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Publishable executive summary

HYBUILD is an EU Horizon 2020 - funded project, led by COMSA Corporación, which will develop two innovative compact hybrid electrical/thermal storage systems for stand-alone and district connected buildings.

This deliverable introduces the main steps and requirements for performing an optimised control of the HYBUILD system energy flows in the residential buildings by considering internal and external requests. The process involves the definition of the systems operations and layouts, along with user scenarios and use cases in order to define high-level functionalities of the Building Energy Management System (BEMS).

The deliverable is part of the work carried on within Task 4.4, which addresses the development of the BEMS in accordance to the monitoring strategy and system defined in Task 4.2. Relying on a strict cooperation between the simulation tools and the optimiser, the models take advantage from Task 4.1 in which the software TRNSYS is used for simulating the behaviour of the building thermal flows.

The dissertation begins from the general layout of the HYBUILD Mediterranean and Continental configurations, which is then adapted to the three demo-sites: Aglantzia (Nicosia district, Cyprus), Almatret (Spain) and Talence (Bordeaux, France). Piping and Instrumentation Diagram (P&ID) and descriptions of sensors and components are provided in order to understand the differences in each specific case.

A thorough work has been done for defining the system operational modes. In this document, for each of them, the specific status of pumps, valves and equipment has been identified in order to schedule all the possible configurations of the Mediterranean and Continental solutions.

The other part of the deliverable is dedicated to the software analysis. It was performed for defining the specifications of the BEMS, also considering its integration with Distribution Service Operators (DSOs) and energy retailer entities, in order to participate to Demand Response (DR) programmes. For this purpose, a methodological approach composed by three main steps has been adopted:

- Usage scenario description;
- Use case definition;
- Requirements elicitation.

The first step is the usage scenarios description; a scenario is a narrative description of a realistic situation which takes place in each demo site. Thanks to this approach, the potential users can well-understand the BEMS functionalities and return feedbacks on the tools features. From the proposed and validated scenarios, pieces of system behaviour can be extracted. These elements are the use cases and represent the second step of the used methodology. By means of the use cases, a step-wise representation of the energy processes performed by the BEMS is given. In the end, functional and non-functional software requirements have been listed taking into account the actions addressed by each step of the use case modelling. While the functional requirements determine the behaviour expected by the software components for reaching the objectives detailed in the use cases, the non-functional requirements define the performance attributes of the system.

In conclusion, three main pillars can be extracted from the present report. The first is the higher detailed P&IDs, better defined in terms of components, sensors and valves and related to both Mediterranean and Continental solutions. Afterwards, the definition of conditions and constraints related to the operational modes is noteworthy since they determine the

activation of the different parts of the system for satisfying the four identified categories of operational modes: heating modes, cooling modes, domestic hot water (DHW) modes, and charging modes. The third pillar is the definition of the BEMS functional requirements, which represent the arrival point of a shared view of the software behaviour and will drive the BEMS implementation activities. Below, some of these identified requirements are listed together with a brief description.

- Building Energy Management System optimiser – BEMS OPT. The module will be able to perform the requested optimisation process, re-working the requests in case of unexpected events and processing operational modes in case of missing connectivity.
- Building Energy Management System energy manager/user dashboard – BEMS EMD/EUD. The modules provide all the graphical interface functionalities to the energy manager and the energy users, respectively. These dashboards are able to get the inputs and show to the energy manager/user the results of the optimisation process.
- Building Energy Management System reporting module – BEMS REP. This module calculates the energy consumptions and other energy and economical related data in a chosen time period.
- Building Energy Management System monitoring module – BEMS MON. This module retrieves energy, temperature and all the relevant data from the building and notifies potential operational discrepancies.

Acronyms and Abbreviations

AI	Artificial Intelligence
BEMS	Building Energy Management System
COP	Coefficient of Performance
DC	Direct Current
DR	Demand Response
DHW	Domestic Hot Water
DSO	Distribution Service Operator
HEX	Heat Exchanger
HP	Heat Pump
KPI	Key Performance Indicator
NFR	Non-Functional Requirements
P&ID	Piping and Instrumentation Diagram
PCM	Phase Change Material
PI	Performance Indicator
PLC	Programmable Logic Controller
PV	Photovoltaic
RPW	Refrigerant-PCM-Water
SoS	State of the System

Glossary

System layouts: system layouts are schema created starting from both the Mediterranean and Continental concepts in which components, sensors and connections needed to guarantee the proper operation of the system have been detailed.

Operational mode: operational modes identify all the possible working conditions that can be actuated by the Mediterranean and Continental solutions.

Scenario: scenarios are a high level and narrative descriptions of the main processes occurring within a defined context, allowing to describe how the users could experience the functionalities put at disposal by this system.

Use cases: use cases are means able to define a piece of behaviour of a system or subsystem without revealing the internal structure of the system itself. A use case consists in a list of steps that describes the action performed and all the related features.

Software requirements: software requirements are declarations of the intended function of a system and its components. Relying upon this declaration, the software developer determines the behaviour expected by software components.

1 Introduction

1.1 Aims and objectives

This report presents intermediate outcomes of Work Package 4 - Smart control and System integration (WP4) in terms of study of the operational modes for the control of smart buildings, and the presentation of the scenarios of the HYBUILD system in both the Continental and Mediterranean cases. From the combination of building status and operational modes, the basic control rules for the building control have been elicited. Basic control rules are supposed to be used at low level, implemented directly from the Programmable Logic Controllers (PLCs), without any intervention of the artificial intelligence (AI). From the scenarios, divided by pilot, the functional and non-functional requirements of the Building Energy Management System (BEMS) have been elicited. The BEMS is supposed to work at high level, exploiting the optimisation and the flexibility of the building consumption. This report is the second one in WP4, which started at M3, and comes after 24 months from the beginning of the Project. So, the main objective of this report is to introduce the specifications of the software that will be implemented within WP4 in the following months.

The operational modes are the building-blocks for both basic control rules and optimisation algorithms. They define the system configurations, in terms of set-points to the actuators of the building, and requirements. The basic strategies have been elicited in terms of flowcharts which can be implemented at low level directly by the PLCs. These control rules can be applied in all those situations in which a high-level optimisation is not needed or not possible, such as no Internet connection or need to take almost instantaneously an action either to cool down or heat up the building, for any reason, or to have availability of DHW or charging the batteries. For each context condition, the most appropriate operational mode can be used, according to the user need. Of course, this method does not and cannot imply a general optimisation of costs and energy consumption, which is possible only with the introduction of artificial intelligence into the system. The building is expected to be governed by an intelligent BEMS which can perform a day-ahead optimisation for the following day. The optimisation plan will be a series of operational modes imposed to the building, time slot by time slot. In this sense, the operational modes are the linkage between the high-level optimisation and the actuators of the building, also in this case, as it happens for the basic control rules already introduced.

For the purpose of the definition of the system specifications, objective of this report, a clear distinction has been given to the top-down and bottom-up approach, and between the high level and low-level control: the top-down approach starts from the general overall targets, creates a general approximated model of the overall system and iteratively tries to arrive at single component level having in mind what the system must do as a whole; the bottom-up, on the contrary, starts from the single components models, links, integrates and merges them in order to produce a model representative of the entire system. A top-down control will be used for the optimisation algorithms, while bottom-up approach is suitable for the control rules of the overall HYBUILD integrated energy system. The first step was to individuate the list of building components involved for operational mode (low-level) and the scenarios for each pilot (high level). The scenarios have been discussed and validated by the pilot managers, in order to define a complete example of usage of the HYBUILD BEMS in each demonstration site and elicit its requirements. The optimization strategy will be the result of the implementation of these requirements into the final BEMS.

This report is a useful resource for the entire consortium according to the related activities described in the following section 1.2. Its dissemination level is “Public” for all external stakeholders potentially interested in a deeper understanding of the functionalities of the

HYBUILD BEMS. The elicited scenarios are also a good way to describe the project objectives to also non-technical people, thus constituting a good instrument also for the dissemination of the project results.

1.2 Relations to other activities in the project

As second report of WP4, this deliverable continues the work already initiated in T4.1 with the definition of the control strategies needed for the whole system operation. The basic control rules have been defined, together with the technology provider partners, in Task 4.2 – "Operational function design" (starting at M12) and here reported in the corresponding flowcharts.

As already briefly described in the previous paragraph, the low-level control will be exploited and integrated with the advanced high-level control which have been studied in Task 4.4 – "Building Energy Management System (BEMS) design". The layouts presented hereby are being also exploited for the advanced control prototyping studied in Task 4.3 – "Control prototyping with hardware in the loop".

As it happened with D4.1, this report could not be released without the collaboration with other partners from different WPs. Detailed descriptions of each component or sub-system of both the Mediterranean and Continental cases have been received from the component developers and studied with the collaboration of Task 3.1 – "Model Based Design and Control". Once received, all the parts have been put together for creating the operational model corresponding to each HYBUILD integrated system (Mediterranean and Continental).

In their turn, the user scenarios methodology have been preliminary discussed with WP1, WP6, WP7 and WP9 leaders since its impact is transversal to all the WPs: WP1 for the exploitation of the key performance indicators (KPIs) and performance indicators (PIs) for the definition of the high level strategies; WP6 for its implication in the pilot sites; WP7 for the re-usability of the scenarios also for exploitation but above all dissemination purposes; WP9 for the general coordination of the work and validation by the Scientific Coordinator. Without any surprise, the main collaboration was with WP6: the scenarios could not be written without the kind collaboration of the WP6 leader and the pilot owners and managers, who were strongly interested and impacted by the formulation of scenarios. The first proposal was discussed with WP6 leader and then refined after a series of calls with the participation of the pilots. The final version here reported is the result of this fruitful and close cooperation.

1.3 Report structure

The deliverable consists of a report divided into five sections and five appendixes. PDFs of the P&ID diagrams shown in Figures 2 and 6 are available on request.

Section 1 describes the scope of the report, its purpose, structure, contributions and relationship with the rest of the project.

Section 2 introduces the system layouts and the operational modes, their concept and implementation, along with the flowcharts describing the basic control rules of the building in both the Mediterranean and Continental cases.

Section 3 describes the software specifications, introducing the methodology adopted for the system requirements elicitation. In this section, the scenarios related to each demonstration pilot are presented, along which the elaborated use cases and completed with the list of functional and non-functional requirements that will be taken into account for the following software implementation.

In Section 4 and 5, the conclusions and the references of the report are given.

In the appendixes, the first outcomes from the dynamic simulation, the tables related to the possible states of the system and the corresponding applicable operational modes, and the lists of components, for both the Mediterranean and Continental are reported.

1.4 Contributions of partners

ENG, as WP leader, coordinated the overall work and designed the structure of the deliverable. As responsible also of the next activities for the optimization, ENG coordinated the work about the definition and refinement of the scenarios, and the elicitation of use cases and requirements.

RINA-C was responsible of the system operation section. RINA-C worked on the definition of the system layouts and the operational modes. In cooperation with EURAC, the basic control rules have been defined and initially tested in the simulation environment. The outcomes of their work are reported in the appendixes and on the P&ID Diagrams depicted in Figures 2 and 6, which are integral parts of the deliverable.

NOBATEK has deeply contributed to the refinement of the proposed scenarios, as WP6 leader and coordinator of all the pilots. As pilot owners of the Continental demonstrator, NOBATEK revised the scenarios proposed for Talence. The same approach was followed with AGLANTZIA and ALMATRET, for the two Mediterranean pilots in Aglantzia and Almatret, with the collaboration of UCY and UDL as well. After their validation, the final version of the scenarios has been issued.

EURAC, UDL and COMSA were also involved in the revision of the final use cases and the functional and non-functional requirements.

2 Definition of the system operation

2.1 HYBUILD Systems layouts

The two layouts have been created starting from the Mediterranean and Continental concepts (Figure 1) which are the core of HYBUILD project. Components, sensors and connections needed to guarantee the proper operation of the system have been detailed according to the input received from WP2 and WP3, where the core components and modules and the storage subsystems have been developed. The definition of the sensors takes into account operational and security issues, as well as the monitoring of the performance.

The Mediterranean has been mainly conceived for single-family houses, hence the Mediterranean P&ID describe in detail the system for a single-family house with fan coils used as emission system. The Continental concept is instead conceived for small multi-family houses: the P&ID in this case represent a system for two apartments, with an Enerboxx system (enerboxx® - Wandspeichersystem, 2019) for DHW supply in each apartment and considering a low temperature heating emission system.

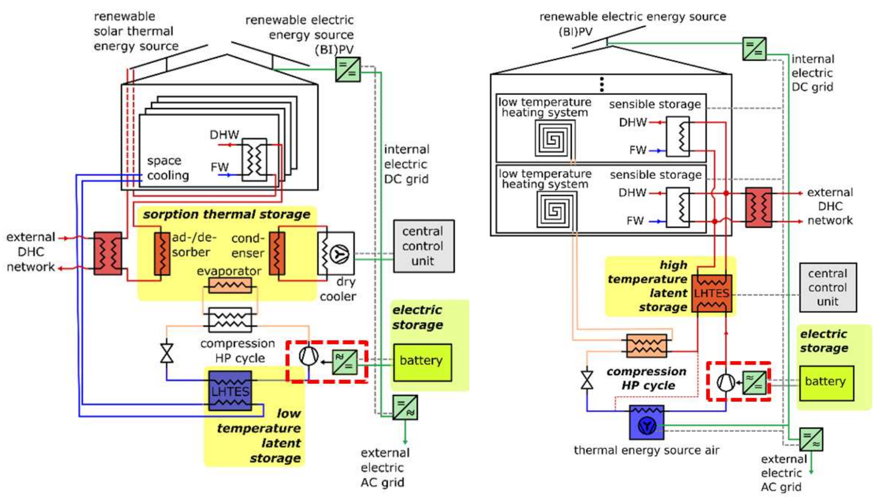

Figure 1 Mediterranean (left) and Continental (right) concepts

2.1.1 Mediterranean solution

In this section, the P&ID of the HYBUILD Mediterranean solution is presented. The general layout of the Mediterranean solution, here shown in Figure 2. The Mediterranean HYBUILD solution has been developed to optimise the cooling production, exploiting renewable energy and increasing the efficiency of the system by coupling different technologies, including thermal and electric storages. The system can also provide heating and domestic hot water. The complete list of sensor and component represented in the Mediterranean P&ID is presented in Appendix D.

The main components of the system are:

- Compression heat pump (HP) (no. 19);
- Refrigerant-PCM-Water Heat Exchanger (RPW-HEX) (no. 23);
- Sorption module (no. 9);
- Buffer tank (no. 4);
- DHW tank (no. 6);
- Fresnel panels (no. 1). HYBUILD will also test integration with a passive solar thermal system (evacuated tube) instead of the Fresnel panels.

The scheme of the control system is also represented, indicating the controllers and the connection with the sensors and actuators. Below, the list of controllers and their main function is shown:

- Master controller: it is connected to the thermal controller, electric controller, solar thermal controller/datalogger and building data logger. The main function is to optimize the operation of the system by processing the data gathered from the different controllers together with external information (e.g. weather forecast).
- Thermal controller: it is connected to the thermal system with exception of the solar field. It controls the operation of the system according to the optimized rules given by the master controller. Basic control rules are implemented in the controller in case the master controller cannot provide the optimized control rules.
- Electric controller: it controls electric part of the HYBUILD system, managing the PV panels and the electric battery in order to provide the electricity needed to the compression heat pump.
- Solar thermal controller/datalogger: In the solution using Fresnel collectors, it is responsible for the solar tracking of the Fresnel system. In both the case with Fresnel system and standard solar system, the solar thermal controller/datalogger is connected to the temperatures, flow and pressure meter of the primary loop of the solar field and it is connected to the master controller to provide information on the thermal solar energy production.
- Solar thermal supply controller: it controls the pumps of the primary and secondary loop of the solar field, based on the temperature in the buffer tank and in the solar field. It is not connected to the master controller and operates for both Fresnel and standard solar thermal systems.
- Building data logger: it is connected to the master controller and to the sensor inside the building.

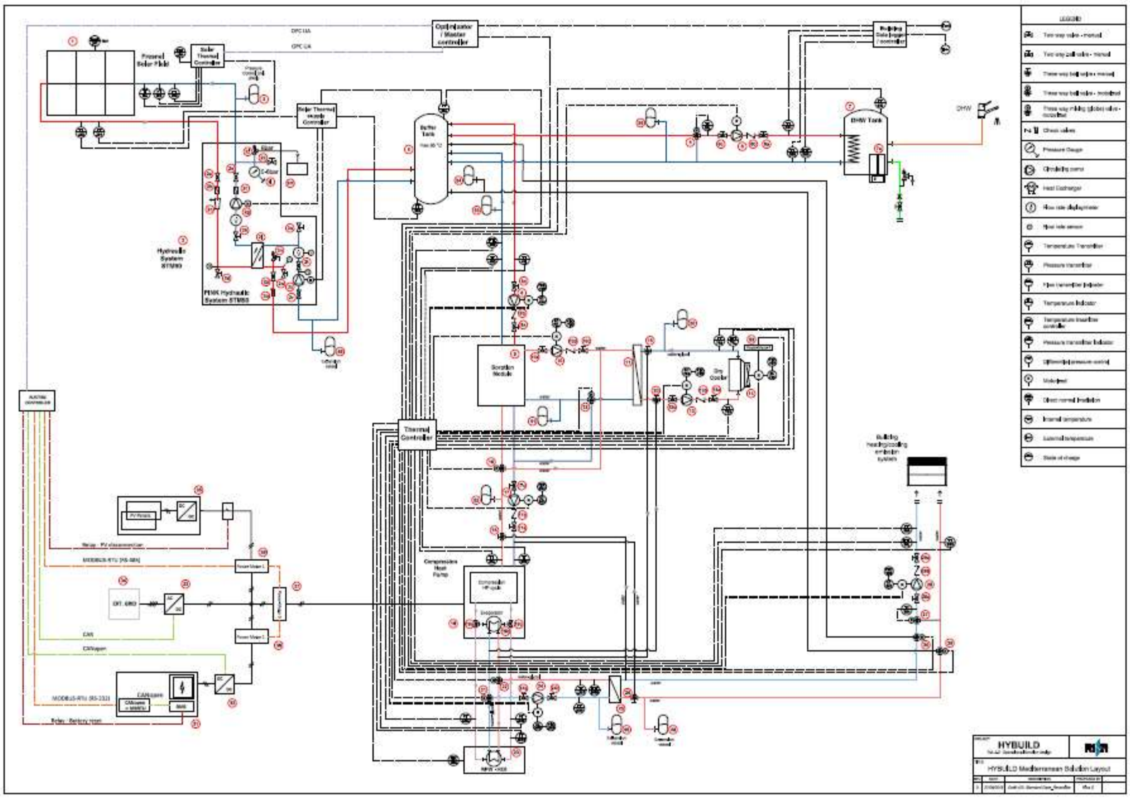

Figure 2 Mediterranean solution P&ID

The following sections describe more in detail the different parts of the layout.

2.1.1.1 Solar heating supply

The Fresnel solar field (1) is able to produce hot water at high temperature, which charges the buffer tank (4) at a maximum temperature of about 95 °C. The solar field is connected to the buffer tank through two loops, divided by the heat exchanger (2l). Pumps 2g and 2s guarantee the fluid circulation in the primary and secondary solar circuits respectively. The two pumps, are controlled by the Solar Thermal Supply Controller according to the temperatures measured in the solar field (TT105) and in the Buffer Tank (TT301; TT302). During summer operation, the main purpose of the solar field is to guarantee the energy needed by the sorption module activating its cycle and improving the efficiency of the overall system. During winter operation, the solar field is used to produce free heating, avoiding the electricity consumption of the compression HP. During the whole year, the heat stored in the buffer tank provides energy for DHW production.

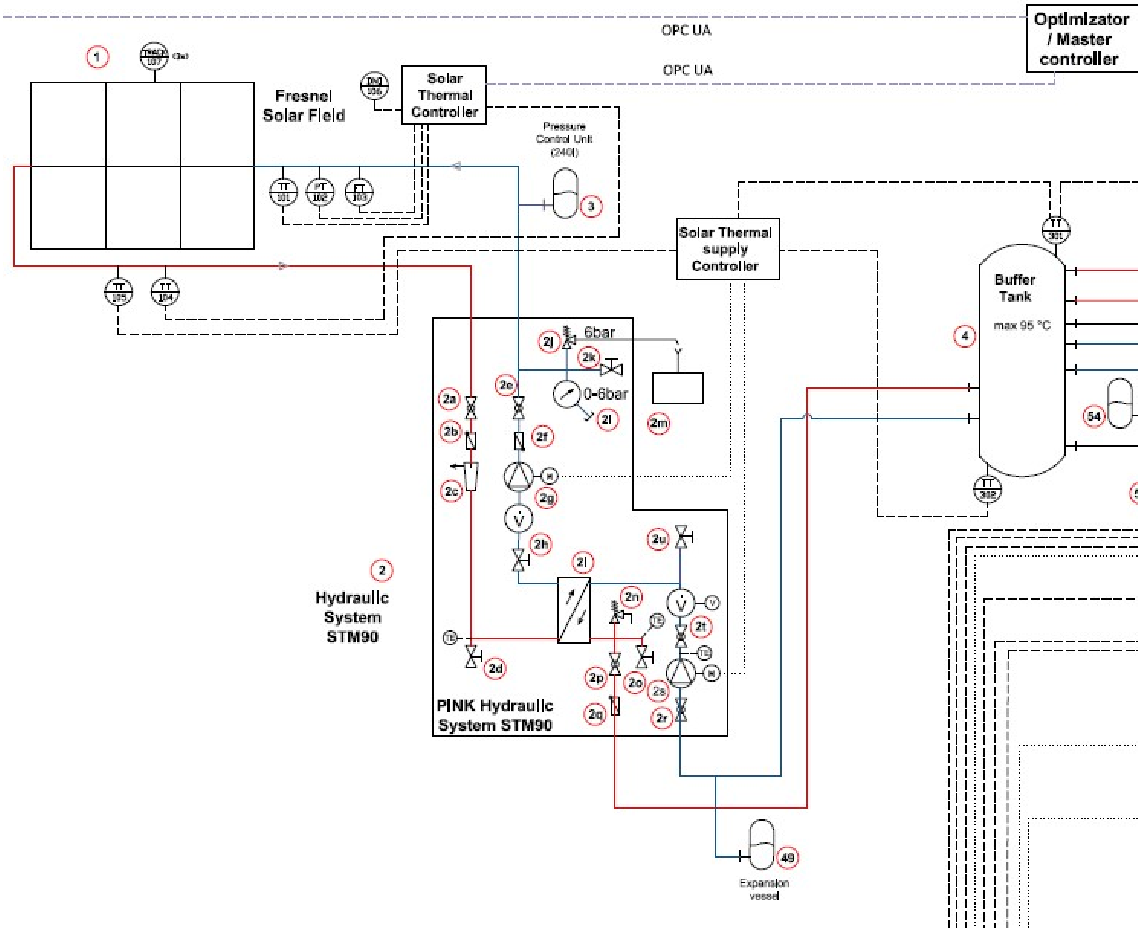

Figure 3 Mediterranean solution - Solar system

2.1.1.2 Sorption module

The sorption module activates the adsorption cycle thanks to the hot water provided by the buffer tank; Pump 8, which is integrated in the sorption module itself (see Figure 4), guarantees the water flow between the buffer tank and the sorption module. The temperature needed is between 75 and 95 Celsius degrees. The evaporator of the sorption module is then connected to the HP condenser side, in order to improve the efficiencies of the HP lowering the condensation temperature. The pump 17 guarantees the flow between the two components. The waste heat produced by the sorption module is drained by the dry cooler (14). The connection between the sorption module and the dry cooler is done using two circuits: the heat exchanger 11 divides the water/glycol dry-cooler circuit from the water circuit coming from the sorption module. This is done because the sorption module works with water in the hydraulic circuit, while the dry cooler need glycol to avoid water freezing, being installed outside.

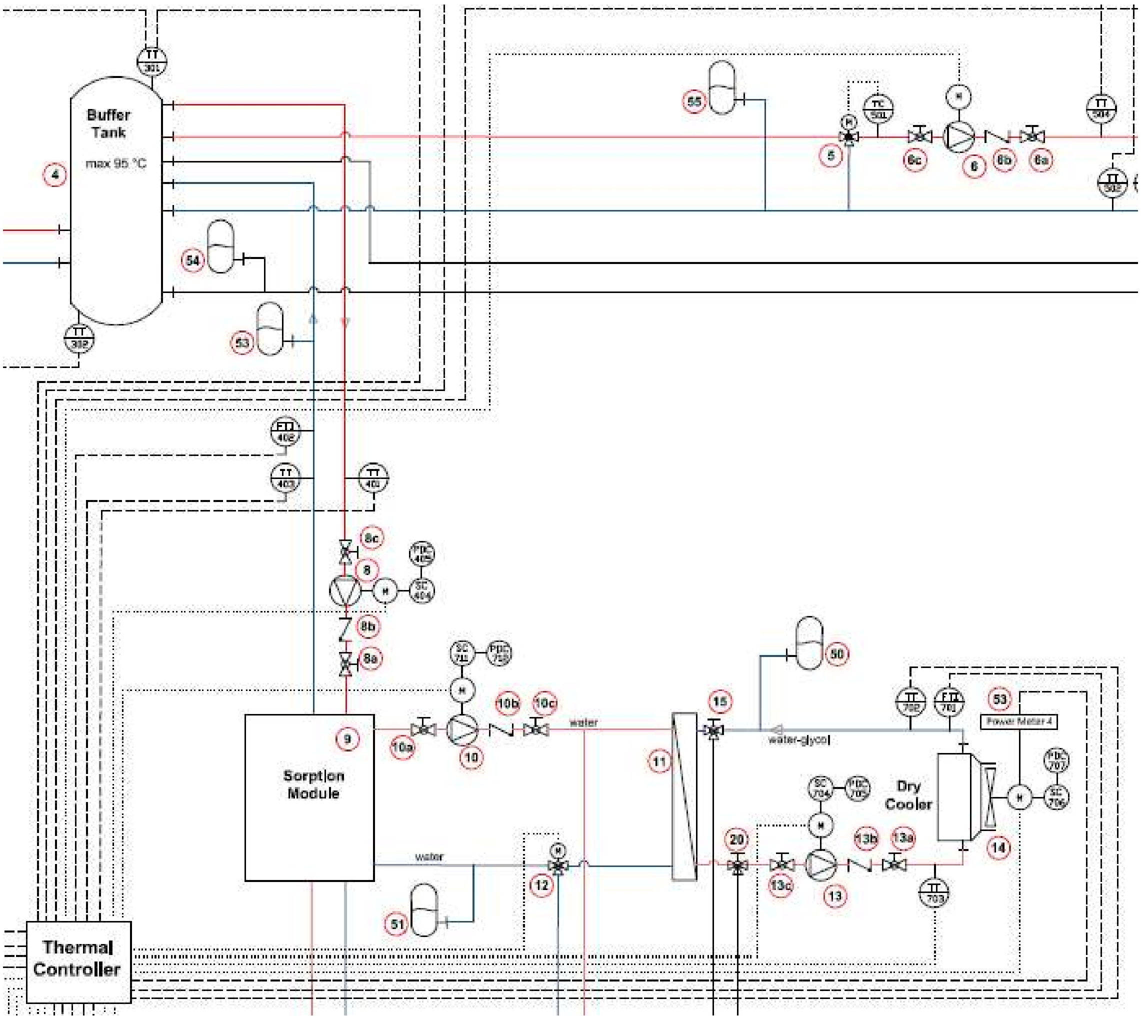

Figure 4 Mediterranean Solution - Sorption module connections

2.1.1.3 Compression heat pump and RPW-HEX (latent storage)

The compression HP (19) provides the cooling energy to the building during summer operation (cooling mode), and heating during winter operation (heating mode) (see Figure 5).

The heat pump is powered by electrical power via either photovoltaic (PV) panels or electric battery or from the external grid. As already mentioned, the condenser of the heat pump is connected with the evaporator of the sorption module, improving the efficiency of the heat pump lowering the temperature seen by the condenser. When the sorption module cannot be activated, the valves 12 and 16 bypass it and connect the HP directly to the dry cooler. On the other side, the standard heat pump evaporator (19c) is bypassed, and the refrigerant loop is directly connected to the RPW-HEX (refrigerant/phase change material/water – heat exchanger) (23). If the RPW-HEX (low temperature latent storage) cannot be used for some technical or safety issues, the valves 19a and 19b bypass the latent storage and connect the standard evaporator, in order to guarantee the operation of the system.

In normal operation, the RPW-HEX can be used in three ways: charging it with the refrigerant to store cooling energy, discharging it with the water-glycol loop to provide cooling to the building, or simultaneously charging/discharging the storage, assuring continuous cooling energy. The simultaneous charging and discharging of the RPW-HEX is due to the possible mismatch between the cooling capacity provided by the HP and the cooling required by the user, with the RPW-HEX used as buffer also in continuous operations.

The heat exchanger 25 separates the water-glycol circulating in the loop connecting the compression heat pump and the RPW-HEX from the water loop going into the building.

When the heating mode is activated, the valves 15, 20, 18 and 26 hydraulically reverse the circuit, connecting the evaporator of the heat pump to the dry cooler and the condenser to the circuit going to the building. In this configuration, the system can provide heating to the building, making possible to use the HYBUILD Mediterranean solution all year long.

An additional source of heating is guaranteed by the solar field. Since during winter operation the sorption module is not exploited, the energy produced by the Fresnel or other solar thermal field and stored in the buffer tank can be used for DHW and heating purposes. To do this, the buffer tank is connected directly to the distribution system going to the building: when the measurement provided by TT301 reaches the temperature set-point needed to provide heat, the valves 29 and 30 can open the free heating circuit.

