INTEGRATION OF COMBINED COOLING, HEATING AND POWER MICROGRIDS IN ZERO-ENERGY PUBLIC BUILDINGS UNDER HIGH POWER QUALITY AND CONTINUITY REQUIREMENTS

IMPROVEMENT Spanish Pilot Plant

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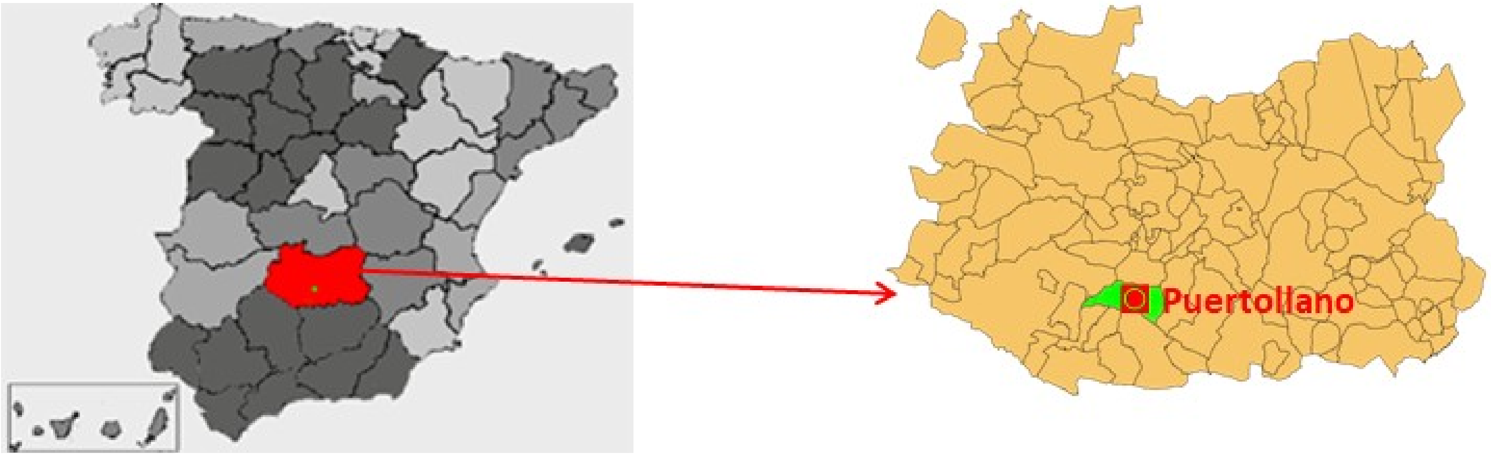
Spanish Pilot Plant



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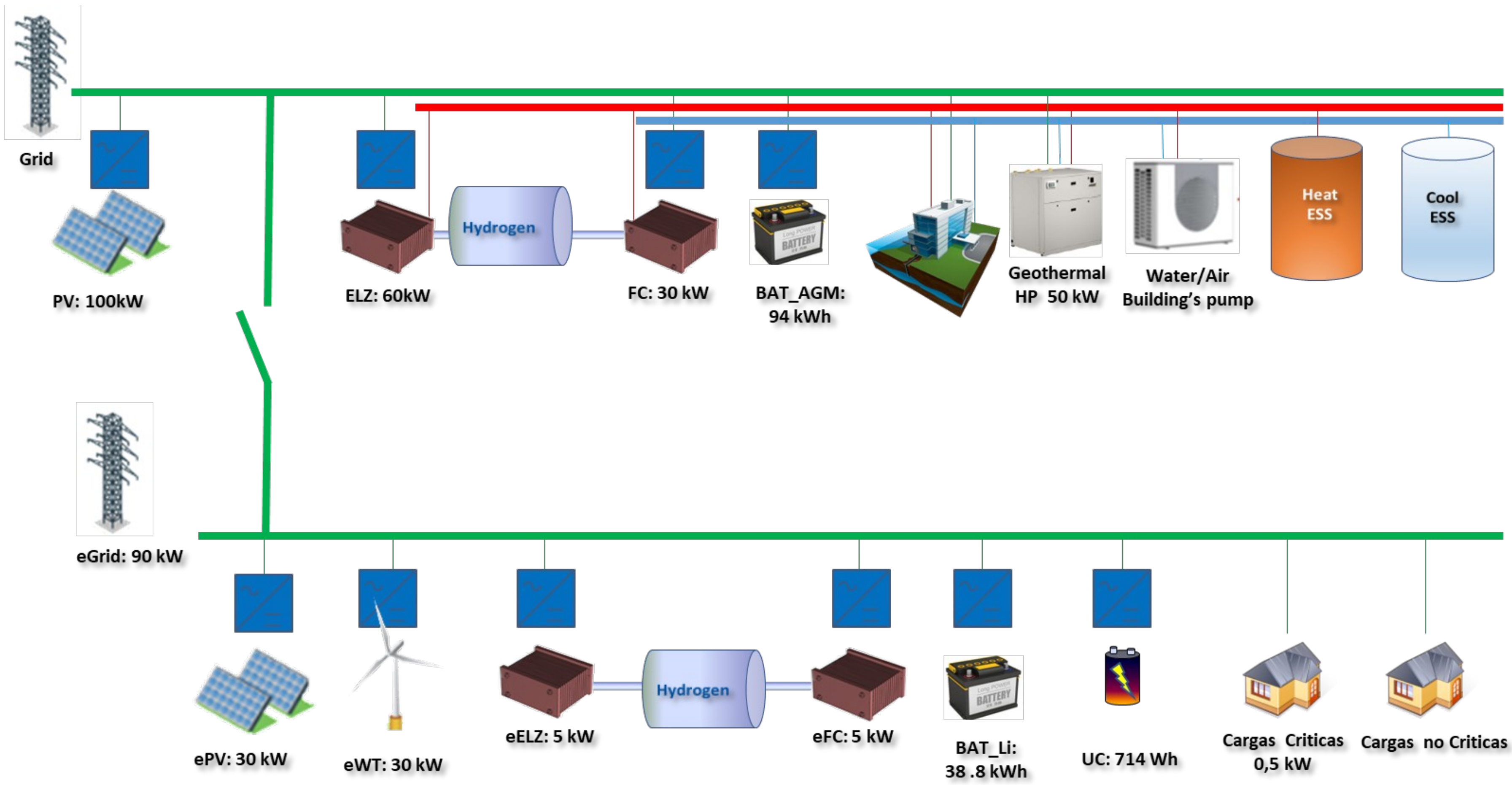

1. Electrical Microgrid

Specific Objectives

- Development of a **fault resistant power control system** for microgrids under high quality design criteria and continuity of supply.

- Development of an **energy management system** for renewable generation microgrids with **a hybrid energy storage system** under criteria of minimum degradation, maximum efficiency and priority in the use of renewable energies

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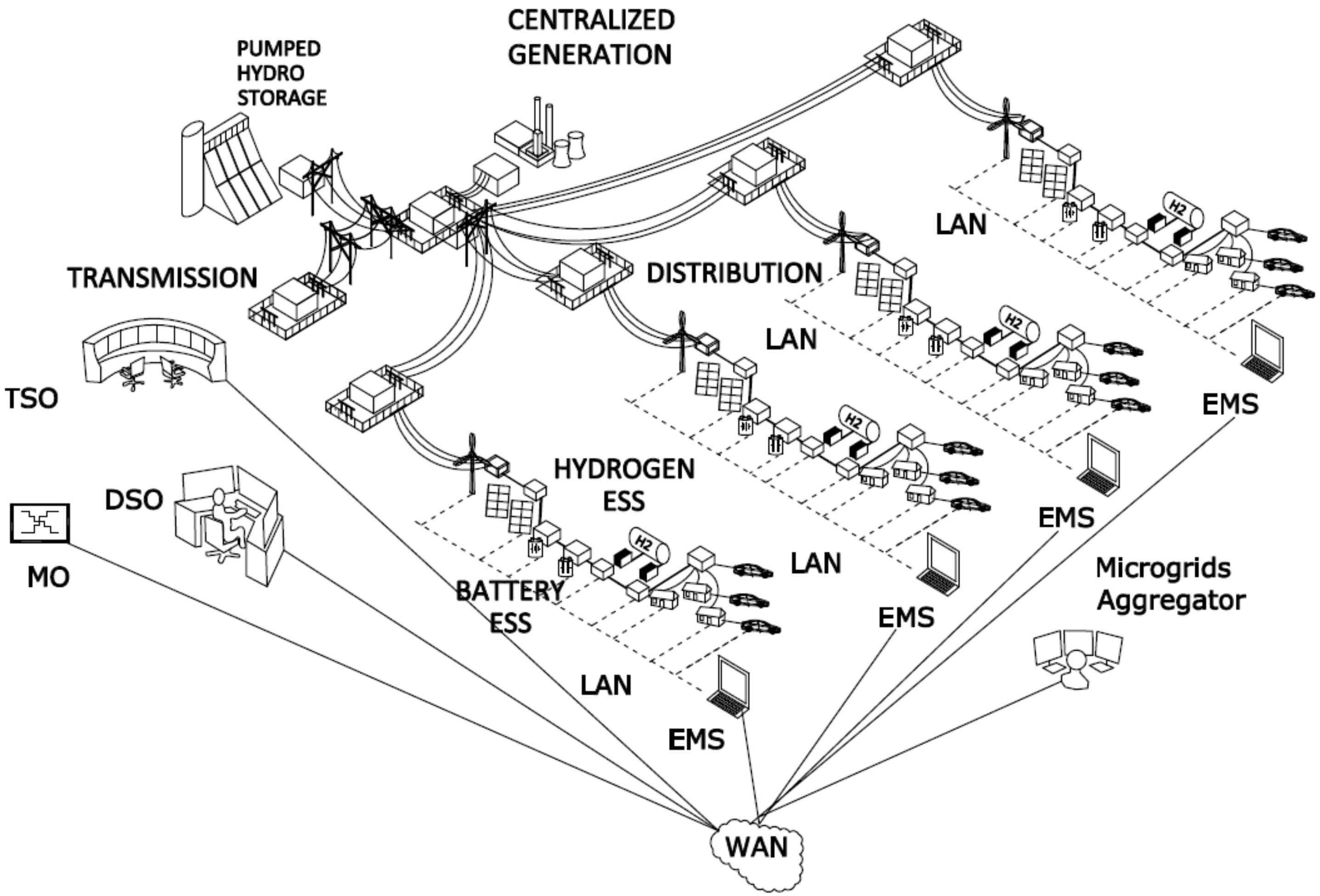
1. Electrical Microgrid

- Resilience to general power grid failures
- Flexibility
- Economic optimization of energy prices
- Grid congestion problems
- Quality of supply



1. Electrical Microgrid

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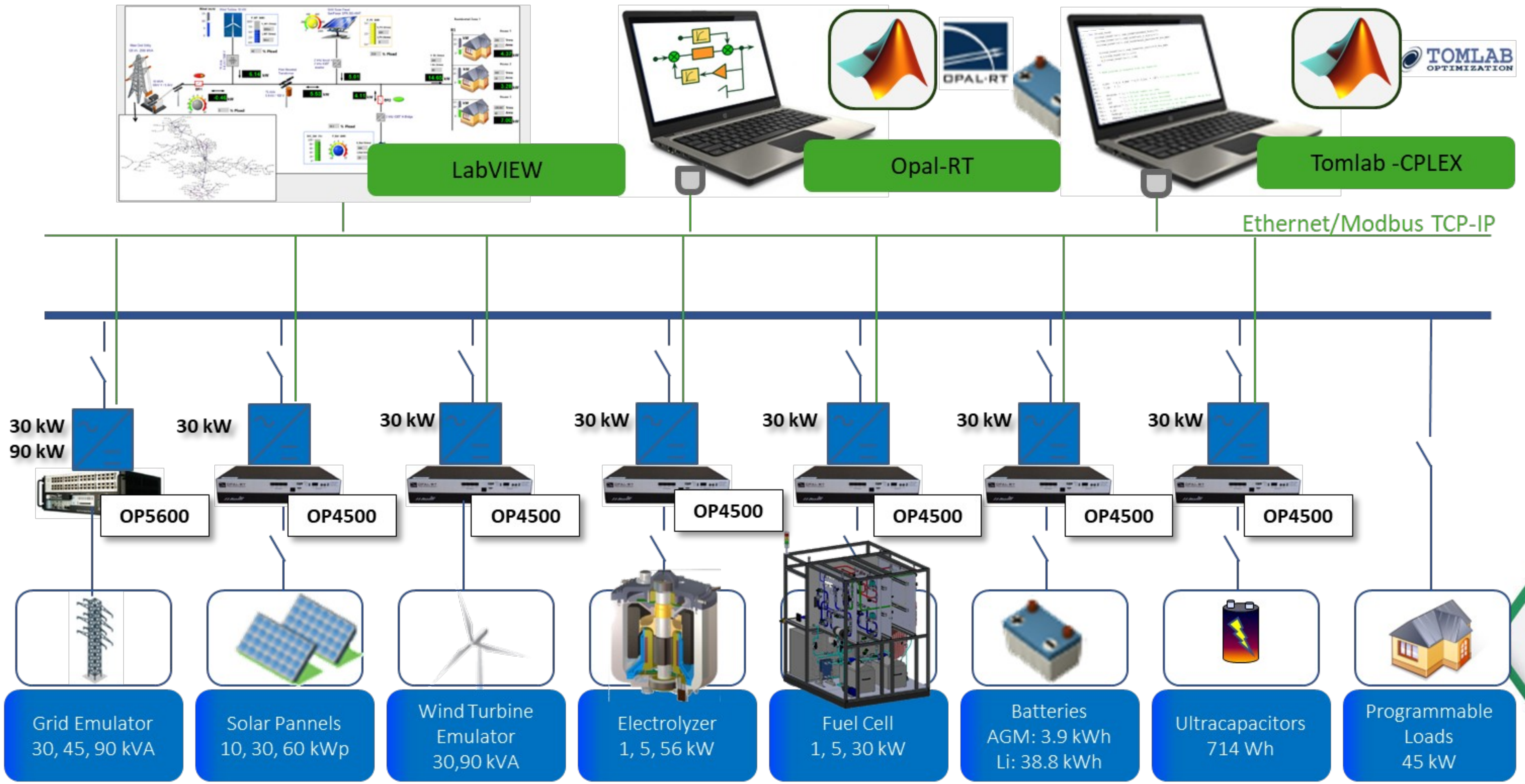
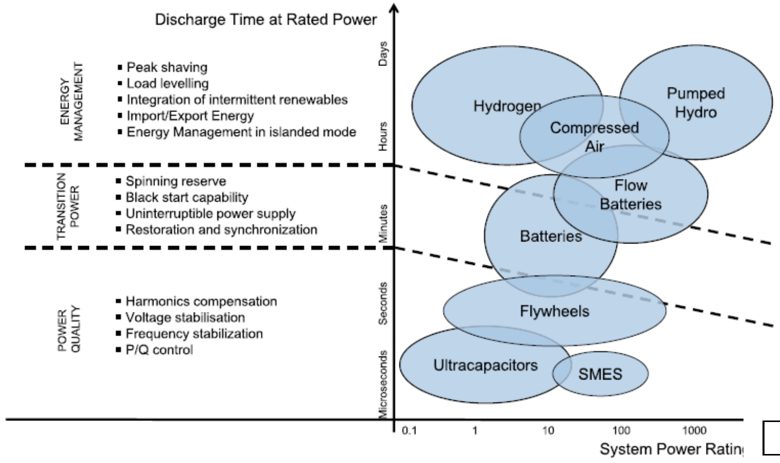
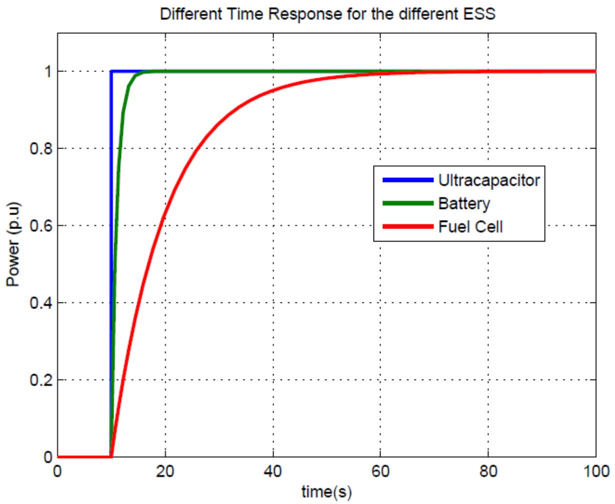
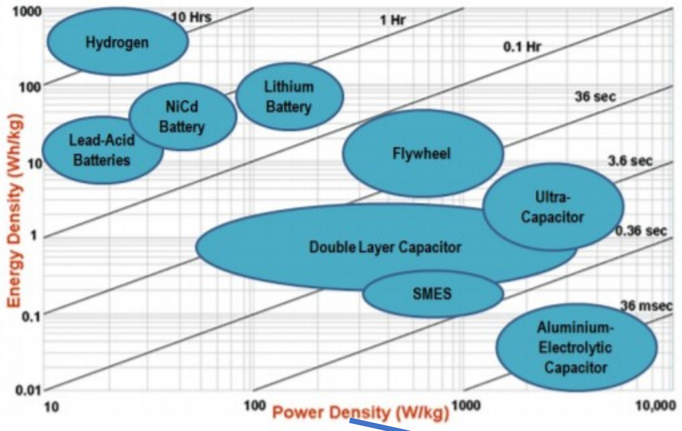


