# DELIVERABLE 4. PILOT PLANT DESCRIPTION

**Research project: Design and evaluation of descarbonisation strategies to achieve near zero emissions indoor swimming pools assisted by renewable energies – nZEPools (TED2021-131173B-I00)**

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## 1. Introduction

One of the objectives of this research project is the design and construction of a pilot plant based on a transcritical CO2 heat pump which satisfies part of the hot water demand of an indoor swimming pool placed in La Aljorra, Cartagena, Spain.

This deliverable describes the different components of the heat pump developed, the inclusion of this in the hot water production system and its coupling with the domestic hot water (DHW) circuit and that of the water pool heating system is described jointly with the control system suggested.

## 2. Heat pump description

The heat pump is an air-to-water heat pump formed by a compressor, a gas cooler for the production of DHW, another gas cooler to heat the swimming pool water, an electronic back-pressure valve to guarantee optimum high pressure, a liquid receiver, an electronic expansion valve to control the superheating, and an evaporator. Their specification are summarised in Table 1 and a schematic view of this is depicted in Figure 1. Gas coolers are SWEP plate heat exchangers and the evaporator is a Gütner fin-and-tube heat exchanger.

Table 1. Heat pump component specifications.

| Device | Model | Specification |
| --- | --- | --- |
| Compressor | Bitzer 2KTE-7K | $W_{e,max}$ = 9.2 kW |
| Gas cooler DHW | SWEP B4TH×52 | $A$ = 0.60 m$^2$ |
| Gas cooler pool | SWEP B4TH×96 (3 in parallel) | $A$ = 1.13 × 3 m$^2$ |
| Back pressure valve | CAREL | E3V30CWM00 |
| Electronic expansion valve | CAREL | E3V45CWM00 |
| Evaporator | GÜNTNER GACC CX | $A$ = 71.30 m$^2$ |

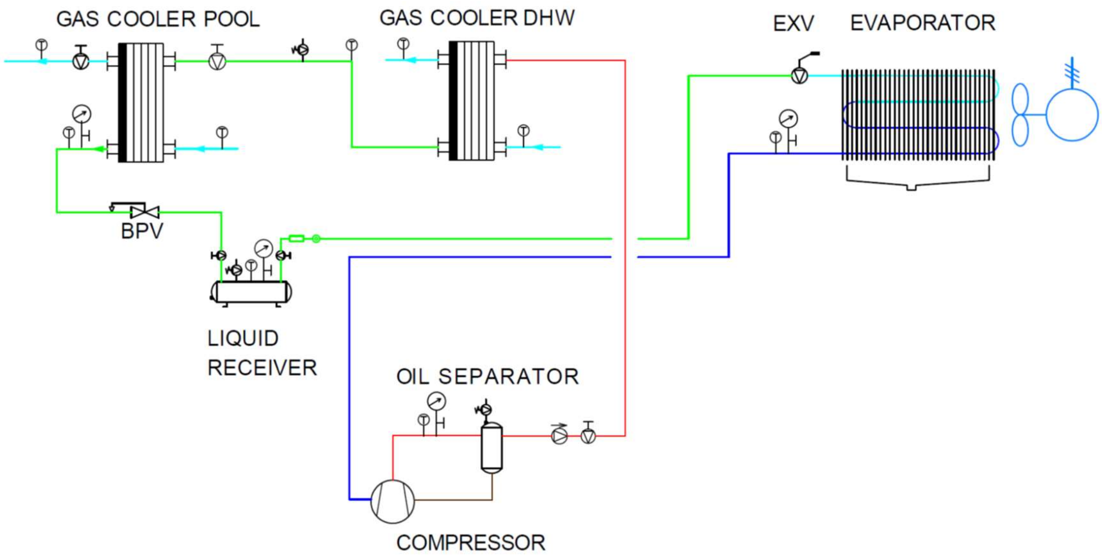



Figure 1. Heat pump schematic view.

### 2.1 Compressor

The compressor selected is a Bitzer transcritical $CO_2$ compressor model 2KTE-7K (Figure 2).