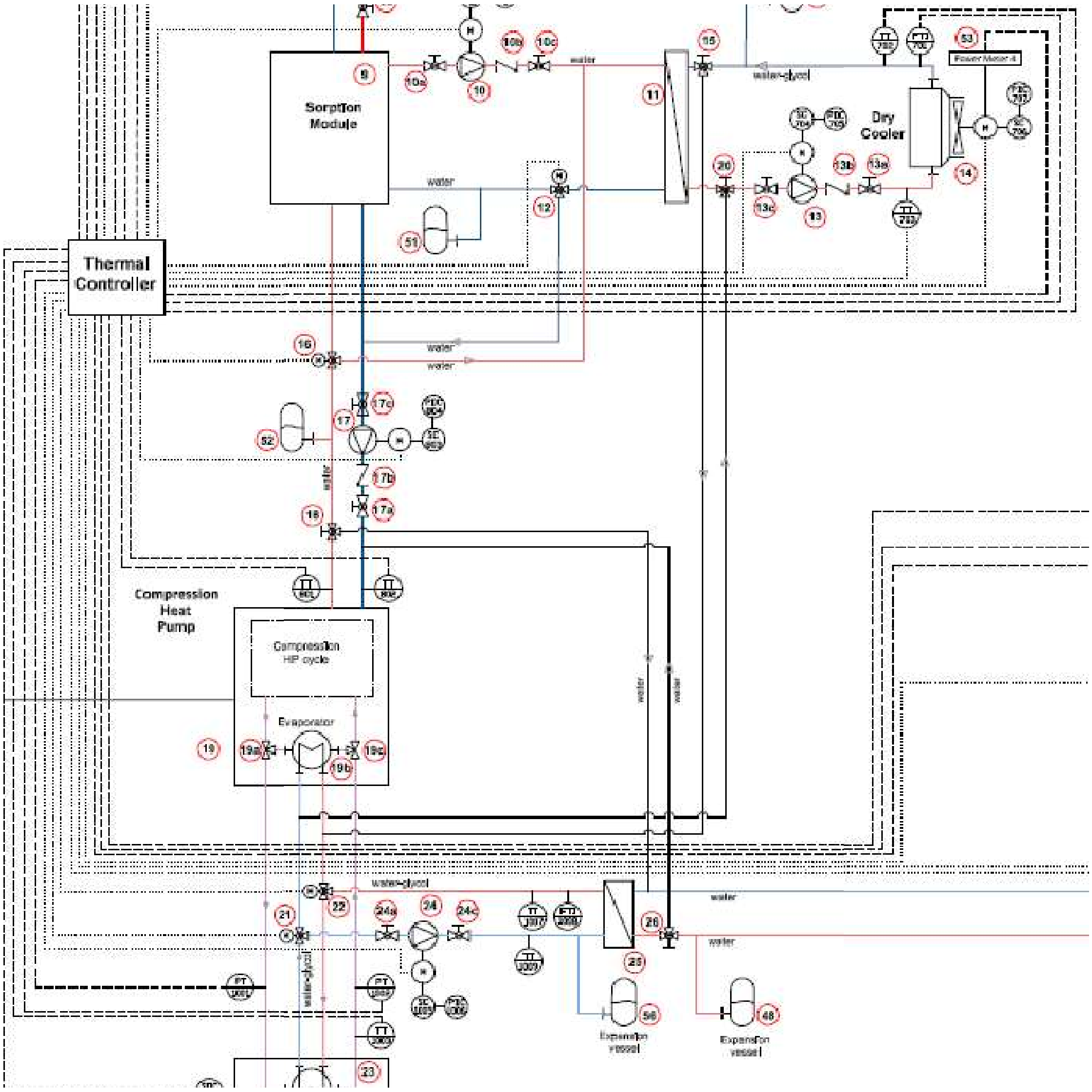

Figure 5 Mediterranean solution - Heat Pump and RPW-HEX connections

2.1.1.4 DHW supply

The DHW is provided to the users thanks to a dedicated DHW tank (7) (see Figure 6). The DHW tank is heated up by the hot water coming from the buffer tank 4. The mixing valve 5 mixes the return flow with the supply in order to control the temperature entering the DHW tank. An electrical heater (7a) is included in the DHW tank in order to guarantee the DHW supply in case technical problem in using the hydraulic loading.

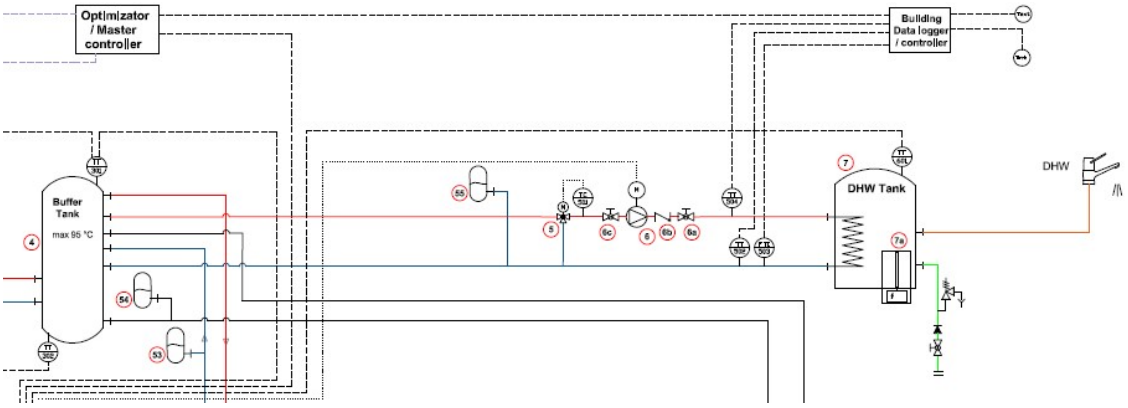

Figure 6 Mediterranean solution - DHW system

2.1.2 Continental solution

The HYBUILD continental solution has been developed to optimise heating and domestic hot water production, exploiting renewable sources and integrating a high-density high temperature latent storage in order to store the sensible energy of the hot gas exiting the compressor of the heat pump. The energy stored in the latent storage is able to cover large share of heating or DHW demand. The aim is to maintain a high coefficient of performance (COP) of the heat pump also during the production of DHW, which requires higher temperature with respect to the low temperature emission system generally coupled to the heat pumps in heating application. The system is reversible, and can produce cooling and DHW during summer operation, exploiting the latent storage all over the year. The main components of the thermal system are the compression HP (1), which provides heating and cooling energy, the RPW-HEX (2), the hydraulic separator (3), the Enerboxx hydraulic unit (7, 9, 21), and the Enerboxx tank (8, 10, 22).

The P&ID shown in Figure 7, represents a general scheme for a two-apartments building but the HYBUILD continental solution has been developed for small multi-family houses with even more than three apartments per building. The scheme represented is only an example to show the general concept, with one generation unit (heat pump and RPW-HEX) per building and the Enerboxx system installed in each apartment. The complete list of sensor and component represented in the Continental P&ID is presented in

Appendix E.

The scheme of the control system is similar to the one implemented in the Mediterranean system, with the master controller connected to the electric and thermal parts, optimizing the system operations. Below, the list of controllers and their main function is shown:

- Master controller: it is connected to the thermal controller and to the electric controller. The main function is to optimize the operation of the system by processing the data gathered from the different controller together with external information (e.g. weather forecast).
- Thermal controller: it is connected to the compression heat pump, to the Enerboxx system and to the sensors and actuators of the primary and secondary loop. Basic control rules are implemented in the controller in case the master controller cannot provide the optimized control rules.
- Enerboxx controller: it is connected to the Enerboxx tank, to the Enerboxx hydraulic unit and to the thermal controller. It provides the thermal controller with information on the temperature inside the Enerboxx tank, and receives from it the operating rules.

- Electric controller: it controls electric part of the HYBUILD system, managing the PV panels and the electric battery in order to provide the electricity needed to the compression heat pump.

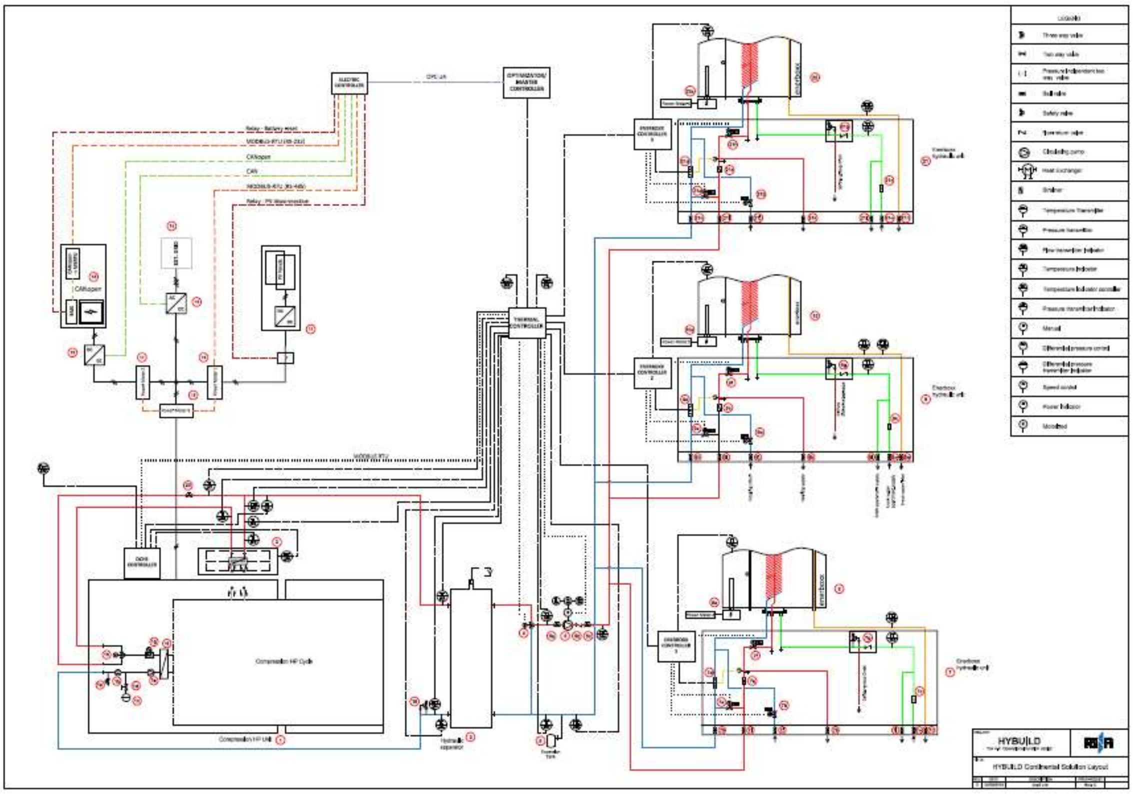

Figure 7 Continental solution P&ID

2.1.2.1 Compression Heat pump and RPW-HEX

The generation of heating and cooling energy is done by compression heat pump (1), integrated with the high-density latent storage (2) (see Figure 8). The heat pump is reversible, and it can produce both heating and cooling energy. The domestic hot water production requires a higher temperature with respect to the heating supply temperature: the RPW-HEX is used to rise the temperature of the water coming from the condenser of the heat pump, exploiting the energy provided by the hot gas exiting the compressor. To do this, the valve 1h opens the circuit connecting the water output of the heat pump to the RPW-HEX. The valve can modulate, according to the temperature obtained after the latent storage and open only partially the RPW-HEX circuit. The hydraulic separator (3) is used to separate the primary circuit and the secondary loop.

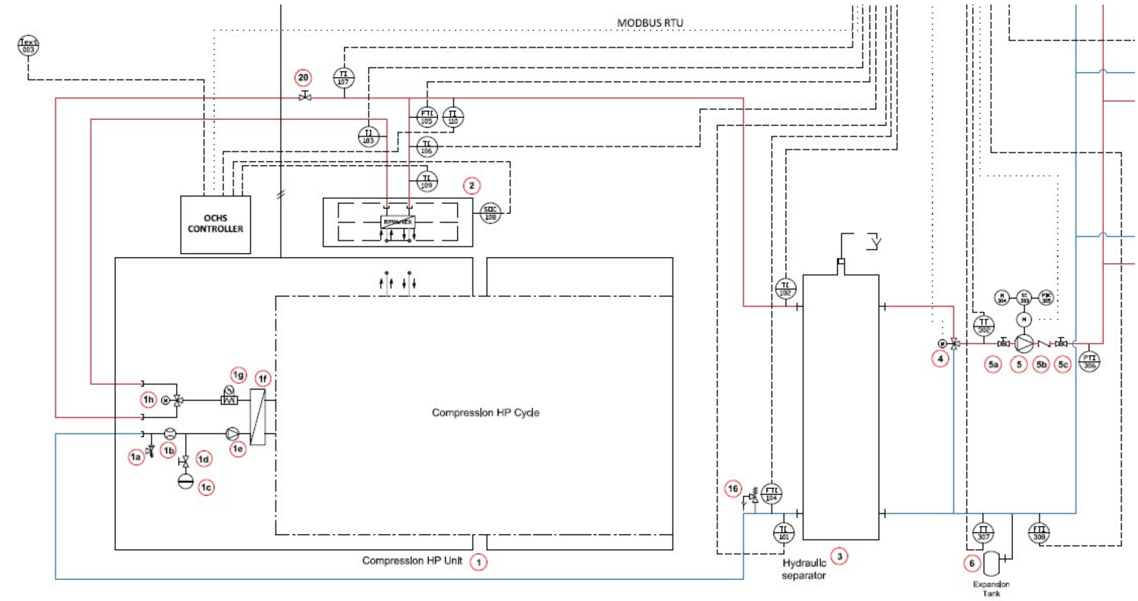

Figure 8 Continental solution - Heat Pump and RPW-HEX

2.1.2.2 *Enerboxx system*

The Enerboxx hydraulic unit (9) and the Enerboxx water tank (10) compose the Enerboxx system (see Figure 9). When the system is in DHW mode, the valves 9b and 9f direct the flow towards the Enerboxx tank heating the water inside the tank thanks to a heat exchanger. An electrical heater is installed inside the Enerboxx tank as back-up system. When the system is in heating or cooling mode, the valves open the circuit going to the apartment emission system, providing heating or cooling to reach the internal temperature set-point.

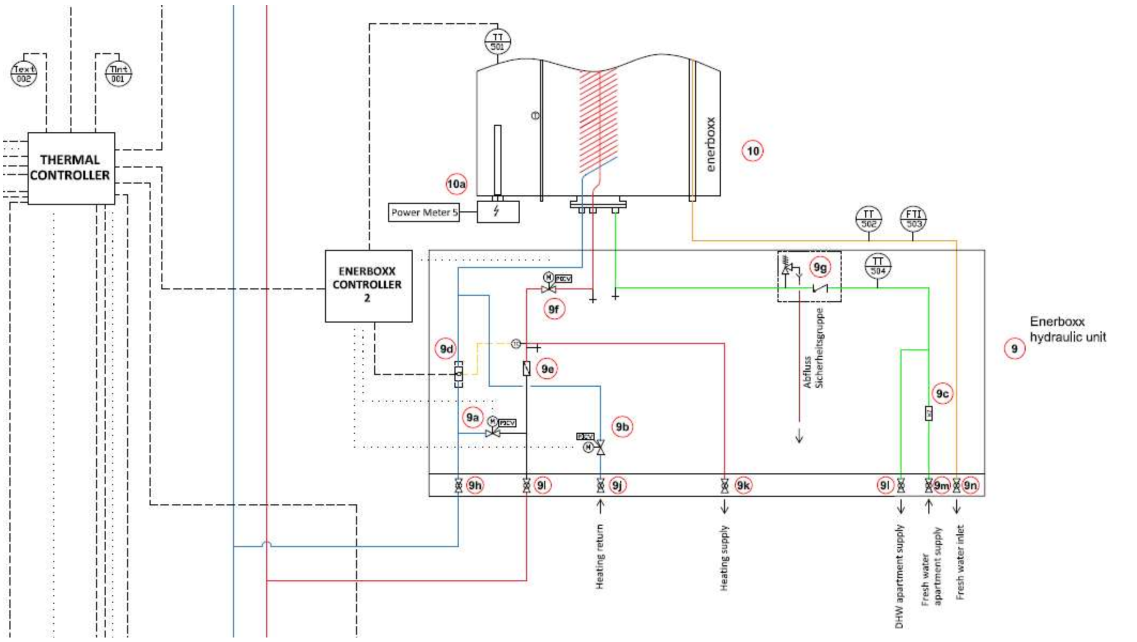

Figure 9 Continental solution - Enerboxx system

2.1.3 Electricity supply system

The electricity supply system is composed by the PV panels (35), the electric battery (31) and the external grid (see Figure 10). In both the Continental and Mediterranean systems, the two elements are connected to heat pumps by means of a Direct Current (DC) bus. The electricity coming from the solar field can be stored in the electric battery, directly provided to the heat pump, or injected into the grid (if permitted by the regulatory framework). On the other side, the HP can receive the energy from the battery, from the solar field, or from the external grid, in case no renewable energy is available.

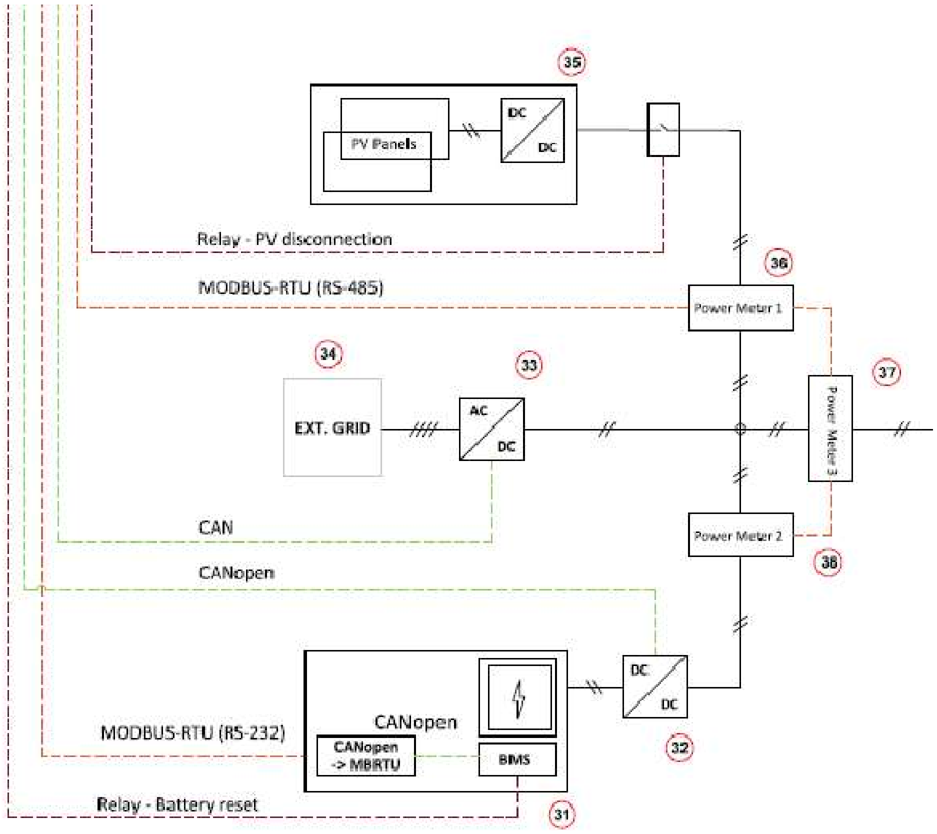

Figure 10 Electricity supply system

2.2 Operational Modes

The operational modes identify all the possible working conditions that can be actuated by the Mediterranean and Continental solutions. Four different categories of operational modes have been identified: Heating modes, Cooling modes, DHW modes and Charging modes. Within the categories, each operational mode identifies a specific status for pumps, valves and main components, in order to satisfy the energy demand. When it comes to the electricity provided by the electric sub-system to run the compression heat pumps, it does not affect directly the operations of the thermal sub-system. In fact, electric energy is always guaranteed, no matter if the source is the battery, the PV panels or the external grid. For this reason, a changing of the electricity source does not define a new operational mode.

After the description of each operational mode, the basic control rules are presented by means of flowcharts. These diagrams indicate which conditions and constraints determine the activation of the different parts of the system and in which modality, in order to satisfy heating, cooling and DHW demands, or to charge the thermal and electrical storages.

In addition to the operational diagrams, a definition of the main States of the System (SoS) has been performed, considering the conditions of the main components of each solution. Then, the definition of all the Operational Modes applicable to each SoS has been identified.

In general, this activity is propaedeutic to the identification of the advanced control rules. It is important to specify that at this stage no optimisation processes have been considered: the identification of the applicable Operational Modes has been done taking into account the technical constraints that are encountered in the different SoS.

2.2.1 Mediterranean solution operational modes and flow chart

In the following tables, cooling modes, heating modes, charging modes and DHW modes for the Mediterranean solution are described. The tables show, for each mode, a brief list of the main components operations (second column), and indicate the status of pump and valves, defining which pumps are on or off and which circuits ore opened of closed (third column). The charging of the DHW tank (7) and the charging of the buffer tank (4) with solar thermal energy are managed independently from the heating and cooling supply and from the charge of the RPW-HEX. For this reason in Heating, Cooling and Charging modes the status of pumps and valves involved in DHW mode and Solar Thermal mode are not specified. For the same reason in DHW and Solar Thermal modes is not specified the status of pump and valves not directly involved in the operations.

After the table, the operational diagrams describing the basic operation or the Mediterranean system for cooling, heating, charging and DHW modes are provided. The solar thermal system present two different diagram: one describing the charging of the buffer tank, related to the solar field mode and the other describing the logic of the solar tracking. This is because the solar tracking activation and the charging of the buffer tank (activation of pumps 2g/2s) are controlled in an independent way by two different controllers: Fresnel controller (solar tracking) and solar thermal supply controller (charging of buffer tank).

Table 1 Mediterranean solution Cooling modes

OPERATIONAL MODE	MAIN COMPONENTS OPERATIONS	ACTUATORS MODE
COOLING Mode 1	• Cooling provided by RPW-HEX (23)	• Valves (21)(22) open 'RPW-HEX - User' circuit; • Pumps (24) (28) mode on; • Pumps (8)(10)(13)(17) mode off;
COOLING Mode 2	• Cooling provided by Compression HP (19); • RPW-HEX (23) bypassed • Adsorption module (9) mode off; • Electricity to compression HP (19) provided by Electric sub-system	• Valves (21) (22) open 'Compression HP - User circuit'; • Valves (12)(16) open 'Dry Cooler - Compression HP' circuit; • Valves (19a) (19c) open standard Evaporator (19b) circuit; • Valves (15) (20) close 'Compression HP Heating mode - Dry cooler' circuit; • Valves (18) (26) close 'Compression HP Heating mode - User' circuit; • Valves (29) (30) close 'Free heating ' circuit; • Pumps (24) (28) mode on; • Pumps (13) (17) mode on; • Pumps (8)(10) mode off; • Electric Controller open external grid circuit (33) (34) or electric battery circuit (31) (32) or PV panel Circuit (35)

COOLING Mode 3	• Cooling provided by Compression HP (19); • RPW-HEX (23) charged/discharged simultaneously • Adsorption module (9) mode off; • Electricity to compression HP (19) provided by Electric sub-system	• Valves (21) (22) open 'RPW-HEX - User circuit'; Valves (12)(16) open 'Dry Cooler - Compression HP' circuit; • Valve (19a) (19c) bypass standard Evaporator (19b) circuit; • Valves (15) (20) close 'Compression HP Heating mode - Dry cooler' circuit • Valves (18) (26) close 'Compression HP Heating mode - User' circuit • Valves (29) (30)close 'Free heating ' circuit • Pumps (24) (28) mode on; • Pump (13)(17) mode on; • Pumps (8)(10) mode off; • Electric Controller open external grid circuit (33) (34) or electric battery circuit (31) (32) or PV panel Circuit (35)
COOLING Mode 4	• Cooling provided by Compression HP (19); • RPW-HEX (23) bypassed; • Adsorption module (9) mode on, exploiting Buffer tank (4) energy; • Electricity to compression HP (19) provided by Electric sub-system.	• Valves (21) (22) open 'Compression HP - User' circuit; • Valve (16) open 'Dry Cooler - Adsorption module' circuit; • Valve (12) open 'Adsorption module- 'Compression HP' circuit; • Valves (19a) (19c) open standard Evaporator (19b) circuit; • Valves (15) (20) close 'Compression HP Heating mode - Dry cooler' circuit • Valves (18) (26) close 'Compression HP Heating mode - User' circuit • Valves (29) (30)close 'Free heating ' circuit • Pumps (24) (28) mode on; • Pumps (8) (10) (13) (17) mode on; • Electric Controller open external grid circuit (33) (34) or electric battery circuit (31) (32) or PV panel Circuit (35)
COOLING Mode 5	• Cooling provided by Compression HP (19); • RPW-HEX (23) charged/discharged simultaneously • Adsorption module (9) mode on, exploiting Buffer tank (4) energy; • Electricity to compression HP (19) provided by Electric sub-system	• Valves (21) (22) open 'RPW-HEX - User' circuit; Valve (16) open 'Dry Cooler - Adsorption module' circuit; • Valve (12) open 'Adsorption module- 'Compression HP' circuit; • Valves (19a) (19c) bypass standard Evaporator (19b) circuit; • Valves (15) (20) close 'Compression HP Heating mode - Dry cooler' circuit • Valves (18) (26) close 'Compression HP Heating mode - User' circuit • Valves (29) (30) close 'Free heating ' circuit • Pumps (24) (28) mode on; • Pumps (8)(10) (13) (17) mode on; • Electric Controller open external grid circuit (33) (34) or electric battery circuit (31) (32) or PV panel Circuit (35)

Table 2 Mediterranean solution Charging modes

OPERATIONAL MODE	• MAIN COMPONENTS OPERATIONS	• ACTUATORS MODE
CHARGING Mode 1	• RPW-HEX (21) charging; • Compression HP (19) mode on; • Adsorption module (9) mode off; • Electricity provided by Electric sub-system.	• Valves (21) (22) open 'RPW-HEX - User circuit'; • Valves (12)(16) open 'Dry Cooler - Compression HP' circuit; • Valves (19a) (19c) bypass standard Evaporator (19b) circuit; • Valves (15) (20) close 'Compression HP Heating mode - Dry cooler' circuit

		• Valves (18) (26)close 'Compression HP Heating mode - User' circuit • Valves (29) (30) close 'Free heating ' circuit • Pumps (24) (28) mode off; • Pump (13) (17) mode on; • Pumps (8)(10)mode off; • Electric Controller open external grid circuit (33) (34) or electric battery circuit (31) (32) or PV panel Circuit (35)
CHARGING Mode 2	• RPW-HEX (21) charging; • Compression HP (19) mode on; • Adsorption module (9) mode on, exploiting Buffer Tank (4) energy; • Electricity provided by Electric sub-system.	• Valves (21) (22) open 'RPW-HEX - User' circuit; • Valve (16) open 'Dry Cooler - Adsorption module' circuit; • Valve (12) open 'Adsorption module- 'Compression HP' circuit; • Valves (19a) (19c) bypass standard Evaporator (19b) circuit; • Valves (15) (20) close 'Compression HP Heating mode - Dry cooler' circuit • Valves (18) (26)close 'Compression HP Heating mode - User' circuit • Valves (29) (30) close 'Free heating ' circuit • Pumps (24) (28) mode off; • Pumps (8) (10)(13) (17) mode on; • Electric Controller open external grid circuit (33) (34) or electric battery circuit (31) (32) or PV panel Circuit (35)

Table 3 Mediterranean solution Heating modes

OPERATIONAL MODE	MAIN COMPONENTS OPERATIONS	ACTUATORS MODE
HEATING Mode 1	• Heating provided by Compression HP (19); • RPW-HEX (21) bypassed; • Adsorption module (9) mode off; • Electricity to compression HP (19) provided by Electric sub-system	• Valves (18) (26)open 'Heating mode Compression HP - User' circuit • Valves (15) (20) open 'Heating mode Dry Cooler - Compression HP' circuit • Valves (12)(16) open 'Dry Cooler - Compression HP' circuit; • Valves (19a) (19c) open standard Evaporator (19b) circuit; • Valves (21) close 'Compression HP - User circuit'; • Valve (22) close 'Compression HP - RPW-HEX' circuit'; • Valves (29) (30) close 'Free heating ' circuit • Pumps (28) mode on; • Pump (13) mode on; • Pumps (8)(10)(17) (24)mode off; • Electric Controller open external grid circuit (33) (34) or electric battery circuit (31) (32) or PV panel Circuit (35)
HEATING Mode 2	• Free heating provided by Buffer Tank	• Valves (29) (30) open Free heating circuit • Pump (28) mode on; • (8) (10)(13) (17) (24)mode off;

Table 4 Mediterranean solution DHW modes

OPERATIONAL MODE	MAIN COMPONENTS OPERATIONS	ACTUATORS MODE
DHW mode 1	• DHW tank (7) fed by Buffer tank (4)	• Valve (5) constantly mix supply and mix return in base of a set temperature (not higher than 65 °C) • Pump (6) mode one
DHW mode 2	• DHW tank (7) heated by Electric backup (7a)	• Pump (6) mode off

Table 5 Mediterranean solution Solar field mode

OPERATIONAL MODE	MAIN COMPONENTS OPERATIONS	ACTUATORS MODE
Solar field mode	• Fresnel or other ST system (1) feeding buffer tank (4)	• Pumps (2g) (2s) mode on

Table 6 Mediterranean solution Solar Tracking mode

OPERATIONAL MODE	MAIN COMPONENTS OPERATIONS	ACTUATORS MODE
Solar Tracking	• Solar tracking heating water in solar field primary circuit.	• Solar tracking (TRACK107) on;

In Figure 11, the cooling flowchart of the Mediterranean Solution is shown. The cooling energy can be provided either by the RPW-HEX stand-alone (cooling mode 1), or by the heat pump integrated with the RPW-HEX, or by the heat pump only (bypassing the RPW-HEX). The heat pump can operate coupled with the sorption module (cooling mode 4 and 5) or without sorption module (cooling mode 2 and 3). In the diagram, the following abbreviation are used:

- T_{INT} (°C) is the internal ambient temperature, measured inside the apartment;
- T_{SETINT_C} (°C) is the temperature set-point in cooling season;
- TT301 is the sensor measuring the temperature of the water on the top of the Buffer Tank;
- db_{INTLOW_C} (K) is the lower dead band of the internal ambient temperature (ΔT) during cooling season, when the temperature is decreasing;
- db_{INTSUP_C} (K) is the upper dead band of the internal ambient temperature (ΔT) during cooling season, when the temperature is increasing;
- SOC (%) is the state of charge of the RPW-HEX, calculated by means of sensor inside the storage;
- L1 is the level of the SOC (%) under which the RPW-HEX cannot provide cooling energy;

- SOH is state of health of the systems, defined on the base of set parameters measured inside the technology;
- HP is the compression Heat Pump;
- SM is the sorption module.

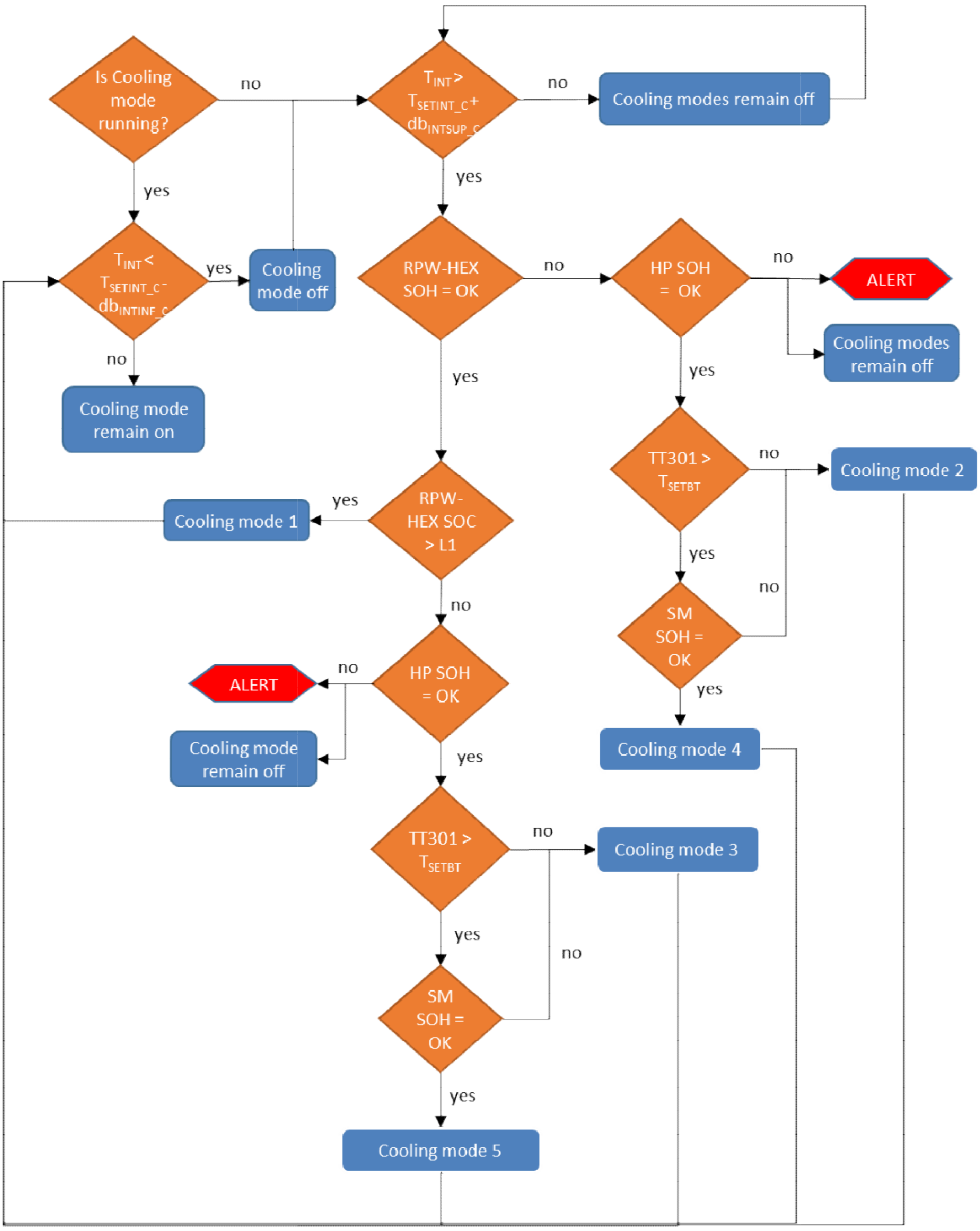

Figure 11 Mediterranean solution Cooling mode flowchart

Figure 12 shows the logic of solar tracking activation in the Fresnel solar field. The following abbreviation are used:

- T_{SETFR} (°C) is the set-point temperature of the Fresnel receiver;
- db_{LOW} (K) is the lower dead band of the Fresnel receiver temperature (ΔT) when the temperature is decreasing.

