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MANAGEMENT TOOL REPORT

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D4.1 Management Tool Report

1. Introduction

The monitoring and visualization is a very important component of any system since what is not measured and monitored cannot be managed and improved[1]. This report (D4.2) describes the implemented monitoring and control architecture for the CHESS SETUP and it can be treated as the CMS (Control and Monitoring System) User's Manual of the HMI (Human Machine Interface) for the system operators and administrators.

Chapter 2 describes the eventual implemented hardware and software control and monitoring architecture. Chapter 3, describe the manual for the user interface for all the tasks of system visualization and operation, plotting and data export. The system provides a synoptic end-user simple and friendly view for non-advanced users and, at the same time, highly descriptive and tuneable screens for adjusting all the parameters involved in the system operation. Finally, in chapter 4, the low-level raw database is described to allow expert users obtain raw data from sensors and actuators, and high-level information calculated by the CMS from the low-level data such as performances or energy savings that will help the operators in the system follow up.

[1] *Lord William Thomson Kelvin*: If you cannot measure it, you cannot improve it.

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2. System control and monitoring

The CHESS SETUP Control and Monitoring System (CMS) is organized into two layers: the low and the high-level control and monitoring subsystems.

Low-Level Control & Monitoring Subsystem (LLCMS): This layer will contain an industrial-like controller (PLC) with a low ratio of failures to obtain a very robust final system.

This controller does not typically have secondary memory, therefore, no databases will be considered at this level. Only absolute counters such as energy, power or temperature will be registered and monitored at this level.

There is no interaction between the end-user of the system and this layer, so any problem at this level must be solved by either the installer if it is a physical problem (sensors, actuators, etc...) or by the developers if it is a software problem. After the system commissioning, unless a modification is required, this system is typically not modified.

High-Level Control & Monitoring Subsystem (HLCMS): This layer provides a less robust PC-like computer controller with large secondary memory (i.e., a hard drive) to store large database logs of variables and parameters. This PC computer also interacts with other computers by using the Internet to obtain the electricity grid hourly energy prices.

This controller offers the possibility to the end-users, i.e. viewers, operators, and administrators, to interface locally (via the local network) or remotely (via Internet) using any device such as a PC, a Smartphone or a Tablet.

2.1. Users

In the CHESS SETUP system, there are four different roles defined from what manipulations can be performed on the system using its input interface and to what subsystems a role can access. The administrator roles are allowed to change different configurations in the system while the operators and the viewer roles can only operate on the CHESS SETUP visualization and control tool (CMS). The different roles are protected by passwords and a physical user can have more than one role.

- **Viewer Role:** This role is allowed to operate locally and remotely and it has full visualization permission of any variable, parameter and alarm from the user interface. It also can generate and export reports.
- **Operator Role:** This role has the full right to modify anything by using the interface locally or remotely. This operator can also validate and clear the alarms and typically also receives them by e-mail. This role will be responsible for ordering the actions to solve the alarms.

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- **Database Administrator:** This role has full rights to create modify, delete, import or export anything in the database locally or remotely.
- **System Administrator:** This role has permission to modify anything in the system: the software, the databases, and the PC operating system. This role is reserved only for the programmers and administrators of the system.

Table 2.1 shows a summary of the tasks that every role can perform in the CHESS SETUP CMS.

Role Name	Viewer	Operator	Database Administrator	System Administrator
View				
View information in local PC Screen	√	√		√
View information remotely	√	√		√
Modify				
Modify variables using local PC Screen		√		√
Modify variables remotely		√		√
Modify setpoints using local PC Screen		√		√
Modify setpoints remotely		√		√
Modify parameters using local PC Screen		√		√
Modify parameters remotely		√		√
Alarms				
View alarms in Local PC Screen	√	√		√
View alarms remotely	√	√		√
Receive alarms via e-mail	√	√	√	√
Administration				
Modify the Database			√	√
Administrate the PC System				√

Table 2.1: Role summary of the Control and Monitoring System (CMS).

2.2. Network Architecture

From the network point of view, the system is in a TCP/IP local area network (LAN). Any user can connect locally by plugging a cable physically to the LAN switch. The LAN is behind a router with a Firewall that protects the system against any intrusion from outside (WAN, Internet).

An authorized user can connect from outside (WAN) by using a VPN software using its credentials (user name and password). The VPN software allows the user to be recognized in the network as if he was connected physically to the LAN.

From the LAN, either physically or virtually through the VPN, a user can use his credentials (user and password) to login to the system and perform any task he is allowed to do.

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Figure 2.1 shows the CHESS SETUP network architecture. Operator and viewer uses are allowed to connect to the local network (LAN) directly to the switch or from the Internet using a VPN-tunneled connection. Once locally, the users can access to the CMS system that is running on top of a PC computer. Administrator users and software developers can connect to other hardware devices such as the heat pump, solar inverters, and PLC controllers.

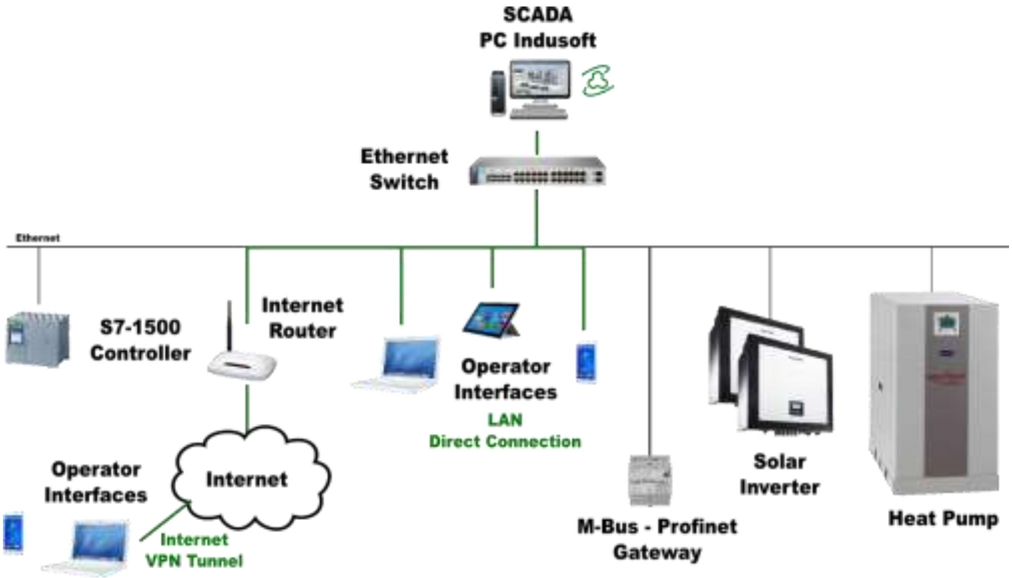

Figure 2.1: CHESS SETUP network architecture.

2.3. Energy flow monitoring

The final implementation of the system has been very similar to the planned in previous deliverable "D4.1 Monitoring report system". From the point of view of the monitoring and control, the CHESS SETUP concept and final implementation can be divided into the following subsystems:

- **Production:** Energy is produced by hybrid solar panels (PVT). Therefore, in this subsystem, both electrical and thermal energy is produced.
- **Distribution:** The energy is moved from a subsystem to another. This subsystem produces thermal energy losses and consumes electrical energy. Direct energy measurement is not available however a combination of lectures can be used to calculate these losses (chapter 3.5.1.2).
- **Storage:** The energy is stored in the form of hot water. This subsystem also produces thermal energy losses.
- **Conditioning:** This subsystem provides thermal energy to the buffer tank using a heat pump that has the Seasonal Thermal Energy Storage (STES) as the source. The CHESS SETUP approach aims to obtain a high Coefficient of Performance (COP) to minimize the electrical input for the heat pump. The

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system will try always to operate without using the heat pump which is the most electrical consuming element.

- **Client:** This subsystem delivers energy to the final customers. In this subsystem, the energy is typically buffered in a hot water tank. An auxiliary heating system is considered to overcome the case of a failure in the main supply or as a last step of conditioning when necessary. This system may consume electrical energy as well as auxiliary energy (Natural Gas).

Figure 2.2 shows the monitoring conceptual version and figure 2.3 shows the final implemented version.

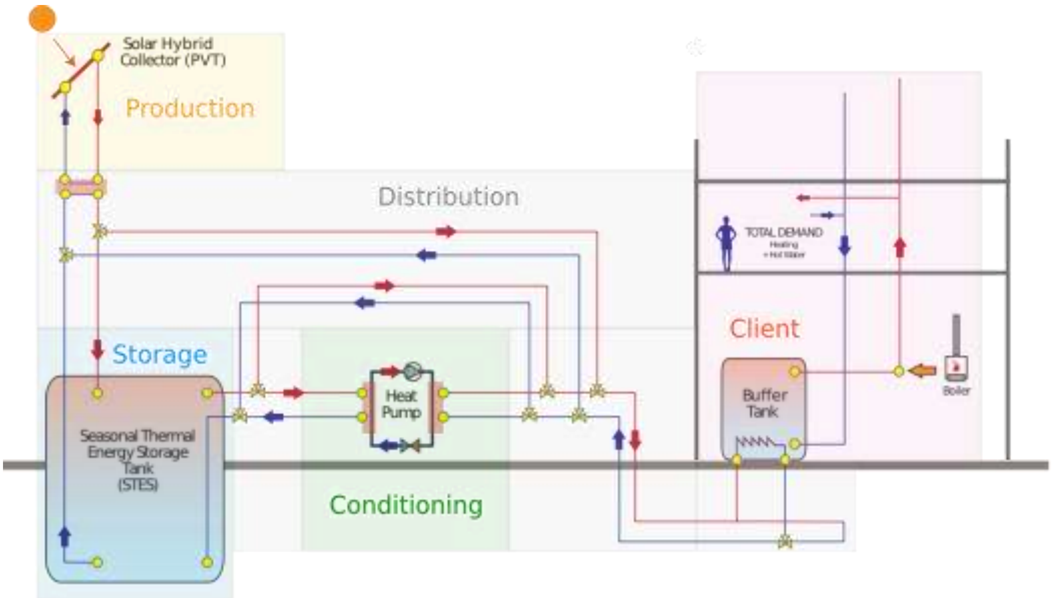

Figure 2.2: Monitoring subsystems in the CHESS-SETUP project (Deliverable 4.1)

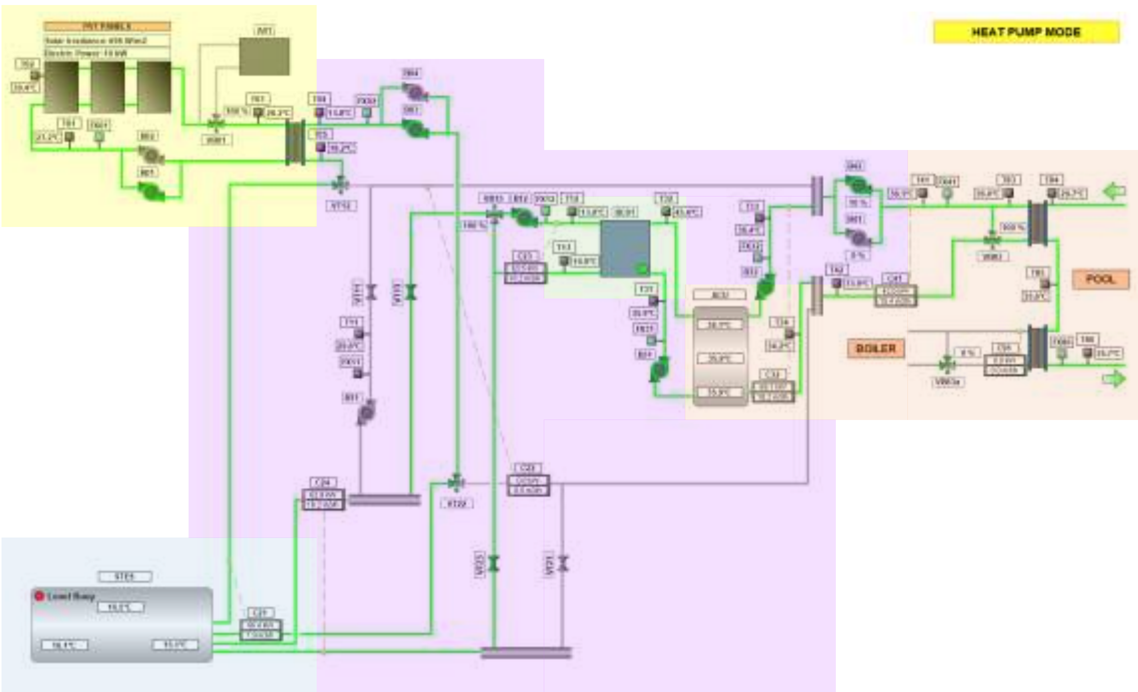

Figure 2.3: Implemented monitoring subsystems in the CHESS-SETUP project

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In order to save resources (i.e. calorimeter devices), the final implementation does not provide extra measurements in order to calculate only energy losses, however combining different calorimeter measurements (chapter 3.5) some of the losses can be calculated, e.g. total energy produced compared to the total energy stored and consumed.

Thermal Energy: It will be produced mainly in the hybrid solar panels, stored in the STES and consumed on the client-side. Different energy flows happen to depend on certain conditions. For instance, if there is enough temperature in the STES tank, it will be delivered directly to the final consumption without being conditioned by the heat pump.

Figure 2.4 shown the three different energy flows within the subsystems:

1) The thermal energy produced in the PVTs is directly delivered to the consumption;
2) The thermal energy produced and stored in the STES is delivered to the final customer;
3) The thermal energy produced is stored in the STES and needs to be conditioned by the heat pump to be finally delivered to the customer.

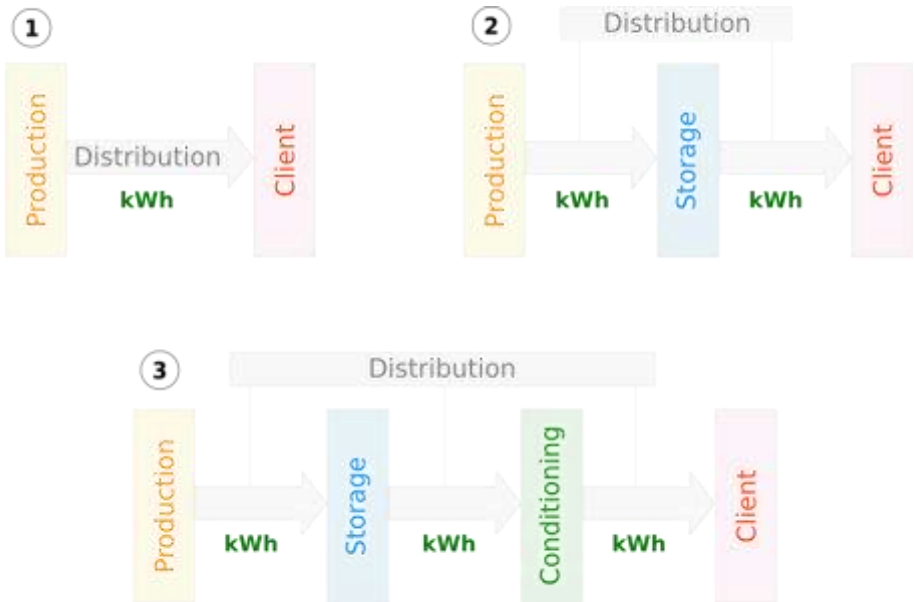

Figure 2.4: The three different energy flows in the CHESS SETUP system.

Electrical Energy: It will be produced in the hybrid solar panels and consumed by the electrical components of the system, mainly the heat pump and the water pumps and elsewhere in the building if not used by the CHESS system. The electrical energy excess will be feed-in the utility grid. The system provides plots that calculate and show the electrical energy that is consumed by the system, the production by the PVT, the injection to the grid and the purchase from the grid (chapter 3.5.11.2).

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2.3.1. Control System General View

The control and monitoring system (CMS) can work either in manual mode: the user selects the working mode; or in automatic mode: the system decides at any moment which is the best current working mode depending on the current conditions and the parameters that are stored in the system. In automatic mode the system will select the most efficient system, i.e. it will provide the energy directly from the STES to the customer without using the heat pump if it is not required.

The system has 3 different working modes (chapter 3.5.5):

1. **Direct PVT Working Mode**. The energy is delivered directly from the PVT panels to the customer.
2. **Direct STES Working Mode**. The system delivers the energy directly from the STES to the customer.
3. **Heat Pump Working Mode**. The system needs the heat pump to perform a conditioning stage, i.e. the STES temperature is too low compared to the customer needs.

From the main task they will be used for, the sensors, are classified into three different groups:

Control Sensors: This group of sensors is used to perform the low-level control of the system. They are temperature sensors that will be used to control the water pumps to move energy from one point to another. This group of sensors is more critical for the normal operation of the system. Therefore, the easiest communication interfaces to the low-level control and monitoring system (LLCMS) will be used to avoid system failures. Sometimes they will have redundant sensors (i.e., it exists another monitoring sensor that provides the same reading) to overcome possible failures.

Although these sensors are mainly for controlling the system, the high-level control and monitoring system (HLCMS) will register them in a database log to perform later evaluations.

Monitoring Sensors: This group of sensors is used to monitor high-level or relevant information, for instance, to evaluate the performance of the system. For this project, the fundamental sensors in this group are those for monitoring the energy flows. The information gathered by these sensors will also be registered in a database log by the HLCMS.

Alarm Sensors: These sets of sensors are used to send alarms to operator users to inform them to perform handling in the system. For instance, if the water pump should be active but a flow meter is not informing about any flow in the tubes, an alarm is released to an operator to correct any possible problem. These sensors may also be redundant to other monitoring sensors. The different alarms will be shown in the HLCMS interfaces as well as sent via e-mail to the corresponding operator roles.

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2.4. External variables

The system acquires the grid energy prices automatically and stores them into the database to calculate the electrical energy savings achieved by the system.

Since this information is available online and updated periodically the system tries to download the data every week and store it locally. The downloaded data contains all the information needed to calculate the final energy price and simulate an invoice. This data is stored locally in the database (chapter 4) and the system uses the plotting interface (chapter 3.5.11) to show the results.

2.5. Data processing and storage

From the data processing and storage, as planned in the deliverable 4.1, the CMS tackles the following points:

- **Control data acquisition:** The main purpose of the monitoring is to gather the physical magnitudes such as temperatures needed by the controller to regulate the system (chapter 3.5.1.2).
- **On-line visualization and control:** A common feature implemented in the monitoring system provides a human-machine interface (HMI) to the different users of the system and show, in a friendly way, the gathered information, the control parameters, and set-points. The user will be able to inspect instantaneous values such as temperatures, powers, device status, to detect possible problems in the system (chapter 3).
- **Data storage:** The information more sensitive to be needed for the later evaluation of the system (failures, performance, etc.) will be stored in a database log by the HLCMS. Therefore, variables related to both sensors, controls, and parameters will be stored in the database periodically (every 5 minutes). The system also has a backup system to extract the data and store periodical copies to preserve the data in a system failure (chapter 4).
- **Historical data visualization:** For the long term evaluation of the performance of the system, the stored data must be friendly presented to the user, for instance, as plots and graphics. The databases will be stored locally in the HLCMS controller database and all the required security and redundancy will be taken into account. No sensible information of any user will be stored in that database (chapter 3 and chapter 4).
- **Determine and send alarms:** Typically extra sensors are used for monitoring problems in the system. Moreover, internal status computed by the LLCMS or the HLCMS may detect problems and trigger alarms. In the case of detecting a possible problem, an alarm will be triggered and the system will inform the defined roles to solve the incidence. The HMI screens are used to inform locally as well as the e-mail will inform remotely to the users (chapter 3.5.12).

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Figure 2.5 shows the interaction of the different CMS subsystems (Hardware, PLC, SCADA, database) with each other. The operator and viewer users access to the control and visualization tool (SCADA) that runs on top of a PC server either locally or remotely. The database administrator is allowed to access through a database client interface directly to the data either locally or remotely. The database administrator user is allowed to manually insert, update, delete, import or export information directly from and to the database using his interface. The SCADA tool is the piece of software responsible to interact between the low-level controller (PLC) and the hardware to keep updated the CMS database.

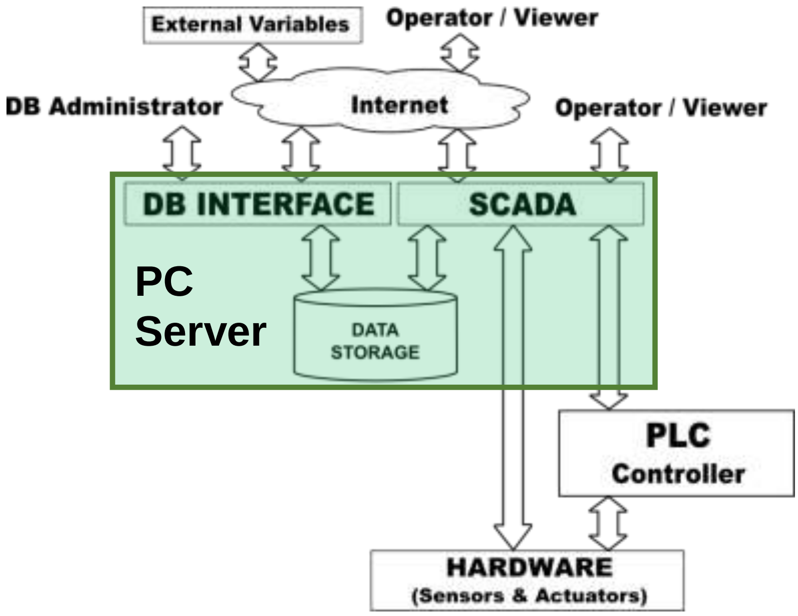

Figure 2.5: Interaction of the different CMS subsystems.

3. CHESS SETUP Control and Monitoring System Tool

This chapter describes the implemented control and monitoring system tool that runs on a PC that can be accessed as described in chapter 1. The main screen of the CMS is represented in figure 3.1.

The different application areas are highlighted in different colours:

1. **Application Menu:** allows the user to exit the application and switch the user level (viewer or operator).
2. **General Information.** In this area, it is shown system general information such as the current user, the current date and time and the outdoor temperature and relative humidity at the installation place.
3. **Language Selection.** The flags allow changing the application language.

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4. **Active Screen.** This area shows the information for the active screen selected by pressing on of the Screen Menu buttons.

5. **Screen Menu.** This left area allows the user to switch among the different application screens by pressing the corresponding button

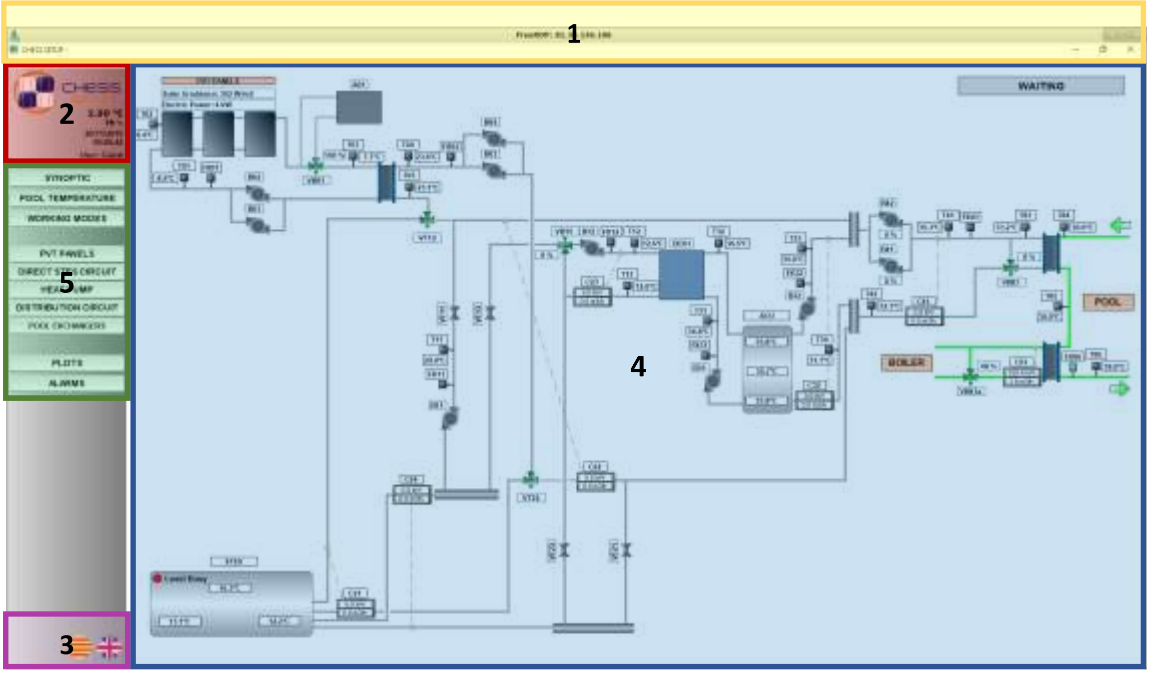

Figure 3.1: Control and monitoring system main window.

3.1. Application Menu

The application menu only contains two options: File and Security.

Application Menu 〉File 〉Exit

This option exits the application. This option should not be used in normal operation since the CMS is stopped and, therefore, no data log is performed.

Application Menu 〉Security 〉Logon

This option allows for changing the current user. The system has two different users: the unprivileged user Guest (Viewer Role) and the privileged user 'Administrador' (Operator Role). Figure 3.2 depicts the 'Log On' the dialogue that allows changing the user level. The dialogue also provides the *Log Off* option in the right button which terminates the current user session and downgrades to the unprivileged user *Guest*. It is equivalent to the Application Menu 〉Security 〉Logoff option.

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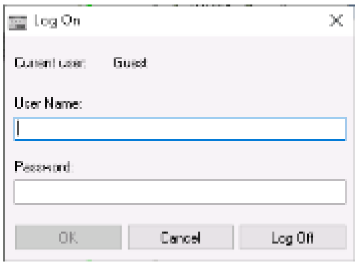

Figure 3.2: Log On dialogue screen

Application Menu 〉Security 〉Logoff

Terminates the current user session and downgrades to the unprivileged user *Guest*.

The following figure shows the appearance of a configuration screen aspect when the 'Administrador' user is logged in. In the bottom snapshot, in the 'CONTROL TEMPERATURE 〉CONTROL' section, the 'Administrator' user can set it to OFF and ON and he is allowed to check the Enable Boiler as a support checkbox. Moreover, he is allowed to enter any of the temperature set points in the 'CONFIGURATIONS' section.

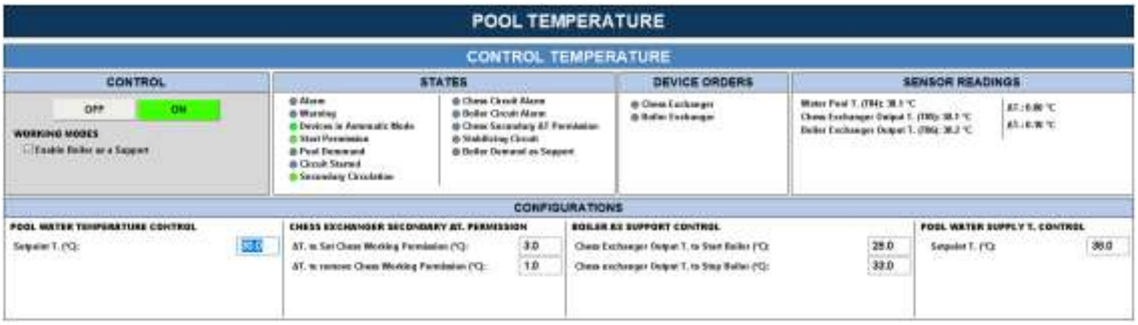

Figure 3.3: Pool temperatures – Control temperature. 'Administrador' view screen

The 'Guest' user viewer shows the 'CONTROL TEMPERATURE 〉CONTROL' section disable (in grey) and not clickable by the `Guest' user, and is not allowed to enter any of the temperature set points in the 'CONFIGURATIONS' section.

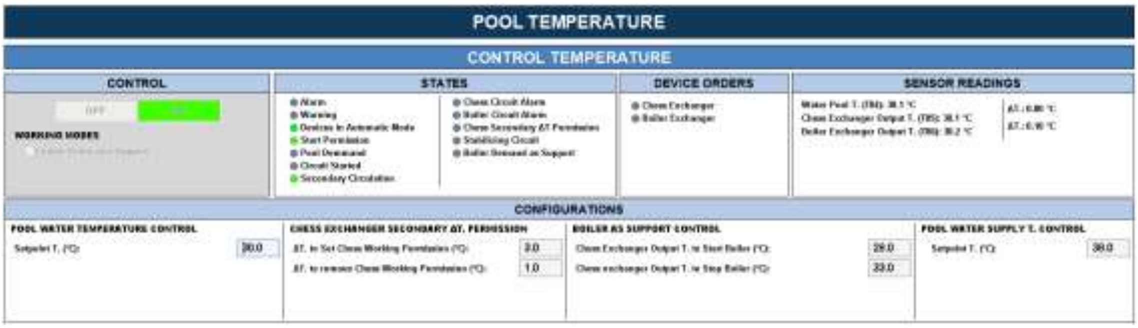

Figure 3.4: Pool temperatures – Control temperature. 'Guest' view screen

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3.2. General Information

The area is located on the top left corner of the CMS application. Figure 3.5 shows the general information, under the CHESS SETUP logo. It is represented the outdoors conditions of the installation place, temperature, relative humidity, the current date and time and the user that is currently logged in the application.

Figure 3.5: General information area.

3.3. Language Selection

This area allows you to change the application language. The different languages available are represented by a circular flag. It does not require any application restart, just clicking in the corresponding language flag; the application changes the language automatically.

Figure 3.6: Language selection area

3.4. Active Screen

The largest area occupied by the application is the 'Active Screen' where the current screen is shown by clicking one of the buttons in the 'Screen Menu' (in the left side of the 'Active Screen').

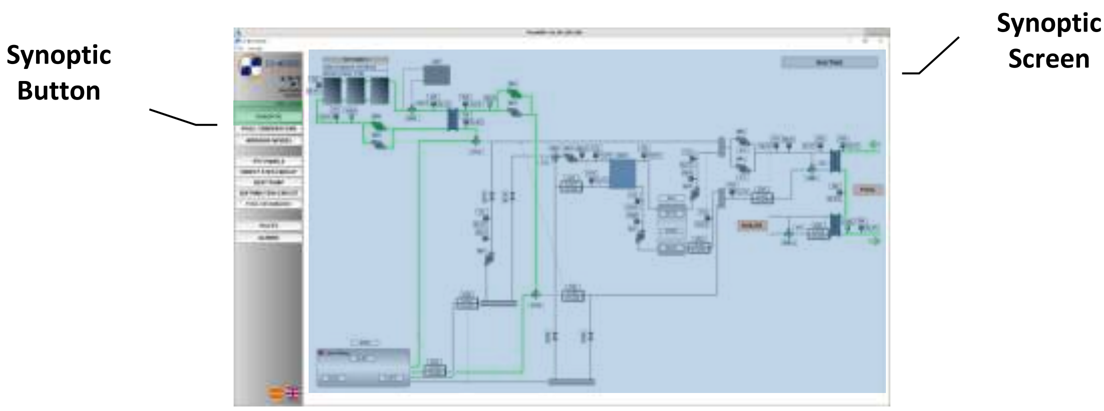

Figure 3.7: The system synoptic representation in the Active Screen

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All the information such as alarms, parameters, debug states and plots are distributed in different screens to facilitate the tasks of the users of the system. The different screens are distributed in the different subsystems of the CMS plus the plots and the alarms and are accessible by clicking the corresponding button in the Screen Menu: Pool Temperature, Working Modes, PVT Panels, Direct STES Circuit, Heat Pump, Distribution Circuit, Pool Exchangers, Plots and Alarms. Every different screen and its content are described in the following chapter 3.5.

3.5. Screen Menu

The Screen Menu allows the current user to change between the different available screens. Each button in this area activates a different screen. Depending on the current user privileges the different screens may contain different options and active inputs. For instance, only the 'Administrador' (operator role) user will find the input boxes active to set parameters such as temperatures and setpoints.

Figure 3.8: Screen Menu

The above figure shows the 'Screen Menu' that contains the buttons following buttons:

- **Synoptic**: It is the main screen of the system where the viewer and the operator roles examine and control the system behaviour visually. All the actuators and sensors such as pumps, valves, heat pump, temperature sensors, flow-switches, calorimeters, etc. are depicted and can be inspected. This screen is very useful since it provides a rapid overview of the current system state and behaviour.
- **Pool Temperatures**: This screen shows the state of the pool control subsystem and all the parameters and set-points that can be tuned in it.
- **Working Modes**: In this screen different CHESS SSTUP system working mode states and tuning parameters are presented.
- **PVT Panels**: This screen allows us to configure and visualize the state of the primary and secondary circuits of the PVT panel exchanger.

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- **Direct STES Circuit**: This screen shows the state of the system when it is working directly from the STES to the customer.
- **Heat Pump**: This screen will be used to visualize and control the system when it has to work by using the heat pump.
- **Distribution Circuit**: This screen is used to visualize and manage the subsystem that controls the thermal energy distribution to the customer (the pool).
- **Pool Exchangers**: This screen shows and allows to control the temperature and the pumps that deliver the thermal energy to the customer (the pool).
- **Plots**: This screen allows the user to select among the different available plots and activate the plot windows to inspect the behaviour of the system by representing the different variables and states in trends.
- **Alarms**: This screen shows the list of alarms and allows the administrator to enter the list of users that will receive the system alarms via e-mail to attend to the system on any urgency.

3.5.1. Synoptic

The 'SYNOPTIC' button in the Screen Menu area activates the Synoptic screen in the Active Screen area. The Synoptic screen is available for all the users, however, only the 'Administrador' is allowed to change parameters. The screen contains a synoptic scheme of the CHESS SETUP system to help the users in the task of monitoring and controlling the system.

