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W.E. DISTRICT
Heating & cooling solutions

D5.8

Virtual demo designs

AUTHORS : ACCIONA

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Technical References

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[1] PU = Public
PP = Restricted to other programme participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

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Document history

V	Date	Author (Beneficiary)	Description
V0.1	23/11/2021	M.Victoria Cambronero (ACC)	Workshop report structure and main contents
V0.2	19/04/2021	M.Victoria Cambronero (ACC)	D5.8 structure
V0.3	02/11/2022	Christophe Saint-sardos (ACC)	D5.8 structure update
V1	15/12/2022	Christophe Saint-sardos (ACC)	Compilation of all studies and contributions.
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V3	24/01/2023	Alberto Abánades Velasco (UPM)	Peer Reviewing
V4	01/02/2023	Christophe Saint-sardos (ACC)	Integration of review comments. Final version for submission.
V5	07/02/2023	Christophe Saint-sardos (ACC)	Correction of references requested by the Project Officer.

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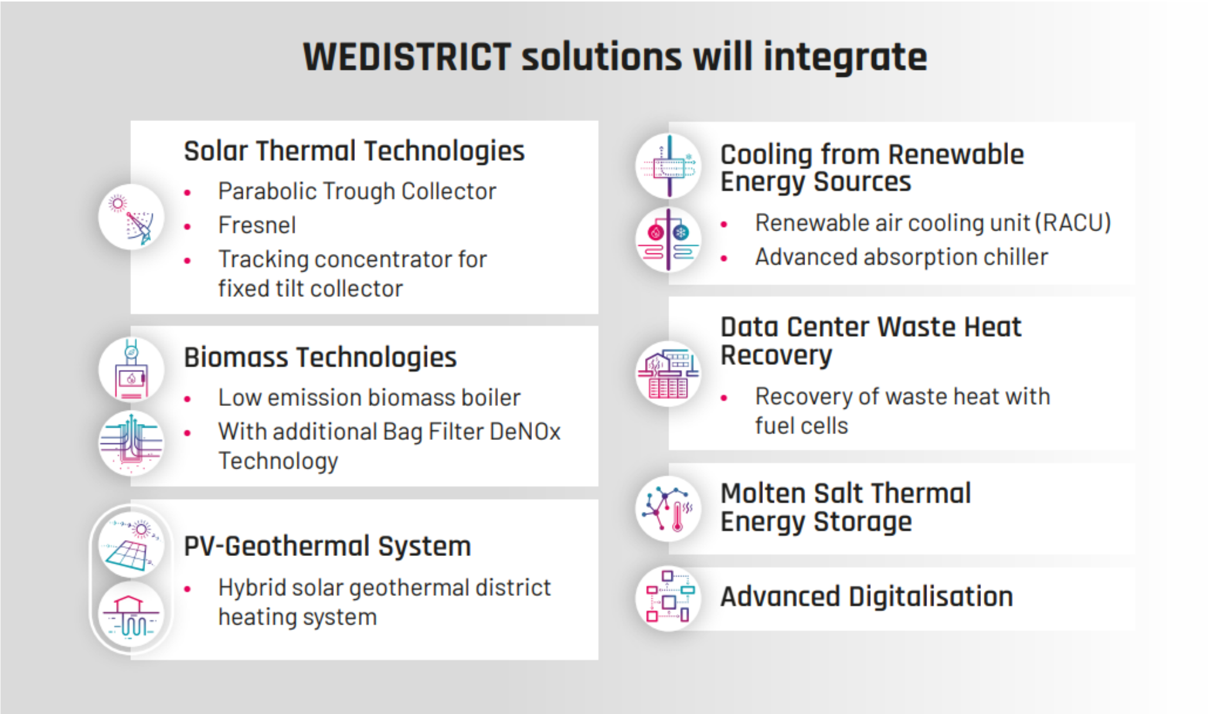
Executive Summary

In WEDISTRICT project, industry innovators from 9 European countries will integrate multiple sources of renewable energy and excess heat to showcase solutions for 100% fossil free district heating and cooling systems being aligned with the foremost goal of the European Green Deal which is reaching climate-neutrality in 2050.



The WEDISTRICT solutions will be implemented in three real-scale projects in Spain, Romania and Sweden. These demosites will showcase technological montages that can be replicated across different climate zones and building types. The demosites will be used to establish best practices that will transform the heating and cooling sector.

As part of the project, other virtual demosites have been set-up. These virtual demosites are based on new or existing DHC system wishing to test improvements based on WEDISTRICT concepts (e.g: RES, waste heat recovery option). The virtual demosites are counted as WEDISTRICT demo-followers. Each virtual demosite has one referent WEDISTRICT partner in charge of its evaluation.

Different existing DHCs has been identified to be part of Demo follower's community which will serve for improving the current DHC system by integrating WEDISTRICT concept (RES and waste heat recovery integration). In this task a first contact will take place for gathering needed inputs and first preliminary improvement ideas and measures. Partners involved in virtual demos evaluation will be able to have a first picture of each of their selected DHC follower. Central station size, equipment features, thermal and cooling profiles, current operation strategies, economic information and other useful inputs will be collected in order to make a first agreement about challenges for energy efficiency and reduction costs challenges.

A set of virtual demos selected from the identification of potential demo-followers will be simulated by the WEDISTRICT Simulation Working Group and different scenarios with technologies developed within the project will be integrated in order to evaluate the most cost-effective system for each particular demo follower.

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The main objective of the activity is to improve the current system by integrating renewable energy systems and demonstrate WEDISTRICT replicability. Each virtual demo will integrate the most suitable technologies and operation strategies for improving the energy efficiency and lowering the emissions.

There are two categories of demo-followers: the first corresponds to new proposals of DH/C systems and the second to the retrofitting of existing DH/C system:

NEW DH/C SYSTEMS		
Demo-follower	**Location**	**Description**
SeiMilano	Milan (Italy)	New modern urban and landscape re-development project that transforms the area by generating a new landscape.
Montegancedo Campus	Madrid (Spain)	School of software engineering and research pole with multiple research institutions currently supplied by individual gas boilers and compression chillers.
Playa del Inglés	Gran Canaria (Spain)	New DHC network in potential Canary Islands area.
Tecnoalcalá	Alcalá de Henares (Spain)	Scientific and Technological Park with individual heating and cooling supply in more than 40 companies located in the park.
Independencia	Santiago de Chile (Chile)	10 clients (4 health clients, 2 residential apartments, 1 university, 1 mall and 2 offices and public clients), with 18 buildings for a new DHC proposal.
RETROFITTING OF EXISTING DH/C SYSTEMS		
Demo-follower	**Location**	**Description**
Parc de l'Alba	Barcelona (Spain)	New urban development with a high efficiency energy system and DHC partially implemented. 2 new production plants are planned.
Cyprus University	Nicosia (Cyprus)	DHC initially developed in 1999, expanded twice (in 2007 and 2010) and new expansion planned for year 2022. Currently operating with oil boilers and air-cooled chillers.
Żyrardów	Żyrardów (Poland)	Existing DH with around 500 heat centres coal-fired based (35-year-old)
Valladolid	Valladolid (Spain)	6 buildings covered by a recent (2018) DH installation biomass-based with extension perspective.
Focsani	Focsani (Romania)	Old DH network retrofitted in 2018 with new CHP and gas boiler facilities.
Mrągowo	Mrągowo (Poland)	Old DH network (247 buildings connected) which has started a retrofitting action replacing coal by biomass.

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The main results of optimal scenario are introduced in the following table.

Virtual demo	Optimal scenario	Justification	Discarded solutions /Comments
SeiMilano	• Geothermal A/W pump • Advanced absorption chiller • PVT	The more feasible scenario considering CO_2 emissions and LCOE.	RACU has been dicarded for humidity issues. FC-WHR is too expensive to be developed.
Montegancedo	• Biomass boiler • Solar field • Gas Boiler	Most promising scenario, helping to reduce a lot of CO_2 emissions and with an acceptable LCOE.	Solar field is necessary to reduce more CO_2 emissions. Advanced absorption and conventionnel chillers combination is advised for cooling extension.
Playa del Inglés	• WESSUN • Advanced absorption chiller • Conventional chiller	This scenario reaches high levels of RES share with good profitability.	It is advised of 4th generation DHC integrating 35% of solar fraction and 11% of IRR.
TecnoAlcalá	• Biomass Boiler • Gas Boiler • Conventional chiller	This scenario enables to optimize both CO_2 emissions reduction and LCOE.	This scenario is expected to be developed for 100% biomass boiler. FC-WHR is discarded for high investment compared to the potential of heat recovery.
Independencia	• WESSUN • Advanced absorption chiller • Conventional chiller	This scenario reaches high levels of RES share with good profitability.	It is advised of 4th generation DHC integrating 15% of solar fraction and 14% of IRR.
Parc de l'Alba	• Biomass Boiler • Gas Boiler • Compression chiller	This scenario enables to optimize both CO_2 emissions reduction and LCOE.	Solar field helps to reduce CO_2 emissions with a correct LCOE. Adding cooling extension provided by chillers increases a lot LCOE being less acceptable even if CO_2 emissions are low.

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Virtual demo	Optimal scenario	Justification	Discarded solutions /Comments
Cyprus	• Biomass boiler • A/W pump	It is the more acceptable scenario for university considering CO_2 emission and LCOE.	Integrating Hybrid PV-Geothermal solution and RACU enables to reach very low CO_2 emissions but for a high LCOE that the university cannot afford.
Zyrardow	• Hybrid PV – Geothermal • CHP	This scenario reaches high levels of RES share with good profitability.	The proposal is to develop a 30 MW geothermal heat pump system with a 15,5% IRR, based on 4th generation DHC.
Focsani	• Biomass Boiler • Hybrid PV - Geothermal	No gas consumption in this scenario, and PV reduces Heat pump consumption.	This solution is very profitable since the cooling demand is covered with a low CO_2 coefficient emission and LCOE thanks to geothermal installation, covering both heating and cooling.
Valladolid	• Biomass Boiler • Absorption and compression chillers	This scenario enables to optimize both CO_2 emissions reduction and LCOE.	Geothermal solution enables to reduce more CO_2 emissions, but the LCOE is increased a lot, that makes it not viable.
Mragowo	• Biomass and Gas boilers • WESSUN	The combination of solar technology and thermal storage allows to reduce CO_2 emissions a lot.	The reduction in the emissions coefficient is more significant than the increase in the LCOE.

The general trends of those optimal scenarios are that combination of renewable solutions help to reduce CO_2 emissions significatively, but the limit is about the rank of LCOE the project may afford. For some virtual demos, it is viable and others not: it depends on the project design.

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Disclaimer

Abbreviations

Abbreviation	Description
ACU	Air-Cooling Unit / Alternating Current
APH	Air Pre-Heating
CHPP	Combined Heat and Power Plant
CSP	Concentrated Solar Power
CPC	Compound Parabolic Concentrator
CW	Cold Water
DC	Data Centre
DCWH	Data Centres Waste Heat
DEC	Direct Evaporative Coolers
DHC	District Heating and Cooling
DRC	Dry Refrigeration Cooler
FC	Fuel Cells
LFC	Linear Fresnel Collectors
O&M	Operation & Maintenance
RACU	Renewable Air-Cooling Unit
RES	Renewable Energy Source(s)
TES(S)	Thermal Energy Storage (System)
WHR	Waste Heat Recovery

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1 Work plan and methodology

A set of virtual demos selected from the identification of potential demo-followers will be simulated by the WEDISTRICT Simulation Working Group and different scenarios with technologies developed within the project will be integrated in order to evaluate the most cost-effective system for each particular demo follower.

The main objective of the activity is to improve the current system by integrating renewable energy solutions and demonstrate WEDISTRICT replicability from 3rd to 5th GDHC.

1.1.1 WORK PLAN

Representative people from demo-followers will be asked for sharing some information (fulfilling always GDPR issues). The Simulation Working Group will develop a template to be filled and it's up to each demo-follower to provide as much detail as they consider, considering that the more information the more accurate study from our side.

Exceptional contacts could be needed from the simulation working group in order to clarify unclear points. Each demo-follower is free to manage the contact procedures with the simulation working group.

In short, demo-followers will be simulated and assessed, following WEDISTRICT DNA (Renewable Energy Sources integration into District Heating and/or Cooling for new and/or retrofitting projects). Demo-followers will obtain a feasibility study without any cost.

In the frame of dissemination WEDISTRICT activity, demo-followers will be shown as virtual demonstration and they will be benefited with a higher visibility and acknowledgement around Europe.

New business contacts will be created thanks to the WEDISTRICT project participation with 22-partner consortium from 9 countries.

1.1.2 SIMULATION METHODOLOGY

All demo followers have been simulating common methodology. This methodology consists of the following steps:

- **Step 1 - Creation of TRNSYS model**: TRNSYS models of systems, so-called 'decks', are built by connecting models created for each technology (description of these models is available on deliverable 5.6) following the methodology described on the deliverable D5.7. These individual models of each technology are called macros. Each macro is identified with a code. Table 1-1 includes the code of each macro. Also, the connections between macros follow code. This code is included in Table 1-2.

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Table 1-1 Code for WEDISTRIC macros

Technology/Process	Code
Meteorological	M0100
Fresnel/Parabolic collector	M1200
WESSUN	M1300
Photovoltaic panels	M1500
Hot Water Storage	M2100
Molten salts Storage	M2200
Cold Water Storage	M2300
Water PTES	M2400
Boiler	M3100
Cogeneration	M3300
Advanced Absorption Chiller	M4100
Conventional Absorption Chiller	M4200
Chiller A/W	M4300
Chiller W/W	M4400
Heat Pump A/W	M4500
Heat pump W/W	M4600
RACU	M4700
Geothermal	M5100
Cold distribution	M7200
Heat Distribution	M7300
Heat Load	M8100
Cold Load	M8200
Interconnection	M9100

Table 1-2 Colour code for connectors between macros

	Code
Heating return	
Heating supply	
Cooling return	
Cooling supply	

A predefined set of decks have been built with different combinations of technologies. Table 1-3 show the code of deck and the technologies included. All decks include a photovoltaic panel system by default. This option can be disabled by setting the collectors capacity to zero.

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Table 1-3. Predefined decks with its technologies.

CODE	FRESNEL /PARABOLIC	WESSUN	PV	HOT WATER STORAGE	MOLTEN SALTS STORAGE	WATER PTES	BOILER	COGENERATION	ADV ABSORTPION CHILLER	CON. ABSORTION CHILLER	GEOTHEMRAL	CHILLER A/W	CHILLER W/W	HEAT PUMP A/W	HEAT PUMP W/W
DCK100		X	X	X			X		X			X			
DCK101	X		X		X					X		X			
DCK102			X	X			X		X			X			
DCK103		X	X	X			X			X		X			
DCK103			X									X			
DCK200	X		X	X	X		X								
DCK201		X	X	X			X								
DCK202			X		X		X								
DCK203	X		X	X			X								
DCK204			X	X			X								
DCK205		X	X	X											
DCK206			X				X				X				X
DCK207			X	X			X	X							
DCK208			X				X	X							
DCK209		X	X	X			X		X						
DCK210		X	X	X			X		X						X
DCK211		X	X	X			X	X			X				X
DCK213	X		X	X			X								
DCK214			X				X								
DCK215		X		X			X								
DCK300	X		X	X	X		X		X			X			
DCK301	X		X	X			X		X			X			
DCK302			X		X		X		X			X			
DCK303		X	X	X			X		X			X			
DCK304			X	X			X		X			X			
DCK305		X	X	X			X		X			X			
DCK306		X	X	X		X	X		X			X			
DCK307							X				X				X
DCK308			X				X					X			
DCK309		X		X			X					X			
DCK310							X	X	X	X		X			
DCK311		X	X	X			X		X			X		X	
DCK312		X	X	X			X		X			X		X	X
DCK313		X	X	X			X	X		X		X		X	
DCK314			X	X			X			X		X			
DCK315		X	X	X			X	X		X		X		X	
DCK316			X				X	X		X		X		X	
DCK317		X	X	X					X					X	X
DCK321	X		X	X			X			X		X			
DCK322	X		X	X			X			X		X			

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CODE	FRESNEL /PARABOLIC	WESSUN	PV	HOT WATER STORAGE	MOLTEN SALTS STORAGE	WATER PTES	BOILER	COGENERATION	ADV ABSORTPION CHILLER	CON. ABSORTION CHILLER	GEOTHEMRAL	CHILLER A/W	CHILLER W/W	HEAT PUMP A/W	HEAT PUMP W/W
DCK323		X	X	X			X			X		X			
DCK324			X				X			X		X			
DCK325			X				X		X		X				
DCK326			X				X			X	X	X			

- **Step 2 - Parametrization of the model**: The “deck” is parametrized using the launcher. A description of the launcher is included on the deliverable D5.7. From this step, the user obtains a folder (DCKXXX) with the *.dck file and all the auxiliary files necessary to run the simulation
- **Step 3 - Parametric study:** A parametric study is carried out using the free-software JEPlus. This software is a tool which allows to carry out parametric analysis for Energy Plus and TRSNYS.

The user must complete different step to carry out a parametric study on JEPLUS.

1. Indicate the path of the folder DCKXX and the name of the *.dck file (
2. Figure **1-1**).
3. Complete the parameter table. The user must complete the following fields for each parameter included on the study (
4. Figure **1-1**):

    - **ID:** A short identification of the parameter used internally by JEPlus.
    - **Parameter Name and Description:** Brief description of the parameter.
    - **Search String**: Special text string (“@@tag_name@@) used by JEPlus to insert the parameter value on *.dck file.
    - **Value Type**: Type of parameter (integer, double, discrete or value sets)
    - **Values**: Different values that the parameter can take.

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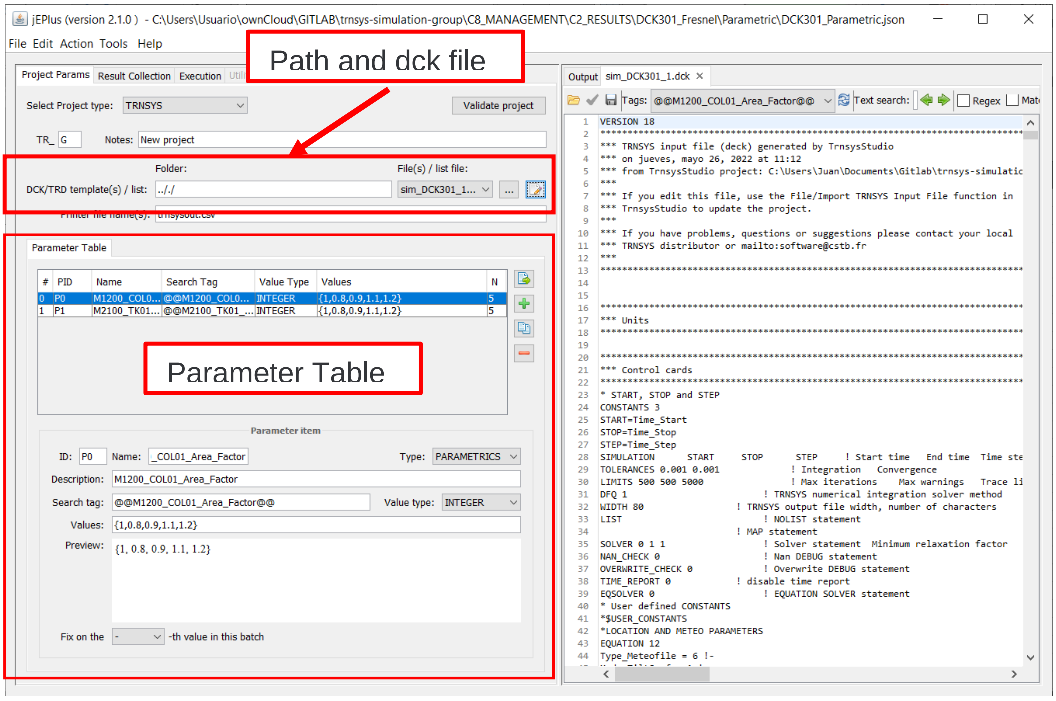

Figure 1-1 Parametric study configuration GUI of the JEPlus

5. Write the search string for each parameter on the *.dck file
6. Indicate the path where the simulation will be stored and the number of simulations that run in parallel (Figure 1-2).

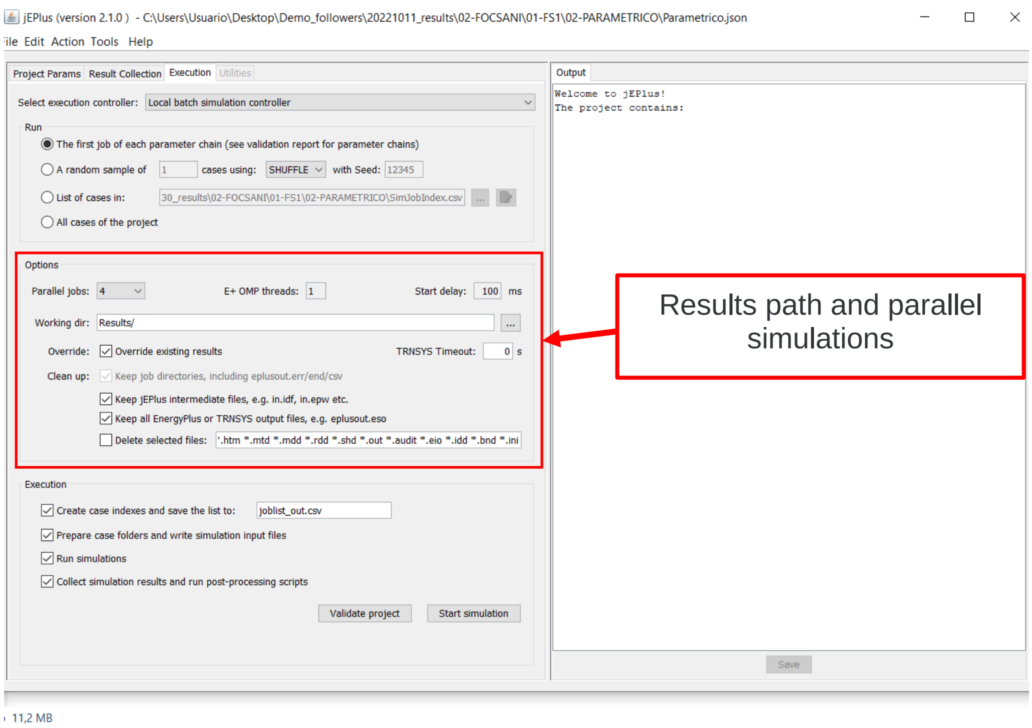

Figure 1-2. Simulation's options GUI of the JEPlus

7. Run the simulation. JEPlus generates copies of the DCKXX folder with a different combination of parameters each one and runs the simulation.

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- **Step 3 - Key parameters calculation:** The key parameters are calculated using a script python. This program is made up of three parts:
    - **Input_template.xls:** It is an excel sheet where the user defines the values of the economic and environmental parameters necessary for the calculation of the key parameters.
    - **WEDISTRIC_results.py** A python program calculates the key parameters of each simulation run by JEPlus**.** To perform this calculation, this program retrieves the parameters and results of each simulation, which are stored in an individual folder, and reads the parameters included in "Input_template.xls".
    - **Results_template.xls:** The key parameters calculated using the program "WEDSITRICT.py" are written in an excel sheet so that the user can analyze them**.**

2 WEDISTRICT technologies

Heating and cooling in buildings and industry represent the largest energy end-use in Europe, with 50% of the total EU's annual energy consumption. Renewables are not widely used in the sector, with 84% of heating and cooling still generated from fossil fuels and only 16% generated from renewable energy.

This issue is of crucial importance if the EU aims to reach its energy and climate objectives, especially when it comes to attaining the 2050 goal of an 80-95% reduction in greenhouse gases compared to 1990's levels. The heating and cooling sector must respond to this demand, and sharply reduce its energy consumption and cut its use of fossil fuels.