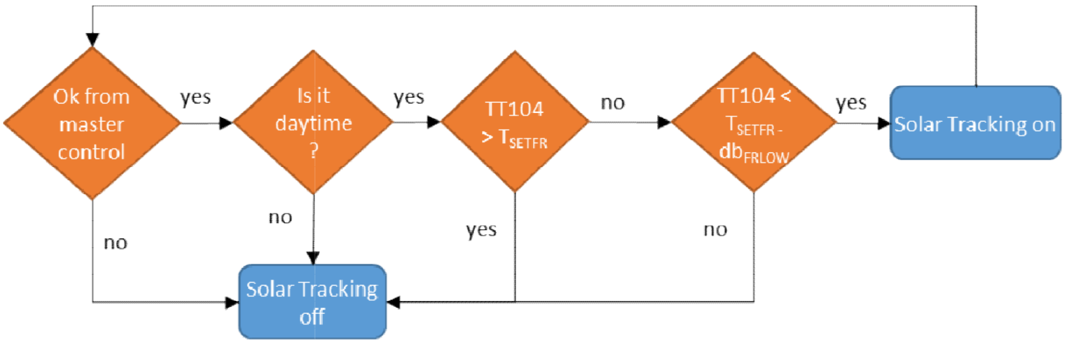

Figure 12 Mediterranean solution solar tracking activation flowchart

In Figure 13 and Figure 14, the charging flowcharts of the Mediterranean solution are shown. The first figure is related to the charging of the Buffer tank by means of the Fresnel or other solar field (solar field mode). The second shows the charging of the RPW-HEX by means of the compression heat pump, which can work alone (Charging mode 1) or integrated with the sorption module (Charging mode 2). The following abbreviation are used in the diagram:

- T_{SETBT} (°C) is the temperature set-point of the buffer tank;
- db_{LOW} (K) is the lower dead band of the buffer tank temperature (ΔT), when the temperature is decreasing;
- db_{SUP} (K) is the upper dead band of the buffer tank temperature (ΔT), when the temperature is increasing;
- db_{CHSUP} (K) is the dead band (ΔT) considered when TT105 is increasing;
- db_{CHLOW} (K) is the dead band (ΔT) considered when TT105 is decreasing;
- TT301 is the sensor measuring the temperature of the water on the top of the Buffer Tank;
- TT105 is the sensor measuring the temperature exiting the solar field primary loop;
- T_{STGN} (°C) is the stagnation temperature of the solar field;
- SOC (%) is the state of charge of the RPW-HEX calculated by means of sensor inside the storage;
- L1 is the level of the SOC (%) under which the RPW-HEX cannot provide cooling energy;
- L2 is the level of the SOC (%) when the RPW-HEX is considered charged;
- SOH is state of health of the systems;
- HP is the compression Heat Pump;
- SM is the sorption module.

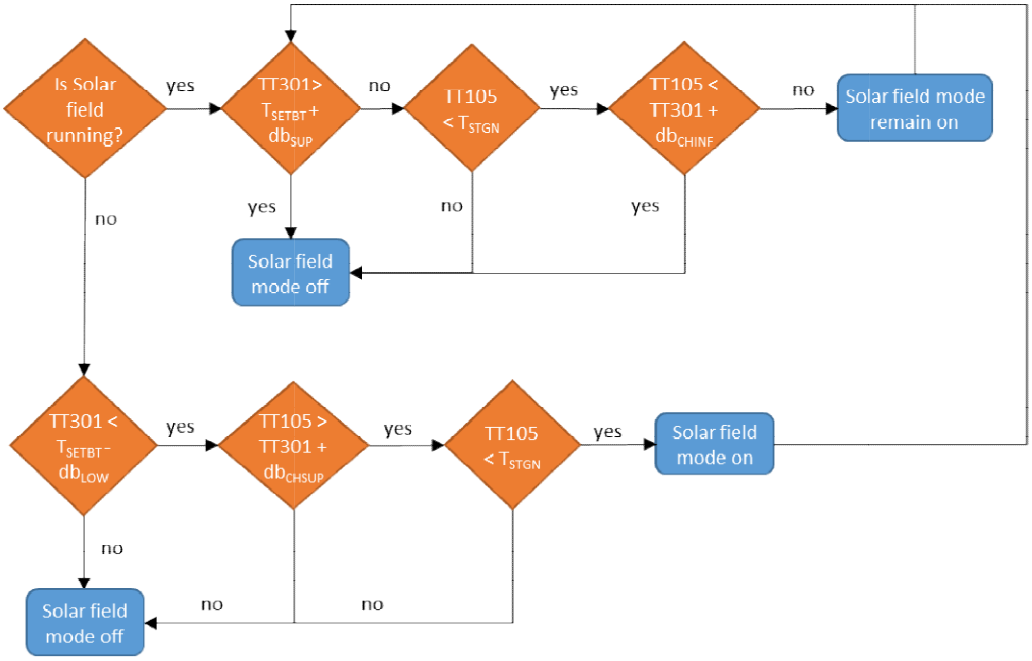

Figure 13 Mediterranean Solution Charging of Buffer Tank (solar field mode) flowchart

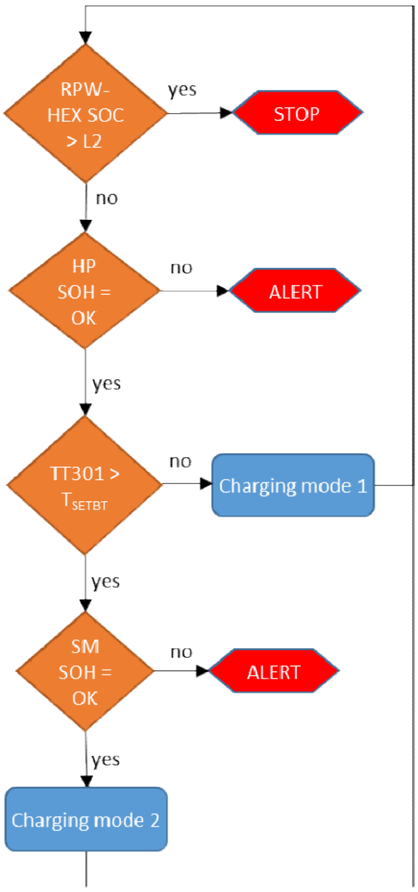

Figure 14 Mediterranean solution - charging of RPW-HEX flowchart

In Figure 15 the DHW mode of the Mediterranean solution is shown. The charging of the DHW tank is done thanks to the hot water stored in the buffer tank if the storage temperature is sufficient (DHW mode 1). If not, an electrical heater inside the DHW tank is activated (DHW mode 2). The following abbreviations are used:

- T_{SETDHW} is the set-point temperature (°C) of the DHW tank;
- db_{DHWLOW} (K)is the lower dead band of the DHW tank temperature (ΔT), when the temperature is decreasing;
- db_{DHWSUP} (K)is the upper dead band of the DHW tank temperature (ΔT), when the temperature is increasing;
- TT601 is the sensor measuring the temperature inside the DHW tank.
- TT301 is the sensor measuring the temperature of the water on the top of the Buffer Tank.
- DHWsyst SOH indicate the state of heath of the Buffer Tank, the pump 6 and the other components of the DHW circuit, connecting the Buffer Tank with the DHW tank.

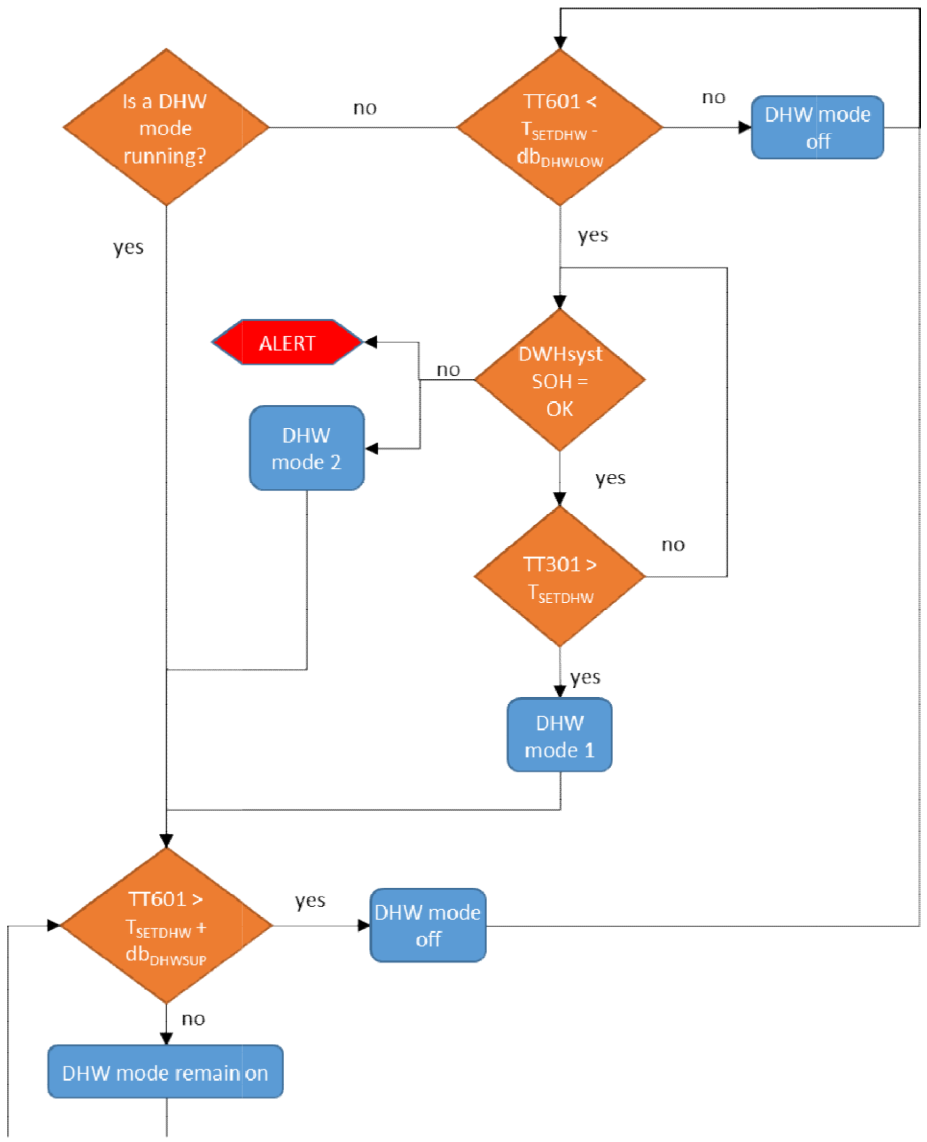

Figure 15 Mediterranean Solution DHW mode flowchart

Figure 16 represents the Heating mode flowchart of the Mediterranean solution. In the heating mode, the sorption module is not exploited, and the heating can be provided by two sources: either by the compression heat pump (Heating mode 1) or by the solar energy stored in the buffer tank (Heating mode 2). The following abbreviations are used in the flowchart:

- T_{INT} (°C) is the internal ambient temperature, measured inside the apartment ;

- T_{SETINT_H} is the temperature set-point (°C) during heating season;
- T_{SETBT} (°C) is the temperature set-point of the buffer tank;
- db_{INTLOW_H} (K) is the lower dead band of the internal ambient temperature (ΔT) during heating season, when the temperature is decreasing;
- db_{INTSUP_H} (K)is the upper dead band of the internal ambient temperature (ΔT) during heating season, when the temperature is increasing;
- TT301 is the sensor measuring the temperature of the water on the top of the Buffer Tank.
- SOH is the state of health of the systems;
- HP is the compression Heat Pump;

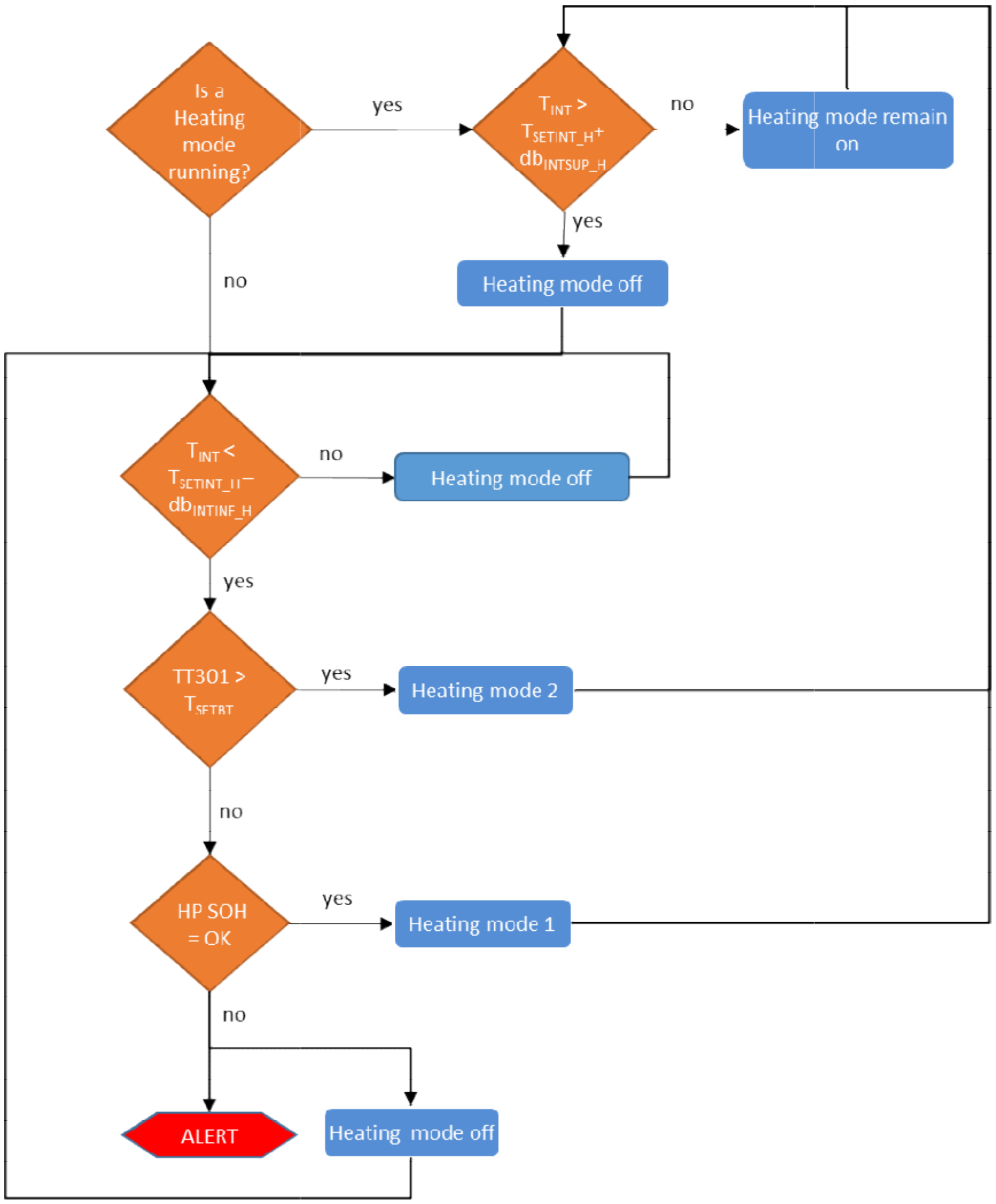

Figure 16 Mediterranean Solution Heating mode flowchart

2.2.2 Continental solution operational modes and flowchart

In the following tables, the heating modes, the cooling modes, and DHW modes for the Continental solution are described. Charging mode is not considered as the RPW-HEX is charged when the compression heat pump is working. The second column describes briefly the operation of the main components for each mode, while the Actuators Mode column describes the mode of the pumps and which circuit the valves are opening. Focusing on the DHW production, the system has been developed to work preferably in DHW mode 1. As described in chapter 2.1.2.1 the valve 1h modulate the flow exiting the HP toward the RPW-HEX in order to rise the water temperature. The flow can be partially or totally diverted toward the RPW-HEX depending on the water temperature provided to the secondary circuit (TT102). In standard operations, the Enerboxx system is set to be charged twice a day.

Table 7 Continental solution Heating mode

OPERATIONAL MODE	MAIN COMPONENTS OPERATION	ACTUATORS MODE
HEATING Mode 1	• Compression HP (1) mode on; • Hot water bypasses RPW-HEX (2); • Enerboxx DHW tanks (8)(10)(22) bypassed by hot water circuit; • Electricity to compression HP (1) provided by Electric sub-system	• Pump (1e) mode on • Pump (5) mode on • Valve (1h) set for bypassing RPW-HEX • Valve (7f) open • Valve (7b) close • Valve (9f) open • Valve (9b) closed • Valve (21f) open • Valve (21b) closed • Electricity to compression HP (1) provided by Electric sub-system

Table 8 Continental solution Cooling mode

OPERATIONAL MODE	MAIN COMPONENTS OPERATION	ACTUATORS MODE
COOLING Mode 1	• Compression HP (1) mode on; • Cold water bypasses RPW-HEX (2); • Enerboxx DHW tanks (8)(10)(21) bypassed by Cold water circuit; • Electricity to compression HP (1) provided by Electric sub-system	• Pump (1e) mode on • Pump (5) mode on • Valve (1h) set for bypassing RPW-HEX • Valve (7f) open • Valve (7b) closed • Valve (9f) open • Valve (9b) closed • Valve (21f) open • Valve (21b) closed • Electricity to compression HP (1) provided by Electric sub-system

Table 9 Continental solution DHW mode

OPERATIONAL MODE	MAIN COMPONENTS OPERATION	ACTUATORS MODE

DHW Mode 1	• Compression HP (1) mode on; • Hot water passes through RPW-HEX (2)*; • Enerboxx DHW tank (8) (10) (22) fed by hot water • Enerboxx Electrical heater (8a)(10a)(22a) off • Electricity to compression HP (1) provided by Electric sub-system	• Pump (1e) mode on • Pump (5) mode on • Valve (1h) opening HP - RPW-HEX circuit* • Valve (7f) closed • Valve (7b) open • Valve (9f) closed • Valve (9b) open • Valve (21f) closed • Valve (21b) open • Electrical heater (8a)(10a)(22a) off • Electricity to compression HP (1) provided by Electric sub-system
DHW Mode 2	• Compression HP (1) mode off; • Enerboxx Electrical heater (8a)(10a)(22a) on	• Pump (1e) mode off • Pump (5) mode off • Electrical heater (8a)(10a)(22a) on • Electricity to compression HP (1) provided by Electric sub-system
DHW Mode 3	• Compression HP (1) mode on providing water at DHW set temperature; • Hot water bypasses RPW-HEX (2); • Enerboxx DHW tank (8) (10)(22) charged by hot water circuit • Electricity to compression HP (1) provided by Electric sub-system • Enerboxx Electrical heater (8a)(10a)(22a) off	• Pump (1e) mode on • Pump (5) mode on • Valve (1h) closing HP - RPW-EX circuit • Valve (7f) open • Valve (7b) closed • Valve (9f) open • Valve (9b) closed • Valve (21f) open • Valve (21b) closed • Electrical heater (8a)(10a)(22a) off • Electricity provided by Electric sub-system
*the valve 1h can direct totally or partially the flow toward the RPW-HEX		

In Figure 17 the heating mode flowchart of the Continental solution is shown. In this mode, the compression heat pump provides the energy needed while the RPW-HEX is bypassed. The waterflow bypasses the Enerboxx system and goes directly to the emission system of each apartment. The following abbreviations are used in the flowchart:

- T_{INT} (°C) is the internal ambient temperature, measured inside the apartment;
- T_{SETINT_H} is the temperature set-point (°C) during heating season;
- db_{INTLOW_H} (K) is the lower dead band of the internal ambient temperature (ΔT) during heating season, when the temperature is decreasing;
- db_{INTSUP_H} (K)is the upper dead band of the internal ambient temperature (ΔT) during heating season, when the temperature is increasing;
- SOH is state of health of the systems;
- HP is the compression Heat Pump.

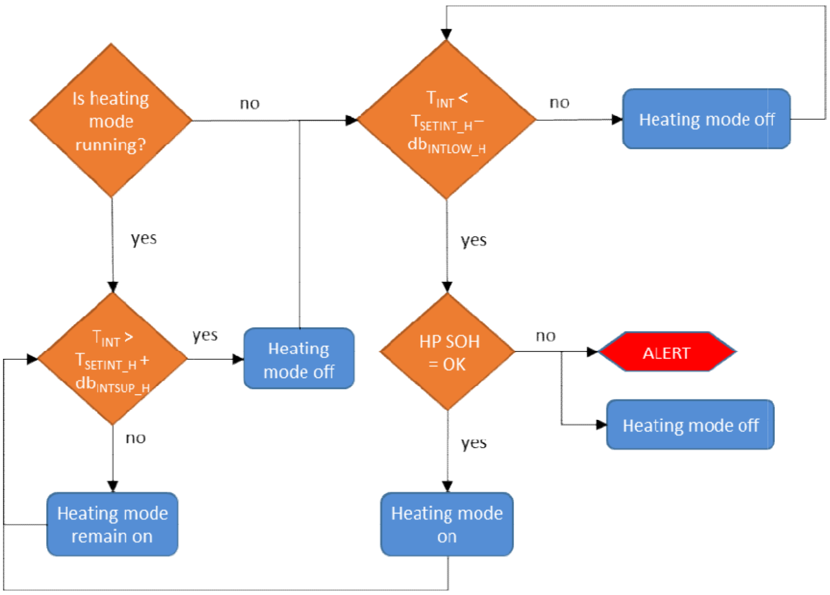

Figure 17 Continental solution Heating mode

In Figure 18 the DHW mode of the Continental solution is shown. The temperature needed for DHW production is higher than the one needed for heating (a low temperature heating system is considered). In DHW mode 1 the water heated by the HP passes through the RPW-HEX which provides further energy, increasing the water temperature. Then, the hot water flow goes to the Enerboxx tank to heat the domestic hot water. Heating mode and DHW mode 1 cannot be operated simultaneously. In case of any technical problem in the heat pump or in the RPW-HEX, a back-up electrical heater can heat the domestic hot water inside the Enerboxx (DHW mode 2). The following abbreviation are used in the flowchart:

- TT401/TT501/TT601 are the sensor measuring the temperature inside the Enerboxx tanks. (In the Continental layout two Enerboxx have been represented. In general, one Enerboxx system for each apartment has to be considered);
- T_{SETEB} is the temperature set-point (°C) inside the Enerboxx tank;
- db_{EBSUP} (K) is the lower dead band of the Enerboxx tank temperature (ΔT), when the temperature is decreasing;
- db_{EBLOW} (K)is the upper dead band of the Enerboxx tank temperature (ΔT), when the temperature is increasing;
- SOC (%) is the state of charge of the RPW-HEX calculated by means of sensor inside the storage;
- L1 is the level of the SOC (%) under which the RPW-HEX cannot provide energy for DHW generation;
- SOH is state of health of the systems;
- HP is the compression Heat Pump.

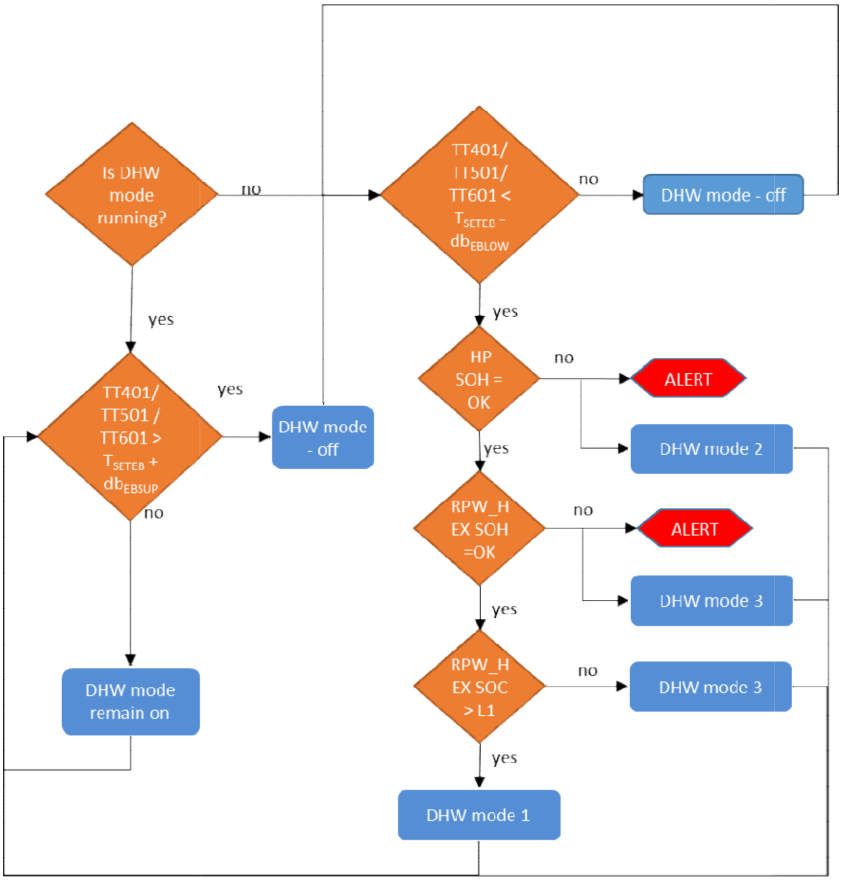

Figure 18 Continental solution DHW mode

In Figure 19, the cooling mode flowchart of the Continental solution is represented. The heat pump used in the Continental solution is reversible, and during summer operation it provides cooling energy to the building. The RPW-HEX is bypassed when the system is in cooling mode, and the DHW mode 1 is alternative to the Cooling mode. The following abbreviations are used in the flowchart:

- T_{INT} (°C) is the internal ambient temperature, measured inside the apartment;
- T_{SETINT_C} is the temperature set-point (°C) during cooling season;
- db_{INTLOW_C} (K) is the lower dead band of the internal ambient temperature (ΔT) during cooling season, when the temperature is decreasing;
- db_{INTSUP_C} (K)is the upper dead band of the internal ambient temperature (ΔT) during cooling season, when the temperature is increasing;
- SOH is state of health of the systems;
- HP is the compression Heat Pump.

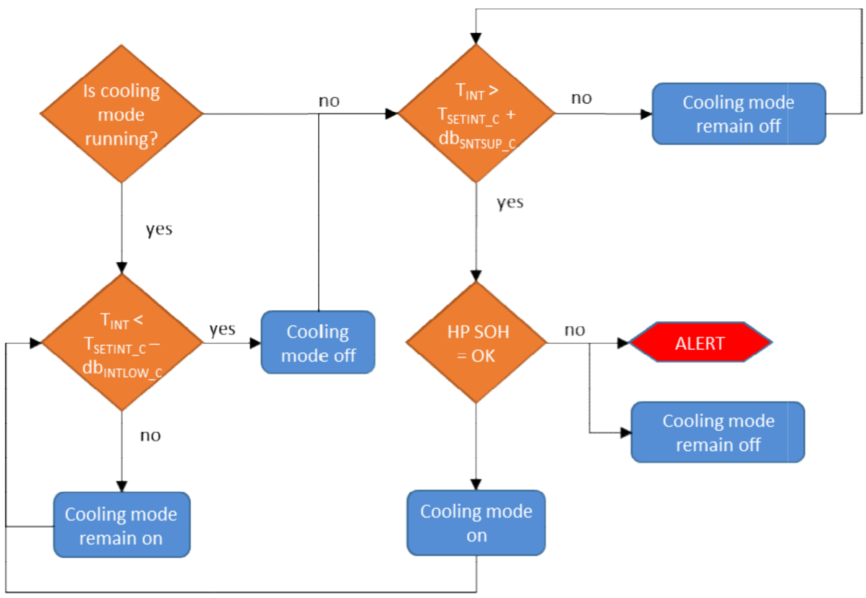

Figure 19 Continental solution Cooling mode

2.2.3 Definition of the possible operational modes according to the state of the system

The possible operational modes of the Mediterranean and Continental solutions are selected according to the status of the system. The letter ‘a’, ‘b’ and ‘c’ represent respectively the electricity supplied by the external grid, the electricity battery, and the PV plant. The selection is reported in Appendix A (Mediterranean solution) and in Appendix B (Continental solution).

3 Software specification

3.1 Introduction and methodology

This section reports the process of software analysis performed for defining the specifications of the BEMS and the results of this process, consisting mainly in the requirements that will drive the development process.

In order to reach such goals, a well-established analysis approach has been proposed by ENG. This approach consists in three main steps and each of them provides a different perspective from which the functional aspects of the BEMS processes are addressed.

The first step is the definition of the usage scenarios. These are a high level and narrative description of the main processes (of every nature, i.e. energy process, business one, etc.) occurring within a defined context, such as that envisioned for each of the HYBUILD pilots. The usage scenario allows to describe how the users of the BEMS could experience the functionalities put at disposal by this system providing real-life realistic situations that are likely to happen within everyday operations of the pilot infrastructure. Thanks to this description, the main users, as well as their roles, the main functionalities, the main objectives and the most relevant objectives of the Pilots are depicted and analysed.

Relying on information provided by the scenarios, the second step entails designing the use cases. A use case is a mean able to define a piece of behaviour of a system or subsystem without revealing the internal structure of the system itself. A use case consists in a list of steps that describes the action performed, the involved actors and their interactions, the other system supporting this action, and the data exchanged in this part of the entire process (Rumbaugh, Jacobson, & Booch, 2004). Through the usage of use cases, the analysis defines in details most of the aspects of a process, allowing also to understand how the objectives of the process are reached.

The third step addresses the creation of the list of software requirements and starts from each single step of the use cases. In software analysis, a requirement is a declaration of the intended function of a system and its components. Relying upon this declaration, the software developer determines the behaviour expected by software components for reaching the objectives defined in the scenarios and detailed in the use cases. In particular, two different kinds of requirements are usually provided in this phase of the analysis process, functional and non-functional requirements. The main difference is that while a functional requirement defines the exact behaviour of a system or its component, a non-functional requirement defines its performance attributes. The real guide and driver for software development are the functional requirements, that describe in details the technical functionality in order to provide as much information to the development team for implementing it.

