Low valued energy sources UPgrading for buildings and industry uses

LowUP Commissioning and Startup Relevant environment 1

Deliverable D4.12

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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 at 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 48 months, 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 three systems will be demonstrated at four demo sites: a pilot office building in Seville (Spain, ACCIONA Construction); a 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

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Executive Summary

This report (D4.12 “LowUP Commissioning and Startup 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 at Seville demo site according to Spanish rules and manufacturer recommendations.

The start-up of the systems is described at the component level, at the system level and finally at the concept level, reporting how equipments were integrated in order to achieve expected performances of operation.

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

The procedures stated in this Commissioning and Start up manual cover all activities included for preliminary tests and inspections, functional performance tests and the start-up of new technologies developed in the frame of the project and re-commissioning of existing ones after integration with new ones.

All the works explained here have been carried out according to the indications of the manufacturers of each equipment, following the instructions of the engineering sector, and following the commissioning procedures of the national regulations.

Each equipment or component has been commissioned and started-up individually, both manually and through the control and monitoring systems. Then the components and equipment have been integrated with others ones.

The objectives of the Testing and Commissioning works are:

a) To verify proper installation of the equipment/system just before operation;
b) To verify how installed equipment/systems meet with specifications of design and fulfilment of operation through a series of tests and adjustments;
c) To set up all system for future activities, in order to facilitate characterization of performance at nominal working condition and during normal operation.

2 Seville Demo Site

Seville demo site includes the biggest part of technologies developed in the project, due to the presence of a real office building, integrated with Acciona thermal lab, which is used for validation activities of Heat and Cool LowUP systems.

Both systems are connected to the same building which is daily used for engineering activities from 8 am to 18 pm. The building is rounded by industrial warehouses and is thermally fed only by LowUP; the ground around the building has been used for placement of Heat and Cool technologies, while thermal lab has been used as core for the development of automation systems.

2.1 Cool LowUP System

COOL LowUP system is composed by different sub-systems: AHU, chiller, chilled beams, cooling tower and PCM tank. Some minor components are installed and it´s described in Auxiliary section. Here below is presented P&ID of the system, with identification of every sub-system as supply limit for each manufacturer.

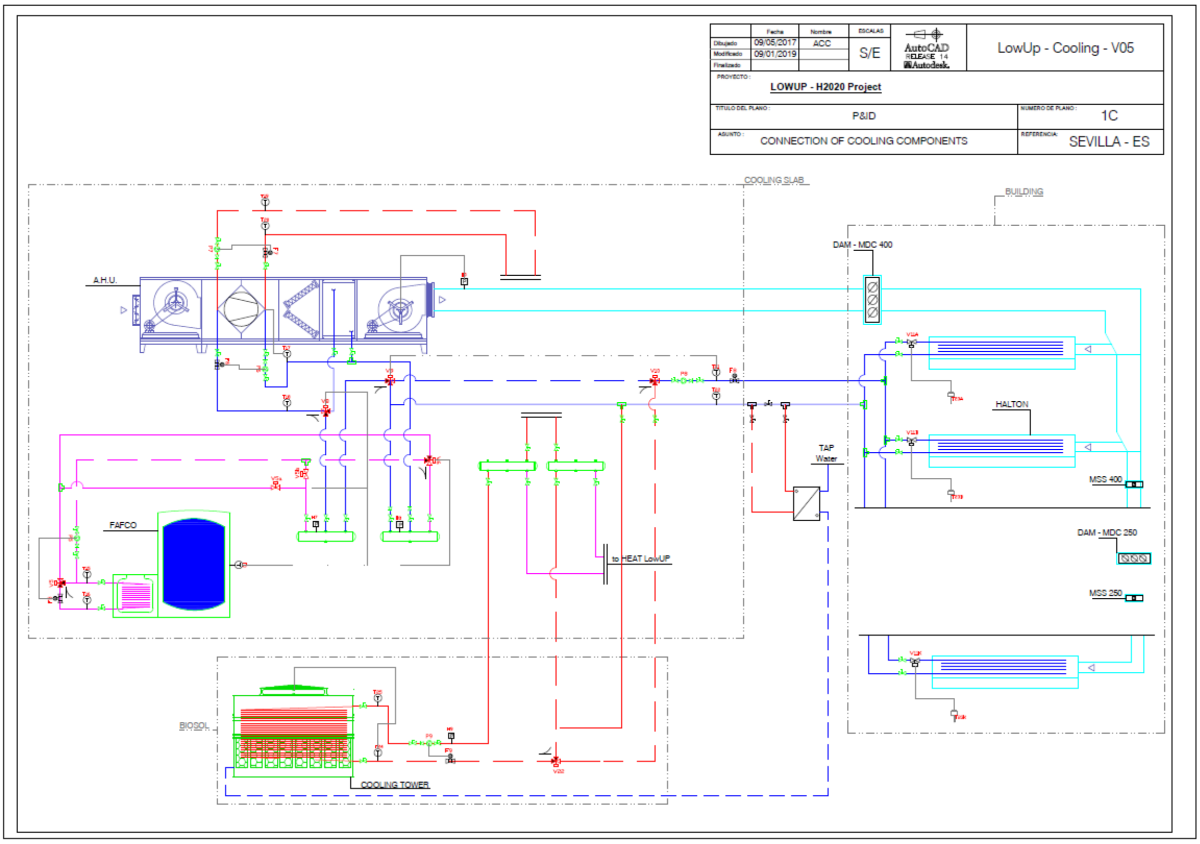

Figure 1. P&ID of the COOL LowUP components

Next sub-sections will be dedicated to COMMISSIONING of each subsystem first and finally to the system as a whole.

2.1.1 Commissioning at component level

Due to different similitudes in operation for all cooling sub-systems, generic mechanical and electrical verification are resumed in this first part as common to all system described in this chapter.

Mechanical verifications:

Before starting with any kind of operation, some checks require to be completed in order to avoid undesired problems for mismatching between design and installation; even more some precautions must be implemented to prevent damages of complex and expensive components.

First thing to check in this system is the unit support on the floor. Unit support is made by rubber to smooth vibrations of fan and compressor, mainly for rooftop installation and has to be checked that each support could hold the weight of the unit. In order to correct performance, according to manufacturer requirements, horizontal position was required as well as minimum spaces around the frame for maintenance. It was necessary check that all the panels are positioned and correctly fastened for assuring water resistance and air tightness.

Figure 2. A type of unit support on the floor

Then, next verifications were related with dampers, checking if actuator motors were installed in accordance with the supplier´s instructions. It was manually checked that damper could close properly and open at all possible positions. Last verification about dampers was powering of units to verify correct operation and end-of-run positions.

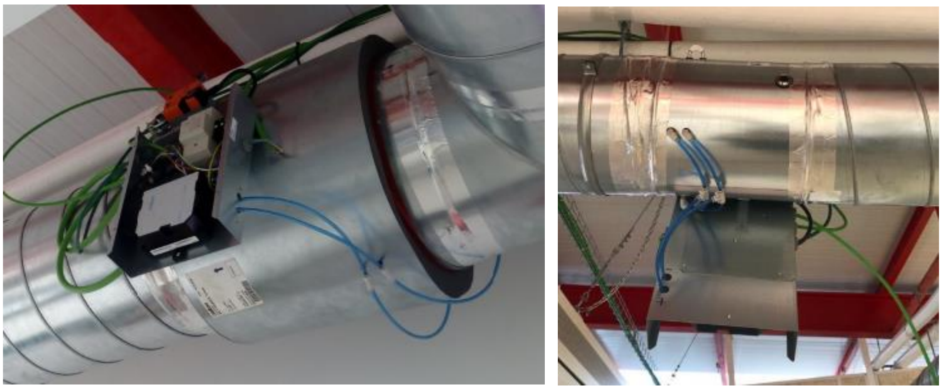

Figure 3. Dampers inside the office

Once AHU and chiller was placed, all brackets had to be removed. Then it was checked if fan could move freely without obstructions with frame, with flexible connection or with wiring.

Figure 4. Plug fan and cooling coil

Next verifications were related with air filters, checking filtering capacity, quality and correct placement. Pressure sensor were checked and calibrated with manufacturer conditions.

Figure 5. Filters inside the AHU

Due to its nature of combined equipment, it´s required a constant water drain for air treatment at cooling coil, de-humidifier and other wet areas of the AHU, due for example to Freon piping. It was checked that siphon had proper location and connection with outside of the frame.

All water connections were checked in accordance with the dimensional drawings. It was verified the proper connection of flanged joints, for leakages, and correct direction of circulation for valves, filters and pumps, checking joints and connections tight, matching connections with piping diagrams. Air purges were checked to be in the top of water loops, drain and fillings in the lowest, while cladding has been verified at all strategic points of the pipes.

Figure 6. Different water connections

Then, air ducts were verified checking correct size and installation with vibrating elements, to avoid pressure and performance loosing and that connection would be enough flexible to avoid vibration transmission from AHU/Chiller, and so possible damages for cracking.

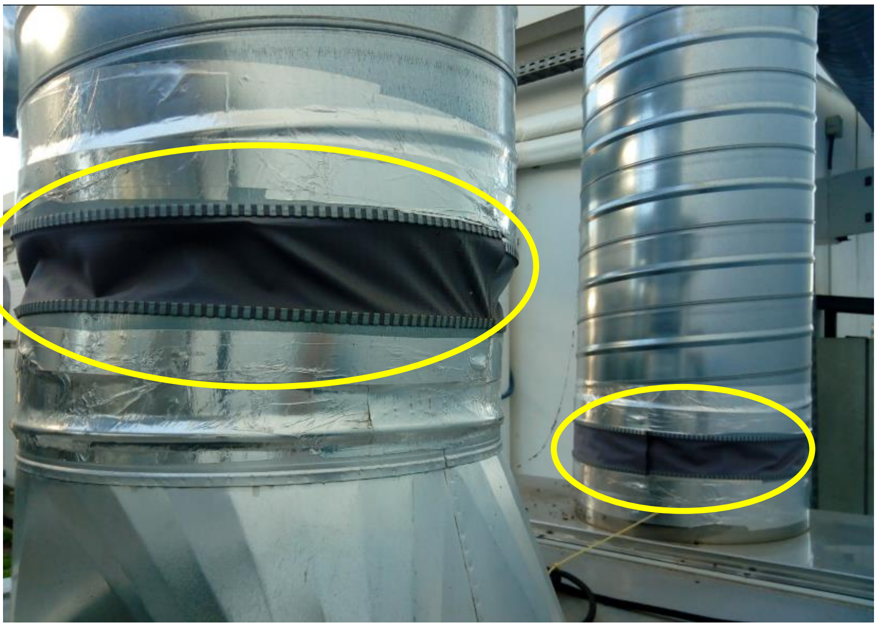

Figure 7. Anti-vibration system in air duct

It´s verified that there were no metal contacts of different nature that may cause oxidation by galvanic couple. It´s verified that the thermal insulation is correctly installed in pipes and fittings as well as conveniently protected from rain and radiation solar in the sections that circulate outdoors.

It was verified that the layout of the pipes corresponds to the drawings of the Project or Technical Report and that it is adequate. The material of the installed pipes corresponded to the project, as well as their thickness.

Verification was made that the installed insulation has the thermal conductivity and thickness specified in the technical documentation. Using a fluid with antifreeze due to the risk of frost, it was verified that the antifreeze fluid used meets the requirements specified in the Technical Documentation.

Figure 8. Different parts of the installation, PPR pipes and the isolation

Next step to check in start-up of this system is piping connections, joints, valves are opened, etc. Visually piping´s verifications made, it had to do loop tests with low and high pressure, firstly it was filled the circuit at low pressure to check drains, and after, it increased at high pressure to check tightness of the system.

In this case of closed circuit, pressure test has to get 2 times of the work pressure with minimum 4 bar. All parts of the system involved in this pressure test had to be without insulation to check possible drains.

Other thing to check with filled circuit was mechanical fixing to ensure could hold the pipes with fully water circuit. This pressure test is recommended during 60 minutes in with 2 times of work pressure, checking every 10 minutes if pressure get low, and once 60 minutes were completed, 90 minutes more at 0,5 time of work pressure, and during this time if water circuit doesn´t show a pressure drop, it means that circuit hasn´t drains.

Expansion and security systems were checked prior to commissioning. The existence of a pressure gauge with a suitable range and precision was verified for measuring the gauge pressures of the circuit. Likewise, it was verified that the filling system allows reaching the minimum pressure required at the filling point.

It was verified that the volume of the expansion vessel was correct, as well as the nominal and maximum pressures of the expansion vessel and the set pressure of the safety valve. It was verified that the filling pressure of the expansion vessel (nitrogen pressure in the vessel) was adequate and otherwise it will be adjusted to the value indicated in the Project or Technical Report. The initial pressure of the vessel must be 0.2-0.3 bar lower than the filling pressure of the circuit.

Figure 9. Expansion vessel

The set pressure of the different installed safety valves was verified, triggering them manually, in addition to checking their operation and the correct operation of the drain (the water outlet must be visible).

Figure 10. Safety valves

Once all the elements of the hydraulic circuit were properly verified, the hydraulic circuit was filled to the minimum or filling pressure. It was found that the air purging is effective and that the filling is therefore carried out without difficulty. Installed traps were found to function properly and were properly located to facilitate air bleeding.

It was verified that the circuit maintains the initial or filling pressure and that there were no fluid leaks. The pressure was subsequently measured with the hot circuit to verify that the pressure increase produced by the change in the density of the water corresponded to the values estimated in the project.

It was verified that the layout of the duct network corresponded to the plans of the Project or Technical Memory and that it was adequate.

It was verified that the conduct support anchorages were adequately fixed to the enclosures of the facility and that they maintain the correct separation distance to avoid deformation of the conduct.

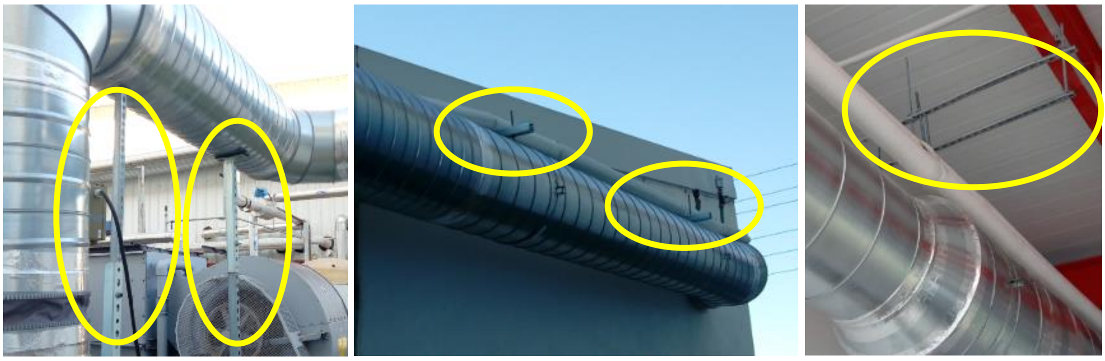

Figure 11. Anchoring of the air duct

During the Commissioning, it was verified that the execution of the network was adequate. Once the ventilation unit was started, it was verified that there are no air leaks at the connections of the ducts to the beams. It was verified that the ductwork is in good condition and that no breaks had occurred after the structural strength and water tightness tests had been carried out.

It was verified that the insulation is properly installed on the ducts and that all the connection elements are properly insulated. Special attention was paid to the insulation of the sections of conduits that are outside, in this case, being a metal conduit there were no problems.

Figure 12. Isolating of different element in the installation

Other side of the chilled beams is primary air supply, and duct test had to do. Two tests to do, structural strength test and leak test. The fan, directly coupled to the motor, will be able to provide a flow between 2 to 3% of the ductwork flow, with an equal static pressure, at least one and a half times the maximum network working pressure or pressure maximum network work plus 500 Pa (the greater of the two).

<u>Electrical verifications:</u>

Before any powering could occur, it was verified correct electric installation with respect to design diagram for power supply and connection with probes, valves, controllers, etc... Special attention was paid to polarity of DC elements and phase connections for AC components in order to avoid wrong signalling or equivocated rotations. Safety protection for intensity and short-circuit have been checked in the main cabinets while all frames and components have been verified in grounding.

It was separately measured the current of the electric motor for each phase. The current intensity of all phases had to be approximately the same and agree with the data on identification plate, checking the motor protection device correspond to nominal value.

Once every component was checked and verified, unit power supply can be turned on; at this point is recommended not to activate anything for next 24 hours, allowing all components to execute their own internal checks and completing preheating of some internal components. In case of wrong installation, problems should rise without affecting dramatically the integrity of the system or of the device.

Sensing and automation verifications:

First verification is based on correspondence between manufacturer connection schemes and real installed connections for sensors and actuators, checking lines from device to terminal block. Once all connections have been checked, the control system can be powered on.

Next step was validation of operation for each sensor (flow, pressure, temperature, electric consumption, etc…), calibrating the range of analogic/digital signal with according to range set at factory by manufacturers. This translation of voltage/current input into operation value according to sensor specification and is done at plc level.

The controlling of the speed of the AHU fan(s) needed to be set properly up so, through local VSD driver, the plc regulated the limits of fan speed limits, according to manufacturer setpoint parameters. Then the variation of speed of the device is tested through the plc, controlling from remote the execution of different checkpoints; at the same time, electrical consumption of the unit was measured in order to verify the correct operation of actuator and verify development made my supplier.

Internal safety/security systems were also checked, like: automatic stop of pumps in case of pressure drop, in case of reduced flow, in case of excess of temperature, etc… validation was achieved for air, water and refrigerant loops.

2.1.1.1 AHU/CHILLER

Specific start-up:

The commissioning and start-up process for this system began with the installation of the unit, which was located near to the cooling tower. This process carried out to the installation consisted of placing the equipment, making connections of the air and water circuits and isolation of the pipes.

The following pictures show the joints of the air ducts and pipes and the isolation of the pipes.

Figure 13. Joints in air and water circuit

Pre-start verifications:

Once all the connections were made, the circuits of each part of the equipment were checked. Chiller evaporation and condensation circuit and supply and return of the air circuit.

The following image shows the supply and return ducts of the air circuit:

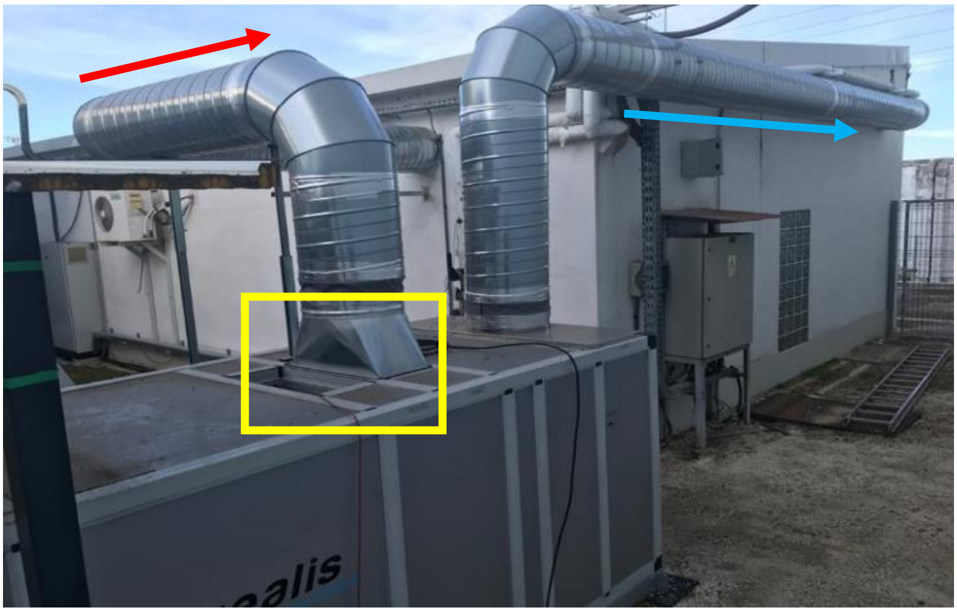

Figure 14. Air supply duct (blue arrow), Return air duct (red arrow), mixing damper (yellow square)

Chiller side present the next circuit. Following figure shows evaporation and condensation circuits pipes.

