D2.1 FLEXYNETS Substations: Energy sources and sinks with short term local storages

Fifth generation, low temperature, high exergy district heating and cooling networks

FLEXYNETS

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FLEXYNETS Substations: Energy sources and sinks with short term local storages.

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1 Summary

This deliverable resumes the activities carried out within Tasks 2.1 and 2.4 of FLEXYNETS, related to the analysis of substations with two different objectives: to assess the different combinations of energy sources and sinks within the FLEXYNETS concept and to simulate the most relevant among them.

FLEXYNETS substations distributed in each building (residential, tertiary, factory etc.) within the FLEXYNETS network have been defined according to possible loads, in order to achieve the possible combinations of consumers/producers/prosumers, which drive the balance of the Flexynets network.

In Chapter 2 of this deliverable, 10 different types of substations – coming from the combination of the most commonly used technologies and solutions in buildings nowadays have been defined. These substations are expected to be applicable to most cases, as they include residential and commercial buildings as well as generation stations. The choice of equipment took into account temperature levels and energy fluxes through the system, though at the level of an initial step of the project.

The substation variants defined in this deliverables, while not representing the totality of the possible cases, give a clear picture of how the integration process is possible and replicable, taking into account specific patterns based on the project partner experience.

It is worth mentioning from the beginning that within FLEXYNETS networks the implementation of heat pumps becomes crucial, due to the thermodynamic principle of transferring heat from a cold sink to a hot one through mechanical work. This peculiarity makes it possible to use the low temperature network for producing heating or rejecting heat for cooling purposes.

For each substation, a specific hydraulic drawing and tailored control strategies have been designed and integrated with the purpose to maximize the operation through the FLEXYNETS network and minimize the contribution of other H&C systems, maintaining the actual temperature levels for the H&C terminals and minimizing the installation impact for refurbished case studies.

In view of simulation purposes, the number of substations variants has been reduced, taking into account the needed simulation efforts and the most interesting cases. In practice, one layout for the residential substations and one layout for generation stations were chosen. It should be noted that both of them are quite general and suitable for two ways of operation, i.e., heating and cooling.

This leads to the core of this deliverable, given by Chapters 3 and 4, where these FLEXYNETS substations (for residential applications in Chapter 3 and for generation applications in Chapter 4) were simulated in detail. Both chapters include a full description of the considered components, of control strategies, and of the results of the simulation activities.

In all cases, simulations were carried out in TRNSYS. The substation performances were assessed for three different locations (Rome, Stuttgart, and London), in order to obtain results representative of the different European climates. Simulations were limited to the boundary with network, focusing on substations alone. However, since the network temperature can clearly affect the substation performance (e.g., in terms of coefficient of performance for heat pumps or in terms of electric efficiency for cogeneration systems), simulations were repeated for different network temperatures in the range from 0 °C to 30 °C (the temperatures expected to be the most suitable for the implementation of a FLEXYNETS network; the case of 0 °C is taken as a limiting case).

After these chapters about simulations, Chapter 5 presents a summary of the main conclusions. Finally, besides references, several Annexes provide details on the considered building types and distribution systems, additional data and figures, as well as more elaborated schemes on the general substations presented in Chapter 2.

2 Definition of substations

The underlying idea of FLEXYNETS is the definition of a new generation heating/cooling network operating at low temperature (about 10-40 °C). It is able to feed the different nodes with lower thermal losses with respect to traditional district networks. It is based on the implementation of water-to-water heat pumps, and able to self-balance the energy delivered (to the nodes) with the energy recovered (from the nodes) on yearly basis. The implementation of heat pumps becomes strategic because of the thermodynamic principle of transferring heat from a cold sink to a hot sink through mechanical work; by this way, it is possible to use the low temperature of the network for producing heating, or for rejecting heat to the network for cooling purposes. If the node requests heat, it operates as "consumer"; if the node rejects heat, it operates as "producer"; whenever both requesting and rejecting heat during the year, it operates as "prosumer".

The definition of the substations, according to possible loads, is the first step in the process of defining the possible combinations of consumers/producers/prosumers that will drive the energetic balance of the FLEXYNETS network (FLEXY-network), making it more competitive with respect to the state of the art.

The presented results about substations came from the necessity to define an efficient way to exchange heat between node and network, along the entire year, according to:

- network working range between 10-40 °C;
- building thermal loads (extracting heat in case of heating [consumer] or rejecting heat in case of cooling [producer]);
- technology used for the production of heating and cooling at substation level;
- typical HVAC installations for different typologies of building (residential, tertiary, industry and specials);
- HVAC technology existing on the market;
- use of energy storage at building and network levels;
- use of special substations for equilibrating network energy balance;
- limited intervention during refurbishment activities;
- most promising interventions in terms of technological complexity and economic viability.

In order to give a clear and quick idea of the principle of operation, it has been decided to use a schematic representation of the energy flows through the building and of the different equipment; then, only most promising substations have been analysed and engineered in detail, before their implementation into dynamic software environment.

The FLEXYNETS concept can be applied both to new and existing buildings, taking into account that, in case of retrofitting, some equipment can be maintained as back-up while other can be dismissed or replaced. For retrofitting, new heat pump based equipment must be adapted to the existing HVAC concept, without affecting the comfort perception for the final user (addressing the same load with more efficiency of generators).

The schemes aim to show how traditional systems can be integrated with the novel FLEXYNETS concepts, both for new and existing constructions. If with new buildings the design can be done from scratch, with existing buildings a renovation approach must be taken into account, in order to maximize the utilization of new technologies and minimize the consumption of the traditional ones.

Table 1. Legend for the drawings – Equipment.

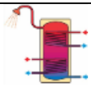
4HP	4 Pipes Heat Pump		RD	Radiators	
ACC	Air Compression Chiller		RHP	Reversible Heat Pump	
AHU	Air Handling Unit		SHW	Sanitary Hot Water	
BO	Boiler		ST	Solar Thermal	
CBO	Condensing Boiler		SG	Steam Generator	
CT	Cooling Tower		TK	Tank	
FC	Fan Coil		TKTK	Tank in Tank	
GS	Ground Storage		TAC	Thermal Absorption Chiller	
HTHP	High Temp Heat Pump		VRV	Variable Refrigerant Volume	
RS	Radiant Surface		WCC	Water Compression Chiller	

Table 2. Legend for drawings – Piping and flows.

	Heating
	Cooling
	FLEXY sink
	Refrigerant
	Medium temperature heat
	Large contribution of Cooling
	Large contribution of Heating
	Reduced contribution of Heating

The presented substations come from the combination of the most commonly used technologies and solutions for buildings nowadays; they are not intended to represent the totality of the state of art, but to give at least a clear picture of how the integration process is possible and replicable, taking into account specific patterns based on experience gimmicks.

The table below (Table 3) introduces and resumes the most significant and, possibly, the most representative case studies determined by the analysis of the existing building market, considering temperature levels and energy fluxes through the system and to the network. In this way, it is possible to give a basis for the development of the simulation environment, which will assess the viability of the project.

Table 3 – Table of solutions.

N°	Name	Activity	Solution
1	Residential building – Block of flats RHP, BO, TK NET, SHW, TK H&C	Prosumer	Hydronic system, 2 pipes, heating- cooling-SHW, fancoils, water storage, boiler-w/w heat pump
2	Residential building – Semi-detached house ST, RHP, TKTK	Prosumer	Hydronic system, 2 pipes, heating- cooling-SHW, fancoils, ground storage, solar thermal-w/w heat pump
3	Special building – Hospital ST, TK, TK H&C, HTHP, BO, CT, WCC, TK NET	Prosumer	Hydronic system, 4 pipes, heating- cooling-SHW, fancoils-radiators, water storage, solar thermal-boiler-chiller- w/w high temp heat pump
4	Special building – Hotel HP, TK H&C, BO, ACC, TK NET, HR, ST, TK, TK HR	Prosumer	Hydronic system, 4 pipes, heating- cooling-SHW, fancoils-air coils, water storage, boiler-chiller-w/w 4pipes heat pump, heat recovery
5	Tertiary building – Shopping mall 4PHP, TK H&C, WCC, CT, BO, TK HR, TK NET	Prosumer	Hydronic and Freon system, 4 pipes, heating-cooling-SHW, fancoils-air coils, water storage, solar thermal- boiler-a/a chiller-w/w heat pump, heat recovery
6	Tertiary building – Offices TK H&C, VRV, ACC, TK NET	Prosumer	Freon system, 4 pipes, heating- cooling, fancoils-air coils, a/a chiller- a/a heat pump
7	Industry- Agro alimentary BO, SG, WCC, CT, TK H&C	Producer	Heat recovery from flue gas and steam generator
8	Industry – Ceramics BO, SG, WCC, CT, TK H&C, ORC, TK NET	Producer	Heat recovery from flue gas, steam generator and ORC
9	Power station – Solar thermal PTC, BO, TK H&C, ORC, TAC, CT, GS, TK NET	Producer	Production of heat at low temperature-cooling-electricity via solar thermal, ground storage, heat dissipation
10	Power station – Solar PV GS, PV, WCC, CT, TK NET	Producer	Production of heat at low temperature-cooling via solar PV, ground storage, heat dissipation

Nevertheless, further combinations of technologies could be considered and defined, according to the definition of towns and settlement areas resulting from WP3, or other identified necessities.

Concepts and sub-stations presented in the table will be further analysed and designed in the following sections, highlighting limits and potentialities, driving to the detailed definition of most interesting substations. In order to understand the impact of FLEXYNETS concept on actual district heating and cooling (DHC) systems, detailed layouts have been defined in order to create a reference for simulations models. According to economic and energetic assumptions, most promising schemes have been identified as closer to market for future implementation.

In order to prevent undesired effects from leakages, the heat exchange between network and building will be achieved via heat exchanger (it can be intended as internal heat exchanger of an equipment like a heat pump or a typical external heat exchanger) or via storage tank, depending on the final network temperature.

Building energy profiles are not taken into account at this stage (but will be considered in the next chapters including simulations), but only operation temperatures, which have been included in simplified drawings.

The integration of the building into a FLEXY-network requires different approaches in case of new construction or renovation of HVAC; most of the times, it is preferable a new construction because of the possibility to shape the station according to load and network requirements, minimizing the impact for the customer.

In case of existing constructions, an integration process is required and is more complex because of the difference in efficiency and technology between heat pump and boiler. This document always considers the most unfavourable condition, namely that of refurbishment, in order to understand how far can move the network owner for the proposition of a FLEXYNETS solution maintaining economic viability.

To maintain such condition, new technology must be competitive with respect to existing, in terms of economic investment and day-to-day operation with respect to traditional fuels and HVAC solutions.

Each of the subsections of this chapter is organized in the following way:

- A first scheme and description referring to a possible existing situation.
- A second scheme and description referring to the proposed improvement/refurbishment.

In the case of new installations, the resulting substations could be further simplified. Note also that the specified temperature, as well as the sizing procedures, have to be considered preliminary estimates and will be further detailed for simulation cases.

While here only a conceptual scheme of substations is presented, the P&IDs for the different substations are reported in Annex VII.

2.1 Substation variants

2.1.1 Substation 1 – Residential building (block of flats)

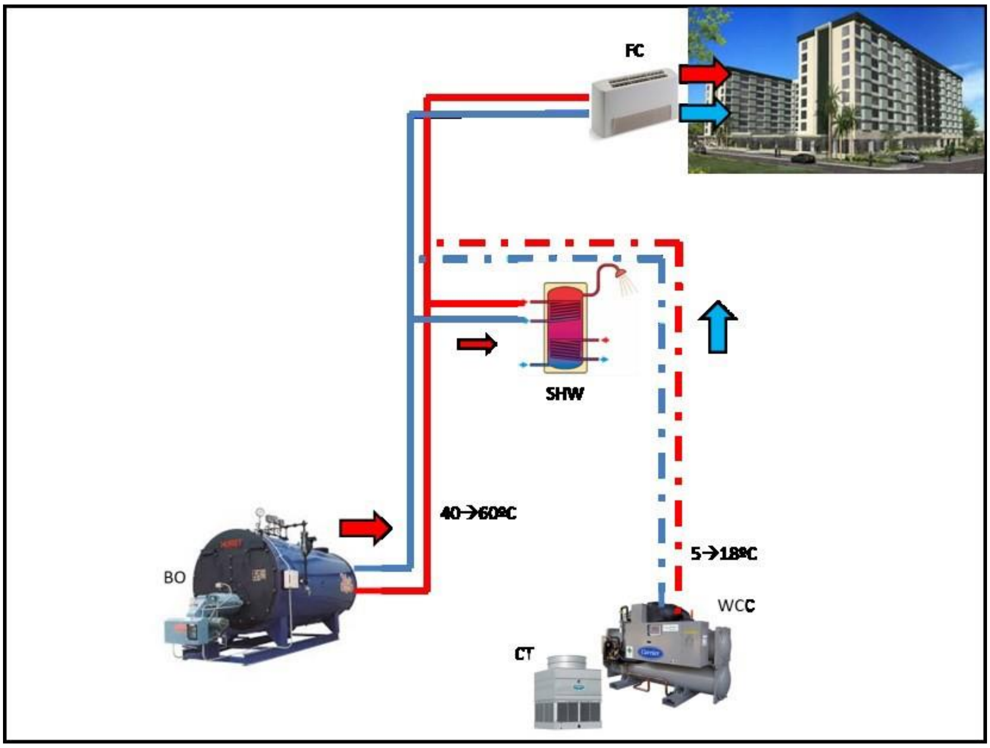


Figure 1 – Block of flats without FLEXYNETS.

Block of flat with:

- 2-pipe distribution;
- centralized heating, via modulating boiler (or auxiliary heat generator), sized for the 100% of the demand;
- centralized cooling (present or not, depending on the load), via modulating chiller, connected on the same heating pipes;
- fan coil heating/cooling terminals;
- centralized SHW done via main heat generator.

The boiler work during heating season for heating and sanitary hot water preparation, while during cooling period for preparation of SHW; this means that the boiler is oversized during cooling season with possible problems of efficiency during modulation.

The chiller (if present) works only during the cooling season, using the same distribution network of the heating system; as consequence heating and cooling cannot be produced, and distributed, at the same time.

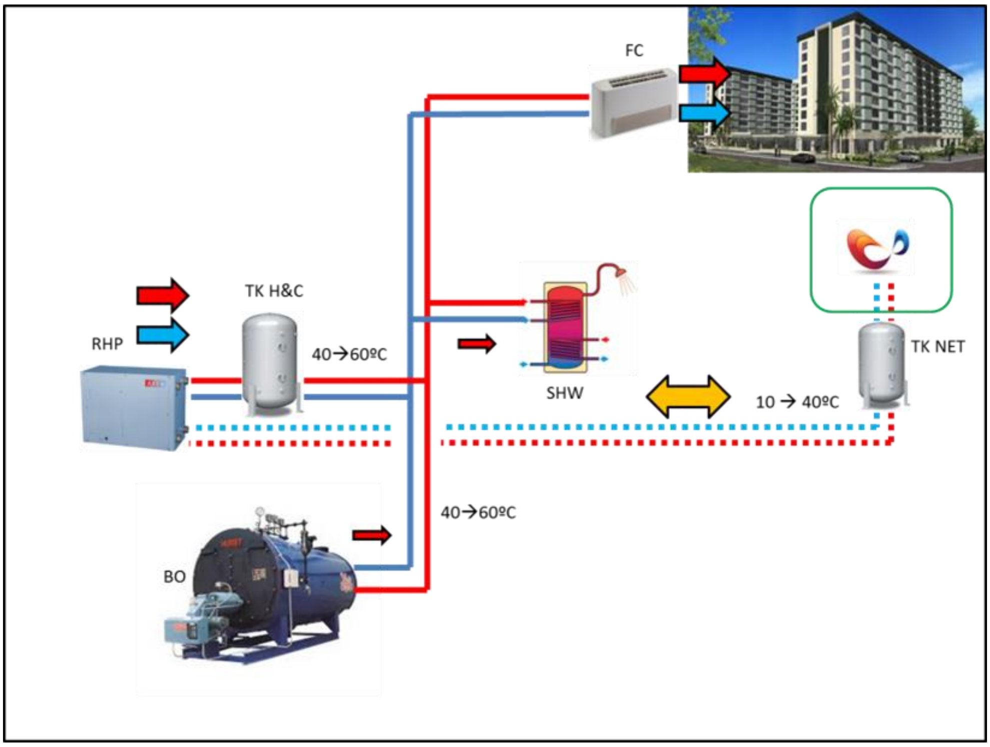


Figure 2 – Block of flats with FLEXYNETS.

Implementation with FLEXY-network:

- introduction of reversible heat pump, as primary heating and cooling generator, sized for the 100% of the demand and for 100% of the energy of the load;
- water storage tank at load side, for load shifting and power reduction for generators, sized for being coupled with the RHP and fulfilling with the 100% of the demand and for 100% of the energy of the load;
- FLEXY-network used as HP cold sink for heating and as hot sink for cooling;
- the HP works in parallel/series with boiler (as backup) for heating and SHW purposes;
- the HP works alone, as chiller, for cooling purposes;
- possibility to use storage tank at network side for network control strategies.

The RHP will work as primary energy generator both for heating and cooling, with the purpose to cover the 100% of base load of the demand, and cover the peaks with the contribution of the buffer tank. The boiler would be left as back-up generator of for topping purposes.

The introduction of a RHP instead of a HP would be economically viable only in case of absence of the chiller (and presence of necessity of cooling) or in case of substitution of the existing chiller for technological obsolescence, otherwise the PBT would assume not affordable values.

During heating season the RHP extract heat from the network, operating as consumer; during the cooling season rejects the heat to the network, operating as producer, while for the preparation of the SHW operates as consumer. During cooling period, being the RHP only 2 pipes, part of the cooling is dissipated in heating the SHW (same pipe for heating and cooling).

2.1.2 Substation 2 – Residential building (semidetached house)

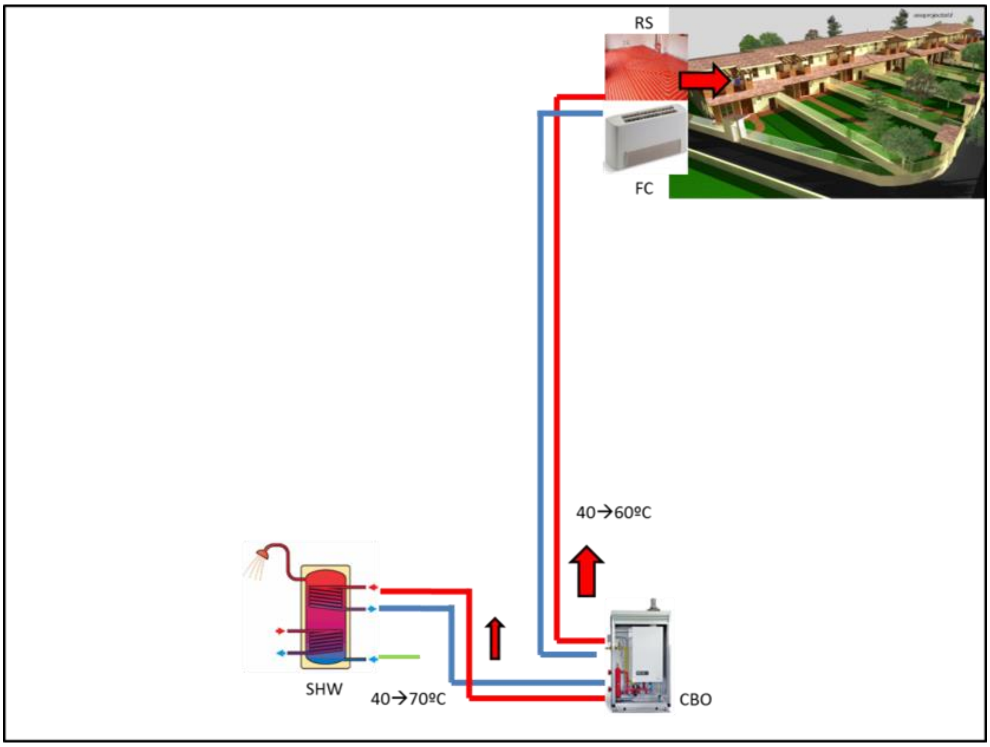


Figure 3 – Semidetached house without FLEXYNETS.

Individual house with:

- 2-pipes distribution;
- autonomous heating, via modulating condensing boiler (or low enthalpy heat generator), sized for the 100% of the demand;
- low enthalpy heating terminals;
- autonomous SHW done via main heat generator.

The boiler work during heating season for heating and sanitary hot water preparation, while during cooling period for preparation of SHW; this means that the boiler is oversized during cooling season with possible problems of efficiency during modulation.

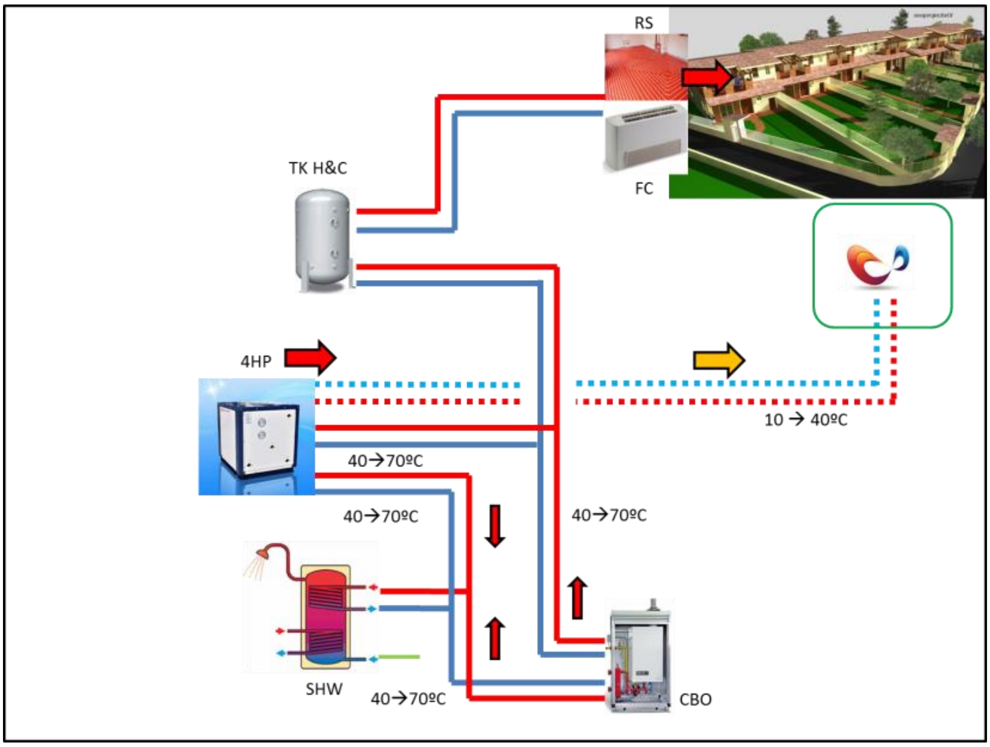


Figure 4 – Semidetached house with FLEXYNETS.

Implementation with FLEXY-network:

- introduction of 4 pipes heat pump (2 pipe dedicated to heating and 2 pipes dedicated to SHW), as primary heating generator, sized for the 100% of the demand and for 100% of the energy of the load;
- FLEXY-network used as HP cold sink for heating;
- the HP works in parallel/series with boiler (as backup) for heating and SHW purposes;
- low thermal inertia and quick response of all equipments, sized for small loads, with high flexibility and modulating capacity; no storage is required .

The 4HP will work as primary energy generator both for heating and SHW. The boiler would be left as back-up generator of for topping purposes.

During heating season the 4HP extract heat from the network, operating as consumer; during the cooling season operates as consumer for the preparation of the SHW. During cooling period, being the 4HP 4 pipes, NO cooling is dissipated in heating the SHW (same pipe for heating and cooling).

2.1.3 Substation 3 – Special building (hospital)

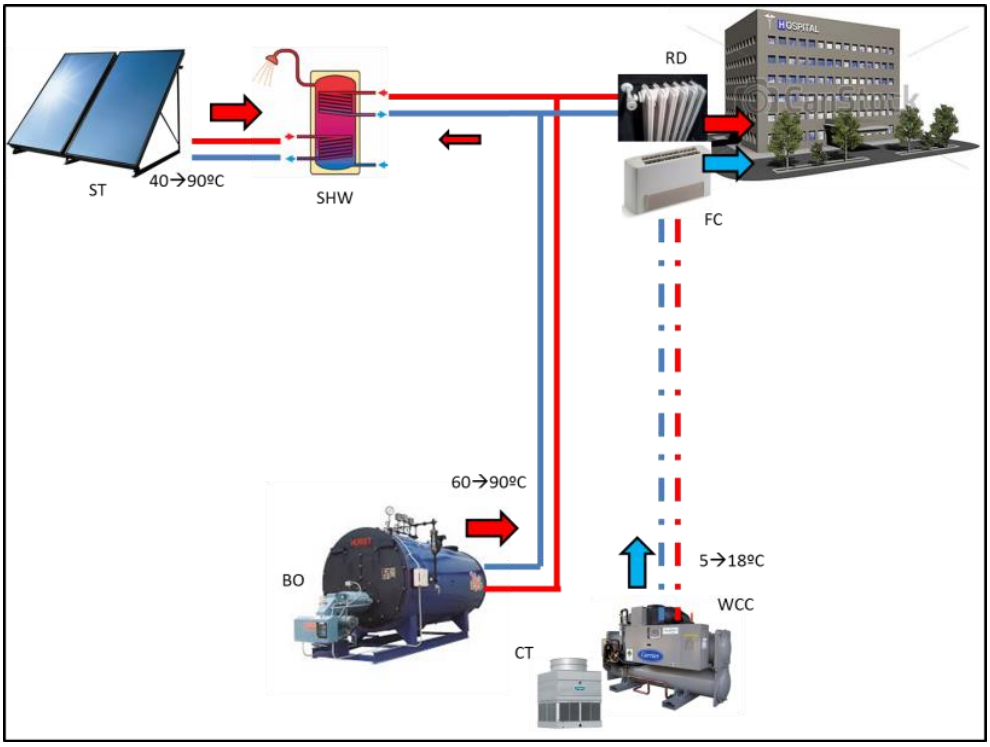


Figure 5 – Hospital without FLEXYNETS.

Special building with:

- 4-pipes distribution, simultaneous production of heating and cooling;
- centralized heating, with gas boiler (or auxiliary heat generator) and w/w heat pump, sized for the 100% of the demand;
- radiators heating terminals;
- centralized cooling with w-t-w electric chiller + cooling tower, sized for the 100% of the demand;
- fan-coils cooling terminals;
- SHW via flat solar panels and boiler.

The heat generator works during all the year for heating and sanitary hot water preparation; this means that the boiler is oversized during cooling season with possible problems of efficiency during modulation.

The chiller works mainly during the cooling season, but can be used also during heating periods for specific applications, through specific distribution network.

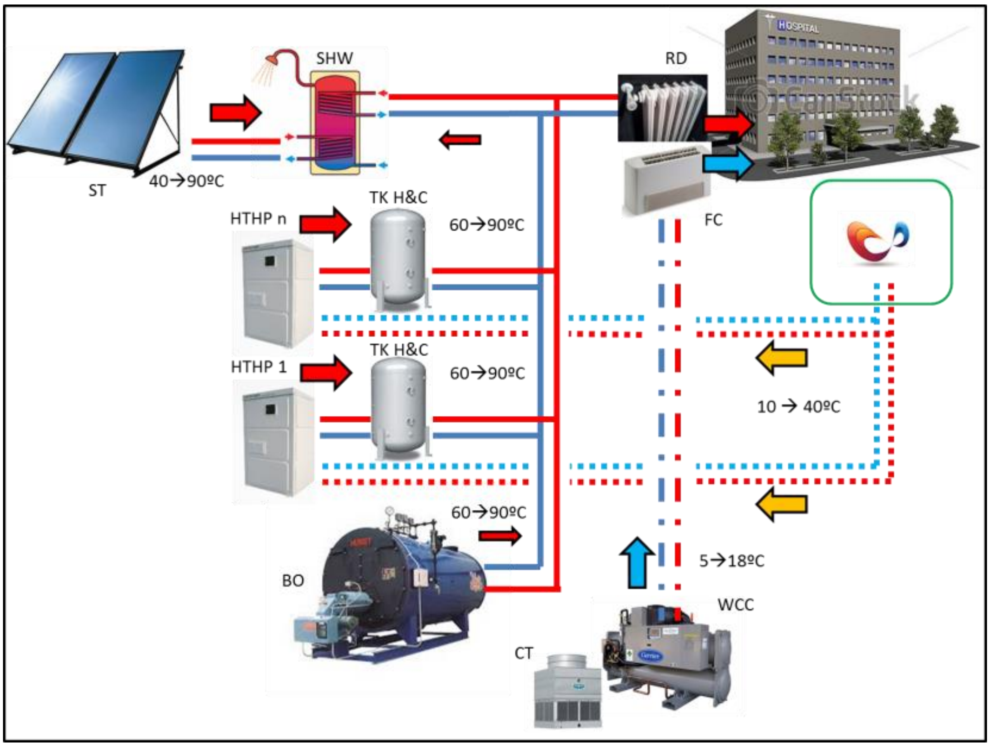


Figure 6 – Hospital with FLEXYNETS.

Implementation:

- integration of CO_2 heat pump (high temperature) into FLEXY network as consumer, sized for the 100% of the demand and for 100% of the energy of the load;
    - only one central HTHP can be integrated for centralized production;
    - more than one HTHP can be integrated for distributed production;
- heat pump used for heating and SHW purposes;
    - with centralized system, only 1 HTHP can produce both;
    - with distributed system, 1 HTHP can be dedicated only for SHW and the others for heating purposes of respective zone;
- water storage tank at load side, for load shifting and power reduction for generators;
- FLEXY network used as HP cold sink;
- the HP works in parallel/series with boiler (as backup system)for heating and SHW purposes;
- replacement of the chiller would be affordable only in case of equipment technical obsolescence.

The HTHP will work as primary energy generator both for heating and SHW, with the purpose to cover the 100% of base load of the demand, and cover the peaks with the contribution of the buffer tank. The boiler would be left as back-up generator of for topping purposes.

In case of multiple HTHPs, the operation will be individual and related to the zone supplied. During the entire year, the HPHT extracts heat from the network, operating as consumer; the quantity of energy extracted from the network depends on the number of units working.

2.1.4 Substation 4 – Special building (hotel)

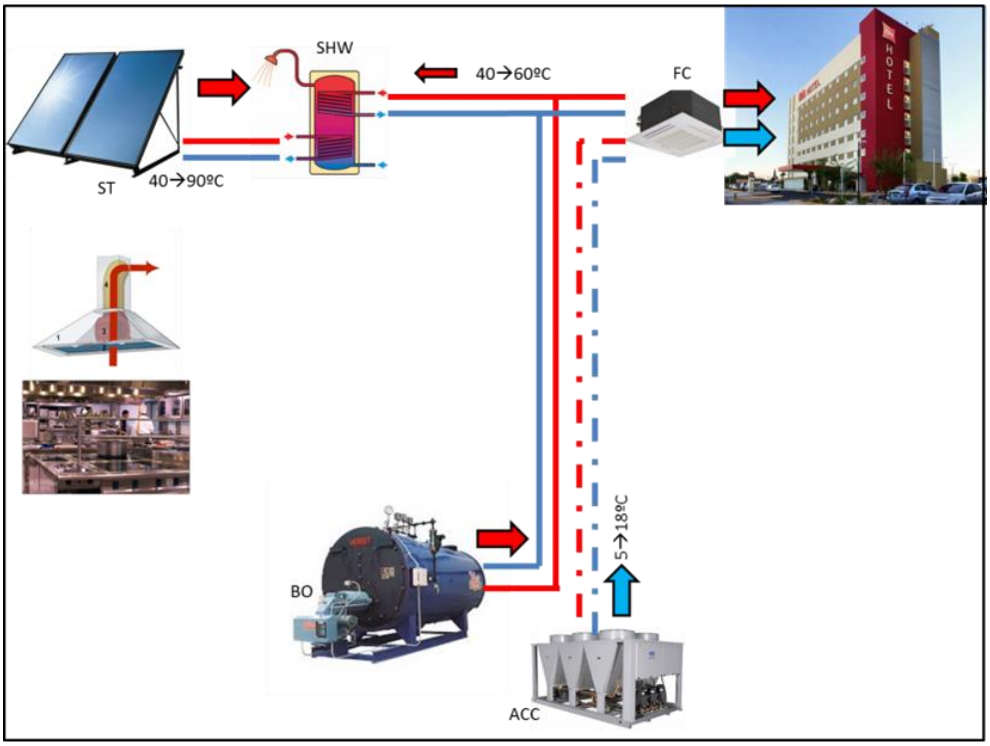


Figure 7 – Hotel without FLEXYNETS.

Special building with:

- 4-pipes distribution;
- centralized heating, with gas boiler (or auxiliary heat generator) and w/w heat pump, sized for the 100% of the demand;
- centralized cooling with a-t-w electric chiller, sized for the 100% of the demand;
- fan coils heating/cooling terminals;
- SHW with flat solar panels and boiler, sized for the energy baseload of SHW;
- presence of heat recovery dedicated to residual gases from the kitchen.

The boiler work during heating season for heating and sanitary hot water preparation, while during cooling period for preparation of SHW; this means that the boiler is oversized during cooling season with possible problems of efficiency during modulation.

The chiller works during the cooling season, using dedicated distribution network respect to the heating system; as consequence heating and cooling can be produced, and distributed, at the same time.

Combustion heat from the kitchen is rejected in the environment without any utilization.

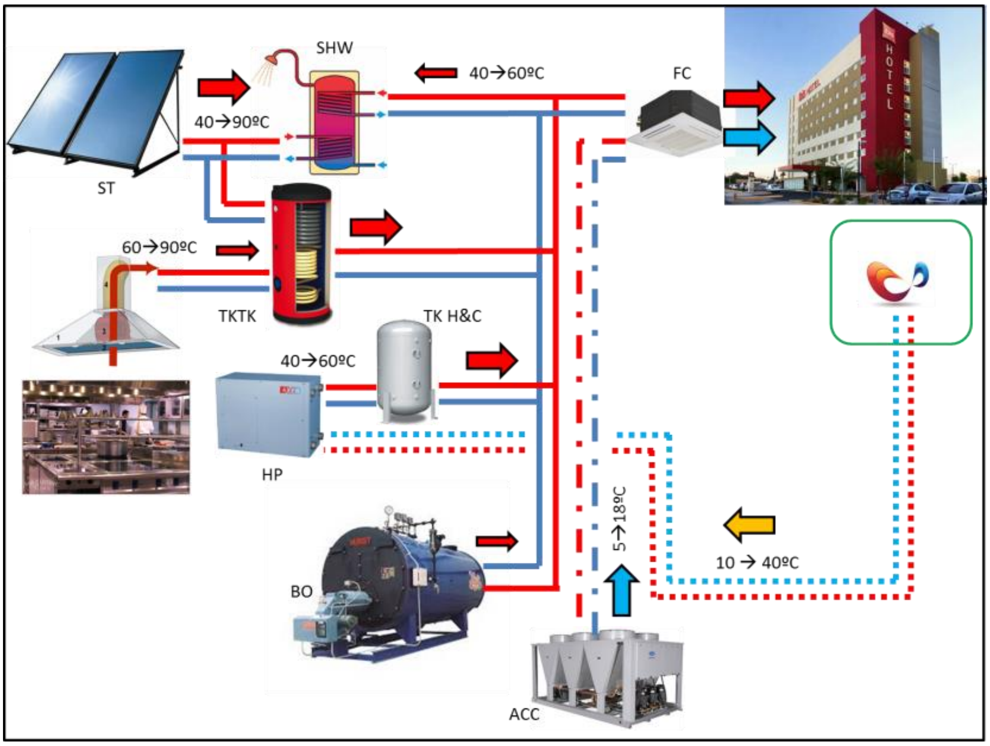


Figure 8 – Hotel with FLEXYNETS.

Implementation:

- integration of HP (only heating) into FLEXY network as consumer, heat pump used for heating and SHW purposes, sized for the xx% of the demand and for 100% of the energy of the load;
- water storage tank at load side, for load shifting and power reduction for generators, sized for being coupled with the HP and fulfilling with the 100% of the demand and for 100% of the energy of the load;
- boiler as backup system, installed in parallel for heating and SHW purposes;
- the HP works in parallel/series with boiler for heating and SHW purposes;
- replacement of the chiller with HP would be affordable only in case of equipment technical obsolescence (otherwise the PBT would assume not affordable values);
- heat from recovery used for heating purposes.

The HP will work as primary energy generator for heating, with the purpose to cover the 100% of base load of the demand, and cover the peaks with the contribution of the buffer tank. The boiler would be left as back-up generator of for topping purposes. SHW will be primary done via ST and secondary via HP.

During heating season the HP extract heat from the network, operating as consumer; during the cooling keeps on operating as producer for the preparation of the SHW. The heat recovery system would give an extra of heat for heating and SHW purposes.

2.1.5 Substation 5 – Tertiary building (shopping mall)

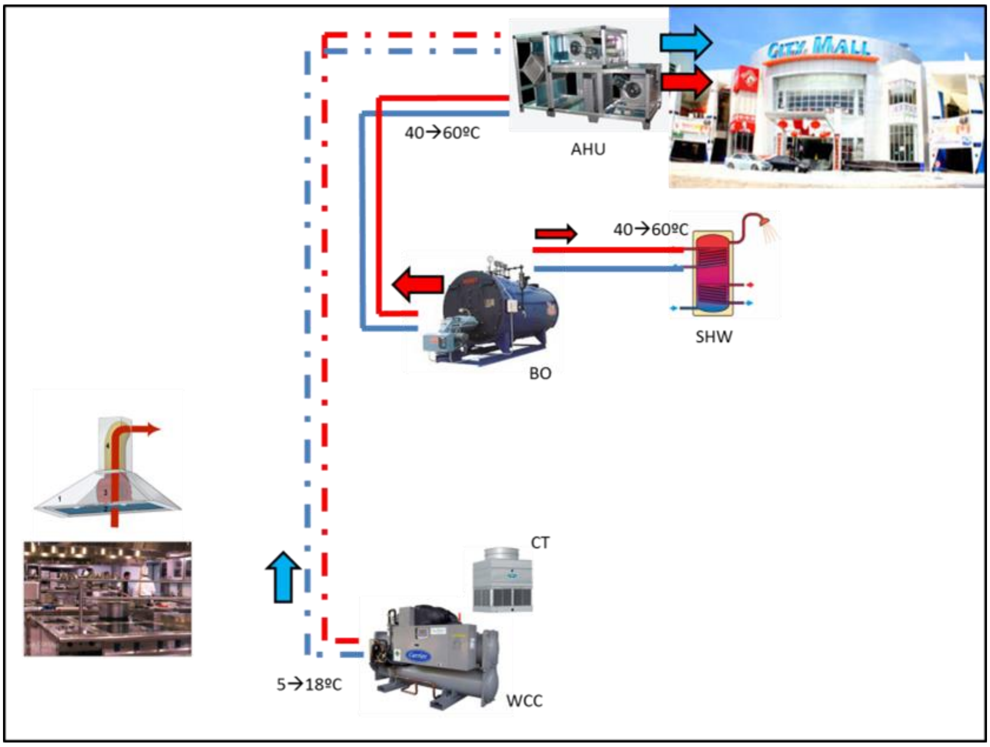


Figure 9 – Mall without FLEXYNETS.

Tertiary building with:

- 4-pipes distribution;
- centralized heating with boiler/heat pump, sized for the 100% of the demand;
- centralized cooling with w-t-w electric chiller, sized for the 100% of the demand;
- air ventilation unit heating/cooling terminals;
- SHW with boiler/heat pump;
- presence of heat recovery.

The boiler work during heating season for heating and sanitary hot water preparation, while during cooling period for preparation of SHW or for dehumidification of primary air; this means that the boiler is oversized during cooling season with possible problems of efficiency during modulation.

The chiller works mainly during the cooling season, with dedicated distribution network; as consequence heating and cooling can be produced, and distributed, at the same time. During heating period cooling is used for dehumidification of primary air.

Combustion heat from the kitchen is rejected in the environment without any utilization.

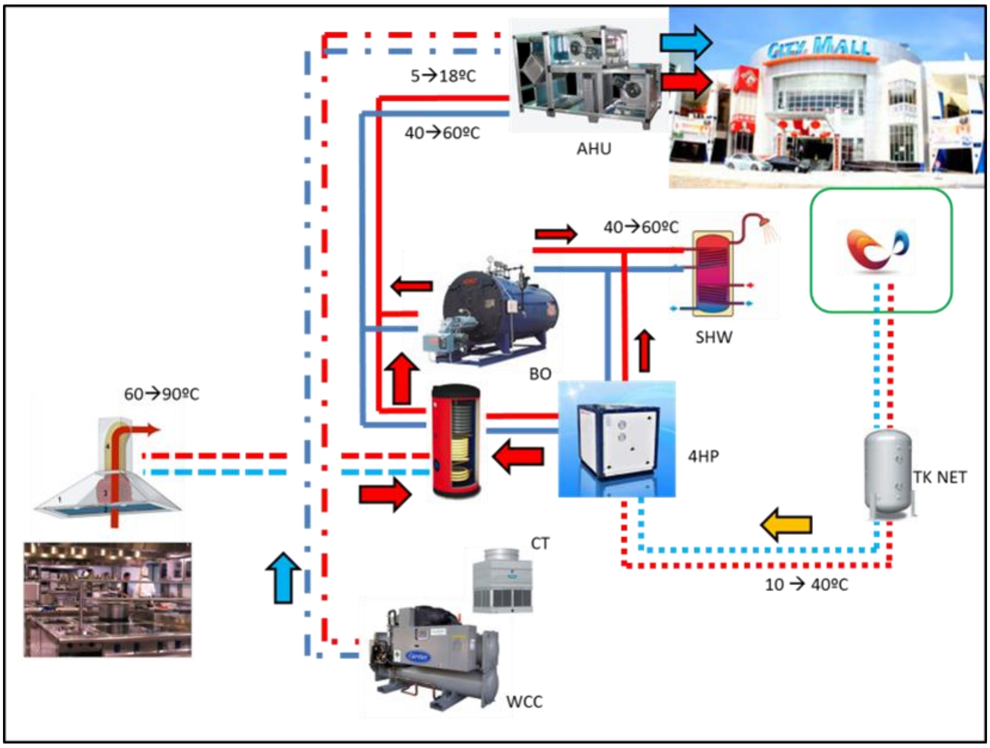


Figure 10 – Mall with FLEXYNETS.

Implementation:

- integration of 4 pipes heat pump (4HP) into FLEXY network as consumer, sized for the 80% of the demand and for 100% of the energy of the load;
- heat pump used for heating and SHW purposes with dedicated loops;
- water storage tank at load side, for load shifting and power reduction for generators, sized for being coupled with the RHP and fulfilling with the 100% of the demand and for 100% of the energy of the load;
- the HP works in parallel/series with boiler (as backup) for heating and SHW purposes;
- heat from recovery used for heating purposes.
- replacement of the chiller with HP would be affordable only in case of equipment technical obsolescence (otherwise the PBT would assume not affordable values)

The 4HP will work as primary energy generator both for heating and cooling, with the purpose to cover the 100% of base load of the demand, and cover the peaks with the contribution of the buffer tank. The boiler would be left as back-up generator of for topping purposes.

During heating season, and for the preparation of the SHW, the 4HP extracts heat from the network, operating as consumer. During cooling period, being the 4HP at 4 pipes, no cooling is dissipated in heating the SHW (same pipe for heating and cooling). The heat recovery system would give an extra of heat for heating and SHW purposes.

2.1.6 Substation 6 – Tertiary building (office)

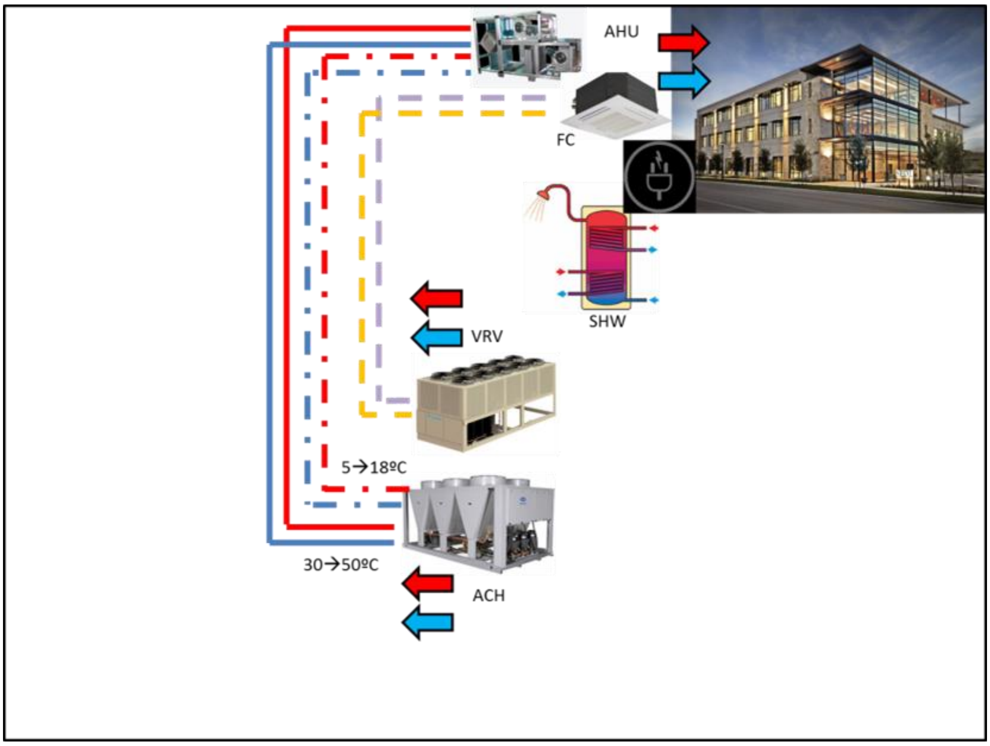


Figure 11 – Office building without FLEXYNETS.

Commercial building with:

- heating and cooling via water for primary air by Air ventilation unit;
- heating and cooling via refrigerant pipes for fan coils heating/cooling terminals, sized for the 100% of the demand
- autonomous heating/cooling with electric a-t-a reversible heat pump;
- neglegible utilization of SHW.

The quantity of SHW is irrelevant respect to the energy necessary for the conditioning of the building, so is done via electric boiler.

Primary air is done via AHU, fed by air-to-water chiller/heat pump. Heat is extracted from or rejected to the external environment.

Heating and cooling are produced via air-to-refrigerant chiller/heat pump. Heat is extracted from or rejected to the external environment.

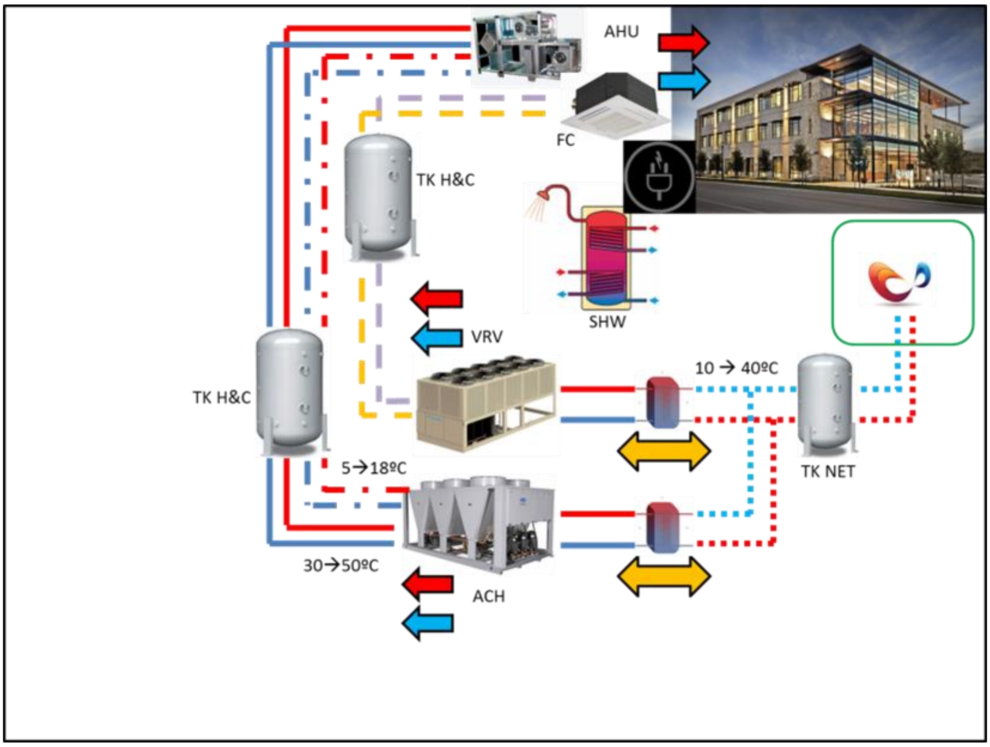


Figure 12 – Office building with FLEXYNETS.

Implementation:

- integration of an air-to-water reversible heat pump (ACH) into FLEXY network as prosumer, requiring modification to the air heat exchanger;
- integration of an air-to-water reversible (VRV) heat pump into FLEXY network as prosumer, requiring modification to the air heat exchanger;
- integration of storage tank into distribution line, sized for being coupled with the equipments and fulfilling with the 100% of the demand and for 100% of the energy of the load;
- possibility to use storage tank to reduce heat exchange with network, sized for being used as buffer in case of not contemporaneity of operation between VRV and ACH;
- replacement of the ACH and/or VRV with RHP would be affordable only in case of equipment technical obsolescence (otherwise the PBT would assume not affordable values).

In case of maintaining existing equipment, modification to the air heat exchanger would be required in order to be able to connect with the FLEXY water network; both heat pumps would work, with variable capacity, during the entire year for production of heating, cooling and ventilation primary air. In this case both would operate as prosumers.

2.1.7 Substation 7 – Industrial application (agro-alimentary)

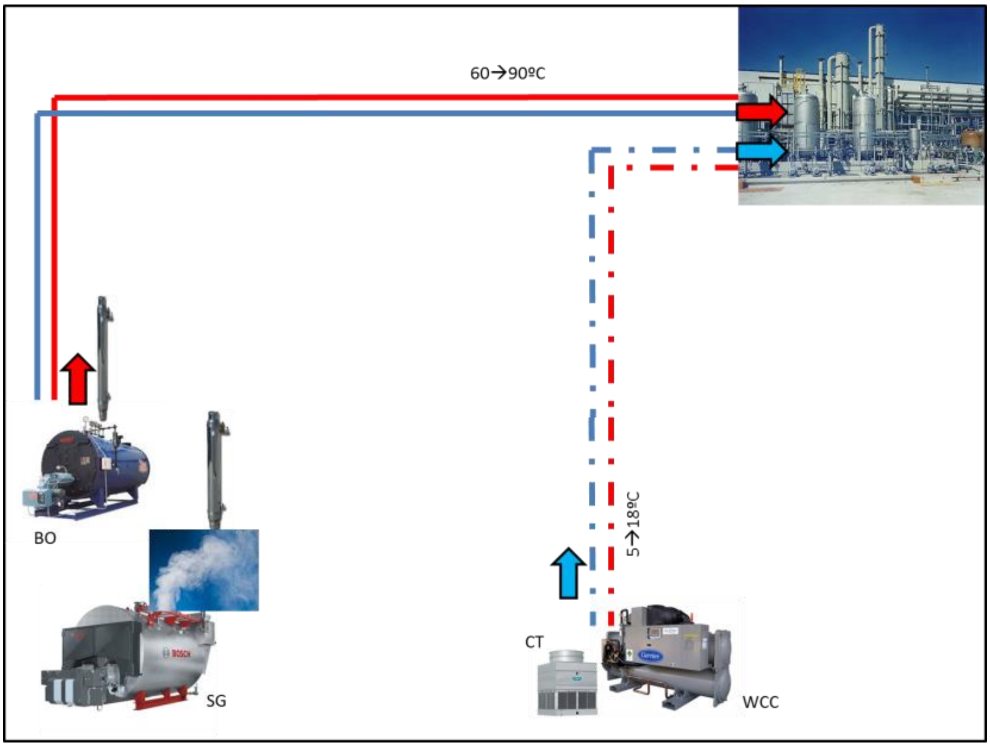


Figure 13 – Agro alimentary without FLEXYNETS.

Industry with:

- 4-pipes distribution;
- autonomous process heating with boiler (or auxiliary generator);
- autonomous process cooling with electric chiller;
- boiler (or auxiliary generator) for process steam generation.

