, economic and environmental evaluation of the system installed on the French demonstrator. This document was compiled by EDF, whereas different partners within the SCORES program have shared their expertise for this document. HELIOPAC, CAMPA, SIEMENS and TNO provided information on the method used and the data to be analysed. This document has also been reviewed by the partners within the SCORES program before publication.

2 Terms, definitions and abbreviated terms

SHS	Space heating system
DHWS	Domestic hot water system
LHSS	Long-term heat storage system
ESCS	Electricity storage & conversion system
EDMS	Energy & data management system
EBS	Electrical battery subsystem
ECS	Electricity converter subsystem
BEMS	Building energy management subsystem
ISHS	Installed space heating sub-system
WHPS	Water-water heat pump
CLCS	Chemical looping combustion subsystem
PVS	Photovoltaic subsystem
DMS	Demo monitoring subsystem
CMV	Centralized Mechanical Ventilation
AHU	Air Handling Unit
HVAC	Heating, Ventilation and Air Conditioning
AHU	Air Handling Unit

3 Executive summary

The SCORES project has the aim of demonstrating hybrid energy production and storage technologies in the build environment at relevant scales. One of the demonstration sites of the SCORES technologies is located in the South of France, in Agen. In Agen, a new state of the art building will be constructed, comprising of 115 apartments and adjacent facilities.

The organization of the demonstration in the south of France is the subject of the work package 8 within the SCORES project. This deliverable (D8.7) aims to provide current status of the design of the SCORES demonstration B in the south of France (DEMO-B)

The SCORES demonstration system in Agen is seen on the one hand as the on-site demonstration where the SCORES technologies will be installed and tested under suitable scenarios.

The main objective of the demonstrator is to validate the implementation of the different equipment, to ensure the proper functioning of each piece of equipment over several months and to verify the feasibility of controlling them through a BEMS. The measurements carried out should also enable them to be compared with the digital model and to calibrate the model's consumption to actual consumption.

This document presents the characteristics of the different equipment, the method for calculating the technical, economic and environmental indicators, the difficulties encountered and the main results of the measurements in terms of thermal and electrical energy.

4 General description of demonstrator

The building selected for Demonstrator B (Figure 1) is a multi-family residence for seniors, located in the Eco-district “Le Parc du Canal” in Agen (France). Close to the city centre, this sustainable district is planned to integrate housing but also to be a technologic centre. The residence was built in 2018 by the project ownership AEGIDE DOMITYS.

Figure 1: view of the building (Source: DOMITYS)

This demonstrator is equipped with different technologies from the SCORES project:

- The space heating system is composed of two sub-systems. Firstly, the sub-system of SCORES technologies which is composed by the Electric Heaters Panels with Phase Changing Materials, named EHP, is installed in à 3-room apartment. This technology is developed by the partner CAMPA. Secondly, in parallel to the SCORES space heating technologies, the Installed Space Heating System (ISHS) will also be completely functional at the DEMO location in Agen.

- The Domestic Hot Water sub-system (DHWS) is developed by the partner HELIOPAC. This heat pump system draws renewable energy from aerial sensors coupled with a system of photovoltaic panels.

- The Electrical Battery sub-system (EBS) developed by FORSEE POWER is part of the electricity storage and conversion system. The EBS will be able to store electrical energy using second life Li-ion batteries.

- The Building Energy Management sub-system (BEMS) is part of the energy and data management system. The BEMS will direct the SCORES systems to have optimized self-consumption, self-generation and flexibility.

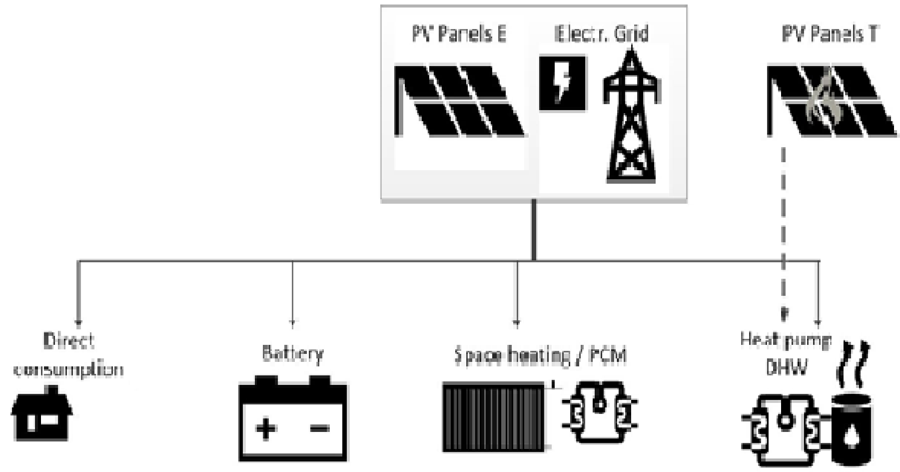

Figure 2 : System setup in demo B (Source: AEE / SIEMENS)

5 Detailed description of equipment

5.1 Installed Space Heating sub-System (ISHS)

5.1.1 Building

The heating and cooling of the building is supplied by a Variable Refrigerant Volume VRV MITSUBISHI Hybrid system and ensures the thermal comfort of the occupants whatever the season.

This system is composed by the following equipment :

- 1 Concealed ducted in ceiling of each apartment with centralized outdoor units
- 10 Outdoor Units (PURY P350 / P500)
- 10 Hybrid Branch Controller (1 HBC per floor/per wing)

The performance is detailed in the following

- Total Heat Power : 528 kWth
- Total Cooling Power 460 kWth
- COP : From 3.1 to 3.3 (20°C indoor/7°C outdoor)
- EER : From 2.5 to 2.7 (27°C indoor/35°C Outdoor)

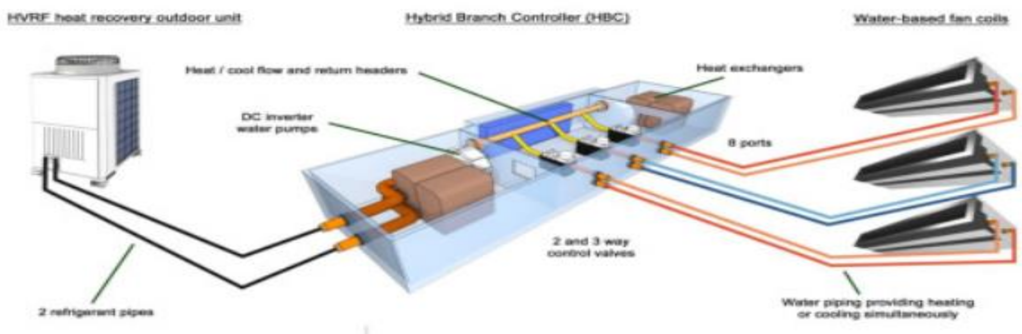

Figure 3 : View of the ISHS (Source: Mitsubishi)

5.1.2 3-rooms apartment

The 3-room apartment (006) is equipped with a Mitsubishi indoor unit that provides heating and cooling for the two bedrooms and the living-room / kitchen. During the test phases the BEMS will control the Mitsubishi unit to ensure that it will not operate simultaneously with the EHP. The electrical heater in the bathroom will continue operating during the test phases.

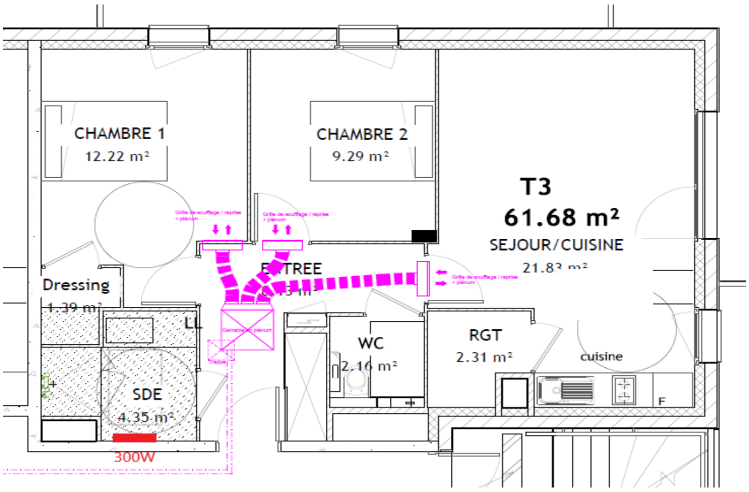

Figure 4 : ISHS in the 3-room apartment

5.2 Electric Heat Panels sub-system (EHPS)

The electric heater with PCM sub-system is part of the space heating system and will be demonstrated in the bigger apartment.

5.2.1 General description

The Electric Heater Panel (EHP) is an electric heater-based appliance that brings comfort into the home and that is enhanced with a storage capacity that can offer peak shaving, load shifting, self-consumption buffer storage services. From the user perspective, it’s a classic heating appliance installed in some or each of his rooms. He can choose his temperature setting and presence schedule.

Figure 5 : Photo of the EHP prototype (room apartment 6)

A PCM (Phase Change Material) is used in the storage core in order to have a higher energy density compared to generally used material in storage heaters such as cast iron or bricks. The PCM heat storage core has 2 dedicated heating elements for a total of 2kW. PCM is encapsulated in a shell that also has the function of heating element, container and heat exchanger. The PCM that will be used is erythritol.

