H2020 - EEB - 2017 - 766464 – SCORES

Self Consumption Of Renewable Energy by hybrid Storage systems

D 7.7 Report on the technic, economic and environmental performances

	Name	**Signature and date**
Prepared by	Mathis Derycke (EDF)	✔ 30-4-2022
Checked by	Keith O'Donovan (AEE)	✔ 30-4-2022
Approved by	Coordinator Erwin Giling (on behalf of General Assembly)	✔ 30-4-2022

Distribution list

External			
European Commission		Archive	1x

Change log

Issue	**Date**	**Pages**	**Remark / changes**	**Page**
1			First issue	All

Table of contents

1 Background

The SCORES project aims is to develop and demonstrate in the field a building energy system including new compact hybrid storage technologies, that optimizes supply, storage and demand of electricity and heat in residential buildings, increasing self-consumption of local renewable energy in residential buildings at the lowest cost. Combination and optimization of multi-energy generation, storage and consumption of local renewable energy (electricity and heat) brings 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 techno-economic and environmental 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.

Work Package 7 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
- Simulate different equipment configurations in order to correctly size the future system

The present report (deliverable D7.7) describes the methodology and results of task 7.4. in the WP7 which is the final step and describe the technical, economic and environmental performance of the system. This document was compiled by EDF, whereas different partners within the SCORES program have shared their expertise for this document. AEE, TNO, SIEMENS provided information on the methods used and the data to be analyzed. 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
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
HP	Heat pumps
PV	Photovoltaic panels
RES	Renewable energy sources
DHW	Domestic hot water
CAPEX	Capital expenditure

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 Gleisdorf, in Austria.

The aim of this document is to carry out a technical, economic and environmental study of the equipment that has been deployed at the Gleisdorf site. This document presents the technologies and their integration on site as well as the KPIs that will highlight the efficiency of the various equipment.

Despite the difficulties encountered during the integration and test phase of the equipment, which at the end of the project did not allow us to calculate all of the expected indicators, it is shown that the technologies will be of high interest for achieving the objectives of self-consumption of renewable energy in the build environment.

4 General description

4.1 Description of the building

The selected building is located in the city of Gleisdorf in the south east of Austria. In the original plan of the buildings built in 1998 was one office building (most southern one) and the two buildings in the back were designed as residential houses, with 3 residential buildings each (in total 2x3 = 6 residential buildings). However, in practise, one house is used as an office.

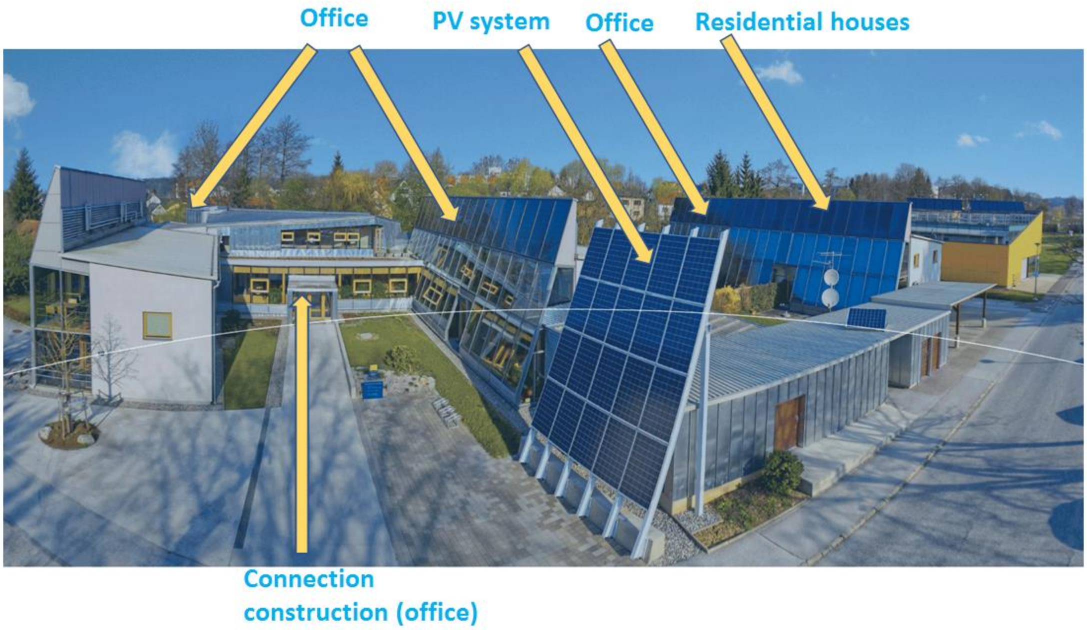

Figure 1: Picture of the building used as demo site A

In 2011, the office was expanded and the two separate buildings were connected via the connection building which contains another 420 m² of office area. The ground floor of the new building is used as reception and social area with a kitchen as well as two meeting rooms. On the north west side of the building a small terrace is located which can be used as social area as well. In the second floor new offices are installed and a transition between the buildings is enabled.