The boiler operates during process period that can be independent from the environment weather conditions. Same consideration can be done for the operation of the chiller and the steam generator.

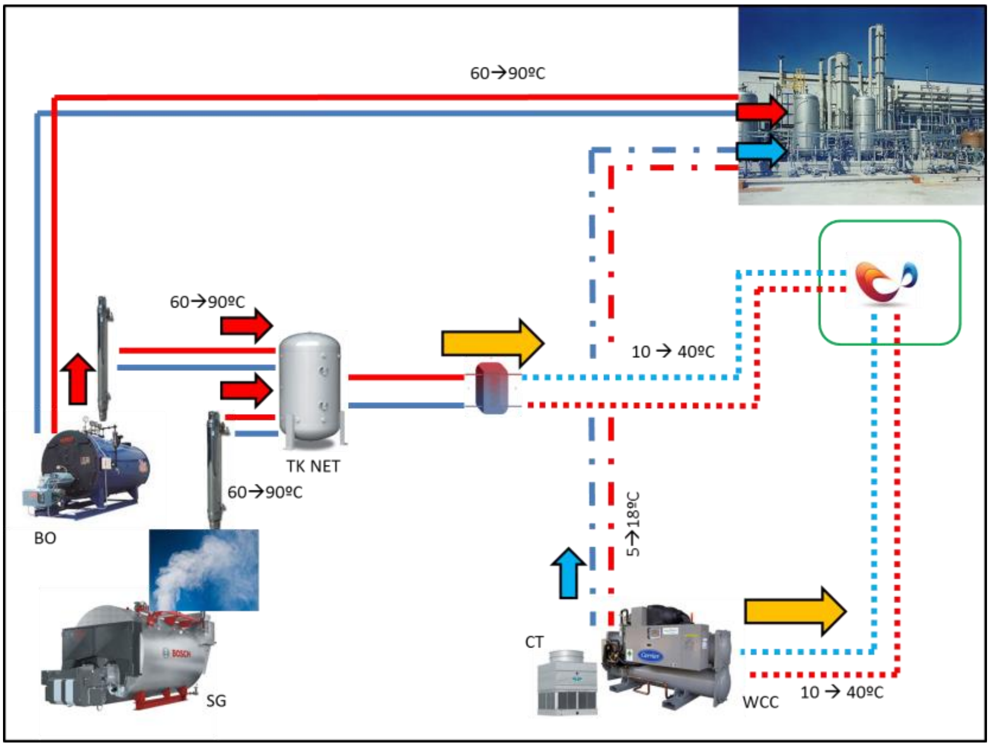


Figure 14 – Agro alimentary with FLEXYNETS.

Implementation:

- integration of combustion gas recovery system into equalization tank;
- integration of steam condensation recovery system into equalization tank;
- integration of equalization tank into FLEXY-network as producer, before connection to the network;
- integration of the chiller into FLEXY-network as producer.

The heat generator operates for production of process heat at high temperature, but there is a big potential in heat recovery if cooling the gases up to low temperatures; on other hand the condensing heat of the steam can be also be recovered efficiently, without affecting the process. Heat recovered can be homogenized into a buffer tank, as intermediate storage, before being injected into the FLEXY-network.

Heat rejected from the chiller into the environment can also be recovered and injected into the FLEXY-network.

The sub-station is always operating as producer.

2.1.8 Substation 8 – Industrial application (ceramics)

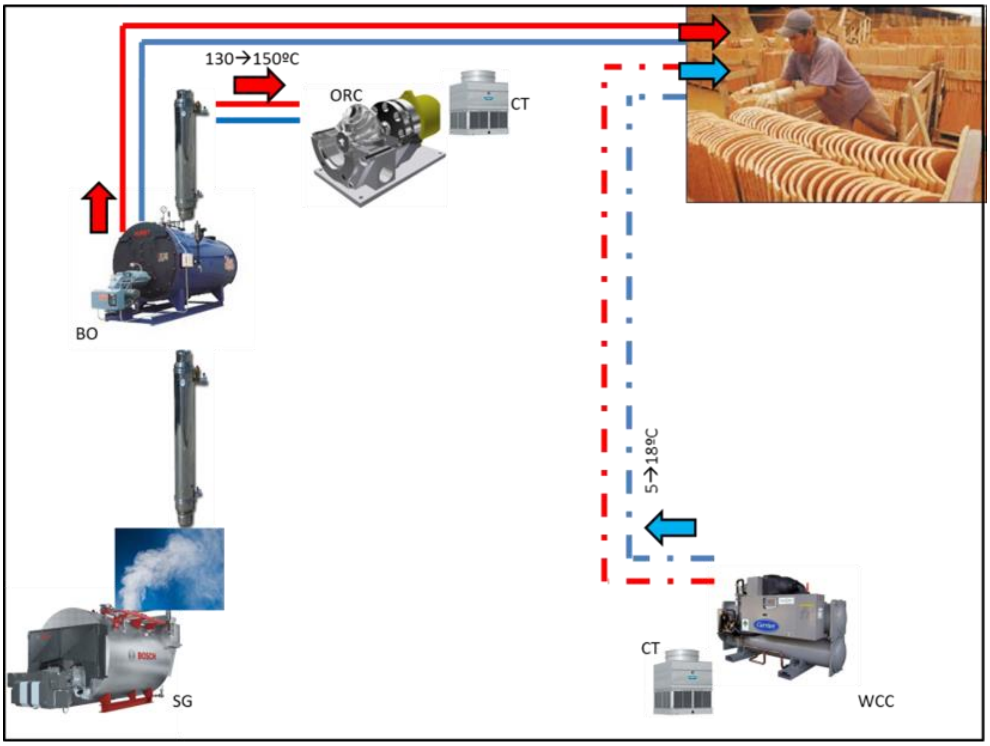


Figure 15 – Ceramics without FLEXYNETS.

Special building with:

- 4-pipes distribution;
- autonomous process heating with boiler (or auxiliary heat generator);
- autonomous process cooling with electric chiller;
- chiller heat rejection via cooling tower.
- boiler for steam generation;
- ORC activated with heat recovery from combustion gases;
- ORC heat rejection via cooling tower.

The boiler operates during process period that can be independent from the environment weather conditions. Same consideration can be done for the operation of the chiller and the steam generator.

The heat recovered from the heat generator can be used for its integration with an ORC, whose condensation heat is rejected to the environment via cooling tower.

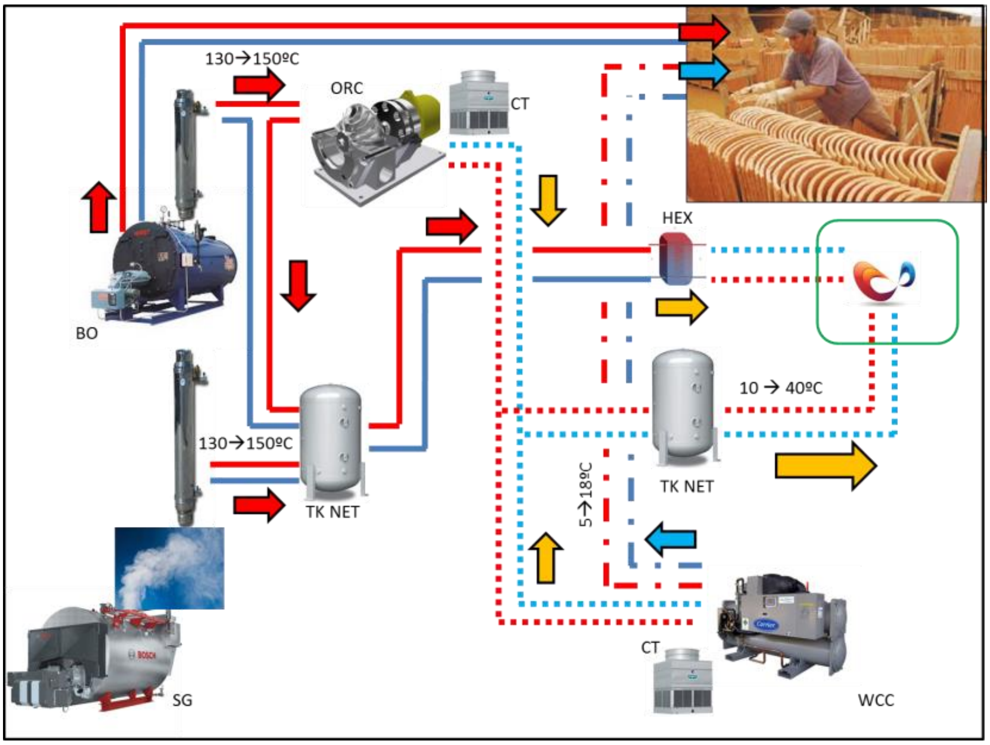


Figure 16 – Ceramics with FLEXYNETS.

Implementation:

- integration of combustion gas recovery system into equalization tank;
- integration of steam condensation recovery system into equalization tank;
- integration of equalization tank into FLEXY-network as producer;
- integration of the rejected heat from chiller and ORC into FLEXY-network as producers.

The heat generator operates for production of process heat at high temperature, but there is a big potential in heat recovery if cooling the gases up to low temperatures; it is possible to plan 2 different steps of cooling: 1) for feeding an ORC and 2) for feeding the FLEXY-network via equalization tank. The condensing heat of the steam can be also be recovered efficiently, without affecting the process. Heat recovered can be homogenized into a buffer tank, as intermediate storage, before being injected into the FLEXY-network.

Heat rejected from the chiller into the environment can also be recovered and injected into the FLEXY-network, as well as the condensation of the ORC, working at similar temperatures.

The sub-station is always operating as producer.

2.1.9 Substation 9 – Power-station (solar thermal)

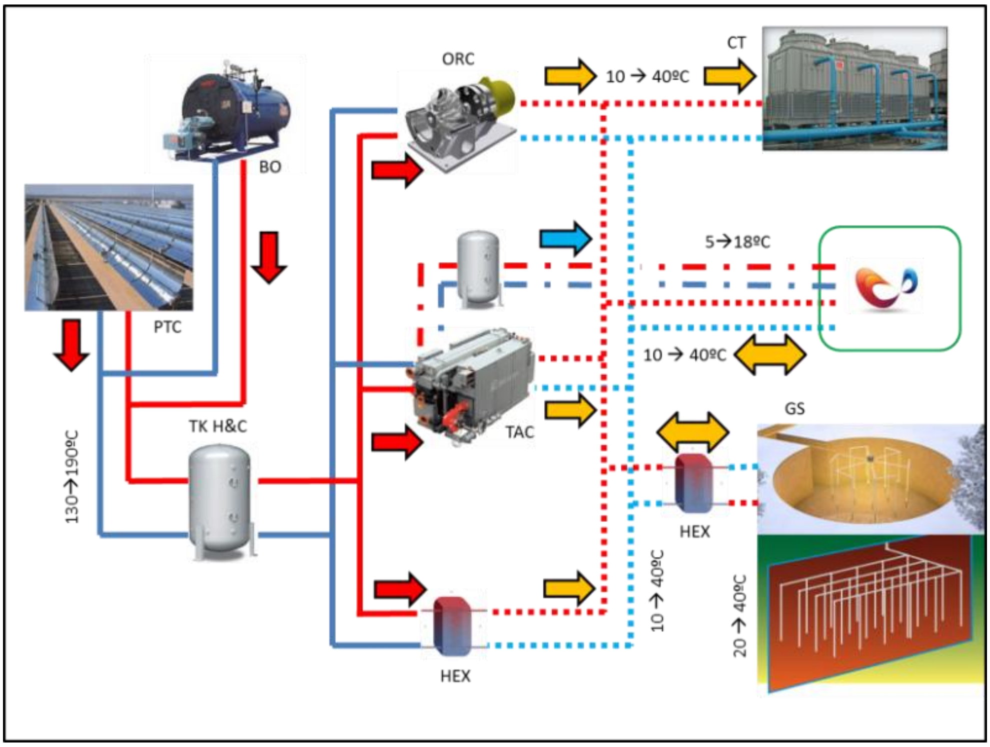


Figure 17 – PTC power station with FLEXYNETS.

Special substation with:

- Solar PTC for low/medium temperature application;
- Auxiliary heat generator (gas boiler or other renewable equipment) used as back-up and topping system connected in series/parallel with the solar field;
- Production of cooling via Double Effect Absorption chiller;
- Production of electricity via ORC;
- Possible simultaneous production of heating, cooling and electricity;
- Use of tank as junction and storage system;
- Use of ground storage (or other seasonal storage) for equilibration of the power station and/or FLEXY-network
- Use of dissipating systems (cooling towers, water basins, rivers, etc…) for rejection of excess heat from FLEXY-network and sub-station equipments.

Implementation:

- Direct production of low temperature heating, via BO and PTC, to be delivered/stored into the network, or rejected via dissipating systems;
- Produced electricity, via ORC, used for multiple purposes and indirect production of heat to be delivered, or stored, or dissipated;

- Direct production of cooling used to equilibrate (reduce) network temperature, while rejection heat (indirect production) can be delivered, or stored, or dissipated;
- Possible dissipation of rejection heat via cooling tower, or lake, or river, etc…;
- Use of cooling storage tank for load-production shifting.

The idea behind the power station is to have a regulating system able to regulate and equilibrate the FLEXY-network when energy balance between consumers and producers cannot be autonomously compensated, with consequent risk of operation out of temperature limits.

The power station can operate in different forms depending on the negative (temperature of the network lowering) or positive (temperature of the network rising) energy balance: when the energy requested by consumers is higher than energy produced by producers, the balance is negative; when the energy produced is higher than energy requested, the balance is positive.

When the balance is negative, the network can be fed directly with: the heat previously stored in the seasonal storages; directly from heat generators when the solar radiation is low; indirectly with the rejection heat of TAC and ORC when the solar radiation is high.

When the balance is positive, the network has to reject heat, and it can be done in different forms: storing excess of heat into seasonal storages; dissipating the excess via rejection systems like cooling towers or water basins. Another way to lower the temperature of the network is through the direct production of cooling via TAC, when enough solar radiation is available, storing or dissipating rejected heat.

2.1.10 Substation 10 – Power-station (PV)

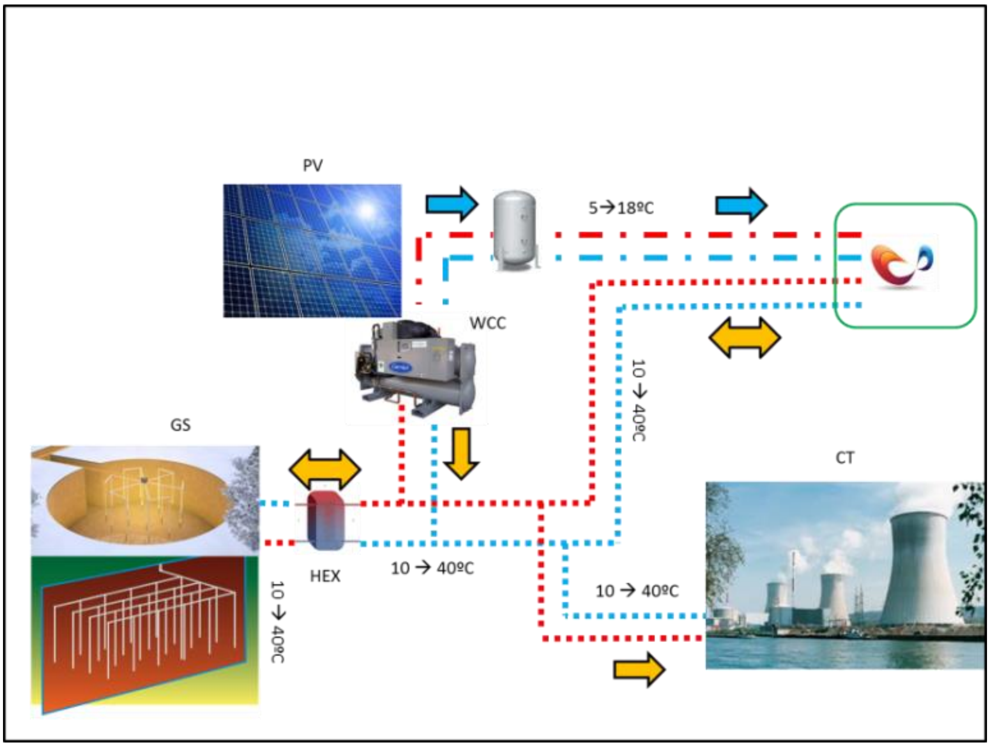


Figure 18 – PV power station with FLEXYNETS.

Special substation with:

- Solar PV for electricity production;
- Production of cooling via compression chiller;
- Possible synchronous use of heating (stored), cooling (directly) and electricity (directly);
- Use of tank as junction and storage system;
- Use of ground storage (or other seasonal storage) for equilibration of the power station and/or FLEXY-network
- Use of dissipating systems (cooling towers, water basins, rivers, etc…) for rejection of excess heat from FLEXY-network and sub-station equipments.

Implementation:

- Direct production of cooling used to equilibrate (reduce) network temperature, while rejection heat (indirect production) can be delivered, or stored, or dissipated;
- Possible dissipation of rejection heat via cooling tower, or lake, or river, etc…
- Use of cooling storage tank;
- Use of cooling storage tank for load-production shifting.

The idea behind the power station is to have a regulating system able to regulate and equilibrate the FLEXY-network when energy balance between consumers and producers cannot be autonomously compensated, with consequent risk of operation out of temperature limits.

The power station can operate in different forms depending on the negative (temperature of the network lowering) or positive (temperature of the network rising) energy balance: when the energy requested by consumers is higher than energy produced by producers, the balance is negative; when the energy produced is higher than energy requested, the balance is positive.

When the balance is negative, the network can be fed directly with: the heat previously stored in the seasonal storages; directly from heat generators when the chiller operates as ait-to-water heat pump, fed by PV.

When the balance is positive, the network has to reject heat, and it can be done in different forms: storing excess of heat into seasonal storages; dissipating the excess via rejection systems like cooling towers or water basins. Another way to lower the temperature of the network is through the direct production of cooling via WCC, when enough PV radiation is available, storing or dissipating rejected heat

2.2 Substations proposed for simulation

With respect to the large number of cases proposed above, due to operative reasons based on limitations of the simulation platform, based on boundary conditions for case study buildings and based on viability of connecting the case studies to the FLEXY-network, it has been decided to reduce the number of sub-stations according to the following assumptions.

Residential substations

- The boiler is maintained as back-up system; it can be operated as alternative (in case of maintenance or other stops) or in synergy with respect to the heat pump (to cover peaks of load). If reversible heat pump is present, the substation is considered as prosumer.

- The chiller can be replaced by a reversible heat pump only if it is at the end of its life or the network operator makes a very convenient offer, to attract customers, so that even “not- too-old” chillers could be dismissed. If a reversible heat pump is present, the substation can be considered as prosumer.
- If the chiller is maintained, connection to FLEXY network is not recommended for cost of adaptation of the chiller to the network. Moreover, this configuration is not considered interesting for simulations as it is expected to cover only a minority of cases.
- In case of presence of a reversible geothermal heat pump, the existing equipment is maintained because of fulfilment with FLEXY network working conditions. In this case, the operator would only act as heat sink, without any modification to the HVAC system.
- Solar heat, even if available and suitable for feeding the network, is excluded from the connection for cost of adaptation of the tank to the network. Moreover, this configuration is not considered crucial for simulations as it is expected the effect of a series of solar thermal installations could be represented in an aggregated way through (to be defined in future work).
- Possible contribution of solar energy to the network will be considered at statistical level in the analysis of the network, as if it were a specific station of the operator for increasing the energy of the network. On the other hand, indiscriminate injection of heat from user would lead the operator to dissipate the energy not required, with related difficulties and costs.
- With presence of simultaneity of heating and cooling loads during the year, chiller cannot be replaced only by a reversible heat pump. A ChillHeat can be implemented but connection to network will be limited and not economically interesting, even more if relationship cooling/heating is 1. On the other hand, big differences between heating and cooling load would drive to network unbalance.
- Air source chillers and heat pumps should require an important modification, to be connected to FLEXY-network, in the part of the condenser, with possible consequences on the efficiency of the machine and on the responsibility of maintenance. For these reasons it is not planned to connect them; at least replaced, if economically interesting for end user.

Industrial substations

- The industrial cases relevant for FLEXYNETS will typically be cases of energy production only. Hence, it is expected that they will be solved by simple exchangers, without the need of detailed simulations as far as the substation is concerned. Typical profiles of industrial processes could be considered on a “statistical” basis, as for special buildings. On the other hand, industries can differ significantly from case to case and entering in the internal details of factories is outside the focus of FLEXYNETS.
- Most of industrial activities take place out of urban environment, or in a marginal and outer district of the city, where the presence of possible consumers (or prosumers) is extremely limited, while the concentration of producer would be extremely high. This consideration must be taken into account during the design phase of the network, to avoid undesired unbalances. On other hand, the substation related with such activity can be extremely simplified as a unique heat exchanger.

Special buildings

- Heat from recovery system, even if available and suitable for feeding the network, is excluded from the connection for cost of adaptation of the tank to the network and difficulty in management of the heat. This is motivated from an economic (difficulty to price the heat not desired) and energetic point of view (the networks is inclined to rise the temperature if no proper balance between consumer and producer is considered).

- Special buildings represent a specific category which, because of its variegated nature in HVAC solutions, has to be treated case by case, with specific analysis of the heating and cooling loads. A homogeneous reference is not present, and a typical case study cannot be considered thorough, even more considering that heating and cooling can be used for processes different from maintaining comfort conditions. Related substations will be considered at a statistical level but not a simulation level.
- Hospitals represent a high potential for the network, but, depending on specificity and population density of each country, for small and medium town, their presence is limited in number and restricted geographically to a specific urban zone that could be not accessible from the network (or with costs not interesting for the user and the manager). Even more energetic balancing of the network can be extremely difficult, depending on the position, in the distribution of the flow, with respect to other actors. Again, they will be considered only at a statistical level.

As results of all above considerations, it has been decided to focus simulations on one specific case for residential prosumers, which can represent the most interesting potential from the network developer point of view, because of more equilibrated distribution of the loads (and easy replicability: dealing with a large number of different solutions would be inconvenient for the network manager). It has been decided to use the reversible 2 pipes w/w heat pump technology, which is technologically established in the market, independently of the temperatures of operation (depending on application and heating terminals).

Clearly, the chosen system mainly addresses the residential building stock. Most of the special building types mentioned in the above list will indeed include more elaborated solutions, e.g., HVAC systems with proper indoor air quality management. At the level of residential buildings, forced ventilation will be considered for new/refurbished buildings, but not for existing ones. As explained in more detail in Chapter 3, in connection with the choice of building types, even restricting to this case it is possible to properly analyse full network scenarios.

Another interesting aspect refers to the possible integration with local renewable systems. From this point of view, photovoltaics offers promising possibilities of coupling with heat pumps, where proper control strategies can maximize electricity self-consumption. On the other hand, the integration with other renewable sources (e.g., solar thermal), while also possible, would require a more complicated substation layout than the one considered here. Since the purpose of FLEXYNETS is to make a first overall assessment of the entire system, this level of detail was considered more suitable for following steps. It is worth pointing out that, according to the typical national implementation of the Directive 2009/28/EC, there are no minimum installation requirements for renewable energies in buildings if they are connected to district heating networks, as the latter are assumed to directly pursue energy sustainability.

Besides residential substations, also generation substations will be considered in simulation, because necessity from the operator of the network to dispose of proper tools for energetic management of the network. This single generation station anyway includes all the needed components to act as both heating and cooling unit. Depending on the simulation mode, only the involved components will be activated. In practice, according to network thermal necessities, 2 different ways of operation (whose timing depends on the specific climate) have been identified and established:

- Heating – generators (CSP and BO) feed the GS via ORC and/or HEX, according to availability of solar source and to price of electricity produced by co-generation with respect to electricity purchased from the grid; in fact, production of electricity is not the main goal, but it is an added value achieved during heating process. In this case the elevated number of hours, generally requested by cogenerators (for being affordable), is limited by the cost necessary for the activation heat and by the cost necessary for the dissipation of the rejected heat. Most favourable conditions would be met by solar activation and water basin dissipations, that do not imply fuel (consumption) nor electricity (dissipation) costs. During winter it is out of scope producing more power than required from the network (co-generation electrically driven) except for medium/short time water storages of the network and of the substations. In fact this consideration cannot be done for seasonal storage, which is used to store excess of heat produced during the cooling period (extremely elevated number of producers and extremely limited number of consumers). The heat, stored (up to saturation) during cooling period, is used as heat source for the heating period.

- Cooling – generators (CSP and BO) feed the TAC in order to cool the network; rejected heat is stored into the ground or is dissipated to the environment (water or air), in case of saturation of the storages; use of ORC is out of scope because not useful for cooling or for heat storage purposes (TAC already generates waste heat). Energy necessary for cooling with TAC can be produced with BO and/or CSP according to maximization of solar contribution during yearly timeframe. Nevertheless, operation of the station should be continuative 24/7, because of the general tendency of the end users, during winter and summer, to operate in the same mode (same type of substation and same type of load), behaving mainly as consumers instead of prosumers. During mid seasons, according to geographic reason and building characteristics of the city where the FLEXY-network is installed, the network can be partially self-balanced, with consequent batch operation of the power substation, or storage of surplus heat, or dissipation via rejection systems.

Power substations can be integrated in the network both as centralized or distributed systems. In the following list are listed possible advantages (AD) and disadvantages (DIS) of both solutions:

1. As centralized, only one or two stations (according to the path of the network and balancing of the loads) will be present, with enough power to fulfil the 100% of the network for maximum required ΔT:
    - AD(vantage) – Totality of the network, before supplying each load, at the same temperature (quality of energy uniform) except for energy losses
    - AD - Equipment will be installed accordingly with reduction in cost and space with respect to distributed systems of equivalent capacity
    - AD - Unique control of the network, with reduction in complication of the global control system
    - AD - Concentred maintenance activity
    - AD - Concentred O&M personnel
    - DIS(advantage) – The power station must compensate the energy losses of all the network
    - DIS - Loss of effectivity in network balancing, for only one (or two) injecting node(s)
    - DIS – If one part of the network does not require load, it is not possible to reduce the temperature without affecting all the network (in principle, different areas of the network could benefit of different temperatures)

- DIS - In case of extension of the network, beyond plant design capacity, another power station would increase unnecessarily the capacity of the manager (duplicating power)
- DIS - For such big capacity (MW), geothermal storage would be difficult, according to urban limits and specific characteristics of the soil. Water basins (rivers, lakes, etc…) can be required closely for cost-effective rejection of excess heat of the network (in case of saturation of the seasonal storages)
- DIS - Placement could only take place into industrial district or outside the city
- Recommended for 2 pipes distribution network

2. As distributed, different number of stations (according to the path of the network and balancing of the loads) will be present, with enough power to fulfil the 100% of the specific part of the network close to the station (not the whole network), for the maximum ΔT:
    - AD - Fast response to network variations, with homogenised quality of delivered energy
    - AD - Reduced impact on space for placement of the station
    - AD - Possibility to install the station for single district, within urban environment
    - AD - Possibility to integrate geothermal as dissipation system without water basins
    - AD - Possibility to extend the network and provide specific substation
    - AD - The power station must compensate the energy losses only of the corresponding part of the network
    - AD - The power station can regulate the temperature of a specific part of the network without affecting the rest of the network
    - DIS – Network at different temperature depending on the number of loads in a specific part of the path (quality of energy not uniform)
    - DIS - Control limited to a part of the network, with complex overall balance
    - DIS - Elevated cost with respect to centralized solution (installation and operation)
    - DIS - Solar field can be a limit if integrated into urban environment
    - DIS - Loss of efficiency for scale effect
    - Recommended for 1 pipe distribution network
    - Suitable for 2 pipes distribution network

Fulfilment of network thermal needs should be the main driver for power substations, able to operate as heater or cooler for maintaining the network into a fixed temperature range, suitable for HP operation; two are the main issues to be taken into account for the sizing of the system:

- Production of useful energy from solar field
- Behaviour of seasonal storages during yearly timeframe (capacity) and during time (saturation)

Sizing of the entire generation stock must be done according to 100% of the fluctuation of the network (peak load), independently from centralized or distributed solution, in order to compensate temperature losses between upper and lower limits. Power size of main systems can be reduced in the presence of storages to cover the peaks, but preliminary energy balance must be carefully checked in intensity and time.

In systems characterized by large capacitances as FLEXYNETS power station or network, the typical approach of sizing components to the maximum heating/cooling power could not be the best choice. This "power-driven" sizing approach in most of the times will determine energy generation units which are over-designed with respect to the real needs.

In this view, the idea of sizing components based on max power should be substituted with a sizing approach based on energy. In this way, system components will exploit heat storage effects at component and network level. This "energy-driven" sizing approach is expected to lead to lower installed heating/cooling capacity and consequently to lower investment costs.

The energy generation units at power station level should follow this approach. The main reason is due to the unpredictability of the energy output of the solar collectors. If the boiler is overdesigned, solar collectors might become unexploited and therefore the investment will never pay back. On the contrary, if the boiler is under-designed, the heating/cooling of the power station might not be sufficient for responding to network's demand. A good trade-off must therefore be found taking into account the dynamics of the network and local availability of solar energy.

A pre-sizing of system components can be done through the usual "max power" approach, but only dynamic simulations will provide sizing rules. This pre-sizing could of course be used to have a starting point for simulations.

Similar considerations can be done also in the case of the network. In this case, it could also be interesting to understand which is the effect of an under-designed power station and to which extent fluctuations of network's temperature are admissible for the substations (heat pumps).

Nevertheless, as far as the considered generation substation is concerned:

- BO must be sized for the 100% of base load (between cooling and heating, considering 1 kWcool = 1 kWheat), to be used as backup and compensating system integrated with CSP. In case of batch operation or quick response of time in modulation, it is strongly suggested the use of gas, or liquid, based fuels (solid biomass is cheap and environmental friendly but has high thermal inertia).
- Sizing of the solar field depends on the geographical locations. In regions with high cooling demand (e.g., Spain), sizing must be done accordingly to cooling conditions, when radiation is higher, in order to feed 100% TAC for most of the critical periods (oil storage must be considered); rejected heat from TAC will be used to re-fill geothermal (seasonal) storage. In case of utilization of negative temperature chiller (and ice storage strategies), it is possible to increase the size of the CSP field, increasing the solar contribution during heating and decreasing the yearly contribution of the BO. In regions with high heating demand (e.g., Denmark) sizing could instead be related to seasonal storage.
- Sizing of borehole thermal energy storage, and other kinds of seasonal thermal storages, should take into account enough capacity to absorb most (to be quantified) of the rejected heat from TAC, or the quantity of energy considered necessary for heating purposes (not yet estimated). Depending on network operating temperatures, FLEXY-network-to-GS heat exchanger can be installed or not.
- Other devices, like TAC, ORC, HE or CT will have more simple sizing process, because of their direct relation with loads.

Utilization of flat plate solar collectors would also be feasible as a heat source, but not for a full generation substation able to produce electricity and cooling with the currently selected technologies, because of the temperature limits required from both Rankine and aBsorption cycles. ADsorption cycles could be integrated, but the cost for implementation and operation would be higher than for aBsorption cycles; furthermore solar flat plate collectors would not be the best solution for this kind of technology, due to the temperature of activation, closer to vacuum tube technology. The case of large flat plate collector fields for heating will be considered separately.

The absence of a TAC would delegate to solar collectors the role of heat source during heating period and inactivity during cooling period, because of the general tendency to transform prosumers in consumers (domestic end-users).

As results of all above considerations, it has been decided to focus simulations on 2 specific sub-cases (one for heating and one for cooling) for power station, which represent the most interesting potential from network developer point of view, because necessary for equilibrating the loads in the network, according to network specifications. Both sub-cases focus on parabolic trough collectors for harvesting solar energy and boosting the renewability of the power station. The inclusion of a cogeneration unit was considered important in order to understand how conventional combined heat and power (CHP) can be readapted in the FLEXYNETS case.

3 Description of substation (residential)

In this chapter simplified schemes (respect to annexed drawings) of the residential substation are reported and explained in their implementation at software level, in order to give a complete view about the way of operation, about the control strategies and about the dependences between sensors and actuators in order to fulfil with thermal and comfort requirements of different building typologies. Most of the boundary conditions and assumption here described are derived from EU FP7 iNSPiRe project and in particular from references [1] and [2].

3.1 Description of the HVAC system

Figure 19 shows the architecture of the system. The system couples, in the generation side (red rectangle) the heat pump as the main generation system. This side of the system includes also storages (yellow part). The distribution side (light blue rectangle) covers the building and DHW thermal loads.

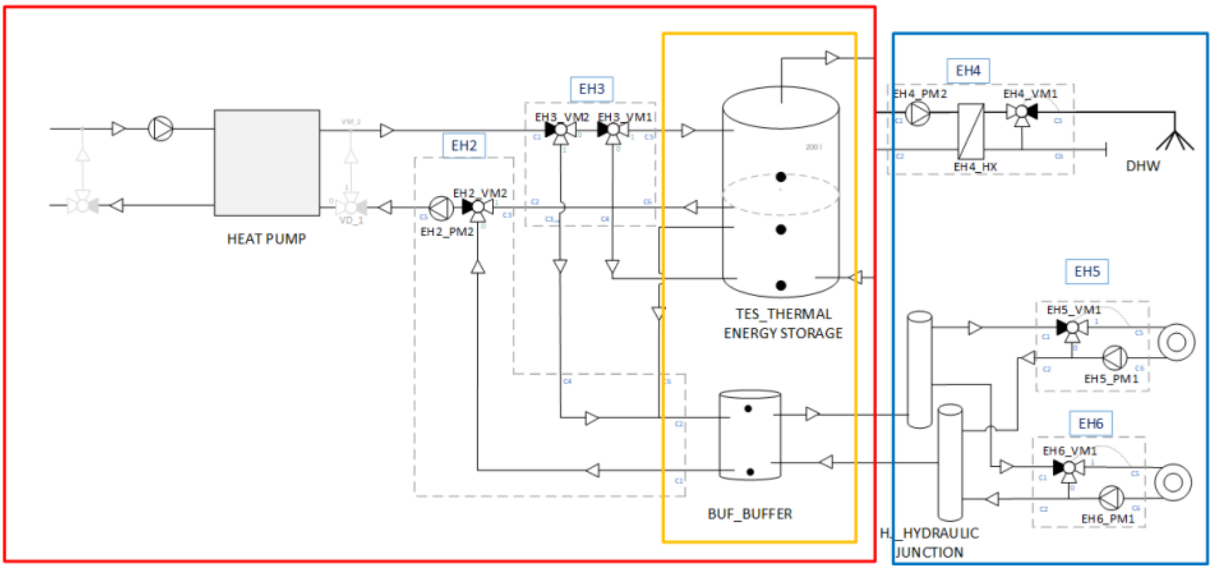


Figure 19 – Schematic of the HVAC system with the identification of the three main zones.

The layout configuration of the HVAC system follows the same characteristics for all the cases analysed, despite the different building typologies. This allows simplifying the numerical models implementation and running parametric analysis. However, some assumptions are made, as explained in each case study.

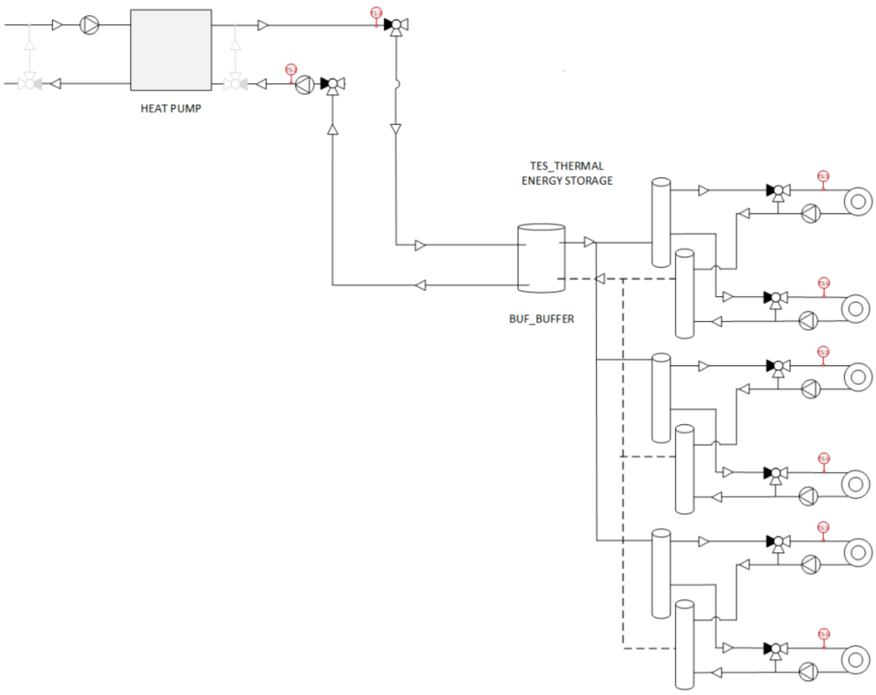
3.1.1 Building typologies

References [1] and [2] from the iNSPiRe project include descriptions of building typologies and motivations for their representativeness. Within the iNSPiRe project, multi-family houses (MFH) were divided into small (s-MFH) and large (l-MFH) ones. It was described how these types of buildings are representative of a large part of the existing building stock. Within the FLEXYNETS project, since the focus is on substations, it was decided to restrict the analysis to single family houses (SFH) and small multifamily houses. This basically preserves the difference between "single" and "multiple" users (form the point of view of load profiles), which is the main difference which can affect substations. The difference between small and large MFH is more a matter of properly scaling the substation size (in terms of power), something which, at the level of network simulations, can be done in several ways[1]. Furthermore, at the level of the network aspects like the diversity factor have anyway to be taken into account. Consequently, even if the chosen building types do not cover the entire building stock, they are expected to provide sufficient information in terms of possible variations of load profiles from the point of view of typical fluctuations and relation between peak power and base load.

Small Multi Family House (s-MFH)

Zoning: The numerical model simulates a three to seven floors Multi Family House. Each floor has two dwellings (50 m^2 each) which have been simulated using two thermal zones each, one per orientation (north/south). A distribution device feeds each of the two dwelling's zones. Furthermore, only three floors have been modelled: ground floor, top floor and middle floor. In fact, all the middle floors have been considered having identical thermal behaviour. Following this assumption, the distribution side has been modelled only for three floors. The generation side, instead, receives the loads as it would face the entire number of floors.

Domestic Hot Water: Normally, an HVAC system in s-MFH is designed with decentralized heat exchanger for DHW production (one heat exchanger per dwelling). In this case, we simulate the entire profile of DHW of the building as unique load acting only on one big heat exchanger. This follows the same configuration used for the SFH numerical model. This simplifies greatly the analysis, since only one demand file for the whole building is used. While the calculation is consistent in terms of energy flows and losses, the sizing of this component is purely theoretical.



[1] From the building stock point of view, an analysis of settlement typologies was carried out in deliverable D3.1 of FLEXYNETS. That analysis provided the range of significant plot ratios and it was possible to observe that this range could satisfactorily be covered already by considering SFH and s-MFH. By properly combining the presence of SFH and s-MFH within the network, it is hence possible to get a largely representative set of cases (from the point of view of the load densities).

Figure 20 - Schematic of the plant used for the s-MFH.

Single Family House (SFH)

Zoning: The numerical model consists in two thermal zones (around 48 m^2 each), one for the ground and one for the first floor. Figure 21 presents the schematic of the HVAC system simulated. A distinct distribution unit feeds each zone.

Domestic Hot Water: on the contrary, the heat exchanger on the DHW distribution side is to be considered also for SFHs, accounting for the most restringing legislations on the legionella disease prevention.

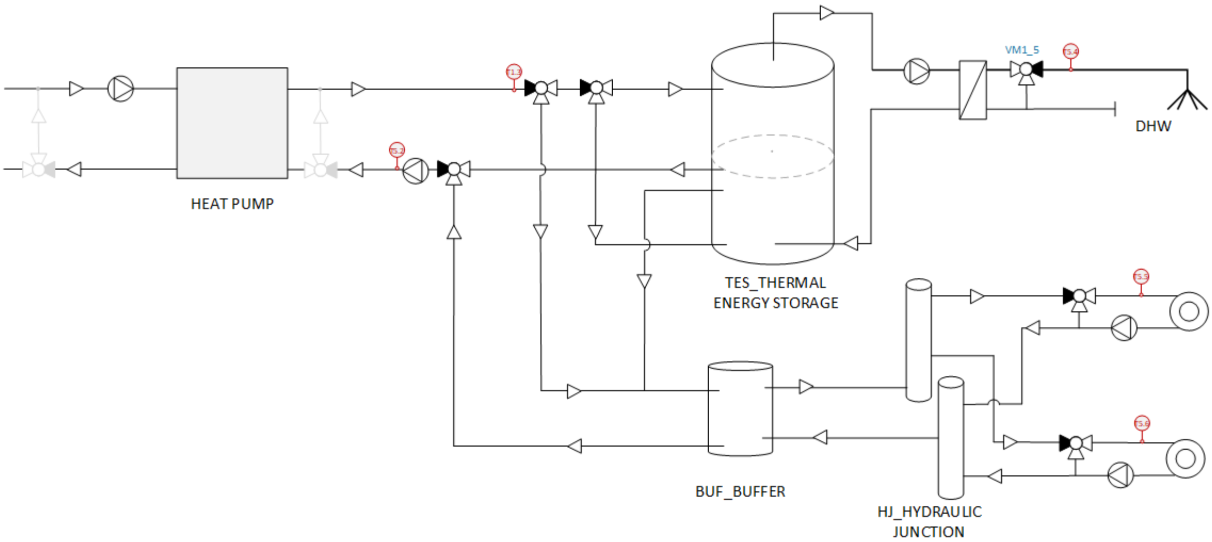


Figure 21 - Schematic of the hybrid system used for the SFH.

In the following bullets, a description of each part of the plant is given referring to Figure 21 and Figure 20.

1. **Generation unit** represents the heat pump for providing space heating and cooling, and for DHW preparation.
2. **Thermal Energy Storage (TES)** is a tank for the medium temperature level water to be used for the DHW preparation.
3. **Buffer (BUF)** is a smaller storage designed for two main objectives. Firstly, this storage is useful to decouple hydraulically the generation side and the distribution side (working as hydraulic junction). Secondly, it is used to provide thermal inertia (thermal flywheel, thermal mass) for the heat pump.
4. **DHW preparation** consists of a heat exchanger sized in a way to guarantee the instantaneous DHW production. On the user side, a thermostatic valve keeps the flow stream temperature to 45°C.
5. **Distribution system** can include different types of units: Radiators, Fan Coils and Radiant Ceilings. As already noticed, the number of devices per dwelling/office depends on the building thermal zoning.

3.1.2 Generation

As shown in the Figure 19, the generation zone is composed generation device for heating and cooling and the storages.

The generation device has been sized according to the maximum load for space heating and DHW. In the residential sector, the use of storage (TES) reduces the simultaneity of the generation and the DHW request. Accordingly, the peak of DHW has been reduced compared to a traditional DHW heater (instantaneous production of DHW). As a consequence, in SFH cases, the DHW load is higher than heating peak, while for s-MFH, the contrary is verified in general.

The procedure followed for calculating the Maximum Power requested (MPX) is presented in the following section. After that, there are paragraphs explaining the sizing rules applied to each HVAC system device.

Assessment of the maximum power for heating/cooling and DHW load

The building loads have been calculated assuming an ideal system with infinite capacity able to maintain the internal temperature at 20°C at wintertime and 25°C in summer in the residential buildings. An average over 1 hour has been used to avoid selecting only peak loads at system start.

For the DHW load, we considered a simplified numerical model, which has been retrieved from norm UNI 9182 [4]. Firstly, the minimum required volume for the DHW is individuated and, secondly, the maximum power required to keep the water temperature within a specific range is calculated. The following tables show the calculation developed for a SFH and a 5 floors s-MFH. It is possible to note that the minimum volume for a SFH is a bit less than 140 litres while for s-MFH the volume increases to 425 litres. Power is double in s-MFHs reaching almost 11 kW, compared to around 5 kW for a SFH.

The “dwelling” and “room” factors are used to estimate the design shower mass flow rate (worst load in DHW usage). The factors account for wealth of households (Rooms factor) and contemporaneity of loads (Dwellings factor), and are fixed according to the standard.

The other parameters used for the calculation are:

- t_{peak} [min]: represents the duration of the peak of DHW request (quantified as the minutes of a shower per number of inhabitants). The duration of the shower has been quantified in 4 minutes per person.
- t_{pr} [h]: is the time of charging the storage when it reaches the minimum temperature allowed (40°C). This parameter depends by choice of experts, it was to set t_{pr} four times t_{peak} for the SFH and eight times for s-MFH.
- T_m [°C]: is the temperature of supply water to the users (40°C).
- T_c [°C]: is the set point temperature for the storage (45°C).
- T_f [°C]: is the tap, cold water temperature (10°C for all climates in this analysis).
- $q_{mshower}$ [l/h] is the nominal mass flow rate for a shower (700 l/h).
- daily consumption [l/d/pers] is the daily consumption per person.
- V_{DHW} [l] is the size of the volume for DHW.
- P_{DHW} [W] is the peak power to guarantee DHW preparation

Table 4 – Calculation table for the DHW volume and power.

Parameter	Unit	SFH	s-MFH
N dwellings	[-]	1	10
Dwellings factor	[-]	1,15	0,47
Rooms factor	[-]	1,2	1,1
Area	[m²]	100	50
persons	[-]	4	3
$q_{mshower}$	[l/h]	745,2	2.791,8
t_{shower}	[min]	4	4
t_{peak}	[h]	0,27	0,20
t_{pr}	[h]	1,07	1,60
T_m	[°C]	40	40
T_f	[°C]	10	10
T_c	[°C]	45	45
V_{DHW}	[l]	136	425
P_{DHW}	[W]	5.200	10.823
daily consumption	[l/day/pers]	50	40

For the peak loads time, the size of the storage guarantees internal water temperature at the temperature T_m. The calculation of this volume is made as follows:

$$V_{DHW} = q_{mshower} \cdot t_p \cdot \frac{T_m - T_f}{t_p + t_{pr}} \cdot t_{pr} \cdot (T_c - T_f) \qquad (1)$$

The power generation device is calculated according to:

$$P_{DHW} = q_{mshower} \cdot t_p \cdot (T_m - T_f) \cdot \frac{cp_w}{t_p + t_{pr}} \qquad (2)$$

Summarizing, in SFHs, the DHW power is around 5 kW, whereas in s-MFHs it ranges between 6,5 kW and 15,2 kW (depending by the number of floors), Space heating power varies from 6,2 to 38 kW all over the climates.

For the SFH cases, the DHW load is higher than heating peak, while for s-MFH, it is lower power for the majority of the cases.

Heat pump

The heat pump used in FLEXYNETS is a water-to-water heat pump coupled with the network. The numerical model of the WWHP is the Type 928 from the TRNSYS TESS library [5]. Thanks to this model, the performance of the heat pumps is evaluated as a function of four independent parameters:

i. Inlet temperature and mass flow rate of the water (source side in winter)

ii. Inlet temperature and mass flow rate of the water (load side)

The capacity of the WWHP has been considered large enough as to cover the Maximum Power requested (MPX) with an outdoor temperature of -5°C. For this reason, a correction factor has been applied to the nominal power assessed at outdoor air temperature of 7°C (EN 14511). Based on the model of heat pump, a coefficient of 0,65 as been considered. In light of this, the nominal power (P_n) of the heat pump is evaluated as:

$$P_n = \frac{MPX}{0,65} \quad (3)$$

Figure 22 shows the COP variation with the evaporator and condensing temperature changing, whereas Figure 23 draws the EER trends depending, again, on the evaporator and condensing temperatures.

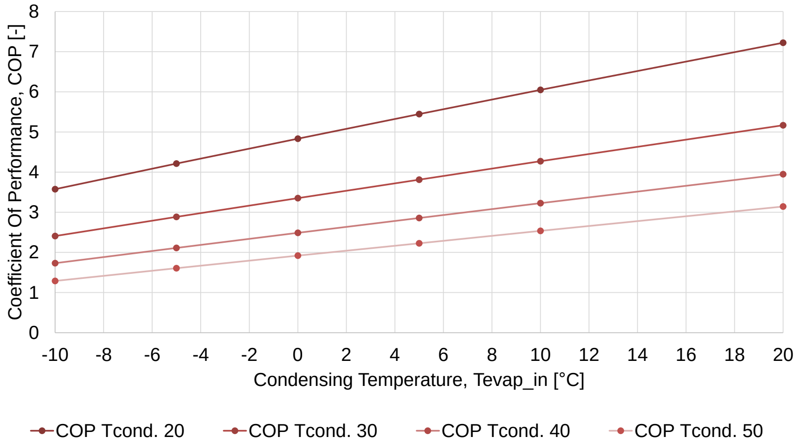


Figure 22 - Coefficient Of Performance for a Water to Water Heat Pump in winter mode as a function of the ambient air and the inlet water temperature at the condensing side.

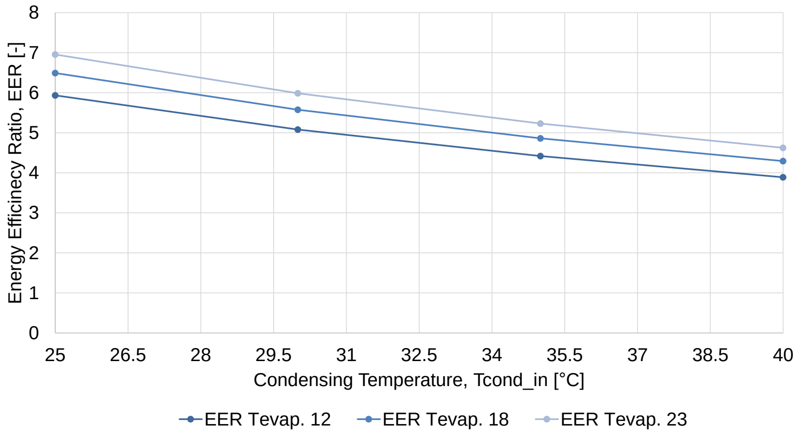


Figure 23 - Energy Efficiency Ratio for the Water to Water Heat Pump in cooling mode as a function of the ambient air and the inlet water temperature at evaporator side.

Circulation pumps

The sizing of the circulation pumps involves the definition of the nominal mass flow rate and electric consumption. The first quantity corresponds to the mass flow defined in the correspondent circuit (generation, DHW distribution, space heating/cooling distribution).

The calculation of the electric consumption is based on the equation below, where the electric power is a function of the head of the pump. To this aim, it has been estimated the quadratic load curve for each circuit which the pump belongs to (Figure 24). Assuming to work with a variable speed pump along the load curve and imposing a constant efficiency value of 0,6 (therefore the pump is properly selected for the specific circuit), the electric consumption of the pump is estimated. Furthermore, as a pump consumes a minimum electric power also when it is in stand-by, a value of 5 W derived by datasheet has been assumed as a stand still consumption.

$$P_{el} = \frac{\dot{m} \cdot g \cdot H}{\eta} \quad (4)$$

Where:

- $\dot{m}$ [kg/h]: is the pump mass flow rate.
- g [m/s^2]: is the gravity acceleration.
- H [m]: is the pressure head.
- η [-]: is the efficiency of the pump (considered equal to 0,6).

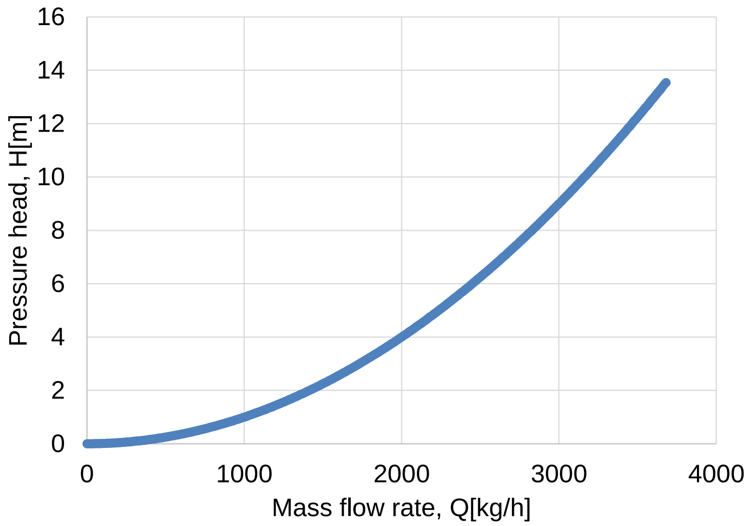


Figure 24 - Example of load curve for a given circuit. This curve represents also the working points for the variable speed pump.