The following elements of the system's environment have been taken in consideration during the design phase :

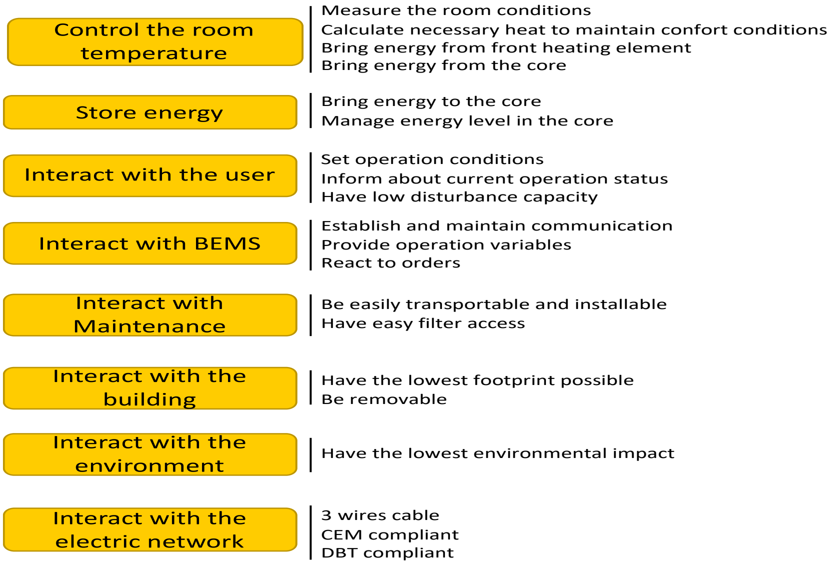

Figure 6 : Main functions of the EHP sub-system

5.2.2 Typical subsystem schemes

According to this functional analysis and to the technical knowledge of the company (Campa), the following components were chosen to achieve these functions:

- Storage Core with PCM (PCM + aluminium heat exchanger)
- Core heating element
- Core sensors
- Thermal insulation
- Wind turbine
- Air shutter system
- Front panel heating element
- Room sensors
- Controller

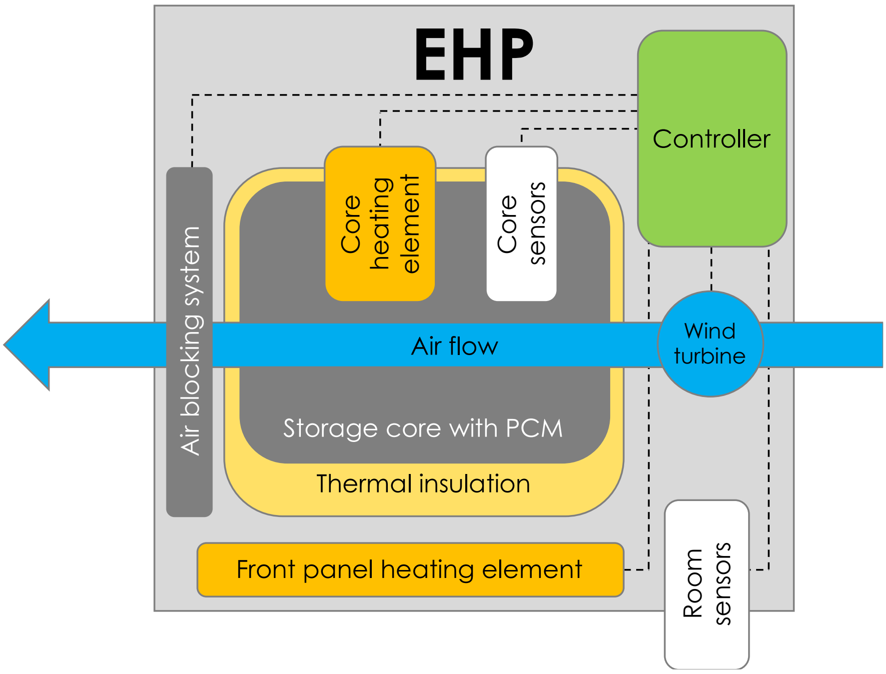

Figure 7 : General components scheme of the EHP sub-system

1- Control philosophy and operating conditions

To assure the 2 main functions of the system (heat up the room and store energy on demand), the EHP will use two control loops:

- The first one will be dedicated to the ambient room temperature control
- The second one will be dedicated to the core charge level management

2- Room temperature control loop – still in development

According to the information provided by the inhabitants (desired room temperature setting, presence information from the schedule) and from the BEMS, the appliance will release heat from its core or from its front panel heating element to reach and maintain the desired temperature in the room.

The appliance will ALWAYS provide enough heat to reach and maintain the desired temperature in the room as it is its main function and we don't want inhabitants to be dissatisfied with their heating system due to lack of comfort.

Heat been released from the appliance to heat up the room ($P_{heating}$) will be determined according to this decision chart:

3- General system drawing

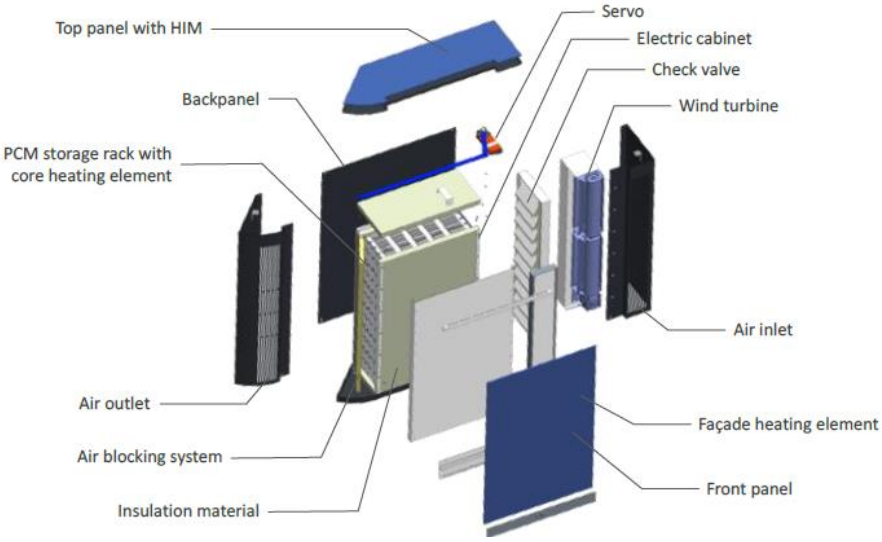

Figure 8 : Components of the EHP sub-system

4- Control philosophy and operating conditions

To assure the 2 main functions of the system (heat up the room and store energy on demand), the EHP will use two control loops:

- The first one will be dedicated to the ambient room temperature control
- The second one will be dedicated to the core charge level management

5- Room temperature control loop – still in development

According to the information provided by the inhabitants (desired room temperature setting, presence information from the schedule) and from the BEMS, the appliance will release heat from its core or from its front panel heating element to reach and maintain the desired temperature in the room.

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Heat been released from the appliance to heat up the room ($P_{heating}$) will be determined according to this decision chart:

The detailed strategy to determine how much energy has to be placed in the heat storage core still has to be determined with IPS / EDF / SIE / CAM. It will mostly depend on:

- current core charge status
- current and expected PV production ($P_{PV\ available}$)
- current and expected room heating needs over the day / next day (weather forecast, occupancy schedule)

- expected events for grid services like peak shaving / low CO_2 electricity available on the grid / …

If we assume that the information been exchanged between the BEMS and the EHP is expected energy consumption to heat the room for the next 8h $E_{heating\ 8h}$ (still has to be determined), the control algorithm may look like this:

The choice for the control electronics platform isn't made yet and different options are still been studied including:
- Use of a SIEMENS PLC
- Use of an existing controller
- Use of an IOT prototyping platform

5.2.3 Expected main performance and physical characteristics

The characteristics of the equipment are detailed in the table 1

Table 1 : Summary of the main physical characteristics

Characteristic	Value	Unit
Height (max.)	1000	mm
Width (max.)	1200	mm
Depth (max.)	250	mm
Input voltage	230	V(AC)
Rated electrical power (max.)	2000	W
Maximum surface temperature	90	°C
Maximum air outlet temperature	110	°C
Maximum inside temperature	200	°C
Stored energy quantity (max.)	4	kWh
Heat output (max.)	1000	W
Full charge time (max.)	150	min
Full discharge time (min.)	240	min
Energy losses after 2h	15	%
Energy losses after 6h	40	%

5.3 Domestic hot water sub-system (DHWS)

5.3.1 General description

The domestic hot water system (DHWS) of the SCORES system B is composed of two sub-systems, working closely together to meet the domestic hot water need of the building in Agen. The sub-systems part of the DHWS include two SCORES technologies: the PVT subsystem and the water-water heat pump subsystem.

The Domestic Hot Water subsystem (DHWS) is a centralized water heating system. It is an assembly of water-to-water heat pumps, a short time buffer storage, a back-up system (electrical component, boiler, other) and several hydraulic components (pumps, valves, heat exchangers, expansion tank, etc.). It also comes with its own control cabinet and energy meters.

The thermal source of the heat pumps is photovoltaic and thermal (PV/T) collectors. These hybrid collectors warm a mix of water and mono propylene glycol (MPG) water passing through a heat exchanger located under the photovoltaic cells. the PV/T panel collect energy from the sun during daytime but also from the air allowing the system to run day and night regardless of the weather conditions.

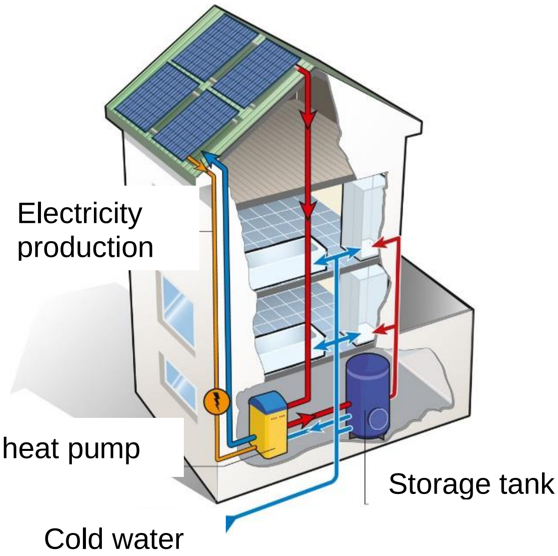


Figure 9 : Domestic hot water subsystem and PVTs

The WHPS produces all year long hot water for a DHW use only.. It is dynamically stratified in order to improve the efficiency of the heat pumps.

The thermal source of the heat pumps is photovoltaic and thermal (PV/T) collectors. These hybrid collectors heat a mix of water and mono propylene glycol (MPG) water passing through a heat exchanger located under the photovoltaic cells. the PV/T panel collect energy from the sun during daytime but also from the air allowing the system to run day and night regardless of the weather conditions.
Connected to the BEMS, the WHPS contributes to optimize the energy consumption by collecting and storing renewable energy when it is the most relevant.

