Low valued energy sources UPgrading for buildings and industry uses

LowUP Operation and Validation results for Relevant environment 1 (heating and cooling solution)

Deliverable D4.14

Lead Beneficiary: ACCIONA
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Silvio Vitali Nari1, Carlos Ramos[1], Josep Pijuan[2]

[1]*ACCIONA*
[2] *Fundació Eurecat*

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About LowUP

LowUp – Low valued energy sources UPgrading for buildings and industry uses – is developing efficient alternatives to supply heating and cooling for building and industries, based on the use of renewable free energy and heat recovery from non-valuated residual energy sources that are currently wasted. As a result, these technologies will contribute to reducing significantly CO_2 emissions and primary energy consumption, and increase the energy efficiency in buildings.

Led by the Spanish firm ACCIONA, the LowUp project gathers 13 partners (3 large companies, 3 research and technology organisations and 7 SMEs) from 7 European countries. During 46months, the consortium will develop efficient alternatives to supply heating and cooling for buildings and industries based on renewable free energy as well as non-valuated wasted thermal sources:

- 3 technologies will be developed and demonstrated: one heating and one cooling system for buildings, and one heat recovery system for industrial processes.
- The systems will be demonstrated at 4 demo sites: A Pilot Office building in Seville (Acciona Construcción, Spain), a Waste Water Treatment plant in Madrid (Canal de Isabel II & Acciona Water), a Pulp and Paper mill in Setubal (Portugal, The Navigator Company) and a Student Hall in Badajoz (Spain, University of Extremadura).

For more information, visit: www.lowup-h2020.eu

Coordinator contact
Rafael C. Socorro Hernández

Acciona Construcción S.A.

Av. Europa 18, 28108 Alcobendas (Madrid, Spain)

email: rafaelclaret.socorro.hernandez@acciona.com

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Executive Summary

This report (D4.14 "LowUP Operation and Validation results for Relevant environment 1") has been elaborated within the LowUP Project (GA #723930) and provides a detailed description of commissioning and star-up of every unit, equipment and system installed for Cool and Heat LowUP in Seville demo site according to Spanish rules and manufacturer recommendations.

Keywords

Industrial heat recovery, monitoring, control of energy systems, high-temperature heat pump, rotary heat exchanger

List of acronyms and abbreviations

AHU	Air handling unit
API	Application Programming Interface
BAS	Building Automation System
BACN	Building Automation and Control Network
BAU	Business-as-usual
BEMS	Building Energy Management System
BMS	Building Management System
HVAC	Heating, Ventilating and Air Conditioning
HX	Heat exchanger
JDBC	Java Database Connectivity
ODBC	Open Database Connectivity
PCM	Phase Change Material
PLC	Programmable Logic Controller
REST	Representational State Transfer
SOA	Service-Oriented Architectures
WC	Water-Cooled
WWTP	Waste Water Treatment Plant

1 Introduction

This deliverable D4.14 includes the characterization and operation in relevant environment of LowUP solutions. Along with deliverables D4.10, D4.11, D4.12, D4.13 and D4.15, is part of the global understanding of real systems operation for the developed solutions 1 and 2.

The procedures stated in this Commissioning and Start up procedure cover the activities in preliminary tests and inspections, functional performance tests and the commissioning of newly completed installations and existing ones after major alteration. They are so compiled to facilitate the work of Project Building Services Engineer (PBSE) and Project Site Staff, who are appointed as the Supervising Officer's Representatives, in the following aspects with respect to testing and commissioning.

1.1 Motivation and objectives

The main objective of deliverable D4.14 is to present data from activities of characterization and operation of Heat and Cool LowUP under real working conditions, as required by necessity of supplying office building of Seville during winter and cooling seasons.

In this context, the specific objectives for the LowUP characterization and operation are the following:

- stable and continuous operation of the LowUP system in a geographically relevant operational environment, for the calibration and validation of each technology and of the whole LowUP System
- implement different variable thermal loads for testing efficiency and reliability of simultaneous heating and cooling concepts;
- perform parametric studies with the objective to achieve reliable conclusions about the impact that LowUP system could plan in future market..).

In this document for each system involved in the Cool-LowUP and Heat-LowUP solutions a surveillance study has been made. In some of the systems new alarms were defined by the experts of Acciona operating those systems in the Seville plant to avoid any damage on the systems an to control possible critical situations. On some other an analysis of their usage during the performance tests given has been made.

1.2 Relation to other project tasks

This deliverable is comprised within Task T4.4 in WP4. It is focused on operation and demonstration of overall efficiencies in relevant environment (Seville office building and Badajoz universitary residence).

Moreover, Table 1 describes in more detail the relationships between the tasks reported in D4.14 and the rest of the project.

Table 1: Relation with WP4 tasks.

Task / WP	Relationship
T4.4	Start-Up of the whole system
T4.4	Characterization of the LowUP system
T4.4	Operation and Validation at system level:

2 Presentation of the system

LowUP project is focused on the application of low exergy concepts for heating and cooling in buildings defining two systems (one for heating and another one for cooling), promoting the advantages of these types of systems by using low grade energy coming from renewable (solar and ambient thermal source) and waste sources.

HEAT-LowUP system is composed by following technologies.

- A PV module with thermal recovery system, able to cool down the temperature of the PV cell during operation, increasing the efficiency of radiation-to-electricity transformation on one hand, and making available for utilization the heat produced by the cell
- A Sewage water heat-recovery system, able to recover and store efficiently energy present in building wastewater, before being totally discharged
- A Stratified temperature multi storage system, based on water sensible heat, able to integrate in the same tank different sources at different temperatures, maintaining efficient separation between different layers
- An novel Radiant floor heating system with an innovative layer composition, in order to efficiently fulfil with building thermal load when operating at lower temperature (<35ºC) respect to traditional radiant solutions.

Cool-LowUP system is composed by following technologies:

- A wet cooling tower for evaporative recovery of cooling, able to extract cool from the air through the evaporative reaction of the water with the air
- A water-to-water heat exchanger, in order to recover cool from TAP water, naturally present between 10-16ºC in the underground network of the municipality
- A PCM latent storage system, able to integrate in the same tank these two sources at different temperatures
- An improved chilled beams cooling system working with tailored coils for operating close to setpoint conditions, in order to to efficiently fulfil with building thermal load when operating at higher temperature (>18ºC) respect to traditional chilling solutions

3 Start-up and Characterization

The purpose is to give a detailed description of operation of individual technologies, though tests executed along different periods, with the purpose of understanding performance, limits and gaps.

3.1 Heat LowUP

All described activities have been executed after commissioning of individual technologies, individual sub-systems and whole system; once right way of operation has been verified, tests focused on understanding performance in nominal conditions and operation in dynamic conditions, before long term operation.

3.1.1 Solar field

The heat recovery kit prototype has been installed in Seville's Demo, giving rise to a photovoltaic-thermal (PV/T) solar field composed by 40 solar panels. The heat recovery kit prototype will be named as PV/T panel hereinafter in this document to facilitate the reading.

To better determine the effect of the PCM, solar field has been distributed in two parallel lines (see Figure 1, left): one with 20 plain PV/T panels (line w/o PCM) and second with 20 PV/T panels with a layer of phase-change material PCM inserted (line w/ PCM).

Figure 1. Physical arrangement of the solar field (left) and stratified storage tank (right)

The analysis of the solar field focuses on the warm months of Spain, that is, from May to the present day. Previous months were used to setup the installation and the monitoring system and results cannot be considered as representative. During warm months, the installation has been subjected to different external conditions such as thermal loads, environmental aspects and temperature control.

The position of the intermediate valves between solar panels, storage tank and thermal loads determines if the solar field operates in a close loop, throws into the storage tank or provides heat to an external device.

The operation mode directly affects to the thermal performance, and indirectly conditions the electrical efficiency due to the working temperature reached in the panels. During the testing months, the solar circuit has worked in different modes, which explain the differences found in the thermal/electrical efficiency values. Other factors, such as hours of operation, wind speed or control settings may also affect to the final performance of the solar panels.

Next tests presents results of operation of electrical part of solar field, with 2 DC arrays (one for PV with PCM and another for PV without) connected to 2 different channels of same AC inverter. In below picture are represented all relevant monitored variables for only some of most interesting days.

Next figure presents main electric values in function of specific environmental conditions.

Color:	Variable:	Unit:	Magnitude:	Operation:
orange	AC power	kW	8,7	Connected to local grid
green	DC power PCM	kW	4,5	
violet	DC power	kW	4,3	
blue	radiation	W/m²	933	
red	Temp amb	ºC	17 to 37	

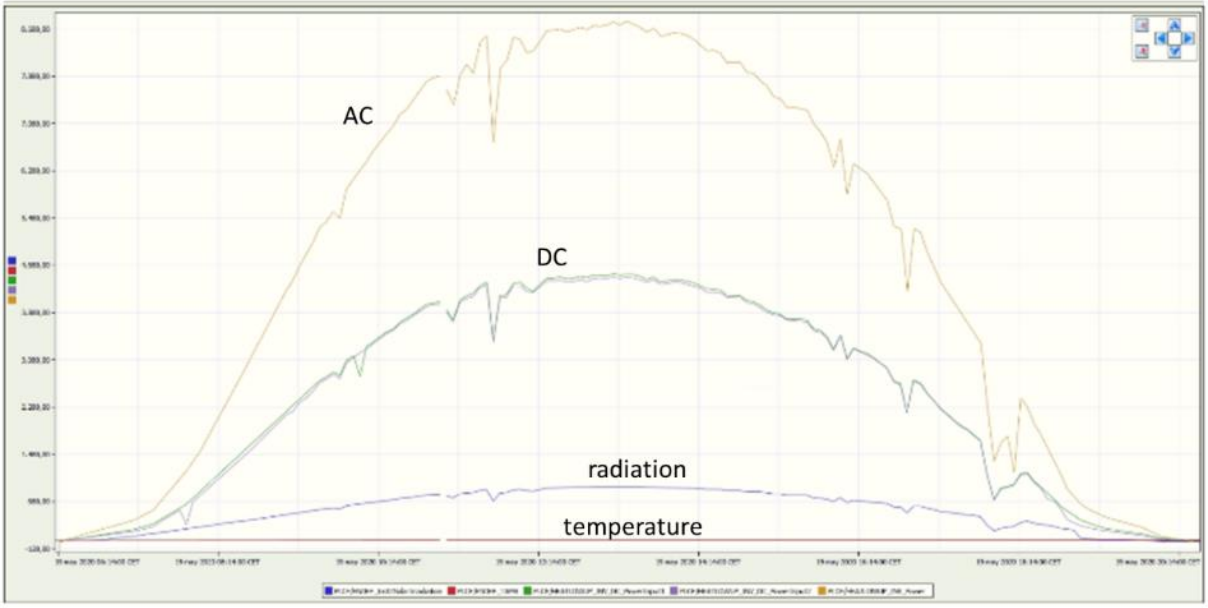


Figure 2. PV production for solar field and DC arrays

Next figure presents a zoom of DC production, evidencing how DC production along the day is different from array with PCM and without; nevertheless, the higher the temperature, the higher the saturation of PCM and the lower the difference between arrays.

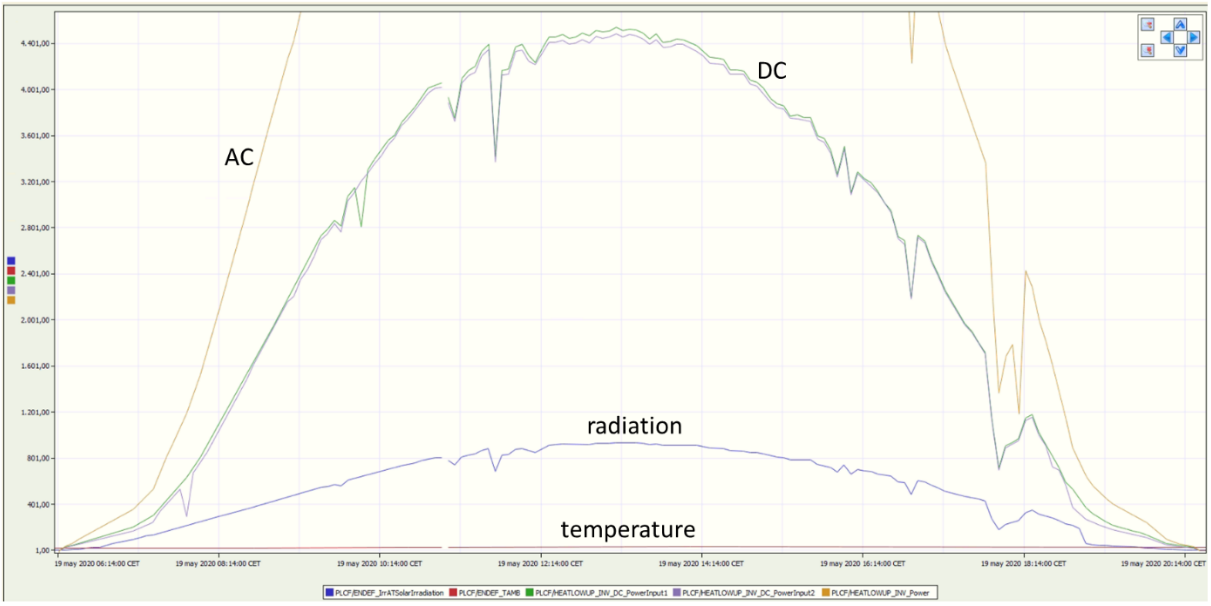


Figure 3: Difference in production between arrays along the day

Next picture presents detail of difference of production during different moments of the day, when PCM effect is more evident because not affected by thermal saturation.

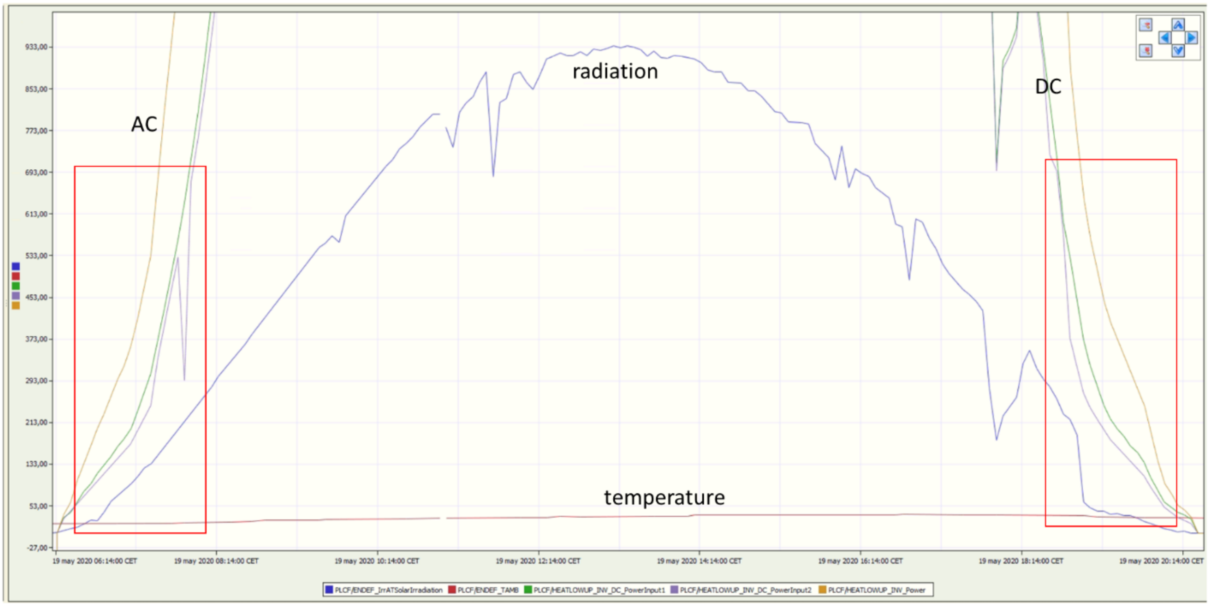


Figure 4: Detail of production for DC arrays during beginning and ending of the day

Next figure presents main electric values in function of specific environmental conditions.

Color:	Variable:	Unit:	Magnitude:	Operation:
orange	AC power	kW	8,8	Connected to local grid
green	DC power PCM	kW	4,7	
violet	DC power	kW	4,5	
blue	radiation	W/m²	860	
red	Temp amb	ºC	23 to 45	

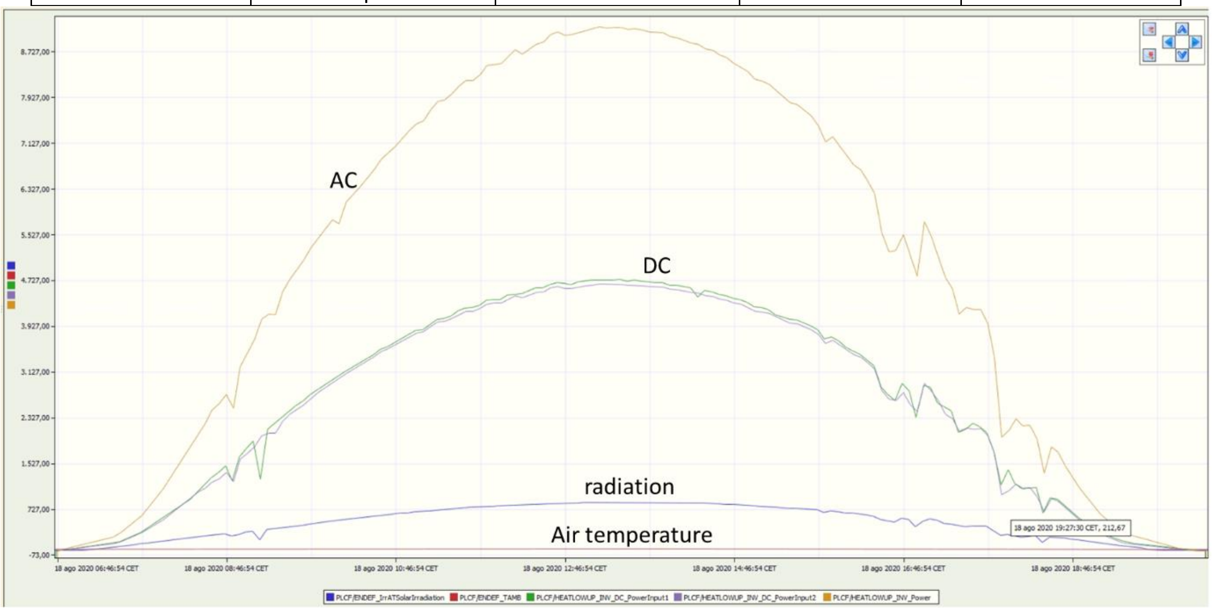


Figure 5: PV production for solar field and DC arrays

Next figure presents a zoom of DC production, evidencing how solar radiation drop off reduces production of DC electricity and so does for AC.

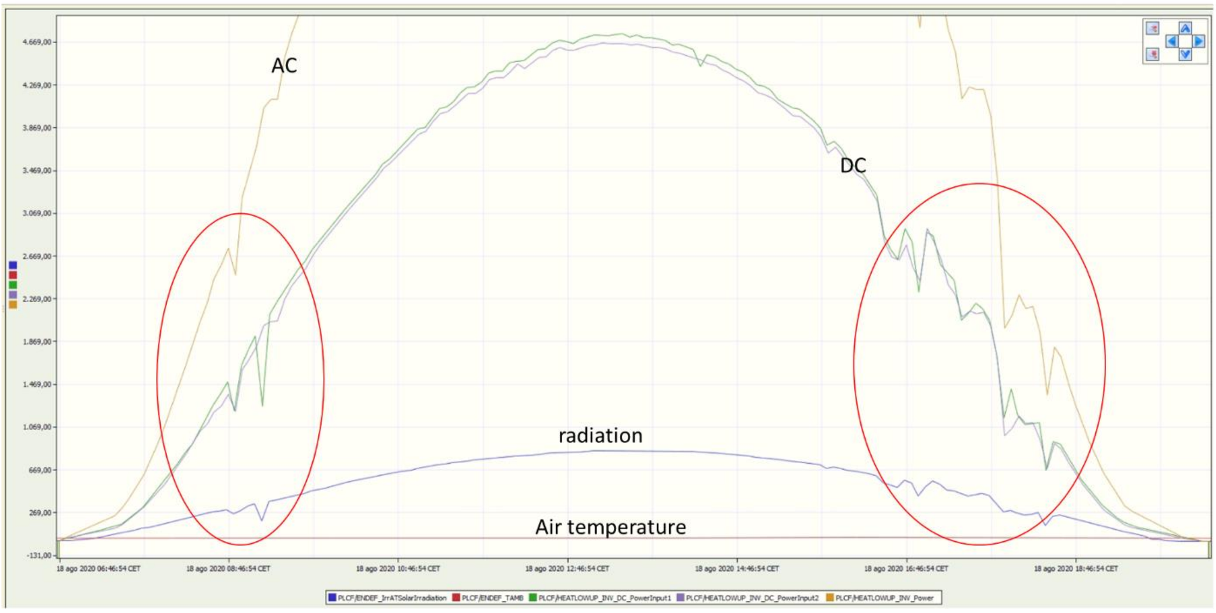


Figure 6: PV reduction due to perturbations of solar radiation

Next figure presents detail of temperature for this day.

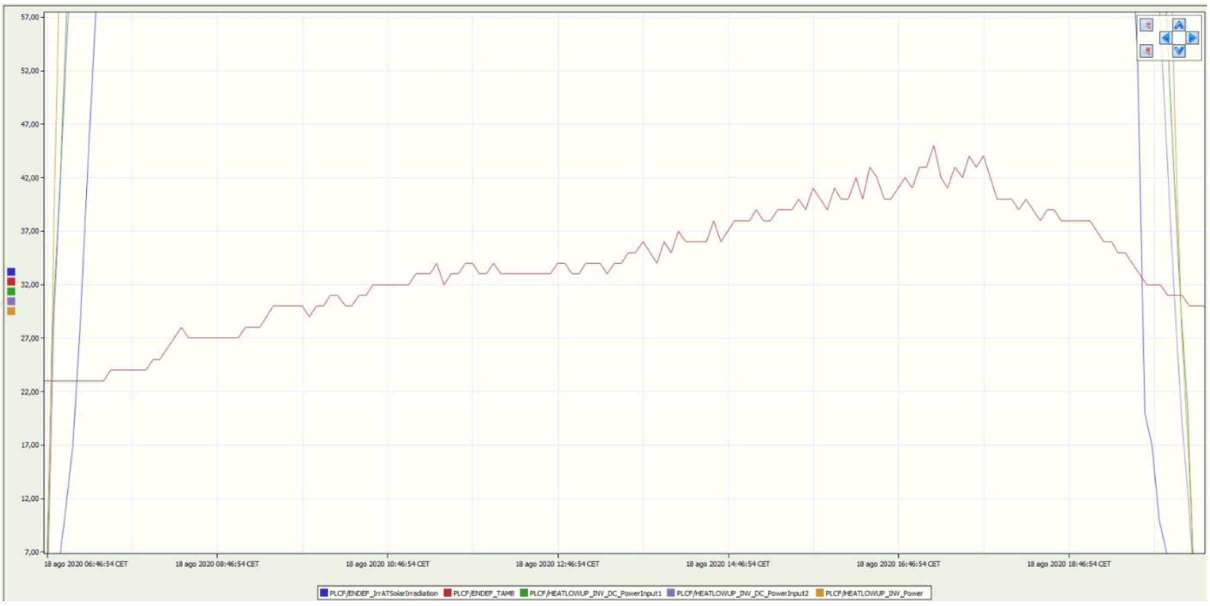


Figure 7: Temperature variation during the day

Once electrical test have been concluded, focus was moved over thermal side of PV/T technology; tests have been realized using stratified tank and drycooler as thermal loads; stratified tank allow testing system in real conditions while drycooler allow generating fictitious profiles, depending on scope of functionality to be proved.

In following pictures are represented in graphic all relevant monitored variables for only some of most interesting days.

Next image reports typical example of test executed with different dissipation temperatures programmed on drycooler; “solar in” corresponds to “drycooler out”, “solar out” corresponds to “drycooler in”. Only global inlet and outlet temperatures of solar field are considered.

Color:	Variable:	Unit:	Operation:
various	tank temperatures	ºC	pump with variable speed for setpoint temperature
blue	Solar out	ºC	
red	Solar in	ºC	

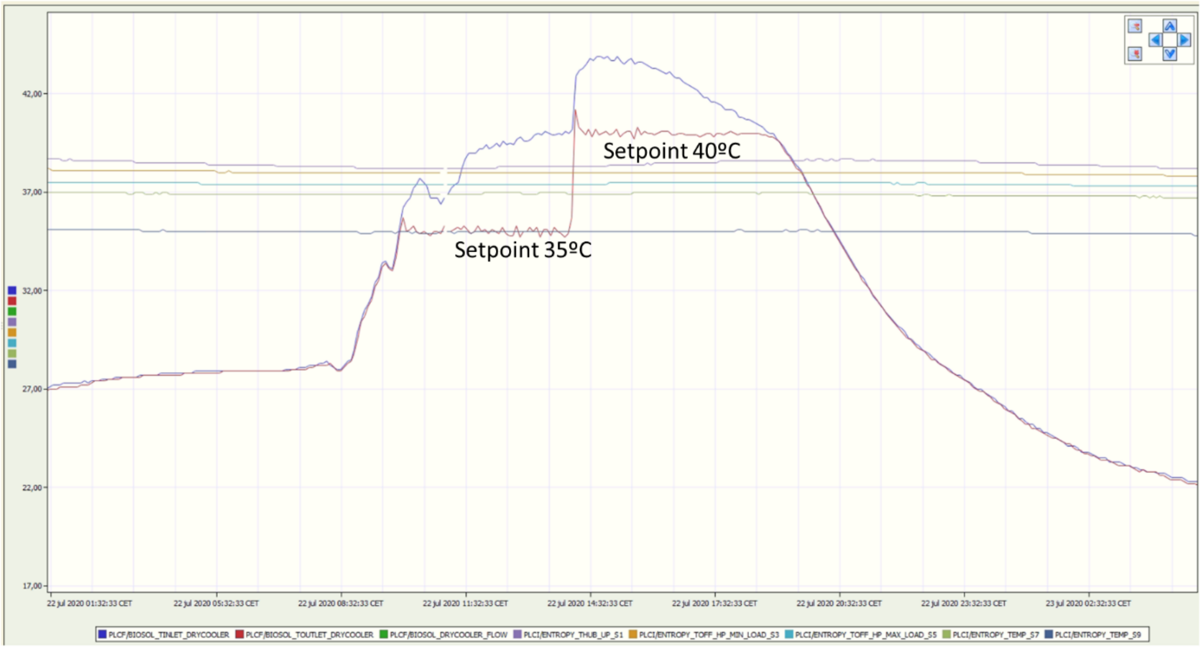


Figure 8: Drycooler dissipation at different setpoints

Next image reports behaviour of drycooler with only one setpoint of dissipation.