Figure 3.9 shows the different sections of the synoptic scheme. Most of them correspond directly to other screens of the Screen Menu. The synoptic sections are the following (represented in different colours in the figure):

1. Current Working Mode
2. PVT Primary
3. Seasonal Thermal Energy Storage (STES)
4. PVT Secondary and STES Output
5. Heat Pump
6. Distribution
7. Pool Exchangers

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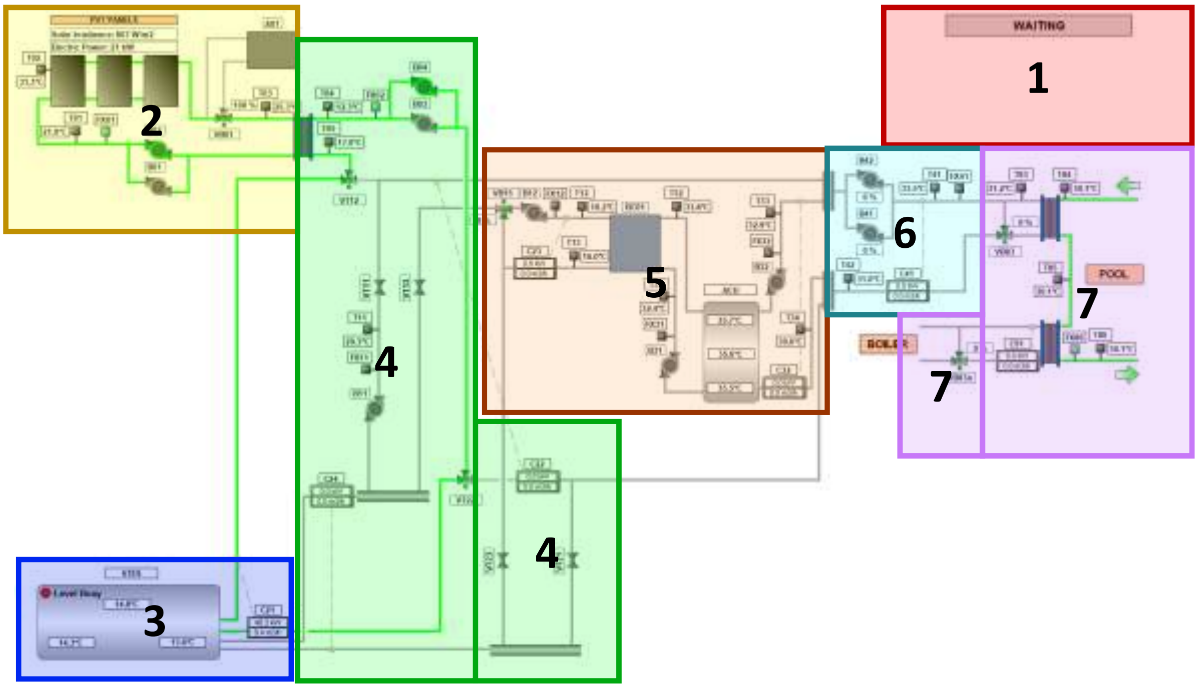

Figure 3.9: The different section areas in the Synoptic scheme

Synoptic Interpretation

The graphical elements that appear in the 'Synoptic' screen change their aspect depending on whether they are active or not. For instance, the pumps, tube lines, and flow switches are displayed in green if they are active and in grey if not. The configurable elements such as the pumps, the heat dissipator, and the heat pump, or elements that have extra information such as the calorimeters, are clickable. If they are clicked, a pop-up window with the configurable or the extra information will appear. Only the 'Administrador' (operator role) is allowed to perform changes.

3.5.1.1. *Current Working Mode*

This area of the 'Synoptic' shows the system's current working mode that refers to how the energy is delivered to the customer. The system has the main concept of 'Operating Mode' that could be either 'Automatic' or 'Manual'. Then, in this Operating Mode there exists the concept of 'Working Mode' that could be: Waiting, Direct PVT Mode, Direct STES Mode or Heat Pump Mode.

System Operating Modes:

The control system has two main operating modes: 'Manual' and 'Automatic'. The system normally operates in 'Automatic Operating Mode' and only when there is a problem in the hardware that has to be fixed or an electrical issue in any part of the physical circuit, the manual mode should be used. The system has three different working modes that are automatically selected in 'Automatic Operating Mode' and they must be manually set in 'Manual Operating Mode'. Only the 'Administrador' user

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(operator role) can switch between 'Manual' and 'Automatic' operating modes and between the different working modes in manual operating mode.

Manual Operating Mode: In this mode, the user 'Administrator' (operator role) is allowed to select the working mode. The working modes should not be set manually in normal operation since in automatic mode the best working mode is selected automatically by the system to provide the best system performance. The working modes should only be selected in manual mode when there is a problem in the system or when some test has to be performed.

Automatic Operating Mode: In this mode, the system switches between the working modes to provide the best system performance in terms of thermal energy provided concerning the electrical energy consumed.

System Working Modes:

The system shows in the top right corner of the **Synoptic** screen the current working mode in different modes:

- Waiting: The system is in 'waiting' mode, either there is no demand from the customer or the conditions are not met to work in any mode.
- Direct PVT mode: The energy is provided from PVT panels directly to the customer. This mode is only available in manual operating mode and can be forced by the 'Administrador' (operator role). This mode is highly inefficient since when there is no demand from the pool the excess of energy will be dissipated by the heat dissipator and it only can provide energy when there is enough power directly from the sun. Therefore, it should only be used for testing purposes or in the case of any failure in the rest of the system that prevents the use of other operating modes.
- Direct STES mode: The energy from the STES is provided directly to the customer. This working mode is the preferred in automatic working mode since it does not require the use of the heat pump, but can only be used when the STES temperature is above the customer supply temperature by a certain configurable threshold. The 'Administrador' (operator role) is allowed to force this working model in manual operating mode.
- Heat pump mode: The energy is provided to the customer by using the Heat Pump. This mode is available in automatic mode and it is set when the STES temperature is below the customer supply temperature and has to be mandatorily raised by the Heat Pump. The 'Administrador' (operator role) is allowed to force this working model in manual operating mode.

The figure 3.10 at the top left shows the system in standby, 'Waiting', there is no pipe highlighted in light green. The top right picture shows the system in 'PVT Direct Working Mode', the bottom left picture shows the active lines for the 'Direct STES

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Working Mode' while the bottom right picture shows the system in the 'Heat Pump Working Mode'.

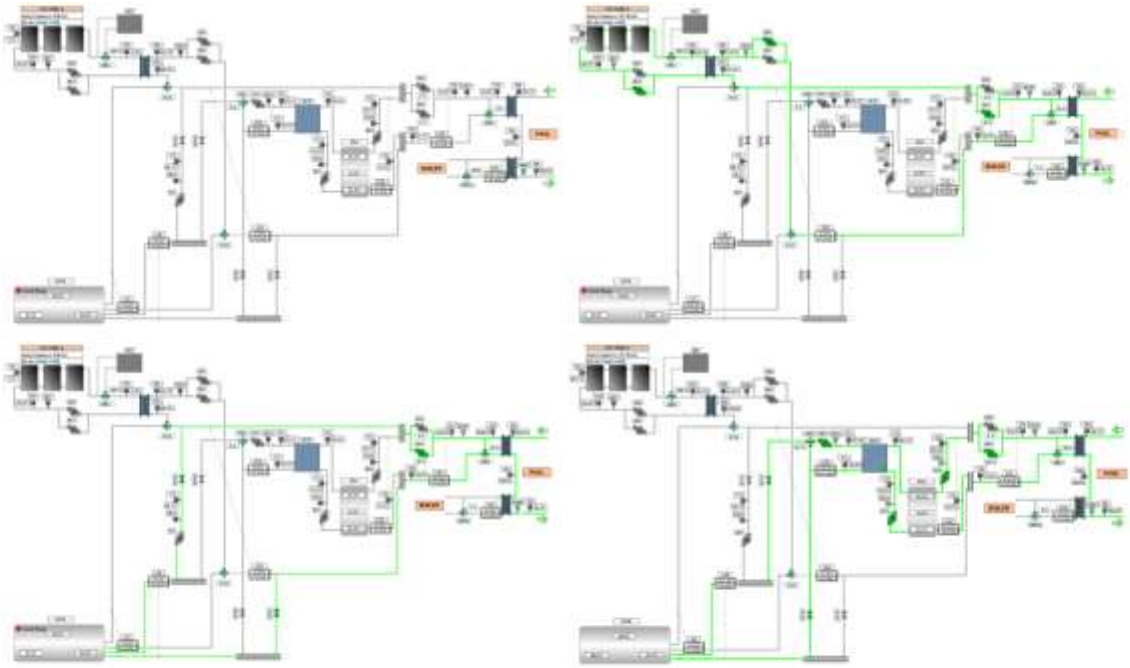

Figure 3.10: Different working modes of the CHESS SETUP system.

Figure 3.11 shows the auxiliary tasks that can be overlapped (running at the same time) in the different working modes. The top left picture is the task of loading energy into the STES tank that can be done at the same time as the 'Direct STES' and 'Heat Pump Working Modes'. The top right picture represents two different tasks: the anti-freezing or the recirculation to homogenize the temperature in the PVT primary circuit. The first task is done when the PVT panels are not used (e.g. at night) to avoid freezing the outdoors water circuit. The second task is done to calculate the real current temperature in the PVT panels and it is done before starting the STES load process (chapter 3.5.6). Finally, the bottom left picture is the energy delivery from the boiler to the customer (pool) that can be done individually or as a support for the 'Direct STES' and 'Heat Pump Working Modes'.

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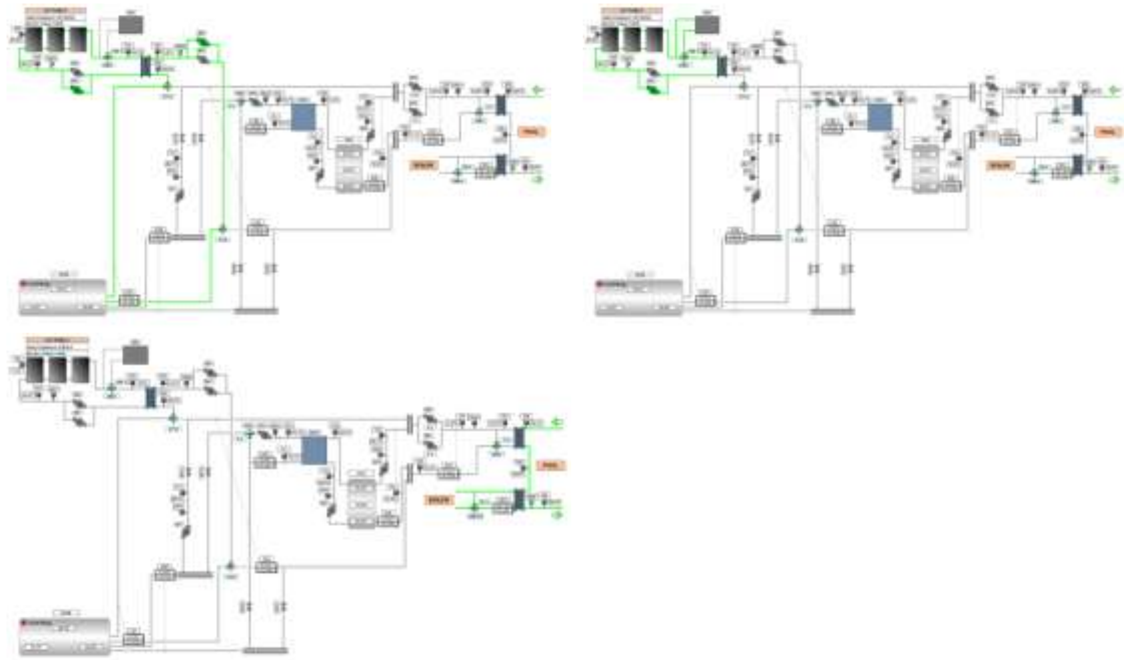

Figure 3.11: These three pictures show different auxiliary tasks done by the system that can run at the same time overlapped with the other working modes.

In the following figure, 3.12, the picture shows an example of the system in 'Heat Pump Working Mode' where the Accumulator tank is at the configured set point, so the Heat Pump is stopped while the system is providing energy to the customer from the Accumulator tank. At the same time, the energy produced by the PVT panels is being stored in the STES tank.

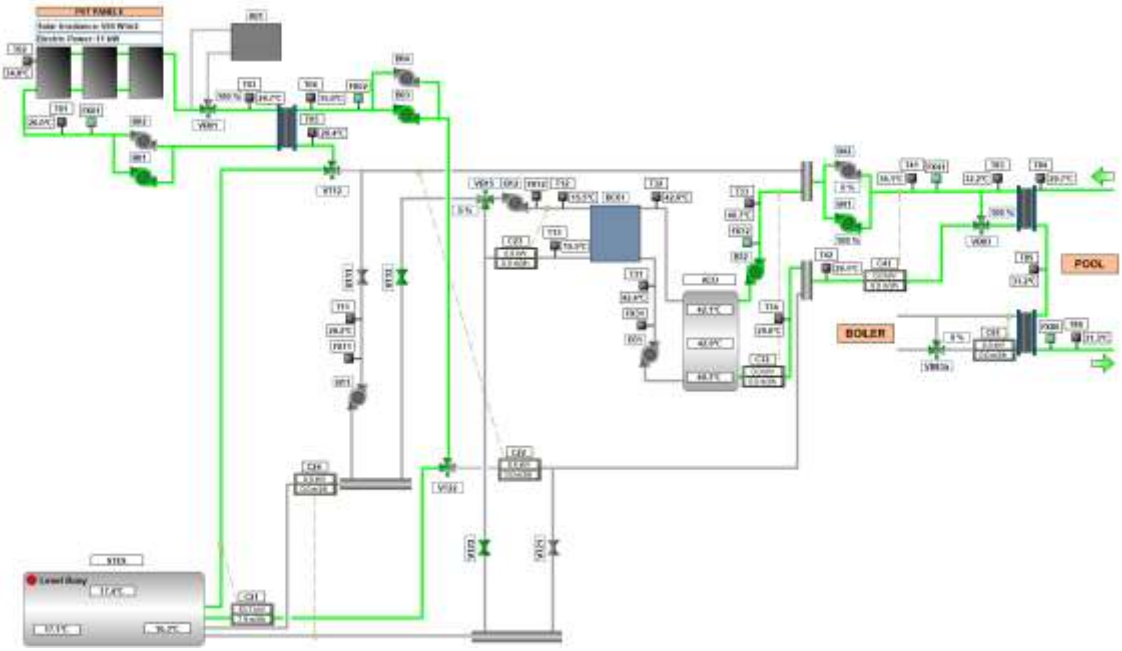

Figure 3.12: Example of the system in Heat Pump Working

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3.5.1.2. *Legend*

This section describes the different elements that appear in the **Synoptic** screen and the meaning of their representations.

Temperature Sensor. The temperature sensors show the current temperature at the location point represented in the synoptic. The available temperatures sensors are:

T01: PVT Primary – Return temperature.

T02: PVT Primary – PVT Panel temperature (at the input of the panels).

T03: PVT Primary – Supply temperature.

T04: PVT Secondary – Return temperature.

T05: PVT Secondary – Supply temperature.

T11: Direct STES – Supply temperature.

T12: Heat Pump Evaporator – Input temperature.

T13: Heat Pump Evaporator – Output temperature.

T31: Heat Pump Condenser – Return temperature.

T32: Heat Pump Condenser – Supply temperature.

T33: Heat Pump Accumulator – Supply temperature.

T34: Heat Pump Accumulator – Return temperature.

T41: Distribution – Supply temperature.

T42: Distribution – Return temperature.

T83: Pool – Chess Primary temperature.

T84: Pool – Water temperature.

T85: Pool – Chess Exchanger Output temperature.

T86: Pool – Supply temperature.

The following temperatures do not have the corresponding icon for space reasons but appear in the synoptic and the database:

T35: Heat Pump Accumulator – Bottom temperature.

T36: Heat Pump Accumulator – Middle temperature.

T37: Heat Pump Accumulator – Top temperature.

T51: STES – Bottom temperature.

T52: STES – Middle temperature.

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T53: STES – Top temperature.

T101: Outdoors temperature.

Flows witch. The flow switch sensors show whether there is the flow or not in the pipe where they are placed (represented in the synoptic). The flow switches are used to generate alarms but do not impact the control, i.e. anything is stared or stopped due to the presence or lack of flow when it is not expected. But, when it is supposed to be flow in a pipe and it is not detected, an alarm and the corresponding e-mail are triggered, and vice versa. Only the flow switch FX86 is used for control purposes (chapter 3.5.10, pg. 69). The available flow switches in the system are:

FX01: PVT Primary flow switch.

FX02: PVT Secondary flow switch.

FX11: Direct STES flow switch.

FX12: Heat Pump Condenser flow switch.

FX31: Heat Pump Evaporator flow switch.

FX32: Heat Pump Accumulator Supply flow switch.

FX41: Distribution flow switch.

FX86: Pool water flow switch.

Pumps. The pumps are clickable elements in the synoptic. If they are clicked the control and monitoring pop up window will appear. There exist two kinds of pumps, the variable flow (driven or regulated) and the fixed flow ones.

The variable flow pumps are:

B41, B42: Regulated set of twin pumps for distribution. Only one is working at the same time. These pumps are responsible for the energy distribution to the customer and they are regulated because the temperature delivered to the pool must be regulated.

The fixed flow pumps are:

B01, B02: PVT panel primary set of twin pumps. Only one is working at the same time. These pumps are performing the recirculation in the PVT primary circuit.

B03, B04: PVT panel secondary set of twin pumps. These pumps are performing the recirculation in the PVT secondary circuit and only one is working at the same time.

B11: Direct STES water pump. It is used when the system is providing energy directly from STES to a customer without using the heat pump.

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B12: Heat pump evaporator water pump. It is used when the system needs the heat pump to provide the energy to the customer.

B31: Heat pump condenser water pump. It is used between the heat pump condenser and the heat pump accumulator tank.

B32: Heat pump accumulator tank output water pump. It is used to provide the energy to the distribution collector.

2-Way, 2-State Valves. These valves are used to allow or cut the flow in a particular circuit and they only have two states: closed or opened. The available 2-Way, 2-State valves are:

VT11, VT21, VT13, VT23: They need to be set in a particular state depending on the working mode describe below.

3-Way, 2-State Valves. These valves are used to allow or cut the flow in a particular circuit and they only have two states: closed or opened. The available 3-Way, 2-State valves are:

VT12, VT22: They need to be set AB → A or AB → B depending on the working mode described below.

3-Way, Regulated Valves. These valves are regulated to fulfil a set point. These valves are controlled depending on the operation mode. These valves have an associated text box that shows the opening percentage. The available 3-Way, Regulated valves are:

VB01: Although it is a 3-Way, Regulated valve it is only used as a 3-Way, 2-State valve that bypasses or not the dissipator in the PVT primary circuit.

VB15: It is used to regulate the input temperature to a defined set point in the evaporator of the heat pump.

VB83: It is used to regulate the temperature delivered to the customer by the CHESS Setup system.

VB83a: It is used to regulate the temperature delivered to the customer by the Boiler.

Calorimeter. The calorimeter sensors provide flows, temperatures, thermal power, and thermal energy. The calorimeters are connected to the system by using an M-BUS communication interface. In the case of a loss of communication between the system and a calorimeter, the icon is shown in red otherwise will be shown in green.

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The available calorimeters are:

C21: Measures energy loaded into the STES from the PVT panels.

C22: Measures all the energy provided directly from PVT panels to the customer. This mode will be rarely used since it can only be set manually, basically, for instance, if there is any physical or electrical problem in the system (in the heat pump, STES, pipes, ...) and the energy can only be delivered directly to from PVT panels to the customer. In that case, the energy accumulated by C22 will be equivalent to the registered by C41.

C23: Measures energy supplied to the heat pump from the STES.

C32: Measures the energy delivered to consumption from the heat pump output.

C41: Measures the total energy delivered to the customer from the CHESS system.

C91: Measures all the energy provided to the customer from the backup boiler.

Calculated energy measurements

The system can provide extra energy measurements given by operating (adding and subtracting) the energy from different calorimeters. Although the calorimeters provide other measurements such as power or supply and return temperatures, these other measurements should not be operated between them since the instantaneous measurements may be delayed due to how the system operates (delays opening or closing valves, starting or stopping pumps, ...).

If enough time is considered (hours, days or more), among other combinations, the energy of the following calorimeters can be operated to the extract extra thermal energy information from the system[2]:

C32 - C23: Heat pump subsystem performance.

C41 + C91: Total customer consumption.

Valve position depending on the Working Mode:

In the different working modes, the valves are set as follows:

PVT Direct Working Mode.

VT11, VT21: Closed

[2] All the different combinations (additions and subtraction) between calorimeters are not done directly in the CMS but the calorimeter energy data can be exported and done externally.

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VT13, VT23: Closed

VT12, VT22: AB → B

STES Direct Working Mode.

VT11, VT21: Opened

VT13, VT23: Closed

VT12, VT22: AB → A

Heat Pump Working Mode

VT11, VT21: Closed

VT13, VT23: Opened

VT12, VT22: AB → A

<u>3-Way Valve Setup physical positions:</u>

The 3-Way valves have a common input named AB that is delivered either to the output A or B. The circuit configuration of the 3-Way valves in the CHESS implementation for the plot in the synoptic is the following:

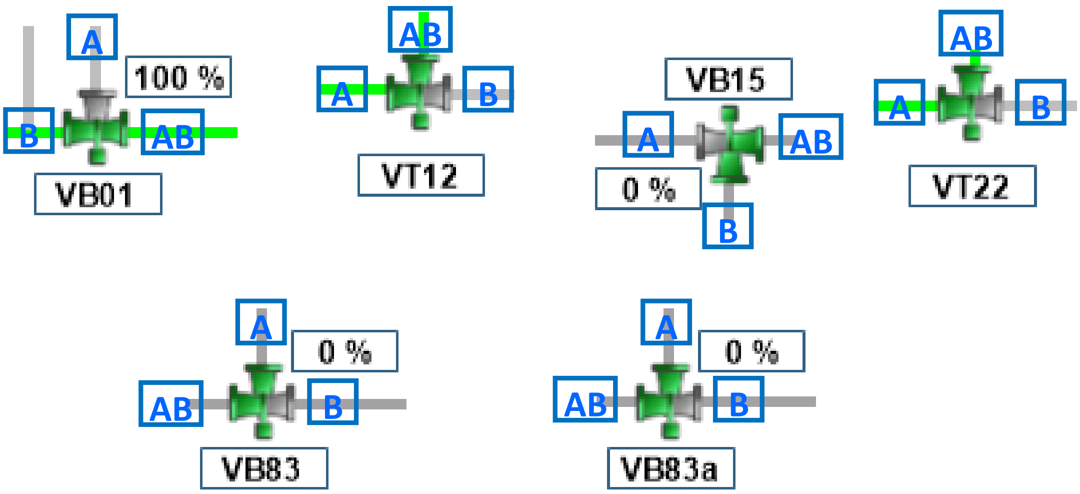

Figure 3.13: Physical positions of the AB, A and B inputs and outputs of the different valves in the CHESS SETUP synoptic.

<u>Engine Device Pop-Up Dialogs</u>

All the devices that have a motor such as the water pumps, the heat dissipator, the heat pump, and the 3-Way, 2-State valves have a similar pop-up configuration window where it is shown the current state, the alarms and the control buttons to set them in automatic, manual or to reset the alarms.

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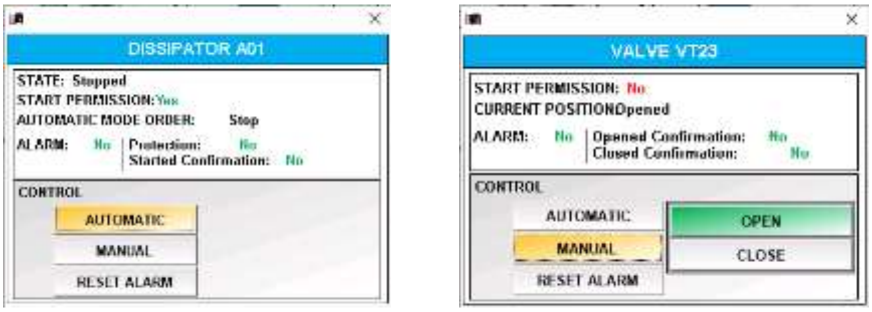

Figure 3.14: Engine Device Pop-Up Dialog

The above figure 3.14 shows the Pop-up dialogue for valves, pumps, the heat pump and the heat dissipator. The top row in white font and blue background describes the device (the dissipator A01 in the left picture and the Valve VT23 in the right picture). The middle area in the white background shows the current status. The 'STATE / CURRENT POSITION' is the current real state that the CMS is detecting from the physical device (dissipator, pump, valve…) and it is confirmed by an input signal (Started Confirmation, Opened / Closed Confirmation). The 'START PERMISSION' refers to that the control system has met all the conditions to start the device (e.g. there is no alarm, every depending device is in automatic mode, …). The 'ALARM' refers to that the device is in alarm which could only be due to its 'Protection' (electrical RCD serialized with a circuit breaker) or due to the 'Confirmation' input signal (for a valve these are the signals of 'Opened' and 'Closed Confirmation', and for a pump the 'Started Confirmation' that comes from an input signal connected to an auxiliary output of the electric contactor that activates the pump. The 'RESET' alarm button in the bottom area in the gray background is used to reset the alarms. In the CHESS SETUP case, this button will only be used to reset the 'Start Confirmation' for a pump, dissipator or the heat pump, or the 'Opened / Closed Confirmation' for a valve. The Protection alarm is automatically reset by solving the problem physically (i.e., switching on the RCD and the circuit breaker), however, the 'Confirmations' need to be confirmed mandatory by the operator. The system will not try to start a pump or open/close the valve after a 'Confirmation' failure, it will only be done if the operator resets the alarm (chapter 3.5.12). The 'AUTOMATIC' and 'MANUAL' buttons are used to set the device in automatic mode or manual mode. In the manual mode, other buttons may appear to allow to start and stop or open and close the pumps or valves, respectively.

3.5.1.3. *PVT Primary*

This area of the 'Synoptic' shows the status of the PVT panel primary circuit. Figure 3.15 shows the different information represented in this area. In this area, the state of the primary circuit of the PVT panels and the information related to it, such as solar irradiance, current electrical production, temperatures (T01, T02, T03), the flow switch (FX01) and the dissipator status are shown.

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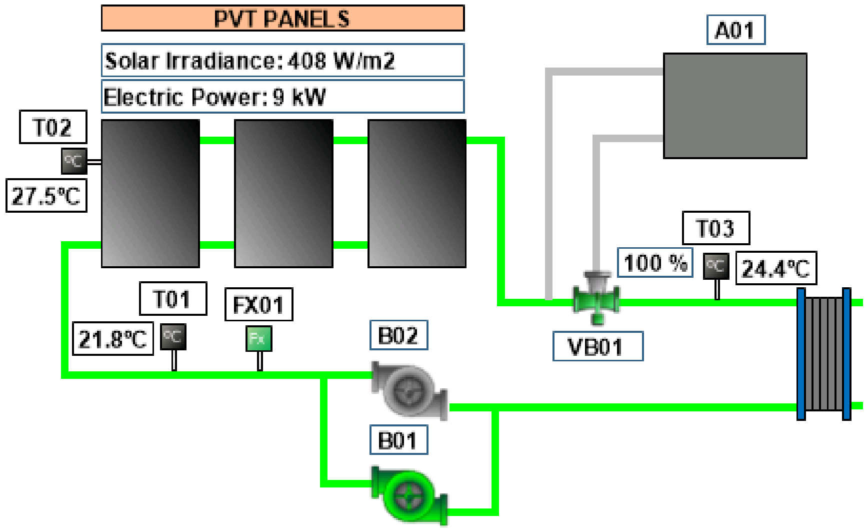

Figure 3.15: PVT primary circuit

PVT Panels: The PVT panels are not clickable, however, above them the information of the current solar irradiance (W/m²), which gives a flavour of how much thermal energy should be produced, is shown. The current electrical produced power (kW) is also represented.

Pipelines. The pipelines are depicted in grey if the circuit is not active while they are shown in light green if they are active. Active means that this pipe should have water flow, however, is not a real reading, it is because the system is making the water flow by starting the pumps and manoeuvring the valves, but the system may not have a real reading. If there is a flow switch in the pipeline as it happens in the figure 3.15 (FX01), if the flow switch is enabled (in light green) means that there is water flow, if the flow switch is grey, no water flow is detected in the pipeline.

Temperatures and Flows: In this area, the T01, T02 and T03 and flow switch FX01 are shown.

Dissipator A01: The dissipator is a clickable element of this area. When the dissipator is clicked, the pop-up dialogue described in figure 3.16, is shown. Only the 'Administrador' user (operator role) can perform this operation.

The pop-up dialogues show in the top row the name of the device (in white colour and blue background) that is being configured (DISSIPATOR A01 in the above pictures). A dissipator can be set-up in manual or automatic (default, left picture) mode. When it is set to 'manual' it can be forced to 'Start' or 'Stop' status (centre and right image, respectively) by pressing the corresponding buttons. The dialogue also has a 'RESET ALARM' button to reset any alarm (Protection or Start Confirmation) that could happen. The central area of the dialogue in white background shows the current 'STATE' (Started / Stopped), the 'START PERMISSION' (Yes / No), the 'AUTOMATIC MODE ORDER' (Start / Stop), the 'ALARM' (Yes / No) the 'Protection' (Yes / No) and the 'Started Confirmation' (Yes / No).

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Figure 3.16: Pop up dialogues of the dissipator

The dissipator picture shows its current status: automatic, manual, started and stopped. Figure 3.17 shows different representations of the dissipator depending on its current state, from left to right, automatic stopped, automatic started, manual stopped and manual started.

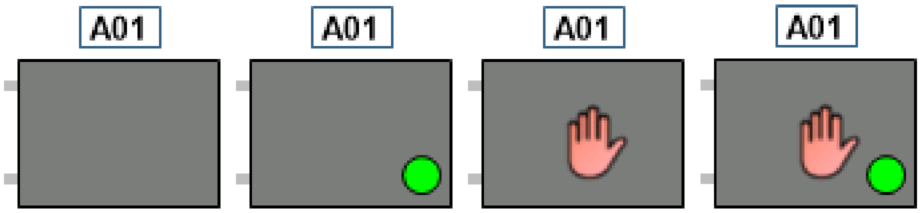

Figure 3.17: Different dissipator current status

Valve B01: This valve is a 3-Way Regulated valve but it is only used as a 2-State valve (0% AB→A and 100% AB→B). Therefore, the dialogue shown is the dialogue for a 3-Way proportional valve, but it will only be used as a 3-Way, 2-State valve, so in automatic mode, it will only take the values 0% (AB→A) or 100% (AB→B). In manual mode, it can be set to any % from 0% to 100% for testing purposes.

Figure 3.18 shows the pop-up dialogue of different valves. In the top row, the name of the device (in white colour and blue background) that is being configured. For a proportional valve, below the title, the actual position in percentage is shown (the 100% in the example). The left example picture shows that the valve is in 'Automatic' mode (default). If the 'Manual' button is clicked the valve is set in manual mode and the set point in percentage can be defined by the 'Administrator'.

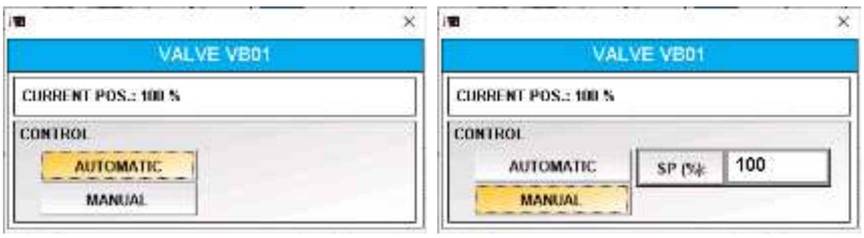

Figure 3.18: Pop-up valve dialogues

The valve icon in the synoptic shows its current status as represented in the following figure 3.19. It shows the Valve B01 in automatic mode (left) and 100% (AB→B) so, the dissipator is bypassed. The right picture shows the same valve in manual mode and also at 100%.

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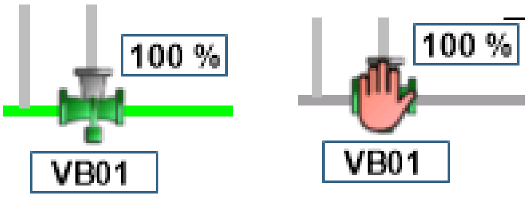

Figure 3.19: Valve synoptic

PUMP B01, B02: These two pumps are a twin set, therefore, only one at the same time is started. The two pumps are set in that configuration for redundancy purposes so, if there is any failure in one of the pumps, the other can continue working. The system takes care of alternating the usage from one to the other to wear both at the same time and ensure they both work (chapter 3.5.3). The current state of a pump is shown through its icon depicted in the synoptic.

The picture 3.20 shows the different icons that describe the current status of the pump B01. From left to the right, automatically stopped, automatically started, manual stopped and manually started

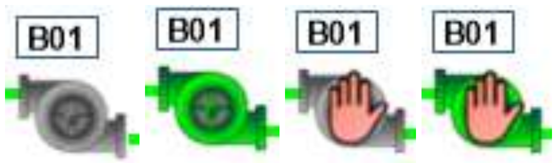

Figure 3.20: Icons that describe the different status of the pumps.

The pumps are a clickable element of the synoptic; therefore, when they have clicked a pop-up configuration dialogue is shown. Figure 3.21, in the top row the name of the device (in white colour and blue background) that is being configured (PUMP B01 in the pictures). A pump can be set-up in 'Manual' or 'Automatic' (default, left picture) mode. When it is set to the manual it can be forced to 'Start' or 'Stop' status (centre and right image, respectively). The dialogue also has a 'RESET ALARM' button to reset any alarm (Protection or Start Confirmation) that could happen. The central area of the dialogue in white background shows the current 'STATE' (Started / Stopped), the 'START PERMISSION' (Yes / No), the 'AUTOMATIC MODE ORDER' (Start / Stop), the 'ALARM' (Yes / No), the 'Protection' (Yes / No), and the 'Started Confirmation' (Yes / No).

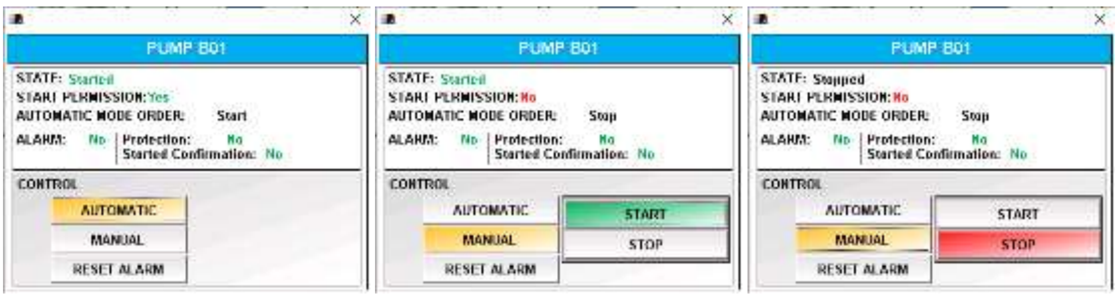

Figure 3.21: Pop-up pump dialogues

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3.5.1.4. *STES*

This area of the Synoptic shows the status of the STES (Seasonal Thermal Energy Storage) tank. The STES tank has three temperature sensors distributed along to the tank and located at different heights. The STES tank also has a level buoy that indicates a loss of water height (water leakage or any other problem).

The calorimeter C21 is used to register all the energy that is loaded into the STES tank.

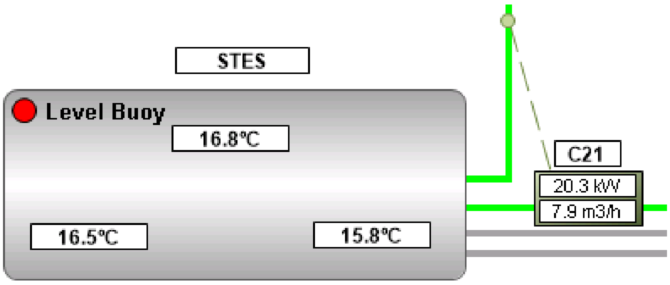

Figure 3.22: STES tank representation.

A calorimeter is a clickable element in the synoptic. Its icon representation always displays the instantaneous thermal power (kW) and flow (m³/h).