5.3.2 Typical subsystem schemes

The water-to-water heat pump system provides the domestic hot water for the building and is made of several components: the heat pumps themselves, the hot water buffers storing the water heated by the heat pumps until it is used by the inhabitants of building, an electrical backup system and all the control components (valves, sensors, electrical cabinet, ..).

The complete list of components included in the WHPS designed to cover the DHW demand of Demo B building is given below:

- 2x 2 500L water vessel

- 1x 2 000 L water vessel
- 3x 12kW water to water heat pumps
- Electrical components (2x 20kW and 2x 15kW)
- 1x Electrical cabinet
- Temperature sensors
- 3x Energy meters (DHW demand, Distribution thermal losses, solar energy)
- 3x Power meters (HP consumption, backup consumption, auxiliary consumption)
- 6x variable flow pumps
- 2x motorized valves
- 1x Expansion vessel
- 1x heat exchanger
- Plumbing components (valves, ..)
- 1x heat exchanger
-

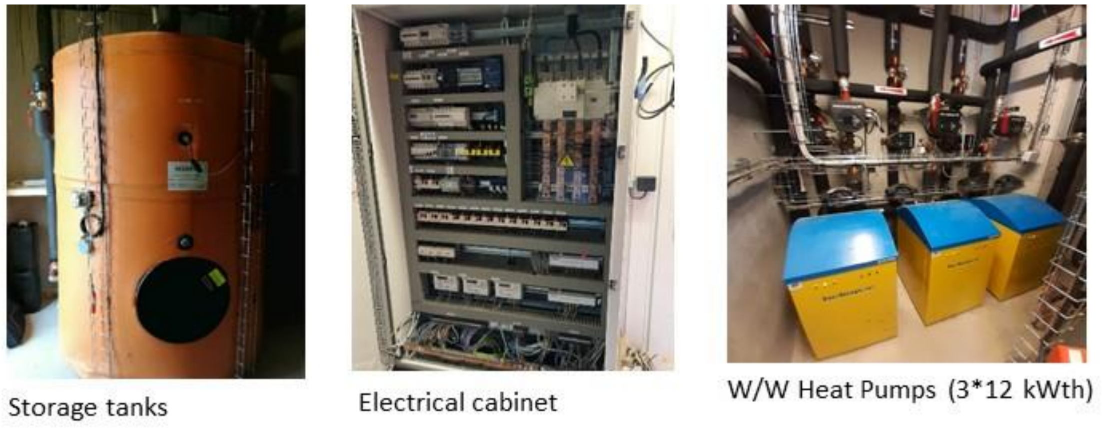


Figure 10 : Photo of the DWHS

The DHW system is composed of three heat pumps of 12 kW of thermal power each supplying three hot water tanks. Each tank is equipped with a back-up heater which operates in support of the heat pump in case of maintenance or failure of the heat pumps. The cold source of the heat pumps is composed of collectors (capillaries) which are connected to the underside of the photovoltaic panels. The first two 2500 litres tanks are used to prepare hot water. The last 2000 litres tank is used to maintain the temperature in the building's circulation loop

The PVT sub-system is part of the domestic hot water system but it is closely related to the electrical storage and conversion system.

The PVT subsystem is made of 129 solar photovoltaic and thermal panels. They produce electricity and provide thermal energy to the W/W heat pumps. Only the electric part of the subsystem will be described in this document. The peak power of the complete subsystem is 36 kWp (129 PVT panels x 280 Wp).
PVT panels produce electricity. This energy can be directly consumed by the equipment of the building like the other SCORES technologies or it can be stored with the electric batteries in order to be used later. If the batteries are loaded and the electricity cannot be consumed by the building equipment then the electricity is injected into the grid.
The electricity production depends on the weather conditions. The electricity produced is delivered to the building electricity distribution network or to the batteries by the converter. If the electricity is injected into the building electric circuit the current is converted in AC by the converter.

An energy meter is positioned on the cold source and alloy to measure the renewable energy from the captors. Another energy meter measures the Hot water energy needed and a third meter measures the losses of the distribution circuit. The electric meters measure the consumption of the heat pumps and back-up heaters. There are also numerous temperature sensors to monitor the operation of the system.

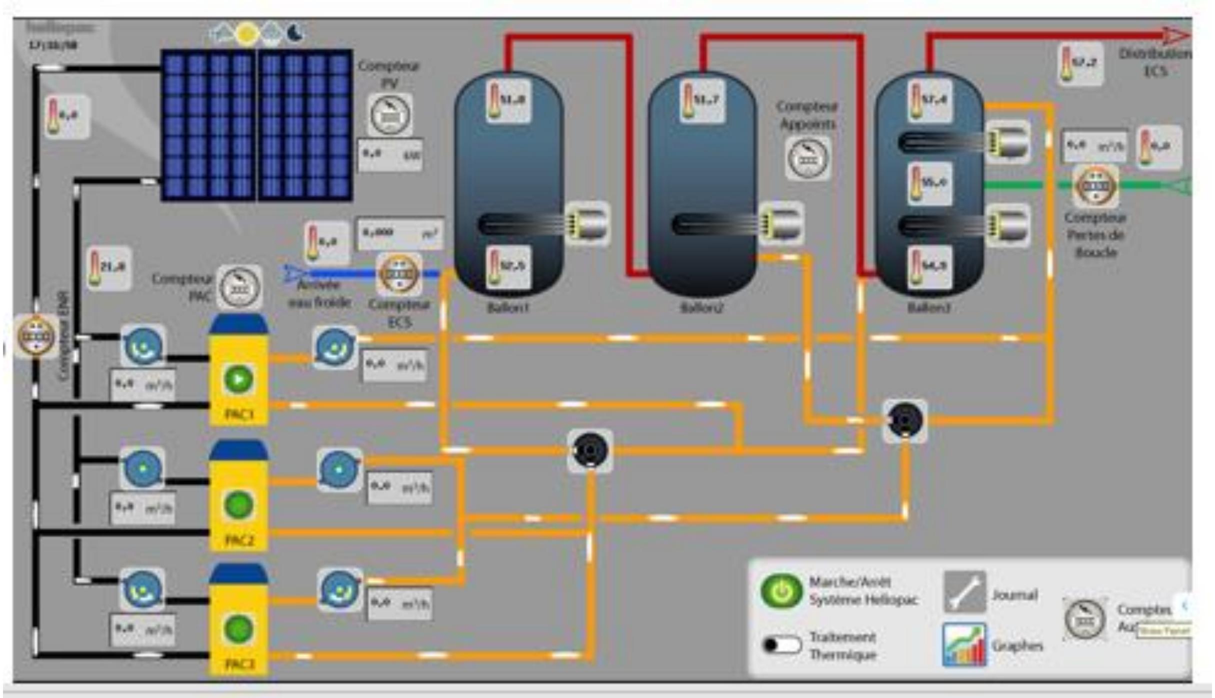


Figure 11 : scheme of the installation

5.3.3 Expected main performance and physical characteristics

<u>Heat pumps :</u>

Table 2 : Summary of the expected performance characteristics of the heat pumps

	unit	*value*
Certified data (glycol water - water)		
Heat capacity		
10 / 7°C - 40 / 45°C	*kW*	12.03
10 / 7°C - 55 / 65°C	*kW*	11.61
Power consumption		
10 / 7°C - 40 / 45°C	*kW*	3.15
10 / 7°C - 55 / 65°C	*kW*	4.19
COP		
10 / 7°C - 40 / 45°C	-	3.82
10 / 7°C - 55 / 65°C	-	2.77
Operating limits		
Min / Max source temperature	*°C*	-5°C / 75°C
Max load temperature	*°C*	65°C
Water hardness	*°F*	12 to 15°F

<u>Storage tanks:</u>
The storage will consist of 2x 2500L and 1x 2000L storage vessels in thermo-lacquered steel, equipped with a 100 mm thick insulation. They will be equipped with a 400 mm access and a

directional water inlet. The thermal losses of the tanks (with insulation) according to EN 15332 are given below:

Table 3 : Estimated thermal losses of the tanks

Volume	Thermal losses
2000 L	1.21 kWh/day
2500 L	1.44 kWh/day

Electrical backup:

The backup consists of electrical components installed in the storage vessels. All of them have a maximum surface power of 12 W / cm². The total power of the electrical components is 70kW

Control cabinet :

The cabinet includes the power supply of the equipment and a regulation of the system. It controls the heat pumps and the pumps, operates the motorized valve. It also includes the energy and electrical consumption meters.

The cabinet will be powered by 380V (Three phases + ground + neutral). The total electrical power to be expected for the DHW subsystem is 85 kW.

The control cabinet has a touch interface allowing access to all operating parameters of the system

Photovoltaic Thermal subsystem

The Table 1Table 4 below give the physical characteristics for one PVT panel.