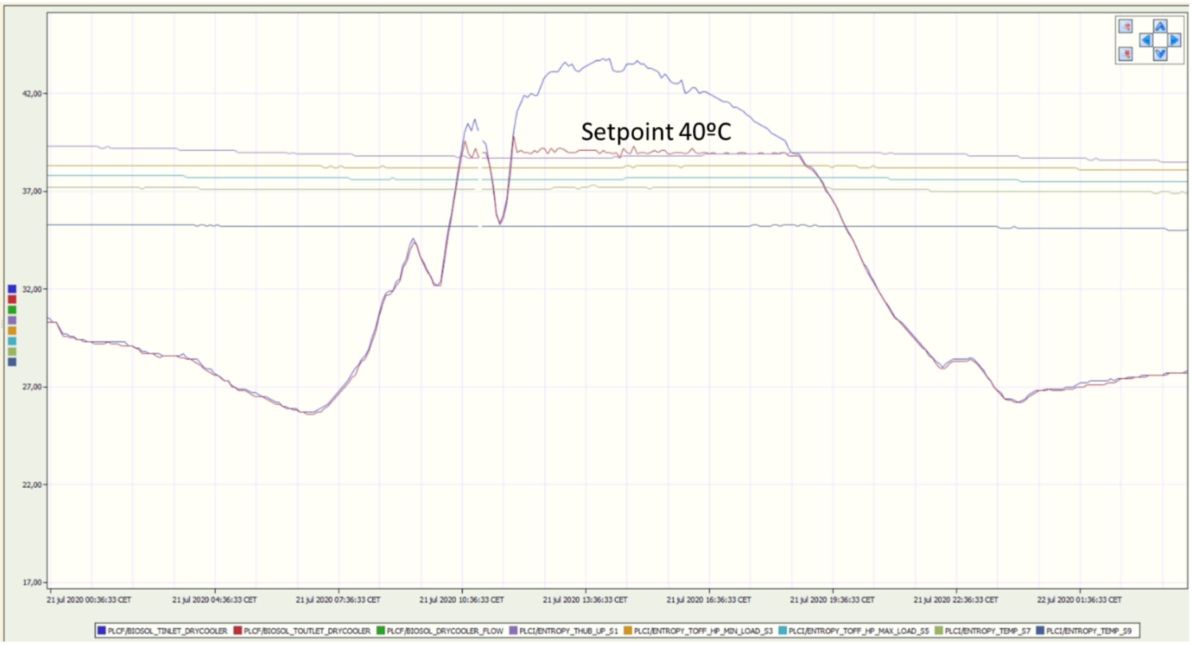


Figure 9: Drycooler dissipation at single setpoint

Next test has been realized in order to understand behavior of thermal transmission of PV to water when back-sheet is integrated with PCM, with respect to conventional PV/T.

It can be seen how initially (blue box) temperatures are in line with expected, when radiation is lower and temperature too. As soon as radiation increase Delta T of PCM array increases respect to array without, with outlet temperature higher and inlet temperature lower.

Color:	Variable:	Unit:	Operation:
blue	radiation	W/m²	pump with variable speed for setpoint temperature
red	air temp	ºC	
light blue	PCM out	ºC	
violet	no PCM out	ºC	
green	no PCM in	ºC	
orange	PCM in	ºC	

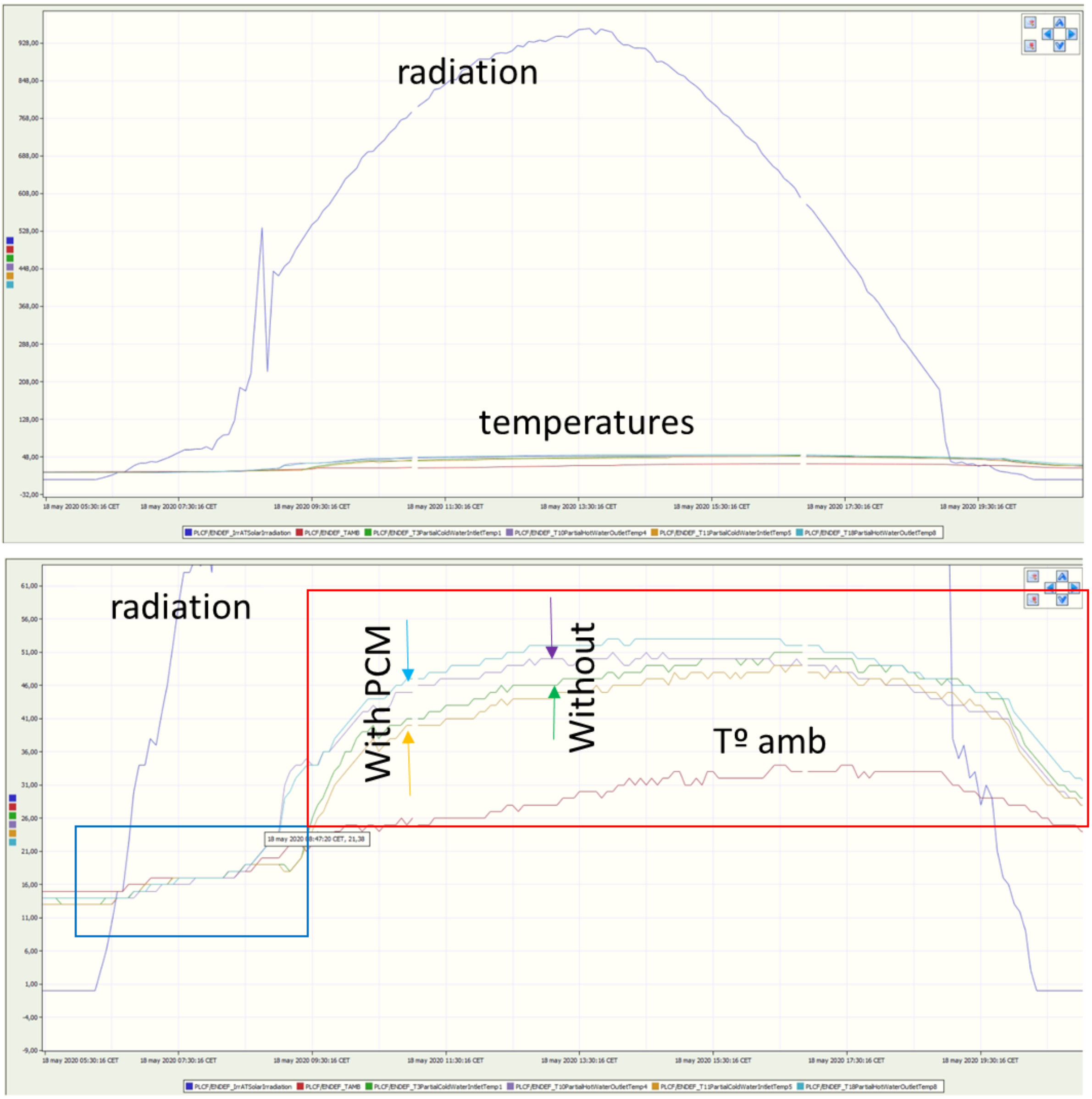


Figure 10: Temperature distribution in and out of different arrays (with and without PCM)

When radiation is too high, and thermal transmission to water is not sufficient, excess heat has to be dissipated and so is transmitted along the structure, generating overheating of mechanic elements like manifolds.

Consequently, when inlet water arrives to manifolds of distribution, increase temperature before starting exchanging heat with back-sheet; heat exchange is less efficient and final output temperature is lower than expected.

Color:	Variable:	Unit:	Operation:
blue	radiation	W/m²	pump with variable speed for setpoint temperature
red	amb temp	ºC	
light blue	PCM out	ºC	
violet	no PCM out	ºC	
green	no PCM in	ºC	
orange	PCM in	ºC	

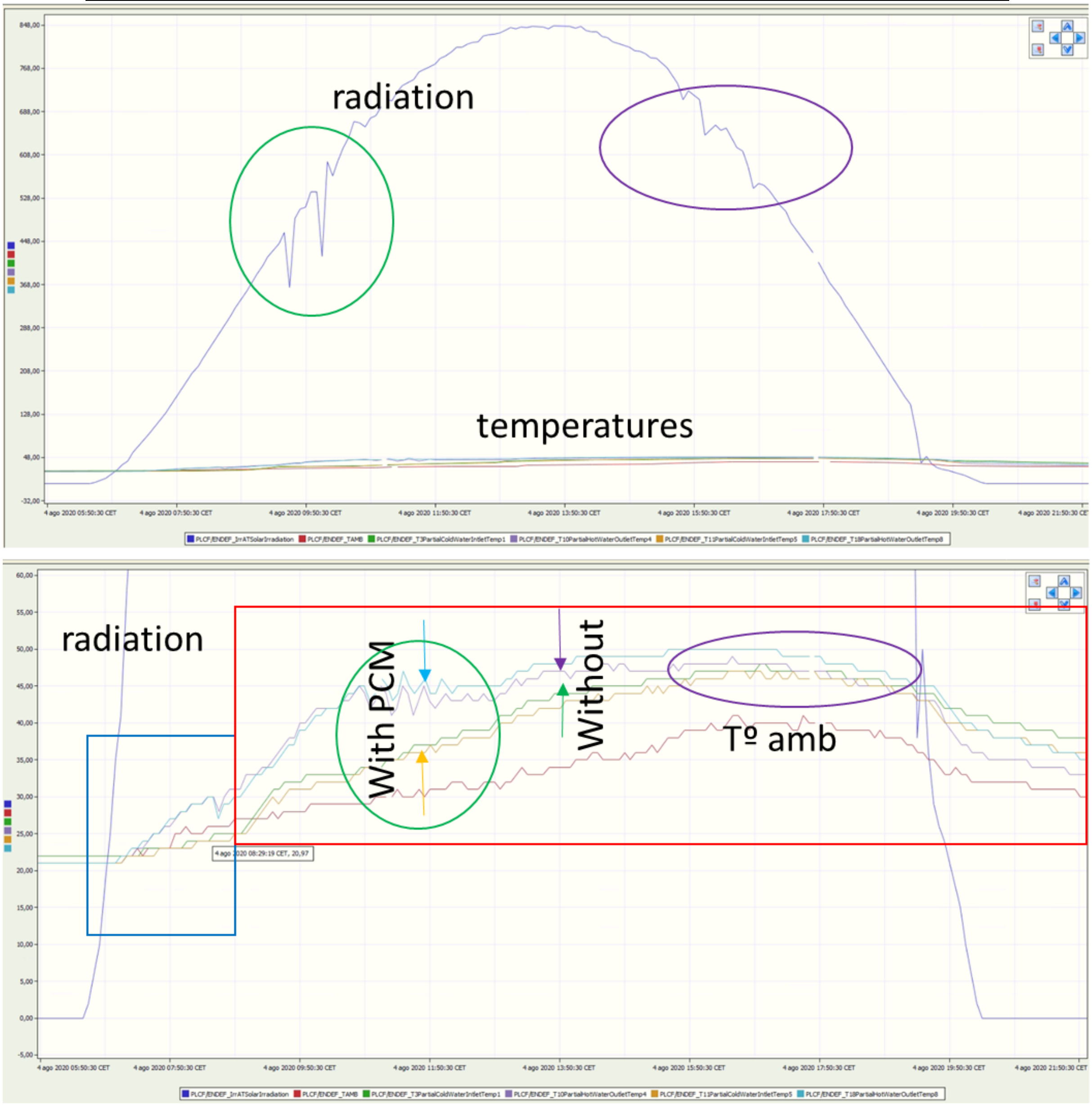


Figure 11: Temperature distribution over arrays with drop of radiation

Previous figure highlights how important reduction of radiation affect outlet temperature from both arrays (green circle), nevertheless small reductions only affect array without PCM (violet circle) because of buffer effect of PCM, with consequent stabilization of temperature.

As a rule, PV/T panels are able to generate thermal and electrical energy in a ratio close to 2:1. This ratio is directly affected by the working mode of the installation and the operation temperature of the panels. Generally, the thermal and electrical efficiencies of the PV/T panels decrease with the operating temperature rise, which is very influenced by the starting temperature of the storage tank at the beginning of the day. The overall performance of the PV/T panels with and without PCM inserted is presented in Figure 12 and Figure 13 for May and August, respectively.

During summer months, average energy production in each line (20 panels) reached values of 48 kWht and 18 kWhe for the line without PCM and 55 kWht and 24 kWhe for the line with PCM. Thermal and electrical efficiencies of PV/T solar panels present average values of 25% - 9%, and 32% - 13% for the line without and with PCM respectively.

During spring and early autumn, solar radiation was slightly lower and environmental temperatures were milder than in months as July or August. As a result, daily energy productions were lower than during the summer. On the contrary, individual efficiencies were higher, especially in the case of the electricity due to the strong relation of Si-cells between operating temperature and performance.

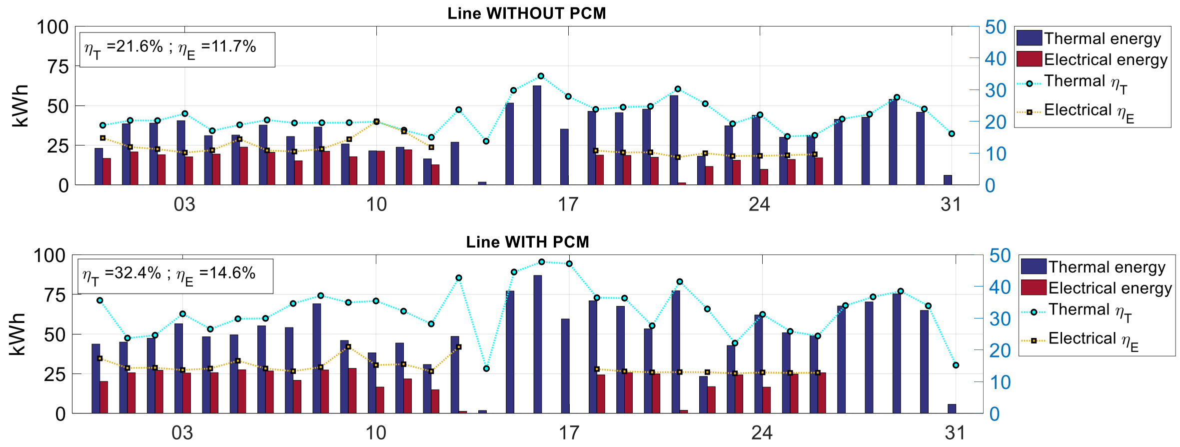


Figure 12: Thermal and electrical performance (daily energy and efficiencies) for May.

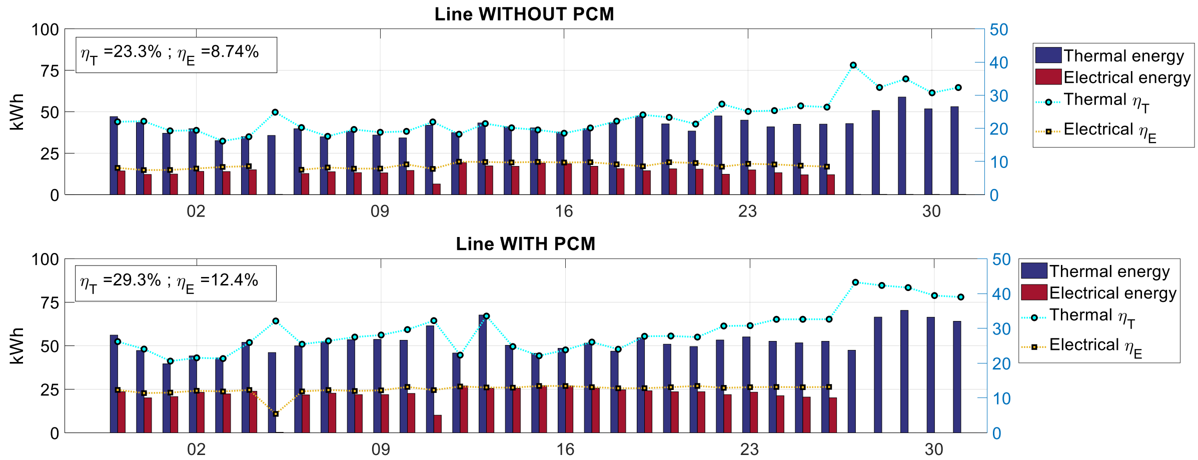


Figure 13: Thermal and electrical performance (daily energy and efficiencies) for August.

Those days with no electrical generation due to inverter switch-off or maintenance works, the solar energy destined to the PV cells is transferred to the thermal absorber, which increases the thermal performance in a 20-30%.

The energy generation profile for a typical day with good solar radiation is presented in Figure 14. To complete the information of the case, temperature daily profiles are also provided in showing temperature data at the inlet and outlet of each line (left) and inside the storage tank (right).

In the beginning of the day (up to 12pm), the thermal generation of the line with PCM remains slightly lower than the one without, due to the inertia provoked by the PCM which consumes part of the heat generated in getting warm the PCM instead of the heat exchange fluid. After midday, the solar field starts providing heat to the storage tank and the gap between inlet/outlet temperatures of solar collectors increases, and around 2 pm, the heating load starts removing heat from the low layers of the storage tank. Since the thermal loads are not much higher than the solar generation, the higher layers of the tank keep storing solar heat, favoring stratification.

In this profile is visible the late energy generation in the line with PCM compared to the line without. This thermal energy generated between 18-20h is not resulting from the sun radiation, but from the heat stored in the PCM during peak sun hours and released at this point because of the temperature decrease.

Instant efficiencies reflect the pattern follow by the thermal and electrical power generation, showing a higher value for the line with PCM than the line without. At the end of the day, it is noticeable a peak on the efficiency of the PCM line, due to the late thermal energy produced in this line at the end of the day. Since this energy is not resulting from the sun but from the energy stored in the PCM, these efficiency values do not reflect “real” values.

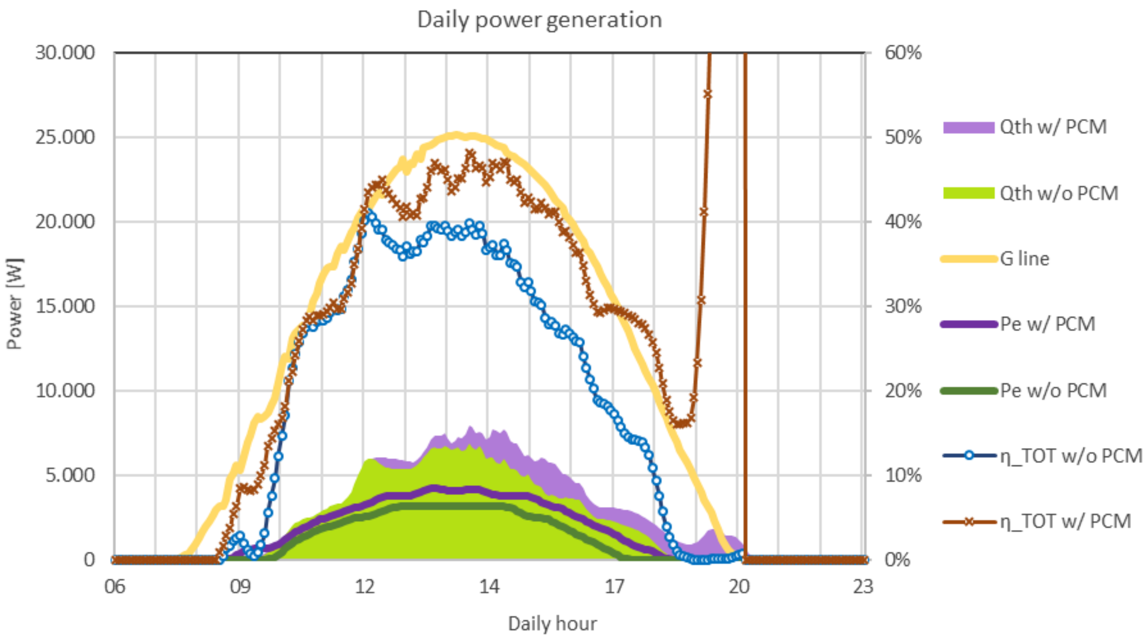


Figure 14: Example of power generation and total efficiency daily profile.

Contrary other studies found in the literature, the use of PCM does not lead to a reduction of the operating temperature, but fluid temperatures keep quite similar in both lines. It may be explained because the PCM used in this case has a melting point (48ºC) much higher than many studies (between 20-30ºC), and then the PV/T solar field is not able to work for a long time over this temperature to provoked a significant reduction. It should be remarked that the goal of the PCM in this project was to make use of the excess of energy, it means, generated in a temperature over that required for the radiant floor.

Despite not finding significant differences in working temperature, the addition of PCM provokes meaningful improvements in the energy performance of the solar circuit, ranged between 25-35% in the PV performance and 20-60% in the thermal performance, depending on the case. The PCM insertion seems to have direct influence not only in the energy generated at the end of the day, but also the thermal and electrical efficiencies exhibited during the sun hours.

This improvement suggests that the inclusion of PCM favours the heat transmission from the backside of the PV laminate to the heat absorber and the PCM enclosure, making the PV cell working in a lower temperature and transferring more heat to the fluid. It would explain the increase on the instantaneous thermal and electrical efficiencies.

The effect of the PCM is more intense in those days with higher working temperature (with 4-5 hours working above 50ºC) than in other with lower values, since more quantity of PCM is melted.

Here below is presented the curve of production in DC for array with and without PCM as function of solar radiation in Seville. It evidences how effect of PCM is preminent below 400 and above 800 w/m^2.

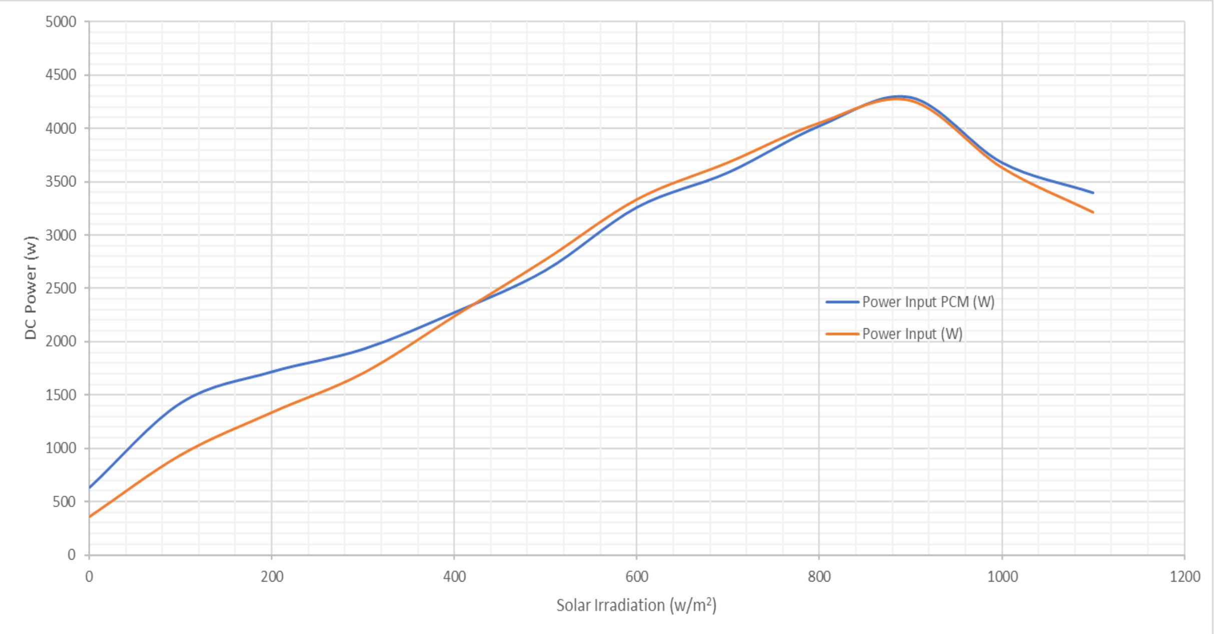


Figure 15: DC power as function of solar.

In next figure is presented behavior of different solar arrays as function of radiation, inlet water temperature and Delta T; thermal power achieved by array with PCM is always higher than without PCM for radiation above 200 w/m^2.

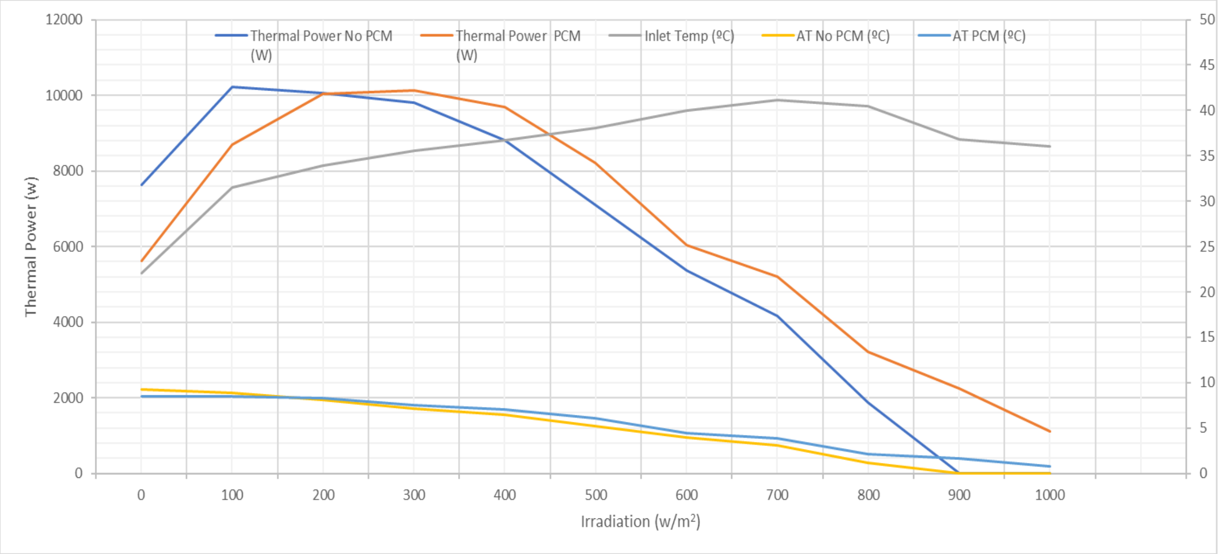


Figure 16: Thermal power as function of solar.

3.1.2 Stratified tank

The storage tank has proved to manage successfully several loads and sources working at different temperature. In this section we refer only to the relation with the solar field.

The total volume of the storage tank is 6.630 lts, which makes a relation between storage volume and solar surface of 106 l/m^2. This value may be medium for thermal panels but it is quite high for PV/T panels, since they have a lower operating temperature and thus required less storage volume.

As a result, we have found that the great volume of the storage tank together with the stratification capacity, hinders the absence of heating demand and allows the solar circuit to operate with acceptable efficiencies even in those days without heating load. Efficiency values are comparable to those obtained with heat evacuation.

Following figures present charging phase of stratified tank with solar thermal during different days and with increasing tank starting temperatures. Below figure shows tank starting temperatures at 22ºC for all sensors (homogeneous).