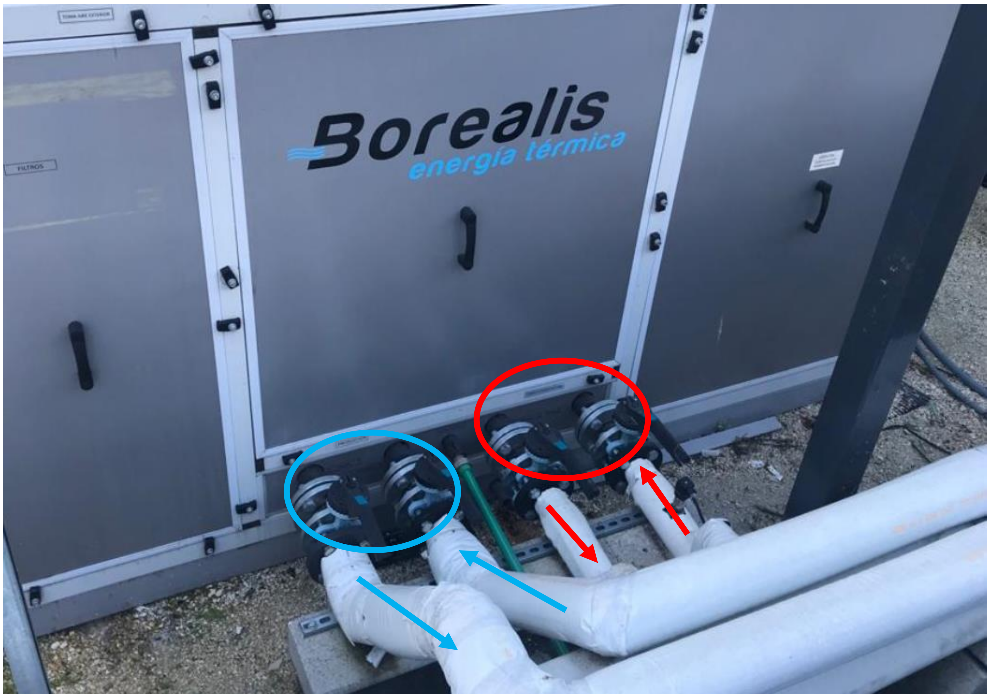

Figure 15. Condensation circuit to cooling tower (red) and evaporation circuit to cold manifold (blue)

Same activity was carried out for all individual devices of the equipment, including valves, dampers, pumps and compressor. Once every sensor and every part were correctly checked, nest step is the validation on the system during simple operation modes, including setpoint of pressure/airflow for AHU and temperature/waterflow for chiller.

2.1.1.2 PCM TANK

Specific start-up:

The commissioning and start-up process for this system began with the installation of the tank, which was located near the chiller. An important and delicate step in the process was to fill the tank completely with the appropriate paraffin for the designed temperature of operation. The following figure shows this step:

Figure 16. PCM tank filling

Pre-start verifications:

Once the tank was completely filled, the next step was to check all the valves and their actuators for the proper functioning of the system. This system has three clearly differentiated modes of operation, stop, charge and discharge; therefore, the valves and the pump have a position in each mode. Mode can be set manually by the user in the control cabinet installed on board of the tank or from remote by the plc; test has been executed in both ways to validate remote communication.

In charge operation mode, the valves have following position and direct the flow (cold water) inside the tank according to the design scheme:

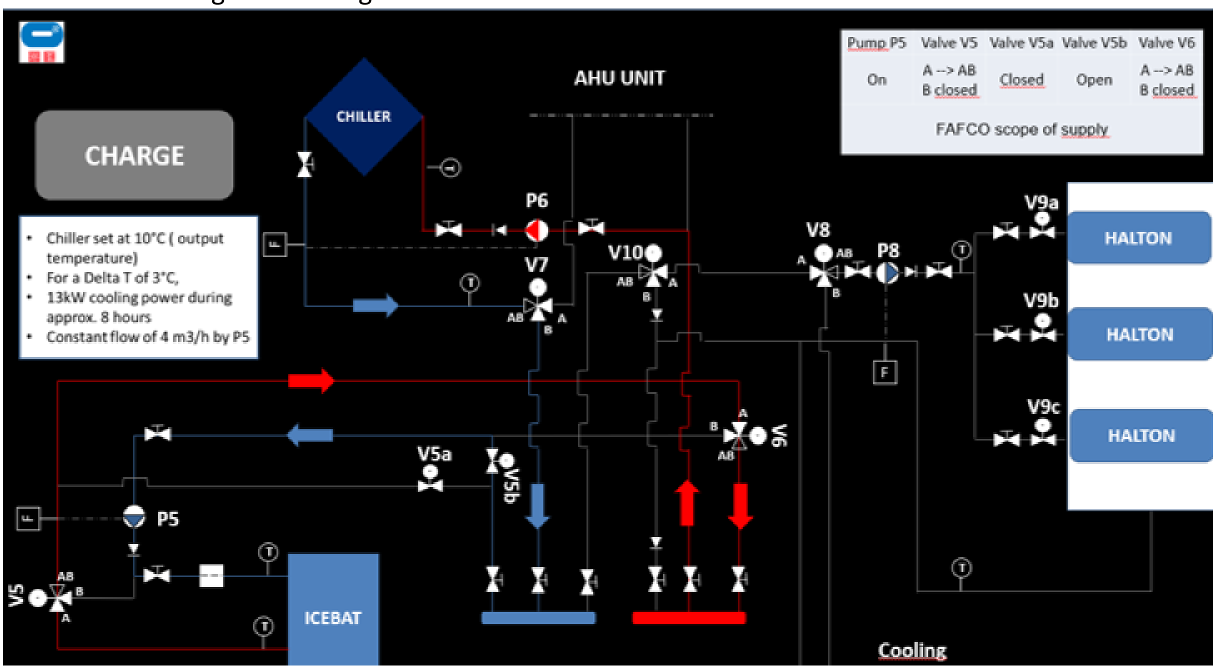

Figure 17. Tank charge mode

- ✓ PUMP P5: ON
- ✓ V5: A → AB; B CLOSED
- ✓ V5a: CLOSED
- ✓ V5b: OPENED
- ✓ V6: A →AB; B CLOSED

Therefore, first test was to put the system in charge mode and checking the valves reached their correct position. The following pictures show the position of the valves during tests:

Figure 18. Position of valves in charge mode

Next test was to put the system in Discharge mode and checking the valves reached their correct position. The following pictures show the position of the valves during tests:

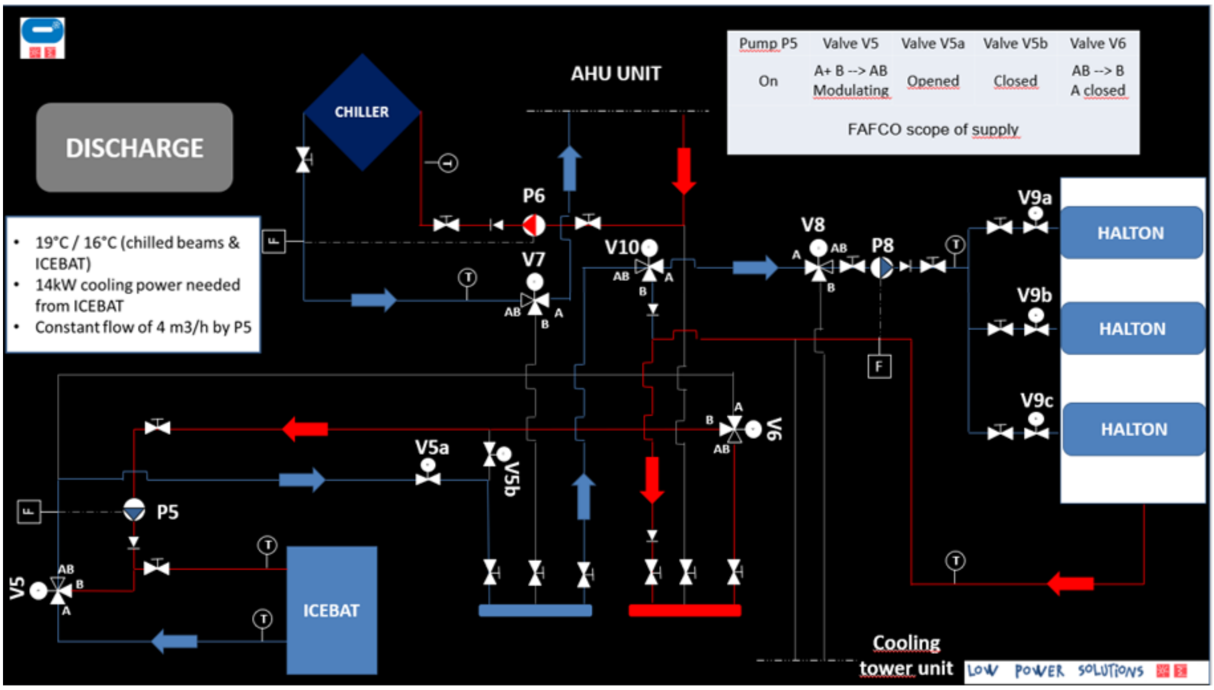

Figure 19. Tank discharge mode

- ✓ PUMP P5: ON
- ✓ V5: A+B → AB; MODULATING
- ✓ V5a: OPENED

- ✓ V5b: CLOSED
- ✓ V6: AB →B; A CLOSED

At this point it was verified that valves reached their correct position, as shown in following images:

Figure 20. Position of valves in discharge mode

Once the system had been checked in different operation modes, the pressure sensor, which gives us a reference to the charge level of the tank, was calibrated according to the real level of melting of PCM that can be checked through a level pipe connected with the interior of the tank itself. This process consists of the following steps:

1. Start with discharge mode, in order to be sure that cool storage level is at 0%. So, it must start with inlet water at +19°C; if cool is stored in the tank, outlet will be lower than starting temperature. When the output water temperature start rising over +16°C, it means the tank is fully discharged and no residual cool is stored. At this step, the sensor level must be manually set at 0%, by pressing the zero offset during 5 sec (the button is inside the level sensor). Therefore 0% will be consequently set at the control cabinet.
2. Then, start a charge with an inlet temperature of +10°C; at the beginning the outlet temperature will be quite high but will reduce accordingly with the charging of the tank. When the output temperature reduces until the +11°C, the charging process can be stopped because of saturation of the PCM; the level sensor can be set at 100%, by pressing at the same time the span+ and span- button during 5 sec inside the level sensor.

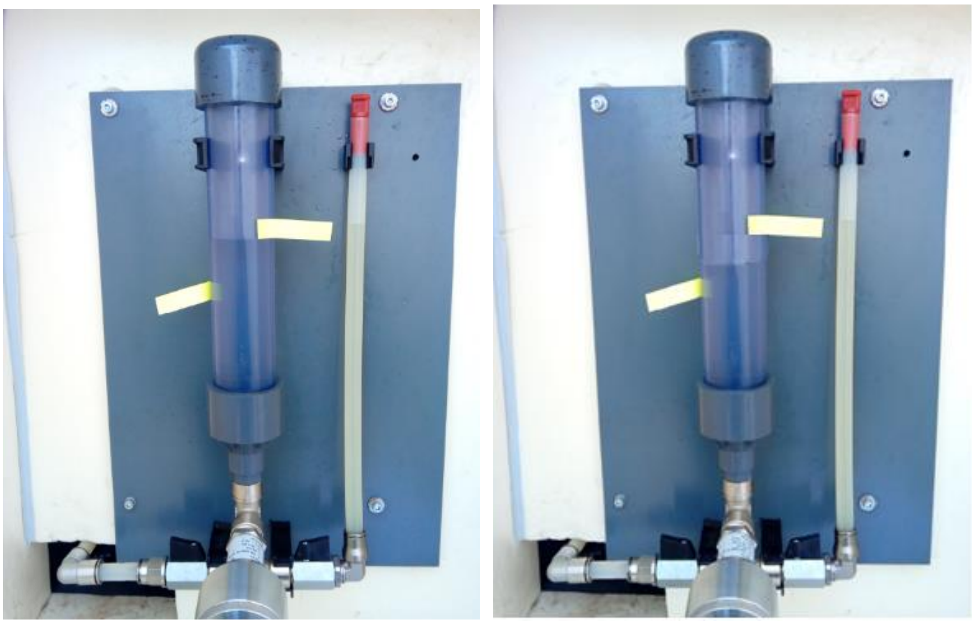

Figure 21. Different level of the PCM. Charged (low level of the PCM), Discharged (High level of the PCM)

Finally, several warning points and stops were established to avoid system malfunction; for instance the minimum flow level for which the system goes into warning mode.

2.1.1.3 CHILLED BEAMS

Specific start-up:

It was verified that the layout of the pipes corresponds to the plans of the Project or Technical Report and that it is adequate. The material of the installed pipes corresponded to the project, as well as their thickness. Verification was made that the installed insulation has the thermal conductivity and thickness specified in the technical documentation.

Next step to check in start-up of this system is piping connections, joints, valves are opened, etc. Visually piping´s verifications made, it had to do circuit tests with low and high pressure, firstly it was filled the circuit at low pressure to check drains, and after, it increased at high pressure to check tightness of the system.

In this case of closed circuit, pressure test has to get 2 times of the work pressure with minimum 4 bar. All parts of the system involved in this pressure test had to be without insulation to check possible drains. Other thing to check with filled circuit was mechanical fixing to ensure could hold the pipes with fully water circuit.

This pressure test is recommended during 60 minutes in with 2 times of work pressure, checking every 10 minutes if pressure get low, and once 60 minutes were completed, 90 minutes more at 0,5 time of work pressure, and during this time if water circuit doesn´t show a pressure drop, it means that circuit hasn´t drains.

It was verified that the layout of the duct network corresponded to the plans of the Project or Technical Memory and that it was adequate. It was verified that the conduit support brackets were adequately fixed to the enclosures of the facility and that they maintain the correct separation distance to avoid deformation of the conduits.

During the Commissioning, it was verified that the execution of the network was adequate. Once the ventilation unit was started, it was verified that there are no air leaks at the connections of the ducts to the beams. It was verified that the ductwork is in good condition and that no breaks had occurred after the structural strength and water tightness tests had been carried out.

Pre-start verifications:
In this part, the verifications carried out consisted of checking the water circulation through the chilled beams. After these verifications, it was verified that the 2-way valves of the chilled beams were working correctly.

The following image shows the hydraulic circuit of a chilled beam:

Figure 22. Some pipes of the hydraulic circuit

The checks in the air part were that there were no air leaks in the ductwork or in the joints with the chilled beams. Later it was verified that the gates of the duct network moved to regulate the pressure and the flow. The image below shows the air duct network.

Figure 23. Air duct with direction of the air

2.1.1.4 COOLING TOWER

Specific start-up:
Before cooling tower start-up, it needed a cleaning and a visual inspection due to that unit it was installed before LowUP project.

Therefore, first main step was cleaning the unit, cleaning and inspect the fan deck, removing dirt and dust from the fan guards and cleaning all spray nozzles. It cleaned and it inspected the mechanical components, such as the fan and motor. Piping connections and joints were checked ensuring the absence of leaks.

After extended shutdown like this, insulation of the engine was tested with an insulation tester before motor start up. Before starting, it was lubricated the screw adjusting engine base and the bearings of the fan shaft.

Pre-start verifications:
About hydraulic system, quality of the water was checked to ensure pH level is between 7.0-7.6; pH level was corrected and it fixed. At the same time, water circuit was filled up to full of charge. Then, water pump was made running during one day for air purging and stabilizing the water loop after long refill and shutdown.
Flow balancing valves and water pump speed were adjusted to equalize the flow with the chilled beams water loop and chiller condensation water loop. Adjustments have been carried out manually first and from remote, via plc, then.

About fan verification, it was verified that starter turned on/off the fan correctly and speed variation was made in manual mode. It was checked fan rotated in the direction shown on the fan cowl by the arrow. Vibrations on the fan were checked running several minutes.

Operation of the sprinklers was checked with and without operation of the fans, with water directly coming from local network. Fictitious setpoint water temperature have been tested in order to see the reaction of the system and validate modulation down different possible working conditions.

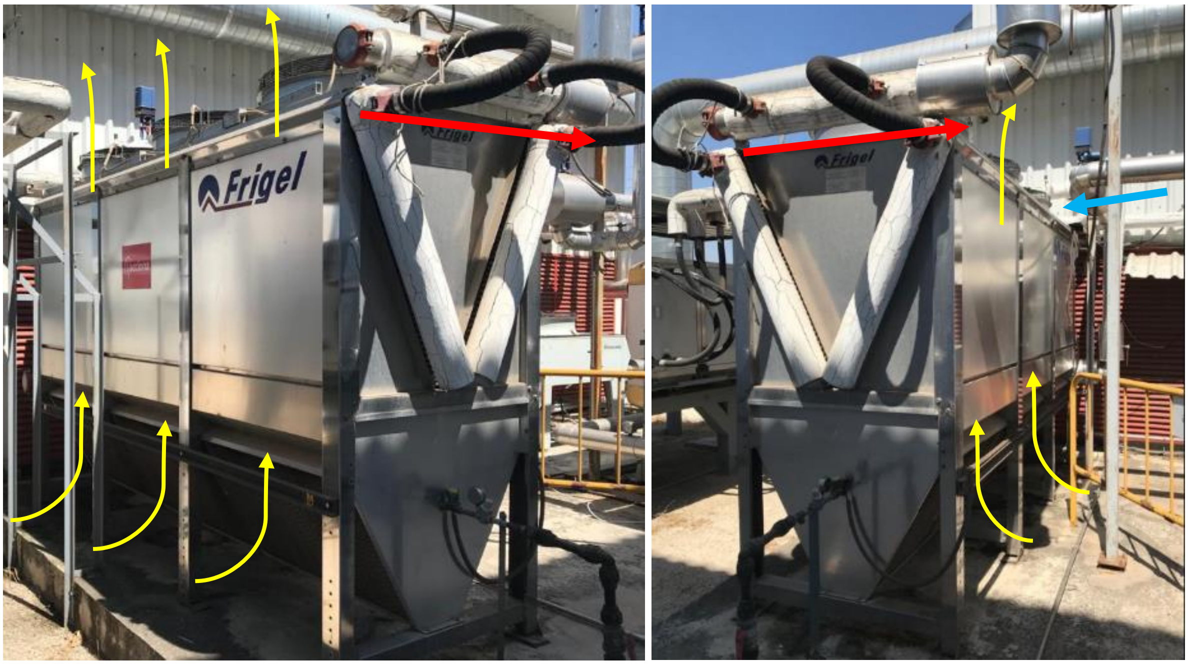

Figure 24. Inlet water manifold (blue), Outlet water manifold (red), direction of air flow (yellow)

2.1.1.5 AUXILIARIES

2.1.1.5.1 TREE-WAY VALVES

<u>Specific start-up:</u>

Main issue is the proper installation of the mixing port with respect to piping; mixing port AB can be used as outlet for mixing fluxes (at different temperatures and flows) or inlet for separating fluxes (at different flows). Depending of the type of operation and system, both type of installation have been implemented.

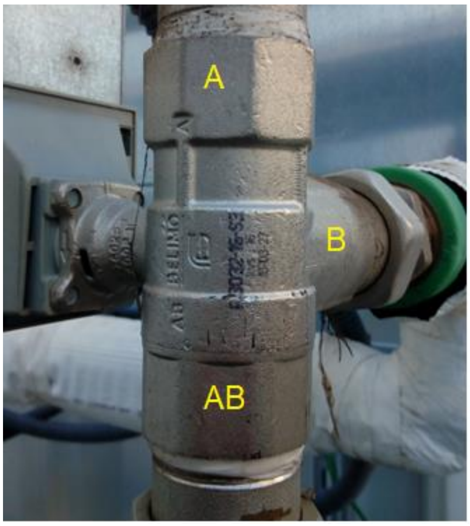

Figure 25. Mixing port in 3-ways valve

Second issue is the correct installation of the electric actuator over the valve body, which affect the proper mixing/separating of A and B ports; main attention must be paid in matching the position of the actuator with respect to the signal proceeding by plc.

Figure 26. 3-ways valve with its actuator

Last step it was the electrical and control connection, that it was necessary connecting two electrical wiring (0-24 V) and two control wiring (0-10 V) with shielded cable. Manual regulation and position blocking have also been verified in case of plc crash.

Pre-start verifications:

To prove manual mode, the actuator was switched to manual mode and the crank turned to no-mixing position; it was checked that water was flowing directly for the pipes checking pressure and temperature sensor.