Table 4 : Physical characteristics of the PVT panels

Length	1677	mm
Width	990	mm
Thickness	45	mm
Weight empty / full	25 / 30	kg
Frame color / Backsheet	Black / Black	-

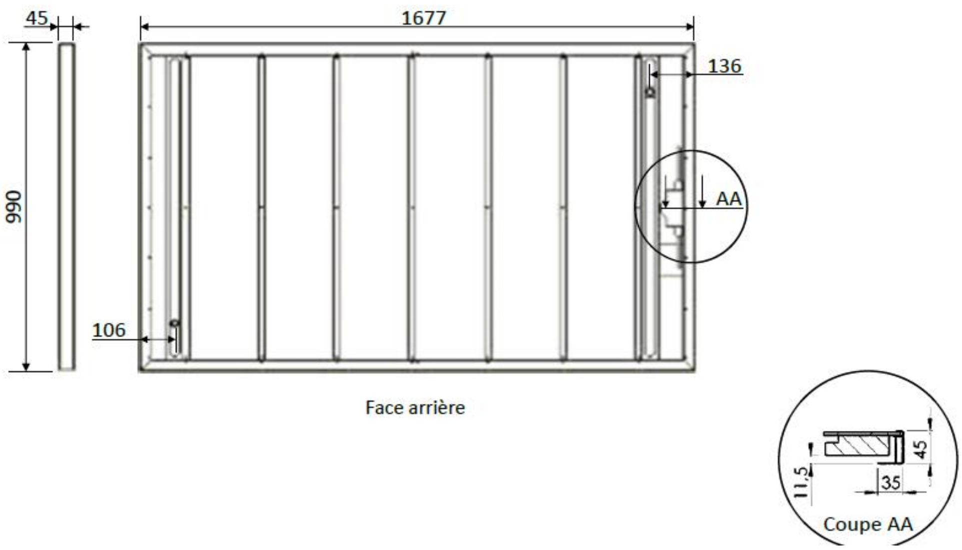


Figure 7. 1 Graphical representation of the PVT panels

The tables below give the thermal and PV performance characteristics for one PVT panel.
Thermal performance characteristics (Certification Solar Keymark – EN 9806)

Table 5 : Summary of thermal performance characteristics of the PVT panel

Gross area	1.65	m²
Volume of liquid	5	L
Stagnation temperature	70	°C

PV characteristics (certifications IEC 61215 and 61730)

Table 6 : Summary of PV characteristics

Number of cells	60	--
Cell type	Monocrystalline silicon	-
Nominal power (P_{mpp})	280	Wp
Efficiency	17.2	%
NOCT	46.9	°C

5.4 Electrical battery sub-system (EBS)

The electrical battery sub-system is part of the electricity storage and conversion system. The EBS will be able to store electrical energy using second life Li-ion batteries.

5.4.1 General description

The Battery Cabinet is controlled by the Electrical Converter Cabinet PLC.
The Battery Cabinet managed a battery system composed by:

- 10 Lithium-ion NMC battery modules of 7,1 kWh, configured as 2 strings parallels of 5 modules in serial connection
- 2 Battery Management System (BMS)
- 1 Master Battery Management
- 1 Power Distributor Unit Electric Box (PDU)

The batteries can be charge and discharge by the Electrical Convert Cabinet several times in a day. [1 cycle = 1 charge and 1 discharge]

5.4.2 Typical subsystem schemes

The Figure 12 shows the location of the different equipment :

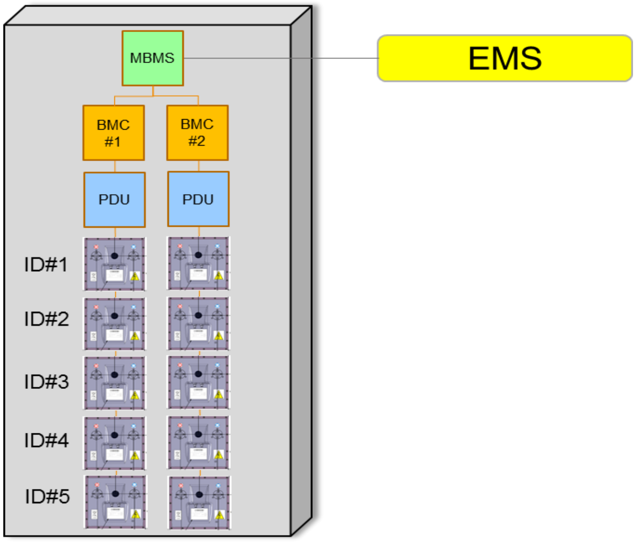


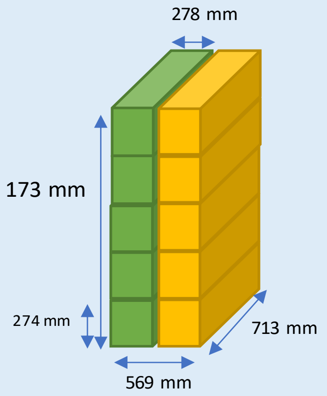
Figure 12 : Typical sub system scheme

5.4.3 Expected main performance and physical characteristics

The Table 7 gives the main characteristics.

Table 7 : Main performance characteristics of the Li-ion batteries

System configuration		5S2P	
Modules Quantity		10	
Main performance ** Figures garantee with external temperature = 25°*		**1st Life**	**2nd Life (1)**
Ambient temperature	°C	-10/ 35 °C	
Water cooling temperature	°C	15 / 25 °C	
Energy	kWh	**71**	**63,9**
Power (SOC = 50%)	kW	**178**	**160,2**
Voltage	V	**890**	**880**
Volume	L	550	
Current	A	200	
Cycles		8 000 cycles with 80 % DOD	? cycles with 80 % DOD
Long life duration		12,5 years	? years
+ SOC = State of charge + DOD = Death			
Physical		**1st Life**	**2nd Life**
Weight	Kg	810	
Width (2)	mm	569	
Depth with connectors (2)	mm	713	
Height (2)	mm	1730	



2 strings of 5 modules
1st Life = 71 kWh
2nd life = 63,9 kWh
440 V
160,2 kW
400 A
2 BMS + 2 PDU + 1 MBMS are required

(1) Scenario 2nd life = Battery lost after 1st Llife = -10% energy, -10% power, -1 % Voltage.
(2) Dimensions minimum - Without cabinet

5.5 *Electricity converter sub-system (ECS)*

5.5.1 General description

The electricity converter makes the interface between the grid, the PV field and the batteries. This equipment is also connected to the BEMS but it has its own control however the main controlling is performed by the BEMS.

Figure 13 : Photo of the Electricity converter system (ECS)

5.5.2 Typical subsystem schemes

The figure Figure 14 shows the location of the different equipment :

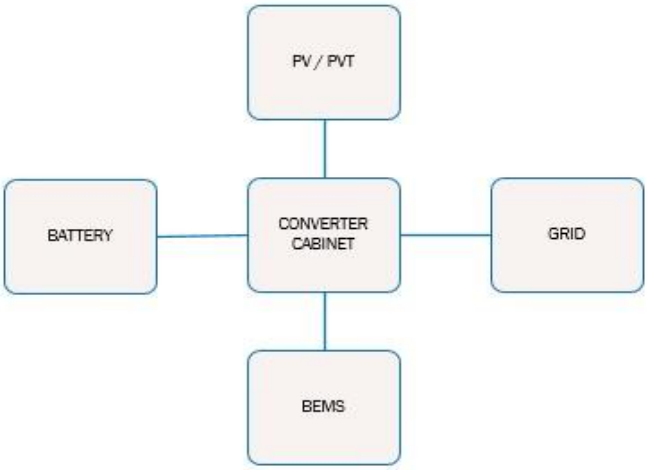


Figure 14 : Schematic of the connections of the ECS sub-system

5.5.3 Expected main performance and physical characteristics

The Figure 15 shows the dimension of the equipment :

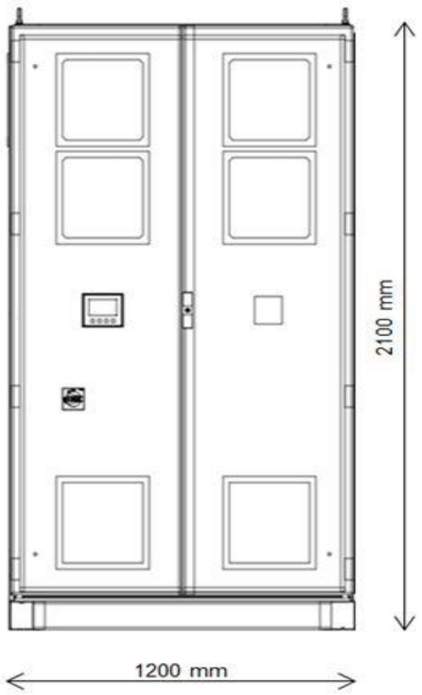


Figure 15 : scheme of the cabinet (ECS)

5.6 Building energy management sub-system (BEMS)

The building energy management sub-system is part of the energy and data management system. The BEMS will direct the SCORES systems to have optimized self-consumption, self-generation and flexibility.

5.6.1 General description

The BEMS consists of three components; the PX Controller (PXC), the Building Management System (BMS) and the Energy Management System (EMS). A more detailed description of these system components can be found in the following sections.

The BEMS will be implemented while the building is inhabited, this applies for all three demonstrations. The system will be designed to function in its envisioned environment and shall in general be compliant to the national and regional regulations.

The BEMS shall be designed in order to be accessible for maintenance, replacement and decommissioning. For the SCORES project all three components will be built together in one cabinet. At the end of the project the cabinets from the sites will be decommissioned.

The system will be able to give the operator insight into the system. The operator is a qualified person who is able to work and control the BEMS. The system notifies the operator on important warnings. The notifications will also be sent to the sub-system owners.