3.1.3 Distribution

The distribution side concerns the terminal units used in the zones. Radiators (RAD), Radiant Ceilings (CEI) or Fan Coil (FC) are used in the residential buildings, while in the offices only FC and CEI.

The evaluation of the nominal performance of each terminal unit is described below. The distribution devices have been sized under different boundary conditions in terms of supply temperature. Accordingly, the circulation pumps have been sized with respect to the different terminal units.

Radiators

For the sizing, the Model "Plantella NT" manufactured by DeLonghi (0.9 m^2 of surface) has been chosen as reference radiator (datasheet in 8.1). This particular model has a nominal power of 1.989 W/radiator (with a temperature supply of 75°C). The manufacturer provides the exponent coefficient equal to 1,33. According to the formula reported, the nominal power has been adapted to different supply temperatures with the logarithmic temperature difference ratio.

$$P_a = P_n \cdot \left(\frac{\Delta T_a}{\Delta T_n}\right)^n \tag{5}$$

Where:

- P_a [W]: actual power under conditions different from nominal.
- P_n [W]: nominal power given by manufacturers.
- ΔT_a [K]: logarithmic difference of temperature, between mean temperature of radiator and sensible temperature of the air surrounding the device, under actual state.
- ΔT_n [K]: logarithmic difference of temperature at nominal conditions.

The following table shows the heating capacity calculated under different conditions.

Table 5 – Calculation table for the DHW volume and power.

Radiator inlet water temperature, $T_{w,in}$ [°C]	Radiator outlet water temperature, $T_{w,out}$ [°C]	Room temperature, T_{room} [°C]	Actual power [W]
75	65	20	1.989
55	47	20	1.048
45	40	20	685
35	30	20	309

The actual power permits to evaluate the needed number of radiators for covering the zone load. In the studied cases, we considered two supply inlet temperatures, 45°C and 35°C. As it is possible to notice by looking at the Table 5, passing from a standard supply temperature of 75°C to a lower one of 45°C, the installed radiators area increases by about 3 times.

The mass flow rate for radiators has been set according to the assumption of 5 K of the temperature difference between input and output of the device.

$$\dot{m}_n = \frac{MPX}{(c_{p,w} \cdot 5)} \tag{6}$$

Radiant ceiling

The TRIPAN panel has been considered as a reference for the radiant ceilings. The capacity of the panel is a function of the inlet temperature as follows (see also paragraph 8.2):

$$P_a = 10{,}796 * (\Delta T_a)^{1{,}036} \tag{7}$$

Where:

- P_a [W/m^2]: actual power of the radiant ceiling.
- ΔT_a [K]: temperature difference, between mean temperature of the radiant ceiling and sensible temperature of the air surrounding the device, under actual state.

Table 6 – Inlet and Outlet temperature and radiant ceilings power calculation at different working conditions.

Rad. ceiling inlet water temperature, $T_{w,in}$ [°C]	Rad. ceiling outlet water temperature, $T_{w,out}$ [°C]	Room temperature, T_{room} [°C]	Actual power [W]
35	30	20	148
30	25	20	87

The mass flow rate for radiant ceiling has been set according to the nominal mass flow rate of 25 kg/h/m^2.

DHW heat exchanger

In the general layout of the HVAC system, the DHW distribution is in charge of a unique heat exchanger. In the reality especially for the s-MFHs cases, each dwelling of the building has its own heat exchanger. For the sake of simplicity, a common layout has been developed for SFH and s-MFH, so only one heat exchanger for the DHW preparation is used. In both cases, the HX has been properly sized.

For what concerns the sizing, for the SFH heat exchanger is reported in Annex III. For the s-MFH a bigger HX has been used. Chapter 7 details the sizes and Table 7 briefly summarizes some details of mass flows an temperature at the two HX sides.

Table 7 – Values for the main heat exchanger classified per building typology.

Building typology	Mass flow rate source side [kg/h]	Mass flow rate load side [kg/h]	Power [kW]	Weight [kg]	Occupied area [cm^2]
SFH	577	600	23	12	12x52
s-MFH	2.545	2.700	103	86	100x30

3.1.4 Storages

The two storages of the HVAC system are the bigger one (TES) which is used for DHW and solar energy and the smaller one used as Buffer (BUF) for the generation device. The TES has been sized according to the complexity of the system: if the solar system is not used, the storage volume is set according to Table 8 as the minimum DHW tank size.

Table 8 – Minimum DHW storage volume.

Building typology	Minimum DHW volume [l]
SFH	140
s-MFH	425

The role of the buffer storage (BUF) depends on which kind of generation device it is connected to. In the case a WWHP, the main aim of the BUF is to avoid continuous ON/OFF cycles of the generation device. The mantle of both storages is insulated with a 15 cm of soft polyurethane.

3.2 Control strategy

To integrate and run homogeneously all the components of the plant, an appropriate control strategy has been developed. For residential buildings, the control strategy is based on setting DHW priority on the other requests and guarantee occupants comfort.

As shown, the layout of the HVAC system uses storage as connection between generation and distribution devices. Following this, the control strategy has been developed keeping the control of generation and distribution separated. This approach makes the control strategy easy to be scalable and adaptable to different building typologies and system configurations.

The structure of the control rules consists of five elements listed in the following:

- Feedback signal: information acquired from the sensors;
- Hysteresis: elaboration of the acquisition signals in Boolean format. The hysteresis, in thermal systems, is useful to avoid continuous oscillation of the signal due to the nature of the system.
- Schemes: represent the working modes used by the HVAC system. The schemes are defined as logical phrase of hysteresis.
- Modulation: refers to pumps and valves and it is used to scale the control signal of the component. The modulation can be either a fixed value or a function of another independent variable (temperature or mass flow rate);
- Control signal: is the command given to the devices to be controlled; it is the combination of schemes and modulations.

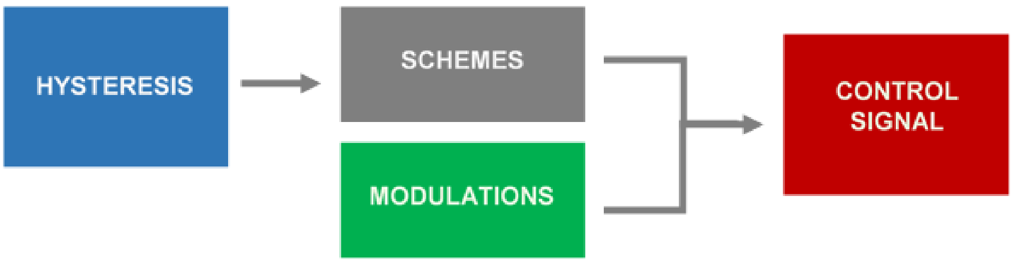


Figure 25 – Structure of the control signal.

3.2.1 Monitored parameters

The measurements considered for the control of the plant refer to temperature, mass flow rate and irradiation on the horizontal plan. The position of the sensors is shown in the HVAC system layout in Figure 26. Hydronic elements have been grouped into Energy Hubs (EH), compact energy boxes that group hydraulic components such as valve, pumps and heat exchanger. In Figure 26 there are five Energy Hubs (EH2 to EH6). For the sake of clarity, Table 9 lists the nomenclature used in the following figure for the HVAC system equipment.

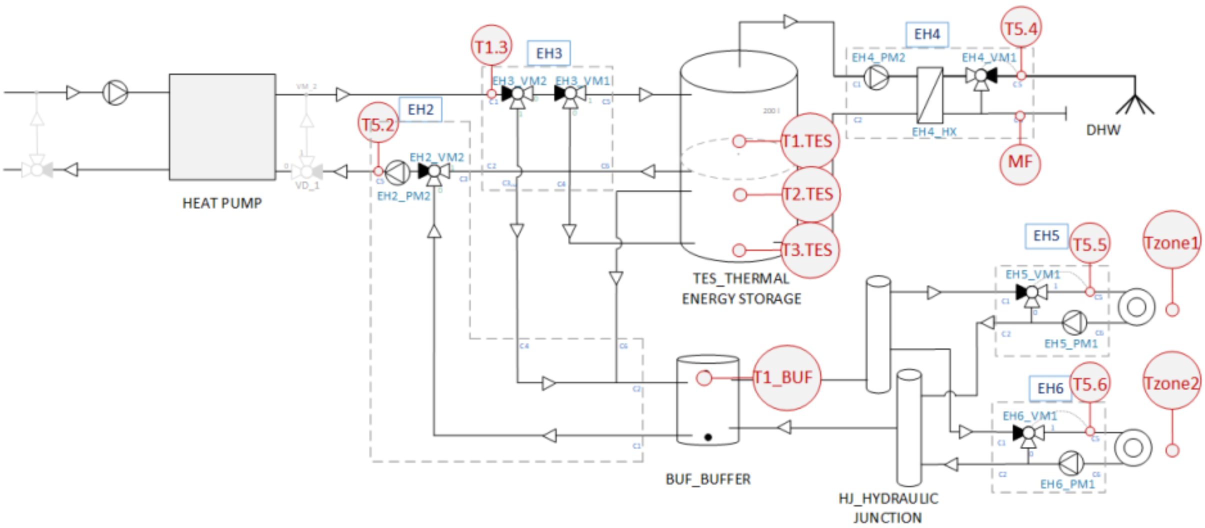


Figure 26 – Monitored sensors.

- AMB [°C]: Ambient temperature
- T1.3 [°C]: outlet temperature of the generation machine (Heat pump or boiler)
- T5.2 [°C]: inlet temperature to the generation machine
- T1.BUF [°C]: sensor of the small storage (buffer)
- T5.4 [°C]: temperature to the user of the DHW
- T5.5 [°C]: supply temperature to the distribution device – zone 1
- T5.6 [°C]: supply temperature to the distribution device – zone 2
- T_{zone1} [°C]: internal temperature of the zone 1
- T_{zone2} [°C]: internal temperature of the zone 2
- MF: flow rate of the DHW demand

Sensors on the main storage:

- T1.TES [°C]: top sensor used to maintain the upper part of the tank at a certain temperature for the DHW production;
- T2.TES [°C]: middle sensor used for solar heating;

- T3.TES [°C]: bottom sensor used for the solar field circuit activation.

The height of the sensors in the main storage depends on the different sizes of the storage. The minimum storage volume guaranteeing that DHW demand is covered has to be kept always within the interval 40-45°C (red part in the Figure 27).

Visualising a fictive division line between the minimum DHW volume (whose height is indicated with H1) and the rest of the tank volume (which height is indicated with H2), the top sensor is located 20% of H1 above the division line. Sensor T2 is located below this fictive line in a distance equal to the 20% of H2. The bottom sensor is instead located at 10% of the overall height.

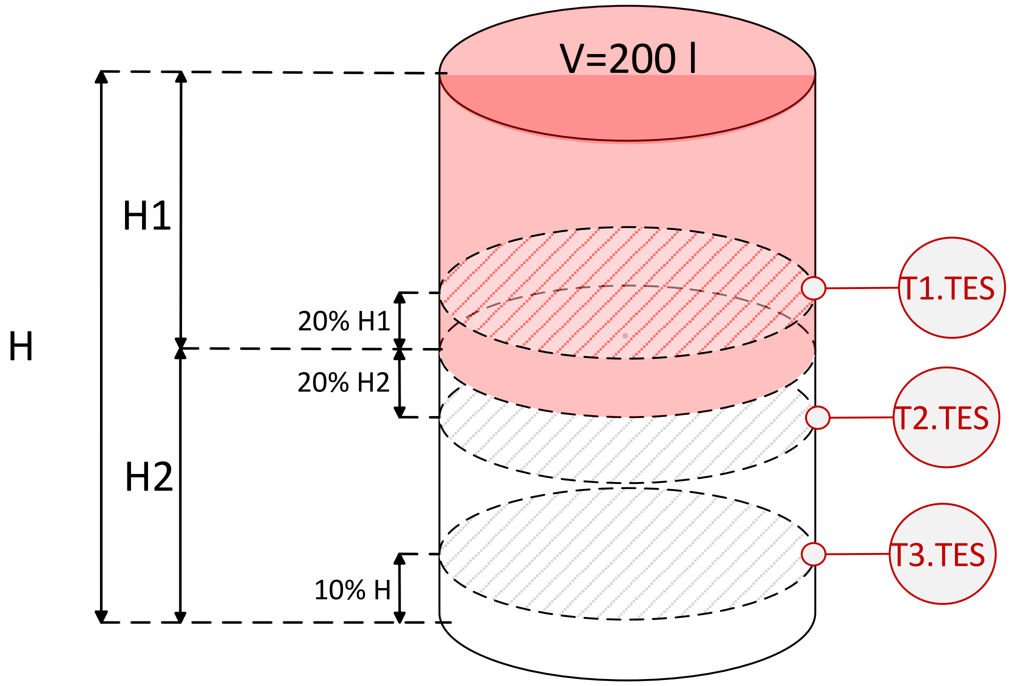


Figure 27 – Representation of the TES for DHW with height of temperature sensors.

Table 9 – List of Hydraulic equipment of the HVAC system for a SFH.

Energy hub	Name	Description
EH2	EH2_PM2	Circulation pump
	EH2_VM2	Mixing valve
EH3	EH3_VM2	Diverter valve
	EH3_VM1	Diverter valve
EH4	EH4_PM2	Circulation pump
	EH4_VM1	Thermostatic valve
	EH4_HX	Heat exchanger
EH5	EH5_PM1	Circulation pump
	EH5_VM1	Thermostatic valve

3.2.2 Functional schemes

The working schemes, of the HVAC system, identify which is the “operating state” based on the hysteresis generated. A scheme identifies the operation condition of each of the system components.

Running generation machine for DHW

This scheme has been developed to activate the generation unit (AWHP, GWHP, BOIL) when it is required to charge the upper part of the main storage. When the top tank sensor (T1.TES) measures a temperature below 45°C, the scheme is activated.

Running generation machine for distribution in winter

This scheme is used to feed the buffer in winter. This scheme is activated when there is no need of DHW preparation and the buffer temperature is lower than a specific set, dependent on the distribution system.

In the cases where solar heating (YSC5) is foreseen because enough solar area is available, an additional condition (NOT(2B)) assures that the buffer is not fed from the TES during this operation.

Running generation machine for distribution in summer

This scheme is used to feed the buffer in summer only whether the generation device is able to provide cooling (reversible heat pump cases). If any other scheme for using the generation unit is activated, and there is the need to cool down the BUF, scheme 4 is ON.

DHW request

This scheme is structured to provide DHW to the user when required. The light-blue circuit in the figure below takes the water from the top of the storage and returns with cooled water to the bottom of the tank. On the user side, tap water is heated up through the heat exchanger and a thermostatic valve modulates up to maintain a fixed supply temperature to the user (45°C).

DHW recirculation

This scheme individuates the recirculation scheme on the DHW circuit in s-MFH only. Differently from other schemes, this scheme involves only the source side of the DHW circuit pipes. This scheme is used to keep all the parts of the circuit warm when there is not request of DHW, allowing for a prompt delivery of HW on demand.

Distribution unit heating and cooling

These schemes are used to run the distribution units of the plant. One valve and one pump per unit regulate the water distribution in order to maintain a comfort temperature in the zones associated at that particular distribution unit. When the internal temperature drops (winter) or rises (summer) across a set value, the scheme of each zone/dwelling is activated. The valve and pump modulations guarantee a fixed supply temperature to the distribution devices.

3.3 Simulation activities for substation: calculation, operation and results

The aim of this section is to report on the calculation methodology followed in the simulation of residential substations. As the description of substation layout is provided in paragraph 3.1 and the control strategy is paragraph 3.2, it is important now to specify how individual HVAC components are sized with respect to building load conditions.

Energy generation units

Generation units' thermal capacity is sized based on the largest of the loads calculated as mentioned above.

In most residential cases, the largest load is the DHW one, since here we are considering high energy efficiency levels both for heating and for cooling. Only in some cases (70 kWh/(m^2y) heating demand) the conditioning loads prevail.

Again, not always heating demand is higher than cooling: in the northern countries and with respect to the best energy efficiency standards (15 kWh/(m^2y) heating demand), the low-rise path of the sun during spring and fall generates significant cooling loads. Nevertheless, in the residential sector, we decided to size the generation units based on the heating loads only, for two reasons:

1. In this way all the systems are easily comparable.
2. During spring and fall when outside air temperature is moderate in northern countries, the cooling loads can be easily covered through natural ventilation (opening windows). This free cooling was, however, not modelled.
3. Therefore, even if the cooling loads are theoretically the highest, in practice they would be lower due to free cooling with extra ventilation, e.g. at nights.

The capacity of the heat pump is strongly dependent on the load's and source's temperatures. This said, this component has been sized to cover the maximum heating load.

The heat pump model used is a stationary model based on a performance map. The data used to build the table are taken from the datasheet of an average heat pump with constant speed compressor. Since data are provided at standard rating conditions, a correction factor (1.2) for the size is used to increase both rated thermal capacity and electric consumption to nominal design conditions. The same factor is used for all climates.

Pipes

In the models elaborated, pipes are included in the DHW circuit only. The diameters of each pipe are designed in a way that the water speed never exceeds 1 m/s. The insulation thickness is equal to the diameter for DHW pipelines.

Buffer tank

The buffer tank volume so designed is also useful to reduce the on-off cycles of the heat pump which thermal capacity is most of the times oversized compared to the space heating and cooling thermal loads.

Energy distribution systems

For the parameterisation and sizing of the different energy distribution systems, manufacturing data and self-made measurements have been considered for radiators and radiant systems.

For the radiators, the “DeLonghi Plantella NT model 21” has been selected (0.9 meter height, 85 mm width). The performance of this radiator is implemented using the standard logarithmic method. The procedure is as follows:

- The water mass flow rate is decided based on the model’s performance at specific inlet water temperatures (35 or 45 °C in the cases considered), in order to install a temperature difference between inlet and outlet of 5 °C.
- As many units are used as the number of the building’s rooms. i.e., in case of a SFH, 3 units per floor are considered, while for MFHs, 5 per dwelling.
- The total space heating capacity of the units is matched to the building/dwelling peak power by varying the length of the units. The length of each unit is checked to avoid unreasonable (too long) solutions.

The n-exponent is provided by the manufacturer (n=1,33), while characteristics of radiative and convective fractions come from manuals (Recknagel 2012). The convective part of the emitted heat is supposed to be the 65% of the total, while the radiative is the 35%.

The performance and properties of TRIPAN radiant ceilings has been considered as a reference. Their nominal capacity is around 140 W/m^2 in heating mode and about 100 W/m^2 in cooling mode (both at ΔT of 10 K).

Their capacity has been evaluated with the equation provided by lab tests as a function of the temperature difference between the average temperature of the panel and the room temperature. With an inlet temperature in the panel of 35 °C and a flow rate per panel of 50 kg/h, the radiant panel capacity is around 140 W/m^2, while with a temperature of 30 °C the capacity decrease to 93 W/m^2. In the cooling conditions the panel capacity is around 87 W/m^2 because of a smaller (ΔT) between the average panel temperature and the ambient. Radiant panels do not dehumidify the air.

The number of radiant panels per zone is consequently calculated in order to cover the building/dwelling peak power.

As reported already, space heating thermal power has been used for sizing purposes in case residential applications are considered (since this is normal praxis). In this way, in some residential cases, the cooling demand cannot be covered guaranteeing full comfort with respect to all outdoor conditions.

Management strategies and setpoints

The operation management can be divided into two parts: one related to the generation side while the second to the distribution. Every working mode regulates the on-off of the system components, the modulation of pumps-valves and determines the system priorities.

The management of the generation circuit does not vary with the different system configurations. This circuit feeds the upper part of the tank for the DHW preparation and provides heated or cooled water to the buffer tank for the space H&C. The priority is the DHW preparation.

The distribution circuit of DHW for the SFH is activated when the user request for it. For MFHs, this circuit is activated also for recirculation to keep the entire circuit warm enough, avoiding users’ temporary discomfort. No DHW distribution is foreseen for the offices.

The request of heating and cooling and of the consequent delivery is evaluated through dynamic simulation from each thermal zone simulated. The setpoints of the indoor air sensible temperature are: 19.5$\pm$0.5 °C for the winter and 25 $\pm$0.5 °C for the summer.

3.3.1 Energetic results

The system so defined is simulated for the reference locations of London, Stuttgart and Rome. Apart from the location, substation's performance is also influenced by FLEXYNETS temperature, obviously. In order to account for this dependency, a parametric analysis is carried out by varying network temperature from 0°C to 30°C each 5 K (it is expected that FLEXYNETS' temperature will vary within this interval). This value is kept constant throughout the whole year.

As previously described, the following cases are evaluated:

- SFHs/s-MFHs representative of the existing building stock ("EX") of the three location, where heating produced by the heat pump is delivered through high-temperature radiators at 55°C and for DHW preparation. No cooling is considered in this case.
- SFHs/s-MFHs representative of the new or renovated buildings with a target heating demand of 45 kWh/(m^2y). This value is achieved by renovating the existing building ("EX") by improving the envelope efficiency (insulation and new windows) until the target heating demand is reached. In this case heating from the heat pump is delivered to the building with low-temperature (35°C) terminals and for DHW preparation as well. Accordingly to the case, cooling can be provided in the case of new buildings, whereas is excluded in the case of renovated case. Cooling demands vary accordingly to the location and building typology.

The focus of the analysis is given to the performance of the substation (in particular of the heat pump) and to its yearly energy performance. In this sense, heat extracted (heating or DHW preparation) or dissipated (cooling) from/to FLEXYNETS is considered as well for the consequent electricity requests.

Simulation results for SFH and s-MFH, for existing and new/renovated buildings, and for three reference locations are shown from Figure 28 and Figure 39. In these, electricity consumption (grey bars) and energy extracted (heating in red, DHW in yellow) from FLEXYNETS is plotted on the left axis for different network temperatures. It appears evident as the sum of these two terms is constant and equal to building energy demands.

In the case of cooling, the blue bar represents the cooling load of the building which is a constant. The grey bar is the electricity consumption and therefore the sum of cooling load and electricity consumption is the amount of energy dissipated into the network. On the right axis, average yearly SPF of substation's heat pump (only) calculated as the ratio between heating, cooling or DHW loads upon the electricity consumption. For sake of clarity, reports a synthesis with energy demands of the building.

FLEXYNETS's temperature has a great impact on residential substations' energetic performance. Because of heat pump's security reasons, the inlet water temperature is limited to 20°C and 25°C in heating and cooling modes, respectively. This is why above and below these thresholds yearly energetic performance does not vary.

The SPF for heating, cooling and DHW in all locations are in the same range of values. This is true for existing ("EX") and new/renovated ("45") buildings. This fact occurs because system components (i.e. heat pump, thermal energy storage, buffers) are sized accordingly to the same criteria and because heat pump performance is not affected by climatic boundary conditions but only to load design temperatures.

Table 10 – Energy demands for the three different locations, different building typologies and energy levels.

Building typology	Location	Energy level	Space heating	DHW preparation	Space cooling
			[MWh]	[MWh]	[MWh]
SFH	London	EX	32,4	3,3	-
		45	4,7	3,3	0,5
	Stuttgart	EX	28,0	3,3	-
		45	6,2	3,3	0,9
	Rome	EX	16,3	3,3	-
		45	5,8	3,3	2,6
s-MFH	London	EX	76,2	17,6	-
		45	30,4	16,6	3,6
	Stuttgart	EX	74,8	16,1	-
		45	26,8	16,8	8,4
	Rome	EX	38,0	17,0	-
		45	30,5	16,8	21,5

The SPF for heating, cooling and DHW is positively influenced by the lower buildings demands and lower design temperatures in the distribution energy system. This makes the SPF for heating rise of about +70-80% with respect to the existing case ("EX"). The increment in DHW preparation is less affected by this change. Space cooling is considered only in the case of new/renovated buildings.

Table 11 – Average yearly SPFs for heating, cooling and DHW.

Building typology	Energy level	Space heating	DHW preparation	Space cooling
SFH	EX	1,9 – 3,1	2,0 – 3,25	-
	45	3,4 – 5,3	2,2 – 3,5	6,3 – 5,4
s-MFH	EX	1,9 – 3,1	1,6 – 2,6	-
	45	3,4 – 5,3	2,0 – 3,2	6,1 – 5,2

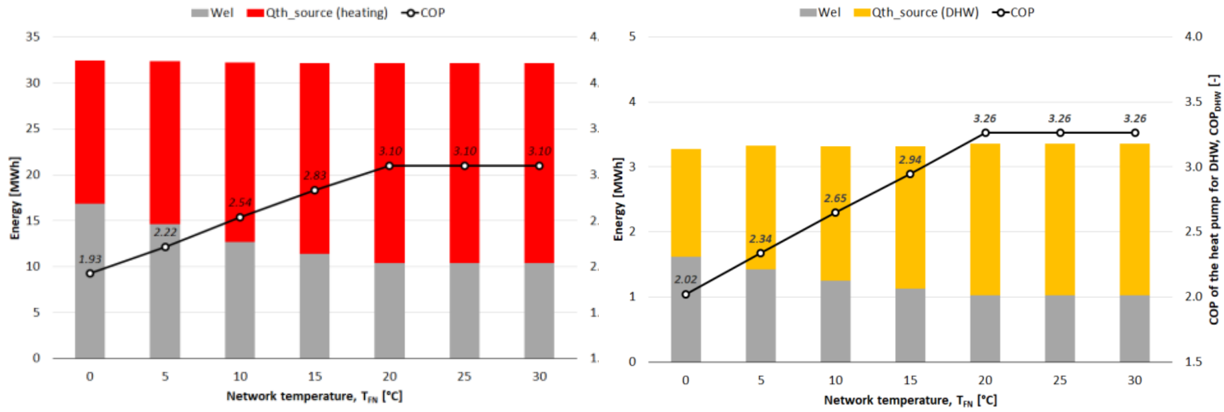


Figure 28 – Yearly energy balance for residential substations: existing ("EX") SFH buildings for the location of London.

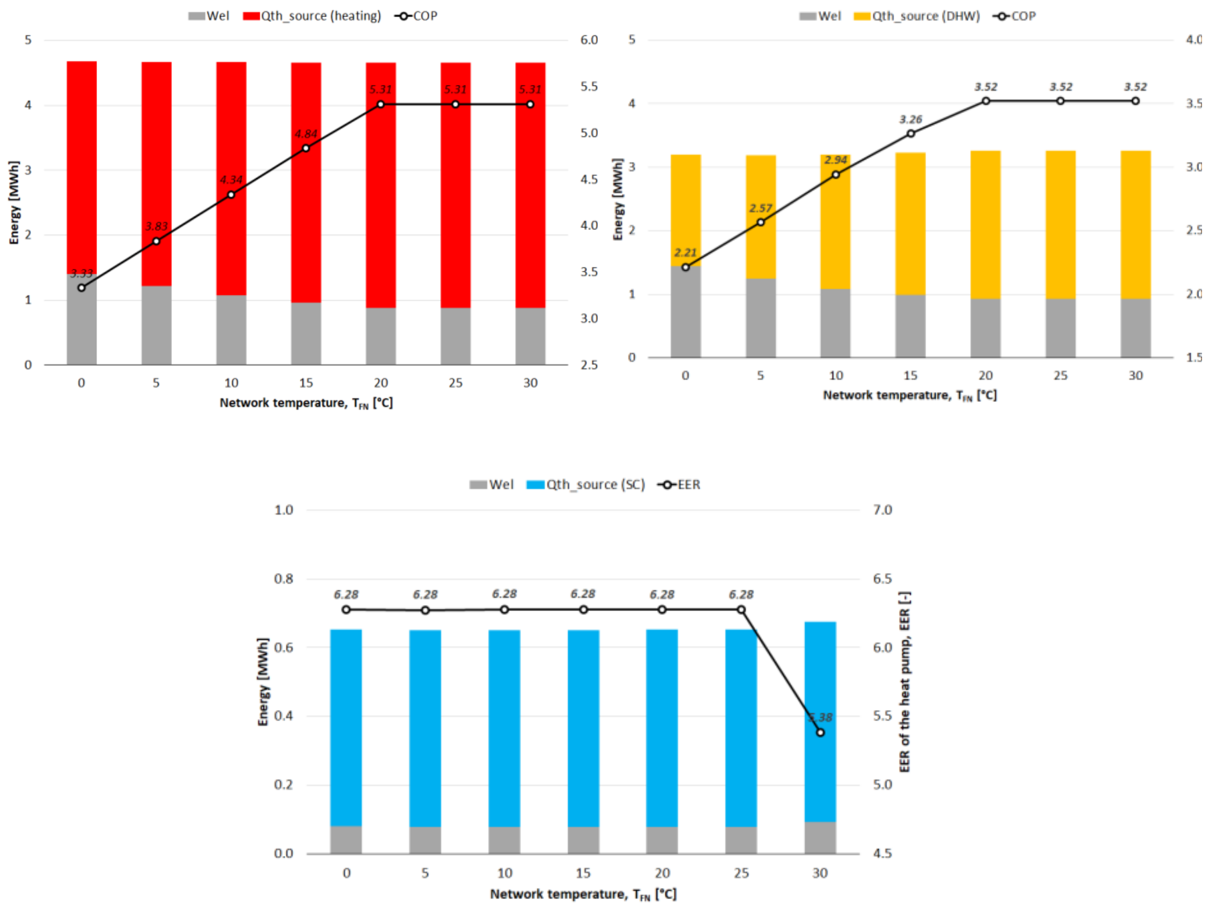


Figure 29 - Yearly energy balance for residential substations: new/renovated ("45") SFH buildings for the location of London.

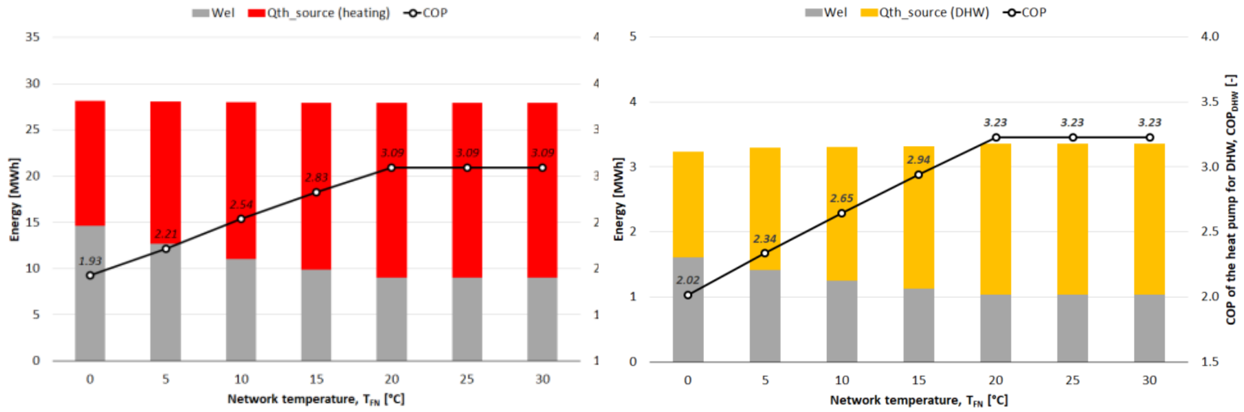


Figure 30 – Yearly energy balance for residential substations: existing ("EX") SFH buildings for the location of Stuttgart.

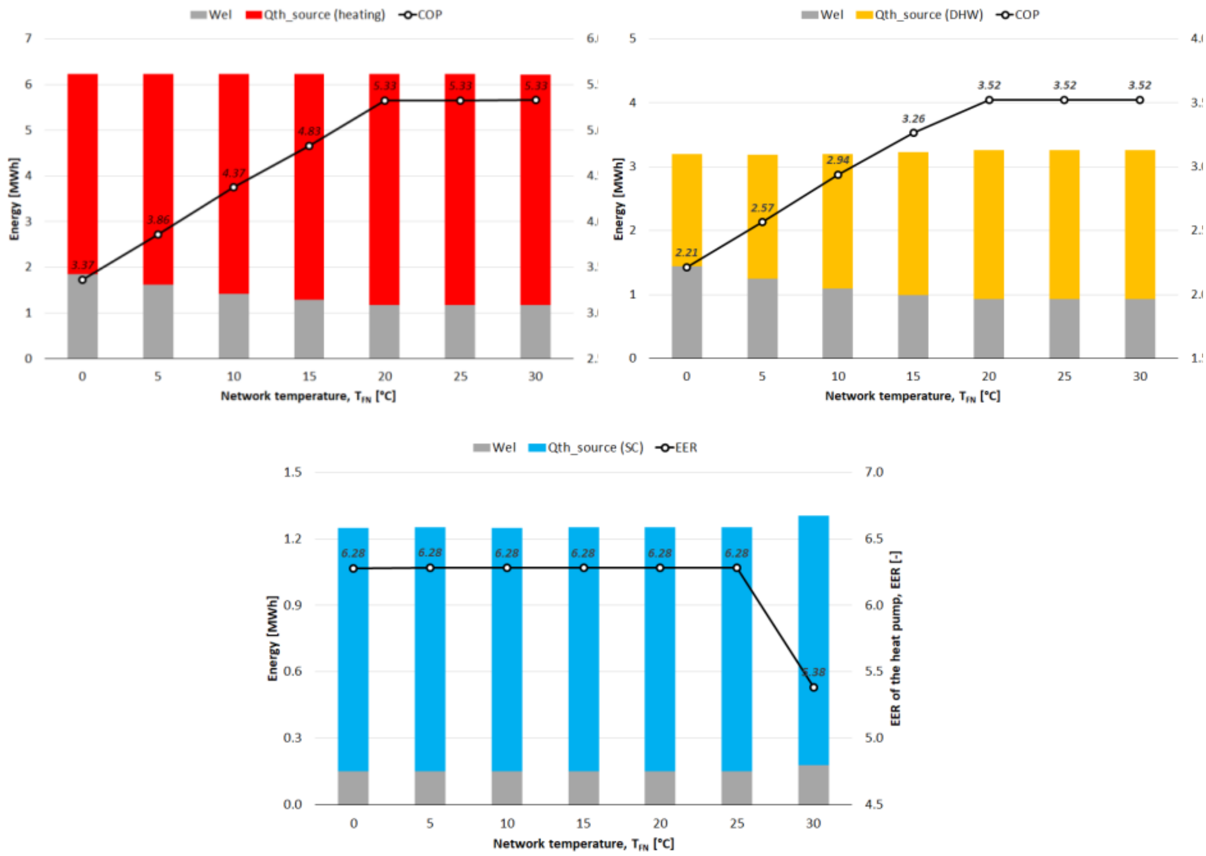


Figure 31 - Yearly energy balance for residential substations: new/renovated ("45") SFH buildings for the location of Stuttgart.

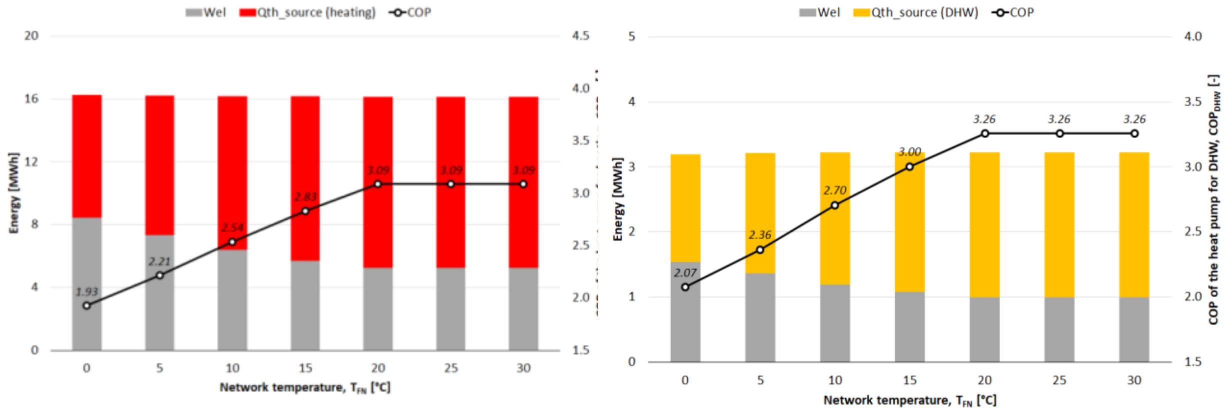


Figure 32 – Yearly energy balance for residential substations: existing ("EX") SFH buildings for the location of Rome.

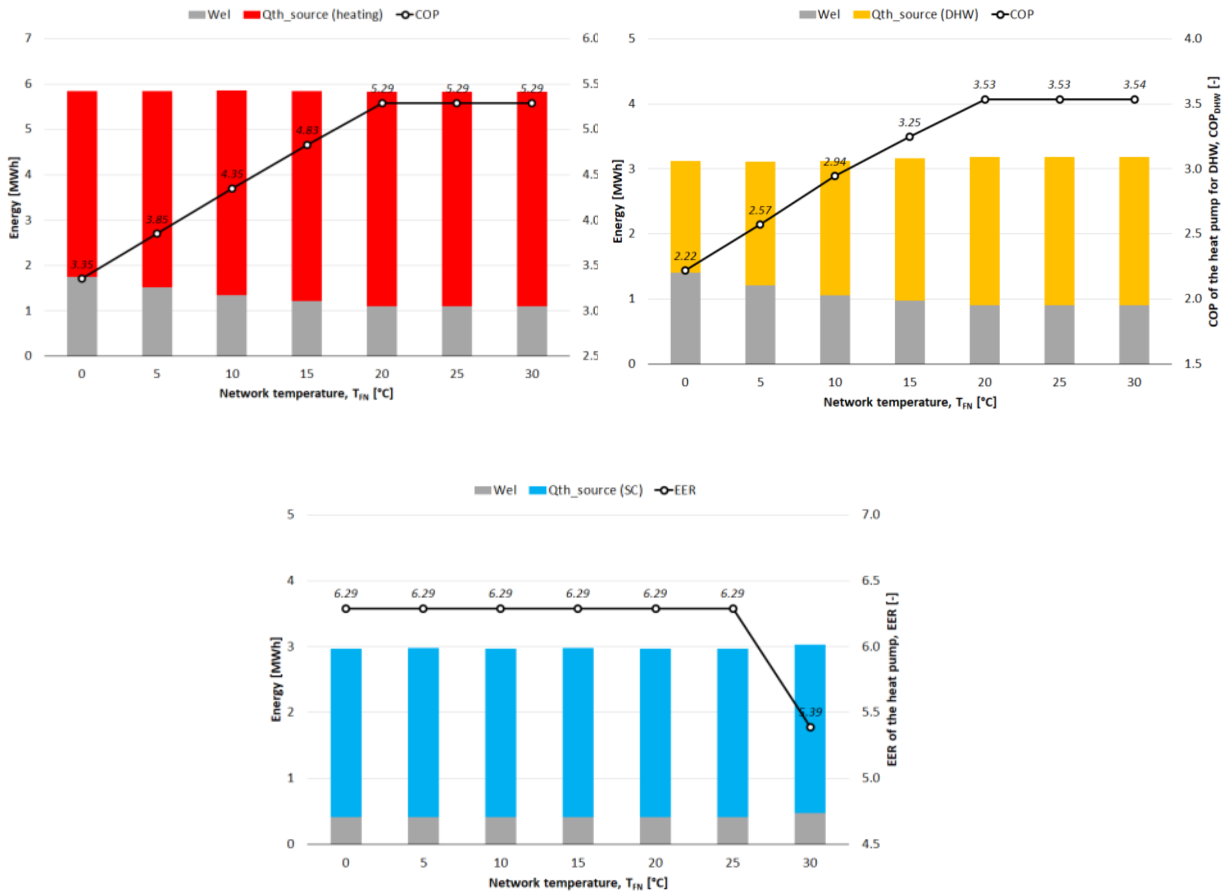


Figure 33 - Yearly energy balance for residential substations: new/renovated ("45") SFH buildings for the location of Rome.

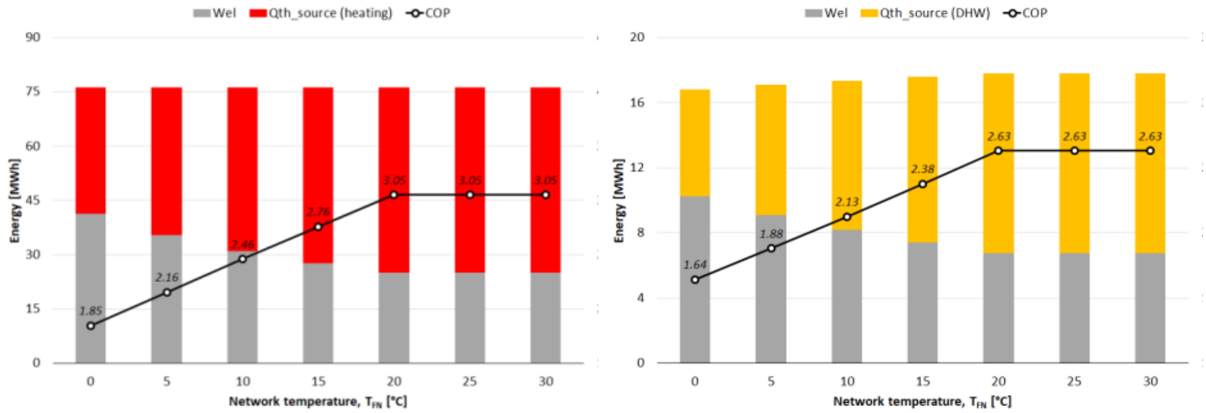


Figure 34 – Yearly energy balance for residential substations: existing ("EX") s-MFH buildings for the location of London.

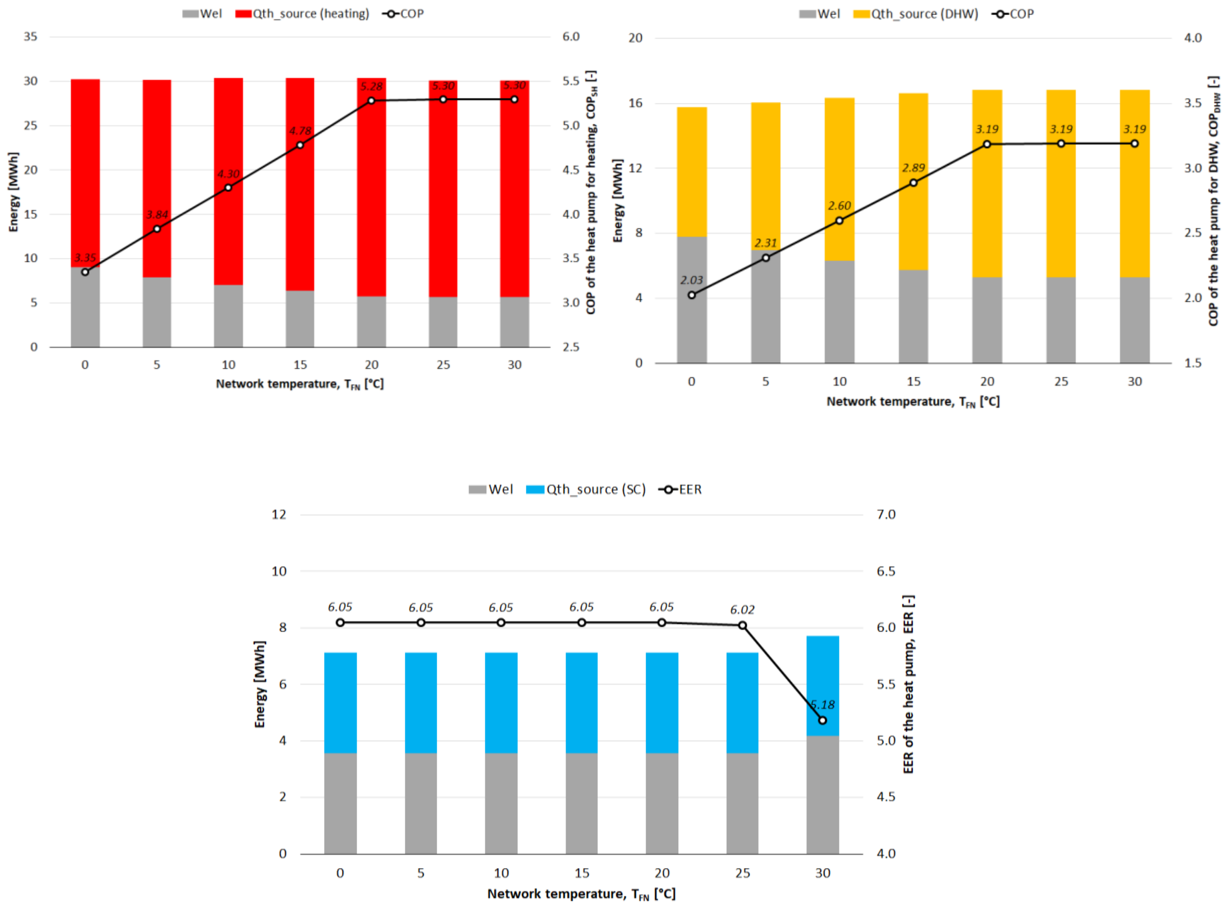


Figure 35 - Yearly energy balance for residential substations: new/renovated ("45") s-MFH buildings for the location of London.

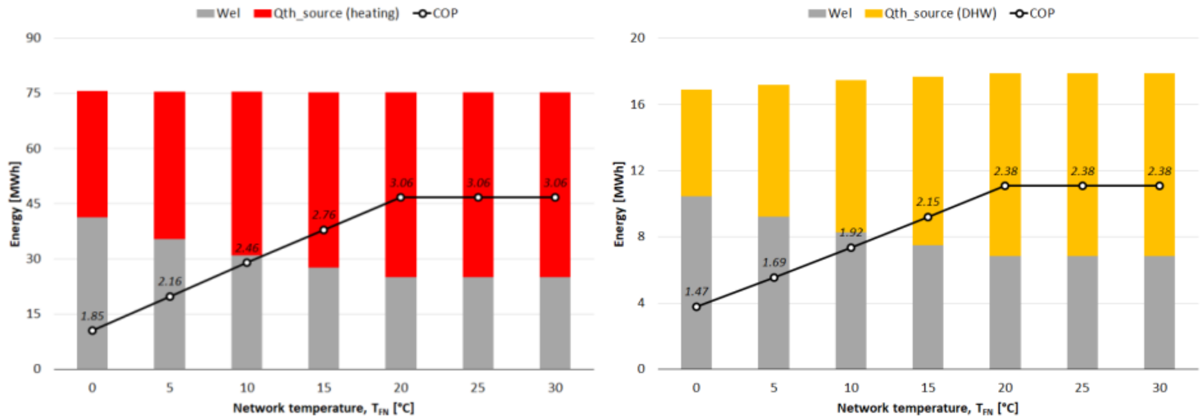


Figure 36 – Yearly energy balance for residential substations: existing ("EX") s-MFH buildings for the location of Stuttgart.

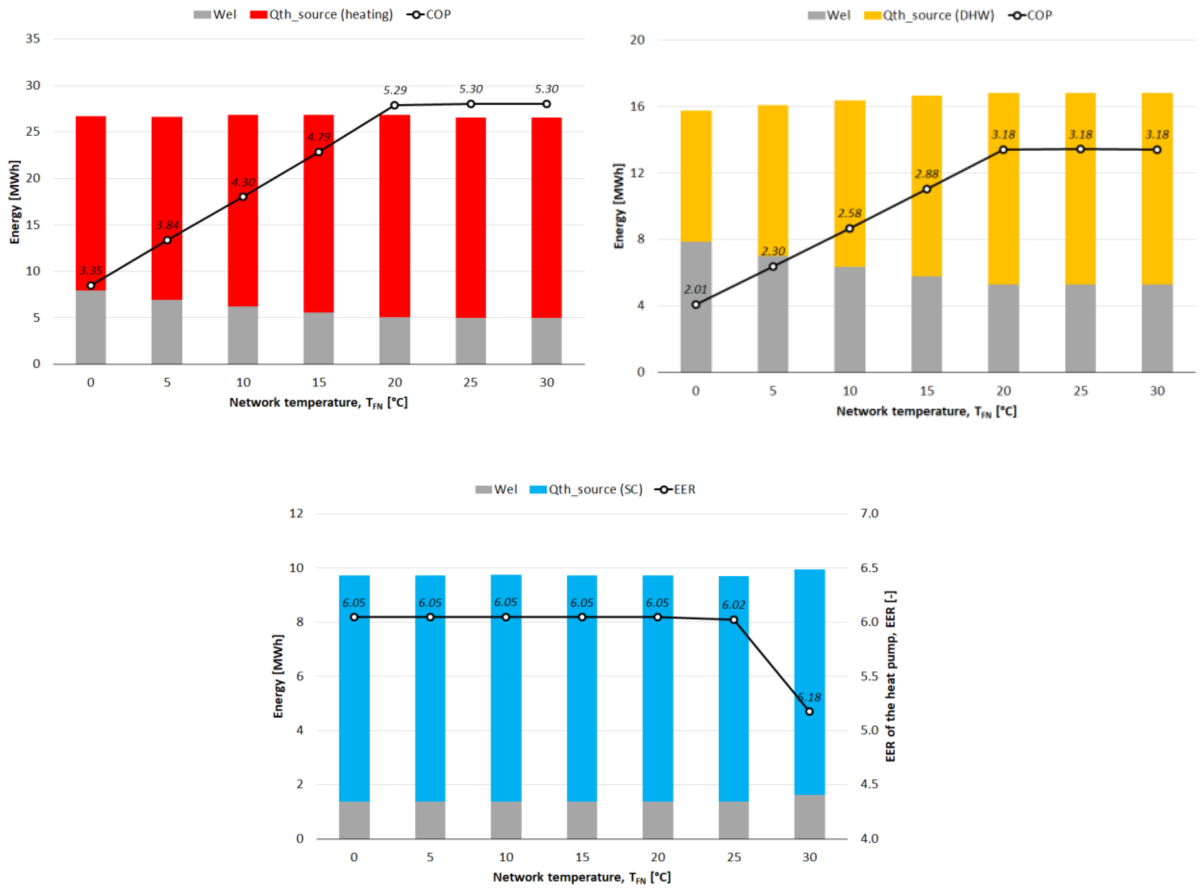


Figure 37 - Yearly energy balance for residential substations: new/renovated ("45") s-MFH buildings for the location of Stuttgart.

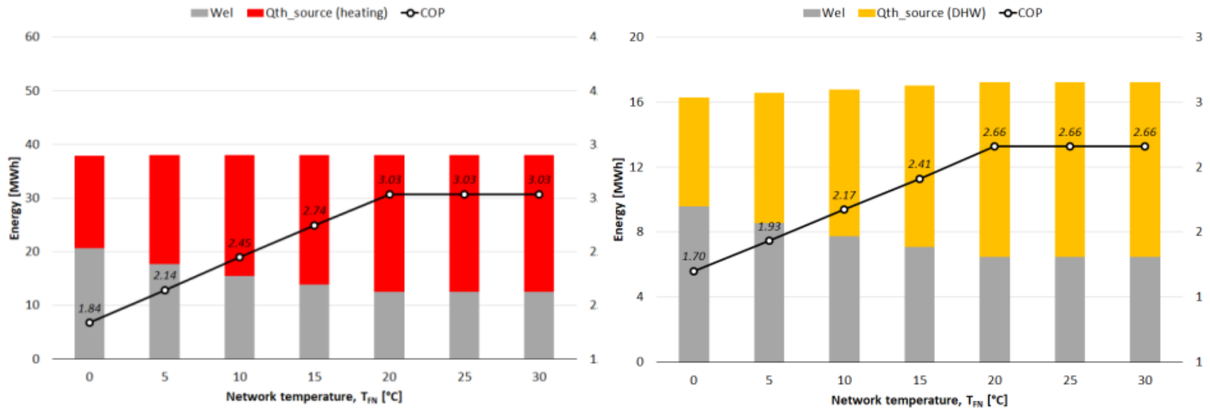


Figure 38 – Yearly energy balance for residential substations: existing ("EX") s-MFH buildings for the location of Rome.