The EU's Heating and Cooling Strategy, has promoted an extensive package of specific proposals leading to a notable evolution of the Heating and Cooling sector, highlighting the following:

- To help buildings and industry shift to efficient and decarbonized energy systems based on renewable energy sources and waste heat use.
- To integrate smart homes and buildings (i.e., DHC digitalization), which use automation and controls to serve their occupants better and to provide flexibility for the system through reducing and shifting demand and thermal storage.
- To integrate thermal storage (in buildings and district heating) into flexibility and balancing mechanisms of the energy system.
- To make consumers the centre of this strategy, using modern technologies and innovative solutions to shift to a smart, efficient, and sustainable heating and cooling system.

Responding to the EU's Heating and Cooling Strategy, WEDISTRICT project proposes the development of clean, smart, and flexible DHC systems to demonstrate 100% fossil-free heating and cooling solution in district networks by integrating/aggregating multiple renewable energy sources and existing excess heating, as a tool for reaching the EU climate goals.

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The overall objective is to demonstrate a DHC solution relying on renewable technologies, thermal storage, and heat recovery technologies that, altogether, satisfies the heating and cooling demand on its whole in new DHC systems and 60-100% on retrofitted DHC. The process to achieve this goal will rely on a better valorization of local resources and the implementation of solutions, such as molten salts tanks, that allow the interaction with other energy networks in order to increase the flexibility of the system, thus optimizing its behavior.

Such process will require a high level of cooperation between all involved parties, from promoters to end users, which facilitates to identify and address each of their requirements in an early stage. This will be essential in order to reduce inefficiencies over the project's lifecycle. Within the 10 specific technical objectives (STOs) of the WEDISTRICT project, it is important to consider the following with their impact on the lean's philosophy:

- The development of 100% renewable DHC based on an optimal combination of local renewable energy sources (RES).
- The optimal integration of new systems (advanced thermal storage) to increase the efficiency of the DHC system.
- The reuse of waste heat (DCWH) to feed DHC network.
- The integration of Advanced Digitalization technologies to smartly manage production, storage, distribution, and consumption of DHC to increase efficiency of networks.
- The possible investment profitability of the project while developing sustainable business models.
- The promotion of citizen participation and public acceptance.

The different technologies to be integrated within the WEDISTRICT project (solar, solar cooling, thermal storage, biomass boiler, geothermal-PV hybridization, and waste heat recovery with fuel cells) has been individually developed to a level of pre-industrialization, according to principles of energy efficiency operation, costs limitation, sustainable premises, and reduced maintenance.

The main WEDITRICT technologies are the one indicated in the following table.

Table 2-1. WEDISTRICT Technologies

Concentration Solar Technologies	Concentrated Solar Collectors for DHCs
	Fresnel Collectors for DHCs
	Concentrated flat plate collectors for DHCs
Geothermal - PV Hybridization	Geothermal-PV Hybridization for DHCs supply
Solar Cooling Technologies	Air cooling technology
	High-efficiency absorption chiller
Optimized Heat Storage	Molten salts for DHCs thermal storage
	Water tank for DHCs thermal storage
Low-Emission Biomass Boiler	Low-emission high efficiency biomass boiler for DHCs supply
Waste Heat Recovery	Waste heat recovery from data centre to district heating

They are the mainly studied technologies in the demo-followers.

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3 New DH/C demo-followers

3.1 SeiMilano (Milano – Italy)

3.1.1 GENERAL DESCRIPTION

SeiMilano is a new DHC demo-follower and concerns the establishment of a new city district in Milan. Heating and cooling will be provided via DHC networks by the local utility A2A, one of Italy's largest multiutilities.

The project was started during 2nd semester of 2019, and the delivery of the first real estate units is planned for 1st semester of 2022. By the 2nd semester of 2022, the work on several sectors (named "R1", "Tertiary" (T), "Commercial" (C) and "Park" is planned to be completed. Preliminary illustrations of the sectors (called lots) are shown in Figure 3-1 through Figure 3-2 below.

The area of investigation is located south-west of Milan, between *Via Calchi Taeggi* and *Via Bisceglie*, adjacent to the metro terminus (M1). The area is part of an impressive urban regeneration project, which will lead to the creation of an innovative multifunctional district integrated in a park.

The area consists of approx. 115,000 m^2, where the following lots will be built:

- Lot "R1": planned to consist of 6 blocks of residences for a total of 550 flats.
- Lot "R2": planned to consist of 470 flats, currently being designed.
- Tertiary Lot, "T".

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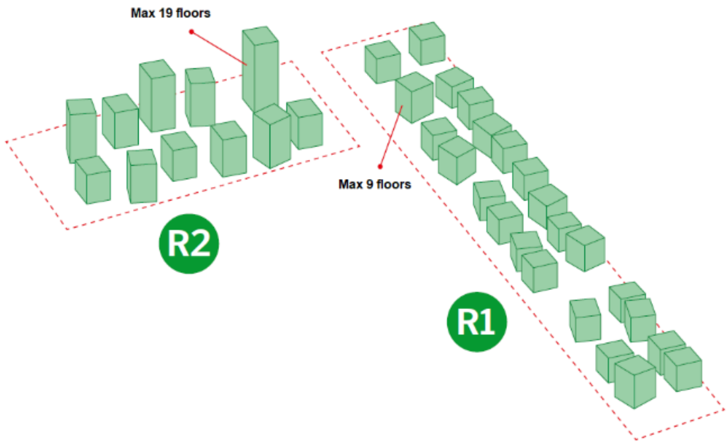
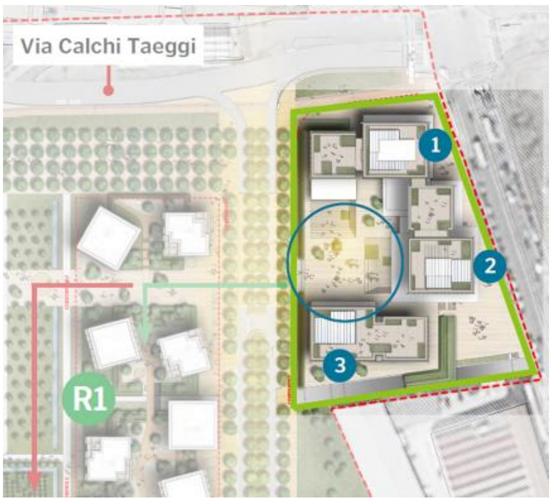


(a) The lots “R1” and “R2” showing the blocks of residences currently being designed.



(b) The Tertiary Lot, “T”, is shown encircled in light green, to the upper right of Lot “R1”.

(c) The Tertiary Lot, “T”, visualised from the road Via Bisceglie (rightmost in (b).)

Figure 3-1. Lots of the area in question, located south-west of Milan [Ref: SeiMilano-IT02.pdf].

These lots are further described and illustrated in the following sections. It is informed that SeiMilano is in the need of two types of energy demands:

- District heating (DH) to a no. of buildings; not yet finally clarified, approx. 1,020 apartments.
- District cooling (DC) to a no. of buildings; not yet finally clarified, approx. 1,020 apartments.

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The areas of investigation in SeiMilano are further illustrated in Figure 3-2, in greater detail, along with the commercial sector, “C”.

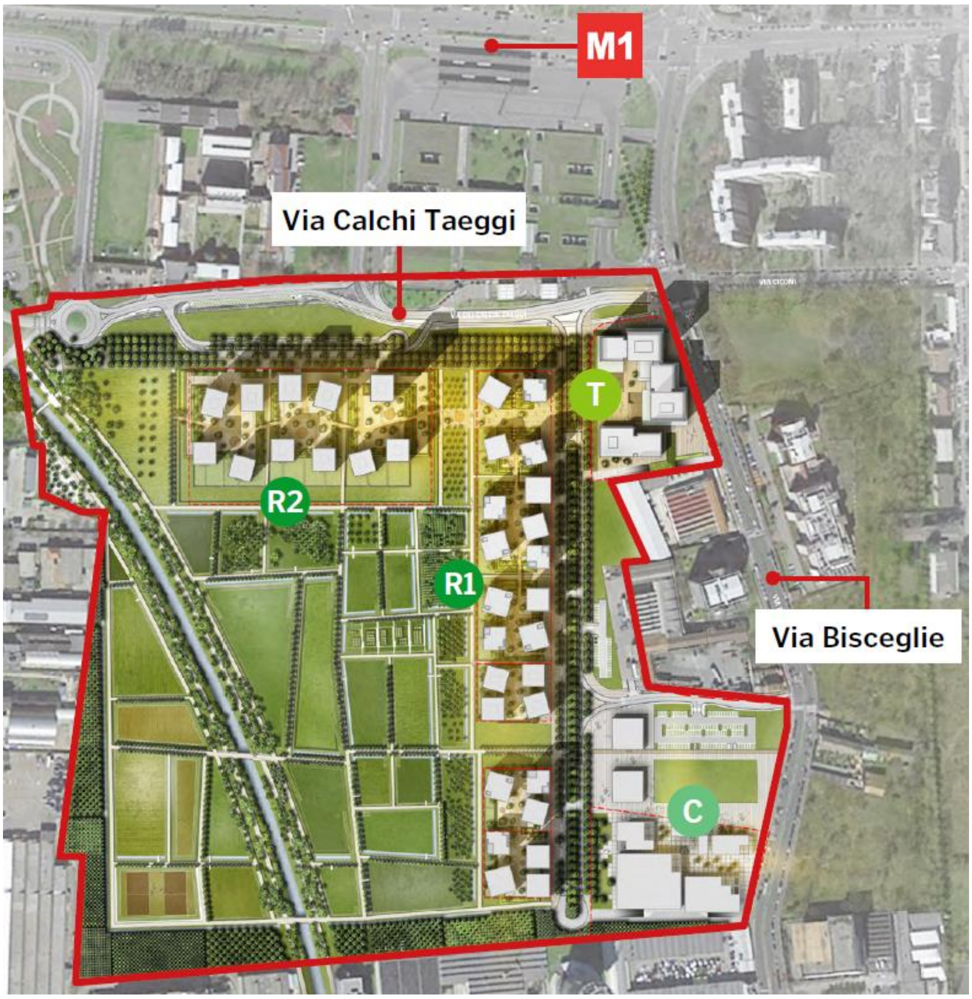

Figure 3-2. Map of SeiMilano showing sections “R1”, “R2”, “T”, “C” and the park area.

In a previous report, “*WEDISTRICT_WP2_D2.3 District Heating and Cooling stock at EU level*”, it is noted that in 2017 only 3% of Italy’s heating demand came from district heating, while 56% came from natural gas, 8% came from oil (or petroleum products), and 6% came from electricity. In Figure 3-3 below “Renewables” include wood pellets, wood chips, biomass, firewood, geothermal and solar thermal.

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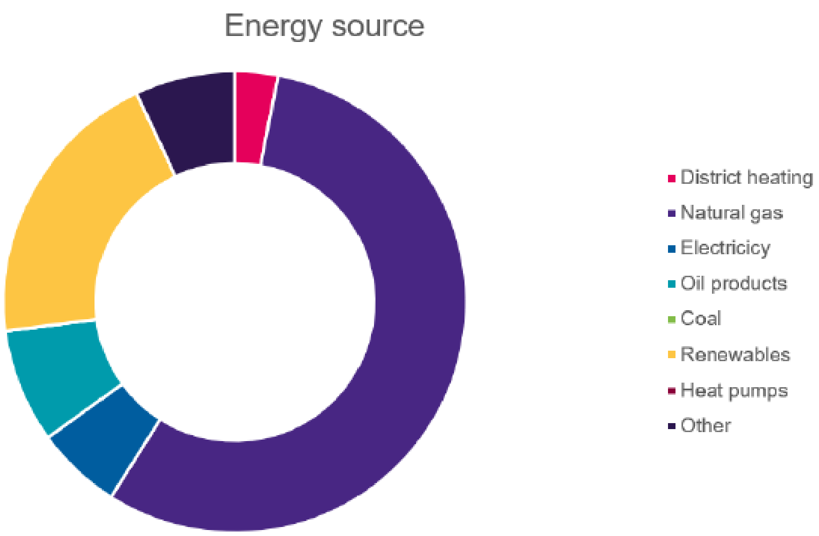

Figure 3-3. Distribution of energy sources used to satisfy heat demand in the Italian residential sector in 2017.

This means that there is a significant potential for reducing Italy's carbon footprint by converting private gas- and oil-fired central heating systems to parts of city-wide district heating and cooling systems using one or more WEDISTRICT technologies for DHC production.

3.1.2 REFERENCE CASE MODEL AND VALIDATION

A first layout of a reference case (i.e., benchmark) model was discussed during the 1st workshop, held December 22nd, 2021, since such a "conventional" solution (S0) will never be considered built in real-life.

The "Benchmark scenario", S0, consists of a gas-fuelled boiler that can provide heat and domestic hot water, a "conventional" heat pump to provide cooling, and the (by Italian law) mandatory photovoltaic (PV) solar collectors to provide power.

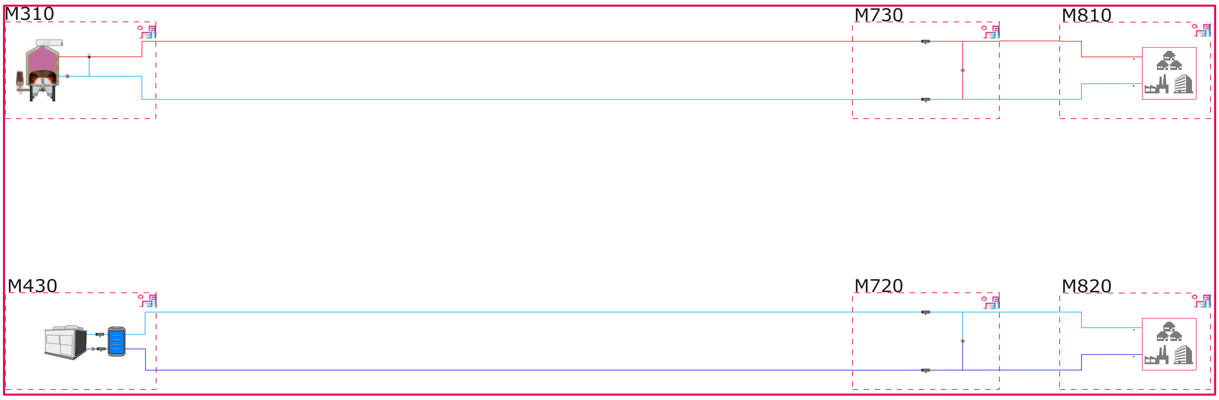

Figure 3-4. Illustration of DCK308.

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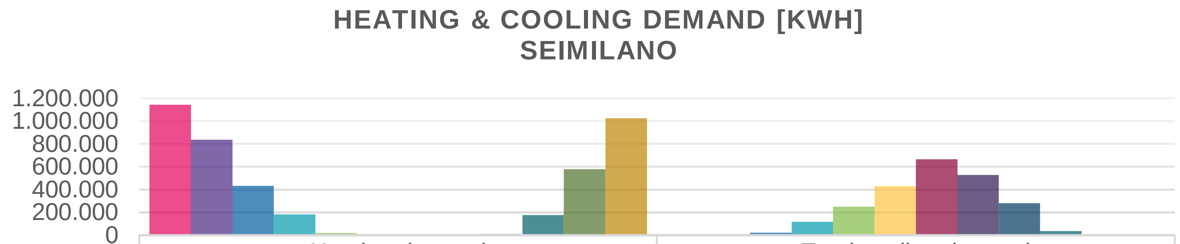
In the illustration given in Figure 3-4, the gas-fuelled boiler (M310) and the heat pump (M430) is seen to the right, delivering energy to the Heat and Cooling Loads (M810 and M820, respectively) through the distribution macros (M720 and M730).

The PV solar collectors (M150) are not visible in this illustration, since this is an option macro added to all simulation decks.

The boiler is laid out to provide heating during the winter and domestic hot water all year round, while the heat pump can assist with heating during winter and provide cooling during summertime. The PV solar collectors are planned to provide power all year round.

A first set of results, based on the simulated heating and cooling demands, was presented during the 1st workshop. The simulations were based on the number and type of buildings planned in the area.



	Heating demand SeiMilano (kWh)	Total cooling demand SeiMilano (kWh)
jan	1.142.163	0
feb	837.596	11
mar	431.690	21.832
apr	183.205	117.811
may	20.669	250.950
jun	5.422	428.699
jul	785	666.045
aug	1.781	526.690
sep	11.345	282.058
oct	177.737	34.894
nov	577.367	524
dec	1.023.340	0

Figure 3-5. Predicted annual heating and cooling demand [kWh] for SeiMilano.

In Figure 3-5, it is seen that heating is needed mostly in the winter, peaking in January, and most cooling is needed during the summer, peaking in July. In Figure 3-6, the heating demand is compared to the almost constant domestic hot water demand.

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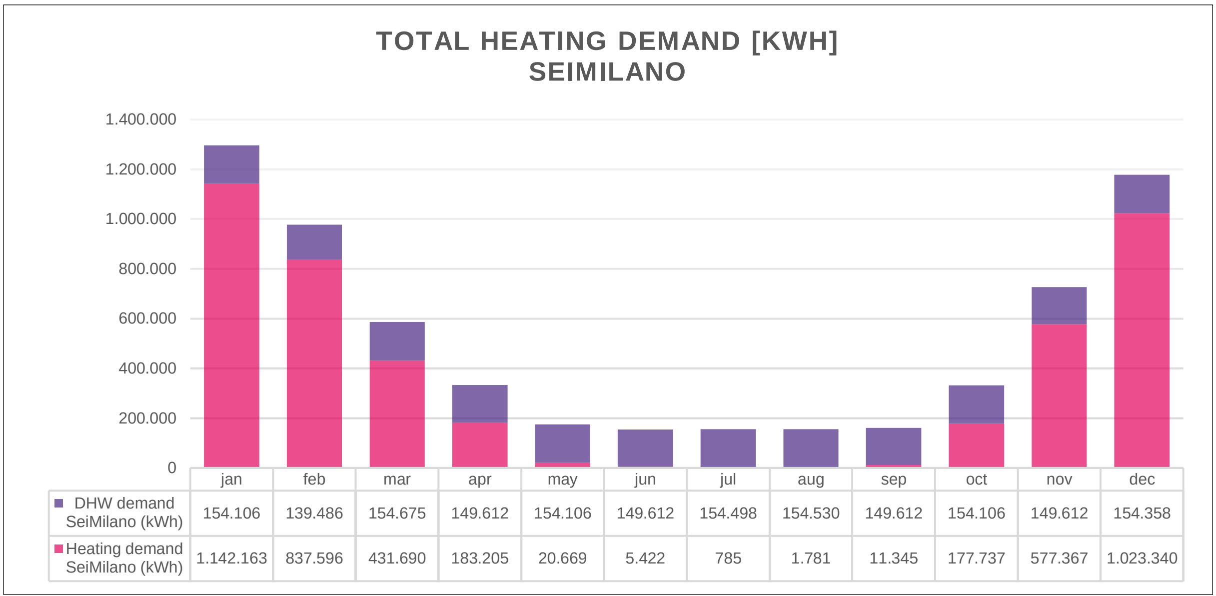

	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
DHW demand SeiMilano (kWh)	154.106	139.486	154.675	149.612	154.106	149.612	154.498	154.530	149.612	154.106	149.612	154.358
Heating demand SeiMilano (kWh)	1.142.163	837.596	431.690	183.205	20.669	5.422	785	1.781	11.345	177.737	577.367	1.023.340

Figure 3-6. Predicted annual domestic how water and heating demand [kWh] for SeiMilano.

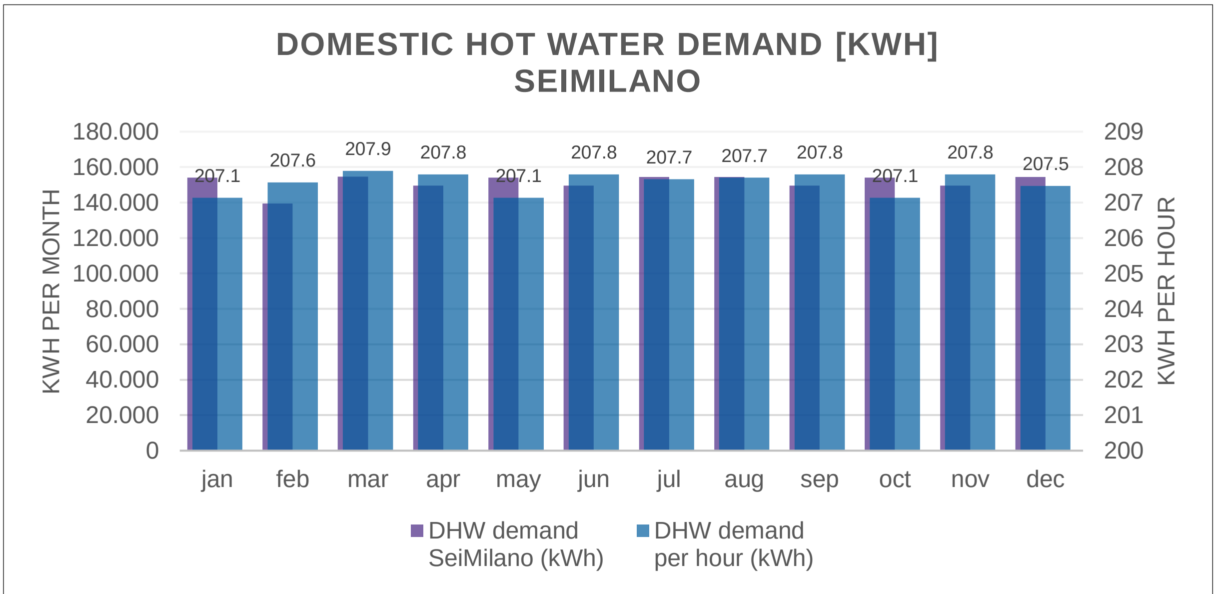

Figure 3-7. Predicted domestic hot water demand [kWh] seen per month (left) and per hour average (right).

Hourly results are simulated and shared by R2M Solution's buildings simulations based on information provided by A2A. The simulation results were subsequently validated with A2A.

Selected results from the TRNSYS DCK308 energy load and production are shown below. Figure 3-8(a) shows the absorption chiller (CHA) cooling production, following the cooling Load seen in Figure 3-8(b). In Figure 3-8(c), the electricity production from the PV solar collectors is compared to the Load as well as the amount of electricity available to the Grid. In Figure 3-8(d), it is seen that the distribution (Simulation) follows the load (Data) (see Figure 3-4, M720/M820). The main KPIs achieved have yet to be addressed.

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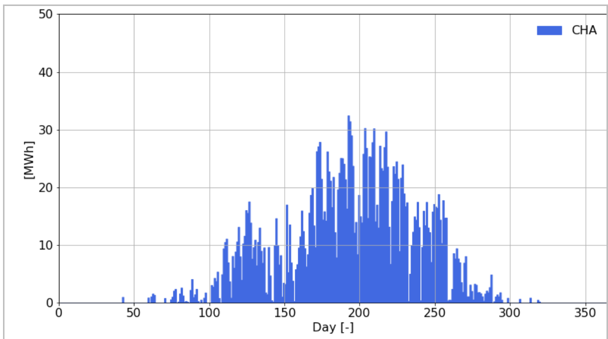
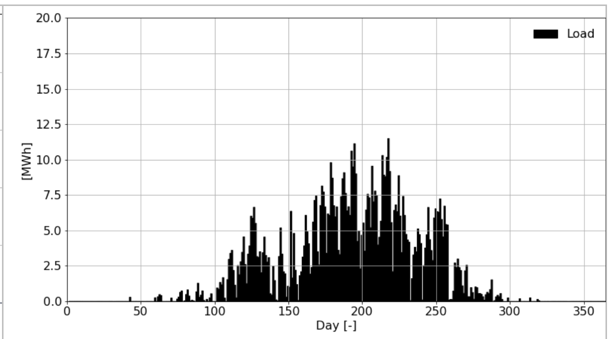
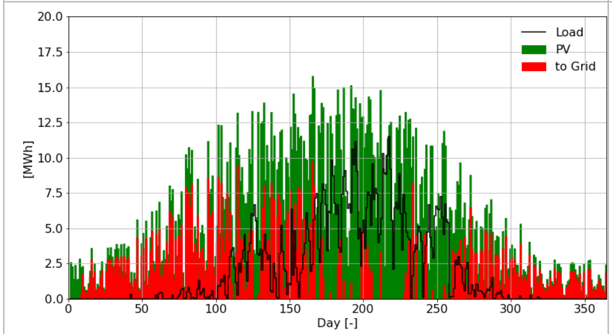


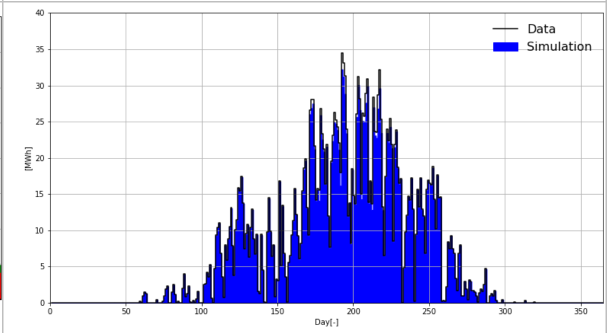
(a) Chiller A/W (M430)



(b) Cooling Load



(c) PV production (M150) and excess electricity



(d) Cooling load (M720) and distribution (M820).