Following the approach explained above, ENG handled in parallel the software analysis processes for the three HYBUILD pilots aiming at obtaining a unique coherent set of functional and non-functional requirements for the BEMS. In this view, The BEMS will be a single comprehensive system to be implemented three times in each different Pilots allowing to perform all the operations envisioned by the scenarios of the Pilots.

In particular, this analysis process required the commitment of all the partners involved in the Pilots, either technical or not, for designing consistent and valuable scenarios that are in line with the objectives of all the actors involved in Pilot activities. The first step was a preliminary assessment of the Pilots processes handled by the BEMS by a draft version of the usage scenarios for each pilot. These proposals have been circulated to all the Pilot partners and on this basis a set of conference calls have been arranged for reviewing and shaping them relying on the wishes and the expectations of the partners that are going to be the final users of the Pilot itself.

After having finalised this relevant process, one scenario per pilot has been drafted on the basis of Pilot partners feedback. The final scenarios guided the definition of the use cases. For each scenarios, thus for each Pilot, a set of use cases have been proposed, depending on the complexity of the actions, the amount of actors and systems involved, data exchanged, etc., following a standard table template, shown in Table 10.

Table 10 Template table for use case definition

<table>
<tr><th colspan="7">USE CASE</th></tr>
<tr><td>ID</td><td colspan="6"><a sequential reference number></td></tr>
<tr><td>Name</td><td colspan="6"><short name of the use case></td></tr>
<tr><td>Goal(s)</td><td colspan="6"><the functionality or behaviour that is expected to be provided by the system once the use case is executed></td></tr>
<tr><td>Actors</td><td colspan="6"><the individuals and their means that trigger system reactions></td></tr>
<tr><td>Preconditions</td><td colspan="6"><those actions that must occur before the execution of the use case in order to obtain the described behaviour></td></tr>
<tr><td>Postconditions</td><td colspan="6"><those conditions that could occur once the use case has been executed and the system continues its operations></td></tr>
<tr><td>Trigger events</td><td colspan="6"><the main action that starts the use case execution></td></tr>
<tr><td>Description</td><td>Step #</td><td>Initiator
<Party responsible for invoking the service of another party such us the Actor or the external system></td><td>Action
<Action performed></td><td>Participant
<Party that provides the service></td><td>Data exchanged among the participants
<Data and information used as input for the action to be performed or the output produced by the action execution></td><td>Remarks
<Remarks considerations (i.e. Additional information needed in order to complete analysis, elaborate ad design time, outside the scope of the system, etc.)>indicates possible</td></tr>
</table>

Once finalised the complete set of use cases, each step has been the source of relevant information about the actual actions that the system is expected to perform. These actions have been arranged in functional requirements that are all referred to the BEMS as a unique system. In particular, in this phase, some modules have been specified in order to have a clear understanding of the different functionalities clusters that imply a layered software architecture for the BEMS. The functional requirements have been detailed through the following template, see Table 11.

Table 11 Template table for functional requirements definition

Tool Name	Functional requirement ID	Description	Note	Priority
<Name of Tool>	*<Unique identifier of the functional requirement like*	*<Textual description of the functionality>*	*<Some important information to be reported>*	*<Implementation priority level>*

	FR1>			

At the end of the process, the elicitation of non-functional requirements has been performed. These aspects are properly addressed in a dedicated section in the following.

It is worth noting that all processes and the actions derived from the analysis process just presented are meant to an ideal configuration of the BEMS. The actual implementation of the BEMS will ensure the main basic energy and thermal management functionalities. For this reason, the functional requirements priority will be taken into account for the software implementation. Thus, the functionalities with highest priority level will be developed first, then the implementation of the other ones will be evaluated in the following months.

In this section, all the above-mentioned process is reported. Firstly, the scenarios and the corresponding use cases for each Pilot are reported; the use case diagram of the Pilot is shown as well. Secondly, all the functional requirements are presented, clustered in modules that will made up the BEMS architecture. Thirdly, the topic of the non-functional requirements and their relevance is addressed and the list of these requirements is provided. Finally, an early version of the BEMS architecture is proposed.

3.2 Scenarios and use cases definition

3.2.1 Almatret pilot

3.2.1.1 Scenario: Costs minimization, users settings and unexpected events

Dr. Gregory is the Almatret doctor and he lives with his wife, Marta, and their two sons, Brian and Chris, in a building where the ground floor is occupied by the medical office whereas on first floor there is the apartment where the doctor lives with his family.

In order to maintain the costs low for the whole year, the watchwords at Gregory's house are "energy savings". For this reason, some months ago, Marta purchased a PV, but she did not notice significant improvement of the costs savings: the cooling costs are still high since the cooling service are used also when the PV cannot provide any support. Searching the Internet, Marta finds a solution called HYBUILD, captured by the opportunity of improving her PV usage. This is a perfect chance to guarantee the optimal temperature conditions for her family, thus, she decides to purchase and install it in her building.

Once installed, she opens the HYBUILD application on the tablet for the first time, she logs as user and requires minimizing the costs and guaranteeing a comfortable ambient. To define what is a "comfortable ambient", the application asks Marta to define a range of desirable temperatures: she selects from 23 °C to 26 °C. The HYBUILD application calculates the expected optimal costs of the building cooling for the next day to maintain the temperature inside that range. The application shows the solution of this process, allowing Marta to choose and implement the desired configuration. Then, the application asks Marta how much she is willing to pay for eventual extra costs (due to the family components manual settings or unexpected events), either in terms of absolute cost in € or relative cost in percentage. She selects 10% more, and the scheduled cooling plan is approved.

Moreover, the application asks to Marta if she wants to participate to the Demand Response programme to compensate potential requests of the DSOs and Marta chooses this option. In this case, the HYBUILD system is able to automatically manage the energy storage in order to guarantee the participation to the Demand Response program and the comfort as required by Marta.

The HYBUILD software manages the system in order to maintain the temperature of the rooms inside the desired range of 23-26 °C. When Chris and Brian come back home and enter in their room, they enjoy the comfortable temperature. Nevertheless, they would like some more refreshment in the room. They have been provided with the HYBUILD application for regulating the room temperature. They decrease the temperature at 21 °C. The HYBUILD software re-optimises the scheduling, recalculates the costs and, the system is rearranged in order to decrease and maintain the temperature at the new desired value of 21 °C. Changing the temperature in their room, the guys have automatically set the same temperature in all rooms of the night zone of the ALMATRET house. At the end of day, the guys enjoyed a perfect environment for their desires. Whereas Gregory and Marta, did not change anything since they were satisfied by the temperature automatically provided by HYBUILD in the living room.

Marta checks the HYBUILD application again and she is satisfied since the costs sustained during the day are the ones she expected. She uses the application again and reschedules the system for the day after, with the same criteria she inserted the day before.

The day after, Chris and Brian leave the room for going fishing to the close river Ebro and forget the window opened. A couple hours later the HYBUILD monitoring system, which records the conditions in each room, notes an unexpected discrepancy between the forecasted temperature and the effective value in the room of the guys. The HYBUILD application re-optimises the system in order to reduce the temperature of the room, calculating the new expected costs. HYBUILD allows this rescheduling until the expected costs do not go over the max costs indicated in the initial settings so, the system is maintained in a minimal cooling condition that allows to provide cooling without going over the allowed costs. When Chris and Brian come back, they notice a higher temperature in the room than expected but they realize that it was their fault. When they close the window, the temperature of the room decreases, and the cooling of the room is restored in an optimal way.

At the end of the day, Marta verifies the data history during her periodic check through the tablet and she notices the discrepancy between the desired and registered temperature, but she is satisfied because the HYBUILD system has maintained the costs under the assigned limits.

3.2.1.2 Use cases

3.2.1.2.1 ALM_UC01 - Optimising building operations by minimizing costs

Table 12 Almatret use case, no.1

USE CASE: Optimising building operations by minimizing costs						
ID	01					
Name	ALM_UC01					
Goal(s)	Provide a set of optimised commands over a day-ahead time horizon to be executed step by step **in order to find the optimum combination of costs and desired temperature.**					
Actors	Energy user					
Preconditions	BEMS orchestrates the operational modes using dedicated algorithms for the optimisation.					
Postconditions	The building is maintained in comfortable thermal conditions with the minimum expenditure.					
Trigger events	The action of the energy user.					
Description	**Step #**	**Initiator**	**Action**	**Participant**	**Data exchanged among the participants**	**Remarks**
	1	Energy user	Energy user logs as shared role account.	BEMS energy manager dashboard	Energy user credentials	The data exchanged must be secured and encrypted for GDPR compliance
	2	Energy user	Energy user requires minimizing costs	BEMS energy manager dashboard	The selected optimisation objective	
	3	Energy user	Energy user defines a range of desirable	BEMS energy manager dashboard	Minimum and maximum comfort temperatures	

			temperatures			
	4	BEMS optimiser module	BEMS Optimiser performs optimisation module.	*(other modules of BEMS architecture, TBD)*	Input: simulated and forecasted energy behaviours, constrains, selected objectives, etc. TBD Output: optimised commands	
	5	BEMS energy manager dashboard	BEMS energy manager dashboard shows the results of the optimisation process.	BEMS optimiser module	Optimised commands	
	6	Energy user	Energy user chooses the percentage for extra costs.	BEMS energy manager dashboard	Chosen percentage	
	7	Energy user	Energy user accepts the average energy consumption per day proposed by the BEMS optimiser module.	BEMS optimiser module.	Optimised commands.	

3.2.1.2.2 ALM_UC02 - Participating to Demand Response programmes

Table 13 Almatret use case, no.2

USE CASE: Participating to Demand Response programmes						
ID	02					
Name	ALM_UC02					
Goal(s)	Provide a set of optimised commands executed step by step in order to **participate to Demand Response programmes.**					
Actors	Energy user					
Preconditions	BEMS is registered to the DSO Demand Response program.					
Postconditions	DSO/aggregator sends flexibility requests to the BEMS. BEMS optimises every 24h the resources based on the DSO/aggregator requests.					
Trigger events	The action of the energy user.					
Description	**Step #**	**Initiator**	**Action**	**Participant**	**Data exchanged among the participants**	**Remarks**
	1	Energy user	Energy user logs as shared role account.	BEMS energy manager dashboard	Energy user credentials	The data exchanged must be secured and encrypted for GDPR compliance
	2	Energy user	Energy user chooses to participate to DR programmes.	BEMS energy manager dashboard	The selected objective (availability to participate to the DR programmes).	
	3	BEMS optimiser module	BEMS optimiser module calculates the average energy consumption per day.	*(other modules of BEMS architecture, TBD)*	Input: temperature values, DR programs availability simulated and forecasted energy behaviours, constrains,	

					selected objectives, etc. *TBD* Output: optimised commands	
	4	BEMS energy manager dashboard	BEMS energy manager dashboard shows the results of the optimisation process.	BEMS optimiser module	Optimised commands	
	5	Energy user	Energy user accepts the BEMS optimisation.	BEMS optimiser module BEMS energy manager dashboard	Optimised commands	

3.2.1.2.3 ALM_UC03 - Configuration reworking due to new settings

Table 14 Almatret use case, no.3

USE CASE: Configuration reworking due to new settings						
ID	03					
Name	ALM_UC03					
Goal(s)	**Reconfiguration due to new temperature values as input**					
Actors	Energy user					
Preconditions	BEMS user is not comfortable with the current ambient temperature					
Postconditions	After a time slot necessary for re-configuring the operational modes, the BEMS enables the required temperature in the ambient.					
Trigger events	The action of the energy user					
Description	**Step #**	**Initiator**	**Action**	**Participant**	**Data exchanged among the participants**	**Remarks**
	1	Energy user	Energy user logs as shared role account.	BEMS energy use dashboard	Energy user credentials	The data exchanged must be secured and encrypted for GDPR compliance
	2	Energy user	Energy user change the current temperature **in the night zone.**	BEMS energy user dashboard	The selected optimisation objective	
	3	BEMS energy user dashboard	BEMS energy manager dashboard shows the results of the optimisation process.	BEMS optimiser module	Optimised commands	
	4	Energy user	Energy user accepts the average energy consumption proposed by the BEMS optimiser module.	BEMS optimiser module BEMS energy manager dashboard	Optimised commands.	

3.2.1.2.4 ALM_UC04 - Configuration re-working due to unexpected events

Table 15 Almatret use case, no.4

USE CASE: Configuration re-working due to unexpected events						
ID	04					
Name	ALM_UC04					
Goal(s)	**Reworking the configuration due to unexpected events**					
Actors	NA					
Preconditions	Unexpected event occurs.					
Postconditions	BEMS executes corrective actions for restoring the required conditions.					
Trigger events	The action of the energy user.					
Description	**Step #**	**Initiator**	**Action**	**Participant**	**Data exchanged among the participants**	**Remarks**
	1	BEMS monitoring module	BEMS monitoring notes a temperature discrepancy between the forecasted temperature and the effective value.	BEMS optimiser module	Alert message	
	2	BEMS optimiser module	The system re-optimises the resources considering the new conditions until the expected costs do not go over the max costs indicated in the initial settings:	(other modules of BEMS architecture, TBD).	Input: temperature, simulated and forecasted energy behaviours, constrains, selected objectives, etc. TBD. Output: optimised commands.	

3.2.1.2.5 ALM_UC05 - Monitoring energy consumptions of the building

Table 16 Almatret use case, no.5

USE CASE: Monitoring energy consumptions of the building						
ID	05					
Name	ALM_UC05					
Goal(s)	**Check the bill and the energy consumptions in a selected time period.**					
Actors	Energy user					
Preconditions	BEMS monitors and records the energy production, consumption and stored energy automatically.					
Postconditions	Undertaking corrective actions for decreasing the energy consumptions or confirming the current settings on the base of the monitored data.					
Trigger events	The action of the energy user.					
Description	**Step #**	**Initiator**	**Action**	**Participant**	**Data exchanged among the participants**	**Remarks**
	1	Energy user	Energy user logs as shared role account.	BEMS energy manager dashboard	Energy user credentials.	The data exchanged must be secured and encrypted for GDPR compliance.
	2	Energy user	Energy manager chooses to check the bill and monitor energy consumptions.	BEMS energy manager dashboard	The selected objective.	
	3	Energy user	Energy user defines a range of days in which wants to check the energy consumptions.	BEMS energy manager dashboard	Start and the end date of the interesting time period.	
	4	BEMS reporting module	BEMS reporting calculates the energy consumptions	*(other modules of BEMS architecture,*	Historical energy consumption data, time	

			for the selected period.	*TBD).*	period (start and end date).	
	5	BEMS energy manager dashboard	BEMS energy manager dashboard shows the required results.	BEMS reporting module	List of the required data in the selected days.	

3.2.1.3 Almatret use cases diagram

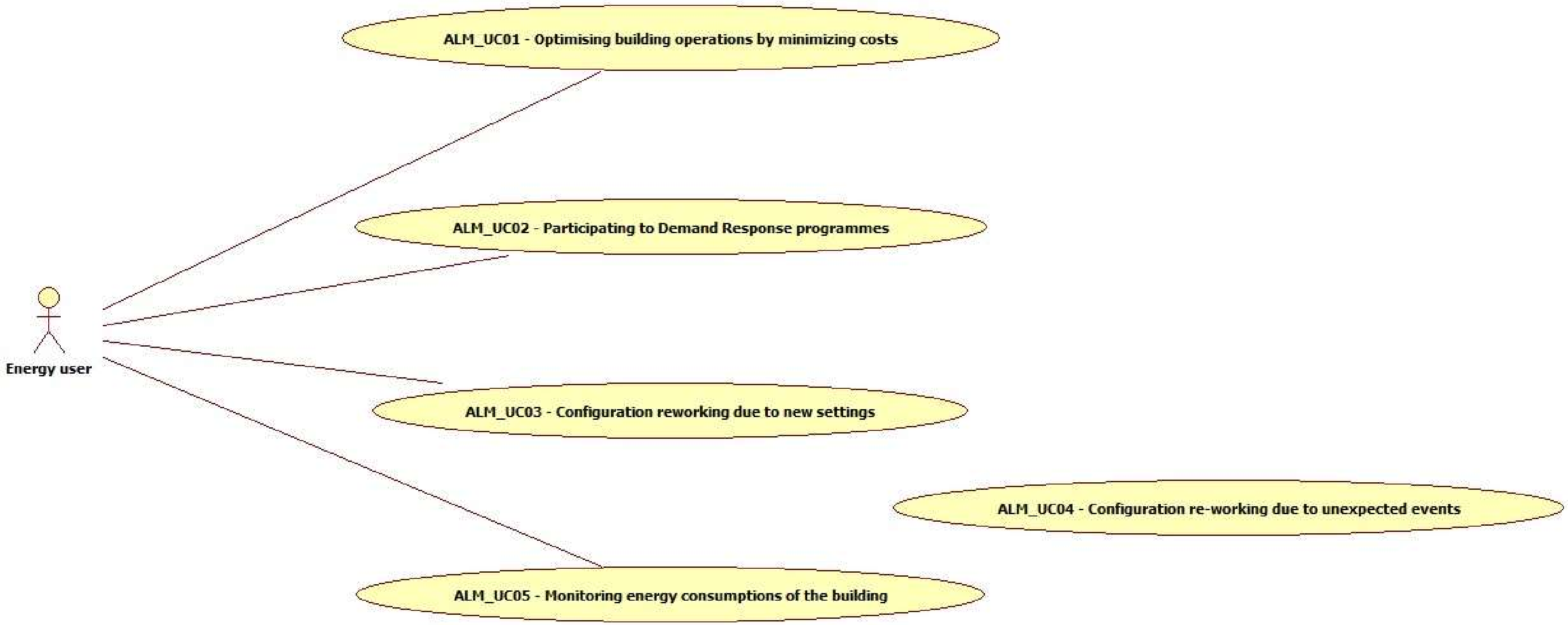

Figure 20 Use cases diagram of Almatret pilot

3.2.2 Aglantzia pilot

3.2.2.1 Scenario: Peaks of temperature during the weekend events, Internet access not available

On behalf of the municipality, Marta manages an exhibition centre at Aglantzia, a municipality located in the middle of Cyprus. The exhibition centre is operational all the year round, all days of the week to host various users and Marta employs an HYBUILD solution as support of her work.

The Aglantzia centre will have a lot of visitors, all the year round since it is used by many users for various activities. The events among others consist in showing of emerging smart energy technologies. In special events policy makers, wider people from Nicosia district take part to the events and the Mayor with his collaborators visit the centre as well.

Accessing to the graphical interface of her HYBUILD application, Marta selects the option “comfort maximization” in order to make the stay at the structure as pleasant as possible. By setting this choice, Marta is implicitly asking the application to prioritise the comfort of the ambient, using the energy batteries, the PV and the national grid as support if needed for stabilizing the internal temperature to a value that Marta set at 22 °C in Winter months and 24°C in the Summer months.

Although the average temperature at Aglantzia is 25 °C, it can reach more than 40 °C from June to September. When these unexpected peaks occur, the HYBUILD application could not be able to guarantee the adequate cooling in the exhibition centre and it is obligated to ask help to the grid for the time of reworking the configuration of the cooling system of the building. Marta has set a maximum energy consumption as a threshold: when the forecast arrives at this value, Marta is alerted.

Moreover, through the function “data history”, she can monitor the energy consumptions and checks the expenditures of the month.

HYBUILD application is based on some indicators provided by Marta and some others provided by Internet. However, some mistakes can arise, mostly in the weather forecast. As it is normal with exposed surfaces, the photovoltaic panels can be covered by clouds or by external objects on the PV cells, causing significant power drops. In these cases, the optimiser must undertake corrective actions for responding to the energy manager request, according to the new conditions (PV power drop). Other weather phenomena like a sudden storm can occur as well and problems like interrupted network connection can also arise. Although the system is not able to elaborate an optimisation process without Internet access, a plan “b” is provided by the application to manage the building cooling/heating also in a non-optimal way. In this case, the energy control passes to the smart controllers of the building which regulates the system based on a predefined set of rules.

3.2.2.2 Use cases

3.2.2.2.1 AGZ_UC01 - Optimising building operations by balancing costs and comfort

Table 17 Aglantzia use case, no.1

USE CASE: Optimising building operations by balancing costs and comfort						
ID	01					
Name	AGZ_UC01					
Goal(s)	Provide a set of optimised commands over a day-ahead time horizon to be executed step by step **in order to find the optimum combination of costs and comfort.**					
Actors	Energy manager					
Preconditions	BEMS orchestrates the operational modes using dedicated algorithms for the optimisation.					
Postconditions	The building is maintained in optimum thermal conditions with the minimum expenditure.					
Trigger events	The action of the energy manager					
Description	**Step #**	**Initiator**	**Action**	**Participant**	**Data exchanged among the participants**	**Remarks**
	1	Energy manager	Energy manager logs as administrator.	BEMS energy manager dashboard	Energy manager credentials	The data exchanged must be secured and encrypted for GDPR compliance.
	2	Energy manager	Energy manager requires to optimise costs and comfort.	BEMS energy manager dashboard	The selected optimisation objective	
	3	Energy manager	Energy manager defines a range of	BEMS energy manager dashboard	Minimum and maximum comfort temperatures	

			desirable temperatures.			
	4	BEMS optimiser module	BEMS optimiser module calculates the average energy consumption per day.	*(other modules of BEMS architecture, TBD).*	Input: temperature values, simulated and forecasted energy behaviours, constrains, selected objectives, etc. TBD. Output: optimised commands	
	5	BEMS energy manager dashboard	BEMS energy manager dashboard shows the results of the optimisation process.	BEMS optimiser module.	Optimised commands.	
	6	Energy manager	Energy manager accepts the average energy consumption per day proposed by the BEMS optimiser module.	BEMS optimiser module.	Optimised commands.	

3.2.2.2.2 AGZ_UC02 - Configuration re-working due to unexpected events

Table 18 Aglantzia use case, no.2

USE CASE: Configuration re-working due to unexpected events						
ID	02					
Name	AGZ_UC02					
Goal(s)	**Reworking the configuration due to unexpected events**					
Actors	NA					
Preconditions	Unexpected internal or external event occurs.					
Postconditions	BEMS executes corrective actions for restoring the required conditions.					
Trigger events	The action of the energy manager					
Description	**Step #**	**Initiator**	**Action**	**Participant**	**Data exchanged among the participants**	**Remarks**
	1	BEMS optimiser module	BEMS optimiser module notifies the energy manager that since unexpected event occurs the system needs time for reworking the configuration.	BEMS energy manager dashboard.	Notification message.	If needed the system asks help to the national grid for guaranteeing the comfort in the building for the time of reworking the configuration.
	2	BEMS optimiser module	The system re-optimises the resources considering the new conditions.	*(other modules of BEMS architecture, TBD).*	Input: temperature, simulated and forecasted energy behaviours, constrains, selected objectives, etc. TBD. Output: optimised	

					commands.	
	3	BEMS energy manager dashboard	BEMS energy manager dashboard notifies the new energy consumption to the energy manager.	BEMS optimiser module.	Notification message.	

3.2.2.2.3 AGZ_UC03 - Monitoring energy consumptions of the building

Table 19 Aglantzia use case, no.3

USE CASE: Monitoring energy consumptions of the building						
ID	04					
Name	AGZ_UC03					
Goal(s)	**Check the bill and the energy consumptions in a selected time period.**					
Actors	Energy manager					
Preconditions	BEMS monitors and records the energy production, consumption and stored energy automatically.					
Postconditions	Energy manager undertakes corrective actions for decreasing the energy consumptions on the base of the monitored data or confirms the current settings.					
Trigger events	The action of the energy manager					
Description	**Step #**	**Initiator**	**Action**	**Participant**	**Data exchanged among the participants**	**Remarks**
	1	Energy manager	Energy manager logs as administrator.	BEMS energy manager dashboard.	Energy manager credentials.	The data exchanged must be secured and encrypted for GDPR compliance.
	2	Energy manager	Energy manager chooses to check the bill and monitor energy consumptions.	BEMS energy manager dashboard.	The selected objective.	
	3	Energy manager	Energy manager defines a range of days in which wants to check the energy consumptions.	BEMS energy manager dashboard.	Start and the end date of the interesting time period.	
	4	BEMS reporting	BEMS reporting calculates	*(other modules of*	Historical energy	

		module	the energy consumptions for the selected period.	*BEMS architecture, TBD).*	consumption data, time period (start and end date).	
	5	BEMS energy manager dashboard	BEMS energy manager dashboard shows the required results.	BEMS reporting module.	List of the required data in the selected days.	

3.2.2.2.4 AGZ_UC04 - System behaviour during the absence of internet access

Table 20 Aglantzia use case, no.4

USE CASE: System behaviour during the absence of internet access						
ID	05					
Name	AGZ_UC04					
Goal(s)	Provide a set of commands executed step by step **in order to define the system behaviour in absence of internet access**					
Actors	Energy manager					
Preconditions	Absence of internet access.					
Postconditions	BEMS executes a solution which does not optimise the resources.					
Trigger events	The action of the energy manager					
Description	**Step #**	**Initiator**	**Action**	**Participant**	**Data exchanged among the participants**	**Remarks**
	1	Energy manager	Energy manager logs as administrator.	BEMS energy manager dashboard	Energy manager credentials.	The data exchanged must be secured and encrypted for GDPR compliance.
	2	Energy manager	Energy manager requires to optimise costs and comfort.	BEMS energy manager dashboard	The selected optimisation objective.	
	3	Energy manager	Energy manager defines a range of desirable temperatures.	BEMS energy manager dashboard	Minimum and maximum comfort temperatures.	
	4	BEMS optimiser module	BEMS optimiser module warns the energy manager that there is no internet access, then it is not	BEMS energy manager dashboard	Alert message.	

			possible to optimise the resources.			
	5	Energy manager	Energy manager confirms to have read the message.	BEMS energy manager dashboard	Alert message.	
	6	BEMS optimiser module	BEMS optimiser module passes the control to the smart controllers of the building.	The smart controllers of the building	Temperature values chosen by the energy manager.	
	7	The smart controllers of the building	The smart controllers of the building send the required commands to the BEMS optimiser module.	BEMS optimiser module	A sequence of commands which come from rules previously defined for orchestrating the operational modes in absence of internet access.	
	8	BEMS energy manager dashboard	BEMS energy manager dashboard shows the results of the process.	BEMS optimiser module	Proposed commands.	
	9	Energy manager	Energy manager accepts the solution.	BEMS energy manager dashboard	Proposed commands.	

3.2.2.3 Aglantzia use cases diagram

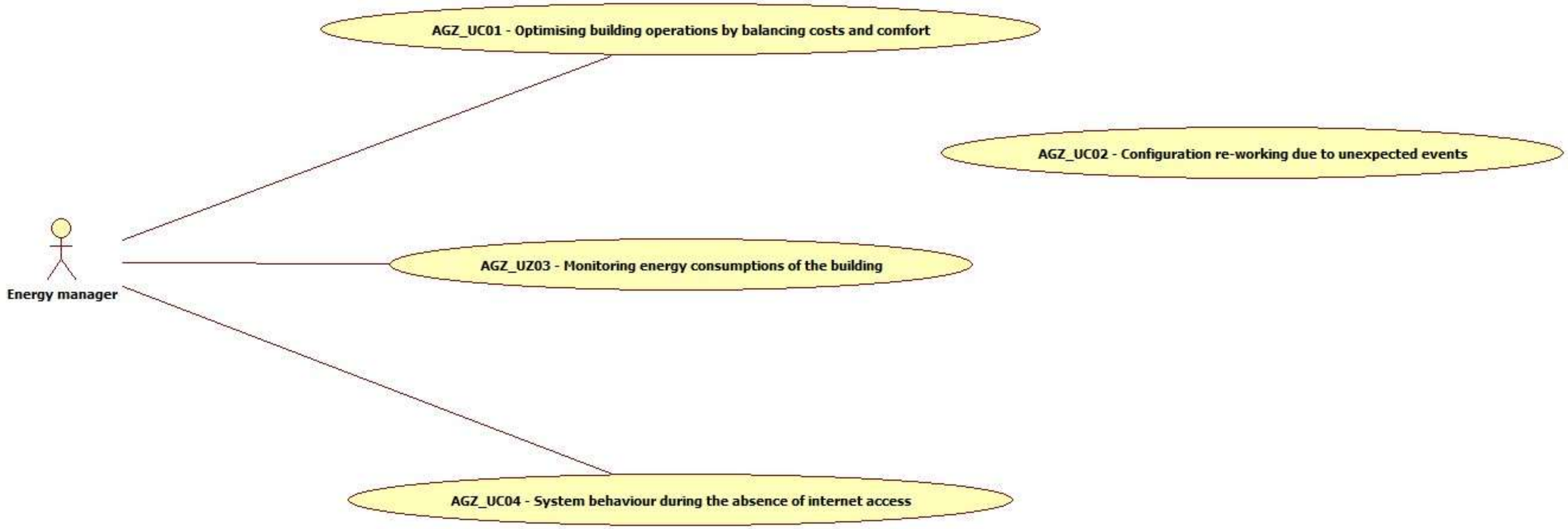

Figure 21 Use cases diagram of Aglantzia pilot

3.2.3 Talence pilot

3.2.3.1 Scenario: Comfort Maximisation and Cost Minimisation on an Ordinary Day

Marta is the head officer of Talence, the building which hosts Nobatek company. Talence is located close to Bordeaux, a city of the south-west of France, characterised by continental climate.

Marta is very careful to the comfort of her employees since she believes that the success of a company is strongly tied to its employees' wellness. She wants to ensure the best working conditions in order to guarantee a comfortable workplace to the employees throughout the year, but also sensitive to environmental problems, trying hard to minimise the use of energy to conserve the environment.

For ensuring an optimum level of the comfort at the building and control the energy consumption, Marta uses an application provided with the HYBUILD solution installed in the building. Through it, she can check the energy provided by HYBUILD system to heat the building, PV panels production, electricity consumption from the grid, and make improvements in the energy management: In particular, she can set the range of temperatures in which the office should be taken.

In winter, Marta choses 21 °C from Monday to Friday, 7:00 AM – 7:00 PM and availability of DHW for working days. Marta allowed the employees to regulate indoor temperature ± 1.5 °C using the users interface. Marta can also define the temperature of the building at night, she chooses 16°C.

The application calculates an average energy consumption per day and Marta confirms it. The application warns if the average energy consumption exceeds 10% the expected value.

In case of unexpected events such as when the employees open the windows or when they use their remote controllers to reduce or increase the temperature manually, Marta sets a 20% of tolerance for the expected energy consumption. In this way, the office building is maintained at the conditions given by Marta, changing its configuration in case of inputs of the employees by their application to manually reduce or increase the temperature of their rooms.

Nobatek plans a series of closing days during the year: a couple of weeks on August, ten days in December and one week on Easter. Since the company remains closed and the building is empty, Marta, the BEMS manager, usually sets the preference “minimisation of costs” in these periods.

However, it may happen that some employees are obligated to work in the holidays due to urgent client requests. Just this year, the employees Benjamin and Antoinette, who occupy the same room in the building, must work for some days during the Christmas holidays.

Since Marta will be on vacation on those days, she shows to Benjamin and Antoinette how to use the HYBUILD application for setting the temperature during the holidays. She also explains to them that the application needs some time for elaborating the input and achieving the conditions chosen by the employees. Thus, it is preferred to choose the settings the day before in order to give to the HYBUILD application the time for optimising the office heating configuration and providing the best working conditions for the employees the day after.

Before leaving, Marta has forgotten to warn her colleagues that the maintenance of the server has been scheduled for the Christmas holidays. The application is able to manage the new conditions by ensuring the heating and the DHW inside: the system does not interrupt its operability in absence of the server connection, even if it is not optimised.