To make sure automatic mode worked, it was connected control and electrical wiring and was checked that had electrical tension in the actuator with voltage tester. Then, valve mixing position was changed by analogic signal from plc (0-10 V); it was checked that if actuator had 0V, mixing position was fully opened and when the actuator had 10V, valve was fully closed.

2.1.1.5.2 WATER PUMPS

Specific start-up:

The pumps must be assembled in one of the positions supported by the manufacturer. If pumps are installed at the floor, they must be installed with a minimum separation from the floor. Before installing pumps, it had to install some components like anti-vibration elements, filters, isolating valves, non-return valve, etc.

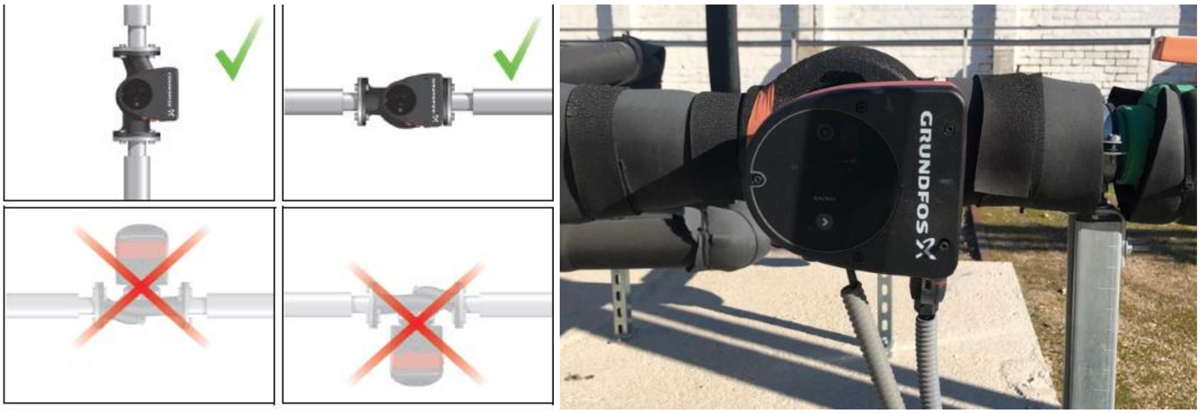

Figure 27. Recommended position by manufacturer and final position of water pump

When pumps are installed first step was made it was control and electrical connection. It was checked that it had 230 V for electrical and 10V signal for controlling speed pump or Start/Stop.

Pre-start verifications:

Starting pumps requires some steps: first filling hydraulic circuit, then, close the isolating valve on the outlet side of the pump. Next step, open the isolating valve in the inlet pipe completely before starting the pump. Fill the pump housing and the inlet pipe completely with liquid until a steady stream of liquid runs out of the filling hole.

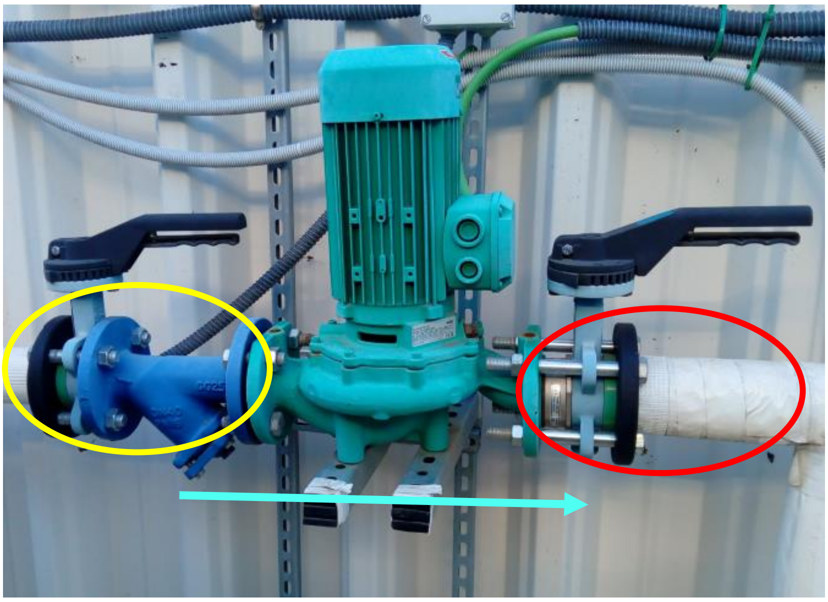

Figure 28. Isolating valves in water pumps

Start the pump and slowly open the outlet isolating valve while the pump is running. This ensures venting and pressure buildup during startup. Pumps were working for ¾ days before operating to lost air inside the circuit.

All the tests and control verifications carried out in this element of the installation were related to its start/stop and speed regulation in some cases.

2.1.1.5.3 TEMPERATURE SENSORS

Specific start-up:

Temperature sensor was installed with shielded cable to avoid signal problems for electromagnetic interference.

That sensors were installed sheathed inside pipes or water tanks, helped by thermal paste inside to facilitate heat transfer and more accurate reading.

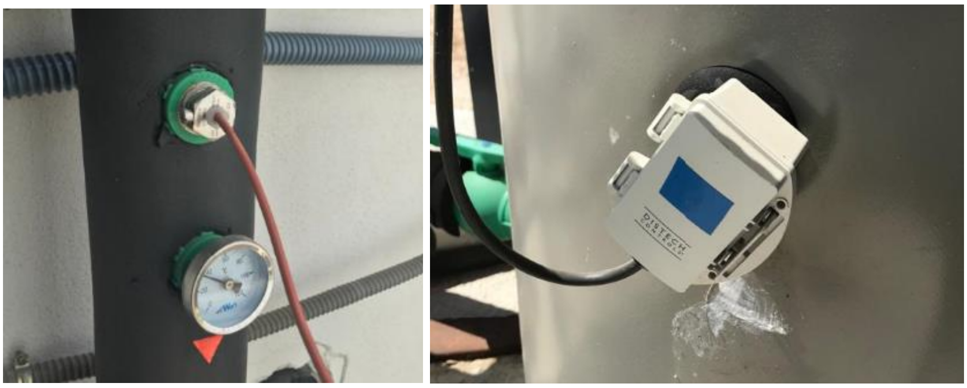

Figure 29. Different type of temperature sensor

Pre-start verifications:

Sensor is directly connected to the PLC as analogic input. Firstly, they were tested connecting and disconnecting one of the terminals of the sensor and then, they were heating with an external component to check if temperature reading changed.

Calibration was made according to technical data provided by manufacturer and helped by mechanical temperature sensor distributed in the installation. Output types is 0-10 Vdc for this kind of sensor and the ambient range is -10ºC to 90ºC.

2.1.1.5.4 PRESSURE SENSORS

Specific start-up:

Static pressure sensor was installed with shielded cable to avoid signal problems for electromagnetic interference.

Pre-start verifications:

Verifications was made in two steps: first, disconnecting and connecting sensor from the PLC to check pressure sensor was working; other step, calibrating pressure sensor with mechanical pressure sensor distributed in the installation.

Specification of this kind of sensor is like, output: 0-10 Vdc, supply voltage: 24 Vac and pressure range: 0 to 10 bar.

Figure 30. Pressure sensor

2.1.1.5.5 WATER ENERGY METER

Mechanical verifications:

This kind of meter is a flanged connection type; it is composed by flowmeter and 2 temperature sensors which calculate the energy flowing between 2 different points of the piping.

Once installed, the first thing was checking if joints and connections were correctly installed, which means on a straight pipe, with minimum distance from curves, sensors and actuators which could affect the linearity of the flow. On other hand, temperature sensors had to be checked as previously described above.

This kind of sensor is active (instead of passive like temperature or pressure) so requires power supply for operating; communication is via bus and specific protocol.

Pre-start verifications:

First of all, system must be powered on, to have first start of electronic devices. Then it was necessary to connect network wiring and configure the flow meter in the plc.

Figure 31. Connection of flow meter (electrical and network)

Once flow meter self-configured, it had to connect flow meter to the MBus network, and this task was made removing the screen and connecting MBus wiring in data-Card inside flow meter. Then, it checked the slave number from the flow meter to connect MBus network through the screen, and it was added to the system.

When SCADA was configured, all variables were created in SCADA to read, and then it was able to check same values in SCADA like in flow meter screen.

Different reading were tested running the pump at different speed and checking if values of temperature and flow change accordingly; temperature measurement was compared with readings of other sensors present on the same loop.

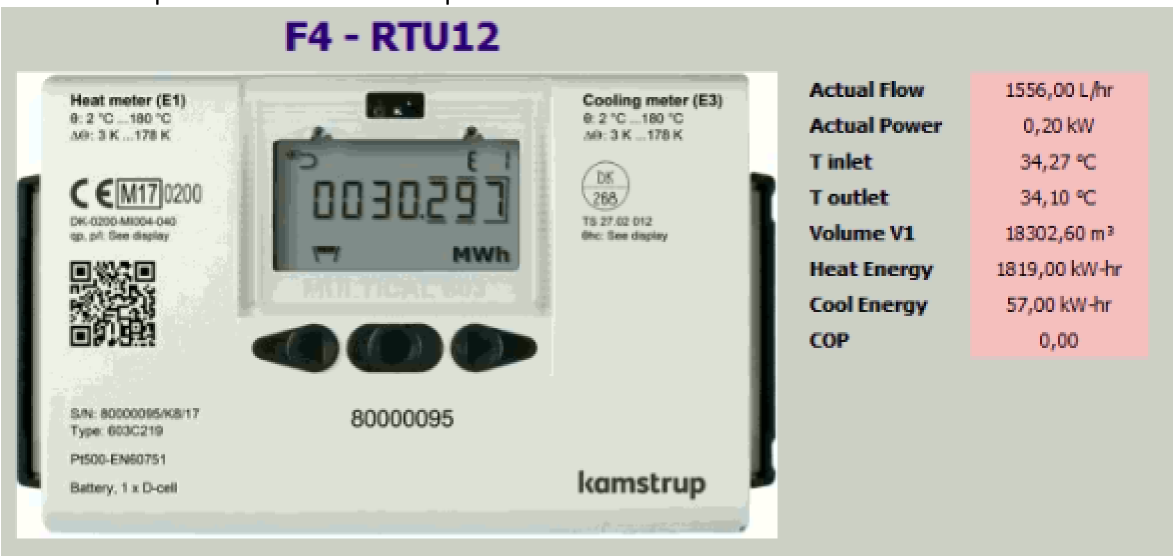

Figure 32. Reading of flow meter in SCADA LowUP

2.1.2 Commissioning at system level

This section will explain the integration of each system with LowUP control and monitoring system in order to achieve operation according designed strategies and expected performance. For each different operation (chiller, AHU, mixed, free cooling, etc…) the process is based on: switching On, defining setpoints, starting operation, achievement of the setpoint through operation, supplying of increasing loads and operation at full capacity.

2.1.2.1 AHU/CHILLER

The system-level commissioning of this equipment was done first through the unit's own control system and later through SCADA.

The first steps were made through the screen built into the unit. The following image shows the icons and buttons of the built-in display.

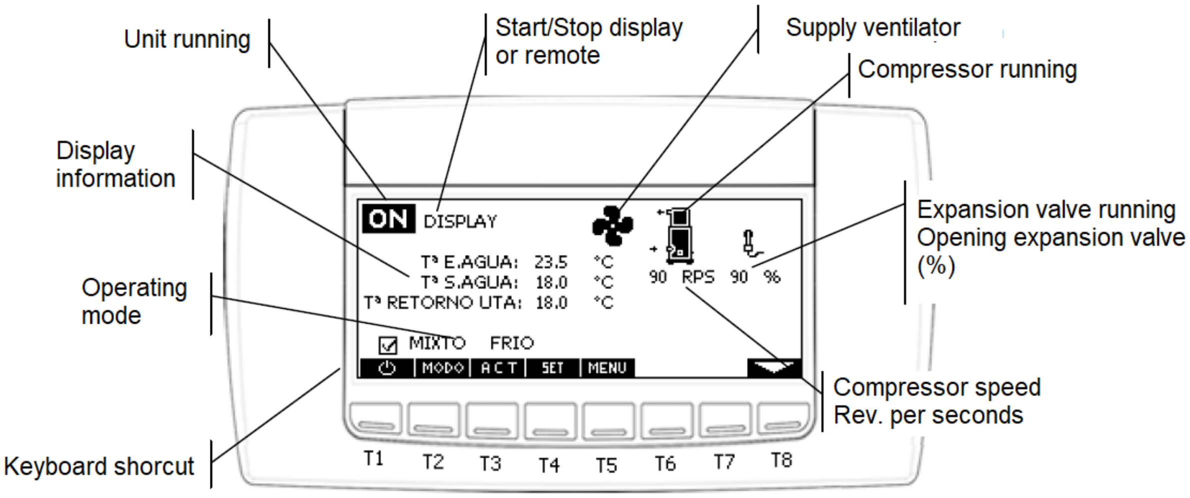

Figure 33. Chiller display explanation

The following figures show the main display:

Figure 34. Different screen in Chiller display

Through machine on board display, the first start-up of the system was made, starting the unit in different modes, changing setpoint temperatures, and other parameters of operation.

In the following screen, the set points for the water temperature of the chiller unit in heating mode and in cooling mode are set, as well as their differentials.

Figure 35. Chiller setpoints

Next screen sets the air supply temperature setpoint for the AHU in heating mode and in cooling mode, as well as their differentials.

Figure 36. AHU setpoints

Next screen allow setting air quality setpoints, its differential and the neutral opening / closing zone of the AHU's free-cooling damper.

Figure 37. AHU setpoints

In following figure, it can configure:
- Supply pressure that the AHU fan has to keep.
- Supply pressure differential.

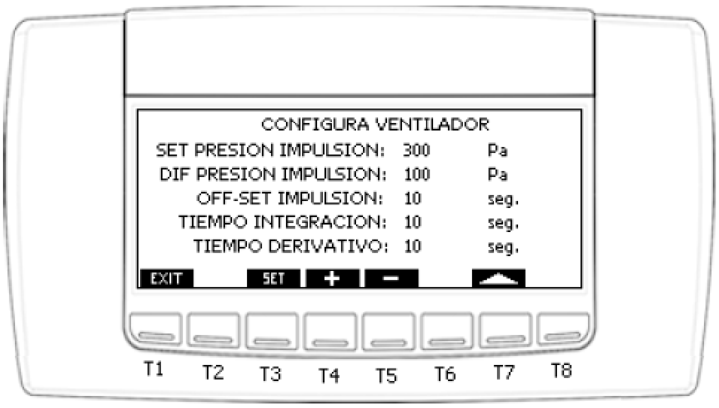

Figure 38. Ventilator setpoints

In following figure, it can configure:
- Desired thermal Delta T in the production circuit and its differential.
- Desired thermal Delta T in the tower circuit and its differential.

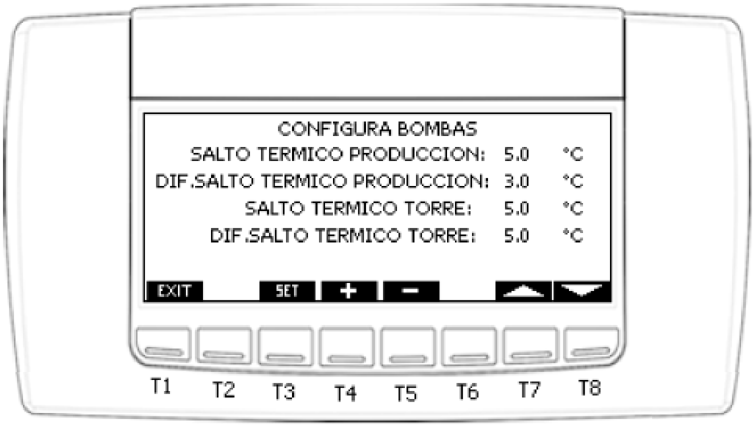

Figure 39. Pumps setpoints

Once operation with local controller has been verified at all described bullets, same sequence of operation is repeated from "remote" with LowUP controller, checking if reading and writing parameters match with local controller and if writing signals are properly executed by the equipment.

Through SCADA, they tried to configure the working variables of the system. The following figure shows the variables that can be changed in the unit.

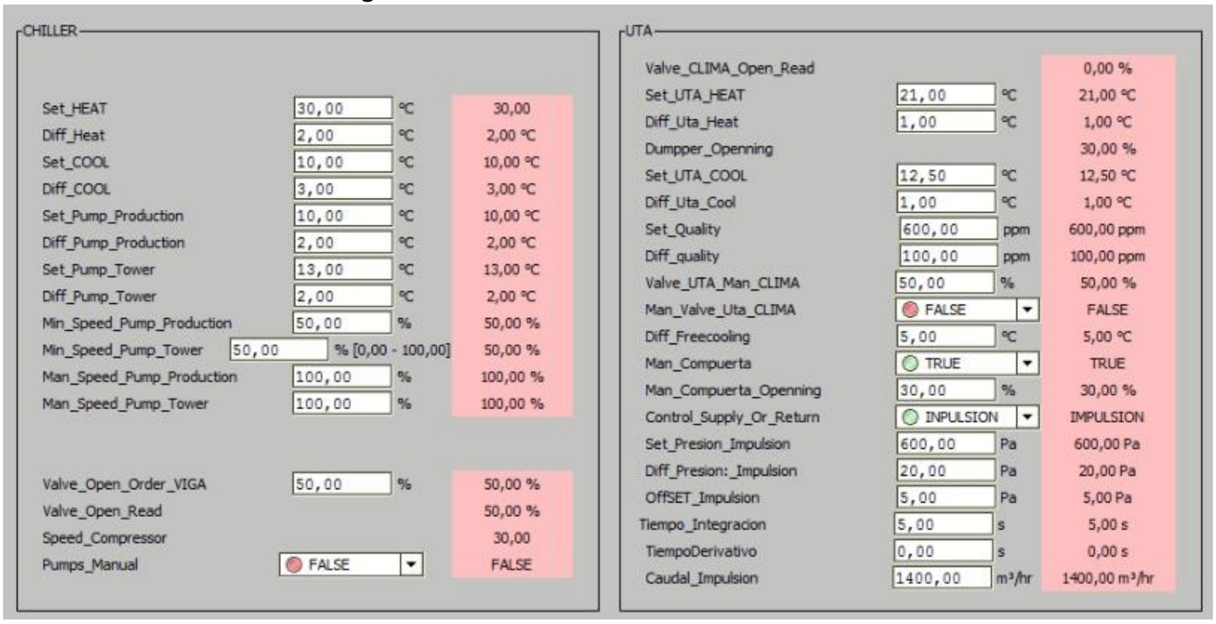

Figure 40. Readings/writings variables in SCADA LowUP

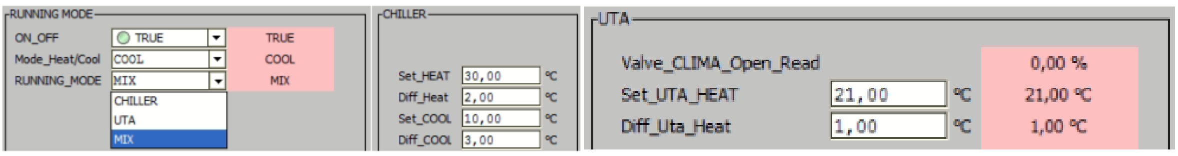

Figure 41. Some writings variables in SCADA LowUP

The water circuit was left running for several hours to purge the inside air, then it was refilled with water to achieve appropriate pressure; during this process the vents were opened to let the air out. This process was carried out during 1 week several times, also opening all the parts of the circuit.

After all this process, the unit began to operate and there were problems with the compressor. After some time working, the low pressure of the compressor reached less than 3 bars and therefore the system stopped for internal safety rules. The problem was that thermal Delta T between the outlet and inlet in the water circuit of the compressor was too large (~ 8ºC) and because of this the compressor stopped. Once the problem was detected, a 3-way valve was installed to control the flow temperature of the water to the beams and thus have a lower thermal Delta T in the compressor. With all this, it was possible to supply water to the beams at 16ºC and control the thermal Delta T of the compressor at around 4-5K.

Another problem in the operation of this system was related to the working profile of the cooling tower and chiller condensing pump. Due to the work profile configured, sometimes the flow was too low, and the unit alarms made the system stop. After detecting this problem and discussing it with the manufacturer, the work profile of operation of the pumps was changed to avoid these flow rate problems.