When a calorimeter is clicked its corresponding pop-up dialogue is shown, figure 3.23. Only information is displayed in this dialogue since there is nothing configurable in a calorimeter. In the top row, the name of the device that is being displayed is shown in a white font and blue background (C21 – PVT Panels to STES in the picture). In the white area, the information of the calorimeter is shown: 'SERIAL NUMBER', 'ERROR' (Code), 'TOTAL ENERGY' (MWh), 'TOTAL VOLUME' (m³), 'INSTANTANEOUS POWER' (kW), 'INSTANTANEOUS FLOW' (m³/h), 'SUPPLY TEMPERATURE' (ºC) and 'RETURN TEMPERATURE' (ºC).

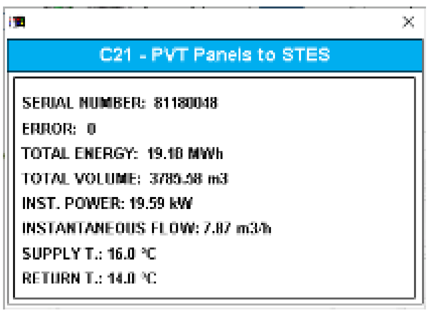

Figure 3.23: Pop-up STES dialogues

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3.5.1.5. *PVT Secondary and STES Output*

This area of the Synoptic shows the status of the devices in the PVT secondary to the STES circuit and the devices involved in the energy delivery to the customer either directly or through the heat pump. Figure 3.24 shows the area.

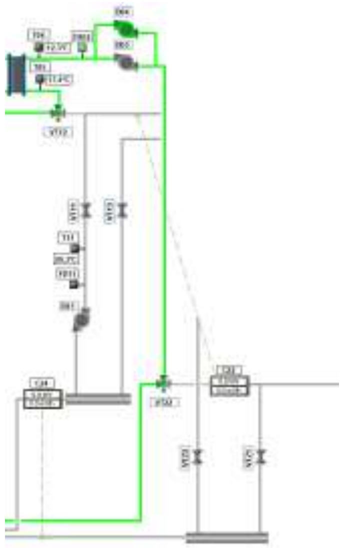

Figure 3.24: Synoptic area referring to the PVT secondary circuit and the STES output to the customer either directly or through the heat pump.

Valves VT12, VT13, VT21, VT22, and VT23. These valves will be set up accordingly to the current working model described in chapter 3.5.5.

Pumps B03, B04, and B11. Pumps B03 and B04 are a set of twin pumps for the PVT secondary circuit that load the energy to the STES tank. The pump B11 is used to deliver the energy from the STES tank directly or through the heat pump to the customer.

Calorimeters C22 and C24. Calorimeter C24 counts the output energy from the STES while C22 counts the energy directly delivered from the PVT panels to the customer.

Temperature sensors T04, T05, T11. Sensors T04 and T05 provide the return and the supply temperatures in the secondary of the PVT panels exchanger while T11 is used to control the temperature delivered to the customer.

Flow switch FX11. It is used to generate an alarm if there is no flow in the circuit when it is activated, i.e. when pump B11 is started.

3.5.1.6. *Heat Pump*

This area of the Synoptic shows the status and allows the control of the heat pump and its buffer tank named Accumulator in the CHESS SETUP CMS. Figure 3.25 shows the synoptic area for heat pump monitoring and control. The valve VB15, the heat pump BC01, calorimeters C23, and C32 and pumps B31 and B32 are clickable elements of the synoptic.

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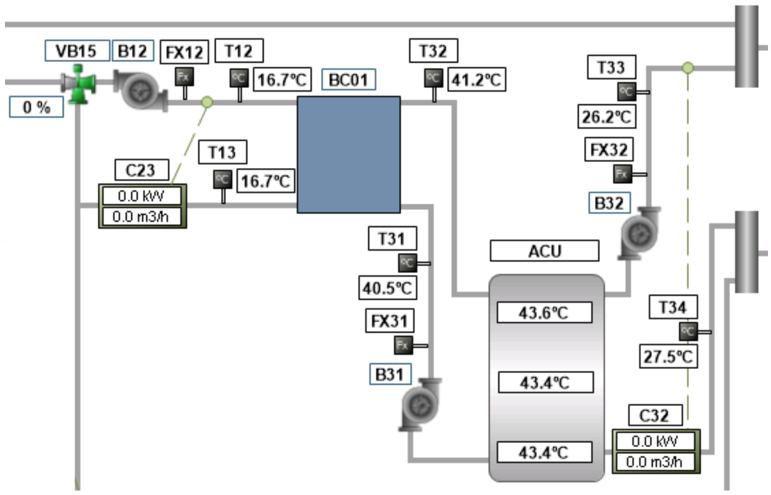

Figure 3.25: Synoptic area for heat pump monitoring and control.

The heat pump is a chiller that has its firmware setup to cool down the evaporator side down to the 10ºC (its theoretical minimum). The CHESS SETUP CMS controls remotely the heat pump (starts and stops it) depending on the system demands. Therefore, the lowest temperature the STES will reach is 10ºC.

Temperature sensors T12, T13, T32, T31, T33, T34. These sensors are used to monitor the supply and return temperatures of the evaporator and the condenser of the heat pump.

Flow switches FX12, FX31. These flow switches are used to release alarms in the case there is no flow in their corresponding pipelines when it should be present.

Acumulator ACU. The accumulator tank has three temperature sensors at three different levels. When the heat pump is used, the system starts it until the set-point reaches the set-point temperature in the accumulator.

Heat Pump BC01. The heat pump is a clickable element that opens a dialogue that allows monitoring and controls the heat pump. Figure 3.26 shows the pop-up dialogue for the heat pump in automatic mode (left), in manual mode, started (middle), and stopped (right). The dialogue is the same described in previous chapters (3.5.1.3) for the pumps.

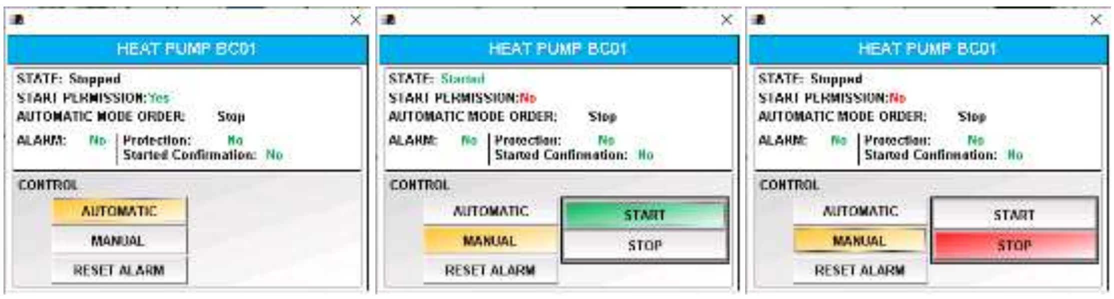

Figure 3.26: Pop-up dialogue for the heat pump

Figure 3.27 shows the heat pump in automatic mode. The heat pump has no physical start confirmation signal, therefore the heat pump does not show the green led when

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it is started (left picture). In manual mode, the heat pump shows the hand overlay icon on top of BC01. When it is stopped the green led is not shown (middle picture) while it is shown when it is started (right image).

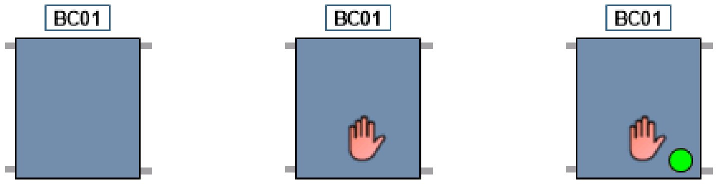

Figure 3.27: Different working modes of the heat pump.

3.5.1.7. *Distribution*

This area of the synoptic shows the distribution to the customer sub-circuit.

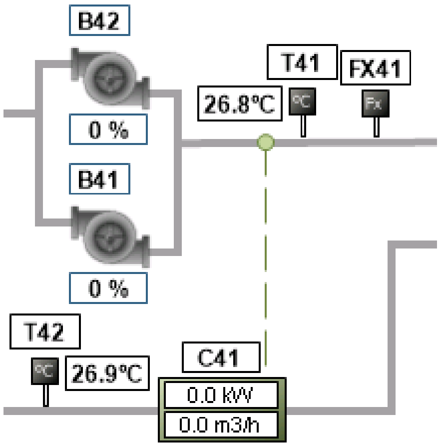

Figure 3.28: Distribution to the customer circuit with its temperature sensors, flow switch, calorimeter, and pumps.

Temperature Sensors T41, T42. These sensors are used to control and monitor the temperature delivered to the customer.

Calorimeter C41. This calorimeter accumulates the thermal energy delivered to the customer by the CHESS Setup system.

Flow switch FX41. This flow switch is used to release an alarm if there is no flow in this sub-circuit when it should be.

Pumps B41, B42. This is a set of twin pumps driven by a speed controller. The system regulates the speed of these pumps to maintain a ΔT (Delta Temperature) between T41 and T42, i.e. T41-T42. The popup dialogue for the variable speed driven pumps (figure 3.29.) is slightly different than the regular fixed speed pumps since it has to take into account the speed % set point. Therefore, when set it to manual and start (middle picture) an input text box is provided to define the speed % that will be sent to the pump driver. Moreover, in the central informative area (white background), the system provides the current speed % set point and one more alarm than the regular pumps: the

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pump drive error. The system behaves the same as with a 'Start Confirmation' alarm for a pump drive error: it will not try to start the pump again unless the operator resets the alarm using the 'RESET ALARM' button.

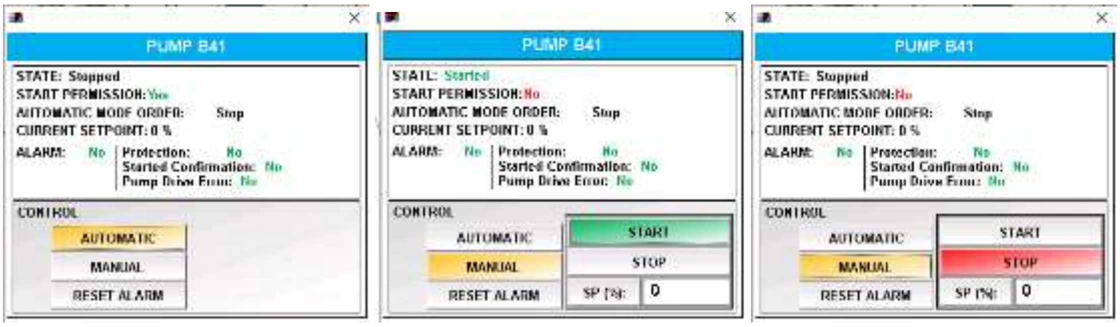

Figure 3.29: The pop dialogue for variable speed pumps

3.5.1.8. *Pool Exchangers*

This area depicts the customer circuit. The operator can monitor and control the sub-circuit responsible to deliver the energy to the end-user, i.e. maintain the pool temperature at a certain set point. Figure 3.30 shows the pool exchangers sub-circuit and its elements. The calorimeters C91, the valves VB83 and VB83a are clickable elements in the same way than in the other sub-circuits.

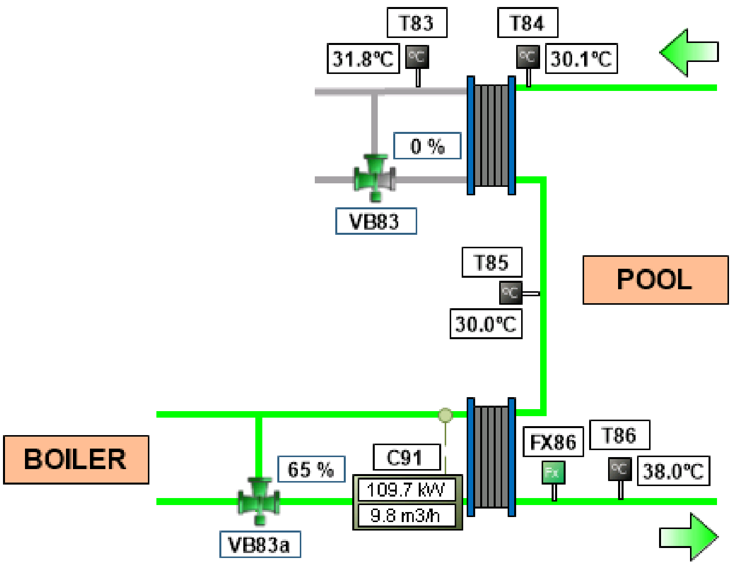

Figure 3.30: Pool exchangers sub-circuit and its elements

Temperature sensors T83, T84, T85, T86. The sensors T84, T86 are used to control the ΔT (Delta Temperature) supplied to the customer pool. The T85 is used to control if the CHESS Setup system can provide all energy demand to the pool or if it is required to use the boiler as support or fully switch to the boiler.

Valves VB83 and VB83a. The valve VB83 is a proportional valve used to control that the temperature sensor T85 reaches the pool temperature set point. Similar control is

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done in the valve VB83a and the temperature sensors T86 so that the system can perform the same control in the Boiler usage (chapter 3.5.1.8, pg. 35).

Calorimeter C91. This calorimeter measures the energy provided to the customer from the boiler.

3.5.2. Control Subsystems

The 'Screen Menu' buttons 'Pool Temperature', 'Working Modes', 'PVT panels', 'Direct STES circuit', 'Heat Pump', 'Distribution Circuit' and 'Pool exchangers' give access to the corresponding subsystem configuration screens. All these buttons in the 'Screen Menu' (apart from Plots and Alarms) will display a screen with parameters and setpoints tuneable by the 'Administrador' user. It also represents several internal system states that are useful to know the system's current state and that may help in the detection and debug of any problem that could arise during the commissioning and follow up. If the current user is the 'Administrador' (operator) the tunable parameters will be enabled and if the current user is a viewer the tuneable parameters are disabled as shown in figure 3.31 below.

Each configuration screen contains different sections (STATE, DEVICE ORDERS, SENSOR READINGS) to inspect the status of the subsystem and other sections (CONFIGURATIONS) that are used to configure the subsystem parameters. The configuration screens contain the following sections (shown in figure 3.31):

- **CONTROL**. This section allows the user to set the main control commands for the subsystem, typically stop and start (OFF / ON) the subsystem.
- **STATES**. This section shows different internal states of the subsystem, typically alarms, warnings, demands and permissions using a led pilot in green (●) when they enabled or in grey (●) when they are disabled.
- **DEVICE ORDERS**. This section shows using the green led (●) if the control of the subsystem is sending different orders to the devices in the subsystem.
- **SENSOR READINGS**. This section displays a list of sensor readings, typically temperature sensors which are used in this subsystem.
- **CONFIGURATIONS**. This section allows the user 'Administrador' through input text boxes to set the parameters for tuning the system, typically, set points and times.

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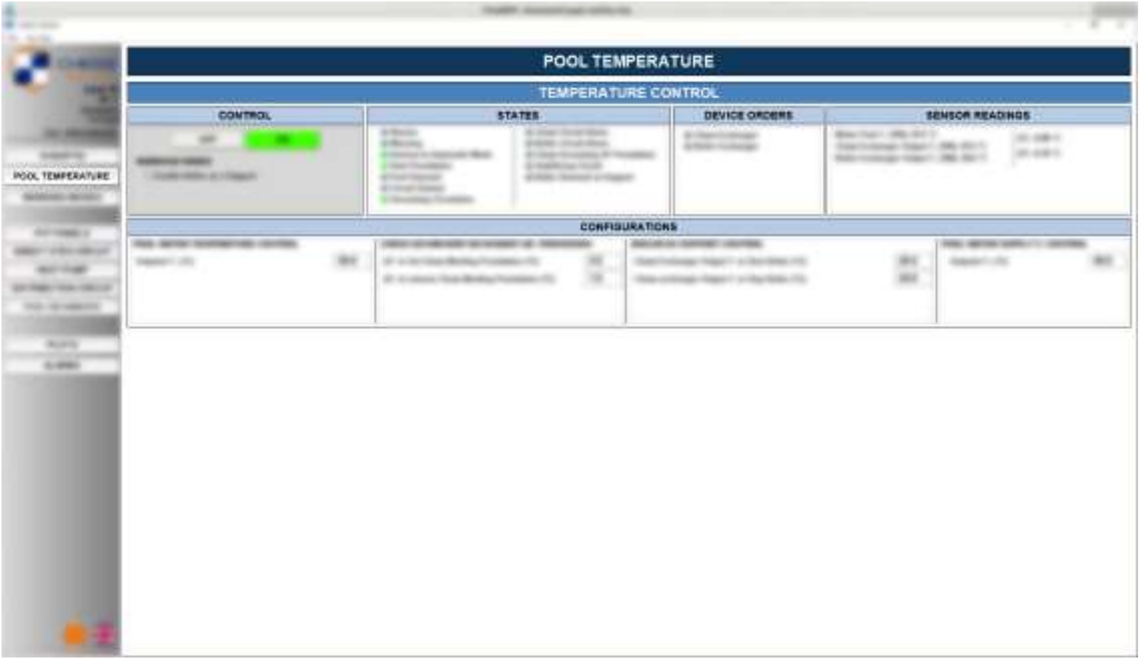

Figure 3.31: Different configuration sections for the POOL TEMPERATURE subsystem.

Figure 3.32 shows in the left picture all the controls enabled: CONTROL OFF / ON buttons, the 'Enable Boiler as a Support' checkbox and the pool temperature set point Setpoint T. (ºC) input box, while the right image shows the same controls disabled because the current logged in user is an unprivileged user (viewer).

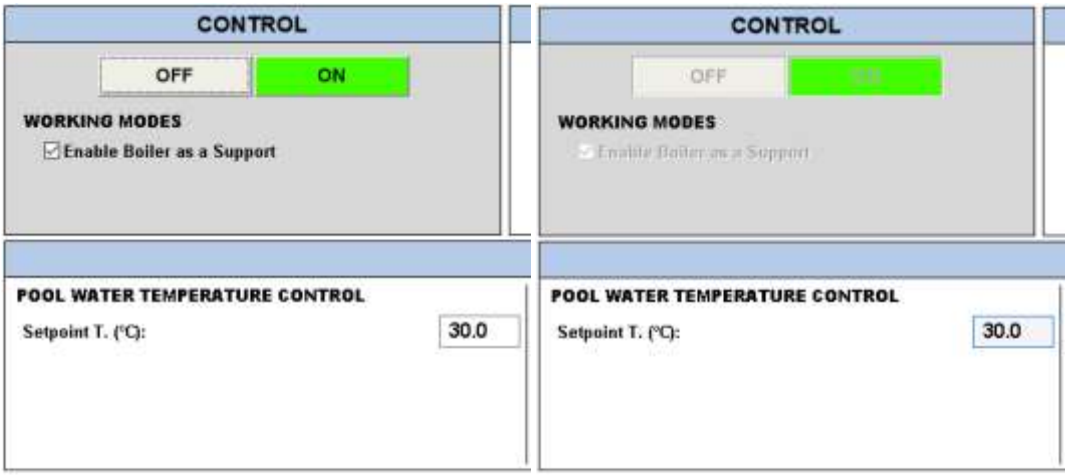

Figure 3.32: View of the status of the different controls subsystems (enable/disabled)

3.5.3. Control Considerations

This section describes several considerations that have been taken into account in the implementation of the CHESS Setup CMS and that the system operators must know:

1. The CMS detects failures in the analogical sensors such as the temperature, irradiance or relative humidity transducers because their readings are

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overflows. For instance, a temperature read that should be in the range -50.0 ºC to 50.0 ºC provides a lecture of 2000.0 ºC. That kind of overflow typically happens when there a physical problem such as an open circuit (cable is cut) or a short circuit (cable is crushed). The system considers this overflowed reads as physical problems in the installed sensors and, under these circumstances, the system releases alarms and, if possible, try to continue or stops the system as described below.

2. The different control subsystems of the CMS that use redundant temperature sensors are used in cascade in the case of failure. The usage is done from the most to least representative. For instance, in the case of the buffer tank (accumulator), since the water is drawn from the top, and the temperature sensors are located at the top (T37), middle (T36) and bottom (T35) of the tank, the system uses by default the temperature T37. If this sensor has reading problems (e.g. the wire is cut or short circuit for any reason), the system detects this state and changes the control to sensor T36. The system, in that case, will release an Alarm, show the subsystem in 'Warning' but will continue working but less accurate than using the sensor T37.

3. When using energy from the STES, the system needs to calculate ΔT (Delta Temperature) between the STES and other systems such as the pool. There are different temperature sensors placed inside the STES at different levels and positions. However, there is not a sensor placed exactly at the output pipe of the STES which would represent the water drawn temperature. Therefore, to calculate the ΔT temperature between the STES and the pool, the system uses first the most representative STES sensor as explained above compared to the pool and, after a predefined hardcoded amount of time, the system switches to another more reliable sensor placed in a used pipe such as T11 or the temperature sensors in the calorimeter C24. The system cannot use directly the temperature sensor in the pipe since all the valves involved in the operation must be set first accordingly, for this reason, the temperature from a sensor inside the STES is used first a later changed to the pipe sensor. Moreover, the hardcoded time involved in the operation to switch from one sensor to the other is not configurable to avoid any user misconfiguration.

4. The system is not using the flow switches to control apart from sensor FX86. All the other flow switches are used to release alarms when a pipe should have water flow (the pump is started and valves opened) and it is not detected by the corresponding flow switch.

5. The system working in the 'Automatic Operation' mode will never set the 'PVT Direct' working mode since it is a very inefficient working mode. For instance, in this working mode, the energy could be delivered directly from PVT panels to the customer and due to an excess of energy, the heat dissipator will start dissipating this energy excess while the STES still has room for more storage. Moreover, if the PVT panels are not able to provide enough power, the system

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will need the Boiler contribution because it is not possible and it has no sense to combine the PVT panels and the heat pump. Therefore, this mode is only reserved to be set in manual, when there is a problem in the hardware and, by using this mode, the customer could still benefit from part of the produced thermal and electrical energy.

6. The Delta Temperatures (ΔT) explained in the following sections and chapters referred to system states and setpoints that are labelled as ΔT. SensorA / SensorB, they mean that ΔT = Temperature SensorA – Temperature SensorB.
7. The system takes care of alternating the usage of the pumps in the twin sets (B01, B02), (B03, B04) and (B41, B42) to wear out all the pumps of the same set in the same way. The system has a time counter per each pump in a set and every time there is a stop/start manoeuvre of a water pump twin set, the system starts the pump with less time accumulated. At the same time, every day, the system rotates the usage of the current started to pump to the other, to prevent large usages of the same pump when there is not a stop/start manoeuvre.

3.5.4. Pool Temperature

The 'Pool temperature' button in the 'Screen Menu' activates the 'Pool Temperature Screen' in the 'Active Screen' area. Figure 3.33 shows the 'Pool Temperature Screen' content with all the states, controls and set points available in the 'Pool Temperature Screen'. The first row shows the current states (STATES, DEVICE ORDERS, and SENSOR READINGS) while the second row (CONFIGURATIONS) all the set-points that can be defined by the privileged 'Administrador' user.

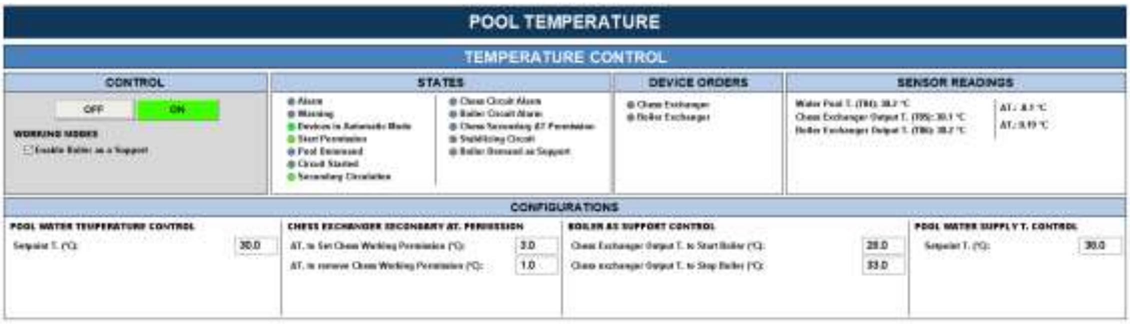

Figure 3.33: States, controls and set points available in the Pool Temperature Screen

The 'Pool Temperature control' subsystem tries to maintain pool temperature (customer) at the defined set point. The control starts when there is demand in the customer (the pool current temperature T84 is below the set-point) and there is flow in the secondary (FX86). The system regulates the valve VB83 to reach the pool set point at T85 but not exceeding the maximum temperature allowed to inject to the pool defined by the parameter POOL WATER SUPPLY T. CONTROL 〉 Set-point T. (ºC). If the system reaches the pool set point, then the subsystem sets the current working mode to 'Waiting'.

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Moreover, this subsystem decides whether the CHESS SETUP system can provide the energy to the customer or not by controlling the ΔT (Delta Temperature or temperature difference) in the CHESS SETUP exchanger. If the system is not able to maintain this ΔT (T85 – T84) in the exchanger, it means that the CHESS SETUP is not able to provide the needed energy by the pool. When this situation happens, the control system checks whether the parameter 'Enable Boiler as support' is enabled or not. If it is enabled, the system starts regulating the valve VB83a to reach the pool set point at T86. In that case, the CHESS SETUP is used as a pre-heating stage. If the Boiler is not enabled as a support, the system disables the control of valve VB83 in the CHESS exchanger and the whole energy is provided by the Boiler.

Once the system has started the Boiler, the system checks whether the temperature at the CHESS SETUP exchanger output (T85) reaches a configurable threshold or not, if the threshold is reached it means the CHESS SETUP temperature is recovered and the system disables the Boiler and starts delivering energy again from the CHESS SETUP side.

The states and configurations in each section of the 'Pool Temperature Screen' are defined below:

CONTROL

In this section, the operator can disable 'Pool Temperature' control. If it is set to 'OFF' the subsystem that controls the pool (customer) temperature is disabled, this means that this subsystem will not demand the previous subsystems, for instance, to the heat pump or the boiler subsystem. However, other subsystems that do not depend on the 'Pool Temperature' control can still perform their work, for instance, the 'PVT Panels' subsystem that loads energy into the STES. Moreover, using the checkbox 'Enable Boiler as support' the operator can configure the boiler in support mode which means that the CHESS Setup is working in serial with the Boiler to do a pre-heating stage. If the boiler is not used as a support, as soon as the CHESS cannot feed the customer because there is no ΔT (T85 – T84) the system will switch to Boiler directly.

STATES

This section displays a set of system internal states that are enabled (in green) or disabled (in grey) that help the operator and the viewer to understand what is happening internally in the control system. The different internal represented states are the following:

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- **Alarm**

  If it is enabled (●) it means that any hardware used to control this subsystem is in alarm, for instance, the system cannot read a temperature, the heat pump is in alarm or there is a protection (RCD or circuit breaker) tripped.

- **Warning**

  If it is enabled (●), there is a warning in the subsystem. The warning in a subsystem means that there is a problem that could be later an alarm, but at the moment the subsystem is still working. For instance, it could be a lecture error of an informative sensor which is not required for the control; or that in a set of twin water pumps, one of them is in alarm, but the other is still working.

- **Devices in Automatic Mode**

  It is enabled (●) if all the devices involved in this subsystem are in automatic mode. If the user sets one of them in manual, this state is disabled (●) and it means the CMS is not allowed to execute the control.

- **Start Permission**

  This state is enabled (●) if all the conditions to start this subsystem are met.

- **Pool Demand**

  This state is enabled (●) if the customer (pool) is demanding energy, i.e. the pool temperature (T84) is below the pool temperature set point.

- **Circuit Started**

  This state is enabled (●) if another subsystem is demanding the current subsystem to start (in this particular case the customer, i.e. 'Pool Demand' is enabled and 'Secondary Circulation' state is enabled) and it is working (i.e. 'Alarm' is disabled and 'Start Permission' is enabled).

- **Secondary Circulation**

  It is enabled (●) if there is water circulating in the secondary of the pool heat exchangers, i.e. flow switch FX86 is enabled.

- **Chess Circuit Alarm**

  It is enabled (●) if there is a lecture error in the temperature sensors T84, T85 or T86.

- **Boiler Circuit Alarm**

  This state is enabled (●) if there is an alarm in the Boiler (currently, not wired).

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- **Chess Secondary ΔT Permission**

  There is permission for ΔT **(**Delta Temperature or temperature difference) to work in CHESS mode (see 'CHESS SECONDARY EXCHANGER ΔT PERMISSION' below).

- **Stabilizing Circuit**

  The valve V83 is regulated by ΔT (T85 - T84) to know if the CHESS is delivering energy to the customer or not. However, this ΔT is not taken into consideration immediately when the subsystem starts the regulation since a temporal filter is required until the temperatures in the pipes are enough stable. This stabilization is required, if it was not done in that way or the stabilization time is too small, the regulation of the valve VB83 might never start because the ΔT condition is out of bounds ('CHESS EXCHANGER SECONDARY ΔT PERMISSION') might never be met. For this criticality, the filter time is hardcoded and not tunable by the user.

  This state is enabled ( )during the stabilization of the circuit temperature.

- **Boiler Demand as a Support**

  This state is enabled ( ) if the Boiler is configured as support.

DEVICE ORDERS

- **Chess Exchanger**

  This state is enabled ( ) when the subsystem is demanding energy to the CHESS heat exchanger and, therefore, the valve VB83 is being regulated.

- **Boiler Exchanger**

  This state is enabled ( ) when the subsystem is demanding energy to the Boiler heat exchanger and, therefore, the valve VB83a is being regulated.

SENSOR READINGS

- **Water Pool T. (T84)**

  This is the temperature in the pool returning pipe and it is considered by the system as the current pool temperature.

- **Chess Exchanger Output T. (T85)**

  This is the temperature at the supply of the CHESS exchanger and the return of the Boiler exchanger. This point is used to regulate the pool supply temperature using the valve VB83 and to know through the ΔT (T85 – T84) if there is heat exchange between the primary and the secondary of the CHESS exchanger.

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- **ΔT**

  The first row ΔT shows the Delta Temperature (difference) between the 'Water Pool T.' (T84) and the 'Chess Exchanger Output T.' (T85).

  This ΔT is used by the system to decide whether there is heat exchange between the CHESS and the pool considering the parameters defined at 'CHESS EXCHANGER SECONDARY ΔT PERMISSION'.

- **Boiler Exchanger Output T. (T86)**

  This state shows the temperature at the output of the Boiler exchanger. The system tries to maintain the pool supply set-point defined in 'Configurations' at this temperature sensor by regulating the valve VB83a.

- **ΔT**

  The second row ΔT shows the Delta Temperature (difference) between the 'Chess Exchanger Output T.' (T85) and the 'Boiler Exchanger Output T.' (T86).

  This ΔT determines if the subsystem is providing energy to the pool using the CHESS or not. It enables and disables the CHESS working permission defined below taking into consideration the stabilization stage.

CONFIGURATIONS

POOL WATER TEMPERATURE CONTROL

- **Setpoint T. (ºC)** **[Default 30.0]**

  This input box allows entering the pool temperature (customer) set point. The system will try to reach this temperature in the sensor T84 (pool return). The fine control is a two-point hardcoded control. The system keeps the T84 between the set-point defined by parameter minus 0,2ºC and 0,2ºC. If the temperature drops below this set point minus 0,2ºC the system starts providing energy until the set-point plus 0,2ºC is reached.

CHESS EXCHANGER SECONDARY ΔT PERMISSION

- **ΔT. To Set Chess Working Permission (ºC)** **[Default 3.0]**

  This parameter is used to enable the CHESS working permission after the stabilization stage is executed. If ΔT = T85 – T84 is larger than this parameter the CHESS enables the working permission.

- **ΔT. To remove Chess Working Permission (ºC)** **[Default 1.0]**

  This parameter is used to disable the CHESS working permission after the stabilization stage is executed. If ΔT = T85 – T84 is smaller than this parameter the CHESS disables the working permission.

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BOILER AS SUPPORT CONTROL

This section is only meaningful when the system has the Boiler enabled as support (configurable in the previous section **CONTROL**).

- **Chess Exchanger Output T. To Start Boiler (ºC)** **[Default** 28.0**]**

  If CHESS exchanger output is lower than this parameter and the Boiler is enabled as a support, the system starts the Boiler. While the CHESS can maintain the configured ΔT in the previous section, the CHESS will act as a pre-heating stage and the system will supply the rest of the energy by maintaining the pool supply temperature at T86 through the Boiler.

- **Chess Exchanger Output T. To Stop Boiler (ºC)** **[Default** 33.0**]**

  If the CHESS exchanger output is higher than this threshold it means that the CHESS recovered and is now able to provide energy, therefore the Boiler is stopped and all the energy will be delivered using the CHESS.

POOL WATER SUPPLY T. CONTROL

Set-point T. (ºC) **[Default** 38.0**]**

This set-point is the supply temperature to the customer. It is the maximum temperature that will be delivered to the pool at the pool temperature supply (T86 sensor). The system may not reach this point especially working only with CHESS but it is not critical, the pool will be warmed up but more slowly.

3.5.5. Working Modes

The 'Working Modes' button in the 'Screen Menu' activates the 'Working Modes Screen' in the 'Active Screen' area. Figure 3.34 shows the states and the controls to start, stop and switch between the different working modes in the 'Working Modes Screen'. The first row shows the current states while the second row all the set-points that can be defined by the 'Administrador' for each working mode (Direct STES, Heat Pump, Direct PVT).

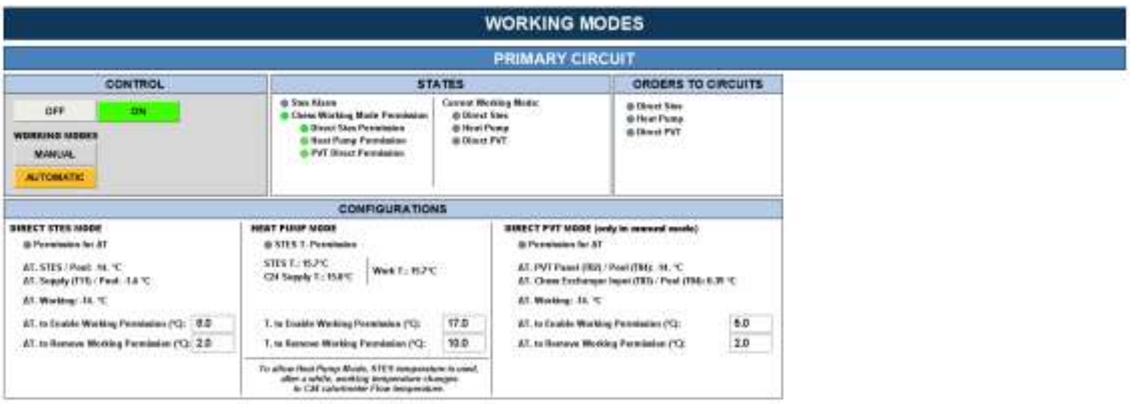

Figure 3.34: Working Modes Screen

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CONTROL

When set to 'OFF' this subsystem does not allow the CMS to work in any mode and it remains disabled. When the subsystem is set to 'ON', it allows defining the 'Operating Mode' in 'Manual or Automatic'. When the 'Operating Mode' is set to 'Automatic', the system decides automatically the 'Working Mode' (Direct STES or Heat Pump) as described in chapter 3.5.5. In manual mode the CMS allows the user to set manually the working mode. In manual mode, as far as the 'PVT Direct' mode is not set, the CMS feeds energy to STES and the anti-freezing subsystem operates normally.