Figure 3-8. Selected results from the TRNSYS DCK308 first results (S0 – Benchmark simulation).

The skewed histogram seen in Figure 3-9 shows the hourly district heating demands sorted from the hour with the highest district heating demand to the hour with the lowest district heating demand.

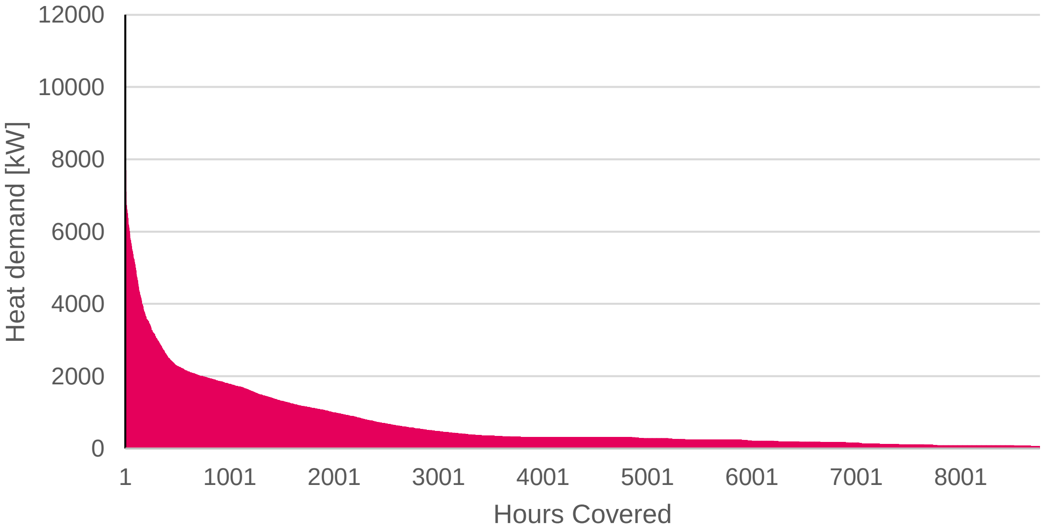


Figure 3-9 SeiMilano Heat Demand Skewed Histogram

The district heating demand summed up for each month can be seen in Figure 3-10, below.

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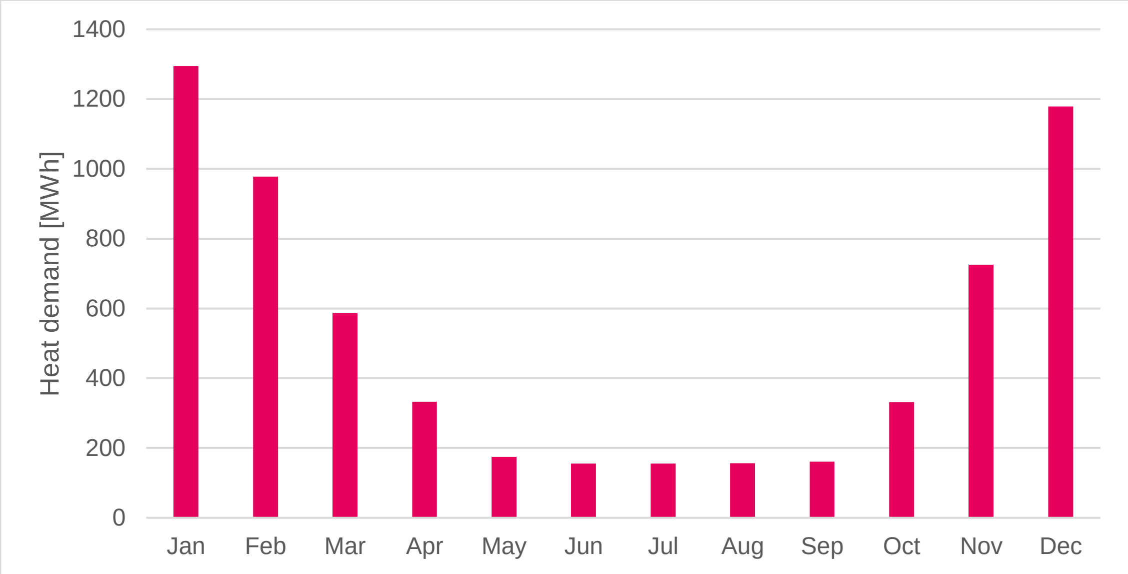

Figure 3-10 SeiMilano Heat Demand per Month

Figure 3-11 shows the district cooling demand sorted from the highest to the lowest district cooling demand in a skewed histogram,

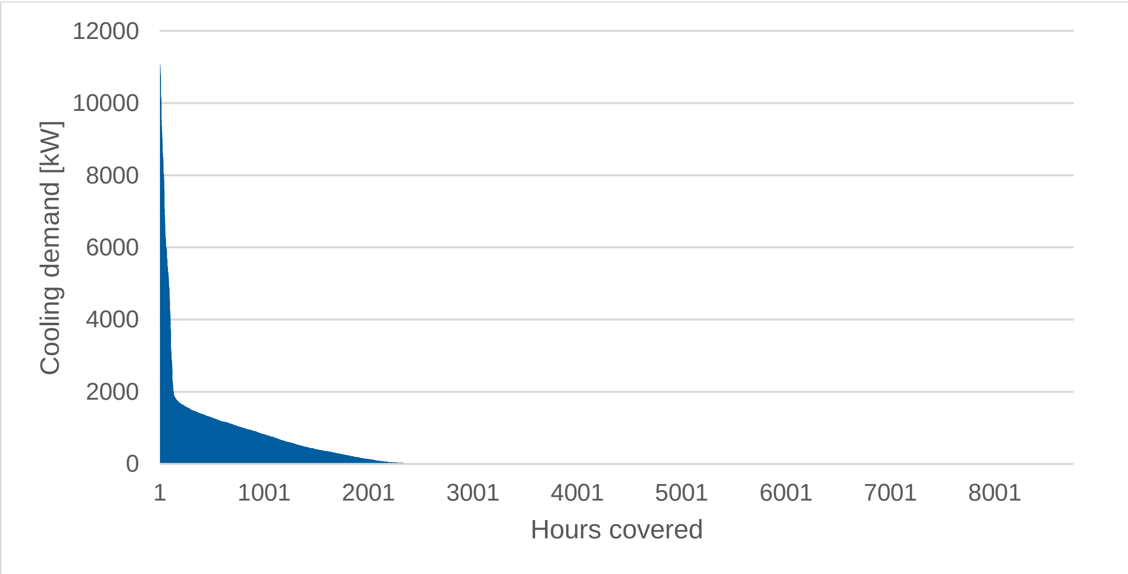

Figure 3-11 SeiMilano Cooling Demand Skewed Histogram

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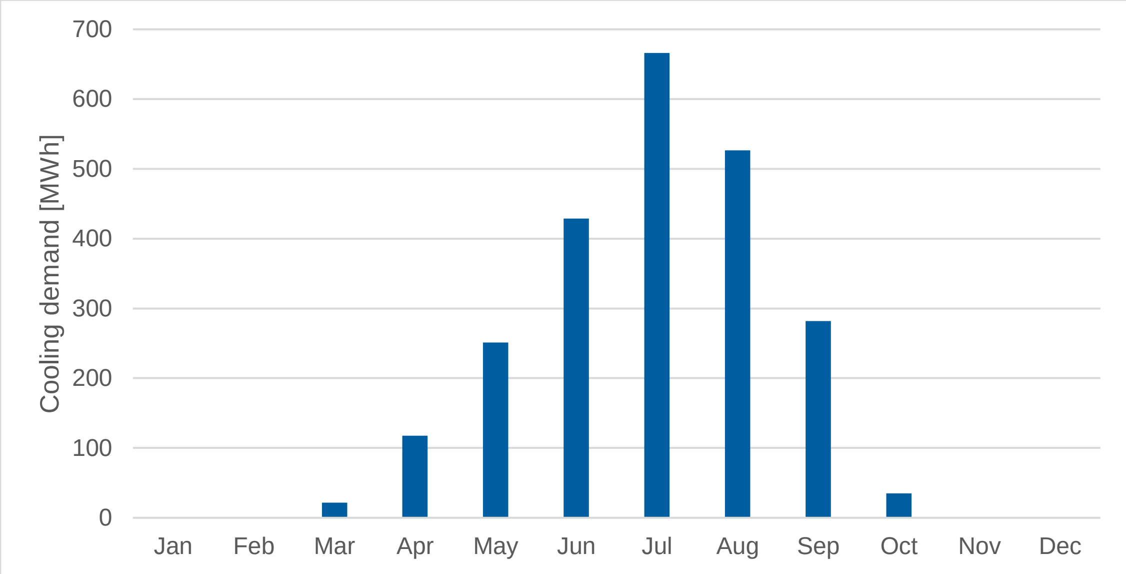

Figure 3-12 SeiMilano Cooling Demand per Month

The sum of district cooling demand for each month can be seen in Figure 3-12, above.

3.1.2.1 FIRST RESULTS

The reference case (conventional DHC) consists of a 10 MW (thermal) boiler and an 11 MW (peak) it also contains a 3 MW (peak) photo voltaic solar field. A TRNSYS deck was set up in the WEDISTRICT launcher so that the technology models fit with a reasonably conventional DHC system with the addition of a PV solar plant.

Parameters	Value	Unit
Boiler	10	MW
Chiller	11	MW

The deck was then set to match the temperatures of the SeiMilano district heating and cooling networks given the hourly heating and cooling demands and the environmental factors such as ambient temperature, wind and humidity. The results of the district heating part of the simulation can be seen in Figure 3-13 and Figure 3-14.

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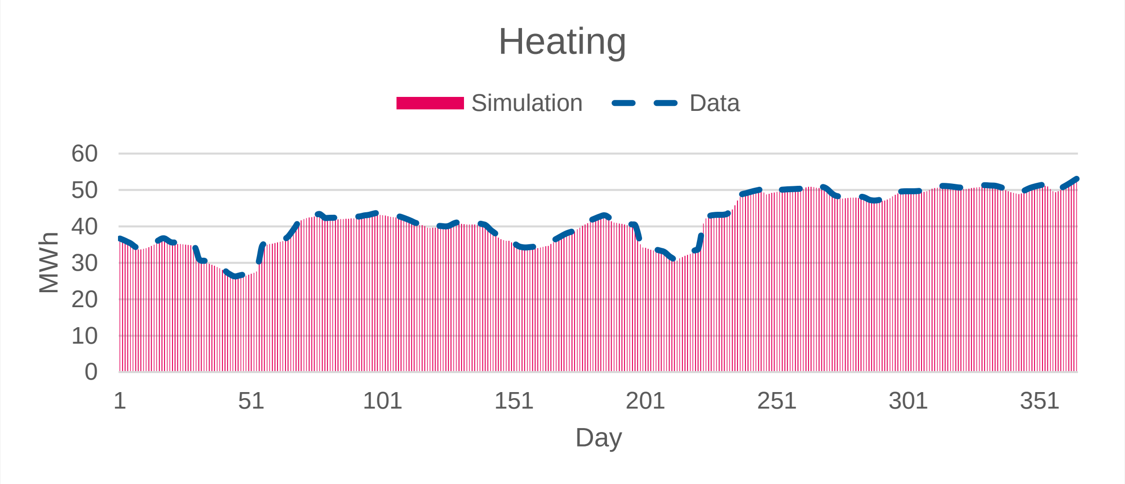

Figure 3-13 Daily Heat Demand Coverage Per Simulation

As it can be seen in Figure 3-13 and Figure 3-17 the result of the reference case simulation model is that 96.81% of the annual heat demand is covered by the boilers in the model the 3.19% deviation is within the expected precision of the calculation model.

	Heating
Heating Non-renewable primary energy factor [-]	0.58 (1)
CO2 emission coefficient [kg/MWh]	128.87 (207)
LCOE [€/MWh]	36.6 (89)

Figure 3-14 Heating KPI Results

A non-renewable energy factor below 1 for a natural gas fuelled hot water boiler does not seem entirely correct unless the natural gas consists partially of biogas as well.
Give that most natural gas consists of 85-95% methane and the rest generally being longer alkanes and alkenes and assuming a boiler efficiency of 95% the expected CO2 emissions should be around 210 kg/MWh

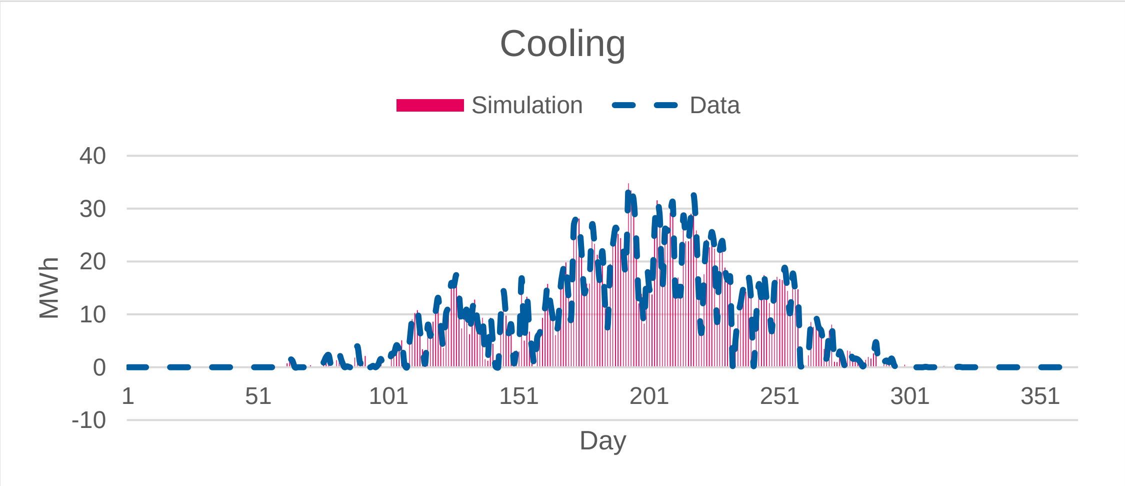

Figure 3-15 Daily Cooling Demand Coverage Per Simulation

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As it can be seen in Figure 3-15 and Figure 3-17 the result of the reference case simulation model is that 100.06% of the annual heat demand is covered by the boilers in the model. The 0.06% deviation is well within the expected precision of the calculation model.

	Cooling
Cooling Non-renewable primary energy factor [-]	-0.88 (0)
CO2 emission coefficient [kg/MWh]	-161.36 (0)
LCOE [€/MWh]	96.3 (64)

Figure 3-16 Cooling KPI Results

A non-renewable energy factor below 0 does not seem correct and that would assume that all the power for the chillers would come from renewable sources. The system includes photo voltaic panels generating power to cover the power demand of the homes, offices and businesses in the new city quarter. Even if the power for the chillers comes from renewable sources the non-renewable factor cannot be less than zero.
The same must be true for the CO2 emissions generated in the power production necessary to power the chillers even if all the power is from renewable sources the CO2 emissions cannot be less than zero.

	Boiler		
	Simulation	Data	Deviation [%]
Heat generated	6034	6233	-3.19
	Chiller		
	Simulation	Data	Deviation [%]
Cooling generated	2331	2329	0.06

Figure 3-17 Simulation Validation Results

The model calculation shows a system that covers the heating and cooling demands reasonably well.

	System
Non-renewable primary energy factor [-]	0.49 (0.72)
CO2 emission coefficient [kg/MWh]	48 (149.35)
LCOE [€/MWh]	53.23 (82.04)

Figure 3-18 Overall System KPIs

The calculations that estimates the overall system KPIs seems reasonable. The numbers seem off but that is due to the individual system KPI calculations being off.

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3.1.3 FEASIBILITY STUDY

3.1.3.1 Selected scenarios

A next step would be to adapt the reference case solution to a case making more sense for comparison with the planned (S1) as well as proposed alternative solutions (S2, S3). The technologies considered are as listed in the following tables.

TECHNOLOGIES PROPOSED	BY MEANS OF
Advanced Absorption Chiller	Investigation of the performance and operation of the WEDISTRICT advanced absorption chiller compared to a conventional absorption chiller. A2A informs to be generally interested in simulations including the advanced absorption chiller technology.
Renewable Air-Cooling Unit (RACU)	Investigation of the option of applying a RACU to deliver cooling instead of the absorption chiller solution(s).
Photovoltaics/PV (+ Thermal)	Comparison of possible PV and PVT solutions (possibly with tracking mirrors) to investigate the possibility of increasing the electrical and thermal outputs. The WEDISTRICT PV-geothermal hybrid will also be considered. A2A informs that a number of PV panels will be installed on the roofs of the buildings, since it is a legal requirement that PV panels will be installed on new or heavily renovated buildings. PVT is proposed as an optimization to this.
Geothermal System	Investigation of the option of a geothermal system layout as well as the WEDISTRICT PV-geothermal hybrid solution.
Heat Pump (A/W)	Investigation of the performance and operation of an absorption heat pump compared to a (conventional) compression heat pump. A2A informs that a number of absorption heat pumps is planned to be installed in order to provide heat in the wintertime and cooling in the summertime. In addition, a compression heat pump will be installed to assist the absorption heat pump if/when the absorption cannot deliver the required cooling.
Fuel Cell	Investigation of the application of a fuel cell to deliver power and heat to homes, offices, and businesses in combination with an air-to-water heat pump to deliver cooling, and possibly hot water.

Table 3-1. Proposed technologies for the investigated SeiMilano solutions.

The combination of the different technologies generates three main solutions which will be studied in the next step (other solutions might arise during the activity):

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SOLUTIONS PROPOSED AFTER PRELIMINARY ASSESSMENT			
WEDISTRICT Technologies	**S1**	**S2**	**S3**
Advanced Absorption Chiller	x		
PV / PVT	x	x	
Geothermal System	x	x	
Heat Pump (A-W)	x	x	x
RACU		x	
Fuel Cell			x

Table 3-2. Solutions proposed for SeiMilano after preliminary assessment.

SOLUTIONS PROPOSED OVERALL DESCRIPTION	
Combination code	SEIMILANO – S1
Justification	The proposed solution S1 reflects the solution already planned for SeiMilano and is intended to be used as a sort of benchmark solution. Thus, solution S1 integrates and combines the technologies of advanced absorption chilling, photovoltaics, a geothermal system as well as the air-to-water heat pump technology. This combination is suitable for SeiMilano, since it includes the solutions already considered to provide district heating (A-W heat pump, geothermal system), district cooling (absorption chilling, possibly advanced), as well as electricity generation (PV), which are in the scope for this new DH/C demo-follower and planned to be applied to a number of 1000+ residences and possibly, offices and businesses.
Expected impact	• Investigation of the installation of the new DHC equipment / plant capacity to cover the expected DHC and electricity demands of the new residential buildings. • Investigation of the possible improvements of the absorption chiller performance. • Investigation of the possible improvements reg. PV or PV-T system layouts. • General advising on planning of energy equipment for the new development of residential buildings and possibly, offices and businesses.
Combination code	SEIMILANO – S2
Justification	The proposed solution S2 is a variation of the planned setup using RACU to deliver cooling instead of the absorption chiller. Note that the PV (PVT), geothermal, and heat pump technologies from S1 are considered here as well, in combination with the RACU.
Expected impact	• Investigation of possible improvements related to the district cooling needs, also considering limitations such as the space available for installation. • General advising on planning of the new development of residential buildings, equipped with RACU instead of absorption chilling units.
Combination code	SEIMILANO – S3
Justification	The proposed solution S3 is a variation of the planned setup using fuel cell technology to deliver power and heat to the residences, and possibly new offices and businesses, combined with an air-to-water heat pump to deliver cooling, and possibly hot water.
Expected impact	• Investigation of possible improvements related to the district heating needs, as well as electricity generation, in the form of the WEDISTRICT fuel cell technology. • Investigation of possible improvements related to the district cooling needs, in the form of the WEDISTRICT heat pump technology. • General advising on planning of buildings' energy equipment alternatives.

Table 3-3. Overall description of proposed solutions for SeiMilano (justifications and expected impacts).

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3.1.3.2 Scenario 1

The scenario 1 model for SeiMilano contains a boiler this is to determine the amount of heating which will be delivered by the existing district heating network which provides heating to neighbouring city districts the district heating will also provide heat to the absorption chiller generator.

Boiler Capacity (District Heating) [kW]	CAC Capacity [kW]	Heat Pump W/W Heating Capacity [kW]	Heat Pump W/W Cooling Capacity [kW]	Geothermal bore holes [-]
3000-6000	300-500	4000-6667	3000-5000	623-1039

Figure 3-19 Scenario 1 Parameter limits

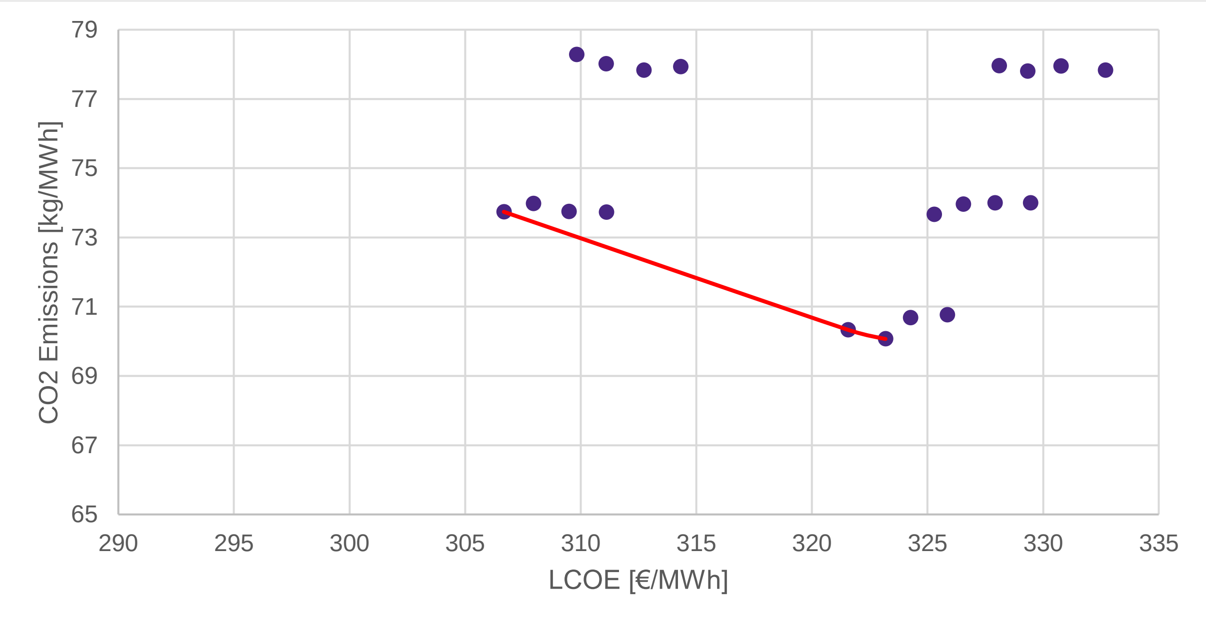

Figure 3-20 Scenario 1 Parametric simulation results

Investigating the parametric simulation results revealed that the shift between individual dots in a line of four dots is due to difference in size of the boiler, or rather maximum heat contribution of the district heating network. While moving from group of four to group of four along the skewed columns up and slightly to the right is due to change in the size of the Absorption chiller. And moving between the columns i.e., right and slightly down is caused by increasing the heat pump capacity.