Color:	Variable:	Unit:	Operation:
blue	S1 - top	ºC	pump with variable speed for setpoint temperature
red	S2	ºC	
green	S3	ºC	
violet	S4	ºC	
orange	S5	ºC	
light blue	S6	ºC	
light green	S7	ºC	
grey	S8	ºC	
dark red	S9	ºC	
esmerald	S10	ºC	
dark violet	S11	ºC	
dark blue	S12 - bottom	ºC	

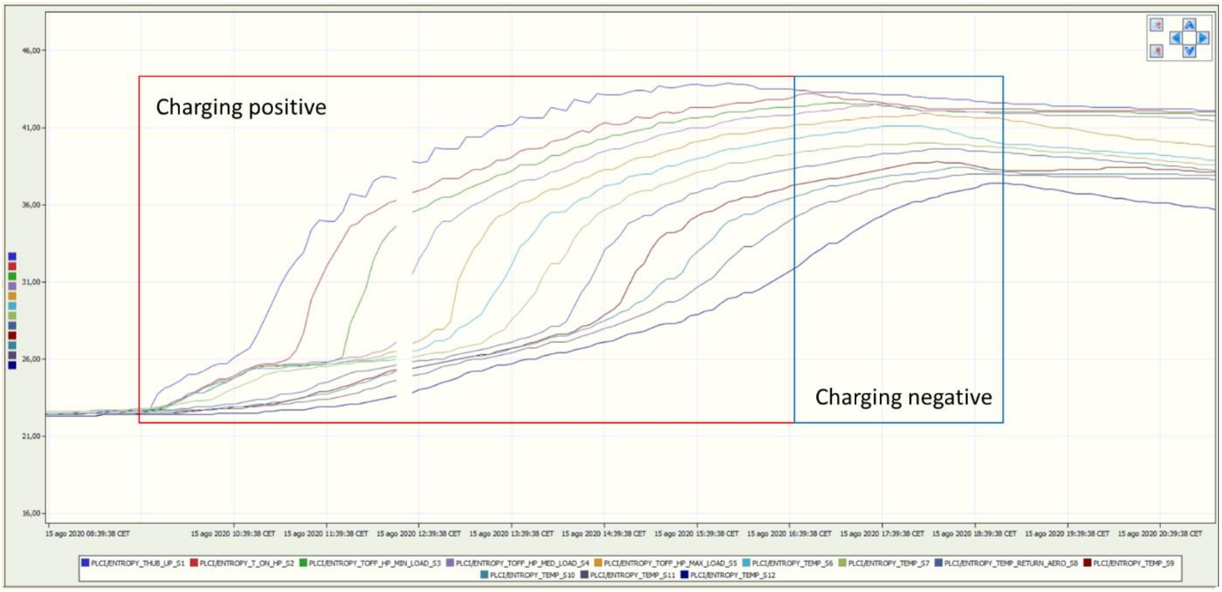


Figure 17: Temperature distribution over tank during day starting at 22ºC

Three phases are present: charging positive (red box), charging negative (blue box) and then stabilization of temperature for absence of heat supply and heat consumption.

Charging positive means that heat supplied by solar field has temperature higher than tank; charging positive means that solar field deliver heat at lower temperature than heat stored in tank, so really temperatures start slowly decreasing (no load is connected to the tank) after peak of radiation. When sola filed stops delivering heat, tank temperatures stabilize and keep almost constant.

Next figure shows the tank starting temperatures between 43 and 55ºC (not homogeneous).

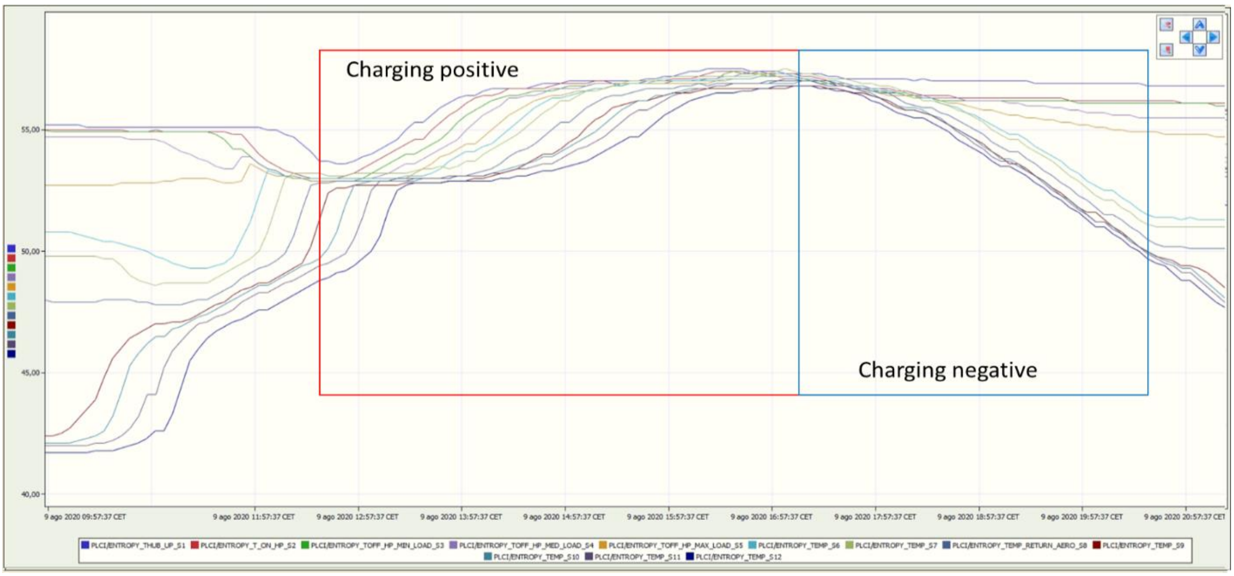


Figure 18: Temperature distribution over tank during day with variable temperatures

Again, effect of negative charging is evident in second part of day, when peak of radiation has passed. To be notices that lower temperatures increase more than 12K but higher temperatures only 3K, because of limits achieved by solar field.

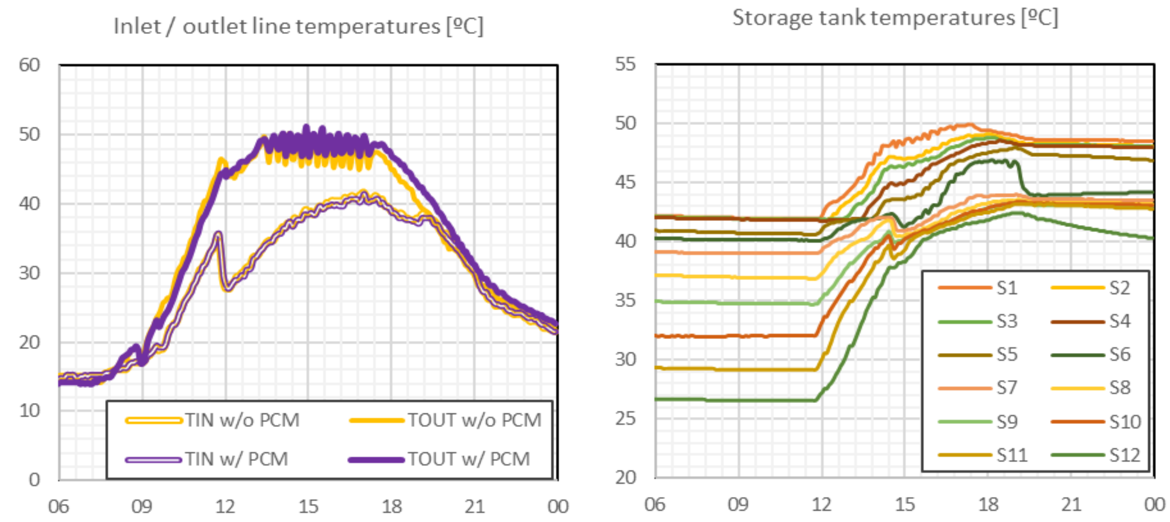


Figure 19: Temperature daily profile in the inlet/outlet lines (left) and storage stratification (right).

In case of high temperature, this storage capacity is endorsed by the storage capability of the PCM. This fact may be very beneficial to guarantee the energy generation during weekends, when the office does not consume thermal energy. Attending to the stratification capacity, it has found to be greater when the starting temperature of the stored water is low. This fact is explained by two reasons:

- First: the valve between the solar field and the storage tank is opened when the outlet temperature of the solar panels exceeds a certain value, commonly set by the user between 35-45ºC. If the stored temperate is low with respect to the solar field, the gradient between the stored water and the liquid coming from the solar panels is really high, which favours the stratification.
- Second: when the solar field operates under the required temperature (also set by the user) the pump reduces the fluid flow circulating through the panels to reach maximum temperature in the outlet. Thus, the amount of hot water entering the storage tank from the solar field is reduced, favouring again the stratification.

Two examples of stratification are shown in Figure 20 and Figure 21, corresponding to days with cold and hot tank at the beginning of the day.

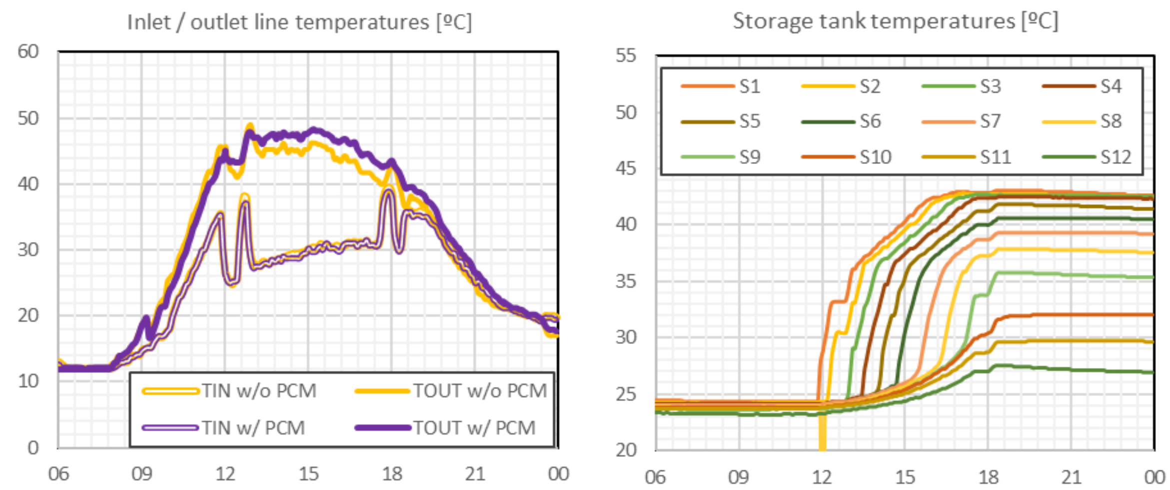


Figure 20: Temperature profile in the inlet/outlet lines (left) and storage stratification (right), cold tank.

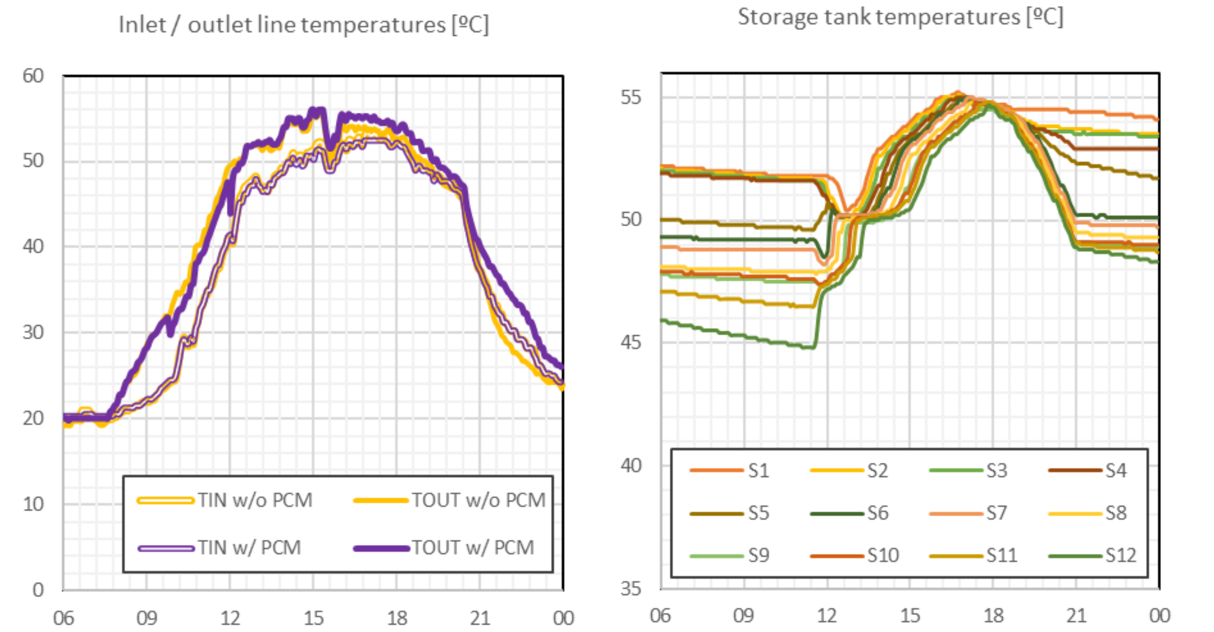


Figure 21: Temperature profile in the inlet/outlet lines (left) and storage stratification (right), hot tank.

Next image show behavior of pumps speed regulating in function of outlet temperature from solar field and effect over stratification of tank.

Color:	Variable:	Unit:	Operation:
blue	spump speed	%	pump with variable speed for setpoint temperature
red	Tout solar	ºC	
others	S1-S12	ºC	

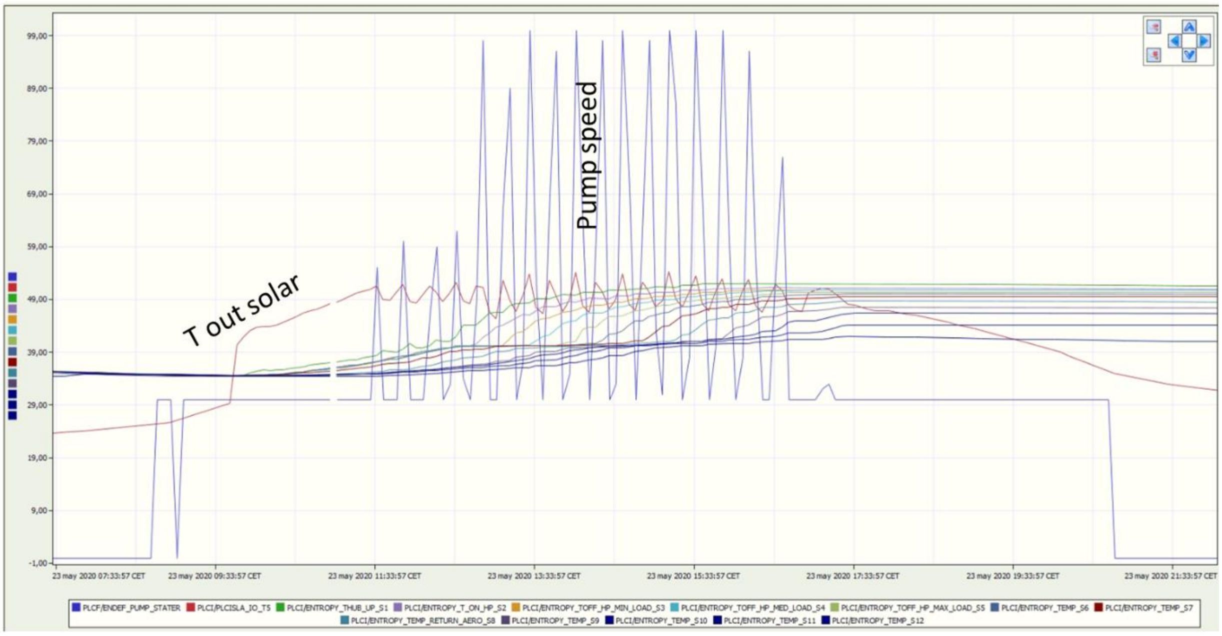


Figure 22: Temperature distribution over tank during day with variable temperatures

Regulation of temperature allows achieving desired temperature on top of stratification tank; when temperature from solar field starts lowering and speeds sets at 30%, the 3ways valve (that connect solar with tank) recirculates flow only over solar field for avoiding negative charge of tank.

Although the energy improvement derived from the use of PCM is undeniable, some small leaks have been observed in the lower part of several PV/T panels. Our belief is that due to the PCM nature (inorganic, a salt hydrate) it solidifies creating sharp spikes, that taking into account the thin space of the PCM layer and the pressure applied from the rest of the solar panel components, may have pierced the aluminium envelope.

Although the total amount of PCM leak is not significant, this constitutes a serious problem, since the it is a very corrosive and conductive material that may damage the material on which it falls or provoke a short circuit in undesirable points.

3.1.3 Sewage heat recovery system

The Sewage heat recovery system, as it was installed at Badajoz, works according to kitchen time of operation inside university residence, which are split in three main period corresponding to breakfast, lunch and other break in the afternoon. Hot water comes from dishwashers and pots, while consumption is used for feeding dishwashers with preheated water.

Unfortunately, dishwashers don't regulate electrical consumption as function of inlet temperature, so reducing proportionally electricity used for heating water to cleaning setpoint temperature; this has been tested by electric analyzer and verified with manufacturer, so no energy saving can be calculated for building.

Nevertheless, the unit has been characterized and operated; initially only sewage water was accessing the recovery system, in order to evaluate temperature variation of storage medium (and so recovered and stored energy), while in a second moment also TAP water was introduced in energetic balance of the system.

Here below is represented the profile of characterization without consumption of energy:

Color:	Variable:	Unit:	Operation:
blue	Storage medium	ºC	Pulsed operation of sewage:
red	Sewage out	ºC	
grey	Sewage in	ºC	
Yellow	sewage pump	lt/min	

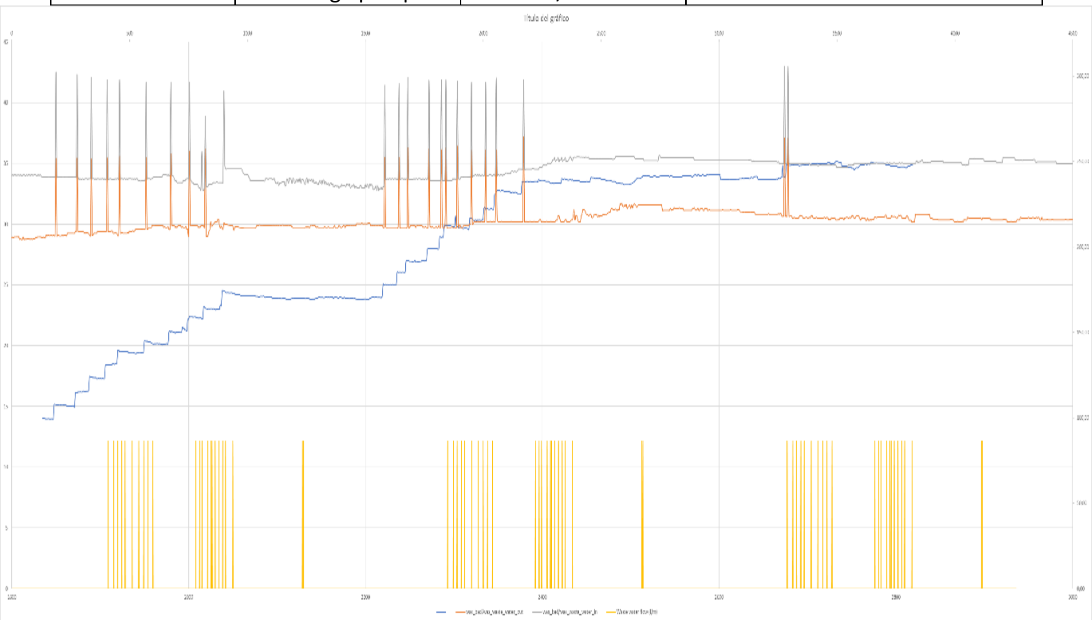


Figure 23: Temperature variation for interior of tank without load

Sewage water enters into the tank with a reduced temperature, with respect to expected when designed at the beginning; furthermore, the effect of pumping station is too quick and instable with respect to initial design, so big part of its energy is lost before recovery could happen.

Consumption of dishwasher impulse in recuperation tank TAP water between 13 and 17ºC, with frequency similar but reduced flow with respect to sewage (the difference in flow is only contribution of pots). The results is an initial charge of tank energy (for recovering heat from pots and washers) until achieving close to 35ºC, even if only at the end of the day.

Following image presents the variation of tank inside temperature for effect of connection of thermal load (TAP water) to sewage recover system.

Color:	Variable:	Unit:	Operation:
blue	Storage medium	ºC	Pulsed operation of sewage:
red	Sewage out	ºC	
grey	Sewage in	ºC	
Yellow	TAP water	lt/min	

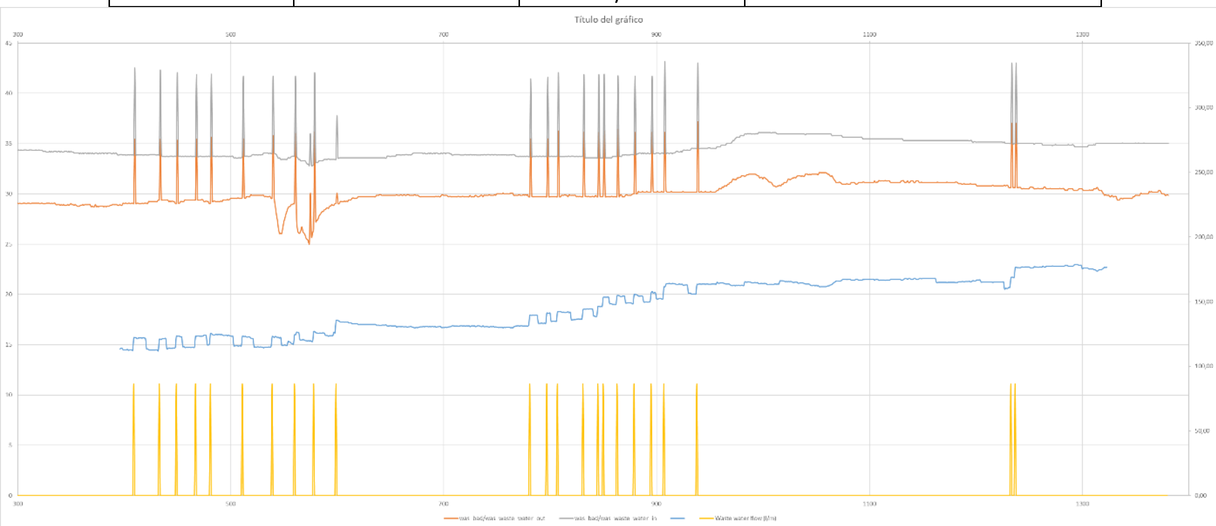


Figure 24: Temperature variation for interior of tank with load

Profile of consumption and production are quite similar from day by day, because of cyclic nature of operation at kitchen. It can be seen how tank increase close to 8K for one entire day. The repetitively of cycles keep maintaining the tank in a temperature suitable for HEAT LowUP purposes after about two days, for low temperature (reduced by grease separator and pump station) and for energy recovered (flows extremely quick).

3.1.4 Radiant floor

The radiant floor has been tested even during cooling period through utilization of 2 air conditioning splits used for generating fictitious heating loads; splits were sets to maintain indoor temperature at 18ºC and tests are executed during night. During heating season, all tests were repeated to confirm results previously achieved; tests have been executed according to following table:

Table 2: Operation points

Parameter	Unit	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8
Water flow rate	l/h)	2000 (~1550)				2600 (~2200-Nominal)			

Inlet water temperature	ºC	25	30	35	40	25	30	35	40
Outlet water temperature	ºC	[Monitored]							
Surface temperature	ºC	[Monitored]							
Room temperature	ºC	20ºC [monitored. Ideally constant]							
Ambient temperature	ºC	[Monitored]							

Indoor temperature achieved is 20ºC by water at 30ºC. In orange box is presented the moment when test finishes and splits are switched off, while the floor is still operating; as consequences indoor temperature rises without control.

Color:	Variable:	Unit:	Operation:
blue	Temp IN	ºC	pump with constant speed and 3ways valve regulating for setpoint temperature
green	Temp OUT	ºC	
light blue	Room temp	ºC	
red	water flow	lt/h	
violet	out temp	ºC	

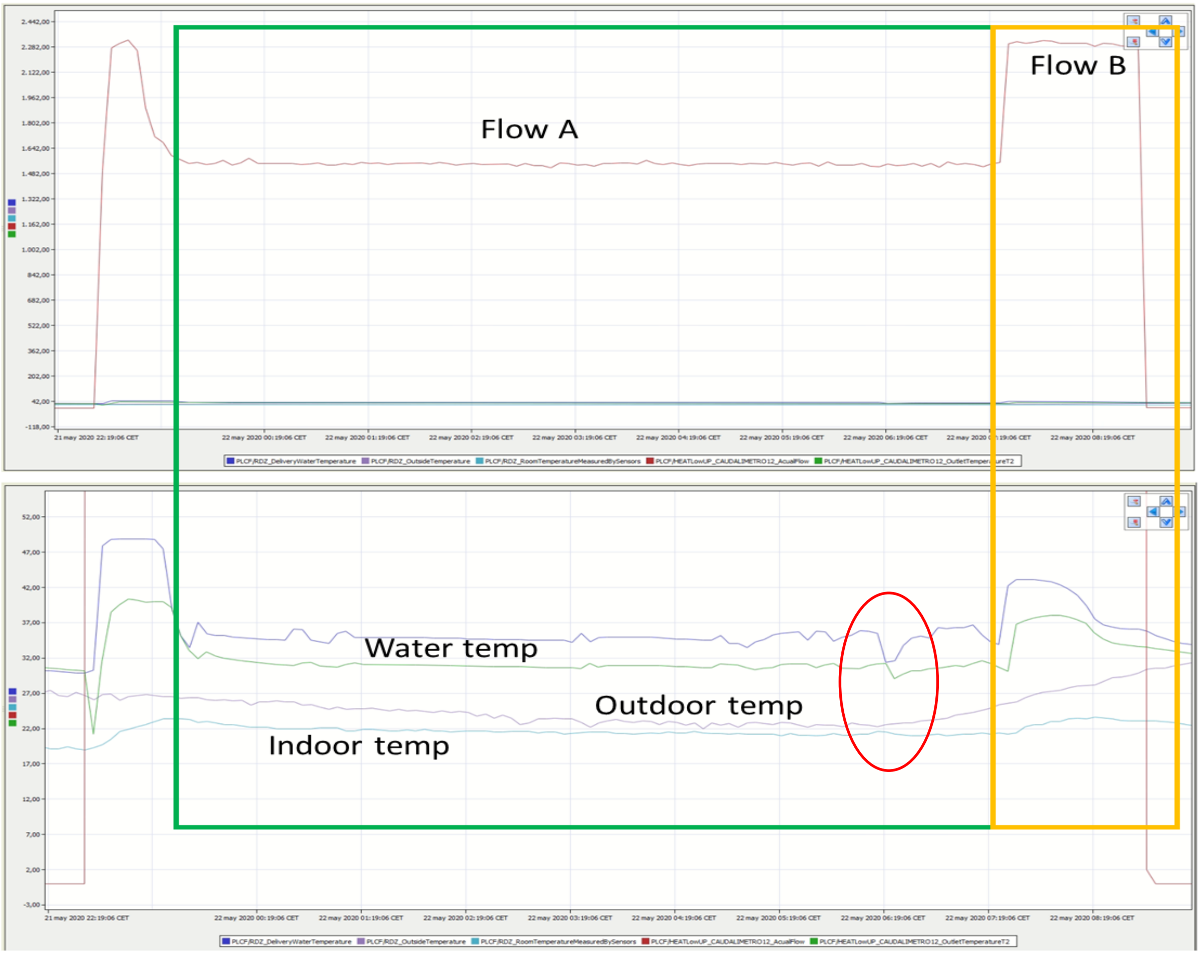


Figure 25: Temperature distribution for indoor office with radiant floor at 35ºC and 1.550 - 2.600 lt/h

Previous figure shows how indoor temperature achieved is 22ºC by water at 35ºC. It can be noticed how sudden increment of flow determines increment of water temperatures because of delay in regulation of 3ways valve; the valve receive heat from stratified tank at higher temperature than radiant floor supply temperature.

Next figure shows how 3ways valves tends to compensate fluctuation of temperature given by splits, which are affected by outside temperature and cannot produce cool in stable way. Temperature are fluctuating but in a range of 2K.