2.1.2.2 PCM TANK

The start-up of this system followed a similar path to that of the chiller, starting with a start-up of the system from the unit's display and then making checks from LowUP SCADA.

In the display integrated on board of the unit, as shown in the following figures, specific variables have to be established in order to define the limit for automatic start/stop and operation of single actuators.

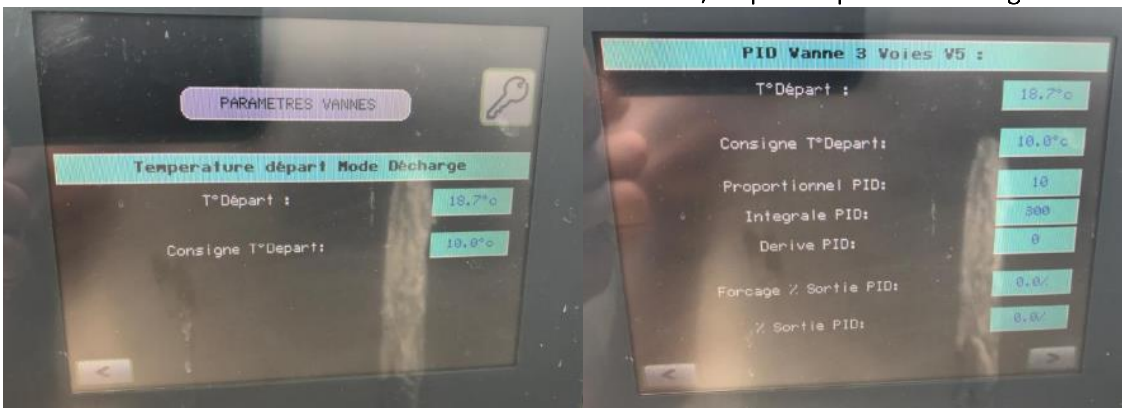

Figure 42. Display configuration for valves

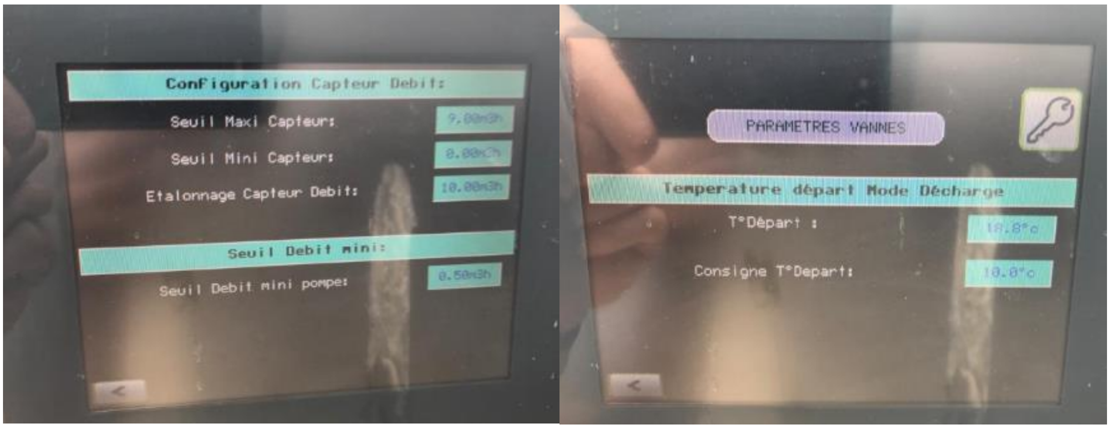

Figure 43. Display configuration for flow

In addition, to have a security control over the system, few alarms were established to warn the plant operator, like: low charge levels, low water circulation flows, very high temperatures, etc. The following figure shows the alarm programming screen.

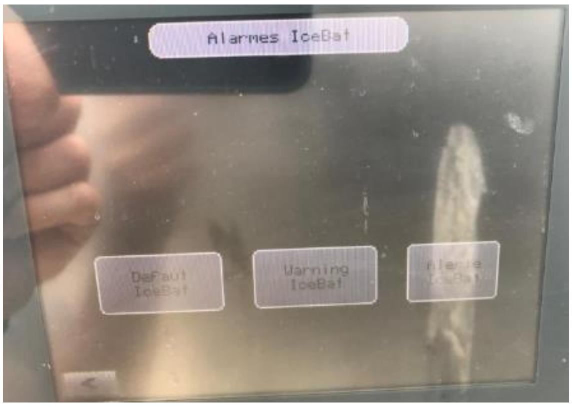

Figure 44. Warnings screen in PCM tank display

Once this was done, the system started up from SCADA. With the IP address programmed by the manufacturer, the programming was carried out in the LowUP PLC and the programmed variables began to be read. From the SCADA it is possible starting the pump and changing the valves manually, as shown in the following figure.

WORD ON MODE

ManuPump5ON	FALSE	FALSE
ManuValveV5AOpen	FALSE	FALSE
ManuValveV5AClose	FALSE	TRUE
ManuValveV5BOpen	FALSE	FALSE
ManuValveV5BClose	FALSE	TRUE
ManuValveV6Open(CHARGE)	FALSE	FALSE
ManuValveV6Close(DISCHARGE)	FALSE	TRUE

Figure 45. Writings variables in SCADA LowUP

In addition, components and sensors that have been in error or warning can be reset, as shown below:

REARMENT POUMP5

ElectricPump5DefaultRearmement	FALSE	FALSE
InletFlowPump5DefaultRearmement	FALSE	FALSE
LakeOfWaterIcebatRearmement	FALSE	FALSE
InhibitionPump5	FALSE	FALSE

REARMENT SENSOR

FlowSwitchIcebatSensorDefaultRearmement	FALSE	FALSE
LevelIcebatSensorDefaultRearmement	FALSE	FALSE

Figure 46. Writings variables in SCADA LowUP

Certain variables can also be configured from the SCADA for the calibration of some sensors. The following image shows some variables that can be edited.

HighTemperatureStartIcebag	25,00	°C	25,00
IceBatMinLevelSensor	4,00	%	4,00 %
IceBatMaxLevelSensor	100,00	%	100,00 %
IceBatFlowSwitchCalibration	0,00	m³/hr	10,00 m³/hr
IcebatMinFlowSwitchSensor	0,00	m³/hr	0,00 m³/hr
IcebatMaxSwitchSensor	9,00	m³/hr	9,00 m³/hr
IcebatInputTempSensorCalibration	0,00	°C	0,00 °C
IcebatOutputTempSensorCalibration	2,00	°C	2,00 °C
IcebatStartTempSensorCalibration	0,00	°C	0,00 °C
FlowDefaultPump5Setpoint	0,15	m³/hr	0,15 m³/hr
DiffOut	1,00	°C	1,00 °C
FullIcebatLevel	95,00	%	95,00 %
EmptyIcebatLevel	5,00	%	5,00 %
ValidationChargeLevel	90,00	%	90,00 %
ValidationDischargeLevel	10,00	%	10,00 %

Figure 47. Calibrations variables in SCADA LowUP

The water circuit was left running for several hours to purge the inside air, then it was refilled with water to achieve appropriate pressure; during this process the vents were opened to let the air out. This process was carried out during 1 week several times, also opening all the parts of the circuit.

One of the problems found when testing this unit was the correct calibration of the different sensors and equipment. When the PCM tank was started in discharge mode, sometimes the water circulation pump would stop because the minimum acceptable flow was too high, therefore warning of min flow of the control system had to be changed to allow the pump to work at low flow rates.

2.1.2.3 CHILLED BEAMS

Start-up of this system was more complex than the other systems, since LowUP's PLC / SCADA controls the chilled beams through a control gateway and this made communication more difficult.

The first step was to program all the variables provided by the manufacturer for the LowUP PLC, checking their types and ranges. After the connection was made through its gateway to read variables and after several changes in the configurations, reading of variable was achieved. Nevertheless before achieving variables writing, it had to change certain parameters of the network configuration.

There were several VPN-related issues for the manufacturer to be able to access to their control system from outside the facility's network. After carrying out changes in the programming, it was possible that the errors in the communications between your PLC and our SCADA ended.

It was necessary to change the system refresh rate and the number of variables read/written at the same time in order to solve all these problems. The problem could be because the reading is done by ModBus in the PLC and then it is transformed to Bacnet in the SCADA. Once these modifications were made, some parts of the system began to be tested from the SCADA to start up.

The following commands were mainly tested to verify that the system was working properly.

- HvacModeCmd = Cool (to turn the CB ON)
- HvacModeCmd = NightPurge (if free cooling operation is desired to be manually forced)
- OccupancyCmd = Occupied/Unoccupied. This command is needed to be sent to the chilled beams in order to notify the chilled beam that the room is being used.
- Temperature for the different set points correspondent to Occupied/Unoccupied modes (OccCoolSP and UnoccCoolSP)
- CO2Setpoint in each individual CB. This will consider default values as mentioned above.

The following figure shows the variables of a single chilled beam that can be read and written.

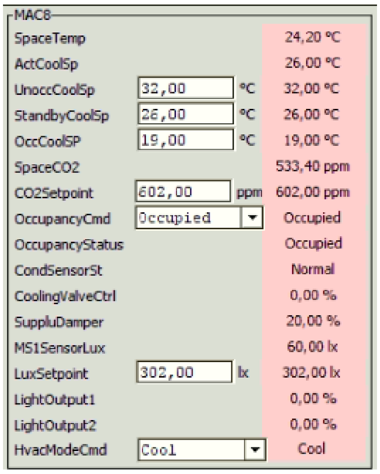

Figure 48. Variables of each chilled beams in SCADA LowUP

The water circuit was left running for several hours to purge the inside air, then it was refilled with water to achieve appropriate pressure; during this process the vents were opened to let the air out. This process was carried out during 1 week several times, also opening all the parts of the circuit.
The chilled beams have a working point of 16ºC in supply of water and 19ºC in return, therefore, it was necessary to install and program a 3-way valve to control the entry of water to the chilled beams. All this avoids condensation problems within the office / warehouse. A PID was programmed to control the opening of the valve with an offset of +/- 1ºC.

After a first start-up and operation, due to the problems that existed in the design of the duct network, between the gate and the sensor that actuated the damper there was a secondary conduit and that influenced the measurement of pressure and flow, the existing damper was modified in place in the duct and a second damper was installed in the second duct of the installation to control the flow.
The following figures show the changes that were made to the supply duct by changing damper 1 and adding damper 2.
It was verified that the gate opens and closes correctly according to the pressure setpoint that is written in the SCADA.

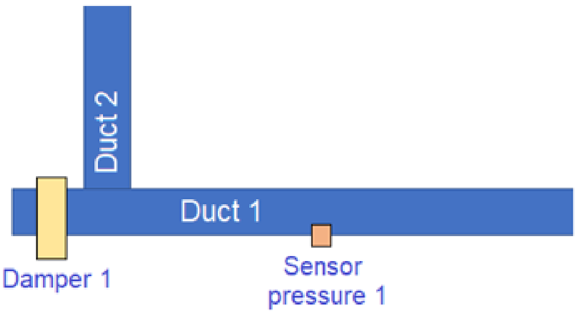

Figure 49. Ducts before changing dampers

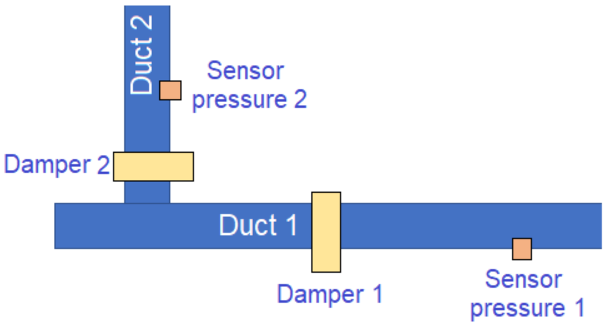

Figure 50. Ducts after changing dampers

Once the work on the ducts had been carried out, the variables of the new damper were added to the SCADA programming and tests were carried out to prove that everything was working correctly. During these tests, certain air leaks were discovered in the supply duct that were quickly fixed.

2.1.2.4 COOLING TOWER

This system was very easy to start up as it was an already installed that had already worked. However, the unit's control system had to be integrated into LowUP's SCADA.

The control of this system was developed in LabView, therefore, the PLC was configured with the IP of the equipment and the necessary variables were programmed. The first checks were made from the SCADA in Labview, verifying that the unit worked correctly and later, it was tested from the LowUP SCADA.

The following image shows the control variables of the cooling tower, Start/Stop of the fans, Start/Stop of the circulation pump, and speed of the circulation pump. In addition, the control of a 3-way valve was added for the different operations of the Cool LowUP modes.

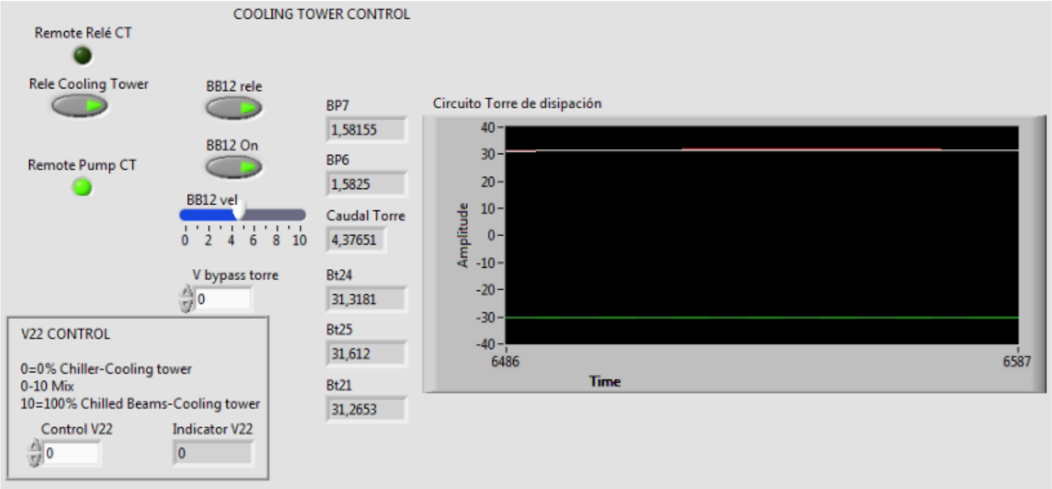

Figure 51. Cooling tower control (LabView)

The following figure shows the variables integrated in the SCADA from where the last connection tests between PLCs, Unit Start/Stop, Pump Start/Stop and pump speed were made.

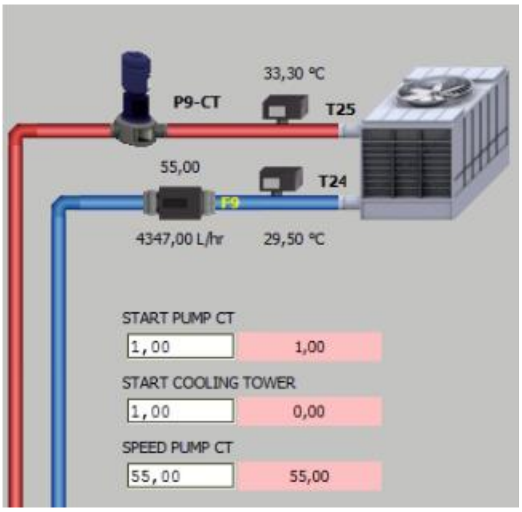

Figure 52. Cooling tower control in SCADA LowUP

2.1.2.5 AUXILIARIES

- 3 WAYS VALVES

The three-way valve checks were done first from the PLC, before integrating its control into the SCADA. To test this element, after connecting it to one of the PLC outputs, it was tested with various control signals with voltages between 0-10V, and its opening was verified.

The following image shows how the changes were made for these verifications.

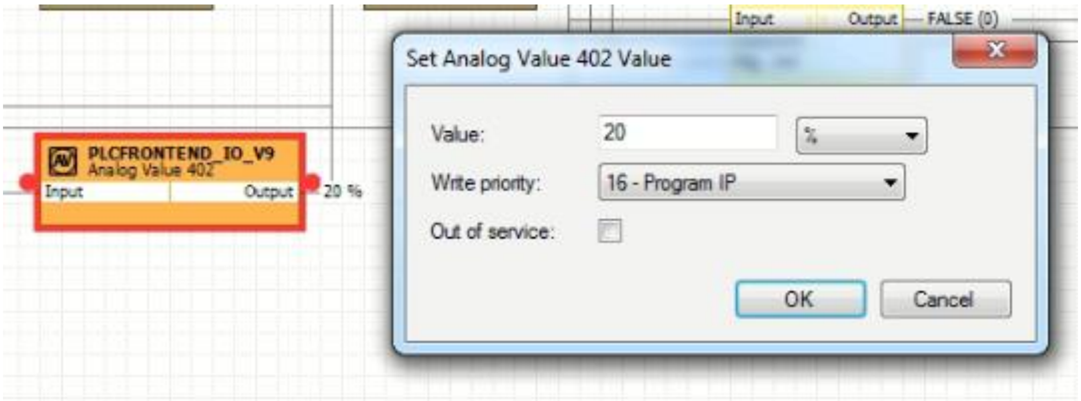

Figure 53. Changing values by PLC

In this way, by writing values of 0-100%, which is equivalent to 0-10V, the movement of the 3-way valves was checked and their start-up was faster.

The next step was integrating this control with PID within the SCADA so that it can be adjusted according to normal operations. In some cases, in addition to programming a control for that valve, the manual control option is always ready. The following figure shows a 3-way valve with manual control from the SCADA. This manual control is open / closed.

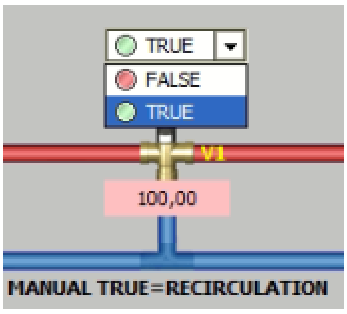

Figure 54. Manual control of 3-way valve

- WATER PUMPS

Last step OF pump start up is was controlling from the SCADA; start and stop control, and then speed controlling through PID control or speed manual controlling. Next two figures, it shows how manage pump operation from SCADA.

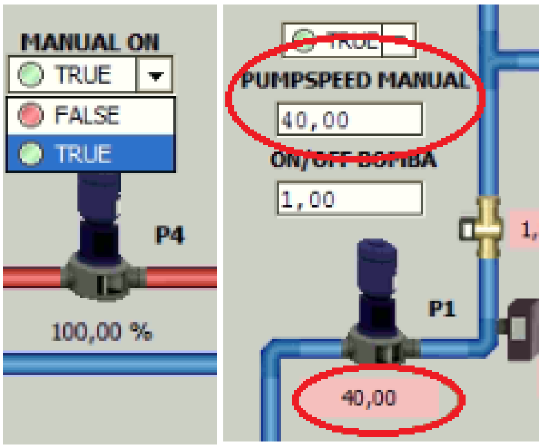

Figure 55. Start/Stop control (Left) and speed manual control (right)

Once pumps were turned on for operating, it had to adjust the performance range to work in designed conditions. Adjusting the performance range of every pump was made with help of flow meter distributed over the installation. Next figure it shows pump P1 (Solar field pump) working at 50% and its flow meter shows flow range.

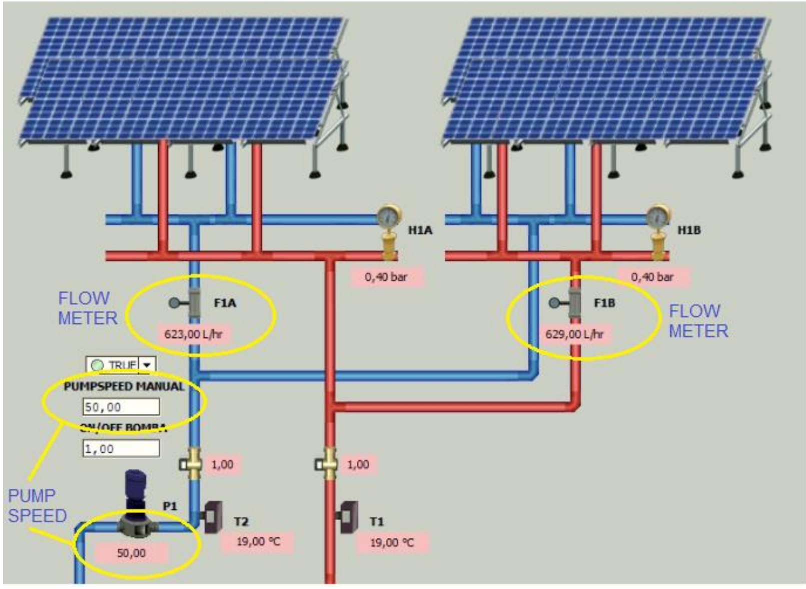

Figure 56. Solar field working at 50% of hydraulic range

- TEMPERATURE SENSORS

The implementation of this element in the SCADA was simple, since it was simply verified that the sensor was read through the PLC and then it was verified that the readings matched with other analogic sensors (gauge) installed in the same sections. The following figure shows a test between the gauge and the SCADA reading.