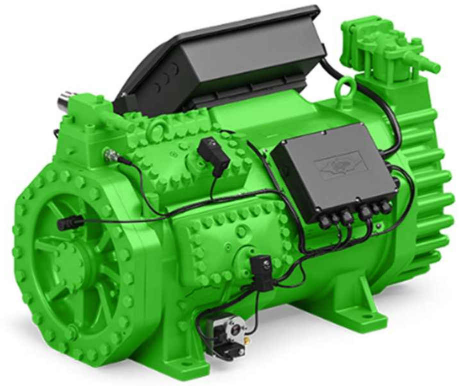


Figure 2. Bitzer compressor, model 2KTE-7K.

Its characteristics are given in the Table 2.

Table 2. Technical characteristics of the compressor.

| | |
|---|---|
| Displacement (1450rpm 50Hz) | 4.8 $m^3/h$ |
| Oil charge | 1.2 l |
| Motor voltage | 380-420V Y-3-50Hz |
| Max. operating current | 16.1 A |
| Max. power input | 9,2 kW |

**2.2 Metering devices**

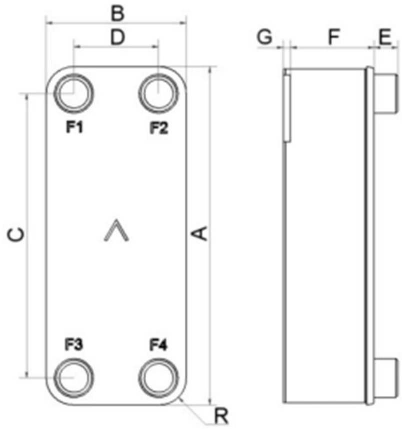
As mentioned, the expansion valves employed in the installation are both CAREL electronic valves. The back pressure valve (Carel E3V30CWM00) allows us to control the pressure in the high-pressure zone and is located at the outlet of the pool gas cooler. On the other hand, the expansion valve (Carel E3V45CWM00) allows us to control the superheating and is located between the liquid receiver and the evaporator (Figure 3a). The control of the valves is carried out by means of two Carel PID model EVD Evolution (Figure 3b).


a) b)

Figure 3. Carel expansion valve E3V and EVD Evolution PID.

## 2.3. Gas coolers

Two SWEP plate heat exchanger has been used in the installation. They are model B4TH (Figure 4a). Their dimensions according to the schematic view of Figure 4b are gathered in Table 3. The pitch 1.06 mm.


a) b)

Figure 3. Swep B4TH plate heat exchanger.

Table 3. Gas cooler dimensions.

| | Dimensions [mm] |
|---|---|
| **A** | 194.50 |
| **B** | 76.90 |
| **C** | 154 |
| **D** | 40 |

The gas cooler used for DHW production is a Swep B4TH x 52 plates. It has an exchange surface of 0.60 $m^2$. According to the manufacturer, its overall heat transfer coefficient (OHTC) at design conditions (Table 4) is 4870 W/ $m^2$.

Table 4. Design conditions for Swep B4TH x 52.

| | R744 ($CO_2$) | Water |
|---|---|---|
| Inlet Temperature [ºC] | 54.40 | 10.00 |
| Outlet Temperature [ºC] | 30.00 | 36.75 |
| Flow rate [kg/s] | 0.2061 | 0.300 |

The gas cooler for the pool used in the installation is formed by 3 units of Swep B4THx96 plates connected in parallel. It has an exchange surface of 1.13 × 3 $m^2$. According to the manufacturer, its overall heat transfer coefficient (OHTC) at design conditions (Table 5) is 2500 W/ $m^2$.

Table 5. Design conditions for Swep B4TH x 96.

| | **R744 ($CO_2$)** | **Water** |
|---|---|---|
| Inlet Temperature [ºC] | 54.40 | 28.00 |
| Outlet Temperature [ºC] | 30.00 | 33.00 |
| Flow rate [kg/s] | 0.0687 | 0.5361 |

**2.4 Evaporator**

The evaporator selected for this installation is a Güntner fin-and-tube evaporator model GACC CX 040.1/2WN/HJA4A.UNNN (Figure 4).


Figure 4. Güntner evaporator.