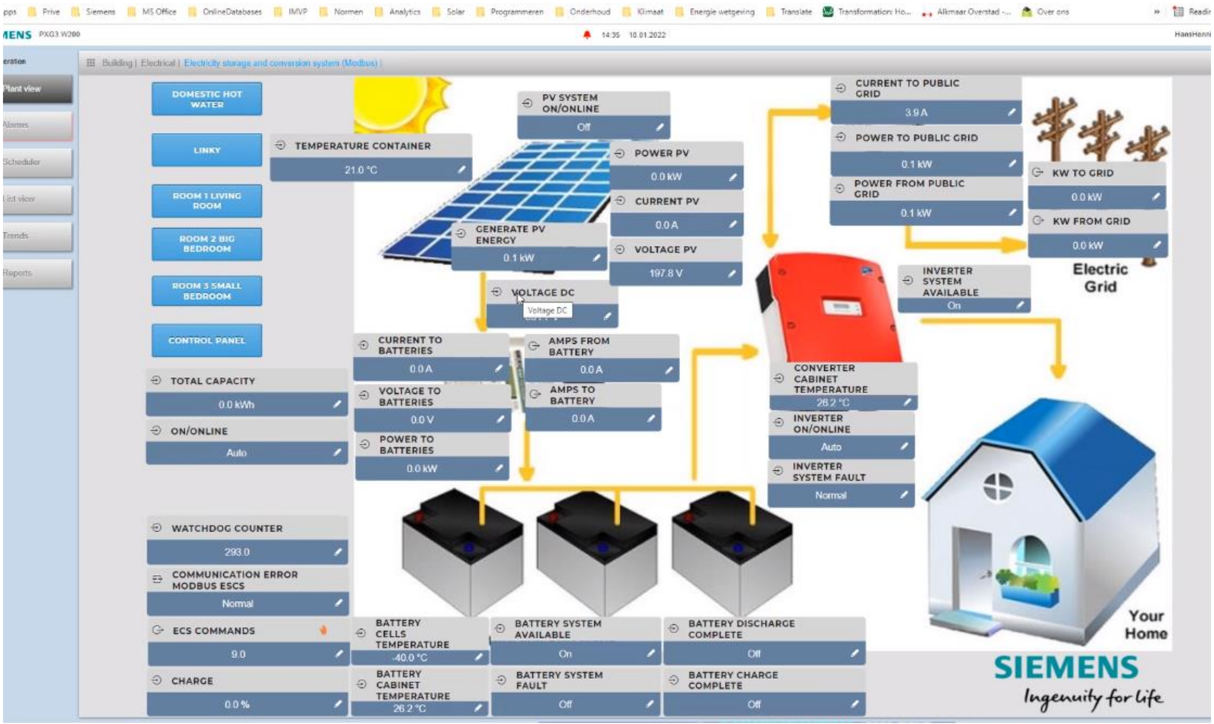


Figure 16 : Supervision interface diagram

5.6.2 Typical subsystem schemes

The system architecture gives an insight in the way the BEMS is built. In the middle of it you find the main block which contains “Building Energy Management Sub-System”. As mentioned before this block is made out of three components which all have a specific task in the total solution. The blocks consist of hardware and software components and shows which functionality they have. It also gives a clear view how the BEMS connects to the sub-systems and what type of interface is used. By using the system architecture the mutual relations between the BEMS and sub-systems can be seen and more clearly understood the components and its functions.

The BEMS has a web-interface for remote access and can be connected to one or more workstations. This gives the flexibility to access the system from various locations and have insight in their sub-systems.

The EMS and the BMS operate on the same level but they have different tasks. The EMS contains the algorithm, this is where the optimization calculations are performed.

The BMS gives insight into the actual status of the sub-systems and when an error occurs it sends notifications to the sub-system owners. The BMS is designed as a user-friendly environment.

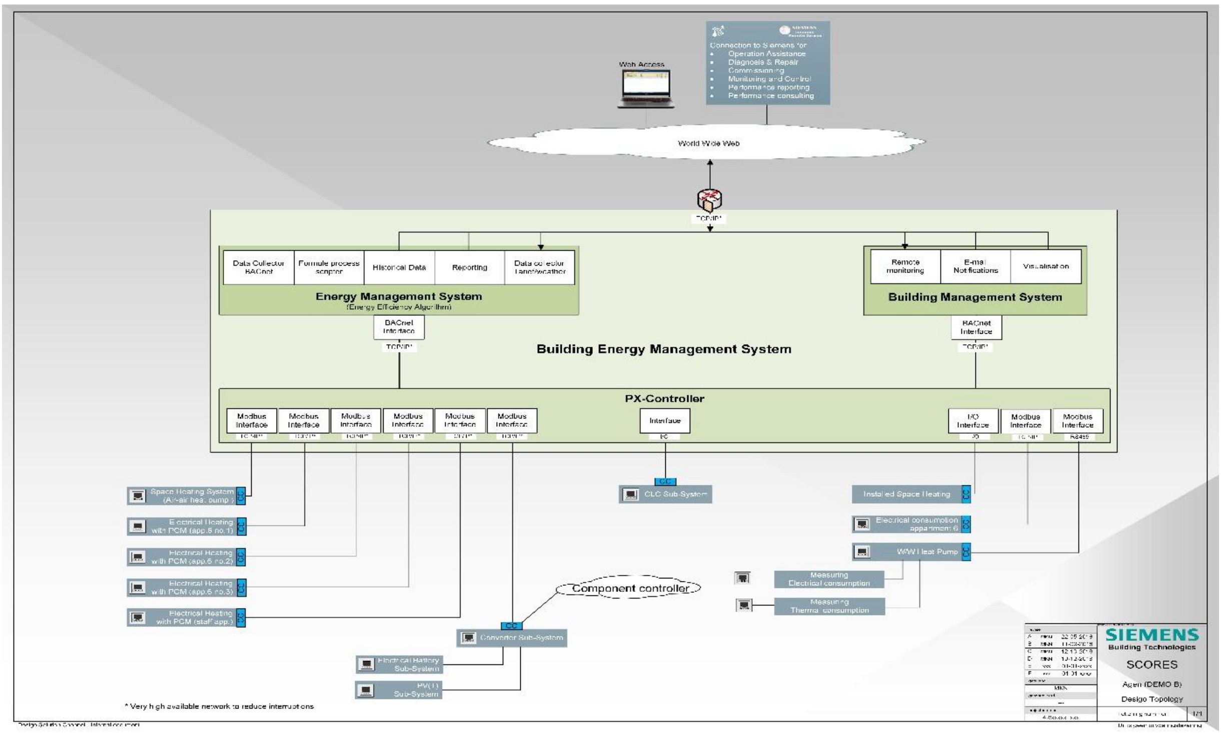


Figure 17 : BEMS interface

5.6.3 Expected main performance and physical characteristics

In **Error! Reference source not found.** 17, you see all the physical connections which the BEMS has. These connections are the cables which refers to the **Error! Reference source not found.**. This figure also shows the dimensions of the cabinet.

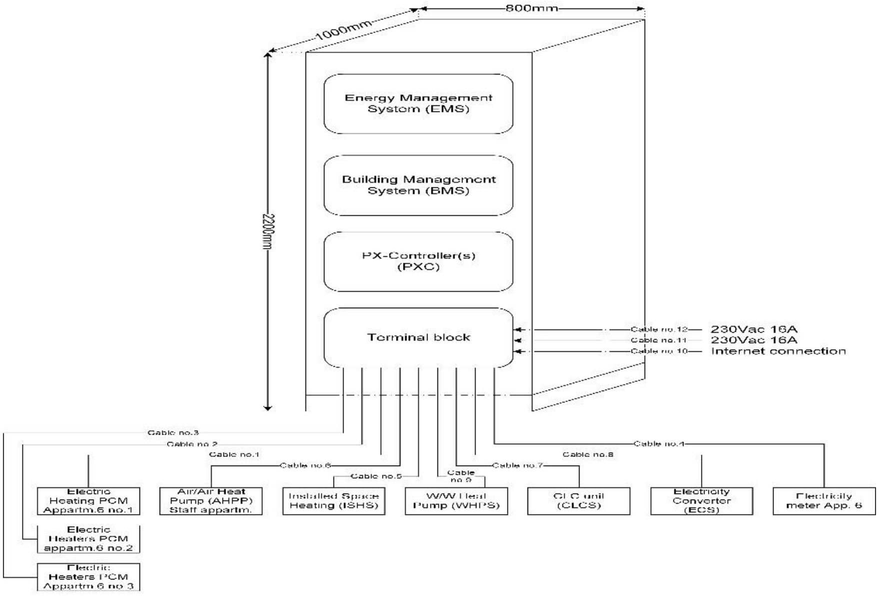


Figure 18 : Dimensions and connections of BEMS cabinet

6 Definition of key performance indicators

6.1 Selection procedure of relevant KPIs

KPIs are of relevant importance in order to define common indicators which can be used as parameters for developing the simulations and to summarize in a clear, measurable and communicable way the most important achievements of the project under technical, economic and ecologic point of view.

To achieve this objective, KPIs have been properly identified, starting from the analysis of past projects in which Rina Consulting was involved. Moreover, the two new demonstrators developed in the framework of the SCORES project have their own specificities and objectives in relation to the specific backgrounds in which they have been conceived and implemented.

An “equipment perimeter” has been defined: some indicators are evaluated at the building level (system level), others are evaluated at SCORES components level (sub system level).

Beyond the specific aspects analyzed for each implemented smart solution, the two SCORES demonstrators have been developed and demonstrated in two different climatic zones. They both aim to significantly reduce CO_2 emissions, reduce the use of electricity from the macrogrid and reduce the use of thermal energy from the DHN (district heating network).

The KPIs were preliminary defined by RINA and then shared among the partners involved EDF, AEE, TNO, HELIOPAC, SIEMENS, FORSEE POWER.

KPIs have been calculated for each demonstrator based on in-situ measurements.

6.2 Description of relevant selected KPIs

6.2.1 Energy indicators

Energy demand

- Useful energy demand

  The energy demand corresponds to the energy required by the system in order to keep operation parameters (e.g. comfort levels). The energy demand is based on the calculated (e.g. simulated) figures and on monitored data. To enable the comparability between systems, the total energy demand is related to the size of the system and the time interval. This indicator can be used to assess the energy efficiency of a system.

Impact on the building

- Energy reduction

  This KPI determines the savings of the energy consumption to reach the same services (e.g. comfort levels) after the interventions, taking into consideration the energy consumption from the reference period. Energy reduction may be calculated separately for thermal (heating or cooling) energy and electricity, or as an addition of both to consider the whole savings.
- Coverage rate

  The coverage rate (supplied by Renewable Energy Sources RES) is defined as ratio of locally produced energy from RES and the energy consumption over a period of time (e.g. month, hour). Coverage rate is separately determined for thermal (heating or cooling) energy and electricity. The quantity of locally generated energy is interpreted as renewable energy sources (RES) produced energy.
- Self-generation rate

  The self-generation rate (supplied by Renewable Energy Sources RES) is defined as ratio of locally consumed (self-generated) energy from RES and the energy consumption over a period of time (e.g. month, hour). Self-generation rate is separately determined for thermal (heating or cooling) energy and electricity. The quantity of locally consumed (self-generated) energy is interpreted as renewable energy sources (RES) produced energy.
- Self-consumption rate

  The self-consumption rate is defined as ratio of locally consumed energy self-generated from RES and the energy locally generated over a period of time (e.g. month, hour). Self-consumption rate is separately determined for thermal (heating or cooling) energy and electricity. The quantity of locally consumed energy is interpreted as renewable energy sources (RES) produced energy.
- Number of hours with possible self-sustainability

  Number of hours where there is no heat or electricity being taken from the grids for the given SCORES building.