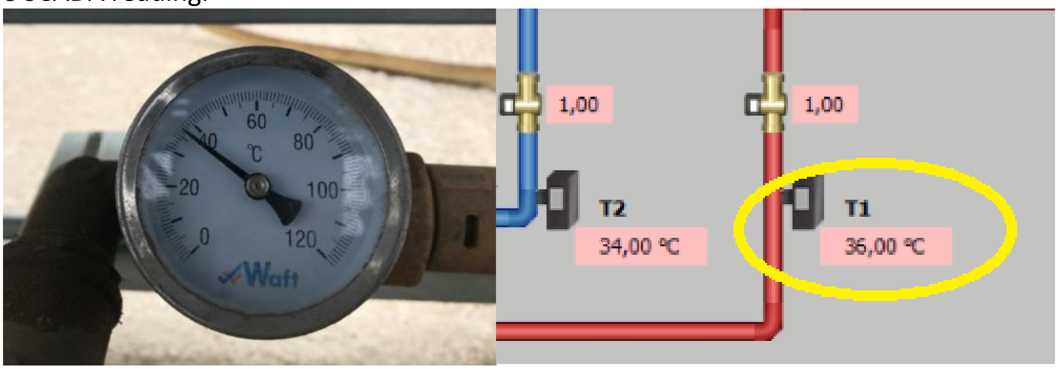

Figure 57. Verification between temperature sensors

- PRESSURE SENSOR

The implementation of this element in the SCADA was simple as well, it was simply verified that the sensor was read through the PLC and then it was verified that the readings matched with other gauge installed in the same sections. The following figure shows a test between the gauge and the SCADA reading.

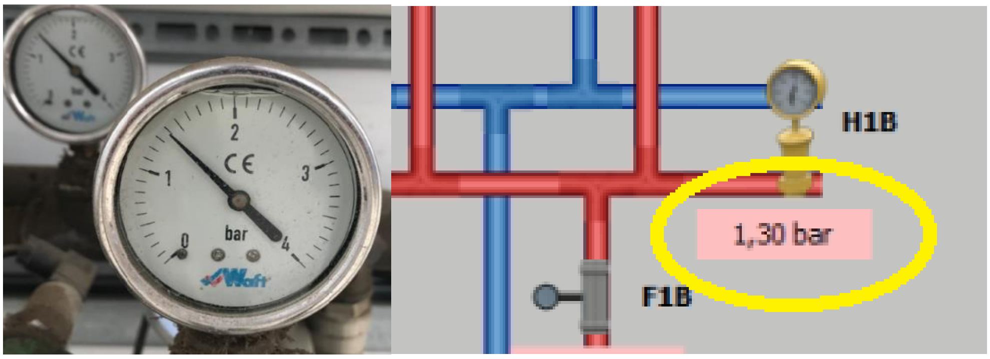

Figure 58. Verification between pressure sensors

- ENERGY/FLOW METER

When SCADA was configured, all variables were created in SCADA to read, and then it was able to check values from SCADA with ones displayed in flow meter screen. In this case, to check variations in the readings, pumps were started and stopped to verify that there were changes in temperatures and flow rates. The following figure shows the most important readings of a flowmeter installed in Seville demo site.

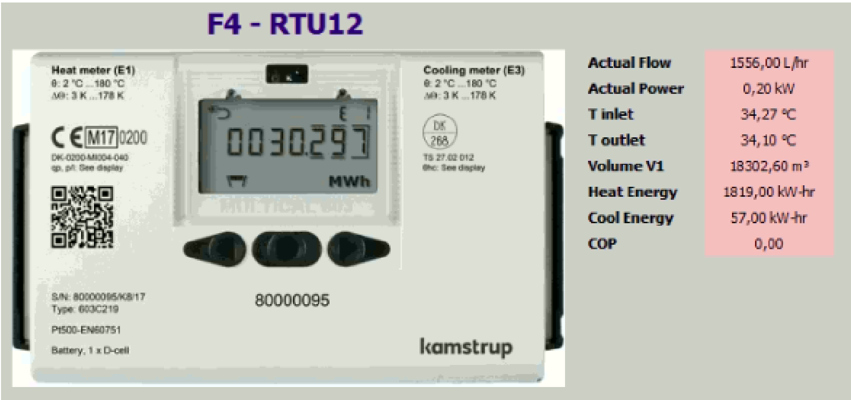

Figure 59. Variables of flow meter in SCADA LowUPç

2.2 Heat LowUP System

HEAT LowUP system is composed by different sub-systems: Solar field, stratified tank storage, Wasenco emulator, radiant floor and dry cooler. Some smaller components are installed and described in Auxiliary section.

Here below the layout of the system to identify every sub-system in the global P&ID.

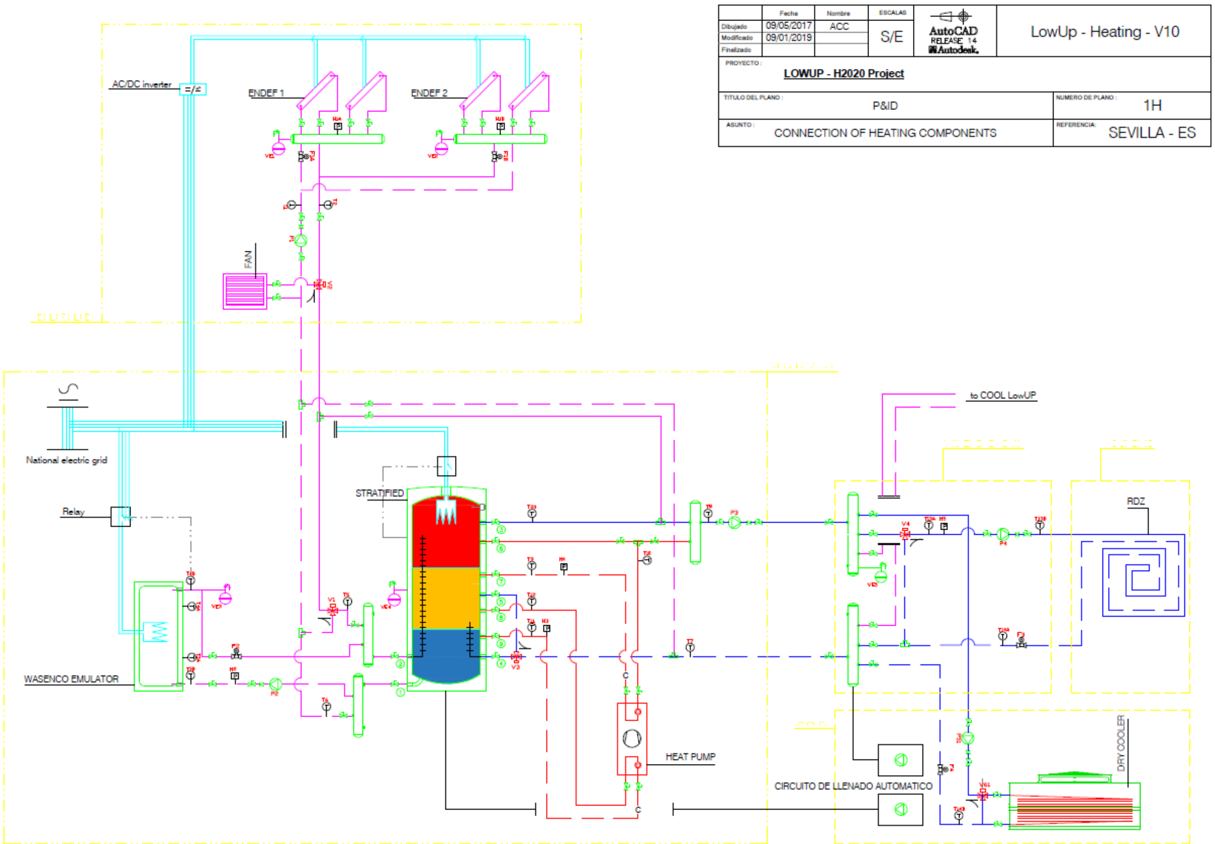

Figure 60. P&ID of the HEAT LowUP components

From now on, it´s going to be explain each sub-system describing all the works carried out to commissioning and start up.

2.2.1 Commissioning at component level

Most of the activities of commissioning for plumbing, insulation and sensors are common with Cool LowUP, so refer to previous section for activities undertaken.

2.2.1.1 SOLAR FIELD

Solar field it has two different parts, photovoltaic energy and thermal energy. Next section shows photovoltaic components starting by panels.

2.2.1.1.1 PV PANELS

Specific start-up:

After the installation of PV system was completed and the inspection was done, the system are ready to be plugged to the grid to transfer energy.

Making sure to use proper settings for DC, it was tested current and voltage expected (from calculations) in each string checking previous design and installation. Other of the things tested was voltage polarity, because it's important thing to connect the inverter correctly.

Before connecting to inverter, continuity and resistance testing verified grounding and bonding connections in electrical systems. These tests also verified the proper operation of disconnecting and the function of overcurrent protection devices like fuses and circuit breakers. Proper grounding of PV systems reduces the risk of electrical shock to personnel and the effects of lightning and surges on equipment.

Polarity testing verified the correct polarity for PV circuits, and proper terminations for DC utilization equipment. The polarity of PV circuit was verified prior to connecting to any dc utilization equipment. Polarity testing were made in photovoltaic modules, photovoltaic output circuits, disconnectors and inverter input terminations. Voltage and current testing verified that PV array and system operating parameters were within specifications. Prior to closing the PV array dc disconnectors, the open-circuit voltage (Voc) for each PV array source circuit was tested and compared with requirements.

Insulation resistance testing verified the integrity of wiring and equipment, and used to detect degradation and faults to wiring insulation.

Performance testing verified the system power and energy output are consistent with expectations. These tests also require measurements of array temperature and solar irradiance.

Once DC system was checked, next step was focused in AC verifications. Using proper energy meter for AC, test line to line a line to neutral were completed making sure that all parameters was according to previous calculations.

Continuity and resistances testing, voltage and current testing, insulation testing was made for AC system as well.

Then, in order to connect PV installation to internal grid, there was some test to do before connecting. PV systems are designed to produce a specified electrical output under certain operating conditions. Performance testing verified the system power output and energy production were as expected, based on component and system ratings and the given operating conditions.

Verifying Power and Energy Production. Power and energy production are the fundamental metrics for PV system performance. Next verifications were related with electrical production of DC panels matching with AC energy introduced in internal grid, considering system loses. Also, it was verified the proper grid voltage and frequency to operate inverters, including evaluating voltage drop between the inverter ac output and point of connection to the grid.

2.2.1.1.2 INVERTER

Specific start-up:

Once the inverter installed, and prior to connect to produce, it´s required make some verifications. Last section shows verifications in DC side and everything was correctly installed. Then, it switched off the DC and AC distribution unit, connect DC to PV terminals of inverter, and connect AC to AC terminals of inverter.

It was checked all parameters in inverter display like, measure and DC voltage, polarities, DC lines voltages, AC lines and neutral voltages, frequency, and we confirmed the VAC voltages are within 5% tolerance to what was tested.

Following figure shows some parameters in inverter display when it was started up and before communication connection.

Figure 61. SMA inverter screen

After that, were made more verifications like open and close the DC breaker, to confirm whether the inverter reboots and shuts down automatically, or disconnect some part of DC side to check if inverter get the maximum power point.

2.2.1.1.3 THERMAL PANELS

Specific start-up:

Thermals panels is the other side of the solar field, contributing to HEAT LowUP system heating water to store and exchange with radiant floor or dry cooler. Process carried out to start up thermal system was a long-time work, first with the installation and then with control of the system.

First thing to do once the system was installed, it was a leak test of the solar panels; it had two chance to do this, with water or without water, we decided doing just with air, because it´s faster to make a repair. This test was made at high pressure ensuring that all components involved in test could work in this condition.

Furthermore, expansion tank had to be tested and calibrated for the system. Once work pressure design was calculated, which is 1.5 bar, expansion tank should have 0.5 bar below the circuit pressure, and it was verified with a tester.

Then, it was necessary cleaning, filling and a leak testing. Cleaning was made with water in open circuit mode. Then Primary circuit was filled with a mixed liquid (95% water, 5% glycol) at a higher pressure of the work pressure. Mixing water with glycol was made to avoid a freezing situation in the primary circuit. That mix proportion allow getting -5ºC outside.

That operation of filling was made in the evening with low solar radiation, because standing water could be evaporate making air inside the circuit. Bleeding the circuit was next step in start-up and it´s one of the most important operation because, air inside of circuit could reduce work flow and efficiency of the system. This operation was made by the bleeder and should be made at same time that water circulate to help the air movement.

Pressure and flow settings was the last part of the operation. To get the pressure setting of the circuit was necessary open the drain valve, because we filled the circuit in overpressure. Doing this action give us a small quantity of fluid inside of expansion tank to prevent low temperature outside.
Adjusting water flow of the system was set like next step according pumps parameter and controlling from the SCADA.

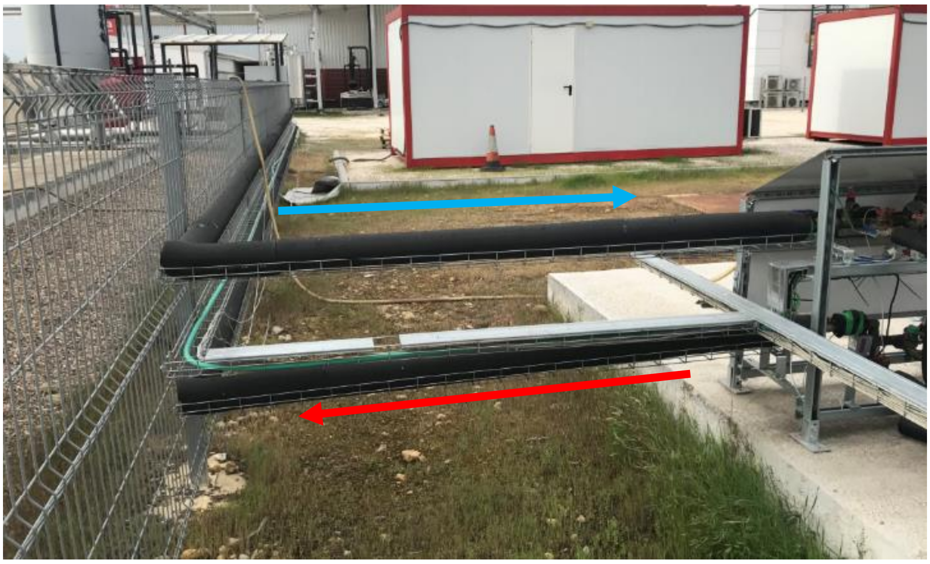

Figure 62. Inlet water (blue) and outlet water (red) in solar field

2.2.1.2 RADIANT FLOOR

Specific start-up:

The commissioning presented here is based on Filling and cleaning of the radiant floor circuit. It was verified that the hydraulic circuit was properly executed, checking the filling elements, draining, purging, expansion and safety.

Once all elements of the security systems were checked, filling the radiant floor circuit was made up to the minimum pressure. Then, air venting was made and repeated different times up to getting a free air circuit, checking all the bleeders worked correctly. This filling process finished when manifolds got roughly 0,4 bar each one.

Next figure shows distribution of the circuit in the floor of the office.

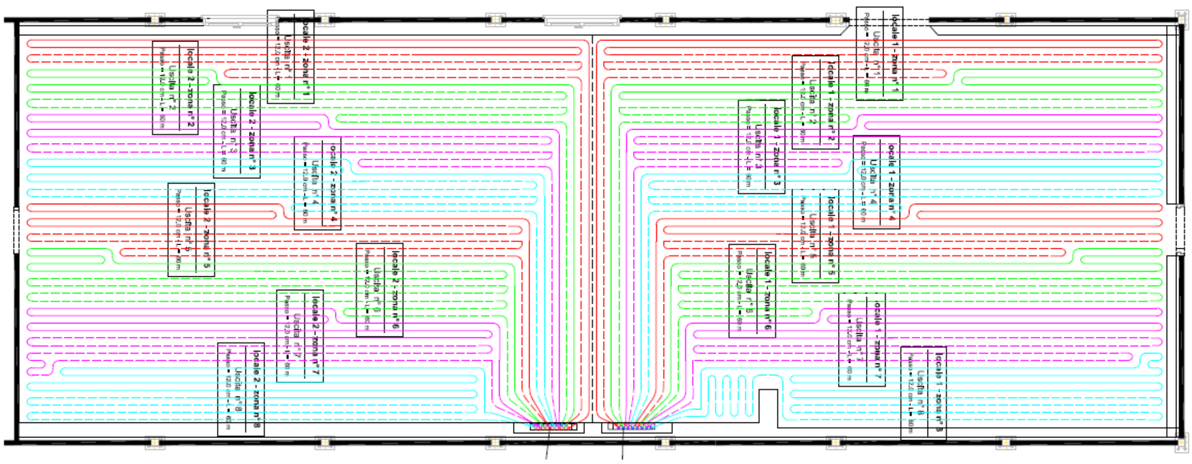

Figure 63. Distribution of the radiant floor circuit

This is the start-up of each pumping group of the circuit and its adjustment to the nominal flow. Once radiant floor filled, the main task was start up the pumps to supply thermal energy via water circulations. Following figure shows pumps of radiant floor system.

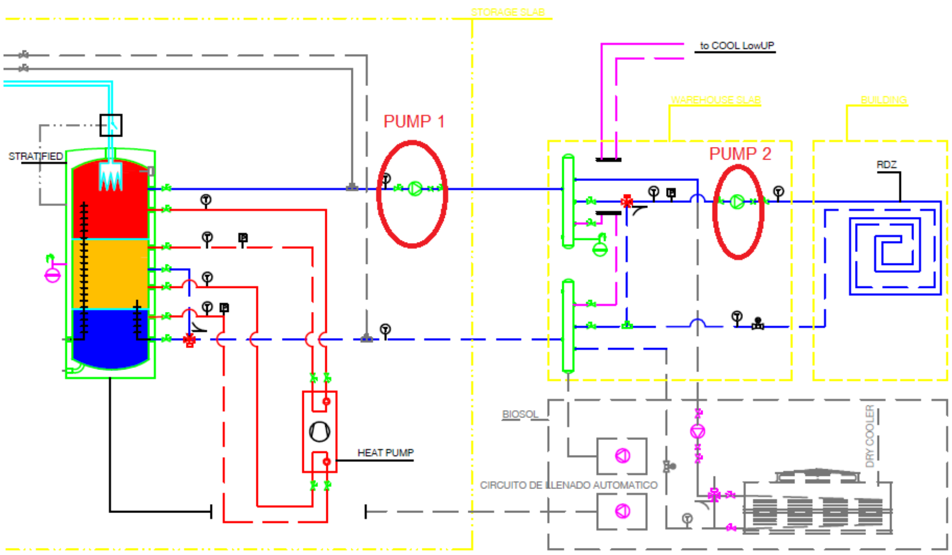

Figure 64. Schema of radiant floor circuit.

There were two pumps installed in series and that gave us many combinations of flow rating. However, reported in next table, nominal flow of the radiant floor was 1200 l/h each manifold and 150 l/h each circuit.

Table 1. Design parameters of radiant floor

TM theorical [°C]	DT theorical [°C]
38,4	5,0

Manifold	att.	TM [°C]	Power [W] High	Power [W] Low	Power [W] Total	Flow [l/h]	PDC [mmH2O]	Fabb. Tueo [m]	H2O tub [l]	Sup. [m²]
Manif 1	8	31,0	3465	778	4243	1200	3927	484	38	
Manif 2	8	31,0	3445	770	4215	1200	3904	481	38	
Totals	16		6910	1547	8457	2400	3927	965	76	116

The radiant loops were conveniently balanced adjusting each section to its nominal flow so that the different connected units work correctly. This task was made in each circuit to get a balancing circuit according to design parameters. To finish start-up verifications, some checks were made through the SCADA to ensure all components working correctly.