The building characteristics are summarized in the following table:

Characteristics	Value
total area	1,350 m²
total heated area	1,025 m²
residential area	150 m² (2 units)
average residents/apartment (2 units)	3 persons
office area	875 m²
average employees	70 persons
heat demand residential buildings (excl. losses)	39 kWh/m²a (150 m² heated area)
heat demand office (excl. losses)	50 kWh/m²a (875 m² heated area)
Total possible PV area	55 m²

Table 1: Characteristics of the demonstration building

4.2 Energy consumption

4.2.1 Electricity demand

The electricity consumption was not monitored as the SCORES project started, but monthly data is available for the office building. In total the yearly electricity consumption of the office is 35 MWh/y. Data from the residential buildings are not available but a typical value of 5.6 MWh/y for both families can be assumed [oesterreichsenergie.at, 2018]. Thus, the overall electricity consumption of the buildings results of about **40.6 MWh/y.**

4.2.2 Heat Demand

The demonstrator is connected to a heating grid which provided thermal energy for domestic hot water and space heating. The heat consumption of the buildings is measured by Stadtwerke Gleisdorf.

The daily average values over an entire year can be seen below. The numbers include the actual heat demand + thermal losses which also need to be covered by the heat supply system.

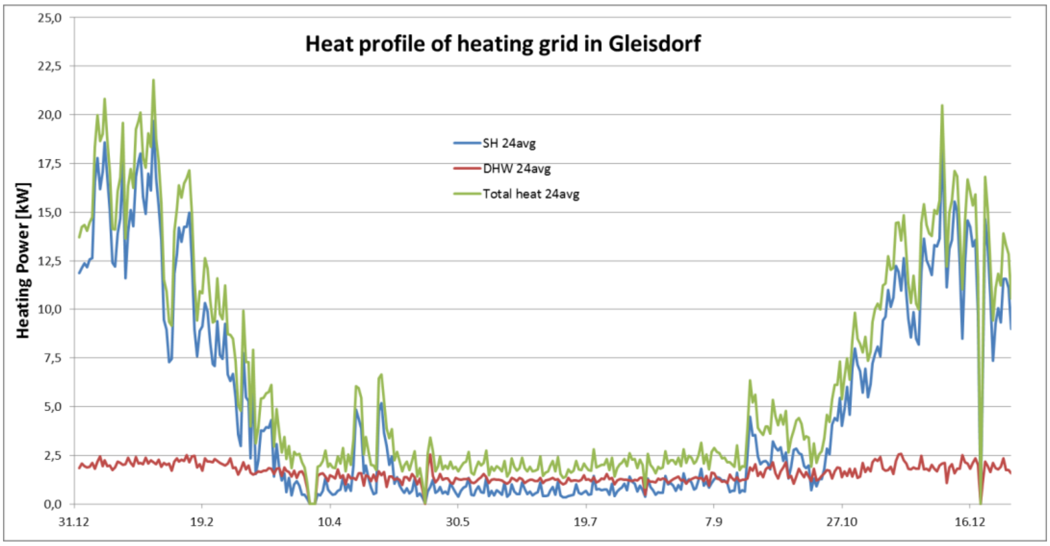

Figure 2: Heat demand profile of the Demo A building in Gleisdorf (daily average)

4.3 Cooling and ventilation

An adsorption cooling machine with a capacity of 19 kW is providing partial cooling during summer. The meeting rooms in the ground floor of the connection building are equipped with chilled ceilings. The cooling machine is also used to pre-cool the fresh air of the ventilation system for the connection building and office north. <u>Cooling is not considered in the SCORES project.</u>

.