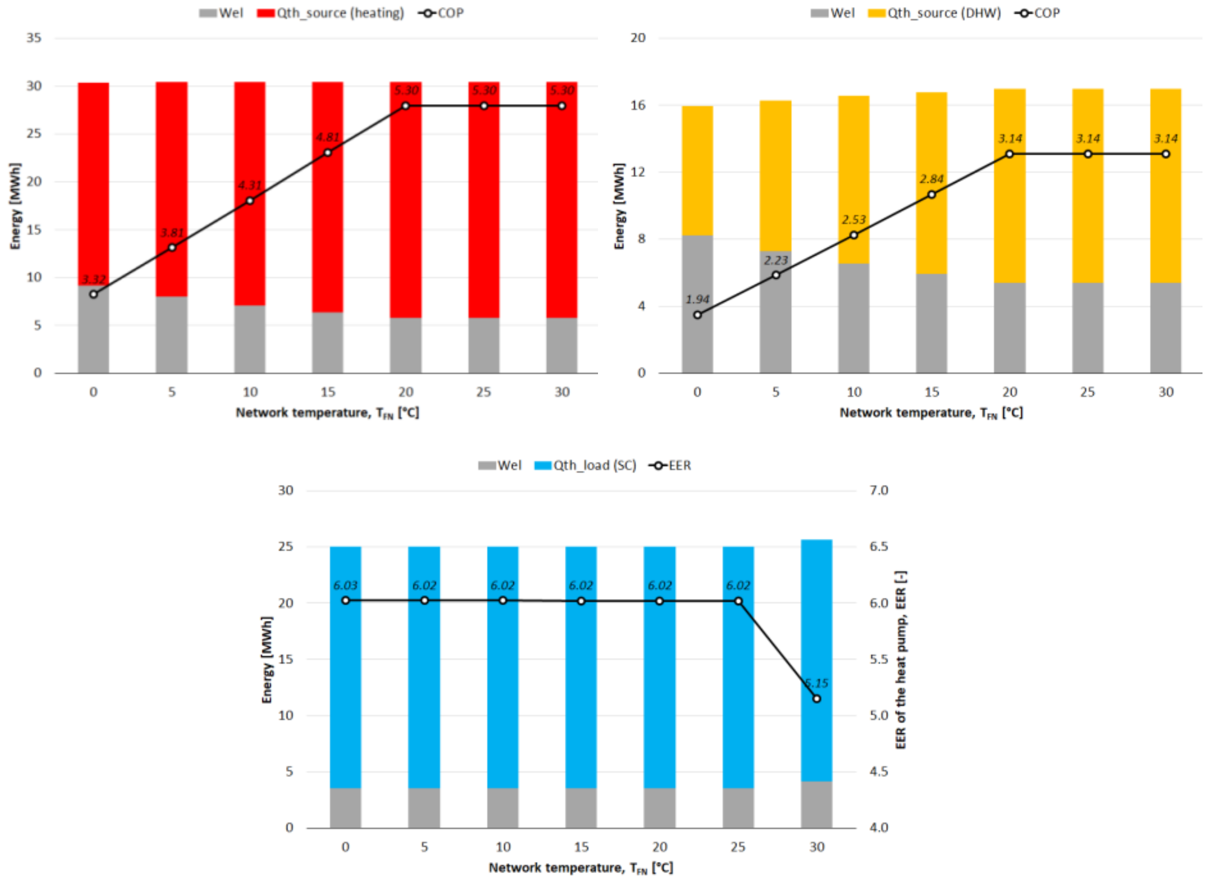


Figure 39 - Yearly energy balance for residential substations: new/renovated ("45") s-MFH buildings for the location of Rome.

Apart from average energy performance of different building scenarios, it is interesting to dwell on the influence of FLEXYNETS temperature on heat pump activation frequency. If from the previous analysis is evident how heating, cooling and DHW demands must be respected under different network temperature, this latter influences operation period of the heat pump and the activation frequency.

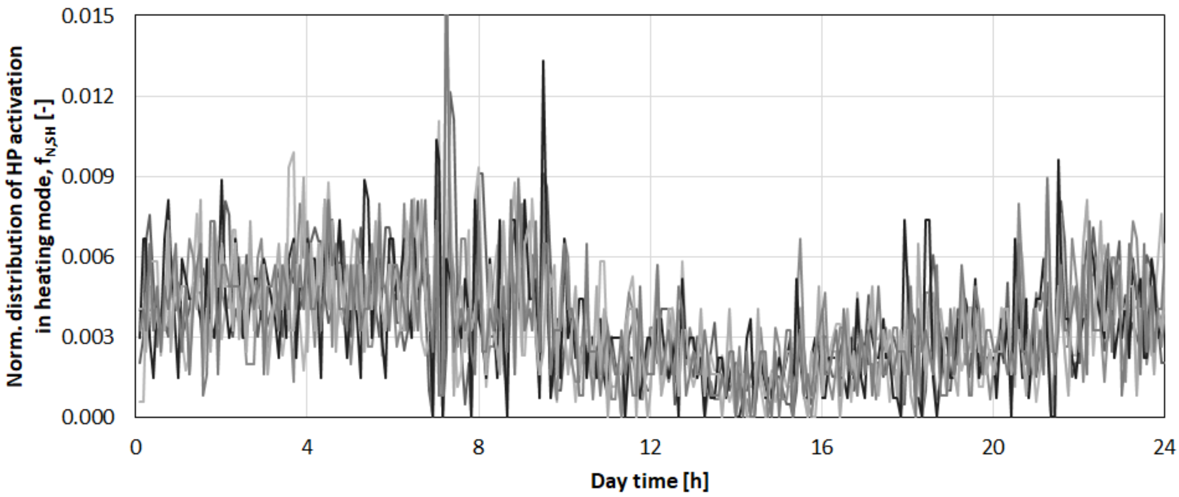


Figure 40 – Normalized distribution of heat pump activation in heating mode for the month of January for different FLEXYNETS temperatures (Building: SFH, Location: London).

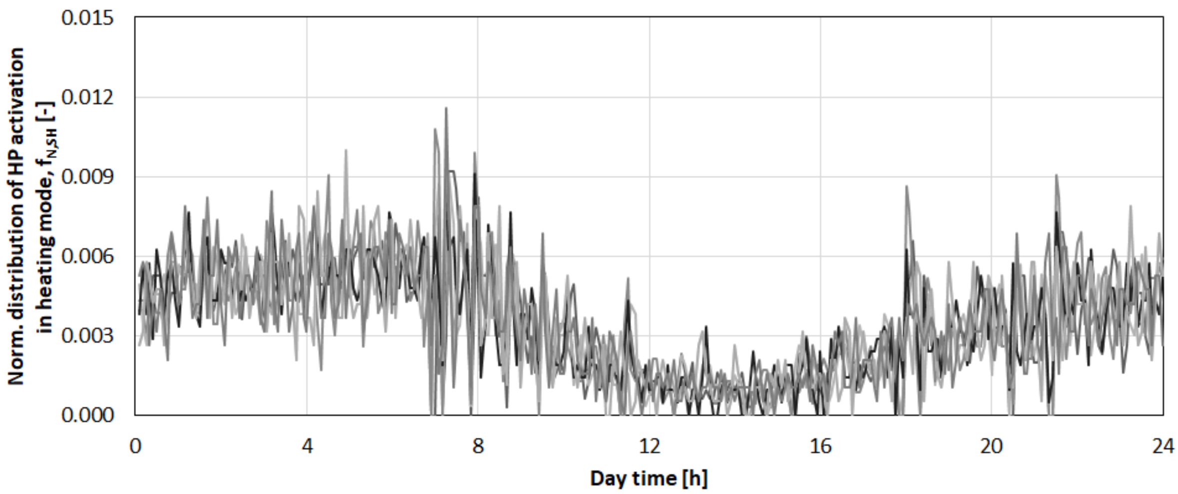


Figure 41 – Normalized distribution of heat pump activation in heating mode for the month of January for different FLEXYNETS temperatures (Building: SFH, Location: Rome).

In Figure 40 and Figure 41, the normalized distribution of heat pump activation in heating mode is plotted for a SFH_45 building the locations of London and Rome. The graphs show the normalized distribution for an average heating day in January for different network temperatures.

It evidences how the curves are pretty close with an average deviation of 4,5%. Comparing Figure 40 and Figure 41, it seems as the activation of the heat pump is independent to network's temperature and the location. This statement can be considered valid highlighting that this analysis is conducted on the month of January (highest heating load, during mid-seasons activation won't be regular) and moreover substation's heat pump is sized accordingly to the same criteria for all location and building typologies (see paragraph 3.1.2). The same conclusion could be drawn for DHW (Figure 42) and for cooling (Figure 43) loads.

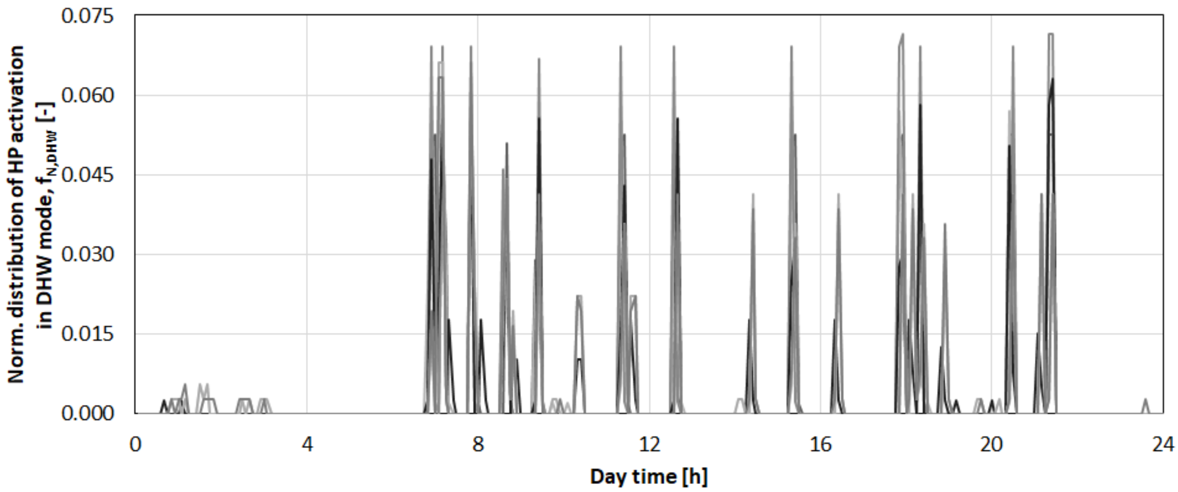


Figure 42 – Normalized distribution of heat pump activation in DHW mode for the month of January for different FLEXYNETS temperatures (Building: SFH, Location: Rome).

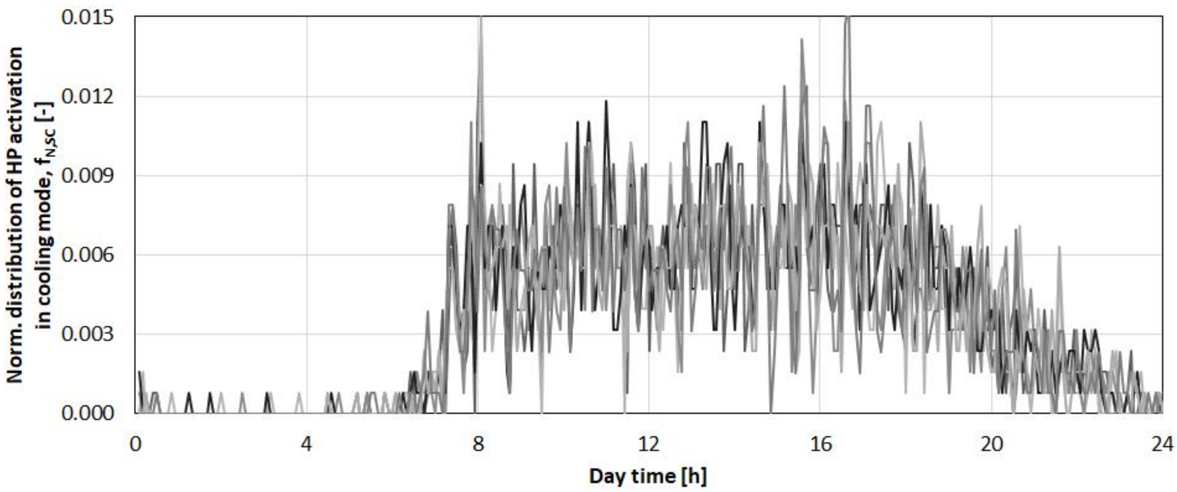


Figure 43 – Normalized distribution of heat pump activation in SC mode for the month of July for different FLEXYNETS temperatures (Building: SFH, Location: Rome).

3.3.2 Model reliability

The TRNSYS model used to simulate the residential substations has been built on the basis of previous models developed for the iNSPiRe project[2]. These building models were validated against PHPP

[2] http.//inspirefp7.eu/

(Passive House Planning Package), which is a well-known software already validated against several real buildings (see reference [3]).

Within the Flexynets project, the TRNSYS models developed within iNSPiRe were fully revised for what concerns the thermo-hydraulic plants (DHW, Space Heating, Space cooling), but the same basic components and the same building models were used. As far as heating and cooling plants are concerned, no additional validation was considered to be needed, as standard and already validated TRNSYS types for single components were used. On the other hand, the heat pump performance maps have been validated against laboratory results (laboratory performances typically showed a reduction of efficiency of the order of 10 % with respect to HP data sheet values).

4 Description of Powerstation

From a high level point of view, the overall Powerstation energy system can be represented by a schematic single line connection diagram as shown in Figure 44 below. It is split into three parts, based on working fluid used. Energy Generation Units (EGUs) use oil, Energy Distribution Units (EDUs) use water, and Energy Conversion Units (ECUs) interact with both oil and water. The main distinguishing point is their relative function in the energy system and in particular:

- EGUs generate thermal energy by utilizing renewable sources, be it solar or biomass. However, storage tank is included as an energy buffer.
- ECUs serve the primary purpose of conversion of thermal energy from the oil loop into either thermal energy in the water loop or generation of electrical energy.
- EDUs comprise components responsible for meeting heating and cooling loads.

The FLEXYNETS Powerstation has EGUs (solar collector field and boiler) able to feed in individual or hybridized way the ORC. Both components charge an oil thermal energy buffer which aims to provide a relative constant inlet oil temperature at both evaporator side of ORC and source side of the primary heat exchanger (HX-I). Then the condensing water of the ORC can be used for directly covering the heating loads of the network (which tends to reduce its temperature because of the request from the users). Alternatively, the use of a sorption chiller for providing chilled water to the network was considered (which otherwise tends to rise up its temperature). In case the energy dissipated by the ORC on the condenser side is not sufficient, the biomass boiler or the solar field can further provide the required amount of heat through HX-I.

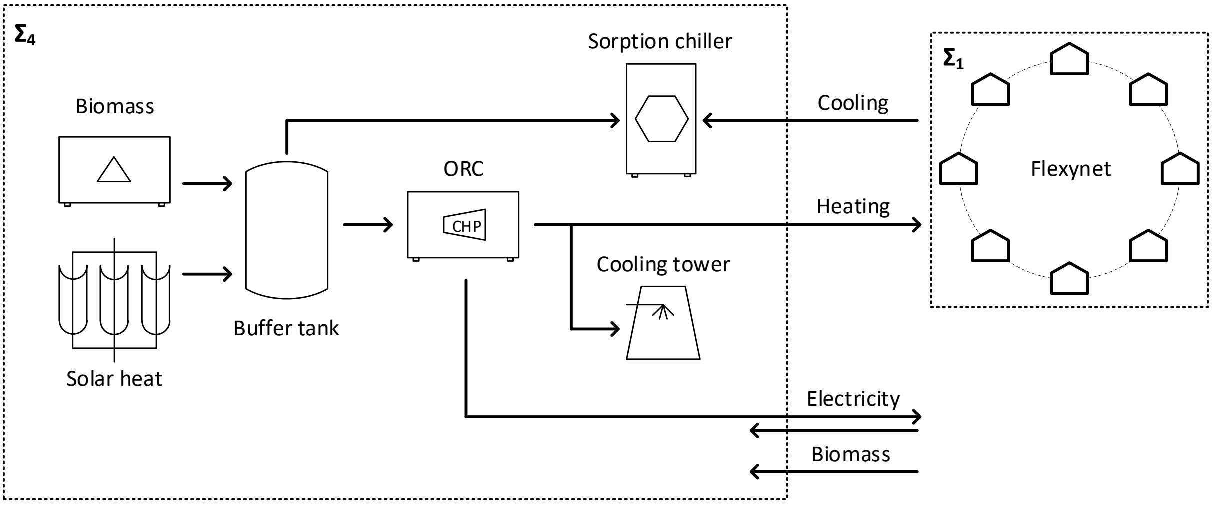


Figure 44 – Single line diagram of the energy system.

4.1 Brief description of system components

Although each component in an energy system is crucial for its effective functioning, components with key roles in operational strategy of the system are briefly described in this section. Whereas a complete list of the existing components, along with overall system control, monitored variables, and components' control signals are discussed in the next sections.

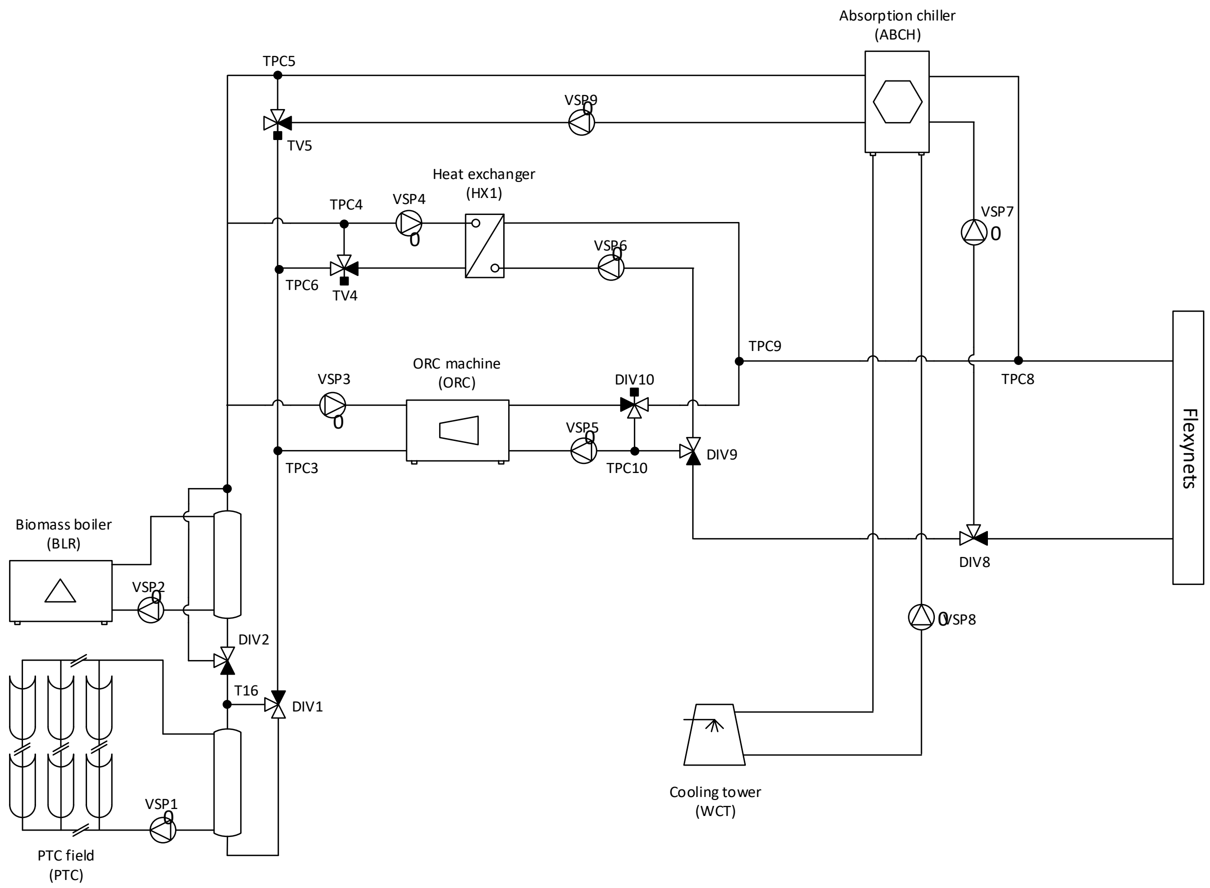


Figure 45 – Layout of power station.

4.1.1 Parabolic Trough Collector (PTC) field

The solar collector field comprises 24 Soltigua manufactured PTMx-24 parabolic collectors in total, arranged in 4 loops of 6 collectors each, in order to achieve the outlet setpoint temperature able to activate and safely run the ORC. Table 12 specifies the design values for the selected collector, calculated for Madrid (Spain) location, with 245ºC setpoint temperature and 541 W/m^2.

Table 12 – Parabolic collectors design specifications.

Parameter	Value	Unit
Specific nominal thermal power	541	W/m^2
Total surface	1488	m^2
Global nominal thermal power	805	kW
Width of a single collector	2,37	m
Length of a single collector	26,16	m
Distance between rows	5,8	m

Mirror accuracy	0,98	-
Reflectivity of mirror	0,94	-
Envelope transmittance	0,92	-
Diameter of absorber tube	0,038	m

PTC field is modelled using TRNSYS Type 1245, which models a tracking concentrating parabolic solar collector that considers the effects of the collector mass on performance. The thermal performance of the total collector field is determined by the number of modules in series and the characteristics of each module. The model requires results from standard collector efficiency tests to be provided as coefficients.

This model relies upon an external data file to provide information on how the optical solar transmittance-absorptance product of the evacuated tube changes with incidence angle. Because linear parabolic concentrators have an axis of symmetry and are often installed such that they track beam radiation throughout the day, only a one-dimensional Incidence Angle Modifier (IAM) is provided by the manufacturer in datasheet. Nevertheless, a 2-dimensional matrix for IAM dependence on transversal and longitudinal incidence angles is created and supplied as the external data file. Please refer to mathematical description of Type 1245 for equations used.

4.1.2 Biomass boiler (BLR)

Boiler is modelled using equations for a generic boiler model capable of either maintaining a setpoint outlet temperature by varying the instantaneous functioning capacity, or working at design capacity and calculating the resultant outlet temperature. It also models the inertial effects in the system due to its thermal capacitance.

Before elaborating on the calculations performed at the subdeck level, it is important to understand what definitions are used for boiler efficiencies and energy flows in the boiler. Overall boiler efficiency (η_{boiler} as shown in Eq. 15) is defined as the ratio of output energy (energy supplied to fluid (Q_{fluid})) and energy input (energy supplied by fuel (Q_{fuel})). Whereas, combustion efficiency (η_{comb} as shown in Eq. 16) is defined as the ratio of summation of output energy (Q_{fluid}) and losses to surroundings (Q_{loss}) to energy input (Q_{fuel}).

$$\eta_{boiler} = \frac{Q_{fluid}}{Q_{fuel}} \tag{15}$$

$$\eta_{comb} = \frac{Q_{fluid} + Q_{loss}}{Q_{fuel}} \tag{16}$$

4.1.3 Organic Rankine Cycle (ORC) cogenerator

In the simulation of the current Powerstation, a commercial ORC model based on the performance of TURBODEN and RANK manufacturers has been implemented, where rated power extracted from the oil loop ranges 768 kWt and electrical efficiencies vary between about 15-30%.

Organic Rankine Cycle (ORC) generator is modelled in TRNSYS using the performance curves received from the manufacturers and calculating the desired outputs. Performance curves received at part load conditions, activation temperature and dissipation temperature are used to create a performance matrix for the model.

At this point, it shall be noted that the performance curves provided by the manufacturer are for particular flow rates on evaporator and condenser sides. These values are 13 m^3/h and 37 m^3/h, respectively. ORC model is only operational when both, the evaporator side and condenser side, mass flow rates are greater than zero. Otherwise, the outlet temperatures and mass flow rates on either sides are set to the inlet values.

The part load performance curves, shown in Figure 46 and Figure 47, are presenting evaporator side thermal power ($Q_{ORC,evap}$) and electrical power (W_{el}) as functions of inlet evaporator side temperature ($T_{ORC,evap,in}$). The data from performance curves is extrapolated to a wider range of inlet oil temperature at the evaporator side i.e. 185-245°C.

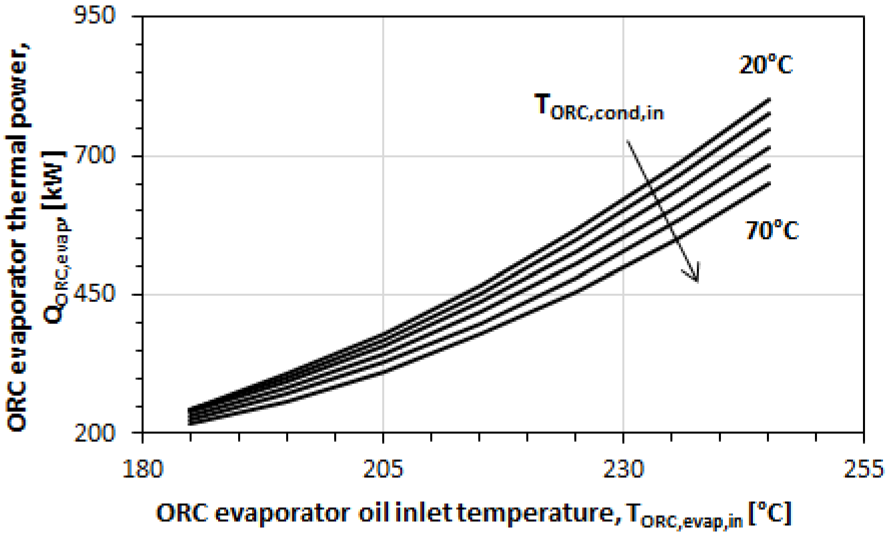


Figure 46 – ORC evaporator thermal power versus oil inlet temperature, for different condensing water temperatures.

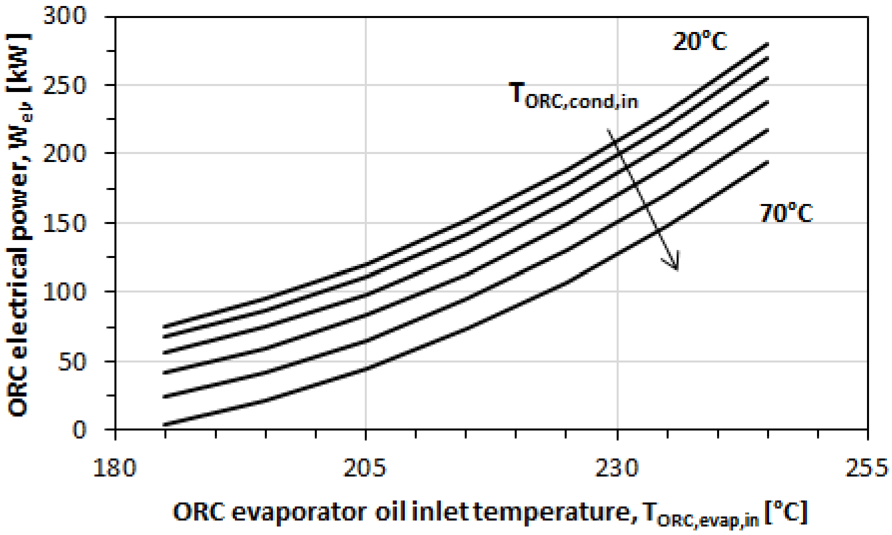


Figure 47 – ORC electrical power as a function of oil inlet temperature for different condensing water temperatures.

The performance matrix is supplied to the data interpolator as an input file. After reading the interpolated values of input thermal power by oil, electrical power produced and output thermal power, outlet temperatures at evaporator side (oil side) and cooling fluid (water) are calculated using energy balance Eq. 17, and Eq. 18.

$$T_{ORC,evap,out} = T_{ORC,evap,in} - \frac{Q_{ORC,evap}}{c_{p,oil} \cdot \dot{m}_{ORC,evap}} \quad (17)$$

$$T_{ORC,cond,out} = T_{ORC,cond,in} + \frac{Q_{ORC,cond}}{c_{p,water} \cdot \dot{m}_{ORC,cond}} \quad (18)$$

Thermal efficiency and electrical efficiency of ORC is calculated using Eq. 19 and 20.

$$\eta_{th} = \frac{Q_{ORC,cond}}{Q_{ORC,evap}} \quad (19)$$

$$\eta_{el} = \frac{W_{el}}{Q_{ORC,evap}} \quad (20)$$

In the figure below is reported the electric efficiency profiles of the ORC in function of the evaporator oil inet temperature and the condenser water inlet temperature:

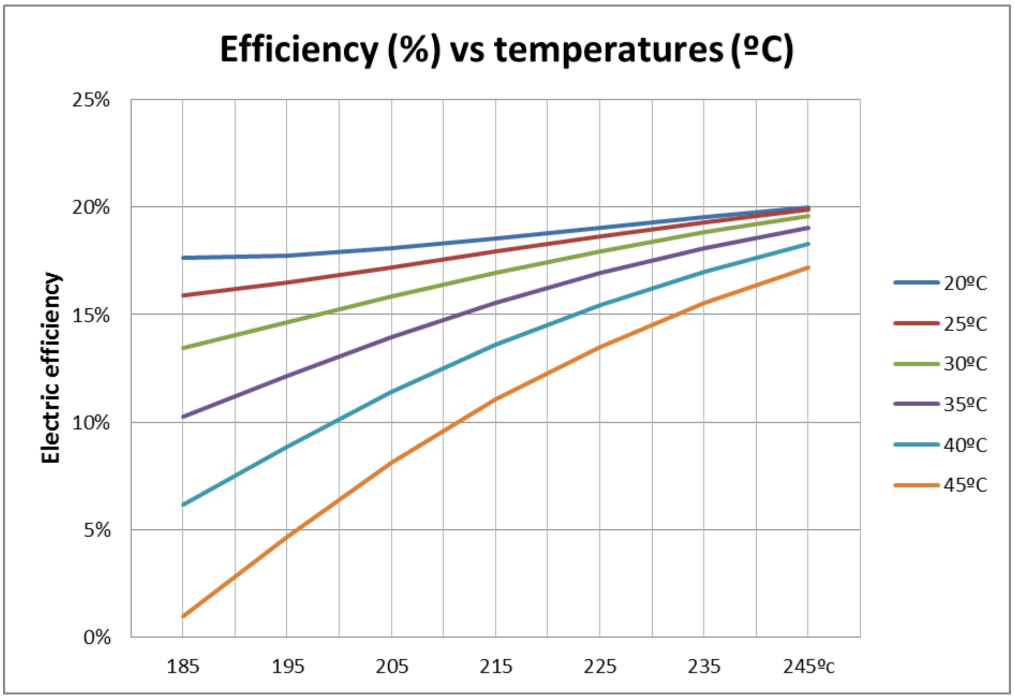


Figure 48 - ORC electrical efficiency of ORC unit as a function of oil inlet temperature for different condensing water temperatures.

4.1.4 Absorption chiller (ABCH)

The performance of absorption chiller is derived from measurements conducted by Acciona at own facility in Seville (Spain). Selected absorption chiller is the oil powered double-effect model "BCT 24" manufactured by BROAD, with design generator ($T_{ABCH,gen,in}$ = 180°C), evaporator ($T_{ABCH,evap,in}$ = 7°C) and condenser ($T_{ABCH,cond,in}$ = 30°C) capacities as 400 kW, 400 kW and 800 kW, respectively. Design value of coefficient of performance for this model is 1.

Absorption chiller is modelled in TRNSYS, using Type 909 from TESS library. This Type relies on user-provided performance data file containing normalized capacity (NC) and normalized COP ratios as a function of three temperatures: hot water inlet temperature, cooling water inlet temperature and chilled water inlet temperature. COP for this model is defined as the energy transferred from the chilled water stream divided by the energy provided to the chiller by the inlet hot water flow stream.

The datasheet from manufacturer provides NC and COP values at different hot water, cooling water and chilled water inlet temperatures. Figure 49 shows the variations in COP and NC values at different hot water and chilled water inlet temperatures. These plots are for a fixed cooling water inlet temperature of 30°C.

Relying on the plots given in the datasheet, a data file is created by interpolating the values at different conditions (through file). Type 909 attempts to cool down the chilled water stream to a setpoint value, when its control signal input is set to a value of 1. When the control signal is set to 0, the device operates in flow-through mode and the temperatures of the three outlet streams are set to the corresponding inlet temperatures. For detailed functioning of Type 909, please refer to the mathematical description of the same.

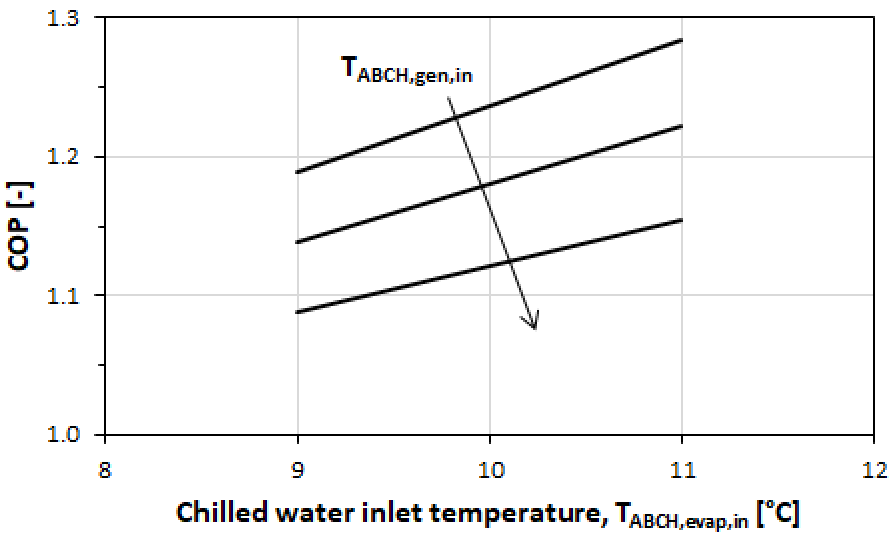


Figure 49 - Thermal COP of the absorption chiller as a function of the chiller water inlet temperature for different generator inlet temperatures (165, 170, 175 °C, increasing along the arrow direction) at 28°C inlet condenser temperature.

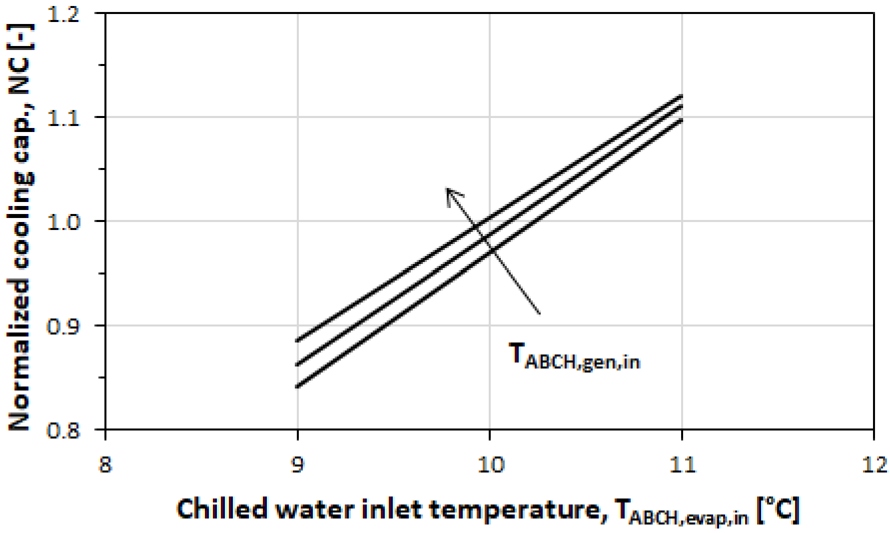


Figure 50 – Normalized cooling capacity of the absorption chiller as a function of the chiller water inlet temperature for different generator inlet temperatures (165, 170, 175 °C, increasing along the arrow direction) at 28°C inlet condenser temperature.

4.1.5 Wet cooling tower

The wet cooling tower has to reject effectively the condensing heat of the absorption chiller during cooling schemes and of the ORC when generation schemes (condensing heat is rejected in the environment) are active. The design performance parameters of Table 13 are identified.

Table 13 – Design performance characteristics of wet cooling tower.

Parameter	Value	Unit
Inlet water temperature	35	°C
Outlet water temperature	30	°C
Water mass flow rate	230.000	kg/h
Dry bulb air temperature	25	°C
Wet bulb air temperature	25	°C
Volumetric air flow rate	516.000	kg/h
Electrical power	160	kW

4.1.6 Heat exchanger

Primary heat exchanger (HX-I) is model “B60H-Lx52” manufactured by SWEP, with a rated heat load of 800 kW. This model is a counter-current heat exchanger with design values specified for Therminol 66 oil and water as working fluids on source and load side respectively. HX-I comprises of 52 plates and a total heat transfer area of 6.4 m^2.

At design conditions a temperature increase of 10 K is achieved on the water side at design inlet of 80°C, as seen in Table 14, which highlights the design values and key physical properties for HX-I.

Table 14 – Design conditions for primary heat exchanger (HX-I).

Parameter	Value	Unit
Heat capacity	800	kW
Source fluid	Therminol 66	-
Load fluid	Water	-
Source inlet temperature	245	°C
Source outlet temperature	141	°C
Source side flowrate	13	m^3/h
Load inlet temperature	80	°C
Load outlet temperature	90	°C
Load side flowrate	37	m^3/h
Total heat transfer area	6,4	m^2
Number of plates	52	-
Heat flux	125	kW/m^2

4.1.7 Hydraulic components

The proposed system utilizes a total of 9 Variable Speed Pumps (VSPs), locations of which are provided in Table 15. The pumps are simulated in TRNSYS using Type 110. The model is able to maintain any outlet mass flow rate between zero and a rated value, varying linearly with the input control signal. Pump power drawn off in the model, however, is modelled using a polynomial. Pump starting and stopping characteristics are not modelled, as the time constants with which pumps react to control signal changes is shorter than the typical time steps used in hydronic simulations.

Table 15 – Variable speed pumps and their location.

Pump	Rated flowrate	Rated power (estimated)	Location
VSP1	13 m^3/h	0,55 kW	Solar field loop
VSP2	20 m^3/h	0,25 kW	Biomass boiler loop
VSP3	13 m^3/h	0,37 kW	Evaporator side of ORC
VSP4	13 m^3/h	0,25 kW	Source side of primary heat exchanger
VSP5	37.000 kg/h	3 kW	Condenser side of ORC
VSP6	37.000 kg/h – 55.000 kg/h	3 kW	Load side of primary heat exchanger
VSP7	80.000 kg/h	7,5 kW	Evaporator side of absorption chiller

VSP8	230.000 kg/h	15 kW	Hybrid cooler loop
VSP9	13 m^3/h	0,37 kW	Generator side of absorption chiller

The thermal behaviour of fluid flow in a pipe or duct is modelled using Type 31, which models this behaviour using a “plug-flow” approach. Here the pipe is divided into variable size segments of fluid, with the entering fluid shifting the position of existing segments. This “plug-flow” model does not consider mixing or conduction between adjacent elements.

4.2 Control strategy

4.2.1 Monitored parameters

The list of crucial temperature and mass flow rate monitoring points to the control strategy are:

- T1: oil temperature at outlet of second tee piece (TPC2) in BLR circuit;
- T5: inlet oil temperature to ORC;
- T10: return oil temperature from ORC / HX-I to solar field;
- T14: outlet oil temperature from the PTC field;
- T42: return temperature from FLEXYNETS to Powerstation.
- VSP1: flow for the PTC field oil loop
- VSP2: flow for the boiler oil loop
- VSP3: flow for the ORC oil loop
- VSP4: flow for the heat exchanger oil loop
- VSP5: flow for the ORC water loop
- VSP6: flow for the heat exchanger water loop
- VSP7: flow for the cooled water loop
- VSP8: flow for the cooling tower water loop
- VSP9: flow for the ABCH oil loop

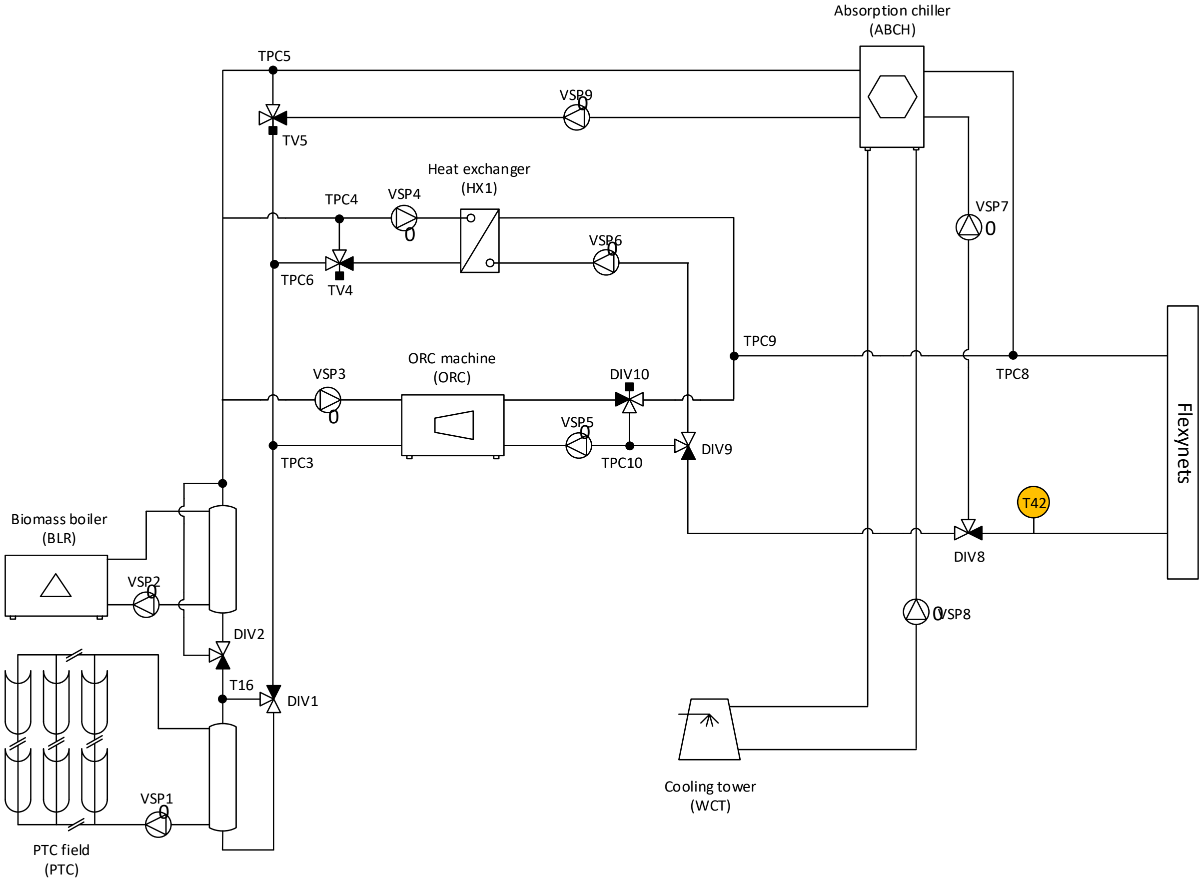


Figure 51 – Sensors location.

4.2.2 Functional schemes

Probable and feasible combinations of different hysteresis based control signals are termed as schemes.

Scheme Sc1: PTC field in harvesting mode

This scheme represents activation of PTC field, based on whether instantaneous Direct Normal Irradiation (DNI) is above the minimum activation value. Subsequent to this condition, for activation of this scheme and hence PTC field, outlet oil temperature from the field should be lower than stagnation value stated by the manufacturer.

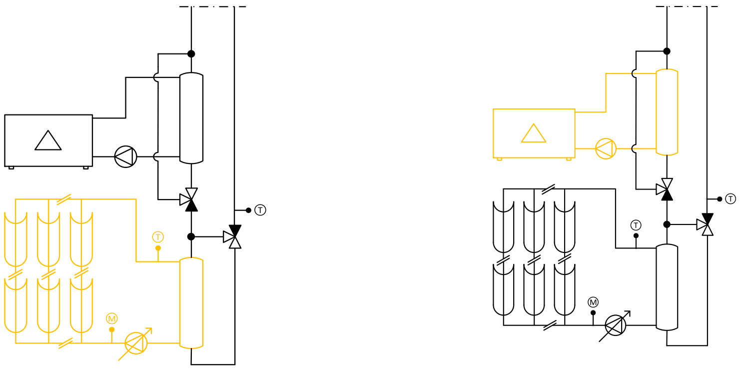


Figure 52 - Working scheme Sc1 (left) and Sc2 (right).

Scheme Sc2: BLR in operational mode

The sole objective represented by this scheme is maintaining the outlet temperature from the second tee piece (TPC2), in boiler (BLR) loop, at a setpoint value. Hence, the activation of BLR is dependent on condition of aforementioned temperature being below a certain value.

Scheme Sc3: Cooling production

Primary scheme for cooling production constitutes of the required activation thermal energy to the absorption chiller being supplied by different combinations of the EGUs (only solar; only boiler; combined solar + boiler). It is used for extracting required chiller activation thermal energy from oil circuit like the ORC.

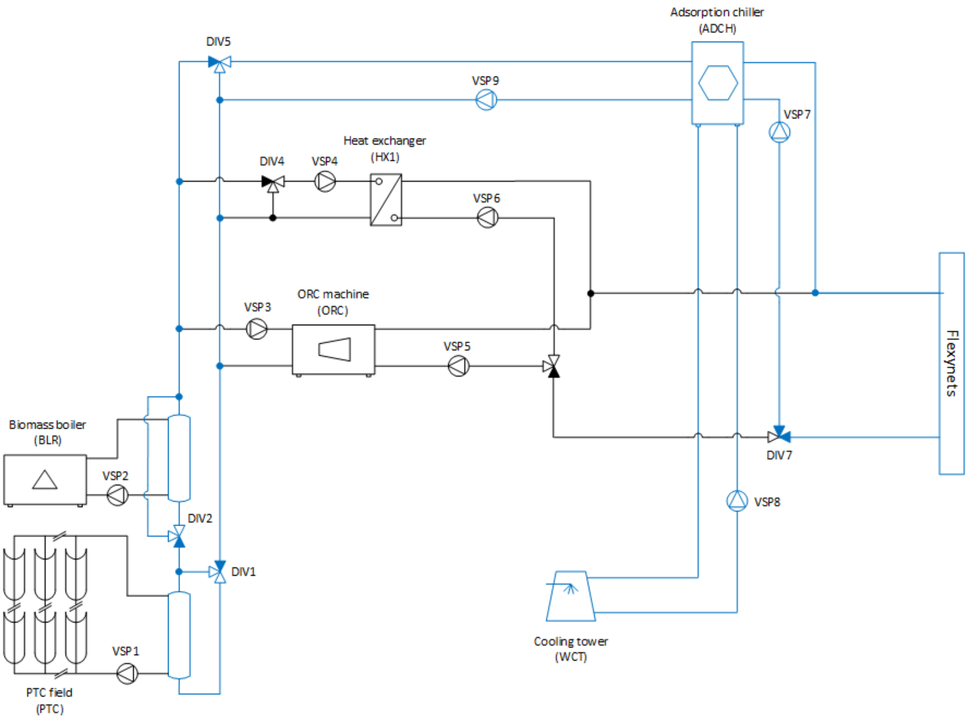


Figure 53 – Working scheme Sc3.

Schemes Sc4a and Sc4b: Heating production through EGUs and ORC

In scheme Sc4a, the Powerstation delivers directly heat from the EGUs to network via heat exchanger. For this purpose, solar and/or gas energy can be used according to the instantaneous conditions, availability of resources and costs.

Next to scheme Sc4a, scheme Sc4b exploits condensing heat of ORC unit. In this working mode, inlet temperature conditions at evaporator and condenser must meet ORC operation conditions and in particular 185°C ≤ $T_{ORC,evap,in}$ ≤ 245°C and 20°C ≤ $T_{ORC,cond,in}$ ≤ 70°C.

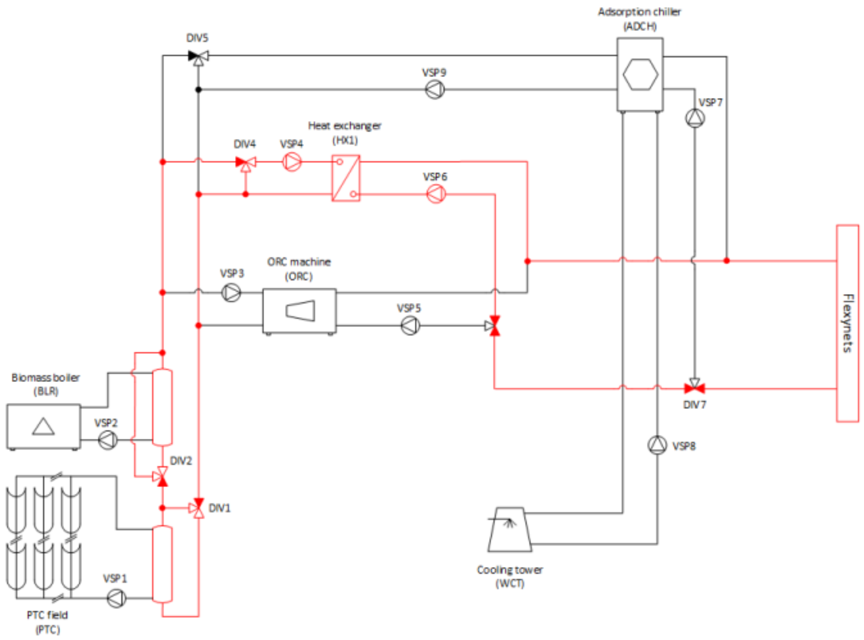


Figure 54 – Working scheme Sc4a.

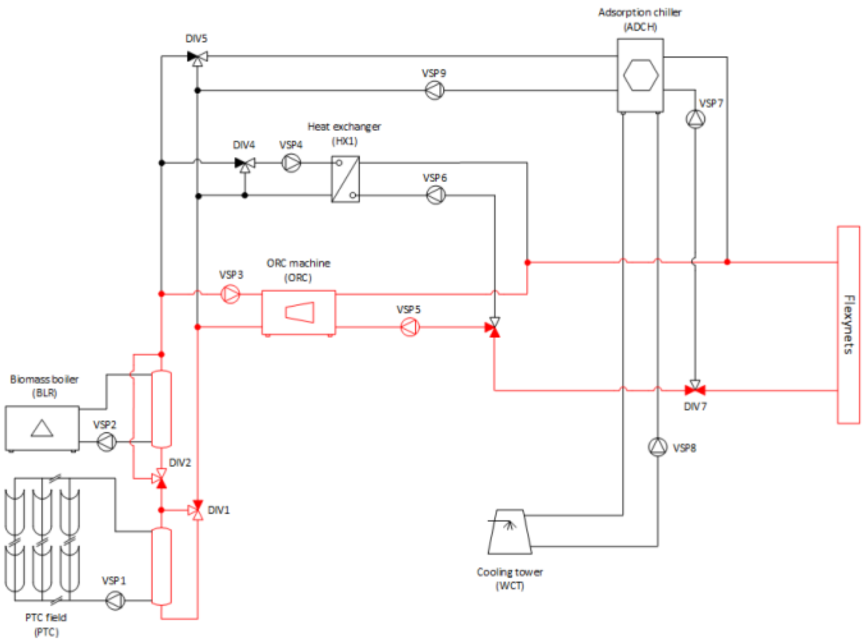


Figure 55 – Working scheme Sc4b.

4.3 Simulation activities for Powerstation: calculation, operation and results

Simulation results derive from the implementation into the software platform of equipment actually existing in the market, with a determined power and operational limits; this means that the achieved numbers of energy produced and consumed by the Powerstation depend on the specific size and characteristic of the selected equipment. Nevertheless, the selected size for the simulations run during the project must not be a limit in the scaling (up or down) process for the design of future Powerstations, once defined the structure of the network in terms of users, producers and prosumers.

Because of this, for the dimensioning activity a parametric approach has been followed, by which it can be possible to define the size of all Powerstation "actors" in function of only one single parameter representative of the ECUs, like the electrical power (and its conversion efficiency) of the ORC. All the other machines must be sized in order to set the ORC in the proper operation conditions at any environmental scenario: 3 generation configurations (PTC, BLR, PTC+BLR) times 3 utilization configurations (HEX, ORC, ABCH) → 9 configurations.

Considering the energy (and no storage system in-between) as main dimensioning KPI, it has been possible to achieve the relationship between generation, transformation and dissipation in terms of power, considering the Powerstation operating at full capacity 24/7/365. In other terms, per each kWel of ORC it is possible to define a direct relation between PTC and BLR power in order to achieve during operation the highest number of hours of operation without penalizing the economic constraints of each technology.

4.3.1 Component sizing

Powerstation's design is based on the concept of multi-generation system, where different components are synchronized, coordinated and harmonized among them with the purpose of generating simultaneously multiple streams of heating/cooling and electricity. The core of this system is the ORC machine, a thermally activated co-generator whose main product is AC current and whose sub-product is low temperature heat. The possibility to use at the same time both heat and electricity makes this machine more competitive with respect to single generators (only heat or only electricity) for producing the same amount of energy, for required space, capital cost, simplicity in operation, etc….