Reviewing the data history of the last six months, Marta noted that the comfort of the office has been guaranteed, with a good containment of costs since the energy consumption was just 5% higher than expected (basically due to some weeks which were much colder than expected, in which the employees manually changed the temperature by 1 °C more) but much less than the max 20% that she set. To keep the costs lower, she decides to participate to DR programmes for the next month. The HYBUILD application also allows that, without varying the same settings of the months before.

3.2.3.2 Use cases

3.2.3.2.1 TLC_UC01 - Optimising building operations by balancing costs and comfort

Table 21 Talence use case, no.1

USE CASE: Optimising building operations by balancing costs and comfort						
ID	01					
Name	TLC_UC01					
Goal(s)	Provide a set of optimised commands over a day-ahead time horizon to be executed step by step **in order to find the optimum combination of costs and comfort.**					
Actors	Energy manager, Energy user					
Preconditions	BEMS orchestrates the operational modes using dedicated algorithms for the optimisation.					
Postconditions	The building is maintained in optimum thermal conditions with the minimum expenditure.					
Trigger events	The action of the energy manager					
Description	**Step #**	**Initiator**	**Action**	**Participant**	**Data exchanged among the participants**	**Remarks**
	1	Energy manager	Energy manager logs as administrator.	BEMS energy manager dashboard.	Energy manager credentials.	The data exchanged must be secured and encrypted for GDPR compliance.
	2	Energy manager	Energy manager requires to optimise costs and comfort.	BEMS energy manager dashboard.	The selected optimisation objective.	
	3	Energy manager	Energy manager defines a range of desirable temperatures.	BEMS energy manager dashboard.	Minimum and maximum comfort temperatures.	

	4	Energy manager	Energy manager defines the time slots in which the DHW must be available in the building.	BEMS energy manager dashboard.	Days and time slots.	
	5	Energy manager	Energy manager sets the range in which the users can change the indoor temperature.	BEMS energy manager dashboard	Chosen range	Winter T = 21°C Summer T = 24°C Range = T ± 1.5 °C
	6	BEMS optimiser module	BEMS optimiser module calculates the average energy consumption per day.	*(other modules of BEMS architecture, TBD).*	Input: temperature values, simulated and forecasted energy behaviours, constrains, selected objectives, etc. TBD. Output: optimised commands	
	7	BEMS energy manager dashboard	BEMS energy manager dashboard shows the results of the optimisation process.	BEMS optimiser module.	Optimised commands.	
	8	Energy manager	Energy manager accepts the average energy consumption per day proposed by the BEMS optimiser module	BEMS optimiser module.	Optimised commands.	
	8.A	BEMS optimiser module	BEMS optimiser module warns the energy manager if the energy consumption exceeds 10% the expected value.	BEMS energy manager dashboard	Alert message.	
	9	Energy manager	Energy manager sets the tolerance for the expected energy consumption related	BEMS energy manager dashboard	Chosen percentage.	

			to unexpected events.			
	10	Energy user	Energy user logs as shared role account.	BEMS energy user dashboard	Energy user credentials	The data exchanged must be secured and encrypted for GDPR compliance
	11	Energy user	Energy user requires a new temperature	BEMS energy user dashboard	The selected optimisation objective	
	12	BEMS energy user dashboard	BEMS energy user dashboard shows the possible temperature within the temperature range previously approved by the energy manager	Energy manager	Range of temperatures	
	13	Energy user	Energy user chooses a new temperature in the approved range	BEMS energy user dashboard	The temperature value (T ± 1.5 °C)	
	14	BEMS optimiser module	BEMS optimiser performs the new input	*(other modules of BEMS architecture, TBD)*	Input: new temperature value, simulated and forecasted energy behaviours, constrains, selected objectives, etc. *TBD* Output: optimised commands	
	15	BEMS user dashboard	BEMS user dashboard shows the results of the optimisation process.	BEMS optimiser module	Optimised results	

3.2.3.2.2 TLC_UC02 - Monitoring energy consumptions of the building

Table 22 Talence use case, no.2

USE CASE: Monitoring energy consumptions of the building						
ID	02					
Name	TLC_UC02					
Goal(s)	**Check the bill and the energy consumptions in a selected time period.**					
Actors	Energy manager					
Preconditions	BEMS monitors and records the energy production, consumption and stored energy automatically.					
Postconditions	Energy manager undertakes corrective actions for decreasing the energy consumptions on the base of the monitored data or he can confirm the current settings.					
Trigger events	The action of the energy manager					
Description	**Step #**	**Initiator**	**Action**	**Participant**	**Data exchanged among the participants**	**Remarks**
	1	Energy manager	Energy manager logs as administrator.	BEMS energy manager dashboard	Energy manager credentials	The data exchanged must be secured and encrypted for GDPR compliance
	2	Energy manager	Energy manager chooses to check the bill and monitor energy consumptions.	BEMS energy manager dashboard	The selected objective	
	3	Energy manager	Energy manager defines a range of days in which wants to check the energy consumptions.	BEMS energy manager dashboard.	Start and the end date of the interesting time period	
	4	BEMS reporting	BEMS reporting calculates	*(other modules of*	Historical energy	

		module	the energy consumptions for the selected period.	*BEMS architecture, TBD)*	consumption data, time period (start and end date)	
	5	BEMS energy manager dashboard	BEMS energy manager dashboard shows the required results	BEMS reporting module	List of the required data in the selected days.	

3.2.3.2.3 TLC_UC03 - Setting day off and temperature conditions

Table 23 Talence use case, no.3

USE CASE: Setting day off and temperature conditions						
ID	03					
Name	TLC_UC03					
Goal(s)	**Set the day off and the off hours in the working days.**					
Actors	Energy manager					
Preconditions	BEMS provides of programming the temperature conditions when the building is empty.					
Postconditions	When the building is empty the minimization of costs is prioritized and the maximum energy savings is guaranteed.					
Trigger events	The action of the energy manager					
Description	**Step #**	**Initiator**	**Action**	**Participant**	**Data exchanged among the participants**	**Remarks**
	1	Energy manager	Energy manager logs as administrator	BEMS energy manager dashboard	Energy manager credentials	The data exchanged must be secured and encrypted for GDPR compliance
	2	Energy manager	Energy manager selects the weekly day off and the off hours of the night in the working days.	BEMS energy manager dashboard	The selected optimisation objective	Ex. Monday – Friday: night hours 7 p.m – 7 a.m.; Day off: Saturday and Sunday.
	3	BEMS optimiser module	BEMS optimiser module shows a notification pop-up and a related calendar view			

3.2.3.2.4 TLC_UC04 - System behaviour during the absence of internet access

Table 24 Talence use case, no.4

USE CASE: System behaviour during the absence of internet access						
ID	04					
Name	TLC_UC04					
Goal(s)	Provide a set of commands executed step by step **in order to define the system behaviour in absence of internet access**					
Actors	Energy manager					
Preconditions	Absence of internet access.					
Postconditions	BEMS executes a solution which does not optimise the resources.					
Trigger events	The action of the energy manager					
Description	**Step #**	**Initiator**	**Action**	**Participant**	**Data exchanged among the participants**	**Remarks**
	1	Energy manager	Energy manager logs as administrator	BEMS energy manager dashboard	Energy manager credentials	The data exchanged must be secured and encrypted for GDPR compliance
	2	Energy manager	Energy manager requires to optimise costs and comfort	BEMS energy manager dashboard	The selected optimisation objective	
	3	Energy manager	EM defines a range of desirable temperatures	BEMS energy manager dashboard	Minimum and maximum comfort temperatures	
	4	Energy manager	EM defines the time slots in which the DHW must be available in the building	BEMS energy manager dashboard	Days and time slots	
	5	BEMS optimiser	BEMS optimiser module	*(other modules of*	Input: temperature	5

		module	calculates the average energy consumption per day.	*BEMS architecture, TBD)*	values, simulated and forecasted energy behaviours, constrains, selected objectives, etc. TBD. Output: optimised commands	
	5A	BEMS optimiser module	BEMS optimiser module warns the energy manager that there is no internet access, then it is not possible to optimise the resources	BEMS energy manager dashboard	Alert message	
	5AA	Energy manager	Energy manager confirms to have read the message.	BEMS energy manager dashboard	Alert message	
	6	BEMS energy manager dashboard	BEMS energy manager dashboard shows the results of the optimised process.	BEMS optimiser module	Optimised commands	
	6A	BEMS energy manager dashboard	BEMS energy manager dashboard shows the results of the process.	BEMS optimiser module	Sequence of commands which come from rules previously defined for orchestrating the operational modes in absence of internet access.	
	7	Energy manager	Energy manager accepts the BEMS optimisation.	BEMS optimiser module	Optimised commands.	
	7A	Energy manager	Energy manager accepts the BEMS solution.	BEMS optimiser module	Proposed commands.	

3.2.3.2.5 TLC_UC05 - Participating to Demand Response programmes

Table 25 Talence use case, no.5

USE CASE: Participating to Demand Response programmes						
ID	05					
Name	TLC_UC05					
Goal(s)	Provide a set of optimised commands executed step by step in order to **participate to Demand Response programmes.**					
Actors	Energy manager					
Preconditions	BEMS is registered to the DSO Demand Response program.					
Postconditions	DSO/aggregator sends flexibility requests to the BEMS. BEMS optimises every 24h the resources based on the DSO/aggregator requests. Energy manager receives a remuneration for having participate to the programme and satisfied the DSO/aggregator requests.					
Trigger events	The action of the energy manager					
Description	**Step #**	**Initiator**	**Action**	**Participant**	**Data exchanged among the participants**	**Remarks**
	1	Energy manager	Energy manager logs as administrator.	BEMS energy manager dashboard	Energy manager credentials	The data exchanged must be secured and encrypted for GDPR compliance
	2	Energy manager	Energy manager chooses to participate to DR programs	BEMS energy manager dashboard	The selected objective (availability to participate to the DR programs)	
	3	BEMS optimiser module	BEMS optimiser module calculates the average energy consumption per day.	*(other modules of BEMS architecture, TBD)*	Input: temperature values, DR programs availability simulated and forecasted energy	

					behaviours, constrains, selected objectives, etc. *TBD* Output: optimised commands	
	4	BEMS energy manager dashboard	BEMS energy manager dashboard shows the results of the optimisation process.	BEMS optimiser module	Optimised commands	
	51	Energy manager	Energy manager accepts the BEMS optimisation.	BEMS optimiser module BEMS energy manager dashboard	Optimised commands	

3.2.3.3 Talence use cases diagram

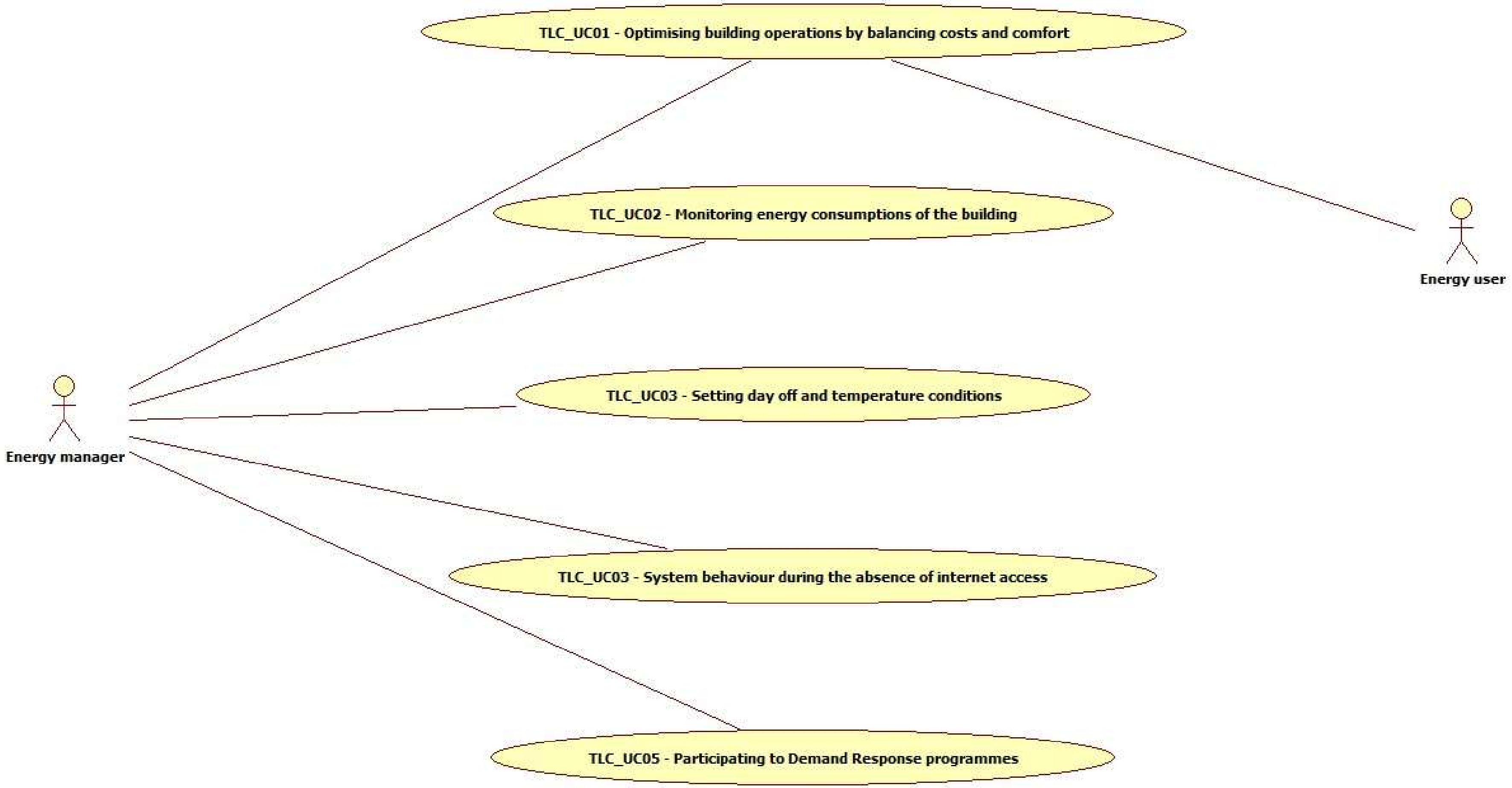

Figure 22 Use cases diagram of Talence pilot

3.3 Functional requirements

3.3.1 BEMS energy manager dashboard (EMD)

Table 26 BEMS energy manager dashboard functional requirements

Tool Name	Functional requirement ID	Description	Note	Priority
Building Energy Management System energy manager dashboard – BEMS EMD	BEMS_EMD_FR01	The EMD shall allow EM to log to the system	ALM AGZ TAL	High
	BEMS_EMD_FR02	The EMD shall allow EM to select the desired objective	ALM AGZ TAL The choice is between: • Cost minimisation • Comfort maximisation • DR participation	High
	BEMS_EMD_FR03	The EMD shall allow EM to select the range of desirable temperature	ALM AGL TAL	High
	BEMS_EMD_FR04	THE EMD shall show the result of the optimisation	ALM AGZ TAL	High
	BEMS_EMD_FR05	The EMD shall allow EM to select/accept the optimised configuration	ALM AGZ TAL	High
	BEMS_EMD_FR06	The EMD shall allow EM to select an percentage range for extra costs	ALM	High
	BEMS_EMD_FR07	The EMD shall allow the EM to select the time slots of DHW availability	TAL	High
	BEMS_EMD_FR08	The EMD shall allow	TAL	High

		EM to select the temperature tolerance for user temperature selection		
	BEMS_EMD_FR09	The EMD shall allow EM to select the reporting functionalities (billing and monitoring)	TAL AGZ	High
	BEMS_EMD_FR010	The EMD shall allow EM to select the range of days in which wants to check the bills and monitor	TAL AGZ	High
	BEMS_EMD_FR011	The EMD shall show the billing and monitor reporting	TAL AGZ	High
	BEMS_EMD_FR012	The EMD shall warn the EM if the optimised energy consumption exceeds the expected one by 10%	TAL	Medium
	BEMS_EMD_FR013	The EMD shall allow the EM to select the energy consumption limits for unexpected events	TAL	Low
	BEMS_EMD_FR014	The EMD shall allow the EM to select the weekly day off and the off hours of the night in the working	TAL	Medium
	BEMS_EMD_FR015	The EMD shall show a notification pop-up and a related calendar view for day-off	TAL	Medium
	BEMS_EMD_FR016	The EMD shall show a notification of missing connectivity/unexpected event and ask for notification acceptance	TAL AGZ	Low

3.3.2 BEMS energy user dashboard (EUD)

Table 27 BEMS energy user dashboard functional requirements

Tool Name	*Functional requirement ID*	Description	Note	Priority
Building Energy Management System energy user dashboard – BEMS EUD	BEMS_EUD_FR01	The EUD shall allow the EU to log to the system	TAL ALM	High
	BEMS_EUD_FR02	The EUD shall allow the EU to select a new temperature	TAL ALM	High
	BEMS_EUD_FR03	The EUD shall show the possible temperature within the temperature range approved by the EM	TAL	High

3.3.3 BEMS optimiser (OPT)

Table 28 BEMS optimiser functional requirements

Tool Name	*Functional requirement ID*	Description	Note	Priority
Building Energy Management System optimiser – BEMS OPT	BEMS_OPT_FR01	The OPT shall perform the requested optimisation process	ALM AGZ TAL	High
	BEMS_OPT_FR02	The OPT shall warn the EM in case of missing connectivity/unexpected event	TAL AGZ	Low
	BEMS_OPT_FR03	The OPT shall perform a scheduling process of operational modes in case of missing connectivity	TAL	Low
	BEMS_OPT_FR04	The OPT shall re-perform the requested optimisation process in case of unexpected event	AGZ	Medium
	BEMS_OPT_FR05	The OPT shall pass the	AGZ	Medium

		control to the smart controllers of the building		

3.3.4 BEMS reporting module (REP)

Table 29 BEMS reporting module functional requirements

Tool Name	***Functional requirement ID***	**Description**	**Note**	**Priority**
Building Energy Management System reporting module – BEMS REP	BEMS_REP_FR01	The REP shall calculate the bills and energy consumptions for the selected period	TAL AGZ	High

3.3.5 BEMS monitoring module (MON)

Table 30 BEMS monitoring module functional requirements

Tool Name	***Functional requirement ID***	**Description**	**Note**	**Priority**
Building Energy Management System monitoring module – BEMS MON	BEMS_MON_FR01	The MON shall monitoring and retrieve energy and temperature data from the building	TAL ALM AGZ	High
	BEMS_MON_FR02	The MON shall note a temperature discrepancy between the forecasted temperature and the effective value	ALM	Medium

3.4 Non-functional requirements

Non-Functional Requirements (NFR) can be defined as the quality attributes of a system architecture that defines how the system should behave. Indeed, while the functional requirements are defined from the use cases and, more in general, from the project goals, the non-functional requirements can be deducted from the literature in relation to the system functionalities.

ISO/IEC 25010:2011 is an example of certification for system and software quality requirements (International Organization for Standardization, 2011) which involves some universal accepted rules which have substantial impact on the software solution development.

Some typical non-functional requirements are:

- Reliability, i.e. system availability to the end user at any given time
- Efficiency, e.g. throughput, response time, transit delay, latency
- Performance
- Scalability, i.e. the system is available to more users and cover wider areas
- Expandability, i.e. the system can be expanded with new types of service
- Interoperability, i.e. the system is able to interact with other external systems
- Security
- Privacy
- Maintainability
- Resilience

Among them, some specific requirements for the BEMS of HYBUILD can be collected. In the table below, each NFR that the BEMS should meet is described as follows:

- ID: univocal identifier of the requirements
- Label: briefly definition of the non-functional requirement
- Description: description for the non-functional requirement
- Priority: priority in requirement implementation (mandatory 1, desirable 2, optional 3)
- Remarks: some important notes to specify the non-functional requirement

Table 31 BEMS non-functional requirements

ID	Label	Description	Priority	Remarks
NFR1	Authentication and authorization mechanism	BEMS system shall grant user access to different tools and sections only after energy manager and energy users authenticate and authorization to each feature is validated.	Priority 1 (mandatory)	This requirement relates to the security and privacy of data utilized for the different processes and the data which is presented to the end user.
NFR2	Misuse protection	BEMS system shall protect the users against any misuse of features and data.	Priority 1 (mandatory)	The requirement relates to privacy of specific of data which should not be displayed to all kind of users who have access to the architecture's layers and tools.
NFR3	Mitigation of security risks	BEMS system shall mitigate all known security risks	Priority 2 (desirable)	
NFR4	Non-repudiation of sent notification	BEMS system shall ensure the non-repudiation aspect of sent notifications	Priority 1 (mandatory)	The requirement is related to the principle of ensuring system performance. The system should not ignore

				notifications received by other layers, components or end users but take them into account in the cases where this is applicable.
NFR5	Threats preventions	BEMS system shall include prevention for the most common threats	Priority 1 (mandatory)	The requirement is related to the principles of security and privacy of the overall system in order to protect exposure of sensitive data to other systems or end users who do not hold authority for access to this information (e.g. protection from hacking).
NFR6	Data confidentiality	BEMS system shall ensure confidentiality of personal data	Priority 1 (mandatory	This concerns the principal of data security and privacy. There is information that the system will handle, which should not be accessible to all end users (such as the consumption profiles).
NFR7	Data integrity	BEMs shall ensure integrity of data	Priority 1 (mandatory)	The results derived by the functionalities of the different layers in the architecture are highly dependent on the input. In order to ensure the quality of results, the system should ensure data integrity.
NFR8	Availability	BEMS shall ensure availability of services made available.	Priority 1 (mandatory)	
NFR9	System availability	Availability of services should be 99% or superior at any time, 24h/24h, 7d/7d, independently from performances of other applications.	Priority 1 (mandatory)	The system should not only be available, but this availability should be independent from other functionalities taking place at the same time. This is derived by the principle of resilience, which should be respected in the overall system architecture.
NFR10	Performance	BEMS shall perform in perfect conditions for the service load such	Priority 1 (mandatory)	The principle of efficiency is of high importance concerning an architecture

		as data exchange and optimisation.		with multiple functionalities and high complexity.
NFR11	Response time	The response time to move between different sections of a form if not displayed on the same page should be 80% within 4 seconds.	Priority 1 (mandatory)	
NFR12	View page time response	After the user requests to view any web site page except the homepage, BEMS shall display the requested page and the associated content accordingly to the following service level: 80% within 4 seconds	Priority 2 (desirable)	The speed of view page adds on to the overall system's performance and efficiency.
NFR13	Concurrency of users	BEMS system shall allow for expected users to work concurrently with a maximum response time accordingly to the following service level: 80% within 4 seconds	Priority 2 (desirable)	Reliability, efficiency and resilience are the main principles that this requirement makes sure are respected.
NFR14	Accessibility	BEMS shall follow the guidelines from Web Content Accessibility Guidelines (WCAG) 2.0 and Authoring Tool Accessibility Guidelines (ATAG) 2.0 issued by the World Wide Web Consortium (W3C).	Priority 1 (mandatory)	
NFR15	Cross-browsing	BEMS interface should work in all most used browsers, and not be linked to any given version of any browser.	Priority 2 (desirable)	Interoperability is of major importance for such a system, since many tools of different manufacturers will be integrated and will need to collaborate.
NFR16	Logs	Logging will be done	Priority 1	

		based on severity, used as input setup parameter	(mandatory)	
NFR17	History	All logging messages will contain a reference to source message code, message explanation in user language, timestamp.	Priority 2 (desirable)	
NFR18	Scalability	BEMS should enable availability to more users as well as cover areas wider than the pilot districts for future implementation.	Priority 1 (mandatory)	The architecture should respect the principle of scalability since the system is not only meant for pilot use but also for actual large-scale implementation. Therefore, it should be applicable and adjustable to the needs of wider areas and also allow the accessibility to more users according to the application's purposes.
NFR19	Expandability	BEMS will be able to be expanded with new types of services.	Priority 1 (mandatory	Compliance with the principle of expandability will allow the architecture to be enhanced with more services and functionalities. Therefore, it is important for the architecture to be easily expandable with new services that will be defined by future requirements and evolutions.
NFR20	Maintainability	BEMS should be easily maintained in order to allow replacements, prolong lifetime of components and cope with changed environments.	Priority 1 (mandatory)	BEMS architecture is based on the collaboration of multiple diverse tools and components on the same conceptual platform. It is important that the wear out of one component or tool should not affect the operation and functionality of the rest. This way each component will be maintained or replaced

				without having to replace the rest still-working tools or components.
NFR21	Interoperability	BEMS system should allow the interaction with external systems.	Priority 2 (desirable)	The interaction with other components, external of the BEMS architecture, is crucial for certain processes since there might be information required which are derived from tools not integrated into the conceptual common platform.
NFR22	Ease of use	BEMS HMI components should promote ease of use being well-designed and self-explanatory for the end user.	Priority 2 (desirable)	The HMI should provide a user-friendly functionality with minimum complexity in order to assist the end user perform the desirable operations.
NFR23	Resilience	BEMS should maintain continuity of operation when abnormal situations occur.	Priority 1 (mandatory)	In case of lack of internet connection or failure of a sub-component the system will be able to continue operating as if in steady-state.
NFR24	Ease of system installation and integration with existing infrastructure	BEMS should allow installation and integration of tools and components with minimum disturbance	Priority 2 (desirable)	The integrated components and tools should be easily installed without the need of extreme modifications in the current infrastructure which might cause confusion and discomfort to the end users.
NFR25	Use of open standards	BEMS should utilize open standards in order to promote interoperability and accessibility.	Priority 1 (mandatory)	The usage of open standards will render end users independent of vendor for products and services thus promoting elasticity and mitigating vendor lock-in.
NFR26	Recoverability	BEMS should return to a functioning state after a system failure or a system restart.	Priority 1 (mandatory)	
NFR27	Robustness	BEMS shall have the ability to resist change	Priority 1 (mandatory)	

		without adapting its initial stable configuration.		
NFR28	Installability	BEMS should allow installation and integration of tools and components with minimum disturbance	Priority 1 (mandatory)	
NFR29	Use of open standards	BEMS should utilise open standards in order to promote interoperability and accessibility	Priority 2 (desirable)	
NFR30	Cutting edge technologies	BEMS aims to integrate cutting-edge technologies, solutions and mechanisms	Priority 1 (mandatory)	
NFR31	Openness, interoperability, and replicability of the solution	The replicability of the solutions needs to be taken into account: the integrated tools and delivered products will be an innovative and powerful set of synergetic components relying on openness and interoperability functionalities with clear replicability potential.	Priority 1 (mandatory)	
NFR32	Compliancy with existing standards, protocols and regulations	BEMS will be compliant with existing standards, protocols and regulations in the field of smart energy deployment and grid infrastructure along with regulatory policies for privacy, data protection and security adhering to the Commission Recommendation (2014/724/EU)	Priority 1 (mandatory)	

3.5 Early software architecture of BEMS

As a result of the software analysis process, one of the main outcomes in terms of BEMS features is a first instance of the software architecture through which the system will be shaped.

It is a layered architecture, as shown in Figure 23, consisting in:

- A user interface layer: the modules implementing the dashboards put at disposal of the final users;
- Optimisation layer: the modules in charge of handling the optimisation and control actions of the BEMS;
- Data gathering layer: modules that retrieve, historicise, and handle the monitoring data coming from the field equipment.

This first version of the BEMS architecture has to be validated with the other partners involved in the BEMS development in the future technical activities.

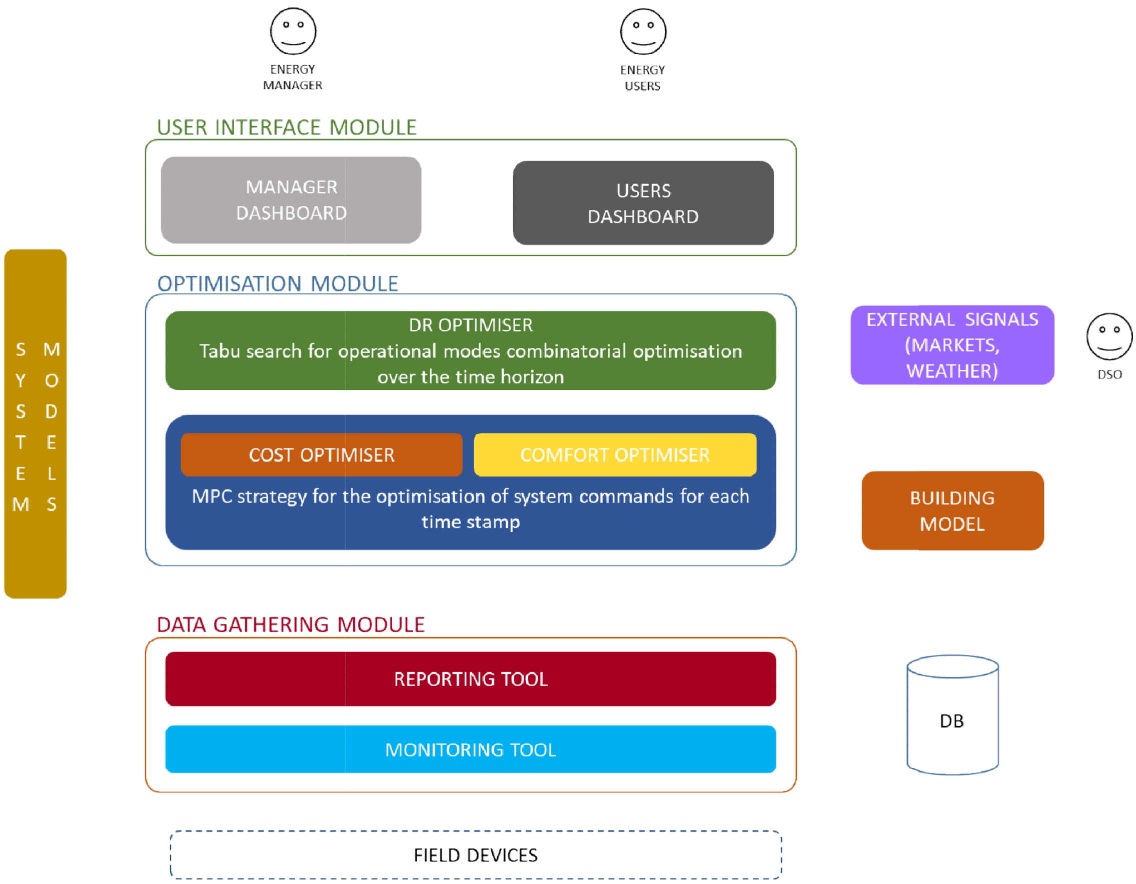

Figure 23 Early BEMS software architecture

4 Conclusions

This report was focused on the definition of the system operations and layouts as well as on the software specification for the development of the BEMS. The main part of the deliverable was dedicated to the analysis process of the system, in order to individuate the main operational modes and functionalities of the final platform.

The work began from the definition of the general layout of the two HYBUILD configurations and their adaptation into the demo-sites. The Mediterranean and the Continental configuration have been detailed in order to show the features of the system operations: the Mediterranean configuration was designed to mainly provide cooling whereas the Continental one for heating.

A section of the report was dedicated to the operational modes, which identify all the possible working conditions of the system. Thus, four modes have been detailed - Heating modes, Cooling modes, DHW modes and Charging modes- showing the status of the equipment and the basic control rules for satisfying the energy demand. Diagrams, tables and numerical results have also been provided.