From this it seems clear that minimizing the capacity of each technology optimizes the LCOE. By increasing the heat pump capacity improves the CO_2 emissions slightly while increasing the LCOE. Increasing the Absorption chiller capacity impacts the CO_2 emissions negatively because the heat that drives the absorption chiller comes from the boiler (district heating network) more chilling means more heat consumption which in turn means more fuel burned and therefore more CO_2. Increasing the capacity of any technology will invariably increase the LCOE given that more capacity means larger equipment and so more material which drives up the cost.

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Case	Boiler Capacity (District Heating) [kW]	CAC Capacity [kW]	Heat Pump W/W Heating Capacity [kW]	Heat Pump W/W Cooling Capacity [kW]	Geothermal bore holes [-]	LCOE [€/MWh]	CO2 Emissions [kg/MWh]
Emissions	5000	300	6667	5000	1039	323.18	70.07
Economical	4500	400	6133	4600	955	306.67	73.74

Figure 3-21 Scenario 1 Optima

When looking at the optima and the pareto front the question becomes is it worth it to increase the LCOE by approximately 5% in order to decrease the CO_2 emissions by approximately 5%.

3.1.3.3 Scenario 2 (reference)

The reference Scenario 2 is calculation the same system as Scenario 2 but letting the heat pump cover the entire cooling demand. This was meant to show how well the Renewable Air Conditioning Units perform relative to a more conventional solution.

Boiler Capacity (District Heating) [kW]	Heat Pump W/W Heating Capacity [kW]	Heat Pump W/W Cooling Capacity [kW]	Geothermal bore holes [-]
3000-5000	15000-23000	11250-17250	2337-3583

Figure 3-22 Reference Scenario 2 Parameter limits

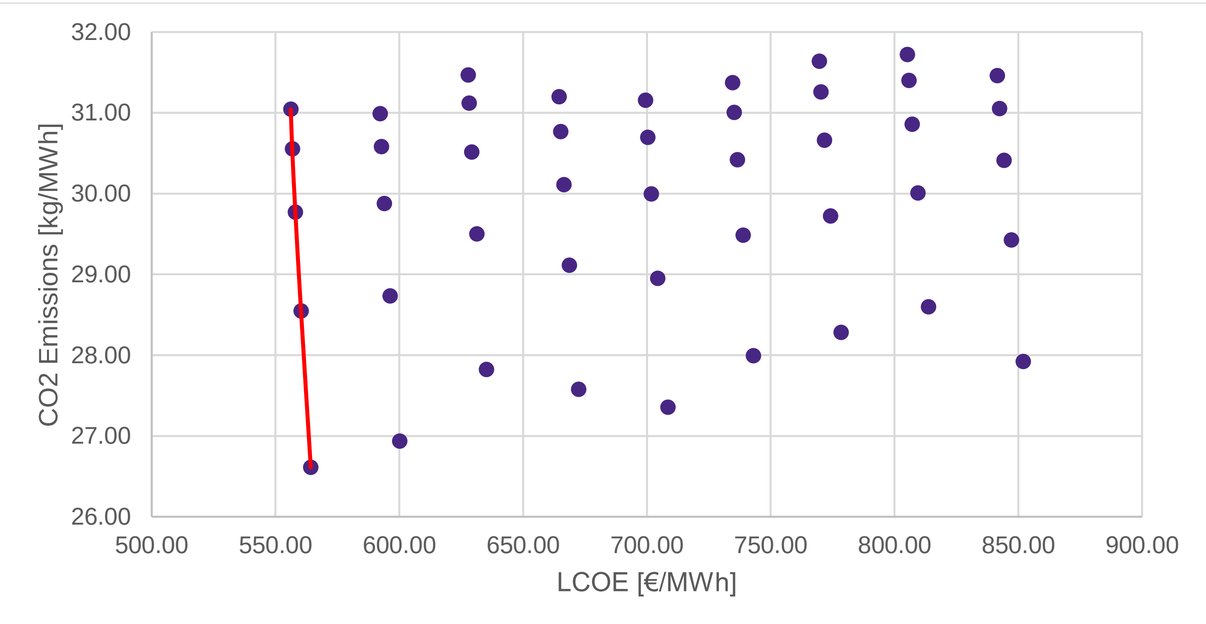

Figure 3-23 Reference Scenario 2 Parametric Simulation Results

The parametric simulation results show that the change along the columns of points see in Figure 3-23 is from the change in boiler (district heating network) capacity. So, changing the district heating has a relatively small impact on the LCOE but a big impact on the CO_2

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emissions. Since it is just a connection to an existing district heating network the impact on the LCOE should be even smaller.

The simulation results also that the change from column is mainly due to the change in the heat pump capacity. This means that the LCOE is impacted more by the change in heat pump capacity and at the same time the heat pump has a more limited impact on the CO_2 emissions. Minimizing the equipment is better for the LCOE but by increasing the Heat from the existing district heating network will limit the CO_2 emissions.

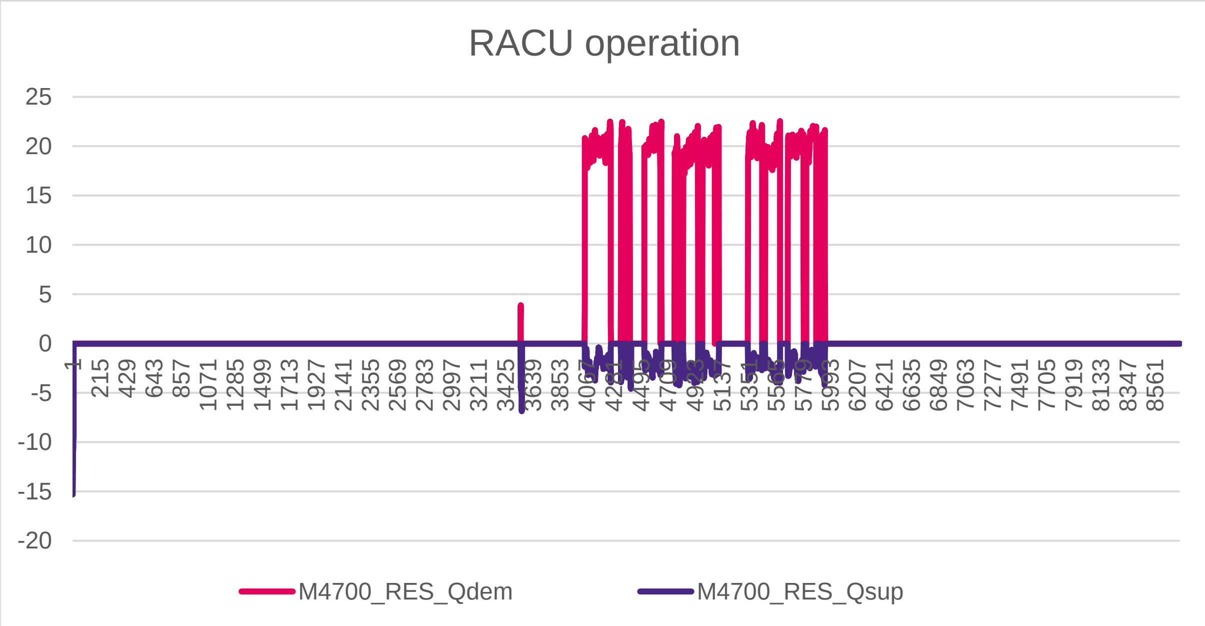

Figure 3-24 RACU operation to provide cooling

The RACU effectiveness is inversly proportional with the relative humidity of the air. This means that installing RACUs in places where the air humidity generally will be problematic. While attempting to run the simulation for scenario 2 with the RACU the RACU under performed. It was then discovered that the Air humidity is quite high in Milano year round which means that the capacity of the RACUs would need to be very large.

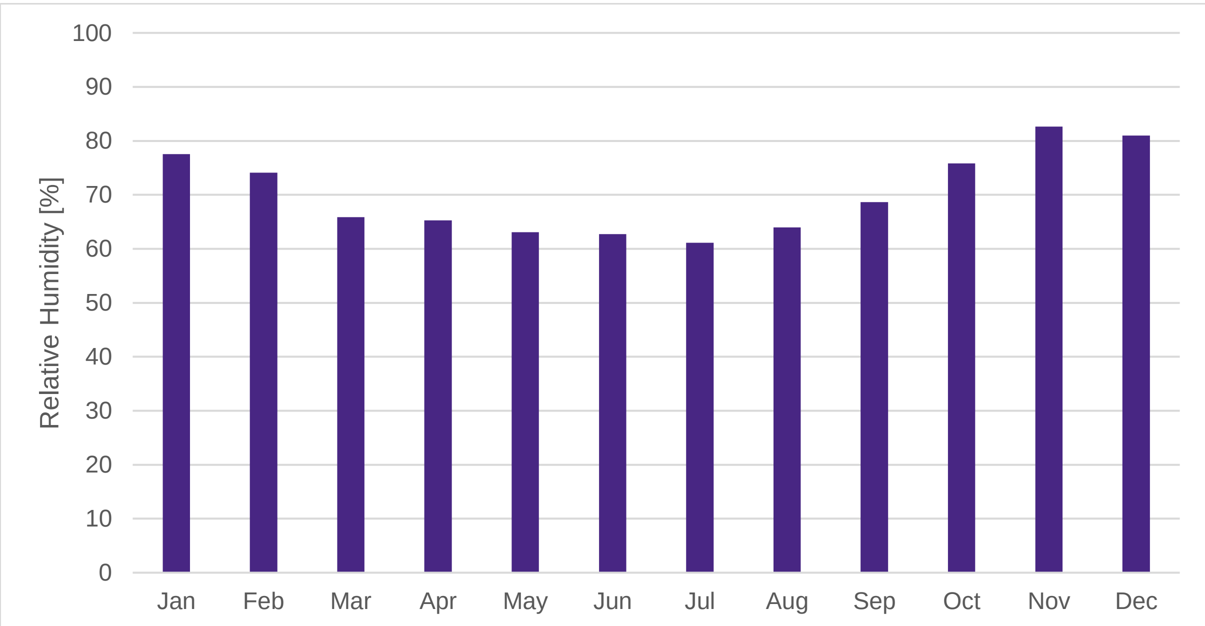

Figure 3-25 Milano average monthly air humidity

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RACUs are approximately 10 times more expensive than air to water chillers so the Scenario 2 model was probably not too viable from the beginning but when the performance is then lowered due to the air humidity this solution becomes even more expensive and therefore certainly not viable.

Case	Boiler Capacity (District Heating) [kW]	Heat Pump W/W Heating Capacity [kW]	Heat Pump W/W Cooling Capacity [kW]	Geothermal bore holes [-]	LCOE [€/MWh]	CO2 Emissions [kg/MWh]
Emissions	3000	21000	15750	3272	564.24	26.11
Economical	5000	15000	11250	2373	556.17	31.04

Figure 3-26 reference Scenario 2 Optima

When it has been concluded that the scenario 2 system will not be viable due to the high relative air humidity issues of the RACU discussing the optima of the reference case for the RACU calculation becomes unnecessary.

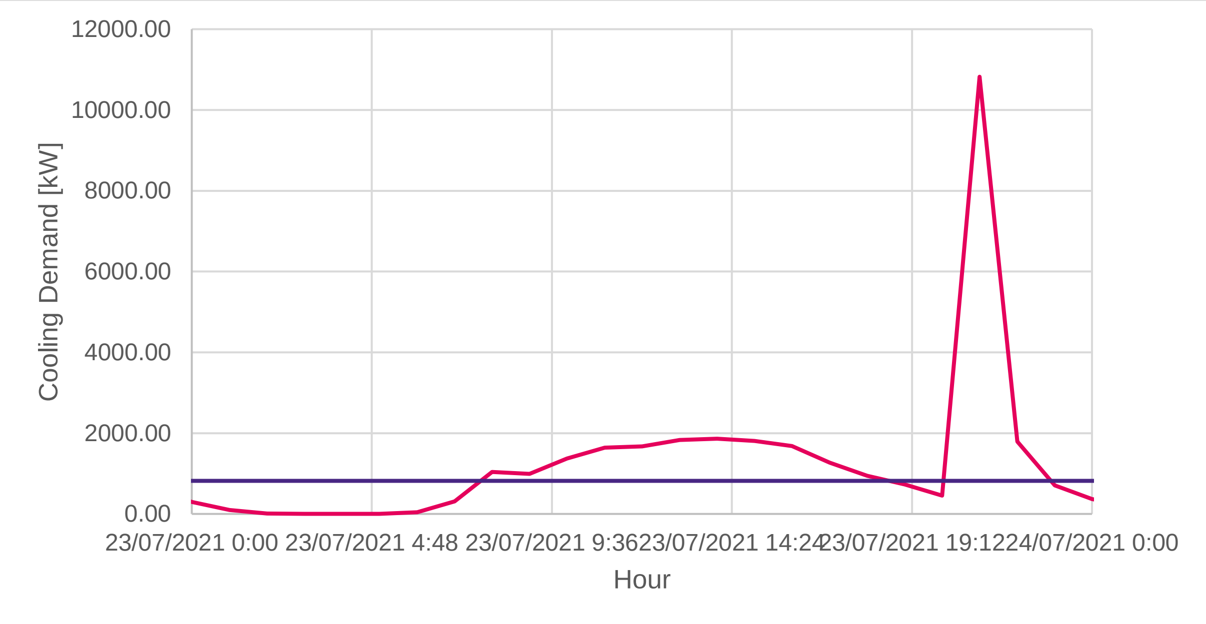

Figure 3-27. SeiMilano simulated cooling demand for the 23rd of July

The simulations of the SeiMilano scenarios have been plagued by very high peak cooling demands. When looking at the cooling demand profile of a day see Figure 3-27 the issue becomes clear. Having a peak cooling demand of approximately 11 MW does not seem unreasonable for 550 flats. But that it's a peak at around 9 p.m. and a sudden jump from 1 MW at 8 p.m. and a sudden drop to around 2 MW at 10 p.m.

3.1.3.4 Scenario 3

While creating the Deck to calculate the performances of scenario 3 it was determined that the necessary size of the Fuel cell to be able to cover the heating demand would be so large that the fuel cell would create enough power to power the city of Milan which in turn would make the solution prohibitively expensive. It was therefore decided that this was a result.

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Parameter	Value
Electricity price	120 €/MWh
Natural Gas Price	25 €/MWh
Lifetime	25 years
Disccount rate	7 %

Figure 3-28 LCOE parameters

Table 3-4 SeiMilano Optima

	LCOE [€/MWh]	CO2 emission coefficient [kg/MWh]
SM S1 CO2	323.18	70.07
SM S1 ECO	306.67	73.74

3.1.4 CONCLUSIONS

As discussed in previous subsections scenarios 2 and 3 are not economically viable. For scenario 2 because the RACU is not an optimal solution for the high humidity environment in the city of Milan. And for scenario 3 because the necessary size of the Fuel cell to provide any meaningful heating would be unreasonably big and therefore expensive. So it is concluded that scenario 1 is the scenario to investigate further.

As discussed previously the cooling demand may not depict a natural cooling demand for flats in a city so rechecking the cooling demand and making it more continuous may make the model more reliable. Changing the heat pumps to water/water pumps and getting rid of the geothermal thermal energy storage may be good changes thereby using the ground water as a heating and cooling source and taking more heating from the existing district heating network which is at least partially powered by waste incineration. These changes will certainly drive down the LCOE.

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3.2 Montegancedo (Pozuelo de Alarcón – Spain)

3.2.1 GENERAL DESCRIPTION

The Montegancedo Campus is a recent development campus belonging to the Polytechnic University of Madrid (UPM). It occupies 480.000 m^2 and it is currently composed by six buildings, among which the school of software engineering (ETSI), a sport facility, and four research buildings. Among these, two are of special interest because of their high energy consumption. On one hand there is the super-computation and visualization centre of Madrid (CESVIMA) with its data centre, and on the other hand the centre of biotechnology and genomics of plants (CBGP) with its greenhouses.

Located in Pozuelo de Alarcón (Madrid, Spain), Montegancedo Campus potential for solar energy harvesting due to its high annual direct nominal irradiation is around 2.053 $kWh/m^2 \cdot year$. Regarding other sources, Madrid has a consolidated biomass market and an average geothermal potential 35-50 W/m^2 with no relevant hydro and wind potential.

Figure 3-29: Left: Montegancedo Campus layout. Right: Montegancedo Campus overview

Currently, the buildings in Montegancedo Campus are supplied by individual systems and withdraw electricity from the grid. The energy consumption of the buildings follows the usual profile of a building driven by thermal comfort demands. Electricity consumption is almost stable along the year due to a large lighting and equipment consumption with peaks in summer for air-conditioning. Among the main consumers, CESVIMA and CBGP show the most interesting features presenting a possible symbiosis due to a potential WHR from data centres and a heat demand from the genomics research centre greenhouses.

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3.2.2 REFERENCE CASE MODEL AND VALIDATION

The reference case for the Montegancedo campus has not been modelled in TRNSYS since KPIs have been calculated using real monitored data.

3.2.2.1 REFERENCE CASE MODEL

Just like mentioned previously, the Montegancedo Campus is composed by six buildings. Among these buildings, there are many similarities and consumption patterns that allows them to be considered as office buildings with special internal gains or electrical demand.
There are three different simulation models used to describe the thermal and electrical demand of the reference case buildings:

- Type 56 greenhouse model drawn in Sketchup, exported to TRNBuild and later to TRNSYS. The designed building has a surface of 1206 m^2 divided in 18 modules and 2 corridors. The greenhouse model imitates real building windows and roof material, internal gains due to lighting, plants photoperiod-irradiation required and evapotranspiration resulting from plants existence.

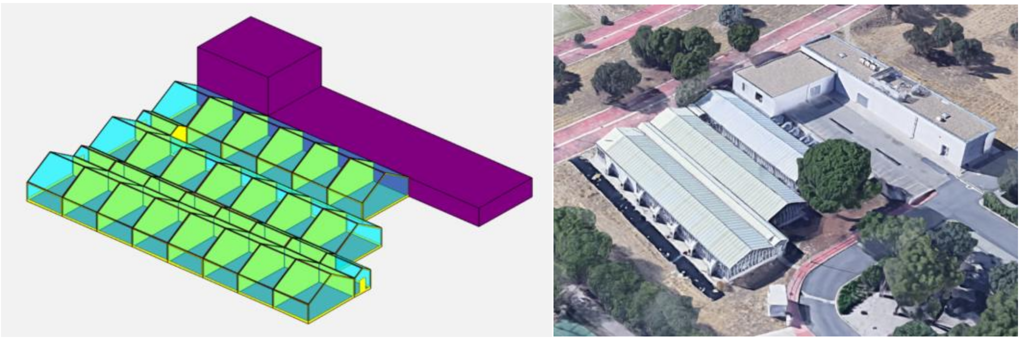

Figure 3-30: Greenhouse model drawn in SketchUp. Right: real greenhouse from CBGP building.

- Air-cooled data centre model in TRNSYS. Data centre demand is calculated using a highly detailed model for air-cooled data centre validated in previous projects.
- Reduced model for offices in TRNSYS. The model is an improved and more detailed version of ISO 13790 resistances-capacitances model. The model uses two sets of parameters to calculate the demand depending on whether the indoor temperature drops below 24ºC, heating mode, or rises above 24ºC, cooling mode. The reduced model considers standard internal gains due to lighting, equipment, and occupancy.

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Among the six different buildings existing in the Montegancedo Campus, these are the simulation models used in each one:

Table 3-5: Montegancedo Campus buildings summary simulation model used

	Acronym	Surface [m²]	Uses	Simulation model used
Escuela técnica superior de ingeniería informática + Polideportivo	ETSI	21,055 (offices) 630 (gym)	Classrooms, laboratories, offices, and gym.	RC Office model
Centro de apoyo a la innovación tecnológica	CAIT	7,439	Offices	RC Office model
Centro de tecnología biomédica	CTB	6,577	Laboratories and offices.	RC Office model
Centro de biotecnología and genómica de plantas	CBGP	7,390 (offices) 1,746 (greenhouses)	Laboratories, greenhouses, and offices.	RC Office model Greenhouse type 56
Centro de I+D+I de la UPM en Eficiencia energética, realidad virtual, ingeniería óptica y biometría + Centro de supercomputación y visualización de Madrid	CEDINT + CESVIMA	4,910	Data centre and offices.	Air-cooled DC model RC Office model
Centro de operación y soporte de usuarios + Centro de investigación y desarrollo aeroespacial	USOC+CIDA	1,135	Offices and laboratories.	RC Office model

3.2.2.2 RESULTS

First results obtained for the Montegancedo Campus show a high dependence on natural gas for heating and an even higher electricity consumption for lighting and equipment. KPIs presented in the table below for each of the Campus buildings are:

- Primary energy factors:
- Primary energy equivalent CO_2, and air pollutant emission coefficient.
- Renewable energy ratio (RER): energy primary renewable/ energy primary
- Non-renewable primary energy factor (fnr)
- Equivalent CO_2 emission coefficient (kCO_2)

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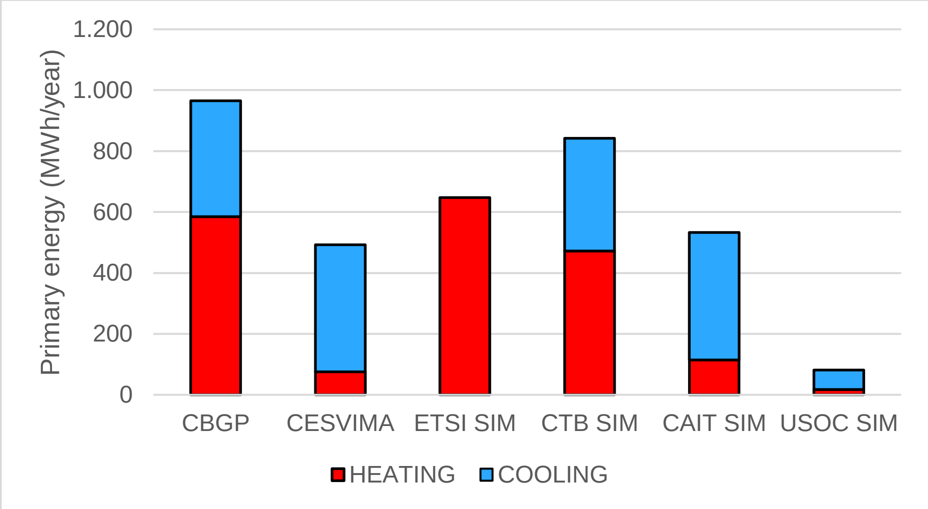

Figure 3-31: Montegancedo Campus primary energy consumption.

As shown in previous results in Figure 3-31, the Montegancedo Campus heating demand accounts for a big part of the primary energy consumption throughout the year for most buildings. Current results are characterised by high non-renewable primary energy consumptions due to the inexistence of renewable sources in the Campus. Results for the whole campus are reported in Table 3-6:

Table 3-6: Montegancedo Campus key performance indicators, overall results

MONTEGANCEDO CAMPUS			
Heating	**Cooling**	**Total**	
3 132	1 248	19 869	**PRIMARY ENERGY**
77	218	3 150	**REN-PRIMARY ENERGY**
3 055	1 030	16 719	**NREN-PRIMARY ENERGY**
634	175	2 912	**CO2 EMISSION**
0.02	0.17	0.16	**RER**
1.44	0.89	-	**FNR**
0.30	0.15	-	**kCO_2**

As mentioned earlier in the general description, each of the Campus of Montegancedo's buildings is supplied by individual systems. Regarding the heating, in three buildings it is provided by natural gas boilers (CBGP, ETSI and CTB), while on the other three heating is supplied by air heat pumps (CESVIMA, CAIT and USOC/ CIDA). To match the natural gas consumption profile of each of the buildings, some adjustments related to the boiler efficiency were required. The following table shows the simulated results obtained for the natural gas consumption.