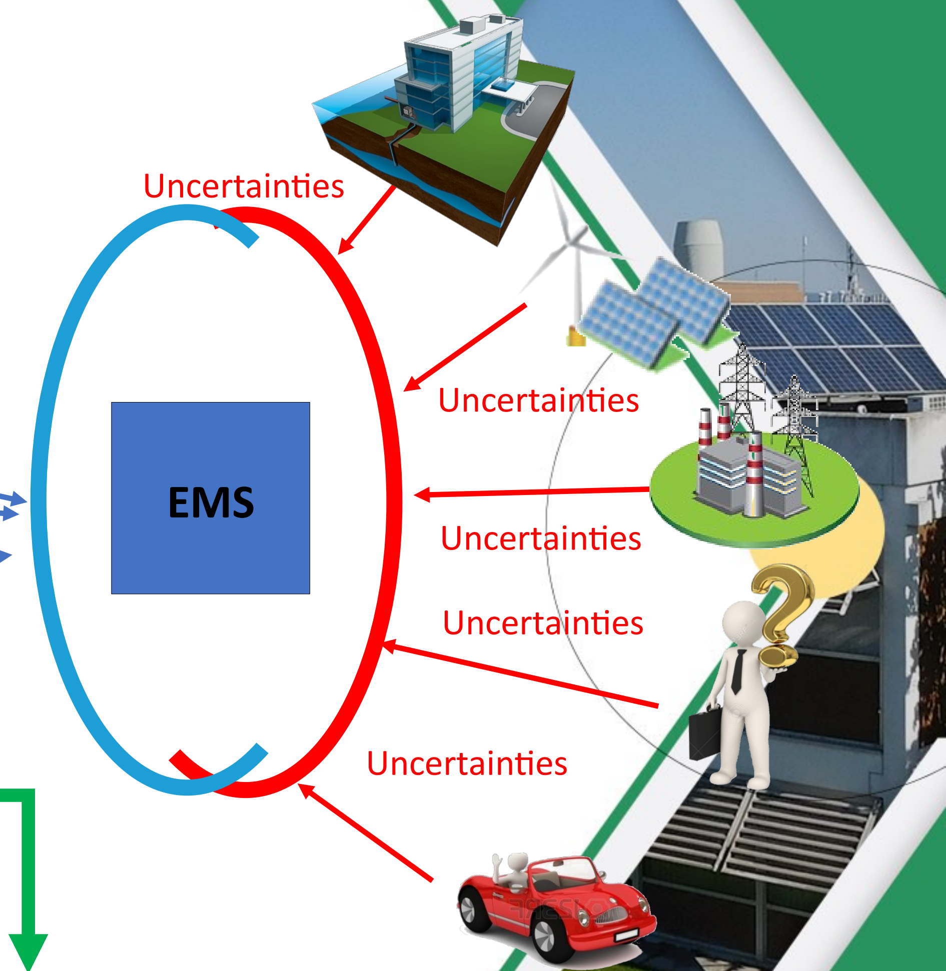
1. Electrical Microgrid







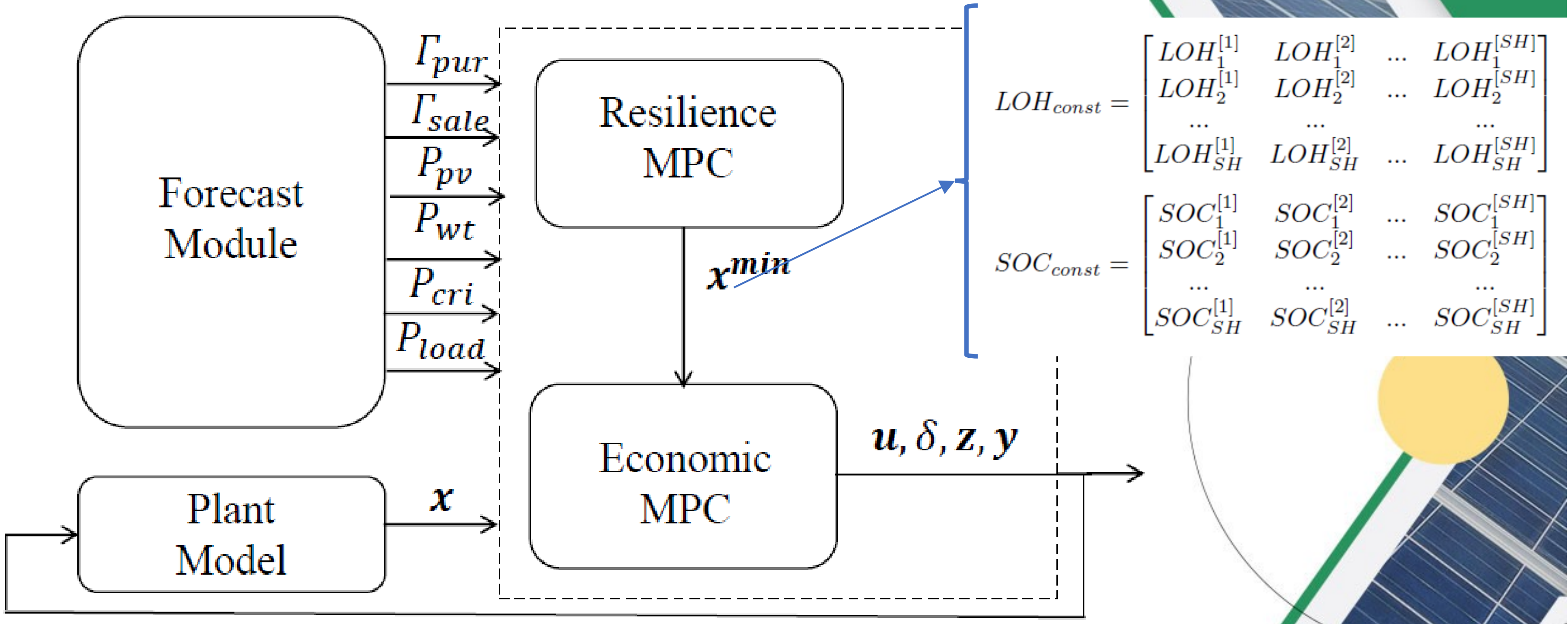
Energy Storage System	Degradation Issues
Ultracapacitors	Overcharge, Undercharge
Batteries **Lifetime:** Cycles	Overcharge, Undercharge High stress current ratio AC Current Ripple
Electrolyzer **Lifetime:** Hours	Fluctuations of current Start/Stop Cycles
Fuel Cell **Lifetime:** Hours	Fluctuations of current Start/Stop Cycles



The use of storage systems is not free to meet service life costs. If the degradation criteria are not met, this useful life may be lower and detract from economic competitiveness. Battery-hydrogen degradation has complementary behavior

1. Electrical Microgrid

- Economic Criteria
- Resilience Criteria
  - Survival Criterion
  - Criticality Criterion
- Renewable Energy Criterion
- Minimum equipment degradation criterion



1. Electrical Microgrid

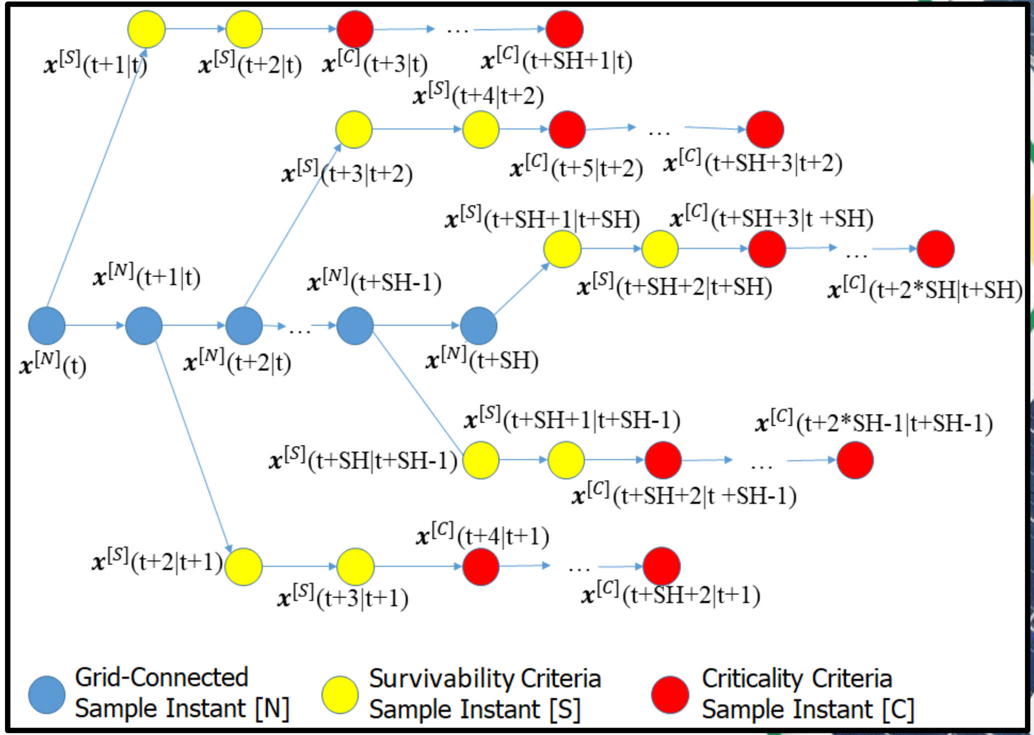
Resilience-Oriented Schedule of Microgrids Algorithm:

A two-stage optimization is proposed:
The minimum storage in each energy storage system is calculated considering economic cost aspects of the energy storage systems according to the forecast of critical loads. Two levels of resilience are established:

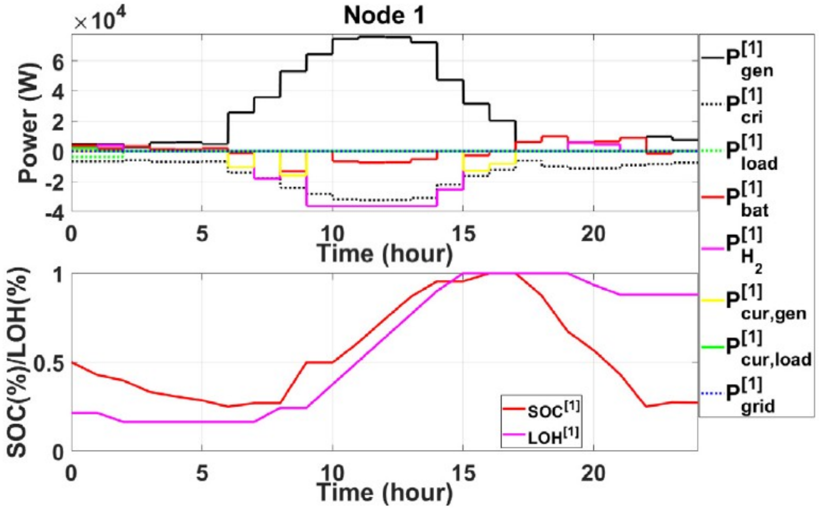
1) **Survivability** (Supply of the greatest number of loads during a certain time 2 hours from the event of loss of the main grid)

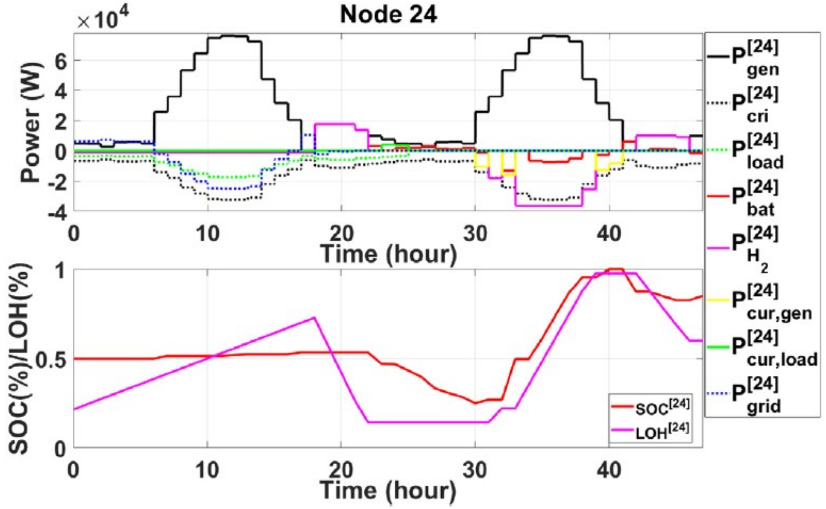
2) **Criticality:** Supply of critical loads during a horizon of 24 hours from the event loss of main network. This is done considering the loss of the main network at each optimization instant.

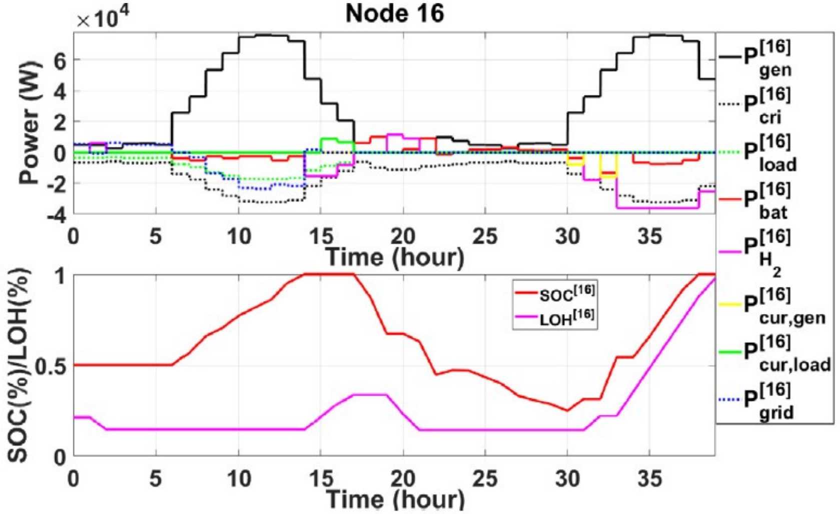
Day ahead Market is optimized by following minimum storage restrictions