This means that the ORC, independently of its efficiency, is the main driver for the optimized dimensioning of all other necessary components (solar field, boiler, cooling tower, pumps, etc…) integrated in the Powerstation concept. Considering the ORC electrical efficiency independently constant, the only terms affected by the size are the installation and operation prices.

As described before, the ORC has minimum and maximum temperature limits for the activation, which, at constant flow, correspond to minimum and maximum power; if the temperature is a function of the model of the ORC, the flows depend on the size of the power of the ORC. According to this, the sizing of some components is a straightforward process: the boiler must be able to provide the 100% of the ORC required thermal input at evaporator nominal power. The cooling tower must be able to dissipate the 100% of the ORC rejected thermal output at condenser nominal power, at worst environmental conditions; the pumps must be able to circulate the 100% of the loads corresponding to nominal power of each machine with design ΔT.

About the solar field, the number of collectors per loop determines the ΔT achieved by PTC, which is the required by the ORC; the number of parallel loops determines the final power of the PTC field. Increasing the number of collectors per loop, or the number of PTC loop per field affect the final outlet temperature and the final power; the lack of storage would drive to the oversizing of the solar energy which must be regulated only through the dissipation (defocusing) of excess of energy. On other hand the economic constrains force to reduce the final power at the minimum necessary for the activation of the ORC without overproduction, even taking into account the possible hybridation with the BLR.

The dimensioning of the chiller has been achieved considering for the generators the same power that would be necessary for the operation of the ORC; by this way is possible to have the same energetic reference in the confrontation of cooling schemes with heating schemes. In the table below are reported global powers for all components of the heating + cooling Powerstation.

Table 16 – Nominal power per each equipment

System	Power [kW]
BIOMASS BOILER (BLR)	**800**
PTC Field	**800**
ABCH	**800**
ORC	**800**
Complementary Installation	**20%**

4.3.2 Energetic results

In order to understand at which operating conditions the Powerstation can maximize its global impact on the network, different configurations (operation schemes) have been tested under the same boundary conditions, generating the basis for the calculation of different economic scenarios.

The Powerstation has been simulated as connected to a virtually infinite load, for both heating and cooling; this means that the Powerstation is assumed as system operating as producer and able to cover only the base load of the network, independently of its thermal level (input temperature at ORC condenser and chiller evaporator). This is due that the base-load operation has been chosen to maximize (100%, where possible) along time the energy produced, being well known that the ORC investment costs are rather high (so that, unless a significant number of operation hours is achieved, it is impossible to pay back the investment).

For each working scheme, 3 different temperatures of the network have been considered (20-25-30ºC), with an operation of the Powerstation 24/7/365 at Madrid location; on the basis of the results for continuous operation, it is possible to estimate the minimum number of yearly operating hours for the achievement of reasonable payback times.

For the primary energy analysis, a factor of:

- 1,028 kWh/kWh_{fin} has been considered for biomass
- 1 kWh/kWh_{fin} has been considered for solar
- 2,403 kWh/kWh_{fin} has been considered for electricity

Where kWh/kWh_{fin} is the primary energy ratio: the ratio between the used primary energy and the produced final energy. If the value is positive, it means generation of primary energy (like heat); if the value is negative, it means consumption of primary energy (like electricity).

About environmental impact, a value of 550 $KgCO_2/MWh$ of electricity has been used for calculation (CO_2 mix for Spain).

Heating production through PTC (Sc1 and Sc4a)

The Powerstation is operating in heating mode, feeding the network via HEX + PTC; all other Powerstation components are switched off.

Table 17:Results in heating mode with PTC

	20ºC	25ºC	30ºC
BIOMASS BOILER (BLR)			
Thermal Energy Production [kWh]	**0,0**	**0,0**	**0,0**
Biomass Consumption [Tn]	**0,0**	**0,0**	**0,0**
PTC Field			
Thermal Energy Production [kWh]	**1.096.825,8**	**1.096.592,5**	**1.096.539,9**
ORC - Efficiency			
Thermal Energy Production [kWh]	**0,0**	**0,0**	**0,0**
Thermal Energy Consumption [kWh]	**0,0**	**0,0**	**0,0**
Electricity Production [kWh]	**0,0**	**0,0**	**0,0**
HEX - Efficiency	**80,1%**	**80,0%**	**80,0%**
Thermal Energy Production [kWh]	**878.557,4**	**877.274,0**	**877.231,9**
TOTAL			
Electric Consumption [kWh]	**-17.750,1**	**-17.817,7**	**-17.884,4**
Electric Balance [kWh]	**-17.750,1**	**-17.817,7**	**-17.884,4**
Biomass Consumption [kWh]	**0,0**	**0,0**	**0,0**
ENVIRONMENTAL IMPACT			
CO_2 Emissions [$TnCO_2$]	**9,8**	**9,8**	**9,8**
Fuel in primary energy [kWh]	**-1.096.825,8**	**-1.096.592,5**	**-1.096.539,9**
Electricity in primary energy [kWh]	**-42.653,4**	**-42.815,9**	**-42.976,1**
Primary energy delivered/energy consumed [kWh/kWh]	**0,77**	**0,77**	**0,77**

As expressed by the results in the table above, the operation of the solar field starts when the solar radiation is present. Due to the independency of each oil loop respect to the others, because of presence of individual pumps for each loop, no thermal energy is extracted by the solar field (VSP1) until setpoint temperature conditions (T14 and T5) have been reached for feeding the HEX (VSP4) at the established setpoint temperature.

It can be evidenced how the PTC thermal production (positive values), and its electric consumption (negative values), is limited during the year because of the dependence from the available DNI. The totality of produced thermal energy is used for feeding the HEX which, through annual exchange efficiency over 80%, is used for delivering heat to the network in case of reduction of its energetic level (T42).

The increment of the inlet temperature of the network (T42) reduces the energy produced by the solar field of 0,02 and 0,03% respect to base scenario, while the energy exchange efficiency of the HEX is reduced of 0,15%.

Heating production through BLR (Sc2 and Sc4a)

The Powerstation is operating in heating mode, feeding the network via HEX + BLR; all other Powerstation components are switched off.

Table 18: Results in heating mode with BLR

	20ºC	25ºC	30ºC
BIOMASS BOILER (BLR)	**61,2%**	**61,2%**	**61,2%**
Thermal Energy Production [kWh]	**7.008.005,6**	**7.008.005,6**	**7.008.005,6**
Biomass Consumption [Tn]	**2.542,8**	**2.542,8**	**2.542,8**
PTC Field			
Thermal Energy Production [kWh]	**0,0**	**0,0**	**0,0**
ORC - Efficiency			
Thermal Energy Production [kWh]	**0,0**	**0,0**	**0,0**
Thermal Energy Consumption [kWh]	**0,0**	**0,0**	**0,0**
Electricity Production [kWh]	**0,0**	**0,0**	**0,0**
HEX - Efficiency	**88,6%**	**88,6%**	**88,6%**
Thermal Energy Production [kWh]	**6.212.388,8**	**6.212.141,6**	**6.211.827,3**
TOTAL			
Electric Consumption [kWh]	**-30.660,0**	**-30.660,0**	**-30.660,0**
Electric Balance [kWh]	**-30.660,0**	**-30.660,0**	**-30.660,0**
Biomass Consumption [kWh]	**11.442.690,0**	**11.442.690,0**	**11.442.690,0**
ENVIRONMENTAL IMPACT			
CO_2 Emissions [TnCO_2]	**16,9**	**16,9**	**16,9**
Fuel in primary energy [kWh]	**-11.763.085,3**	**-11.763.085,3**	**-11.763.085,3**
Electricity in primary energy [kWh]	**-73.676,0**	**-73.676,0**	**-73.676,0**
Primary energy delivered/energy consumed [kWh/kWh]	**0,52**	**0,52**	**0,52**

As expressed by the results in the table above, the operation of the boiler doesn't depend on any climatic conditions. Due to the independency of each oil loop respect to the others, because of presence of individual pumps for each loop, no thermal energy is extracted by boiler (VSP2) until setpoint temperature conditions (T1 and T5) have been reached for feeding the HEX (VSP4); this last condition is due only during start-up phase.

It can be evidenced how the BLR thermal production, and its electric consumption, is continuous during the year because of the dependence from the network requirements. The totality of produced thermal energy is used for feeding the HEX which, through annual exchange efficiency over 88%, is used for delivering heat to the network in case of reduction of its energetic level (T42).

The increment of the inlet temperature of the network (T42) doesn't affect the energy produced by the boiler because operating at full power the 100% of the time; nevertheless, while the energy exchange efficiency of the HEX is reduced of 0,01% respect to base scenario.

Heating production through PTC and BLR (Sc1, Sc2 and Sc4a)

The Powerstation is operating in heating mode, feeding the network via HEX + BLR + PTC; the PTC field has the priority and the BLR is used as back-up system to achieve setpoint at T5.

Table 19: Heating mode with PTC+BLR

	20ºC	25ºC	30ºC
BIOMASS BOILER (BLR)	**61,2%**	**60,5%**	**60,5%**
Thermal Energy Production [kWh]	**5.440.116,6**	**5.358.248,5**	**5.352.890,3**
Biomass Consumption [Tn]	**1.974,6**	**1.968,1**	**1.966,2**
PTC Field			
Thermal Energy Production [kWh]	**1.110.247,5**	**1.109.803,8**	**1.108.693,9**
ORC - Efficiency			
Thermal Energy Production [kWh]	**0,0**	**0,0**	**0,0**
Thermal Energy Consumption [kWh]	**0,0**	**0,0**	**0,0**
Electricity Production [kWh]	**0,0**	**0,0**	**0,0**
HEX - Efficiency	**89,0%**	**90,0%**	**90,0%**
Thermal Energy Production [kWh]	**5.829.824,1**	**5.821.247,1**	**5.815.425,8**
TOTAL			
Electric Consumption [kWh]	**0,0**	**0,0**	**0,0**
Electric Balance [kWh]	**-41.276,1**	**-41.276,1**	**-41.276,1**
Biomass Consumption [kWh]	**-41.276,1**	**-41.276,1**	**-41.276,1**
ENVIRONMENTAL IMPACT			
CO_2 Emissions [TnCO_2]	**22,7**	**22,7**	**22,7**
Fuel in primary energy [kWh]	**-10.244.654,6**	**-10.214.326,9**	**-10.204.103,8**
Electricity in primary energy [kWh]	**-99.186,4**	**-99.186,4**	**-99.186,4**
Primary energy delivered/energy consumed [kWh/kWh]	**0,56**	**0,56**	**0,56**

As expressed by the results in the table above, the operation of the solar field starts when the solar radiation is present while the boiler compensates the hours of reduction and absence of sun. Due to the independency of each oil loop respect to the others, because of presence of individual pumps for each loop, no thermal energy is extracted by the solar field (VSP1) until setpoint temperature conditions (T14) have been reached; when PTC conditions are not met, the BLR heats up (T1) and provides necessary energy (VSP2) for feeding the HEX (VSP4).

It can be evidenced how the PTC thermal production, and its electric consumption, is limited during the year because of the dependence from the available DNI; the thermal contribution (80%) and the electric consumption of the boiler is discontinuous in order to compensate the solar field (20%). The totality of produced thermal energy is used for feeding the HEX which, through annual exchange efficiency over 89%, is used for delivering heat to the network in case of reduction of its energetic level (T42).

The increment of the inlet temperature of the network (T42) reduces respect to base scenario:

- the energy produced by the solar field of 0,04 and 0,614%
- The energy produced by the boiler of 1,5 and 1,6%
- The global energy exchanged by the HEX of 0,15 and 0,25%.

Heating production through ORC supplied by PTC (Sc1 and Sc4b)

The Powerstation is operating in heating mode, feeding the network via ORC + PTC, being all other Powerstation components switched off.

Table 20: Results in heating mode ORC+PTC

	20ºC	25ºC	30ºC
BIOMASS BOILER (BLR)			
Thermal Energy Production [kWh]	**0,0**	**0,0**	**0,0**
Biomass Consumption [Tn]	**0,0**	**0,0**	**0,0**
PTC Field			
Thermal Energy Production [kWh]	**1.049.013,6**	**1.046.719,2**	**1.042.491,5**
ORC - Efficiency	**18,9%**	**18,7%**	**18,5%**
Thermal Energy Production [kWh]	**827.318,2**	**826.726,7**	**825.631,9**
Thermal Energy Consumption [kWh]	**1.020.016,7**	**1.017.482,3**	**1.013.179,6**
Electricity Production [kWh]	**192.698,6**	**190.755,7**	**187.547,7**
HEX			
Thermal Energy Production [kWh]	**0,0**	**0,0**	**0,0**
TOTAL			
Electric Consumption [kWh]	**-19.469,2**	**-19.479,5**	**-19.491,7**

Electric Balance [kWh]	**173.229,4**	**171.276,2**	**168.056,0**
Biomass Consumption [kWh]	**0,0**	**0,0**	**0,0**

ENVIRONMENTAL IMPACT			
CO_2 Emissions [TnCO_2]	**10,7**	**10,7**	**10,7**
Fuel in primary energy [kWh]	**-1.049.013,6**	**-1.046.719,2**	**-1.042.491,5**
Electricity in primary energy [kWh]	**-46.784,4**	**-46.809,2**	**-46.838,6**
Primary energy delivered/energy consumed [kWh/kWh]	**0,93**	**0,93**	**0,93**

As expressed by the results in the table above, the operation of the solar field starts when the solar radiation is present. Due to the independency of each oil loop respect to the others, because of presence of individual pumps for each loop, no thermal energy is extracted by the solar field (VSP1) until setpoint temperature conditions (T14 and T5) have been reached for feeding the ORC (VSP3).

It can be evidenced how the PTC thermal production, and its electric consumption, is limited during the year because of the dependence from the available DNI. The totality of produced thermal energy is used for feeding the ORC which, through annual thermal exchange efficiency over 80%, is used for delivering heat to the network in case of reduction of its energetic level (T42); on other hand the annual electric conversion efficiency is maintained over 18%.

The increment of the network inlet temperature (T42) reduces the energy transformed by the ORC and consequently the energy required from the PTC for the activation. As consequence the energy produced by the solar field is reduced of 0,22 and 0,62% respect to base scenario, while the energy delivered by the ORC to the network is reduced of 0,07 and 0,2% because of the reduction of the electric conversion efficiency by 0,2 and 0,4%.

Heating production through ORC supplied by BLR (Sc2 and Sc4b)

The Powerstation is operating in heating mode, feeding the network via ORC + BLR; all other Powerstation components are switched off.

Table 21: Results in heating mode ORC +BLR

	20ºC	**25ºC**	**30ºC**
BIOMASS BOILER (BLR)	**61,2%**	**61,2%**	**61,2%**
Thermal Energy Production [kWh]	**6.757.276,6**	**6.541.830,9**	**5.989.468,8**
Biomass Consumption [Tn]	**2.451,8**	**2.373,7**	**2.173,3**
PTC Field			
Thermal Energy Production [kWh]	**0,0**	**0,0**	**0,0**
ORC - Efficiency	**19,8%**	**19,6%**	**19,3%**
Thermal Energy Production [kWh]	**5.184.975,1**	**5.026.493,4**	**4.620.919,7**
Thermal Energy Consumption [kWh]	**6.462.228,0**	**6.255.671,1**	**5.726.178,6**
Electricity Production [kWh]	**1.277.252,9**	**1.229.177,7**	**1.105.258,9**

HEX			
Thermal Energy Production [kWh]	0,0	0,0	0,0

TOTAL			
Electric Consumption [kWh]	-40.138,4	-40.138,4	-40.138,4
Electric Balance [kWh]	1.237.114,5	1.189.039,3	1.065.120,5
Biomass Consumption [kWh]	8.851.142,4	8.568.948,7	7.845.432,5

ENVIRONMENTAL IMPACT			
CO_2 Emissions [$TnCO_2$]	22,1	22,1	22,1
Fuel in primary energy [kWh]	-11.342.211,8	-10.980.597,4	-10.053.454,5
Electricity in primary energy [kWh]	-96.452,5	-96.452,5	-96.452,5
Primary energy delivered/energy consumed [kWh/kWh]	0,56	0,56	0,56

As expressed by the results in the table above, the operation of the boiler doesn't depend on any climatic conditions. Due to the independency of each oil loop respect to the others, because of presence of individual pumps for each loop, no thermal energy is extracted by boiler (VSP2) until setpoint temperature conditions (T1 and T5) have been reached for feeding the ORC (VSP3); this last condition is due only during start-up phase.

It can be evidenced how the BLR thermal production, and its electric consumption, is continuous during the year because of the dependence from the network requirements. The totality of produced thermal energy is used for feeding the ORC which, through thermal annual exchange efficiency over 80%, is used for delivering heat to the network in case of reduction of its energetic level (T42); on other hand the annual electric conversion efficiency is maintained over 19%.

The increment of the network inlet temperature (T42) reduces the energy transformed by the ORC and as consequence the energy required from the BLR (full power operation constantly). As consequence the energy produced by the boiler is reduced respect to reference scenario, while the energy delivered by the ORC to the network is reduced of 0,06 and 1,88% because of the reduction of the electric conversion efficiency by 0,2 and 0,5%.

Heating production through ORC supplied by PTC and BLR (Sc1, Sc2 and Sc4b)

The Powerstation is operating in heating mode, feeding the network via ORC + BLR + PTC.

Table 22: Results in heating mode ORC+PTC+BLR

	20ºC	25ºC	30ºC
BIOMASS BOILER (BLR)	61,2%	61,2%	61,2%
Thermal Energy Production [kWh]	5.265.433,6	5.089.449,3	4.688.101,5
Biomass Consumption [Tn]	1.910,5	1.846,7	1.701,1

PTC Field			
Thermal Energy Production [kWh]	1.054.866,1	1.052.166,5	1.047.352,3

ORC - Efficiency	19,6%	19,5%	19,2%
Thermal Energy Production [kWh]	4.880.894,4	4.750.066,7	4.453.238,4
Thermal Energy Consumption [kWh]	6.071.623,0	5.899.933,9	5.510.319,6
Electricity Production [kWh]	1.190.728,5	1.149.867,3	1.057.081,3

HEX			
Thermal Energy Production [kWh]	0,0	0,0	0,0

TOTAL			
Electric Consumption [kWh]	-50.752,7	-50.752,7	-50.752,7
Electric Balance [kWh]	1.190.728,5	1.149.867,3	1.057.081,3
Biomass Consumption [kWh]	1.139.975,8	1.099.114,5	1.006.328,5

ENVIRONMENTAL IMPACT			
CO_2 Emissions [TnCO_2]	27,9	27,9	27,9
Fuel in primary energy [kWh]	-9.892.977,9	-9.594.908,2	-8.916.409,6
Electricity in primary energy [kWh]	-121.958,8	-121.958,8	-121.958,8
Primary energy delivered/energy consumed [kWh/kWh]	0,61	0,61	0,61

As expressed by the results in the above table, the operation of the solar field starts when the solar radiation is present while the boiler compensates the hours of reduction and absence of sun. Due to the independency of each oil loop respect to the others, because of presence of individual pumps for each loop, no thermal energy is extracted by the solar field (VSP1) until setpoint temperature conditions (T14) have been reached; when PTC conditions are not met, the BLR heats up (T1) and provides necessary energy (VSP2) for feeding the ORC (VSP3).

It can be evidenced how the PTC thermal production, and its electric consumption, is limited during the year because of the dependence from the available DNI; the thermal contribution (over 80%) and the electric consumption of the boiler is discontinuous in order to compensate the solar field (over 19%). The totality of produced thermal energy is used for feeding the ORC which, through annual exchange efficiency around 80%, is used for delivering heat to the network in case of reduction of its energetic level (T42).

The increment of the inlet temperature of the network (T42) reduces the amount of thermal energy that can be transformed into electricity, due to the drop of efficiency of the ORC; respect to base scenario, this is translated into:

- the energy produced by the solar field reduces of 0,26 and 0,71%
- The energy produced by the boiler reduces of 3,44 and 10,96%
- The global thermal energy transformed by the ORC reduces of 2,68 and 8,76%.

- The global electric energy transformed by the ORC reduces of 0,1 and 0,4%.

Cooling production through ABCH supplied by PTC (Sc1 and Sc3)

The Powerstation is operating in cooling mode, feeding the network via ABCH + BLR + PTC. Due to the temperature of operation of the network, which is relevantly above the maximum temperature that can be provided by the chiller, only one case will be analysed because no variation in the EER of the chiller can be evidenced.

Table 23: Results in Cooling mode ABCH+PTC

	20ºC	25ºC	30ºC
BIOMASS BOILER (BLR)			
Thermal Energy Production [kWh]	-	0,00	-
Biomass Consumption [Tn]	-	0,00	-
PTC Field			
Thermal Energy Production [kWh]	-	1.096.825,76	-
ABCH			
Cooling Energy Production [kWh]	-	1.096.825,76	-
Heat Energy Consumption [kWh]	-	1.096.825,76	-
WTC			
Heat rejected [kWh]	-	2.193.651,52	-
Electricity Consumption [kWh]	-	-21.936,52	-
TOTAL			
Electric Consumption [kWh]	-	-100.495,15	-
Electric Balance [kWh]	-	-100.495,2	-
Biomass Consumption [kWh]	-	0,0	-
ENVIRONMENTAL IMPACT			
CO_2 Emissions [$TnCO_2$]		55,27	
Fuel in primary energy [kWh]		-1.096.825,8	
Electricity in primary energy [kWh]		-241.489,8	
Primary energy delivered/energy consumed [kWh/kWh]		0,82	

As expressed by the results in the table above, the operation of the solar field starts when the solar radiation is present. Due to the independency of each oil loop respect to the others, because of presence of individual pumps for each loop, no thermal energy is extracted by the solar field (VSP1) until setpoint temperature conditions (T14 and T5) have been reached for feeding the ABCH (VSP9).

The chiller is connected to the network for chilling and to the cooling tower for heat rejection with independent loops (VSP7-8). Cooling tower is always operating accordingly to hours of operation of the chiller and in this case represents a costs for the system; in case of storing the energy (in ground storages) during the summer for latter utilization during the winter, the associated costs would reduce and the potential incomes would increase.

It can be evidenced how the PTC thermal production, and its electric consumption, is limited during the year because of the dependence from the available DNI. The totality of produced thermal energy is used for feeding the ORC which, through annual thermal COP over 1, is used for delivering cooling to the network in case of saturation of its energetic level (T42).

The increment of the inlet temperature of the network (T42) doesn't affect the efficiency of the chiller, already at its point of maximum EER.

Cooling production through ABCH supplied by BLR (Sc2 and Sc3)

The Powerstation is operating in cooling mode, feeding the network via ABCH + BLR. Due to the temperature of operation of the network, which is relevantly above the maximum temperature that can be provided by the chiller, only one case will be analysed because no variation in the EER of the chiller can be evidenced.

Table 24: Results in cooling mode ABCH+BLR

	20ºC	25ºC	30ºC
BIOMASS BOILER (BLR)		61,2%	
Thermal Energy Production [kWh]	-	6.757.276,6	-
Biomass Consumption [Tn]	-	2.451,8	-
PTC Field			
Thermal Energy Production [kWh]	-		-
ABCH			
Cooling Energy Production [kWh]	-	6.757.276,6	-
Heat Energy Consumption [kWh]	-	-6.757.276,6	-
WTC			
Heat rejected [kWh]	-	13.514.553,2	-
Electricity Consumption [kWh]	-	-135.145,5	-
TOTAL			
Electric Consumption [kWh]		-280.808,8	
Electric Balance [kWh]		-280.808,8	
Biomass Consumption [kWh]		11.033.280,0	
ENVIRONMENTAL IMPACT			
CO_2 Emissions [$TnCO_2$]		154,44	

Fuel in primary energy [kWh]		**-11.342.211,8**	
Electricity in primary energy [kWh]		**674.783,5**	
Primary energy delivered/energy consumed [kWh/kWh]		**0,63**	

As expressed by the results in the table above, the operation of the boiler starts doesn't depend on any climatic conditions. Due to the independency of each oil loop respect to the others, because of presence of individual pumps for each loop, no thermal energy is extracted by boiler (VSP2) until setpoint temperature conditions (T1 and T5) have been reached for feeding the ABCH (VSP9); this last condition is due only during start-up phase.

The chiller is connected to the network for chilling and to the cooling tower for heat rejection with independent loops (VSP7-8). Cooling tower is always operating accordingly to hours of operation of the chiller and in this case represents a costs for the system; in case of storing the energy (in ground storages) during the summer for latter utilization during the winter, the associated costs would reduce and the potential incomes would increase.

It can be evidenced how the BLR thermal production, and its electric consumption, is continuous during the year because of the dependence from the network requirements. The totality of produced thermal energy is used for feeding the ABCH which, through thermal annual EER over 1, is used for delivering cooling to the network in case of saturation of its energetic level (T42).

The increment of the inlet temperature of the network (T42) doesn't affect the efficiency of the chiller, already at its point of maximum EER.

Cooling production through ABCH supplied by PTC and BLR (Sc1, Sc2 and Sc3)

The Powerstation is operating in cooling mode, feeding the network via ABCH + BLR + PTC. Due to the temperature of operation of the network, which is relevantly above the maximum temperature that can be provided by the chiller, only one case will be analysed because no variation in the EER of the chiller can be evidenced.

Table 25: Cooling ABCH+PTC+BLR

	20ºC	**25ºC**	**30ºC**
BIOMASS BOILER (BLR)		**61,2%**	
Thermal Energy Production [kWh]	**-**	**5.265.433,6**	**-**
Biomass Consumption [Tn]	**-**	**1.910,5**	**-**
PTC Field			
Thermal Energy Production [kWh]	**-**	**1.096.825,76**	**-**
ABCH			
Cooling Energy Production [kWh]	**-**	**6.362.259,32**	**-**
Heat Energy Consumption [kWh]	**-**	**-6.362.259,32**	**-**
WTC			
Heat rejected [kWh]	**-**	**12.724.518,64**	**-**

Electricity Consumption [kWh]	-	-127.245,19	-

TOTAL			
Electric Consumption [kWh]		268.958,3	
Electric Balance [kWh]		-268.958,3	
Biomass Consumption [kWh]		8.597.385,0	

ENVIRONMENTAL IMPACT			
CO_2 Emissions [$TnCO_2$]		147,93	
Fuel in primary energy [kWh]		-9.934.937,5	
Electricity in primary energy [kWh]		646.306,8	
Primary energy delivered/energy consumed [kWh/kWh]		0,68	

As expressed by the results in the table above, the operation of the solar field starts when the solar radiation is present while the boiler compensates the hours of reduction and absence of sun. Due to the independency of each oil loop respect to the others, because of presence of individual pumps for each loop, no thermal energy is extracted by the solar field (VSP1) until setpoint temperature conditions (T14) have been reached; when PTC conditions are not met, the BLR heats up (T1) and provides necessary energy (VSP2) for feeding the ABCH (VS93).

The chiller is connected to the network for chilling and to the cooling tower for heat rejection with independent loops (VSP7-8). Cooling tower is always operating accordingly to hours of operation of the chiller and in this case represents a costs for the system; in case of storing the energy (in ground storages) during the summer for latter utilization during the winter, the associated costs would reduce and the potential incomes would increase.

It can be evidenced how the PTC thermal production, and its electric consumption, is limited during the year because of the dependence from the available DNI. The thermal contribution (25%) and the electric consumption of the boiler is discontinuous in order to compensate the solar field (75%). The totality of produced thermal energy is used for feeding the ABCH which, through annual EER around 1 is used for delivering cooling to the network in case of saturation of its energetic level (T42).

The increment of the inlet temperature of the network (T42) doesn’t affect the efficiency of the chiller, already at its point of maximum EER.

Final considerations for heating

According to presented results, it can be evidenced how the operation with the ECUs allows transmitting heat from generators to the network without significant energy reductions due to increasing temperature of the network. Respect to operation with ORC, the HEX is able to provide more of thermal energy to the network because of the electric transformation efficiency specific of the ORC, as it can be shown in the figure below. Independently from the ECUs, the BLR is the generator that allows the higher energy transmission to the network, because its capacity of operation at 24/7.

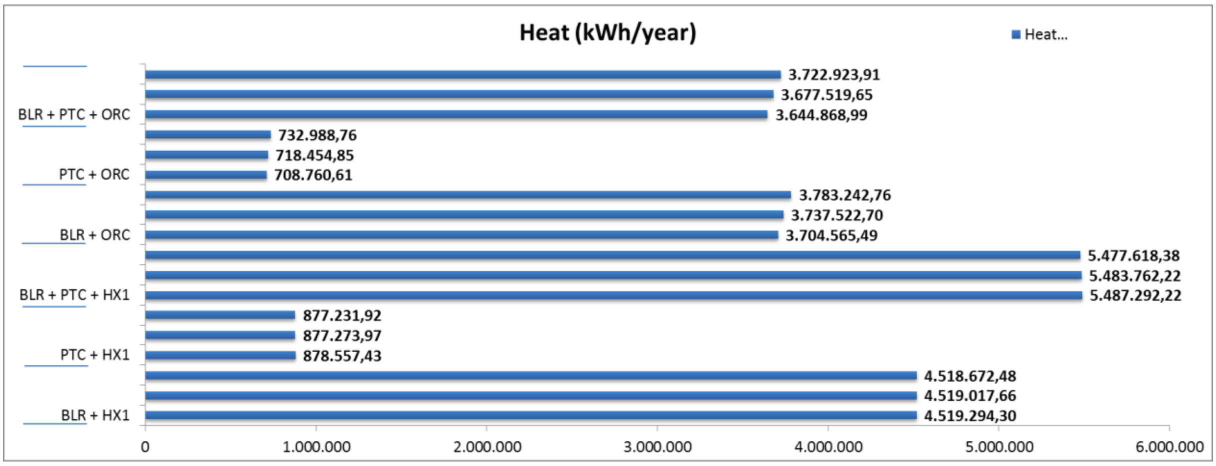


Figure 56 – Comparison of heating production between different Powerstation heating combinations.

Nevertheless, the electric balance of the Powerstation with ORC, respect to HEX, is extremely different because of the capacity of the ORC of producing electricity from thermal energy; although more elements are involved in the operation of the Powerstation, with consequent more electric consumption, the ORC produces higher amount of electricity driving to a positive net balance (with negative values the consumption balance and with positive values the production balance).

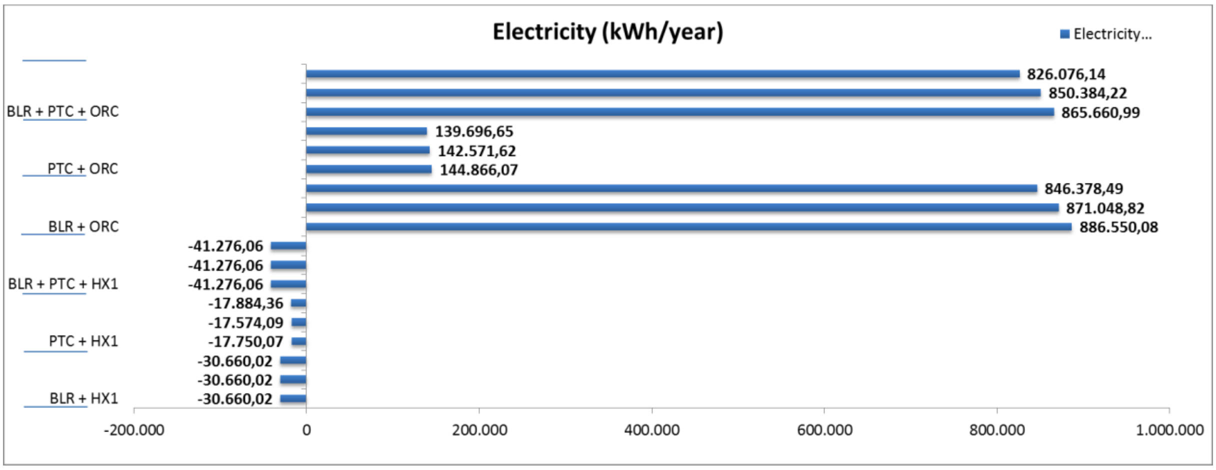


Figure 57 - Electric balance comparison between different Powerstation heating combinations.

It can be concluded how the operation with only PTC, among generators, has the minor impact for the consumption of electric energy, but also has the minor contribution in terms of heat delivered to the network, because of the intermittency of production; on the other hand, the boiler is able to provide the highest amount of energy to the network but with the highest electricity consumption, because of the continuity of production.

In order to better understand the specific energetic efficiency of each layout, a specific relationship between energy produced (thermal + electric) and primary energy consumed has been carried out accordingly to below figure.

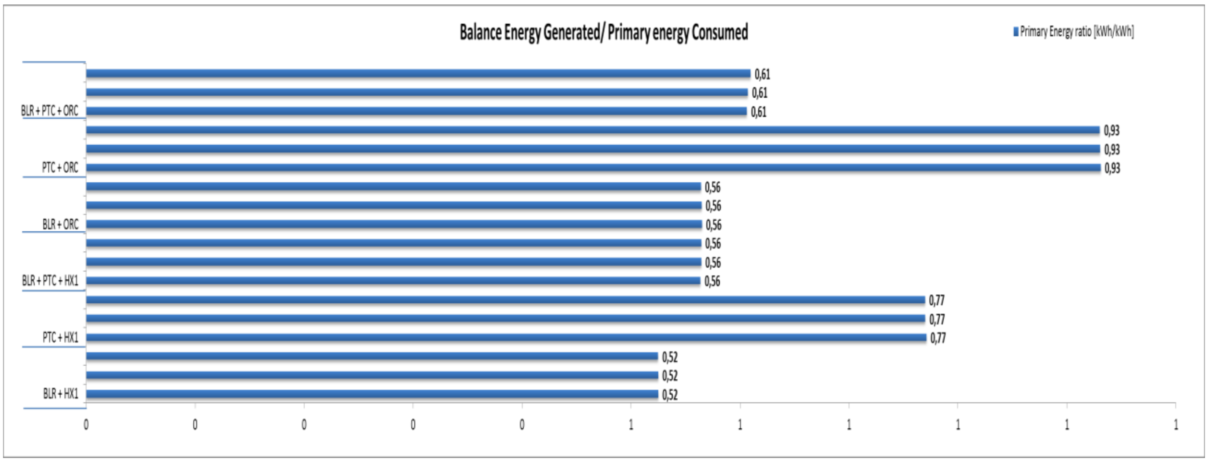


Figure 58 - Energetic balance of heat generated in function of primary energy consumed.

It can be evidenced how, among HEX combinations, the PTC achieves the best "first-principle" efficiency with respect to other combinations, because of the reduced consumption of the circulation pumps of the boiler with respect to the BLR; furthermore the solar energy produced has less primary energy impact respect to biomass, which has to include the transport contribution

The same pattern, of specific energetic efficiency between PTC and BLR, can be evidenced also in the operation of the ORC; nevertheless it must be stated how the use of the ORC increases this KPIs because of the production of electricity, which has a high conversion factor when produced with fossil fuels.

It can be concluded that the PTC achieves the best specific energetic generation efficiency, because of the nature of the technology; nevertheless has lover global production, because of the discontinuous contribution of the solar radiation. Of course, if biomass were not assumed 100 % renewable, the solar field would offer a clear environmental advantage (which is anyway present in terms of pollution).

Diagrams based on primary energy, as reported in Annex IV, show the same tendencies.

Final considerations for cooling

According to presented results, it can be evidenced how the operation with the ECUs allows transmitting cooling from generators to the network without any reductions due to variation of temperature of the network. About the heat of condensation, it can be evidenced how the condensing heat can be considered as un-useful heat, and so must be rejected into the environment through the CT, or can be useful heat to be stored for the winter period, with low temperature storages like boreholes; depending if rejected or stored, the condensing heat can be a cost or a benefit.

Results presented below report the results of the simulation taking into account the worst condition: rejection of heat into the environment.

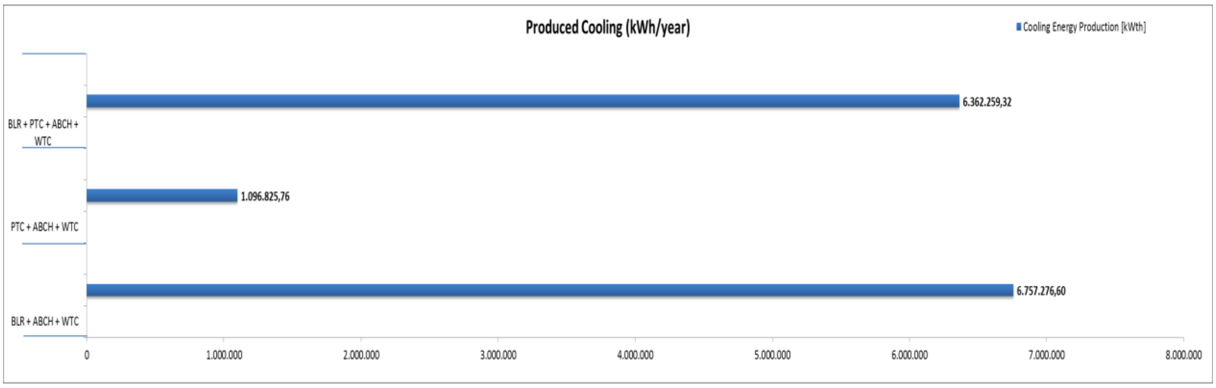


Figure 59 – Cooling production according to different operating schemes

It can be evidenced how the schemes of BLR only and BLR hybridized with PTC can produce the highest quantity of cooling, due to the possibility of operating 24/7, while PTC are affected by solar radiation.

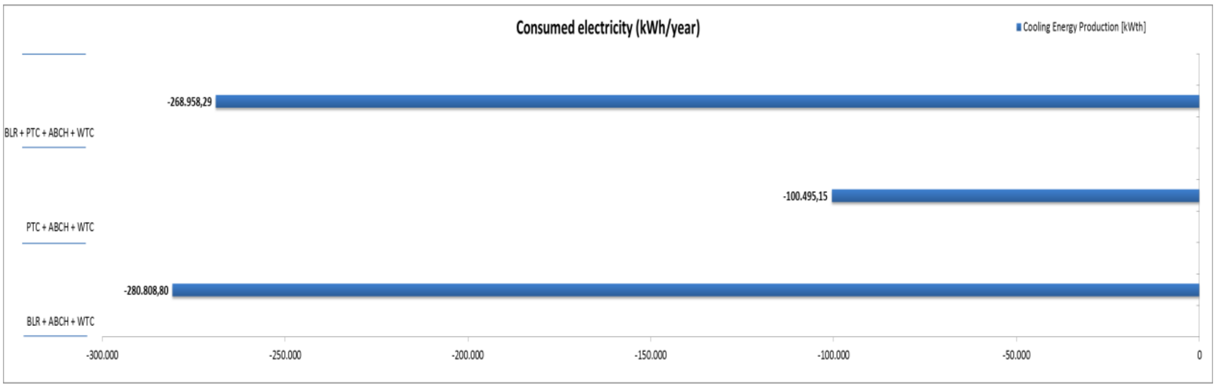


Figure 60 – Electricity consumption according to different operating schemes

The electric consumption results proportional to hours of operation of the scheme: the lower the hours of cooling, the lower the electric consumption of the equipments.

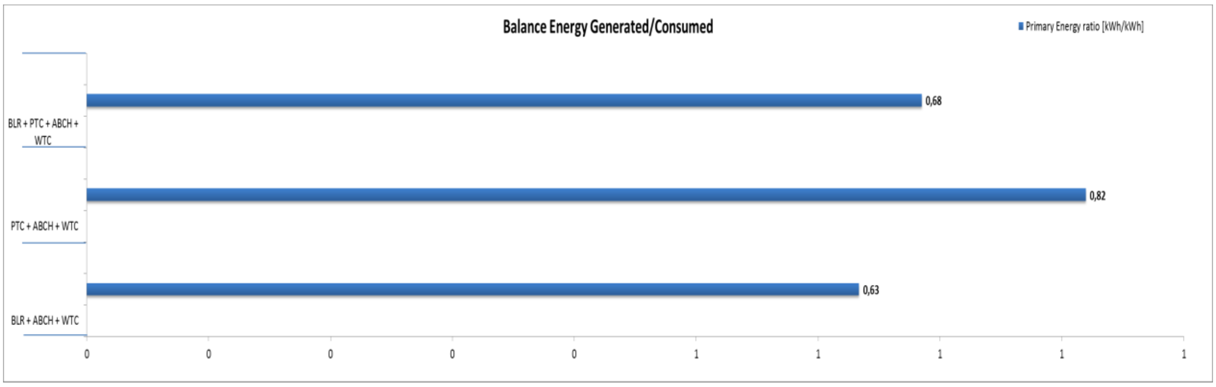


Figure 61 – Cooling production efficiency according to different operating schemes

The better annual efficiency (of produced respect to consumed) of the PTC with respect to BLR depends on the reduced number of auxiliaries necessary for the operation of the system; PTC has less energetic impact in the production of cooling respect to biomass.

4.3.3 Economic results

The results of the previous chapter represent the basis for the development of an economic analysis based on actual market energy prices; in this chapter, the value of the kWh produced/consumed will be the driver for the definition of the trading policies for the network manager.

The analysis will take into consideration the capital cost necessary for the installation of the Powerstation and the operation costs related with fuel consumption and O&M. Taking into account the contribution of these two elements, one constant and the other variable, and considering a life cycle of at least 20 years for the installation, it would be possible to calculate the simple payback time as a function of the minimum number of equivalent hours of operation at full capacity.

The capital costs have been calculated as a function of the size of the specific equipment for the "Base Scenario" (ORC 150 kWel at Spanish location), while the operation costs depend on the total amount of energy and fuel consumed with actual prices used for EU28.

Table 26: Opertaion costs

Technology	Operation cost €/MWh	Installation €/Wp
PTC collectors without storage	0,17060	1,00
Biomass boiler of 15 MW	0,06790	2,20
Biomass boiler of 5 MW	0,08620	0,25
ORC co-generator (electricity first)	0,13122	2,6
ORC co-generator (heat first)	0,07743	0,49
Absorption Chiller (Cooling capacity)	0,13122	1,00

Reference energy parameters	Value	Unit
Electric GRID	0,1340	€/kWh
Heating GRID	0,0658	€/kWh
Natural gas	0,0340	€/kWh
Biomass Cost (sliver)	0,0700	€/kg
Biomass Cost (sliver)	0,0200	€/kWth
Biomass Power heating (sliver)	3,6100	kWh/kg
Average COP	2,50	--------
Natural gas	0,22	$kgCO_2$/kWth
$C0_2$(electricity mix Spain)	0,55	$kgCO_2$/kWth

From the previous tables it can be showed how, depending on the technology involved in the energy production process, the operation cost (outcomings) has been calculated as the result from the contribution depending on the number of kWh produced by each technology, and on the kWh of fuel and electricity necessary for the operation. On other hand, the price of produced heat and net electricity represent the revenues for the Powerstation. The difference between revenue and costs determines the benefit achieved by each specific configuration.

It must be stated how simulations have been run for 8.760 hours with a network able to absorb the 100% of the energy produced during the entire year. As a consequence, the benefit by year, and so the PBT, have been calculated under these specific network conditions.

Due to the necessity to present economic calculations that can be replicated and spread along different climatic scenarios (mainly for PTC), it has been decided to consider the concept of equivalent hour, which corresponds to one hour of the heat generator/s operating at full capacity. The amount of necessary hours for the achievement of the payback time (PBT) at 50% and 75% of Powerstation useful life is expressed in equivalent hours (which represent the total amount of energy that must be generated with the above costs/prices). The real number of operating hours will depend on the efficiency of the system and on the availability of the renewable resources.

Due to the fact that the Powerstation can be assimilated to a small power plant, a measure of a power source which attempts to compare different methods of energy generation on a consistent basis is more suitable for this scenario; the Levelized Cost Of Energy (LCOE) model, which is the sum of costs over lifetime and the sum of TOTAL energy produced over lifetime:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad (21)$$

Where:

- I_t := investment expenditures in the year t;
- M_t := operations and maintenance expenditures in the year t (fuel included);
- E_t := energy generated in the year t;
- r := discount rate;
- n := expected lifetime of system or power station.

This parameter represents the average minimum cost at which energy must be sold in order to break-even over the lifetime of the project, or to achieve a full payback at 20 years (Powerstation lifetime).

LCOE electric is the price of selling electricity in case of not selling thermal heat produced by ORC; LCOE thermal is the price of selling heat in case of self-consumption of electricity produced by ORC. LCOE total mix is the price of selling 100% of energy produced by the ORC (80% heat + 19% electricity); the price of each one of them, sold by separately, is reported in the cells below the mix.

Corporations use Internal Return Rate (IRR) in capital budgeting to compare the profitability of capital projects in terms of the rate of return. For example, a corporation will compare an investment in a new plant versus an extension of an existing plant based on the IRR of each project. To maximize returns, the higher a project's IRR, the more desirable it is to undertake the project. If all projects require the same amount of up-front investment, the project with the highest IRR would be considered the best and undertaken first. Applying the internal rate of return method to maximize the value of the firm, any investment would be accepted, if its profitability, as measured by the internal rate of return, is greater than a minimum acceptable rate of return.

In finance, the Net Present Value (NPV) is a measurement of profit calculated by subtracting the present values (PV) of cash outflows (including initial cost) from the present values of cash inflows over a period of 20 years. Incoming and outgoing cash flows can also be described as benefit and cost cash flows, respectively. NPV is determined by calculating the costs (negative cash flows) and benefits (positive cash flows) for each period of an investment. Because of its simplicity, NPV is a useful tool to determine whether a project or investment will result in a net profit or a loss. A positive NPV results in profit, while a negative NPV results in a loss.

In order to give a better understanding of the presented results, here below are reported the boundary conditions for the calculation of the different economic values.

Table 27: Boundary conditions

Investment	
Total (€)	***
Own Funds (%)	100
External Funds (%)	0
Funding	
Period (years)	20
Interest Type (%)	0
Inflation	
Tax (%)	**3**
NPV Interest Rate (%)	**3**

*** values achieved for each specific simulation.

In some cases, the de-evaluation of the money during drives to negative values for these KPIs.

Heating production through PTC (Sc1 and Sc4a)

The Powerstation is operating in heating mode, feeding the network via HEX + PTC.

Table 28: Results in Heating mode PTC+ HEX

	20ºC	**25ºC**	**30ºC**
BIOMASS BOILER (BLR)			
Operation Cost [€]	**0,0**	**0,0**	**0,0**
PTC Field			
Operation Cost [€]	**187,1**	**187,1**	**187,1**
ORC			
Operation Cost Electricity / Heating [€]	**0,0**	**0,0**	**0,0**
TOTAL			
Fuel Cost [€/year]	**0,0**	**0,0**	**0,0**
Operational Costs [€/year]	**2.565,6**	**2.574,7**	**2.583,6**
Electric Cost(-)/Sale(+) [€/year]	**-2.378,5**	**-2.387,6**	**-2.396,5**
Heating Sale [€/year]	**57.809,1**	**57.724,6**	**57.721,9**

Economic Balance by year [€/year]	52.864,9	52.762,4	52.741,8
System Cost [€]	960.000,0	960.000,0	960.000,0
Simple Payback [years]	18,16	18,19	18,20
Hours to RETURN investment	159.077,1	159.386,2	159.448,5
Hours/year to PBT=50%	15.907,7	15.938,6	15.944,9
Hours/year to PBT=75%	10.605,1	10.625,8	10.629,9
Hours/year to PBT=100%	7.953,9	7.969,3	7.972,4

The solar field presents a maintenance cost based on energy produced and on the operation cost coming from the electric consumption necessary for the production of heat; the net incoming (revenues – costs) corresponds to 52.864,9 € front to an initial cost of 960.000 € for this Powerstation configuration. Operation at higher network temperature affects the net incoming decreasing of 0,19 and 0,23% respectively.

In order to have a payback period of 10 years (ROI=50%), there would be necessary 15.907,7 equivalent hours per year of operation at full capacity of Powerstation; to achieve a payback period of 20 years (ROI=100%) the Powerstation should operate 7.953,9 equivalent hours per year. The other way round, working at these specific simulated conditions, for a simple payback time calculation more than 18 years are necessary. Operation at higher network temperature affects the number of equivalent hours increasing of 0,07 and 0,23% respectively.

Table 29. LCOE, IRR and NPV

	20ºC	25ºC	30ºC
LCOE elect (€/kWh)	---------	---------	---------
LCOE therm (€/kWh)	0,0742	0,0743	0,0744
LCOE total (€/kWh)	0,0742	0,0743	0,0744

	20ºC	25ºC	30ºC
IRR	0,94%	0,92%	0,91%
NPV	-168.449,7 €	-169.930,7 €	-170.228,6 €

In the LCOE it can be stated how the temperature variation of the network affects the final price of energy of 0,0001 and 0,0002 €/kWh; nevertheless the IRR reduces of 0,1%, while the NPV reduces of 0,88 and 1,06% respectively.

Heating production through boiler (Sc2 and Sc4a)

The Powerstation is operating in heating mode, feeding the network via HEX + BLR.

Table 30: Results in heating mode BLR

	20ºC	25ºC	30ºC
BIOMASS BOILER (BLR)			
Operation Cost [€]	604,1	604,1	604,1

PTC Field			
Operation Cost [€]	0,0	0,0	0,0

ORC			
Operation Cost Electricity / Heating [€]	0,0	0,0	0,0

TOTAL			
Fuel Cost [€/year]	177.997,1	177.997,1	177.997,1
Operational Costs [€/year]	4.712,5	4.712,5	4.712,5
Electric Cost(-)/Sale(+) [€/year]	-4.108,4	-4.108,4	-4.108,4
Heating Sale [€/year]	408.775,2	408.758,9	408.738,2
Economic Balance by year [€/year]	221.957,1	221.940,9	221.920,2
System Cost [€]	240.000,0	240.000,0	240.000,0
Simple Payback [years]	1,08	1,08	1,08
Hours to RETURN investment	9.472,1	9.472,8	9.473,7
Hours/year to PBT=50%	947,2	947,3	947,4
Hours/year to PBT=75%	631,5	631,5	631,6
Hours/year to PBT=100%	473,6	473,6	473,7

The solar field presents a maintenance cost based on energy produced and on the operation cost coming from the electric consumption necessary for the production of heat; the net incoming (revenues – costs) corresponds to 221.957 € front to an initial cost of 240.000€ for this Powerstation configuration. Operation at higher network temperature affects the net incoming decreasing of 0,01 and 0,02% respectively.

In order to have a payback period of 10 years (ROI=50%), there would be necessary 947,2 equivalent hours per year of operation at full capacity of Powerstation; to achieve a payback period of 20 years (ROI=100%) the Powerstation should operate 473,6 equivalent hours per year. The other way round, working at these specific simulated conditions, for a simple payback time calculation more than 1 year is necessary. Operation at higher network temperature affects the number of equivalent hours increasing of 0,01 and 0,02% respectively.

Table 31: LCOE, IRR and NPV

	20ºC	25ºC	30ºC
LCOE elect (€/kWh)	---------	---------	---------
LCOE therm (€/kWh)	0,0319	0,0319	0,0319
LCOE total (€/kWh)	0,0319	0,0319	0,0319

	20ºC	25ºC	30ºC
IRR	92,5%	92,5%	92,5%
NPV	2.972.972,2 €	2.972.737,2 €	2.972.438,4 €

In the LCOE it can be stated how the temperature variation of the network doesn't affects the final price of energy; nevertheless the IRR doesn't change, while the NPV reduces of 0,01 and 0,02% respectively.

Heating production through PTC and boiler (Sc1, Sc2 and Sc4a)

The Powerstation is operating in heating mode, feeding the network via HEX + BLR + PTC

Table 32: Results in heating mode HEX+PTC+BLR

	20ºC	25ºC	30ºC
BIOMASS BOILER (BLR)			
Operation Cost [€]	**468,9**	**461,9**	**461,4**
PTC Field			
Operation Cost [€]	**189,4**	**189,3**	**189,1**
ORC			
Operation Cost Electricity / Heating [€]	**0,0**	**0,0**	**0,0**
TOTAL			
Fuel Cost [€/year]	**138.220,8**	**137.768,5**	**137.630,8**
Operational Costs [€/year]	**6.189,3**	**6.182,2**	**6.181,6**
Electric Cost(-)/Sale(+) [€/year]	**-5.531,0**	**-5.531,0**	**-5.531,0**
Heating Sale [€/year]	**383.602,4**	**383.038,1**	**382.655,0**
Economic Balance by year [€/year]	**233.661,3**	**233.556,3**	**233.311,7**
System Cost [€]	**1.200.000,0**	**1.200.000,0**	**1.200.000,0**
Simple Payback [years]	**5,14**	**5,14**	**5,14**
Hours to RETURN investment	**44.988,2**	**45.008,4**	**45.055,6**
Hours/year to PBT=50%	**4.498,8**	**4.500,8**	**4.505,6**
Hours/year to PBT=75%	**2.999,2**	**3.000,6**	**3.003,7**
Hours/year to PBT=100%	**2.249,4**	**2.250,4**	**2.252,8**

The hybrid solution presents a maintenance cost based on energy produced and on the operation cost coming from the electric consumption necessary for the production of heat; the net incoming (revenues – costs) corresponds to 233.661 € front to an initial cost of 1.200.000 € for this Powerstation configuration. Operation at higher network temperature affects the net incoming decreasing of 0,04 and 0,15% respectively.