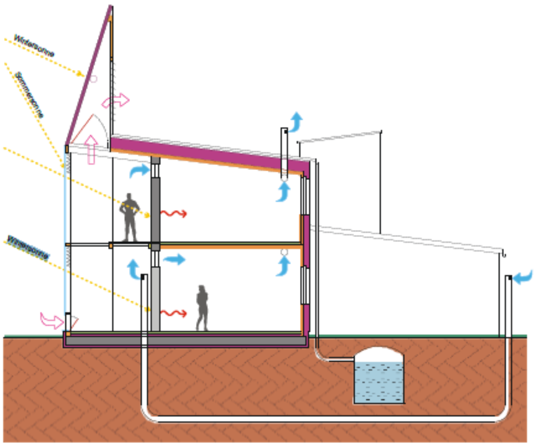

Figure 3: Section of office building – describing the air ventilation system

5 Integration of the SCORES technologies in the Demo building

5.1 *Thermal system*

The SCORES system is integrated in the existing low-temperature distribution loop in Gleisdorf. The hydraulic scheme of the distribution loop is shown below:

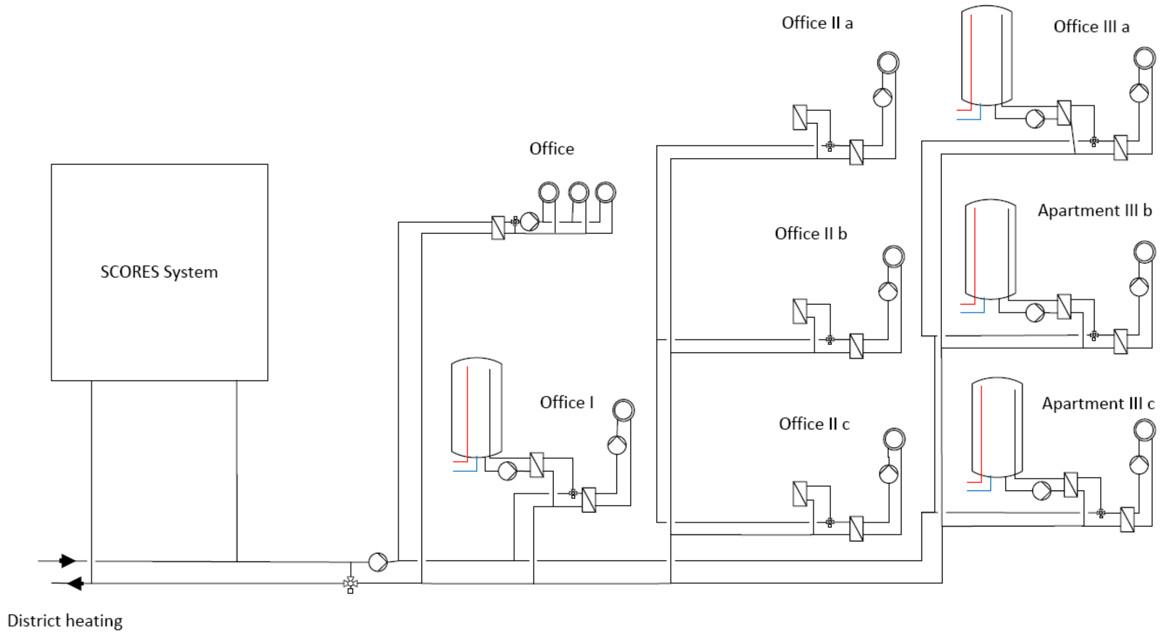

Figure 4: Detailed hydraulic scheme of the existing distribution loop of the demonstration site in Austria and integration point of SCORES System

Installed SCORES system components are: PV modules, containerized CLC heat storage, electrical batteries, heat pumps and water buffer storage. The figure below shows the hydraulic scheme of the integrated SCORES system.