STATES

This section displays a set of internal states that are enabled (●) or disables in grey (●) that help the operator and the viewer to understand what is happening internally in the control. The different internal states represented are the following:

- **STES Alarm**

  This state is enabled (●) when there is a lecture error in one of the temperature sensors or the water level sensor.

- **Chess Working Mode Permission**

  If this estate is enabled (●), the STES system can operate in, at least, one of the possible working modes, therefore the conditions are met to work in one or more of the modes (typically the conditions are that all the devices are in automatic mode and there is not an alarm).

  The different permissions are also represented per working mode in the next states:

  - **Direct STES Permission**

    If this state is enabled (●) it means that all conditions are met to deliver the energy directly from STES to the customer.

  - **Heat Pump Permission**

    If this state is enabled (●) it means that all the conditions are met to deliver energy from the STES to the client but using the heat pump.

  - **PVT Direct Permission**

    If this state is enabled (●) the energy can be delivered directly from PVT panels to the consumer. This mode can only be activated when the system is in manual mode it will never be enabled by the system itself in **Automatic Operating** mode.

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- **Current Working Mode**

  This state shows the current working model. Only one of the three different working modes can be enabled at the same time:

  - **Direct STES:** The control system is currently working in 'Direct STES Working Mode'.
  - **Heat Pump:** The control system is currently working in 'Heat Pump Working Mode'.
  - **Direct PVT:** The control system is currently working in 'Direct PVT Working Mode'.

ORDERS TO CIRCUITS

This state shows which working mode the system is ordering to be set. If no one is enabled the system is in 'Waiting' mode. Even if one of the following modes is set, it does not mean the system is operating in this mode, since the conditions to start it can be not yet met (for instance, there is no demand from the customer). The current working mode can be found in the synoptic top right corner (chapter 3.5.5).

- **Direct STES.** The system is activating the 'Direct STES Working Mode'.
- **Heat Pump.** The system is activating the 'Heat Pump Working Mode'.
- **Direct PVT.** The system is activating the 'Direct PVT Working Mode'.

CONFIGURATIONS

This section allows inspecting the states and configuring the parameters separated in three subsections, one per each different working mode:

DIRECT STES MODE

This subsection contains the states and parameters related to the 'Direct STES Working Mode'.

Permission for ΔT

If this state is enabled (●) the control system has permission to work in 'Direct STES Working Mode'. The configurations to enable and disable this permission are shown below.

ΔT. STES / Pool: -12. **ºC**

This state shows the Delta temperature (ΔT) between the STES and the customer to know if it is possible to start delivering the energy directly from the STES to the pool. In this example (ΔT = T STES – T. Pool = -12ºC) it is not possible

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since the STES temperature is lower than the customer needs. The configuration ΔT. 'To Enable/Remove Working Permission (ºC)' below is used to define the Delta temperature (ΔT) to start and stop the 'Permission for ΔT'. As explained in chapter 3.5.3 the most representative sensor in the STES will be used if available.

ΔT. Supply (T11) / Pool: -1.6 **ºC**

To be more accurate, the system, after a predefined amount of time, hardcoded in the CMS, switches from the STES temperature sensor to the T11 to calculate the ΔT. Therefore, this sensor, the pool temperature, and the computed ΔT are used to stop the permission to work in this mode by comparing it to the parameter ΔT. 'To Remove Working Permission (ºC)' below.

ΔT. Working: -12 **ºC**

This state shows which one of the previous ΔT the system is currently using.

ΔT. To Enable Working Permission (ºC): [Default 8.0**]**

This ΔT setpoint is used to enable the 'ΔT Permission' to allow the system to work in 'Direct STES Working Mode'.

ΔT. To Remove Working Permission (ºC): [Default 2.0**]**

This ΔT temperature set point is used to remove the 'ΔT Permission' to forbid the system work in 'Direct STES Working Mode'.

HEAT PUMP MODE

This subsection contains the states and parameters related to the 'Heat Pump Working Mode'.

STES T. Permission

This state is enabled (●) if the system has permission to work using the heat pump. The state depends on the readings and configurations below.

STES T.: 17.6 **ºC**

This temperature from the STES tank is used to start and stop the 'Heat Pump Working Mode' depending on the configured set points below. This temperature is used at the beginning (when there is no water flow in the pipes) to start, but later on, the system switches to the 'C24 Supply T'. below.

C24 Supply T.: 14.0 **ºC**

This state shows the supply temperature available from the calorimeter C24. The system initially uses the STES tank temperature to start, but when there is water flow in the C24 pipe, this temperature is more reliable since inside the

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STES tank there are different temperature sensors at different levels and positions along the tank, however, the STES output pipe is connected to a collector that draws the water from different points along the STES tank. Therefore, this C24 supply temperature is a more reliable temperature sensor when there is water flow.

Work T.: 14.0 ºC

This state shows the current working temperature, which must be one of the two above 'STES T.' or 'C24 Supply T.', in the example it is 14ºC which matches with 'C24 Supply T.', therefore, the current working temperature is the one from the calorimeter C24. This strategy of switching the temperature sensor is the same used in the previous working mode.

T. to Enable Working Permission (ºC): [Default 15.0]

The system enables the 'Heat Pump Working Mode' permission if the 'Work T.' is above this set point. In the current example, the 'STES T. Permission' is enabled since 15.0ºC > 14.0ºC.

T. to Remove Working Permission (ºC): [Default 10.0]

The system removes the 'Heat Pump Working Mode' permission if the 'Work T.' drops below this set point. In the current case, the 'STES T. Permission' must not be removed since 14.0ºC > 10.0ºC.

DIRECT PVT MODE (*only available in manual mode*)

This subsection contains the states and parameters related to the 'Direct PVT Working Mode'.

Permission for ΔT

This state is enabled (●) if the system has permission to work in 'Direct PVT Working Mode'. The state depends on the readings and configurations defined below.

ΔT. PVT Panel (T02) / Pool (T84): 4.89ºC

This state shows the Delta temperature (ΔT) between the PVT Panels measured by the sensor T02 and the customer (pool) measured by the sensor T84. If the Delta temperature (ΔT) is high enough (defined in the configurations below) the system enables the 'Permission for ΔT' in this mode.

ΔT. Chess Exchanger Input (T83) / Pool (T84): 6.70ºC

This state shows the Delta temperature (ΔT) between the CHESS exchanger input measured by the sensor T83 and the current pool temperature represented by the pool return temperature sensor T84. In this working mode,

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the system considers the Delta temperature (ΔT) between the CHESS exchanger input (T83) and the current pool temperature (T84) to stop the system because it is not possible to deliver more energy to the system.

ΔT. Working: 4.89**ºC**

This state shows which ΔT of the two above the system is currently using to operate. The system starts with PVT Panel versus Pool and later on passes to CHESS exchanger input versus Pool.

ΔT. to Enable Working Permission (ºC): **[Default** 5.0**]**

The system enables the 'Direct PVT Working Mode Permission for ΔT' if the 'ΔT. Working' is above this set point. In the current case, the 'Permission for ΔT' is enabled since 5.0ºC > 4.89ºC.

ΔT. to Remove Working Permission (ºC): **[Default** 2.0**]**

The system removes the 'Direct PVT Working Mode Permission for ΔT' if the 'ΔT Working' drops below this setpoint. In the current example, the 'Permission for ΔT' must not be removed since 4.89ºC > 2.0ºC

3.5.6. PVT Panels

The 'PVT panels' button in the 'Screen Menu' activates the 'PVT Panels Screen' in the 'Active Screen' area. This screen shows all the states and different controls that are performed by the PVT panel subsystem to deliver energy to the STES or directly to the customer, avoid the circuit freezing in winter or cool down the PVT panels using the heat dissipator in the case of an excess of temperature in the PVT primary circuit. Figure 3.35 shows all the states, controls and set points available in the PVT Panels Screen. This screen is populated with a large set of states and parameters due to the complexity and the number of tasks done by this subsystem. The subsystem has a primary and secondary circuit separated by a heat exchanger and a part of providing energy to either the STES or the customer, the tasks of anti-freezing, temperature homogenization and cooldown have to be performed by the control, and therefore, each task needs its parameters and states.

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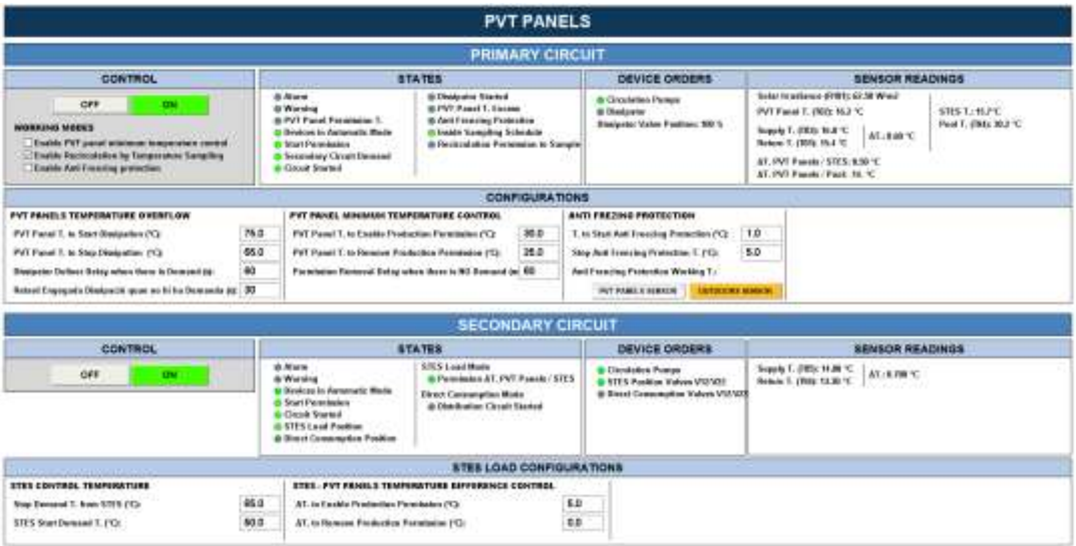

Figure 3.35: PVT Panels Screen.

The 'PVT Panels screen' is divided into two main sections each one corresponding to one of the two main control subsystems: the 'Primary Circuit' corresponding to the primary side of the 'PVT Panels' exchanger, and the 'Secondary Circuit' corresponding to the secondary side of the 'PVT Panels' exchanger.

PRIMARY CIRCUIT – CONTROL

- The **'OFF / ON'** buttons, disable and enable, respectively, the primary circuit control.

- **Enable PVT panel minimum temperature control** **[Default** Disabled**]**

  The system normally uses the ΔT of the PVT panels concerning the STES to start delivering energy from the PVT panels to the STES as described below. In small size systems with very little inertia, an extra mechanism is used to avoid a sudden temperature drop down as soon as the system starts pulling energy from the PVT panels: the system only starts if the PVT panel temperature is above a minimum temperature threshold. If this checkbox is enabled, the system takes into account that the panel temperature sensor T02 reaches the threshold 'PVT Panel T. to Enable Production Permission (ºC)' to start delivering energy to the STES. In the case of the CHESS SETUP, this option is not necessary, only using the Delta temperature (ΔT) between PVT Panels and STES is enough.

- **Enable Recirculation by Temperature Sampling** **[Default** Enabled**]**

  If this checkbox is enabled, when the system is not working, during the day (hard coded from 7 AM and 8 PM), the recirculation control subsystem takes the control of the PVT primary to perform a recirculation to stabilize the primary circuit temperature at sensor T02. This recirculation stabilizes the

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temperature in the circuit and avoids sudden temperature rising and drops down when the system starts later for energy delivery. The water also circulates through the dissipator.

- **Enable Anti-Freezing protection** **[Default Enabled]**

  This checkbox enables the anti-freezing protection by software. The system starts a water recirculation in the PVT primary circuit including the dissipator every 30 minutes and during 5 minutes if the outdoors temperature is lower than a threshold defined below in the parameters. These times are hardcoded to avoid misconfigurations.

PRIMARY CIRCUIT – STATES

- **Alarm**

  This state is enabled (●) if there is any device controlled by this subsystem in alarm (e.g. the dissipator). If there is an alarm in this subsystem, the water pumps and the dissipator are started to make the water flow in the PVT primary circuit to avoid any problem in the PVT panels, for instance, a failure in the temperature sensor in winter could damage the PVT panels by freezing the water if there is no water circulation.

- **Warning**

  This state is enabled (●) if there is a device used but not required in this subsystem that is in alarm, for instance, one of the twin set of pumps B01 and B02.

- **PVT Panel Permission T.**

  This state is enabled when there is permission enabled to work from PVT panels to the STES. The permission depends on the 'PVT Panel T. to Enable Production Permission (ºC)' defined below.

- **Devices in Automatic Mode**

  This state is enabled if the system has all the devices related to the PVT primary circuit enabled and in automatic mode. If any device is in manual mode, this state is disabled (●) and, therefore, the system does not allow any automatic task that uses the PVT primary circuit.

- **Start Permission**

  If it is enabled (●) it means that all conditions are met to allow the PVT primary circuit to start.

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- **Secondary Circuit Demand**

  If it is enabled (●) it means that the PVT secondary circuit is demanding energy to the primary, so the primary control should start the PVT primary circuit.

- **Circuit Started**

  If it is enabled (●) it means that the PVT primary circuit is started.

- **Dissipator Started**

  It is enabled (●) when de dissipator control is activated, therefore, the system starts the dissipator device and allows the water flow to enter in it.

- **PVT Panel T. Excess**

  This state is enabled (●) when the PVT panel temperature T02 is higher than the threshold defined by the parameter 'PVT Panel T. to Start Dissipation (ºC)' and, therefore, the dissipation algorithm should start.

- **Anti-Freezing Protection**

  If it is enabled (●) the system is executing the anti-freezing algorithm, i.e. the algorithm forces water circulation in the PVT primary circuit if the outdoor temperature drops below the parameter 'T. to Start Anti- Freezing Protection (ºC)'. The system stops the algorithm when the outdoors temperature surpasses the 'Stop AntiFreezing Protection T. (ºC)'. The anti-freezing algorithm is started independently of the time of the day if the PVT primary circuit is not producing energy. In the case of energy production in the PVT primary, the water is already circulating.

- **Inside Sampling Schedule**

  This state is enabled (●) when the system is inside the hardcoded sampling schedule (during the day from 7 AM to 8 PM).

- **Recirculation Permission to Sample**

  When the system is inside the sampling schedule defined above and the conditions to send energy to the PVT secondary are NOT met (i.e. the ΔT between panels and STES and the minimum temperature to start described above), the permission to start a recirculation sample is enabled (●).

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PRIMARY CIRCUIT - DEVICE ORDERS

- **Circulation Pumps**

  The system is sending the order to start the circulation pumps (i.e. the twin pumps B01 and B02).

- **Dissipator**

  If this state is enabled (●), the PVT primary circuit control is starting the dissipator.

- **Dissipator Valve Position:** 100**%**

  This state shows the current dissipator 3-Way Proportional valve position.

PRIMARY CIRCUIT - SENSOR READINGS

- **Solar Irradiance (R101):** 370.2 **W/m2**

  This state shows the current solar irradiance measured by the sensor R101.

- **PVT Panel T. (T02):** 31.7 **ºC**

  This state shows the current PVT panel temperature measured by the sensor T02. This sensor is placed in the output of a PVT panel row, therefore it represents the highest temperature that a module is having.

- **STES T.** 17.5 **ºC**

  This state shows the current STES temperature. The temperature shown follows the criteria explained in chapter 3.5.3, pg.37.

- **Pool T. (T84)** 29.5 **ºC**

  This state shows the current pool temperature measured by the sensor T84.

- **Supply T. (T03):** 27.5 **ºC**

  This state shows the supply temperature measured in the primary input of the PVT exchanger.

- **Return T. (T01):** 24.4 **ºC**

  This state shows the return temperature measured in the primary output of the PVT exchanger.

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- **ΔT.:** 3.10 **ºC**

  This state shows the difference between the above 'Supply' and 'Return' temperatures in the PVT primary input and output. In the example ΔT = 27.5 - 24.4 = 3.10ºC.

- **ΔT. PVT Panels / STES:** 14.2 **ºC**

  This state shows the Delta Temperature (ΔT) between the PVT panel temperature and the STES. This difference is used to start loading energy into the STES tank depending on the configurations below.

- **ΔT. PVT Panels / Pool:** 2.29 **ºC**

  This state shows the Delta Temperature (ΔT) between the PVT panel temperature and the pool (customer). This difference is used when delivering the energy directly from PVT panels to the customer (**Direct PVT Working Mode**).

PRIMARY CIRCUIT – CONFIGURATIONS

This section describes the configuration parameters that are used to tune the control for the PVT panels' primary circuit.

PVT PANELS TEMPERATURE OVERFLOW

This subsection contains the parameters for the temperature dissipation in the PVT panels.

- **PVT Panel T. to Start Dissipation (ºC): [Default** 75.0**]**

  This parameter allows defining at which PVT panel temperature (given by sensor T02) the system starts the dissipator to avoid a failure in the PVT panels. There is no regulation during the dissipation, the water pumps are started and the valve VB01 delivers all the water through the dissipator.

- **PVT Panel T. to Stop Dissipation (ºC): [Default** 65.0**]**

  This parameter defines at which PVT panel temperature (given by sensor T02) the system stops the dissipator.

- **Dissipator Start Delay when there is Demand (s): [Default** 60**]**

  This parameter allows to set a delay between the detection of a temperature overflow in the PVT panels (T02 > PVT Panel T. to Start Dissipation (ºC)) and the physical start of the dissipator. This temporal filter is only applied when

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the system is demanding energy and it is separated from the case when there is no demand (parameter defined below) because when there is demand, the filter could be larger since the system is already utilizing the energy.

- **Dissipation Start Delay when there is NO demand (s): [Default 30]**

  This parameter is a temporal filter with the same meaning tan the parameter above but when there is no energy demand to the PVT primary. This parameter is typically lower than the parameter above because when there is no demand the system is not benefiting from the generated energy, therefore it could be dissipated as soon as possible.

PVT PANEL MINIMUM TEMPERATURE CONTROL

The system has a PVT panel temperature measurement (T02) to obtain the PVT panel temperature. When there is no water flow, for instance, in the morning when the system starts for the first time, the water temperature inside the panels and the pipes are not homogeneous, therefore, the system has a control that forces the water circulation during a certain amount of time hardcoded in the CMS (5 minutes). This subsection contains the parameters related to the control of the production permission given this homogeneous temperature measurement in the PVT primary.

PVT Panel T. to Enable Production Permission (ºC): [Default 30.0]

This parameter defines when there is permission to deliver energy to the PVT panel secondary, i.e. the homogeneous PVT panel temperature T02 is higher than this parameter.

PVT Panel T. to Remove Production Permission (ºC): [Default 25.0]

This parameter defines the threshold where the system removes the permission to deliver energy to the PVT panel secondary, i.e. the homogeneous PVT panel temperature T02 is lower than this parameter.

Permission Removal Delay when there is NO Demand (m) 60 [Def. Value]

This parameter is used to avoid night or inter-day issues with the temperature homogeneity in the panels. When there is no demand during the time specified by this parameter, the system removes the permission even though the PVT panel T02 did not drop below the parameter above. Therefore, the system is forced to reach again the **PVT Panel T. to Enable Production Permission (ºC)** and avoid the next start with non-homogeneous temperature water in the circuit (that, depending on the season, could even be the next day).

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ANTI-FREEZING PROTECTION

This subsection allows defining the parameters for the anti-freezing control subsystem.

T. to Start Anti-Freezing Protection (ºC): [Default 1.0]

If the temperature drops below this parameter, the system starts the anti-freezing protection algorithm. The temperature sensor used to compare with this parameter is defined by the buttons described below ('PVT panels sensor', 'Outdoors sensor').

Stop Anti-Freezing Protection T. (ºC): [Default 5.0]

If the temperature surpasses the value of this parameter, the anti-freezing protection algorithm stops. The temperature sensor used to compare with this parameter is defined by the buttons described below.

Anti Freezing Protection Working T.: 'PVT panels' [Default 'Outdoors sensor']

By pressing the button 'PVT PANELS' or 'OUTDOORS SENSOR' the system selects which temperature sensor is used as the reading to start and stop the anti-freezing protection algorithm. When one of the sensors is used the button background is set in orange, in the example, the outdoors temperature sensor is currently used.

SECONDARY CIRCUIT – CONTROL

In this section, the 'Administrador' user is allowed to disable ('OFF') or enable ('ON') the PVT panel secondary control.

SECONDARY CIRCUIT – STATES

- **Alarm**

  If this estate is enabled (●) there is a device in this subsystem (PVT panel secondary) that is in alarm (e.g. a water pump or a valve)

- **Warning**

  If this state is enabled (●), there is a device in alarm in this subsystem not required to continue working. In the state of 'Warning', the subsystem can continue its work normally but the operator should check and solve the problem, typically, an alarm by email is sent.

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- **Devices in Automatic Mode**

  This state is enabled (●) if the system has all the devices involved in the PVT secondary circuit in automatic mode. If any device is in manual this state is disabled (●) and this subsystem will not be started.

- **Start Permission**

  If this state is enabled (●) it means that all the conditions are met to allow the PVT panel secondary to start.

- **Circuit Started**

  This state is enabled (●) if the PVT panel secondary circuit is started.

- **STES Load Position**

  This state is enabled (●) if the valves involved in the PVT panel secondary circuit are in **STES Load** position, therefore, set in the way that the energy can be delivered into the STES tank.

- **Direct Consumption Position**

  This state is enabled (●) if the valves involved in the PVT panel secondary circuit are in 'Direct Consumption' position, therefore, set in the way that the energy can be delivered directly to the customer.

- **STES Load Mode – Permission ΔT. PVT Panels / STES**

  When the PVT panel secondary circuit is in 'STES Load Mode', this state shows the user if the system has permission to load energy into the STES due to the Delta temperature (ΔT) between the PVT Panels and the STES.

SECONDARY CIRCUIT – DEVICE ORDERS

- **Circulation Pumps**

  If this state is enabled (●), it shows to the user that the system has already started the circulation pumps, therefore, they should be started physically. If they are not started, it means there is a physical problem in the system such as an I/O issue or protection (RCD or circuit breaker) tripped.

- **STES Position Valves V12/V22**

  This state shows to the user whether the valves V12/V22 are in 'Load STES Position' or not.

- **Direct Consumption Valves V12/V22**

  This state shows to the user whether the valves V12/V22 are in 'STES Direct Consumption' or not.

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SECONDARY CIRCUIT – SENSOR READINGS

- **Supply T. (T05):** 19.40 **ºC**

  This state shows the current supply temperature in the secondary of the PVT panel exchanger given by the temperature sensor T05.

- **Return T. (T04):** 14.60 **ºC**

  This state shows the current return temperature in the secondary of the PVT panel exchanger given by the temperature sensor T04.

- **ΔT.:** 4.80**ºC**

  This state shows the Delta temperature (ΔT) in the PVT panel exchanger secondary.

STES LOAD CONFIGURATIONS

STES CONTROL TEMPERATURE

- **Stop Demand T. from STES (ºC):** **[Default** 65.0**]**

  This parameter adjusts the STES upper-temperature limit. If the STES tank temperature exceeds the limit set in this parameter, the system will stop feeding energy to the STES tank to prevent any physical damage due to the temperature of the water. The representative temperature from the STES is used as described in chapter 3.5.3, pg. 37.

- **STES Start Demand T. (ºC):** **[Default** 50.0**]**

  If the STES temperature drops below the temperature specified by this parameter, the system starts loading energy into the STES tank again. The representative temperature from the STES is used as described in chapter 3.5.3, pg. 37.

STES – PVT PANELS TEMPERATURE DIFFERENCE CONTROL

- **ΔT. To Enable Production Permission (ºC):** **[Default** 5.0**]**

  This parameter defines the Delta temperature (ΔT) between STES and PVT panels from which the system considers that energy can be fed into the STES from the PVT panels. The system is allowed to load energy into the STES tank independently of the absolute temperature, therefore, if the STES is, for instance, at 15ºC, and this parameter is set to 5.0ºC when the PVT panel temperature is above 20ºC, the system is allowed to load energy

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into the STES. The representative temperature from the STES is used as described in chapter 3.5.3, pg. 37.

- **ΔT. To Remove Production Permission (ºC): [Default** 0.0**]**

  If the Delta temperature (ΔT) between STES and PVT panels drops below this parameter, the system stops feeding energy into the STES tank to prevent heating up the PVT panels using the energy from the STES. The representative temperature from the STES is used as described in chapter 3.5.3, pg. 37.

3.5.7. Direct STES Circuit

The 'Direct STES circuit' button in the 'Screen Menu' activates the 'Direct STES Screen' in the 'Active Screen' area. This screen shows all the states and different controls that are performed by the 'Direct STES Circuit' subsystem to deliver energy directly from the PVT panels to the consumer.

Figure 3.36: States available in the Direct STES Circuit.

CONTROL

In this section, the Administrator user is allowed to disable ('OFF') or enable ('ON') the 'Direct STES' subsystem control.

STATES

- **Alarm**

  This state is enabled (●) if any required device in this subsystem is in alarm.

- **Warning**

  This state is enabled (●) if any NON required device in this subsystem is in alarm. When the subsystem is in the 'Warning' state, it does still operate normally.

- **Devices in Automatic Mode**

  This state is enabled (●) if the system has all the devices involved in the 'Direct STES Circuit' subsystem in automatic mode. If any device is in manual this state is disabled and this subsystem will not be started.

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- **Start Permission**

  If this state is enabled (●) it means that all the conditions are met to allow the 'Direct STES Circuit' subsystem to start.

- **Pool Demand**

  This state is enabled (●) if the control subsystem for the customer (pool) is in demanding state, therefore the other subsystems that provide energy to the pool should start.

- **Circuit Started**

  This state shows to the user that the 'Direct STES Circuit' subsystem is started.

- **VT11 Valve Opened**

  This state shows whether the valve VT11 is opened (●) or not (●).

- **VT21 Valve Opened**

  This state shows whether the valve VT21 is opened (●) or not (●).

DEVICE ORDERS

- **Circulation Pump (B11)**

  This state shows to the user that the 'Direct STES' control subsystem is sending the order to start the circulation pump B11, therefore, this pump should start physically. If the pump B11 is not started this means that there is a physical problem with an I/O signal or an electrical protection (RCD or circuit breaker) tripped.

- **Open Valves (VT11/VT21)**

  This state shows to the user that the 'Direct STES' control subsystem is sending the order to open the valves VT11 and VT12.

- **Close Valves (VT11/VT21)**

  This state shows to the user that the 'Direct STES' control subsystem is sending the order to close valves VT11 and VT12.

SENSOR READINGS

- **Supply T. (T11):** 30.0 ºC

  This state shows the supply temperature given by temperature sensor T11 to the customer using the 'Direct STES Working Mode'.

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3.5.8. Heat Pump

The 'Heat pump' button in the 'Screen Menu' activates the 'Heat Pump Screen' in the 'Active Screen' area. This screen shows all the states and different controls that are performed by the 'Heat Pump' subsystem to deliver energy to the customer from the STES to the customer by using the heat pump.

Figure 3.37 shows all the states, controls and set points available in the 'Heat Pump Screen'. This screen is populated with a large set of states and parameters due to the complexity and the number of tasks done by this subsystem. The subsystem has the production circuit that contains the heat pump (chiller) and the 'Accumulator Output Circuit' that has the buffer tank and the connection to the distribution circuit.

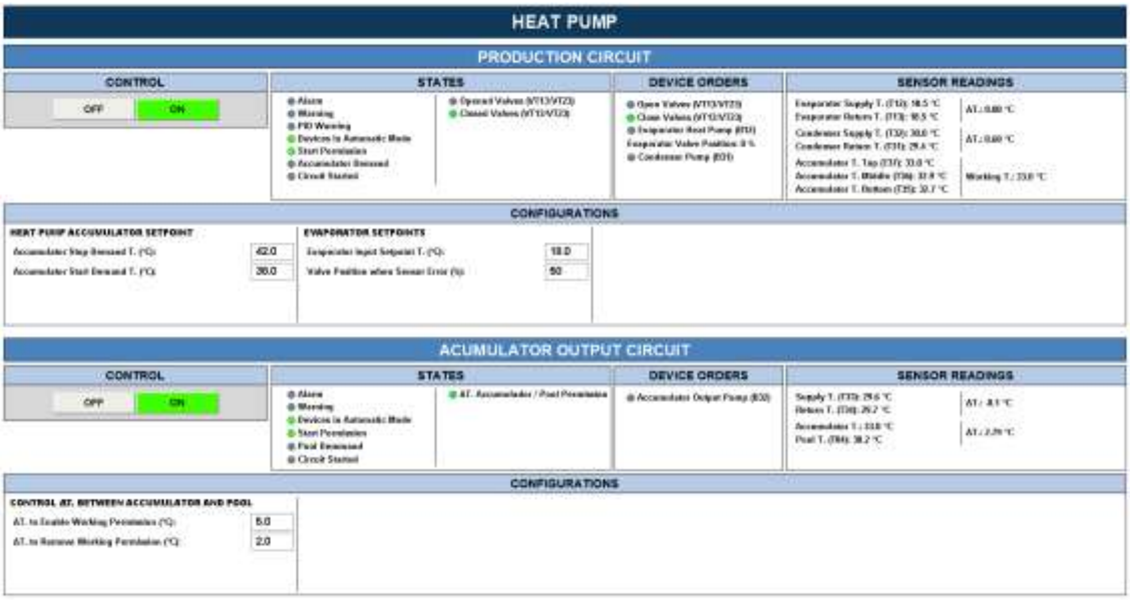

Figure 3.37: States, controls and set points available in the Heat Pump Screen.

The 'Heat Pump Screen' is divided into two main sections corresponding each to one of the two main control subsystems: the 'Production Circuit' which contains the heat pump and the 'Accumulator' circuit which contains the buffer tank and the connection to the distribution circuit.

PRODUCTION CIRCUIT – CONTROL

In this section, the administrator user is allowed to disable ('OFF') or enable ('ON') the 'Production Circuit' control.

PRODUCTION CIRCUIT – STATES

- **Alarm**

  This state is enabled (●) if any required device in this subsystem is in alarm. When the subsystem is in alarm it does not operate.

- **Warning**

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This state is enabled (🟢) if any NON required device in this subsystem is in alarm. When the subsystem is in the 'Warning' state, it does still operate normally.

- **PID Warning**

  This state is enabled (🟢) if there is a lecture error in the temperature sensor T12 used to regulate the valve VB15. In the case this warning is released, the valve VB15 is set to the setpoint defined by the parameter below 'Valve Position when Sensor Error (%)' to allow the user to define the default system behaviour on this error.

- **Devices in Automatic Mode**

  This state is enabled (🟢) if the system has all the devices involved in the 'Heat Pump Production Circuit' are in automatic mode. If any device is in manual this state is disabled (⚫) and this subsystem will not be started.

- **Start Permission**

  If this state is enabled (🟢) it means that all the conditions are met to allow the 'Heat Pump - Production Circuit' to start.

- **Accumulator Demand**

  This state is enabled (🟢) if the control subsystem for the 'Accumulator' is in demanding state, therefore the 'Heat Pump - Production Circuit' subsystem that provides energy to the heat pump accumulator should start.

- **Circuit Started**

  This state shows to the user that the 'Heat Pump - Production Circuit' is started.

- **Opened Valves (VT13 / VT23)**

  This state shows whether the valves VT13 and VT23 are opened (🟢) or not (⚫).

- **Closed Valves (VT13 / VT23)**

  This state shows whether the valves VT13 and VT23 are closed (🟢) or not (⚫).

PRODUCTION CIRCUIT – DEVICE ORDERS

- **Open Valves (VT13/VT23)**

  If this state is enabled (🟢) the 'Heat Pump – Production Circuit' subsystem is sending the command to open the valves.

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- **Close Valves (VT13/VT23)**

  If this state is enabled (🟢) the 'Heat Pump – Production Circuit' subsystem is sending the command to close the valves.

- **Evaporator Heat Pump (B21)**

  If this state is enabled the 'Heat Pump – Production Circuit' subsystem is sending the command to start the pump B21 in the evaporator side of the heat pump, therefore, if the pump does not physically start it means there is an I/O problem or an electrical problem (typically an RCD or circuit breaker) tripped.

- **Evaporator Valve Position: 0%**

  This state shows the current evaporator valve position read by the system in %.

- **Condenser Pump (B31)**

  If this state is enabled (🟢) the 'Heat Pump – Production Circuit' subsystem is sending the command to start the pump B31 in the condenser side of the heat pump, therefore if the pump does not physically start it means there is an I/O problem or an electrical problem (typically, an RCD or circuit breaker tripped).

PRODUCTION CIRCUIT – SENSOR READINGS

- **Evaporator Supply T. (T12): 21.4 ºC**

  This state shows the supply temperature in the evaporator side of the heat pump given by the sensor T12.

- **Evaporator Return T. (T13): 21.2 ºC**

  This state shows the return temperature in the evaporator side of the heat pump given by the sensor T13.

- **ΔT.: -0. 1ºC**

  This state shows the Delta temperature (ΔT) in the evaporator side of the heat pump.

- **Condenser Supply T. (T32): 31.7 ºC**

  This state shows the supply temperature in the condenser side of the heat pump given by the sensor T32.

- **Condenser Return T. (T31): 30.6 ºC**

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This state shows the return temperature in the condenser side of the heat pump given by the sensor T31.

- **ΔT.: 1. 19ºC**

  This state shows the Delta temperature (ΔT) in the condenser side of the heat pump.

- **Accumulator T. Top (T37): 36.0 ºC**

  This state shows the temperature at the top (highest height) of the buffer tank.

- **Accumulator T. Middle (T36): 35.9 ºC**

  This state shows the temperature in the middle (middle height) of the buffer tank.

- **Accumulator T. Bottom (T35): 35.2 ºC**

  This state shows the temperature at the bottom (lowest height) of the buffer tank.

- **Working T. 36.0 ºC**

  This state shows the temperature that the 'Heat Pump – Production Circuit' subsystem is using as the working temperature.

PRODUCTION CIRCUIT – CONFIGURATIONS

HEAT PUMP ACCUMULATOR SETPOINT

This subsection shows the parameters for the 2-point control (start and stop temperatures) to maintain the temperature between this interval in the buffer tank.

- **Accumulator Stop Demand T. (ºC):** **[Default** 42.0**]**

  The accumulator subsystem stops demanding energy if the 'Working T.' in the buffer tank surpasses this set point.

- **Accumulator Start Demand T. (ºC):** **[Default** 38.0**]**

  The accumulator subsystem starts demanding energy if the 'Working T.' in the buffer tank drops below this temperature.

ACCUMULATOR OUTPUT CIRCUIT – CONTROL

In this section, the administrator user is allowed to disable ('OFF') or enable ('ON') the 'Production Circuit' control.

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ACCUMULATOR OUTPUT CIRCUIT – STATES

- **Alarm**

  This state is enabled (●) if any required device in this subsystem is in alarm. When the subsystem is in alarm it does not operate.

- **Warning**

  This state is enabled (●) if any NON required device in this subsystem is in alarm. When the subsystem is in the 'Warning' state, it does still operate.