In red circle is showed reduction of inlet water temperature because of regulation of 3ways valve due to “peak” of indoor temperature.

Color:	Variable:	Unit:	Operation:
blue	Temp IN	ºC	pump with constant speed and 3ways valve regulating for setpoit temperature
green	Temp OUT	ºC	
light blue	Room temp	ºC	
violet	out temp	ºC	

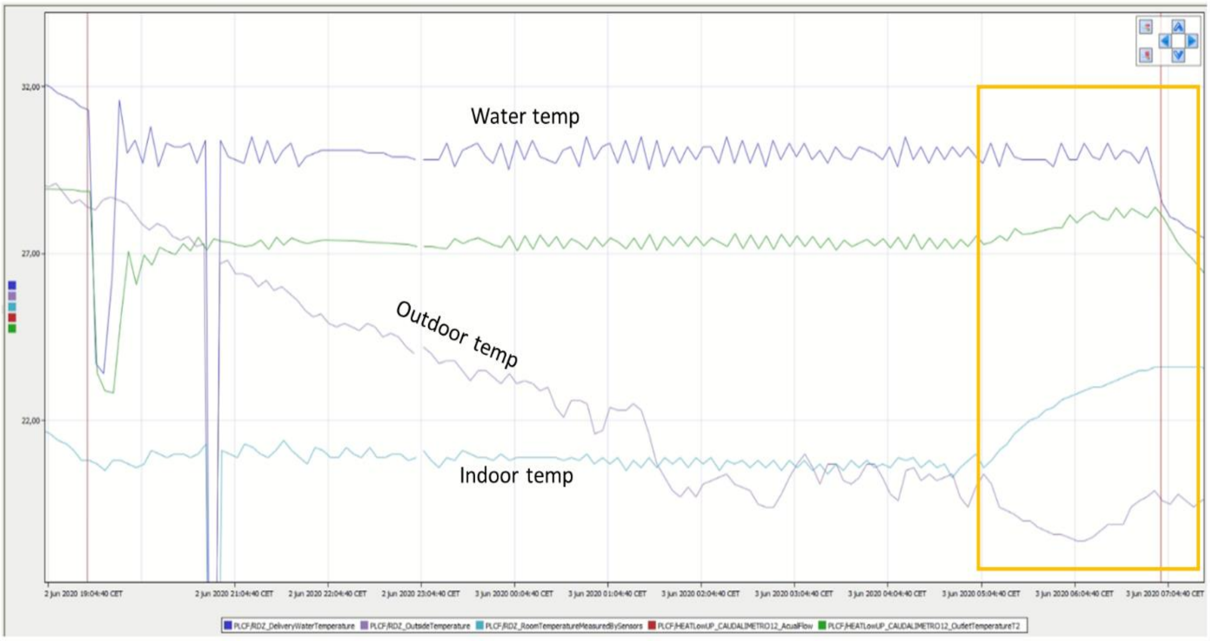


Figure 26: Temperature regulation of floating load by radiant floor at 30ºC

Next figure presents combination of stratified tank with radiant floor; water from higher tank layers is moved to radiant floor where is regulated by 3ways valve for room temperature control.

Color:	Variable:	Unit:	Operation:
blue	Temp IN	ºC	pump with constant speed and 3ways valve regulating for setpoit temperature
green	Temp OUT	ºC	
light blue	Room temp	ºC	
violet	out temp	ºC	

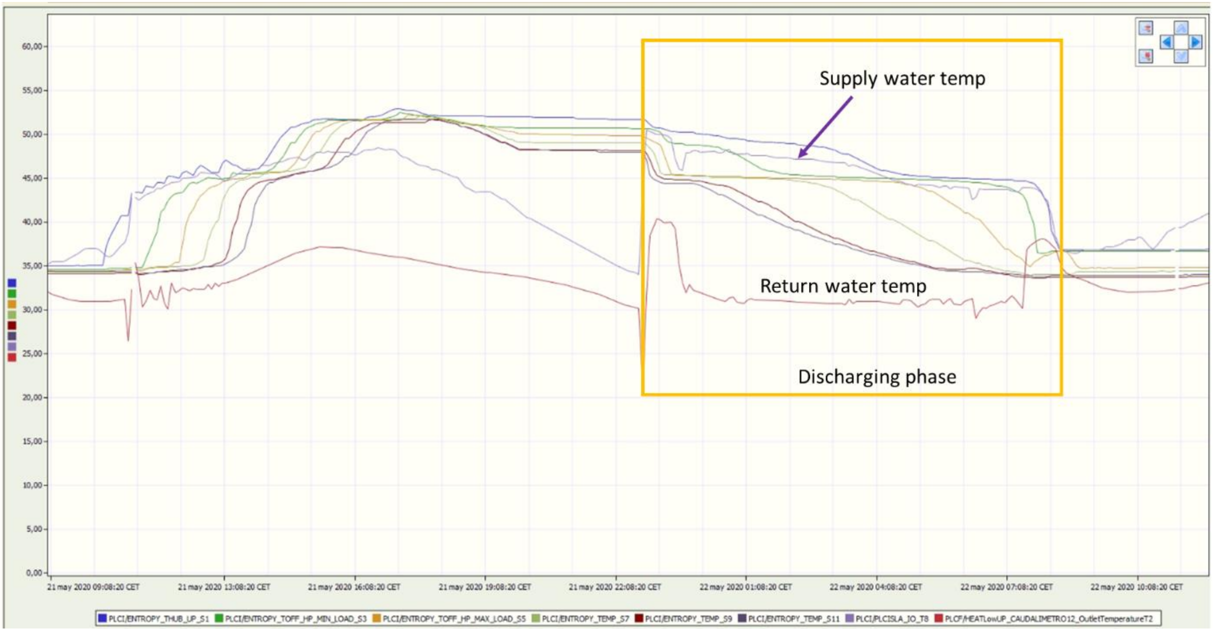


Figure 27: Radiant floor supplied by stratified tank

Next image presents energy delivered as function of supply temperature:

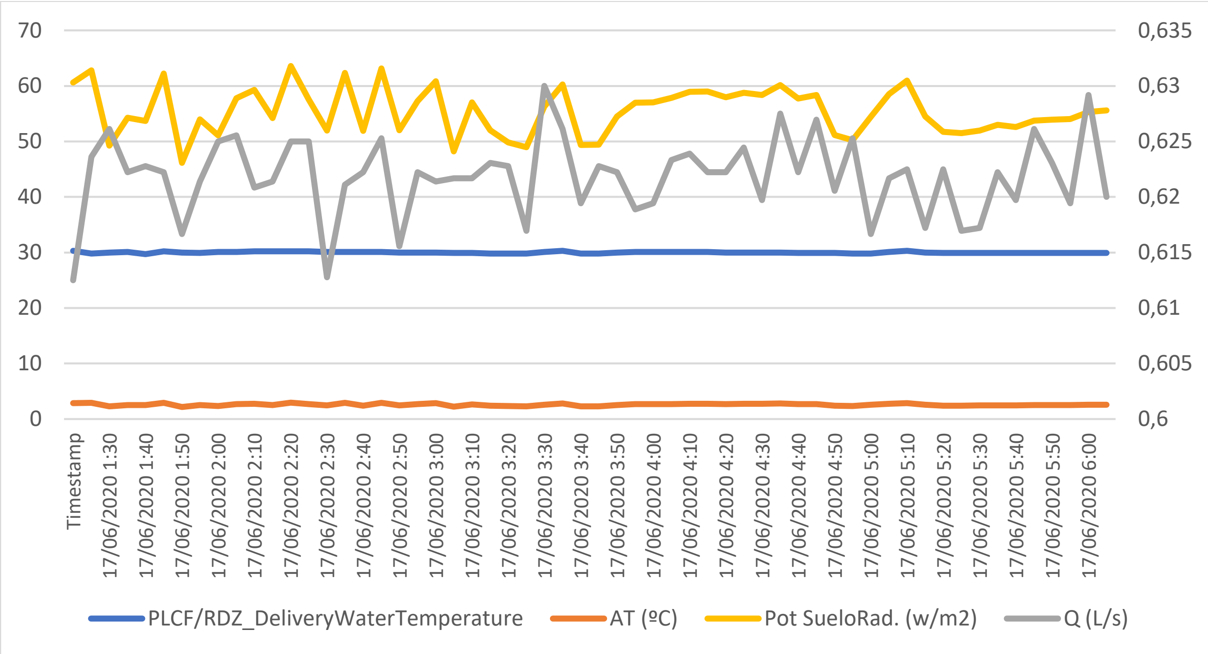


Figure 28: Radiant floor delivered power at 30ºC

It is possible appreciate how radiant floor is close to 60 W/m^2 and in different moments overcome this target value; here below resumed are shown average calculated results from monitoring:

Table 3 – Radiant floor performance

PLCF/RDZ_DeliveryWater Temperature	PLCF/RDZ_RoomTemperatureMeasuredBySensors	AT Imp-Amb (ºC)	AT (ºC)	Q (L/s)	P=4·Q·AT (kW)	Pot SueloRad. (w/m2)
30,00	21,39	8,61	2,59	0,62	6,43	55,45
34,98	22,33	12,64	2,95	0,63	7,43	63,87

3.2 Cool LowUP

All described activities have been executed after commissioning of individual technologies, individual sub-systems and whole system; once right way of operation has been verified, tests focused on understanding performance in nominal conditions and operation in dynamic conditions, before long term operation.

3.2.1 Chilled beams

Chilled beams works with fixed airflow and with fixed water flow for delivering energy at full capacity; if regulation is necessary, for reducing power, the beams actuate primary over the flow of water with a 2 way valve and secondary with a damper. Both devices are embedded in the beam.

On other hand, the air arriving to the beam is regulated by a damper installed upstream on air duct; mission of duct damper is maintaining the pressure downstream (before beams) constant. Constant pressure means constant flows to the beams, if the air network is properly sized and equilibrated.

For operating correctly, duct damper requires constant pressure upstream, which is given by the AHU; AHU regulates flow and pressure according to pressure setpoint requested by duct damper. If beam dumper closes, pressure upstream rises; increase of pressure makes duct damper closing, reducing pressure downstream and make it rising upstream. Increase of pressure make AHU reducing flow to maintain the pressure setpoint.

Below image presents status of opening (from 0 to 100%) for both dampers (orange) and 2ways valve (violet) embedded in office beam type, operating in cooling mode (red) to achieve setpoit temperature (green).

Color:	Variable:	Unit:	Operation:
green	Indoor temp	ºC	pump with constant speed and AHU at constant pressure
violet	Damper opening	%	
orange	Valve opening	%	
red	Beam operation	mode	

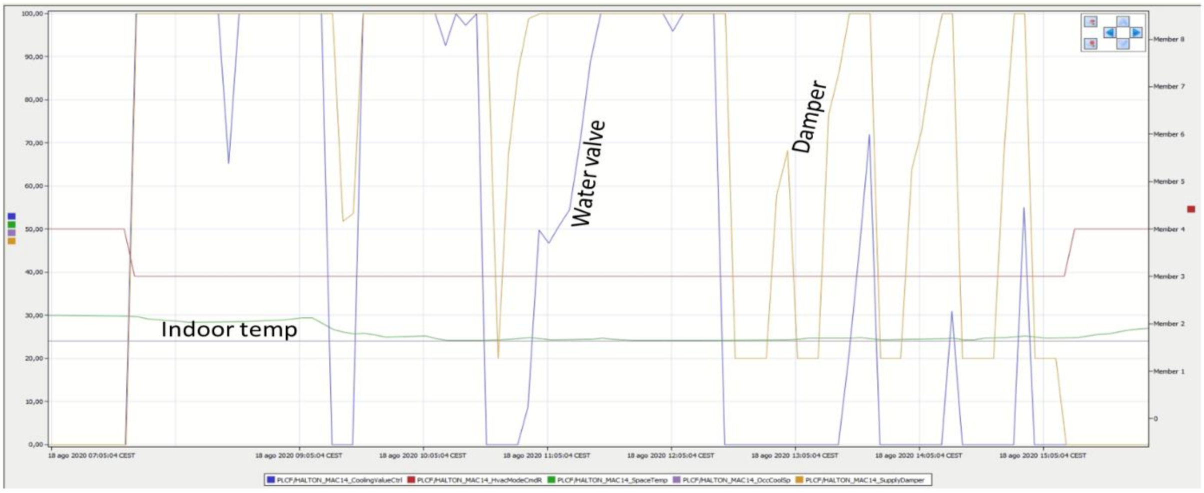


Figure 29. Operation of actuators for office chilled beam

At the beginning, both valve and dumper are fully open in order to reduce the gap of 6K between setpoint and indoor temperature, while, as soon as the gap reduces, operation is modulated for maintain achieved conditions. As commented before, the valve operates with priority with respect to chelled beam

Next image presents same operation for warehouse chilled beams, maintaining indoor temperature close to setpoint. Way of operation is the same, but warehouse and office have different duct dampers.

Color:	Variable:	Unit:	Operation:
grey	Indoor temp	ºC	pump with constant speed and AHU at constant pressure
blue	Damper opening	%	
Light blue	Valve opening	%	
Light green	Beam operation	mode	

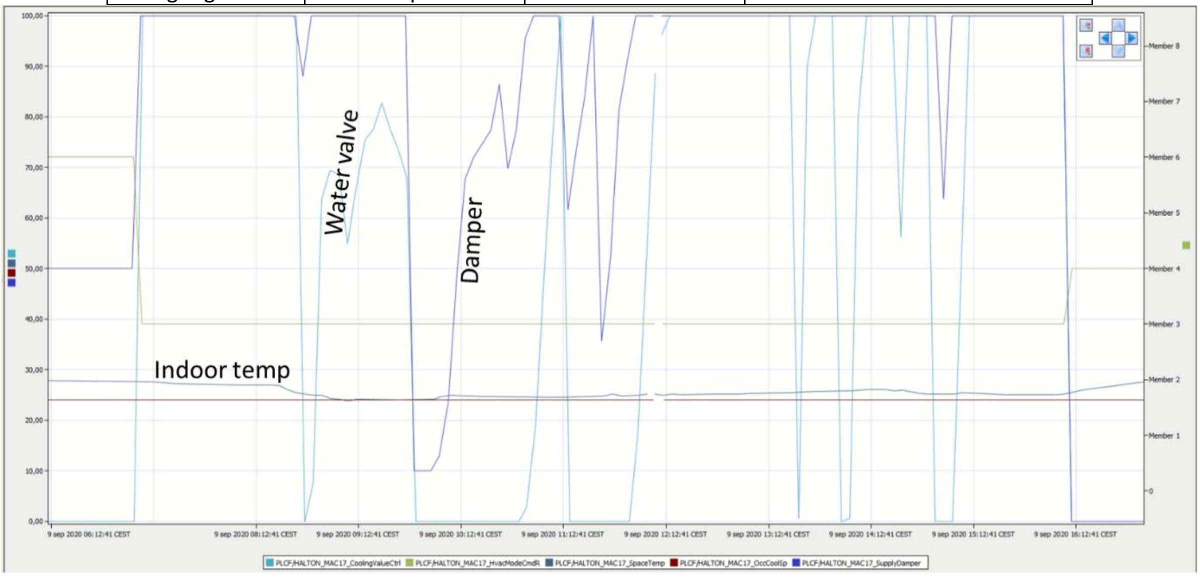


Figure 30. Operation of actuators for warehouse chilled beam

Next image presents behaviour of temperatures participating in the process of cooling.

Color:	Variable:	Unit:	Operation:
orange	Temp office	ºC	pump with constant speed and AHU at constant pressure
grey	Temp warehouse	ºC	
Light blue	Chill water in	ºC	
violet	Chill water out	ºC	
red	AHU air temp	ºC	

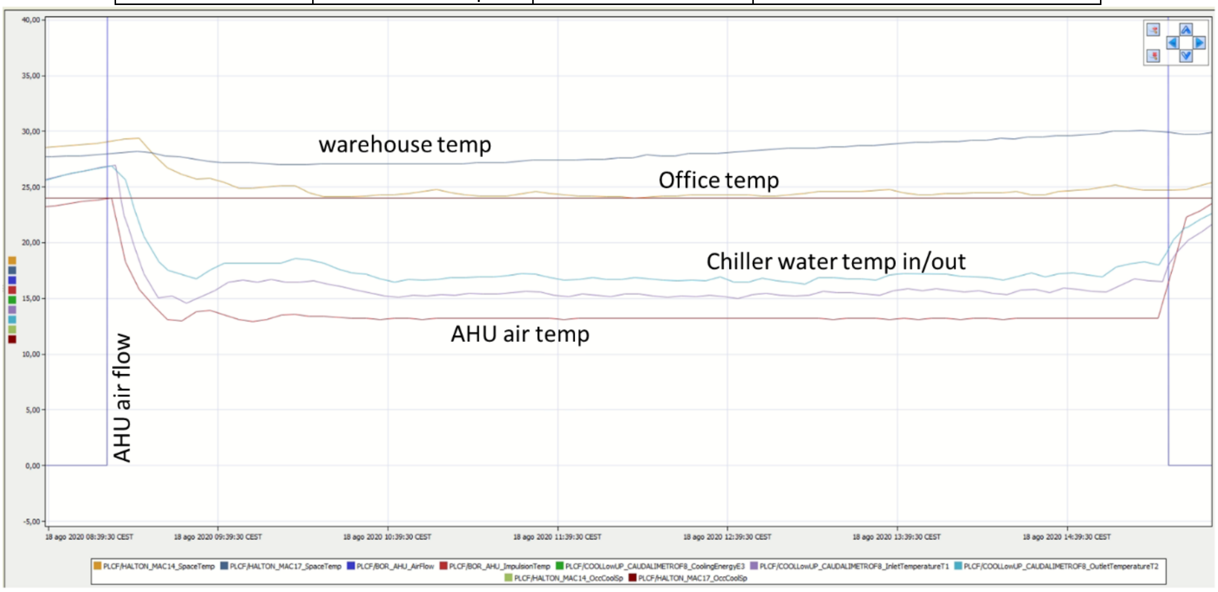


Figure 31. Variation of operating temperatures for chilled beam

Next image presents behaviour of control system over dampers in order to maintain pressure downstream (to the damper) constant; in this case airflow (measured through pressure) to warehouse is already at its maximum so no more air is required for this branch.

The flow is increased because of increment of occupancy at office, so from 1.400 m^3/h is moved to 1.550 m^3/h; as highlighted in violet box, warehouse duct damper reacts to increase of pressure modifying its position, reducing opening (lowering downstream pressure) and so deviating excess of air to office. It can be checked through monitored airflows of both rooms.

Color:	Variable:	Unit:	Operation:
orange	Warehouse flow	m^3/h	pump with constant speed and AHU 2 fixed airflows
green	Office flow	m^3/h	
Light blue	Damper opening	%	
blue	AHU operation	mode	
red	AHU flow	m^3/h	

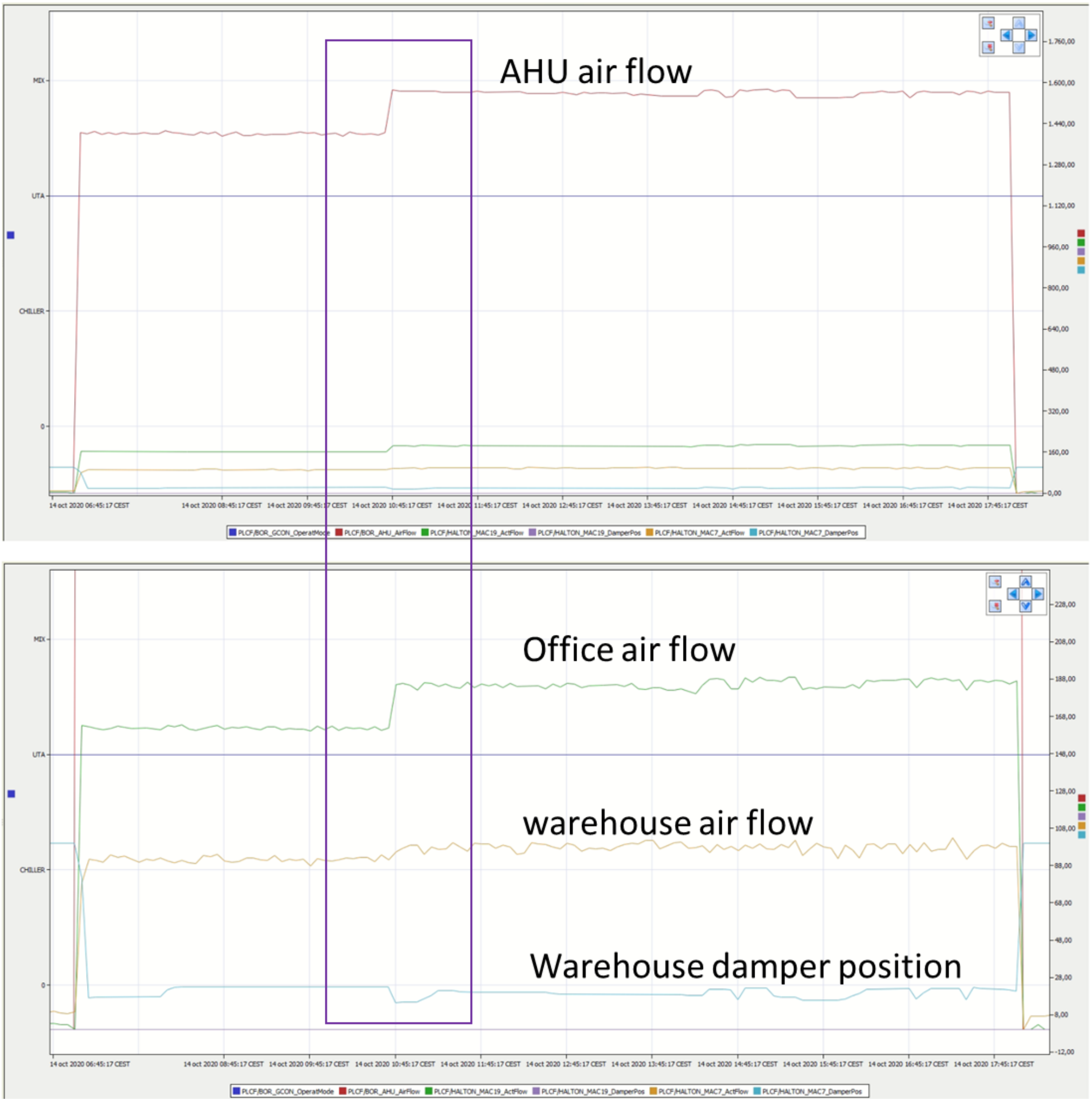


Figure 32. Variation of airflow as function of damper opening

More tests have been executed with operation out of nominal working conditions, in order to stress the system and understanding limits of operation, as shown in following picture.

AHU airflow is blown at 100%, while water temperature and supply air temperature are supplied with quite lower temperature with respect to nominal beams working conditions; temperature are so low to generate instability in compressor, attempting to produce chilled water at 6ºC; indoor temperature reduces considerably but bringing the system to the limit of crashing (red box).

Re-setting values of operation to nominal conditions (orange box), reactivate correct operation and stability along all parameters of the system. The system respond efficiently in dynamic conditions.

It can be seen how chilled water temperature affect the power delivered by beams to office; low temperatures reduces quickly indoor temperature, but creating instability in the compressor. On other hand correct temperatures correctly maintain indoor air temperature, in compressor safer conditions.

Color:	Variable:	Unit:	Operation:
orange	Warehouse flow	m³/h	pump with constant speed and AHU 2 fixed airflows
green	Office flow	m³/h	
Light blue	Damper opening	%	
blue	AHU operation	mode	
red	AHU flow	m³/h	

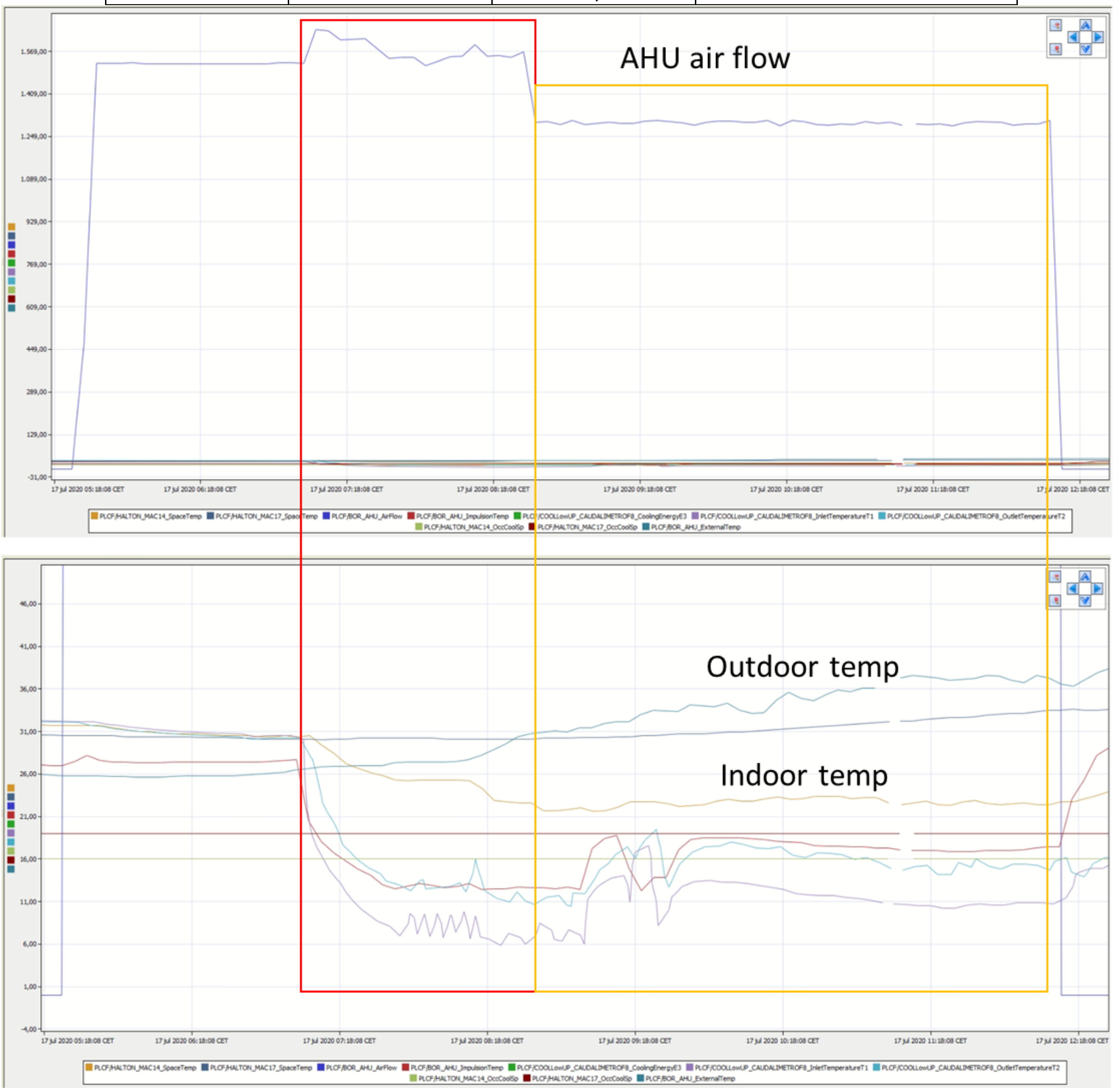


Figure 33. Instability of the system working over nominal limits

According to calculation achieved through data from monitoring, in next picture is represented performance of individual chilled beams (contribution of air and water) as function of indoor temperature at different experimented points:

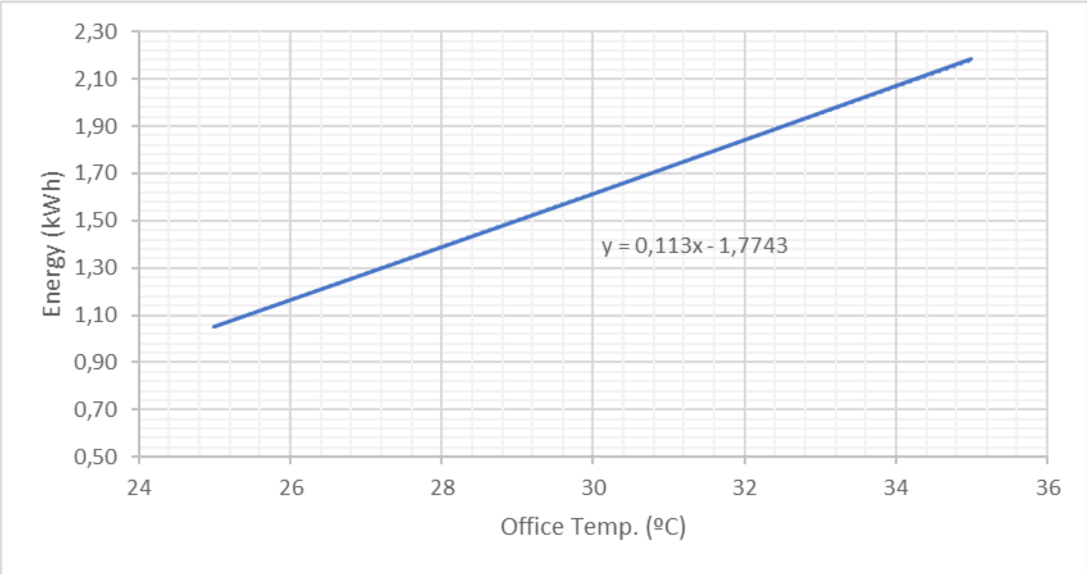


Figure 34. Power of office beam as function of office temperature

3.2.2 AHU-chiller

Hybrid units can work in different modes: only chiller, only AHU or mixed. Objective of test and operation were detecting and understanding real operation limits under different boundaries conditions, for latter optimization of normal operation. Understating thermal dynamic of unit connected with cooling tower is important for maximizing efficiency of the entire cooling concept.