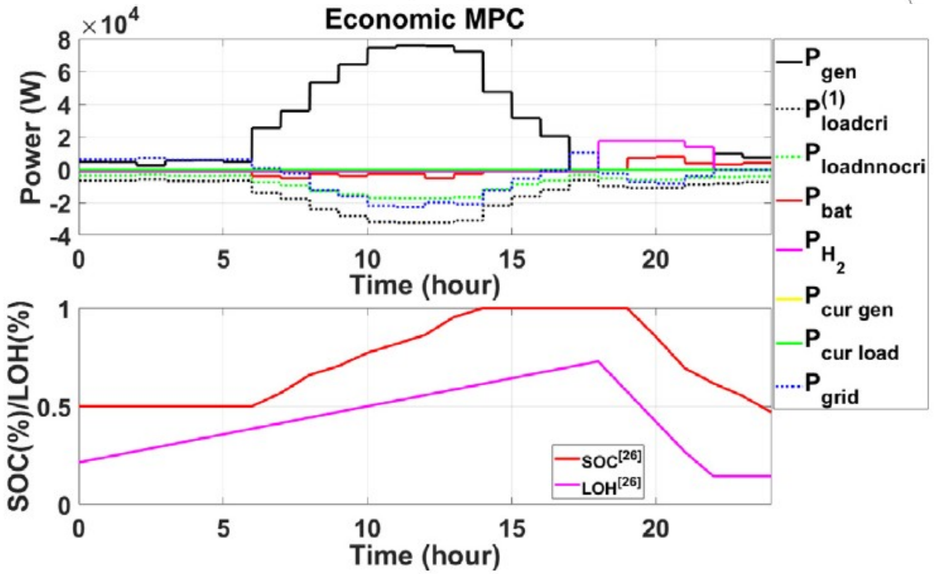


1. Electrical Microgrid



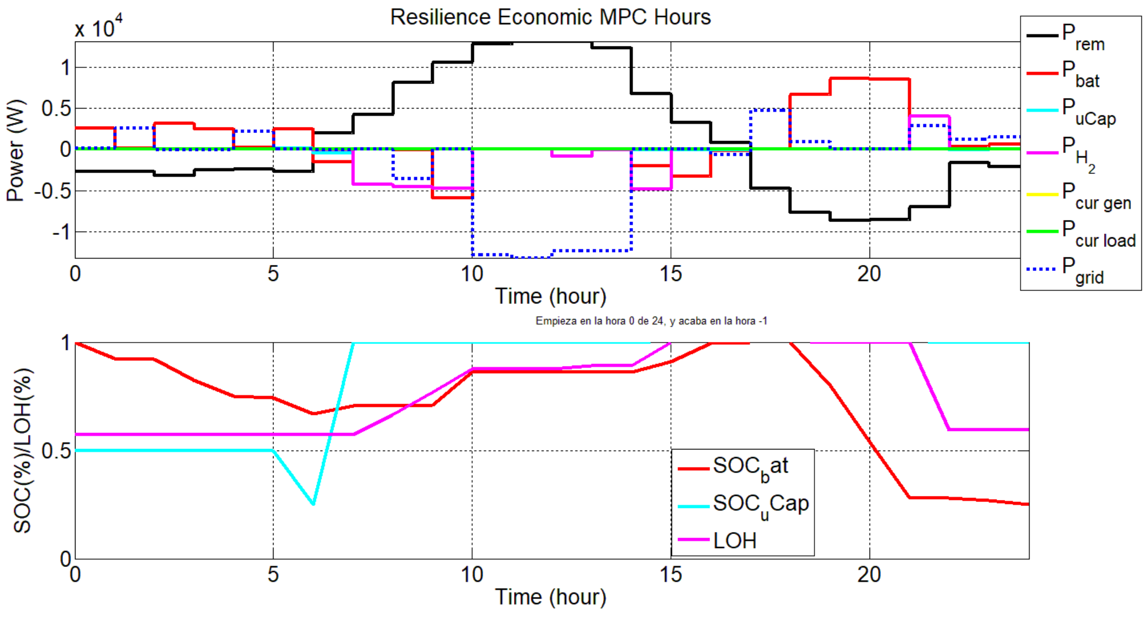


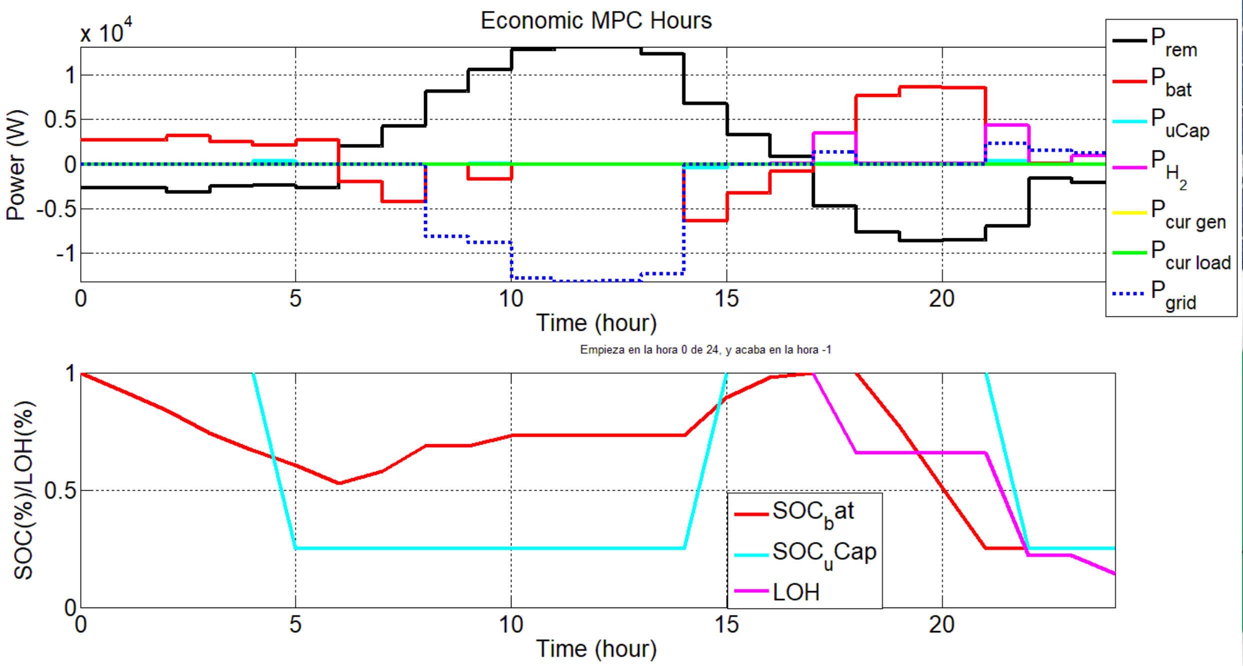




1. Electrical Microgrid

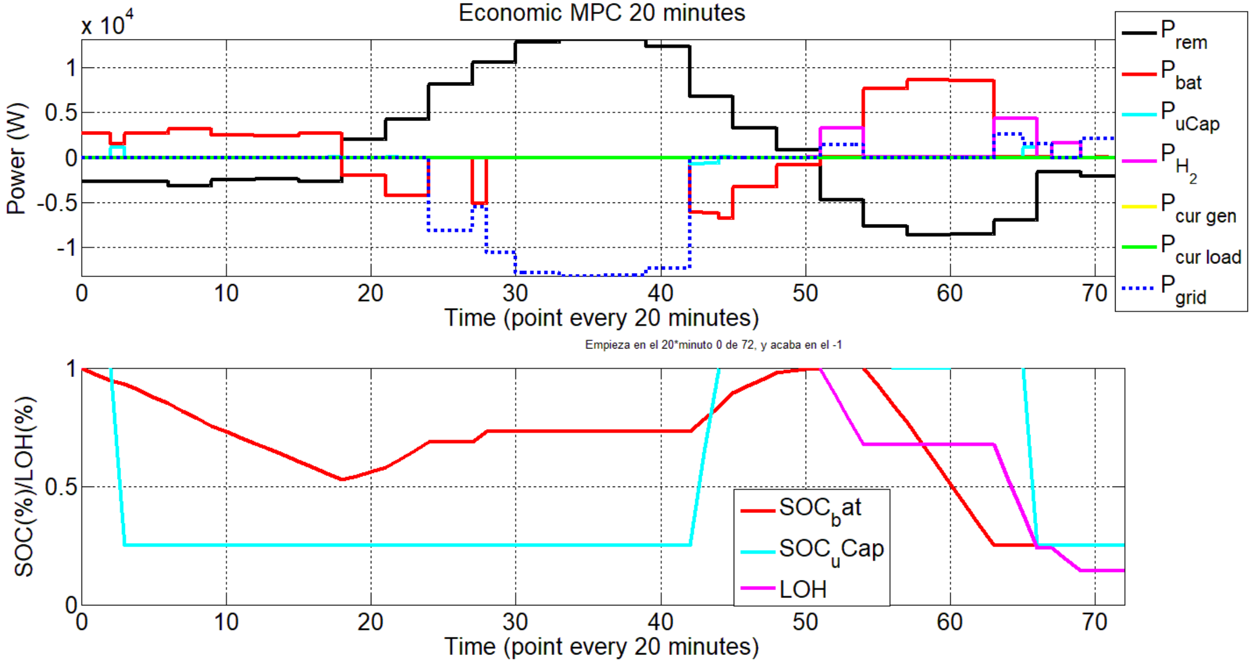
- Once the Resilience criterion has been calculated and stablished, the algorithm focused in the Economic criteria is launched.

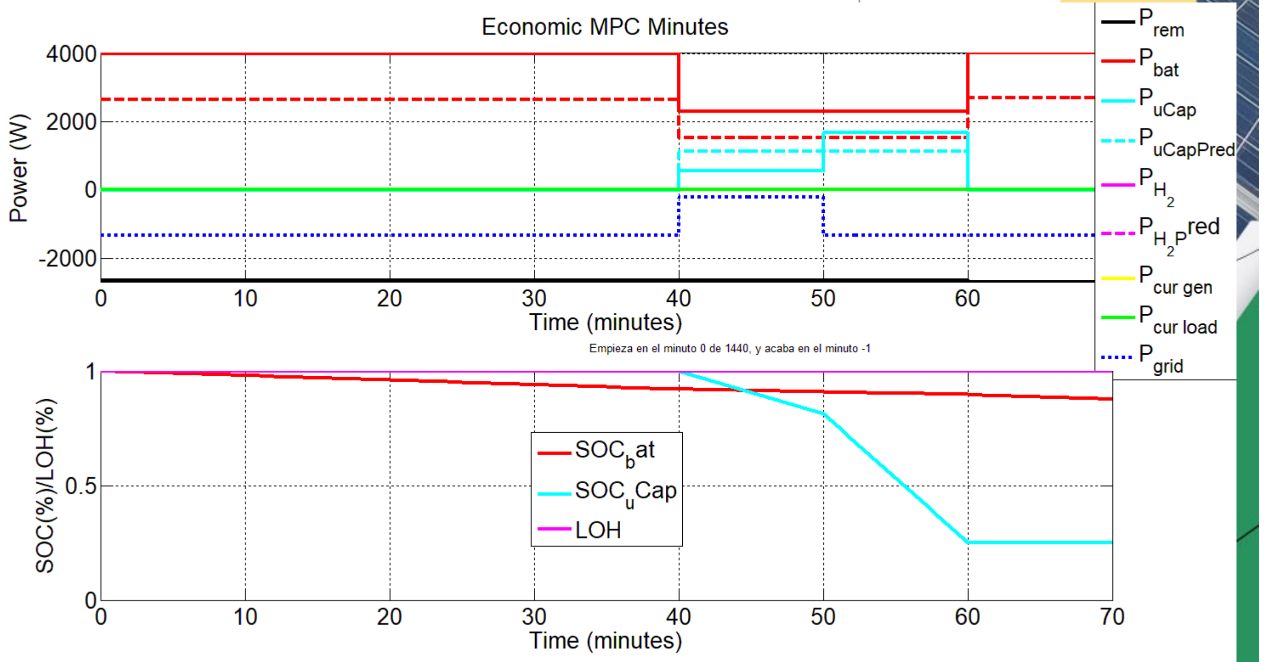




1. Electrical Microgrid

Once calculated the Economic prediction by next 24 hours, we discretize it to control the system every minute





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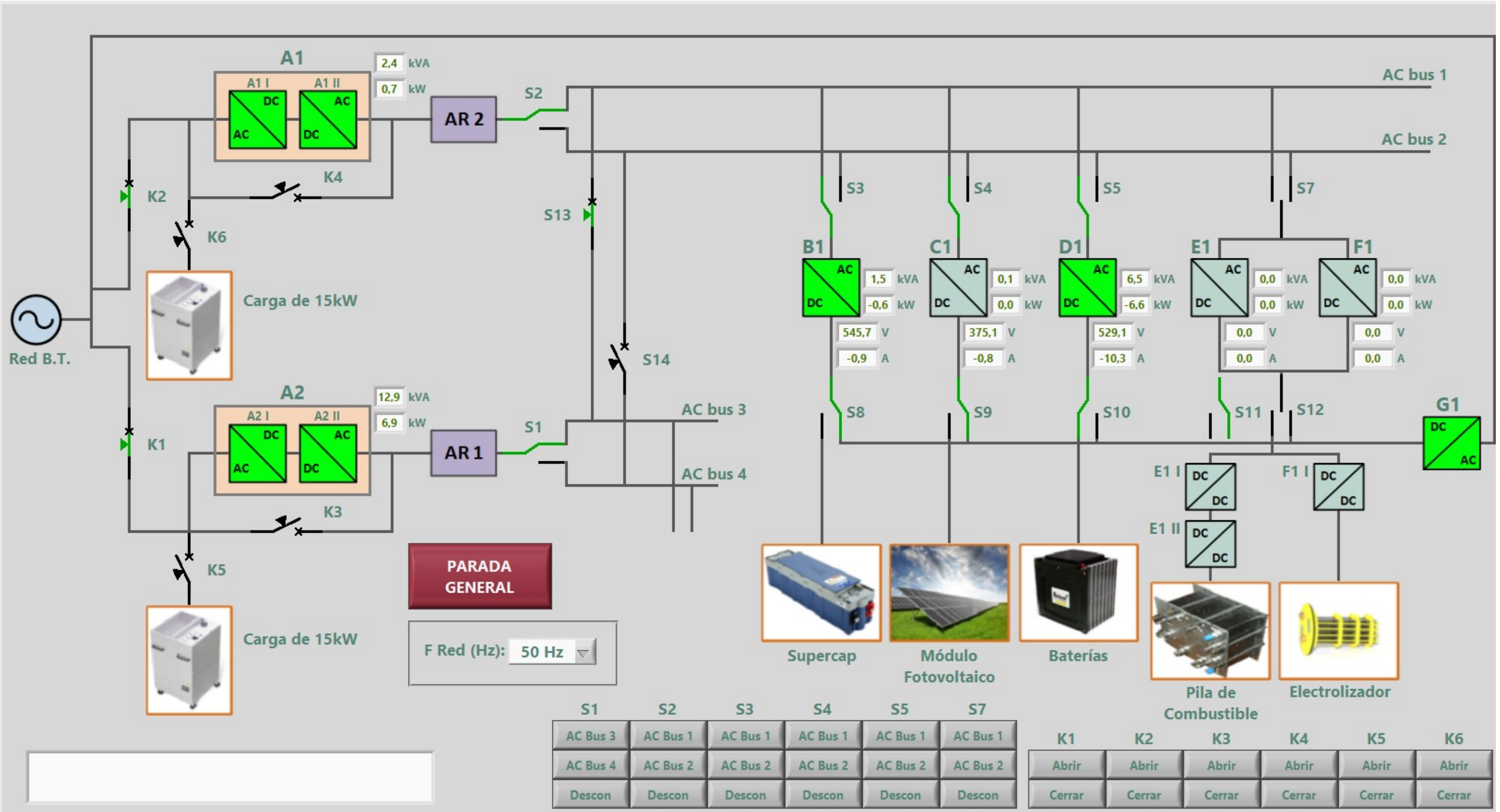
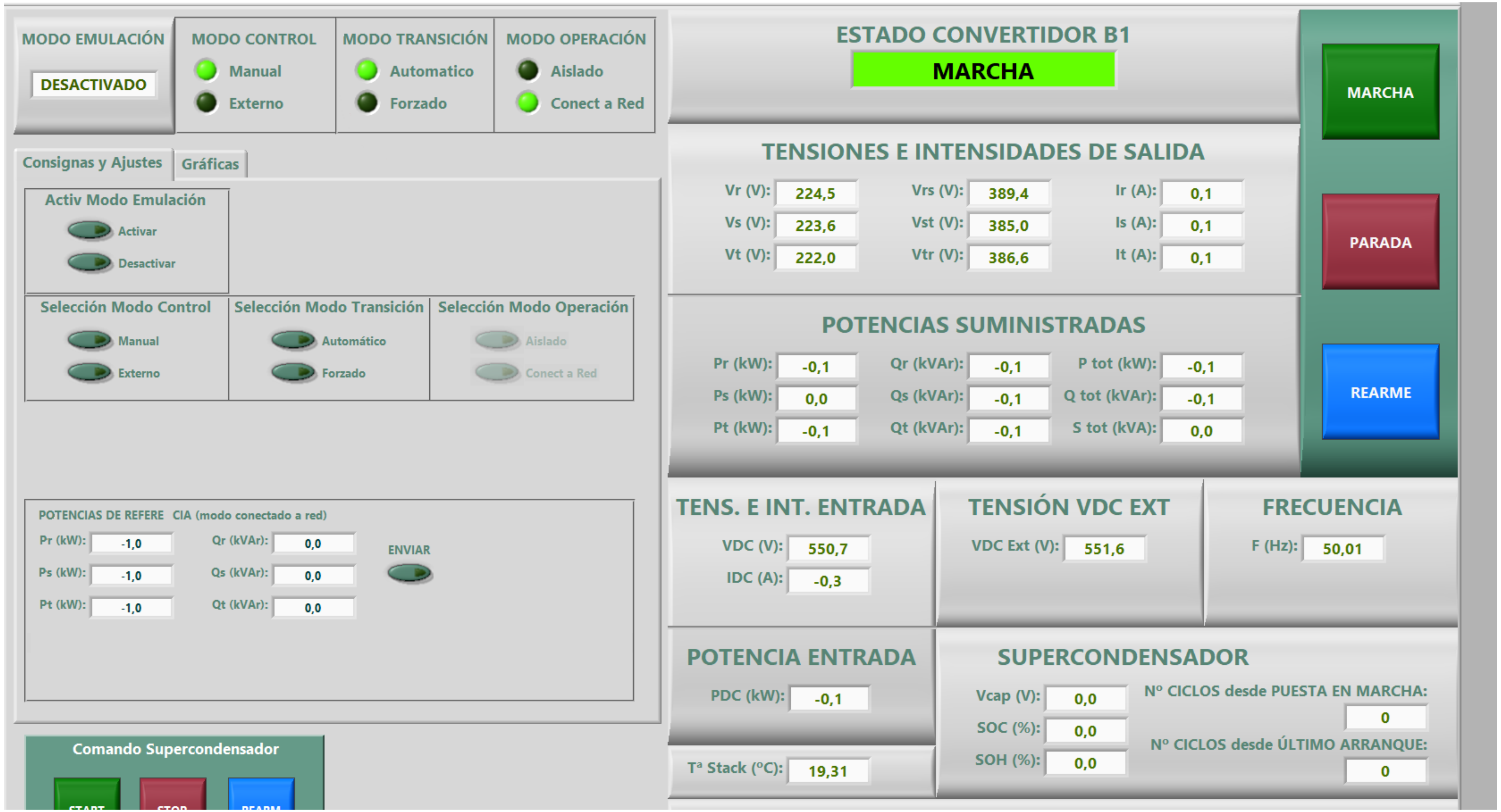
1. Electrical Microgrid



1. Electrical Microgrid



2. Thermal Recovery System (CNH2)

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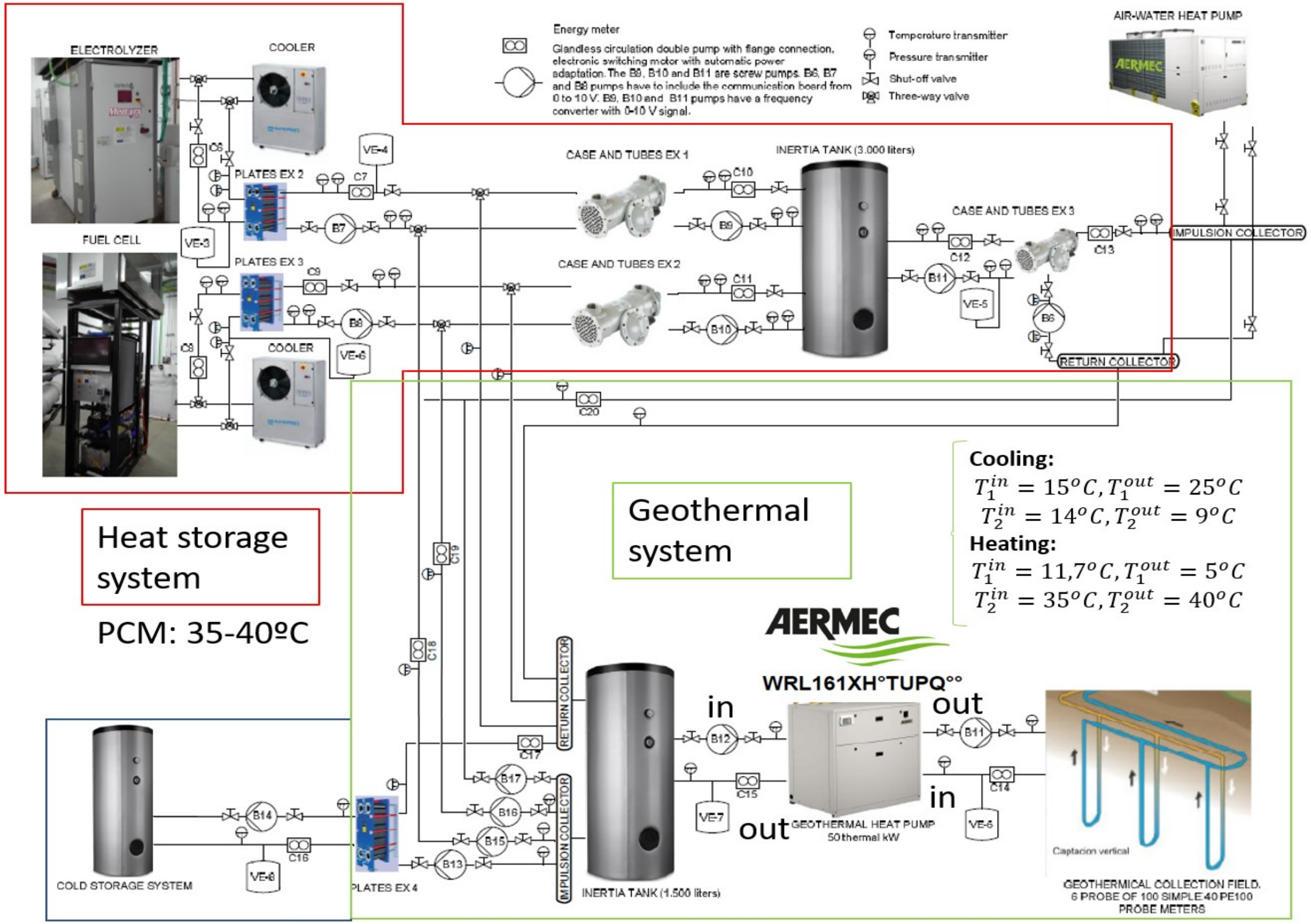
3 main parts:

- CESS
- HESS
- GRS

Capable of injecting recover heat to air conditioner system of the building

Reduce electrical consumption



Heat storage system

PCM: 35-40ºC

Geothermal system

Cooling:
$T_1^{in} = 15^oC, T_1^{out} = 25^oC$
$T_2^{in} = 14^oC, T_2^{out} = 9^oC$

Heating:
$T_1^{in} = 11{,}7^oC, T_1^{out} = 5^oC$
$T_2^{in} = 35^oC, T_2^{out} = 40^oC$

Cold storage system

PCM: 10-14ºC

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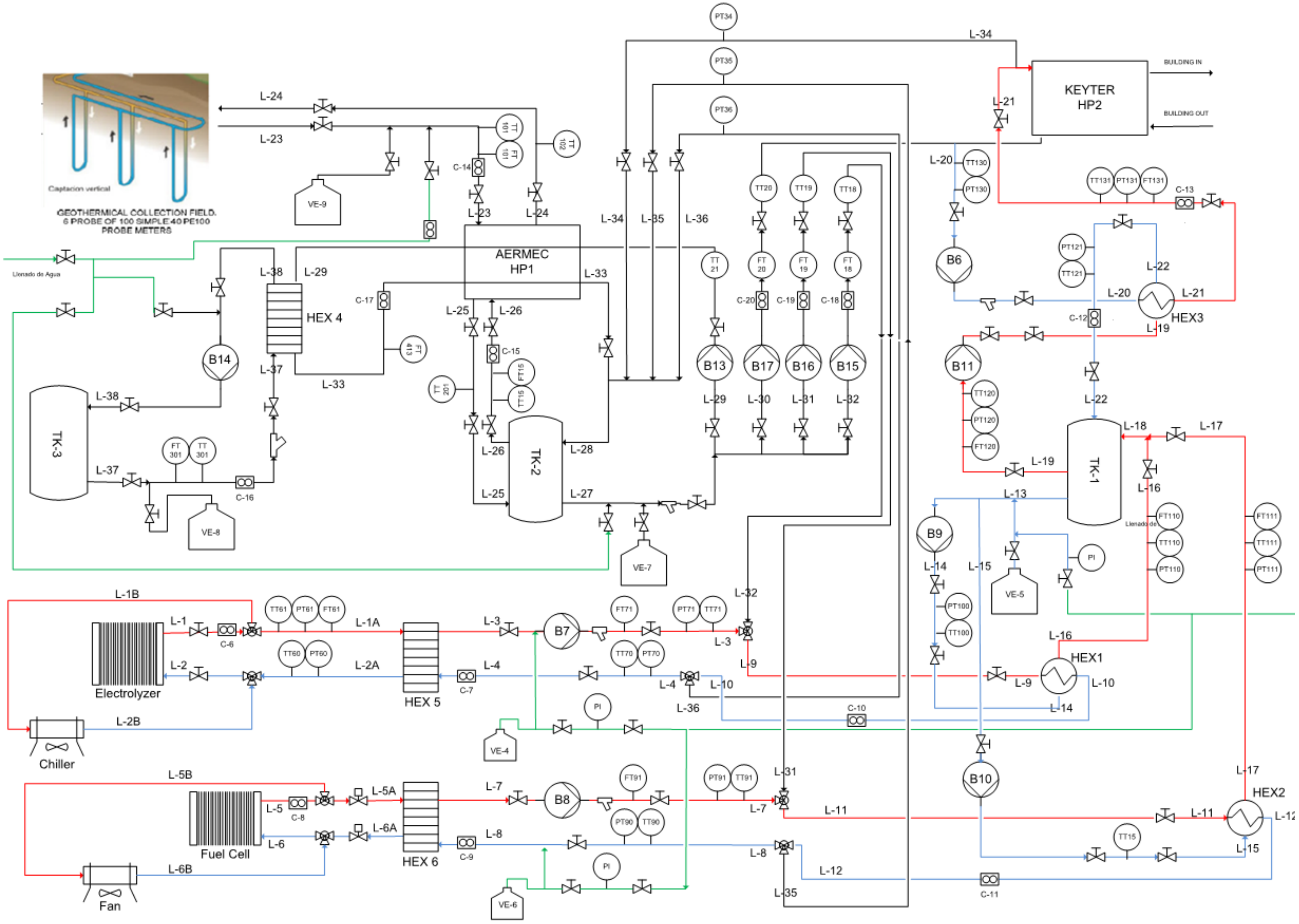
2. Thermal Recovery System (CNH2)

P&ID



Innovations techniques

Reducing energy consumption is where relevant **findings and results** of the thermal part of the CNH2 pilot plant are aimed at:

A. The use of new and disruptive techniques currently applied in a minor way to public buildings:

- **Hydrogen cycle Integration**. Both the electrolyser and the fuel cell are electrochemical devices capable of generating electricity and heat during their operation. Fuel cells can be classified, according to its operating temperature, low or high temperature fuel cells. Depending on the applications one type of technology or the other must be selected. In the case of fuel cells for stationary applications (electricity or heat generation) it makes sense to use polymer membrane technologies (PEM) for small size applications. Molten carbonates (MCFC) or solid oxide (SOFC) in the case of large cogeneration.
- **Use of geothermal energy**
- **Use of Phase Change Materials (PCMs),** using specific ones for heating mode (**organic slurry**), and others for cooling mode (**inorganic**). PCMs are materials with high latent heat, that is, materials that at the phase change temperature can store or releasing large amounts of energy. During the phase change, temperature remains constant, and the material absorbs or releases energy progressively.

B. Improvement of energy efficiency

- By **taking** advantage of waste heat from CNH2 facilities implemented equipment: alkaline electrolyzer and PEM fuel cell.

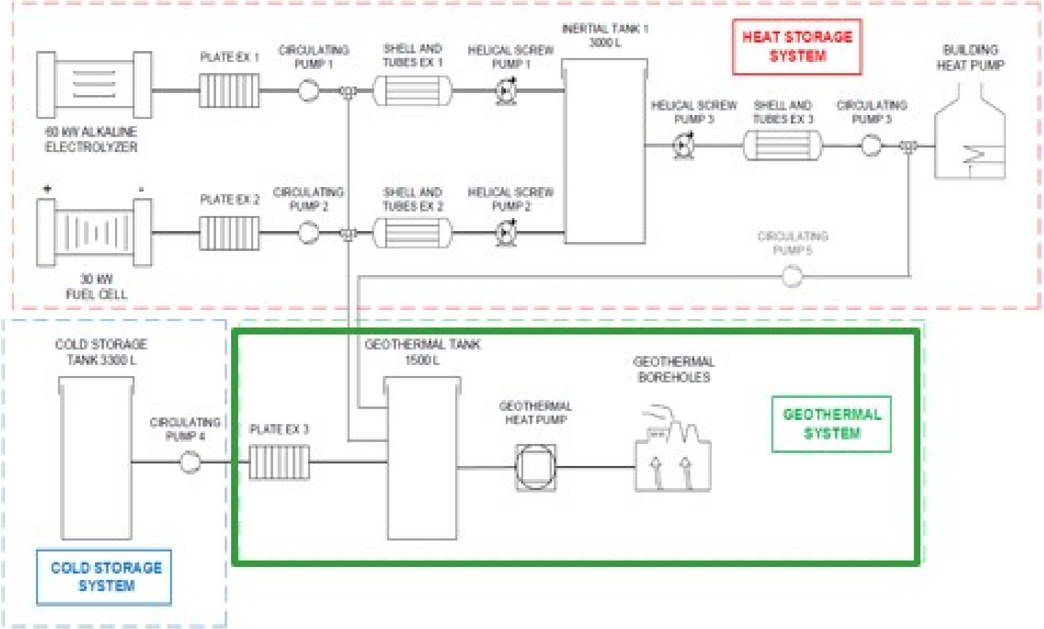
C. Joint integration of innovative technologies

- **Geothermal-PCMs and hydrogen cycle-PCMs according to needs and external climatic conditions to increase thermal yields of the microgrid.**

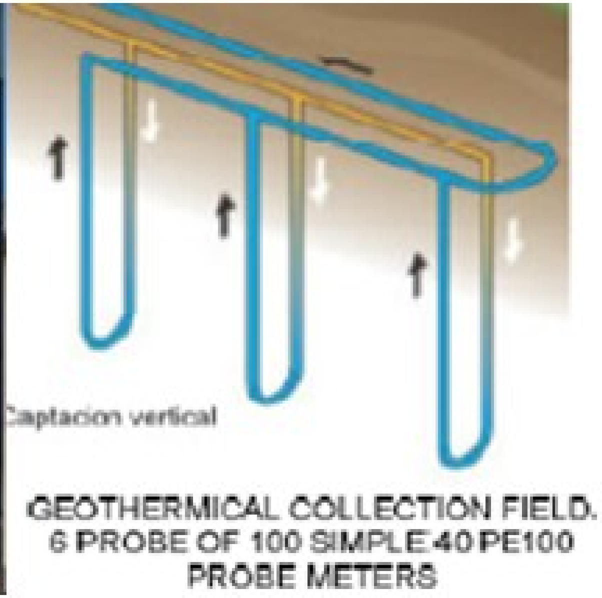
2.1. Geothermal Recovery System (GRS)

GEOTHERMAL RECOVERY SYSTEM

- **OBJECTIVE:** Take advantage of the **heat / cool** from the subsoil to **reduce the building's energy consumption**
  - **6 U-shaped boreholes of 100 meters in deep** were carried out
  - Boreholes are connected to a **50 kW geothermal heat pump**
  - Downstream of the geothermal, is integrated a **1500 L inertial tank**
  - The **geothermal recovery system** is connected to:
    - **Heat storage system**
    - **General building air-conditioning pump**



2.1. Geothermal Recovery System (GRS)



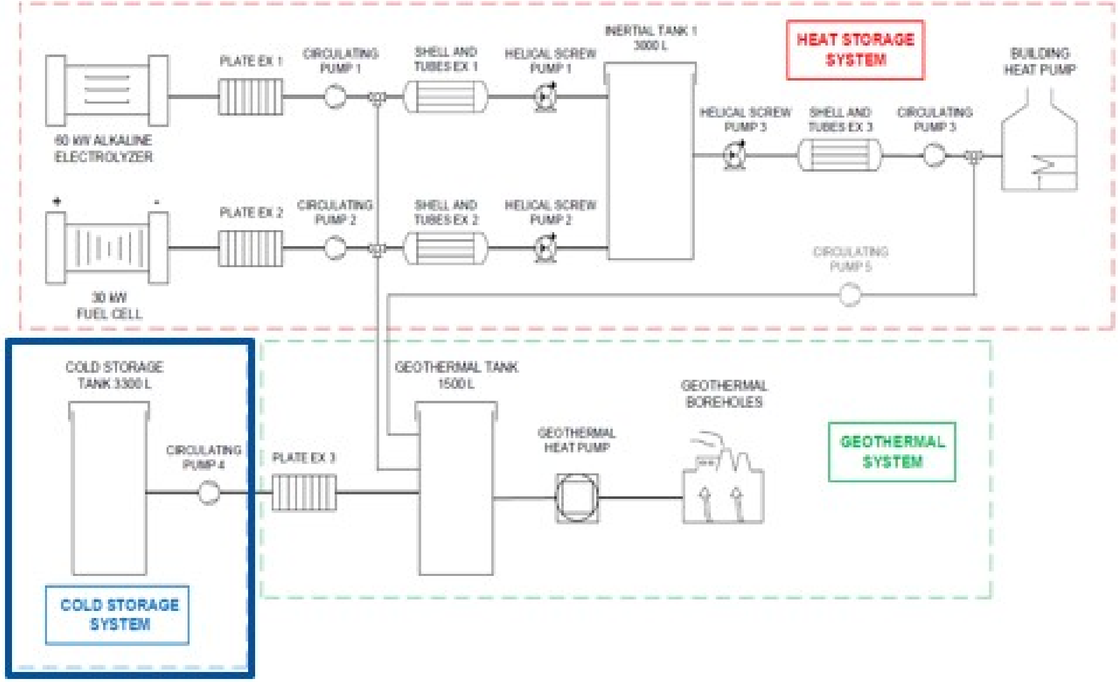
6 U boreholes of 100m in deep

Geothermal installation internal part

2.2. Cold Energy Storage System (CESS)

COLD ENERGY STORAGE SYSTEM

- **OBJECTIVE: Storing** the **cool from the subsoil**
  - **100 kW macroencapsulated PCM** are placed inside **the 3300 L storage tank**
  - **PCM are immobile inside the tank**
  - **6 U-shaped boreholes of 100 meters in deep** were carried out
  - The **cold storage tank** is connected to:
    - **Geothermal inertia tank** through a plate heat exchanger



2.2. Cold Energy Storage System (CESS)


PCM of CESS (fix and inorganic)

The PCM used in this system is a type of macro-encapsulated inorganic PCM (Figure 22) with a melting point between 10-13 ºC. At this range of temperature, when the material is cooled, would begin to change its phase from liquid to solid state. In this way the energy communicated to PCM will be employed as latent heat (180 kJ/kg), which it is much higher than its specific heat (4 kJ/(kg*K)), allowing a higher accumulation of energy that can be used when it will be necessary.

2.3. Heat Energy Storage System (HESS)

HEAT STORAGE SYSTEM

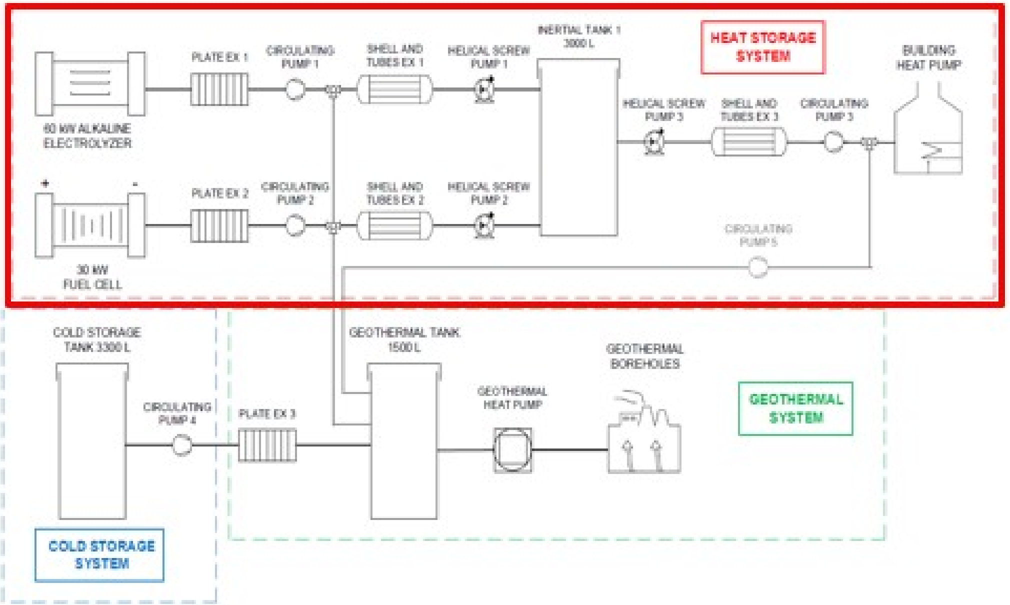
- **OBJECTIVE:** Take advantage of the **waste heat** generated from the **electrolyzer** and the **fuel cell** to **reduce the building's energy consumption**
  - **Waste heat** is recovered though different **heat exchangers**
  - The recovered heat is stored in **an inertial tank (3000 L)** which contains **100 kW slurry microencapsulated PCM**
  - The outlet of the inertial tank is injected in the general building air-conditioner

Alkaline electrolyzer

- Electric power: 60 kW
- Thermal power: 60 kW
- Operating temp: 60 – 75°C
- H_2 production: 10,66 Nm^3/h
- H_2 pressure: 10 bar

PEM Fuel Cell

- Electric power: 30 kW
- Thermal power: 30 kW
- H_2 consumption: ≤ 500 L/min
- Air consumption: ≤ 2500 L/min



2.3. Heat Energy Storage System (HESS)

Hydrogen Cycle

Heat

Alkaline Electrolyzer

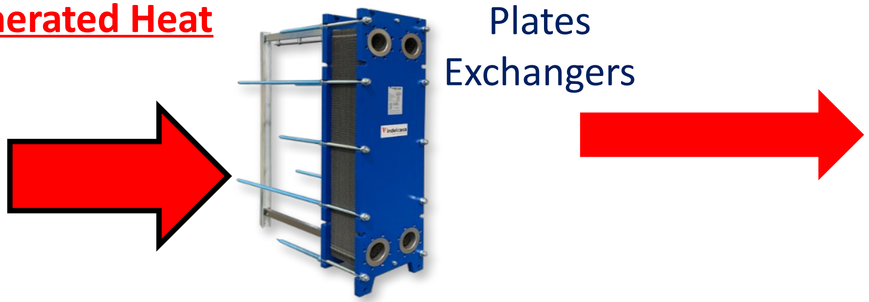
H2 Storage Park (10 bar) and (200 bar)

Heat

PEM FC

2.3. Heat Energy Storage System (HESS)

Generated Heat



Shell/Tubes Exchanger Water + PCM Slurry Circuit

In this case, the PCM is a type of **micro-encapsulated organic PCM slurry**, which consists in an aqueous dispersion of microcapsules based on highly **crosslinked polyurethane polymer and encapsulated paraffin wax**, with a melting point between 33-37 ºC. **When the material is heated**, would begin to **change its phase from solid** to liquid state, with **a latent heat of 180 kJ/kg** that provides a higher energy storage capacity.

The PCM has caused difficulties:

Storage: potential separation of organic/inorganic phase after some time. Coagulation and flocculation phenomena appear. This important unstability resulted in the generation of a high viscosity organic phase and an aqueous phase, and thus a potential loss of its heat storage power.

Use: when the PCM is in motion (flowing) throughout the installation of the pilot plant, its high viscosity and potential phase separation can cause "jams" and important "fouling" of equipment and instrumentation. In case the pumps that drive the fluid (screw pump) are not working, the fluid, after some period laying still can suffer the separation of phases even within the installation. This forces its continuous operation or to remove the said fluid once the tests are finished.

2.3. Heat Energy Storage System (HESS)

Connection between GRS and HESS through 4 motorized 3-way valves

In both cases, the heat generated is transmitted by a water + glycol fluid to a shell-tube heat exchanger through the tube side, where it will exchange heat with a fluid of microencapsulated PCM slurry (shell side), which will be sent through screw pumps to a 3000L inertial tank, where heat will be stored. From this tank, the PCM slurry (shell side) exchanges, in other shell-tube exchanger, heat with a water-glycol circuit (tubes side), which directly injects the heat into the air conditioner system.