- **Devices in Automatic Mode**

  This state is enabled (●) if the system has all the devices involved in the 'Heat Pump Accumulator Output' in automatic mode. If any device is in manual this state is disabled (●) and this subsystem will not be started.

- **Start Permission**

  If this state is enabled (●) it means that all the conditions are met to allow the 'Heat Pump Production Circuit' to start.

- **Pool Demand**

  This state is enabled if the control subsystem for the Pool (customer) is demanding, therefore, the other subsystems that provide to the pool should start.

- **Circuit Started**

  This state shows to the user that the 'Heat Pump – Production Circuit' is started (●).

- **ΔT Accumulator / Pool Permission**

  This state is enabled (●) if the Delta temperature (ΔT), i.e. the difference between the accumulator and the customer Pool, allows the 'Heat Pump - Accumulator Output Circuit' to deliver energy to the pool. The setpoints for this permission are defined in 'ACCUMULATOR OUTPUT CIRCUIT – CONFIGURATIONS' below.

ACCUMULATOR OUTPUT CIRCUIT – DEVICE ORDERS

- **Accumulator Output Pump (B32)**

  If this state is enabled (●), the 'Heat Pump – Accumulator Output Circuit' subsystem is sending the order to start the pump B32, therefore, the water pump should start physically if there is not any I/O or electrical problem.

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ACCUMULATOR OUTPUT CIRCUIT – SENSOR READINGS

- **Supply T. (T33): 30.7 ºC**

  This state shows the supply temperature output from the accumulator given by the temperature sensor T33.

- **Return T. (T34): 30.7 ºC**

  This state shows the return temperature input to the accumulator given by the temperature sensor T34.

- **ΔT.: 0.0 ºC**

  This state shows the Delta temperature (ΔT) between the 'Supply T.(T33)' and 'Return T. (T34)' in the accumulator output.

- **Accumulator T.: 36.0 ºC**

  This state shows to the user the current accumulator 'Working T.' the system is using.

- **Pool T. (T84): 30.0 ºC**

  This state shows the current pool (customer) temperature read by sensor T84.

- **ΔT.: 6.09 ºC**

  This state shows the Delta temperature (ΔT) between the 'Accumulator T.' and 'Pool T. (T84)' that the system is using to know if the energy could be delivered from the buffer tank to the pool.

ACCUMULATOR OUTPUT CIRCUIT – CONFIGURATIONS

- **ΔT. to Enable Working Permission (ºC):** **[Default 5.0]**

  This parameter is used to define the Delta temperature (ΔT) at which the 'Heat Pump – Accumulator Output Circuit' enables the permission to work. The ΔT is calculated as the difference between the accumulator temperature (obtained as described in chapter 3.5.3, pg. 37) and the pool temperature return is given by sensor T84. If this ΔT is higher than this parameter the subsystem has permission to work.

- **ΔT. to Remove Working Permission (ºC):** **[Default 2.0]**

  This parameter is used to define the Delta temperature (ΔT) at which the 'Heat Pump – Accumulator Output Circuit' removes the permission to work. The ΔT is calculated as the difference between the accumulator temperature (obtained as described in chapter 3.5.3, pg. 37) and the pool temperature return is given by

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sensor T84. If this ΔT is lower than this parameter the subsystem does not have the permission to work.

3.5.9. Distribution Circuit

The 'Distribution Circuit' button in the 'Screen Menu' activates the 'Distribution Circuit Screen' in the 'Active Screen' area. This screen shows all the states and different controls that are performed by the 'Distribution Circuit' subsystem to deliver energy to the customer from the buffer tank.

Figure 3.38 shows all the states, controls and set points available in the 'Distribution Circuit Screen'. This screen is populated with all the states and parameters available in the 'Distribution Circuit' control subsystem.

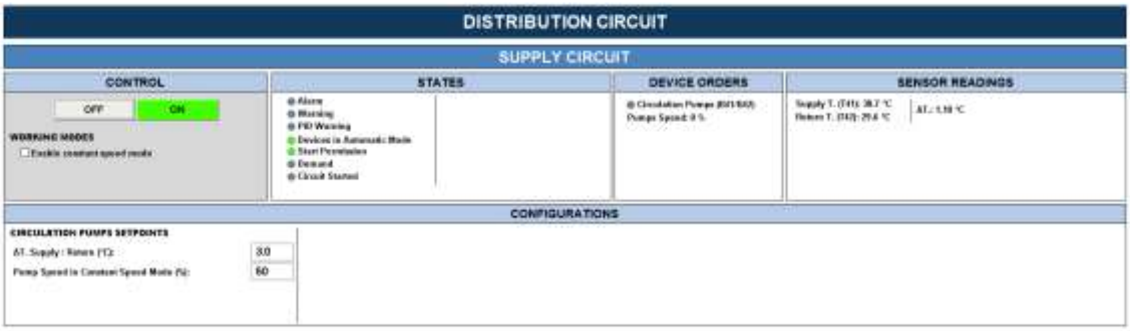

Figure 3.38: States, controls and set points available in the Distribution Circuit Screen

CONTROL

In this section, the 'Administrador' user is allowed to disable ('OFF') or enable ('ON') the 'Production Circuit' control.

Working Modes – Enable constant speed mode **[Default Disabled]**

This checkbox enables (☑) the system to set the distribution pump (one of the twins set B41, B42) to a constant speed specified by the parameter 'Pump Speed in Constant Speed Mode (%)' every time there is energy demand.

If this checkbox is disabled (☐), the system tries to maintain the Delta temperature (ΔT) between the Supply (T41) and Return (T42) to the setpoint 'ΔT. Supply / Return (ºC)' defined below.

The distribution pumps are also set at a constant speed when there is a warning in the PID control.

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STATES

- **Alarm**

  This state is enabled (●) if any required device in this subsystem is in alarm. When the subsystem is in alarm it does not operate.

- **Warning**

  This state is enabled (●) if any NON required device in this subsystem is in alarm (e.g. one of the pumps in the twin pump set B41, B42). When the subsystem is in the 'Warning' state, it does still operate.

- **PID Warning**

  If there is any lecture error in the temperature sensors T41 or T42, the system cannot regulate the driven twin set of pumps (B41, B42), therefore, the system sets the driven twin set of pumps to the constant speed specified by the parameter 'Pump Speed in Constant Speed Mode (%)' below.

- **Devices in Automatic Mode**

  This state is enabled (●) if the system has all the devices involved in the 'Distribution Circuit' in automatic mode. If any device is in manual this state is disabled (●) and this subsystem will not be started.

- **Start Permission**

  If this state is enabled (●) it means that all the conditions are met to allow the 'Distribution Circuit' to start.

- **Demand**

  This state is enabled (●) if the control subsystem for the pool (customer) is in demanding state, therefore the other subsystems that provide to the pool should start.

- **Circuit Started**

  This state shows to the user that the 'Heat Pump – Production Circuit' is started (●).

DEVICE ORDERS

- **Circulation Pumps (B41 / B42)**

  If it is enabled (●), the system is sending the order to the twin set of pumps (B41, B42) to start.

- **Pumps' Speed: 0%**

  This state shows the current driven pumps' speed.

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SENSOR READINGS

- **Supply T. (T41): 30.5 ºC**

  This state shows the current temperature sensor T41 lecture.

- **Return T. (T42): 29.9 ºC**

  This state shows the current temperature sensor T42 lecture.

- **ΔT.: 0.60 ºC**

  This state shows the current 'ΔT = Supply T. (T41) - Return T. (T42)' used in the PID control that tries to keep the set point defined below.

CONFIGURATIONS

CIRCULATION PUMPS SETPOINTS

- **ΔT. Supply / Return (ºC):** **[Default 3.0]**

  This parameter is the ΔT setpoint used in the PID control of the driven set of twin pumps.

- **Pump Speed in Constant Speed Mode (%):** **[Default 50]**

  This set point defines the constant speed for the set of driven twin pumps when there is a 'PID Warning' or the checkbox 'Working Modes – Enable constant speed mode' is enabled.

3.5.10. Pool Exchangers

The 'Pool Exchangers' button in the 'Screen Menu' activates the 'Distribution Circuit Screen' in the 'Active Screen' area. This screen shows all the states and different parameters to tune the 'Pool Exchangers' subsystem to control the energy delivered to the customer from the distribution subsystem in the two heat exchangers (CHESS and Boiler) built-in serial physically.

Figure 3.39: Controls and setpoints available in the 'Pool Exchangers subsystem'

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CONTROL

CHESS EXCHANGER

In this section, the 'Administrador' user is allowed to disable ('OFF') or enable ('ON') the 'CHESS Exchanger' control.

BOILER EXCHANGER

In this section, the 'Administrador' user is allowed to disable ('OFF') or enable ('ON') the 'Boiler Exchanger' control.

STATES

- **Chess Exchanger**
  - **Devices in Automatic Mode**

    This state is enabled (●) if the system has all the devices involved in the 'Chess Exchanger' are in automatic mode. If any device is in manual this state is disabled (●) and this subsystem will not be started.
  - **Circuit Started**

    This state shows to the user that the 'Chess Exchanger' circuit is started.
  - **Exchanger Output Setpoint T.(ºC):**

    This is a visualization of the current 'POOL TEMPERATURE 〉 Pool Water Supply T. Control 〉 SetPoint T. ºC' parameter value described in chapter 3.5.4. The user can directly change the parameter in the 'POOL TEMPERATURE' Screen.

- **Boiler Exchanger**
  - **The device in Automatic Mode**

    This state is enabled if the system has all the devices involved in the 'Boiler Exchanger' are in automatic mode. If any device is in manual this state is disabled and this subsystem will not be started.
  - **Circuit Started**

    This state shows to the user that the 'Boiler Exchanger' circuit is started.
  - **Exchanger Output Setpoint T.(ºC):**

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This is a visualization of the current 'POOL TEMPERATURE 〉 Pool Water Supply T. Control 〉 SetPoint T. ºC' parameter value described in chapter 3.5.4, pg. 39. The user can directly change the parameter in the 'POOL TEMPERATURE' Screen.

DEVICE ORDERS

- **Chess Valve Position: 0%**

  This state shows the current position % of the regulated valve VB83.

- **Boiler Valve Position: 0%**

  This state shows the current position % of the regulated valve VB83a.

SENSOR READINGS

- **Chess Exchanger Output T. (T85): 29.9 ºC**

  This state shows the CHESS exchanger output temperature provided by the sensor T85.

- **Boiler Exchanger Output T. (T86): 30.1 ºC**

  This state shows the Boiler exchanger output temperature provided by the sensor T86.

3.5.11. Plots

The 'Plots' button in the 'Screen Menu' activates the 'Plot Menu Screen' in the 'Active Screen' area. This screen contains a button menu that gives access to the different available plots.

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Figure 3.40: The picture shows all the buttons that give access to each different plot.

The 'Plots Screen' contains two different kinds of plots: the low-level trends generated directly from sensors or meters (SENSORS, CALORIMETERS, and PHOTOVOLTAICS) and the high-level plots calculated using the raw data (ELECTRIC SAVINGS, THERMAL SAVINGS, THERMAL CONSUMPTIONS, ELECTRICAL CONSUMPTIONS, PVT PERFORMANCE, and COP).

The plots are executed over sets of data stored in the database where each row is identified by a 'Time Stamp' (the X-axis in the plots is always time). The 'Time Stamps' are in the format 'YYYY-MM-DD hh:mm:ss' and represent date and time in the system local time zone (e.g. CET).

3.5.11.1. *Low-Level Plots*

The low-level plots are trends that represent states and variables that come directly from sensor or meter readings. The low-level plots do not allow export their information to external files (e.g. CSV) from the interface itself. Therefore, if the information is required outside the CMS plotting and visualization tool, the information must be exported by the Database Administrator user.

Figure 3.41 shows an example of a low-level trend:

1. The top icon bar is the trend tool menu bar which allows performing different operations and configurations related to the plot such as zoom, print, ...
2. The plot screen has a main window with the trend plot containing different selected variables represented in different colours (purple, green, red and cyan) the current cursor (vertical blue line).
3. On the left, the different scales for each variable are shown.

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4. The timeline is shown below the variable plot which contains the start, duration, and end date.

5. Finally, the variable legend is represented at the bottom of the plot.

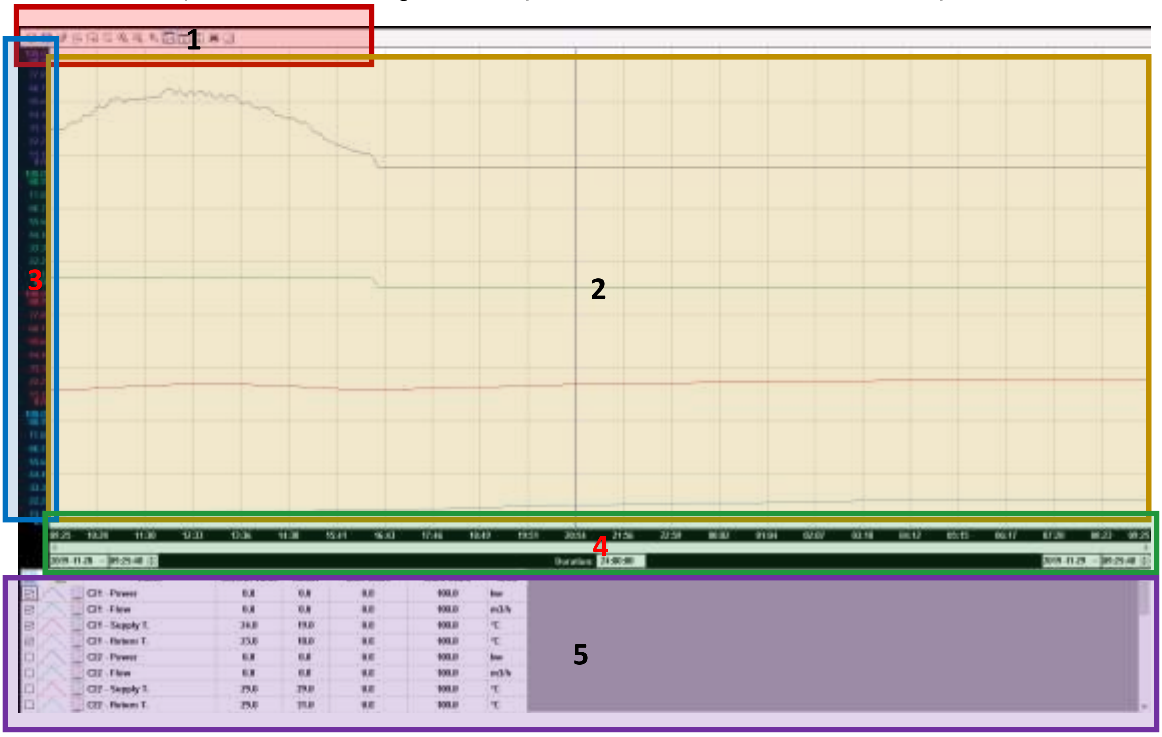
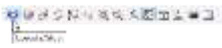


Figure 3.41: The picture shows a low-level trend

<u>Trend Menu</u> 

The first top row of the trend contains the trend menu where different configurations options can be selected: 'Start, Stop, Period, Extension Screen, Horizontal Increase, Vertical Extend, Increase In, Move Away, Cancel Zoom, Multiple Sections, Cursor, Autoscale, Print, SPC'.

The trends are a kind of plots that show live data; therefore, since the system is registering every 5 minutes, the plot is being updated every 5 minutes. When a new reading is acquired the plot moves one position to the left and the new point is inserted on the right.

<u>Start</u> 

This button starts the plot update functionality; therefore, every newly registered reading is updated in the plot. By default is activated.

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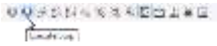
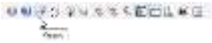
Stop 

This button stops the plot update functionality; therefore, every newly registered reading is NOT updated in the plot.

Period 

This button opens the dialogue box with parameters to define de current window. The parameters to the define the screen are the duration, i.e. the length of the period the user wants to display at the same time, e.g. 1, 10, 25 hours, and the start or end time, i.e. define at which point of time the trend window starts or ends.

This information can also be set directly in the 'Timeline' of the trend (below the 'Trend Plot'). Figure 3.42 shows the Period dialogue, the viewer is allowed to set the duration of the trend window and the start or the end time of this window

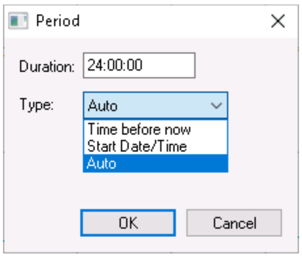


Figure 3.42: Period dialogue screen.

- **Duration**. The user can select the duration of the trend window, by default the duration time is 24:00:00 which means that the trend will show 24 hours of data at the same time on the screen.

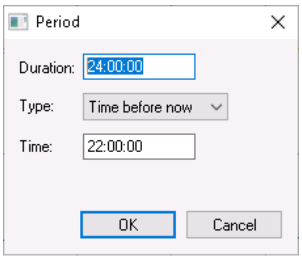


Figure 3.43: The duration parameter in the Period Dialog is 24:00:00 by default.

- **Type**. The user can select among: 'Time before now, Start Date/Time' and 'Auto'.
    - **Time Before now**. If this option is selected, an input box where the user can define an amount of time will appear below. If the user set, for instance, 22:00:00, it means the end time of the trend window (right side of the trend) will be set to the current time minus 22:00:00 hours.

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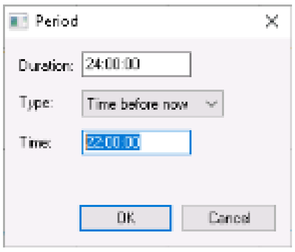


Figure 3.44: The picture shows an example of a trend with 24:00:00 hours of duration and the trend window will end at the current time minus 22:00:00 hours.

- **Start Date/Time.** If the user selects this option, the dialogue will allow the input of a Date and a Time below. The user then can select the start date and time of the trend window (left side of the trend). Figure 3.45 shows an example for a trend with 24:00:00 hours of duration and the trend window will start to the specified date and time (2019-11-28 14:21:41 in the picture)

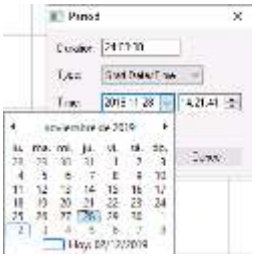
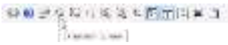


Figure 3.45: Example of a trend with 24:00:00 hours of duration and the trend window will start to the specified date and time (2019-11-28 14:21:41).

- **Auto.** The system decides where the trend visible data starts or ends.

Extension Screen



This option is only available when the 'Multiple Sections' button ( ) of this menu bar is disabled. This tool allows the viewer to select a rectangular area of the plot and zoom in the current view of the selected area. Once this selection is done, the 'Cancel Zoom' button ( ) changes to enabled. If the 'Cancel Zoom' button ( ) is later clicked the view returns to the original.

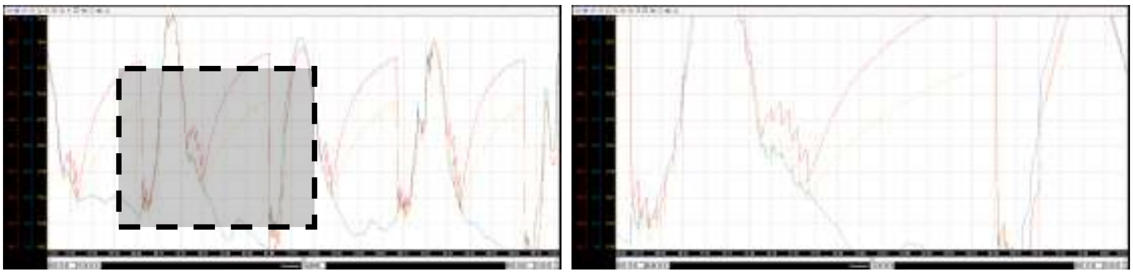


Figure 3.46: The left picture is zoomed to the right picture using the 'Extension Screen' tool in the selected area.

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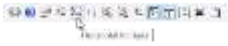
Horizontal Increase 

This tool is available always and allows the viewer to zoom horizontally an area by clicking two points (left and then right) in the plot window. The system zooms to the area between the two clicked points but keeping all the vertical extent of the plot.

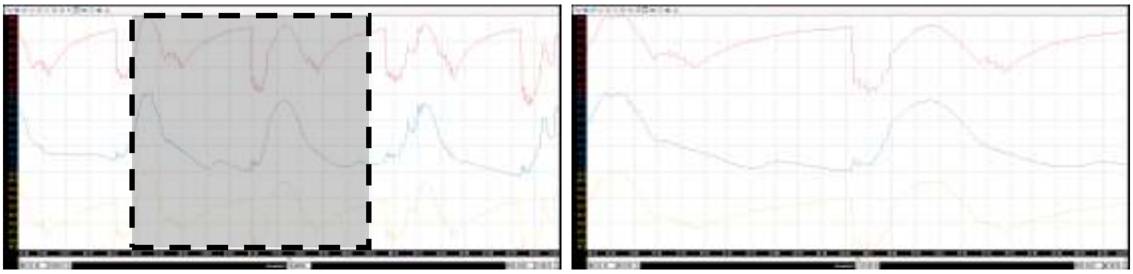
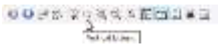


Figure 3.47: The left picture is zoomed to the right picture using the 'Horizontal Increase' tool clicking the left and right of the shown area.

Vertical Extend 

This tool is only available when the 'Multiple Sections' button () of this menu bar is disabled. This tool allows zooming by clicking two points (top and bottom) in the plot window. The system zooms to the area between the two clicked points but keeping all the horizontal extent of the plot.

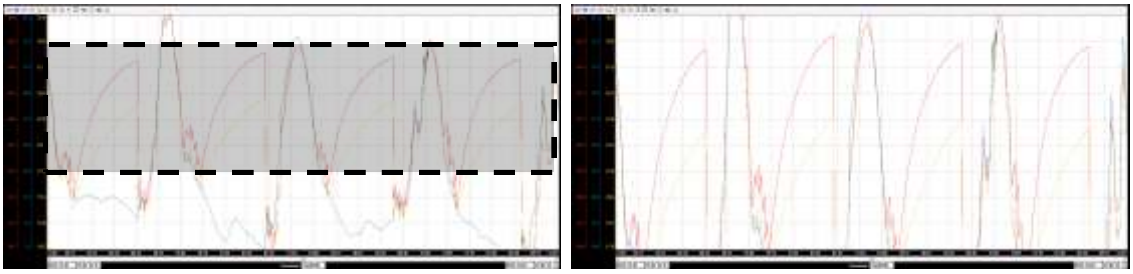
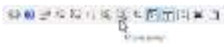


Figure 3.48: The left picture is zoomed to the right picture using the 'Vertical Extend' tool clicking the top and the bottom of the shown area.

Increase In  , Move Away 

These two buttons are used to zoom in and zoom out the current trend view. This tool is enabled always but the behaviour when the 'Multiple Sections' is disabled can be misleading since the different plots may be out of their verticals scale and may overlap.

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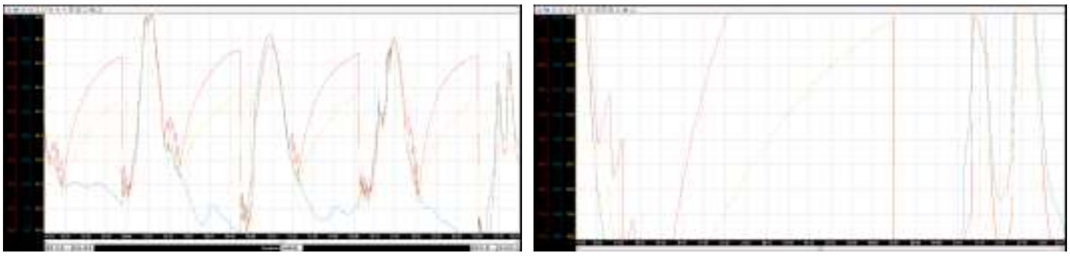
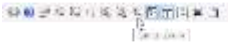
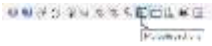


Figure 3.49: The left picture has been zoomed in twice in the right picture using the 'Increase In' tool.

Cancel Zoom 

This tool resets all the zooms performed by 'Extension Screen', 'Horizontal Increase', 'Vertical Extend', 'Increase In' and 'Move Away'. All these zooming tools can be combined to inspect the current plot, the 'Cancel Zoom' button ( ) cancels all the previous zooming operations and the button turns to the disabled state ( ).

Multiple Sections 

When this tool is enabled ( ), it allows the user to show the different plotted variables overlapped in the same trend and showing different scales on the vertical axis. If it is disabled ( ), all the variables are displayed in different rows one below the other, every one with its vertical axis.

Figure 3.50 shows on the left how three variables are displayed in different independent rows in a trend with the 'Multiple Sections' disabled ( ), while the right picture shows the same trend with the 'Multiple Sections' tool enabled ( ) and all the variables overlapped one on top of the others. In the right picture, the different scales for each variable are represented in black background and share the colour with the respective variables.

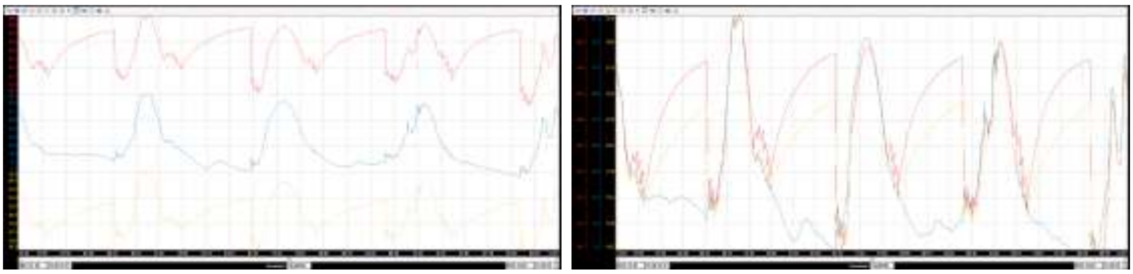


Figure 3.50: Multiple Sections disabled (left) and Multiple Sections enabled (right)

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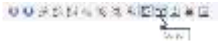
Cursor 

When the cursor is enabled (), a vertical line is shown in the trend plot and the cursor value of every variable in the plot is shown in the 'Variable Legend' area.

Figure 3.51 shows the plot on the left picture the plot without the cursor while in the right picture the cursor is enabled. When the cursor is enabled, the cursor variable values appear in the variable legend column named cursor. If there is not a reading for this particular cursor position, the system provides an interpolated value

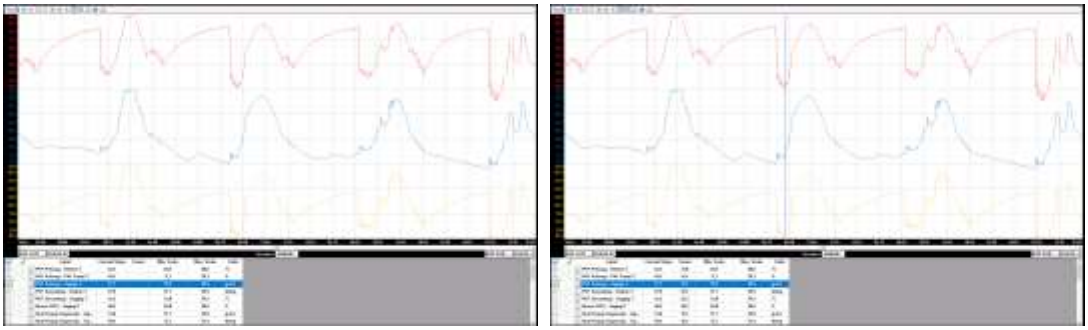
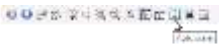


Figure 3.51: Plot function.

Autoscale 

This button sets the vertical scale automatically to maximize the visualization size, extending it to reach the top and the bottom of the plot view area.

Figure 3.52 shows on the left picture the plot that is not adjusted to the top and the bottom of the trend viewport while the right plot is adjusted after 'Autoscale' is clicked.

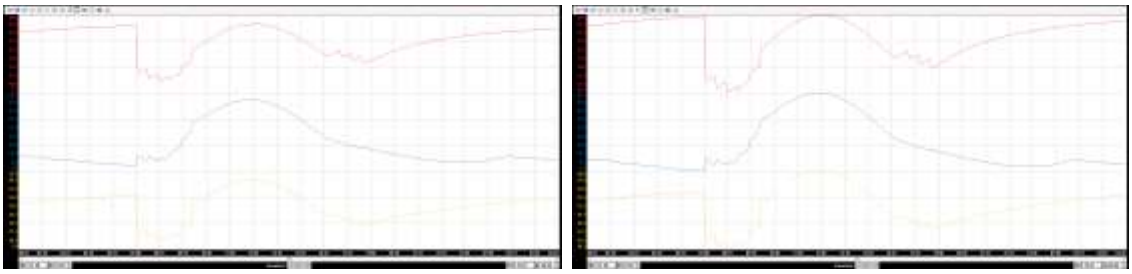
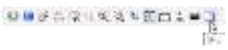


Figure 3.52: Autoscale function.

Print 

If a printer is installed in the system this button allows plot the current trend.

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SPC

If this tool button is clicked, the system shows a dialogue where the user can select variable statistics (average, standard deviation, minimum and maximum) that will be added to each variable in the trend. The user can also select two ways of representing these statistics in the plot: 'Shade' or 'Line'.

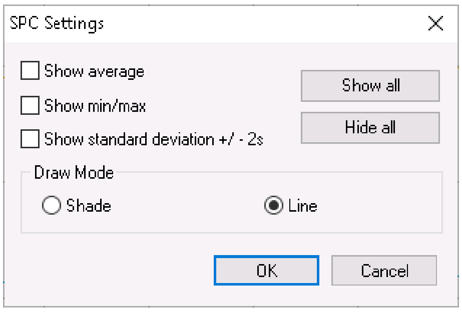

Figure 3.53: SPC dialogue box.

In the following pictures (3.54), the left picture shows a plot with three variables and the SPC disabled ( ) while the right plot contains the same variables when the SPC button is enabled ( ) with all the statistics.

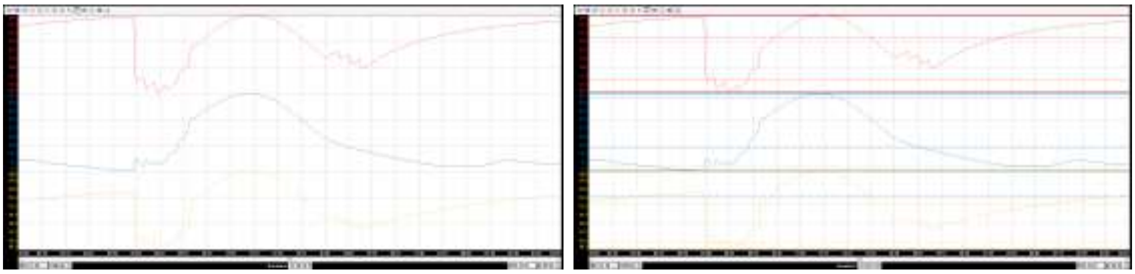

Figure 3.54: SPC functions.

Trend Plot

This area of the screen corresponds to the trend viewport, i.e. where all the variables are shown. The plotting system shows always the background grid that is automatically adjusted depending on the zoom.

Scale

On the left side of the 'Trend Plot', the system shows the axis with a vertical scale adjusted. If the 'Multiple Sections' tool in the menu bar is enabled ( ), a scale per each variable is shown and the variables in the plot are represented overlapped one on top of the other. If the 'Multiple Sections' tool is disabled ( ), every variable is plotted independently on its row and every row has its independent axis scale. The legend is represented in a black background and the colour can be used to associate the axis scale and the variable.

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Timeline

'Timeline' corresponds to the horizontal axis of the plot which is always the time. This area allows the user to define the same parameters configured in the 'Period' tool: 'Duration', 'Start Date and Time' or 'End Date and Time'. These parameters allow defining the viewport of the trend.

Variable Legend

The variable legend is shown at the bottom of the trend dialogue. The legend is displayed as a table that contains every variable in a row and every column is a field that is either information of the variable or a field to configure the variable trend.

The columns available in the legend are shown in figure 3.55: 'Show', 'Pen Style', 'Label', 'Current Value', 'Cursor', 'Min. Scale', 'Max. Scale' and 'Units'.

		Label	Current Value	Cursor	Min. Scale	Max. Scale	Units
☑	...	PVT Primary - Return T.	15.4	16.8	10.7	26.1	°C
☑	...	PVT Primary - PVT Panel T.	14.7	14.2	5.3	36.2	%
☑	...	PVT Primary - Supply T.	15.2	16.3	10.3	30.0	g/m3
☐	...	PVT Secondary - Return T.	13.0	17.5	12.0	25.9	kJ/kg
☐	...	PVT Secondary - Supply T.	13.4	17.6	15.6	25.4	°C
☐	...	Direct STES - Supply T.	30.4	30.5	28.8	30.6	%
☐	...	Heat Pump Evaporator - Inp...	12.5	21.9	12.2	25.3	g/m3
☐	...	Heat Pump Evaporator - Ou...	9.6	21.8	9.4	25.5	kJ/kg

Figure 3.55: The picture shows the 'Variable Legend' of a plot with 8 different variables and all the corresponding columns per each variable.

1. **Show**. This column contains a checkbox that enables or disables the visualization of the variable.
2. **Pen Style**. When button ... of this column is clicked, the system shows a popup dialogue to configure the pen style of the variable in the plot.

   Figure 3.56 picture shows the different parameters related to the pen style that can be set for each variable. The adjustable parameters of the pen-style are 'Expansion': step-style plot or normal plot; 'Marker': the style of every point in the plot; 'Type': the line type; 'Color': the line and marker colour; 'Weight': the line width; 'Size': the marker size.

Figure 3.56: Pen Style screen

3. **Label**. The variable name that allows identifying the variable.

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4. **Current Value**. Shows the value of the variable for the last reading.
5. **Cursor**. If the cursor button is enabled ( ) in the menu bar, this column shows the cursor value, i.e. the intersection of the vertical line with the variable line. If there is no reading for this point, the system calculates a linear interpolation.
6. **Min. Scale.** This value shows the minimum variable value in the vertical axis. This parameter has a default value set by the system automatically but can be changed individually per each variable using this column. Setting a 0.0 value reset the axis to the default state. This parameter changed alone allows us to offset the vertical axis, but combined with 'Max. Scale' can be used to scale the axis as well.
7. **Max. Scale**. This value shows the maximum variable value in the vertical axis. This parameter has a default value set by the system automatically but can be changed individually per each variable using this column. Setting a 0.0 value resets the axis to the default state. This parameter changed alone allows us to offset the vertical axis, but combined with 'Min. Scale' can be used to scale the axis as well.
8. **Units**. This column displays the variable scientific units.

3.5.11.1.1. Sensors

The button 'Sensors' activates the 'Low-Level Plot Sensors' where all the variables related to the different sensors can be selected to be plotted.

The sensors plot allows basically representing the data from the temperature sensors plus the outdoors relative humidity and solar radiation.