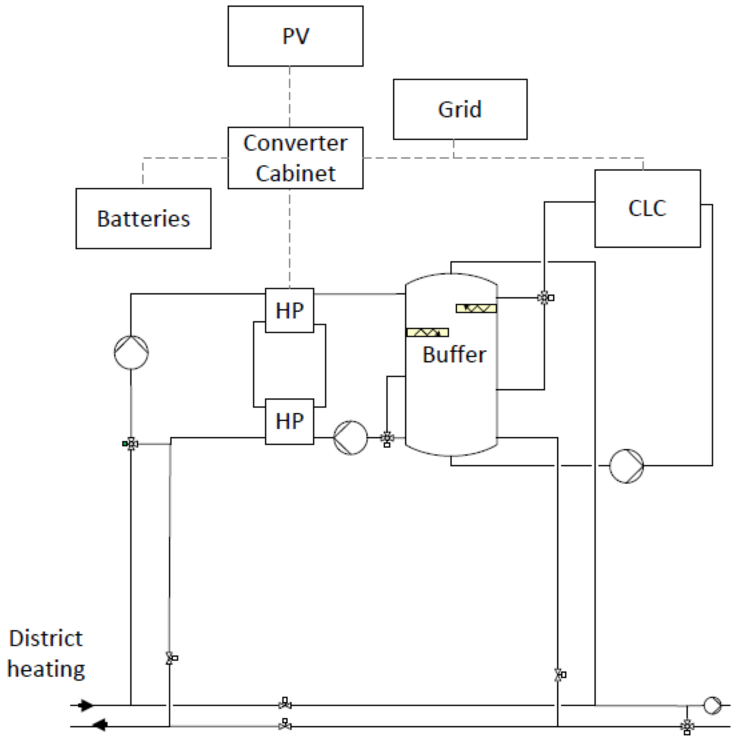

Figure 5: Hydraulic scheme of the integrated SCORES System for Demo A in Gleisdorf

The central component of the SCORES System is the buffer storage which is connected to the heat pumps and a CLC-storage. The heat pumps and the CLC storage are shifting heat to the buffer and from there it is extracted to cover the heat demand and deliver the required amount of heat at sufficient power to the distribution loop. The buffer will be equipped with electrical heaters to have a backup for the demonstration in case no sufficient temperature can be achieved by the heat pumps alone.

The maximum thermal power available by the heat pumps is 24 kW. If there is a higher power requested from the control, the additional energy needs to be coved by the previously stored heat in the buffer. The maximum power (15 min average value) was 52 kW. In the coldest days in winter there was a peak demand of about 42 kW over 5 hours. The additional power needs to be provided by stored heat in the buffer or the district heating grid when the buffer no longer has heat at an adequate temperature to supply space heating or domestic hot water.

The SCORES System has been integrated in the distribution loop as shown above. Nevertheless, Since, there is no actual ground source (cold water well) available on the demo site, the low temperature heat source for the heat pumps has been emulated with heat extracted from the district heating network. Therefore, heat is directly going to the heat pumps cold side, but the temperature needs to be mixed down by a mixer. The inlet temperature of the cold side of the heat pump will be controlled according to a typical annual temperature profile of a ground source around 10 °C. In addition, the SCORES system or more precisely the buffer storage part of the SCORES system is connected to the distribution loop. The district heating grid and distribution loop can be separated by two 2-way valves.

5.2 Electrical system

The main hardware components of the electrical system for Demo A are the PV system, the converter cabinet and the (second-life) batteries.

The PV system of 25 m² (~ 4.4 kWp) has been mounted on a construction above the container. It was placed on the site in a way that no shading is influencing the performance of the PV field. Since the CLC container is only installed during part of the demonstration period, the PV system is mounted on a second container with the converter cabinet and electrical batteries. The PV electricity can be used for driving the heat pumps, charging the CLC, charging the electrical battery or fed into the grid and the BEMS controls when each mode is used.

It has to be guaranteed that the cabinet and batteries are operated within a certain temperature range. Since the building's boiler room is too warm, the converter cabinet together with the electrical batteries was placed in a container. In addition, in a container ventilation can be easily provided.

5.3 Description of equipment

5.3.1 Installed space heating sub-system (ISHS)

The existing heating system of the buildings is a wall heating system for the “SUNDAYS” building on the inner and outer building walls. A prefabricated wall heating integrated in a gypsum concrete panel was used for this purpose for a maximum flow temperature of 50 °C. For the new connection building a floor heating is used. The heat for space heating is provided over the distribution loop which is connected to a buffer storage and the district heating grid. The average flow temperature in the micro grid is 40 to maximum 50 °C.