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Table 3-7: Natural gas consumption simulated results

Natural gas consumption [MWh]				
Month	**CBGP Greenhouses**	**CBGP Main Building**	**ETSI**	**CTB**
January	63	382	246	179
February	60	281	181	132
March	54	140	90	66
April	39	0	40	29
May	15	0	0	0
June	1	0	0	0
July	0	0	0	0
August	0	0	0	0
September	1	0	0	0
October	8	30	20	14
November	32	240	155	113
December	52	378	244	178
Total	325	1451	976	711

When comparing these results with real data provided by the Campus of Montegancedo authorities for late 2019 – early 2020, a good approach in most of the buildings is achieved. Some disparities are to be considered, specially Covid-19 pandemic in the early 2020 months.

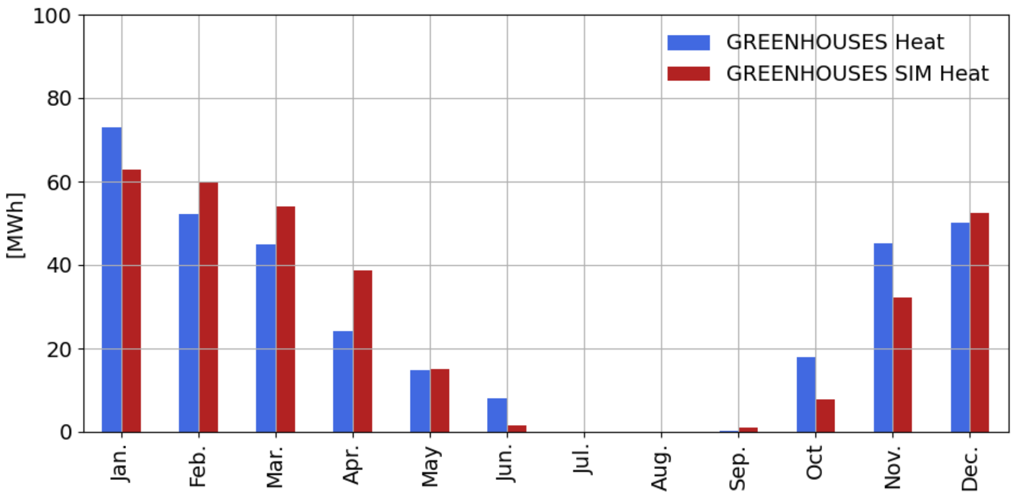

Figure 3-32: CBGP Greenhouses natural gas consumption simulated results versus real data

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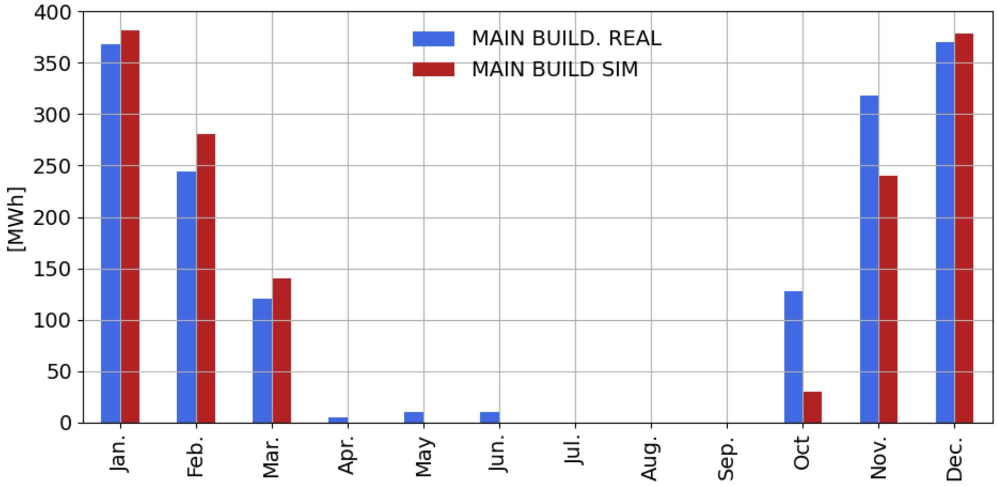

Figure 3-33: CBGP Main building natural gas consumption simulated results versus real data.

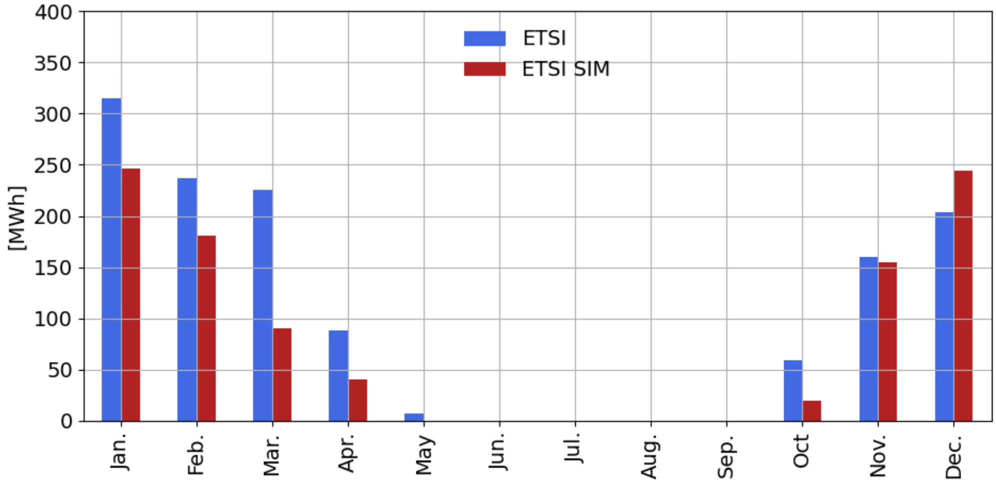

Figure 3-34: ETSI building natural gas consumption simulated results versus real data.

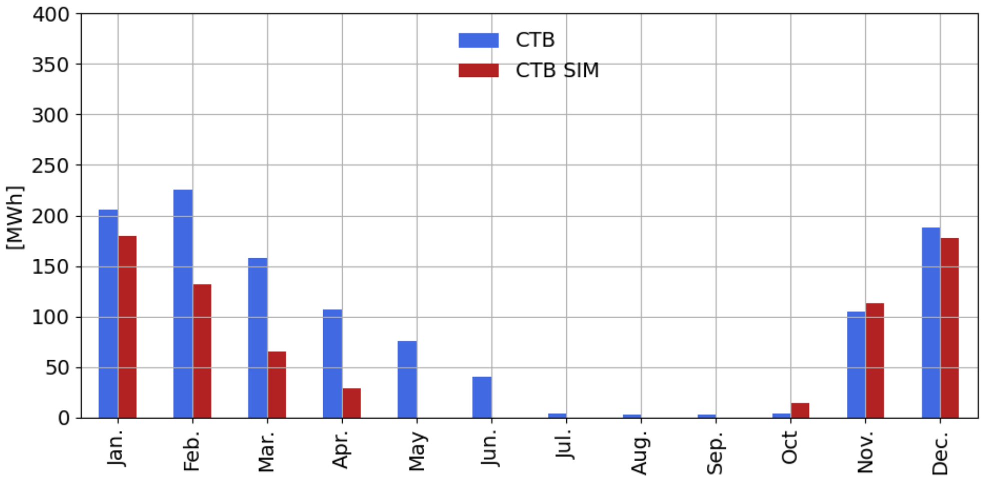

Figure 3-35: CTB Building natural gas consumption simulated results versus real data.

In a similar way, the electricity consumption of the simulated results was also adjusted to match real data provided. The main reason is due to unknown loads not properly addressed which leads most buildings to have a minimum consumption during its operation. Regarding the

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electricity consumption, the same disparities that could have possibly occurred with the natural gas profile obtained could apply to the following results.

Table 3-8: Electricity consumption simulated results.

	Electricity consumption [MWh]					
Month	**CBGP**	**CESVIMA**	**ETSI**	**CTB**	**CAIT**	**USOC/CIDA**
January	249	114	106	77	81	19
February	220	100	95	69	69	16
March	238	104	105	76	65	17
April	226	98	101	73	59	15
May	245	108	106	88	71	17
June	247	116	101	99	83	19
July	261	124	105	107	92	21
August	263	123	106	106	91	20
September	242	107	100	88	71	17
October	243	102	106	78	61	16
November	239	105	102	74	70	17
December	250	113	104	75	79	19
Total	2922	1315	1235	1011	892	214

As before, the following figures show the comparison between the simulated results obtained for electricity consumption versus the real data provided from Montegancedo Campus' authorities.
Regarding the adjustment performed on the electricity consumption profile obtained, more emphasis has been put on the bigger consumers of the Campus: CBGP, ETSI and CESVIMA.

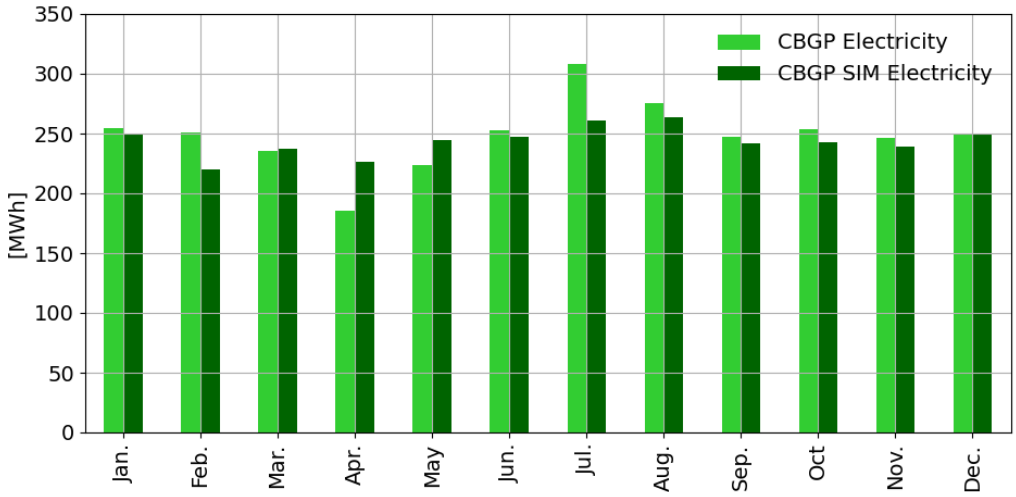

Figure 3-36: CBGP building + greenhouses electricity consumption simulated versus real data.

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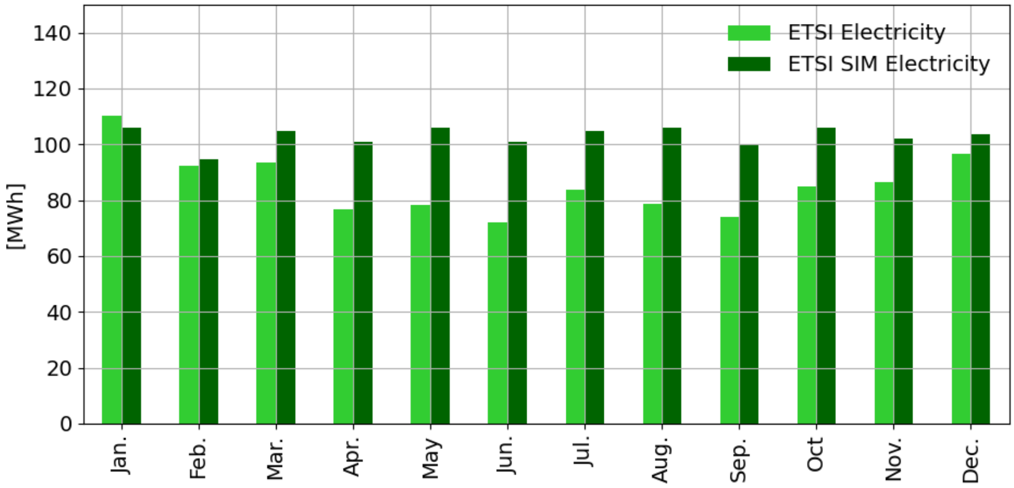

Figure 3-37: ETSI electricity consumption simulated versus real data.

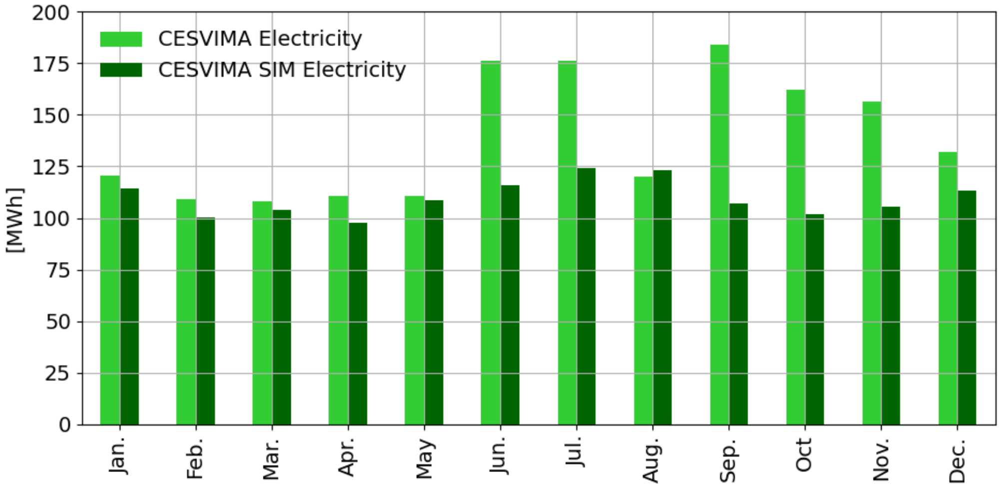

Figure 3-38: CESVIMA electricity consumption simulated versus real data.

3.2.3 FEASIBILITY STUDY

3.2.3.1 Selected scenarios

Considering the previous information, the technologies and solutions proposed to be studied for Montegancedo Campus are the following.

Table 3-9: Summary of technologies proposed for Montegancedo campus.

Technologies proposed	By means of
Waste heat recovery from data centres	Waste heat recovery from the chiller condenser with booster heat pump.
Absorption chillers	Main supply of cooling with solar driven heat.
Solar technologies	Main heat source of the generation plant for RES district heating.
Hot water storage	Optimized water storage sized for acting as solar buffer.
Biomass boiler	Biomass boilers installation for covering peak loads

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Different plant layouts from the WEDISTRICT portfolio have been identified as interesting layouts to be investigated as a possible implementation. Figure 3-39, Figure 3-40 show thermal plants that provides heat to a DH network by means of a biomass boiler and solar thermal panels. A gas boiler is used as backup/peak.

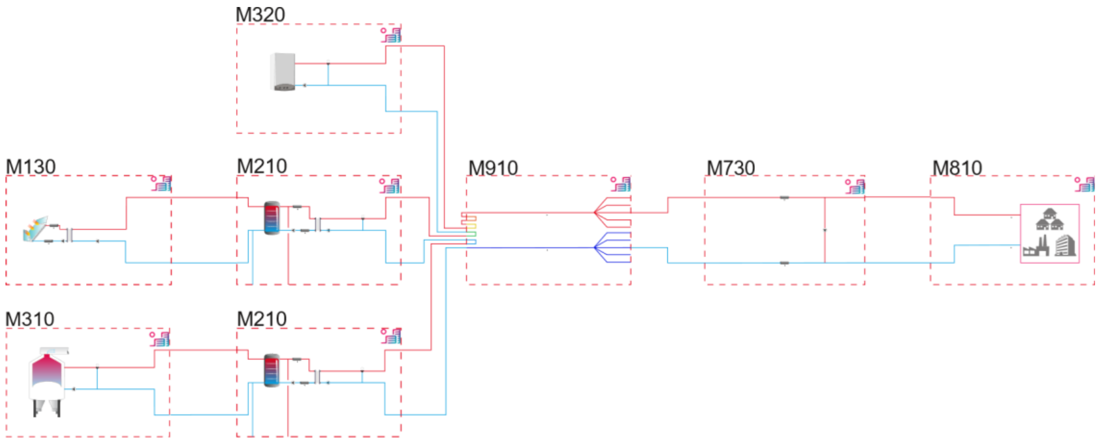

Figure 3-39: WEDISTRICT DECK 201- biomass boiler, solar field, and gas boiler

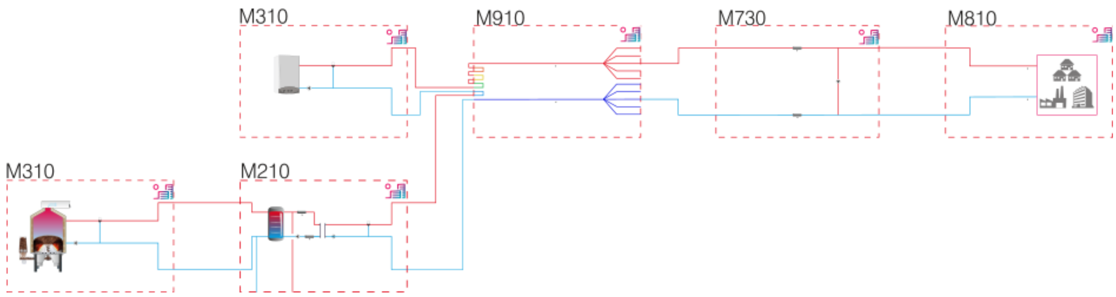

Figure 3-40: WEDISTRICT DECK 204 - biomass boiler, and gas boiler

With a similar configuration, Figure 3-41 represents the same systems as before but with the addition of a cooling network for cold water production. Cooling is provided by an absorption chiller and by a conventional air-cooled chiller used as backup/peak.

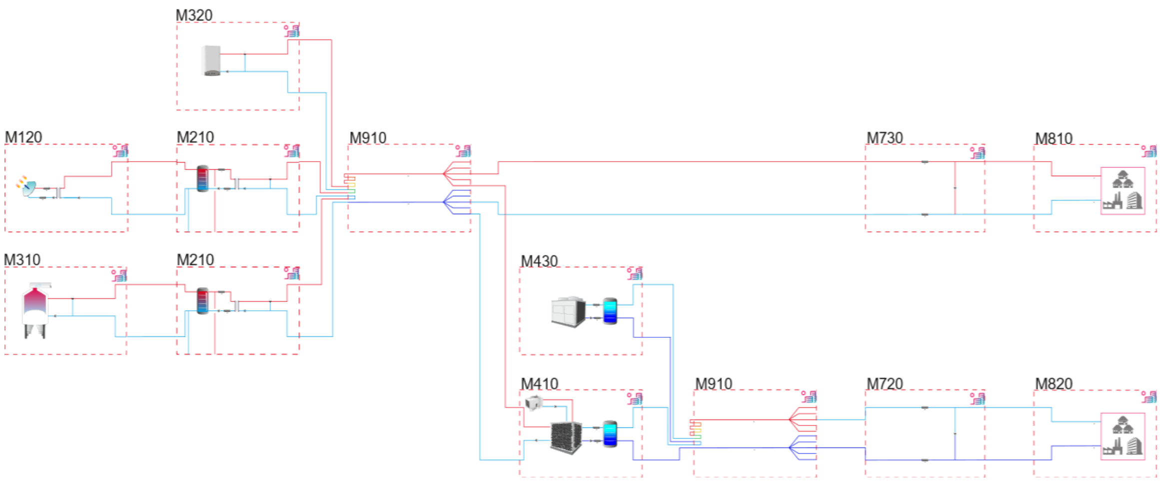

Figure 3-41: WEDISTRICT DECK 321: biomass boiler, solar field, and gas boiler, abs. and conv. chillers

Referring to the previously defined layouts, Table 3-10 resumes the simulation scenarios proposal.

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Table 3-10: Summary of solutions proposed for Montegancedo Campus

Solutions proposed overall description	
Combination code	MONTEGANCEDO – S1
Justification and plants description	This combination integrates biomass and gas boiler with a thermal storage to analyse the energy performance of a new heating generation plant. The integration of a solar collector field (Fresnel Collectors) is investigated and compared.
Expected impact	• Assess the preliminary design of a new district heating network that will replace the existing individual heating systems of the campus. • Obtain better environmental and economical KPIs respect to conventional technologies.
DHC layout and temperature regime	• Two-pipe networks (DCK204 and DCK201) working at high (90°C supply – 70°C return) or low (60°C supply – 40°C return) temperature.
Data centre cooling and waste heat recovery options	• No district cooling network. Data centre cooling supplied by individual existing equipment. No waste heat recovery.
Combination code	MONTEGANCEDO – S2
Justification and plants description	The heating part of this combination is like S1 (including Fresnel Collectors). Cooling is provided by an absorption and compression chiller technologies. The aim is to analyse the energy performance of a new heating and cooling generation plant.
Expected impact	• Assess the preliminary design of a new district heating network that will replace the existing individual heating and cooling systems of the campus. • Obtain better environmental and economical KPIs respect to conventional technologies.
DHC layout and temperature regime	• Four-pipe network (DCK321) working at high temperature (90°C supply – 70°C return).
Data centre cooling and waste heat recovery options	• Data centre as consumer of the district cooling network.
Combination code	MONTEGANCEDO– S3
Justification and plants description	This combination integrates biomass and gas boiler with a thermal storage as S1. However, this combination includes data centre waste heat recovery.
Expected impact	• Evaluate the possibility of implementing a data centre waste heat recovery solution through heat pump high temperature booster.
DHC layout and temperature regime	• Two-pipe networks (DCK204) working at high (90°C supply – 70°C return)
Data centre cooling and waste heat recovery options	• Data centre not as consumer of the district cooling network. Data centre waste heat recovery with heat pump implemented.

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3.2.4 FEASIBILITY STUDY

The feasibility study concerns a parametric analysis on the main equipment size of the power plant, mainly the biomass and gas boilers capacities, the solar collector field area, and the storage tanks volumes. To calculate the KPIs described in D2.2, the following boundary conditions are applied:

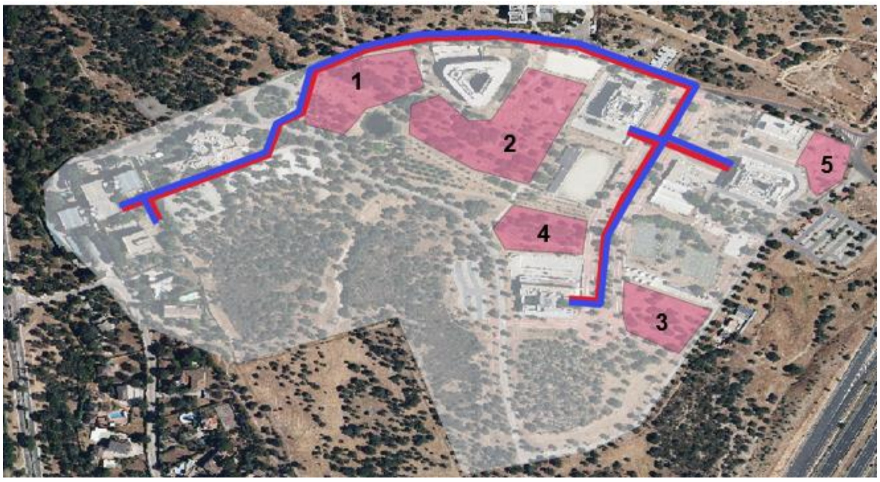
Table 3-11: Energy and price parameters considered

Energy Carrier	Non renewable	Renewable	Total	CO_2 emission factor [kg/MWh]	Price €/MWh
Fossil fuels solid	1.1	0	1.1	360	-
Fossil fuels liquid	1.1	0	1.1	290	-
Fossil fuel gas.	1.19	0.005	1.195	252	42.5
Bio fuels solid	0.2	1	1.2	40	35
Bio fuels liquid	0.5	1	1.5	70	-
Bio fuels gas.	0.4	1	1.4	100	-
Electricity	1.954	0.414	2.368	357	105
District heating	1.3	0	1.3	260	65
District cooling	1.3	0	1.3	260	65
Electricity to the grid	1.954	0.414	2.368	357	-
Electricity to non EPB uses	1.954	0.414	2.368	357	-

Table 3-12: Economical analysis parameters

Description	Value	Units
Lifetime	25	[years]
Discount rate	7	[%]

Moreover, it is interesting to identify the possible land availability of the campus to propose reasonable solar collector areas as well as a future possible layout of the district heating and cooling network. The layout proposed in this study is represented in Figure 3-42.