In order to have a payback period of 10 years (ROI=50%), there would be necessary 4.498,8 equivalent hours per year of operation at full capacity of Powerstation; to achieve a payback period of 20 years (ROI=100%) the Powerstation should operate 2.249,4 equivalent hours per year. The other way round, working at these specific simulated conditions, for a simple payback time calculation around 5,14 years are necessary. Operation at higher network temperature affects the number of equivalent hours increasing of 0,04 and 0,15% respectively.

Table 33: LCOE, IRR and NPV

	20ºC	25ºC	30ºC
LCOE elect (€/kWh)	---------	---------	---------
LCOE therm (€/kWh)	0,0382	0,0382	0,0382
LCOE total (€/kWh)	0,0382	0,0382	0,0382

	20ºC	25ºC	30ºC
IRR	18,86%	18,85%	18,83%
NPV	2.209.989,8 €	2.208.474,3 €	2.204.941,0 €

In the LCOE it can be stated how the temperature variation of the network doesn't affect the final price of energy; nevertheless the IRR reduces of 0,01 and 0,03%, while the NPV reduces of 0,04 and 0,15% respectively.

Heating production through ORC supplied by PTC (Sc1 and Sc4b)

The Powerstation is operating in heating mode, feeding the network via ORC + PTC.

Table 34: Results in Heating mode ORC+PTC

	20ºC	25ºC	30ºC
BIOMASS BOILER (BLR)			
Operation Cost [€]	0,00	0,00	0,00
PTC Field			
Operation Cost [€]	179,0	178,6	177,9
ORC			
Operation Cost Electricity / Heating [€]	25,3	25,0	24,6
TOTAL			
Fuel Cost [€/year]	0,0	0,0	0,0
Operational Costs [€/year]	2.813,1	2.813,9	2.814,4
Electric Cost(-)/Sale(+) [€/year]	23.212,7	22.951,0	22.519,5
Heating Sale [€/year]	54.437,5	54.398,6	54.326,6
Economic Balance by year [€/year]	74.837,1	74.535,8	74.031,7
System Cost [€]	1.590.000,0	1.590.000,0	1.590.000,0
Simple Payback [years]	21,25	21,33	21,48
Hours to RETURN investment	186.116,1	186.868,7	188.140,9
Hours/year to PBT=50%	18.611,6	18.686,9	18.814,1
Hours/year to PBT=75%	12.407,7	12.457,9	12.542,7
Hours/year to PBT=100%	9.305,8	9.343,4	9.407,0

The solar field presents a maintenance cost based on energy produced and on the operation cost coming from the electric consumption necessary for the production of heat; the net incoming (revenues – costs) corresponds to 74.837 € front to an initial cost of 1.590.000€ for this Powerstation configuration. Operation at higher network temperature affects the net incoming decreasing of 0,4 and 1,08% respectively.

In order to have a payback period of 10 years (ROI=50%), there would be necessary 18.611,6 equivalent hours per year of operation at full capacity of Powerstation; to achieve a payback period of 20 years (ROI=100%) the Powerstation should operate 9.305,8 equivalent hours per year. The other way round, working at these specific simulated conditions, for a simple payback time calculation more than 21 years are necessary. Operation at higher network temperature affects the number of equivalent hours increasing of 0,4 and 1,09% respectively.

Table 35: LCOE, IRR and NPV

	20ºC	25ºC	30ºC
LCOE elect (€/kWh)	0,6152	0,6222	0,6342
LCOE therm (€/kWh)	0,1288	0,1289	0,1291
LCOE total mix (€/kWh)	0,1065	0,1068	0,1073
LCOE elect partial (€/kWh)	0,2819	0,2848	0,2898
LCOE therm partial (€/kWh)	0,0657	0,0659	0,0663

	20ºC	25ºC	30ºC
IRR	-0,57%	-0,61%	-0,67%
NPV	-462.730,26 €	-467.083,42 €	-474.363,82 €

In the LCOE it can be stated how the temperature variation increases of 0,0003 and 0,0008 € the final price of energy; nevertheless the IRR reduces of 0,04 and 0,11%; while the NPV reduces of 0,94 and 2,51% respectively.

Heating production through ORC supplied by boiler (Sc2 and Sc4b)

The Powerstation is operating in heating mode, feeding the network via ORC + BLR

Table 36: Results in Heating mode ORC+BLR

	20ºC	25ºC	30ºC
BIOMASS BOILER (BLR)			
Operation Cost [€]	582,5	563,9	516,3
PTC Field			
Operation Cost [€]	0,0	0,0	0,0
ORC			
Operation Cost Electricity / Heating [€]	167,6	161,3	145,0

TOTAL			
Fuel Cost [€/year]	171.628,8	166.156,7	152.127,2
Operational Costs [€/year]	6.128,6	6.103,7	6.039,9
Electric Cost(-)/Sale(+) [€/year]	165.773,4	159.331,3	142.726,2
Heating Sale [€/year]	341.171,4	330.743,3	304.056,5
Economic Balance by year [€/year]	329.187,3	317.814,1	288.615,6
System Cost [€]	870.000,0	870.000,0	870.000,0
Simple Payback [years]	2,64	2,74	3,01
Hours to RETURN investment	23.151,6	23.980,1	26.406,1
Hours/year to PBT=50%	2.315,2	2.398,0	2.640,6
Hours/year to PBT=75%	1.543,4	1.598,7	1.760,4
Hours/year to PBT=100%	1.157,6	1.199,0	1.320,3

The solar field presents a maintenance cost based on energy produced and on the operation cost coming from the electric consumption necessary for the production of heat; the net incoming (revenues – costs) corresponds to 329.187 € front to an initial cost of 870.000 € for this Powerstation configuration. Operation at higher network temperature affects the net incoming decreasing of 3,45 and 12,32% respectively.

In order to have a payback period of 10 years (ROI=50%), there would be necessary 1.890,4 equivalent hours per year of operation at full capacity of Powerstation; to achieve a payback period of 20 years (ROI=100%) the Powerstation should operate 1.260,3 equivalent hours per year. The other way round, working at these specific simulated conditions, for a simple payback time calculation more than 2 years are necessary. Operation at higher network temperature affects the number of equivalent hours increasing of 3,58 and 14,06% respectively.

Table 37: LCOE, IRR and NPV

	20ºC	25ºC	30ºC
LCOE elect (€/kWh)	0,1896	0,1926	0,2018
LCOE therm (€/kWh)	0,0452	0,0456	0,0465
LCOE total mix (€/kWh)	0,0365	0,0368	0,0378
LCOE elect mix (€/kWh)	0,0923	0,0936	0,0979
LCOE therm mix (€/kWh)	0,0227	0,0229	0,0234

	20ºC	25ºC	30ºC
IRR	37,78%	36,46%	33,06%
NPV	3.910.170,5 €	3.745.894,8 €	3.324.147,4 €

In the LCOE it can be stated how the temperature variation of the network increases of 0,0003 and 0,001 the final price of energy; nevertheless the IRR reduces of 0,01 and 0,05%, while the NPV drops of 4,2 and 14,9% respectively.

Heating production through ORC supplied by PTC and boiler (Sc1, Sc2 and Sc4b)

The Powerstation is operating in heating mode, feeding the network via ORC + BLR + PTC

Table 38: Results in heating mode ORC+PTC+BLR

	20ºC	25ºC	30ºC
BIOMASS BOILER (BLR)			
Operation Cost [€]	**453,9**	**438,7**	**404,1**
PTC Field			
Operation Cost [€]	**180,0**	**179,5**	**178,7**
ORC			
Operation Cost Electricity / Heating [€]	**156,3**	**150,9**	**138,7**
TOTAL			
Fuel Cost [€/year]	**133.737,3**	**129.267,5**	**119.073,6**
Operational Costs [€/year]	**7.591,0**	**7.570,0**	**7.522,4**
Electric Cost(-)/Sale(+) [€/year]	**152.756,8**	**147.281,4**	**134.848,0**
Heating Sale [€/year]	**321.162,9**	**312.554,4**	**293.023,1**
Economic Balance by year [€/year]	**332.591,3**	**322.998,3**	**301.275,1**
System Cost [€]	**1.830.000,0**	**1.830.000,0**	**1.830.000,0**
Simple Payback [years]	**5,50**	**5,67**	**6,07**
Hours to RETURN investment	**48.199,7**	**49.631,2**	**53.209,8**
Hours/year to PBT=50%	**4.820,0**	**4.963,1**	**5.321,0**
Hours/year to PBT=75%	**3.213,3**	**3.308,8**	**3.547,3**
Hours/year to PBT=100%	**2.410,0**	**2.481,6**	**2.660,5**

The solar field presents a maintenance cost based on energy produced and on the operation cost coming from the electric consumption necessary for the production of heat; the net incoming (revenues – costs) corresponds to 332.591 € front to an initial cost of 1.830.000 € for this Powerstation configuration. Operation at higher network temperature affects the net incoming decreasing of 2,88 and 9,42% respectively.

In order to have a payback period of 10 years (ROI=50%), there would be necessary 4.820 equivalent hours per year of operation at full capacity of Powerstation; to achieve a payback period of 20 years (ROI=100%) the Powerstation should operate 2.410 equivalent hours per year. The other way round, working at these specific simulated conditions, for a simple payback time calculation more than 5 years are necessary. Operation at higher network temperature affects the number of equivalent hours increasing of 2,97 and 10,39% respectively.

Table 39: LCOE, IRR and NPV

	20ºC	25ºC	30ºC
LCOE elect (€/kWh)	**0,2287**	**0,2332**	**0,2445**

LCOE therm (€/kWh)	0,0534	0,3897	0,0552
LCOE total mix (€/kWh)	0,0433	0,0438	0,0451
LCOE elect mix (€/kWh)	0,1104	0,1124	0,1175
LCOE therm mix (€/kWh)	0,0269	0,0280	0,0307

	20ºC	25ºC	30ºC
IRR	17,45%	16,87%	15,55%
NPV	3.027.300,29 €	2.888.736,93 €	2.574.964,39 €

In the LCOE it can be stated how the temperature variation of the network affect the final price of energy of 0,0004 and 0,0016 €; nevertheless the IRR reduces of 0,58 and 1,9%; while the NPV drops of 4,58 and 14,94% respectively.

Cooling production through ABCH supplied by PTC (Sc1 and Sc3)

The Powerstation is operating in heating mode, feeding the network via ORC + PTC.

Table 40: Results in cooling mode ABCH+PTC

	20ºC	25ºC	30ºC
BIOMASS BOILER (BLR)			
Operation Cost [€]	-	0,0	-
PTC Field			
Operation Cost [€]	-	187,12	-
Cooling station			
Operation Cost ABCH [€]	-	1.469,75	-
Operation Cost CT [€]	-	2.939,49	-
TOTAL			
Fuel Cost [€/year]	-	0,00	-
Operational Costs [€/year]	-	13.653,47	-
Electric Cost(-)/Sale(+) [€/year]	-	-13.466,35	-
Heating Sale [€/year]	-	72.171,13	-
Economic Balance by year [€/year]	-	45.051,3	-
System Cost [€]	-	1.920.000,0	-
Simple Payback [years]	-	42,62	-
Hours to RETURN investment	-	373.334,27	-
Hours/year to PBT=50%	-	37.333,43	-
Hours/year to PBT=75%	-	24.888,95	-
Hours/year to PBT=100%	-	18.666,7	-

The PTC+ABCH+CT presents a maintenance cost based on energy produced and on the operation cost coming from the electric consumption necessary for the production of cooling; the net incoming (revenues – costs) corresponds to 45.051 € front to an initial cost of 1.920.000 € for this Powerstation configuration.

In order to have a payback period of 10 years (ROI=50%), there would be necessary 37.333,43 equivalent hours per year of operation at full capacity of Powerstation; to achieve a payback period of 20 years (ROI=100%) the Powerstation should operate 18.666,7 equivalent hours per year. The other way round, working at these specific simulated conditions, for a simple payback time calculation almost 45 years are necessary.

Table 41: LCOE, IRR and NPV

	20ºC	25ºC	30ºC
LCOE elect (€/kWh)	-	-	-
LCOE therm (€/kWh)	-	0,1267	-
LCOE total (€/kWh)	-	0,1267	-

	20ºC	25ºC	30ºC
IRR	-	-6,33%	-
NPV	-	-1.213.349,69	-

Cooling production through ABCH supplied by BLR (Sc2 and Sc3)

The Powerstation is operating in heating mode, feeding the network via ABCH + BLR

Table 42: Result in cooling mode ABCH+BLR

	20ºC	25ºC	30ºC
BIOMASS BOILER (BLR)			
Operation Cost [€]	-	582,48	-
PTC Field			
Operation Cost [€]	-	0,0	-
Cooling station			
Operation Cost ABCH [€]	-	9.054,75	-
Operation Cost CT [€]	-	18.109,50	-
TOTAL			
Fuel Cost [€/year]	-	171.628,80	-
Operational Costs [€/year]	-	10.464,13	-
Electric Cost(-)/Sale(+) [€/year]	-	-37.628,38	-
Heating Sale [€/year]	-	444.628,80	-

Economic Balance by year [€/year]	-	197.163,6	-
System Cost [€]	-	1.200.000,00	-
Simple Payback [years]	-	6,09	-
Hours to RETURN investment	-	46.739,22	-
Hours/year to PBT=50%	-	4.673,92	-
Hours/year to PBT=75%	-	3.115,95	-
Hours/year to PBT=100%	-	2.337,0	-

The BLR+ABCH+CT presents a maintenance cost based on energy produced and on the operation cost coming from the electric consumption necessary for the production of heat; the net incoming (revenues – costs) corresponds to 197.163 €, front to an initial cost of 1.200.000 € for this Powerstation configuration..

In order to have a payback period of 10 years (ROI=50%), there would be necessary 4.673,92 equivalent hours per year of operation at full capacity of Powerstation; to achieve a payback period of 20 years (ROI=100%) the Powerstation should operate 2.337 equivalent hours per year. The other way round, working at these specific simulated conditions, for a simple payback time calculation more than 6 years are necessary.

	20ºC	25ºC	30ºC
LCOE elect (€/kWh)	-	-	-
LCOE therm (€/kWh)	-	0,0426	-
LCOE total (€/kWh)	-	0,0426	-

	20ºC	25ºC	30ºC
IRR	-	15,51%	-
NPV	-	1.682.811,60	-

Cooling production through ABCH supplied by PTC field and BLR (Sc1, Sc2 and Sc3)

The Powerstation is operating in heating mode, feeding the network via ABCH + BLR + PTC

Table 43:Results in cooling mode ABCH+PTC+BLR

	20ºC	25ºC	30ºC
BIOMASS BOILER (BLR)			
Operation Cost [€]	-	453,9	-
PTC Field			
Operation Cost [€]	-	187,12	-
Cooling station			
Operation Cost ABCH [€]	-	8.525,43	-
Operation Cost CT [€]	-	17.050,85	-

TOTAL			
Fuel Cost [€/year]	-	133.737,10	-
Operational Costs [€/year]	-	36.681,41	-
Electric Cost(-)/Sale(+) [€/year]	-	-36.040,41	-
Heating Sale [€/year]	-	418.636,66	-
Economic Balance by year [€/year]	-	212.177,7	-
System Cost [€]	-	2.160.000,00	-
Simple Payback [years]	-	10,18	-
Hours to RETURN investment	-	89.178,06	-
Hours/year to PBT=50%	-	8.917,81	-
Hours/year to PBT=75%	-	5.945,20	-
Hours/year to PBT=100%	-	4.458,9	-

The hybrid solution presents a maintenance cost based on energy produced and on the operation cost coming from the electric consumption necessary for the production of heat; the net incoming (revenues – costs) corresponds to 212.177 € front to an initial cost of 2.160.000 € for this Powerstation configuration.

In order to have a payback period of 10 years (ROI=50%), there would be necessary 8.917,81 equivalent hours per year of operation at full capacity of Powerstation; to achieve a payback period of 20 years (ROI=100%) the Powerstation should operate 4.458,9 equivalent hours per year. The other way round, working at these specific simulated conditions, for a simple payback time calculation more than 10 years are necessary.

Table 44: LCOE, IRR and NPV

	20ºC	25ºC	30ºC
LCOE elect (€/kWh)	-	-	-
LCOE therm (€/kWh)	-	0,0489	-
LCOE total (€/kWh)	-	0,0489	-

	20ºC	25ºC	30ºC
IRR	-	7,52%	-
NPV	-	967.639,85	-

Final considerations for heating

According to presented results, it can be evidenced how the operation with ORC brings more cash flow with respect to the operation with only HEX, because of the positive electric balance of the ORC and because of higher price of electricity with respect to heat (considering selling the electricity at the same price of purchase). It can also be highlighted how the BLR technology allows achieving higher incomes because of the higher number of hours of operation with respect to the PTC.

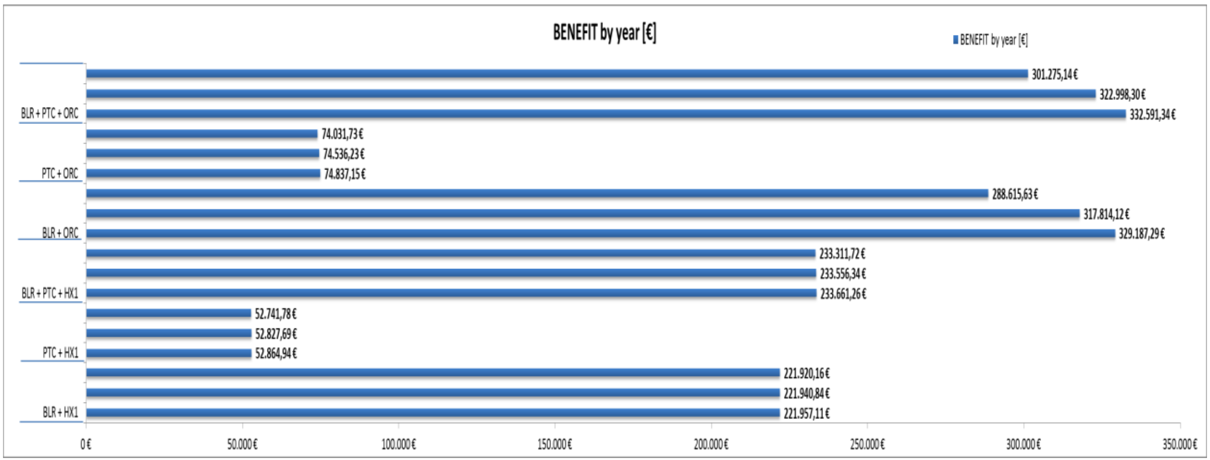


Figure 62 – Comparison of incomes between different Powerstation combinations.

Considering the yearly benefit obtained by the operation of each combination of substation, in order to achieve a payback period of 10 years (the 50% of PowerStation lifetime), it can be shown how the number of equivalent hours of operation per year increases with the utilization of PTC; on the other hand, the HEX requires less number of hours of operation respect to the ORC, for achieving the PBT, because of lower cost.

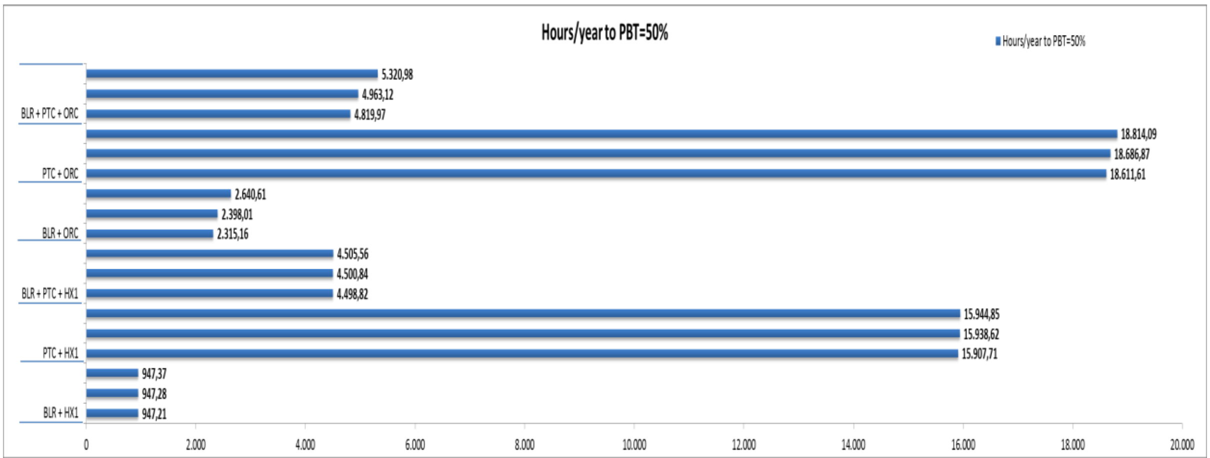


Figure 63 - Comparison of yearly required operation hours between different PowerStation combinations.

From the investment point of view, the BLR, with its constant and extended operation, is the generator which presents the better opportunity for investors, while the combination with HEX (and its reduced capital cost) represents the case with the best economic profitability.

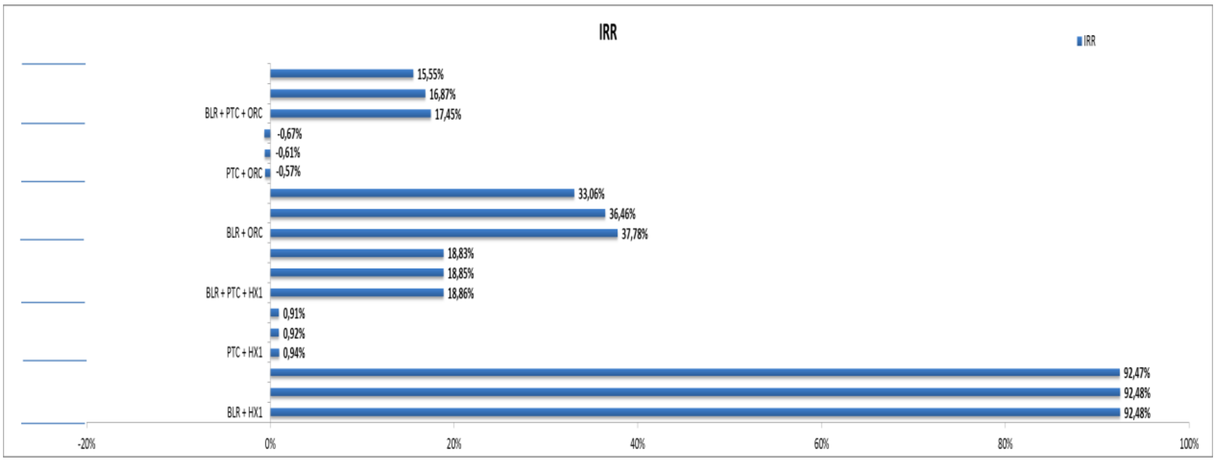


Figure 64 - Comparison of internal return rates between different PowerStation combinations.

The results from the NPV evidence how the introduction of the PTC in the PowerStation reduces the positive cash flow of the BLR, achieving negative values in the case of operation with only PTC. If we use a NPV interest rate of 3%, this kind of installation has negative results; where NPV has been calculated by subtracting the present values (PV) of cash outflows (including initial cost) from the present values of cash inflows over a period of time. The main reasons to understand this situation are:

- increasing of the initial installation cost (PTC increases this cost considerably);
- cashflow with PTC and interest rate of 3% makes the investment economically unviable;
- sun hours available to produce thermal energy insufficient to obtain a good economic return.

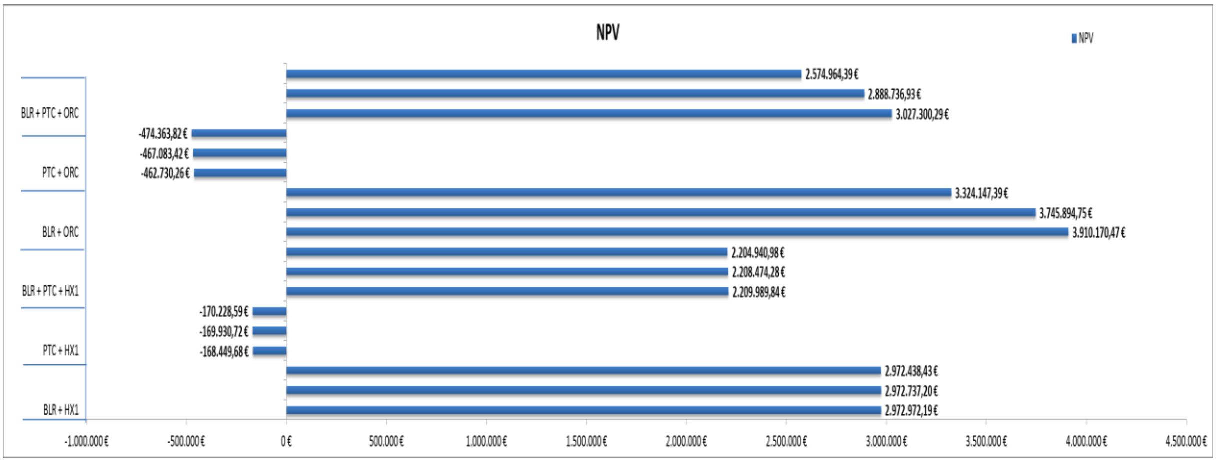


Figure 65 - Comparison of net present values between different PowerStation combinations.

The higher the LCOE (and so the cost of production), the lower is the benefit coming from the selling of energy and the competiveness respect to actual market; it must be stated that this value depends on the cost of the fuel + the cost of operation of the generator. According to the premises by which the investment must be returned after 20 years (lifetime), the following picture shows how the cost for the operation of the PTC (no fuel is required but only electricity) is higher with respect to boiler operation + biomass costs.

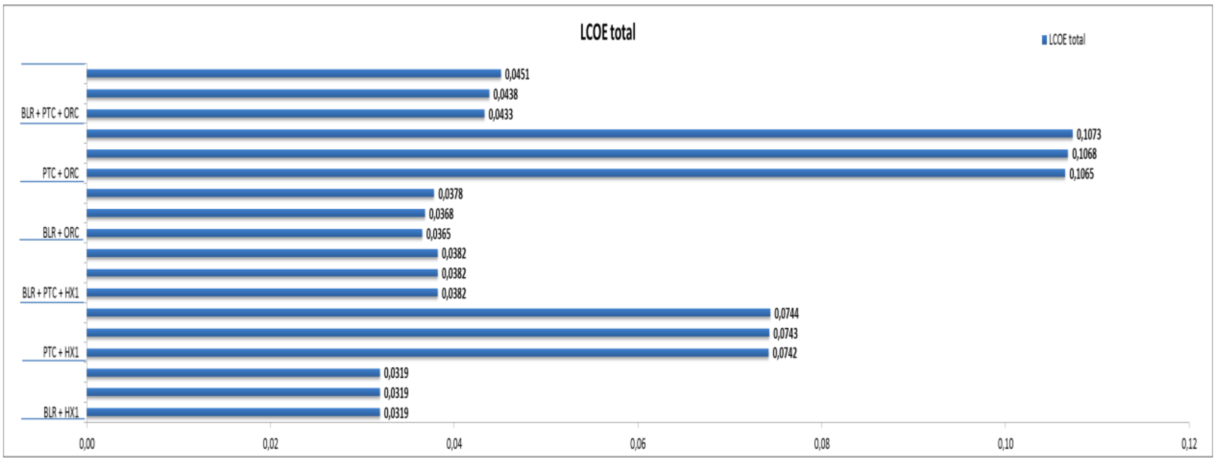


Figure 66 - Comparison of LCOE between different PowerStation combinations.

It can be evidenced how the cases with only PTC are the most unfavourable, because of the reduced number of operating hours, while the BLR + HEX is the cheapest solution because of reduced capital cost and high number of hours of operation. As shown in previous tables, it has been calculated a price for electricity and a price for heat; in case of simultaneous production of both, an average price of these two terms has been taken into consideration.

Final considerations for cooling

According to presented results, it can be evidenced how the operation with ABCH and CT, with consequent heat rejection into the environment without storage, can have economic consistency mainly when coupled with the boiler, due to the high price of PTC technology and to the limited efficiency of the chiller. Nevertheless it is shown in the table higher benefit with the combination of PTC+BLR because of the capacity of the chiller, able to accept more energy respect to the ORC.

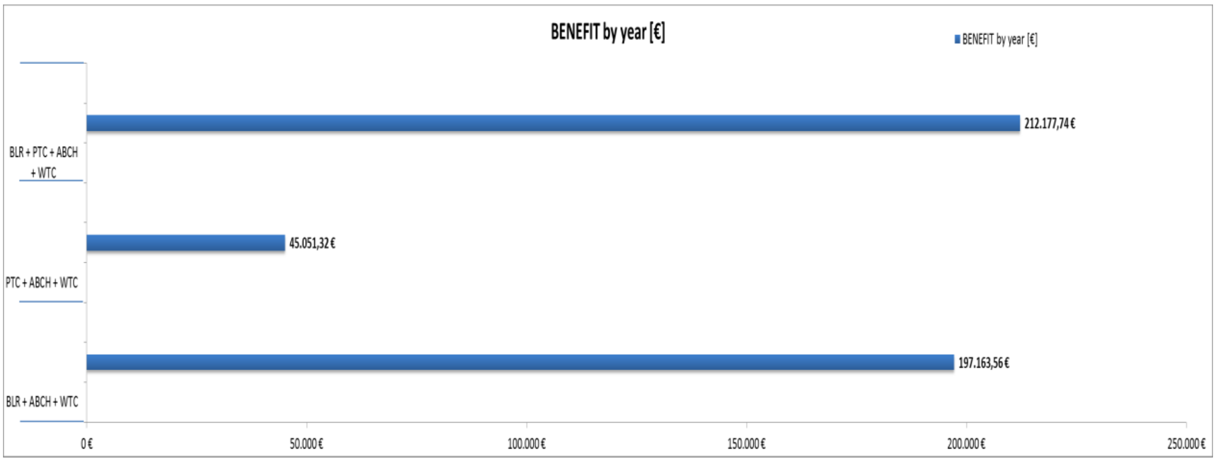


Figure 67 - Comparison of direct incomes for cooling production

The combination of ABCH with BLR+PTC is the best combination in terms of incoming but not the most expensive, in terms of capital cost. The most reliable solution excludes the PTC from the substation, because they are characterized by the lowest PBT because of low production respect to global cost.

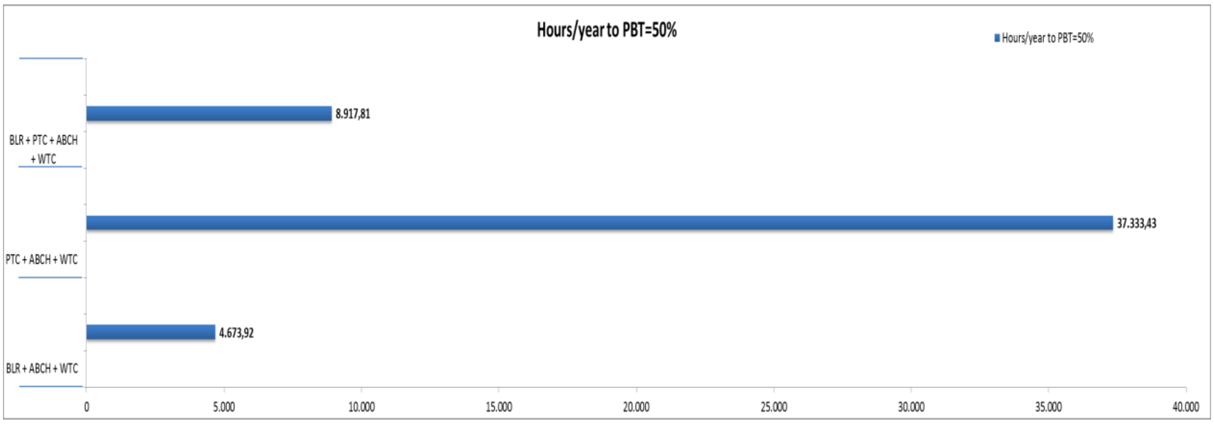


Figure 68 - Comparison of numbers of hours for the PBT at 50% of lifetime

IRR and NPV show how the cooling with thermal chiller, especially when coupled with the BLR, can have real market implementation, with economic values in some cases attractive.

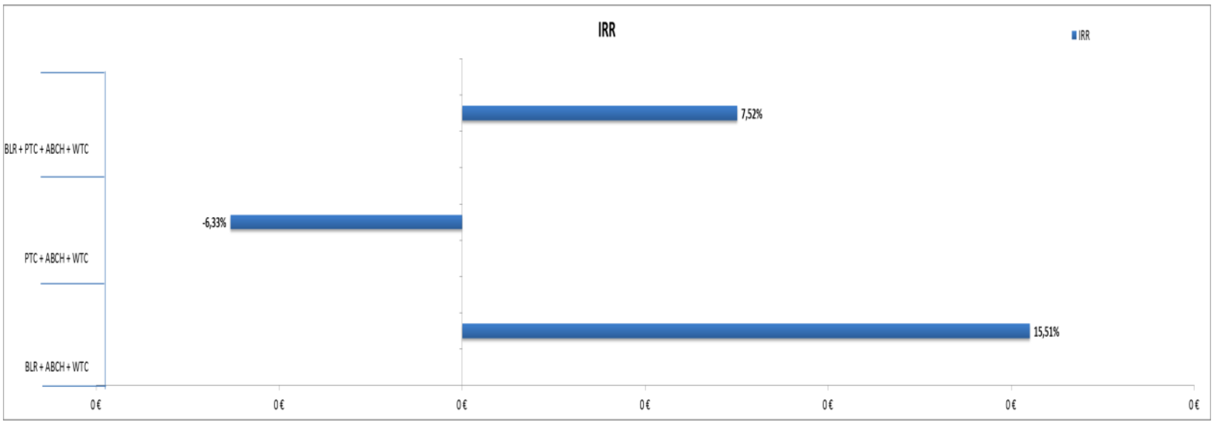


Figure 69 - Comparison of IRR at 20 years

It can be evidenced how introduction of PTC dramatically affects the economic balance in the cooling production.

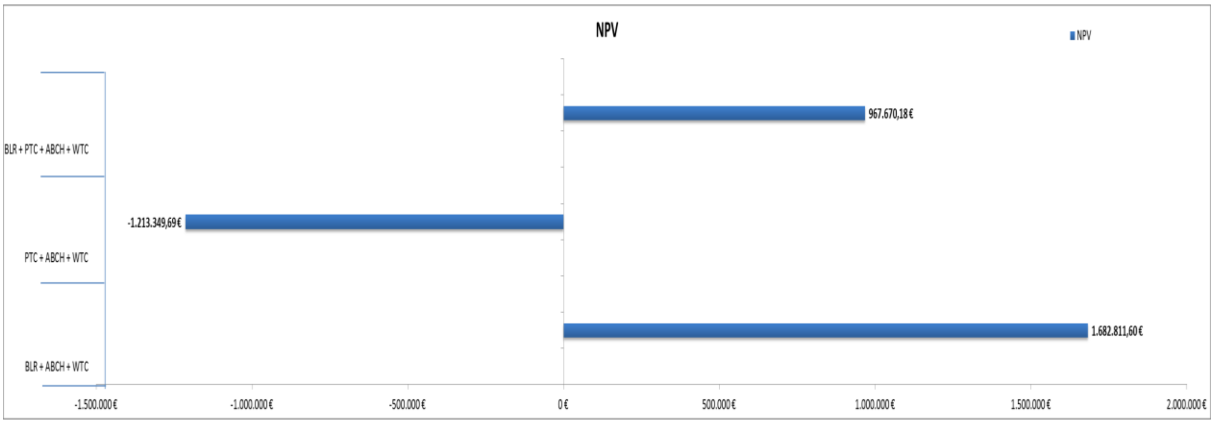


Figure 70 - Comparison of NPV at 20 years

The combination with BLR is the most competitive in terms of return on investment for the elevated number of hours of operation with respect to the initial cost.

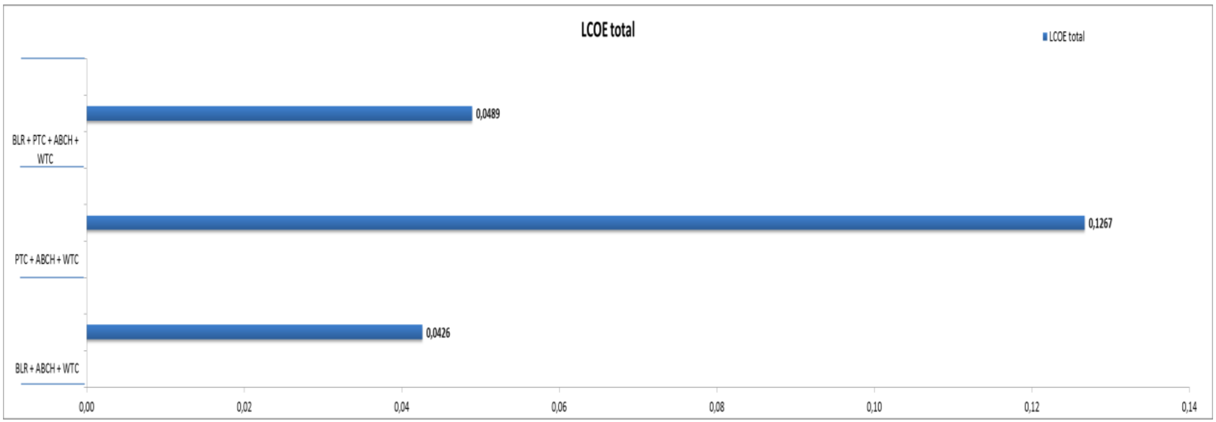


Figure 71 - Comparison of LCOE at 20 years of lifetime

Among the three combinations, the solution with only BLR results to be the scheme with higher margin of benefit because of the lowest cost of energy produced.

In the following figure, it is possible to appreciate the difference of LCOE between all systems, including heating and cooling, in order to show the impact that each solution has on the final costs.

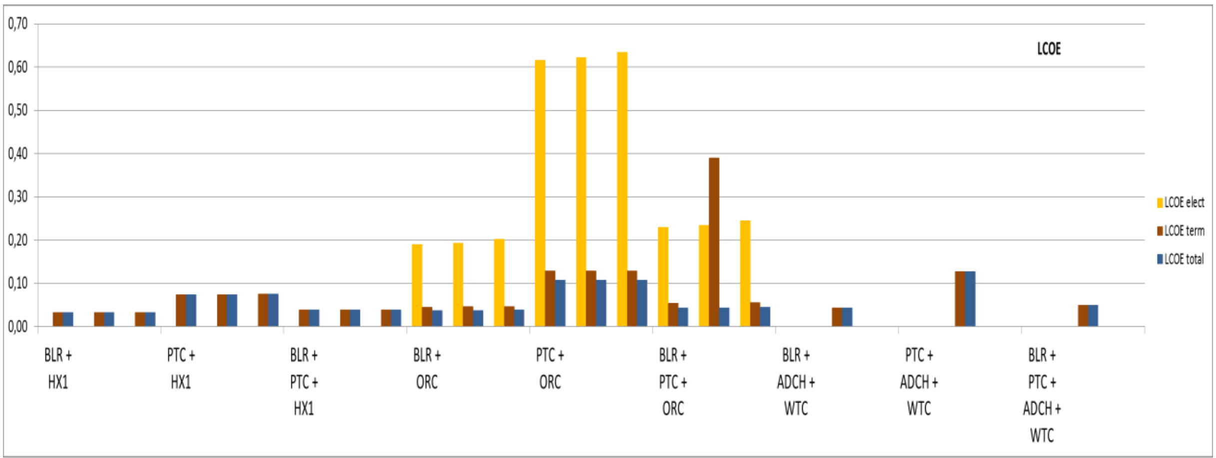


Figure 72 - Comparison of LCOE for different combinations.

Parametrization study according to scale effect for heating

In order to understand how the scale effect can influence the economic impact of the system, different electric sizes of the ORC (the main driver of the PowerStation), and of all necessary auxiliary components to make run the plant, have been considered according to following estimations.

Table 45: Estimations for parametrization

ORC Technology	Operation cost €/MWh	Installation €/Wpe
ORC - 300 kWe	0,13122	1,90
ORC - 600 kWe	0,13122	1,65
ORC - 1.000 kWe	0,13122	1,45

The equipment most affected for scale effect is the ORC, as reported in the table above; nevertheless some reduction in unit prices with increasing size could apply to PTC as well. Here below are reported the different case studies (reference scenario + scaled scenarios) with respective capital costs depending on the size of the PowerStation; the chiller has been scaled according to the scaling of the ORC, in order to have the same reference for the economic assessment between different solutions, as reported below:

- PTC + HEX
- BLR + HEX
- PTC + BLR + HEX
- PTC + ORC
- BLR + ORC
- PTC + BLR + ORC
- PTC + ABCH + WTC
- BLR + ABCH + WTC
- PTC + BLR + ABCH + WTC

Table 46: Parametric designs

Initial Design (ORC 150 kWe)			
System	Power [kWt]	Cost [€]	[€/kW]
BIOMASS BOILER (BLR)	800,00	200.000,00	250,00
PTC Field	800,00	800.000,00	1.000,00
ORC (150 kWe)	800,00	525.000,00	656,25
Chiller	800,00	800.000,00	1.000,00
Complementary Installation	20%	465.000,00	

Parametric Design nº1 (ORC 300 kWe)			
System	Power [kWt]	Cost [€]	[€/kW]
BIOMASS BOILER (BLR)	1.600,00	400.000,00	250,00
PTC Field	1.600,00	1.600.000,00	1.000,00
ORC (300 kWe)	1.600,00	570.000,00	356,25
Chiller	1.600,00	1.600.000,00	1.000,00
Complementary Installation	20%	716.000,00	

Parametric Design nº2 (ORC 600 kWe)

System	Power [kWt]	Cost [€]	[€/kW]
BIOMASS BOILER (BLR)	3.200,00	800.000,00	250,00
PTC Field	3.200,00	3.200.000,00	1.000,00
ORC (600 kWe)	3.200,00	990.000,00	309,38
Chiller	3.200,00	3.200.000,00	1.000,00
Complementary Installation	20%	1.402.000,00	

Parametric Design nº3 (ORC 1000 kWe)			
System	Power [kWt]	Cost [€]	[€/kW]
BIOMASS BOILER (BLR)	5.333,33	1.333.333,33	250,00
PTC Field	5.333,33	5.333.333,33	1.000,00
ORC (1000 kWe)	5.333,33	1.450.000,00	271,88
Chiller	5.333,33	5.333.333,33	1.000,00
Complementary Installation	20%	2.296.666,67	

In the analysis, it has been considered that the scale effect does not have any relevance on the efficiency of the technology, so the total amount of energy produced is perfectly linear with the increment of power, so no further energetic analysis is required. As a consequence, the incomes, directly related to energy produced, follow the same linear increment, so are not relevant for the study.

On other hand, the increment of size affects the costs of the PowerStation in all its combinations, and consequently all the economic calculations (PBT, LCOE and IRR) as reported in following figures; due to the poor impact that the variation of network temperature has on the economic balance, only T=25°C case study has been considered.

In the following picture, it is represented the variation of hours of operation in order to achieve the PBT at 10 years (50% lifetime), as a function of the increment of size (electric and thermal power) of the ORC and the other PowerStation components.

For this size of of PowerStation (<5MW) no relevant variations in prices have been considered for the generators; on other hand ORC has more relevant impact on the final price of the station.

Chiller is not represented in the scale effect analysis because of the linearity of this equipment in the price variation for the size considered.

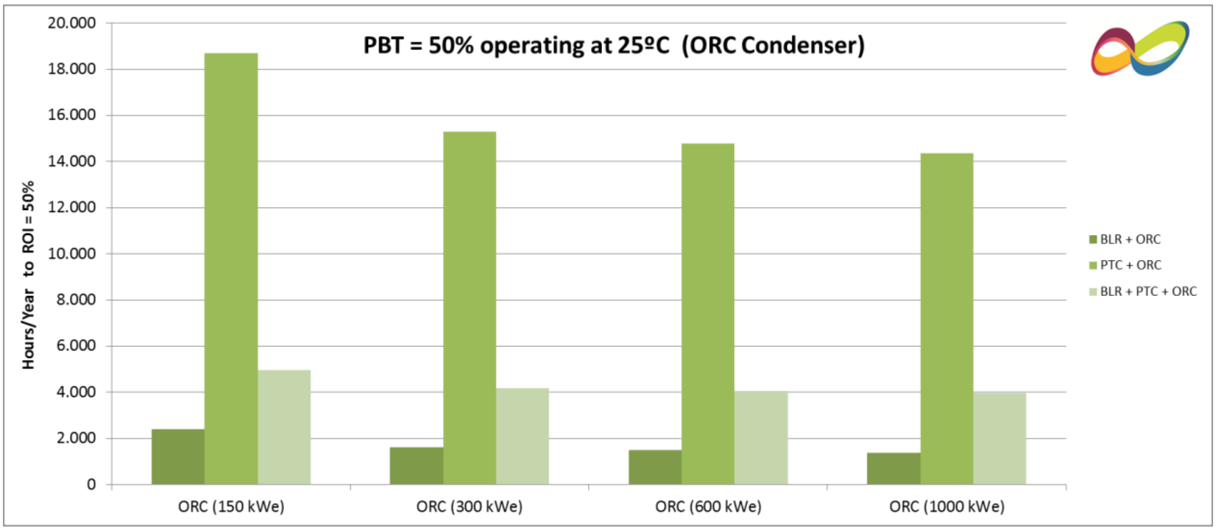


Figure 73 – Variation of hours of operation respect to different ORC sizes.

It can be evidenced how the main variation in price is represented by the ORC, with un-linear reduction of cost according to size scaling up; all the combinations are affected from the reduction of the capital cost of the ORC, but only BLR + ORC is the most affected at all scales because of the reduced number of components. The reduction of needed equivalent hours, with respect to base scenario, is around:

- BLR+ORC - 33% for 300 kWel; 38% for 600 kWel; 43% for 1.000 kWel.
- PTC+ORC - 9% for 300 kWel; 20% for 600 kWel; 23% for 1.000 kWel.
- PTC+BLR+ORC - 14% for 300 kWel; 19% for 600 kWel; 20% for 1.000 kWel.

In the following picture, it is represented the variation of LCOE according to PowerStation scaling up:

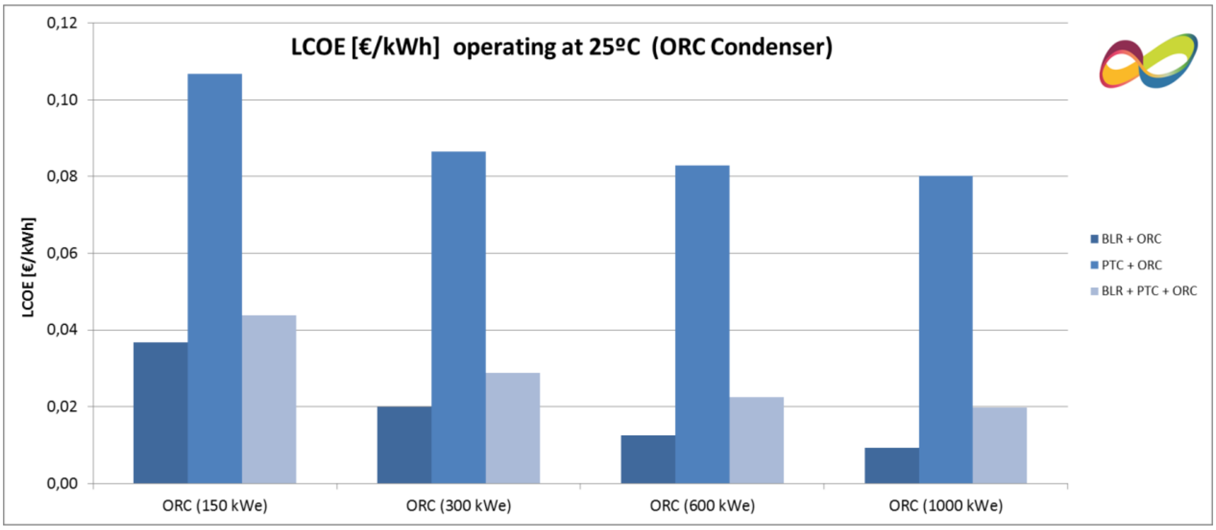


Figure 74 - Comparison of LCOE with respect to different ORC sizes.

It can be shown how the reduction of production cost is more linear through the scaling process:

- BLR+ORC - 45% for 300 kWel; 65% for 600 kWel; 75% for 1.000 kWel.
- PTC+ORC - 19% for 300 kWel; 22% for 600 kWel; 25% for 1.000 kWel.
- PTC+BLR+ORC - 34% for 300 kWel; 49% for 600 kWel; 65% for 1.000 kWel.

In the following picture, it is represented the variation of IRR according to PowerStation scaling up:

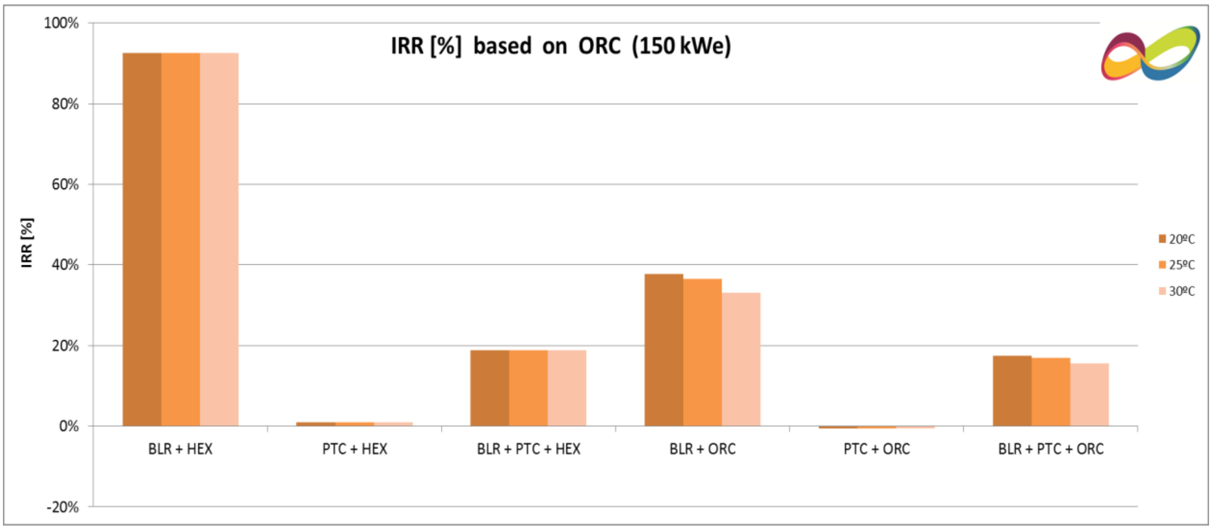


Figure 75 - Comparison of IRR with respect to different ORC sizes.

It can be shown how the increment of profitability is more linear through the scaling process with respect to PBT analysis:

- BLR+ORC – 18% for 300 kWel; 22% for 600 kWel and 27% for 1.000 kWel.
- PTC+ORC – 1,9% for 300 kWel; 2% for 600 kWel and 2,3% for 1.000 kWel.
- PTC+BLR+ORC – 3,6% for 300 kWel; 4,2% for 600 kWel and 4,8% for 1.000 kWel.

About cooling system, it must be evidenced how the scale effect doesn't affect actual economic figures; for this reason, no results are presented.

Parametrization study for heating according to European energy prices

Finally, in order to understand how local energy tariffs can economically affect the implementation of the PowerStation into EU28, and its viability from a business point of view, a parametric study have been presented with 4 different case studies (central, Mediterranean and northern countries + EU average), to contemplate the diversity that exists into the EU, as reported in tables below*:

Table 47: parametric study case studies

	Electricity prices (2015) €/kWh		Gas prices (2015) €/kWh		Biomass prices	
	Households	Industry	Households	Industry	[€/kWh]	[€/kg]
EU-28	0,2110	0,1190	0,0710	0,0340	0,0374	0,1349
Denmark	0,3040	0,0910	0,0760	0,0340	0,0302	0,1091
Spain	0,2370	0,1130	0,0930	0,0320	0,0620	0,2238
Sweden	0,1870	0,0590	0,1170	0,0420	0,0199	0,0717

For a preliminary analysis, only the PowerStation reference case study (150 kWel) has been taken into consideration, in order to be able to compare the same configuration at different locations and have conclusive results about the viability of different solutions around Europe.