Storage

- Amount of energy fed into the single storage technology
- Amount of energy taken from the single storage technology
- State of charge of the single storage technology

Interaction with the electricity grid

- Percentage of electrical energy injected into the power grid
- Peak demand on the grid.
  This indicator identifies the average strong consumer demand for a defined period of time.
- Auxiliary energy used for transportation of energy
  It can be both electrical and thermal energy according to the reference technology.

Table 8 : Technical indicators

KPI	Formula	Units	Description
Useful thermal energy demand	$E_{dt} = \frac{(TE_d)}{A_b}$	kWh/ m²	E_{dt} Thermal Energy demand (monitored) EE_d Electrical energy demand (monitored) [kWh/(hour)] A_b : living space of the building [m²]
Useful electrical energy demand	$E_{de} = \frac{(EE_d)}{A_b}$		E_{de} Electrical Energy demand (monitored) EE_d Electrical energy demand (monitored) [kWh/(hour)] A_b living space of the building [m²]
Electrical energy reduction	$EE_s = EE_r - EE_c$	kWh/m² or %	EE_s Electrical energy savings EE_r Electrical energy reference demand or consumption (monitored) of the demonstration-site [kWh/(m² hour)]. EE_c Electrical energy consumption of the demonstration-site [kWh/(m² hour)] This KPI can be expressed also in % of reduction, in accordance to DoW specifications.
Coverage rate (electrical)	$CR_{EE} = \frac{LG_{EE}}{EE_c}$	%	CR_{EE} Coverage rate of electrical energy based on RES LG_{EE} Locally generated electrical energy [kWh/hour] EE_c Electrical energy consumption of the demonstration-site [kWh/hour]
Self-generation rate (electrical)	$DG_{EE} = \frac{LC_{SGEE}}{EE_c}$	%	DG_{EE} Degree of electrical energy self-supply based on RES LC_{SGEE} Locally consumed (self-generated) electrical energy [kWh/hour] EE_c Electrical energy consumption of the demonstration-site [kWh/hour]
Self-consumption rate (electrical)	$DC_{EE} = \frac{LC_{SGEE}}{LP_{EE}}$	%	DC_{EE} Degree of electrical energy self-consumed based on RES LC_{SGEE} Locally consumed (self-generated) electrical energy [kWh/hour] LP_{EE} Locally generated electrical energy [kWh/hour]
Percentage of electrical energy injected into the power grid	$G_{EE} = \frac{LP_{EE} - LC_{SGEE}}{LP_{EE}}$	%	G_{EE} Percentage of electrical energy injected into a heat district network LP_{EE} Locally generated electrical energy [kWh/hour] LC_{SGEE} Locally consumed (self-generated) electrical energy [kWh/hour]

Number of hours with possible self-sustainability		h	Number of hours where there is no heat or electricity is being taken from the grids for the given SCORES building
Peak demand on electricity grid		kW	This indicator identify the average strong consumer demand (electric energy) for a defined period of time

6.2.2 Environmental indicator

The indicator provides information on the level of direct greenhouse gas emissions and is expressed in kg of CO_2 equivalent. Each energy source has a conversion coefficient that transforms kWh of final energy (net calorific value) into kg equivalent CO_2.

According to the Europe an Environment Agency[1] the conversion factors are given in the following list :

- Electricity from Grid* : CF = 0.0585 kgeqCO_2/kWhfe (for all uses)

* Electricity from Grid and except self-consumption from Photovoltaic Production

Table 9: Environmental indicators

KPI	Formula	Units	Description
Potential GHG emission	PGE = Energy saved * CF	kg CO_2 eq./year	Evaluation of the potential GHG emissions related to the SCORES system. The evaluation is based on the increase/reduction of electricity imported from the grid.

6.2.3 Economic indicators

The evaluation of the economic indicators will be performed based on the economic data provided by the demonstrators' responsible partners on the following cost category: investment cost, depreciation time, operating costs, maintenance costs, savings/revenues deriving from the operation of the demonstrator:

- Hourly total cost to supply the buildings needs
- Net present value (NPV : NPV Net Present Value is the present value of an investment by the discounted sum of all cash flows received from the project
- Internal rate of return (IRR) of the new investment;
- Return Of Investment (ROI) : Demonstration of the economic viability of the overall storage systems with return of investment of less than 20 years and proof of the

[1] https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-5

potential for market penetration. The cost of the kWh of electricity is fixed at 0.15 € VAT (assumption flat tariff)

A detailed description is given in table 10.

Table 10: Economic indicators

KPI	Formula	Units	Description
Hourly total cost	$Q_{year,DH} = \sum_{year} Q_{sector,DH}$	€/h	Overall cost to supply buildings needs for an hour Hypothesis : flat tariff included all taxes : 0.15 € / kWh
Net present value (NPV)	$NPV = -C_0 + \sum_{i=1}^{T} \frac{C_i}{(1+r)^i}$	€	NPV Net Present Value is the present value of an investment by the discounted sum of all cash flows received from the project $-C_0$ Initial investment [€] C_i Cash flow [€] T Duration of the project r Discount rate
IRR	$IRR = r_a + \frac{NPV_a(r_b - r_a)}{(NPV_a - NPV_b)}$	%	IRR Internal rate of return (IRR) of the new investment NPV_a NPV using lower discount rate NPV_b NPV using higher discount rate r_a lower discount rate r_b higher discount rate
return of investm ent	*ROI = CAPEX (€) / yearly Savings (€/year)*	years	Demonstration of the economic viability of the overall storage systems with return of investment of less than 20 years and proof of the potential for market penetration

7 Availability of data for the calculation of indicators

During the commissioning and testing phase of the demo system, a number of technical and operational difficulties were encountered, which is not uncommon when new technology is developed and integrated. However in addition the COVID-19 pandemic that we experienced forcefully limited the number of on-site interventions and trips, since travel to the demo sites was not allowed or very difficult for more than a year.

As a result, there is a lack of available data from the BEMS which makes it difficult to analyze system performance. This lack of data is related to several technical events:

- Delay in the delivery of the batteries
- Communication problems between battery and cabinet
- Communication problem between PV production and cabinet

7.1 Commissioning history

March 2019 : First phase of commissioning with the installation of the domestic hot water production system and the connection of the PV production to the inverters of the HELIOPAC system. This system was put into production at the same time as the reception of the building.

November 2019 : Decommissioning of the PV production and removal of the HELIOPAC inverters. Waiting for the inverter cabinet of the system scores.

February 2020: The first commissioning took place in (just before the first COVID-19 related confinement) with the following events:

- Delivery and installation of the BEMS cabinet
- Reception and installation of the EHP in the model apartment.
- Electrical connection and connection to the communication bus of the BEMS
- Configuration of the tariff meter and transfer to the BEMS for the follow-up of the consumption of the apartment.
- Installation of an on/off switch on the ISHS. This switch, remotely controlled by the BEMS, allows the ISHS to be turned off while the EHP tests are in progress. It also allows the ISHS to be turned back on automatically after the EHPs are turned off.

June 2021 : Delivery of the batteries and installation. function test. connection of the electric cabinet, the PV production, the battery for production and storage.

November 2021: Data feedback from the different systems is available from BEMS. Verification of the consistency of the data going back to the BEMS before starting any analysis. Inconsistencies were found in the PV generation and battery storage data.

7.2 Data Checklist

The storage system seems to have worked for a few days in November. Despite numerous tests and troubleshooting (neutral regime, communication fault...), the data feedback did not allow us to analyse the functioning of the following system to date.

Table 11: Data check list

Equipment	Status on 2022/02/16	Status as of end of March, 2022
Battery storage	Status to be confirmed with ForseePower	Does not work
PV Production	Status to be confirmed with Siemens / HelioPac	There are still communication problems – Data is not exploitable
Impact on grid	Require data on the ECS from the BEMS	ECS data from the BEMS consistency

The available and exploitable data's concern the following equipment's:
- Electric Heat Panels
- Domestic Hot water
- Meter from apartment
- Weather API

In parallel to the SCORES project, EDF R&D has instrumented the building and set up a consumption monitoring system which allows to draw up a consumption balance for the different uses of the building and the load curve of the tariff meters of the building.

7.3 impact of the lack of data on the calculation of KPIs

In the absence of usable data on photovoltaic production and energy stored in the batteries over a sufficiently long period of time (from November to February), it was not possible to calculate certain KPIs. This is the case in particular for the following technical KPI's:
- Coverage rate (electrical)
- Self-generation rate (electrical)
- Self-consumption rate (electrical)
- Percentage of electrical energy injected into the power grid
- Number of hours with possible self-sustainability
- Peak demand on electricity grid

Moreover, the calculation of the annual environmental and economic KPI's was possible on the DHWS system for which we had sufficient historical data (more than 1 year).

Notes :

These data come mainly from the complementary instrumentation of the building which had been set up by the project owner AEGIDE DOMITYS according to the recommendations of EDF R&D. Indeed, these metering by uses were installed in order to respect the metering requirements fixed in force in France by :
- The 2012 thermal regulation on the thermal characteristics and energy performance of buildings (http://rt-re-batiment.developpement-durable.gouv.fr)
- The Decree No. 2016-710 of May 30, 2016 on the individual determination of the amount of heat consumed and the apportionment of heating costs in collective buildings (https://www.legifrance.gouv.fr).

In addition, with the agreement of this project owner, we were able to access the consumption and load curve data of the two tariff meters serving the building.

8 Main results on the demonstrator

8.1 Technical KPIs

8.1.1 Building

The building consumption on 2021 amounts to 636 MWhfe/year or 98 kWhfe/m².y in final energy. This consumption doesn't include the consumption of Domestic electricity consumption of each apartment, which in counted separately.

The Variable Refrigerant Volume VRV system for heating and cooling the building accounts for the largest share of consumption with respectively 147 MWhfe/y (23 kWhfe/m².y) for the estimated part of heating and 76 MWhfe/y (12 kWhfe/m².y) for the estimated part of cooling.