The chiller produces chiller water that is internally distributed between air coil and external loads (like beams or PCM tank); 2 different 3ways valves regulate sharing of flow and outlet temperature from the unit. By this way the user can set two different temperatures for outlet air and outlet water; this means that lower temperature is the production setpoint temperature for chiller.

For instance if user set air temperature at 12ºC and water for load at 10ºC, chiller will produce water at 10ºC and then will mix return with supply for feeding air coil at 12ºC; this means that COP is affected by mode of operation of unit and respective setpoint.

Next image presents position of 3ways valve used for regulation of air temperature, while the unit is supplying chilled water to air coil and to chilled beams at same time; the control maintain stable indoor temperature of office building through use of air and water.

Color:	Variable:	Unit:	Operation:
blue	Valve opening	%	pump with constant speed and AHU fixed airflow
green	Condens temp out	ºC	
violet	Condens temp in	ºC	
Light green	Outdoor temp	ºC	
esmerald	Indoor temp	ºC	
Dark blue	AHU air supply	ºC	
Light blue	Evapor out		
orange	Evapor in	ºC	

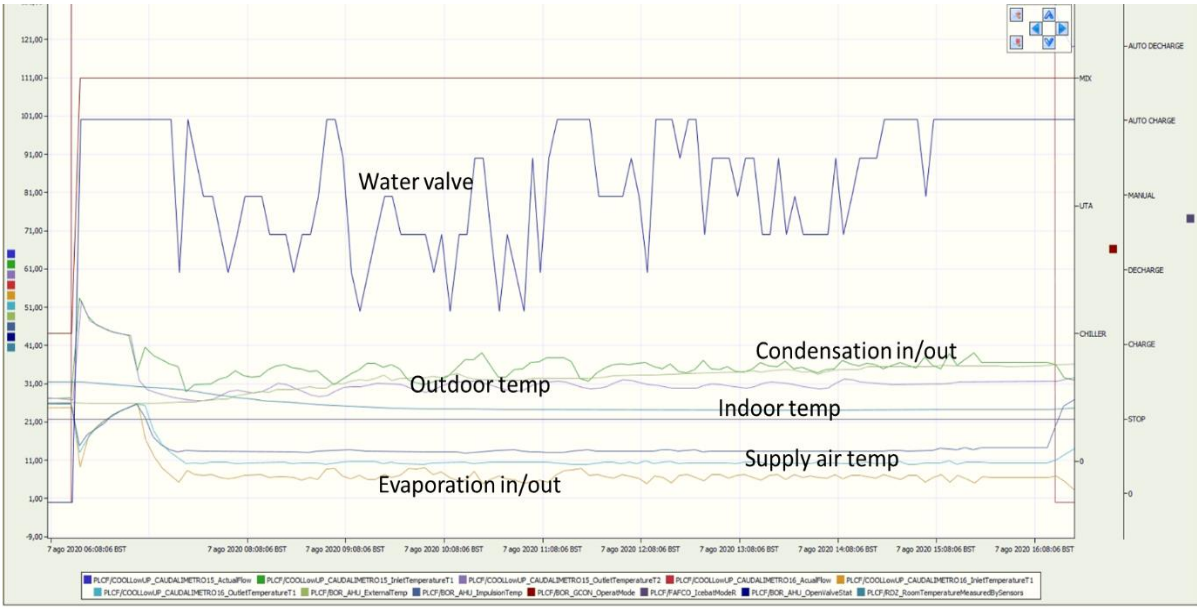


Figure 35. Operation of valve for producing stable air inside office

In next image is presented operation of the unit working only in chiller mode, operating at constant flows of evaporation and condensation, with chilled water production fixed at 10ºC.

Cooling tower is operating autonomously for maintaining outlet cooled water between an optimal temperature range (its control limit to 35ºC maximum water outlet but, below this temperature, regulates according to energy saving principles within an hysteresis, so outlet temperature can be variable). This is because air temperature is lower than condensing temperature. It can be seen how variation of return from cooling tower doesn't affect the temperature production of chilled water, which is compensated by compressor.

Color:	Variable:	Unit:	Operation:
Green	Condens out	ºC	Pump of evaporator and condenser at nominal flows
violet	Condens in	ºC	
olive	Outdoor temp	ºC	
Light blue	Evap in	ºC	
orange	Evap out	ºC	

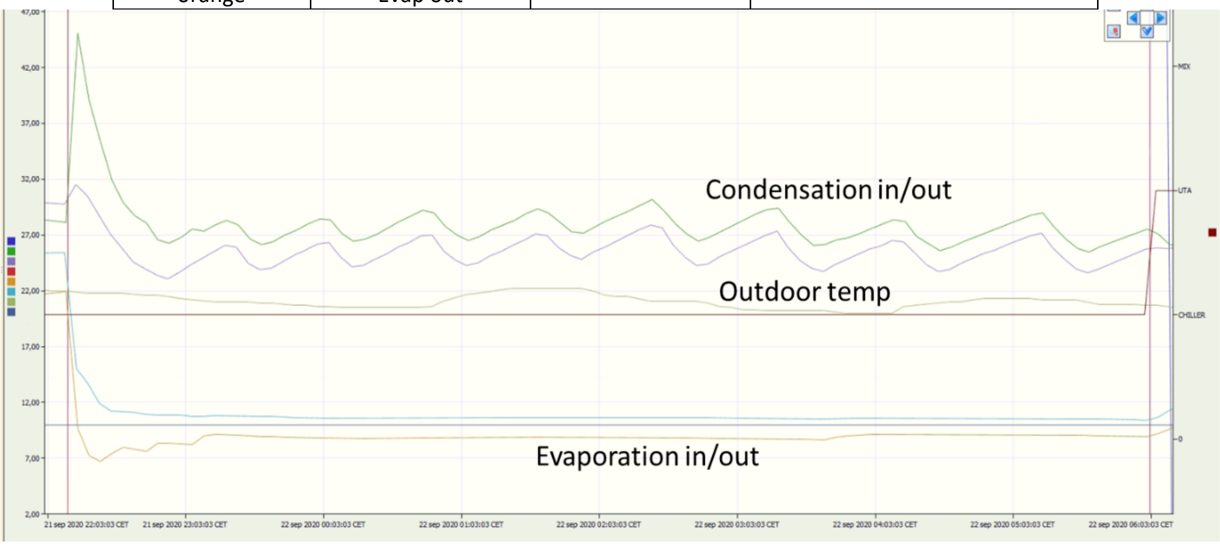


Figure 36. Stable operation for chiller with regulation of cooling tower

In next image is present a case with external air temperature higher than condensing temperature so the adiabatic chamber of the cooling tower have to start at full power; condensation is more stable but higher than previous case.

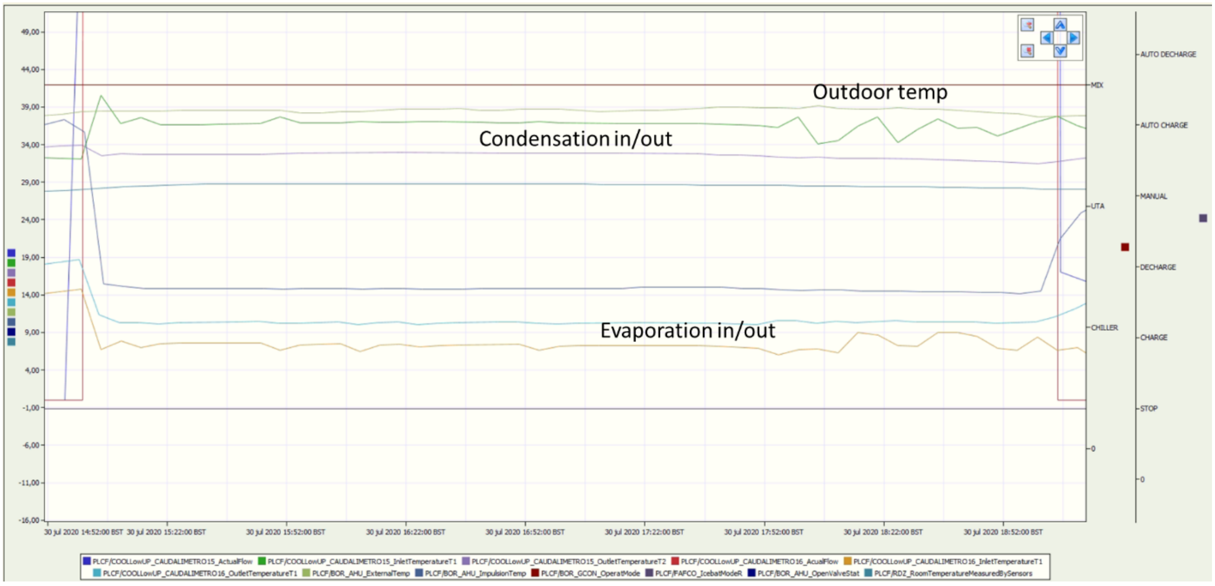


Figure 37. Stable operation for chiller with cooling tower at full power

Next image shows how unit has been tested under stress conditions, forcing the setpoint for chilled water close to 8ºC (nominal design is 10ºC) and so increasing pressure inside compressor Freon loop; the operation is still inside manufacturer limit so the unit keeps stable and correct even if compressor is overloaded. In green box is highlighted this working point.

In red box is presented how the unit is forced to operate close to 6ºC for producing chilled water, with consequent increase of Freon loop pressure. The compressor interrupts automatically operation because of high pressure alarm, stopping production of chilled water until recovering of normal pressure conditions and starting again the cycle of operation.

The results is an intermittent operation with intermittent production of cooling, which is also reflected in rejection of heat through cooling tower loop.

Color:	Variable:	Unit:	Operation:
blue	Condens out	ºC	Pump of evaporator and condenser at nominal flows
red	Condens in	ºC	
olive	Outdoor air	ºC	
violet	Evapor in	ºC	
green	Evapor out	ºC	

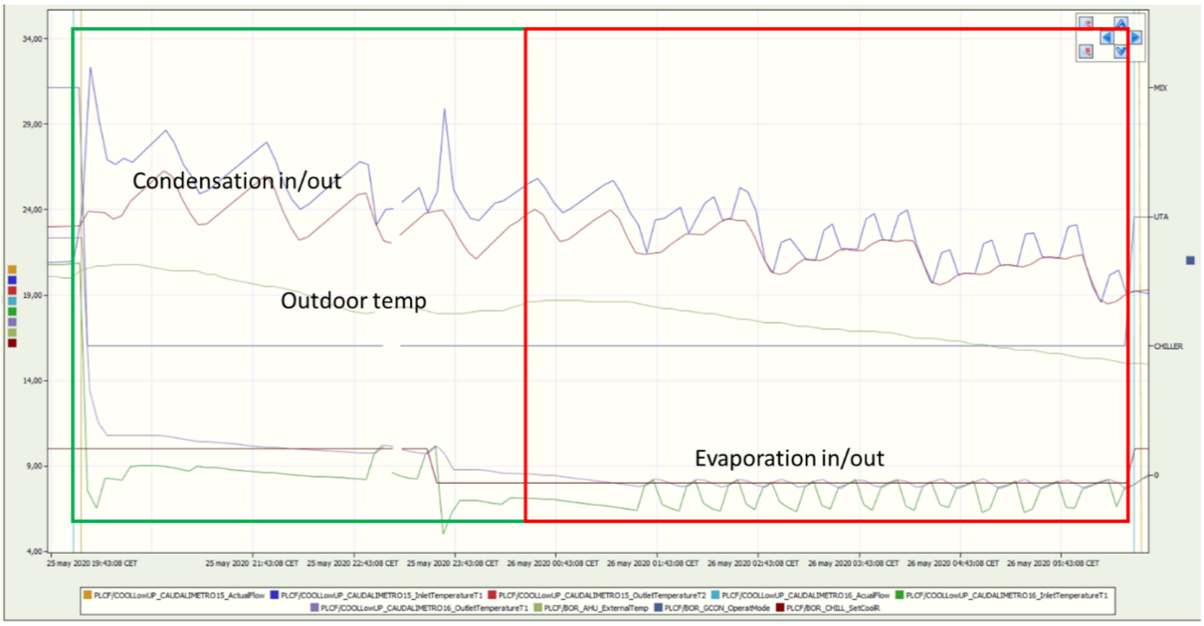


Figure 38. Instability of chiller working over nominal limits

The chiller is working always combined with cooling tower for dissipation of condensation; cooling tower is works as semi-wet, so operation at lower temperatures is based on dryccoler principles, while higher temperatures requires use of sprinkled water over the adiabatic chamber. So combination between condensing temperature and outside temperature determine kind of operation of the tower according to manufacturing control system (Frigel).

Due to the fact that operation of both cannot be split, here below is presented the results of calculation of performance of both equipment together as function of environment temperature achieved during period of characterization and operation; calculation have been achieved with chiller operating at chiller water design temperature and full capacity, with cooling power dissipating 100% of condensation:

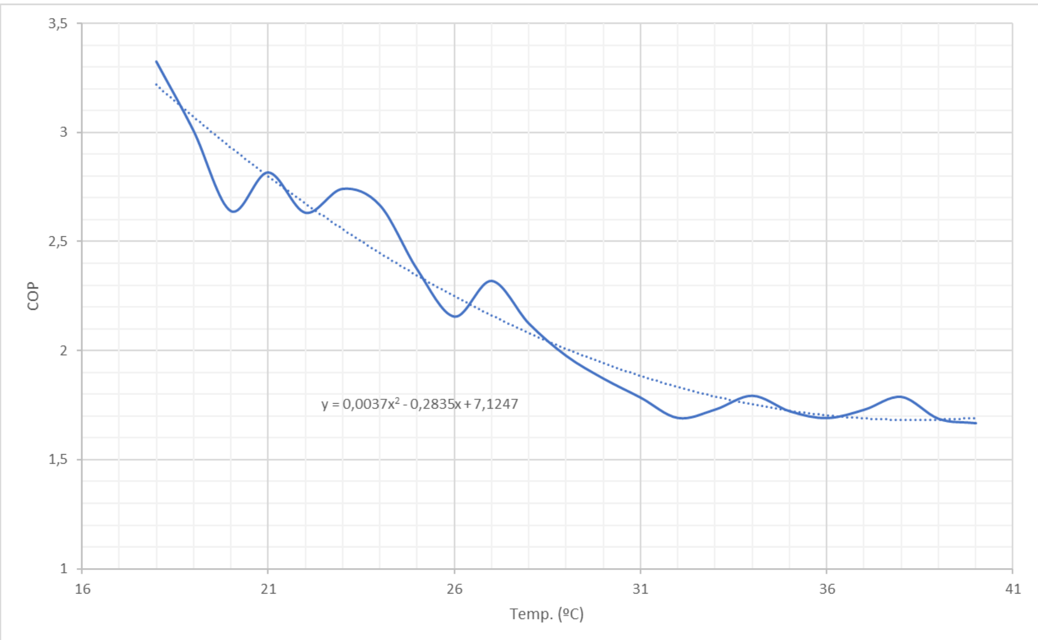


Figure 39. COP of chiller + cooling tower as function of outdoor temperature

3.2.3 PCM tank

PCM tank stores cooling through chilled water temperatures lower than PCM melting temperature and supply cooling at temperature higher than PCM melting temperature. The system requires operation at constant inlet temperature and constant flow for charging; on other hand, it requires constant flow for discharging but outlet temperature is regulated by 3ways mixing valve.

The system has been designed for operating according to chiller charging conditions and chilled beam discharged conditions; this means that inlet temperatures for charging and discharging move within a small controlled range (chilled beams require fixed temperature and PCM requires chilled fixed temperature).

In next figure are represented both phases of operation: charging with chiller and discharging with chilled beams. The different boxes highlight different moment of operation; it must be stated that the chiller wasn't stopped when PCM tank achieved its limit of capacity: charging in blue box, charging with saturation in green box and discharging in red box.

Color:	Variable:	Unit:	Operation:
Violet	Chilled water out	ºC	Pump at constant nominal flow
Green	Chilled water in	ºC	
Blue	Tank operation	mode	
Red	Water flow	ºC	

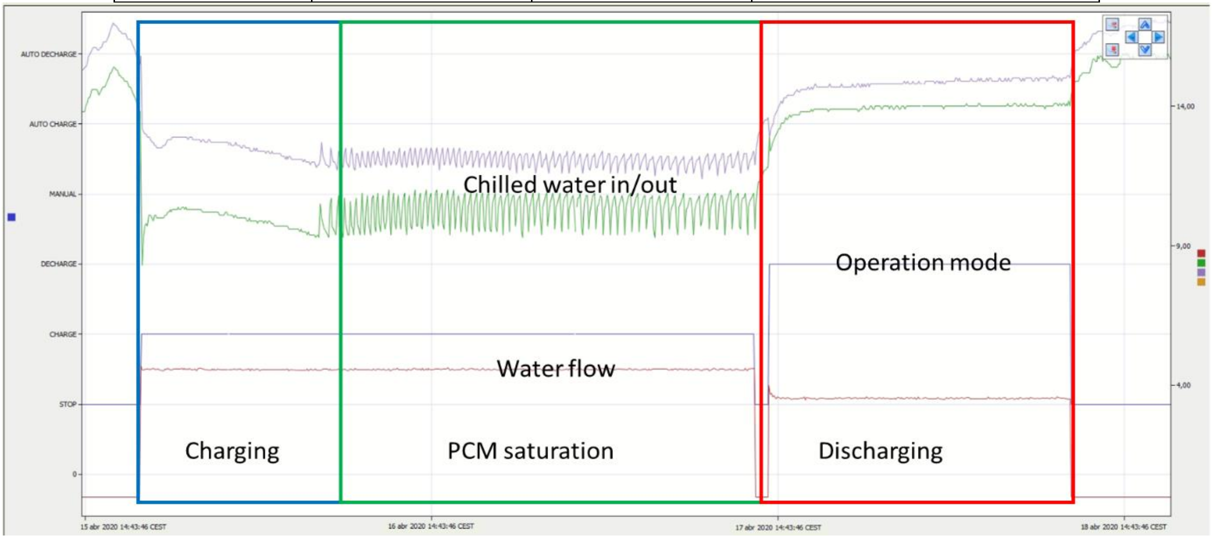


Figure 40. Different phases of operation for PCM tank

During charging, chiller starts operation and gradually wins thermal inertia of the system, delivering chilled water at 11ºC to tank which stores cooling, maintaining a constant delta Tº between inlet and outlet (blue box).

Once PCM is saturated (fully charged) energy required from chiller is zero, so compressor start and stops with the purpose of maintaining constant temperature inside water loops, which are recirculating water through tank (green box) even if not necessary.

During discharging, due to plumbing pressure drops reasons, flows reduces a bit still but maintaining minimum requirements of tank; it can be seen how temperatures are maintained constant with stable Delta Tº until achieving empty of tank (end of red box). Next image shows regulation of outlet 3ways valve to supply chilled water at constant temperature to chilled beams.

Figure 41. Operation of 3ways valve over PCM tank outlet temperature

Mixing valve oucoming from the tank, used for supplying setpoint temperature during discharge, allow maintain operation temperature of PCM optimal independently from possible peak of charge that would reduce designed working conditions, affecting long term stability of the storage medium.

4 Operation

Once finalized characterization, focus of operation moved to combined operation of system for long term tests; control used for these activities was in "automatic" mode first (where human operator defines setpoints, when operating and which operation strategy) and in "optimized mode" then (LowUP optimizer defines setpoints, time of operation and which operation strategy).

4.1 Heat LowUP

Next images will present combined (all equipment together for a specific purpose) operation of HEAT LowUP during different moment of winter season, showing most relevant variables monitored during process of heat transfer, from generator to terminals.

Following image presents operation of solar field supplying stratified tank, whose upper part (S1 sensor) is connected to radiant floor, which is maintaining the building at requested temperature.

Color:	Variable:	Unit:	Operation:
Violet	Solar out	ºC	floor Pump at constant flow solar pump at variable flow
Green	Floor in	ºC	
Light Blue	Tank S1	ºC	
Red	outside	ºC	
Grey	Office	ºC	

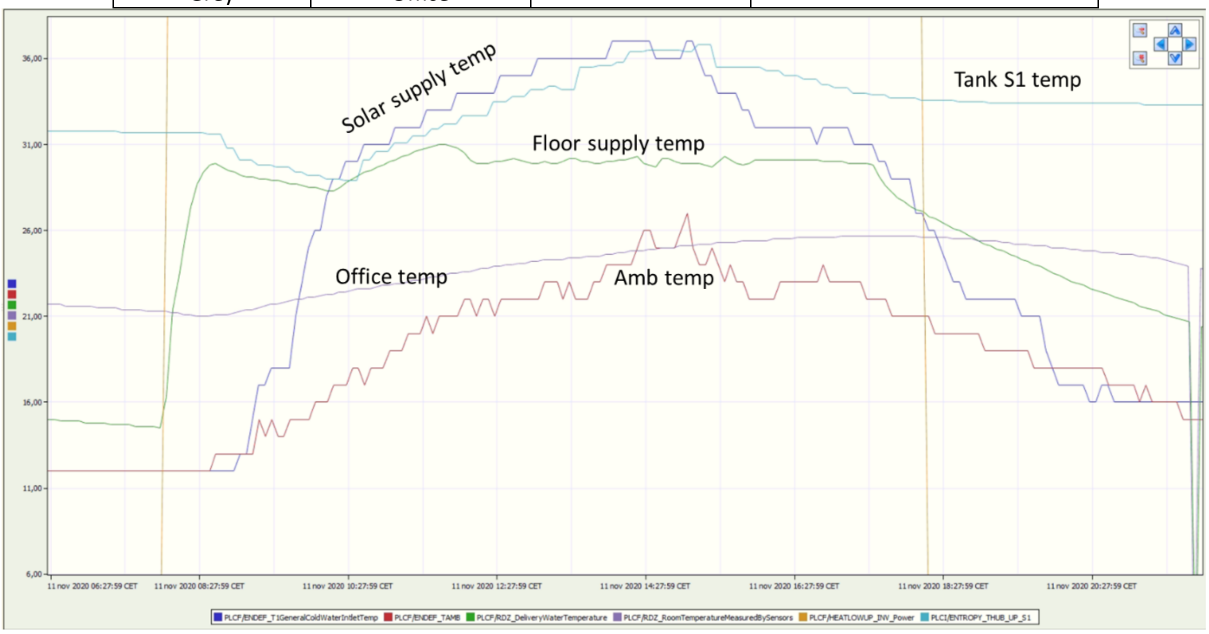


Figure 42. Operation of Heat LowUP with fixed floor supply temperature

With an indoor temperature of 21ºC and outdoor of 12ºC, solar field supplies tank with temperature up to 36ºC increasing, generating increment of its temperature; at same time tank supplies radiant floor which regulates around 30ºC, pushing indoor office temperature up to 26ºC.

it's evident how solar contribution is higher than building load, so tank temperature, after an initial moment with presence of load and absence of solar, keeps rising; at the end of the day when load is still present but solar is not enough, reduction is visible like beginning of the day.

Once achieved indoor setpoint temperature, the system regulates supply of water to radiant floor, with consequent stabilization of tank storage temperature; solar heat, not enough hot for supplying tank, works starts recirculating over its loop, avoiding negative charge of tank.

Following image present same case study but with different boundary conditions: indoor temperature and tank storage temperature are lower with respect to previous case, but outdoor temperature is higher.

Color:	Variable:	Unit:	Operation:
Violet	Solar out	ºC	floor Pump at constant flow solar pump at variable flow
Green	Floor in	ºC	
Light Blue	Tank S1	ºC	
Red	outside	ºC	
Grey	Office	ºC	

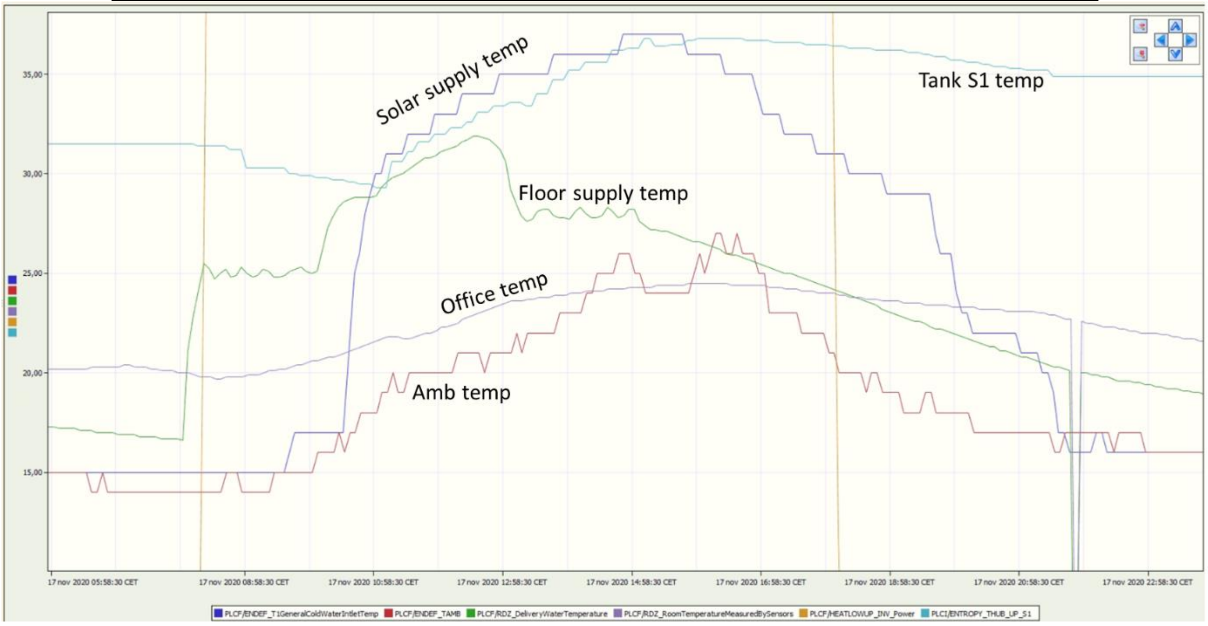


Figure 43. Operation of Heat LowUP with different floor temperatures

Initially 25ºC setpoint temperature is fixed for supplying radiant floor, nevertheless was not enough for desired indoor comfort conditions, so it was changed to 35ºC first but is not achievable because of limited temperature in the tank.