Building air conditioner is a reversible air-water heat pump, model KEYTER WE 8270 which uses R410A as a refrigerant with 3 refrigeration circuits and 6 compressors. It can provide a heat nominal power of 236,9 kW in cooling mode and 273,3 kW in heating mode.

Both in heating or cooling mode, the plant pilot pretends to inject an extra energetic supply that reduces the electrical energy consumption of the building air conditioning.

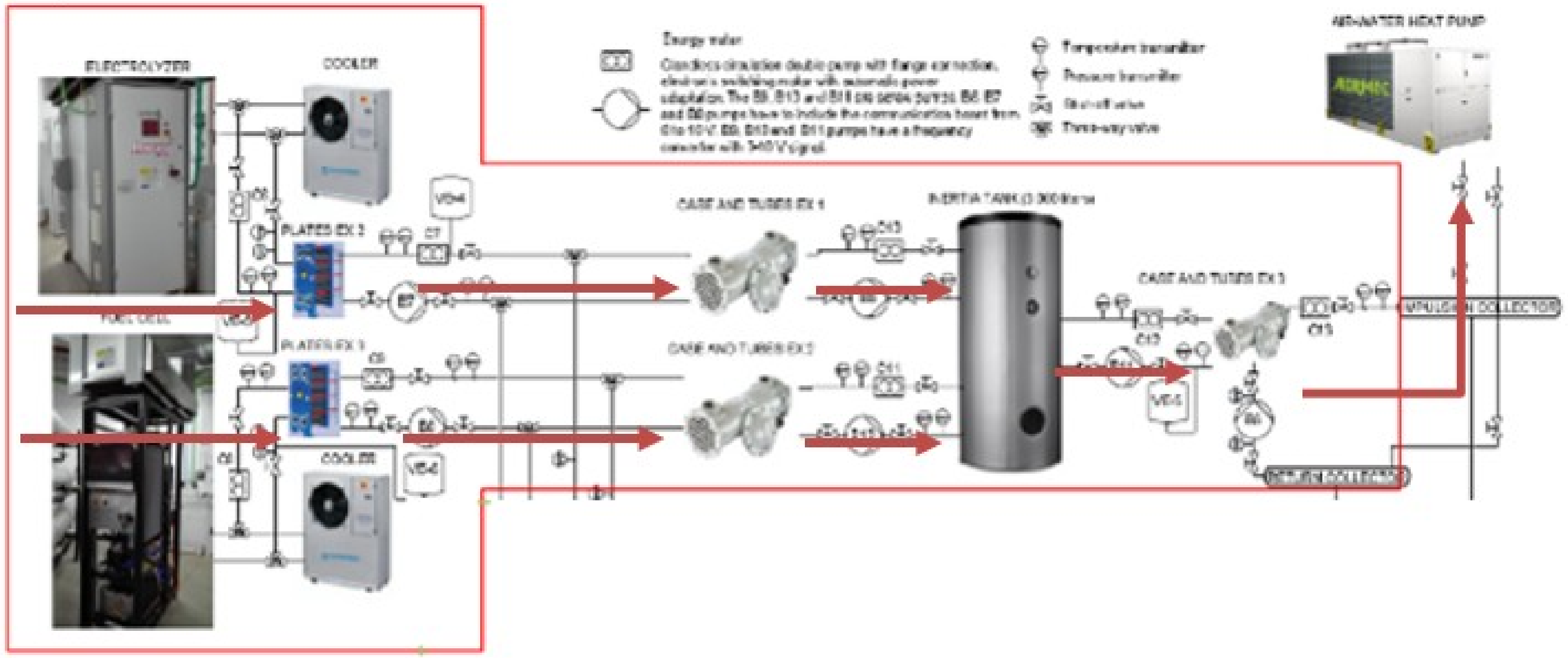
2.4.Operation Modes

Operation Modes

- WINTER MODE (HEATING)
  - 1.) Hydrogen + HESS + Injection (PLAN WINTER 22/23)
  - 2.) GRS + HESS + Injection (PLAN WINTER 22/23)
- SUMMER MODE (COOLING)
  - 3.) GRS + Injection (DONE)
  - 4.) GRS + CESS + Injection (DONE)

2.4.Operation Modes

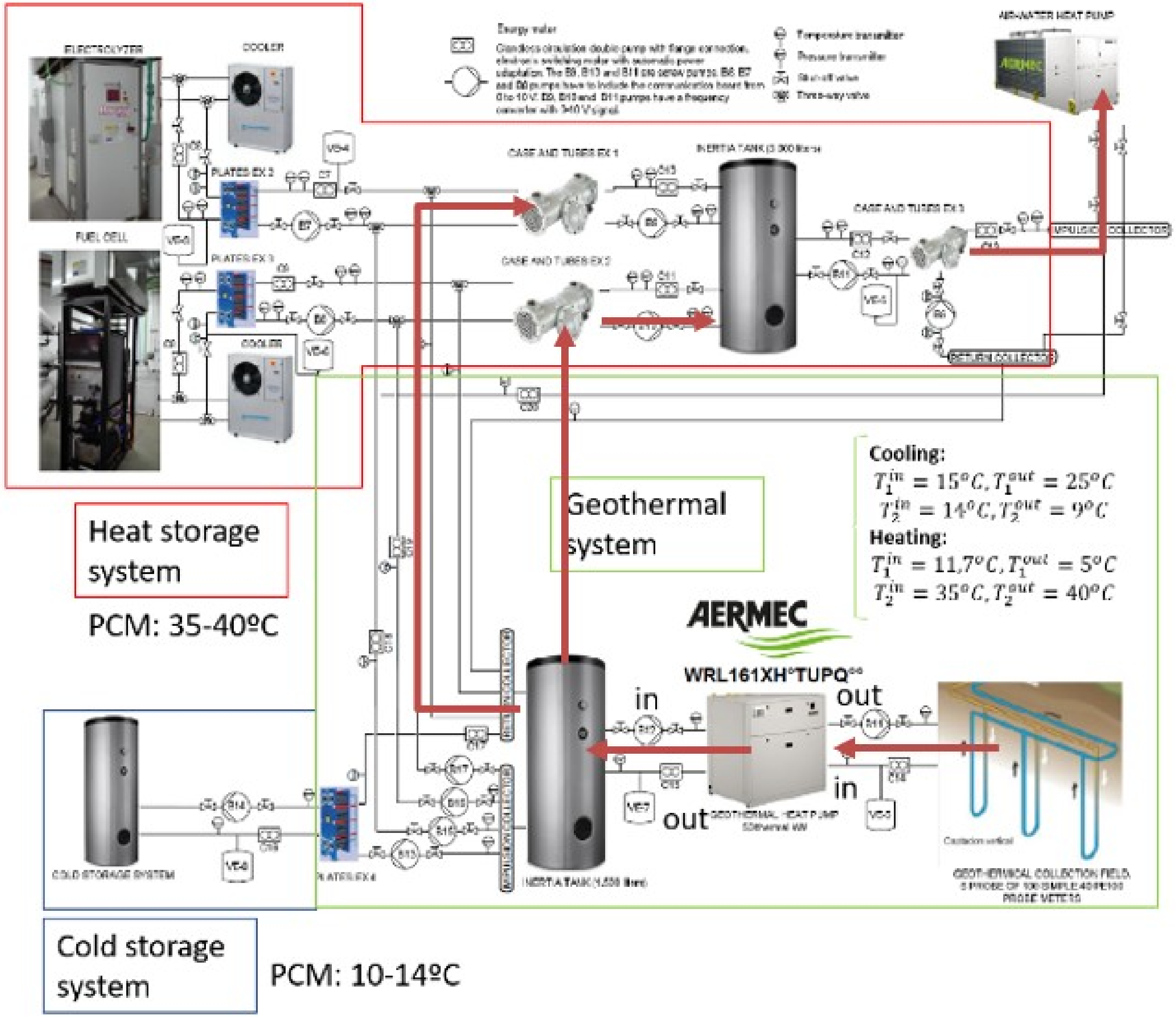
Mode 1: Hydrogen + HESS + Injection



Heat storage system

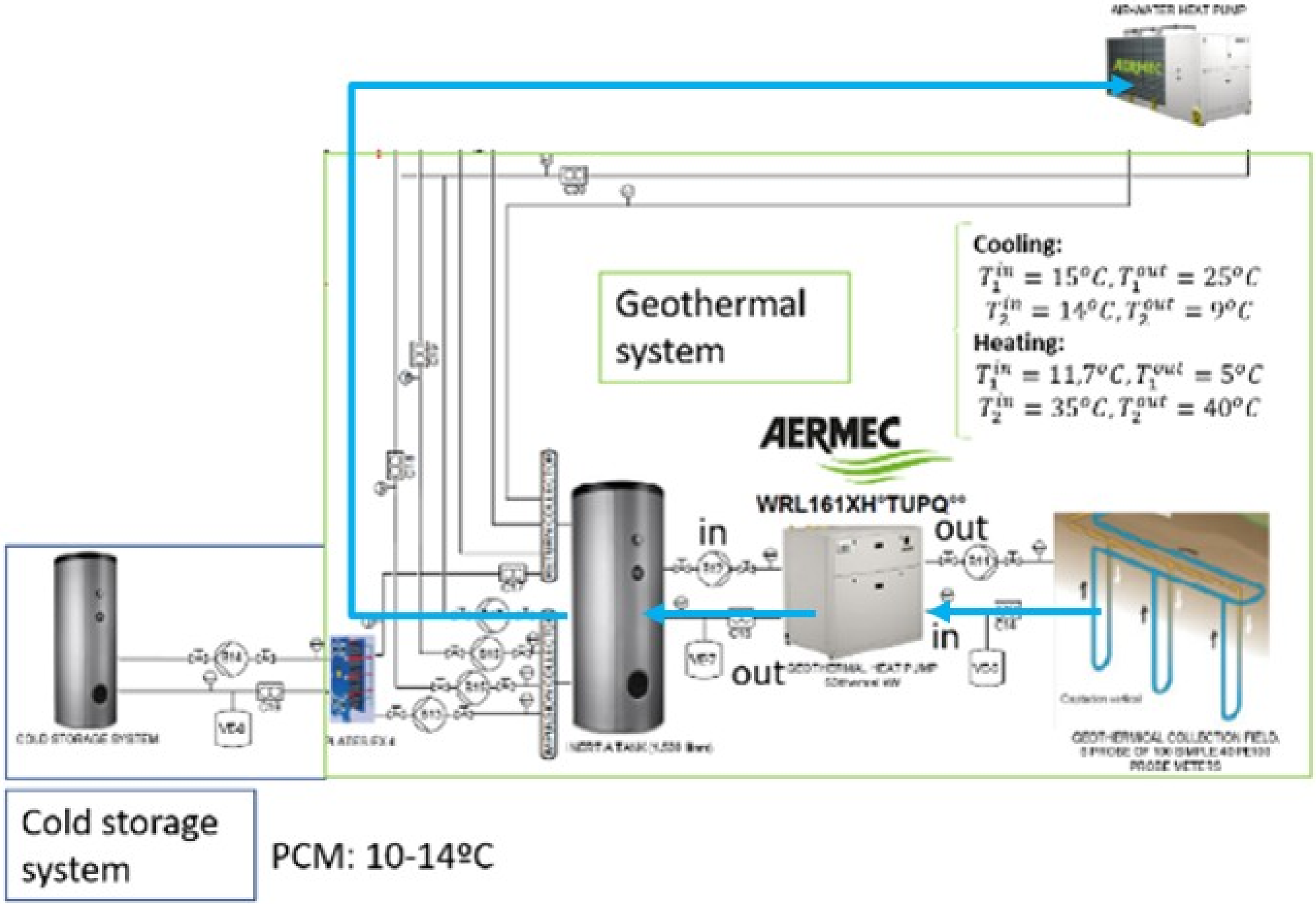
2.4.Operation Modes

Mode 2: GRS + HESS + Injection



2.4.Operation Modes

Mode 3: GRS + Injection



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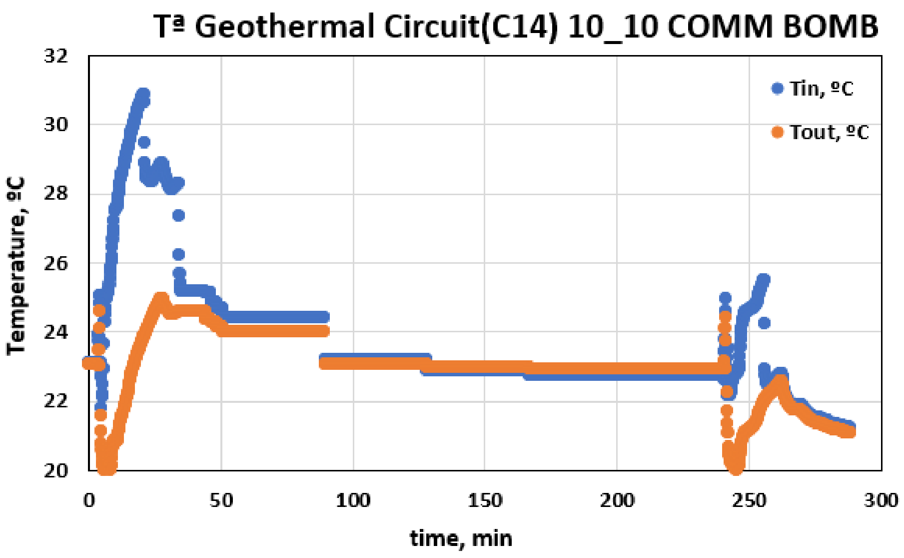
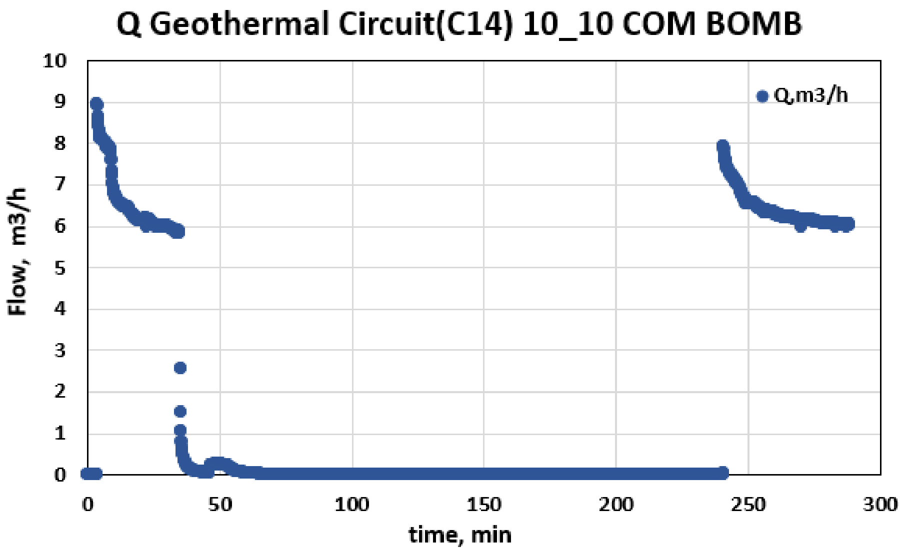
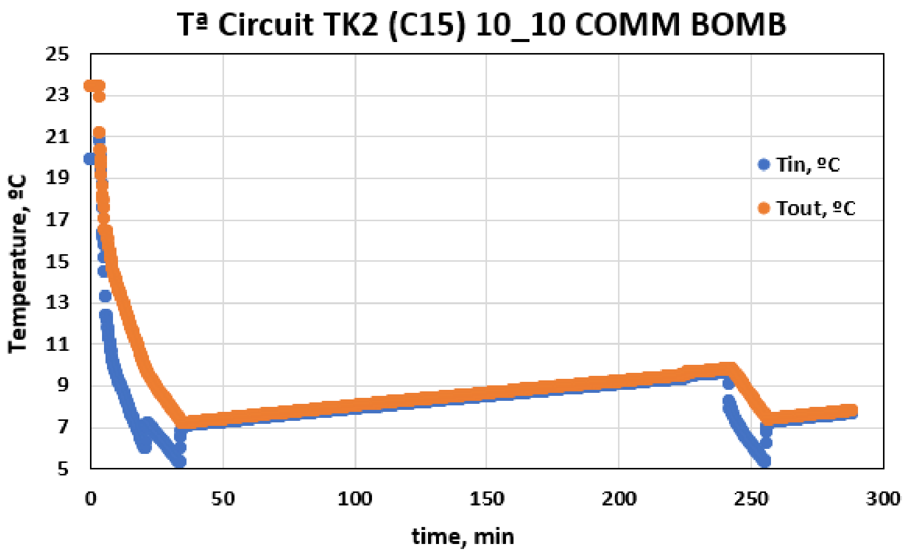
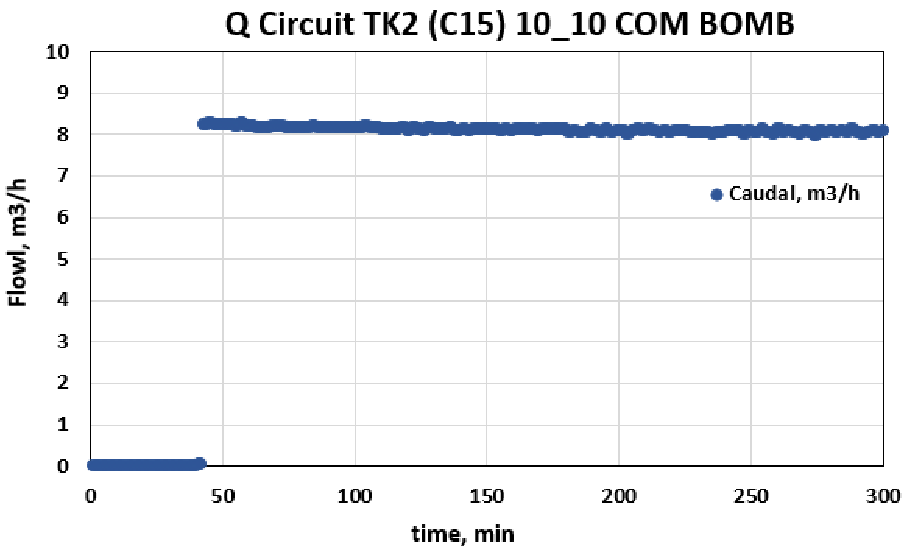
Results Mode 3: GRS + Injection