According to Figure 5 view, evaporator dimensions are as follows:

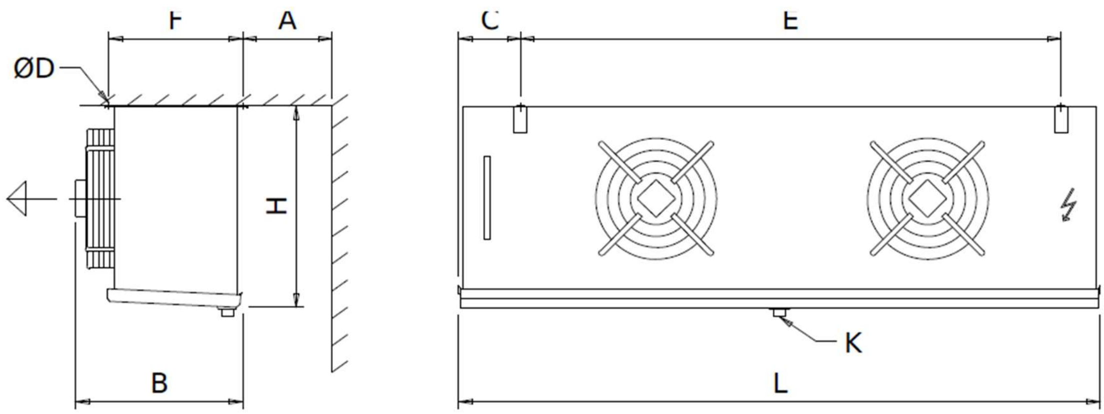



Figure 5. Güntner evaporator schematic.

L =1866mm B =560mm H =565mm E =1360mm F =406mm C =177mm
A =400mm D =11mm K=G1$_{1/4''}$

Its general characteristics are as shown in Table 6:

Table 6. General evaporator characteristics.

| | |
|---|---|
| Exchange surface | 71.30 $m^2$ |
| Tube volume | 7.3 l |
| Fin pitch | 4 mm |
| Number of pitches | 20 |
| Distributions | 4 |

As was said in Deliverable 2, to characterise this evaporator, the IMST-ART software has been used, which requires the geometrical data of the heat exchanger in Table 7.

Table 7. Geometrical data of the heat exchanger.

| **General dimensions** | |
|---|---|
| Exchanger width [m] | 1.36 |
| Longit. spacing [mm] | 25 |
| Trans. spacing [mm] | 25.4 |
| **Tube data** | |
| Tube material | Copper |
| Outer diameter [mm] | 9.525 |
| Thickness [mm] | 0.8 |
| Inner surface | Smooth |
| **Fin data** | |
| Thickness [mm] | 0.1 |
| Fin pitch [mm] | 4 |
| Type | Plain |
| Material | Aluminium |

**3. Instrumentation**

Next, we will describe the sensors that have been used in the installation for its monitoring. The sensors used in the installation are depicted in Figure 7 and are described below specifically.

**Temperature sensors**, these sensors incorporate a silicon rubber patch with an adhesive silicone rubber sheet inside where the sensor element is located. To improve the response time, favouring the thermal contact is recommended by cleaning the surface on which the sensor is applied. The Pt100 element complies with IEC 60751 class B standard and has a 4-wire configuration (Figure 8).