Se the floor is set at 30ºC which is achievable by the system, because lower than tank temperature; then is maintained until achieving 24ºC of indoor temperature when the pump of floor is switched off (outside temperature is higher than indoor temperature), with consequent smoothing of indoor temperature.

Since that moment, solar is disconnected from tank, which stabilizes its temperature, and keeps circulating over its loop, avoiding negative charge.

In next figure, is presented the case when solar radiation has low intensity (never above 33ºC), while indoor temperature starts at 21ºC and outdoor at 17ºC; the setpoint of radiant floor at 28ºC is set and the system operated.

Tank starts delivering energy to the floor reducing his temperature gradually, and so reducing inlet temperature to radiant floor, until solar has enough power to start charging the tank. Nevertheless is sufficient to maintain the temperature of tank and floor stable only for a short period; when solar reduces intensity, both tank and floor start reducing temperature, affecting office temperature.

Color:	Variable:	Unit:	Operation:
Violet	Solar out	ºC	floor Pump at constant flow solar pump at variable flow
Green	Floor in	ºC	
Light Blue	Tank S1	ºC	
Red	outside	ºC	
Grey	Office	ºC	

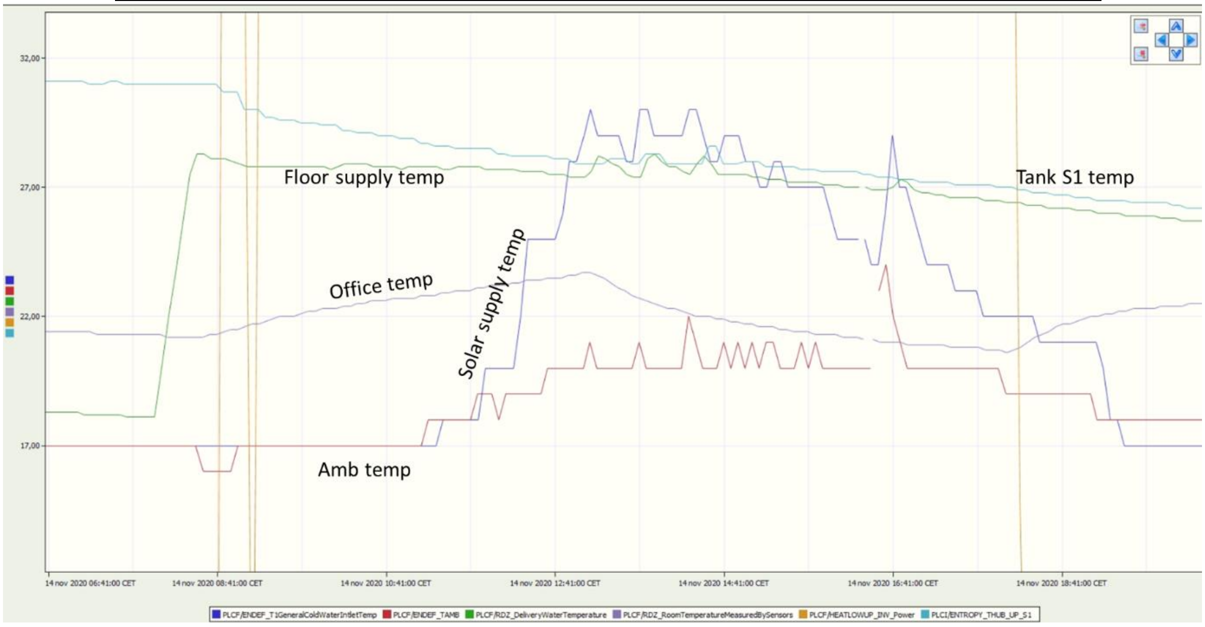


Figure 44. Operation of Heat LowUP with poor solar production

Integration of sewage heat recovery system into HEAT LowUP has been achieved through thermal emulator able to replicate thermal profiles. the profile of heat recovery without load (as described in previous section) has been emulated at Seville demo, but contribution to energetic balance is not relevant with respect to solar system in terms of energy and temperature, even during days with poor radiation.

With respect to optimized operation for HEAT, below is presented a typical example of combined operation of radiant floor and solar field as function of occupancy, outside temperature and solar radiation.

Optimizer, according to scheduled occupancy, pre-heat the office before starting of working day, considering thermal inertia of radiant floor, while injection of heat from solar field to stratified tank doesn't occur until produced temperature and stored temperature match for positive charge.

Color:	Variable:	Unit:	Operation:
Violet	Tank S1	ºC	floor Pump at constant flow solar pump at variable flow
Orange	outdoor	ºC	
Light Blue	indoor	ºC	
Blue	Pump operation	On/off	

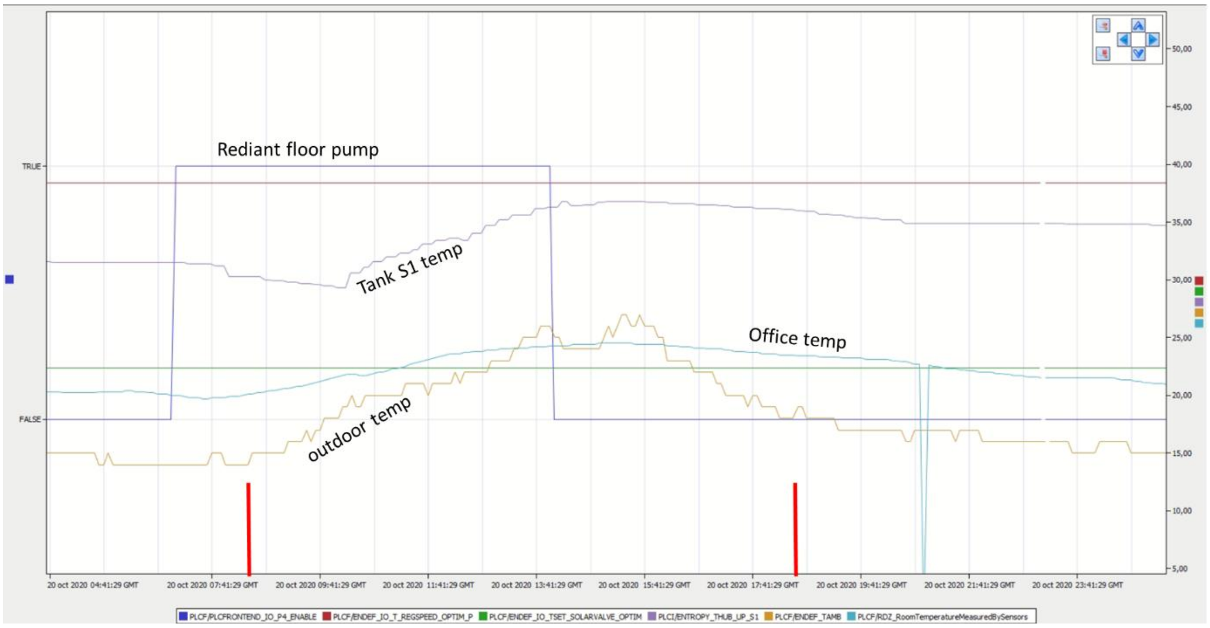


Figure 45. Operation of Heat LowUP with optimizer

The day start with consumption of tank energy, because of lack of solar radiation; stored temperature starts decreasing until intervention of solar field, which brings energy to tank. Since this moment tank is charged and discharged at same time, increasing its temperature with irregular profile; when outdoor temperature is higher than indoor temperature, the pump of floor is switched off; after peak of the day, outdoor temperature start reducing but indoor temperature keeps stable, so pump never switches on again.

4.2 COOL LowUP

Next images will present combined (all equipment together for a specific purpose) operation of COOL LowUP during different moment of winter season, showing most relevant variables monitored during process of cool transfer, from generator to terminals.

In next image present operation of chilled beams during the day, with primary air supplied by AHU (fed by chiller) and cooling water proceeding by PCM storage tank; the system provides stable air and stable water enough to win increasing outdoor temperature and building inertia, lowering temperature from 35 to 23ºC.

It can be evidenced how chiller presents stability problems related with cold production, which are reflected in oscillation of air temperature; it also evident how PCM was gradually loosing temperature for effect of poor charge during night.

Due to inconsistency of the system, Cool lowUP had to be switched off before ending of the day.

Color:	Variable:	Unit:	Operation:
Blue	Outdoor temp	ºC	PCM tank discharging AHU supplying primary air Beams in cooling mode
Green	Indoor temp	ºC	
Orange	PCM tank	mode	
Olive	Beams water in	ºC	
Light blue	AHU air	ºC	

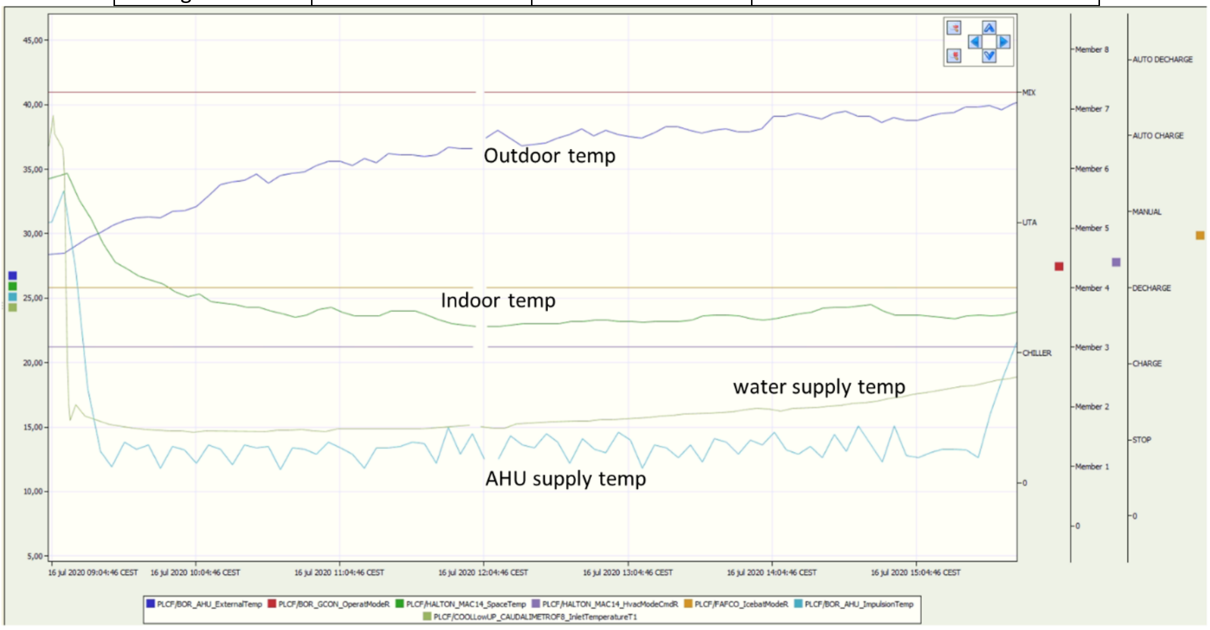


Figure 46. Operation of Cool LowUP in mixed mode but instable power

Same operation as before is here presented with more stable conditions for chiller and PCM tank with lower chilling load, and office temperature at 25ºC.

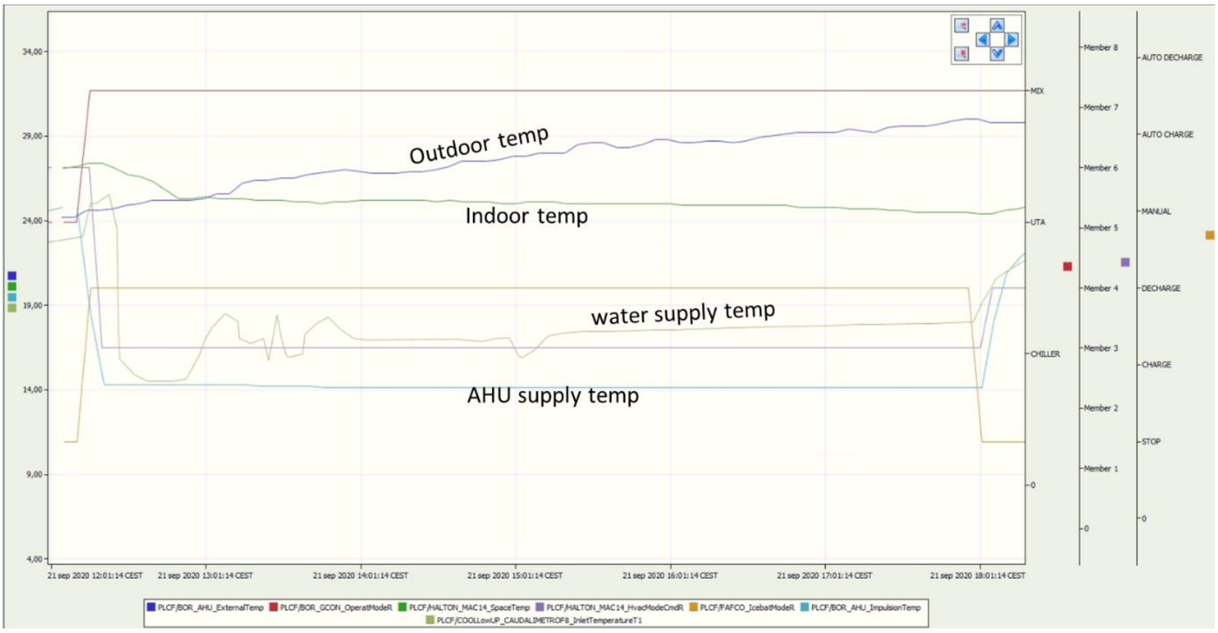


Figure 47. Operation of Cool LowUP in mixed mode with stable power

Tests with heat exchanger, for pre cooling return from beams to PCM tank during day, have also been conducted in order to assess its impact on energy saving of COOL LowUP. The heat exchanger in installed on return pipe from chilled beam to operate on secondary loop with TAP water of local network, which is used to feed adiabatic cooling tower.

From experience it has been verified that adiabatic mode starts when air temperature is around 28ºC, so flow of water is present only during moments of office day time when outdoor conditions fulfil with this restriction of manufacturer. For lower temperatures, drycooler mode is operating so no water flow is present.

The heat exchanger can be by passed only with manual valves and no actuator is present; so when tap water is higher then return temperature from chilled beam, the heat exchanger deliver energy to the system and so decrease global efficiency. Next figure presents a day of monitoring with reduced number of hours available for adiabatic operation mode of cooling tower.

Color:	Variable:	Unit:	Operation:
Blue	Outdoor temp	ºC	Constant flows for all pumps AHU supplying primary air at constant flow Return from chilled beams with TAP water precooling
Green	Tap water	ºC	
Orange	Chilled water to beams	mode	
Light blue	Chilled water from beams	ºC	
Dark blue	Chilled water after HEX	ºC	

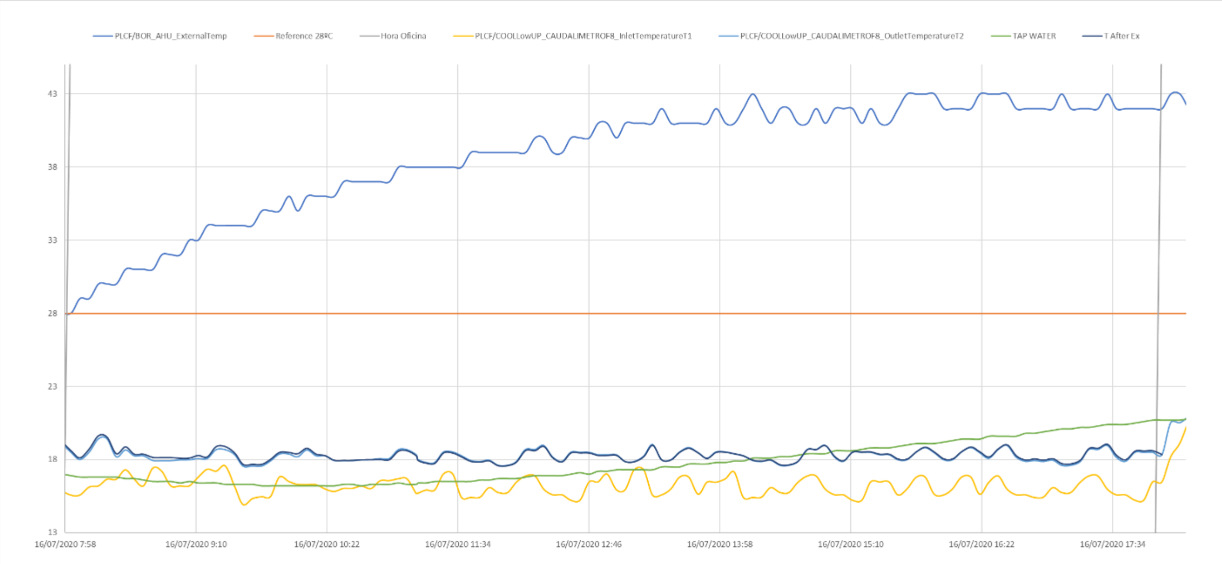


Figure 48. Operation of Cool LowUP with heat exchanger over beams loop

As shown better in figure below, the reduction is small but is present, until green line crosses with light blue line; since that point beams loop is wasting energy to cooling tower tap water loop.

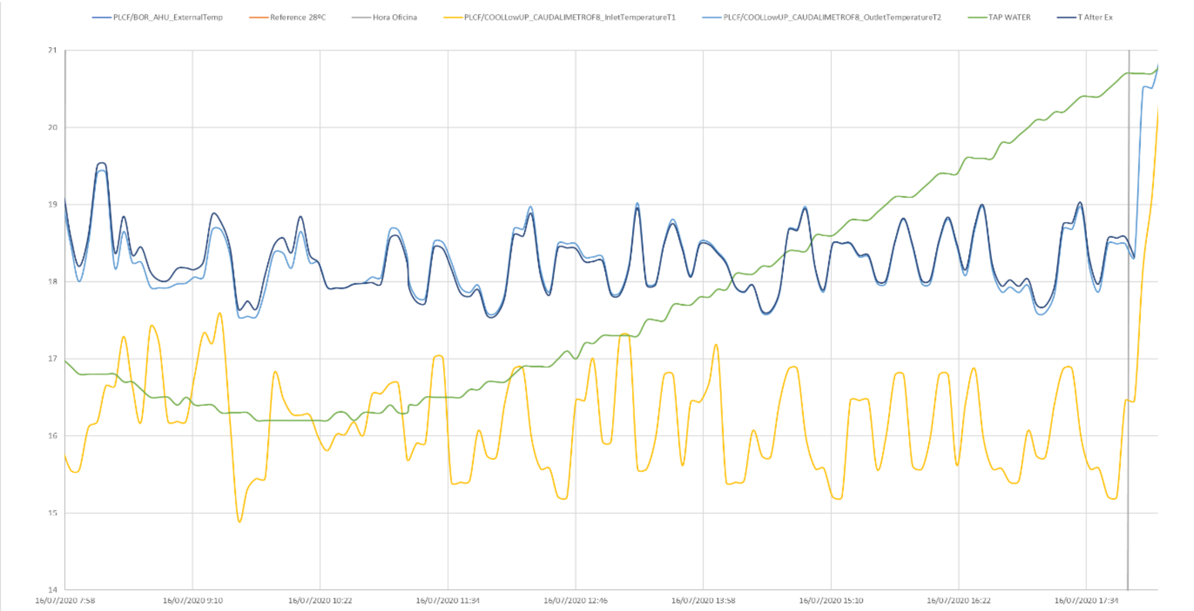


Figure 49. Variation of temperature for effect of heat exchanger during hot day

For a more tempered day, positive impact is lower with respect to hotter days:

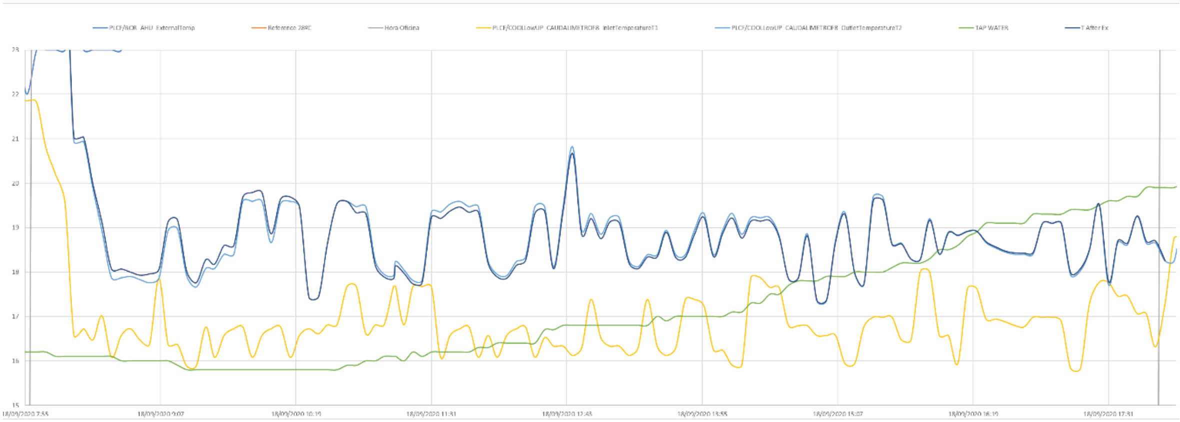


Figure 50. Variation of temperature for effect of heat exchanger during tempered day

With respect to strategy of chilled beams pre-chilled by cooling tower, the operation for office building cooling has not been achieved during period of test of cooling season. Even during intermediate temperature of Seville weather, air temperature is higher than requested for this kind of special configuration which seems being more suitable for kind of building like Data Center, which have constant load along the entire year at higher temperatures than building offices.

As presented in figure below, outdoor temperature is always above return of water from chilled beams, while, for being operative, it should be between 3 and 5K below. Furthermore, thermal load of data center could not be replicated for typology of demos and boundary conditions of operation at today date.

Color:	Variable:	Unit:	Operation:
Red	Indoor temp	ºC	AHU supplying primary air PCM tank supplying beams Chilled beams precooled by tower
Orange	Outdoor temp	ºC	
Green	Return chilled water	ºC	
Violer	Supply chilled water	ºC	

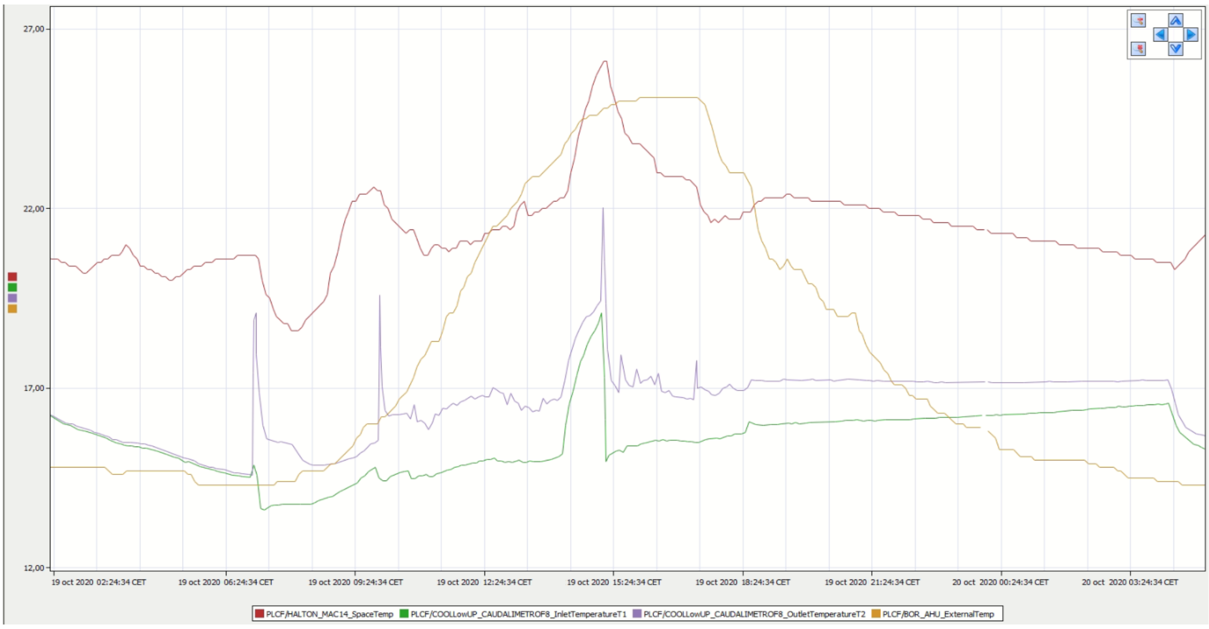


Figure 51. Variation of outdoor temperatures during October

In next figure is represented the operation during 24 hours, including discharge during day (green box), and charge during night (blue box).

Really the day is composed by 4 phases: free-cooling, daily discharge, end of the day with no occupancy (no load necessary) and night charge; all of them have been decided by LowUP supervisor operating in "optimized" mode.

Color:	Variable:	Unit:	Operation:
Blue	Outdoor temp	ºC	Constant flows for all pumps AHU supplying primary air at constant flow Optimized mode activated
Green	Indoor temp	ºC	
Orange	PCM tank	mode	
Olive	Beams water in	ºC	
Light blue	AHU air	ºC	

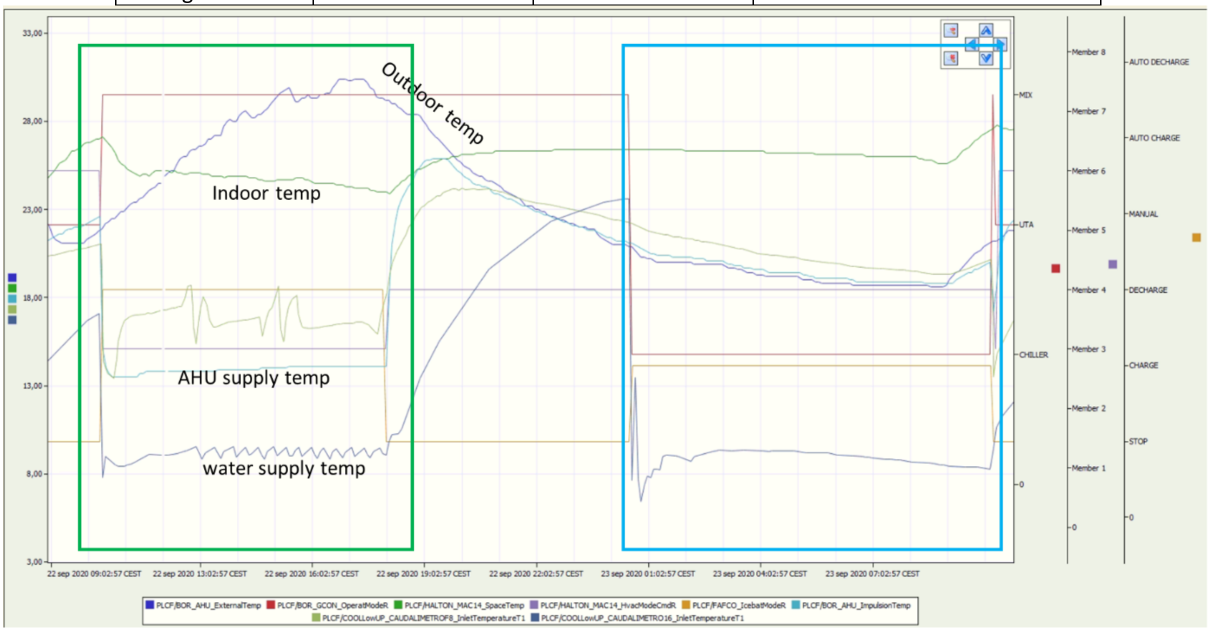


Figure 52. Operation of Cool LowUP during 24 hrs

Phase 1: before starting the scheduled occupancy at 8 am, and during early hour of occupancy, the beams and AHU are working in free-cooling mode, until indoor temperature reaches 26ºC.