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			Label	Current Value	Cursor	Min. Scale	Max. Scale	Units
☑		...	PVT Primary - Return T.	13.8	25.2	10.7	26.1	°C
☑		...	PVT Primary - PVT Panel T.	10.8	3.2	5.3	36.2	%
☑		...	PVT Primary - Supply T.	13.3	24.2	10.3	30.0	g/m3
☐		...	PVT Secondary - Return T.	14.7	25.2	12.0	25.9	kJ/kg
☐		...	PVT Secondary - Supply T.	14.9	24.9	15.6	25.4	°C
☐		...	Direct STES - Supply T.	30.5	30.8	28.8	30.6	%
☐		...	Heat Pump Evaporator - Input T.	11.8	19.8	12.2	25.3	g/m3
☐		...	Heat Pump Evaporator - Ouput T.	9.0	19.6	9.4	25.5	kJ/kg
☐		...	Head Pump Condenser - Return T.	36.3	36.8	31.2	43.8	°C
☐		...	Heat Pump Condenser - Supply T.	45.3	37.7	33.2	49.8	%
☐		...	Heat Pump Accum. - Supply T.	36.6	32.8	29.4	37.0	g/m3
☐		...	Heat Pump Accum. - Return T.	34.0	31.8	30.6	33.6	kJ/kg
☐		...	Heat Pump Accum. - Bottom T.	36.1	42.0	35.9	43.7	°C
☐		...	Heat Pump Accum. - Middle T.	36.1	43.0	36.2	43.5	°C
☐		...	Heat Pump Accum. - Top T.	36.3	43.3	36.3	43.6	%
☐		...	Distribution - Supply T.	36.3	33.7	30.4	36.5	g/m3
☐		...	Distribution - Return T.	33.5	31.8	30.0	33.6	kJ/kg
☐		...	STES - T. Top	13.0	14.0	13.3	17.1	°C
☐		...	STES - T. Middle	13.8	14.9	14.1	17.8	%
☐		...	STES - T. Bottom	15.4	19.0	16.3	19.0	kJ/kg
☐		...	Pool - Chess Primary T.	36.5	31.4	30.9	37.1	°C
☐		...	Pool - Water T.	29.9	30.1	29.8	30.2	%
☐		...	Pool - Chess Exch. Output T.	35.4	30.0	29.9	36.4	°C
☐		...	Pool - Supply T.	35.4	30.2	30.0	36.5	°C
☐		...	Outdoors - T.	10.0	5.3	7.7	20.9	°C
☐		...	Outdoors - Relative Humidity	83.6	96.6	52.1	97.9	%
☐		...	Outdoors - Solar Irradiation	2.2	3.0	1.5	746.0	W/m2

Figure 3.57: Variable Legend with all the available variables for the sensors plot.

The following figure shows an example plot of the 'Outdoors - Solar Irradiation' (orange) against the 'PVT Primary – PV Panel Temperature' (blue). The plot shows a window of 48 hours from 2019-11-30, 18:52:00. It can be easily checked that when the solar radiation increases (up to 963 W/m²) the panel temperature increases, but the control system keeps it bounded to the 35ºC.

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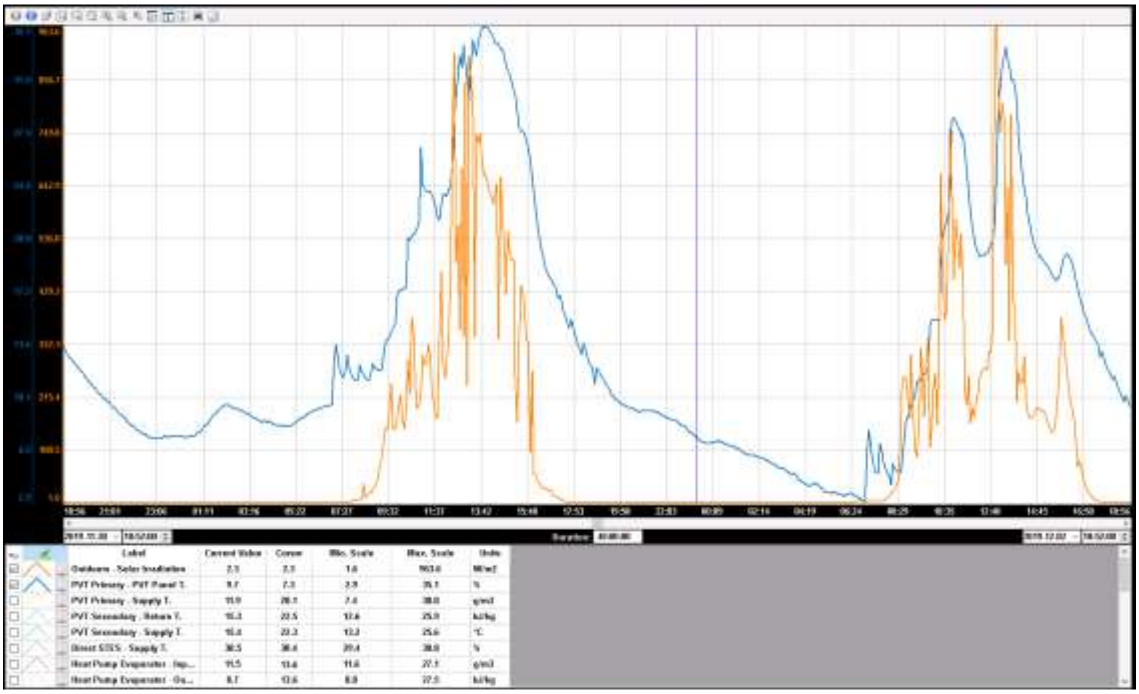

Figure 3.58: Plot of the 'Outdoors - Solar Irradiation' (orange) against the PVT Primary – PV Panel Temperature (blue).

3.5.11.1.2. Calorimeters

The button 'Calorimetres' activates the 'Low-Level Plot Calorimeters' that allows the user to display all the information given by the calorimeters. The system can display all the calorimeters shown in the synoptic: C21, C22, C23, C24, C32, C41, and C91. Each calorimeter provides a subset of variables that can be plotted: 'Power', 'Flow', 'Supply Temperature' and 'Return Temperature'. Figure 3.59 shows the different variables.

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			Label	Current Value	Cursor	Min. Scale	Max. Scale	Units
☑		...	C21 - Power	0.0	0.0	0.0	100.0	kw
☑		...	C21 - Flow	0.0	0.0	0.0	100.0	m3/h
☑		...	C21 - Supply T.	15.0	25.0	0.0	100.0	°C
☑		...	C21 - Return T.	14.0	24.0	0.0	100.0	°C
☐		...	C22 - Power	0.0	0.0	0.0	100.0	kw
☐		...	C22 - Flow	0.0	0.0	0.0	100.0	m3/h
☐		...	C22 - Supply T.	32.0	31.0	0.0	100.0	°C
☐		...	C22 - Return T.	34.0	33.0	0.0	100.0	°C
☐		...	C23 - Power	59.8	0.0	0.0	100.0	kw
☐		...	C23 - Flow	18.2	0.0	0.0	100.0	m3/h
☐		...	C23 - Supply T.	11.0	20.0	0.0	100.0	°C
☐		...	C23 - Return T.	8.0	20.0	0.0	100.0	°C
☐		...	C24 - Power	58.9	0.0	0.0	100.0	kw
☐		...	C24 - Flow	18.2	0.0	0.0	100.0	m3/h
☐		...	C24 - Supply T.	11.0	17.0	0.0	100.0	°C
☐		...	C24 - Return T.	8.0	16.0	0.0	100.0	°C
☐		...	C32 - Power	108.4	0.0	0.0	100.0	kw
☐		...	C32 - Flow	22.5	0.0	0.0	100.0	m3/h
☐		...	C32 - Supply T.	36.0	33.0	0.0	100.0	°C
☐		...	C32 - Return T.	32.0	31.0	0.0	100.0	°C
☐		...	C41 - Power	80.9	0.0	0.0	100.0	kw
☐		...	C41 - Flow	25.3	0.0	0.0	100.0	m3/h
☐		...	C41 - Supply T.	35.0	33.0	0.0	100.0	°C
☐		...	C41 - Return T.	33.0	30.0	0.0	100.0	°C
☐		...	C91 - Power	0.0	0.0	0.0	100.0	kw
☐		...	C91 - Flow	0.0	0.0	0.0	100.0	m3/h
☐		...	C91 - Supply T.	49.0	46.0	0.0	100.0	°C
☐		...	C91 - Return T.	38.0	33.0	0.0	100.0	°C

Figure 3.59: Variable Legend with all the available variables for the calorimeters plot.

The following figure 3.60 shows a plot during 48 hours of the power and flows (in violet and green) for the calorimeter that measures the energy accumulated to the STES (C21) and, in orange and blue, the calorimeter that counts energy extracted from the STES (C24). As can be seen in the picture, the charge and the extraction of energy in the STES do not match in time.

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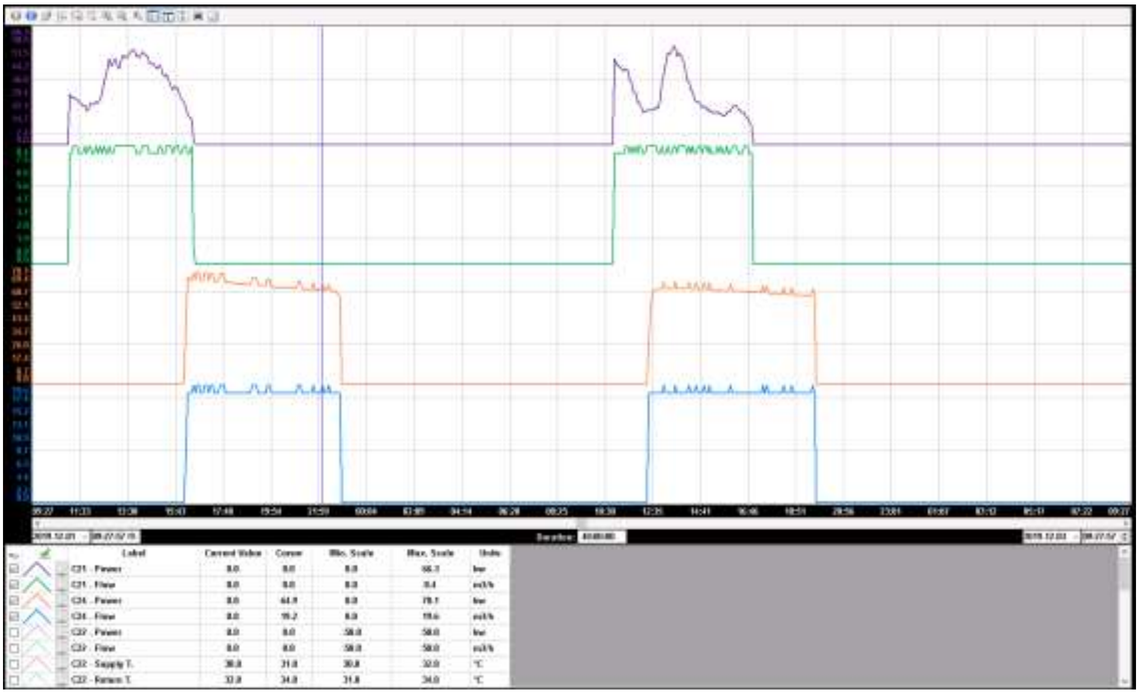

Figure 3.60: plot during 48 hours of the power and flows (in violet and green) for the calorimeter that measures the energy accumulated to the STES (C21) and, in orange and blue, the calorimeter that counts energy extracted from the STES (C24)

3.5.11.1.3. Photovoltaics

The button 'Photovoltaics' activates the 'Low-Level Plot Photovoltaics' that allows the user to display all the information given by the FV Inverters and the solar irradiation. The system allows display all the variables register for each PV Inverter (1 and 2): 'Daily Energy', 'Active Power' and the 'Direct Self Consumption'.

			Label	Current Value	Cursor	Min. Scale	Max. Scale	Units
☑		...	Solar Irradiance	389.0	306.9	0.0	1000.0	w/m2
☑		...	Inverter 1 - Daily Energy	28.9	0.0	0.0	500.0	kWh
☑		...	Inverter 1 - Active Power	0.0	0.3	0.0	100.0	kW
☑		...	Inverter 1 - Direct Self Consumption	0.0	0.0	0.0	100.0	%
☐		...	Inverter 2 - Daily Energy	24.3	0.3	0.0	500.0	kWh
☐		...	Inverter 2 - Active Power	0.0	0.3	0.0	100.0	kW
☐		...	Inverter 2 - Direct Self Consumption	0.0	0.0	0.0	100.0	%

Figure 3.61: 'Variable Legend' with all the available variables for each 'PV Inverter' plus the 'Solar Irradiance'.

The following figure 3.62, shows a plot for 48 hours of 'Solar Irradiance' (orange) and the power output of every FV Inverter (blue and green). It can be appreciated that the first day (2019/11/19) is sunny while the second day it is partially cloudy. It also can be checked that the two inverters do not produce the same power during a sunny day, this could be due to a problem in the installation if both PV systems are equivalent or due to shadows.

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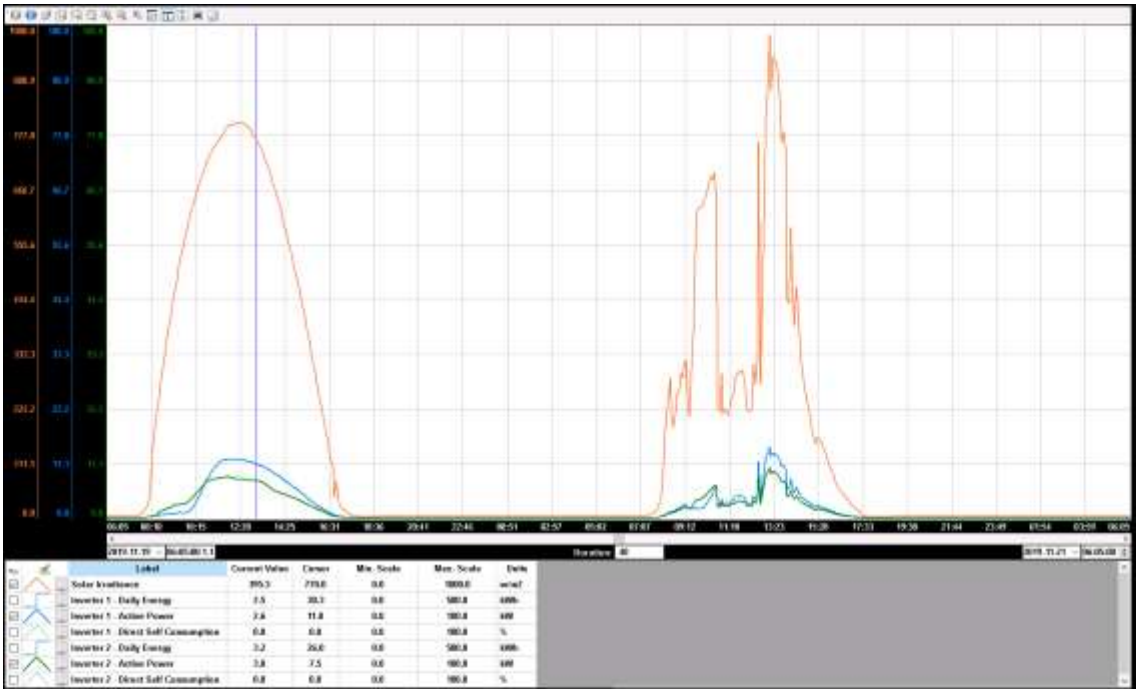

Figure 3.62: The picture shows a plot for 48 hours of 'Solar Irradiance' (orange) and the power output of every FV Inverter (blue and green).

3.5.11.2. *High-Level Plots*

The high-level plots are trends that the control system generates from the raw sensor data. The represented information is a higher level such as the system COP (Coefficient of Performance), the thermal and electrical consumptions and the savings.

This set of plots is more complex to generate and the user must enter a date interval and an aggregation time (hour, day, week, month, etc.). This set of plots has the option to export the data to a datasheet in CSV format.

The 'Menu Bar' for the high-level plots has a set of fields the user must enter to generate the plot.

- **Start Date.** This field allows the user to set the starting date of the time interval.
- **End Date.** This field must be the ending date of the time interval.
- **Mode.** This field is a time aggregation that could be 'Hour', 'Day', 'Week', 'Month' or 'Year'. For instance, if the variable to the plot is energy and the aggregation time is 'Week', the plot will display the aggregated energy for each week in the interval ['Start Date', 'End Date'].
- **Y-Axis Max.** This field allows the user to set the maximum scale for the vertical axis in the plot. It is automatically calculated by the system in the interval of time

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['Start Date', 'End Date'] when the 'Load Data' button is pressed, however, the user can change it to zoom in.

- **Load Data.** This button will generate the data in the defined interval ['Start Date', 'End Date'] with the aggregation 'Mode' when it is clicked.

- **Create File.** Once there is loaded data in the plot, click this button, the data is automatically exported to 'C:\Temp\Mysql-Exports\'. The files are named automatically with a 'PlotPrefix_StartDate-EndDate__GenerationTime.csv'. The 'PlotPrefix' identifies the plot ('*EnergiaElectricaInc*', '*EnergiaTermicaInc*', '*RendimentPVTResum*', '*COP*', '*CostosTermicsResum*', '*CostosElectricsResum*'), the 'StartDate' and 'EndDate' is the data interval and the 'Generation Time is the hour-minute-second when the ''Create File' button was clicked.

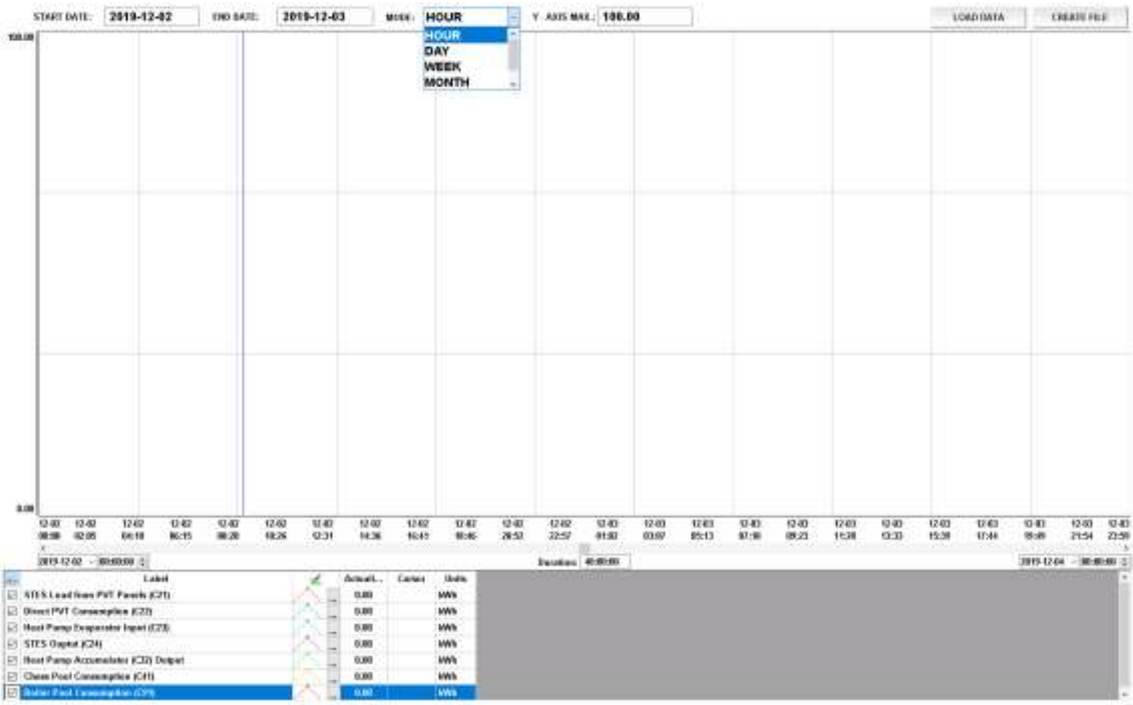

Figure 3.63: The top row of the picture displays the 'Menu Bar' for the 'High-Level Plots' that has the 'Start Date', 'End Date', 'Mode' (aggregation) and 'Y-Axis Max' input box and the 'Load Data' and 'Create File' buttons.

3.5.11.2.1. Thermal Consumptions Plot

The button 'Thermal Consumption' activates the 'High-Level Plot Thermal Consumptions' that allows the user to display the different thermal energies available in the system that are read from the different calorimeters. Any combination such as the total energy consumed by the customer (C22 + C41 + C91) it can be generated externally using the 'Create File' functionality. Can be seen in the following figure.

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	Label		Actuali...	Cursor	Units
☑	STES Load from PVT Panels (C21)	...	0.00		kWh
☑	Direct PVT Consumption (C22)	...	0.00		kWh
☑	Heat Pump Evaporator Input (C23)	...	0.00		kWh
☑	STES Ouptut (C24)	...	0.00		kWh
☑	Heat Pump Accumulator (C32) Output	...	0.00		kWh
☑	Chess Pool Consumption (C41)	...	0.00		kWh
☑	Boiler Pool Consumption (C91)	...	0.00		kWh

Figure 3.64: 'Variable Legend' with all the available thermal energies in the system to be plotted and exported.

Figure 3.65 shows a plot of the thermal energy for two months (2019/10/01 – 2019/11/30) aggregated in weeks. The visible energies (shown in the legend) are the energy loaded into the STES (C21) in orange, the energy consumed directly from the PVT panels (C22) in green, the energy provided to the client by the CHESS system (C41) in cyan and the energy provided by the Boiler (C91) in red.

Figure 3.65: plot of the thermal energy for two months (2019/10/01 – 2019/11/30)

3.5.11.2.2. Electrical Consumptions Plot

The button 'Electrical Consumption' activates the 'High-Level Plot Electrical Consumptions' that allows the user to display the different electrical energies available (produced and consumed) in the system.

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	Label			Actuali...	Cursor	Units
☑	Consumed Active Energy		...	0.00		kWh
☑	Generated Reactive Energy		...	0.00		kVarh
☑	Total Produced Active Energy		...	0.00		kWh
☑	Inverter 1 Produced Active Energy		...	0.00		kWh
☑	Inverter 2 Produced Active Energy		...	0.00		kWh

Figure 3.66: Variable Legend with all the available electrical energies in the system to be displayed and exported.

In the following figure (3.67), it shows a plot of electrical energy for 15 days (2019/11/01 – 2019/11/15) daily aggregated. The visible energies (shown in the legend) are the energy consumed by the system (in red) and the energy produced by the PVT panels (in green).

Figure 3.67: Plot of electrical energy for 15 days.

3.5.11.2.3. PVT Performance Plot

The button 'PVT performance' activates the 'High-Level Plot PVT Performance' that allows the user to compare the PVT Panel theoretical production with the real measured outcome (thermal and electrical).

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	Label		Actuali...	Cursor	Units
☑	Measured Thermal Energy	...	0.00		kWh
☑	Theoretical Electrical Energy	...	0.00		kWh
☑	Measured Electrical Energy	...	0.00		kWh
☑	Thermal Performance Ratio	...	0.00		%
☑	Electrical Performance Ratio	...	0.00		%
☑	Performance Ratio	...	0.00		%

Figure 3.68: 'Variable Legend' with all the available theoretical electrical and thermal energies, the respectively measured energies and the resulting thermal, electrical and total performance ratios (PRs).

The 'Measured' variables are the measured electrical and thermal energies gathered by the system sensors while the 'Theoretical' variables are calculated from the PVT panel datasheet specifications.

The performance ratios (PR) are the coefficients between the theoretical and the measured energies and provide an estimation of how well are the PVT performing comparing the reality with the theory.

Several important factors that affect the results of the PRs must be taken into account:

1. Since the measured energy integration is done by the respective meters (calorimeters, power meters, and inverters) the accuracy is very high. However, the theoretical energy is calculated by the CMS system using a 5-minute interval (measurement frequency), therefore some error is introduced in the theoretical energy estimation.

2. The thermal and electrical losses are not modelled in the theoretical energy estimation (that could be around 10% - 15% each).

Due to the factors explained above it is difficult to use the PRs as a measurement of how well the installed panels match the datasheet specification, or to compare to the PRs of other panels. However, these PRs will be useful to verify the degradation of the performance along the time, so the customer will be able to compare the PRs from the 1st year to the following years to see if the performance ratios vary or not.

Figure 3.69 shows a plot of the 'Thermal', 'Electrical' and 'Total Performance Ratios' (PRs) for 2 months [2019/10/01 – 2019/11/30] aggregated weekly. The Electrical PR (in green) is very low at the beginning due to problems in the inverter productions. The total 'Performance Ratio' is around 60% that taking into account the errors and the losses it means the system is generating around 80% of the theoretical total production.

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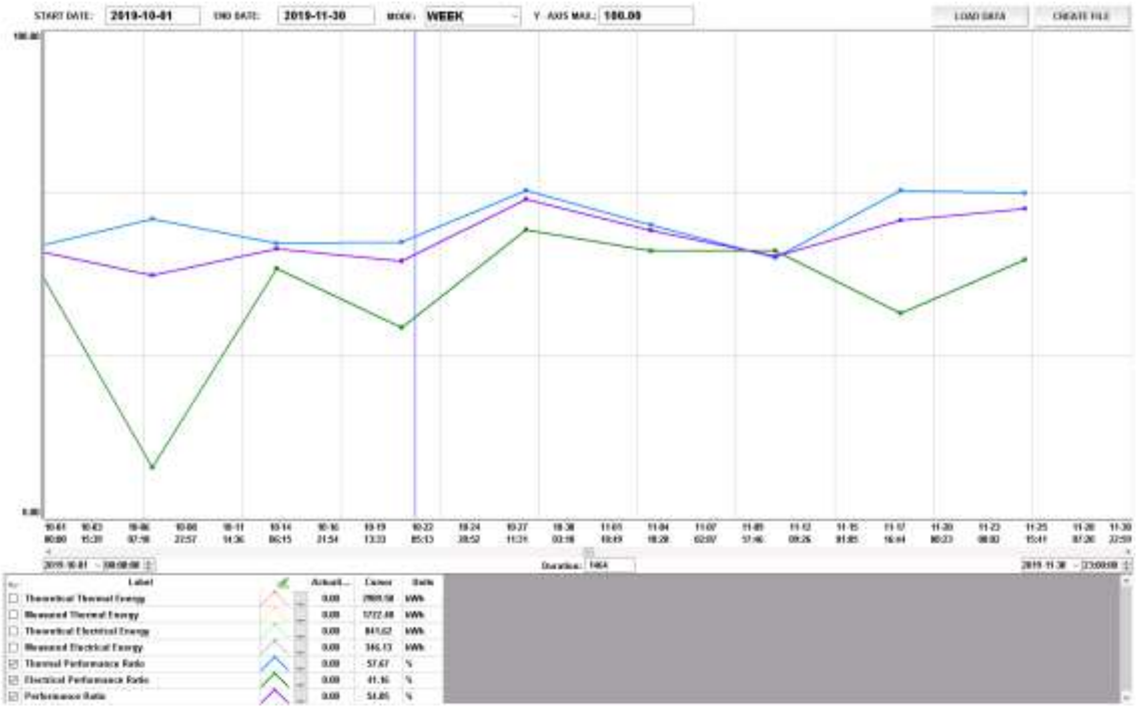

Figure 3.69: Plot of the 'Thermal', 'Electrical' and 'Total Performance Ratios' (PRs) for 2 months [2019/10/01 – 2019/11/30] aggregated weekly.

3.5.11.2.4. COP Plot

The button `COP' activates the 'High-Level Plot COP' that allows the user to plot the Coefficient of Performance (COP) of the whole system.

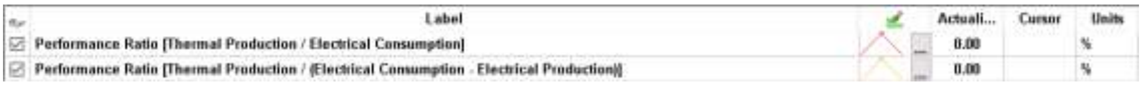

Figure 3.70: 'Variable Legend' with the two COP available variables to display.

The system allows plot two different versions of the COP:

Performance Ratio [Thermal Production / Electrical Consumption]. The system calculates the ratio between the energy delivered to the customer divided by the whole system's electrical consumption discounting the production.

Performance Ratio [Thermal Production / (Electrical Consumption – Electrical Production)]. The system discounts the PV production from consumption. The calculations are done using the instantaneous values and the aggregation is only for displaying reasons, this means that the system does not consider the grid or the building as a *battery*, therefore the energy that is injected (when Production > Consumption) is considered as lost (not used).

Figure 3.71 shows on the left picture a plot of the daily COP aggregated during the period [2019/10/01, 2019/11/30] while the right picture shows the COP aggregated weekly during the same period. The daily COP in the left could be very high in the

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summer months since the heat pump is not used because the STES temperature is enough high to provide the energy directly to the customer.

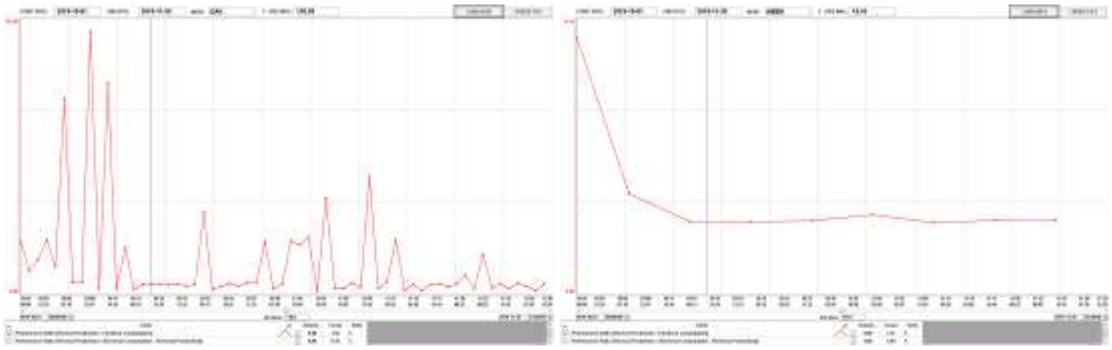

Figure 3.71: The left picture shows a plot of the daily COP aggregated during the period [2019/10/01, 2019/11/30] while the right picture shows the COP aggregated weekly during the same period.

The thermal energy measured by the calorimeters (depending on the calorimeter) has resolutions of around MWh / 10 while the resolution of the power meters and inverters is Wh. The results are regularized in kWh, this means that the system is linearly distributing the thermal consumption between two measurements. For instance, if at 2019/10/25 13:00:00 a calorimeters measure 37.5 MWh and the next energy increment 37.6 MWh is at 15:40:00 the same day, this 100kWh of thermal energy are distributed linearly between the 13:00:00 and the 15:40:00, therefore, 3.125 kWh every 5 minutes between 13:00:00 and 15:40:00, and later, they are compared to the electrical consumption. The same procedure is applied to electrical energy measurements. However, since the resolution of the power meters is very high (Wh), the situation of no increment in 5 minutes seldom happens.

3.5.11.2.5. Electric Savings Plot

The button 'Electric Savings' activates the 'High-Level Plot Electric Savings' that allows the user to plot the electric savings generated by the system in €.

The system takes into account the indexed tariff available for the customer. Therefore, it downloads automatically from the Internet all the fixed costs and taxes and all variable costs (that change every hour) and variable taxes applied to the customer. The system also takes into account that the exported energy (energy produced by the installation and not consumed in it) is consumed in the rest of the installation, therefore not exported to the grid, but that generates savings to the same customer.

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	Label		Actuali...	Cursor	Units
☑	Imported Energy	...	0.00		kWh
☑	Imported Energy Cost	...	0.00		€
☑	Exported Energy Taxes Cost	...	0.00		€
☑	Imported Energy Total Cost	...	0.00		€
☑	Exported Energy	...	0.00		kWh
☑	Exported Energy Cost	...	0.00		€
☑	Imported Energy Taxes Cost	...	0.00		€
☑	Exported Energy Total Cost	...	0.00		€
☑	Total Cost	...	0.00		€

Figure 3.72: 'Variable Legend' with the 'Electric Savings' variables available to display.

The variables that can be plot are 'Imported Energy' and 'Exported' energies and their costs split into energy and taxes. The 'Total Cost' is the savings variable which is positive when there is savings or negative if the system is eventually purchasing electrical energy to the grid.

Figure 3.73 shows a plot with the savings during October 2019 daily aggregated. The picture only shows the total costs: the red line is the cost of the energy imported while the blue line is the total cost of the exported energy. The green line is the savings (Total Cost), therefore it could be positive in the case there is savings or negative that means the system is finally purchasing electrical energy to the grid. This plot is the only one that can contain negative values; therefore, it contains a 'Y-AXIS MIN' input box to adjust the minimum for the vertical axis.

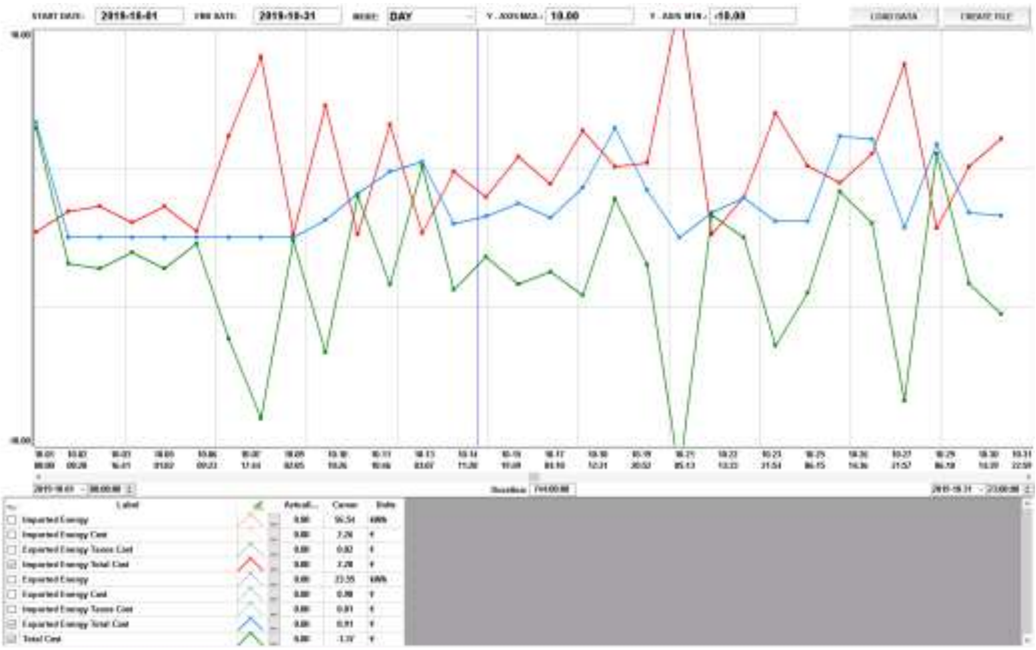

Figure 3.73: Plot with the savings during October 2019 daily aggregated.

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3.5.11.2.6. Thermal Savings Plot

The button 'Thermal Savings' activates the 'High-Level Plot Thermal Savings' that allows the user to plot the thermal savings generated by the system in €.

	Label		Actuali...	Cursor	Units
☑	Thermal Energy	...	0.00		kWh
☑	Energy Cost	...	0.00		€
☑	Energy Taxes Cost	...	0.00		€
☑	Total Cost	...	0.00		€

Figure 3.74: 'Variable Legend' with the 'Thermal Savings' variables to display.