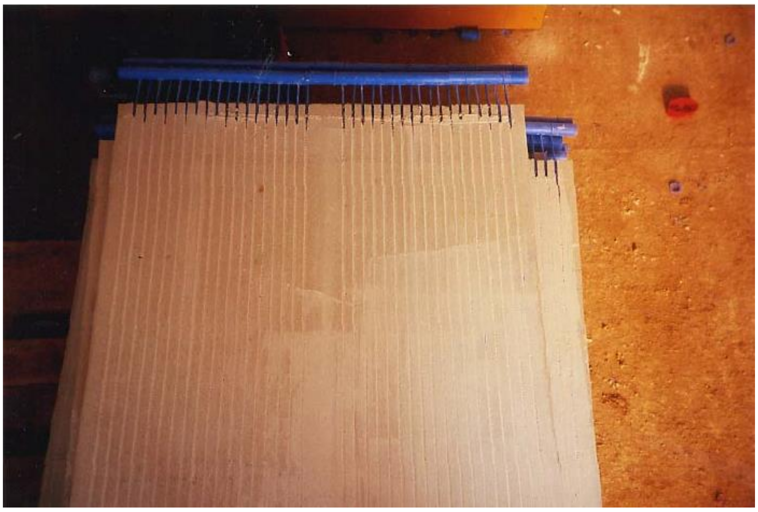

Figure 6 : Wall heating element integrated in gypsum concrete panel

5.3.2 Installed domestic hot water sub-system (IHWS)

In each residential house and the main office, a 120 l DHW boiler is installed. The boiler does not include any electric heaters and can only be charged by heat supplied over the distribution loop. Therefore, a certain time frame is reserved where the temperature in the distribution loop is increased from the target heating temperature to the target DHW temperature. The distribution loop and DHW loop is separated via a plate heat exchanger with typical temperatures of 70/35 °C on the primary side and 65/12 °C secondary side (measured degree of straightness: 10 K). The pump used in the DHW loop is a Grundfos UP 20-15. The installed DHW system is composed of following equipment:

- 120 l boiler
- Plate heat exchanger
- Pump (Grundfos UP 20-15)
- 2 temperature sensors in the boiler (info charged/discharged)
- 4 temperature sensors to measure flow and return temperatures

5.3.3 Heat pump sub-system (WHPS)

The WHPS produces all year long hot water for DHW use. A short-term water buffer is included in the system in order to prepare for the peak demand. It is divided in two zones. The upper one at higher temperature (70°C) is aimed to store the water used for the DHW. The lower zone is the storage for the space heating at lower temperature (45°C). This storage is also used by the CLC when it is discharging. The water-to-water heat pumps only heats the water up to 65°C. An electrical heater or the CLC heats the water up to 70°C for DWH production if necessary. The thermal source of the heat pumps is an emulated ground source for Demo-A (heat is provided by district heating grid for demonstration). The average temperature of the ground source is about 10 °C. Connected to the BEMS, the WHPS contributes to optimize the energy consumption by collecting and storing renewable energy when it is the most relevant.

5.3.4 CLC sub-system (CLCS)

The purpose of the CLCS is to provide long term heat storage for periods of weeks or months, thus allowing to considerably increase the contribution of self-consumption to the building's energy needs. The system is able to store excess electrical energy from the grid in the form of chemical potential energy. When there is an actual demand for heat, the energy can be recovered through a chemical reaction, balancing the building its energy supply and demand more evenly and potentially reducing the loads on the electrical grid itself. For medium to long term storage, the CLC system is preferred over a hot water storage (HWS), as a HWS suffers from heat losses continuously. A CLCS on the other hand stores the energy in chemicals, which in turn can be stored at ambient temperatures, permanently. The stored energy can be converted to heat at any moment through another chemical reaction without further significant losses.

CLC as foreseen within the SCORES project is based on the principle of energy storage by reducing a metal oxide (MeO) inside the CLC reactor (charge phase) using hydrogen gas (H_2) and oxidizing it back (discharge phase) using oxygen contained in air. A sketch of the two consecutive reactions in the CLC reactor is shown in Figure 7.

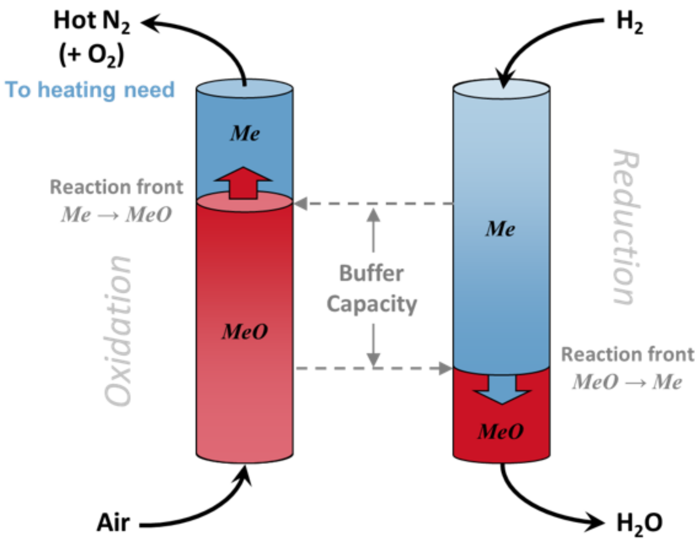

Figure 7 : Oxidation (discharge) and reduction (charge) of a reactor

Due to the problems encountered in the field, for the demo it was decided to emulate the core CLC reactor with a controlled electrical resistance with a simulated behaviour based on laboratory data.