Figure 65. Schema of the radiant floor supply and return water

<u>Pre-start verifications:</u>
After doing the physical verifications, the RDZ controller that manages the radiant floor installation was connected to the network. This controller had to first be connected to the installation's modbus network and then configured to read/write its variables. The temperature and humidity sensors integrated into the controller were calibrated and working properly.

2.2.1.3 STRATIFIED TANK

<u>Specific start-up:</u>
Some verifications were made before stat-up. Good anchoring to the floor. Correct distance between tank and the elements around in order to be accessible for maintenance. All the security components must be installed. That drains and overflows were connected and free from blockage.

Before filling the circuit, it was necessary firstly a visual inspection of the system involved and then, a cleaning of the system isolating or bypassing item which were particularly sensitive to dirt like pumps, feed tank, etc.

All the connections had to be correctly tightened, expansion tank correctly installed and all the valves in filling position by designed plan. Stratified tank and its circuit were filled during 20 hours and it was carefully examined that all joints were correctly installed.
Then, all water distribution pipeworks from stratified tank were hydraulically tested section by section, mainly making test pressure. This test pressure had to be at least 1.3 times the maximum static pressure for 12 hours without loss of pressure or loss of water or leakage in pipes joints. All joints and sections pipes were visually tested and accepted.

Verification with resistances consisted of turn it on and check if temperature sensor changes its value. At same time, an electrical analyser measured current phase by phase and consumption.

<u>Pre-start verifications:</u>
Element control to stratified tank was provided by ENTROPY, and its PLC can be seen in the following figure. Entropy´s PLC shows temperature sensor inside the tank and resistance can be turn ON/OFF in according to the project specifications.

Figure 66. Entropy SCADA

In LowUP ´ SCADA it can be showed the same information than Entropy´s SCADA, and resistance can be controlled as well, thank to remote communication network of the demo. Verifications with SCADA consisted of heating temperature sensor one by one and checking if this action reflects a change by SCADA.

1 Heat side of the heat pump. HP to tank.
2 Heat side of the heat pump. Tank to HP
3 Cold side of the heat pump. Tank to HP
4 Cold side of the heat pump. HP to tank.
5 Hot water to Radiant floor
6 Cold water from radiant floor
7 Supply pump to radiant floor (Pump 1)

Figure 67. Connection of the stratified tank

2.2.1.4 HEAT PUMP

Specific start-up:

Before start-up, some preliminary checks were made to ensure everything was correctly installed. The unit should be installed properly and in conformity with manufacture manual. The electrical power supply line should be sectioned at the beginning. The coils must be clean and free of obstacles. The ventilators must be free of leaves, cardboard, fixed obstacles (beams, barriers, etc.), snow, etc.

It was ensured that the plumbing system has been claned. Drained the wash water before connecting the unit to the system. Checked that the water circuit has been filled and pressurised. It was made sure there are no leaks and checked that the shut-off valves in the circuit are in the "OPEN" position. Checked that there is no air in the circuit. After some days bleeding it using the vent valves in the system.

It was used antifreeze solutions and we made sure the glycol percentage is suitable for the type of use envisaged. It was chosen a 10% weight of ethylene glycol, ensuring freezing point was at -4ºC and a safety temperature point at -2ºC.

It was made sure that the tension and net frequency values were within the limit of: 6% single/three phase unit, and controlled the unbalancing of the phases: it was lower than 2%.

It was obligatory by manufacturer to connect the oil heaters on the compressor crankcase at least 8 hours before the compressor is to be starter. It was made sure that the temperature oil of the crankcase was not below operating temperature before starting the compressor.

Pre-start verifications:

After physical verifications, control system was started up as following steps. First was start up the keypad integrated in the unit and check if every button worked, and check if it was able to change parameter with this keypad. Following figure shows button function of the keypad. It shows cool and heat modes.

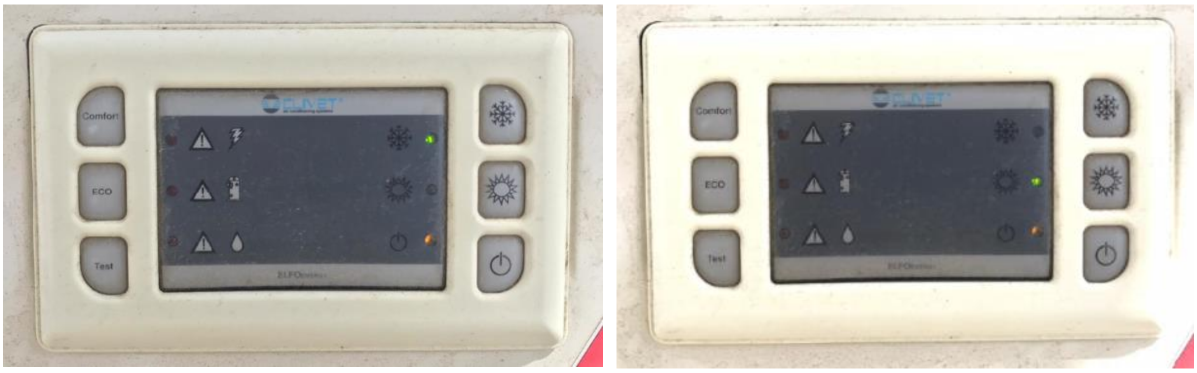

Figure 68. Integrated heat pump keypad. Cool mode (left) and Heat mode (right)

With the integrated keypad it was changed all setting mode and it was checked that none alarm was active. Unfortunately, there was an active led alarm, like it showed in the figure above, but it was resolved quickly resetting the unit. Then, functioning test mode was activated, and checked proper functioning of the all six signalisation LEDs.

Next step was the verification of the service keypad included with this unit as well. Following figure shows technical data form this keypad.

Figure 69. External heat pump keypad

With service keypad, it´s able to check many parameters temperature, pressure, etc… Furthermore, it possible to change some operating parameters.

2.2.1.5 THERMAL EMULATOR

<u>Specific start-up:</u>

Some verifications were made before stat-up. Good anchoring to the floor. Correct distance between tank and the elements around in order to be accessible for maintenance. All the security components must be installed. That drains and overflows were connected and free from blockage.

Before filling the circuit, it was necessary firstly a visual inspection of the system involved and then, a cleaning of the system isolating or bypassing item which were particularly sensitive to dirt, like pumps, feed tank, etc.

<u>Electrical verifications:</u>

One important verification in this case was the resistance inside tank, because this system simulates a heating profile from Wasenco performance, and the resistance needs turn ON/OFF many times a day. Resistances were connected to a circuit breaker in the cabinet and a control signal from de PLC.

To check this component was necessarily make an input setpoint control, and work verifications resistances were checked with an electrical analyser.

<u>Pre-start verifications:</u>

This system combines some components that its star-up is explained in other section like pump, flow meter, temperature and pressure sensor.

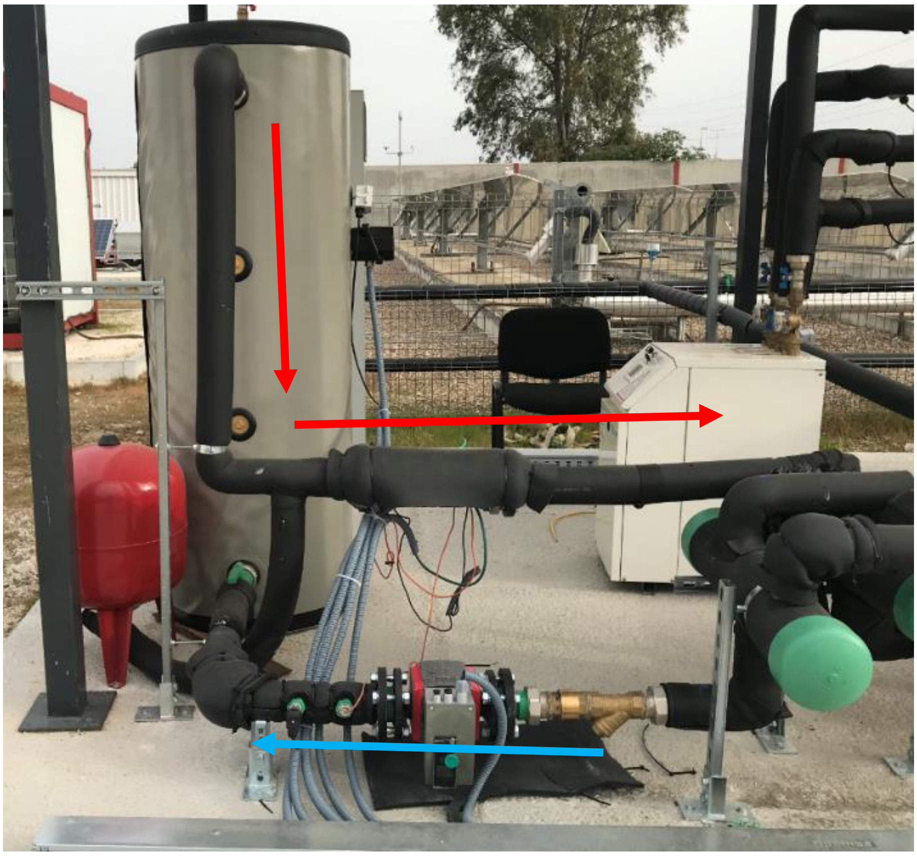

Figure 70. Schema of the inlet (blue) and outlet (red water) from emulator to tank

2.2.1.6 DRY COOLER

<u>Specific start-up:</u>

Before start-up and after positioning the unit, the first thing to do was check all the joints and components like the fan rotation, ensuring the fans run freely. The system was pressure tested before adding water/glycol solution and it could be tested all joints and piping connections.

It was checked electrical protection in the cabinet and connection in the unit, voltage verification was made as well. It was checked that connections have been done according to the wiring diagrams provided by manufacturer. All terminal boxes and cables entries were firmly closed and tight.

Then, it was tested the direction of rotation of the fans and current consumption, checking for compliance with the technical data.

Filling and purging were the next step in order the start-up. System was filled with the same quantity of water/glycol that the rest of the installation and then, circuit was operating for two hours to purging all vents, filling again with water/glycol. This task was repeated sometimes until the system was ready.

<u>Pre-styart verifications:</u>
When all verifications were correct, unit was operated by its SCADA checking all operating modes, sensors distributed in the equipment, etc.

FOTO

Figure 71. Water and air direction on the dry cooler. Inlet hot water (red arrow), outlet cold water (blue arrow) and air (Yellow arrow)

2.2.1.7 AUXILIARY

<u>Mechanical verifications:</u>
Same procedure and activities already described for Cool LowUP.

<u>Electrical verifications:</u>
Same procedure and activities already described for Cool LowUP.

<u>Sensing and automation verifications:</u>
Same procedure and activities already described for Cool LowUP.

2.2.2 Commissioning at system level

This section is going to explain how each system was star-up and what kind of verifications was made.

All components were checked one by one when they were installed, so, components had to work together, and this task was made through the SCADA.

2.2.2.1 SOLAR FIELD

2.2.2.1.1 PV PANELS

At the system level, this part of the installation does not have information, all of them are collected in the inverter section since it is the system that shows the information of both DC and AC.

2.2.2.1.2 INVERTER

Last step was communication connection and assigning an IP address to this equipment inside the network. In order to commission a speedwire system it was necessary to install and to configure through Sunny Explorer by SMA. Once connection was set, it was able read and write all inverter parameters, and following figure shows how is the SMA Interface.

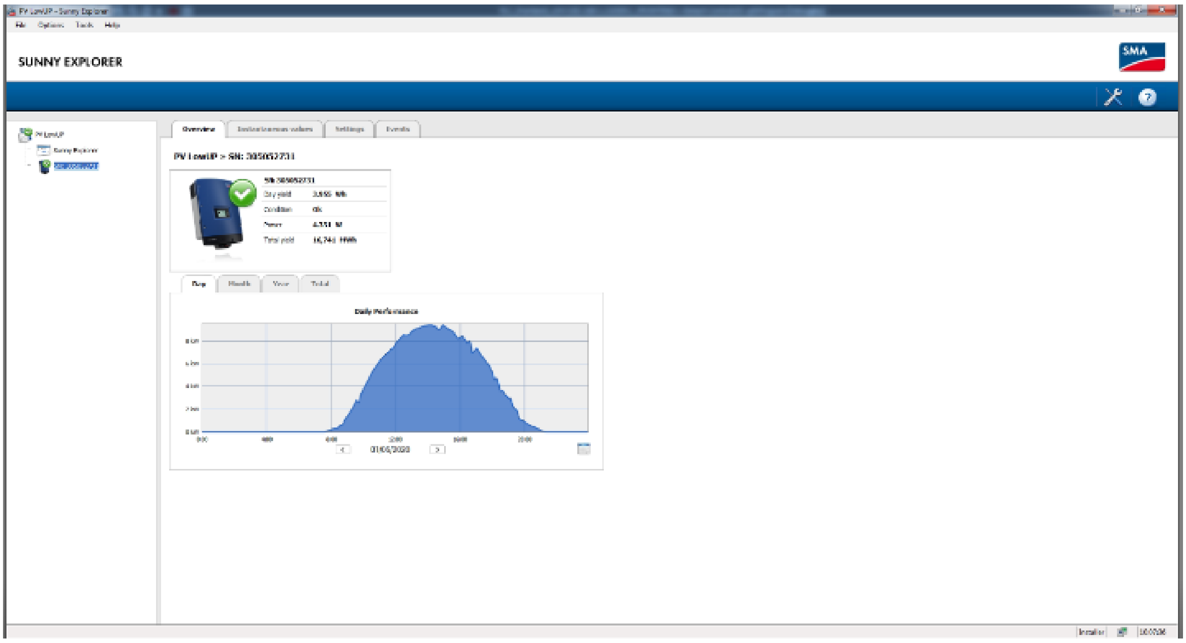

Figure 72. SMA interface desktop

When Sunny Explorer by SMA was connected and configured, the main task was transferring all parameters in SCADA and be able to manage the PV system. Next figure shows parameters reading in SCADA from the inverter and they were checked one by one.

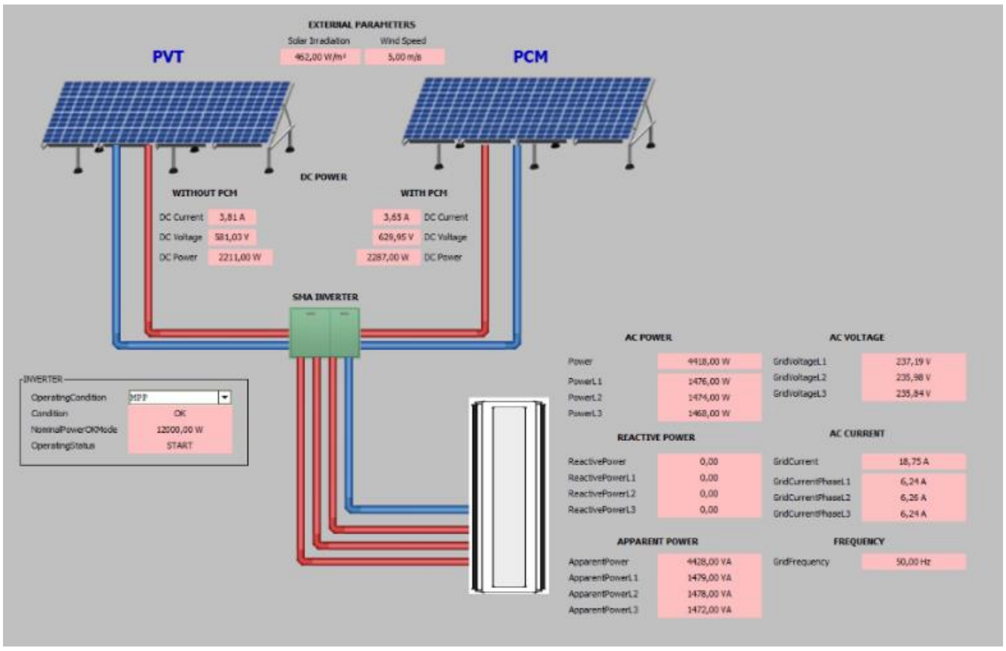

Figure 73. SCADA interface of Inverter parameters

2.2.2.1.3 THERMAL PANELS

This section it going to explain verifications in solar field at SCADA level, and next figure shows how was SCADA when checks began.

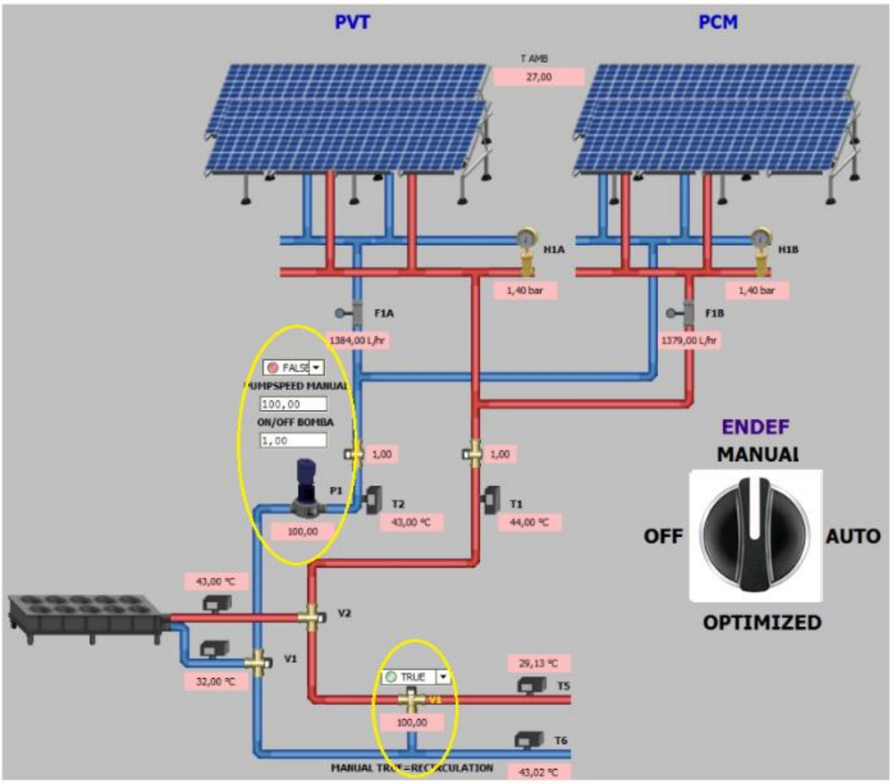

Figure 74. Solar field parameters

When control signal of solar field´s components were connected to PLC and configured, it had to do some checks from SCADA like open/close 3-way valve, turn ON/OFF pump, change pump speed, etc. To change pump´s parameters is necessary send the order to ENDEF control, and when SCADA change some parameter is sent to ENDEF control and it control activates it.

To start-up this system, was checked turning ON/OFF the pump and it worked correctly. Other check to do was change pump speed and turn ON with a set speed; unfortunately it had problems with pump´ speed because the minimum speed to work is around 30% and it was necessary modify this operation rule.

To verify the 3-way valve, it had to turn to automatic mode in the valve, and when verifications started, it had problems about ground wire: it wasn´t the same reference wire that the rest of the system and because of that, valve didn't work correctly. Once identify the problem, ground wire was changed, and open/close verification were made easily.

Last verifications were checking flow meters, changes in temperature and pressure sensors, etc. Figure above, shows controls to change pump and valve parameters.

2.2.2.2 RADIANT FLOOR

Radiant floor control is made by RDZ Manager, and from LowUP SCADA are sent the parameters to the RDZ Manager and this manager controls the system. Thinking how this system work, verifications consisted of turn ON/OFF radiant floor pump, and OPEN/CLOSE 3-way valve.

To ensure that pump turn ON from SCADA, was changed the setpoint temperature to 35º C, and due to temperature indoor was around 25º C, pump turned ON and 3-ways valve was opened in order to give heating to the office.

Once it checked, it changed the setpoint temperature below indoor temperature and that turned OFF the radian floor pump, and 3-ways valve was closed. Next figure shows controls in LowUP SCADA to make these verifications.