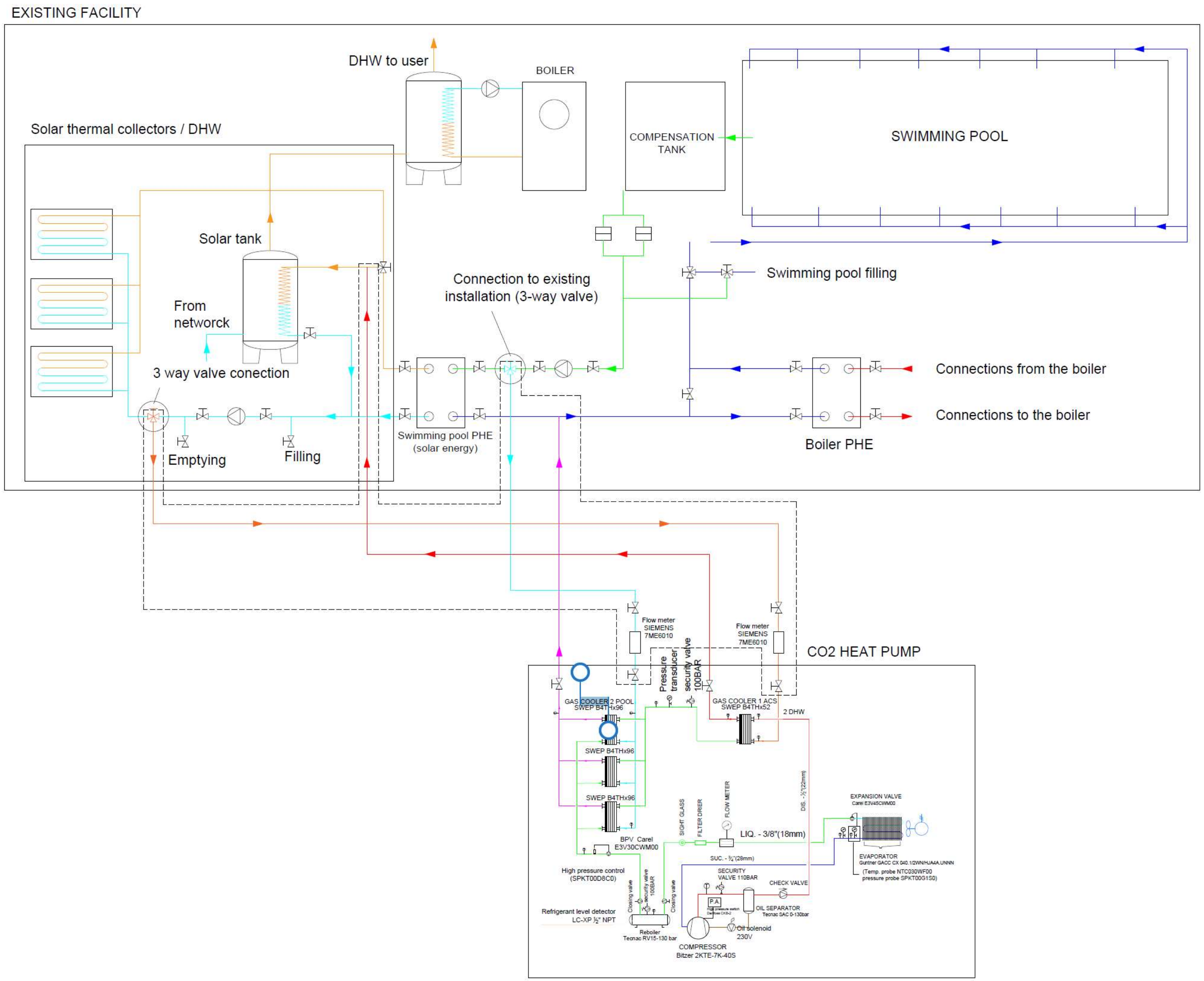



Figure 7. View of the installation with the different sensors installed.

Figure 8. Temperature sensor Pt100.

**RS PRO Manometric Pressure Sensor**, used to measure the pressure of specific quantity, such as air, water and gas, by changing the pressure into electrical energy. The probe uses a piezoresistive ceramic sensor that provides excellent media compatibility within a stainless-steel housing (Figure 9). It measures pressure over the range of 0 bar to 250 bar with an accuracy of ±2.5%. Its output signal is in the range of 4 mA-20 mA. When the sensor measures 4 mA it will correspond to 0 bar and when it measures 20 mA it will measuring 250 bar, so the PLC software will make a linear relationship to determine the pressure as a function of the mA measured by the sensor.


Figure 9. RS PRO Manometric Pressure Sensor.

**Humidity and temperature meter.** The sensor used to measure relative humidity and air temperature is an EE160 by E+E Elektronik which according to the manufacturer, is a sensor optimised for cost effective, accurate measurement of relative humidity (RH) and temperature (T) in building automation (Figure 10). Two such sensors are used, one to measure pool ambient temperature and humidity and the other outside to measure ambient street conditions.

The measured data is available on two voltage or current (2-wire) outputs, or on the RS485 interface with Modbus RTU protocol. Additionally, the EE160 features a passive T output, and an optional display visualises RH and T values simultaneously.