5.3.5 PV sub-system (PVS)

For the PV system 15 modules of Multikristallin REC Twinpeak 2 have been installed. The PV-area of 25 m² (~ 4.43 kWp) was placed on a construction above the container in such a way that no shading is influencing the performance of the PV field.

5.3.6 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.
The Battery Cabinet is controlled by the Electrical Converter Cabinet PLC. The Battery Cabinet managed a battery system composed by:

- 5 Lithium-ion NMC battery modules of 7,1 kWh
- 1 Battery Management System (BMS)
- 1 Power Distributor Unit Electric Box (PDU)

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

5.3.7 Electricity Converter sub-system (ECS)

The Electrical Converter Cabinet governed the electric currents between the solar panels (PVS), batteries (EBS) and the grid. The Electrical Converter Cabinet has its own control however the main controlling is performed by the BEMS.

5.3.8 Building energy management 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.

The BEMS has the functionality to interact with the sub-systems, to read the status and values of the various sub-systems and give commands (setpoints) towards them. In the BEMS it is possible to adjust the overall control set points and set trigger points if measurements are exceeded. This will result in a notification towards the operator.

The unique part of the BEMS solution lies within the optimization algorithm. It is specially designed to find the optimal way to make use of the capabilities of the sub-systems. It is done in such a way that locally produced energy, i.e. self-production, is used in an optimal way to reduce energy consumption from the grid. The algorithm aims to achieve the project goals.

The BEMS has a web-interface for remote access and can be connected to one or more workstations. This gives the SCORES participants the flexibility to access the system from various locations and have insight in their sub-systems. This functionality was used to read-out data remotely.

5.4 Photographs of the SCORES system

5.4.1 CLC container

The CLC container is located next to the technical room of the office building. It hosts the CLC-reactor, the CLC-buffer storage as well as the control unit and heat.

Figure 8: Pictures of the CLC container

5.4.2 Electric system container

The electric system container is also located next to the technical room of the office building. It contains 5 second life batteries, the PV converter as well as the BEMS. On the top of it, photovoltaics panels have been installed.

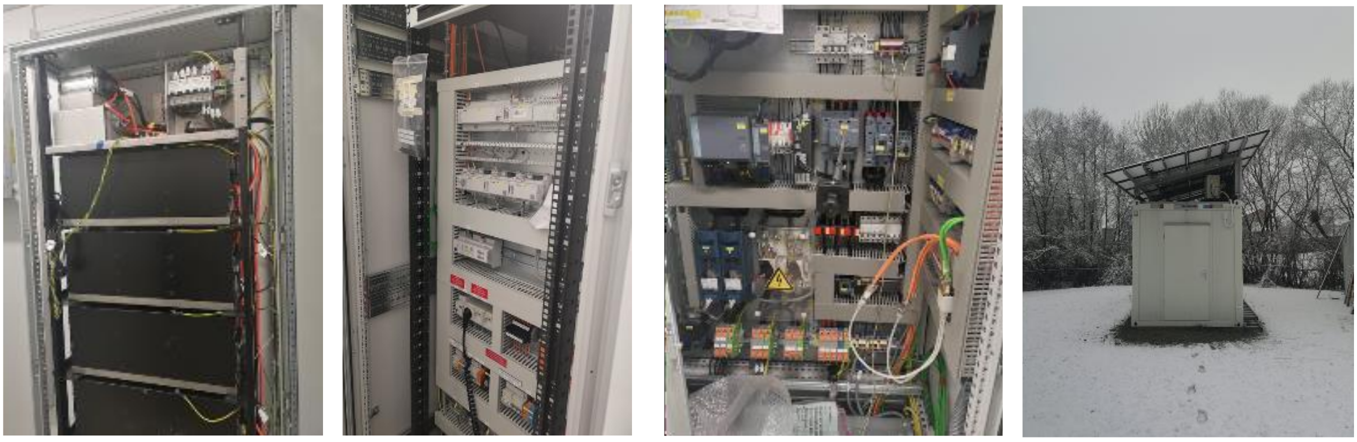

Figure 9: Pictures of the electric system container

5.4.3 Thermal equipment

Finally, the control room integrates the heat pumps control unit as well as the distribution loop control, the storage tank and the two heat pumps.

Figure 10: Pictures of the thermal equipment

6 Definition of Key Performance Indicators

6.1 Selection procedure of relevant KPIs

KPIs are of 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 points of view.