Phase 2: free cooling is not enough to win building load, so PCM tank discharge is activated, beams are set in cooling mode and hybrid unit is in mixed mode for producing primary air. Indoor temperature lower to setpoint of 25ºC, until end of office day at 6 pm.

Phase 3: no load s required from the building because of absence of occupancy so all system are in standby mode, which means energy saving; optimal temperature for night charge (according to energy requested to refill the tank) has not been achieved yet.

Phase 4: optimal temperature, considering minimum number of necessary hours at chiller full power for filling refilling the tank, is achieved and night charge can start. When tank is filled again the process stops and chiller is paused, waiting for next cycle.

After a relatively short time, free cooling jumps in again to start 24 hours cycle with phase 1; in some case it is possible having contemporaneity of night charge and free cooling, depending on weather forecast and building expected occupancy.

Next two figure present the same cycle (in this case divided in night and day) from supervisor point of view. During the day Phase 1, 2 and 3; during night Phase 3, 4 and 1.

Color:	Variable:	Unit:	Operation:
Blue	AHU-chiller	Operation mode	Constant flows for all pumps AHU supplying primary air at constant flow Optimized mode activated
Red	PCM tank	Operation mode	
Green	Occupancy	Operation mode	
Violet	Beam	Operation mode	

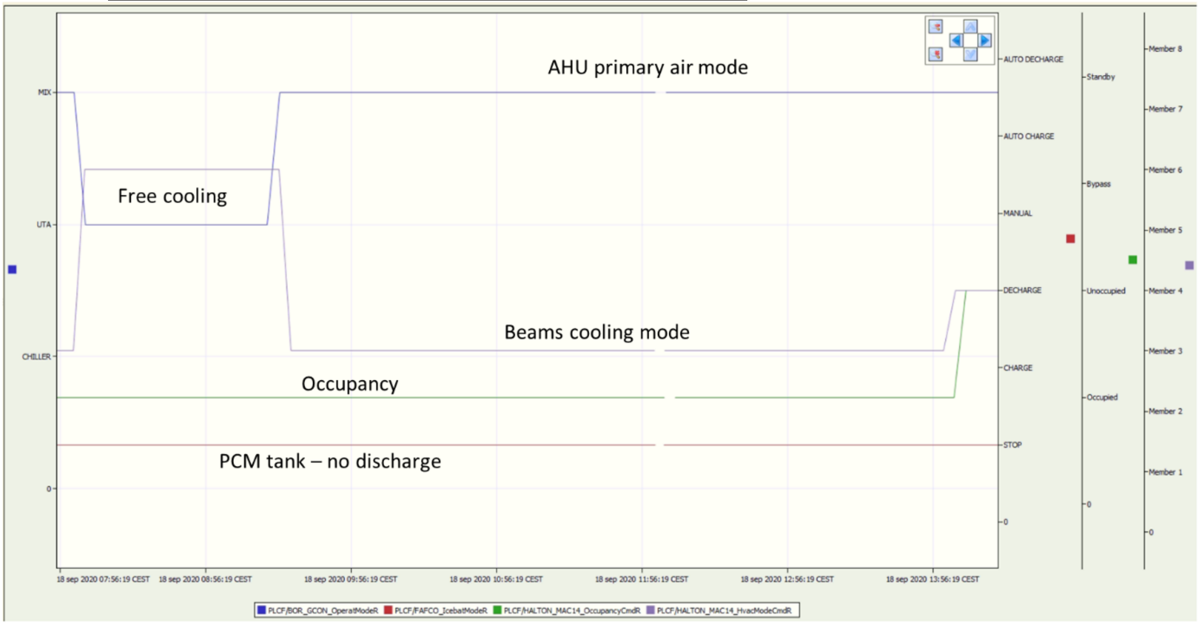


Figure 53. Supervisor during 24 hrs (day)

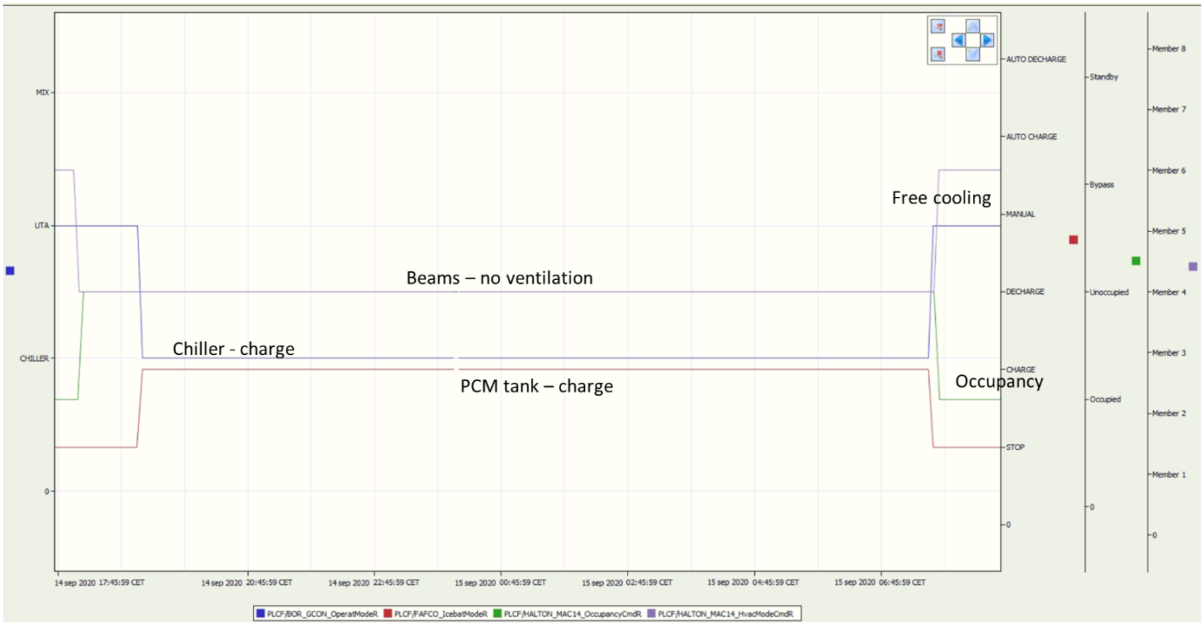


Figure 54. Supervisor during 24 hrs (night)

During manual or automatic operation, the chiller would have started normal operation, charging of electrical consumption the energetic balance of the system.

5 Surveillance study

In this document for each system involved in the Cool-LowUP and Heat-LowUP solutions a surveillance study has been made. In some of the systems new alarms were defined by the experts of Acciona operating those systems in the Seville plant to avoid any damage on the systems and to control possible critical situations. On some other an analysis of their usage during the performance tests given has been made.

5.1 Solar field

Next Focusing on the security and reliance of the Solar Field equipment, a special focus has been done over the ENDEF sensorial data. The data taken for this purpose focuses around two main sensors, the *ENDEF_T21InternalPanelTemp3* sensor and the *ENDEF_T31InternalPCMPanelTemp3* sensor. The first one gets the inside temperature from a panel without PCM, and the second one the inside temperature from the one panel with PCM. Both getting data along all day and from the panels installed in the Seville pilot site.

For this pair of sensors, the Acciona Experts defined some monitoring conditions around which two types of alarm arise. The first and most basic condition to be triggered can be mathematically represented as:

$$\nabla temp\_record \in [endef21, endef31];$$
$$temp\_record \geq 70$$

From this basic rule arises the first type of alarm. Which is obtained when the second condition of the formula arises. The behavior of the alarm will end up recording all the time periods in which the temperature inside the Solar Field was higher or equal to 70ºC. This premise makes possible to register consecutive records of *Alarm1* since up until the sensor registers a temperature below 70ºC (70ºC not included), it will classify all the samples as an anomaly.

Since having to register a record of temperature under 70ºC it is an essential condition to stop reporting samples under the Alarm1 category, a new Alarm was created to denote the exact moment in which this event happens. So, the mathematical rule for this Alarm1 earns a new layer of conditions:

$$\nabla temp\_record \in [endef21, endef31];$$
$$(temp\_record_{n-1} \geq 70) \; and \; (temp\_record_n < 70) \; for \; n = 0 \; \dots \; len(endef)$$

As a result, the data contained inside each ENDEF dataset was classified under these two conditions. Due to the sensorial systems high clock speed, the temporal registers of the ENDEF dataset had very small-time gaps among each one, resulting in a large and very detailed dataset.

Having big amounts of data is always a good scenario. Nevertheless, when it comes into performing analysis over these large datasets a resample operation is often recommended to reduce the computational times. Resampling a dataset takes the data from a specified temporal frequency (for this analysis was 5 minutes) and merges the data from all the contained registers taking advantage of an aggregation operation.

Since we were looking for these sensorial data in which the temperature recorded was under the 70ºC, leaves us with a new challenge. It is necessary to keep both the minimum and maximum values from this 5-minutes period to perform the Alarm 1 and Alarm 2 check (look **¡Error! No se encuentra el origen de la referencia.** to have a reference for this procedure).

Table 4: ENDEF dataset resample and aggregation procedure*

Timestamp	Temp. (ºC)
2019-02-21, 06:43:19	64.0
2019-02-21, 06:44:45	68.0
2019-02-21, 06:46:03	70.0
2019-02-21, 06:48:28	75.0
2019-02-21, 06:50:01	72.0
2019-02-21, 06:52:53	67.0

Timestamp	Min. Temp. (ºC)	Max. Temp. (ºC)
2019-02-21, 06:40:00	64.0	68.0
2019-02-21, 06:45:00	70.0	75.0
2019-02-21, 06:50:00	67.0	72.0

(*) This scenario is a fictitious example which was created to force and explain the Worst-Case-Scenario. The left side represents the original dataset meanwhile the right side represents the resulting dataset after applying the *resample* and *aggregate* operations.

Once the resample and aggregate operation have ended, the resulting dataset (look right result in **¡Error! No se encuentra el origen de la referencia.**) contains the desired result, minims and maxims from each 5-minute period. From now one it will only remain the apply the mathematical conditions which trigger alarms from both types 1 and 2. Nevertheless, this resulting scenario introduces a new challenge.

By looking once again at the resulting table 4, it is easy to classify the first record as “No alarms present” and the second record as “Alarm 1 triggered” but a classification problem arises with the third register. For this specific case, the third register should trigger at the same time an Alarm1 and an Alarm2. This will generate confusion since Alarm1 notices the start and continuation of an anomaly while Alarm2 is triggered once this anomaly ends, leading in an uncertain and misclassified result.

The solution to this classification problem was reached by implementing a new subsystem which detects these scenarios as a completely new anomaly and solves it by going to the original data (look left records on Table 4) and resolving this uncertainty by looking and storing which of both alarm was triggered first. Once the problem is solved, both alarms will be plotted at the exact time they took place to avoid any possible confusion in the final plot.

The result of this classification procedure was represented in a succession of tables containing the total amount of alarms triggered in each month of recorded sensorial data. Referring to tables Table 5 and Table 6, the months which were not included had their whole data represented as zeros. Meanwhile, on Table 7 and

Table 8 only the months with alarms on their data were represented. In these tables, the green lines represent the alarm1 events, the orange lines represents the Alarm2 events, the blue lines represents the minimum value every 5 minutes (which is the period used to show the data) and the red line is the maximum value.

Table 5: Alarm types surveillance analysis over ENDEF_T21InternalPanelTemp3 sensor

Month	Alarms1	Alarms2
February, 2019	4	2
March, 2019	0	0
April, 2019	9	2
May, 2019	10	6
June, 2019	0	0
November, 2019	0	0
December, 2019	0	0

Month	Alarms1	Alarms2
April, 2020	1	1
May, 2020	4	1
June, 2020	0	0
July, 2020	0	0
August, 2020	0	0
September, 2020	0	0
October, 2020	0	0

Table 6: Alarm types surveillance analysis over ENDEF_T31InternalPCMPanelTemp3 sensor

Month	Alarms1	Alarms2
February, 2019	0	0
March, 2019	0	0
April, 2019	0	0
May, 2019	5	3
June, 2019	0	0
November, 2019	0	0
December, 2019	0	0

Month	Alarms1	Alarms2
April, 2020	0	0
May, 2020	1	1
June, 2020	0	0
July, 2020	0	0
August, 2020	0	0
September, 2020	0	0
October, 2020	0	0

With the data from these alarms, we can observe that the panels with PCM material inside suffer less episodes of high temperatures, which is interesting for its installation on places with high temperatures to avoid losses on efficiency and deterioration of their components.

Table 7: Alarms graphical representation over ENDEF_T21InternalPanelTemp3 sensor

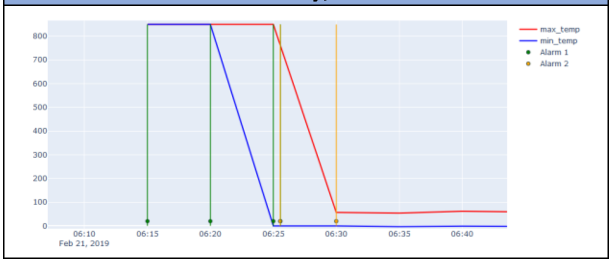
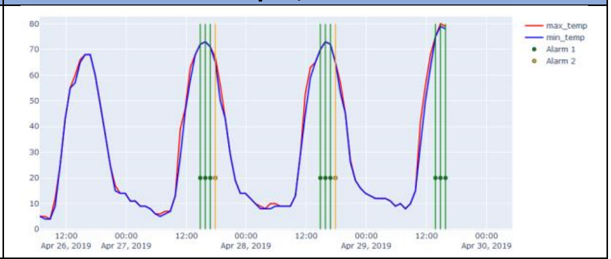
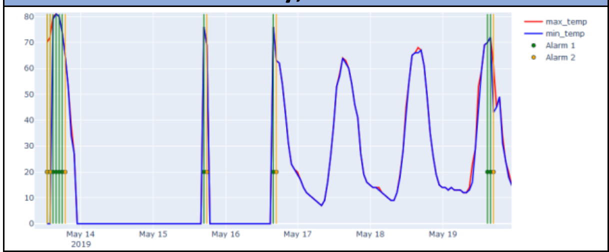
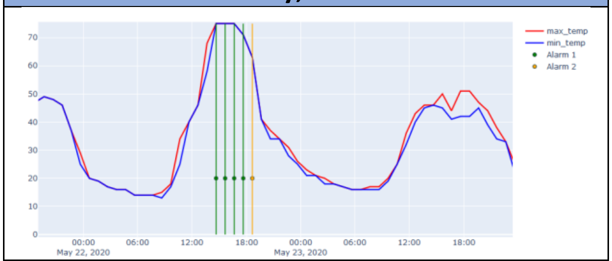
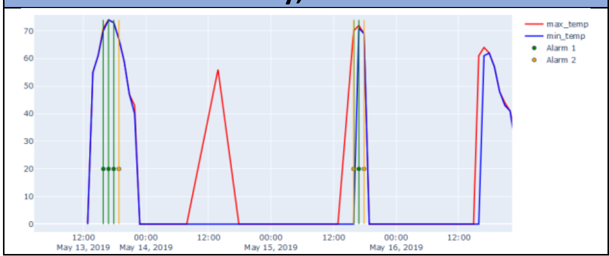
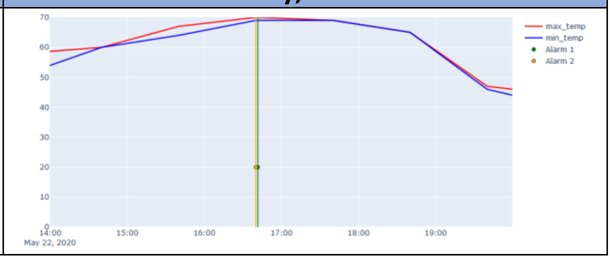
February, 2019	April, 2019
	
May, 2019	**April, 2020**
	
May, 2020	
	

Table 8: Alarms graphical representation over ENDEF_T31InternalPCMPanelTemp3 sensor

May, 2019	May, 2020
	

It is important to denote that this procedure can be easily converted into a system which registers only the first Alarm of type 1 while avoiding successive alarms produced by the sensor still registering records of a temperature higher than 70ºC. Since the already presented Alarm of type 2 will be triggered once the sensors goes down from these 70ºC. It can be deduced that all the registers between Alarm 1 and Alarm 2 will be of type 1.

This behavior has a good and bad approach. On one side, this new method will generate less "spam" since the number of Alarms will be notary reduced, this could be a good approximation if it will be connected to an email system in a near future. On the other side, in terms of data science, important data is getting ignored.

This always ends into having to build a new implementation to classify these Alarm 1 ignored records, leading into more cost and time for the project. A mixture of the two services can be reached adding an intermediate layer which will ignore all the arriving Alarm1 if an Alarm1 was already registered and reported, up until an Alarm2 arrives, then the behavior will be reset.

5.2 Radiant floor

For this specific surveillance analysis and based on the recommendations form the Acciona Experts, a combination of a sensor and an actuator are involved. The sensor involved in the analysis is *RDZ_RoomTemperature*. Meanwhile the actuator involved is *RDZ_WinterTemperature*. For this specific scenario the operation instructions of the system specified a behavior given by a mathematical relation among the measurements performed by each of the two systems.

$$\nabla sensor\_record\ \mathbf{where}\ sensor\_record \in\ RDZ\_RoomTemperatureMeasuredBySensors;$$

$$\nabla actuator\_record\ \mathbf{where}\ actuator\_record \in\ RDZ\_WinterTemperatureSetEachSensor;$$

$$sensor\_record\ < actuator\_record$$

By this rule, all the records contained inside *RDZ_RoomTemperature* sensor dataset should be correlated with a record of the same temporal period from the *RDZ_WinterTemperature* actuator dataset. By looking at the data it can be deduced how these two systems does not work under the same clock speed (performing records of the temperature at the same instance of time). As a result, a Feature Engineering procedure was applied over the data to resample all the records into frames of 5 minutes. T

his data resample presents a new challenge since all the data under a certain period of 5 minutes needs to be grouped. This *aggregate* operation was based in the previously seen mathematical relation among the sensor and the actuator. Since this relation want to find if in a certain period the sensorial data was lower than the actuator data, the aggregation procedure can keep the highest sensorial record in a 5-minute period and the lowest actuator record. We want to force the error over:

$$A: (a, \dots, a_n), B: (0, \dots, b_m)$$

$$A < B;$$

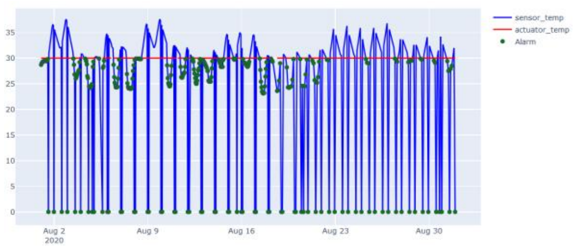
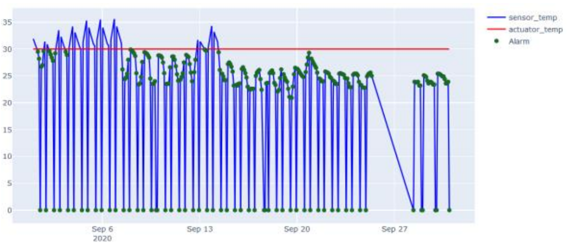
$$\nabla a \in A\ \&\ \nabla b \in B, a\ lt\ b;\ \mathbf{highest}\ a\ from\ A\ still\ \mathbf{lower}\ than\ \mathbf{lowest}\ b\ from\ B$$

$$(max.)\ sensor\_record\ < (min.)\ actuator\_record$$

Once the data is collected and aggregated, the relation seen before can be applied to the entire dataset to spot those samples that does not meet the condition, these ones will be considered anomalies, while resulting in alarms see Table 9. The blue line represents the sensorial data meanwhile the red line represents the actuator set value. It can be seen very clearly how any sensory data under the actuator setting value triggers an alarm (green dot).

For this specific analysis done, a series of considerations were taken because of the plotting activities and the visible results. The firsts records date of February 21, 2019 but it is not until reaching April 9, 2020 that the sensorial data differed from 0. For this reason, the months compressed inside this period were omitted from the general analysis of Table 9. All the records inside them are considered alarms which does not provide any value to the overall study.

Table 9: Radiant floor alarms analysis

April, 2020	May, 2020
	
June, 2020	**July, 2020**
	
August, 2020	**September, 2020**
	
October, 2020	
	

This analysis was centred in noticing when the sensorial temperature remains or goes under a specific value (actuator set value). This is one possible way of interpretating this scenario. It is important to notice which is the desired behaviour for the system and when this system is in danger. Since this is a surveillance analysis, the focus should be in those scenarios in which the system can be forced into error due to inviable conditions.

To reach a valuable statement for this analysis both scenarios should be put into consideration. Focusing in two main questions “Can the system survive under the set value of the actuator?” and “It is normal for the system to reach temperatures higher than the value which was set by the actuator?". Taking this as the starting point, the overall alarm system can be filtered to provide more meaningful reports avoiding what can be considered false alarms, alarms without a valuable usage or reporting conditions that are not helpful for the overall study.

5.3 AHU-chiller

Regarding the AHU/Chiller system, a special analysis over the alarms report systems was done. For this scenario, the alarms were already defined, spoted and stored in datasets under the timestamp they were reported.

Since the analysis was already done, it only remains to plot the data to find specific patterns or correlations among the different alarms. Almost all the datasets related to the AHU/Chiller system had a high amount of alarm report on its data. Most of these reports take place in very short time ranges leading into total values which can't be plotted, otherwise the plot will barely have sense due to the alarm reports being plotted one above the others.

To solve this situation, the data needs to be grouped taking a new time frequency as the key to join all the samples. The data starts to be plottable when this time frequency reaches the time unit of the week (groups of 7 days). This was taken as the procedure to go with since this was also the scenario which retrieved the highest granularity (in a *group-by* operation, the highest the granularity is, the highest is the information that keeps untouched).

Every single *group-by* operation needs to be followed by an *aggregate* function if the resulting data of the procedure wants to be retrieved in a Dataframe format. Taking advantage of a constant column "value" inside the dataset which always contains an Integer value 1, a *count* operation can be performed as the *aggregate* function to obtain the total amount of alarms.

This *count* operation works just as a common reduce-procedure. It starts taking two samples of the sub-dataset returned by the *group-by* operation and performs a sum over the specified field. The result is a dataset divided in temporal samples of one week while storing inside the "value" column the total amount of alarms compressed in this week temporal range.

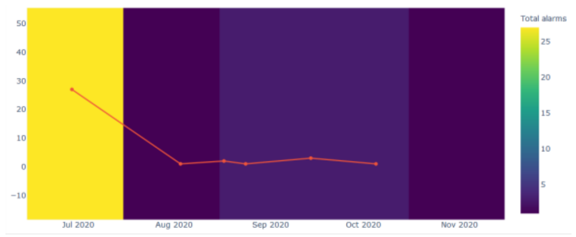
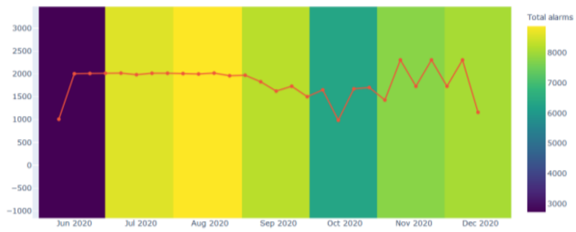
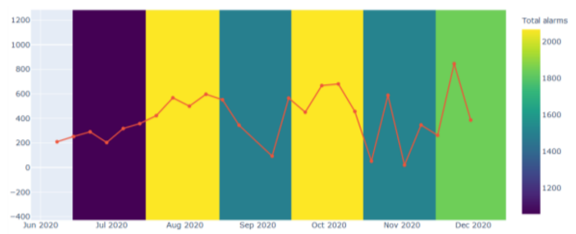
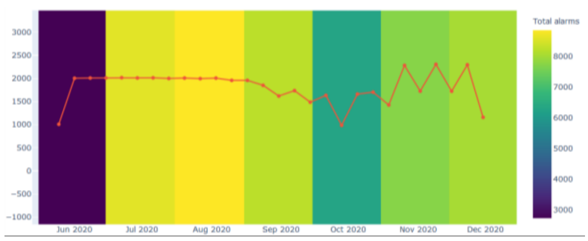
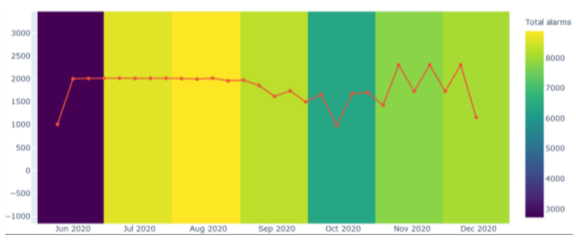
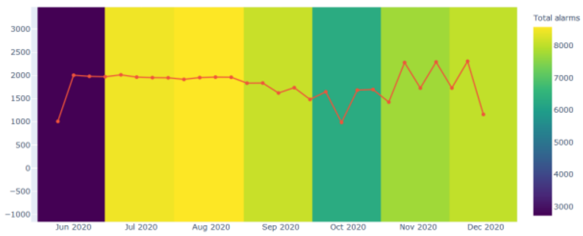
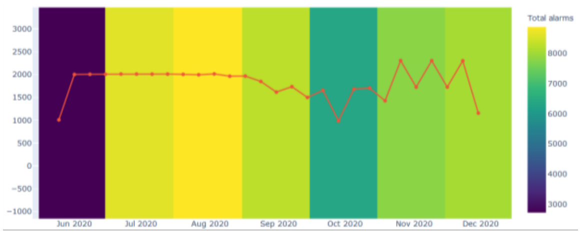
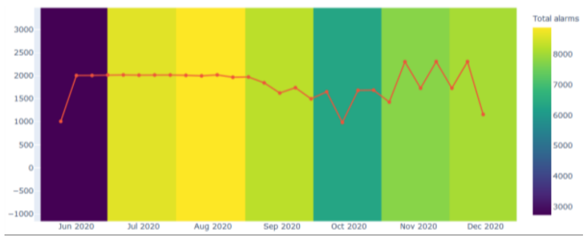
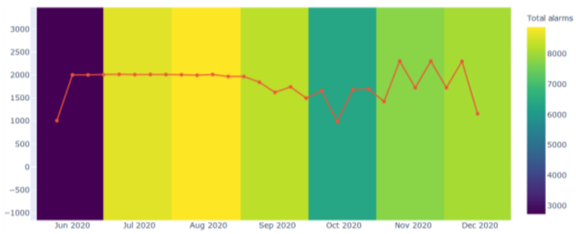
Once this procedure was already defined it can be reused taking a different time range approach. The time range of weeks was chosen due to the incompatibility of the Scatterplot with a time range with less granularity than the week unit of time. To improve the overall readability of the plot it would be good to preserve some data with a lower level of granularity, trying to plot the alarms information upon month time unit while plotting this new data in a new plot approach. The final solution to this new concern was to plot the monthly data over a new axis (Z axis) represented by a heatmap under the original Scatterplot since both plots can work together since they share a common axis (X axis).