It measures temperatures in the range of -40°C to 60°C with an accuracy of ±0.3°C. Relative humidity is measured in the range of 0%-100% with an accuracy of ±2.5%.


Figure 10. Humidity and temperature meter EE160.

**Coriolis flowmeter** measures the mass flow rate and density in the refrigerant circuit with high accuracy. The Coriolis sensor installed is a Siemens Sitrans FCS500 with an FCT020 transmitter (Figure 11). Measures are allowed at temperatures in the range of -50ºC to 150ºC. It is of the compact one with “urethane-cured polyester powder coating” coated aluminium transmitter housing.

Figure 11. Coriolis flowmeter SITRANS FCS500 with FCT020 transmitter.

**Electromagnetic flow meters.** The flow meters used in the water circuits are Siemens SITRANS FM100 full-bore electromagnetic flowmeter (Figure 12). They are designed for measuring the flow rate and temperature of conductive liquids in industrial applications, including the process industry, dosing systems, and so on. This model features a process connection range of G 1/2 to G 2 (with an available adapter for 1/4" to 2" NPT) and a G1" male thread, allowing it to integrate seamlessly into various industrial setups. With a compact, cable-free design and FKM/FPM seals, it is built for precision and durability in demanding environments, though it does not come with a calibration certificate.

The only difference between the two models selected for the facility lies in the measuring range: the '3AA00' model measures flow rates from 0.2 to 50 l/min, while the '3CA00' model extends the measuring range from 0.4 to 100 l/min. We use them to measure the water flow rate of the swimming pool circuit and the domestic hot water circuit.


Figure 12. SITRANS FM100 Electromagnetic flowmeter.

**Pyranometer.** The one used in the installation is the SMP3 is a smart pyranometer with low maintenance and industry standard digital and analogue amplified outputs. Based on the proven CMP3 technology the SMP3 adds Modbus® interface, improved response time and temperature corrected measurement data (Figure 13). The wide and low power supply range from 5 to 30 VDC makes integration in meteorological stations easy. The SMP is protected against over voltage, reversed polarity and short circuiting. Because all SMP's have identical sensitivity and connections exchanging instruments during recalibration is easy.

SmartExplorer Windows™ for data logging, display of data and Modbus® address setting is provided as standard.

SMP3 measures global solar radiation on a horizontal plane. When tilted with the same angle as a PV panel it measures the tilted global radiation, for PV module efficiency calculations. It complies with ISO 9060 spectrally flat Class C, has an analogue output of 0 to 1 volt or 4 to 20 mA and an active temperature correction from -40 °C to +80 °C.

Figure 13. SMP3 Pyranometer

Table 8 summarises the main characteristics of the pyranometer.

Table 8. Pyranometer characteristics.

| | |
|---|---|
| Temperature sensor Pt100 | ±0.3°C |
| RS PRO Manometric Pressure Sensor | ±2.5%. |
| Humidity and Temperature Meter EE160 | ±0.3°C |
| Coriolis Flowmeter | |
| SITRANS FM100 Electromagnetic Flowmeter | |
| SMP3 Pyranometer | ±10% |

**4. PLC or Monitoring system**

The PLC used in the installation is a Siemens SIMATIC S7-1200 (Figure 14). This has a series of cards for reading RTD sensors (6ES7231-5PF32-0XB0), sensors with analogue voltage and current outputs (6ES7231-4HF32-0XB0), and an analogue output card (6ES7232-4HB32-0XB0). Their main characteristics are in Table 9. This configuration allows the control of the back-pressure expansion valve, in charge of regulating the high pressure of the heat pump and optimise its value.

Figure 14. Siemens SIMATIC S7-1200 PLC.

The PLC calculates the optimum pressure by means of a programmed expression already presented in deliverable 2 and adjusts the opening of the valve to maintain the pressure at the right level in the high-pressure part, optimising the operation of the installation. In addition, the PLC is used as a data acquisition system to record the monitored variables, storing this information for further processing.

Table 9. Description of the analogue input/output cards.

| Units | Card | Type | Function |
|---|---|---|---|
| 2 | 6ES7231-5PF32-0XB0 | Input | RTD measurement (up to 8 sensors) |
| 2 | 6ES7231-4HF32-0XB0 | Input | Voltage or current measurement |
| 1 | 6ES7232-4HB32-0XB0 | Output | Voltage or current output (Act on the back pressure valve) |

A SCADA has been developed to have a real time view of the system (Figure 15).