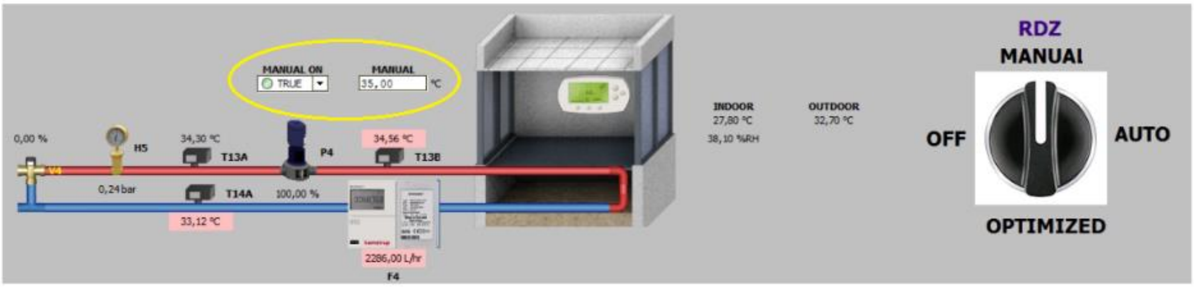

Figure 75. Radiant floor SCADA system

Next section, explains every control modes of this system:

To be manually set in the SCADA system: (i) Supply water temperature setpoint and (ii) pump on/off signal. The corresponding PID for the valve is programmed in the Frontend PLC.

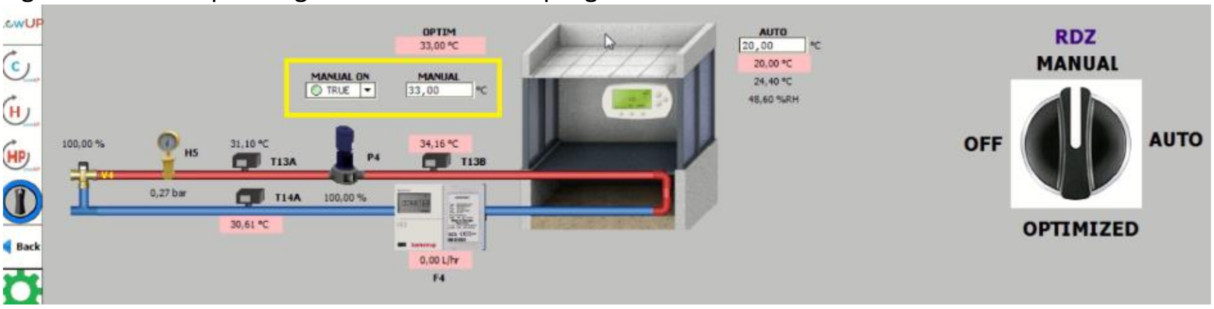

Figure 76. Radiant floor parameter in manual mode

2.2.2.3 STRATIFIED TANK

Verifications in stratified tank consisted of check temperature pressure and changes in these sensors due to supply of heat from solar field or emulator. No direct actuators are present in this specific system. Next figure shows changes in temperature sensors read from LowUP SCADA.

Figure 77. Temperature sensors distributed in Stratified tank

Another important element in this system are the resistors to heat the temperature of the water in the tank.There are three resistors installed inside and they are driven from the SCADA through the PLC and the digital outputs.

2.2.2.4 HEAT PUMP

Through LowUP´SCADA, it can monitor some parameters distributed around the heat pump. Next figure shows that sensors working.

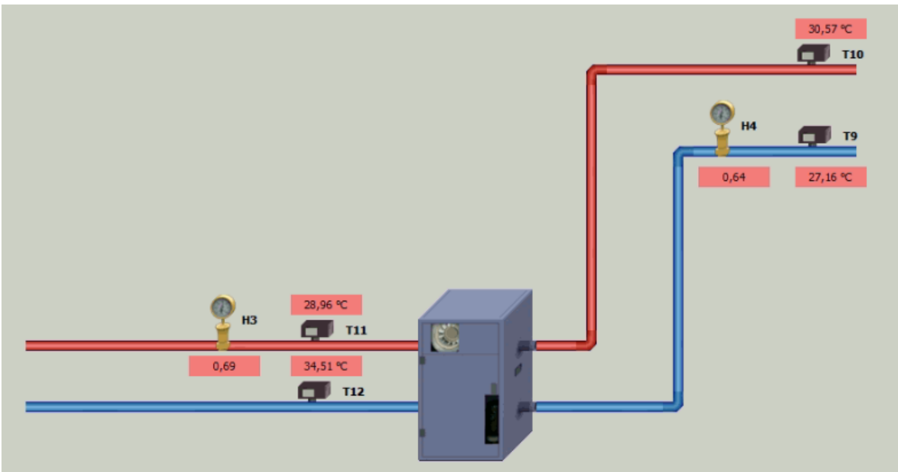

Figure 78. Heat pump SCADA

In this section, in addition to the sensors installed at the inputs and outputs of the heat pump, the unit gives us some values through the Modbus network. The first thing was to change the operating parameters of the unit to adapt it to our MBus network, and to be able to access its information. The following figure shows the variables that the heat pump gives:

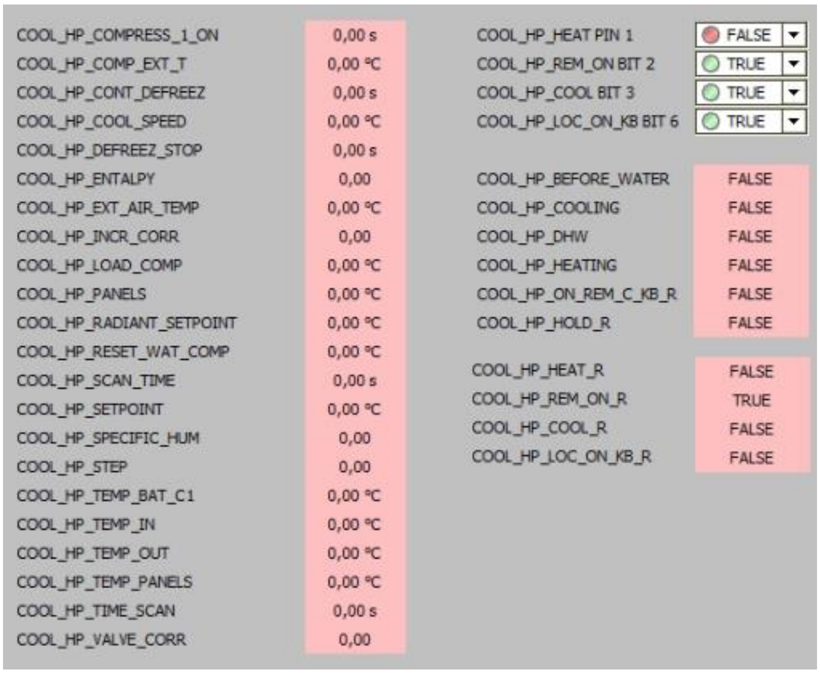

Figure 79. Heat pump parameters

The next step was to test start/stop and change modes (Cold/Heat) from the SCADA, checking if LowUP manager could control it switching automatically.

An added difficulty was to make the appropriate combination in the SCADA to carry out these operations, since the manufacturer, through his machine book, has a combination of bits that must be sent. The following table shows the mode combination table:

Table 2. Combination table of heat pump operation

Bit	7	6	5	4	3	2	1	0	Value
Length	128	64	32	16	8	4	2	1	
Command									
Power on unit and / or switch to Test mode	0	64	0	0	0	4	0	1	69(0x45)
Turn on unit and / or switch to Heat mode	0	64	0	0	0	4	2	0	70(0x46)
Power on unit and / or switch to Cool mode	0	64	0	0	8	4	0	0	76(0x4C)
Unit shutdown (as per ON / OFF key)	0	0	0	0	0	4	0	0	4(0x04)
Power off unit and / or switch to Heat mode	0	0	0	0	0	4	2	0	6(0x06)
Power off unit and / or switch to Cool mode	0	0	0	0	8	4	0	0	12(0x0C)
Unit shutdown (as per digital input)	0	64	0	0	0	0	0	0	64(0x40)

2.2.2.5 DRY COOLER

Due the dry cooler was a system already installed at Seville demonstrator, and it had its own control system, it was necessary to integrate its control system (LabView) with LowUP's SCADA. Being installed on the same network was not very complicated, integrating the two systems.
The following figure shows the SCADA of the Dry cooler:

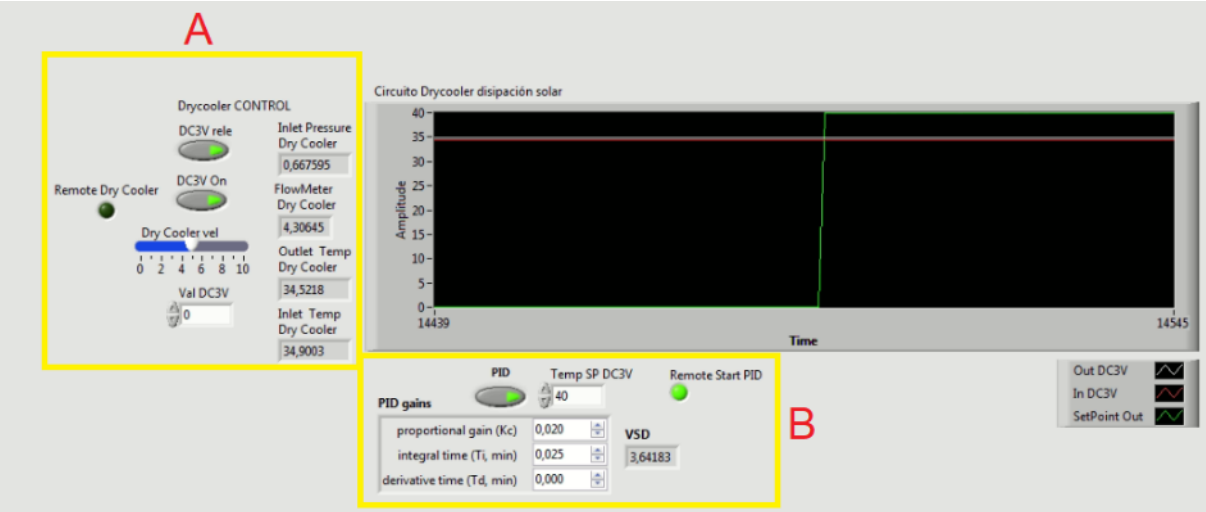

Figure 80. Parameters in Labview SCADA of cooling tower

In part A, the system can be controlled manually, and this is how the start-up was done; the system controls a relay to start the dry cooler and a frequency inverter for the speed of the fans. Part B controls the 3-way valve that sets a desired temperature at the outlet of the dry cooler.

The SCADA LowUP connect with the SCADA of the dry cooler and through the Scada LowUP the system can be controlled. The following figure shows the variable control of the dry cooler:

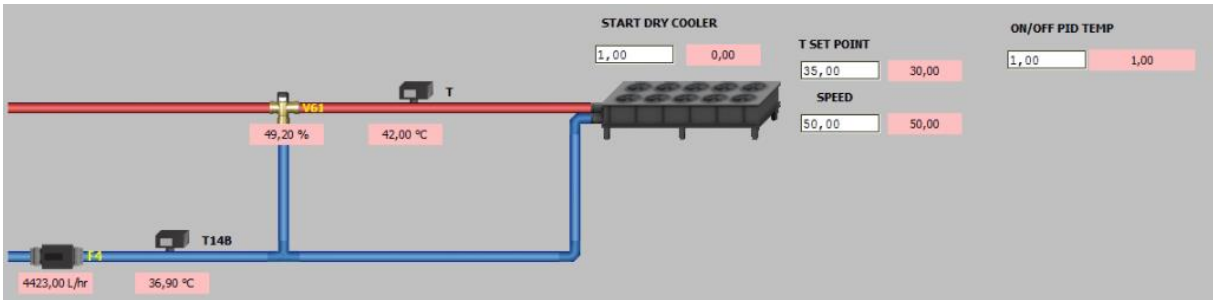

Figure 81. Parameters in SCADA LowUP of cooling tower

2.2.2.6 THERMAL EMULATOR

Start-up of this system was simple and this system only has a few resistors and a pump without speed variation.

The first thing checked was the pump control (Start/Stop), checking the flow variation with the flow meter. Later it was verified that the temperature and pressure probes measure correctly with other analogic equipment installed.

Finally, the Start/Stop of the resistors was checked, and that they worked together with the time programming.

To check this component was necessary making a work in the SCADA and checking if it worked. In the Thermal emulator view of the SCADA, it was necessary make test with Stat/Stop of the pump, Start/Stop of the resistance inside the tank and verifying control system of the resistance and pump to work automatically.

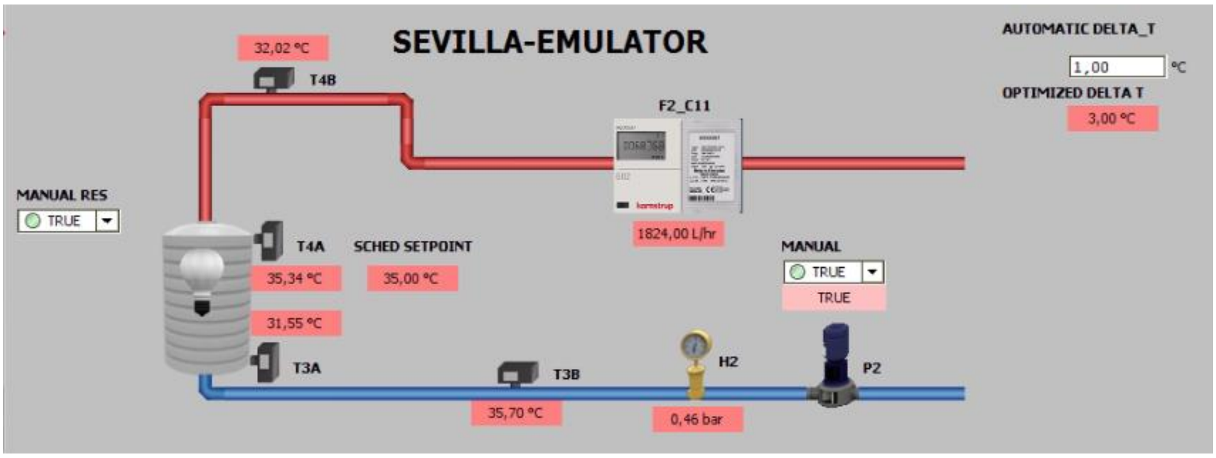

Figure 82. Thermal emulator view of the SCADA

Then it was developed a schedule to simulate profile performance and it´s showed in the following figure.

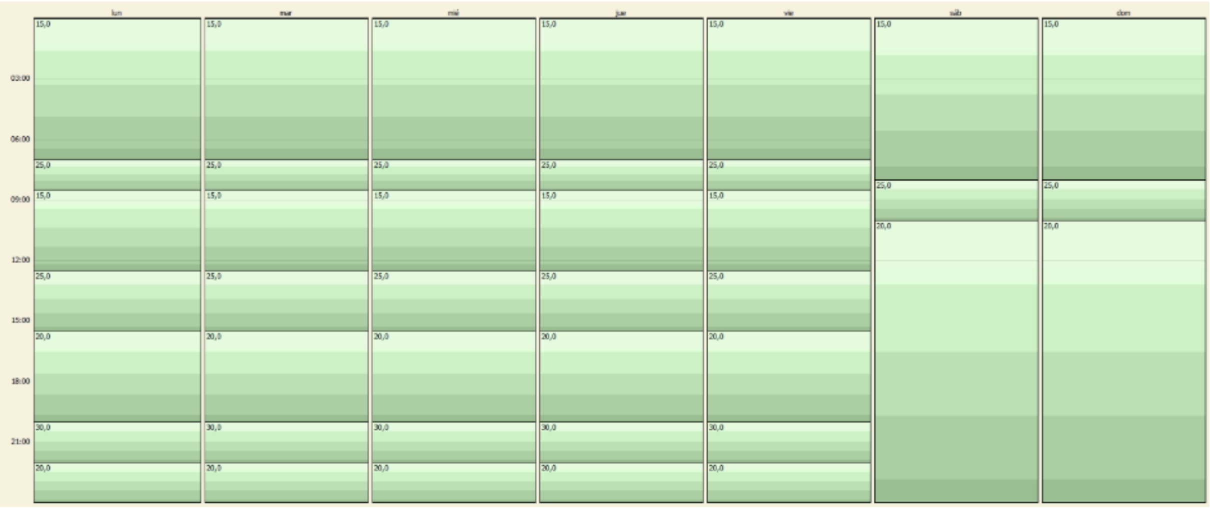

Figure 83. Schedule of Wasenco profile performance

With schedule, it was able to check if resistance, temperature and pressure sensor, circulating pump worked correctly.

2.2.2.7 AUXILIARIES

Same procedure and activities already described for Cool LowUP.

2.3 LowUP Manager

2.3.1 Commissioning at system level

2.3.1.1 COOL LOWUP

The manager of both heat and cool also had a multi-step start-up. The first one, once deployed on the server, was to verify that the manager executed each mode according to the evaluated conditions. Each mode is selected according to atmospheric conditions inside and outside the office; these conditions were forced to verify that the manager executed each mode correctly.

The following table shows the conditions that were evaluated to change modes in Cool LowUP:

Table 3. Cool LowUP modes

MODE	Description	Conditions
0	All equipment OFF	Unoccupied Free-cooling not needed (Tint < T_INT_MIN_FC) OR Free-cooling not possible (Text > T_EXT_MAX_FC_OFF) PCM charge not needed (PCM_melted% < PCM_MELT_CHARGE) OR PCM charge not possible (Twb > TWB_MAX_CHARGE)
1	Outdoor Air (OA) free-cooling <u>only</u>	Unoccupied Free-cooling needed (Tint > T_INT_MIN_FC) AND Free-cooling possible (Text < T_EXT_MAX_FC_OFF) PCM charge not needed (PCM_melted% < PCM_MELT_CHARGE) OR PCM charge not possible (Twb > TWB_MAX_CHARGE) ---------------------------- OR ---------------------------- Occupied Free-cooling needed (Tint > T_INT_MIN_FC) AND Free-cooling possible (Text < T_EXT_MAX_FC_ON)
2	OA free cooling + Charge of PCM storage	Unoccupied Free-cooling needed (Tint > T_INT_MIN_FC) AND Free-cooling possible (Text < T_EXT_MAX_FC_OFF) PCM charge needed (PCM_melted% > PCM_MELT_CHARGE) AND PCM charge possible (Twb < TWB_MAX_CHARGE)
3	Chilled Beams (CB) Auto ON; cold water supply from Cooling Tower (CT)	Occupied Free-cooling not possible (Text > T_EXT_MAX_FC_ON) Water FC from CT enabled (Twb < TWB_MAX_CTtoCB)
4	CB Auto ON; cold water supply from PCM storage (discharge)	Occupied Free-cooling not possible (Text > T_EXT_MAX_FC_ON) Water FC from CT not enabled (Twb > TWB_MAX_CTtoCB) PCM discharge enabled (PCM_melted% < PCM_MELT_DISCH)
5	CB Auto ON; cold water supply from chiller	Occupied Free-cooling not possible (Text > T_EXT_MAX_FC_ON) Water FC from CT not enabled (Twb > TWB_MAX_CTtoCB) PCM discharge not enabled (PCM_melted% > PCM_MELT_DISCH)
6	Charge of PCM storage <u>only</u>	Unoccupied Free-cooling not needed (Tint < T_INT_MIN_FC) OR Free-cooling not possible (Text > T_EXT_MAX_FC_OFF) PCM charge needed (PCM_melted% > PCM_MELT_CHARGE) AND PCM charge possible (Twb < TWB_MAX_CHARGE)

In order to force the conditions and be able to test the change between modes, it was necessary to establish some variables read by the manager to simulate certain atmospheric conditions.

The next step was to test that the manager was executing each mode correctly by setting PLC / SCADA variables and writing each variable necessary to activate each mode. By changing the conditions evaluated by the manager, this was done by setting values in the variables red by the manager, it was found that the manager could not write variables in the PLC / SCADA due to issues related to software permissions.