The process of specification of the software structure has been addressed using a well-established analysis methodology. Starting from the demo sites description and from the HYBUILD configurations' P&ID, three scenarios related to the pilots have been proposed into the report. The scenarios take into account the system configuration of each pilot, its usual thermal conditions and the designated use of the building (i.e. residential or working space).

The scenarios were validated by the pilot leaders and the collected feedbacks have been addressed to obtain a list of use cases which reflect a shared view of the BEMS frameworks. BEMS optimiser module is an example of these tools, it is able to manage inputs and, thanks to dedicated algorithms, will return an optimised solution in terms of comfort and costs minimization. In order to answer to the DSO/Energy retailers' requests, the scenarios consider the opportunity of participating to DR programmes as well.

This cascade process has produced a complete list of functional requirements for the BEMS of HYBUILD. A final section was dedicated to the non-functional requirements since aspects such us the performance and the interoperability of a system cannot be neglected during the development activity.

Another outcome of the specification and elicitation process is an early architectural representation of the BEMS subdivided in functional layers, each addressing a specific task of the overall energy management process. For all the exposed results, the cooperation work between WPs and the involved partners has been crucial.

In the following steps of the Project, in general, and WP4, in particular, the operational modes and basic control rules will be furtherly tested in the simulation environment and refined accordingly. The control system will be detailed inside the work in Task 4.3 and 4.4. In M30, the first release of the BEMS is expected, with the implementation of the functionalities here reported with high priority. The collaboration between the two final and active tasks of the WP will be increased in order to produce a final platform to be installed in the three pilots for the energy management of the buildings.

5 References

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6 Appendixes

6.1 Appendix A

To evaluate the performance and the concept´s validity of the HYBUILD systems, dynamic simulations in TRNSYS have been performed. For system dynamic simulation one important step is the setting and implementation of control logics that governs the system. Starting from the flow charts reported in section 2.2, the logics have been translated in useful schemes that cannot be used only in TRNSYS but also constitute a base for future implementation in the control that will govern the real system. The choice of the presented numerical values has been guided by indications/numerical limits given directly by partners responsible of the specific components and, where these were not available, imposed and verified through simulations. The structure of the control strategies follows the below steps:

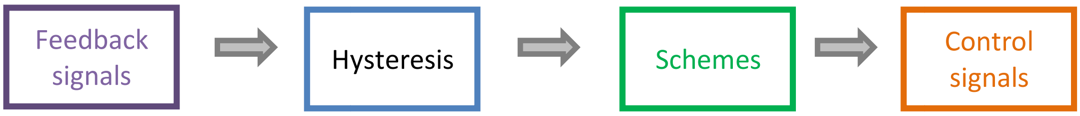

Figure 24 – Structure of the control strategies

- **Monitored parameters/Feedback signal**: information acquired from the sensors and used for the control;
- **Hysteresis**: comparison of the acquisition signals with a threshold in Boolean format;
- **Schemes**: working modes used by the HVAC system. The schemes are defined as logical phrase of hysteresis.
- **Control signal**: command given to the device to be controlled.

This structure is valid for all the demo cases and references cases control strategies. In the following, we report hysteresis, schemes and control of the Mediterranean layout only.

Monitored parameters /Feedback signals

For the Mediterranean layout, the used sensors and their position are reported in the list below and in Figure 25. The measured quantities refer to temperatures and irradiation on the horizontal plane.

Sensor list:

- DNI 106: total solar radiation on the horizontal plane
- TT 105: outlet temperature from the solar thermal field
- TT 301: Buffer Tank top temperature
- TT 601: DHW Tank top temperature
- TT 702: Adsorption module cooling circuit return temperature
- TT 801: Adsorption module chilled circuit return temperature
- SoC 1011: PCM storage SoC
- Tint: indoor zone temperature

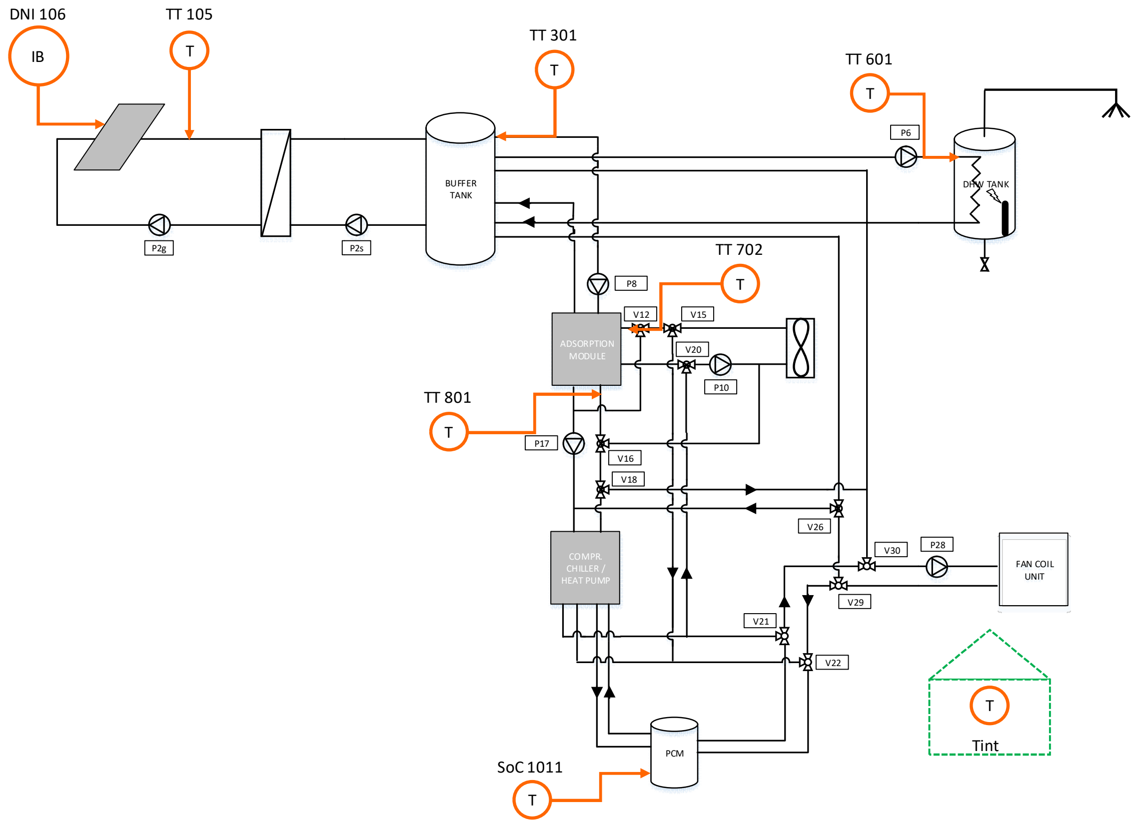

Figure 25 Sensors´ position in the Mediterranean system

A detailed description of the double ports and sensor position in the Buffer Tank is instead reported in Figure 26 (taken from www.pink.co.at). The highest double port is used as inlet and outlet of the adsorption chiller hot circuit as in the upper part there are the highest temperature, around 60 °C (inlet water) up to 95°C (maximum allowed temperature).

The DHW circuit is connected to the double port located around half of the total height as the working temperatures are around 40-45°C. In case the operating conditions for free space heating are verified, the lowest double port is used as inlet and outlet to the radiators.

Solar thermal circuit is connected to a heat exchanger that crosses the tank for the whole height.

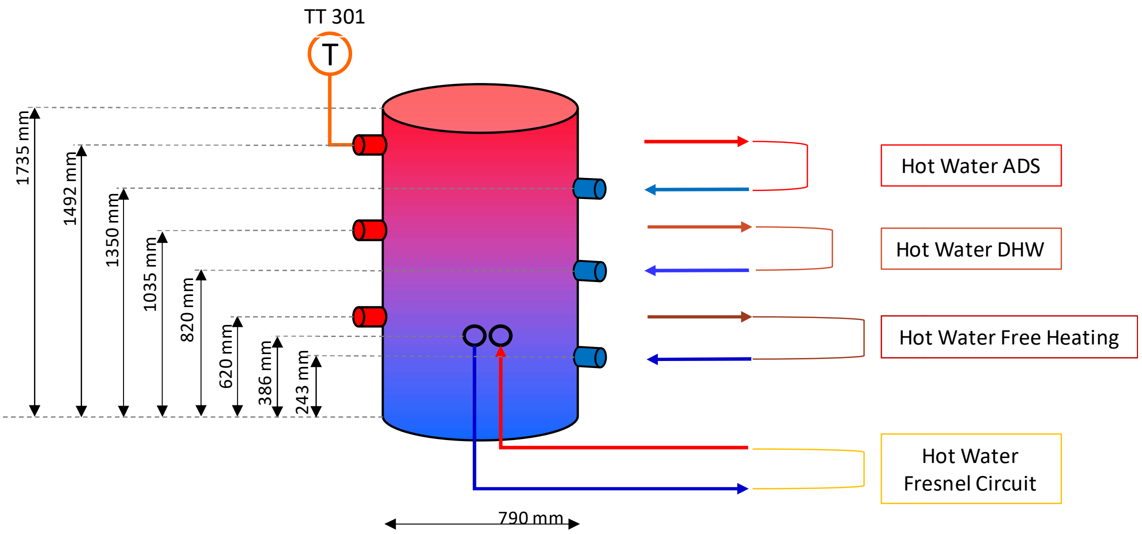

Figure 26 Sensors, double ports and geometrical characteristics of the Buffer Tank

Hysteresis

Hysteresis become necessary in these control strategies to reduce continuous oscillation of the control signal around a set value. Being the system subdivided in sub-systems (Figure 27), hysteresis have been grouped with different numbers referring to different specific sub-systems. Subsequently, Table 32 summarizes the hysteresis implemented with the set value and dead bands.

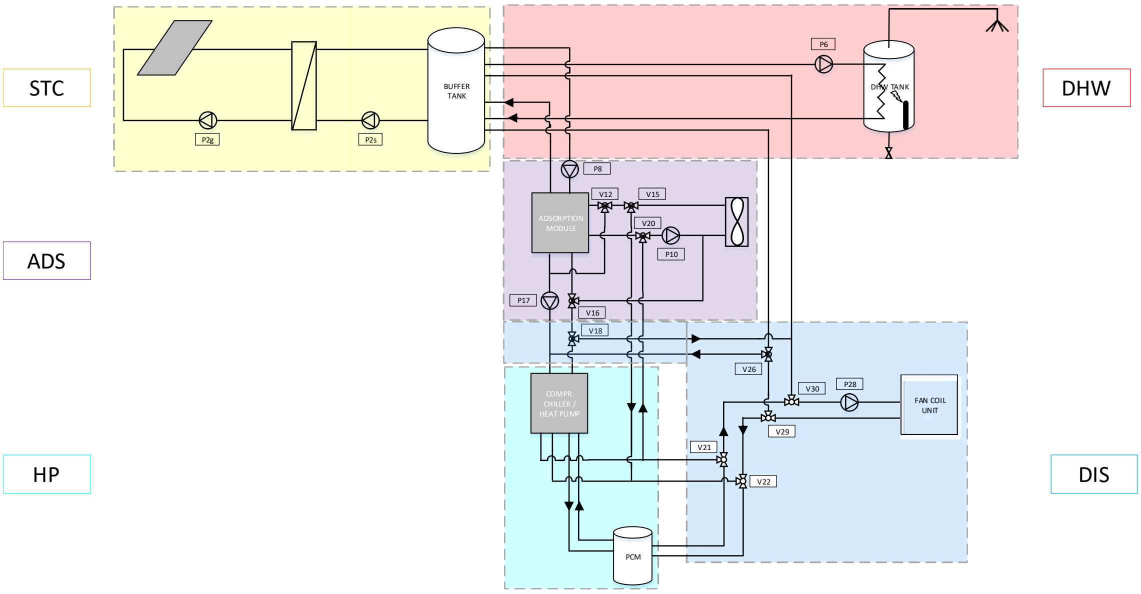

Figure 27 Sub-system identification in the Mediterranean plant

- Hysteresis of group 1 used to evaluate solar source availability and for controlling Solar Thermal Collectors (STC).
- Hysteresis of group 2x for controlling the Adsorption module (ADS).
- Hysteresis of group 3x used to control the Compression Chiller (HP).
- Hysteresis of group 4x for controlling the distribution circuit (DIS).
- Hysteresis of group 5x for controlling domestic hot water (DHW) circuit.

Hysteresis 1A: Control of the irradiation on the horizontal plane with respect to a set value to evaluate solar source availability.

Hysteresis 1B: Compare the STC outlet temperature with a set value to activate the solar thermal circuit.

Hysteresis 1C: Compare the temperature difference between the outlet of STC and the top temperature of the Buffer Tank with a set value to activate the solar thermal circuit.

Hysteresis 1D: Compare the STC outlet temperature with a set value to avoid stagnation in STC.

Hysteresis 1E: Compare the Buffer Tank top temperature with a set value to avoid boiling.

Hysteresis 1F: Compare the Buffer Tank top temperature with a set value to activate free heating mode.

Hysteresis 2A: Compare the Adsorption module hot water inlet temperature with a set value to activate the machine.

Hysteresis 2B: Compare Adsorption module cooling water return temperature with a set value to activate the machine.

Hysteresis 2C: Compare the Adsorption module chilled water return temperature with a set value to activate the machine.

Hysteresis 3A: Compare SoC of the PCM storage with a set value to activate discharging of PCM.

Hysteresis 3B: Compare SoC of the PCM storage with a set value to activate charging of PCM.

Hysteresis 3C: Compare SoC of the PCM storage with a set value to bypass PCM.

Hysteresis 4A: Compare the indoor air temperature of the considered zone with a set value to activate space heating.

Hysteresis 4B: Compare the indoor air temperature of the considered zone with a set value to activate space cooling.

Hysteresis 5A: Compare the DHW Tank top temperature with a set value to activate DHW Tank charging.

Hysteresis 5B: Compare the difference between Buffer Tank top temperature and the top temperature of DHW Tank with a set value to select the appropriate DHW Tank charging mode.

Table 32 Hysteresis characteristics: Hysteresis name, Feedback signal, Set value, Upper dead band, Lower dead band

Hysteresis name	Feedback signal	Set Value	Upper dead band	Lower dead band
Hysteresis 1A	Irradiation on horizontal (DN 106)	150	0	-50
Hysteresis 1B	Temperature outlet STC (TT 105)	30	5	0
Hysteresis 1C	Difference of temperature between the outlet of STC (TT 105) and Buffer Tank top temperature (TT 301)	0	5	0
Hysteresis 1D	Temperature outlet STC (TT 105)	120	0	-5
Hysteresis 1E	Buffer Tank top temperature (TT 301)	95	0	-5
Hysteresis 1F	Buffer Tank top temperature (TT 301)	40	5	0
Hysteresis 2A	Hot water inlet temperature (measured at the top of Buffer Tank, TT 301)	65	3	0
Hysteresis 2B	Cooling water inlet temperature (TT 702)	50	0	-3
Hysteresis 2C	Chilled Water Inlet Temperature (TT 801)	40	0	-5
Hysteresis 3A	PCM storage SoC (SoC 1101)	0.9	0	-0.8
Hysteresis 3B	PCM storage SoC (SoC 1101)	0.1	0.8	0

Hysteresis 3C	PCM storage SoC (SoC 1101)	0.1	0.1	0
Hysteresis 4A	Indoor zone sensor temperature (Tint)	21	0.5	0
Hysteresis 4B	Indoor zone sensor temperature (Tint)	26	0	-0.5
Hysteresis 5A	DHW Tank top temperature (TT 601)	50	5	0
Hysteresis 5B	Difference between Buffer Tank top temperature (TT 301) and DHW Tank top temperature (TT 601)	0	5	2

Functional schemes

The working scheme of the HVAC system identifies which are the "operating state" of the plant based on the hysteresis generated. Schemes are defined through an equation that combines in a logical way the hysteresis presented above. In the following the various schemes are presented.

Scheme 1 (SC1): Solar source availability

The aim of this scheme is to evaluate the availability of the solar source. It allows to manage in different ways the system based on this renewable source availability. The scheme is defined using the following equation:

$$SC1 = 1A$$

This simple equation is described by the following condition:

- Solar irradiation control: when beam radiation on horizontal surface exceeds 150 W/m^2, the condition is verified, and Hysteresis 1A is 1, while turns to 0 when it is lower than 100 W/m^2.

Scheme 2 (SC2): Solar Thermal Circuit activation

This scheme governs the solar thermal circuit and the purpose of its activation is to charge the Buffer Tank. The logic equation that defines the considered scheme is the following:

$$SC2 = 1B * 1C * NOT(1D) * NOT(1E)$$

Conditions that describe SC2 equation are:

- STC outlet temperature control: the outlet temperature of the solar thermal collector must be above 35°C, while the value of hysteresis turns to 0 if TT 105 measures temperature lower than 30 °C.
- Temperature difference control: difference between STC outlet temperature (TT 105) and Buffer Tank top temperature (TT 301) is evaluated. If this difference exceeds 5 °C Hysteresis 1C is equal to 1, while turns to 0 when it falls below 0°C
- STC Stagnation control: STC outlet temperature (TT 105) must be lower than 120°C. This control is used to prevent stagnation problem in the solar collectors.
- Buffer Tank boiling control: Buffer Tank top temperature (TT 301) must not exceed 95°C. This control is used to avoid boiling problem in the Buffer Tank.

Figure 28 shows the solar thermal circuit with its components and sensors.

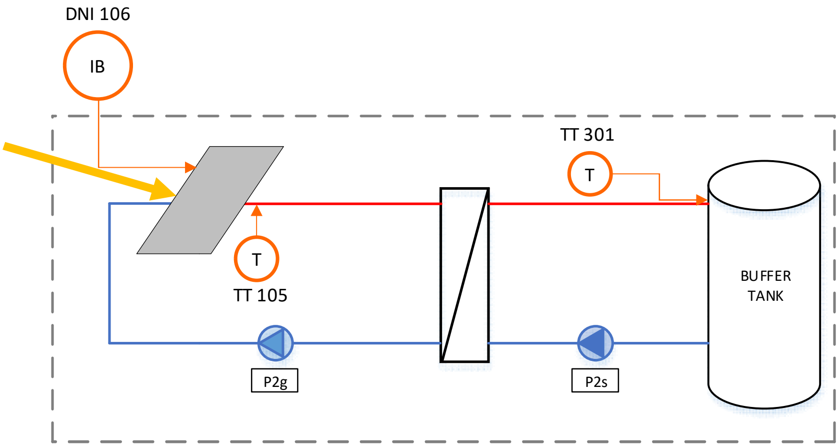

Figure 28 Schematic of the STC part with interested sensors and components

Scheme 3 (SC3): PCM storage bypass

This scheme is foreseen to directly connect the evaporator side of the Compression Chiller to the distribution circuit bypassing the PCM storage. This scheme can be verified, for example, to cover a sudden peak of cooling demand occurring when PCM storage is empty. SoC of PCM and space cooling identification are the feedback signals present in the equation. Other conditions that verify this scheme are the operative status of Adsorption module, responsible of the split of scheme 3 in two sub-schemes SC3a and SC3b in which the compression chiller works respectively coupled and decoupled with Adsorption module depending on the availability of the Adsorption machine.

$$SC3a\ (cooling\ MODE\ 2) = NOT(2A) * 2B * 2C * NOT(3C) * 4B$$

$$SC3b\ (cooling\ MODE\ 4) = 2A * NOT(2B) * NOT(2C) * NOT(3C) * 4B$$

The conditions that describe schemes SC3 are:

- PCM SoC charging control: Hysteresis 3C indicates if the PCM is charged or not. In SC3, the PCM is not charged, this means that SoC is lower than 0.1.
- Space cooling demand identification: Hysteresis 4B is equal to 1 because indoor temperature is higher than 26°C and maintains this condition until internal temperature falls below 25.5 °C.
- ADS availability control: hysteresis 2A, 2B, 2C summarize the Adsorption module availability. Hysteresis values equal respectively to 1, 0, 0 imply the availability of the Adsorption module and therefore the possibility for the compression chiller to work coupled with it (SC3b), while if at least one of the three hysteresis presents a different value the Compression chiller must be connected directly to dry cooler (SC3a).

In Figure 29 and Figure 30 active circuits of SC3a and SC3b are reported.

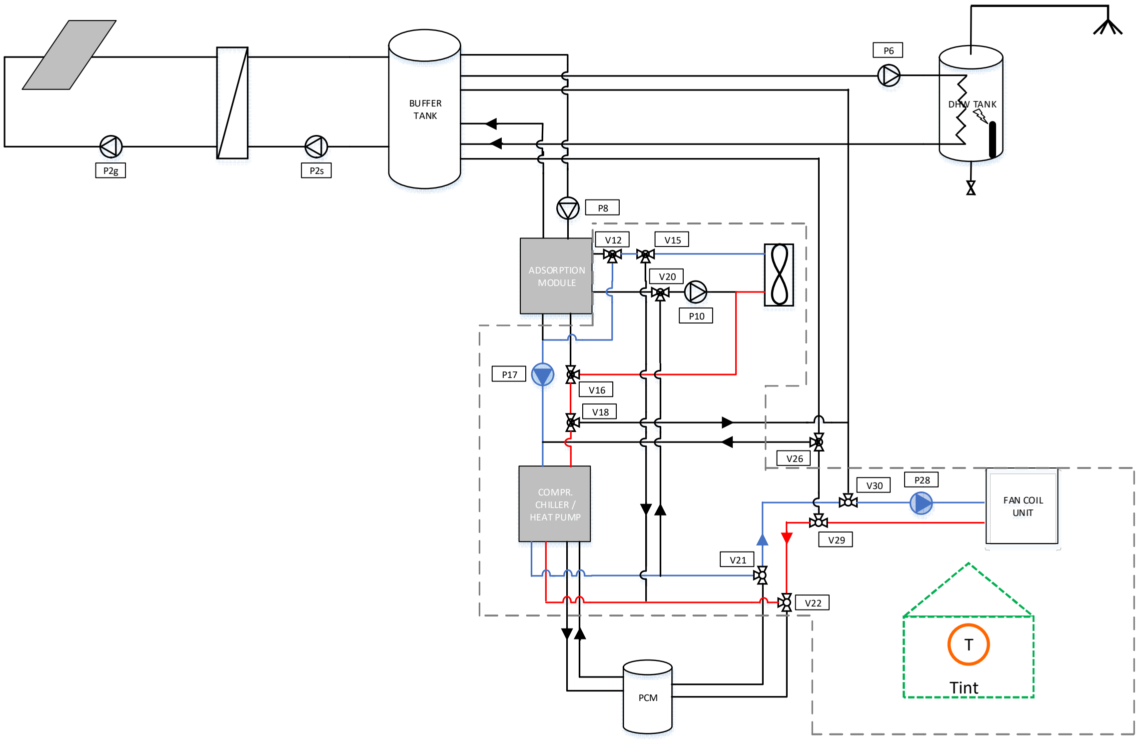

Figure 29 Schematic of the plant with the circuit involved by the scheme SC3a (cooling MODE 4)

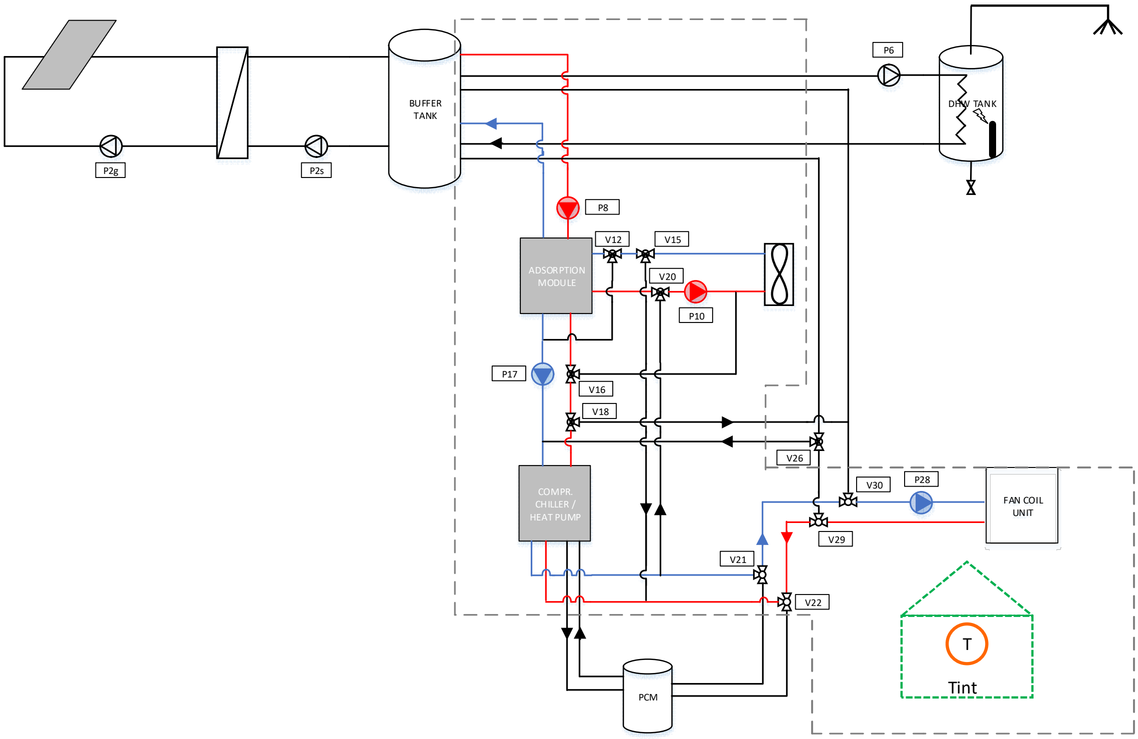

Figure 30 Schematic of the plant with the circuit involved by the scheme SC3b (cooling MODE 4)

Scheme 4 (SC4): PCM storage charging (charging MODE 1 and charging MODE 2)

This scheme is used to charge the PCM storage when it is empty and there is no cooling demand. Its activation depends on measured PCM SoC as well as cooling demand of the building. The charging of the PCM storage could be performed with Compression machine coupled with Adsorption module (scheme SC4b) or not (scheme SC4a). To discriminate between these two schemes, Hysteresis 2A, 2B and 2C, representing the necessary conditions for Adsorption machine activation, are included at the beginning of the schemes equations. Figure 31 and Figure 32 show respectively the active circuits in scheme SC4a and SC4b.

$$SC4a\ (charging\ MODE\ 1) = NOT(2A) * 2B * 2C * NOT(3B) * NOT(4B)$$

$$SC4b\ (charging\ MODE\ 2) = 2A * NOT(2B) * NOT(2C) * NOT(3B) * NOT(4B)$$

Conditions that describe schemes SC4 are:

- PCM SoC charging control: Hysteresis 3B indicates if the PCM is charged or not. In SC4, the PCM is not charged, this means that SoC is lower than 0.1
- Space cooling demand identification: Hysteresis 4B is equal to 0 because indoor temperature is lower than 26°C.
- ADS availability control: hysteresis 2A, 2B, 2C summarize the Adsorption module availability. Hysteresis values equal respectively to 1, 0, 0 imply the availability of the Adsorption module and therefore the possibility for the compression chiller to work coupled with it (SC4b), while if at least one of the three hysteresis presents a different value the Compression chiller must be connected directly to dry cooler (SC4a).

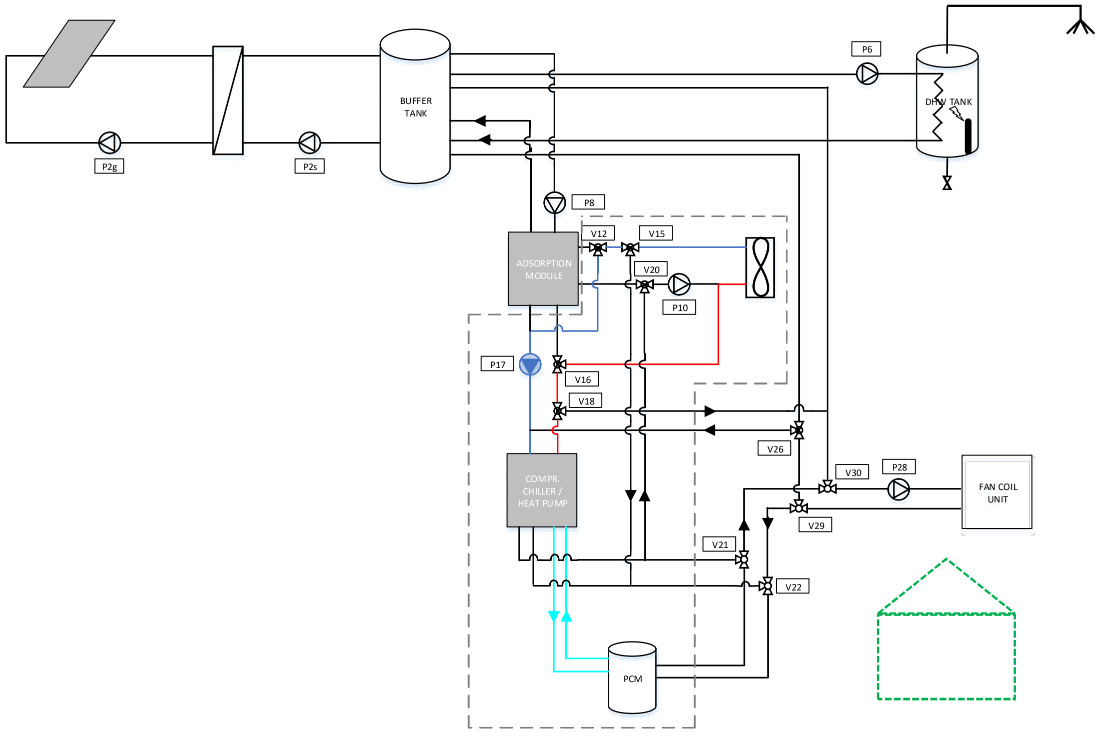

Figure 31 Schematic of the plant with the circuit involved by the scheme SC4a (charging MODE 1)

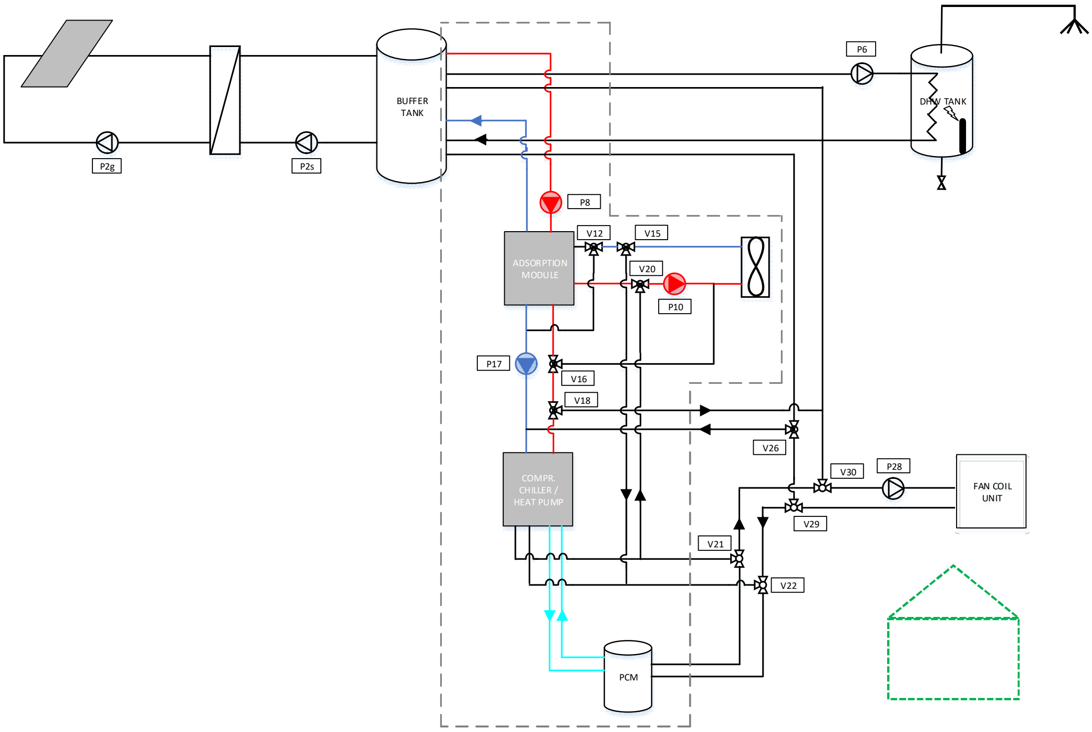

Figure 32 Schematic of the plant with the circuit involved by the scheme SC4b (charging MODE 2)

Scheme 5 (SC5) PCM storage discharging (cooling MODE 1)

This scheme aims to cover space cooling demand using only the energy previously stored in the PCM. Therefore, SoC of the PCM and space cooling demand identification are the variables used in this scheme. The logic equation that defines the considered scheme is the following:

$$SC5 = 3A * 4B$$

This equation is described by the following conditions:

- PCM SoC charging control: Hysteresis 3A indicates if the PCM is charged or not. In SC5, the PCM is charged, this means that SoC is higher than 0.1.
- Space cooling demand identification: Hysteresis 4B is equal to 1 because indoor temperature is higher than 26°C and maintains this condition until internal temperature falls below 25.5 °C

Figure 33 reports the circuits involved by scheme SC5.