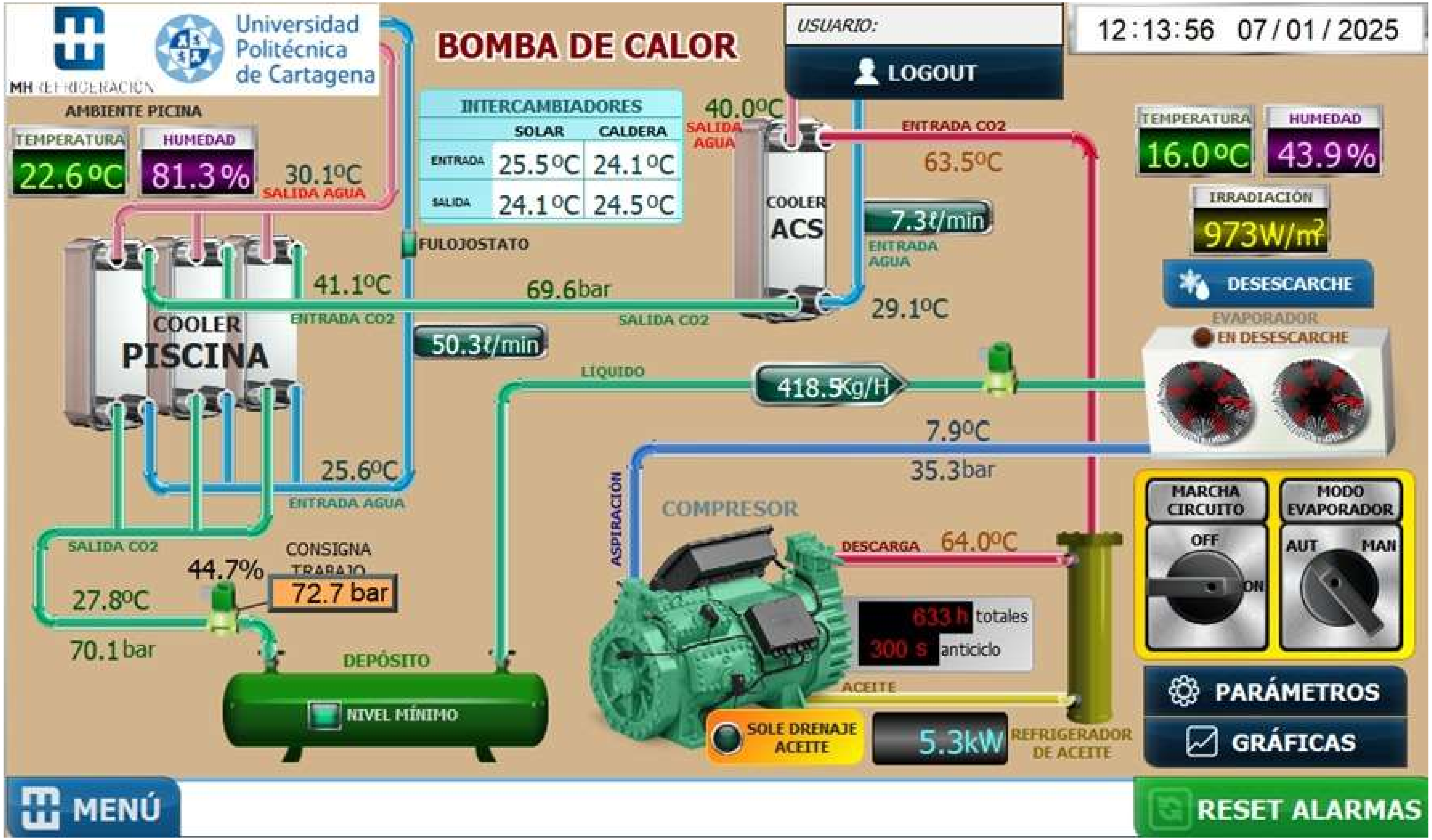



Figure 15. View of SCADA developed to monitor the installation.

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