Zona	Area (m2)
1	9826
2	17193
3	5497
4	6115
5	3540

Figure 3-42: DHC layout and solar area availability zones considered

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3.2.4.1 SCENARIO1 (S1)

The aim of S1 is to evaluate the performance of two centralized power plants (DCK201 and DCK204) that would substitute the individual heating equipment of the campus. Moreover, to estimate the benefits of implementing a low temperature district heating network, simulations are performed for both high temperature and low temperature district heating regimes. In this way, each set of parameters identifies a simulation. Results are reported as comparison between the CO_2 emissions coefficient [kgCO_2/MWh] and the LCOE [€/MWh] for each simulation. Figure 3-43 shows the results obtained from the simulations at high and low temperature of DCK204 (Biomass + gas boilers).

The plot of the results creates a Pareto optimality, where there is no unique optimal solution. In the upper part of the graph, the results represent the scenarios where the entire heating capacity is supplied by the natural gas boiler. The CO_2 emission coefficient is close to the emissions factor used for natural gas and the LCOE considers the natural gas price and the CAPEX of the natural gas boiler installed. Notice that results create a “tail”. This tail is formed by the set of equal simulations that only differs in the volume of the storage tank that works against the biomass boiler. In the upper part of the graph the tail tents to an increase in LCOE and CO_2 emissions while in the lower part of the graph it tents to an increase in LCOE but to a decrease in CO_2 emissions. The explanation is that oversizing the storage tank respect the heating capacity of the biomass boiler only leads to further thermal losses. Instead, when the biomass capacity increases, a bigger storage tank allows increasing the usage of biomass respect to natural gas and so allows reducing emissions.

Another aspect investigated in this scenario is the operation of the same thermal plant in two temperature regimes: high temperature “HT” (90°C supply temperature – 70°C return temperature); and low temperature “LT” (60°C supply temperature and 40°C return temperature).In Figure 3-43, red dots represent simulation for the high temperature (HT) and light blue dots for the low temperature (LT). KPIs slightly improve due to lower thermal losses, which is related to the small size and length of the DH network (estimated in 1.3 km). Consequently, the thermal losses represent a small fraction of the energy balance, hence the advantages of low temperature are not seen on the distribution side. Despite this slight improvement, it must be considered that the implementation of a low temperature grid requires major changes in the emission systems of the campus that are not considered in this economic analysis. Moreover, the synergy of improving the buildings energy efficiency coupled with a low temperature grid is beyond the scope of the study.

Table 3-13: Range of parameters considered in Montegancedo S1 parametric HT and LT analysis

Biomass Boiler capacity [kW]	Gas Boiler capacity [kW]	TES capacity [m3]	Absorption chiller capacity [kW]	Conventional chiller capacity [kW]	Solar collectors field area [m2]
100-3400	100-3400	100-400	-	-	-

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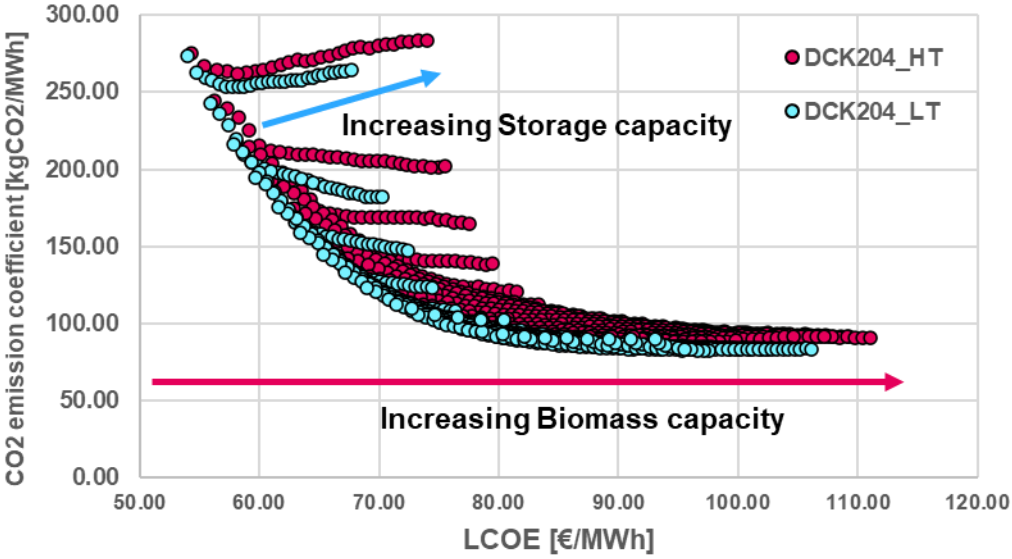

Figure 3-43: S1- DCK204 parametric HT and LT analysis results

The next step in the evaluation of S1 is the analysis of the impact of introducing a solar thermal collector field. Figure 3-44 shows the results for DCK201 (Biomass + gas boilers + solar field) and DCK204 (Biomass + gas boilers) working at high temperature. The solar field allows reducing the emissions of the system in a major way. However, due to the higher initial investment of these scenarios, the LCOE tents to be higher. Notice also an optimal region exists between LCOE of 70-90 €/MWh, where for the same value of LCOE, DCK201 (with solar) presents a reduction in CO2 emissions compared to the same LCOE value obtained in DCK204 (without). This highlights the capability of the solar system to be competitive against the other fossil fuels solutions. The limitations of the solar field collectors and thermal storage are evidenced in Figure 3-44. Beyond a certain threshold, the increase solar collector field does not further reduce the CO_2 emissions, as it become oversized for the summer and mid-season period with a minor gain on covering the peak demands in winter.

Table 3-14: Range of parameters considered in Montegancedo S1 parametric study of the new plant

Biomass Boiler capacity [kW]	Gas Boiler capacity [kW]	TES capacity [m3]	Absorption chiller capacity [kW]	Conventional chiller capacity [kW]	Solar collectors field area [m2]
900-4100	400-3600	200-600	-	-	250-4750

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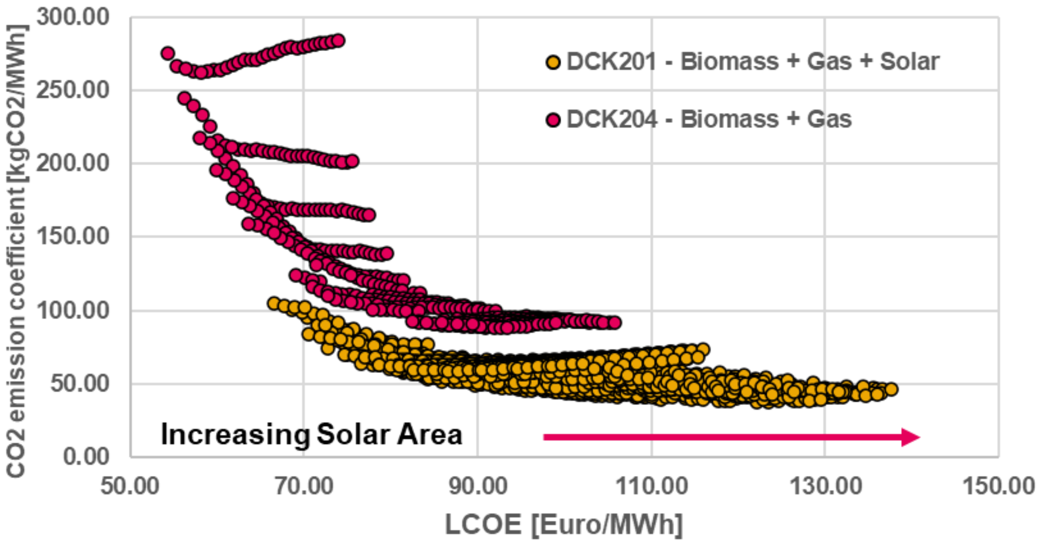

Figure 3-44: Parametric analysis results of Montegancedo S1

3.2.4.2 SCENARIO #2 (S2)

The aim of S2 is to evaluate the performance of a centralized power plant (DCK321) that would substitute both the individual heating and cooling equipment of the campus. Results are reported as comparison between the CO_2 emissions coefficient [kgCO_2/MWh] and LCOE [€/MWh], as well as with the absorption chiller capacity for each simulation. As general consideration, the decks including absorption chillers must be analysed in high detail with regards of sizing and controls, consequently a generic parametric analysis does not properly identify the optimum behaviour of these power plants. Indeed, they present a higher level of complexity due to the interaction of a several number of equipment and controls. Figure 3-45 show the results for the parametric analysis of S2 simulated with DCK321. Simulations not covering at least the 95% of the demand are not reported. Notice how the parametric approach used for cooling networks leads to few acceptable results. With the current demand of Montegancedo Campus, it does not seem reasonable to build a four-pipe network. Best cases present an acceptable CO_2 emission coefficient, but the LCOE value is too high to consider the investment. Economical results are indeed affected by the high auxiliary consumption of the absorption chillers as well as their low COP value (maximum 0.7). Moreover, absorption chillers are profitable if they can exploit a waste heat source coming for example from a CHP plant, but it is not reasonable to build an oversized heating plant to feed the heat source of the absorption chillers.

Table 3-15: Range of parameters considered in Montegancedo S2 parametric study of the new plant

Biomass Boiler capacity [kW]	Gas Boiler capacity [kW]	TES capacity [m3]	Absorption chiller capacity [kW]	Conventional chiller capacity [kW]	Solar collectors field area [m2]
2500-4500	1000-3000	200-600	100-3100	400-3400	1000-5000

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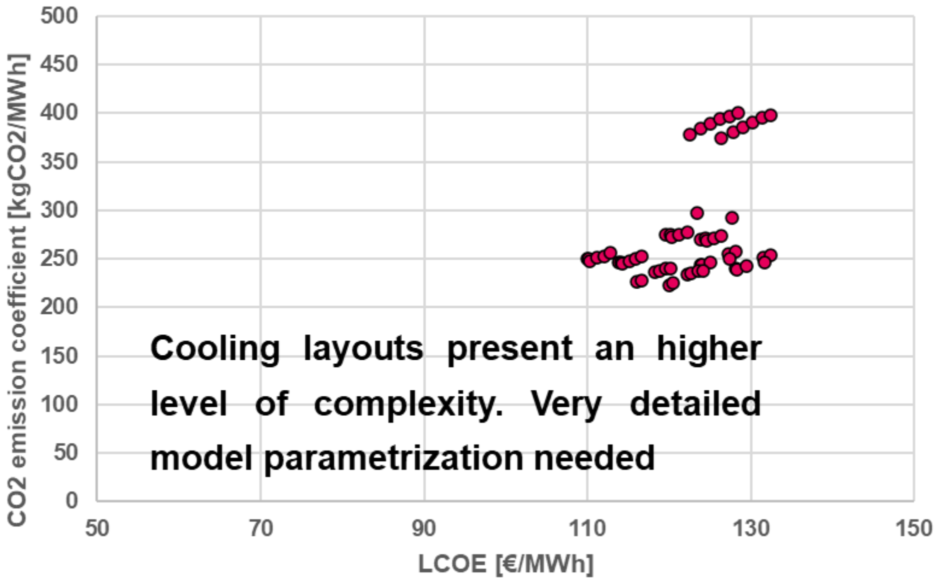

Figure 3-45: Parametric analysis results of Montegancedo S2

Figure 3-46 highlights that there are limitations in the modelling approach of the cooling generation with absorption chillers. Both LCOE and CO_2 emissions increase for an increase in power capacity of the chiller. It is important to remark that the sizing approach considers an absorption chiller to cover the base load and a compression chiller to cover the peak. The parametric study balances the both nominal power to ensure that the peak load is covered by the sum of their capacities. The compression chiller is assumed to have nominal COP of 5, which makes very difficult to find feasible scenarios for the absorption chiller if operation aspects are not taken in further detail, which is beyond the scope of the study.

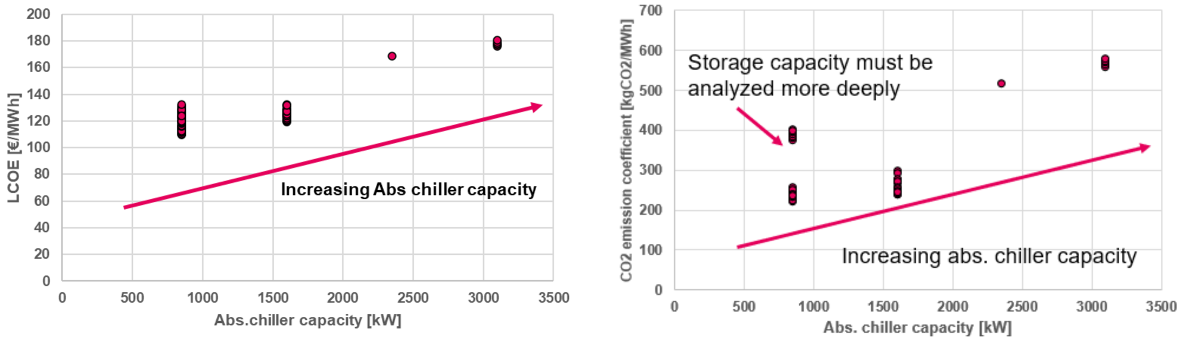

Figure 3-46: LCOE and CO2 emissions compared to abs. chiller capacity

3.2.4.3 SCENARIO 3 (S3)

The aim of S3 is to evaluate the performance of a centralized power plant running a high temperature network (DCK204) that would substitute the individual heating equipment of the campus. This scenario includes the waste heat recovery from the CESVIMA data centre. Figure 3-47 shows the data centre waste heat recovery solution considered and modelled. The solution concerns the introduction of a high temperature heat pump (60kW) that extracts heat from the condensing loop of the main cooling unit of the data centre and boosts this temperature to match district heating supply temperature. The data centre modelling approach has been already validated in previous projects (RenewIT, http://www.renewit-project.eu/).

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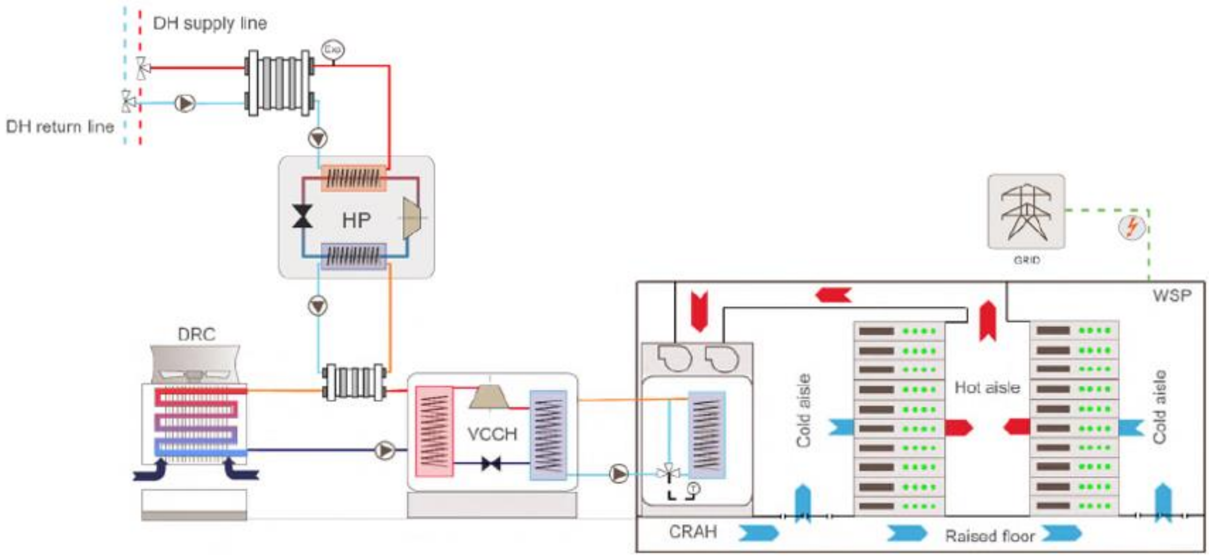

Figure 3-47: Waste heat recovery solution considered

Figure 3-48 shows the integration of the waste heat recovery solution with the whole generation plant where heat can be injected from the condenser side of the heat pump into the district heating network.

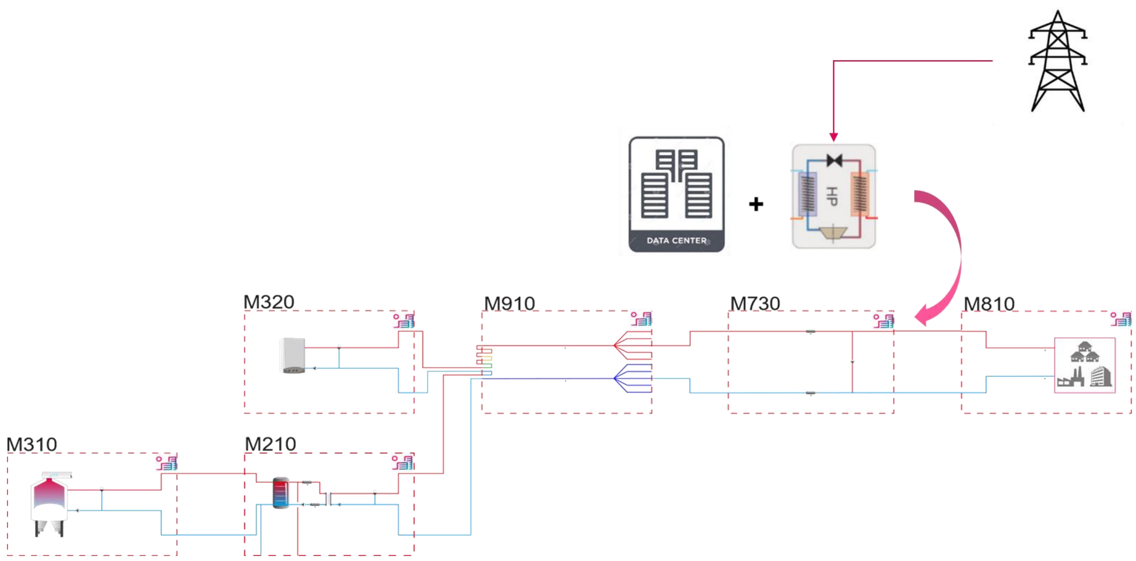

Figure 3-48: Waste heat recovery coupling with heating generation plant

Figure 3-49 shows the results for S3. Red dots represent results for the set of parameters that do not include the waste heat recovery (WHR) solution while purple dots are the results of the exact same system (same equipment sizing and operation) but with the waste heat recovery included. To properly calculate the system KPIs, the heat recovered from the WHR system has been subtracted from the overall heating demand of the plant and the additional electrical consumption to run the integration (mainly the heat pump power consumption) has been considered. Results shows that the WHR solution bring benefits in terms of overall CO_2 emission but increases the cost of the system. This is justified by the high price of electricity that must be bought from the grid to run the heat pump and from the low selling price of the

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heat. Moreover, it must be considered that the data centre capacity its small compared to the overall heating demand of the campus and this limits the impact of the solution. Furthermore, the design approach assumes that the central plant must be able to cover the whole demand, hence it is sized without considering the contribution of the HP. This causes an excess of capacity and redundancy of equipment, which in small networks cause increase of investment cost. Therefore, as general conclusion, it can be stated that, to avoid system oversizing, it is important to include the data centre waste heat recovery already in the design phase of the generation plant.

Table 3-16: Range of parameters considered in Montegancedo S3 parametric study of the new plant

Biomass Boiler capacity [kW]	Gas Boiler capacity [kW]	TES capacity [m3]	Heat pump capacity [kW]	Conventional chiller capacity [kW]	Solar collectors field area [m2]
900-4100	400-3600	100-600	60	-	-

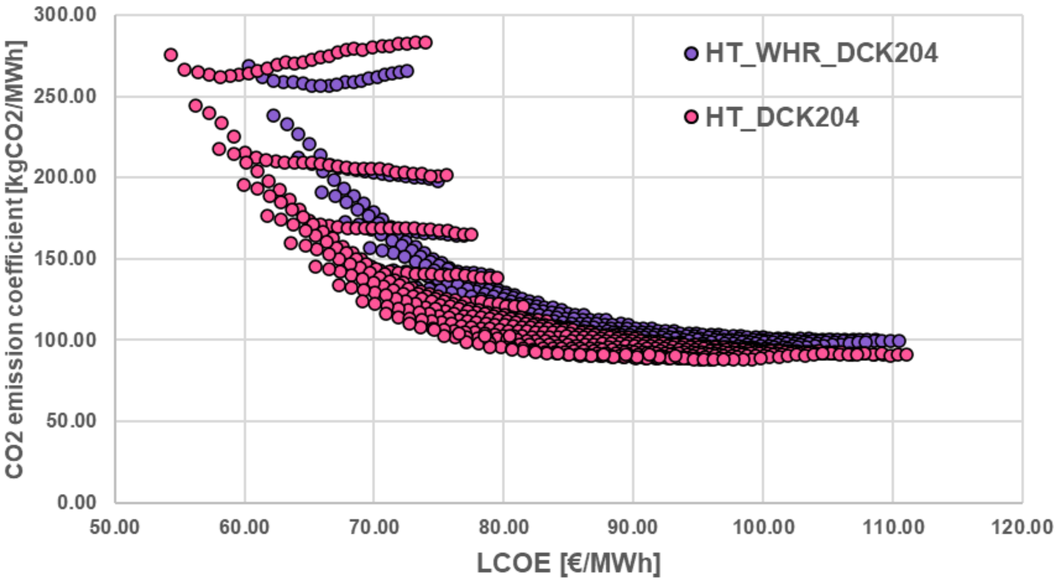

Figure 3-49: Parametric analysis results of Montegancedo S3

Another important consideration is that the data centre generates heat along all the year. However, the heat demand of the campus drops in summer. The simulations do not account for short of long term storage of the DC heat, hence this can only be injected to the grid when there is demand. Notice in Figure 3-50 how the waste heat recovered (Qsupplied, red bars) decreases during warmer months limiting the heat recovery capabilities of the integration. It is interesting to consider a seasonal storage solution that will enable heat storing during summer period to be discharged in winter.

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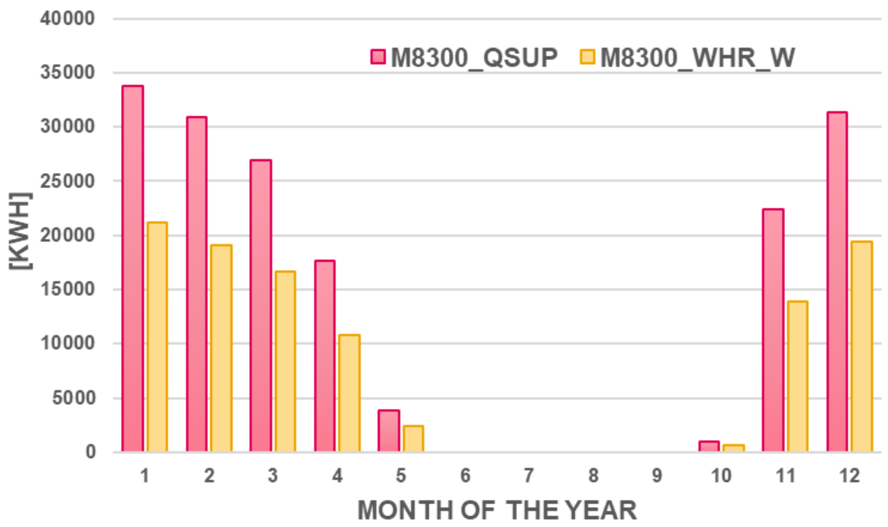

Figure 3-50: Electrical power consumption of the WHR solution (M8300_WHR_W) and total heat supplied to the DH network (M8300_QSUP) to cover the demand.