The domestic hot water DHW represents 88 MWhfe/y (13 kWhfe/m².y). This consumption corresponds to the HELIOPAC system consumption and the other hot water systems of the building (as pool shower, hairdresser, laundry room).

The cooking and restaurant[2] consumption presents an important part which amounts to 82 MWh/y.

[2] In SCORES the energy consumption of the building is limited to residential areas only (i.e excluding the restaurant, pool etc)

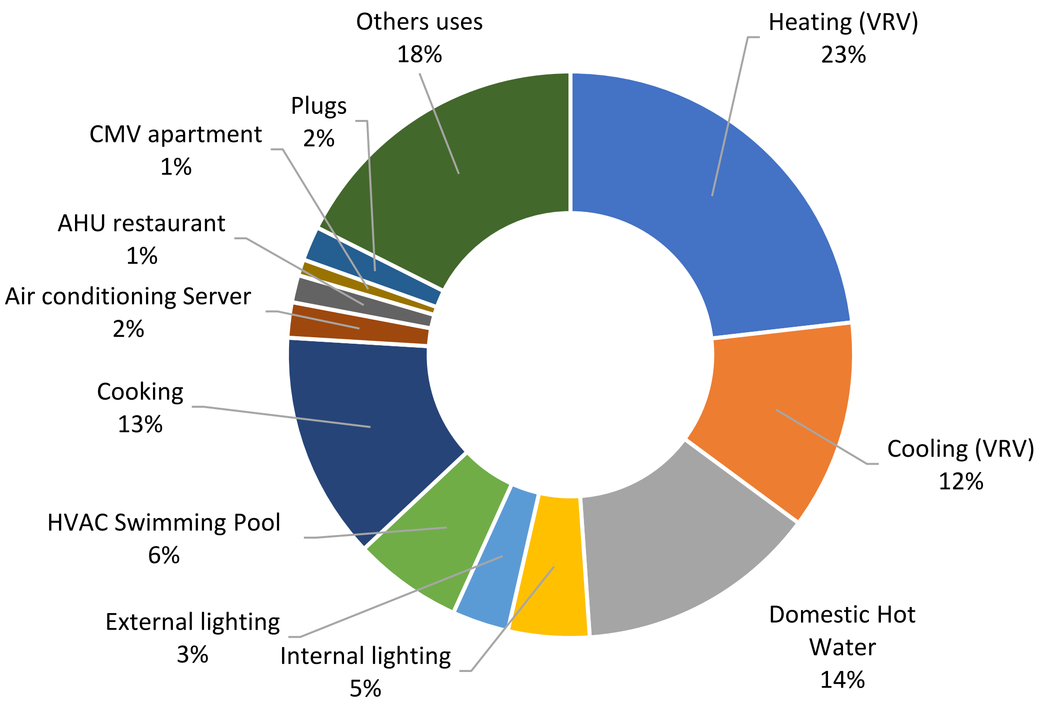


Figure 19 : Useful electrical energy demand by uses (Electrical counters S01 and C01- 2021)

Table 12 : Consumption per uses

Uses	EEd (MWh/y)	Ede (kWh/m².y)
Heating	148	23
Cooling	76	12
Domestic Hot Water (HELIOPAC + Others)	88	13
Internal lighting	30	5
External lighting	21	3
HVAC Swimming Pool	39	6
Cooking	83	13
Air conditioning Server	13	2
AHU restaurant	10	2
CMV apartment	6	1
Plugs	12	2
Others uses	111	17
TOTAL	637	98

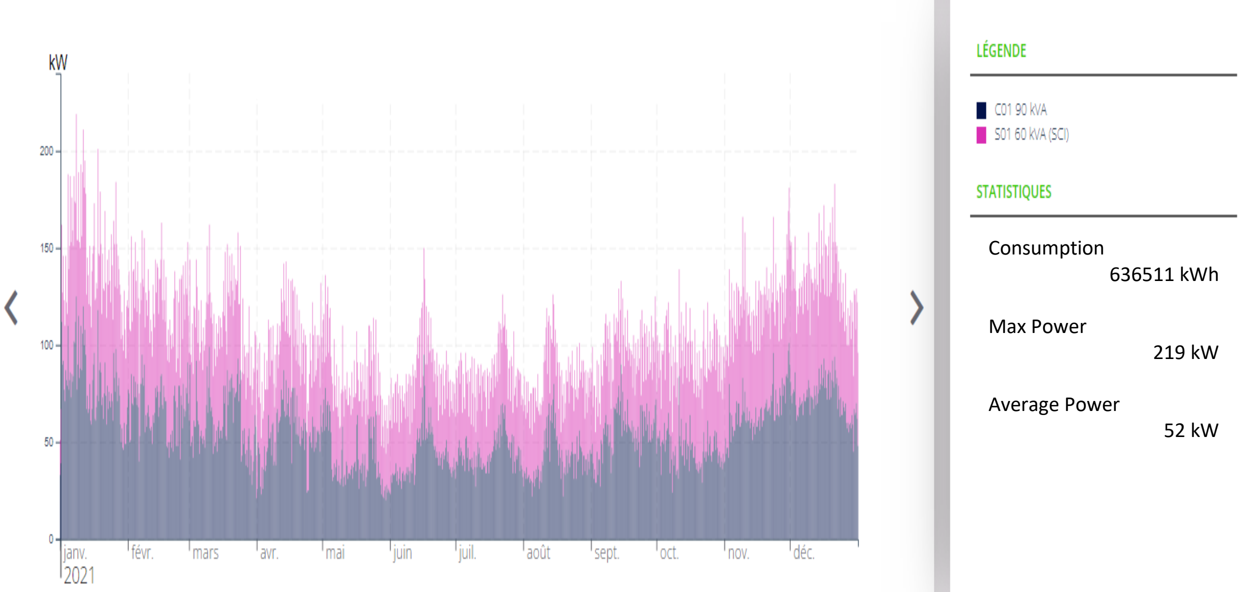


Figure 20 : Aggregate of the two tariff meters C01 90kVa and S01 60 kVA

Buiding Peak demand on electricity grid : 219 kW (33 W/m²)

8.1.2 Electric heaters panels (3-rooms apartment)

Load curve

The graph below shows the evolution of the load curve for each EHP over one week in winter (from November 27 to December 3)

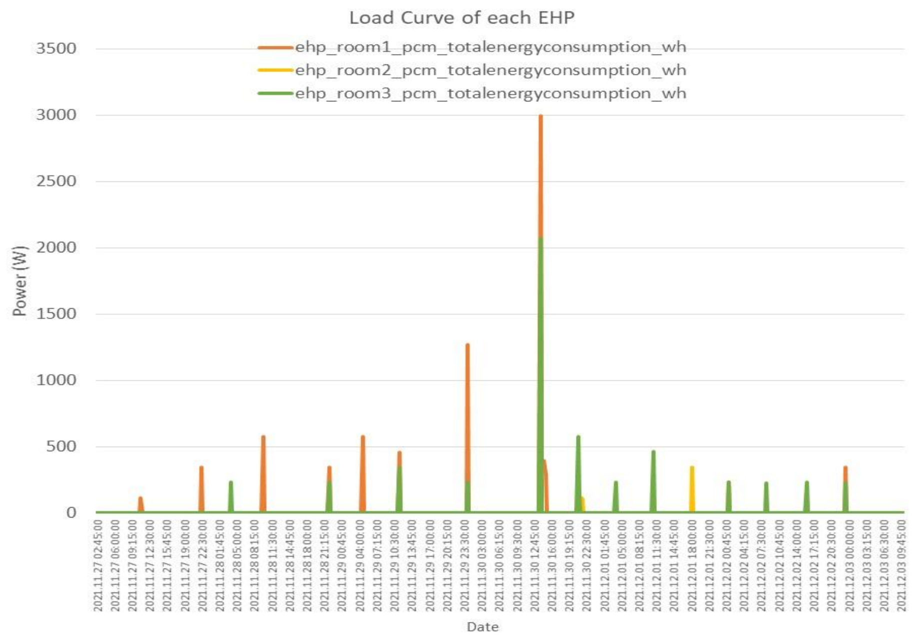


Figure 21 : Evolution of the load curve for each EHP

State of charge

The graph below shows the evolution of the core charge level and the core element duty rate (from january 5 to 7). The core recharges when the duty rate setpoint asks the core to charge. This set point will be addressed by the BEMS according to the PV production, the energy cost and the weather forecast. Should be noted that the BEMS never charged the PCMs based on PV production or user demand in reality. These charges were just carried out manually to see the behavior.Then, the core will keep its heat or will be discharged according to the heating demand of the room.

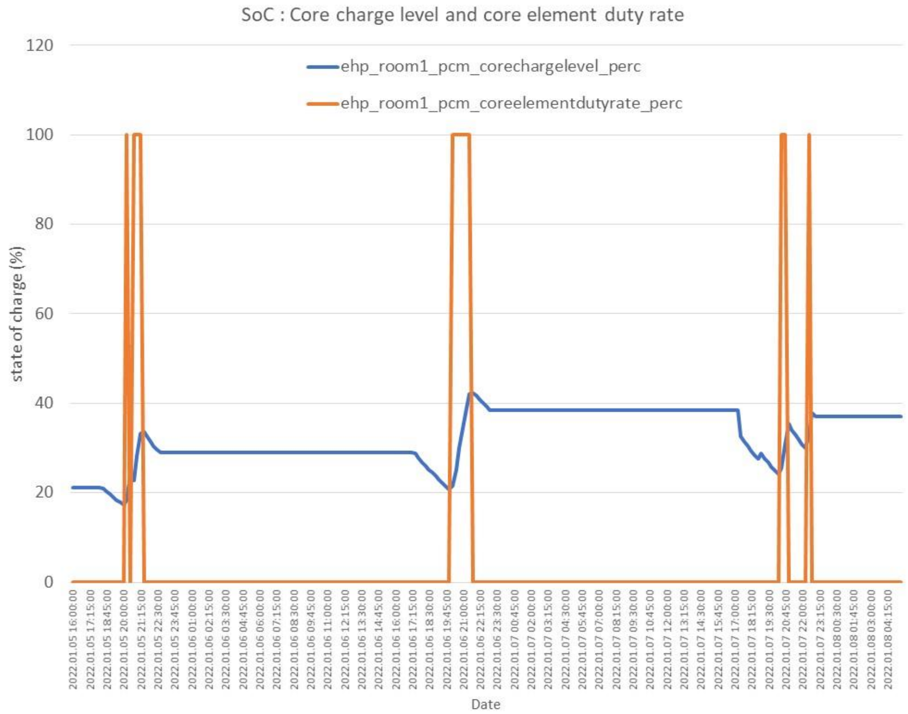


Figure 22 : evolution of the core charge level and the core element duty rate

8.1.3 Domestic Hot Water

The following graph details the monthly consumption and the Coefficient Of Performance of the system which is given by the relation :