To achieve this objective, KPIs have been properly identified, starting from the analysis of past projects (both private industrial projects and co funded H2020 projects), in the fields of energy efficiency in buildings in which Rina Consulting was involved. Moreover, the two 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 and agreed upon among the partners involved in WP2, WP7 and WP8: 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 2: Expression of the technical KPIs

KPI	Formula	Units	Description	Au
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]	Y
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]	Y
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.	Y
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]	Y
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]	Y
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]	Y
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]	Y
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	Y
Peak demand on electricity grid		kW	This indicator identify the average strong consumer demand (electric energy) for a defined period of time	Y

6.2.2 Environmental indicator

This 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 Austrian regulation, the conversion factors is given below:

- Electricity from Grid: CF = 0.0851 kgeqCO_2/kWhfe (for all uses)

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

Table 3: Environmental indicators

KPI	Formula	Units	Description	Au
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.	Y

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 potential for market penetration

A detailed description is given in Table 4.

Table 4: Economic indicators

KPI	Formula	Units	Description	Au
Hourly total cost	$Q_{year,DH} = \sum_{year} Q_{sector,DH}$	€/h	Overall cost to supply buildings needs for an hour	Y
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	Y
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	Y
return of investment	*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	Y

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, a large amount of data that was planned is missing or inconsistent, which does not allow us to calculate all the technical, economic and ecological indicators for each element of the SCORES project.

A list of the different missing or inconsistent parameters will be given in the next section.

7.1 Commissioning history

Around the beginning of the demo-period the BEMS and the convertor cabinet were installed on site. The convertor cabinet was commissioned for the first time in February 2020. Most of the equipment was still missing or not operational at that time.

The initial system consisted of PV panels, domestic hot water system, BEMS, convertor cabinet, AEE data-hub and weather API.

The batteries arrived in August 2020 but one of the batteries was defective and needed to be replaced. Because of travel restrictions, the batteries could not be serviced in time. The remaining batteries went into deep discharge and were destroyed too. They needed to be replaced as well which was finally done in May 2021. Software updates were executed by Siemens to prevent future systems to go into deep discharge when not used.

At the end of Q1-2021, The CLC was replaced by an emulator system, which behaved electrically and thermally similar to the designed CLC but did not have the actual thermochemical reactor in place. This change was necessary because of process issues in the reactor that caused too much delays.

The demo system was 'completed' in the last weeks of the demonstration period, but the system as a whole did not function properly. This was an obstacle for proper field testing and could not be resolved before the end of the project (30 April 2022)

7.2 Data Checklist

Because of the pandemic, the equipment testing phase was drastically reduced. During this period, a first phase of study was dedicated to the verification of the coherence and the reporting of the different parameters. Unfortunately, this analysis phase revealed a large number of issues.

Indeed, we noticed at first the following problems:

- The energy storage through the storage battery was not working.
- The production of electrical energy through the photovoltaic panels is non-existent.
- The state of charge of the water storage tank cannot be measured due to the absence of a temperature sensor on the tank.
- The energy production of the CLC is non-existent
- The data feedback via the BEMS revealed several communication errors between it and the equipment

After several weeks of research and analysis by all the actors, a number of answers were provided:

- While defective batteries were replaced, electromagnetic interference interfered communication with the BEMS. Despite joint efforts of Foresee Power and Siemens, no solution was found. Towards the end of the project, the equipment was abandoned from the SCORES perimeter.

- The inverter that had been installed was not consistent with the level of production of the photovoltaic panels. Thus, the PVs work correctly but all the energy is absorbed by the inverter. No technical solution could be provided to this problem, so we were forced to abandon the technical and economic analysis of this equipment.

- To compensate for the absence of the temperature sensor on the storage tank, an assumption of a constant temperature of 40°C was made and was to be verified by simulation. However, this could never be verified because the simulation model could never be calibrated due to too many missing data.

- Concerning the CLC emulator, at first we realized that only 3 reactors were working which could justify the absence of energy production. Then, when all the reactors were available, the energy production remained null. A test phase showed that the energy requirement was entirely covered by the HPs, which justified the absence of CLC data.

- The correction of some communication problems allowed to obtain a significant monitoring period for the HP.

Thus, out of all the parameters monitored by the SCORES equipment during the test phase, we can only present a technical and economic analysis of the following subsystem:

- The 2 HP for hot water production
- The thermal and electrical energy consumption of the apartments and offices.