Figure 3.75: The picture shows a plot with the daily thermal savings in € during the period [2019/10/01, 2019/11/30].

In that case, since the system cannot export thermal energy in any way, the cost is always positive and it directly represents saving.

The thermal savings (Total Cost) can be split into the energy cost savings (Energy Cost) and the tax cost savings (Energy Tax Cost) in €.

3.5.12. Alarms

The 'Alarms' button in the 'Screen Menu' activates the 'Alarms Screen' in the 'Active Screen' area.

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The CHESS CMS system releases alarms at the device level, not at the circuit or system level. This means that when there is a problem in a device such as a lecture error in a temperature sensor or protection (RCD or circuit breaker) that tripped, the system releases and alarm and sends the corresponding information via e-mail.

There are alarms released by the system that are considered initially 'Warnings' until other conditions are met. For instance, if an electrical protection (RCD or circuit breaker) of one of the water pumps in a set of twin pumps trips, the system releases an alarm for this pump, but it is considered as a 'Warning' in the CMS. This means that the control can still operate until an alarm is produced in the other water pump of the twin set. This redundancy is the mission of a set of twin pumps. The operator, in the case, should try to solve the 'Warning' as soon as possible to avoid system failure.

The 'Alarm' and 'Warning' states are represented in each circuit ('Pool Temperature', 'Working Modes', 'PVT Panels', 'Direct STES Circuit', 'Heat Pump', 'Distribution Circuit' and 'Pool Exchangers') explained in chapter 3.5.12, pg. 94 in the section 'STATES' which helps the operator to find and solve this kind of problem.

All the flow switches installed in the system except the FX86 are not used for control purposes, only for monitoring alarms. Therefore, when a flow switch should measure flow in a circuit and it does not, the system releases an alarm about that situation but the system keeps working.

From the operator, there are two kinds of alarms:

1. **User intervention is NOT required**. This set of alarms, once they are physically recovered, they cease to be alarmed. For instance, a temperature sensor lecture error or an electrical protection (such as an RCD or a circuit breaker) tripped, when the alarm is recovered, i.e. the sensor gives correct lectures again or the user switches on again the RCD and the circuit breaker, the system recovers automatically from the alarm, therefore, the device (temperature sensor, water pump, ...) will be operated automatically by the system again.
2. **User intervention is required**. This set of alarms requires the user intervention to validate them and to allow the system to continue operating again. For instance, if a 'Start Confirmation' signal from a water pump is not received, the system does not try to recover automatically from the alarm since the CMS could enter in a loop trying to start forever the water pump and damage the hardware. To continue, the system operator ('Administador') must reset the alarm in the corresponding device dialogue or use the button 'Validate' explained below (to validate all the alarms).

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Figure 3.76: The picture shows the 'Alarms screen', the 'VALIDATE ALARMS' button and the input box that allows entering a list of semicolon-separated destination e-mail addresses.

ALARM HISTORY

This list is the alarm history list of the released, recovered and not validated alarms. A device only appears once in the list in its current state (released, recovered or validated). A complete log of all generated, recovered and validated alarms will be available in the e-mail of the users specified in the 'Send e-mail to' the input box.

The columns that describe each alarm are:

- **Start Time**

  This column shows the date and time the alarm was released.

- **Recuperation Time**

  This column shows the date and time of the alarm recuperation.

- **Group**

  This column classifies the alarms in different groups. In the CHESS CMS this column is always CHESS.

- **Priority**

  This column contains the alarm priority level. Only two different priority levels exist 0 (highest) and 1 (lowest).

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- **Message**

  This column displays the alarm descriptive message to help the user identify the problem.

When an alarm is released it shows up in the 'Alarm History' list and an e-mail is sent to all the users available in the 'Send e-mail to' the input box. The 'Administrador' user must provide a semicolon (;) separated list of e-mail addresses. Typically the 'Administrador' user and the maintenance operators are added to this list. The e-mail sent by the system contains the installation identification (name) in the subject and the 'Alarm History' table columns plus the current state (ACTIVE, ACK, NORM) in the body.

An alarm state can be:

- **Active (ACTIVE).** There is an event in the system that triggers the alarm, for instance, an electrical RCD that tripped.
- **Recovered (NORM).** The alarm has been active in the past, but the event that triggered the alarm is not doing it now. For instance, an operator switched on again an RCD that triggered a 'Protection Alarm'.
- **Acknowledged (ACK).** The operator used acknowledged the alarm by double-clicking the alarm in the 'History List'. In that case, the alarm is not recovered but an authorized user (*Administrador*) informed the system that he is aware of the problem. This option is useful for alarms that are, for the moment, 'Warnings'. Then, all the users that receive the alarm by e-mail, will receive the corresponding 'ACK' e-mail which informs them that someone is taking care of the problem.

The alarms in the 'Alarm History' list are highlighted in different colours depending on their state:

- **Red**. The alarm is active ('ACTIVE').
- **Green**. The alarm in the list has been acknowledged ('ACK') by double-clicking its row in the list when it was active (red). If the user double clicks in an acknowledged alarm (green) and the alarm is recovered (no still physically present), it is automatically erased from the list.
- **Blue**. The alarm has been recovered ('NORM'). It was active in the past but currently is recovered. If a user doubles click on a row with a recovered alarm it disappears from the list.

Send Mail To:

The operator user ('Administrador') must provide a list of semicolon-separated e-mail addresses of the users that will receive the 'ACTIVE', 'NORM' and 'ACK' alarms. Typically this list will contain the 'Administrador' itself, other operators and viewers of the system and the operators responsible for the installation maintenance.

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VALIDATE ALARM

The alarms that need user intervention (e.g., a 'Start Confirmation' for a water pump and the dissipator; or the 'Opened / Closed Valve Confirmation' for a valve) the system provides the corresponding 'Reset Alarm' in their dialogues in the synoptic by clicking the device icon.

The button 'VALIDATE ALARMS' is used to send a reset of all the alarms to the low-level controller (PLC) to try to restart the system again. The alarms will be triggered again after the validation if the problem persists.

Table 3.1 describes all the alarms the CHESS Setup CMS can release and the reason that triggers them. There are only two different priorities (column 'Pri'), the high (0) when the dissipator is started and all the others with the regular priority (1).

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#	Prio	Name	Description
1	0	Solar Dissipator Working - PVT T. (T02): ##,# ºC	The dissipator has been started since the temperature in the PVT primary is too high. The system also sends the real value (##,#) of the temperature in the triggering and recovering moment.
2	1	STES Low-Level Water Alarm	The STES water level decreased below a threshold, possible water leakage in the circuit.
3	1	Solar Irradiance Sensor (R101) Error	Lecture error from a low-level sensor that could be temperature, the solar irradiance or the humidity sensor. The last reading acquired by the system for the sensor is out of range. This lecture error is typically due to an overflow in the sensor reading caused by either a short circuit (cable crush) or an open circuit (cable cut) in the physical sensor wiring.
4	1	Outdoors Temperature Sensor (T101) Error	
5	1	Outdoors Humidity Sensor (T101) Error	
6	1	PVT Primary Return Temperature Sensor (T01) Error	
7	1	PVT Panel Temperature Sensor (T02) Error	
8	1	PVT Primary Supply Temperature Sensor (T03) Error	
9	1	PVT Secondary Return Temperature Sensor (T04) Error	
10	1	PVT Secondary Supply Temperature Sensor (T05) Error	
11	1	STES Bottom Temperature Sensor (T51) Error	
12	1	Middle Part STES Temperature Sensor (T52) Error	
13	1	STES Top Temperature Sensor (T53) Error	
14	1	Direct STES Circuit Supply Temperature Sensor (T11) Error	
15	1	Heat Pump Evaporator Input Temperature Sensor Error (T12)	
16	1	Heat Pump Evaporator Output Temperature Sensor (T13) Error	
17	1	Heat Pump Condenser Return Temperature Sensor (T31) Error	
18	1	Heat Pump Condenser Supply Temperature Sensor (T32) Error	
19	1	Heat Pump Supply Output Temperature Sensor (T33) Error	
20	1	Heat Pump Acc. Output Return Temperature Sensor (T34) Error	
21	1	Heat Pump Accumulator Lower-Temperature Sensor (T35) Error	
22	1	Heat Pump Accumulator Middle-Temperature Sensor (T36) Error	

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23	1	Heat Pump Accumulator Top-Temperature Sensor (T37) Error	
24	1	Distribution Supply Circuit Temperature Sensor (T41) Error	
25	1	Distribution Supply Circuit Temperature Sensor (T42) Error	
26	1	Chess Exchanger Primary Input Temperature Sensor (T83) Error	
27	1	Pool Water Temperature Sensor (T84) Error	
28	1	Chess Exchanger Secondary Output T. Sensor (T85) Error	
29	1	Boiler Exchanger Secondary Output T. Sensor (T86) Error	
30	1	Direct STES Circuit Flowmeter FX11 Alarm	The flow switches are not used to control, this means that a flow error does not stop or triggers anything (except FX86). However, they are used to monitor. This means that if a circuit should have flow (e.g. a water pump is started) and the flow switch does not detect flow, an alarm is triggered to advise the operator that the system might have a problem such as water leakage or low pressure in the circuit.
31	1	PVT Secondary Flowmeter FX01 Alarm	
32	1	Distribution Circuit Flowmeter FX41 Alarm	
33	1	PVT Primary Fluxometer FX01 Alarm	
34	1	Heat Pump Acumulator Ouptut Fluxometer FX32 Alarm	
35	1	Heat Pump Evaporator Flowmeter FX12 Alarm	
36	1	Heat Pump Condenser Flowmeter FX31 Alarm	
37	1	Heat Pump Evaporator Pump B12 Circuit Breaker Alarm	The circuit breaker alarms are released when an RCD (Residual Current Device) or a circuit breaker in the electrical circuit trips. This could be an earthing problem or a short circuit or an overload problem, respectively. Before acknowledging the alarm an operator must switch on again the tripped circuit.
38	1	Direct STES Circuit Pump B11 - Circuit Breaker Alarm	
39	1	Heat Pump Condenser Pump B31 Circuit Breaker Alarm	
40	1	Heat Pump Accumulator Output Pump B32 Circuit Breaker Alarm	
41	1	Distribution Circuit Pump B42 Circuit Breaker Alarm	
42	1	Distribution Circuit Pump B41 Circuit Breaker Alarm	
43	1	Solar Pump B02 - Circuit Breaker Alarm	
44	1	PVT Secondary Pump B03 Circuit Breaker Alarm	
45	1	PVT Secondary Pump B04 Circuit Breaker Alarm	
46	1	PVT Panel Dissipator A01 Circuit Breaker Alarm	
47	1	Heat Pump BC01 Circuit Breaker Alarm	
48	1	PVT Primary Pump B01 Circuit Breaker Alarm	
49	1	Heat Pump Evaporator Pump B12 Start Confirmation Alarm	The start conformation alarms are related to devices that have a digital line input into the CMS to confirm they are started. For
50	1	Heat Pump BC01 Start Confirmation Alarm	

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51	1	Heat Pump Condenser Pump B31 Start Confirmation Alarm	instance, when a regular on/off water pump is started by the system, there is a digital signal from the water pump electrical contactor that returns the confirmation to the CMS indicating that the contactor is switched on and, therefore, the pump should be started. If this alarm is triggered it means there is a physical problem (e.g. the contactor device is broken) or an electrical problem (e.g. the RCD or the circuit breaker in the contactor manoeuvre side tripped).
52	1	Heat Pump Accum. Output Pump B32 Start Confirmation Alarm	
53	1	PVT Primary Pump B01 Start Confirmation Alarm	
54	1	Solar Dissipator A01 Start Confirmation Alarm	
55	1	PVT Primary Pump B02 Start Confirmation Alarm	
56	1	PVT Secondary Pump B03 Start Confirmation Alarm	
57	1	PVT Secondary Pump B04 Start Confirmation Alarm	
58	1	Distribution Circuit Pump B41 Start Confirmation Alarm	
59	1	Direct STES Circuit Pump B11 Start Confirmation Alarm	
60	1	Distribution Circuit Pump B42 Start Confirmation Alarm	
61	1	Distribution Circuit Pump Drive B41 Alarm	The pumps B41 and B42 are regulated. The alarm is triggered by the pump drives and it means a problem in the pump or the driver.
62	1	Distribution Circuit Pump Drive B42 Alarm	
63	1	Head Pump Evaporator Valve VT13 Opened Confirmation Alarm	The opened confirmation alarms are related to the valves that should be opened and the opened detector does not trigger. This alarm could mean a physical problem in the valve, typically a seized valve.
64	1	Head Pump Evaporator Valve VT23 Opened Confirmation Alarm	
65	1	Direct STES Circuit Valve VT11 Opened Confirmation Alarm	
66	1	Direct STES Circuit Valve VT21 Opened Confirmation Alarm	
67	1	PVT Secondary Valve V12 Opened Confirmation Alarm	
68	1	PVT Secondary Valve V22 Opened Confirmation Alarm	
69	1	Heat Pump Evaporator Valve VT13 Cuttoff Confirmation Alarm	The cut off confirmation alarms are related to the valves that should be closed and the closed detector does not trigger. This alarm could mean a physical problem in the valve, typically a seized valve.
70	1	Heat Pump Evaporator Valve VT23 Cuttoff Confirmation Alarm	
71	1	PVT Secondary Valve VT12 Cutoff Confirmation Alarm	
72	1	PVT Secondary Valve VT22 Cutoff Confirmation Alarm	
73	1	Direct STES Circuit Valve VT11 Cutoff Confirmation Alarm	
74	1	Direct STES Circuit Valve VT21 Cutoff Confirmation Alarm	

Table 3.1: List of alarms, classified by type, that are triggered by the CHESS Setup CMS system and that are sent via e-mail. There are only two different priorities (column **Pri**), the high (0) when the dissipator is started and all the others with the regular priority (1).

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4. Database access

The CMS (Control and Monitoring System) tool is built on top of MySQL, an Open Source standard SQL database storage system. The database administrator user has raw access locally and remotely to the data to extract information for any particular application, for instance, feeding the data to another monitoring system or change electrical or thermal energy prices.

The Database administrator is allowed to use any MySQL client able to connect to MySQL 8.0 server to download, upload, select, delete or update any information.

The database has three types of elements usable by the database operator:

1. **Tables**. The tables are the basic element in an SQL Database. They are regular tables with columns and rows. Each column has a different data type and, in the case of the CHESS CMS, every row represents a sensor or actuator reading or a calculation. Every row in the CHESS CMS is identified by a Time Stamp, i.e., the acquisition date and time for a sensor reading.

2. **Views.** The views are a read-only table that does not exist physically but when they are accessed (read) the data is obtained from a subset of other existing tables or views. For instance, a view could be the table formed by the subset of rows and columns of a given table with the 'Time Stamp' inside a predefined interval.

   In the following table, it can be seen on the left the table 'Sensor Data' containing the 'Power', 'Flow' and 'Energy' from a given sensor, for instance, a calorimeter. The right view, the 'Energy October' table, is a read-only table that only matches a subset of rows and columns (Energy in October) from the real 'Sensor Data' table (it does not exist physically in the system).

Sensor Data			
Timestamp	Power	Flow	Energy
...	...	...	...
2019/09/31 23:55	13,20	6,20	5,20
2019/10/01 00:00	10,12	4,20	5,30
2019/10/01 00:05	15,70	4,12	5,50
...	...	...	...

VIEW → October Energy

Energy October	
Timestamp	Energy
...	...
2019/01/01 13:35	5,30
2019/01/01 13:40	5,50
...	...

Table 4.1: Views of different data tables.

3. **Procedures**. This element is an embedded script that, given input and the tables, views and other procedures available the database, generates an outcome that could be a scalar result or one or more tables. For instance, a script that generates a table with the incremental consumed energy, i.e. the amount of energy consumed in each interval of time, from the readings of a power meter

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that are stored in another table which is by definition accumulative (incremental).

Sensor Energy Table			Sensor Incremental Energy Table	
Timestamp	Acc. Energy		Timestamp	Inc. Energy
...	...		...	...
2019/01/01 13:30	1340,20	PROCEDURE	2019/01/01 13:30	10,40
2019/01/01 13:35	1350,60	→	2019/01/01 13:35	15,10
2019/01/01 13:40	1375,70	CalcEnergy()	2019/01/01 13:40	-
...	...		...	...

Table 4.2: The left table 'Sensor Energy' is a regular table containing the accumulated (incremental) energy acquired from a sensor. The database 'Procedure CalcEnergy()', when called, it generates the content of the table 'Sensor Incremental Energy' from the 'Sensor Energy' table which is more informative for a viewer: it is the consumed energy at every 5 minutes.

4.1. Database tables, views, and procedures

This section will describe the set of tables, views, and procedures provided by the CHESS CMS system to a database administrator user. For better understanding, the description will be done bottom-up, i.e., the three types of objects (tables, views, and procedures) will be described all together instead of being described by their type. Therefore, the following sections, the available tables, views, and procedures will be described in the way they are constructed inside the system: from the lower level tables that are the data log from the system sensors and actuators which are filled periodically (every 5 minutes), to the higher level tables and views containing, for instance, incremental energy or the system COP which are generated by calling the corresponding procedures during the plotting process.

The four levels of complexity from the lowest to the highest are:

1. **States, Sensors, and Actuators**. Set of real tables with the current system state, and the sensor and actuator data log.
2. **Incremental Energy**. Set of tables and views containing the calculated incremental energy calculated using the corresponding procedures using the information of the low-level tables.
3. **Performance.** Set of tables and views containing performance calculations such as the PVT Performance and the system COP. The set of procedures that calculate these tables and views operate on top of the tables and views of the previous levels.

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4. **Savings.** Set of tables and views containing the electrical and thermal energy savings calculated with procedures that operate over tables and views in the previous levels.

All the table and view rows of the system are identified by a 'Time Stamp' which is a time mark (date + time) in the format: 'YYYY-MM-DD hh:mm: ss'. These stamps are stored in UTC, therefore, are not affected by any Daylight Savings Time. When the CMS system represents the data in the plots it converts these timestamps to the system local time, however, if a Database administrator uses (selects, inserts or updates) the data in the tables or exports it into files, he must take into account that the 'Time Stamps' must be in 'UTC' format.

4.2. States, Sensors, and Actuators

This section will describe the lowest level tables. This level only contains real tables generated by the CMS registration algorithm that logs a row every 5 minutes. This level contains the following tables: 'Estats' (States), 'Bombes' (water pumps), 'Calorimetres' (Calorimeters), 'Consums_Electrics' (Electrical Consumptions), 'Fotovoltaica' (Photovoltaics), 'Sensors' (Sensors) and 'Valvules' (Valves). The following sections will describe the content of every table and the columns it has.

4.2.1. Table 'Estats'

The table 'Estats' contains the data log for several devices of internal states: the dissipator, the heat pump, and the flow switches. The system stores a register (row) in this table containing several fields. Every flow switch has the detection row (FX01, FX02, FX11, FX12, FX31, FX32, FX41, FX86), the dissipator and the heat pump provide their internal states ('Manual Mode', 'Start Confirmation', 'Start Permission', and 'Alarm'). The inverters (1 and 2) store their state for the connection to the grid.

The physical location of every device can be found in the synoptic screen.

#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD hh:mm:ss	datetime
2	Time_Stamp_ms	int(11)	The register millisecond	ms
3	F***xx***	int(11)	1: if the flow switch ***xx*** is detecting flow	boolean
4	A01_Manual	int(11)	1: the dissipator is in manual mode	boolean
5	A01_ConfMarxa	int(11)	1: system receives dissipator start confirmation signal	boolean
6	A01_PermisMarxa	int(11)	1: dissipator has the start permission enabled	boolean
7	A01_Alarma	int(11)	1: dissipator alarm: an alarm is triggered	boolean
8	BC01_Manual	int(11)	1: Heat Pump is in manual mode	boolean
9	BC01_ConfMarxa	int(11)	1: system receives Heat Pump start confirmation signal	boolean
10	BC01_PermisMarxa	int(11)	1: Heat Pump has start permission enabled	boolean
11	BC01_Alarma	int(11)	1: Heat Pump alarm: an alarm is triggered	boolean
12	INVERSOR1_Estat	int(11)	0: Not Ready, 1: Waiting to Connect, 2: Connected to the grid	Code
13	INVERSOR2_Estat	int(11)	0: Not Ready, 1: Waiting to Connect, 2: Connected to the grid	Code

Table 4.3: Description of table 'Estats' columns. The row number 3 is repeated for each flow switch, therefore '*xx*' is substituted by 01, 02, 11, 12, 31, 32, 41 and 86.

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4.2.2. Table 'Bombes'

The table 'Bombes' contains the data log for the water pumps. The system stores a register (row) in this table containing several fields per each pump: B01, B02, B03, B04, B11, B12, B31, B32, B41, and B42. The physical location of every pump can be found in the synoptic screen.

For all the water pump the system stores the following columns: 'Manual', 'ConfMarxa', 'PermisMarxa', 'Alarma', 'Alarma_Proteccio', 'Alarma_ConfMarxa'. For the driven water pumps (B41 and B42) the system registers two more columns: 'Alarma_Variador' and 'SpActual'.

#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD hh:mm:ss	datetime
2	Time_Stamp_ms	int(11)	The register millisecond	ms
3	B***xx***_Manual	int(11)	1: the water pump ***xx*** is in Manual mode	boolean
4	B***xx***_ConfMarxa	int(11)	1: system receives water pump start confirmation signal	boolean
5	B***xx***_PermisMarxa	int(11)	1: water pump has start permission enabled	boolean
6	B***xx***_Alarma	int(11)	1: water pump alarm: an alarm is triggered	boolean
7	B***xx***_Alarma_Proteccio	int(11)	1: water pump alarm: protection (RDC, breaker) tripped	boolean
8	B***xx***_Alarma_ConfMarxa	int(11)	1: water pump alarm: not receiving start confirmation signal	boolean
9	B***yy***_Alarma_Variador	int(11)	1: water pump driver is signalling an alarm	boolean
10	B***yy***_SpActual	int(11)	1: current-driven pump set point	boolean

Table 4.4: Description of table 'Bombes' columns. The rows number 3 – 8 are repeated for each pump, therefore '*xx*' is substituted by 01, 02, 03, 04, 11, 12, 31, 32, 41 and 42. The rows '*yy*' are only available for regulated water pumps; therefore they only will be available for '*yy*' equal to 41 and 42.

4.2.3. Table 'Calorimetres'

The table 'Calorimetres' contains the data log for all the calorimeters. The system stores a register (row) in this table containing several fields per each calorimeter: C21, C22, C23, C24, C31, C41 and C91. The physical location of every calorimeter can be found in the synoptic screen.

#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD hh:mm:ss	datetime
2	Time_Stamp_ms	int(11)	The register millisecond	ms
3	C***xx***_Estat	int(11)	**0**: Ok; **99**: Gateway M-Bus Error; **Other**: M-Bus node state	Code
4	C***xx***_Volum	double	Calorimeter accumulated volume	m^3
5	C***xx***_Energia	double	Calorimeter accumulated energy	MWh
6	C***xx***_Cabal	double	Calorimeter current flow	m^3/h
7	C***xx***_Potencia	double	Calorimeter current power	kW
8	C***xx***_Error_Flag	int(11)	Fit field error flags: **B0**: Forward flow sensor flag — **B4**: Reset **B1**: Return flow sensor fault — **B5**: E^2PROM fault **B2**: Internal calibration error — **B6**: Checksum fault **B3**: Timeout TDC (Air in the circuit) — **B7**: N/A	Bitfield
9	C***xx***_Temp_Impulsio	double	Calorimeter supply temperature	ºC
10	C***xx***_Temp_Retorn	double	Calorimeter return temperature	ºC

Table 4.5: Description of table 'Calorimetres' columns. The columns number 3 – 10 are repeated for each calorimeter, therefore '*xx*' is substituted by 21, 22, 23, 24, 31, 41, 91.

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4.2.4. Table 'Consums_Electrics'

The table 'Consums_Electrics' contains the data log for the electrical energy consumed by the system as well as the reactive energy.

#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD hh:mm:ss	datetime
2	Time_Stamp_ms	int(11)	The register millisecond	kWh
3	Comptador_Energia_Activa_Importada	double	Active imported energy	kWh
4	Comptador_Energia_Activa_Exportada	double	Active exported energy	kWh
5	Comptador_Reactiva_Q1	double	Imported Reactive Inductive energy (Q1)	kVArL
6	Comptador_Reactiva_Q2	double	Exported Reactive Capacitive energy (Q2)	kVArC
7	Comptador_Reactiva_Q3	double	Exported Reactive Inductive energy (Q3)	kVArL
8	Comptador_Reactiva_Q4	double	Imported Reactive Capacitive energy (Q4)	kVArC

Table 4.6: Description of table 'Calorimetres' columns. The columns number 3 – 7 are repeated for each inverter, therefore 'x' is substituted by 1 and 2.

4.2.5. Table 'Fotovoltaica'

The table 'Fotovoltaica' contains the data log for the photovoltaic inverters. The system stores a register (row) in this table containing several fields per each inverter: 'INV1' and 'INV2'.

#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD hh:mm:ss	datetime
2	Time_Stamp_ms	int(11)	The register millisecond	ms
3	Inversor**x**_Total_Energy	int(11)	Inverter **x** accumulated energy.	kWh
4	Inversor**x**_Daily_Energy	double	Inverter **x** daily accumulated energy.	kWh
5	Inversor**x**_Direct_SelfConsumption	double	Inverter **x** direct self-consumed energy	kWh
6	Inversor**x**_Status	int(11)	Inv. **x** status: Refer to table ***States.INVERSOR1_Estat***	Code
7	Inversor**x**_Active_Power	double	Inverter **x** current active power.	kWh

Table 4.7. Description of table 'Fotovoltaica' columns. The row number 3 – 7 are repeated for each inverter, therefore 'x' is substituted by 1 and 2.

4.2.6. Table 'EnergiaElectrica'

The table 'EnergiaElectrica' is only created by convenience since it contains all electrical energy information together (consumption and production) in the same table. It is not created as a view for performance reasons since a view of electrical energy must join the two tables ('Consums_Electrics' and 'Fotovoltaica') by the 'Time_Stamp' field and this operation has quadratic order cost concerning the number of selected rows. Therefore, the CHESS CMS fulfils directly this table and the higher-level procedures such as 'CalcEnergiaElectricaInc()' use directly only this table.

#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD hh:mm:ss	datetime
2	Time_Stamp_ms	int(11)	The register millisecond	kWh
3	Inversor1_Total_Energy	double	Inverter 1 accumulated energy.	kWh

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4	Inversor2_Total_Energy	double	Inverter 2 accumulated energy.	kWh
5	Comptador_Energia_Activa_Importada	double	Active imported energy	kWh
6	Comptador_Reactiva_Q1	double	Imported Reactive Inductive energy (Q1)	kVArL

Table 4.8: Description of table 'EnergiaElectrica' columns. This table contains the most used registers related to electrical energy: electrical active and reactive energy consumption and electrical active energy production.

4.2.7. Table 'Sensors'

The table 'Sensors' contains the data log for the temperature, solar irradiance, and humidity sensors. The system stores a register (row) in this table containing the sensor readings (temperature, solar irradiance, and relative humidity) for each available sensor (T01, T02, T03, T04, T05, T11, T12, T13, T31, T32, T33, T34, T35, T36, T41, T42, T51, T52, T53, T83, T84, T85, T86, T101, R101, H101).

#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD hh:mm:ss	datetime
2	Time_Stamp_ms	int(11)	The register millisecond	ms
3	T***xxx*** _escalat	double	Temperature reading for sensor ***xxx***	ºC
4	R101_escalat	double	Solar irradiance reading for sensor R101	W/m²
5	H101_escalat	double	Outdoors Relative Humidity reading for sensor H101	%

Table 4.9: Description of table 'Sensors' columns. The row number 3 is repeated for each temperature sensor, therefore '*xxx*' is substituted by 01, 02, 03, 04, 05, 11, 12, 13, 31, 32, 33, 34, 35, 36, 37, 41, 42, 41, 51, 52, 53, 83, 84, 85, 86 and 101.

4.2.8. Table 'Valvules'

The table 'Valvules' contains the data log for the valves. The system stores a register (row) in this table containing several fields per each valve: VT11, VT12, VT13, VT21, VT22, VT23, VB01, VB15, VB83, VB83a.

#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD hh:mm:ss	datetime
2	Time_Stamp_ms	int(11)	The register millisecond	ms
3	VB***xx***_Manual	int(11)	1: the valve ***xx*** is in Manual mode	boolean
4	VB***xx***_ConfOberta	int(11)	1: system receives valve opened confirmation signal	boolean
5	VB***xx***_ConfTancada	int(11)	1: system receives valve closed confirmation signal	boolean
6	VB***xx***_PermisMarxa	int(11)	1: valve has start permission enabled	boolean
7	VB***xx***_Alarma	int(11)	1: valve alarm: an alarm is triggered	boolean
8	VB***xx***_Alarma_Proteccio	int(11)	1: valve alarm: protection (RDC, breaker) tripped	boolean
9	VB***xx***_Alarma_ConfObertura	int(11)	1: valve alarm: not receiving an opened confirmation signal	boolean
10	VB***xx***_Alarma_ConfTancament	int(11)	1: valve alarm: not receiving a closed confirmation signal	boolean
11	VB***yyy***_Manual	int(11)	1: water pump driver is signaling an alarm	boolean
12	VB***yyy***_SpActual	double	Driven water pump current set value	%

Table 4.10: Description of table 'Valvules' columns. The rows number 3 – 10 are repeated for each 3-Way, 2/3-Point valves, therefore '*xx*' is substituted by 11, 12, 13, 21, 22 and 23. The columns 11 – 12 '*yyy*' are only available for 3-Way regulated valves, therefore the '*yYy*' is substituted by 01, 15, 83 and 83a.

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4.3. Incremental Energy

This section will describe the next level of complexity tables which are set of tables that contain the incremental thermal and electrical energy. These tables are not automatically generated by the CHESS CMS, they are fulfilled on-demand using the high-level plotting interface described in chapter 3.5.11.2, pg. 86.

This level contains two tables:

1. **EnergiaElecricaInc.** This table is fulfilled with the electrical incremental energy from the accumulated energy registered in the low-level table 'EnergiaElectrica'.
2. **EnertiaTermicaInc.** This table is fulfilled with the thermal incremental energy from the accumulated energy registered in the low-level table 'Calorimeters'.

And a view over the two previous tables:

1. **EnergiaIncResum.** This table joins together the content of all the incremental energy (thermal and electrical) in a single table.

The tables in this level are filled by calling two procedures:

1. **CalcEnergiaElectricaInc()**. Calculates the table 'EnergiaElectricaInc' from the data registered in 'EnergiaElectrica' low-level table.
2. **CalcEnergiaTermicaInc()**. Calculates the table 'EnergiaTermicaInc' from the data registered in 'the Calorimeters' low-level table.

4.3.1. Procedures 'CalcEnergia{Electrica Termica}Inc()'

The procedures 'CalcEnergiaElectricaInc()' and 'CalcEnergiaTermicaInc()' are called from the CHESS CMS plotting system to generate the content of the table 'EnergiaElectricaInc' and 'EnergiaTermicaInc', respectively, and to eventually use the view 'EnergiaIncResum'. Every time in the plotting system, a new view over a different set of data, i.e., change in the time interval, is performed, a call to this procedure is done.

Although the procedures are coded to allow the CMS plot the incremental (electrical and thermal) energy, they can be also be used by a database administrator to generate the incremental energy in the desired interval to inspect it or export the result.

Procedure signatures

```
PROCEDURE CalcEnergia{Electrica Termica}Inc
     (     IN StartDateTime DateTime,
           IN EndDateTime DateTime,
           IN TimeZone VARCHAR(255),
           IN GroupBy VARCHAR(255) );
```

Input parameters

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'StartDateTime', 'EndDateTime': These two parameters are date and time in the format 'YYYY-MM-DD hh:mm:ss' that specifies the time interval filter that will be applied to select the data in the table 'EnergiaElectrica'.

TimeZone: Specifies the time zone in which 'StartDateTime' and 'EndDateTime' are defined, e.g. CET, UTC, etc.

GroupBy: Specifies the aggregation level of the resulting data. It can be one among 'HOUR', 'DAY', 'WEEK', 'MONTH' or 'YEAR'.

4.3.2. Table 'EnergiaElectricaInc'

The table 'EnergiaElectricaInc' contains the incremental electrical energy production and consumption of the system. The aggregation varies depending on the call done to the procedure 'CalcEnergiaElectricaInc()', therefore, for instance, if 'DAY' was specified as 'GroupBy' input parameter, the incremental energy will be provided daily ('Time_Stamp' will be 'YYYY-MM-DD 00:00:00'). If 'WEEK', 'MONTH' or 'YEAR' was specified in the call to the procedure, the 'Time_Stamp' will be the first day of every year week, month (YYYY-MM-01) and year (YYYY-01-01), respectively, plus the time (00:00:00).

#	Name	Data Type	Description	nits
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD hh:mm:00	datetime
2	EnergiaInversor1	double	Incremental energy produced by the inverter 1	kWh
3	EnergiaInversor2	double	Incremental energy produced by the inverter 2	kWh
4	EnergiaProduida	double	Total incremental produced energy	kWh
5	ActivaConsumida	double	Total incremental consumed energy	kWh
6	ActivaImportada	double	Total incremental imported energy from the grid	kWh
7	ActivaExportada	double	Total incremental exported energy to the grid	kWh
8	ReactivaInductiva	double	Total incremental reactive inductive energy	kVArL

Table 4.11: Description of table 'EnergiaElectricaInc' columns.

4.3.3. Table 'EnergiaTermicaInc'

The table 'EnergiaTermicaInc' contains the incremental thermal energy calculated from the calorimeter accumulated (incremental) energy data. In the same way, it happens with the table 'EnergiaElectricaInc', the aggregation varies depending on the call done to the procedure 'CalcEnergiaTermicaInc()'.

#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD hh:mm:00	datetime
2	C21_Energia	double	Incremental energy accumulated in the calorimeter C21	kWh
3	C22_Energia	double	Incremental energy accumulated in the calorimeter C22	kWh
4	C23_Energia	double	Incremental energy accumulated in the calorimeter C23	kWh
5	C24_Energia	double	Incremental energy accumulated in the calorimeter C24	kWh
6	C32_Energia	double	Incremental energy accumulated in the calorimeter C32	kWh
7	C41_Energia	double	Incremental energy accumulated in the calorimeter C41	kWh
8	C91_Energia	double	Incremental energy accumulated in the calorimeter C91	kWh

Table 4.12: Description of table 'EnergiaTermicaInc' columns.

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4.3.4. View 'EnergiaIncResum'

The view 'EnergiaIncResum' is a view over the tables 'EnergiaTermicaInc' and 'EnergiaElectricaInc', therefore it only has a meaning when the other two tables are created by calling the two respective procedures 'CalcEnergiaElectricaInc()', 'CalcEnergiaTermicaInc()'.

The view does not perform any extra calculation over the data, it simply joins the columns of tables 'EnergiaElectricaInc' and 'EnergiaTermicaInc' in a single row by matching the respective 'Time_Stamp'.