This new mixed plot made by combining the precision of the Scatterplot with the clean representation for big sets of samples which provides the Heatmap will follow the following axis distribution:

- Scatterplot:
    - X axis: Time frequency in which the original dataset was grouped-by (weeks).
    - Y axis: Total amount of alarms triggered in a week. Result of performing a *count* operation over the data obtained from the group-by procedure applied for week unit of time.
- Heatmap:
    - X axis: Time frequency in which the original dataset was grouped-by (weeks).

- Z axis (colour): Total amount of alarms reported in a month. Result of performing a *count* operation over the data obtained from the group-by procedure applied for month unit of time.

Table 10: Borealis alarms report analysis

Active Alarm	Alarm Compress
	
Alarm Flux Prod	**Alarm Flux Tower**
	
Alarm High Pressostat	**Alarm KLYXON Comp**
	
Alarm Low Pressostat	**Alarm Pump Product**
	
Alarm Pump Tower	**Alarm Vent AHU**
	
General Alarm	

Taking a general view of the entire Table 10, a common pattern can be extracted from the last set of alarms. It can seem like a plotting error but all the alarms: Alarm High Pressostat, Alarm KLYXON Comp, Alarm Low Pressostat, Alarm Pump Product, Alarm Pump Tower, Alarm Vent AHU and General Alarm seem to share a common behaviour.

Even if all these plots seem to be the same one, once we check each one of the samples provided by the Scatterplot it can be seen how all of them differ in the total amount of alarms (see Table 11). Even most of the register were numerically different, it is very hard to have the exact number of alarms triggered, just differing by the units of the value. This can be an important discover since it seems to be a certain correlation among the different types of alarm for the provided Borealis dataset.

Table 11: Borealis alarm analysis differentiation

Total amount of alarms							
Alarm / **Month**	Alarm High Pressostat	Alarm KLYXON Comp	Alarm Low Pressostat	Alarm Pump Product	Alarm Pump Tower	Alarm Vent AHU	General Alarm
Jun, 2020	2723	2723	2723	2723	2723	2723	2715
Jul, 2020	8617	8624	8478	8610	8619	8611	8591
Aug, 2020	8870	8894	8593	8887	8890	8886	8865
Sep, 2020	8244	8269	8169	8260	8266	8264	8261
Oct, 2020	6313	6350	6328	6353	6349	6464	6364

By looking at all the results which have been collected during the study, a general appreciation can be done. By looking at the plots performed, a common profile can be extrapolated. Reporting an average of almost 5600 alarms per month does not seem like a valuable report. If a profitable result wants to be extracted from this alarm report, a filtering procedure should be considered.

To perform this specific filtering activity, some extra information must be essential to start understanding the alarms report. Since the database presents the report as a binary value 1 or 0, an extra linkage with the sensorial, actuator data which triggers these alarms is strongly required. By looking at this data and the trigger condition, it can be readjusted, or a new one can be created specifically adapted to the conditions in which the system is working.

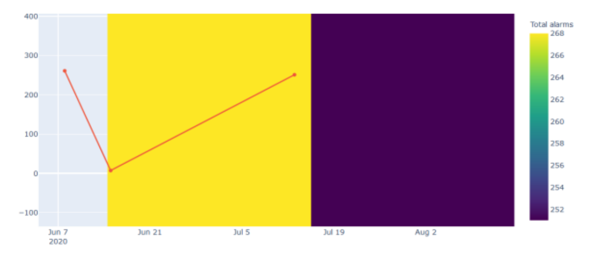
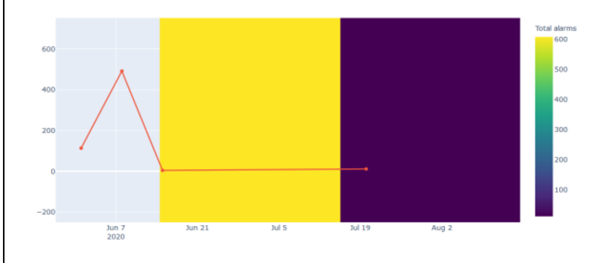
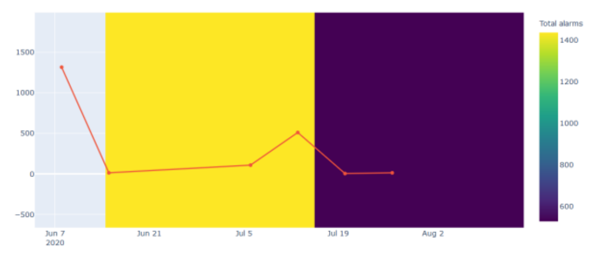
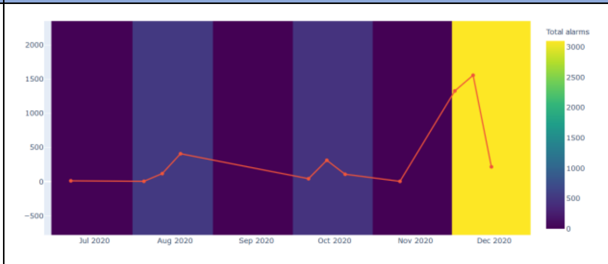
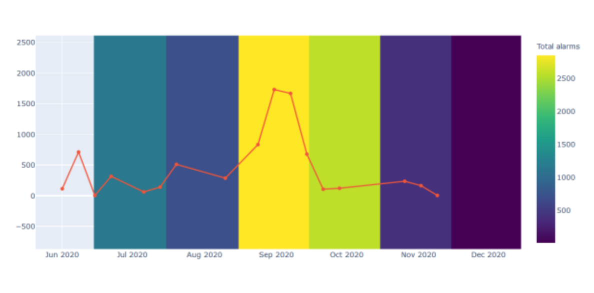
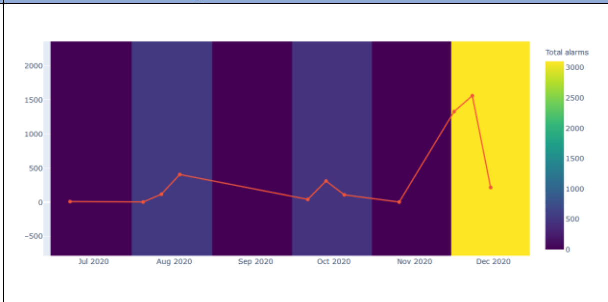
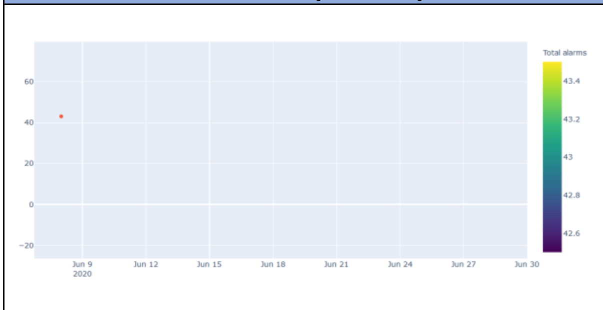
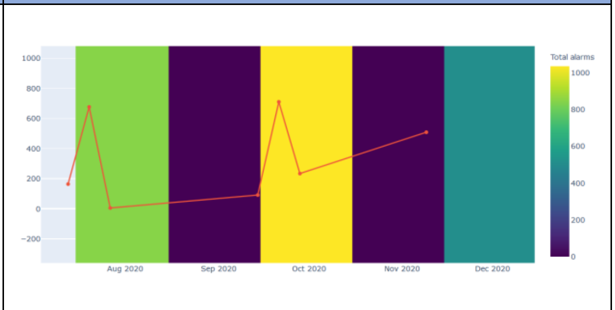
5.4 PCM tank

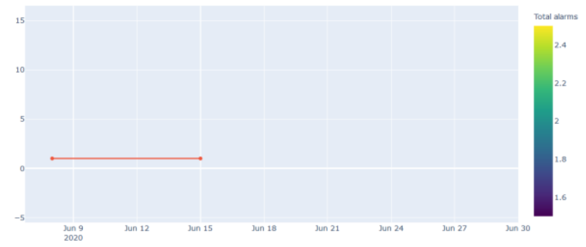
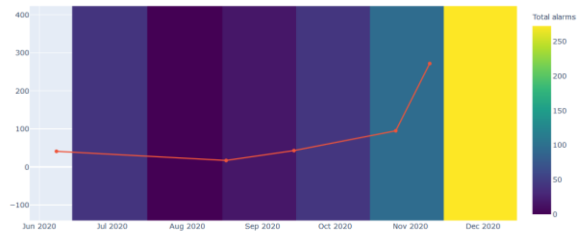
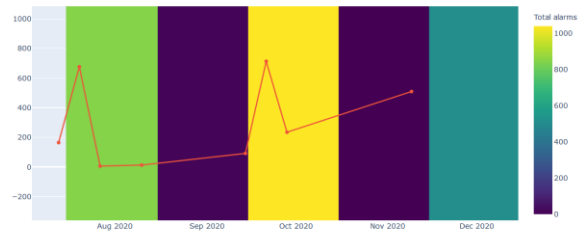
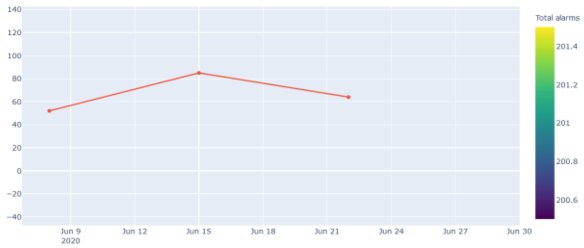
Focusing on PCM Tank surveillance study, the data available to perform an analysis follows the distribution already presented in section 3.1, AHU/Chiller. This distribution presents the data around a set of alarms, leaving the possible sensorial or actuator data a part. Since both scenarios share the same schema, the only appreciable difference will be on the alarm data of each one of the studies. In the specific case of the PCM Tank dataset, this one contains a total amount of 12 alarms. For each one of these alarms, a report of triggers will be performed while showing the months with the most and least activity.

This procedure has divided the entire dataset taking as the reference for doing it the id of the alarm which is reporting the data. Once this data is isolated by the primary key identifier, it only lasts to perform both *groupby* operations resampling the entire dataset in time ranges of one month and one week. The first one will be used to perform the respective heatmap plot which rapidly shows which month has the most activity on it.

The second set of data resamples using the week unit of time will be used to plot a scatterplot to explain oh the alarm triggers evolve during the time. Once again, this unit of time allows to see a pattern while keeping the plot clean thank to the reduction in the number of alarm reports (Table 12).

Table 12: FAFCO alarms report analysis

High Alert Icebat Input Temperature	High Alert Icebat Start Temperature
	
High Warning Icebat Input Temperature	**High Warning Icebat Level**
	
High Warning Icebat Start Temperature	**Hight Alert Icebat Level**
	
Low Alert Icebat Input Temperature	**Low Alert Icebat Level**
	
Low Alert Icebat Start Temperature	**Low Warning Icebat Input Temperature**

	
Low Warning Icebat Level	**Low Warning Icebat Start Temperature**
	

As a conclusion, the overall study seems to present alarm triggering levels which are quite similar to the ones seen in the previous AHU/Chiller study. Being capable of reaching 3000 alarm reports in a single month. When comparing these two analyses, a difference seems to appear. This one can be spotted by looking at the average number of reports triggered by FAFCO alarms each month.

This amount reaches the 456 alarm reports triggered per month. This is due to having a mix of alarms which have a behaviour which present a single report in a specific timestamp and alarms which triggers a constant and enormous amount of reports. While looking a t the value of the data, the first scenario seems to be better.

It does not require a filtering or patter extraction process since the reports seem to sport real anomalies in the system which occur under certain conditions and not all the time. When an anomaly is reported consistently during the whole month it differs from what can be understand an unexpected event report.

The alarms that seem to share a behaviour which can be classified as anomalies are:

- High Alert Icebat Input Temperature
- High Alert Icebat Start Temperature
- Low Alert Icebat Input Temperature
- Low Alert Icebat Start Temperature
- Low Warning Icebat Start Temperature

All these alarms share a common pattern. An initial set of reports during the first three months and no more reports from that ones on. Since all of them work around the Icebat Temperature system, if the sensorial or actuator data referent to these systems can be extracted a pattern could be spotted.

6 Savings

This chapter present scalable results obtained from analysis of performance of LowUP component and systems during operation. KPI of efficiencies have been used for calculating potential saving and impact over monitored heating and cooling seasons, thank to testing over different operation points, as shown in previous sections.

6.1 HEAT LowUP

If photovoltaic can be parametrized as function of radiation, with production as function solar radiation because the load is constant, for solar thermal quantity of energy generated is in function of variation of load, especially for return temperature to solar field.

As presented during characterization, thermal exchange reduces according to increasing of return temperature; on other hand, constant return temperature would not guarantee achieving optimal setpoint temperature.

In order to estimate savings achievable with solar thermal during period of most intense radiation, here below are presented different days of calculation, according to monitoring; in red produced PV without PCM and in blue with PCM:

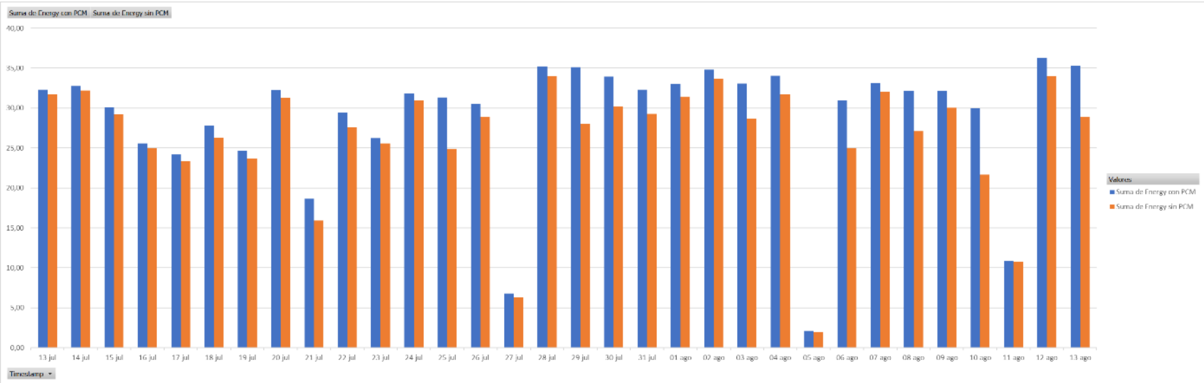


Figure 55. Comparison of PV production between with PCM and without

Next figure represents thermal energy produced during same period of time:

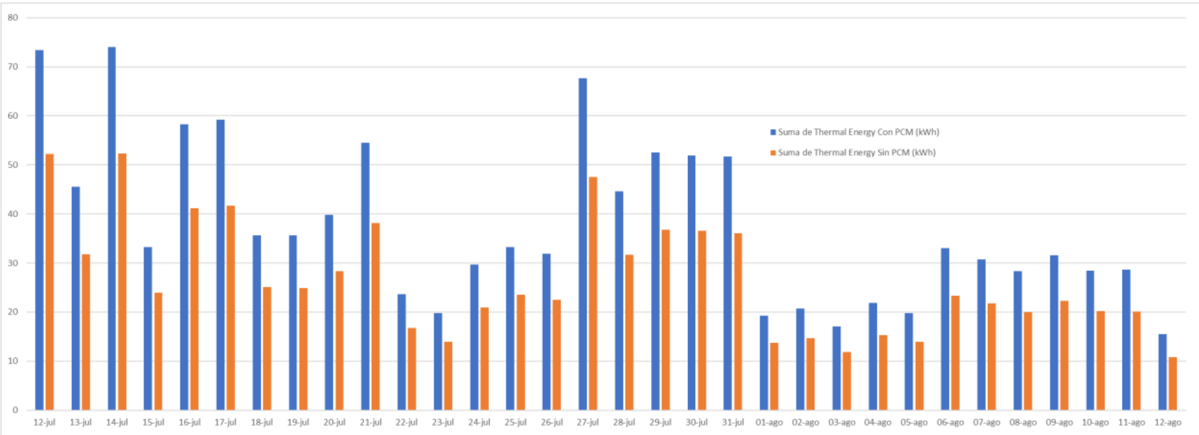


Figure 56. Comparison of Solar thermal production between with PCM and without

Final savings are then calculated with respect to previous period of monitoring:

Table 13: total increment of production for Solar

HEAT		
Thermal production		**30%**
w PCM	1210,81	kWh
w/o PCM	853,59	kWh

Electrical production		**8%**
w PCM	919,02	kWh
w/o PCM	841,39	kWh

TOTAL		**20%**
w PCM	2129,83	kWh
w/o PCM	1694,97	kWh

The total represents the benefit provided by solar technology with PCM with respect to without PCM calculated in primary energy, whose conversion factor for renewable thermal and electrical is 1.

Contribution of sewage water heat recovery is resumed in table below:

Table 14: Energy saving with sewage heat exchanger

Recovered energy from sewage (kWh)	14,21
Delivered energy to TAP (kWh)	5,24
Energy Savings	**36,88%**

6.2 COOL LowUP

Consumption of chiller and cooling tower at stable conditions, as presented during characterization, during night operation have been extrapolated as function of outdoor temperature and has been confronted with same operation during day for producing the same amount of cooling, which are around 100 kWh (necessary quantity for charging PCM tank considering errors and thermal losses).

Here is presented for 5 typical days of summer period, with calculation of produced energy based of profile of operation achieved during monitoring of day and night.

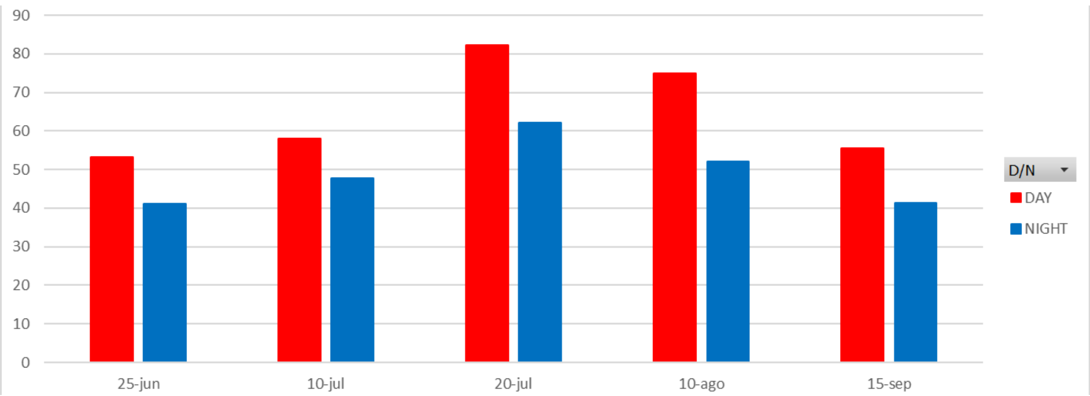


Figure 57. Comparison of electric consumption between day and night for PCM tank charging

Final savings are then calculated with respect to calculated period of monitoring:

Table 15: Reduction of electric consumption between day and night

COOL		
June 25th		
Consumption (kWh)	Day	53,31
Consumption (kWh)	Night	41,13
Energy Savings		23%
July 10th		
Consumption (kWh)	Day	58,14
Consumption (kWh)	Night	47,65
Energy Savings		18%
July 20th		
Consumption (kWh)	Day	82,15
Consumption (kWh)	Night	62,19
Energy Savings		24%
August 10th		
Consumption (kWh)	Day	75,01
Consumption (kWh)	Night	51,99
Energy Savings		31%
Sept 15th		
Consumption (kWh)	Day	55,47
Consumption (kWh)	Night	41,38
Energy Savings		25%
Total Energy Savings		**24%**

It can be seen how day-night operation shift has, own operation condition tested at Seville demo, a reduction of 24% of electric energy.

The use of TAP water heat exchanger, during tested day with high temperature can reduce up to 24% the consumption of energy extracted from the PCM tank, used to cool the beams.

Table 16: Energy saving with heat exchanger during hot day

Consumption without heat exchanger (kWh)	33,17
Consumption with heat exchanger (kWh)	10,69
Energy Savings	28%

During tempered days, the reduction is lower because of reduced number of suitable hours.

7 Conclusions

As an average, unglazed PV/T panels were able to produce higher quantity of thermal energy versus the electrical energy on the same module. Thermal generation is higher during summer months due to the greater solar radiation, but the solar field works with higher thermal and electrical efficiencies during colder months due to the decrease of temperature.

The use of PCM did not lead to a reduction on the fluid temperature, contrary to that exposed in literature. It may be explained because the PCM used in this case has a melting point (48ºC) much higher than other studies (between 20-30ºC), and then the PV/T solar field is not able to work for a long time over this temperature to provoked a reduction in the operating temperature.

However, the addition of PCM provokes significant improvements in the thermal and electrical performance of the solar circuit, with direct influence not only in the energy generated at the end of the day, but also in the instantaneous efficiencies. This improvement increases with the operating temperature of the circuit or the storage tank, since more amount of PCM is activated.

The great volume of the stratification storage tank, as well as the stratification capacity, allows the solar circuit to operate with acceptable efficiencies even in those days with no heat demand. This fact can be very interesting for the energy generation during weekends, where no heat demand is expected under the absence of workers. In case of reaching high temperature, the storage tank capacity is endorsed by the storage capability of the PCM.

The stratification showed great potential for energy savings if combined with more tank connections for withdrawal of energy at different layers, instead of only one on the top as designed originally; this would require a more complex engineering design and more expensive installation because of presence of different actuators, but for multiple consumers at different temperatures would present important benefits.

The analysis of the solar installation during these months shows a great performance of the PV/T panels, able to produce thermal and electrical energy on the same module and operate under acceptable temperatures (up to 50ºC) even in an extreme climate as Seville's weather is.

This capacity to control maximum temperature may be very attractive for Mediterranean areas or countries with very hot climates, where the excess of heat usually punishes the electrical efficiency. The use of the heat recovery kit for those areas may give the possibility to enhance the PV electrical performance while obtaining low-grade thermal energy, eventually used by other systems as those developed in the LowUP.

The use of PCM inside the panels, although very interesting and beneficial from the energy performance point of view, still presents some objections from the economical perspective, since the elevated cost of the PCM packages is not compensated by the energy enhancement. Moreover, the PCM leaks observed in some panels during testing entails a strong concern about its use inside solar panels and suggest that currently, it may be reserved to hermetic places until the enclosure technology is developed.

The radiant floor is working properly in terms of control, response to indoor temperature variation and capacity to maintain comfort conditions (over 21º) even if with supply temperature below than design setpoint. When tank temperature is above the 30°C the system can achieve 60 W/m^2; for Seville demo 35ºC resulted excessive for comfort temperature, while 30ºC allowed development of office activities with pleasant sensations.

The prototype we used in the Seville site satisfy all the technical request in term of efficiency, power achieve and low inertia but the first restraint we found in the market is the price. It's a good technology and product but is too much particular and only for specific application (high efficiency or low temperature running) and where the customer doesn't concern for price. We have to work in order to reduce its cost and make it cheaper for a large-scale market.

The PCM tank is a relatively simple kind of technology that only requires correct working conditions for operating according to nominal specifications; calculation of stored energy is around to 94 kWh of energy stored.

The technology has the great advantage of being compact and has elevated energy capacity, but the price has to be optimized for fully going to market, being competitive with other systems.

Chilled beams performed as expected at different operation points, maintaining comfort conditions of indoor temperature through regulation of air flow and water flow; the produced effect of cooling is comfortable and efficient at same time, without any kind of noise to end user, thank to static pressure concept used for air ducts.

The regulation of flow, as function of measured pressure in air duct, because of reduced air flow and cooling necessities in one of two specific environment (warehouse for most of cases), present different advantages in terms of energy efficiency, mainly when different room (with different loads) are covered at same time with same machine.

The use of chilled water-to-tap water heat exchanger showed proficiency during hottest day, when number of hours of operation of cooling tower is similar and contemporaneous with office time; during template days is reduced and during intermediate season doesn't bring any benefit to the system.

Hybrid unit chiller-AHU, was properly operating in different modes, showing desired flexibility for strategies of operation planned for the project, responding correctly from remote, achieving elevated number of operation hours.

The AHU mode correctly responded to different working points requested by "extreme" weather in Seville, with severe summer temperature during day (when AHU is operating for supplying building during occupancy); regulation of flow as function of number of people, mixing of outdoor and return air from building also presented positive impact over operability of COOL LowUP in dynamic conditions. Regulation of pressure as function of chilled beam setpoint also facilitated the integration with this peculiar developed technology

Nevertheless, hybrid equipment has revealed a COP of operation is quite below to expected performance and nominal working condition in chiller mode, as shown in characterization curve presented in the document. This reduces initially calculated impact of day-night shift for cooling production, increasing general consumption of COOL LowUP, especially during day when unit operates in mixed mode (AHU + chiller) for supplying primary air according to required conditions of chilled beams.

Sewage heat recovery system was tested in real condition but results of operation resulted not sufficient for being relevant during real integration in HEAT LowUP, because of reduced temperature of recovery; main reason of this low temperature is due to inconstant hot sink (dishwashers) whose temperature is affected by time spent inside grease separator before accessing the tank, which determines losses of temperature.

Furthermore, the batch hot sink supply, and the rapid evacuation through the pumping station, doesn't allow exchanging heat in proper way for this kind of system that would require lower flow speed. It is recommended to use the tank for different able to provide more constant sewage water inlet flow, able to provide more constant energy for building applications and integration with solar.

Optimizer showed its potential during office time operation mainly during beginning and ending of the shift, which correspond to central part of the day (from 8 to 18 hrs): when outdoor air temperature allowed use of free-cooling at early hours instead of AHU in mixed mode; when thermal inertia of the building allowed operation with only AHU in mixed mode during late hours (scheduling of occupancy affect switching OFF of equipment).

About heat, manager is responsible for decision about operation of radiant floor for preparing indoor comfort conditions at beginning of the day, and delivery of heat from solar to storage tank for optimizing storage temperature as function of floor supply temperature. Activation of radiant floor in function of is thermal inertia and delivery of heat to solar tank have been main target of optimization.

Global operation of HEAT and COOL LowUP was tested and verified down dynamic operation conditions and presented satisfactory results in term of functionality, time of response, adaptability and coordination of all systems for fulfilling all operation strategies in different moment of same day, according to optimized decision generated by "optimizer" and managed by supervisor along the entire chain of distributed control system.

The surveillance developments for WP2 systems have been centered in their alarm historical data analysis. Some systems have not been studied because they are passive systems, like the stratified tank, and some other have no alarms and low-quality data for surveillance purposes, like the sewage recovery system.

In this way, for the studied systems, a behavioral and frequency analysis of the alarms have been done to provide novel approaches on how to tackle the situations lived during the project, so for each system some conclusions have been presented in order to deliver valuable information to the manufacturers and plant operators.

Finally, calculation of increment of production and energy saving showed positive impact over for both LowUP solutions.