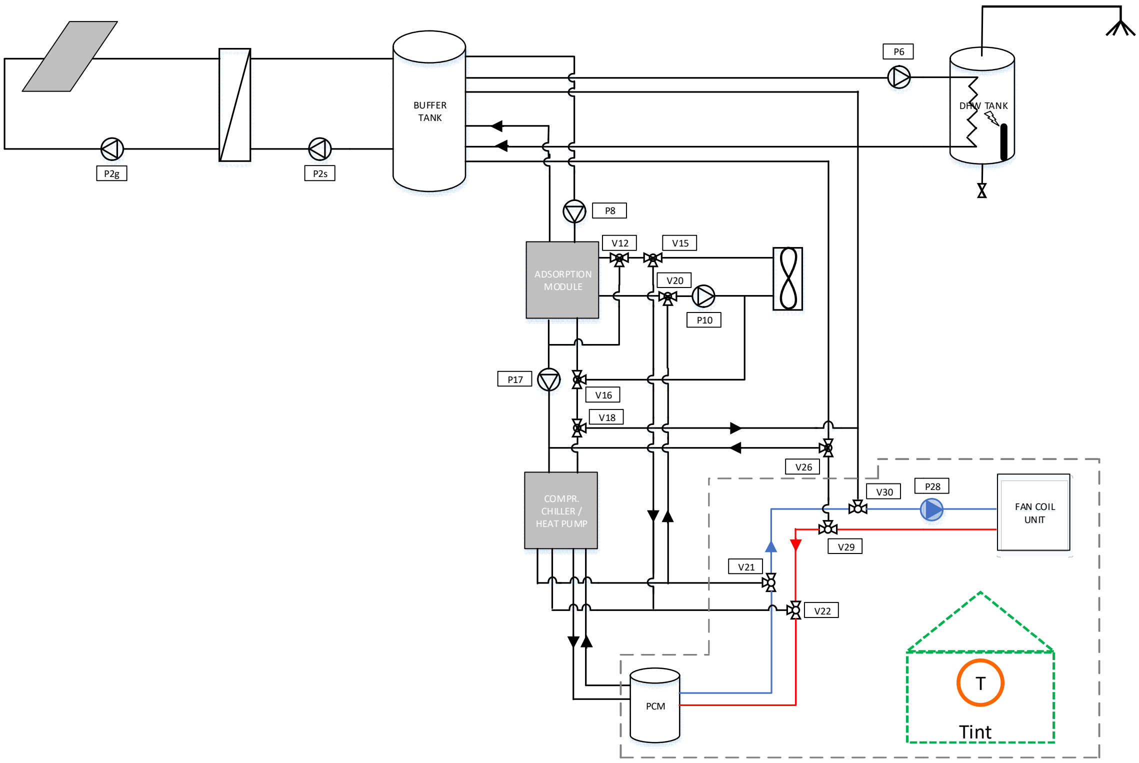

Figure 33 Schematic of the plant with the circuit involved by the scheme SC5 (cooling MODE 1)

Scheme 6 (SC6) PCM storage charging/discharging (cooling MODE 3 and cooling MODE 5)

Scheme 6 is used when there is space cooling demand but only PCM cannot cover it through SC5. As in SC5, SoC of PCM and space cooling identification are the variables present in the equations. Moreover, they comprise also Hysteresis 2A, 2B, 2C, that, representing the operative status of Adsorption module, are responsible of the split of scheme 6 in two sub-schemes SC6a and SC6b considering respectively the coupling of Compression Chiller with Adsorption module (SC6b) or not (SC6a).

$$SC6a\ (cooling\ MODE\ 3) = NOT(2A) * 2B * 2C * NOT(3A) * 4B$$

$$SC6b\ (cooling\ MODE\ 5) = 2A * NOT(2B) * NOT(2C) * NOT(3A) * 4B$$

Conditions that describe schemes SC6 are:

- PCM SoC charging control: Hysteresis 3A indicates if the PCM is charged or not. In SC6, the PCM is at the beginning not charged, this means that SoC is lower than 0.1. This condition is maintained until SoC equal to 0.9 is reached.
- Space cooling demand identification: Hysteresis 4B is equal to 1 because indoor temperature is higher than 26°C and maintains this condition until internal temperature falls below 25.5 °C
- ADS availability control: hysteresis 2A, 2B, 2C summarize the Adsorption module availability. Hysteresis values equal respectively to 1, 0, 0 imply the availability of the Adsorption module and therefore the possibility for the compression chiller to work coupled with it (SC6b), while if at least one of the three hysteresis presents a different value the Compression chiller must be connected directly to dry cooler (SC6a)

In Figure 34 and Figure 35 scheme SC6a and SC6b are shown.

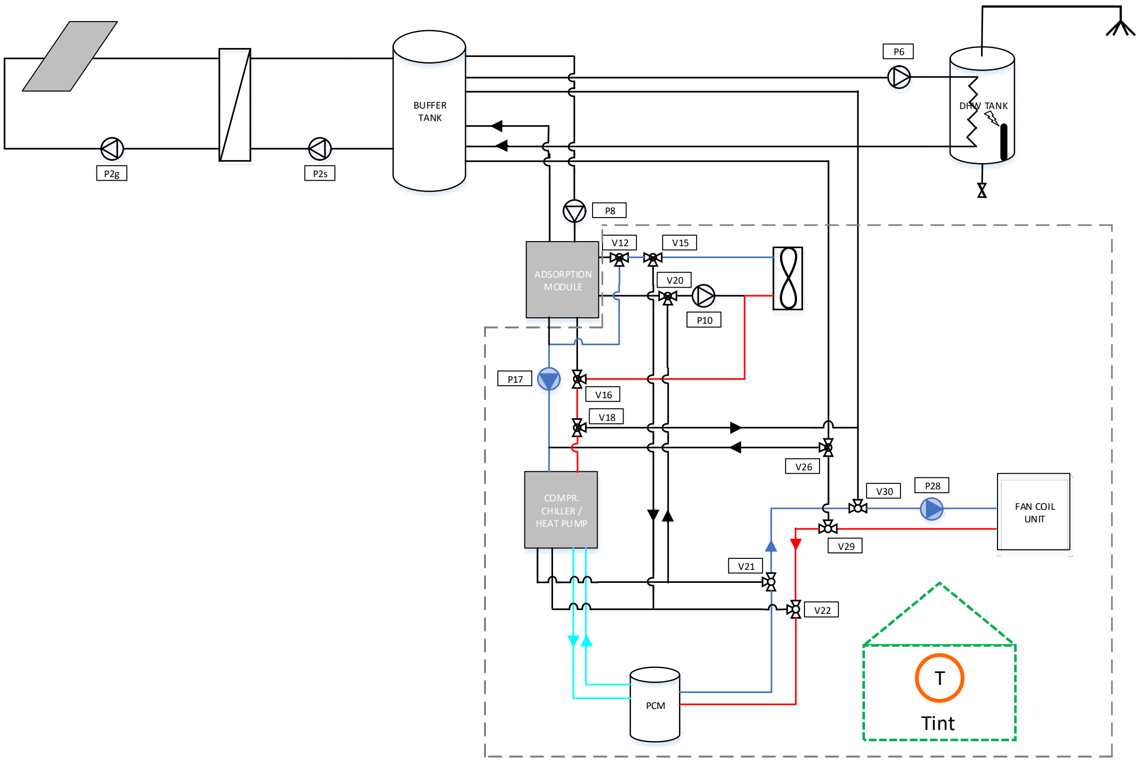

Figure 34 Schematic of the plant with the circuit involved by the scheme SC6a (cooling MODE 3)

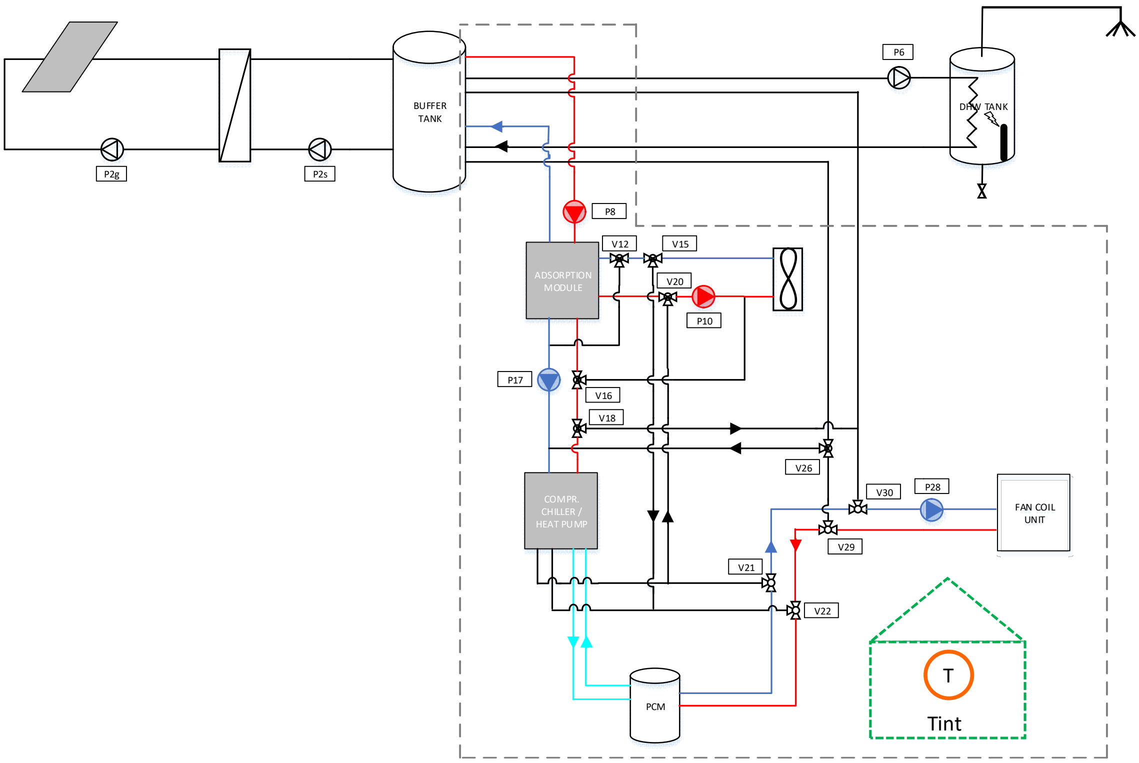

Figure 35 Schematic of the plant with the circuit involved by the scheme SC6b (cooling MODE 5)

Scheme 10 (SC10) space cooling demand identification

This scheme is used to identify space cooling demand. Hysteresis 4B assumes value equal to 1 if measured indoor air temperature reaches 26 °C and turns to 0 when it falls below 25.5 °C.

$$SC10 = 4B$$

Scheme 11 (SC11) DHW Tank charging

Scheme 11 is structured to charge DHW Tank and ensures DHW availability to the users. In addition to traditional ways to charge DHW Tank as gas boiler or electrical resistance (SC11a), HYBUILD system, foreseen also the possibility to exploit solar source to contribute to DHW production (SC11b). Figure 36 and Figure 37 show the active circuits respectively in scheme SC11a and scheme SC11b.

$$SC11a\ (DHW\ MODE\ 2) = NOT(5A) * NOT(5B)$$

$$SC11b\ (DHW\ MODE\ 1) = NOT(5A) * (5B)$$

The equations above are described by the following conditions:

- DHW Tank top temperature control: Hysteresis 5A is related to DHW Tank top temperature. If this temperature falls below 50°C Hysteresis 5A turns from 1 to 0 and remains 0 until DHW Tank top temperature reaches 55°C.
- Temperature difference control: Buffer Tank top temperature and DHW Tank top temperature are compared. If the difference between the first and the second is greater than 5°C Hysteresis 5B is 1. When the same temperature difference falls below 2 °C Hysteresis 5B turns to 0.

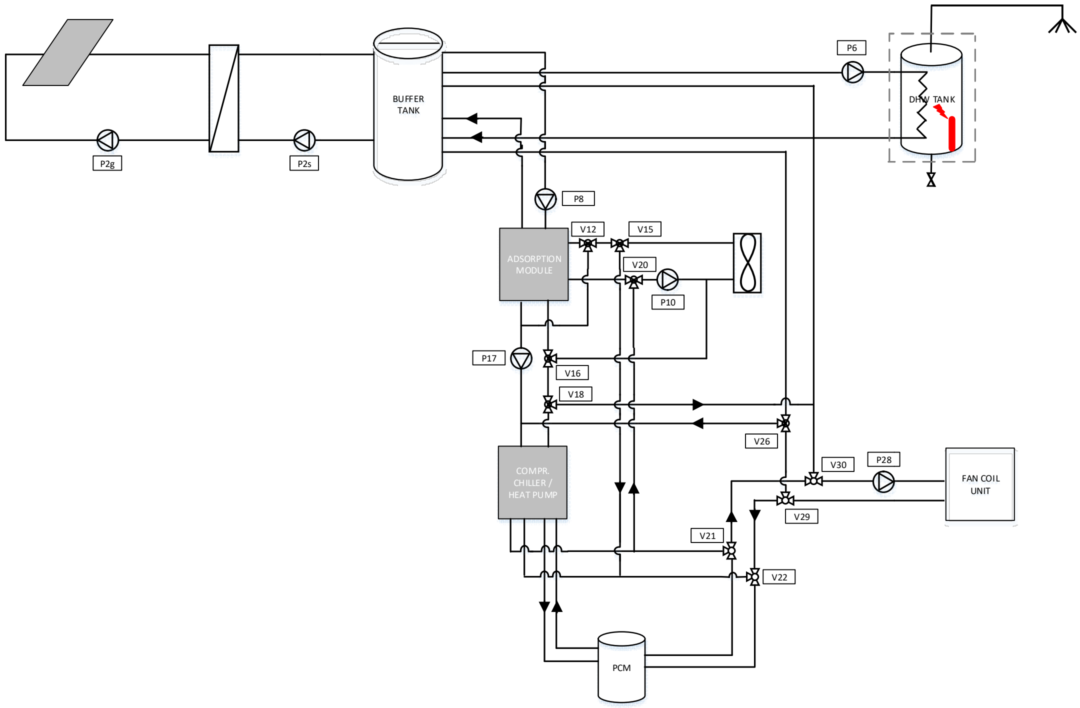

Figure 36 Schematic of the plant with the circuit involved by the scheme SC11a (DHW_MODE_2)

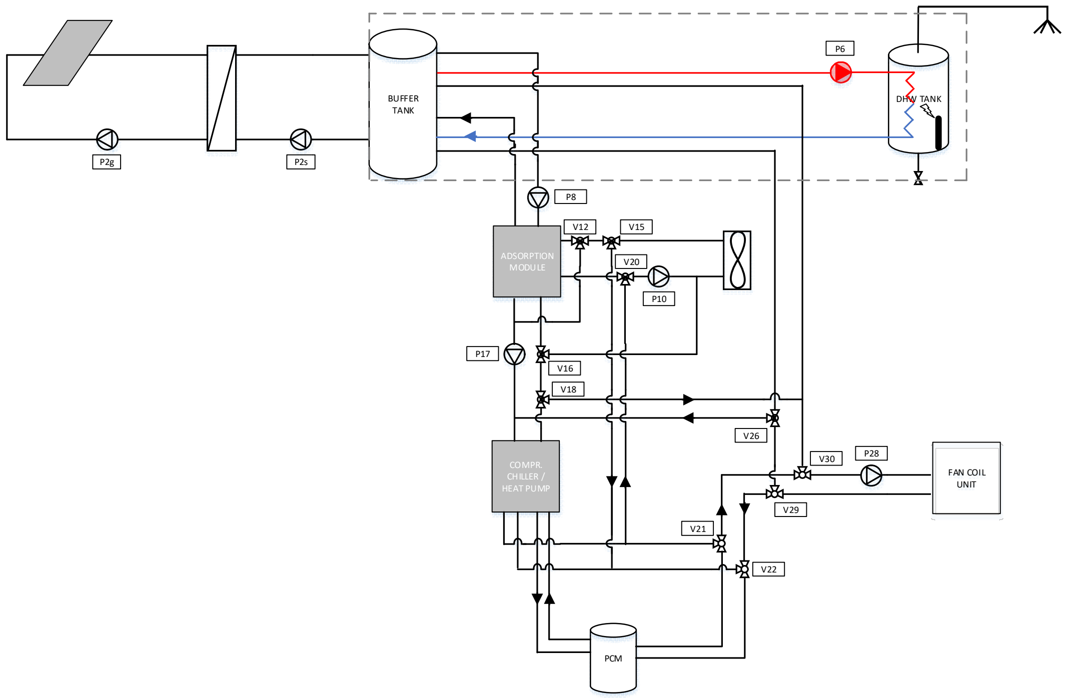

Figure 37 Schematic of the plant with the circuit involved by the scheme SC11b (DHW_MODE_1)

Scheme 12 (SC12) space heating demand identification

This scheme is used to identify space heating demand. Hysteresis 4A turns from 1 to 0 if measured indoor air temperature falls below 21 °C and turns again to 1 when it reaches 21.5 °C.

$$SC12 = NOT(4A)$$

Scheme 13 (SC13) free heating (Heating MODE 2)

Scheme 13 is used to cover space heating demand not using the conventional heat source but instead the free heating mode exploiting one of the HYBUILD MED system possibility. The definition of the scheme using logic representation is reported in the following equation:

$$SC13 = 1F * NOT(4A)$$

Conditions that describe scheme SC13 are:

- Buffer Tank temperature control: Hysteresis 1F is 1 if Buffer Tank top temperature is higher than 45 °C, while turn to 0 if it falls below 40 °C.
- Space heating demand identification: Hysteresis 4A is equal to 0 because indoor temperature is lower than 21°C and maintains this condition until internal temperature reaches 21.5 °C

Figure 38 shows the active circuits in SC13.

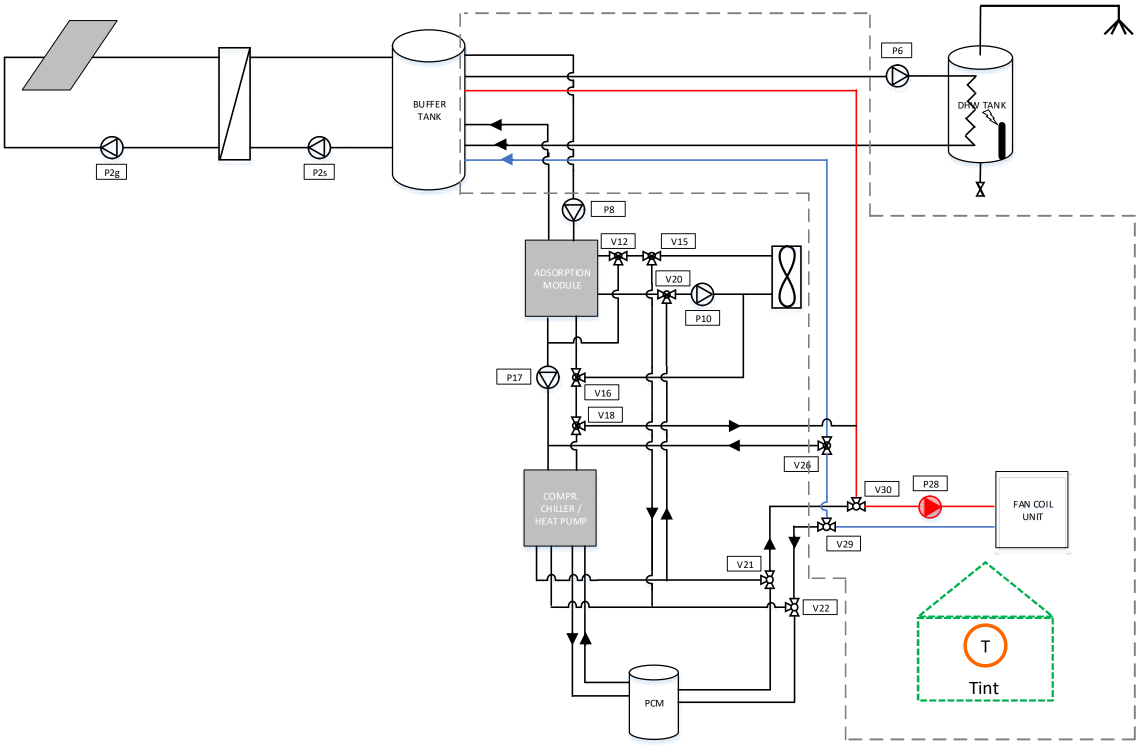

Figure 38 Schematic of the plant with the circuit involved by the scheme SC13 (Heating_MODE_2)

Scheme 14 (SC14) space heating through auxiliary source (Heating MODE 1)

If space heating demand is identified but SC13 cannot be activated an auxiliary heating system is activated. Scheme 14 identifies this solution and regulates the operation of the components involved by the scheme. The equation that defines SC14 is reported below, while Figure 39 reports the circuits activated by the scheme.

$$SC14 = NOT(1F) * NOT(4A)$$

This equation is described by the following conditions:

- Buffer Tank temperature control: Hysteresis 1F is 0 because in SC14 Buffer Tank top temperature is lower than 40 °C.
- Space heating demand identification: Hysteresis 4A is equal to 0 because indoor temperature is lower than 21°C and maintains this condition until internal temperature reaches 21.5 °C.

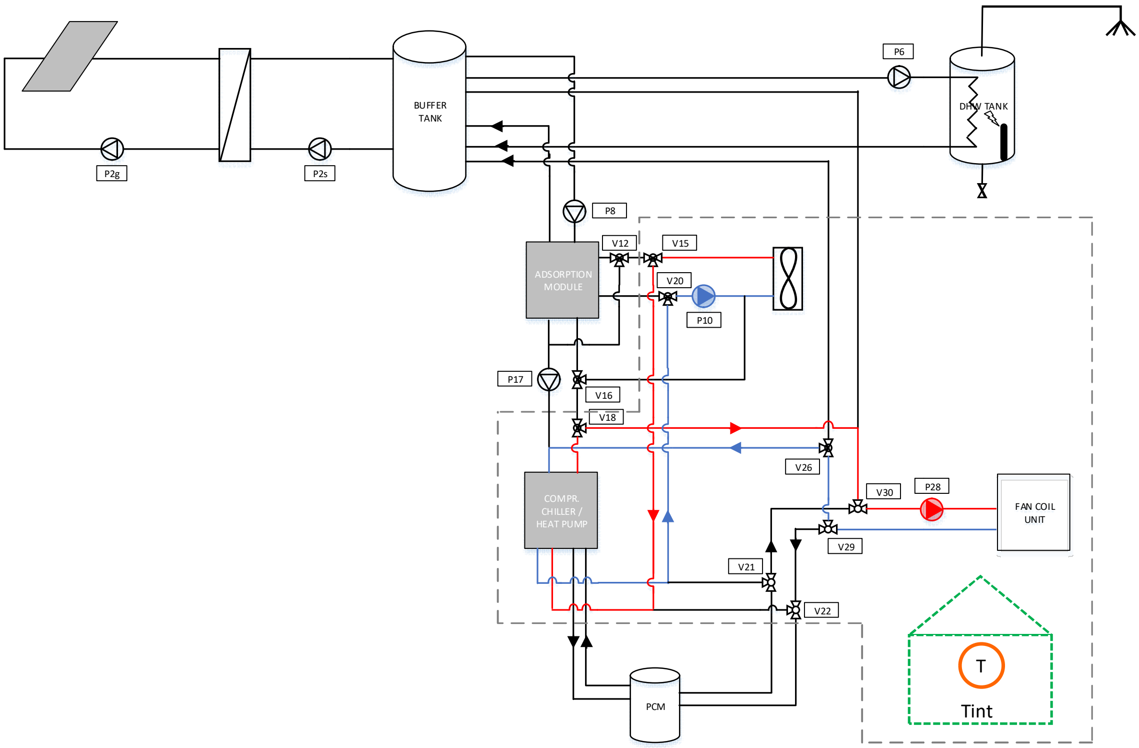

Figure 39 Schematic of the plant with the circuit involved by the scheme SC13 (Heating_MODE_1)

Control Signal

Each active component of the plant is connected to a general or local controller that sends a specific control signal for defining the operation state, result of the combination of the aforementioned schemes. For the sake of clarity, in the following the control signals are grouped based on the sub-system division reported in Figure 27. For each sub-system, a table reports the controlled components label and description, and the schemes in which the component is activated.

Solar Thermal Circuit

Circulating pumps P2g and P2s are the components controlled in the solar thermal circuit. Their activation, following the conditions presented above, allows the charging of Buffer Tank using the solar thermal collector field. Table 33 summarizes the controlled components of the considered sub-system and the schemes responsible of their activation.

Table 33 STC sub-system components´ control signals

Component	Description	Control Signal
STC P2g	Solar Thermal Circuit circulating pump	SC2
STC P2s	Solar Thermal Circuit circulating pump	SC2

Adsorption module

Adsorption module´s aim is to ensure cold water at the condenser side of the compression chiller. The considered sub-system is composed by the adsorption module, the three circulating pumps P8, P10, P17 responsible of the water flowing in hot water, cooling water and chilled water circuits, two three-way valves V12 and V16 that operate to bypass the Adsorption module when there are not the conditions for running the adsorption module and two three-way valves V15 and V20 that operate in winter to connect the dry cooler at the evaporator side of the compression chiller allowing to deliver hot water to the distribution system (Figure 27). Table 34 summarizes the components of the adsorption module sub-system and the schemes responsible of their activation.

Table 34 ADS sub-system components´ control signals

Component	Description	Control Signal
ADS	Adsorption module	SC3b+SC4b+SC6b
ADS DRY-C	Dry cooler	SC3a+SC3b+SC4a+SC4b+SC6a+SC6b
ADS P8	Adsorption module hot circuit circulating pump	SC3b+SC4b+SC6b
ADS P10	Adsorption module cooling circuit circulating pump	SC3b+SC4b+SC6b
ADS P17	Adsorption module chilled circuit circulating pump	SC3a+SC3b+SC4a+SC4b+SC6a+SC6b
ADS V 12	Adsorption circuit three-way valve	SC3a+SC4a+SC6a
ADS V 15	Adsorption circuit three-way valve	SC14
ADS V 16	Adsorption circuit three-way valve	SC3a+SC4a+SC6a
ADS V 20	Adsorption circuit three-way valve	SC14

Compression chiller

Compression Chiller activation is meant to charge the PCM storage (schemes 4a, 4b and, depending on cooling demand schemes 6a, 6b) or to cover space cooling demand directly through the direct connection to the fan coil units (schemes 3a and 3b). Table 35 summarizes the schemes responsible of compression chiller´s activation.

Table 35 HP sub-system components´ control signals

Component	Description	Control Signal
HP	Compression Chiller	SC3a+SC3b+SC4a+SC4b+SC6a+SC6b

Distribution circuit

Distribution circuit scope is the delivering of thermal energy to the building. The components of this sub-system are the circulating pump P28 (that ensures water flow to the terminal units), valves V18 and V26, responsible of the connection between condenser side of the compression chiller and fan coil units to deliver space heating through compression machine in winter, valves 21 and V22, responsible of the PCM storage bypass (schemes 3a and 3b) and valves V29 and V30, responsible of the selection of the appropriate space heating mode between SC13 and SC14 based on the aforementioned conditions. Table 36 summarizes the components of the distribution circuit and the schemes responsible of their activation.

Table 36 DIS sub-system components´ control signals

Component	Description	Control Signal
DIS P28	Distribution circuit circulating pump	SC3a+SC3b+SC4a+SC4b+SC5+SC6a+SC6b+SC13+SC14
DIS_V 18	Distribution circuit three-way valve	SC14
DIS_V 21	Distribution circuit three-way valve	SC3a+SC3b
DIS_V 22	Distribution circuit three-way valve	SC3a+SC3b
DIS_V 26	Distribution circuit three-way valve	SC14
DIS_V 29	Distribution circuit three-way valve	SC13+SC14
DIS_V 30	Distribution circuit three-way valve	SC13+SC14

Domestic Hot Water circuit

DHW is ensured to the final user through a DHW Tank that can be charged using the Buffer Tank, therefore, exploiting solar availability (SC11b) or using an electrical resistance (SC11a). In the first case circulating pump P6 is the active component, while the second foresees the activation of the auxiliary heater. Table 37 summarizes the controlled components of the DHW circuit and the schemes responsible of their activation.