Once this problem had been solved, different situations were simulated and it was verified that the manager activated all the systems in optimized mode, activated equipment and regulated speeds, to make each Cool LowUP mode work. After these tests, it was necessary to change some things in the manager's programming because, in some modes, not all the necessary variables were activated and others were incorrect.

The next step was to leave the manager running daily every hour without writing variables in the PLC / SCADA and recording all activity in a log document. After several days, the log was reviewed to verify that, in real atmospheric conditions, the manager changed modes.

Finally, the manager's writing mode was activated and it began to function autonomously every day. In the first days it was necessary to make several corrections of lost connection and some exceptions. The following figure shows a log window where the manager has been run and the necessary variables have been written to activate mode 5.

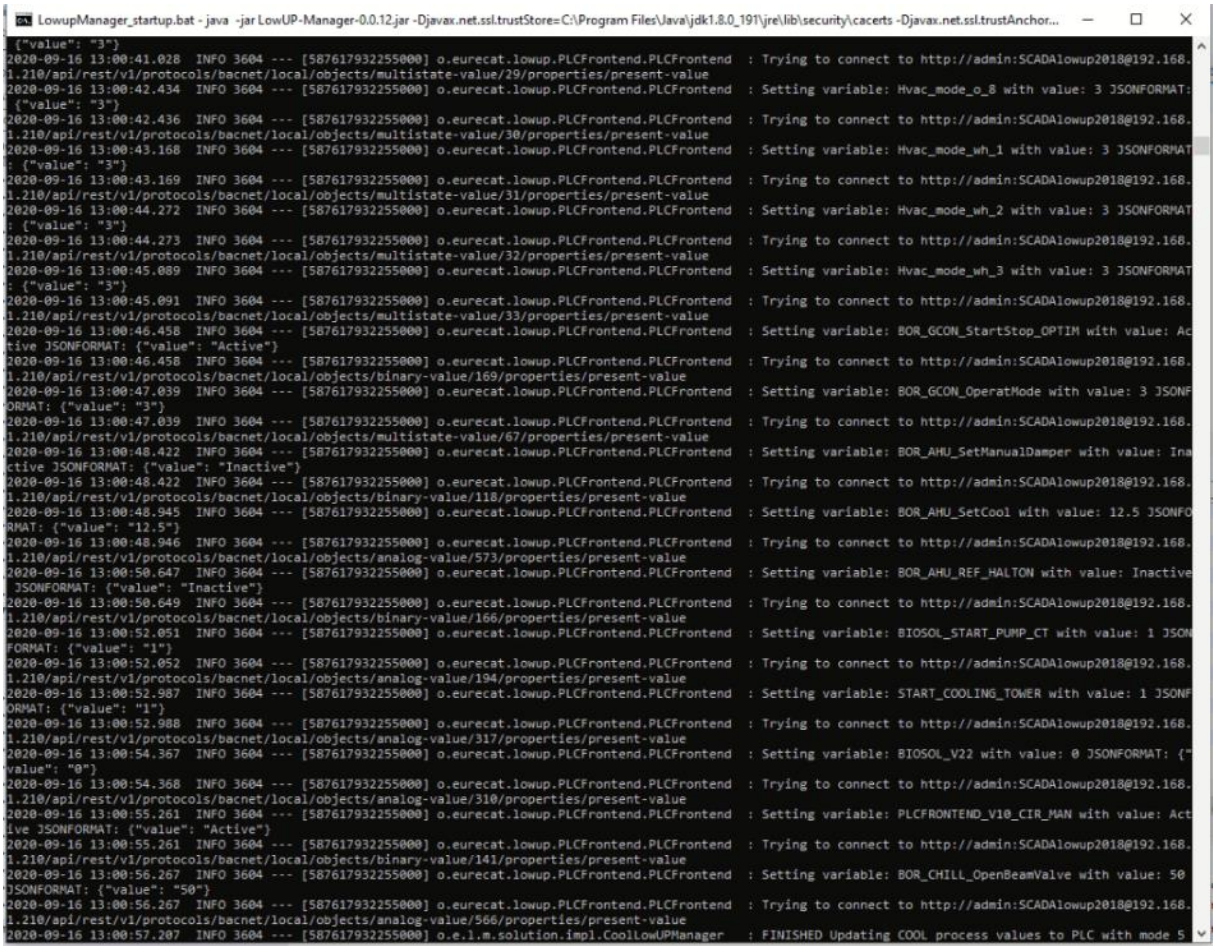

Figure 84. Manager setting variables

2.3.1.2 HEAT LOWUP

In the case of the Heat LowUP manager startup, it was much easier because many procedural errors had already been fixed in the Cool LowUP startup. However, the steps were the same. First, the change of modes was tested with non-real conditions, that is, setting variables in the PLC / SCADA on demand.

Fixed some bugs in the programming as, due to some error, it always kept between two modes. The variables evaluated for switching between HEAT LowUP modes are shown in the following table.

Table 4. Heat LowUp modes

MODE	Description	Conditions
1	No demand; backup disabled	Radiant floor system disabled No backup required (Ttank > T_SET_SUP + deltaT01) ---------------------------- OR ---------------------------- Radiant floor system enabled No demand (Troom >= T_SET_room) No backup required (Ttank > T_SET_SUP + deltaT01)
2	No demand; backup enabled	Radiant floor system disabled Backup required (Ttank < T_SET_SUP + deltaT01)
3	Existing heating demand; backup disabled	Radiant floor system enabled Existing demand (Troom < T_SET_room) No backup required (Ttank >= T_SET_SUP + deltaT01)
4	Existing heating demand; backup enabled	Radiant floor system enabled Existing demand (Troom < T_SET_room) Backup required (Ttank < T_SET_SUP + deltaT01)

Once this was solved, the next step was to write variables to the PLC / SCADA by the manager. This step ran smoothly because the permission issues had been fixed previously. In addition, it was verified that all the variables necessary to activate each mode were correctly written by the manager.

After this, the manager was left running for several days and supervised by the plant operators to check that everything was running properly.

2.3.2 Commissioning at concept level

This section explains the commissioning of the Cool and Heat LowUP concept.

2.3.2.1 COOL LOWUP

The Cool LowUP concept consists of charging the PCM tank in the less hot hours of the day and discharging the PCM tank with dehumidified and cold air from the AHU during the hours of daytime at office.

In order for the manager to execute the different modes of the system, it was necessary to configure the writing of variables in the PLC and check that the entire system worked correctly as a whole.In the system loading mode, it was necessary to supervise the system checking that all the flows, pressures, temperatures were correct.

In the first tests, a lack of flow was detected at certain points of the installation and once detected the problem was solved by purging the system. Another problem in this charging mode was that in the PCM tank unit the network connection was lost and the system stopped, which caused the chiller to stop due to not having a thermal gap in the production of cold water. The connections and cables were changed and this problem was solved.

In tank discharge mode together with dehumidified air, the chilled beams, AHU / chiller and PCM tank had to be checked and all worked well with each other. In this case, the chiller only cools and dehumidifies the give air from the AHU and the cold water that supplied the cold beams comes from the PCM tank.

Therefore, it was necessary to have very controlled that the thermal gap in the AHU / chiller was adequate so as not to have problems with the compressor shutdown, since this caused condensation problems within the office. The following figures show the condensation problems that existed inside the office due to a high relative humidity problem.

Figure 85. Condensation problems in chilled beams

It was also necessary to verify the operation of the water circuit that works between the chiller and the cooling tower so as not to have problems of overheating and loss of flow.

It was also necessary to check that the PCM tank had a constant flow and within the working ranges. In addition, the cold water supplied to the chilled beams was around 16ºC. Once all these parts of the system were working correctly it could be said that the system in this mode was working properly and the manager could activate it safely.

2.3.2.2 HEAT LOWUP

The main and most representative operation mode in HEAT LowUP is charging of hot water from solar thermal, accumulation in a stratified tank and discharge of the heat accumulated in the tank through radiantfloor heating.

For this, it was necessary to check the hydraulic part of the solar panels, secondary elements in the installation (pumps, 3-way valves, etc.), the temperatures in the stratified tank, and the impulsion of water towards the radiant floor.

In the hydraulic part of the solar panels, it was tested that setting a temperature setpoint to be achieved in the solar field; the speed of the pump varied to achieve it. Then it was necessary to check that the 3-way valve installed between solar panels and stratified tank from the solar panels, it supplies water when temperature setpoint is overcome.

To supply hot water from the tank to the radiant floor, it was necessary to check that the two pumps installed in series were working correctly and at the same time. Once this check was done, the 3-way valve should check the inlet temperature of hot water to the heated collector of the underfloor heating.

Once these checks were carried out part by part, the operation mode was activated and the temperature and relative humidity of the room was controlled by the RDZ controller to keep the comfort state within the office.

When it was verified that this mode worked correctly, control was left to the manager so that, according to certain conditions, it could modify the setpoints of the pump, the 3-way valves and the room temperature.

3 Badajoz Demo Site

Part of Heat LowUP was installed in the university residence of Badajoz, in order to have a relevant environment where to test installation procedures and operation of waste water heat recovery system by Wasenco.

The hat recovery system can operate against a real load and can return to the building part of the heat proceeding from waste water, with the objective to reduce part of the boiler operation necessary to operate dishwashers.

3.1 Waste heat recovery system

Key technology of waste water heat recovery system is the storage tank manufactured by Wasenco, able to store in water the heat from kitchen waste and transmit to local tap water network. The tank is composed by 2 different tubular heat exchangers (waste and tap) submerged in neutral water, used like storage/buffer for heat transmission.

The under specific conditions, the heat recovery system would be able to work only by gravity, but for Badajoz case auxiliary components were required due to installation of the tank below the level of municipality sewage collectors.

This level mismatching required an additional pumping station able to win necessary pressure head; as consequence the pumping station required a grease separator tank to avoid problems of grease condensation around rotating elements of the pumps.

In scheme below, is possible appreciate the lay-out of the system, completed with sensors and actuators.

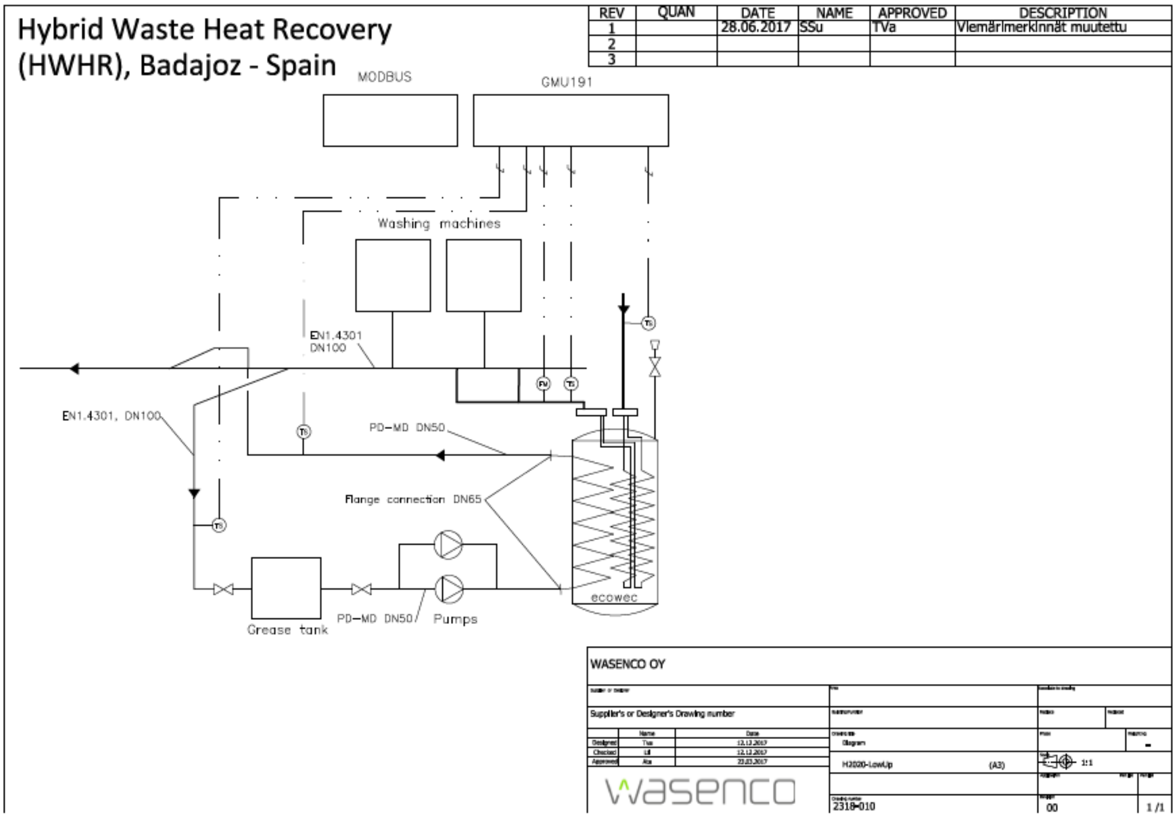

Figure 86. P&ID of Wasenco system installed in RUCAB

3.1.1 Commissioning at component level

Some minimal requirement of stability of the equipment during emplacement are common to all components of the system, and so do for piping over walls or suspended in the air with anchorages and electric cables from main power supply cabinet.

3.1.1.1 Hybrid Waste Heat Recovery Tank

The tank, as individual element, is composed only by passive elements of steel and copper, which compose the connections with waste water piping and tap water. No moving parts are present nor electrical so the verification was mainly focused on identification of leakages of joints and air purging.

Purging was necessary for filling the heat storage medium of the tank, through specific connection of tap water with the interior of the tank; the safety valve was used to purge the air pushed out from inlet water.

Tap water piping is an open loop whose flow is pushed by gravity, so purging is not necessary; test was mainly conduced over resistance of valves to network pressure, automatic purge of tank in case of excess of dilatation of water for heat, and correct circulation within the tank.

On other hand, waste water piping doesn't require any purge, because of the batching nature of waste flow toward municipality collectors; main activity was ensuring the correct connections for circulation of waste inside the tank and tightening of joints for avoiding leakages.

In next image is possible to appreciate tap and waste water connection to tank during commissioning.

Figure 87. Connections of piping to tank

Special attention was given to the static pressure of water inside the tank, in order not to damage the metallic components over time, for cyclical expansion events.

3.1.1.2 Degrease Tank

The grease separator tank works as passive elements where separation between liquid and solid is achieved during time for natural flocculation of grease and floatation aver the surface of water;

connections are made in a way that this process is pushed naturally and only liquid flows toward pumping station.

Attention was paid to piping joints, in order to avoid leakages and so undesirable smells, and possible obstructions of separation channel during the first charge of the tank with waste water. Great attention was also paid to first visual inspection in order to detect possible cracks in the structure, due to shipping, which could cause great disease during operation.

In following picture the tank during leakage tests with clean water before first waste water.

Figure 88. Grease tank

3.1.1.3 Pump System

Pump station is the only active element of the system and is composed by a group of twin pumps installed over a smaller tank, whose control system is driven by minimum and maximum levels of fluid inside the tank; this means that every cycle the station moves the same amount of fluid.

Main attention was paid to tightness of the joints, mainly toward the heat recovery system, where pressure head can have more influence; on other hand, correct connection of the phases of the pumps was checked to avoid wrong rotation.

Sensors of minimum and maximum was cleaned and tested in dry conditions, to check proper signal transmission to proprietary control station; at the same time voltage for power supply was checked and connection to local electricity cabinet were verified with overcurrent and shortcircuit tests.

Once pump tank was partially filled with clean water, pumps were activated manually to validate individual, alternate and twin operation of both pumps; next test was conducted with the tank full of water and with continuous flow of incoming water.

Once manual test were completed, the control of the pumps was set in automatic, to check operation between both level limits, with automatic ON/OFF according to water quantity. At lower water level the pump switches off; at higher switches on.

Figure 89. Pumping tank station

3.1.1.4 Monitoring and remote communication system

In order to transfer to Seville demo results of operation, the entire system have been provided with different kind of sensors, in order to monitor temperature, pressure, flow and electricity.

All sensors were connected to wasenco plc, which was connected via Modbus to local embedded pc. The pc is communication via 3G to remote SCADA of Seville, where data are used for emulated operation of the tank.

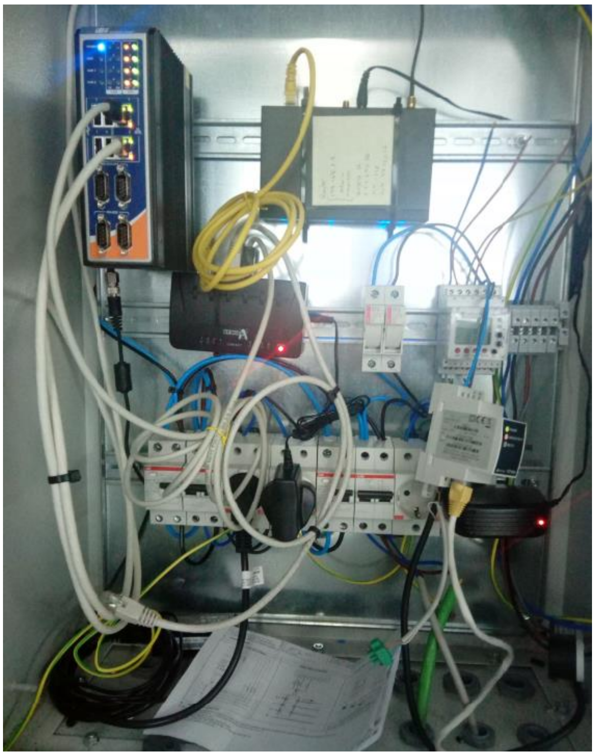

Figure 90. Electrical cabinet with embedded pc.

All sensor were individually tested in terms of voltage and connection with the plc, for having coherent reading. Once all reading were confirmed, next step was the communication between plc and pc, in order to store locally all data gathered during operation.

Once communication was established, following step was communication of pc to Seville plc via internet, using master-slave hierarchy over 3G; this step required configuration of the router and of communication protocol on both sides of the transmission.

Final attention was paid to automatic restoring systems in case of energy breakdown, which is quite frequent due to the poverty of the existing electrical system of the building. Al system have to switch on when powered, restoring correct configuration and recovering session where interrupted.

Figure 91. Global view of the plc of Wasenco system

3.1.2 Commissioning at system level

Final commissioning was achieved switching on one by one each component, starting from the monitoring and control system, in order to manage the pumps and verify the correct distribution of temperature along the loops and tanks.

Then waste water loop was opened maintaining closed the outlet valve of grease tank, in order to fill up to a consistent level; after a prudential time, valve was opened and water was moved to pumping tank gradually; once maximum level was achieved, pups stared automatically filling the recovery tank until reaching minimum level and so stopping again.

Temperature changes were detected in the different points of the loops and registered al plc and pc level. Communication with remote was tested and data transferred as expected. Power was cut off and then supplied again to check auto restore of all the system at operating conditions.

Finally clean water circuit was opened and checked in water modification of temperatures. The system was now totally and correctly operating.

4 Conclusions

In order to commissioning each concepts, some previous steps required to be fulfilled for preparing the operation as a whole: verification of basic components, verification of sensors and actuators, verification of loops and circuits, verification of equipments, verification of communication and control systems, and finally operation of combined elements.

Main issue was related with purging water loops from air; short time purges most of time are inefficient because able to remove only part of the air dissolved in the water. Longer times of operation with pumps at different speeds and with utilization of manual valves for sectioning the systems gave the best results.

Main troubles raised with individual controllers for all manuafactures; setting the proper configuration was the most complex thing because of reduced flexibility of manufacturer control system. Long time was spend testing different parameters until reaching the most optimal configuration for operation according to LowUP strategies.

On other hand communication through bus, according to distributed control, evidenced how lack of uniformity in utilization of communication protocols, from manufacturer to manufacturer, make harder the right interpretation of transmitted data. Most of time plc LowUP plc had to be reconfigured for adapting to existing gateways.

Unfortunately project experience rose how proprietary control systems are hardly modifiable, implying a huge amount of time in finding the right configuration for operating as expected. In this case the hardest work is done by the integrator which have to modify the master operation according to slave logic, which results time eater and not standardized because one only device had be adaptive for many other different among them.

Nevertheless integration was achieved and total control can be set from LowUP plc-SCADA in manual, automatic and optimized operation. Integration between manager and SCADA was successfully achieved, allowing sensor data transmission in both way and setpoints writing over LowUP subsytems.

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