COP = Heating supplied by the system / Electric consumption of the system

The average annual COP reaches the value of 2. This means that 1 kWh consumed produces 2 kWh of thermal energy

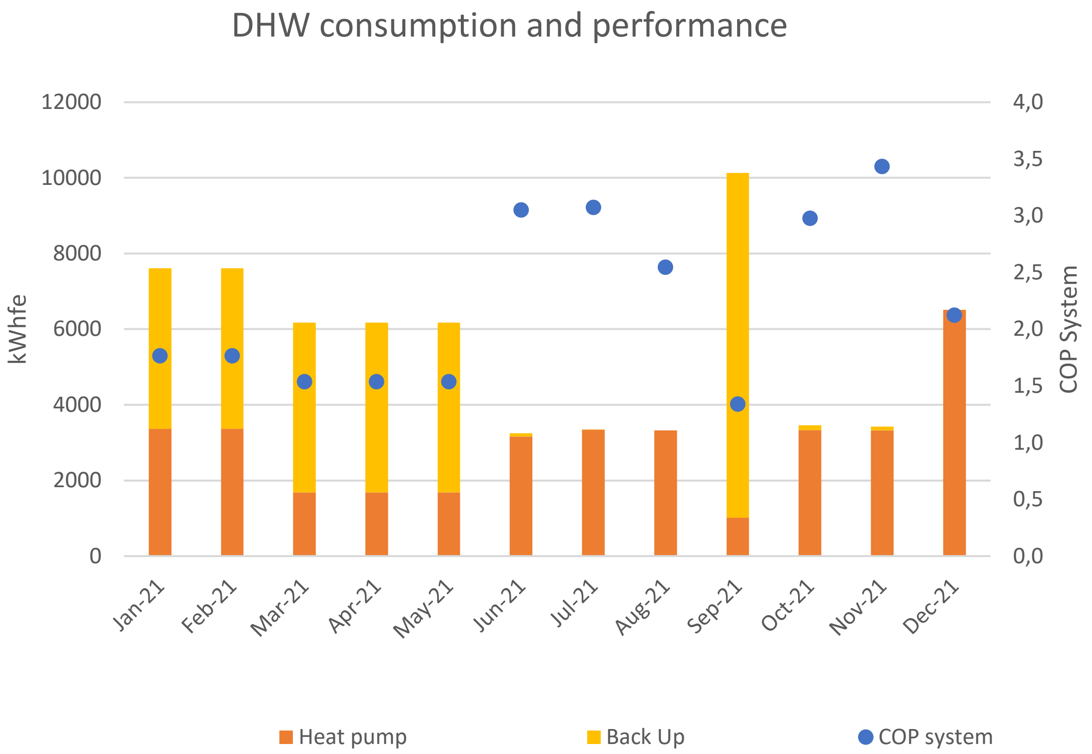


Figure 23 : Monthly evolution of DHW consumption and performance

The COP reached a value of 2.0 over the year and corresponds to the operation of the heat pumps and the back-up heating units of each storage tank. When the heat pumps malfunctioned, the back-up heaters worked well to ensure the necessary production but resulted in a deterioration of the COP. Indeed, the COP takes into account the consumption of the heat pumps and theses back up heaters. The heat pump operating problems were linked to regulation faults which have been resolved in the last 3 months of the year.

It is possible to compare the SCORES DHW system with a conventional hot water production system such as an electric boiler (baseline in our case).The efficiency values of the reference system are taken with a production efficiency of 0.95 (from 8.4). For the case of the Demo B Heat Pump system, In order to take into accounts the consumption of the pump to circulate the fluid in the cold source, the measured Coefficient Of Performance is degraded by 10%. Thus, the two systems are comparable, all other things being equal. The input data are detailed in the table below

Table 13 : Technical KPI - DHWS

KPI – Technical - DHW 2021	Baseline	SCORES DHW
Energy efficiency (.)	0.95	1.8
Thermal Energy need (kWh thermal)	133367	133367
Electric consumption (kWh)	140386	74093
Electric Energy saving EEs (kWh)	66294	
Electric Energy saving EEs (kWh/m2)	10	

The energy saving reached to 66 MWh or 10 kWh/m² either 12% of energy saving regarding the total consumption of the building.

8.2 Environmental KPIs

8.2.1 Building

The carbon emissions, excluding domestic electricity of each apartment, reach almost 41 teq CO2 per year or 6.2 kgeq CO2/m².

Table 14 : Environmental KPI - Building

KPI - Environmental	SCORES
Total Electric consumption (kWh/year)	636550
Total Green House Emissions (kg CO2 eq./year)	40739
Green House Emissions per sq.m (kg CO2 eq./m².year)	6.244

8.2.2 Domestic Hot Water

It is possible to compare the HELIOPAC system with a conventional hot water production system such as an electric boiler (Reference for the simulation in our case).The efficiency values of the reference system are taken with a production efficiency of 0.95 (from 8.4). For the case of the Demo B Heat Pump HELIOPAC, In order to take into accounts the consumption of the pump to circulate the fluid in the cold source, the measured Coefficient Of Performance is degraded by 10%. Thus, the two systems are comparable, all other things being equal. The input data are detailed in the table below

Table 15 : Environmental KPI - Building

KPI - Environmental - DHW 2021	Ref B	SCORES SHW
DHW Electric consumption (kWh/year)	140386	74093
Total Green House Emissions (kg CO2 eq./year)	8985	4742
GHE Reduction (kg CO2 eq./year)	4686	
GHE Reduction per sq.m (kg CO2 eq./m².year)	0.650	

The annual gain avoids 4686 kg of carbon emissions or the equivalent of 52 000 km driven in a thermal vehicle.

8.3 Economic KPIs

8.3.1 Building

The annual bill for the building (Table 16) includes heating and cooling, domestic hot water production and the various uses presented in chapter 8.1.1 . It is calculated from the measured consumption from the two tariff meters S01 and C01 and the unit rate of the kWh given in chapter 6.2.3.. This cost does not include the electricity bill for the private apartments.

Table 16 : Economic KPI - Building

Results	
Total Costs of electricity supply	95550 €/year
Hourly Total Costs	10.91 €/hour

8.3.2 Domestic Hot Water

By comparing the SCORES DHW system with a conventional hot water production system such as an electric boiler (baseline in our case), the opex save reaches to almost 10 k€/year (Table 17)

Table 17 : Economic KPI - DHW

Hypothesis	Baseline	SCORES DHW
Initial Investment	14700 €	92300 €
Lifetime of technology	20 years	20 years
Saved OPEX compared to Baseline	9944 €/year	
Discount rate	4 %	

The annual bill for the DHW includes only the domestic hot water production by SCORES system and doesn't include others hot water systems of the building (as pool shower, hairdresser, laundry room). It is calculated from the measured consumption and the unit rate of the kWh given in chapter 6.2.3.

The Net Present Value reaches to 42800 € with a IRR of 9% ant a ROI of 8 years (Table 18)

Table 18 : Economic KPI - DHW

Results	
Cost of electricity supply (€/year)	11114 €/year
Hourly Total Costs (€/h)	1.27 €/hour
Net Present Value (€)	42800 €
Internal Rate of Return (%)	9 %
Return Of Investment (year)	8 years

9 Conclusion and outlook

The SCORES project started in 2017 but its objectives of increased self-consumption and improved grid flexibility in the build environment are still very relevant in 2022. The project developed and demonstrated the value of new technologies on two demo sites. However the integration of the technologies on the demo sites was not as straightforward as planned and huge delays due to the COVID-19 pandemic in the end resulted in the demo sites being only partly commissioned.

The SCORES demo B allowed the implementation and demonstration of several innovative systems. The Domestic Hot Water sub-system is a mature and efficient technology that has been proven through this demonstrator. In operation since the beginning of 2019, this system has been able to ensure the production of hot water for all 115 dwellings. The COP reached a value of 2.0 over the year and corresponds to the operation of the heat pumps and the back-up heating units of each storage tank. Thanks to its energy efficiency, this system has avoided 4.6 tons of carbon emissions compared to a conventionnel DHW system. This type of installation could therefore be widely used in collective housing as well as in tertiary buildings with significant DHW needs, such as community housing.

The Electric Heat Panels sub-system could be implemented in the test apartment provided by the project ownership and we were able to verify their proper functioning. Unfortunately, the apartment did not find a buyer and remained vacant during the test period. The test is therefore difficult to transpose to a normal use.

The Electrical Battery Sub-system coupled to the Electrical Cabinet Sub-system and the Photovoltaic Production seems to have worked for a few days in November. Despite numerous tests and troubleshooting the data feedback did not allow us to analyse the functioning of the system.

Despite these malfunctions, we were able to use the available data to evaluate the correct operation of the EHPS and the performance of the DHWS thanks to the possibility of data remotely from the Building Energy Management Sub-system.

A CLC heat storage subsystem was not implemented on the French demo site and was only present on the Austrian demo site. However, from the CLC technology developments a new breakthrough has been realized which was not foreseen in the project and lead to an additional key exploitable result. A patent has been applied for it and two partners in the projects started a spin-off company to market this technology further. This would not have been possible without SCORES.

For these reasons the SCORES project has been a tough but successful journey. The project has provided valuable lessons and feedback on breakthrough technologies that have been difficult to implement and has demonstrated the effectiveness of more mature technologies.

The SCORES partners are open to partner up and pursue the SCORES technologies further in follow-up projects.