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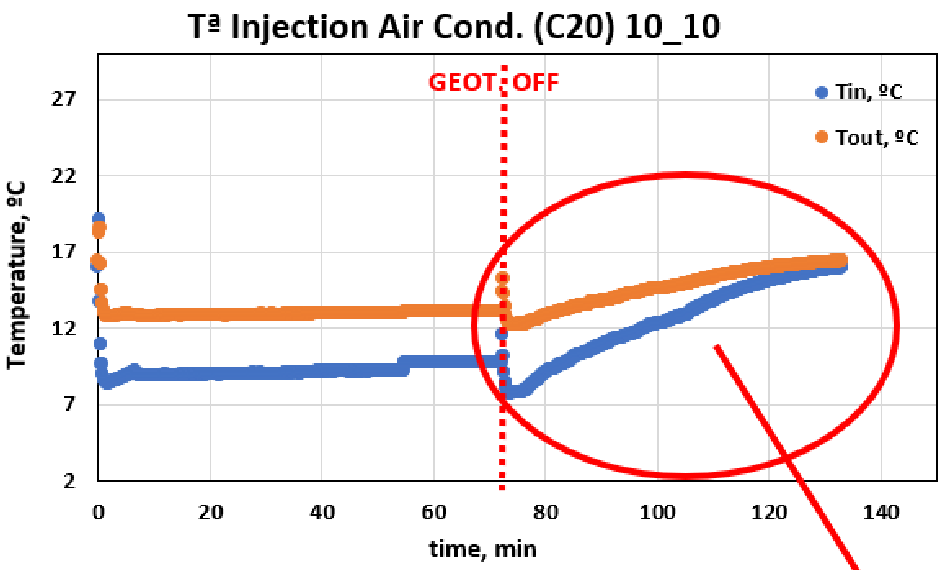

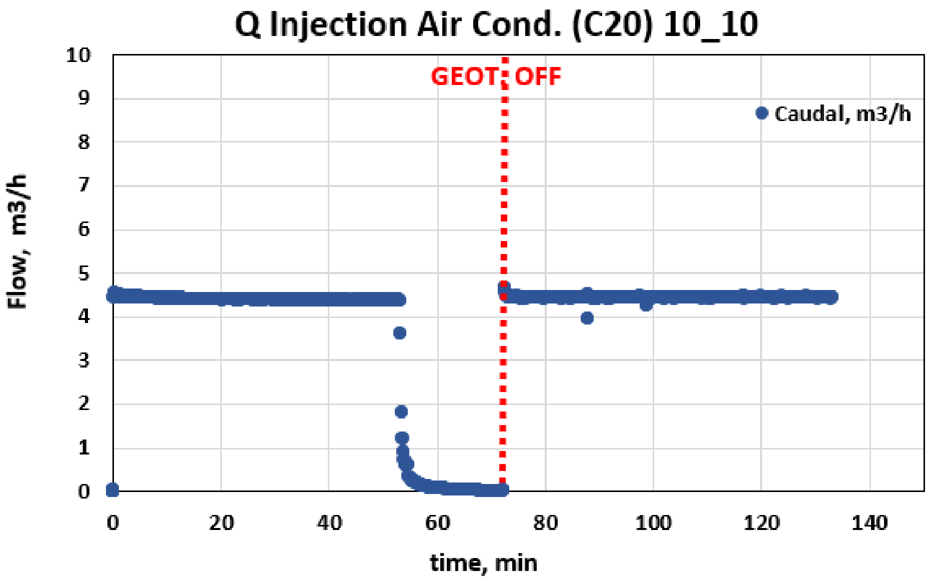

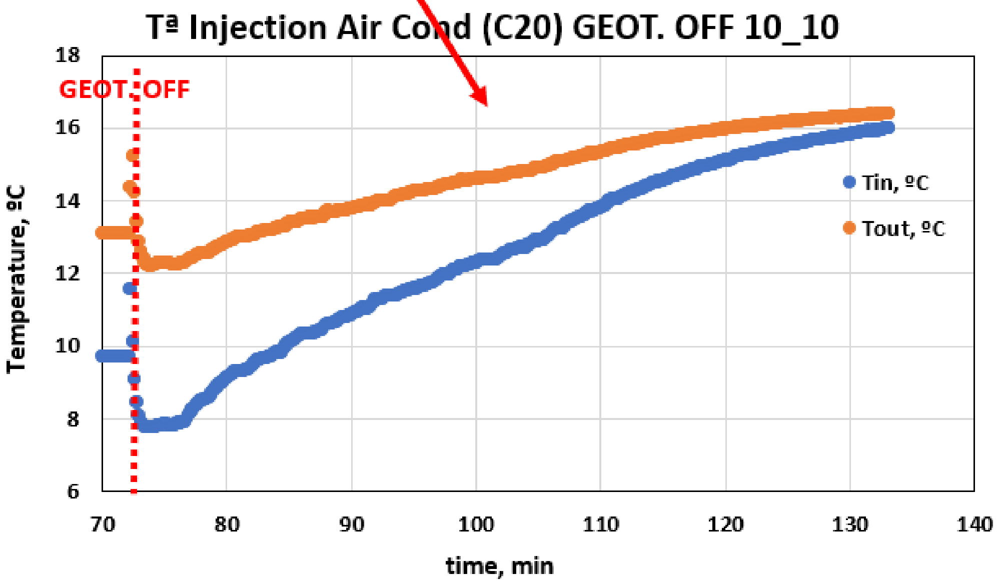

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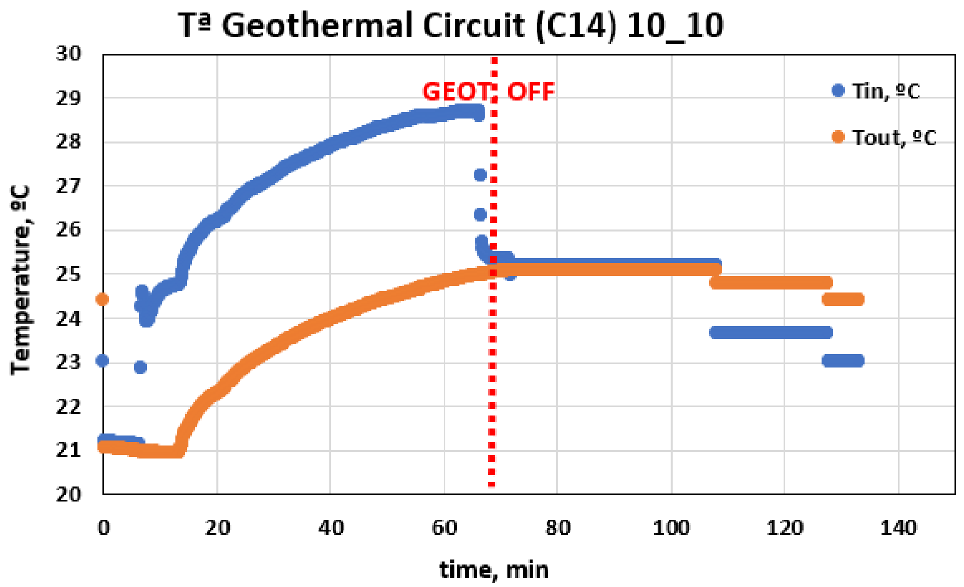

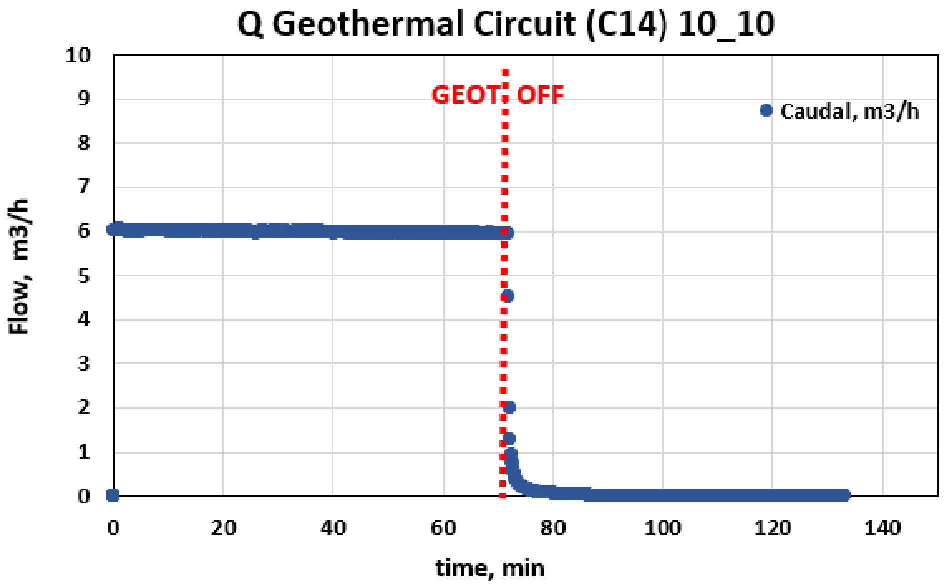

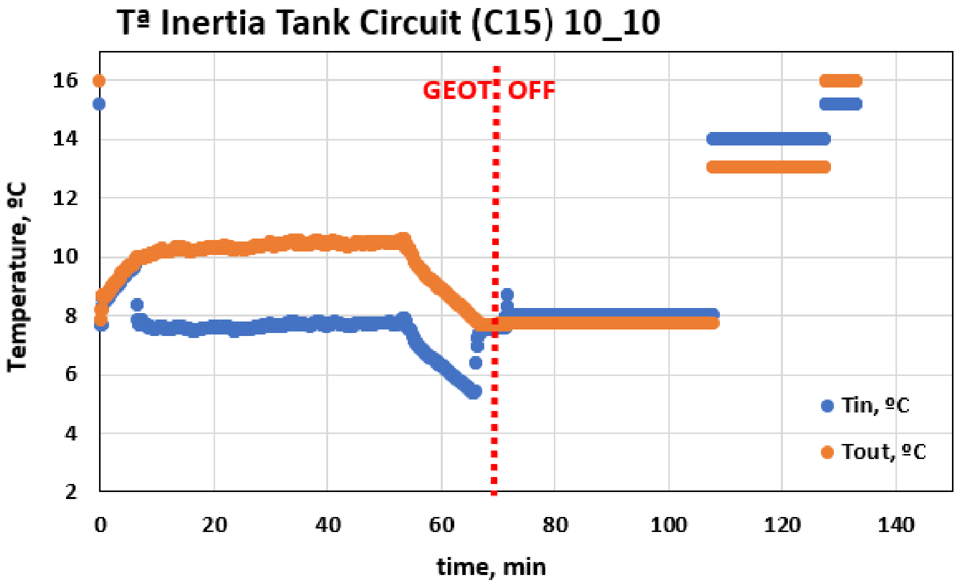

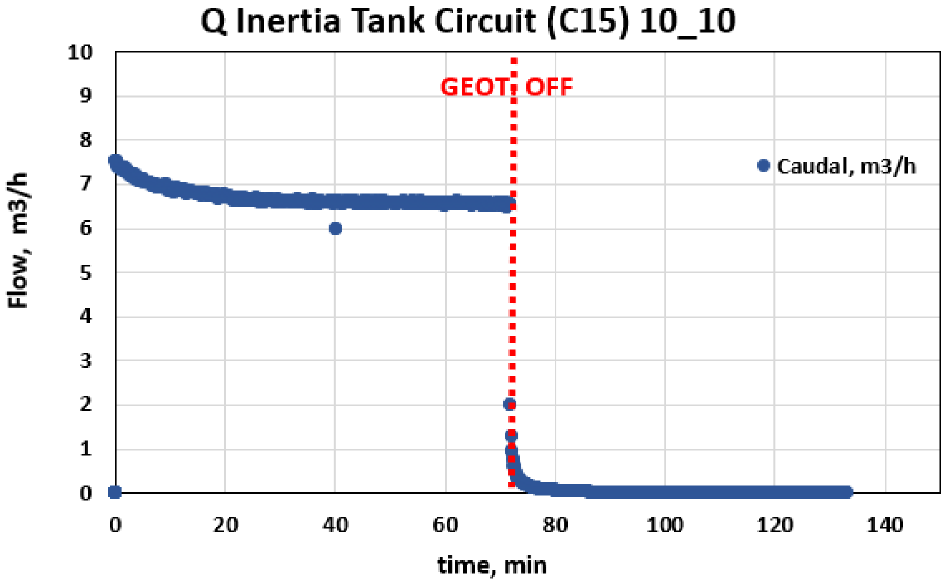

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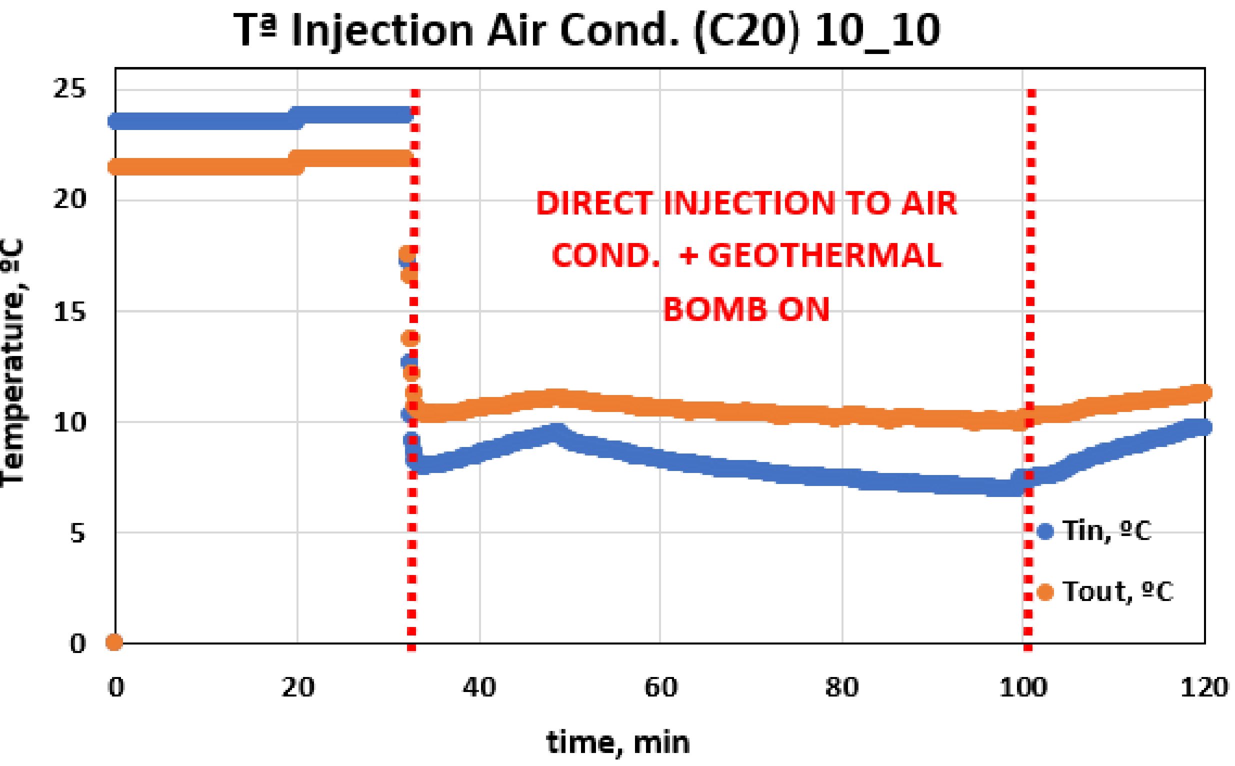

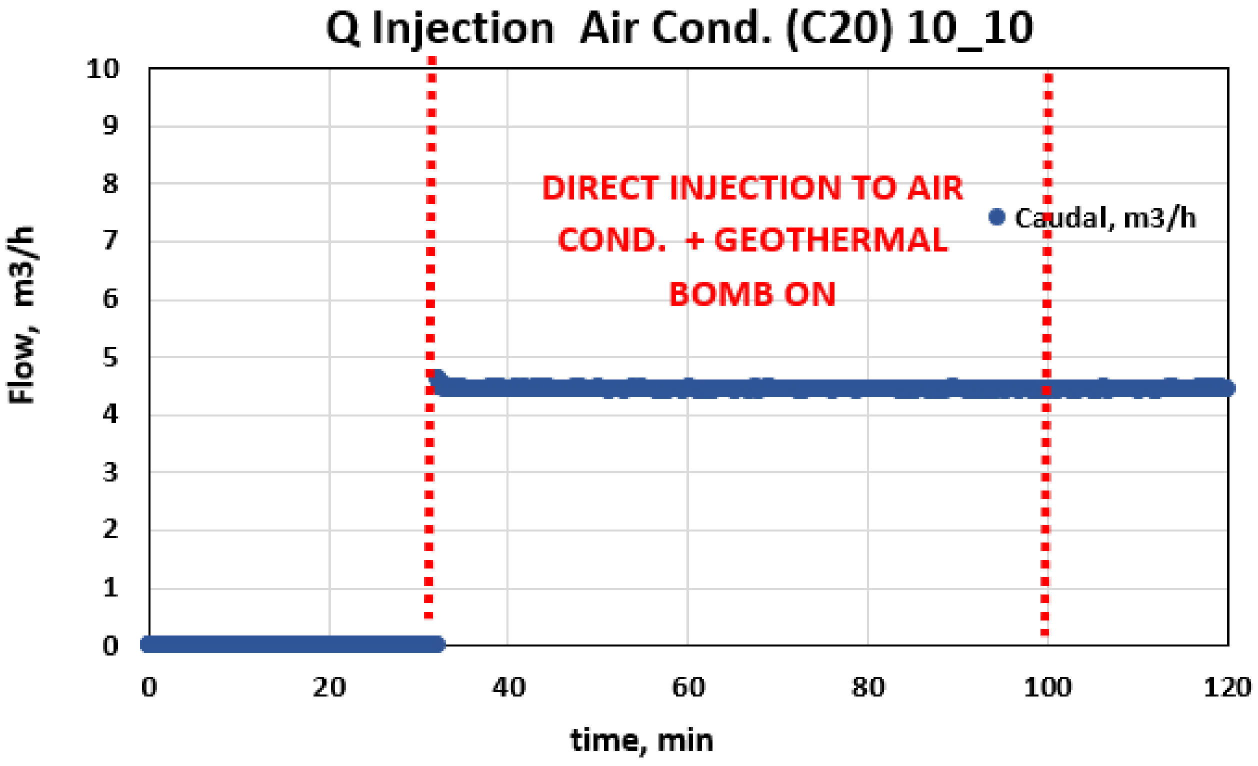

The main conclusion of this test is that geothermal energy is able to maintain the water injection temperature more or less stable (at the cost of continuing to use electricity in the geothermal pump).