3.2.4.4 SCENARIOS COMPARISON

Tables below present two sets of parameters for each Scenario. The cases with minimum CO_2 emission coefficient (S1-CO_2) and LCOE (S1-ECO) are summarized on the following tables.

Table 3-17: Montegancedo S1 Optimum results

S1	Biomass boiler [kW]	Gas boiler [kW]	Heat storage vol. [m3]	Solar Area [m2]	Abs chiller cap. [kW]	Conv. Chiller cap. [kW]	Cold storage vol. [m3]
S1-ECO	100	4400	15	-	-	-	-
S1-CO_2	3300	1200	380	5750	-	-	-

Best LCOE = 54.30 €/MWh, Best kCO_2 = 37.98 kg/MWh

Table 3-18: Montegancedo S2 Optimum results

S2	Biomass boiler [kW]	Gas boiler [kW]	Heat storage vol. [m3]	Solar Area [m2]	Abs chiller cap. [kW]	Conv. Chiller cap. [kW]	Cold storage vol. [m3]
S2-ECO	2500	3000	200	3000	850	2650	145
S2-CO_2	3500	2000	200	5000	850	2650	145

Best LCOE = 109.95 €/MWh, Best kCO_2 = 223.34 kg/MWh

Table 3-19: Montegancedo S3 Optimum results

S3	Biomass boiler [kW]	Gas boiler [kW]	Heat storage vol. [m3]	Solar Area [m2]	Abs chiller cap. [kW]	Conv. Chiller cap. [kW]	Cold storage vol. [m3]
S3-ECO	100	4400	15	-	-	-	-
S3-CO_2	4300	200	140	-	-	-	-

Best LCOE = 54.30 €/MWh, Best kCO_2 = 87.87 kg/MWh

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3.2.4.5 SCENARIO TO BE DEVELOPED

The most promising solution is Scenario #1. Indeed, especially the solution with solar collector panels shows a great potential in reducing CO_2 emissions even without compromising the economical side. Moreover, solar collector area has been estimated considering land availability to stick with a realistic design that would not affect the woodland on the Campus.

3.2.5 CONCLUSIONS

Results of this preliminary feasibility study highlight that there's room for implementing a heating district network which will be able to improve both economic and environmental indicators of the Campus. Further improvements can be made in the demand profile characterization, with an even more detailed data collection that could be useful to address specific "special" loads as can be the greenhouses heating and cooling needs in the CBGP. Moreover, cooling plant layouts could be analysed more in detail with special focus on absorption chillers controls and cold storage optimization.

3.2.5.1 Extended study proposal

In the framework of WEDISTRICT the study put focus on the heating and cooling generation side of the power plants. However, another important aspect of the overall picture is the location and optimization of the heating and cooling distribution network. The proposed extension of the study concerns the design of several distribution network layouts inside the Campus with the aim of evaluating the optimal configuration that minimizes costs and emissions. A first proposal of the different layouts that can be investigated is presented in Figure 3-51.

Figure 3-51: DHC distribution layouts proposal for Montegancedo Campus

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The analysis showed promising results in the implementation of solar collector field. Further studies should consider the specifics of the location, as the influence of the surrounding shadows and the available space.

Finally, the promising results, together with the energy prices crisis invite to further evaluated the implementation of the district heating network. This requires increasing the detail of the buildings demand profile and the feasibility of substituting the existing equipment by substations in each building. Also, the market for suppliers of biomass should be analysed in detail. Finally, the funding opportunities need to be incorporated into the economic evaluation, as it may increase the economic feasibility of the development.

3.3 Playa del Inglés (Gran Canaria – Spain)

3.3.1 GENERAL DESCRIPTION

The Canary Islands is a Spanish archipelago in the Atlantic Ocean, in a region known as Macaronesia. At their closest point to the African mainland, they are 100 kilometers west of Morocco. They are the southernmost of the autonomous communities of Spain and are located in the African Tectonic Plate. The archipelago is economically and politically European and is part of the European Union.

The eight main islands are (from largest to smallest in area) Tenerife, Fuerteventura, Gran Canaria, Lanzarote, La Palma, La Gomera, El Hierro and La Graciosa. The archipelago includes many smaller islands and islets, including Alegranza, Isla de Lobos, Montaña Clara, Roque del Oeste, and Roque del Este. The Canary Islands are the southernmost region of Spain, and the largest and most populous archipelago of Macaronesia. Because of their location, the Canary Islands have historically been considered a bridge between the four continents of Africa, North America, South America, and Europe.

Figure 3-52. Canarias archipelago. Google Maps

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In 2019, the Canary Islands had a population of 2,153,389[2] (with a density of 287.39 inhabitants per km2), making it the eighth most populous autonomous community. The population is mostly concentrated in the two capital islands: around 43% on the island of Tenerife and 40% on the island of Gran Canaria.[1]

Gran Canaria island is called a "miniature continent" due to the different climates and variety of landscapes found, with long beaches and dunes of white sand, contrasting with green ravines and picturesque villages. A third of the island is under protection as a Biosphere Reserve by UNESCO. The number of annual visitors was 3.6 million in 2014 (of which 450.000 Spaniards). Most of the tourists visit the southern part of the island. The north tends to be cooler, while the south is warmer and sunny. The east coast of the island is flat, dotted with beaches, while the western coast is rockier and mountainous.

Figure 3-53. Gran Canarias Island. Google Maps

In the south there is a large bird park, Palmitos Park, as well as many beach resort communities. Resorts are concentrated in the central eastern part of the southern coast in the Maspalomas area, which includes the towns of San Agustín, Playa del Inglés and Meloneras.

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[1] https://en.wikipedia.org/wiki/Canary_Islands

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The Maspalomas Dunes are located between Playa del Inglés ("The Englishman's Beach") and the distinctive 19th century Maspalomas lighthouse. Playa del Ingles is home to the Yumbo Centre, which was opened in 1982 and has almost 200 shops, including bars, restaurants, cafes, fashion boutiques, electronic outlets and jewellery stores.[2]

As shown in the image below, a huge number of hotels and touristic services are located in few kilometers in this south-east part of the Gran Canaria island, in the area around the site known as “Playa del Inglés”

Figure 3-54. Available hotels in Playa del Ingles, according to Google Maps

According to the Köppen climate classification, Gran Canaria is considered to have a desert climate (Bwh) due to its severe lack of precipitation. Gran Canaria has consistent warm temperatures in spring, summer and fall, and mild winters. Gran Canaria is noted for its rich variety of microclimates. Generally speaking though, the average daytime high ranges from 20 °C in winter to 26 °C in summer. Some cool nights occur in winter, but lows below 10 °C are unknown near the coast. Inland the climate is still mild but mountainous areas see the occasional frost or snow. Cloud cover and sunshine is often quite variable during the cooler months, and there can be several rather cloudy days at times in winter. Summers are generally quite sunny however, with the south of the island being most favored.[3]

[2] https://en.wikipedia.org/wiki/Gran_Canaria
[3] https://en.wikipedia.org/wiki/Gran_Canaria

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	January	February	March	April	May	June	July	August	Septem.	October	November	Decem.
Avg. temperature (°C)	16	15.9	16.9	17.6	18.8	20.4	22.1	23.1	22.3	21.5	19.1	17.3
Min temperature (°C)	13.9	13.7	14.4	15	16.1	17.6	19.2	20.2	19.8	19.2	17.1	15.3
Max temperature(°C)	18.4	18.5	19.9	20.5	21.8	23.6	25.9	26.8	25.4	24.2	21.5	19.6
Precipitations (mm)	18	20	18	13	10	4	0	1	9	24	18	32
Humidity	70%	71%	69%	69%	67%	69%	66%	67%	73%	74%	72%	72%
Rainy days	3	3	3	3	2	1	0	0	2	5	3	4

Figure 3-55. Weather Table for Playa del Inglés[4]

The high density of hotels, the continuous occupation during the year and the warm weather, configurates the perfect case for a district cooling and, provably, heating, due to de DHW and swimming pool heating load. By now, the ITC (Canarian Technological Institute) is developing a georeferenced map of cooling and heat demand in Canary Islands tourist areas based on the size and category of the tourist establishment, the size of the swimming pools and the number of users. It will also incorporate the availability of space in the vicinity and will generate an approximation with little detail of the type of fuel used in the chosen area.

The focus area and the load profile will be defined using the results of ITC's work, still under development.

PRELIMINARY ASSESSMENT

With a latitude 27º 44' north and 0 m above the sea level, Playa del Inglés has a global yearly solar radiation of 2.153,5 kWh/m2, according to the CIEMAT's[5] solar radiation data base, as shown in the following figure.

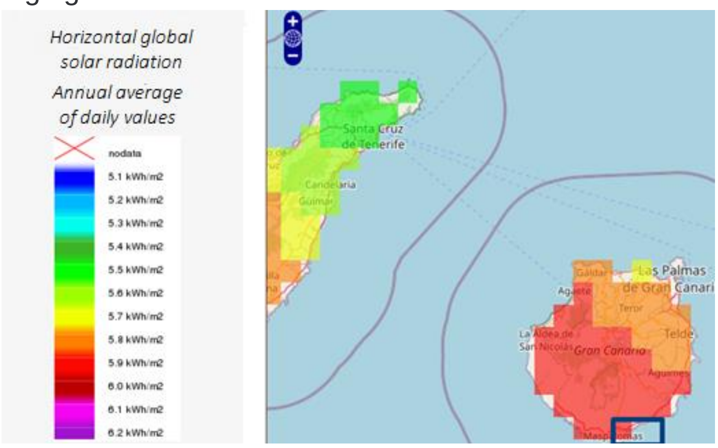

Figure 3-56. Solar radiation in Gran Canarias. Selected area indicated by blue rectangle[6] (

[4] https://es.climate-data.org/europe/espana/canarias/playa-del-ingles-18298/#climate-table
[5] http://www.adrase.ciemat.es/mapa-zona-canarias/index.php
[6] http://www.adrase.ciemat.es/mapa-zona-canarias/index.php

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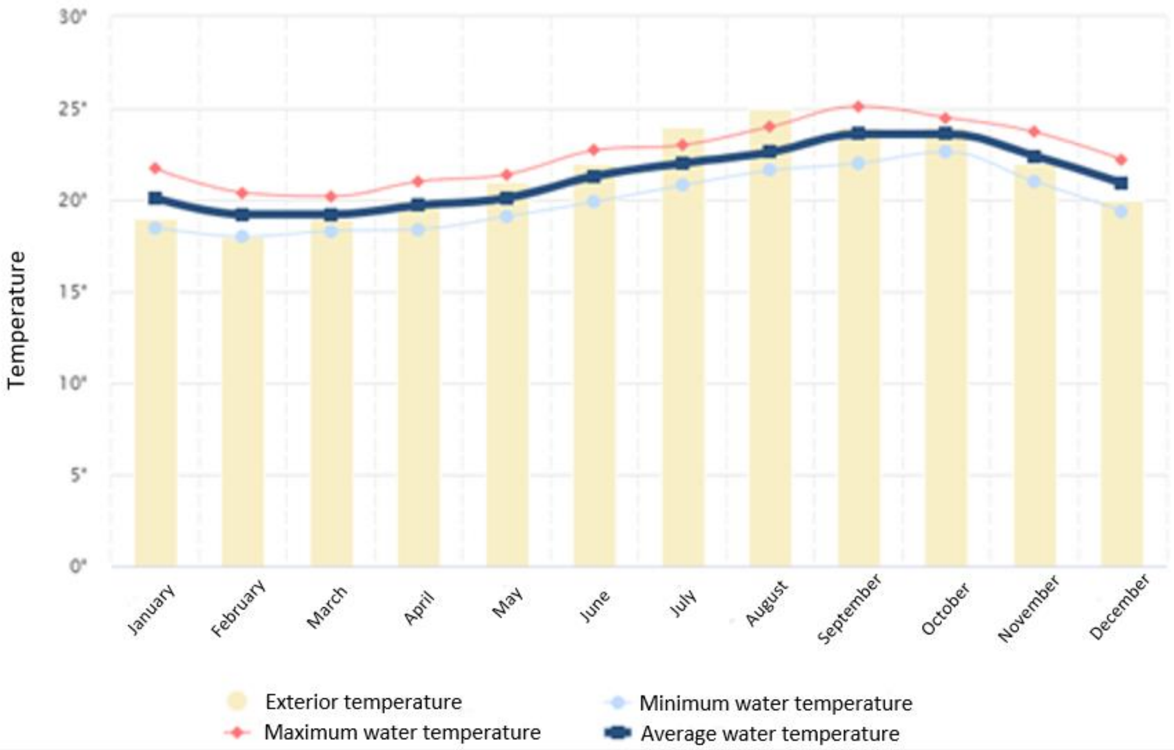

Figure 3-57. Seawater temperature in southern Gran Canarias's coast[7]

Based in the previous information, regarding heating demand, a base of continuous DHW load is expected increased by the end of autumn and the beginning of spring by outdoor swimming pool conditioning, and with some space heating winter needs. Regarding to cooling demand, at least 6 months of required climatization is expected.

Assuming this loads hypothesis and looking for taking the maximum profit of boundary resources, sun and sea, solar absorption cooling could well be a well fitted solution, using the sea for refrigeration purposes, in order to cover the main seasonal cooling demand phased with solar resource. Heating load may be covered directly with surplus solar heat, both in summer and winter, and supported by an electrical heat pump that would be able to use the sea, but also the absorption chiller rejected heat, as heat source. Electricity power shall be generated, at least partially, by PV on-site.

According to recent analysis done in Transhotel project by ITC, this solution with conventional technology is still not competitive with mechanical compression chillers but expected increase of absorption COP of the Advanced Absorption Chiller and the expected reduction of thermal energy cost thanks to Wessun solar collector, should be enough to reach the reference energy cost or even overcome it.

[7] https://www.temperaturadelmar.es/europa/gran-canaria-las-palmas/maspalomas/when.html

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	Cost $[€/kW_{th}]$	Emissions $[kgCO_2/kW_{th}]$
Absorption water chillers (100 kW) operated with thermal solar energy (energy surplus)	**0,047**	**0,000**
Air-condensation, electrically-actuated, mechanical-compression water chillers	0,033	0.262
Electrically driven mechanical compression water chillers for geothermal condensing (groundwater)	0,020	0.159

Figure 3-58. ITC's cooling technologies comparison for Islas Canarias weather from Transhotel[8] project

Considering the previous information, the technologies and solutions proposed to be studied in Playa del Inglés demo-follower are the following:

Table 3-20 Summary of technologies for Playa del Ingles demo-follower.

Technologies proposed	By means of
Solar technologies	Massive use of solar technology in a large thermal system to drive advanced absorption chiller in summer and to produce heat in winter
Advanced Absorption chiller	Use of the advanced absorption chiller solar driven, to produce a significant part of the summer cooling demand. Cooled by seawater and/or by an electrical heat pump
Electrical Heat Pump	Coupled to the advanced absorption chiller condenser, instead of the cooling tower or the cooling well, this heat pump may produce heating recovering the rejected heat
Hot water storage	Optimized water storage sized for acting as solar buffer

[8] *https://www.solarthermalworld.org/sites/default/files/news/file/2015-02-21/trnshotel_simulation_results_pilar_navarro.pdf*

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Table 3-21 Solution for Playa del Ingles demo-follower.

Technology	Scenario
PTC	
Fresnel	
TF-FTC	X
Biomass	
Molten Salts	
Hybrid PV-Geothermal	
Advanced Absorption Chiller	X
RACU	
FC-WHR	
Gas Boiler	
Electrical Chiller	X

Table 3-22 Solutions proposed for Playa del Ingles demo-follower.

Solutions proposed overall description	
Combination code	Playa del Inglés – S1
Justification	This combination uses Wessun solar collector and the advanced solar absorption chiller, in order to cover the main seasonal cooling demand phased with solar resource. Heating load may be covered directly with surplus solar heat, both in summer and winter, and supported by an electrical heat pump but also the absorption chiller rejected heat, as heat source.
Expected impact	• Maximise solar resource. • Reduction of heat island effect • Improvement of absorption chiller performance. • Avoidance of the CO_2/NOx emissions associated to the current electrical system • CAPEX and OPEX comparison with the BAU solution

POTENTIAL COSTUMERS

Potential customers for the district system were chosen within the area indicated and are shown in Figure 3-59, while the heatmap of the area is shown in Figure 3-60.

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Figure 3-59. District system analysis area

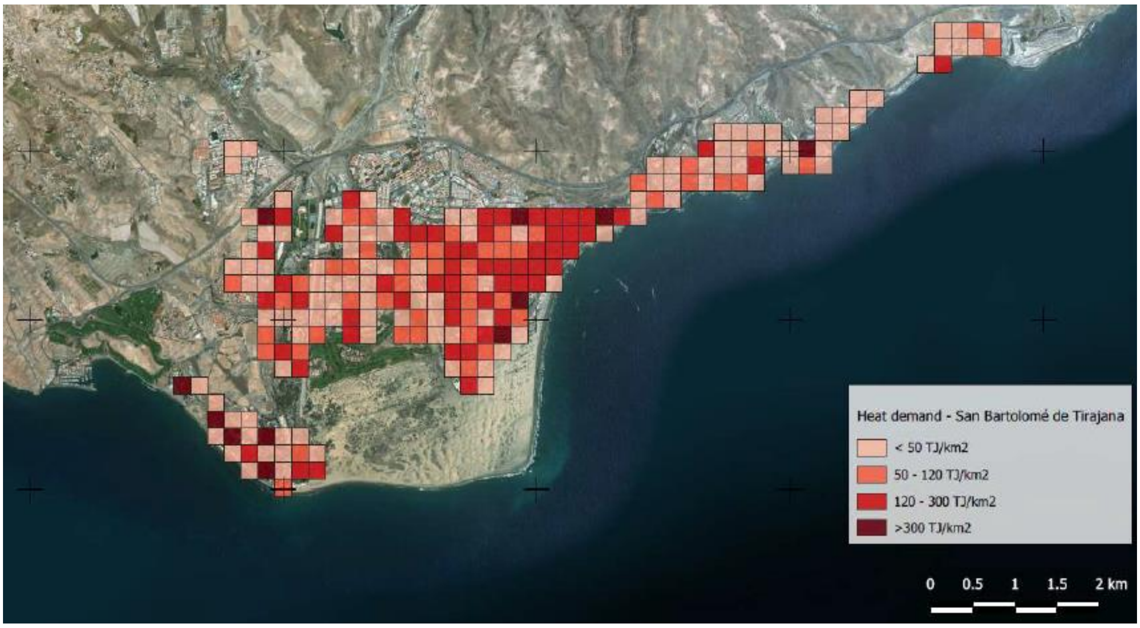

Figure 3-60. Heatmap of the study area

As can be seen, the heat map indicates that there is a high demand for heat in the coastal sector from where 18 potential customers were chosen.

The 18 buildings initially evaluated correspond to hotels with different characteristics in terms of year of construction and category, ranging from individual residence-type hotels to 4-star buildings. In general, all buildings have a demand for space air conditioning, DHW and heat for swimming pools and have a boiler or heat pump system for heat and a cooling system that can be centralized or through a split system.

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Of the 18 buildings initially evaluated, 8 have been selected as potential customers due to the feasibility of connecting them to a centralized system. The remaining buildings have not been considered because they have an individual cooling system per room, making it difficult and possibly very expensive to connect them. This type of buildings corresponds mainly to individual residence-type hotels.

The main characteristics of 8 buildings are shown in Table 3-23.

Table 3-23 Main characteristics of the 8 buildings finally selected as potential customers

Hotel Name	Year of Construction	Category	Land Area [m²]	Constructed Area [m²]	Number of Rooms	Capacity [people]	Superficie de piscinas [m²]
ESCORIAL (EL)	1973	Tres estrellas	9 356,00	14556	250	558	280,42
CASERIO	1997	Cuatro estrellas	4 873,00	9233	170	234	221,89
LABRANDA PLAYA BONITA	1972	Cuatro estrellas	12 662,00	10656	260	520	322,66
GREEN FIELD	1987	Tres estrellas	9 196,00	15431	324	730	370,99
PARQUE TROPICAL	1971	Cuatro estrellas	11 983,00	11590	234	445	630,50
LUCANA	1985	Cuatro estrellas	6 230,00	11584	182	366	375,45
EUROPALACE	1974	Tres estrellas	6 856,00	13776	208	581	205,85
IFA CONTINENTAL HOTEL	1972	Tres estrellas	15 021,00	24633	383	728	577,66

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ENERGY LOADS

Thanks to the data that was provided, it was possible to determine the heating, DHW and cooling loads for all 8 buildings. The graph in the images below shows the energy loads, allowing the seasonality of said demand to be observed.

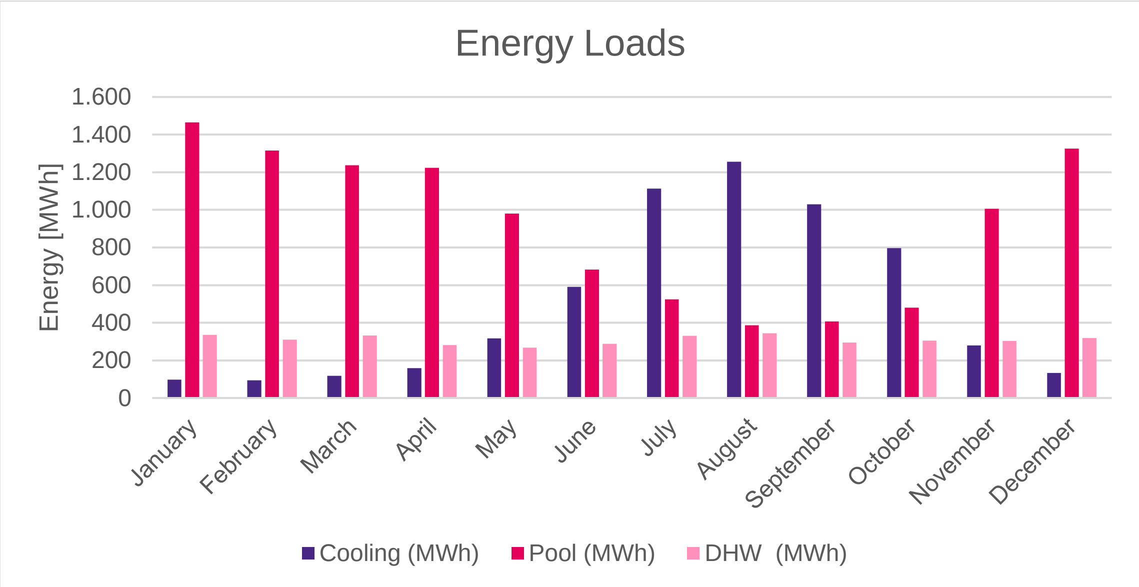

Figure 3-61. Monthly energy loads for Playa del Ingles, Gran Canaria

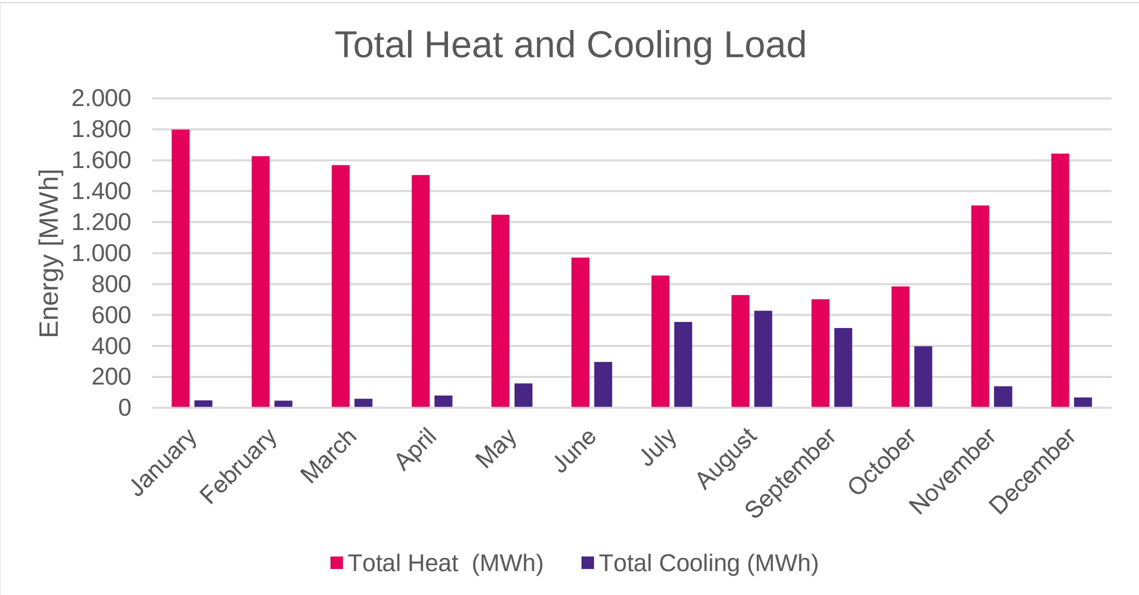

Figure 3-62. Monthly total energy loads for Playa del Ingles, Gran Canaria

The Figure 3-63 on the other hand, shows the monotonous curve for the energy loads in the Gran Canaria area, where it can be seen the heating and cooling power demand.