*EUROSTAT Statistics Explained: Electricity and gas prices 2013-2015 (EUR/kWh). [http://ec.europa.eu/Eurostat]

In the following picture, it is shown the resume of the number of hours of operation in function of the configuration of the PowerStation (the smaller the better), according to the country and to the configuration of the PowerStation, to achieve the payback in 10 years:

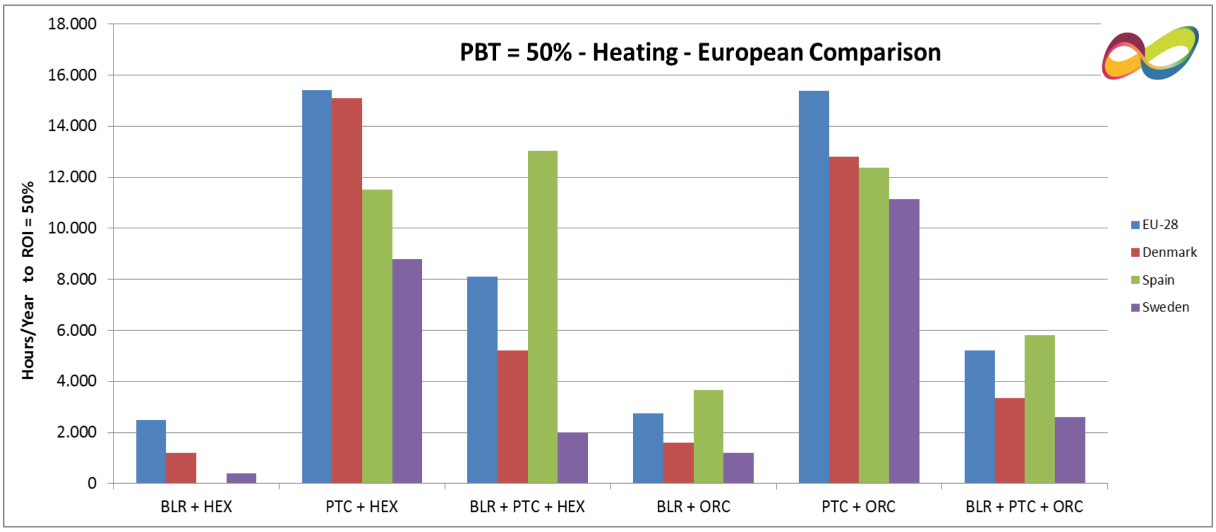


Figure 76 - PBT comparison for different countries for basic PowerStation

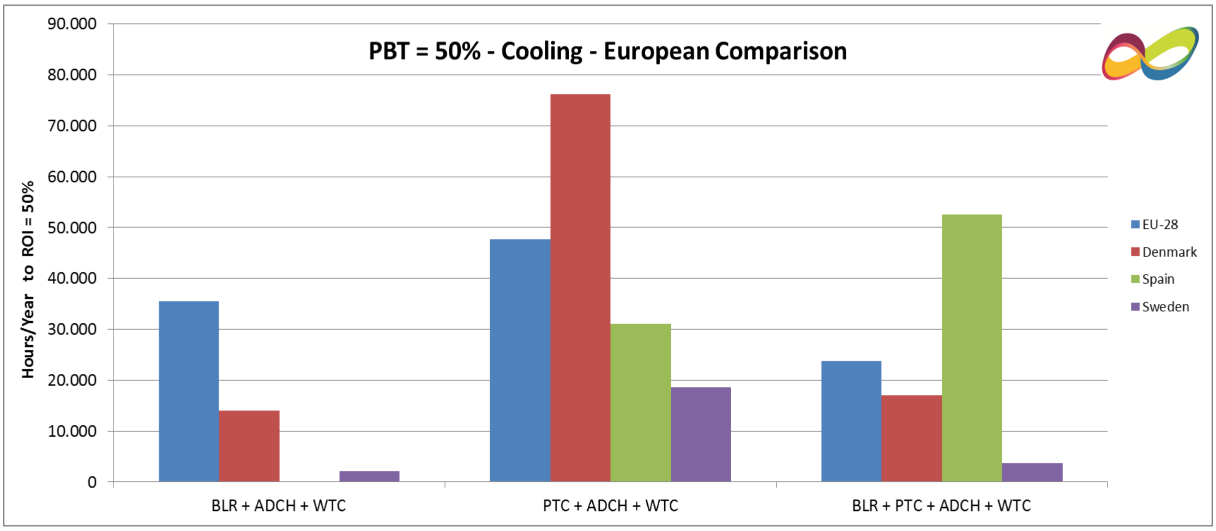


Figure 77 - PBT comparison for different countries for basic PowerStation

It can be evidenced how:

- for Mediterranean location the best scenario requires the presence of ORC, while the worst implies the only production of heat via HEX, due to the high cost of biomass. For cooling, the solution with only PTC results to be the most effective.
- for Central location the best scenario requires the presence of BLR (with or without ORC), while the worst implies the use of PTC for only production of heat; this is due to the high capital cost respect to the price of heat. The same pattern is respected for cooling.
- for Northern location the best scenario requires the presence of BLR for production of heat, while the worst implies the use of only PTC; this is due to the high difference of price between fuel and heat. The same pattern is respected for cooling.

In the following picture, it is represented the mixed LCOE (the smaller the better) according to the country and to the configuration of the PowerStation:

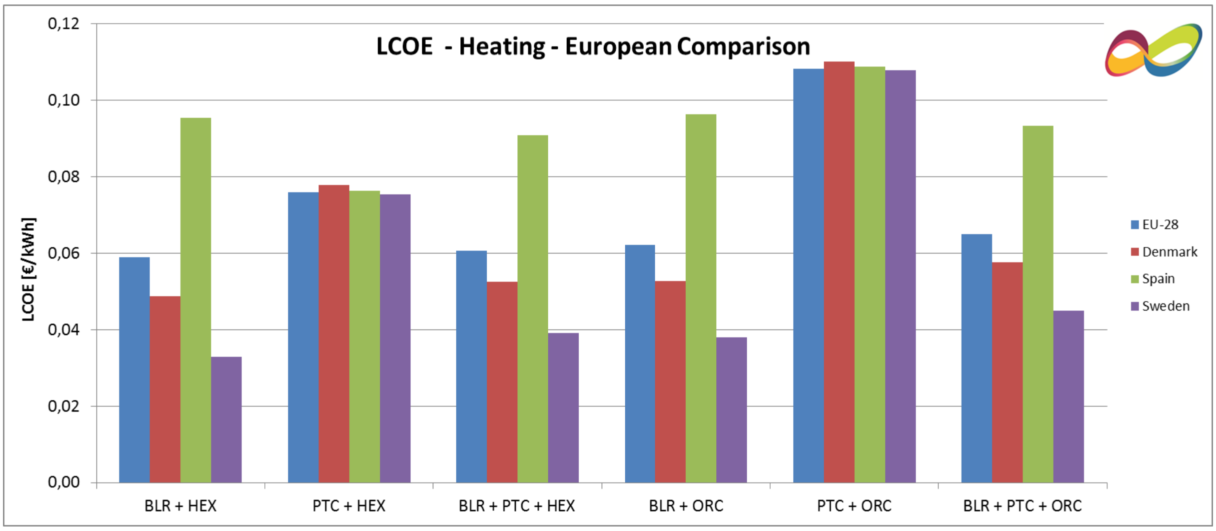


Figure 78 - LCOE confrontation for different countries for basic PowerStation

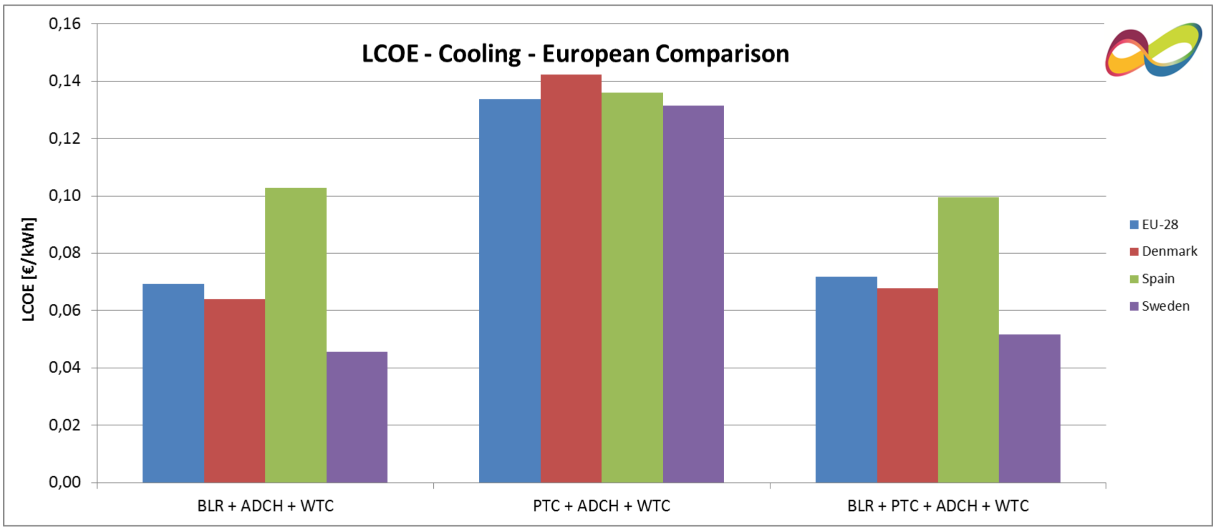


Figure 79 - LCOE confrontation for different countries for basic PowerStation

Due to the small difference between the different possible locations (with slightly exception for Spain which has a higher biomass cost), it is interesting the confrontation among the different configurations:

- Presence of PTC dramatically affects the cost of energy, especially when operating alone; if operating with BLR the increase is consistent but significantly lower.
- The presence of ORC affects the cost of the energy produced respect to HEX

In the following picture, it is represented the IRR (the higher the better) according to the country and to the configuration of the PowerStation:

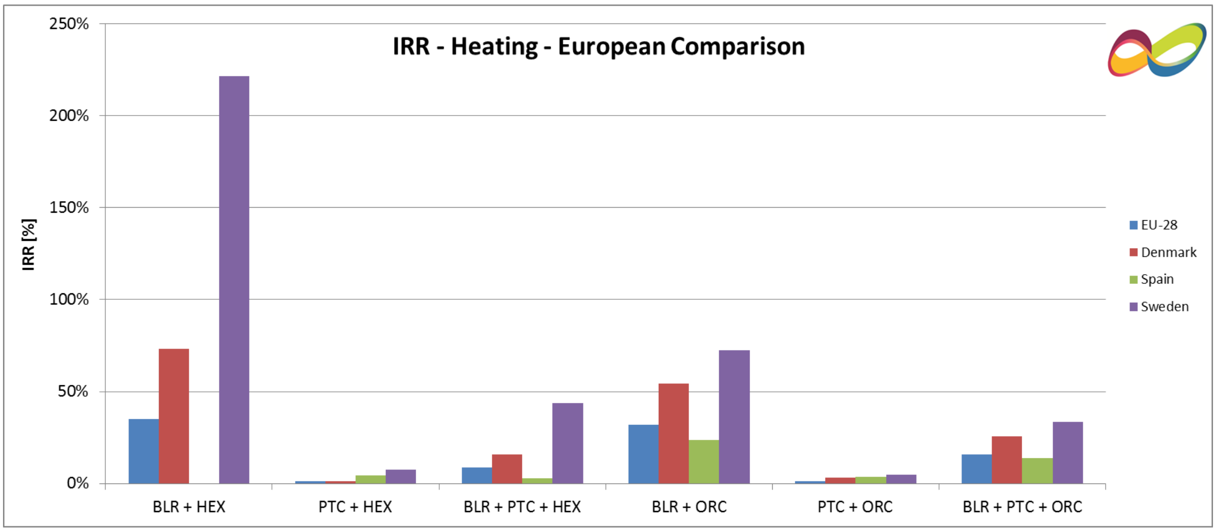


Figure 80 - IRR confrontation for different countries and PowerStation with ORC = 150 kWel.

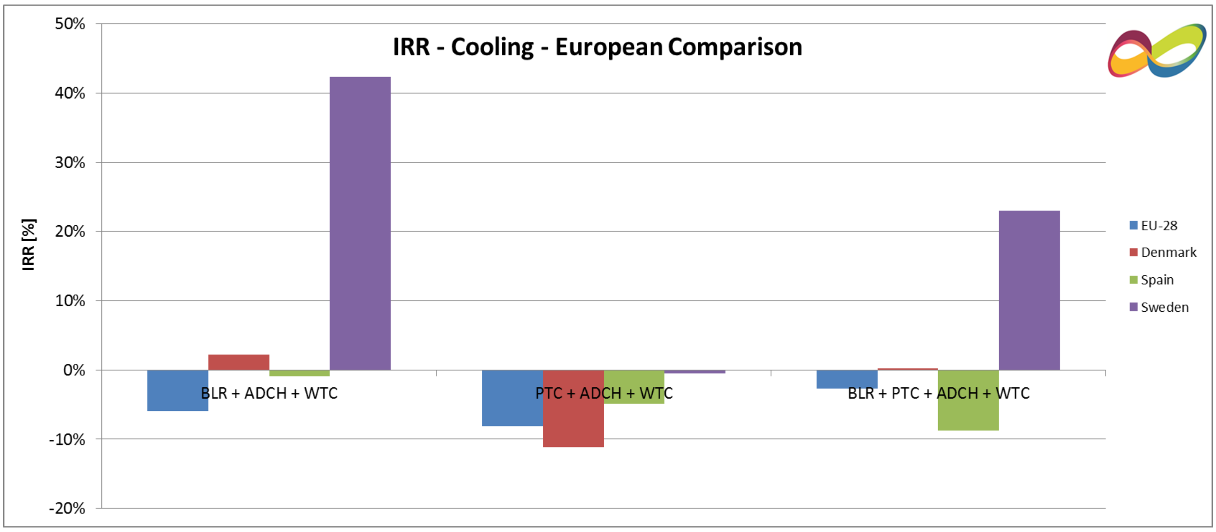


Figure 81 - IRR confrontation for different countries and PowerStation with ORC = 150 kWel.

It can be evidenced how in heating mode:

- for Northern countries the most interesting solution implies the operation of BLR, possibly without PTC; all solutions can be exploited.

- for Central countries the most interesting solution implies the operation of BLR+ORC, possibly without PTC; solutions with only presence of PTC cannot be exploited.
- for Mediterranean countries the only solutions imply the operation of ORC; solution where HEX is operating cannot be exploited.

In conclusion, biomass and PTC costs are the main factors which affect the economic European parametrization; the second one is the electricity sell price. These factors make Denmark and Sweden the best countries to develop the PowerStation projects. EU-28 and Spain does not present good economic results, it is not viable to propose projects using these technologies.

4.3.4 Model reliability

Regarding the TRNSYS model used for solar CHP power stations, this has been developed from the preliminary work performed by EURAC within the BRICKER project[3]. The configuration conceived in BRICKER is very similar to the one considered in the FLEXYNETS project, though with different details in terms of connection between the single components. Within the FLEXYNETS project, the model was readapted in order to simulate the new required combinations.

For the case of power stations, it has not been possible to validate the entire model against an equivalent existing power station. Nevertheless, it has been possible to develop models of single components (solar field, boiler, ORC engine) that have been compared with available laboratory data and nominal performances in the pilot plant in Sevilla (Biosol3Gen plant). On the other hand, results on how these components were modelled and compared with real data can be found in three deliverables of the BRICKER project, namely D4.42c . "Simulation report of Turkish demonstrator- Active system integration", D4.43c: "Simulation report of Belgian demonstrator- Active system integration", D4.44c: "Simulation report of Spanish demonstrator- Active system integration".

[3] BRICKER EU FP7 Project 2014, http://www.bricker-project.com.

5 Conclusions

In this deliverable, different possible substation solutions were discussed and analysed at different levels of detail, ranging from qualitative analysis to detailed TRNSYS simulations.

The work first presented the screening of 10 starting solutions. These were identified on the basis of building types (residential and commercial) and network needs (power stations to provide balance of the network in terms of heating and cooling). The analysis took into account the following criteria: the need of distinguishing between existing systems (e.g., with already installed boilers) and new systems, the need of distinguishing between residential and special (e.g., hospitals) buildings, the need of considering renewable sources and proper storages. From the latter point of view, it was considered not relevant to focus on conventional solutions like independent centralized boilers, as their usage in a FLEXYNETS network, while to be minimized, is possible without any special adaptation.

Conceptual layouts for these starting solutions were presented in Chapter 2. At the end of this chapter, after reviewing some general assumptions, only 2 main substation solutions were selected for specific simulations, one for residential substations and one for power stations (both of them with reversible or multiple equipment, in order to provide both heating and cooling). In this case, the driving criteria mainly took into account the need of analysing in detail residential substations (typically being the large majority of the network nodes) and the need of properly analysing the renewable power stations specifically designed for FLEXYNETS (in particular the ones exploiting solar collectors). This choice also allowed for a reasonable compromise with the large computational effort needed by TRNSYS simulations.

Detailed simulations were important in order to assess the entire yearly performance of the chosen systems. Moreover, repeating the simulations assuming different network temperatures at the substation boundary, a valuable mapping of the system behaviour (collected in a simulation database exploitable for network simulations) was obtained, which is one of the main results of this work.

The yearly simulations on residential substations, presented in Chapter 3, have been conducted for three reference European locations (London, Stuttgart and Rome) and for different building typologies and energy demands. In order to put in evidence the dependency of the substation performance on the network temperature, it has been carried out a parametric analysis varying the FLEXYNETS water temperature between 0 °C (only for comparison purposes) and 30 °C. It has been highlighted that the network temperature has a great impact on residential substation energetic performance for all climates, building typologies and energy standard, as it is shown in the simulation results plotted in section 3.3.1 In the case of new or renovated buildings, for instance, a change in FLEXYNETS temperature from 5 °C to 30 °C increases the SPF for heating from 3.83 to 5.31 and for DHW from 2.57 to 3.52. Because of the limitation in inlet water temperatures for the chosen heat pump model, cooling is not much affected by such a change. The heat pump limitations proved the importance of introducing a recirculation solution (here developed with a 3-way valve) on the network side of the heat pump. While this cannot be considered a universal need – low temperature networks exploiting ground source heat, for example, typically operate always far from heat pump operational limits – for cases where e.g. waste heat at temperatures above 30 °C is present, it is considered a recommendable option.

Concerning the simulation results for electricity consumption and heat exchanged with the network, it was verified that that the overall energy balances are constant for each of the considered network temperatures and corresponded to the building demand. This can be considered as a consistency check for the models, as the useful energy should not depend on the network temperature.

Simulations on power stations were tackled in Chapter 4. Here, a few variants were analysed separately, in terms of source (solar, biomass), mode/equipment (direct heating through heat exchanger, cogeneration through organic Rankine cycle, cooling through absorption chiller), location, and network temperature. In particular, a renewable, solar-based, version of combined heat and power (CHP) was considered. A preliminary investigation about system costs highlighted that the ORC and the absorption chiller investment costs are very high and need a large number of operation hours to be recovered. This forced the choice of considering cases were this type of power station is used to cover base load, so that a continuous operation throughout the year could be considered. In other words, it was assumed that there is always enough demand to absorb the output generated by the power station. On the other hand, available output was determined on the basis of real availability of solar energy.

It was also considered important to understand to which extent the considered power station solutions are economically viable when covering more than the base load – in other words, when there is not always enough demand to match the power station production. Hence, extrapolating from the results about the base load simulations, it was also calculated the needed amount of operation hours in order to reach a payback time which corresponds to different fractions of the system lifetime. For example, for the solar CHP option (ORC supplied by parabolic trough collectors and boiler) it was found that, while only a continuous operation could yield very competitive economic performances, in order to get a payback time equal to 50 % of the system lifetime (i.e., a payback time of 10 years assuming a system lifetime of 20 years), a minimum of about 5000 yearly operation hours was required. Accepting a payback time equal to 100 % of the system lifetime, only about 2500 yearly operation hours would be required. In all these cases, it turned out the solar source alone can never provide enough operation hours for the ORC-based cogeneration system to be economically viable and that a backup boiler is always needed. The worst economic figures were obtained for the absorption chiller.

Concerning the dependence on the various analysed parameters, it was found that the variation of the network temperature within the chosen limits does not affect much the system performances. Geographical effects are instead clearly important for the performance of solar collectors, though in the cases were a large fraction of operation hours are provided by the boiler the overall effect on the entire system is limited. On the economic side, the different types of considered solutions have strongly varying performances especially depending on the number of feasible operation hours, but also depending on the type of output energy (due to the different prices of heat and electricity). In terms of capital cost and payback period, the presence of PTC, ORC, and absorption chiller strongly affects the return on investment and the cost of production of energy to be sold to the network. The scaling effect, on the economy of the power station, depends mainly on the size of the ORC, independently of the configuration used, with evident variation between 150 and 300 kWel, but not so significant up to 1 MWel. Besides the economic convenience, which typically favours the simplest solutions (in particular the boiler for direct heat generation only), one has also to take into account energetic efficiency and the FLEXYNETS context, where the direct production of high temperature heat is not the most sustainable choice, due to the presence of heat pumps with their electricity consumptions.

The current investigation shows the wide number of possibilities for FLEXYNETS substations, focusing on their individual performances. A discussion from a system perspective is instead presented in Deliverable D3.2 of FLEXYNETS.

6 Literature reference

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5. Klein S. and et al, 2010. TRNSYS 17: A Transient System Simulation Program, Solar Energy Laboratory, University of Wisconsin. Solar Energy Laboratory, University of Wisconsin, Madison, USA.
6. Dott R., Haller M. Y., Ruschenburg J., Ochs F., Bony J., The reference framework for system simulations of the IEA SHC Task 44 / HPP Annex 38. Part B: Building and space heat load. A technical report of subtask C. Report C1 part B, IEA Solar Heating & Cooling Programme, 2013.
7. Widén, J. and E. Wäckelgård, A high-resolution stochastic model of domestic activity patterns and electricity demand. Applied Energy, 2010. 87: p. 1880-1892.
8. Birchall S., Wallis I., Churcher D., Pezzutto S., Fedrizzi R., Causse E., D2.1a Survay on the energy needs and architectural features of the EU building stock, iNSPiRe EU FP7 Project 2014, www.inspirefp7.eu 2014.

7 Annex I – Reference building boundary conditions

7.1 Building geometry

Table 48 – SFH main geometrical features.

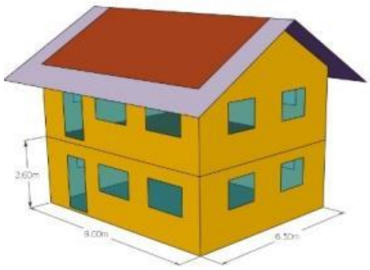
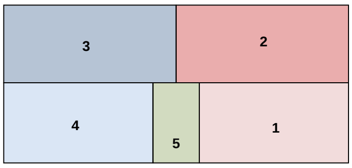
SFH	
Sketch and picture	 
Number of floors	2
Living area per floor	50 m^2
Ceiling/floor height	2,5 / 3,0
Building width /depth	6,5 / 8,0
Roof type and materials	Tilted (30°) saddle roof
Glazing ratio	20%

Table 49 – s-MFH main geometrical features.

s-MFH	
Sketch and picture	 
Zone / Floor	
Number of floors	3 to 7
Living area per dwelling	50 m^2
Number of dwelling per floor	2
Ceiling/floor height	2,5 / 3,0

Building width /depth	16,3 / 7,6 m
Roof type and materials	Flat concrete roof
Glazing ratio	20%

7.2 Internal gains

Internal gains are divided into occupational and electric (appliances + lighting).

7.2.1 Occupancy loads

For the occupancy, the sensible and latent heat follows the norm ISO 7730 where an activity of seated, very light writing is considered. Consequently, the sensible heat per person is 65 W, with a convective part of the 40%, and latent heat amounts to 55 W (which corresponds to a value of latent production 0.059 kg/h/person).

Table 50 – Buildings' occupancy.

Building typologies	Persons per dwelling [-]
SFH	4
s-MFH	3

For the SFH, a daily occupancy profile is used (Dott R. et al, 2013) while in the MFHs a yearly stochastic profile generated with the method developed by Widén at the University of Uppsala (Widén J. et al, 2010) is used. According to the dwelling area and number or people per dwelling, the average internal gain due to persons amounts to 1.18 W/m² for SFHs and 2.36 W/m² for s-MFHs.

7.2.2 Electric loads

Internal gains due to appliances are calculated taking into account the lighting and also the losses due to hot water of washing machine and dishwasher, dryer, cooking, cold water (e.g. Toilet water heated to room temperature), evaporation (towels, plants). It has been evaluated a value of 2100 kWh/dwelling/year due to electrical loads. From existing to renovated case, it has been assumed that the appliances consumption does not change, while the lighting is reduced by a half due to improved technologies' used (LED luminaires). The average value of internal gains along the year for the three building typologies is reported in the following table.

As for the occupancy, the appliances have been considered with a daily profile for the SFHs and with a stochastic profile for the MFHs.

Table 51 – Buildings' electric loads.

Building typologies	Area [m²]	Gain [W/m²]
SFH	97	2,4
s-MFH	50	4,8

7.2.3 DHW loads

According to the statistics, the DHW demand has been considered with a value of 21 kWh/m²a (Birchall S. et al., 2014). For the simulation, the DHW profiles have been generated using a stochastic generator software (Widén J. et al., 2010) both for SFH (one single profile) and for s-MFH (multiple profiles).

A tap water temperature oscillating between 8 and 12 °C along the year with a sinusoidal behaviour has been considered for all climates.

7.3 Infiltration and mechanical ventilation

Infiltration rate is strongly connected to the building airtightness and occupants' behaviour and it varies during the year. For the sake of simplicity, a fixed value through the day and the year is defined. Different values of infiltration rate have been defined by experience depending on the Climate and on the building energy level. For the different building typologies and efficiencies, the blower door test is assumed to provide the following infiltration n50 values. These values have to be divided by a factor of 20 before to use in dynamic simulations.

Table 52 – Infiltration rate n50 [1/h].

Location	SFH		s-MFH	
	EX	45	EX	45
London	3,0	1,5	3,0	1,0
Stuttgart	3,0	1,5	3,0	1,0
Rome	3,0	1,5	3,0	1,0

Mechanical ventilation in SFHs has been considered for all the buildings with an air rate of 0.40 1/h. No heat recovery has been considered for existing and new/renovated buildings of 45 kWh/(m²y).

7.4 Opaque and transparent structures

U-values for existing residential buildings (SFH and s-MFH) are derived from a survey on the EU-27 building stock within the framework of EU FP7 iNSPiRe project. Main outcomes of this analysis are summarized as follows:

- The residential building stock is largely dominated by SFHs, in particular detached.
- Among MFHs, low rise buildings cover the vast majority in particular in Mediterranean, Oceanic and Continental reference conditions.
- Most of SFH and s-MFH existing buildings are comprised between the period 1945-1970.

Table 53 – Weighted average U-value of wall and windows for SFH and s-MFH existing buildings ("EX").

Climate	Building typology	Avg U-value of wall [W/(m²K)]	Avg U-value of floor [W/(m²K)]	Avg U-value of roof [W/(m²K)]
London	SFH / s-MFH	1,8	1,6	2,0
Stuttgart	SFH / s-MFH	1,3	1,4	1,4

Rome	SFH / s-MFH	1,6	1,9	2,1

For the renovated/new cases, an insulation layer is added to the external surfaces (external walls, floors and roofs) in order to reach the energy level of 45 kWh/(m²y). The insulation layer is an EPS (expanse polystyrene) with good thermal properties summarized here below:

Table 54 – Thermo-physical properties of the insulation layer.

Thermal conductivity	λ	W/(mK)	0.039
Thermal capacity	cp	kJ/(kgK)	1.25
Density	ρ	kg/m³	30

The following tables summarize all the insulation thickness for SFHs and s-MFHs. For the SFHs it has been chosen to apply the insulation on the vertical surfaces (wall) on the roof and on the cellar (a SFH with cellar is always considered). In the numerical model, the cellar is not implemented, but the effect of the transmission losses through it is accounted for as a thermal bridge with the ground floor. The perimeter insulation in the table has been used to reduce this thermal bridge effect. The insulation has been considered only with respect to external walls and roof for the MFHs, while it is not considered between cellar and ground.

Table 55 – Insulation thickness for SFH and s-MFHs new/renovated buildings ("45").

Climate	Building typology	Wall [cm]	Roof [cm]	Ground [cm]	Perimeter [cm]
London	SFH	12,9	22,9	10,0	-
	s-MFH	4,0	4,0	-	-
Stuttgart	SFH	21,4	31,4	10,0	10,0
	s-MFH	8,0	8,0	-	-
Rome	SFH	12,0	18,0	-	-
	s-MFH	5,0	5,0	-	-

Three different levels of windows have been identified for new/renovated and existing buildings: good (3), medium (2) and poor (1). The poor window is supposed to be referred to the existing cases; the 2 and 3 are used for new/renovated residential buildings accordingly to the climatic conditions. Characteristics of the windows are reported in **Error! Reference source not found.**. By experience, a ypology of window has been assigned to the different buildings depending on the climate and energy level (see **Error! Reference source not found.**).

Table 56 – Window options.

Windows	Good (3)	Medium (2)	Poor-existing (1)
TRNSYS ID	13.007	2.304	1.002
Number of panes	3	2	2
g / [-]	0,584	0,622	0,755
U_g / [W/(m²K)]	0,59	1,40	2,83
U_f / [W/(m²K)]	2,87	3,34	4,20
Uf_{TRNSYS} /[kJ/(hm²K)]	10,34	27,82	52,87

Table 57 – Window typologies for different boundary conditions (new/renovated building "45").

Climate	Building typology	Window typology
London	SFH	3
	s-MFH	2
Stuttgart	SFH	3
	s-MFH	2
Rome	SFH	2
	s-MFH	2

7.5 Shading devices

Shading devices have a strong influence in cooling demands. The position (internal or external), the shading factor, and the strategy of shading determine a high or low cooling demand both for warm and cold climates. Here it is presented the strategy adopted for residential buildings and offices. In Southern Europe, external shading is commonly used both for single and multi-family houses, while buildings in Northern and Central Europe rarely are equipped with external shading. Despite that, for residential new/renovated buildings external shading is assumed for all the climates because of the not negligible solar gains contribution. The shadings of the reveals are not considered in this study.

A common shading factor of 0.3 has been used for all the locations that means when activated: total solar irradiation is 70% blocked when the shadings are activated. The shading system is activated when the following conditions are all verified for both SFH ands- MFH:

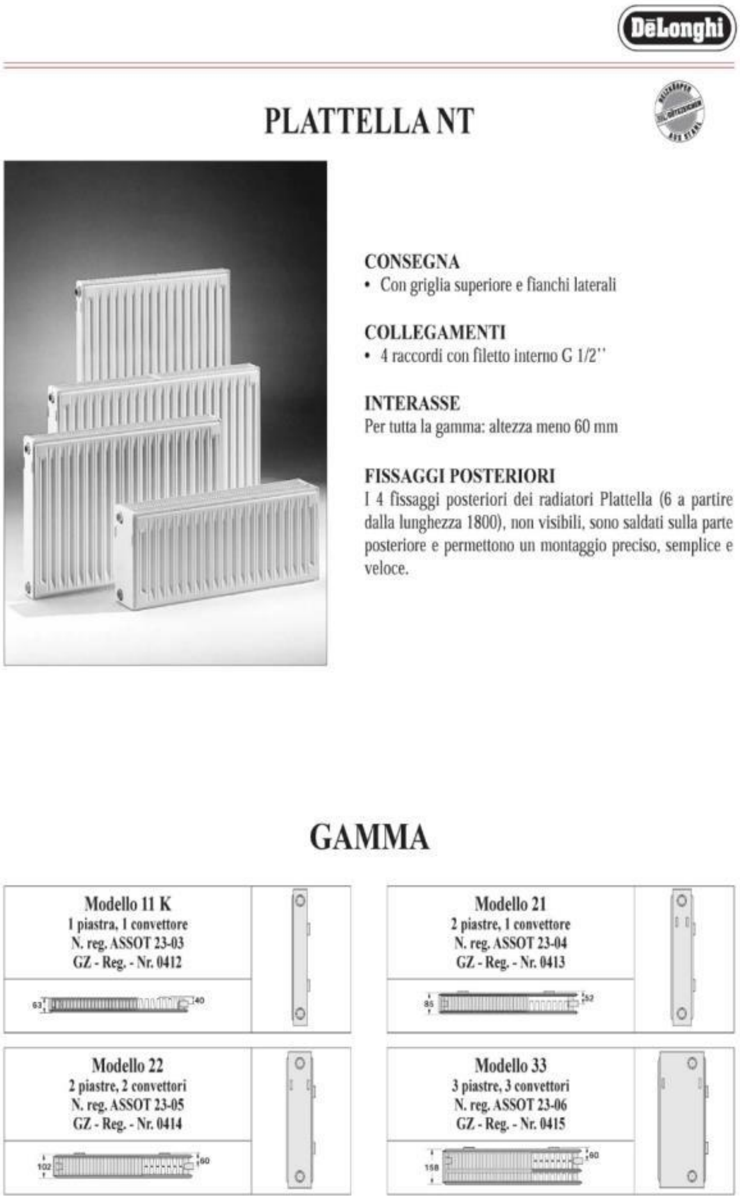
- Horizontal global irradiation greater than 300 W/m² (shades removed if < 250 W/m²);
- Room temperature greater than 24 °C (shades removed if < 23 °C);
- 24-hour moving average ambient temperature greater than 12 °C.

The beam irradiation is used as a parameter assuming that users close the manual external shadings, when the sun is directly entering the windows on the specific façade.

8 Annex II – Distribution units' performance

This annex is a collection of the datasheets for the distribution unit (radiators and radiant ceilings) adopted for the numerical modelling.

8.1 Radiators


DēLonghi

PLATTELLA NT

CONSEGNA
- Con griglia superiore e fianchi laterali

COLLEGAMENTI
- 4 raccordi con filetto interno G 1/2''

INTERASSE
Per tutta la gamma: altezza meno 60 mm

FISSAGGI POSTERIORI
I 4 fissaggi posteriori dei radiatori Plattella (6 a partire dalla lunghezza 1800), non visibili, sono saldati sulla parte posteriore e permettono un montaggio preciso, semplice e veloce.

GAMMA

Modello 11 K
1 piastra, 1 convettore
N. reg. ASSOT 23-03
GZ - Reg. - Nr. 0412

Modello 21
2 piastre, 1 convettore
N. reg. ASSOT 23-04
GZ - Reg. - Nr. 0413

Modello 22
2 piastre, 2 convettori
N. reg. ASSOT 23-05
GZ - Reg. - Nr. 0414

Modello 33
3 piastre, 3 convettori
N. reg. ASSOT 23-06
GZ - Reg. - Nr. 0415

Figure 82 – Datasheet of radiator used for the calculations (mod. 21), by manufacturer manuals (DeLonghi) – part 1 main page.

Altezza (H) 900

	10	11	20	21	22	30	32	33
Profondità	62 mm	62 mm	69 mm	85 mm	102 mm	159 mm	159 mm	159 mm
Esponente n	1,292	1,291	1,270	1,334	1,346	1,319	1,348	1,350
Lunghezza (L mm)								
400	350	569	543	796	921	766	943	1.320
500	438	711	679	995	1.151	958	1.178	1.650
600	526	853	815	1.193	1.382	1.149	1.414	1.980
700	613	995	950	1.392	1.612	1.341	1.649	2.310
800	701	1.137	1.086	1.591	1.842	1.533	1.886	2.640
900	789	1.280	1.222	1.790	2.072	1.724	2.121	2.970
1.000	876	1.422	1.358	1.989	2.303	1.916	2.357	3.300
1.100	964	1.564	1.493	2.188	2.533	2.107	2.592	3.630
1.200	1.051	1.706	1.629	2.387	2.763	2.299	2.828	3.959
1.400	1.227	1.990	1.901	2.785	3.224	2.682	3.300	4.619
1.600	1.402	2.275	2.172	3.182	3.684	3.065	3.771	5.279
1.800	1.577	2.559	2.444	3.580	4.145	3.448	4.242	5.939
2.000	1.752	2.843	2.715	3.978	4.605	3.832	4.714	6.599
2.300	2.015	3.270	3.122	4.575	5.296	4.406	5.420	7.589
2.600	2.278	3.696	3.530	5.171	5.987	4.981	6.127	8.579
3.000	2.629	4.265	4.073	5.967	6.908	5.747	7.070	9.899

75/65-20
Politecnico di Milano

Figure 83 – Datasheet of radiator used for the calculations (mod. 21), by manufacturer manuals (DeLonghi) – part 2 performance data.

8.2 Radiant ceiling

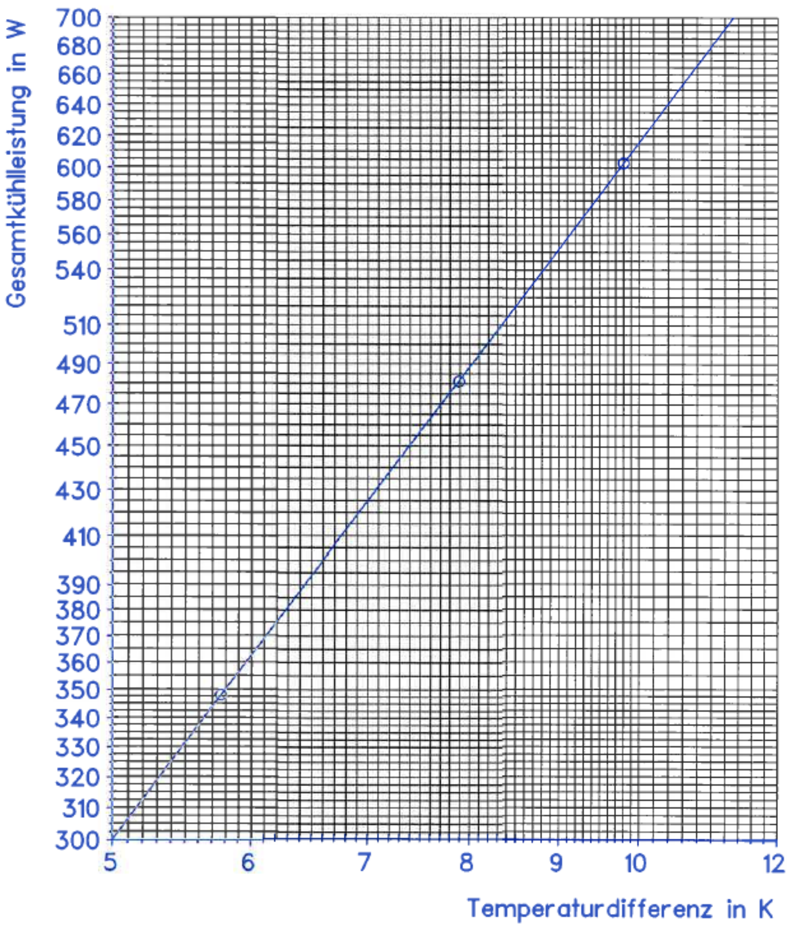


Figure 84 – Characteristic curve of the radiant ceiling TRIPAN®.

9 Annex III – Heat exchangers' performance

SWEP
A DOVER COMPANY

SSP G7
(v 7.0.3.39)

SINGLE PHASE - Performance
Heat Exchanger : B15Tx43/3P

Fluid Side 1 : Di EthyleneGlycol-Water (10,0 %)
Fluid Side 2 : Ethylene Glycol - Water (10,0 %)

Flow Type : Counter-Current

DUTY REQUIREMENTS		**Side 1**		**Side 2**
Heat load	kW		28,89	
Inlet temperature	°C	90,00		30,00
Outlet temperature	°C	35,79		85,01
Flow rate	kg/s	0,1300		0,1300
Max. pressure drop	kPa	50,0		50,0
Thermal length		10,08		10,23

PLATE HEAT EXCHANGER		**Side 1**		**Side 2**
Total heat transfer area	m²		1,39	
Heat flux	kW/m²		20,7	
Mean temperature difference	K		5,38	
O.H.T.C. (available/required)	W/m²,°C		3850/3850	
Pressure drop -total*	kPa	20,3		20,2
- in ports	kPa	0,200		0,198
Port diameter	mm	16,0		16,0
Number of channels		7		7
Number of plates			43	
Oversurfacing	%		0	
Fouling factor	m²,°C/kW		0,000	
Reynolds number		1122		884,0
Port velocity	m/s	0,654		0,647

PHYSICAL PROPERTIES		**Side 1**		**Side 2**
Reference temperature	°C	62,89		57,50
Dynamic viscosity	cP	0,473		0,600
Dynamic viscosity - wall	cP	0,489		0,577
Density	kg/m³	989,1		999,1
Heat capacity	kJ/kg,°C	4,100		4,040
Thermal conductivity	W/m,°C	0,6038		0,5902
Min. fluid temperature at wall	°C	33,36		
Max. fluid temperature at wall	°C			87,29
Film coefficient	W/m²,°C	9190		8440
Minimum wall temperature	°C	60,49		60,15
Channel velocity	m/s	0,134		0,133
Shear stress	Pa	15,5		15,4

Figure 85 – DHW heat exchanger datasheet.

10 Annex IV – Energetic results

- Energy

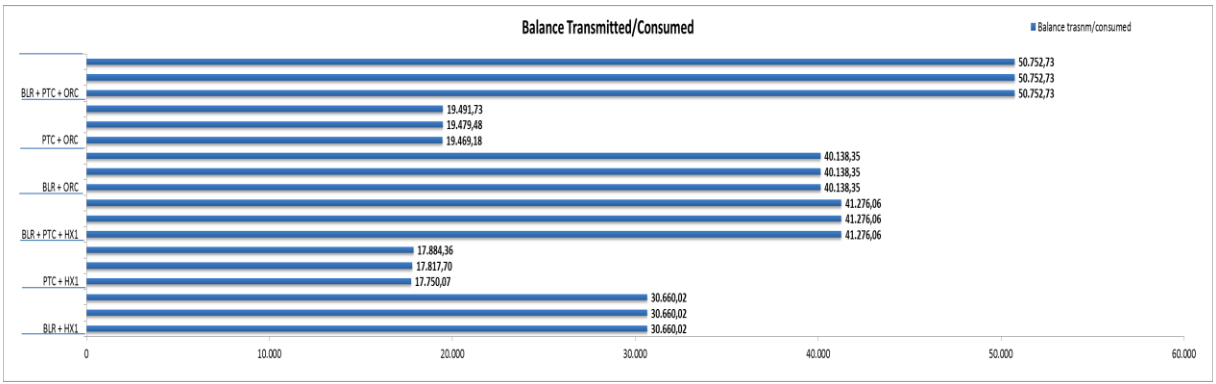


Figure 86 – Balance between energy transmitted to the network and electricity consumed

- Primary Energy

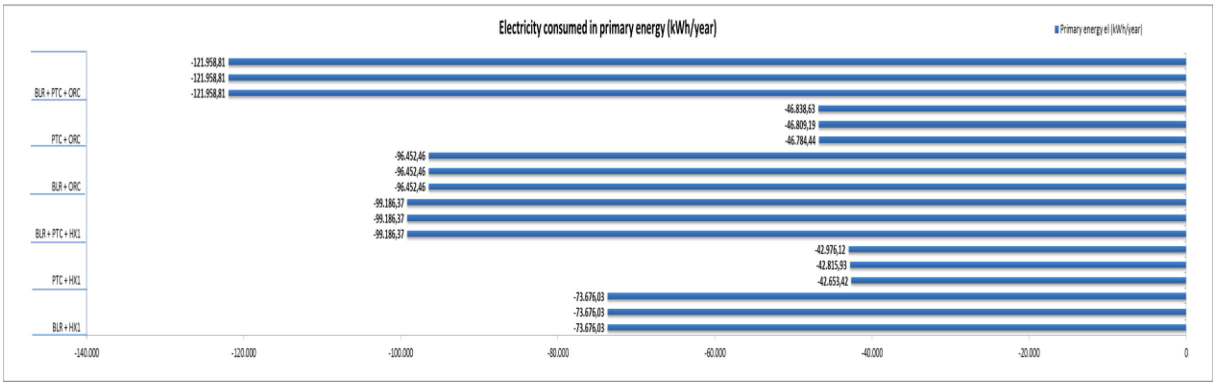


Figure 87 – Electricity consumed in primary energy according to Spanish mix

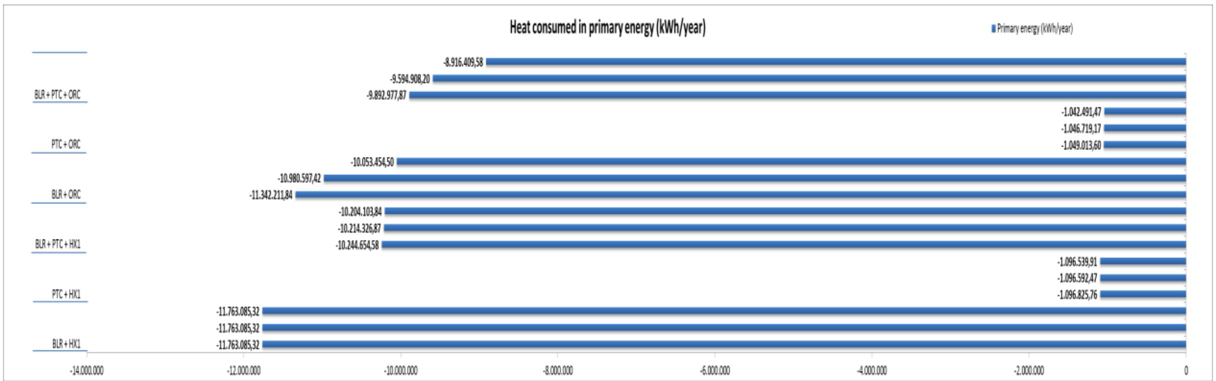


Figure 88 – Heat produced in primary energy according to Spanish mix

11 Annex V – LCOE in function of scaling

Solution	BLR+ORC @ 150 kWel		
Temp	20ºC	25ºC	30ºC
LCOE total mix	0,1896	0,1926	0,2018
LCOE elect partial	0,0452	0,0456	0,0465
LCOE therm partial	0,0365	0,0368	0,0378

Solution	PTC+ORC @ 150 kWel		
Temp	20ºC	25ºC	30ºC
LCOE total mix	0,6152	0,6222	0,6342
LCOE elect partial	0,1288	0,1289	0,1291
LCOE therm partial	0,1065	0,1068	0,1073

Solution	PTC+BLR+ORC @ 150 kWel		
Temp	20ºC	25ºC	30ºC
LCOE total mix	0,2287	0,2332	0,2445
LCOE elect partial	0,0534	0,3897	0,0552
LCOE therm partial	0,0433	0,0438	0,0451

Solution	BLR+ORC @ 300 kWel		
Temp	20ºC	25ºC	30ºC
LCOE total mix	0,1025	0,1044	0,1099
LCOE elect partial	0,0245	0,0247	0,0253
LCOE therm partial	0,0198	0,0200	0,0206

Solution	PTC+ORC @ 300 kWel		
Temp	20ºC	25ºC	30ºC
LCOE total mix	0,4986	0,5043	0,5140
LCOE elect partial	0,1044	0,1045	0,1046
LCOE therm partial	0,0863	0,0865	0,0869

Solution	PTC+BLR+ORC @ 300 kWel		
Temp	20ºC	25ºC	30ºC
LCOE total mix	0,1503	0,1538	0,1629
LCOE elect partial	0,0351	0,3185	0,0368
LCOE therm partial	0,0284	0,0289	0,0300

Solution	BLR+ORC @ 600 kWel		
Temp	20ºC	25ºC	30ºC
LCOE total mix	0,0642	0,0657	0,0700
LCOE elect partial	0,0153	0,0155	0,0161
LCOE therm partial	0,0124	0,0126	0,0131

Solution	PTC+ORC @ 600 kWel		
Temp	20ºC	25ºC	30ºC
LCOE total mix	0,4776	0,4830	0,4923
LCOE elect partial	0,1000	0,1001	0,1002
LCOE therm partial	0,0827	0,0829	0,0833

Solution	PTC+BLR+ORC @ 600 kWel		
Temp	20ºC	25ºC	30ºC
LCOE total mix	0,1167	0,1200	0,1285
LCOE elect partial	0,0273	0,3024	0,0290
LCOE therm partial	0,0221	0,0226	0,0237

Solution	BLR+ORC @ 1000 kWel		
Temp	20ºC	25ºC	30ºC
LCOE total mix	0,0480	0,0492	0,0529
LCOE elect partial	0,0114	0,0116	0,0122
LCOE therm partial	0,0092	0,0094	0,0099

Solution	PTC+ORC @ 1000 kWel		
Temp	20ºC	25ºC	30ºC
LCOE total mix	0,4622	0,4674	0,4764
LCOE elect partial	0,0968	0,0968	0,0970
LCOE therm partial	0,0800	0,0802	0,0806

Solution	PTC+BLR+ORC @ 1000 kWel		
Temp	20ºC	25ºC	30ºC
LCOE total mix	0,1022	0,1054	0,1136
LCOE elect partial	0,0239	0,2923	0,0257
LCOE therm partial	0,0193	0,0198	0,0209