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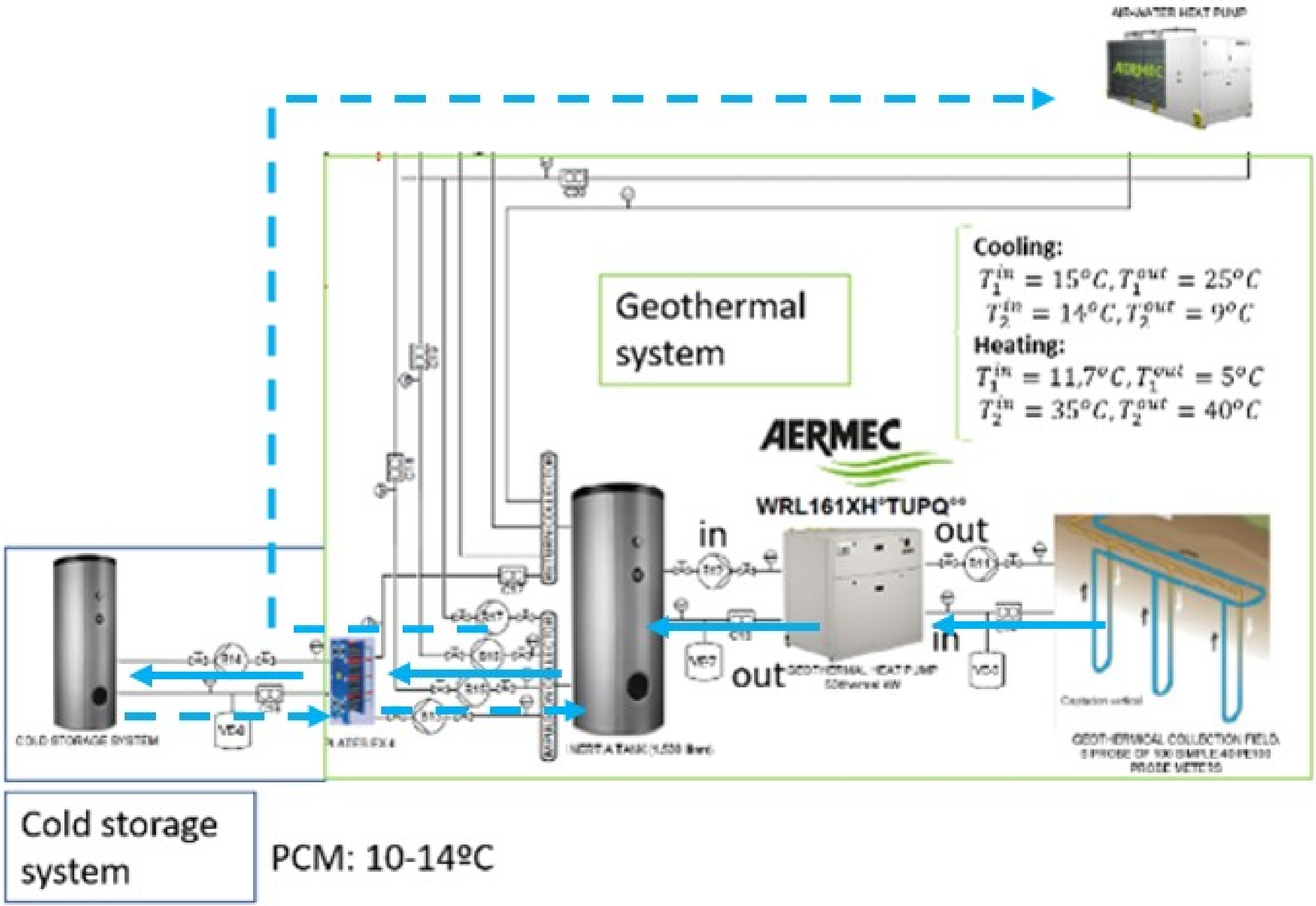
2.4.Operation Modes

Mode 4: GRS + CESS + Injection



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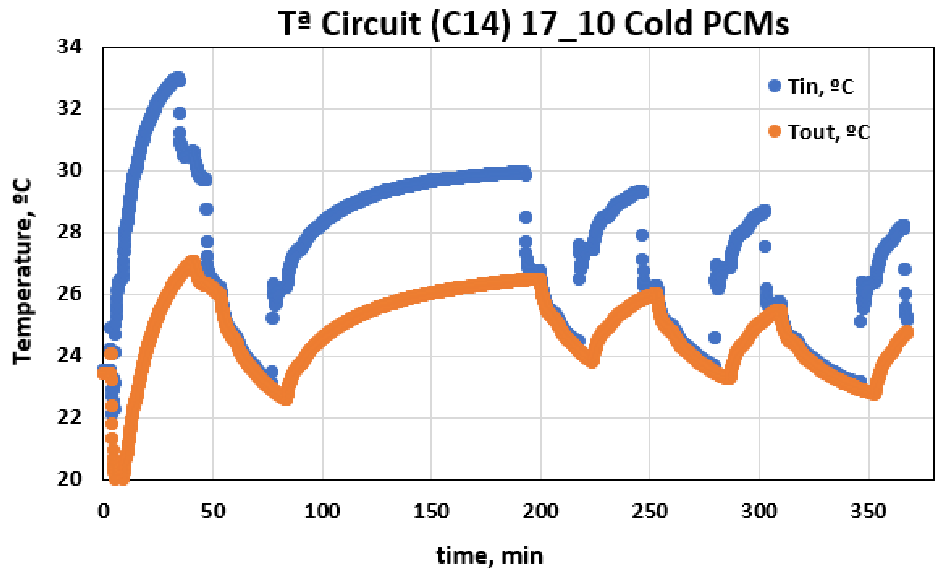
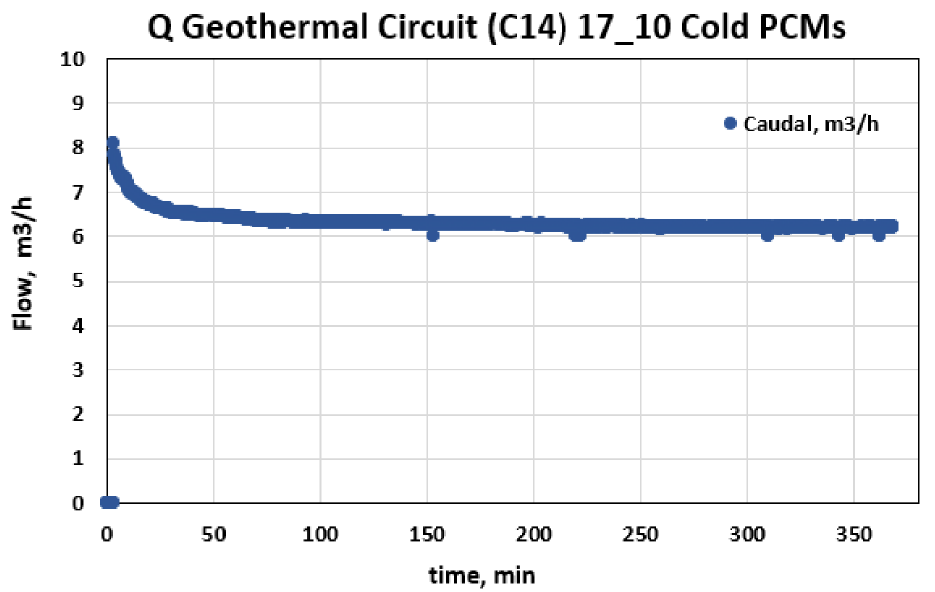
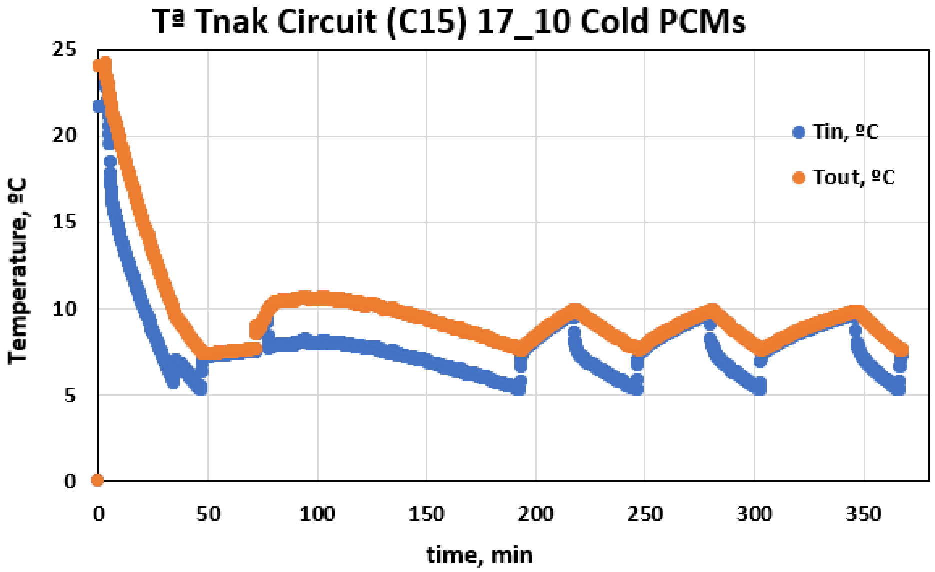
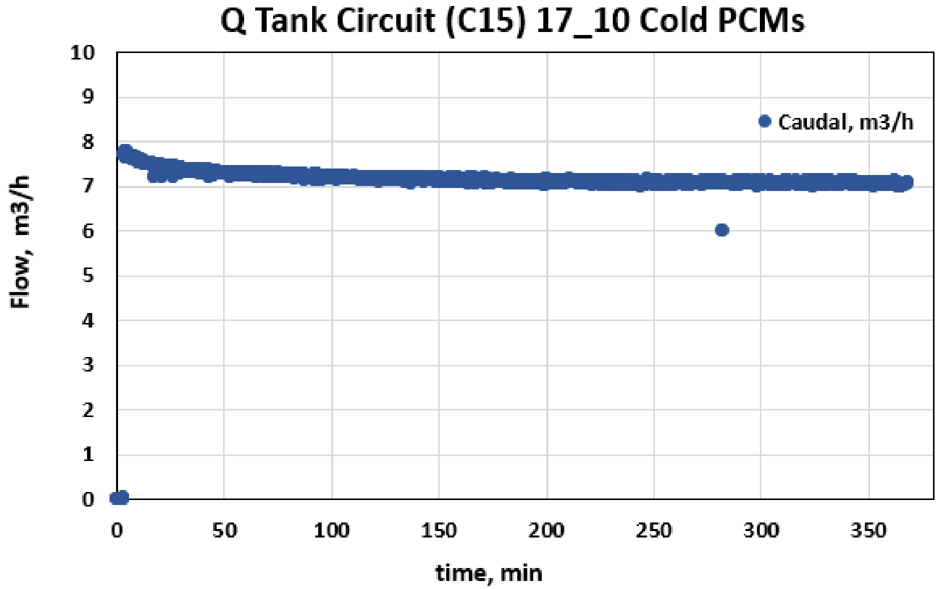
2.4. Results Mode 4: GRS + CESS + Injection