4.4. Performance

This section will describe the tables related to the calculation of the 'PVT Performance' and the system 'COP'. These calculations are performed using the tables described in the previous sections, therefore, the procedures in this level use the low-level tables and the resulting tables of calling the electrical and thermal incremental energy procedures described in the previous section. The call to the procedures in this section needs first a call to the 'CalcEnergiaTermicaInc()' and 'CalcEnergiaElectricaInc()' with the same parameters.

4.4.1. COP

This section describes the tables and procedures involved in the calculation of the system 'COP' (Coefficient of Performance). The 'COP' is calculated using the procedure 'CalcCOP()' and it stores the result in the 'COP' table.

Procedure signatures

```
PROCEDURE CalcCOP()
```

Input parameters:

The 'CalcCOP()' does not need any parameter since it operates on the already calculated tables 'EnergiaTermicaInc' and 'EnergiaElectricaInc', therefore the Database administrator must first call the 'CalcEnergiaTermicaInc()' and 'CalcEnergiaElectrica()' and then call the 'CalcCOP()' procedure. Therefore, the implicit parameters in the 'CalcCOP()' are those given to the 'CalcEnergiaTermicaInc()' and 'CalcEnergiaElectricaInc()'.

#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD hh:mm:00	datetime
2	EnergiaElectricaImportada	double	Incremental electrical imported energy	kWh
3	EnergiaElectricaExportada	double	Incremental electrical exported energy	kWh
4	EnergiaElectricaConsumida	double	Incremental electrical consumed energy	kWh
5	EnergiaTermicaConsumida	double	Incremental thermal consumed energy	kWh
6	COPc	double	COP: Thermal Consumption / Electrical Consumption	%
7	COPi	double	COP: Thermal Consumption / Electrical (Cons.– Prod .)	%

Table 4.13: Description of table 'COP' columns.

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The 'COP' table is a table that contains the Coefficient Of Performance of the whole system, not the heat pump independently. Therefore, the CMS calculates a relationship between all the thermal energy delivered to the customer concerning all-electric energy consumption.

The 'CalcCOP()' procedure calculates on top of the resulting tables 'CalcEnergiaTermica', 'CalcEnergiaElectrica' and the procedures that calculate these tables use the higher resolution on the data (every 5minutes) and perform the desired aggregation given in the call to the procedure ('HOUR', 'DAY', 'WEEK', 'MONTH' or 'YEAR').

Table 4.13. shows that the 'COP' table contains two different COPs columns: COPc and COPi.

1. **COPc**. It is the standard COP: Thermal Energy delivered to the customer divided by the whole system electrical consumption.
2. **COPi**. It takes into account the electrical PVT production, therefore, this production is subtracted from the electrical consumption. The calculations are done instantaneously (at 5-minute interval registering frequency) and are later aggregated.

4.4.2. *PVT Performance*

This section describes the tables, procedures, and views involved in the calculation of the 'PR' (Performace Ratio) coefficients over the PVT electrical and thermal production.

The performance ratios are calculated by calling the procedure 'CalcRendimentPVT()' which fulfils the table 'RendimentPVT', and later, the user can select the useful information from the views 'RendimentPVTResum', 'RendimentPVTResumHora', 'RendimentPVTResumDia', 'RendimentPVTResumSetmana', 'RendimentPVTResumAny'.

4.4.2.1. *Procedures 'CalcRendimentPVT()'*

The procedure 'CalcRendimentPVT()' performs the calculation of the 'Performance Ratio' of the PVT panels using the low-level data registered in the low-level tables 'Sensors', 'Estats', 'Calorimetres' and 'Fotovoltaica'.

The calculation of the PVT performance is performed by estimating the theoretical (electrical and thermal) outcome from the PVT panels compared to the measured (thermal and electrical) production. The equations used to calculate the outcome are provided by the PVT panel manufacturer. These equations allow calculating the electrical and thermal power given the PVT panel parameters, the solar irradiation and the PVT panel and outdoors temperature. These measurements are acquired using the CHESS sensors R101, T02, T101.

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The energy readings to compare the theoretical outcome are obtained from the calorimeters C21 and C22 and the PV Inverters production.

#	Parameter	Value	Units
1	STC @ AM	25	ºC
2	STC @ Irradiance	1000	W/m^2
3	Peak Power	260	Wp
4	Width	1,641	m
5	Height	0,992	m
6	Total Area	1,65	m^2
7	Usable Area	1,57	m^2
8	Optical Performance	0,59	
9	MPPT Losses	0,43	% / ºC
10	Thermal Losses Coefficient a1	3,3	$W/m^2 \cdot {}^oK$
11	Thermal Losses Coefficient a2	0,021	$W/m^2 \cdot {}^oK^2$
12	Electrical efficiency	16,01	%

Table 4.14: Datasheet parameters of the PVT panels.

#	Parameter	Value	Units
1	Number of Modules	160	#
2	Usable Area	251,2	m^2

Table 4.15: CHESS Setup installation dimensions.

The best sample interval that can be used to integrate the theoretical energy is the system sample (5 minutes). The algorithm obtains sensor information at time t1 and time t2 (t1+Δt, where Δt = 5 minutes), and calculates the power at these two points of the interval. Then, it integrates this power into energy assuming the sensor measurements were the same in the whole interval, therefore the lower the sample time Δt the better accuracy in the results are obtained.

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#	Name	Parameter	Value	Units
1	t1	Interval Start Time	Time_Stamp	h
2	t2	Interval End Time	Time_Stamp	h
3	I1	Solar Irradiance at time t1	R101	W/ m²
4	I2	Solar Irradiance at time t1	R101	W/ m²
5	Tai	Outdoors temperature at t1	T101	ºC
6	Taf	Outdoors temperature at t2	T101	ºC
7	Tmi	Module Temperature at t1	T02	ºC
8	Tmf	Module Temperature at t2	T02	ºC
9	Eer	Measured Electrical Energy at t2	Inv1 + Inv2	kWh
10	Etr	Measured Thermal Energy at t2	C21+C22	kWh

Table 4.16: Description of the measurements (rows 3 - 8) needed to calculate the PVT theoretical power outcome (electrical and thermal) and to integrate them into the theoretical energy, given the measurements at time **t1** and **t2** (rows 1 and 2). Note that the real measured energies (rows 9 and 10) are already integrated energies (from inverters and calorimeters) at times **t1** and **t2** (the systems calculates the absolute energies by subtracting the energy at **t2** minus the energy at **t1**), therefore, the energy estimation is only done in the theoretical calculations.

#	Name	Parameter	Value	Units
1	A	Area (# Modules * Usable Area)	251,2	m²
2	Re	Electrical Efficiency	16,01	%
3	Ro	Optical Performance	0,59	
4	PPmpp	MPPT Losses	0,43	% / ºC
5	Tstc	Standard Temperature	25	ºC
6	t	Sample Interval	t2- t1	h
7	I	Mean Irradiance	(If + Ii) / 2	W/ m²
8	Ta	Mean Outdoors Temperature	(Taf – Tai) / 2	ºC
9	Tm	Mean Module Temperature	(Tmf – Tma) / 2	ºC

Table 4.17: Variables calculated from the datasheet parameters and the sensor readings.

<u>Theoretical Electrical Energy (Eet):</u>

Rc is the electrical performance in % corrected by the temperature:

Rc = Re – Re* (Tm – Tstc)* PPmpp / 100

Eet = I * A * (Rc / 100) * t

<u>Theoretical Thermal Energy</u>:

Rt is the thermal performance in % corrected by the temperature. Note that G is calculated in ºC while a1 and a2 are expressed in ºK. However since the conversion is ºK

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= ºC - 273.15 and the temperature operated against a1 and a2 is an increment (Tm – Ta), the 273.15 offsets are cancelled.

G = (Tm – Ta) / I

Rt = Ro – a1 * G – a2 * 1000 * G^2

Ett = I * A * Rt * t

These two theoretical energies 'Eet' and 'Ett' estimated in the interval [t1, t2] and, then, compared with the real energies 'Eer' and 'Etr' measured by inverters and calorimeters, respectively, in this same interval [t1, t2].

It must be taken into account that both the electrical and thermal losses are not considered. The theoretical electrical energy is estimated in the panels, but the electrical production is done in the inverters. Since the performance of the inverter and the losses in the DC wiring are not available and, therefore, are not taken into account. In the same way, the theoretical thermal energy is calculated in the panels and the losses in the pipelines and the heat exchangers are unknown and, therefore, not integrated into the calculations. This means the calculated PRs will result in a little worse (between 10 % and 20 %) both in the electrical and the thermal side than they should be.

Moreover, the real measured thermal and electrical energy is integrated by the meters (inverters, power meters, and calorimeters) therefore it is done very accurately at the meter level. However, in the case of the theoretical energies, the system realizes periodic measurements at a frequency of 5 minutes.

Procedure signatures

```
PROCEDURE CalcRendimentPVT
     (     IN StartDateTime DateTime,
           IN EndDateTime DateTime,
           IN TimeZone VARCHAR(255),
           IN SampleInterval VARCHAR(255),
           IN GroupBy VARCHAR(255) );
```

Input parameters:

'StartDateTime', 'EndDateTime': These two parameters are date and time in the format 'YYYY-MM-DD hh:mm:ss' that specifies the time interval filter that will be applied to select the data in the low-level tables.

'TimeZone': Specifies the time zone in which 'StartDateTime' and 'EndDateTime' are defined, e.g. 'CET', 'UTC', etc.

'SampleInterval': Allows the user to specify different (higher) sample interval in seconds (default 5*60) than the frequency of registration (5 minutes). This interval must be multiple of 5 minutes, i.e., the sample rate, otherwise the resulting table will be empty. The minimum interval is the sample rate of 5*60 seconds.

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'GroupBy': Specifies the aggregation level of the resulting data. It can be one among '**HOUR**', '**DAY**', '**WEEK**', '**MONTH**' or '**YEAR**'.

4.4.2.2. *Table 'RendimentPVT'*

The table 'RendimentPVT' will contain the raw detailed output PVT performance result of the 'CalcRendimentPVT()' execution.

The thermal energy measurement has a lower resolution than the electrical measurements. The most precise calorimeter is C21 which has a resolution of MWh/10 while the others have a resolution of MWh. The electrical energy is measured at the level of Wh, therefore practically all the electrical energies vary at every 5-minute reading.

In the calculation of the PVT performance, an energy measurement different from 0 is required to have a real result, therefore the 'CalcRendimentPVT()' procedure performs the linear interpolation of the measurements (shown in the table Table 4.18). This ensures there is always a usable 'PR' calculation per every row and that a later aggregation is also possible. Table 4.19 shows the columns available in the 'RendimentPVT' database table.

Time_Stamp	Abs Thermal Energy C21 + C22	Abs Electrical Energy Inv 1 + Inv2	Thermal ΔEnergy C21 + C22	Electrical ΔEnergy Inv 1 + Inv 2	Interpolated Th. ΔEnergy C21 + C22	Interpolated El. ΔEnergy Inv 1 + Inv 2
2019/09/03 09:55:00	...	...	...	...	...	...
2019/09/03 10:00:00	5000	121,1	-	-	-	-
2019/09/03 10:05:00	5100	121,2	XX	0,1	YY	0,1
2019/09/03 10:10:00	5100	123,2	0	2,0	20	2,0
2019/09/03 10:15:00	5100	126,3	0	3,1	20	3,1
2019/09/03 10:20:00	5100	127,9	0	1,4	20	1,4
2019/09/03 10:25:00	5100	128,4	0	0,5	20	0,5
2019/09/03 10:30:00	5200	130,1	100	1,7	20	1,7
2019/09/03 10:34:00	...	...	...	...	...	...

Table 4.18: The table shows how from absolute energy readings from the sensors (columns 1-3) the system calculates the incremental readings (columns 4-5). Finally, the system fills all the zeros in the incremental energy columns by interpolating the first incremental non zero row to the past until the last non zero is found (as shown in the 6th column). In the example, there is no need to interpolate the last column (electrical energy) since it changes at every row (read), but in the case, the electrical readings do not change in consecutive readings, the equivalent interpolation is performed over the electrical data.

#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Interval start t1 Time Stamp in the format YYYY-MM-DD hh:mm:00	datetime
2	Time_Stampf	datetime	Interval end t2 Time Stamp in the format YYYY-MM-DD hh:mm:00	datetime
3	Ii	double	Solar Irradiance at interval start t1	W/m²
4	Iff	double	Solar Irradiance at interval end t2	W/m²
5	Im	double	Average Irradiance in the interval [t1, t2]	W/m²
6	Tai	double	Outdoors temperature at interval t1	ºC

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7	Taf	double	Outdoors temperature at interval t2	ºC
8	Tam	double	Average outdoors temperature at interval [t1, t2]	ºC
9	Tmi	double	Module temperature at interval start t1	ºC
10	Tmf	double	Module temperature at interval end t2	ºC
11	Tmm	double	Average module temperature in the interval [t1, t2]	ºC
12	Ett	double	Theoretical thermal energy in the interval [t1, t2]	kWh
13	Eet	double	Theoretical electrical energy in the interval [t1, t2]	kWh
14	Etr1i	double	Measured real absolute thermal energy from calorimeter C21 at t1	kWh
15	Etr1f	double	Measured real absolute thermal energy from calorimeter C21 at t2	kWh
16	Etr2i	double	Measured real absolute thermal energy from calorimeter C22 at t1	kWh
17	Etr2f	double	Measured real absolute thermal energy from calorimeter C22 at t2	kWh
18	Etri	double	Measured real absolute thermal total energy t1	kWh
19	Etrf	double	Measured real absolute thermal total energy t2	kWh
20	Etr	double	Measured real total thermal energy in the interval [t1, t2]	kWh
21	Eer1i	double	Measured real absolute electrical energy from inverter 1 at t1	kWh
22	Eer1f	double	Measured real absolute electrical energy from inverter 1 at t2	kWh
23	Eer2i	double	Measured real absolute electrical energy from inverter 2 at t1	kWh
24	Eer2f	double	Measured real absolute electrical energy from inverter 2 at t2	kWh
25	Eeri	double	Measured real absolute electrical total energy t1	kWh
26	Eerf	double	Measured real absolute electrical total energy t2	kWh
27	Eer	double	Measured real total electrical energy in the interval [t1, t2]	kWh
28	PRt	double	Thermal PR at interval [t1, t2]: (Etr / Ett)	% / 100
29	Pre	double	Electrical PR at interval [t1, t2]: (Eer / Eet)	% / 100
30	PR	double	PR at interval [t1, t2]: (Etr + Eer) / (Ett + Eet)	% / 100
31	EttAcc	double	Interpolated theoretical thermal energy in the interval [t1, t2]	kWh
32	EetAcc	double	Interpolated theoretical electrical energy in the interval [t1, t2]	kWh
33	EtrAcc	double	Interpolated real thermal energy in the interval [t1, t2]	kWh
34	EerAcc	double	Interpolated real electrical energy in the interval [t1, t2]	kWh
35	PRtAcc	double	Interpolated thermal PR at interval [t1, t2]	% / 100
36	PReAcc	double	Interpolated electrical PR at interval [t1, t2]	% / 100
37	PRAcc	double	Interpolated PR at interval [t1, t2]	% / 100

Table 4.19: Description of table 'RendimentPVT' columns. The columns '*Acc' are the interpolated version of the respective columns without the 'Acc' suffix.

4.4.2.3. *Views 'RendimentPVTResum'*

After the table 'RendimentPVT' is fulfilled by the procedure 'CalcRendimentPVT()' as described in previous sections, there is a view 'RendimentPVTResum' over the 'RendimentPVT' with the most useful information and 6 already aggregated views per 'HOUR', 'DAY', 'WEEK', 'MONTH' and 'YEAR' which are 'RendimentPVTResumHora', 'RendimentPVTResumDia', 'RendimentPVTResumSetmana', 'RendimentPVTResumMes', 'RendimentPVTResumAny', respectively.

Table 4.20 describes the visible columns for these 6 views. The 'Time_Stamp' column format in each view depends on the aggregation:

- **RendimentPVTResum,**

  RendimentPVTResumHora: YYYY-MM-DD hh:mm:00
- **RendimentPVTResumDia**: YYYY-MM-DD 00:00:00
- **RendimentPVTResumSetmana**: YYYY-MM-DD 00:00:00

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- **RendimentPVTResumMes**: YYYY-MM-01 00:00:00
- **RendimentPVTResumAny**: YYYY-01-00 00:00:00

The weeks of the year are numbered according to 'ISO8601' where the first day of the week is considered the Monday, therefore the 'RendimentPVTResumSetmana' 'Time_Stamp' will match to the Monday of every i^{th} week of the year.

#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD hh:00:00	datetime
2	Ett	double(14,2)	Theoretical thermal energy at Time_Stamp	kWh
3	Etr	double(14,2)	Real measured thermal energy at Time_Stamp	kWh
4	Eet	double(14,2)	Theoretical electrical energy at Time_Stamp	kWh
5	Eer	double(14,2)	Real measured electrical energy at Time_Stamp	kWh
6	PRt	double(14,2)	Thermal PR at Time_Stamp	%
7	PRe	double(14,2)	Electrical PR at Time_Stamp	%
8	PR	double(14,2)	Electrical PR	%

Table 4.20. Description of tables 'RendimentPVTResum*' columns. The resulting table has only the table 'RendimentPVT' useful columns from the user point of view. Moreover, the number of decimals and units have been adjusted. Note that the interval ['Time_Stamp', 'Time_Stampf'] disappears in the columns: only the interval start is represented by the 'Time_Stamp'. The 'Time_Stamp' must change from one row to the following according to the parameter 'SampleInterval' used in the call 'CalcRendimentPVT()'. The correct way of interpreting the data in this view is that the energies and PRs at a particular point at 'Time_Stamp' correspond to the energies and PRs from this point 'Time_Stamp' until the next row 'Time_Stamp' that should match to 'Time_Stamp + SampleInterval' unless there is any corrective filtering applied to the data (e.g. a sensor such as a flow switch is telling that the data should not be used) or due to missing data (no registration for any reason).

4.5. Energy Savings

This section will describe the tables, views, procedures related to the calculation of the energy and monetary savings. Since the system is provided with PVT panels, i.e. hybrid solar panels, which produce both electrical and thermal energy, the savings are considered and calculated separately.

4.5.1. Thermal Energy Savings

This section describes the tables, views, and procedures related to the computation of thermal energy savings. The database system provides a procedure to calculate thermal savings from the previous thermal incremental energy calculations described in chapter 3.5.11.2.6 and the procedure 'CalcCostEnergiaTermica()'. Therefore, before calling the procedure 'CalcCostEnergiaTermica()' it is mandatory to call the procedure 'CalcEnergiaTermicaInc()' using the same parameters.

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Procedure signature

```
PROCEDURE CalcCostEnergiaTermica
      (     IN StartDateTime DateTime,
            IN EndDateTime DateTime,
            IN TimeZone VARCHAR(255),
            IN GroupBy VARCHAR(255) );
```

Input parameters:

'StartDateTime', 'EndDateTime': These two parameters are date and time in the format 'YYYY-MM-DD hh:mm:ss' that specifies the time interval filter that will be applied to select the data in the low-level tables.

TimeZone: Specifies the time zone in which 'StartDateTime' and 'EndDateTime' are defined, e.g. 'CET', 'UTC', etc.

GroupBy: Specifies the aggregation level of the resulting data. It could be one among 'HOUR', 'DAY', 'WEEK', 'MONTH' or 'YEAR'.

4.5.1.1. *Table 'PreusGas'*

This section describes the table 'PreusGas' that contains the information to calculate the *Natural Gas* (boiler) invoices.

The table 'PreusGas' will contain a row at every change in either the *Natural Gas* price (€ / kWh) or any change in hydrocarbon or VAT taxes.

#	Name	Data Type	Description	Units
1	Id	int(11)	Incremental Counter	Id number
2	Preu	double	Natural Gas Price	€ / kWh
3	ImpostHidrocarburs	double	Hydrocarbon taxes	€ / kWh
4	IVA	double	VAT Tax	%
5	StartDate	datetime	Date of application start	datetime

Table 4.21: Description of table 'PreusGas' columns. Every row represents a change in the Natural Gas pricing, therefore, if the table rows are sorted by the 'StartDate' column, each row represents at which day the prices in the row start to be valid, and they are valid until the next row 'StartDate'.

4.5.1.2. *Table 'CostosTermics'*

The execution of the procedure 'CalcCostEnergiaTermica()', the table 'CostosTermics' contains all the information that represents the thermal energy savings in kWh and €.

The energy taken into account is the energy provided to the customer using the CHESS system, therefore the 'CalcCostEnergiaTermica()' uses this energy calculated by the 'CalcEnergiaTermicaInc()' (described in chapter 3.5.11.2.6) and applies the costs

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available in the table 'PreusGas'. Therefore, the result in table 'CostosTermics' is directly the system savings in kWh and €. Note that the call to 'CalcCostEnergiaTermica()' must be preceded always by the call to 'CalcEnergiaTermicaInc()' with the same parameters.

#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD 00:00:00	datetime
2	EnergiaTermica	double	Thermal energy from Time_Stamp to Time_Stamp+GroupBy	€ / kWh
3	Preu	double	Natural Gas Energy Cost	€ / kWh
4	ImpostHidrocarburs	double	Hydrocarbon Tax Cost	€ / kWh
5	IVA	double	VAT Cost	%
6	CostEnergia	double	Energy Cost	€
7	CostImpostos	double	Taxes Cost	€
8	CostTotal	double	Total	€

Table 4.22: Description of table 'CostosTermics' columns. Each row contains the thermal energy and its cost (which is directly the savings) of a different time interval depending on the parameter 'GroupBy' given to the 'CalcEnerigaTermicaInc()'.

4.5.1.3. *Views 'CostosTermicsResum'*

After the table 'CostosTermics' is fulfilled by the procedure 'CalcCostosTermics()' as described in previous sections, there is a view 'CostosTermicsResum' over the 'CostosTermics' with the most useful information and 6 already aggregated views per 'HOUR', 'DAY', 'WEEK', 'MONTH' and 'YEAR' which are 'CostosTermicsResumHora', 'CostosTermicsResumDia', 'CostosTermicsResumSetmana', 'CostosTermicsResumMes', 'CostosTermicsResumAny'.

Table 4.24 describes the visible columns for these 6 views. The 'Time_Stamp' column format in each view depends on the aggregation:

- **CalcCostosTermicsResum,**

  CalcCostosTermicsResumHora: YYYY-MM-DD hh:mm:00
- **CalcCostosTermicsResumDia**: YYYY-MM-DD 00:00:00
- **CalcCostosTermicsResumSetmana**: YYYY-MM-DD 00:00:00
- **CalcCostosTermicsResumMes**: YYYY-MM-01 00:00:00
- **CalcCostosTermicsResumAny**: YYYY-01-00 00:00:00

The weeks of the year will be numbered according to 'ISO8601' where the first day of the week is considered the Monday, therefore the 'CalcCostosTermicsSetmana' 'Time_Stamp' will match to the Monday of every i^{th} week of the year.

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#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD 00:00:00	datetime
2	EnergiaTermica	double(19,2)	Thermal energy from Time_Stamp to Time_Stamp+GroupBy	€ / kWh
3	CostEnergia	double(19,2)	Energy Cost	€
4	CostImpostos	double(19,2)	Taxes Cost	€
5	CostTotal	double(19,2)	Total	€

Table 4.23: Description of views 'CostosTermicsResum*' columns. The resulting table has only the useful columns from the user point of view, moreover, the number of decimals and units have been adjusted.

The 'CostTotal' column represents directly thermal energy savings in €.

4.5.2. *Electrical Energy Savings*

This section describes the tables, views, and procedures related to the computation of electrical energy savings. The database system provides a procedure to calculate electrical savings from the previous electrical incremental energy calculations described in chapter 3.5.11.2.5 and the procedure 'CalcCostEnergiaElectrica()'. Therefore, before calling the procedure 'CalcCostEnergiaElectrica()' it is mandatory to call the procedure 'CalcEnergiaElectricaInc()' using the same parameters.

Procedure signature

```
PROCEDURE CalcCostEnergiaElectrica
      (     IN StartDateTime DateTime,
            IN EndDateTime DateTime,
            IN TimeZone VARCHAR(255),
            IN GroupBy VARCHAR(255) );
```

Input parameters:

'StartDateTime', 'EndDateTime': These two parameters are date and time in the format 'YYYY-MM-DD hh:mm:ss' that specifies the time interval filter that will be applied to select the data in the lower-level tables.

'TimeZone': Specifies the time zone in which 'StartDateTime' and 'EndDateTime' are defined, e.g. 'CET', 'UTC', etc.

'GroupBy': Specifies the aggregation level of the resulting data. It could be one among 'HOUR', 'DAY', 'WEEK', 'MONTH' or 'YEAR'.

4.5.2.1. *Table 'Periodes'*

This section describes the table 'Periodes'. Every hour of the year is identified by a period number that is used for energy billing. Typically, it exists tariffs with 1, 2, 3 or 6 different periods. Depending on the period assigned to a determinate hour, different costs and taxes are applied.

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#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD hh:00:00	datetime
2	Periode	Smallint(6)	Period Number	[1,2,3,4,5,6]

Table 4.24: Description of table 'Periodes' columns. Every row represents a period for the corresponding hour of the year identified by 'Time_Stamp'.

4.5.2.2. *Table 'PreusNIElectrics'*

This section describes the table 'PreusNIElectrics'. This table contains per each row the concepts for the electrical energy billing that do not depend on the period (the hour of the day in the year). These costs are applied to the full invoice, such as the VAT.

#	Name	Data Type	Description	Units
1	Id	int(11)	Incremental Counter	Id Number
2	Desviaments	double	Cost for the electrical detours	%
3	RemuneracioOM	double	Market Operator Remuneration	€ / MWh
4	RemuneracioOS	double	System Operator Remuneration	€ / MWh
5	MargeComercial	double	Trader Margin	% / 100
6	IEE	double	Electricity Specific Tax	% / 100
7	VAT	double	VAT Tax	% / 100
8	IdPerduesTransport	int(11)	Id for Transport losses table	Id Number
9	IdATR	int(11)	Id for the ATR tax table	Id Number
10	StartDate	datetime	Date of application in the format YYYY-MM-DD 00:00:00	datetime

Table 4.25: Description of table 'Periodes' columns. Every row represents a change in any of its billing concepts, therefore, if the table rows are sorted by the 'StartDate' column, each row represents at which day any of the concepts change in the billing, and they are valid until the next row 'StartDate'.

4.5.2.3. *Table 'ATRElectric'*

This section describes the table 'ATRElectric'. This table contains per each row the electrical ATR: a direct tax for the consumed energy which depends on the period (consumption hour in the year) and it is regulated by the government.

#	Name	Data Type	Description	Units
1	Id	int(11)	Incremental Counter	Id Number
2	P1	double	ATR Cost for period P1	€ / kWh
3	P2	double	ATR Cost for period P2	€ / kWh
4	P3	double	ATR Cost for period P3	€ / kWh
5	P4	double	ATR Cost for period P4	€ / kWh
6	P5	double	ATR Cost for period P5	€ / kWh
7	P6	double	ATR Cost for period P6	€ / kWh
8	StartDate	datetime	Date of application in the format YYYY-MM-DD 00:00:00	datetime

Table 4.26: Description of table 'ATRElectric' columns. Every row represents a change in the ATR values, therefore, if the table rows are sorted by the 'StartDate' column, each row represents at which day the ATR changes in the billing and they are valid until the next row 'StartDate'.

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4.5.2.4. *Table 'PerduesTransportElectric'*

This section describes the table 'PerduesTransportElectric'. This table contains each row of the electrical transport losses applied at every period.

#	Name	Data Type	Description	Units
1	Id	int(11)	Incremental Counter	Id Number
2	P1	double	Transport losses for P1	% / 100
3	P2	double	Transport losses for P2	% / 100
4	P3	double	Transport losses for P3	% / 100
5	P4	double	Transport losses for P4	% / 100
6	P5	double	Transport losses for P5	% / 100
7	P6	double	Transport losses for P6	% / 100
8	StartDate	datetime	Date of application in the format YYYY-MM-DD 00:00:00	datetime

Table 4.27: Description of table 'PerduesTransportElectric' columns. Every row represents a change in the transport losses values, therefore, if the table rows are sorted by the 'StartDate' column, each row represents at which day the transport losses change in the billing, and they are valid until the next row 'StartDate'.

4.5.2.5. *Table 'PreusIElectrics'*

This section describes the table 'PreusIElectrics'. This table contains each row of the different energy terms involved in the energy cost that is applied individually per every hour of the year.

#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD hh:00:00	datetime
2	PreuMercat	double	Energy Market Cost	€ / MWh
3	MercatIntradiari	double	Intraday Market Cost	€ / MWh
4	Restriccions	double	Restriction Cost	€ / MWh
5	ProcessosOS	double	System Operator Cost	€ / MWh
6	PagamentCapacitat	double	Capacity Payment Cost	€ / MWh
7	ServeiInterrumpibilitat	double	Interruptibility Service Cost	€ / MWh

Table 4.28: Description of table 'PreusIElectrics' columns. Every row represents the different energy costs applied to each year hour identified by 'Time_Stamp'.

4.5.2.6. *Table 'CostosElectrics'*

This section describes the table 'CostosElectrics'. This table is fulfilled by calling the procedure 'CalcCostosElectrics()' and it contains all the costs for the imported energy and the exported energy per each hour of the year. Therefore, it contains, per each row, the energy and all the costs for imported and exported energy during the hour identified by the 'Time_Stamp' column.

#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD hh:00:00	datetime
2	EnergiaProduida	double	Produced Energy	kWh
3	EnergiaConsumida	double	Consumed Energy	kWh
4	EnergiaImportada	double	Imported Energy from the Grid	kWh
5	EnergiaExportada	double	Exported Energy to the Grid	kWh
6	PreuMercat	double	Energy Market Cost	€ / MWh
7	MercatIntradiari	double	Intraday Market Cost	€ / MWh

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8	Restriccions	double	Restriction Cost	€ / MWh
9	ProcessosOS	double	System Operator Cost	€ / MWh
10	PagamentCapacitat	double	Capacity Payment Cost	€ / MWh
11	ServeiInterrumpibilitat	double	Interruptibility Service Cost	€ / MWh
12	Periode	double	Period Number	[1,2,3,4,5,6]
13	Desviaments	double	Cost for the electrical detours	%
14	RemuneracioOM	double	Market Operator Remuneration	€ / MWh
15	RemuneracioOS	double	System Operator Remuneration	€ / MWh
16	MargeComercial	double	Trader Margin	% / 100
17	IEE	double	Electricity Specific Tax	% / 100
18	IVA	double	VAT Tax	% / 100
19	PerduesTransport	double	Transport losses	% / 100
20	ATR	double	ATR Cost	€ / kWh
21	CostATREnergiaImportada	double	ATR Cost for Imported Energy	€
22	CostMercatEnergiaImportada	double	Market Cost for Imported Energy	€
23	CostAjustamentsEnergiaImportada	double	Adjustments Cost for Imported Energy	€
24	CostServeiInterrumpibilitatEnergiaImportada	double	Interruptibility Service for the Imported Energy	€
25	CostPagamentCapacitatEnergiaImportada	double	Cpacity Payment Cost for the Imported Energy	€
26	CostRemuneracioOMOSEnergiaImportada	double	Mark. & Sys. Operator Remuneration for the Imported Energy	€
27	CostPerduesTransportEnergiaImportada	double	Transport Losses for the Imported Energy	€
28	CostMargeComercialEnergiaImportada	double	Trader Margin for Imported Energy	€
29	CostEnergiaImportada	double	Total Cost of Imported Energy	€
30	CostImpostosEnergiaImportada	double	Taxes Cost for Imported Energy	€
31	CostATREnergiaExportada	double	ATR Cost for Exported Energy	€
32	CostMercatEnergiaExportada	double	Market Cost for Exported Energy	€
33	CostAjustamentsEnergiaExportada	double	Adjustments Cost for Exported Energy	€
34	CostServeiInterrumpibilitatEnergiaExportada	double	Interruptibility Service for the Exported Energy	€
35	CostPagamentCapacitatEnergiaExportada	double	Cpacity Payment Cost for the Exported Energy	€
36	CostRemuneracioOMOSEnergiaExportada	double	Mark. & Sys. Operator Remuneration for the Exported Energy	€
37	CostPerduesTransportEnergiaExportada	double	Transport Losses for the Exported Energy	€
38	CostMargeComercialEnergiaExportada	double	Trader Margin for Exported Energy	€
39	CostEnergiaExportada	double	Total Cost of Exported Energy	€
40	CostImpostosEnergiaExportada	double	Taxes Cost for Exported Energy	€

Table 4.29: Description of table 'CostosElectrics' columns. Every row represents the different energy production, consumption, imported and exported energy and all the costs involved in the billing of the energy for the 'Time_Stamp' hour.

4.5.2.7. *Views 'CostosElectricsResum'*

After the table 'CostosElectrics' is fulfilled by the procedure 'CalcCostosElectrics()' as described in previous sections, there is a view 'CostosElectricsResum' over the 'CostosElectrics' with the most useful information and 6 already aggregated views per 'HOUR', 'DAY', 'WEEK', 'MONTH' and 'YEAR' which are 'CostosElectricsResumHora', 'CostosElectricsResumDia', 'CostosElectricsResumSetmana', 'CostosElectricsResumMes', 'CostosElectricsResumAny'.

Table 4.32 describes the visible columns for these 6 views. The 'Time_Stamp' column format in each view depends on the aggregation:

- **CalcCostosElectricsResum,**

  CalcCostosElectricsResumHora: YYYY-MM-DD hh:mm:00
- **CalcCostosElectricsResumDia**: YYYY-MM-DD 00:00:00
- **CalcCostosElectricsResumSetmana**: YYYY-MM-DD 00:00:00
- **CalcCostosElectricsResumMes**: YYYY-MM-01 00:00:00

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- **CalcCostosElectricsResumAny**: YYYY-01-00 00:00:00

The weeks of the year will be numbered according to 'ISO8601' where the first day of the week is considered the Monday, therefore the 'CalcCostosElectricsSetmana' 'Time_Stamp' will match to the Monday of every week of the year.

#	Name	Data Type	Description	Units
1	Time_Stamp	datetime	Time Stamp in the format YYYY-MM-DD 00:00:00	datetime
2	EnergiaImportada	double(19,2)	Imported Electrical Energy	kWh
3	CostEnergiaImportada	double(19,2)	Imported Energy Cost	€
4	CostImpostosEnergiaImportada	double(19,2)	Imported Energy Taxes Cost	€
5	CostTotalEnergiaImportada	double(19,2)	Imported Energy Total Cost	€
6	EnergiaExportada	double(19,2)	Exported Energy	kWh
7	CostEnergiaExportada	double(19,2)	Export Energy Cost	€
8	CostImpostosEnergiaExportada	double(19,2)	Exported Energy Taxes Cost	€
9	CostTotalEnergiaExportada	double(19,2)	Exported Energy Total Cost	€
10	CostTotal	double(19,2)	Total Cost	€

Table 4.30: Description of views 'CostosElectricsResum*' columns. The resulting table contains only the useful columns from the user point of view, moreover, the number of decimals and units have been adjusted.

The 'CostTotal' in the views is calculated as exported energy cost minus imported energy cost, therefore if the 'CostTotal' column is positive are savings and if it is negative it means the system is purchasing energy to the grid.

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