12 Annex VI – Simulation calculations per country

- PBT

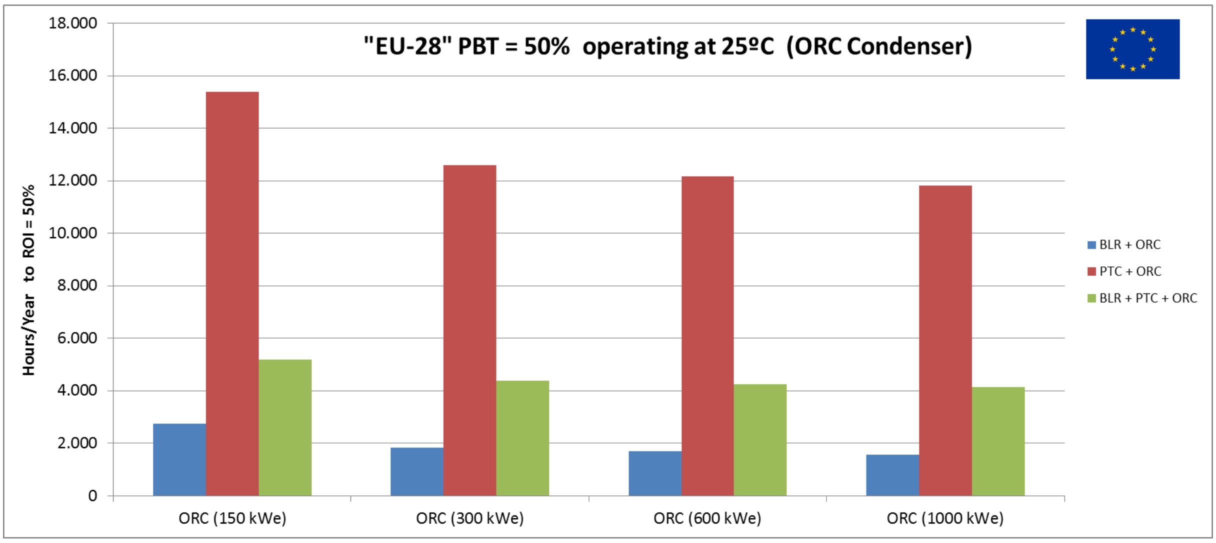


Figure 89 – PBT for EU28 in function of ORC scaling

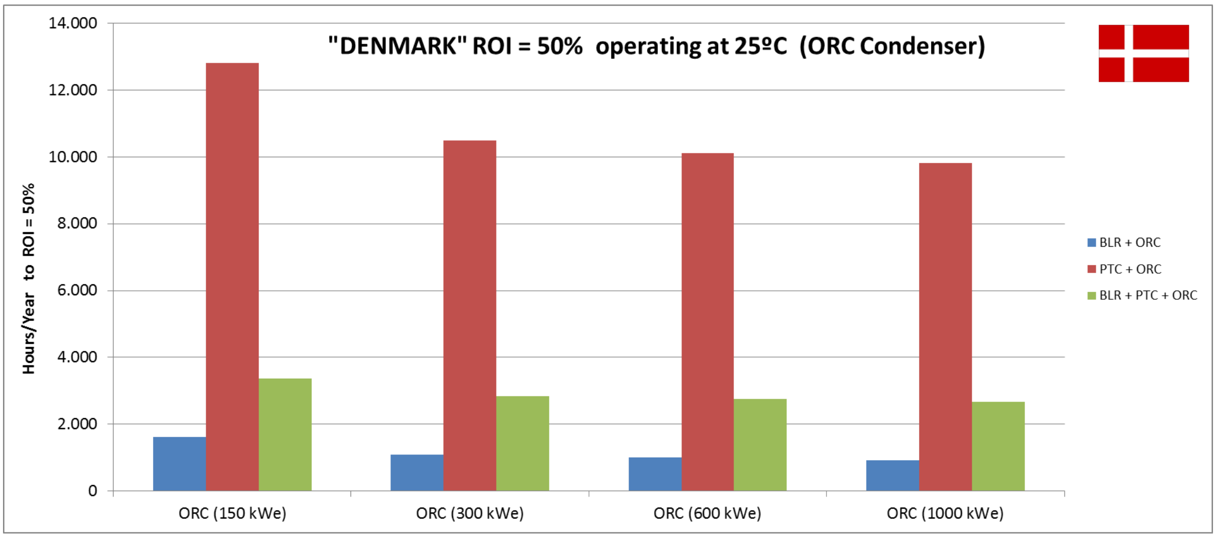


Figure 90 – PBT for Denmark in function of ORC scaling

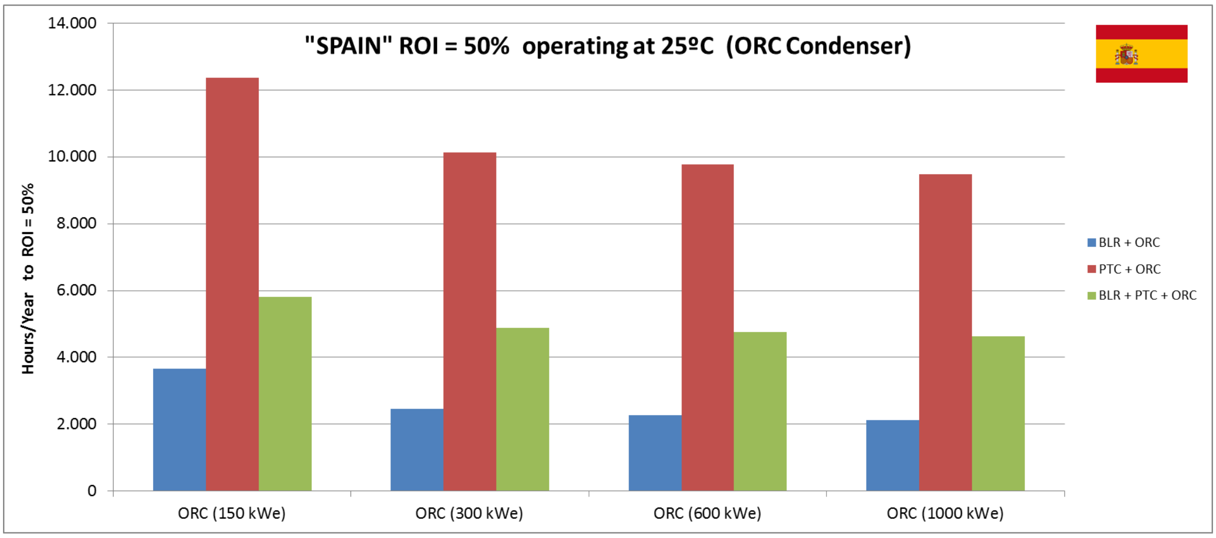


Figure 91 – PBT for SPAIN in function of ORC scaling

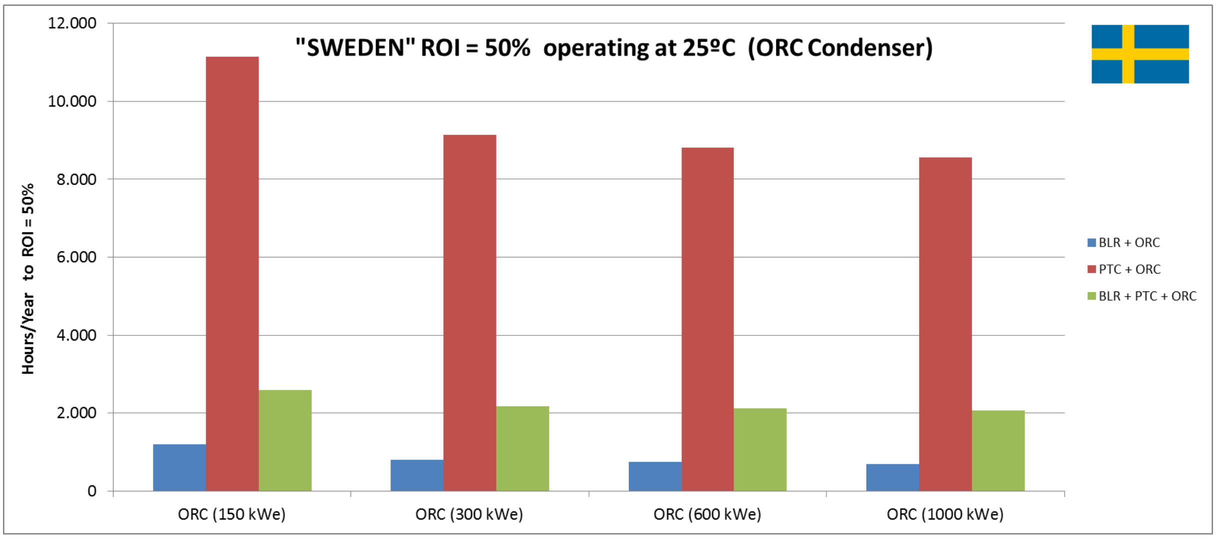


Figure 92 – PBT for SWEDEN in function of ORC scaling

- LCOE

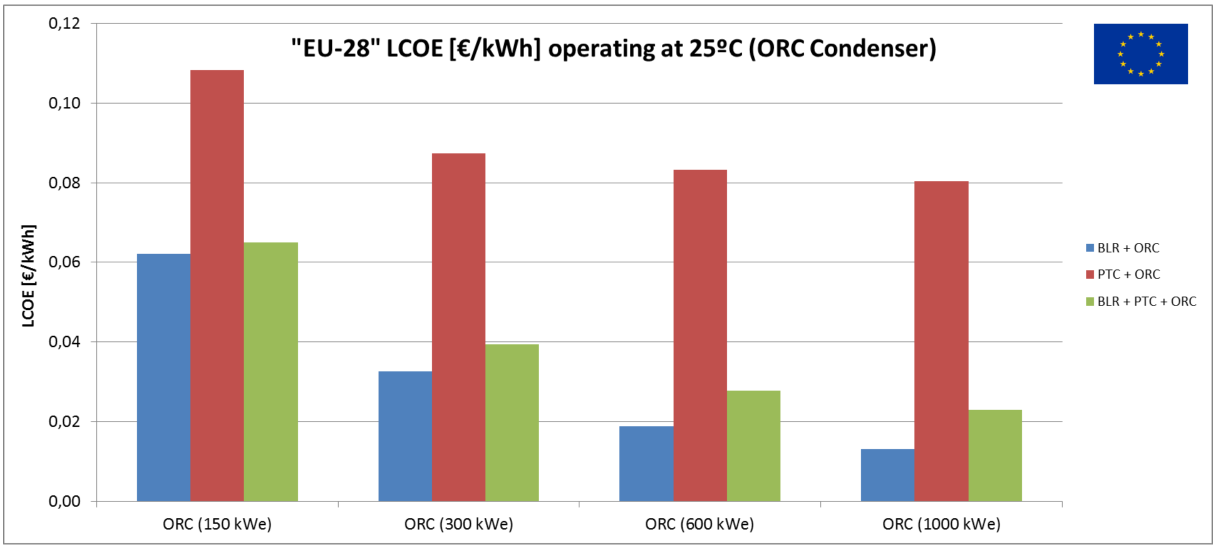


Figure 93 – LCOE for EU28 in function of ORC scaling

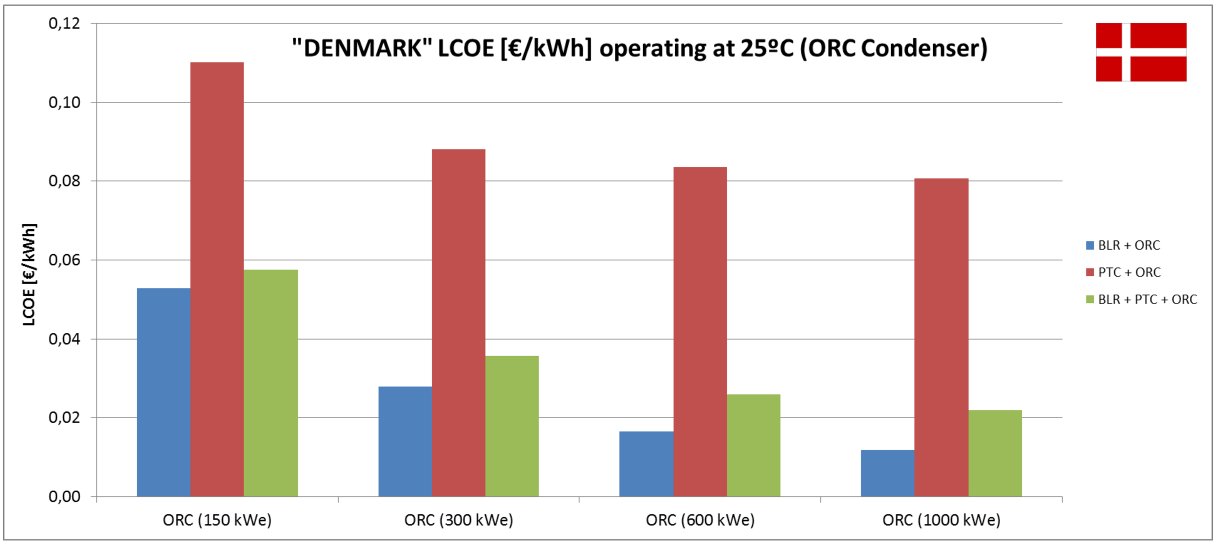


Figure 94 – LCOE for DENMARK in function of ORC scaling

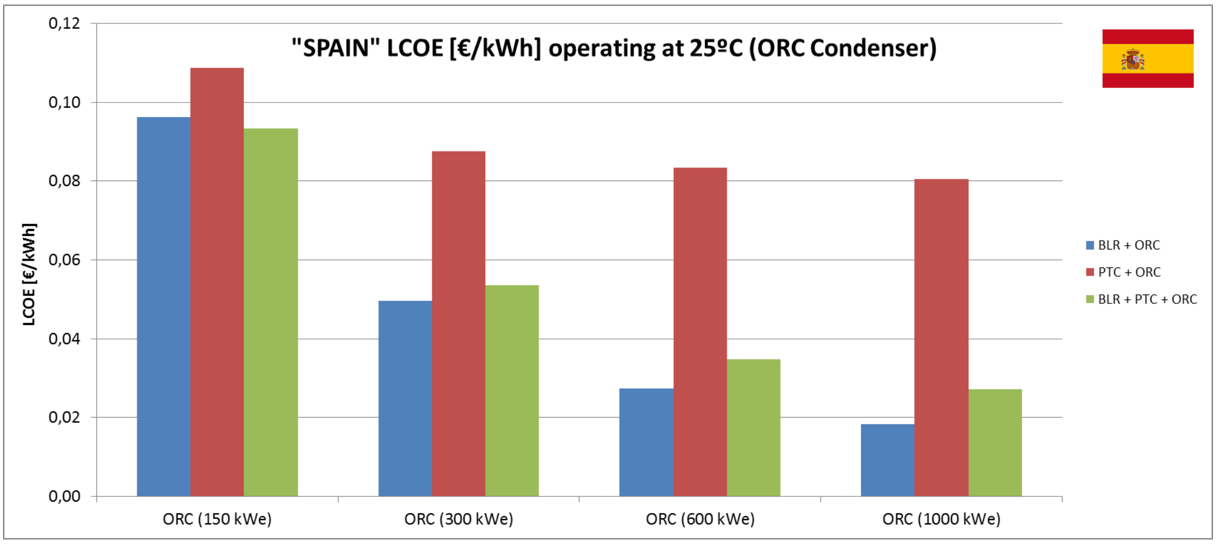


Figure 95 – LCOE for SPAIN in function of ORC scaling

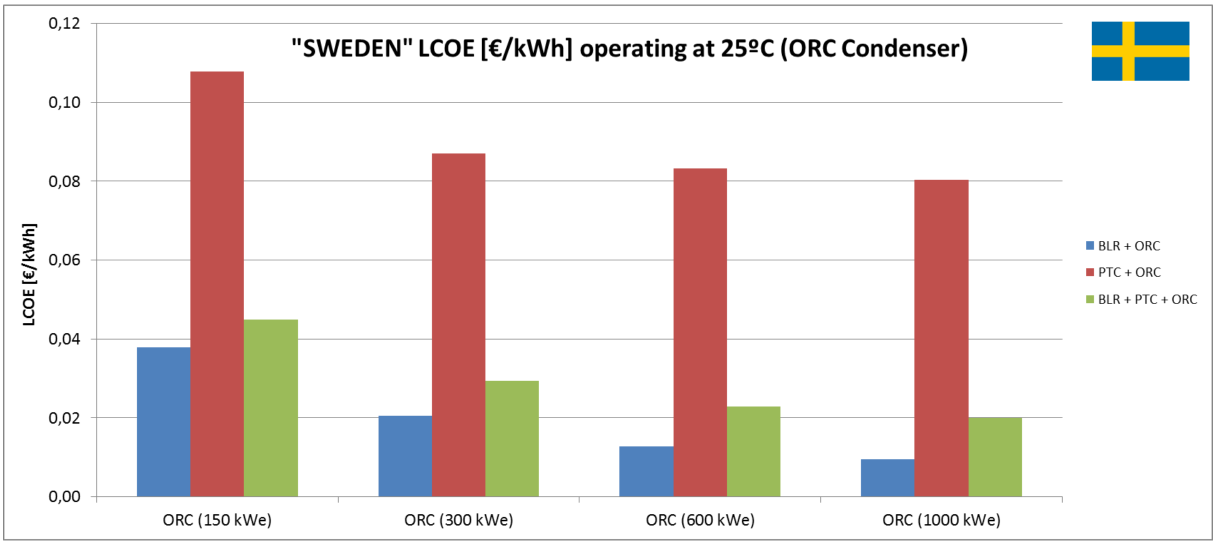


Figure 96 – LCOE for SWEDEN in function of ORC scaling

- IRR

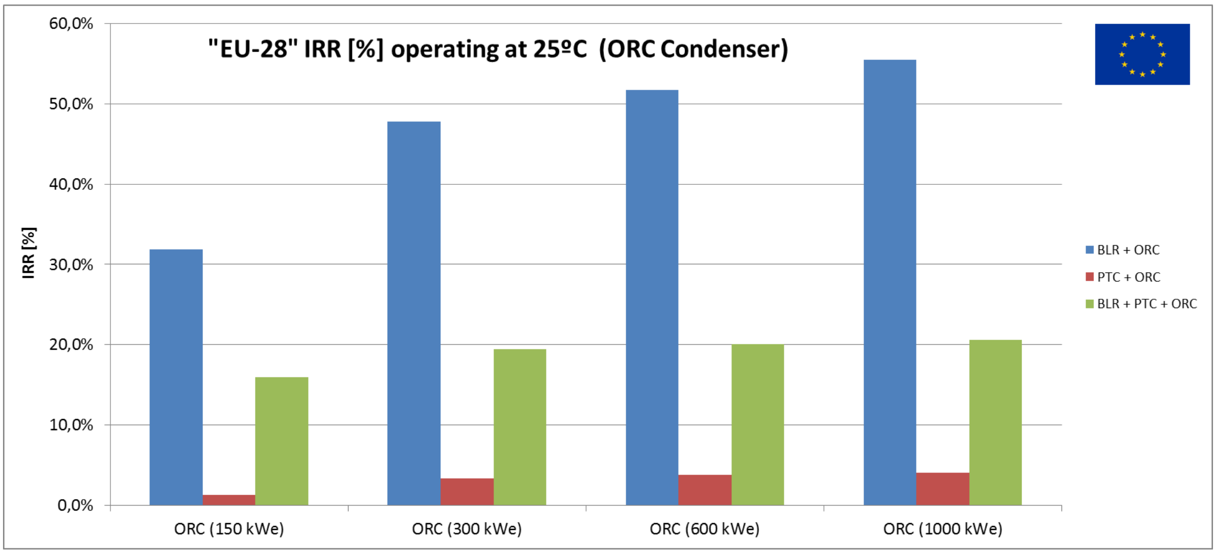


Figure 97 – IRR for EU28 in function of ORC scaling

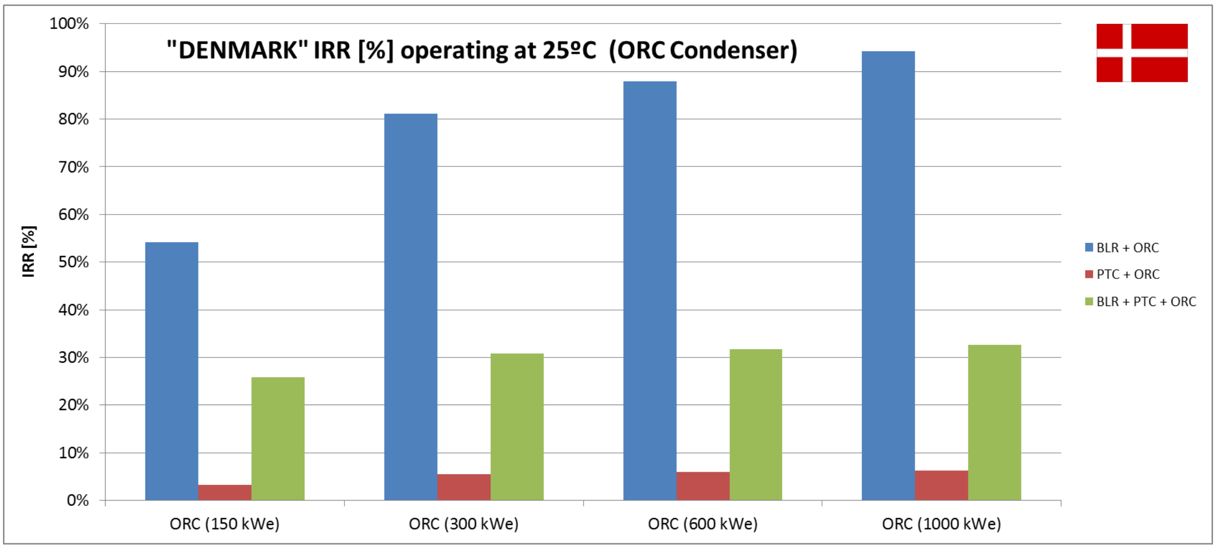


Figure 98 – IRR for DENMARK in function of ORC scaling

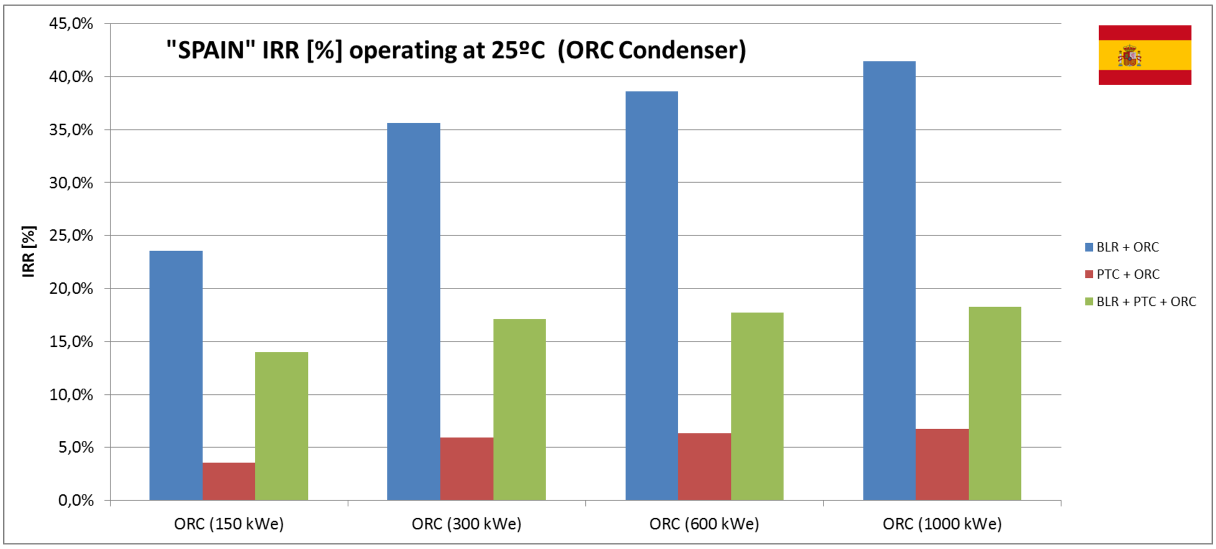


Figure 99 – IRR for SPAIN in function of ORC scaling

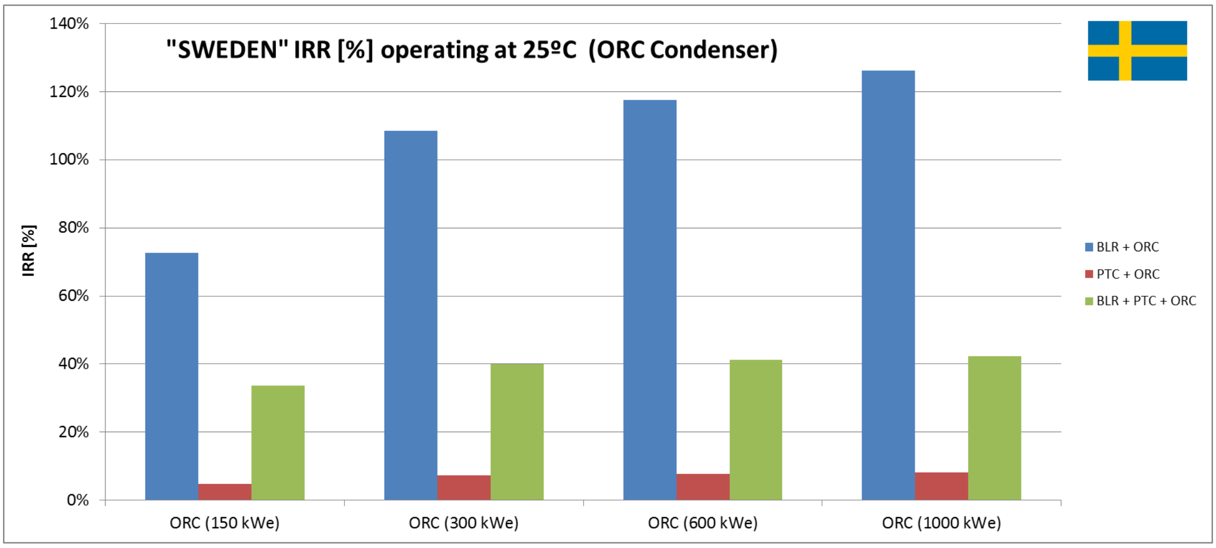


Figure 100 – IRR for SWEDEN in function of ORC scaling

- LCOE

300 kWe	BLR + ORC (25ºC)			
	EU-28	Denmark	Spain	Sweden
LCOE total mix	0,1706	0,1462	0,2597	0,1071
LCOE elect partial	0,0403	0,0346	0,0614	0,0253
LCOE therm partial	0,0326	0,0280	0,0497	0,0205

300 kWe	PTC + ORC (25ºC)			
	EU-28	Denmark	Spain	Sweden
LCOE total mix	0,5087	0,5140	0,5101	0,5073

LCOE elect partial	0,1054	0,1065	0,1057	0,1051
LCOE therm partial	0,0873	0,0882	0,0876	0,0871

300 kWe	PTC + BLR + ORC (25ºC)			
	EU-28	Denmark	Spain	Sweden
LCOE total mix	0,2102	0,1905	0,2854	0,1566
LCOE elect partial	0,3315	0,3270	0,3489	0,3191
LCOE therm partial	0,0395	0,0358	0,0536	0,0294

600 kWe	BLR + ORC (25ºC)			
	EU-28	Denmark	Spain	Sweden
LCOE total mix	0,0988	0,0866	0,1433	0,0671
LCOE elect partial	0,0234	0,0205	0,0339	0,0159
LCOE therm partial	0,0189	0,0166	0,0274	0,0128

600 kWe	PTC + ORC (25ºC)			
	EU-28	Denmark	Spain	Sweden
LCOE total mix	0,4852	0,4879	0,4860	0,4845
LCOE elect partial	0,1005	0,1011	0,1007	0,1004
LCOE therm partial	0,0833	0,0837	0,0834	0,0832

600 kWe	PTC + BLR + ORC (25ºC)			
	EU-28	Denmark	Spain	Sweden
LCOE total mix	0,1482	0,1384	0,1858	0,1214
LCOE elect partial	0,3089	0,3066	0,3176	0,3027
LCOE therm partial	0,0278	0,0260	0,0349	0,0228

1000 kWe	BLR + ORC (25ºC)			
	EU-28	Denmark	Spain	Sweden
LCOE total mix	0,0691	0,0617	0,0958	0,0500
LCOE elect partial	0,0163	0,0146	0,0227	0,0118
LCOE therm partial	0,0132	0,0118	0,0183	0,0096

1000 kWe	PTC + ORC (25ºC)			
	EU-28	Denmark	Spain	Sweden
LCOE total mix	0,4688	0,4703	0,4692	0,4683
LCOE elect partial	0,0971	0,0974	0,0972	0,0970

LCOE therm partial	0,0804	0,0807	0,0805	0,0804

1000 kWe	PTC + BLR + ORC (25ºC)			
	EU-28	Denmark	Spain	Sweden
LCOE total mix	0,1223	0,1164	0,1448	0,1062
LCOE elect partial	0,2962	0,2948	0,3014	0,2925
LCOE therm partial	0,0230	0,0219	0,0272	0,0200

13 Annex VII – Main sub-stations P&ID

- Domestic sub station

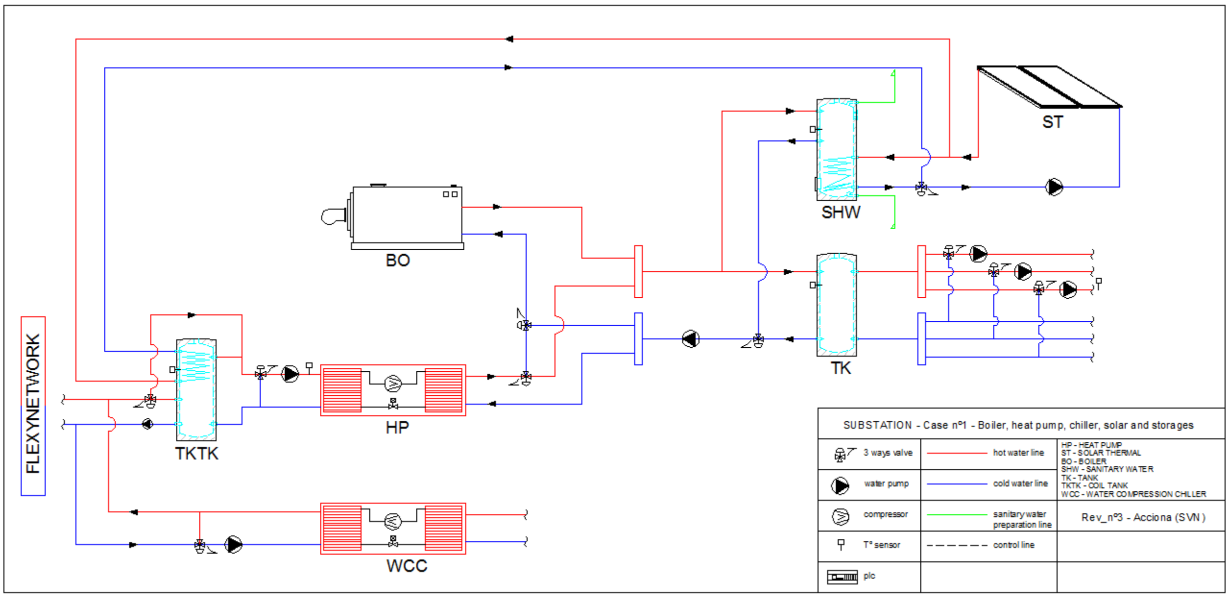


Figure 101 – Global P&ID for 2 pipes domestic sub-station

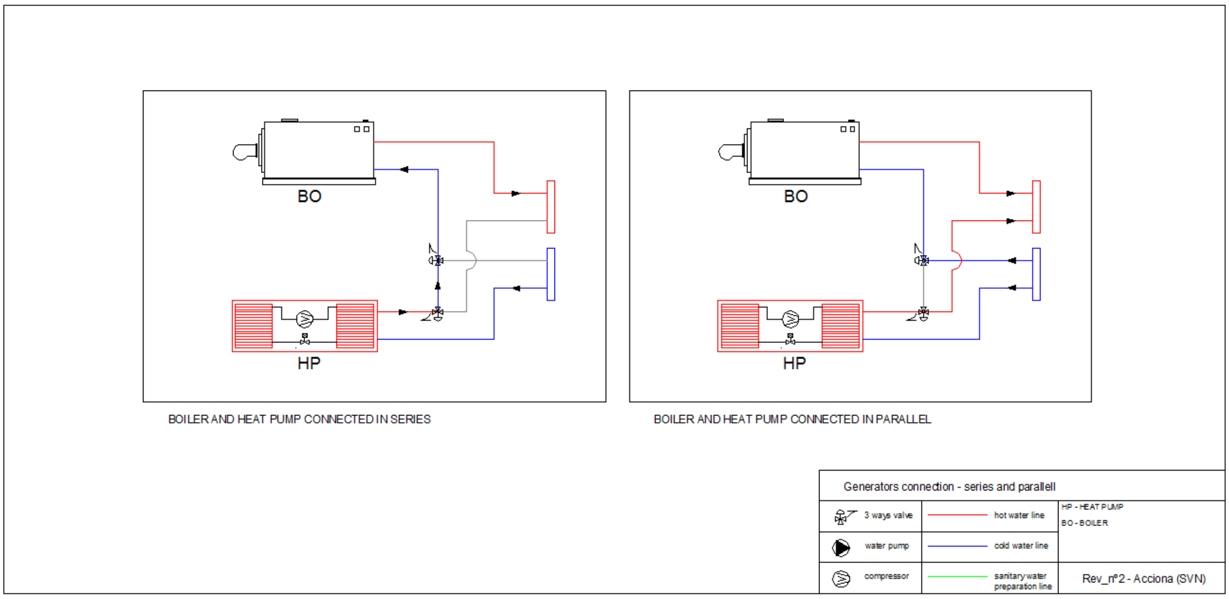


Figure 102 – Detail of connection boiler with HP

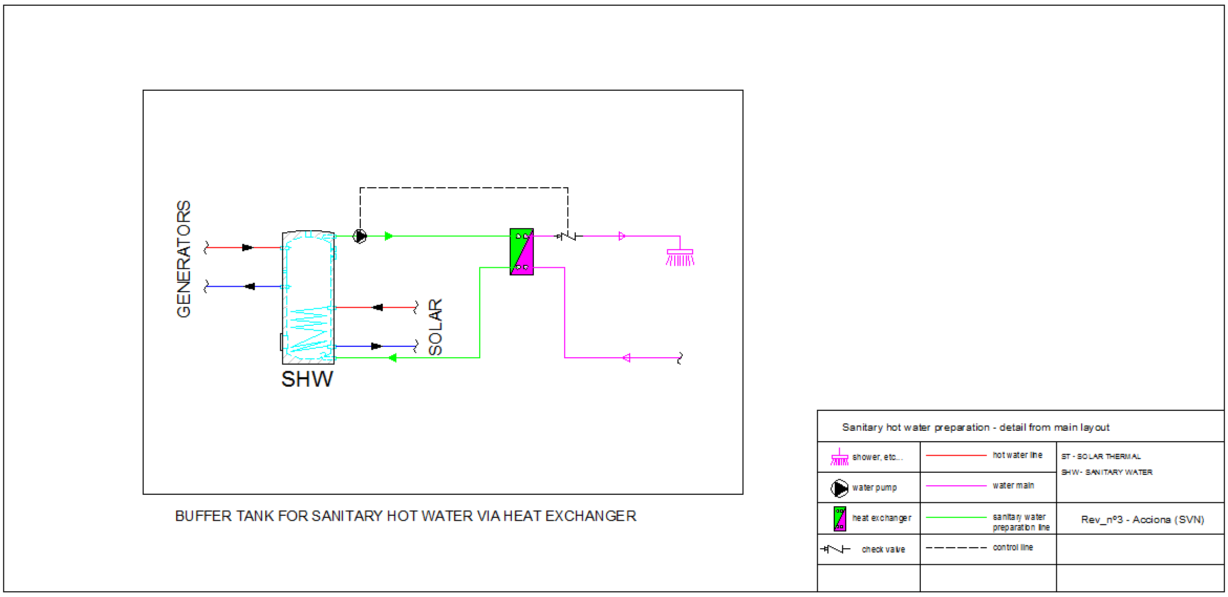


Figure 103 – Detail of SHW production

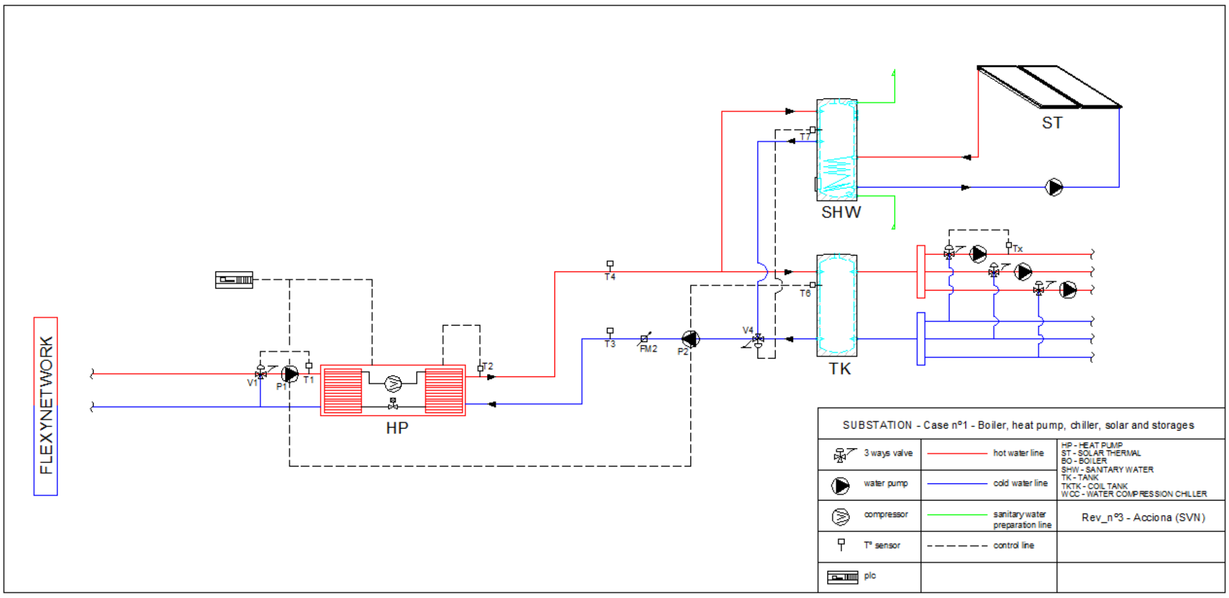


Figure 104 – Simplified lay-out for software implementation (2 pipes HP)

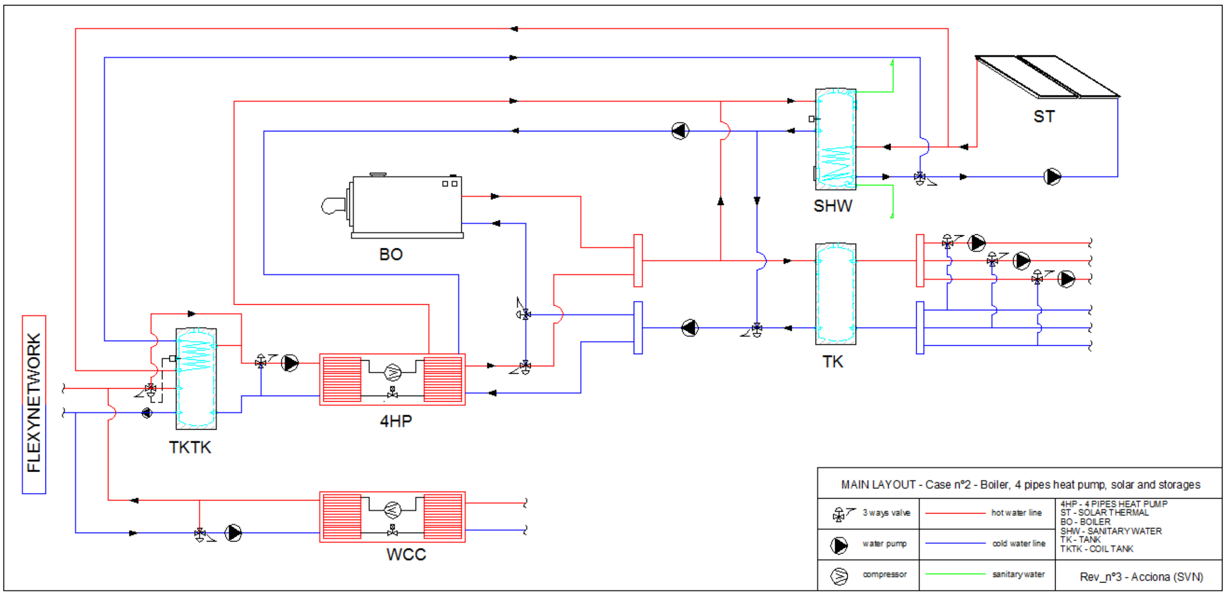


Figure 105 – Global P&ID for 4 pipes domestic sub-station

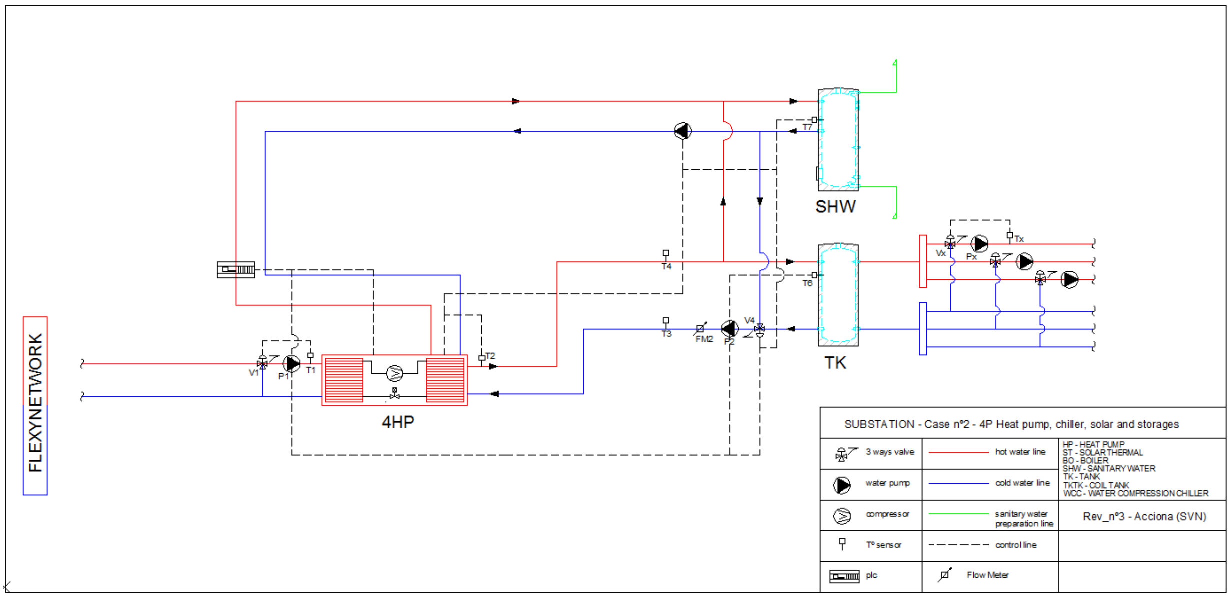


Figure 106 – Simplified lay-out for software implementation (4 pipes HP)

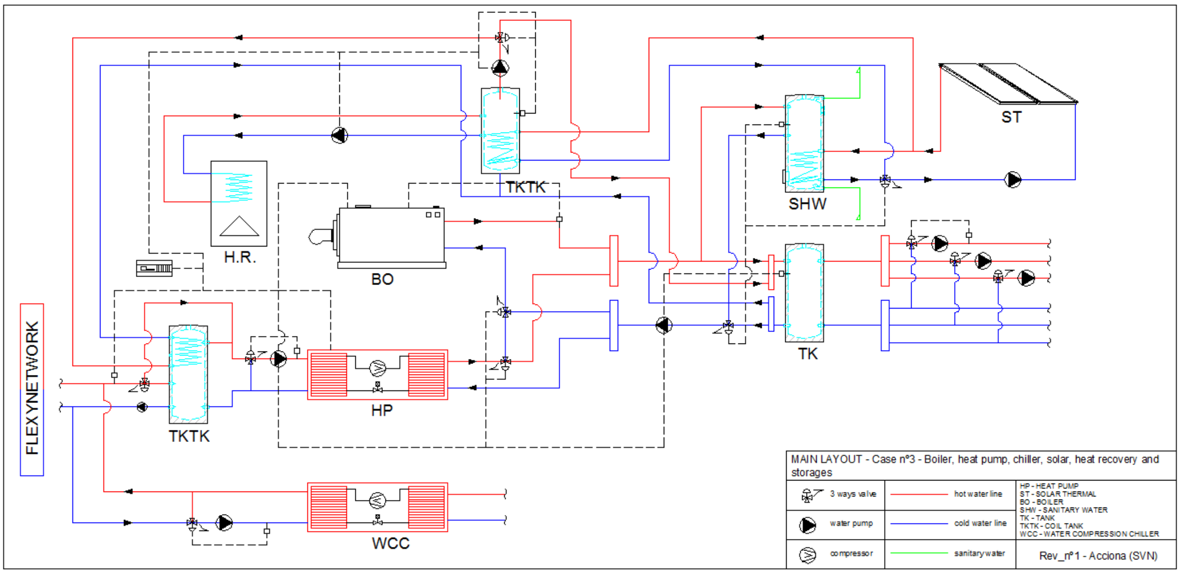


Figure 107 – Global P&ID for 4 pipes domestic sub-station with heat recovery

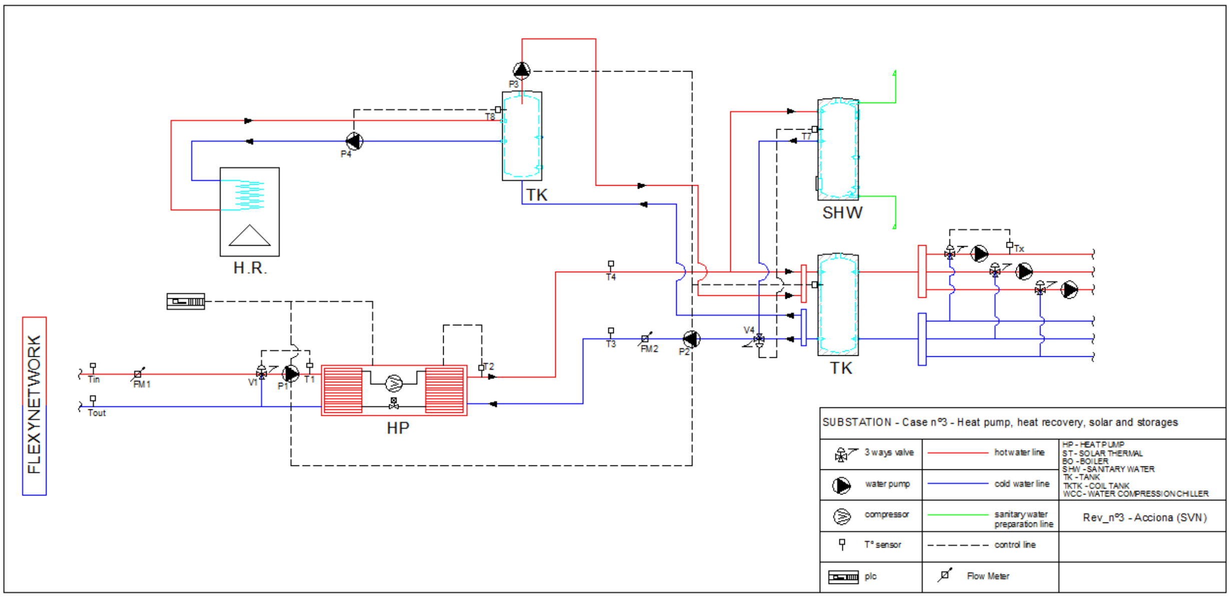


Figure 108 – Simplified lay-out for software implementation (4 pipes HP with HR)

- PowerStation

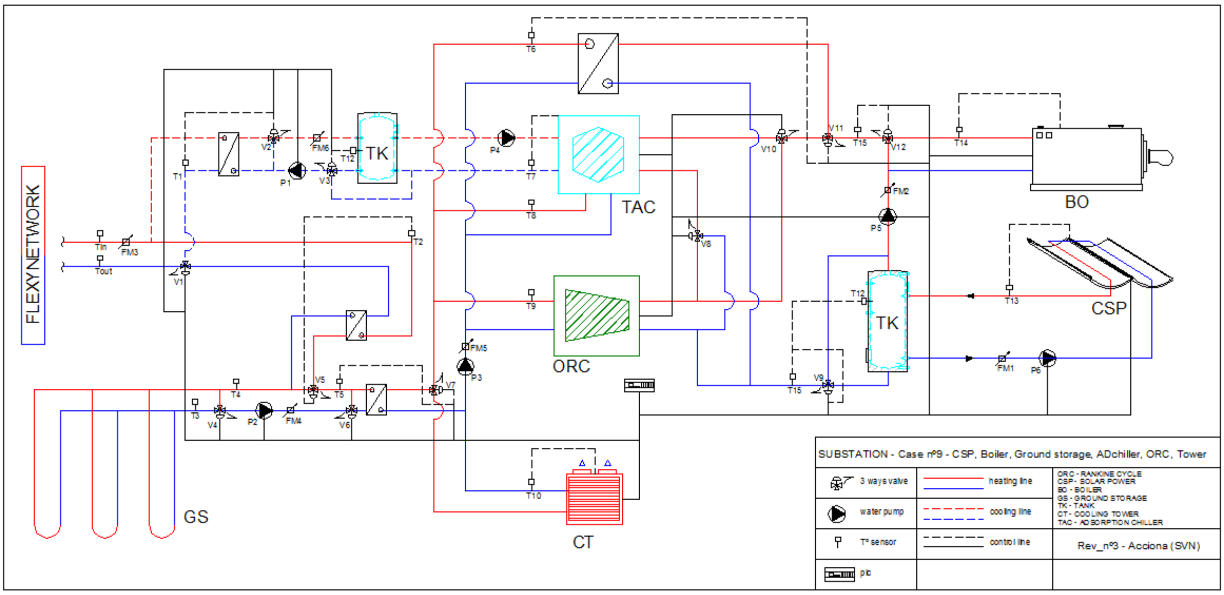


Figure 109 – Global P&ID for thermal powerstation

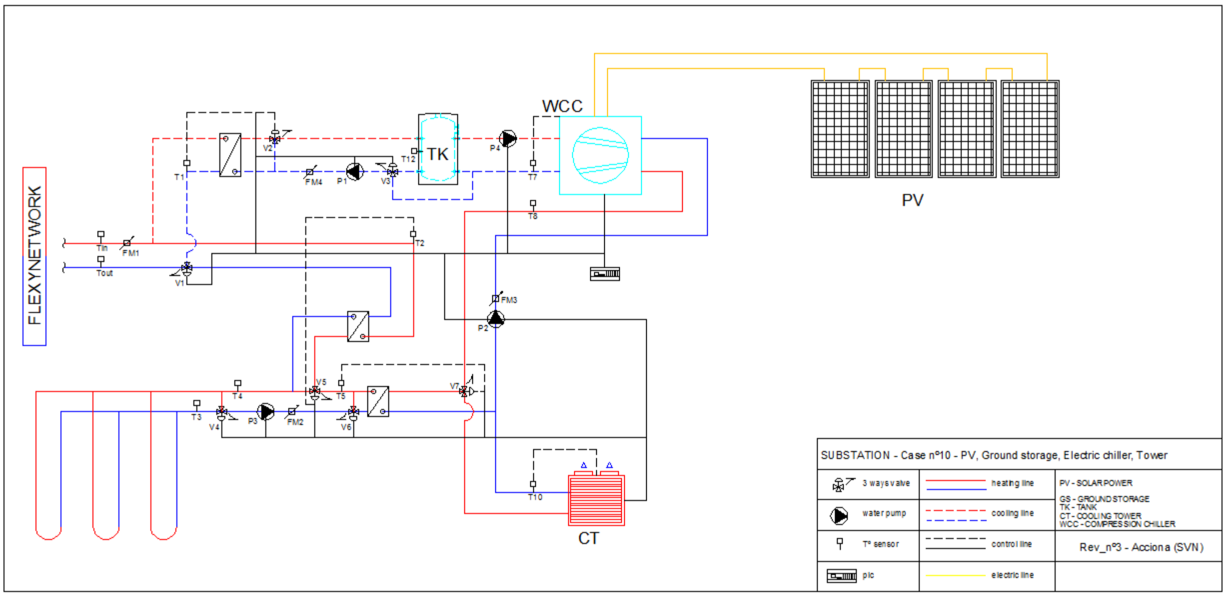


Figure 110 – Global P&ID for PV powerstation

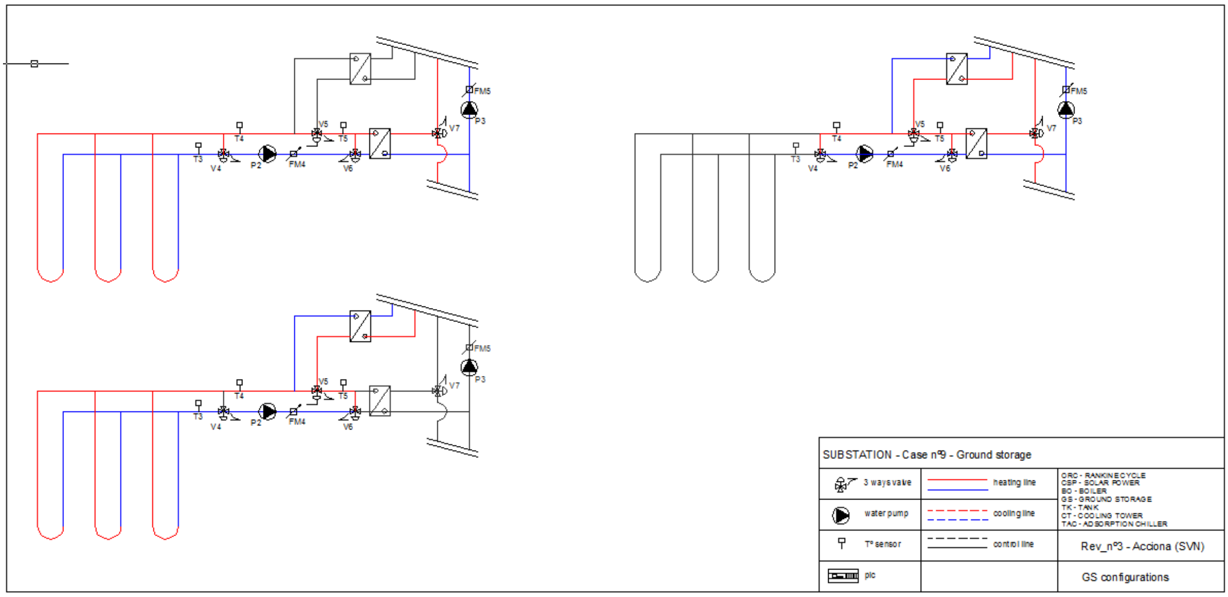


Figure 111 – Details of operation of the ground storage and network connection