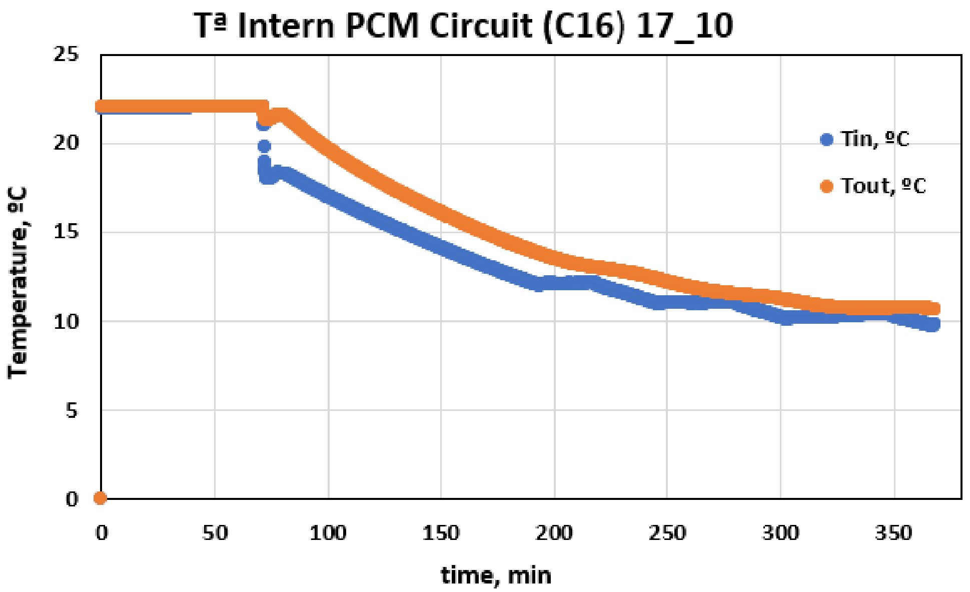


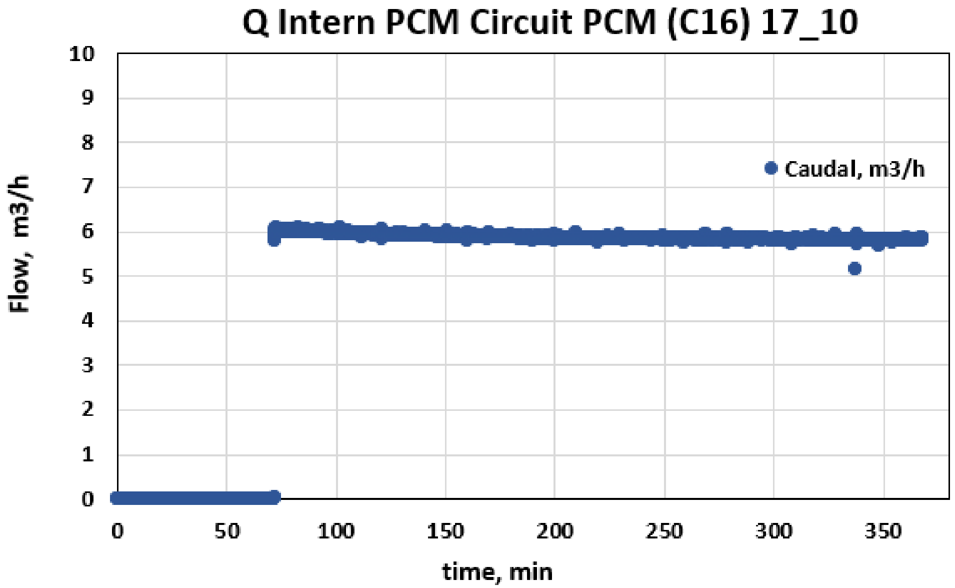


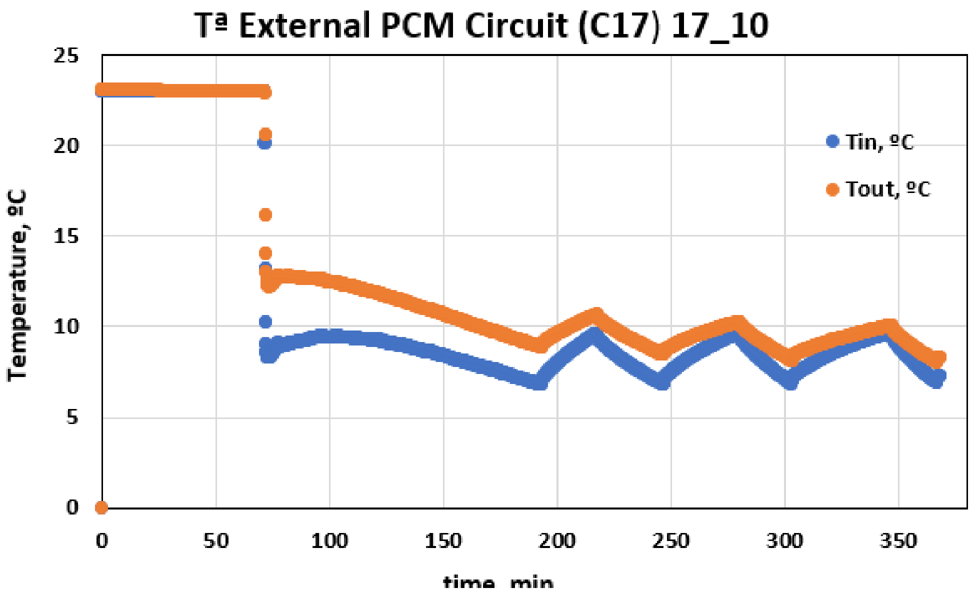


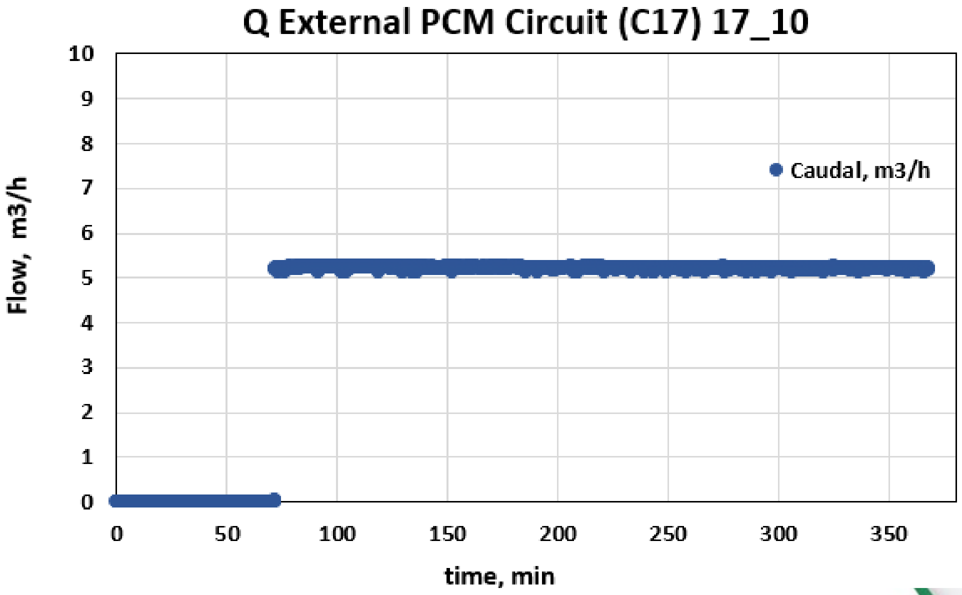


2.4. Results Mode 4: GRS + CESS + Injection

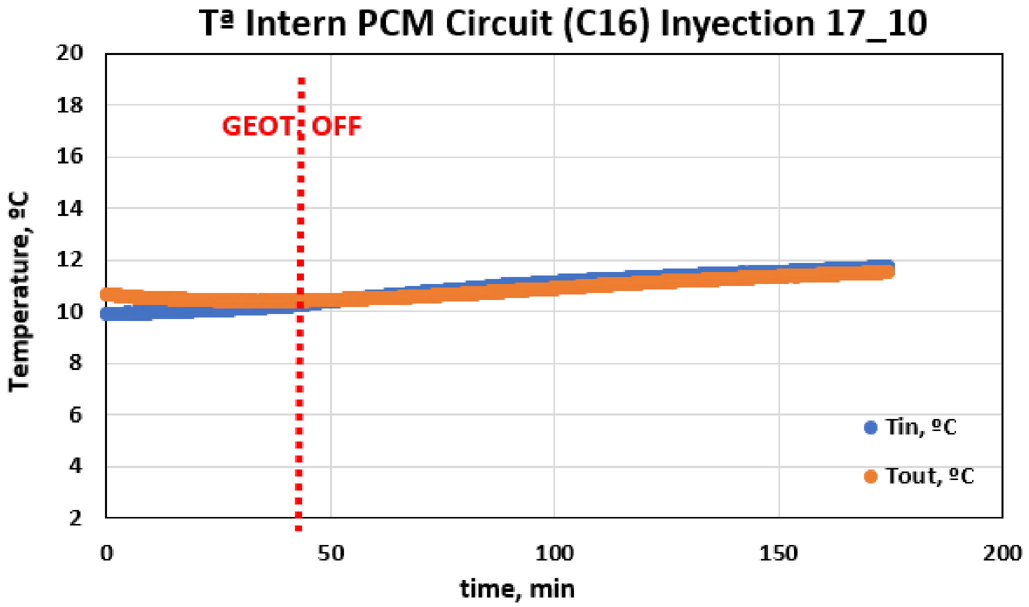


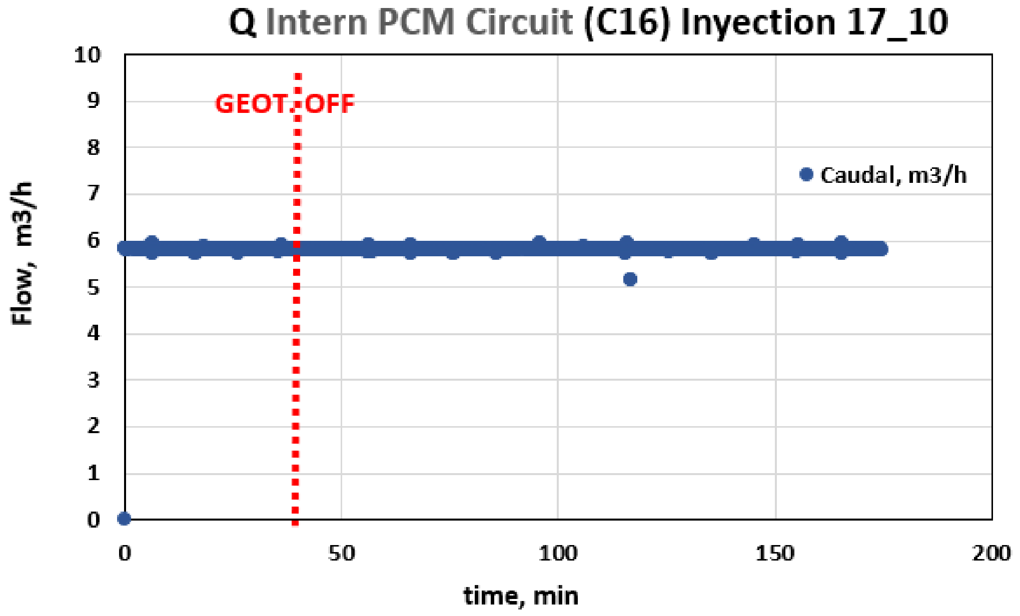


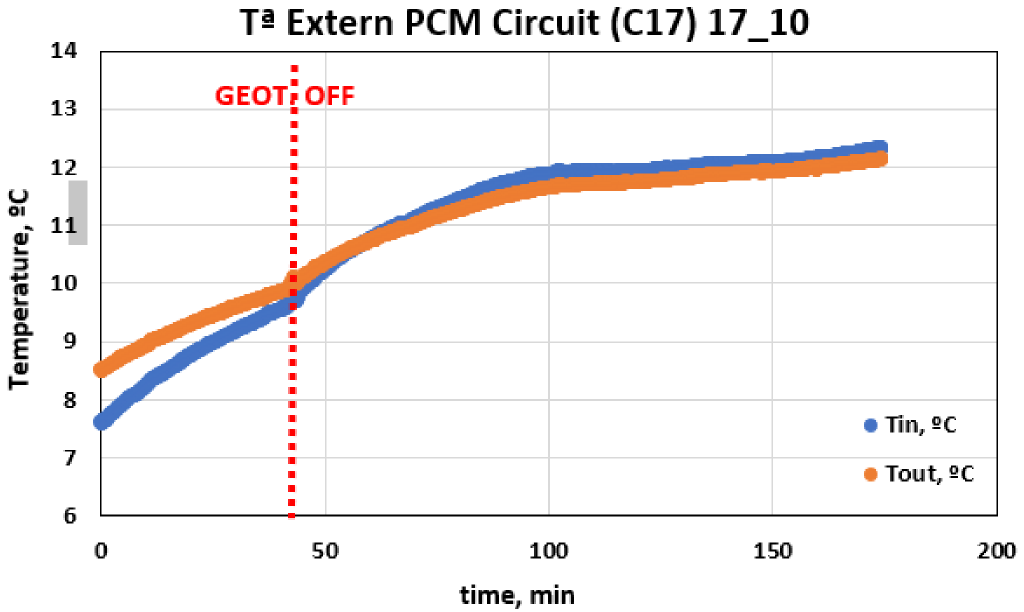


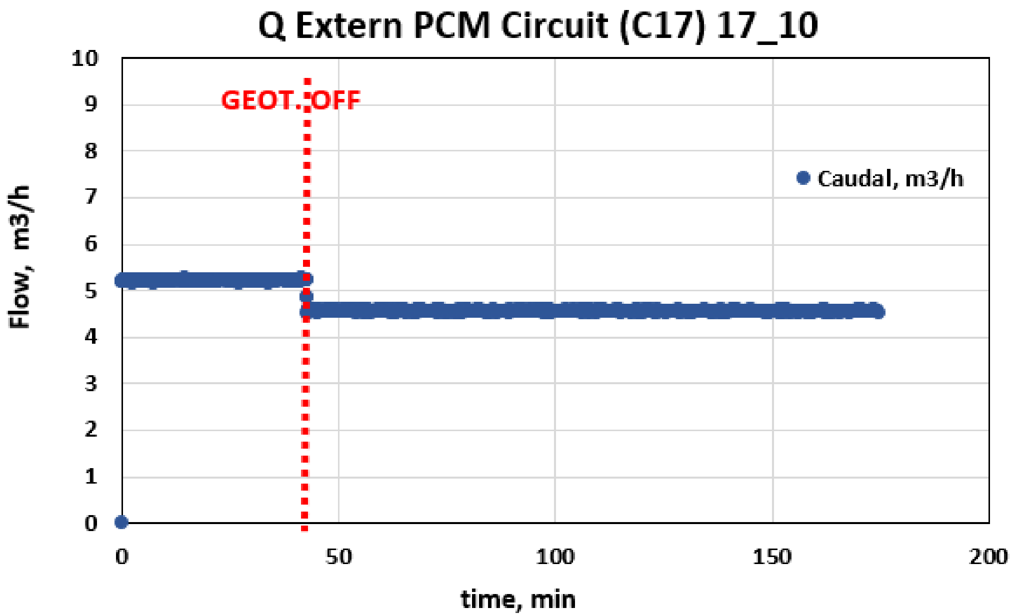


2.4. Results Mode 4: GRS + CESS + Injection

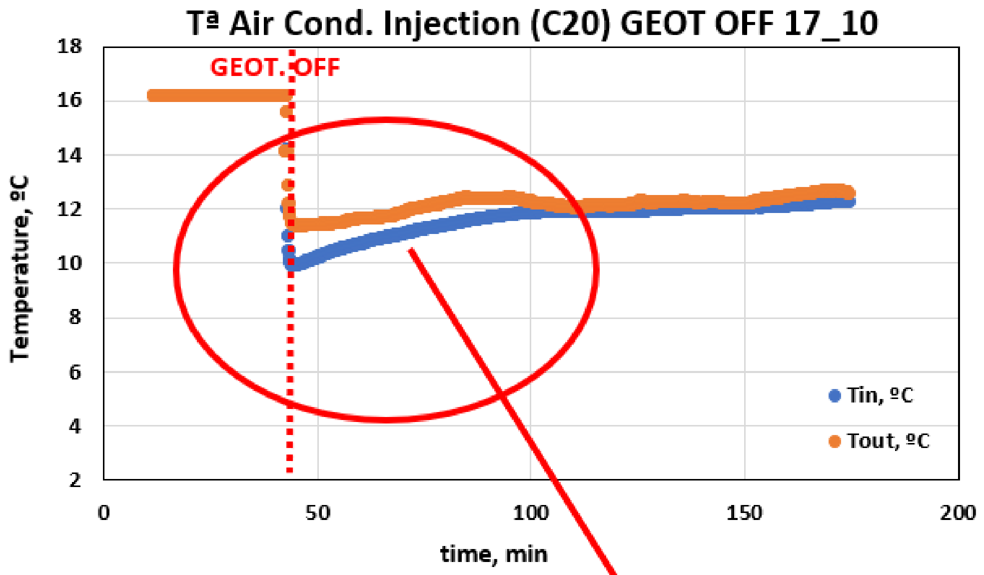


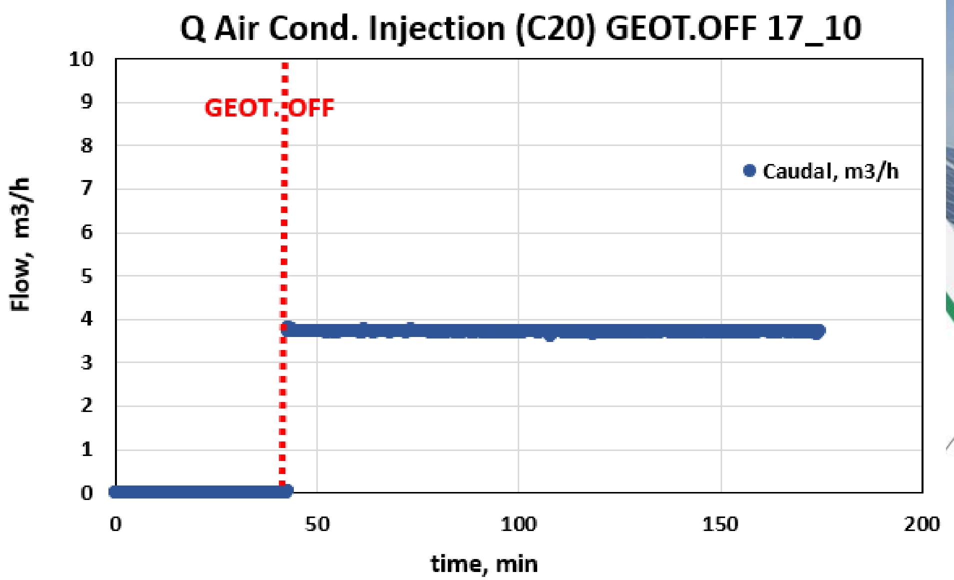


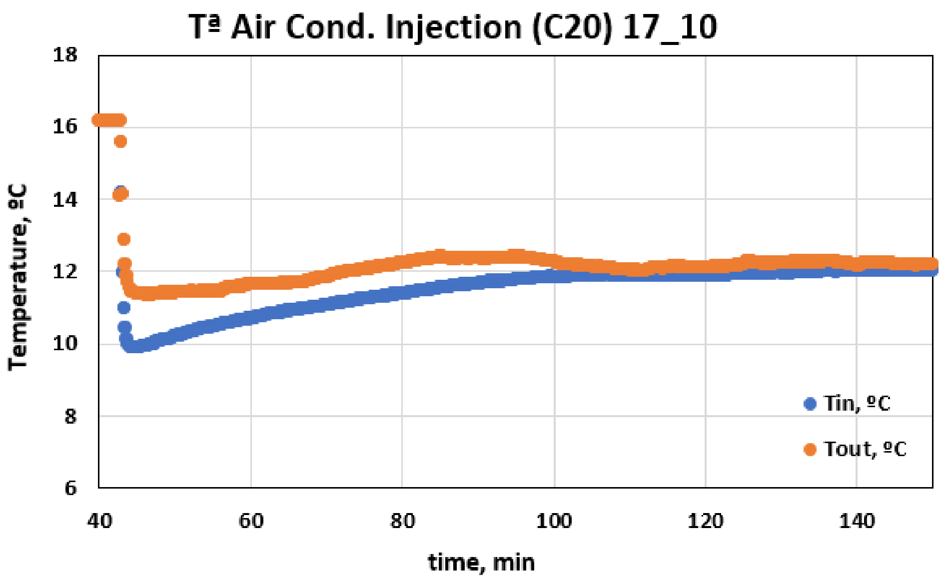




2.4. Results Mode 4: GRS + CESS + Injection







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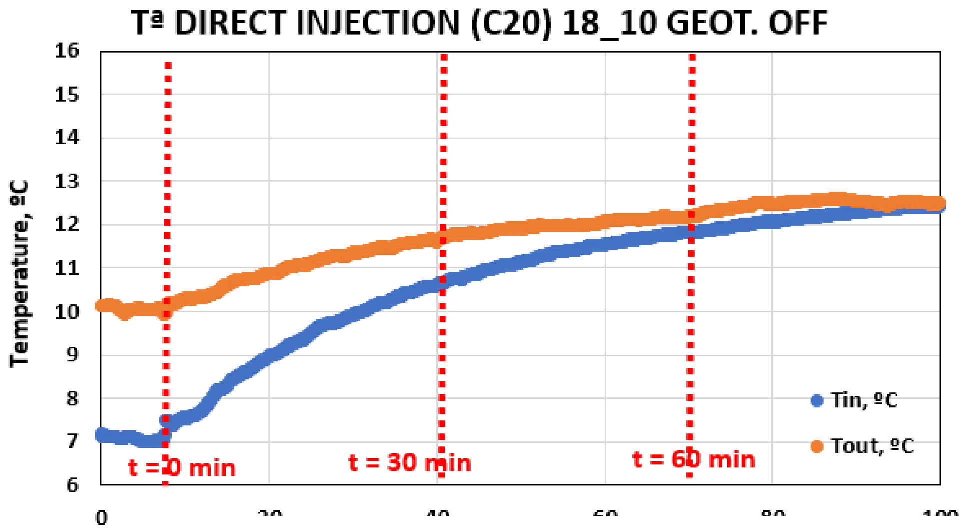
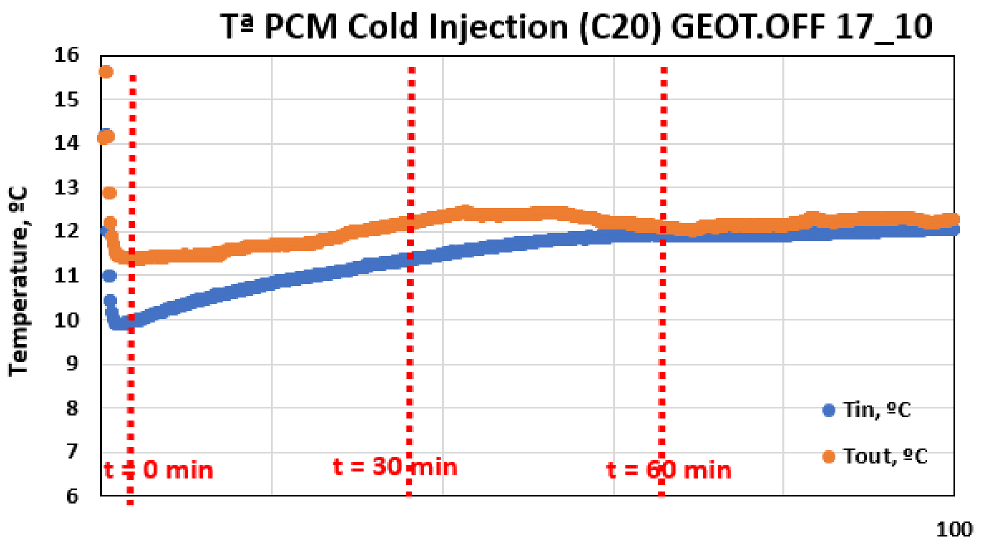
2.4. Results Mode 3 and 4

	Thermal Utilization	%COLD resp. ELECTRIC		%COLD resp. THERMAL	
	Max. Value	%Resp. MAX ELEC.	%Resp. ELEC. OPERATION	%Resp. THERM.MÁX	%Resp. THERM. OPERACION
PCMs (17/10)	**6,04 kW**	**7,03%**	12,08%	**2,55%**	4,31%
Direct Injection (18/10)	**15,68 kW**	**18,25%**	31,36%	**6,61%**	11,2%

It can be established how, case with PCMs, the cold yielded has been lower due to both the lower flow of operation and the lower initial thermal gradient, caused by both the external weather conditions and the operating conditions for that day, such differences should not occur for a total level playing field.

2.4. Results Mode 3 and 4





	COLD STORAGE LOSSES	
	*Refrigeration losses after 1 hour of injection	% Losses Direct Injection vs PCM
PCMs (17/10)	**9,29 kWh**	**64,4%** More Direct Injection Losses than PCMs
Direct Injection (18/10)	**26,13 kWh**	

THANK YOU!

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