Table 37 DHW sub-system components´ control signals

Component	Description	Control Signal
DHW P6	DHW circuit circulating pump	SC11_b
DHW AUX HEATER	DHW auxiliary heater	SC11_a

6.2 Appendix B

Table 38 Definition of the possible Mediterranean Solution modes according to the state of the system (SoS)

State of the system	Components status					Cooling Modes	Charging Modes	Heating Modes	DHW Modes	Solar Field Mode
	RPW-HEX	Buffer Tank	Fresnel or other ST	PV plant	Electric Storage					
SoS1	SoC > L1	Water @ T < T_{SETBT}	Solar energy below threshold level	Solar energy below threshold level	SoC > E1	C mode 1 C mode 2a C mode 2b C mode 3a C mode 3b	\	H mode 1a H mode 1b	DHW mode 2	\
SoS2	SoC > L1	Water @ T > T_{SETBT}	Solar energy below threshold level	Solar energy below threshold level	SoC > E1	C mode 1 C mode 2a C mode 2b C mode 3a C mode 3b C mode 4a C mode 4b C mode 5a C mode 5b	\	H mode 1a H mode 1b H mode 2	DHW mode 1	\
SoS3	SoC > L1	Water @ T> T_{SETBT}	Solar energy above threshold level	Solar energy above threshold level	SoC > E1	C mode 1 C mode 2b C mode 2c C mode 3b C mode 3c C mode 4b C mode 4c C mode 5b C mode 5c	\	H mode 1b H mode 1c H mode 2	DHW mode 1	\
SoS4	SoC > L1	Water @ T < T_{SETBT}	Solar energy above threshold level	Solar energy above threshold level	SoC > E1	C mode 1 C mode 2b C mode 2c C mode 3b C mode 3c	\	H mode 1b H mode 1c	DHW mode 2	Solar field mode

SoS5	SoC > L1	Water @ T < T_{SETBT}	Solar energy below threshold level	Solar energy below threshold level	SoC < E1	C mode 1 C mode 2a C mode 3a	\	H mode 1a	DHW mode 2	\
SoS6	SoC > L1	Water @ T > T_{SETBT}	Solar energy below threshold level	Solar energy below threshold level	SoC < E1	C mode 1 C mode 2a C mode 3a C mode 4a C mode 5a	\	H mode 1a H mode 2	DHW mode 1	\
SoS7	SoC > L1	Water @ T> T_{SETBT}	Solar energy above threshold level	Solar energy above threshold level	SoC < E1	C mode 1 C mode 2c C mode 3c C mode 4c C mode 5c	\	H mode 1c H mode 2	DHW mode 1	\
SoS8	SoC > L1	Water @ T < T_{SETBT}	Solar energy above threshold level	Solar energy above threshold level	SoC < E1	C mode 1 C mode 2c C mode 3c	\	H mode 1c	DHW mode 2	Solar field mode
SoS9	SoC < L1	Water @ T < T_{SETBT}	Solar energy below threshold level	Solar energy below threshold level	SoC < E1	C mode 2a C mode 3a	Ch mode 1a	H mode 1a	DHW mode 2	\
SoS10	SoC < L1	Water @ T > T_{SETBT}	Solar energy below threshold level	Solar energy below threshold level	SoC < E1	C mode 2a C mode 3a C mode 4a C mode 5a	Ch mode 1a Ch mode 2a	H mode 1a H mode 2	DHW mode 1	\
SoS11	SoC < L1	Water @ T> T_{SETBT}	Solar energy above threshold level	Solar energy above threshold level	SoC < E1	C mode 2c C mode 3c C mode 4c C mode 5c	Ch mode 1c Ch mode 2c	H mode 1c H mode 2	DHW mode 1	\
SoS12	SoC < L1	Water @ T < T_{SETBT}	Solar energy above	Solar energy above	SoC < E1	C mode 2c C mode 3c	Ch mode 1c	H mode 1c	DHW mode 2	Solar field mode

			threshold level	threshold level						
SoS13	SoC < L1	Water @ T < T_{SETBT}	Solar energy below threshold level	Solar energy below threshold level	SoC > E1	C mode 2a C mode 2b C mode 3a C mode 3b	Ch mode 1a Ch mode 1b	H mode 1a H mode 1b	DHW mode 2	\
SoS14	SoC < L1	Water @ T > T_{SETBT}	Solar energy below threshold level	Solar energy below threshold level	SoC > E1	C mode 2a C mode 2b C mode 3a C mode 3b C mode 4a C mode 4b C mode 5a C mode 5b	Ch mode 1a Ch mode 1b Ch mode 2a Ch mode 2b	H mode 1a H mode 1b H mode 2	DHW mode 1	\
SoS15	SoC < L1	Water @ T> T_{SETBT}	Solar energy above threshold level	Solar energy above threshold level	SoC > E1	C mode 2b C mode 2c C mode 3b C mode 3c C mode 4b C mode 4c C mode 5b C mode 5c	Ch mode 1b Ch mode 1c Ch mode 2b Ch mode 2c	H mode 1b H mode 1c H mode 2	DHW mode 1	\
SoS16	SoC < L1	Water @ T < T_{SETBT}	Solar energy above threshold level	Solar energy above threshold level	SoC > E1	C mode 2b C mode 2c C mode 3b C mode 3c	Ch mode 1b Ch mode 1c	H mode 1b H mode 1c	DHW mode 2	Solar field mode

6.3 Appendix C

Table 39 Definition of the possible Continental Solution modes according to the state of the system (SoS)

State of the system					Heating Modes	DHW Modes	Cooling Modes
SoS1	**Enerboxx**	**PV plant**	**Electric storage**	**RPW-HEX**			
SoS1	T Enerboxx > T_{SETEB}	Solar energy above threshold level	SoC > E1	SoC > L1	H mode 1a H mode 1b H mode 1c	No charging needed	C mode 1a C mode 1b C mode 1c
SoS2	T Enerboxx > T_{SETEB}	Solar energy above threshold level	SoC > E1	SoC < L1	H mode 1a H mode 1b H mode 1c	No charging needed	C mode 1a C mode 1b C mode 1c
SoS3	T Enerboxx > T_{SETEB}	Solar energy above threshold level	SoC < E1	SoC > L1	H mode 1a H mode 1c	No charging needed	C mode 1a C mode 1c
SoS4	T Enerboxx > T_{SETEB}	Solar energy above threshold level	SoC < E1	SoC < L1	H mode 1a H mode 1c	No charging needed	C mode 1a C mode 1c

SoS5	T Enerboxx > T_{SETEB}	Solar energy below threshold level	SoC > E1	SoC > L1	H mode1a H mode1b	No charging needed	C mode 1a C mode 1b
SoS6	T Enerboxx > T_{SETEB}	Solar energy below threshold level	SoC > E1	SoC < L1	H mode1a H mode1b	No charging needed	C mode 1a C mode 1b
SoS7	T Enerboxx > T_{SETEB}	Solar energy below threshold level	SoC < E1	SoC > L1	H mode1a	No charging needed	C mode 1a
SoS8	T Enerboxx > T_{SETEB}	Solar energy below threshold level	SoC < E1	SoC < L1	H mode1a	No charging needed	C mode 1a
SoS9	T Enerboxx < T_{SETEB}	Solar energy above threshold level	SoC > E1	SoC > L1	H mode 1a H mode 1b H mode 1c	DHW mode 1a DHW mode 1b DHW mode 1c DHW mode 2	C mode 1a C mode 1b C mode 1c
SoS10	T Enerboxx < T_{SETEB}	Solar energy above threshold level	SoC > E1	SoC < L1	H mode 1a H mode 1b H mode 1c	DHW mode 2 DHW mode 3a DHW mode 3b DHW mode 3c	C mode 1a C mode 1b C mode 1c

SoS11	T Enerboxx < T_{SETEB}	Solar energy above threshold level	SoC < E1	SoC > L1	H mode 1a H mode 1c	DHW mode 1a DHW mode 1c DHW mode 2	C mode 1a C mode 1b
SoS12	T Enerboxx < T_{SETEB}	Solar energy above threshold level	SoC < E1	SoC < L1	H mode 1a H mode 1c	DHW mode 2 DHW mode 3a DHW mode 3c	C mode 1a C mode 1b
SoS13	T Enerboxx < T_{SETEB}	Solar energy below threshold level	SoC > E1	SoC > L1	H mode1a H mode1b	DHW mode 1a DHW mode 1b DHW mode 2	C mode 1a C mode 1b
SoS14	T Enerboxx < T_{SETEB}	Solar energy below threshold level	SoC > E1	SoC < L1	H mode1a H mode1b	DHW mode 2 DHW mode 3a DHW mode 3b	C mode 1a C mode 1b
SoS15	T Enerboxx < T_{SETEB}	Solar energy below threshold level	SoC < E1	SoC > L1	H mode1a	DHW mode 1a DHW mode 2	C mode 1a
SoS16	T Enerboxx < T_{SETEB}	Solar energy below threshold level	SoC < E1	SoC < L1	H mode1a	DHW mode 2 DHW mode 3a	C mode 1a

6.4 Appendix D

Table 40 Mediterranean solution components list

ID n°	Sensor/Component	Measurement	Functionality	Reference controller	Note
Tint	**Temperature indicator transmitter**	Building internal temperature	It is the building internal temperature to be compared to the set-point to switch on and off the space heating and cooling systems	Building data logger / PLC	To be verified which data will be actually collected in each demo and using which system
Text	**Temperature indicator transmitter**	External ambient temperature	Used to adjust set-points accordingly	Building data logger / PLC	
Solar field and Buffer Tank					
TT101	**Temperature transmitter**	Temperature of the flow entering solar field		Solar thermal controller/datalogger	
PT102	**Pressure transmitter**	Pressure of the flow entering solar field		Solar thermal controller/datalogger	
FT103	**Flow rate transmitter**	Water flow rate entering solar field		Solar thermal controller/datalogger	
TT104	**Temperature transmitter**	Output water temperature of solar panel	Used by Fresnel system controller	Solar thermal controller/datalogger	
TT105	**Temperature transmitter**	Output water temperature of solar panel	Used by Solar Thermal supply controller (together with (TT301) for activating pumps2 and pump 5	Solar Thermal supply controller	
DNI106	**Direct normal irradiance indicator transmitter**	DNI on Fresnel solar panels	Used to activate Fresnel loop	Solar thermal controller/datalogger (only with Fresnel system)	
TRACK107 (3x)	**Direct normal irradiance indicator transmitter**	DNI on Fresnel solar panels	Used to activate Fresnel loop	Solar thermal controller/datalogger (only with Fresnel system)	3 track sensors in the solar field
TT301	**Temperature transmitter**	Water temperature at the top of buffer tank	Used to activate pump 7, pump 5 and pump 2	Solar Thermal supply controller / Thermal Controller	

TT302	**Temperature transmitter**	Water temperature at the bottom of buffer tank		Solar Thermal supply controller	
1	**Fresnel or other Solar Panel**	\	Solar Heat production	\	
2	**Hydraulic System STM90**	\	It contains all the element necessary to run the solar circuit	\	
2a	**Two way ball valve**	\		\	
2b	**Check valve**	\	It allows the water flow only in one direction.	\	
2c	**Air separator**	\		\	
2d	**Shut-off valve**	\		\	
2e	**Two way ball valve**	\		\	
2f	**Check valve**	\	It allows the water flow only in one direction.	\	
2g	**Circulating pump**	\	Activate primary solar circuit	Solar Thermal supply controller	
2h	**Shut-off valve**	\		\	
2i	**Heat exchanger**	\	Separate primary from secondary solar circuit.	\	
2j	**Security valve**	\		\	
2k	**Shut-off valve**	\		\	
2l	**Manometer**	\		\	
2m	**Collecting vessel**	\		\	
2n	**Security valve**	\		\	
2o	**Shut-off valve**	\		\	
2p	**Two way ball valve**	\		\	
2q	**Check valve**	\	It allows the water flow only in one direction.	\	
2r	**Two way ball valve**	\		\	
2s	**Circulating pump**	\	It activates the secondary	Solar Thermal supply	

			solar circuit	controller	
2t	**Two way ball valve**	\		\	
2u	**Shut-off valve**	\		\	
3	**Pressure Control Unit**	\	Pressure control in the loop	\	
4	**Buffer Tank**	\	Storage of hot water produced by solar plant	\	
49	**Expansion vessel**	\	It accommodates the increase in the volume of water due to the raising of its temperature		
Domestic Hot water circuit					
TC501	**Temperature controller**	Supply temperature to DHW tank	Control the mixing valve 5, in order to regulate the flow temperature entering the DHW tank	\	
TT504	**Temperature transmitter**	Supply temperature to DHW tank	TT504, TT502, FTI503 are meant to monitor water temperatures and flow in the DHW circuit and measure the energy provided to DHW tank.	Building data logger / PLC	The 3 sensor can be replaced by a single energy meter.
TT502	**Temperature transmitter**	Return temperature to DHW tank		Building data logger / PLC	
FTI503	**Flow rate transmitter**	Flow rate in DHW circuit		Building data logger / PLC	
TT601	**Temperature controller**	Temperature inside the DHW tank	Used to control the pump 6 to activate DHW circuit	Thermal controller	
5	**3-way valve**	\	Mixing (modulating) valve regulating temperature according to TC501 set-point value	Directly controlled by TC501	
6	**Circulating pump**	\	DHW circuit circulating pump (constant speed?)	Thermal controller	
6a	**2-way ball valve**	\	It separates pump 6 in case of maintenance	\	
6b	**Check valve**	\	It allows the water flow only in one direction	\	
6c	**2-way ball valve**	\	It separate pump 6 in case of maintenance	\	

7	**DHW Tank**		Storage of domestic hot water	\	
7a	**Electrical heater**		Back-up heater to heat-up the water inside the DHW tank	\	
55	**Expansion vessel**		It accommodates the increase in the volume of water due to the raising of its temperature		
Sorption module - dry cooler circuit					
TT401	**Temperature transmitter**	Sorption module water flow inlet temperature form buffer tank	TT401, TT403, FTI402 are meant to monitor temperatures and flow in the 'buffer tank-Sorption module' circuit and measure the energy provided to the sorption module.	Thermal controller	The 3 sensor can be replaced by a single energy meter.
TT403	**Temperature transmitter**	Sorption module water flow outlet temperature to buffer tank		Thermal controller	
FTI402	**Flow meter**	Water flow rate from buffer tank to sorption module		Thermal controller	
SC404	**Speed control**	\	Together with PDC405, it regulates the speed of the pump according to circuit pressure variations	\	Included in sorption module equipment
PDC405	**Pressure differential controller**	Pressure difference between suction and pressure sides	Together with SC404 it regulates the speed of the pump according to circuit pressure variations	\	Included in sorption module equipment
53	**Expansion vessel**	\	It accommodates the increase in the volume of water due to the raising of its temperature		
8	**Circulating pump**	\	It activates 'Buffer Tank-Sorption module' circuit.	Thermal controller	Included in sorption module equipment
8a	**2-way valve**	\	It separates Pump 8 in case of maintenance	\	Included in sorption module equipment
8b	**Check valve**	\	It allows the water flow only in one direction	\	Included in sorption module equipment

8c	**2-way valve**	\	It separates Pump 8 in case of maintenance	\	Included in sorption module equipment
9	**Sorption module**	\	\	\	
SC711	**Speed control**	\	Together with PDC712, it regulates the speed of the pump 10 according to circuit pressure variations	\	Included in sorption module equipment
PDC712	**Pressure differential controller**	Pressure difference between suction and pressure sides	Together with SC711 it regulates the speed of the pump 10 according to circuit pressure variations	\	Included in sorption module equipment
FTI708	**Flow meter**	Flow rate in 'sorption module - Hex 11' circuit (or 'HP - Hex11' circuit)	TT710, TT709, FTI708 are meant to monitor temperatures and flow in the 'Sorption module-Hex 11' circuit and measure the energy provided to the Hex 11.	Thermal controller	The 3 sensor can be replaced by a single energy meter.
TT709	**Temperature transmitter**	Sorption module water flow supply temperature to heat exchanger		Thermal controller	
TT710	**Temperature transmitter**	Sorption module water flow return temperature to heat exchanger		Thermal controller	
SC704	**Speed control**	\	Together with PDC705, it regulates the speed of the pump 13according to circuit pressure variations	\	
PDC705	**Pressure differential controller**	Pressure difference between suction and pressure sides	Together with SC704 it regulates the speed of the pump 13 according to circuit pressure variations	\	
SC706	**Speed control**	\	Together with PDC707 it regulates the speed of the dry cooler according to circuit pressure variations		
PDC707	**Pressure differential controller**	Pressure difference between suction and pressure sides	Together with SC706 it regulates the speed of the dry cooler according to		

			circuit pressure variations		
FTI701	**Flow meter**	Water flow rate in 'Hex 11 - dry cooler' circuit (or 'HP evaporator - Dry cooler' circuit)	TT702, TT703, FTI708 are meant to monitor temperatures and flow in the 'Hex 11-Dry cooler' circuit and measure the energy provided to the Dry cooler.	Thermal controller	The 3 sensor can be replaced by a single energy meter.
TT702	**Temperature transmitter**	Outlet water temperature of Dry cooler		Thermal controller	
TT703	**Temperature transmitter**	Inlet water temperature of Dry cooler		Thermal controller	
10	**Circulating pump**	\	It activates 'Sorption module-Hex 11'' circuit.	Thermal controller	Included in sorption module equipment
10a	**2-way valve**	\	It separates Pump 10 in case of maintenance	\	Included in sorption module equipment
10b	**check valve**	\	It allows the water flow only in one direction.	\	Included in sorption module equipment
10c	**2-way valve**	\	It separates Pump 10 in case of maintenance	\	Included in sorption module equipment
11	**Heat exchanger**	\	Separate water circuit (Sorption module side) form the water-glycol circuit (dry cooler side)	\	
12	**3-way valve**	\	Selective valve: together with valve 16 connects HP condenser to dry-cooler if the sorption module is not working	Thermal controller	
51	**Expansion vessel**	\	It accommodates the increase in the volume of water due to the raising of its temperature		
13	**Circulating pump**	\	It activates 'Hex 11-Dry cooler' circuit.	Thermal controller	
13a	**2-way valve**	\	It separates Pump 13 in case of maintenance	\	

13b	**check valve**	\	It allows the water flow only in one direction.	\	
13c	**2-way valve**	\	It separates Pump 13 in case of maintenance	\	
14	**Dry cooler**	\	It removes the waste heat produced by Sorption module or by the heat pump		
Power meter 4	**Power meter 4**	Electricity consumed by dry cooler			
15	**3-way valve**	\	Selective valve: together with valve 20 connects HP evaporator to dry-cooler when heating mode is operating	Manual	
50	**Expansion vessel**	\	It accommodates the increase in the volume of water due to the raising of its temperature		
Sorption module Heat pump circuit					
16	**3-way valve**	\	Selective valve: together with valve 12 connects HP condenser to dry-cooler if the sorption module is not working	Thermal controller	
SC803	**Speed control**	\	Together with PDC804 regulates the speed of the pump 17 according to circuit pressure variations	Thermal controller	
PDC804	**Pressure differential controller**	pressure difference between suction and pressure sides	Together with SC803 regulates the speed of the pump 17 according to circuit pressure variations	\	
17	**Circulating pump**	\	Is activates 'HP-Sorption module' or 'HP - Dry cooler' circuit	Thermal controller	
17a	**2-way valve**	\	It separates Pump 17 in case	\	

			of maintenance		
17b	**Check valve**	\	It allows the water flow only in one direction.	\	
17c	**2-way valve**	\	It separates Pump 17 in case of maintenance	\	
18	**3-way valve**		Selective valve: together with valve 26 connects HP condenser to the building to provide heat in heating mode	Manual	
TT801	**Temperature transmitter**	Compression HP condenser water flow inlet temperature	It activates pump 17 depending on the condensing temperature of the HP	Thermal controller	
TT802	**Temperature transmitter**	Compression HP condenser water flow outlet temperature	It indicates the temperature of the water leaving the HP condenser	Thermal controller	
52	**Expansion vessel**	\	It accommodates the increase in the volume of water due to the raising of its temperature		
Heat pump - RPW-HEX - Fan coil circuits					
19	**Compression Heat Pump**	\	It provides cooling or heating energy	\	
19a	**3-way valve**	\	Used to bypass standard evaporator	\	
19b	**standard evaporator**	\	Used in heating mode and in case of RPW-HEX should be bypassed	\	
20	**3-way valve**	\	Selective valve: together with valve 15 connects HP evaporator to dry-cooler when heating mode is operating	Manual	
21	**3-way valve**	\	Selective valve: together with valve 22 selects between HP and latent storage when cooling mode	Thermal controller	

			is operating		
22	**3-way valve**	\	Selective valve: together with valve 21 selects between HP and latent storage circuits when cooling mode is operating	Thermal controller	
23	**RPW-HEX**	\	Latent storage: it stores the cooling produced by HP	\	
PT1001	**pressure transmitter**	latent storage inlet pressure	It transmits the latent storage inlet pressure	Thermal controller	
PT1002	**Pressure transmitter**	Latent storage outlet pressure	It transmits the latent storage outlet pressure	Thermal controller	
TT1003	**Temperature transmitter**	Temperature inside the latent storage	It allows to know the temperature inside the latent storage	Thermal controller	
SOC1004	**State of charge**	State of charge of RPW-HEX	State of charge of RPW-HEX	Thermal controller	
SC1005	**Speed control**	\	Together with PDC1006, it regulates the speed of the pump 24 according to circuit pressure variations	Thermal controller	
PDC 1006	**Pressure differential controller**	pressure difference between suction and pressure sides	Together with SC1005, it regulates the speed of the pump 24 according to circuit pressure variations	\	
24	**Circulating pump**	\	It activates the RPW-HEX - Hex 25' circuit (or 'cHP-Hex25' circuit)	Thermal controller	
24a	**2-way valve**	\	It separates Pump 24 in case of maintenance	\	
24b	**Check valve**	\	It allows the water flow only in one direction.	\	
24c	**2-way valve**	\	Separate Pump 24 in case of maintenance	\	

39	**Expansion vessel**	\	It accommodates the increase in the volume of water due to the raising of its temperature		
25	**Heat exchanger**	\	It separate water-glycol circuit (HP and RPW-Hex side) form the water circuit (building side)	\	
26	**3-way valve**	\	Selective valve: together with valve18 connect HP condenser to the building emission system	Manual	
48	**Expansion vessel**	\	It accommodates the increase in the volume of water due to the raising of its temperature		
TC904	**Temperature controller**	Supply temperature to Emission system	It controls pump 27 for regulating the supply temperature	Directly control Pump 27	
SC905	**Speed control**	\	Together with PDC906 regulates the speed of the pump 28 according to circuit pressure variations	Thermal controller	
PDC906	**Pressure differential controller**	Pressure difference between suction and pressure sides	Together with SC905 regulates the speed of the pump 28according to circuit pressure variations	\	
FTI901	**Flow meter**	Water flow rate in 'Hex 25 - Emission system' circuit (or 'HP evaporator - Dry cooler' circuit)	TT902,TT903, FTI901 are meant to monitor temperatures and flow in the 'Hex 25- Emission system' circuit and measure the	Building data logger / PLC	

TT902	**Temperature transmitter**	Outlet temperature of Dry cooler	energy provided to the building.	Building data logger / PLC	
TT903	**Temperature transmitter**	Inlet temperature of Dry cooler		Building data logger / PLC	
27	**3-way valve**	\	Mixing valve: it regulate the flow temperature in 'Hex11- Emission system ' circuit	Controlled by TC904	
28	**Circulating pump**	\	It activates ‘Hex11- Emission system' circuit	Thermal controller	
28a	**2-way valve**	\	It separates Pump 8 in case of maintenance	\	
28b	**Check valve**	\	It allows the water flow only in one direction.	\	
28c	**2-way valve**	\	It separates Pump 8 in case of maintenance	\	
29	**3-way valve**	\	Selective valve: together with valve 29 connect the free heating circuit to the Emission system	Thermal controller	
30	**3-way valve**	\	Selective valve: together with valve 30 connect the free heating circuit to the Emission system	Thermal controller	
54	**Expansion vessel**	\	It accommodates the increase in the volume of water due to the raising of its temperature		
Electric circuit					
31	**Electric battery**	\			
32	**DC-DC Converter**	\			
33	**AC-DC Converter**	\			
34	**Ext grid**	\	\	\	\
35	**PV Panels and DC-DC converter**	\			
36	**Power meter 1**	Electricity produced by PV panels			

37	**Power meter 2**	Electricity provided to/by the Electric battery			
38	**Power meter 3**	Electricity provided to the HP			

6.5 Appendix E

Table 41 Continental solution components list

ID n°	Sensor/Component	Measurement	Functionality	Reference controller	Note
Tint(001)	**Temperature indicator transmitter**	Building internal temperature	It is the building internal temperature to be compared to the set-point to switch on and off the space heating and cooling systems	Thermal Controller	
Text(002)	**Temperature indicator transmitter**	External temperature	Used for optimization strategies definition and climate condition monitoring	Thermal Controller	
Primary and secondary circuits					
Text(003)	**Temperature indicator transmitter**	External temperature	Used to adjust HP set-points accordingly	OCHS Controller	
1	**Compression HP unit**	\	Reversible HP: it provides both apartment heating and cooling and heating for DHW	OCHS controller	
1f	**Heat exchanger**	\	Heat exchanger between refrigerant circuit and water circuit		
1g	**Electric heater**	\	It heats the hot water if the set temperature is not reached by the Compression Heat pump	OCHS controller	
1h	**Diverter 3 way valve**	\	It drives the flow to the HP - RPW-HEX circuit or to the HP - Hydraulic separator circuit		

1a	**Security valve**	\	It opens the drain pipe in case of overpressure		
1d	**Manual two way valve**	\	It opens or closes the connection with the expansion vessel		
1c	**Expansion vessel**	\	It accommodates the increase in the volume of water due to the raising of its temperature		
1e	**Circulating pump**	\	It runs the flow of the primary circuit (from HP to the Hydraulic separator)	OCHS controller	
FTI104	**Flow Transmitter indicator**	Water flow on the primary circuit	Used to measure the energy provided by HP+RPW-HEX: TT101;TT102;FTI104	Thermal Controller	
TI107	**Temperature transmitter**	Outlet water temperature of HP only.	Used to measure the energy provided by heat pump only: FTI104; TT107; TT101	Thermal Controller	
2	**RPW-HEX**	\	It harvests heating form the Compression HP cycle (superheating before the condensation) and provide it to the hot water when high temperature is required	\	
20	**Two way valve**	\		\	
SOC108	**State of charge**	Measure state of charge of the RPW-HEX		OCHS Controller	
TI103	**Temperature Transmitter**	Inlet water temperature of the RPW-HEX (2)	Energy provided by the RPW HEX: FTI105; TT103; TT106	Thermal Controller	
FTI105	**Flow Transmitter indicator**	Water flow exiting the RPW-HEX	Energy provided by the RPW-HEX: FTI105; TT103; TT106	Thermal Controller	
TI106	**Temperature Transmitter**	Temperature outlet of RPW-HEX	Energy provided by the RPW-HEX: FTI105; TT103; TT106	Thermal Controller	
TI109	**Temperature Transmitter**	Temperature outlet of RPW-HEX		OCHS Controller	
TI110	**Temperature Transmitter**	Supply water temperature going to		OCHS Controller	

		the hydraulic separator (3).			
TI101	**Temperature Transmitter**	Return water temperature, between hydraulic separator (3) and the heat pump (1)	Energy provided by HP+RPW-HEX: TT101;TT102;FTI104	Thermal Controller	
TI102	**Temperature Transmitter**	Supply water temperature entering the hydraulic separator (3).	Energy provided by HP+RPW-HEX: TT101;TT102;FTI104	Thermal Controller	
3	**Hydraulic separator**	\	It separates the primary circuit (HP - Hydraulic separator) from the secondary circuit (Hydraulic separator to the apartments	\	
4	**Mixing three way valve**	\	It regulates the supply temperature to the apartments.	Thermal controller	
TT302	**Temperature Transmitter**	Supply water temperature after the mixing valve 4	It regulates the mixing valve 4 accordingly; Used to measure the total energy provided to the building after the hydraulic separator: FTI308; TT307 ;TT302	Thermal Controller	
FTI308	**Flow transmitter indicator**	Water flow rate of the secondary circuit	Used to measure the total energy to the building after the hydraulic separator: FTI308; TT307 ;TT302	Thermal Controller	Since the water volume in the hydraulic separator is low, the energy performance of the HYBUILD system can be assessed considering measurement in the primary circuit, and at Enerboxx and heating system level (7d/9d).
TT307	**Temperature Transmitter**	Return water temperature from the building.	Used to measure the total energy to the building after the hydraulic separator: FTI308; TT307 ;TT302	Thermal Controller	
5	**Circulating pump - variable speed**	\	It runs the flow of the secondary circuit (from Hydraulic separator to the apartments)	Thermal controller	

5a	**Shut-off (ball) valves - manual**	\	It allows separating the pump from the circuit in case of maintenance operation.	\	
5c	**Shut-off (ball) valves - manual**	\	It allows separating the pump from the circuit in case of maintenance operation.	\	
5b	**Check valve**	\	It allows the water flow only in one direction. It prevents the water to come back into the pump	\	
SC303	**Speed controller**	-		\	
PDC305	**Pressure differential controller**	Differential pressure	It automatically adjusts the differential pressure before and after the circulating pump.	\	
H304	**Manual speed controller**	\		\	
PTI306	**Pressure transmitter indicator**	Pressure in the circuit after circulating pump (5)		Thermal controller	
6	**Expansion vessel**	\	It accommodates the increase in the volume of water due to the raising of its temperature	\	
Enerboxx system					
7 \ 9d	**Thermal Energy meter**	Energy (water flow and temperatures)	It measure the energy provided to the apartment (for both heating and cooling) and to the Enerboxx tank	Enerboxx controller	
7 \ 9 c	**Water meter**	m^3 of cold water	It measures the cold water consumed	Enerboxx controller	
7 \ 9	**Enerboxx hydraulic units**	\	It comprehends al the pipes and components connecting the	\	

			apartment to the HYBUILD system		
7 \ 9 h, i, j, k , l, m, n	**Shut-off (ball) valves - manual**	\	Shut off valves of the Enerboxx Hydraulic Units	\	
7 \ 9 a	**Bypass valve - pressure independent**	\	It bypasses the circuits going apartment and DHW Enerboxx tank)	\	
7 \ 9 b	**Heating zone valve**	\	It closes the heating circuit (on the return side	Enerboxx controller	
7 \ 9 e	**Strainer**	\	It filters the water entering the heating and DHW circuit	\	
7 \ 9 f	**Enerboxx charging valve**	\	It regulates the flow entering the Enerboxx (DHW tank)	Enerboxx controller	
7 \ 9 g	**Security group**	\	It opens the drain pipe in case of overpressure	\	
8\10	**Enerboxx DHW tanks**	\	It stores the DHW hot water to be provided to the apartment	\	
8 \ 10 a	**Electric heater**	\	It works as back up heater in case the set temperature in the Enerboxx is not guaranteed by the HYBUILD system.	Enerboxx controller	
TT401	**Temperature Transmitter**	Enerboxx water temperature	It measure the temperature inside the Enerboxx, in order to verify if it is below of above the set point.	Enerboxx controller	
FTI403	**Flow Transmitter indicator**	DHW flow rate	Used to calculate DHW energy exiting the Enerboxx	Enerboxx controller	For DHW performance calculation, we can calculate the energy supplied after the Enerboxx, or as alternative consider only the energy provided to the storage.
TT404	**Temperature Transmitter**		Used to calculate DHW energy exiting the Enerboxx	Enerboxx controller	
TT501	**Temperature Transmitter**	Enerboxx water temperature	It measures the temperature inside the Enerboxx, in order to verify if it is below of above the set point.	Enerboxx controller	
FTI503	**Flow Transmitter indicator**	DHW supply flow rate	Used to calculate DHW energy exiting the Enerboxx	Enerboxx controller	For DHW performance calculation, we can calculate the energy supplied after

TT504	**Temperature Transmitter**	Temperature of fresh water	Used to calculate DHW energy exiting the Enerboxx	Enerboxx controller	the Enerboxx, or as alternative consider only the energy provided to the storage.
Electric system					
Electric power meter 1	**Electrical power meter**	Electrical energy produced by solar panels	It measures the electrical energy produced by solar panels	Electric controller	
Electric power meter 2	**Electrical power meter**	Electrical energy provided to and by Electric storage	It measures the electrical energy provided to and by Electric storage	Electric controller	
Electric power meter 3	**Electrical power meter**	Electrical energy provided to the HP	It measures the electrical energy provided to theHP	Electric controller	
Electric power meter 4	**Electrical power meter**	Electrical energy consumed by electrical heater (inside Enerboxx)	It measures the electrical energy consumed by electrical heater (inside Enerboxx)	Enerboxx controller	Is this sensor foreseen?
Electric power meter 5	**Electrical power meter**	Electrical energy consumed by electrical heater (inside Enerboxx)	It measures the electrical energy consumed by electrical heater (inside Enerboxx)	Enerboxx controller	Is this sensor foreseen?
11	**PV panel and DC inverter**			Electric Controller	
12	**DC-DC inverter**			Electric Controller	
13	**Electric Battery**			Electric Controller	
14	**AC-DC inverter**			Electric Controller	