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

In the absence of usable data on photovoltaic production, CLC production and energy stored in the batteries, followings KPI will not be calculated:

- 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

8 Main results on the demonstrator

8.1 Technical, economical et environmental KPIs

8.1.1 Building

The measurement period for the electrical and thermal consumption of the offices and apartments is **from January 17, 2022 at 1:20 pm to March 28, 2022 at 9:15 am.**

Over this period, the measurements are consistent, and no problems have been observed. Thus, we were able to calculate the following KPIs:

Table 5: Building analysis

	Total office	Total Apartment
Electrical peak power [kW]	15,2	10,3
Useful electrical energy demand [kWh]	75 696	12 374
Surface [m²]	875	150
Specificelectrical energy demand[kWh/m²]	87	82
Thermal peak power [kW]	34,1	12,5
Useful thermal energy demand [kWh]	84 723	22 425
Specific thermal energy demand [kWh/m²]	96,8	149,5

8.1.2 Domestic Hot Water

For the HP equipment, the measurement period where the data is consistent is **restricted to February 14 at midnight to March 7 at 11:00 p.m.** The available measurements stop at this date because the HPs were shut down to perform the CLC tests.

Over this measurement period, we were able to determine the energy taken from the grid, the energy consumed by the HPs and thus the energy stored in the buffer.

Table 6: Domestic Hot Water results

DHW Results		
Total electricity consumption	195	kWh
Total thermal energy taken from the grid	438	kWh
Number of running hours	492	hours
Number of running day	20,5	days
Electricity power peak	9	kW
Mean COP	3,17	/
Thermal energy delivered	633	kWh

When we compare these results to the expected performance, we realize that the HPs work very well.

Table 7: Comparison with expected performance

Comparison with expected performance		
Expected thermal energy consumption	44,11	kWh/d
Energy consumption measured	30,88	kWh/d
COP expected for 40/45°C	4,04	/
COP expected for 55/65°C	2,86	/
Real COP	3,17	/

In order to compare energy, economic and environmental gains, we propose to refer to a hot water production with an electric resistance. We will consider four electric hot water tanks to ensure the hot water needs of the residential and main office buildings.

For this purpose, we considered the following assumptions:

- The price of a hot water tank (150 L) is 250 € and its efficiency is 95%.
- We assume a flat tariff of the electricity: 0,15€/kWh.
- To calculate the net present value, we assumed a life of 20 years and a discount rate of 4%.
- We assume that the need for hot water is the same throughout the year.

We therefore obtained the following results:

Table 8: Technical, economical and environmental KPIs compared to a conventional technology

	Ref: Electric water tank	Demo A solution
	Energetical KPI	
Thermal energy demand on the measurement period [kWh]	**633**	
Efficiency / COP	**95%**	**3,17**
Energy consumption [kWh]	**666,3**	**199,8**
Savings on the measurement period [kWh]	**466**	
Savings expected for a year [kWh/y]	**8 306**	
Energy savings (%)	**70%**	
	Environmental KPI	
CO2 emission [kg]	**56,70**	**17,01**
Savings on the measurement period [kg]	**39,70**	
Savings expected for a year [kg/y]	**707**	
Emission savings (%)	**70%**	
	Economical KPI	

Investment [€]	**1 000**	**4380**
Total energy cost [€]	**99,95**	**29,98**
Savings on the measurement period [€]	**69,97**	
Savings expected for a year [€]	**1 246**	
Net Present Value (NPV) - 20 years [€]	**12 554**	
Internal Rate Return (IRR) [%]	**28 %**	
Return of investment (ROI) -[years]	**3,5**	

We can see that the solution deployed at the Gleisdorf site is much more interesting than standard electric water heaters.

Indeed, from an energy point of view, the use of a HP allows to save 70% of energy which is really interesting. This would represent an annual saving of 8 306 kWh.

From an environmental point of view, this solution would avoid the emission of 707 kg of CO_2.

Finally, from an economic point of view, although the CAPEX of the HP solution is higher, the economic indicators show that this solution is much more interesting in the medium/long term. As shown in the table above, the ROI near to 3 years and the NPV at 20 years is 12 554 €.

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.

Despite the difficulties encountered, the close involvement of all parties in the project and all the technologies developed still enables conclusions to be drawn on the implementation of SCORES equipment and the methodologies to be applied on the Austrian demo site. Valuable lessons have been learned. Based on the data available, the implementation of this equipment has led to significant energy and financial savings already, even with a less than complete system. In particular, we should note the performance of heat pumps at the Gleisdorf demo site for the production of hot water, which allows for a gain of 70% compared to a conventional technology.

Additionally 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.

Finally, the simulation work that has been done in the project shows the performance of each sub-system over a full year. The results are encouraging and the SCORES partners are open to partner up and pursue the SCORES technologies further in follow-up projects.