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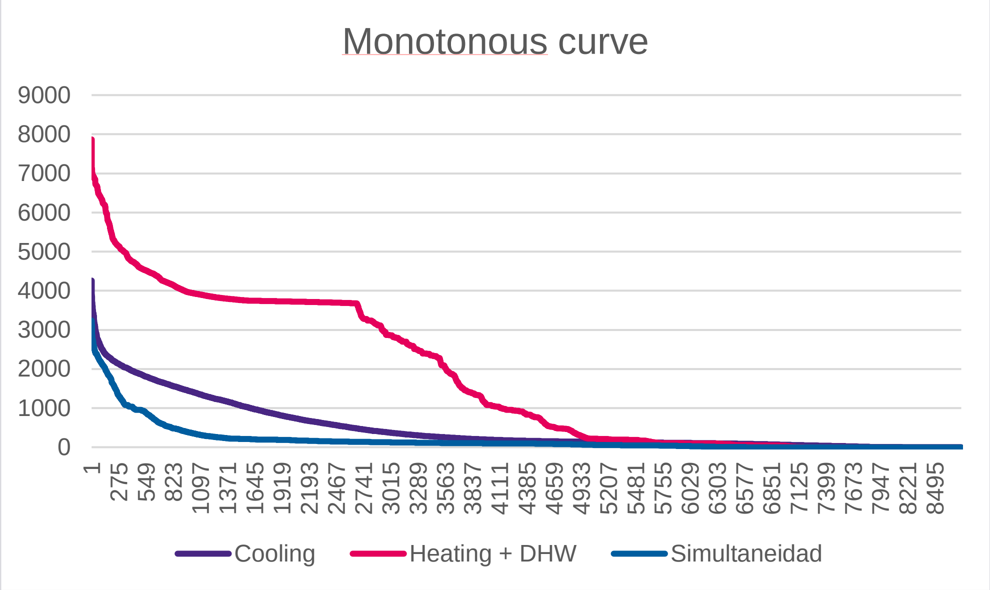

Figure 3-63. Monotonous Curve of loads

Finally, the Table 3-24 summarizes the results of the energy loads evaluation for the 8 potential customers.

Table 3-24 Energy loads for 8 buildings

	Cooling	Heating	DHW	Pools
Energy [kWh]	4.267.020	549.594	3.608.952	11.030.262
Power [kW]	4.258,0	2.117,8	3.240,2	3.751,2

3.3.2 REFERENCE CASE MODEL

A base case model has been developed in order to serve as a baseline for assessing the effect of the proposed system. The reference case is based on the actual heating and cooling systems for each building in the study area. The reference case diagram for Playa del Inglés Virtual Demo is as shown in the image below.
As can be seen, the system is made up of a hot water circuit for the supply of water for swimming pools and domestic hot water for each hotel individually. The system also contains a cold-water circuit generated by a chiller, for cooling in each hotel.

Each hotel has an individual heating and cooling system, generally represented by the diagram. In terms of the services for which supply is required, hotels are very similar to each other. In summary, each hotel has a heated swimming pool, with water at approximately 35°C and they require a supply of domestic hot water, at approximately 45°C to 50°C. In this way, the individual systems generate hot water at a high temperature to accumulate in a domestic hot water storage and by mixing it with cold water, they also generate water at a lower temperature to supply the swimming pools.

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In the case of cooling, some hotels have individual systems such as multisplit, while other hotels have a centralized cool generation system through a chiller and a distribution system to each room. In the case of hotels with an individual system, the investment that would be required to connect them to the district system would be very high since they do not have an internal distribution system, so it is decided not to connect these buildings to the district cooling service. In the case of buildings that currently have a centralized system, the connection to the district system in its entirety can be made.

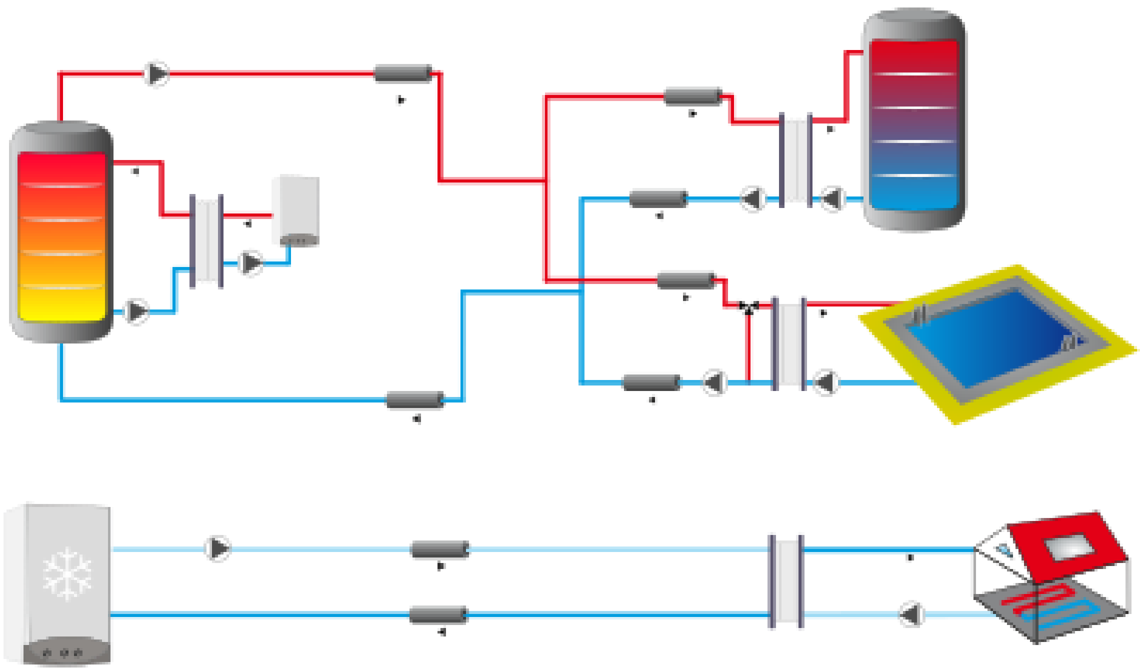

Figure 3-64. Reference case diagram for Playa del Ingles demo-follower.

3.3.2.1 WEDISTRICT TECHNOLOGIES CASE MODEL AND TRNSYS MODEL

The diagram for the proposed system design is shown in Figure 3-64. The diagram shows that the main generation equipment, both cooling and heating, is the absorption heat pump with heat recovery (AHPHR) coupled with WESSUN solar technology. The operation of the system consists of the following:

- The AHPHR transforms the high temperature stream from the WESSUN solar system into medium and low temperature streams that are both exploited in these systems due to its low use temperature.
- An aerothermal heat pump supports the AHPHR capacity working at the same temperature is serial connected through another storage tank. At this point, the heat that is being generated is distributed through pipes to each building.
- In each building there are two heat transfer station:
  - A heat exchanger supplies directly heat to the swimming pools
  - In parallel, a water condensed heat pump raises the water temperature level from the distribution one to of the water to approximately 60°C to prepare DHW
- For cooling generation, the main equipment is the AHPHR with a supply temperature of 12°C. This equipment is supported by a conventional chiller.

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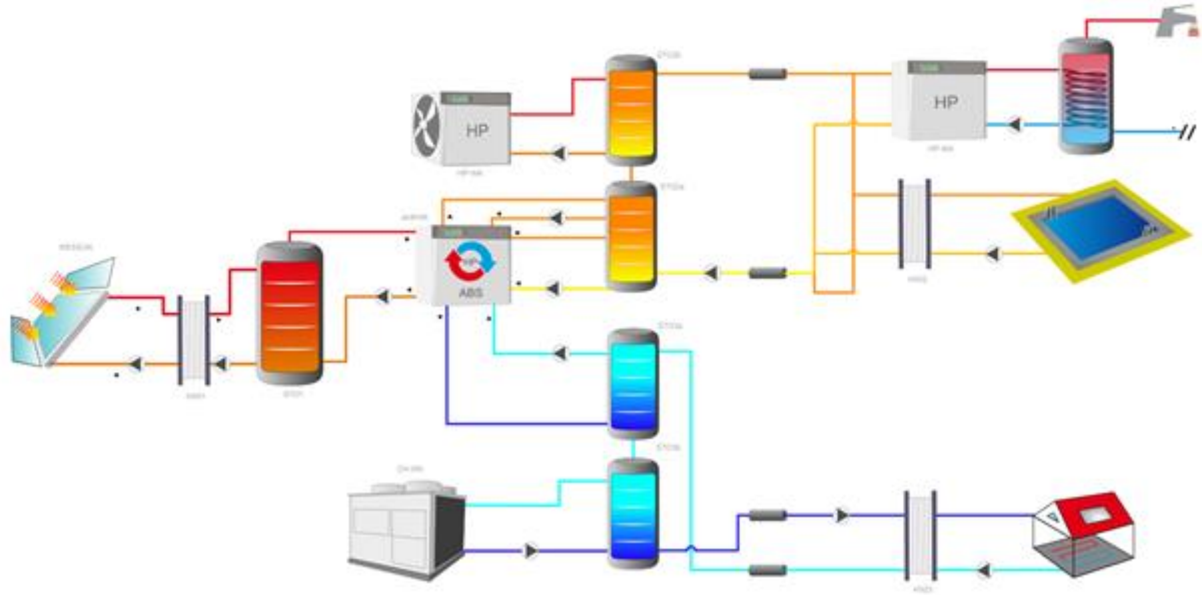

Figure 3-65. WEDistrict technologies case model diagram for Playa del Ingles demo-follower.

3.3.2.2 TRNSYS MODEL

A TRNSYS model was developed for the dynamic simulation of the system behaviour and performance. The TRNSYS macros used were as follows:

- M0100: Weather conditions
- M1300: WESSUN Technology
- M2100: Hot water Storage
- M4100: Advanced absorption chiller
- M4310: Conventional chiller
- M4500: Heat pump
- M7200: Cold distribution
- M7300: Heat distribution
- M8100: Heat Load
- M8200: Cold load

With the mentioned macros the corresponding deck was generated (DCK311), and their diagram is shown in Figure 3-66.

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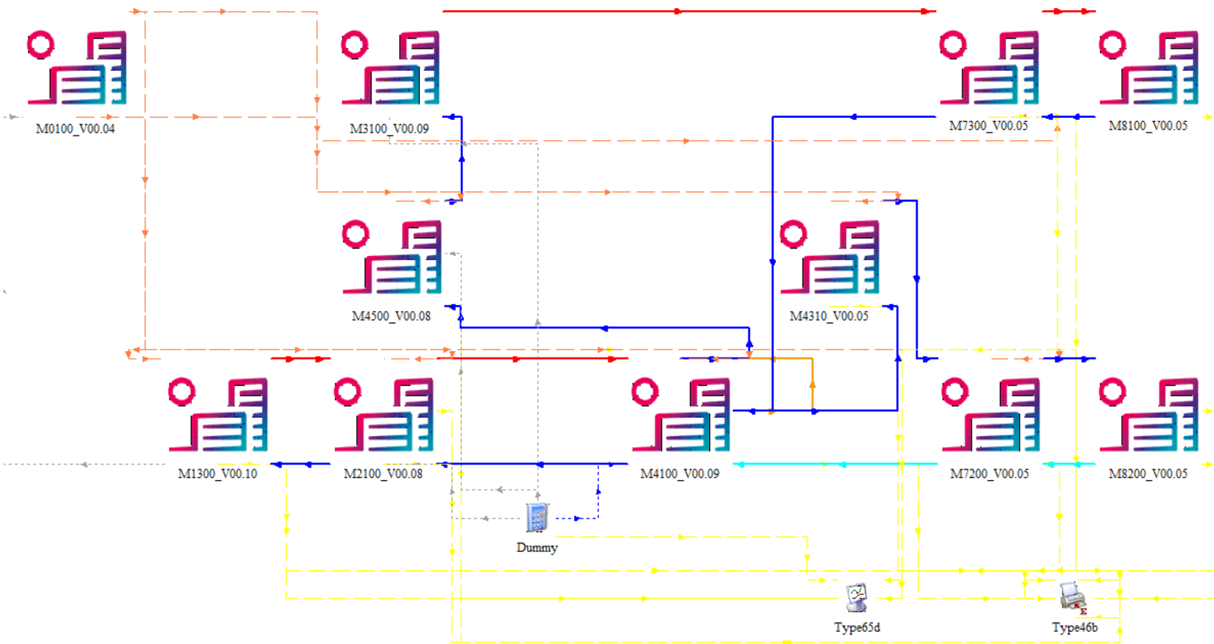

Figure 3-66. DCK structure of the TRNSYS Model

Table 3-25 shows the parameters used in the initial TRNSYS model.

Table 3-25 Parameters of the TRNSYS model

Parameters	Value	Unit
AHPHR Power	400	kWth
Chiller Power	3.200	kWth
Heat Pump Power	700	kWth
Storage Volume	2.000	m^3
Solar Area	1.500	m^2
Supply Temperature Cold Water	12	°C
Return Temperature Cold Water	7	°C
Supply Temperature Hot Water	50	°C
Return Temperature Hot Water	30	°C

3.3.2.3 RESULTS

Table 3-26 shows the main results, where CONCEPT refers to the system composed of the WESSUN technology and the advanced absorption chiller.

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Table 3-26 Main results of the TRNSYS simulation.

Parameter	Value	Unit
Total Heat Generation	15,854,682	kWhth/year
CONCEPT Heating Fraction	0.12	
Total Cooling Generation	3,635,423	kWhth/year
CONCEPT Cooling Factor	0.24	
SYSTEM F_SOLAR	0.14	
SYSTEM F_RES	0.55	
SYSTEM Total Heating Power consumption	6,755,233	kWhe/year
SYSTEM Total Cooling Power consumption	569,708	kWhe/year
SYSTEM Total Power consumption	7,207,094	kWhe/year
COPe SYSTEM	2.35	
EERe SYSTEM	6.38	
SPFe SYSTEM	2.70	

3.3.3 FEASIBILITY STUDY

Based on the results obtained from the TRNSYS simulation, a parametric analysis was developed. The different simulation scenarios were chosen based on the performance of both the AHPHR system and the entire generation system. In this sense, we were interested in knowing different configurations of two of the most sensitive parameters in terms of system performance and capacity to meet demand. Different sizes of both the AHPHR and the solar area of the WESSUN collectors were considered, considering the ratio factor between the two.

For the performance analysis, KPIs such as IRR, CO2 emissions to the environment in tons per year and renewable fraction were chosen. Simulations of the different scenarios were developed on the reference case using a model parameterization using softwares like JEPlus and TRNEdit and a data mining model.

Table 3-27 shows the parameters of the parametric analysis.

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Table 3-27 Parameters of parametric analysis

AAC CAP GEN [kW]	WESSUN Collectors Area [m2]
250	357.1
250	714.3
250	1,071.4
500	714.3
500	1,428.6
500	2,142.9
750	1,071.4
750	2,142.9
750	3,214.3
1,000	1,428.6
1,000	2,857.1
1,000	4,285.7
1,250	1,785.7
1,250	3,571.4
1,250	5,357.1
1,500	2,142.9
1,500	4,285.7
1,500	6,428.6
1,750	2,500.0
1,750	5,000.0
1,750	7,500.0
2,000	2,857.1
2,000	5,714.3
2,000	8,571.4

3.3.3.1 RESULTS

Based on the results obtained from the TRNSYS simulation, the following graphs show the results of the parametric analysis where the numbers next to the dots correspond to the solar multiple of each case.

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Solar Yield

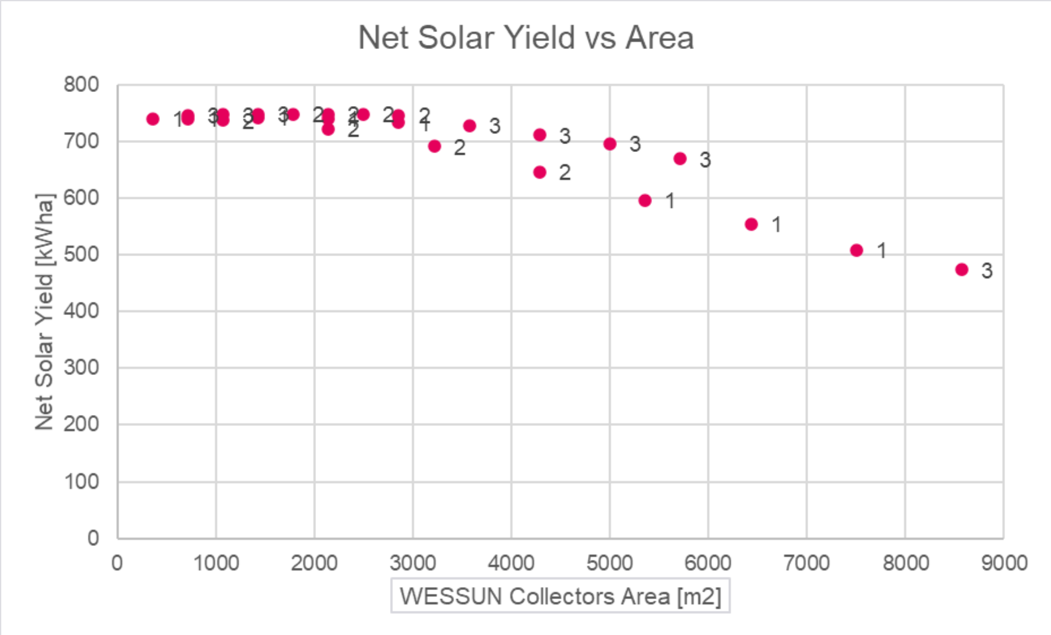

Figure 3-67. Net Solar Yield vs Area

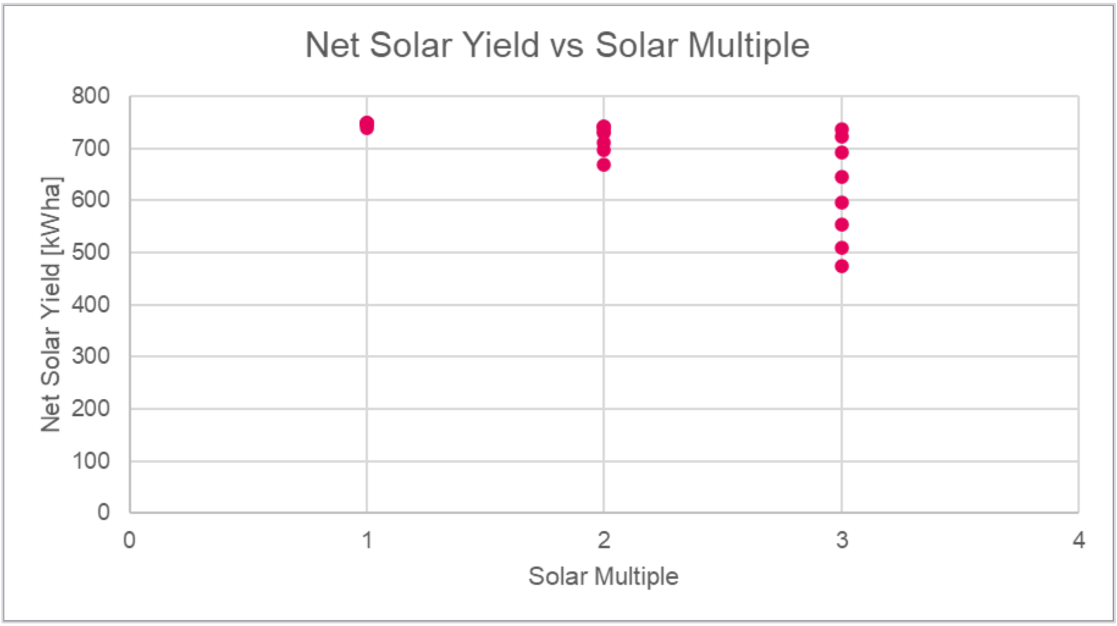

Figure 3-68. Net Solar Yield vs Solar Multiple

First, as can be seen from the graphs in Figure 3-67 and Figure 3-68 the Net Solar Yield decreases as the WESSUN collector area increases. This occurs because the power capacity of the AHPHR does not increase at the same rate as the collector area, limiting its ability to harness the solar energy produced by the WESSUN system.

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Concept Performance

The graphs in Figure 3-69, Figure 3-70 and Figure 3-71 show the behaviour of the performance indicators with respect to variables that account for the amount of heat and cold generated respect to total energy generated by the system. This allows to know the total performance of the system in relation to the energy generated by both the condenser and the evaporator of the AHPHR.

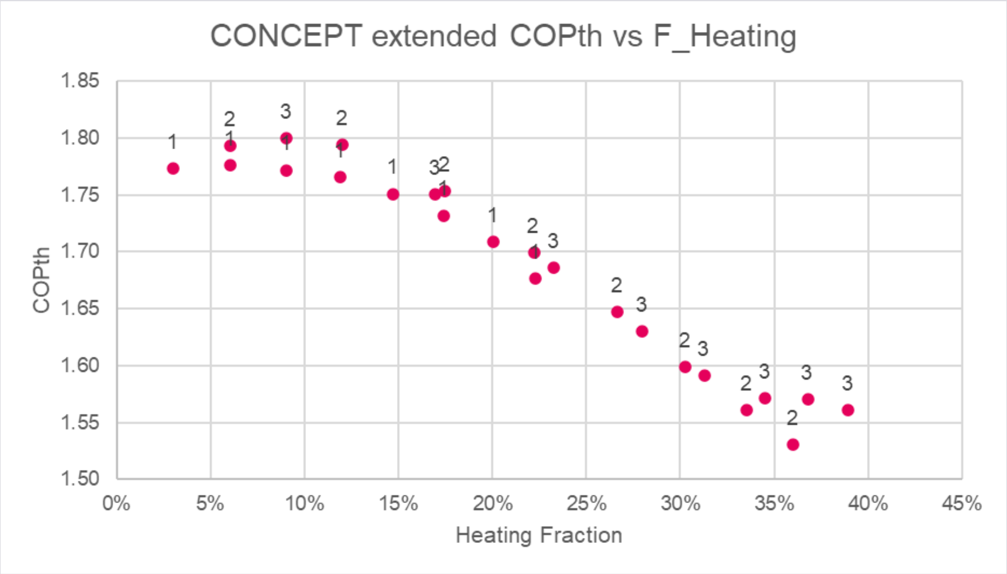

Figure 3-69. Extended CONCEPT COPth vs Heating Fraction

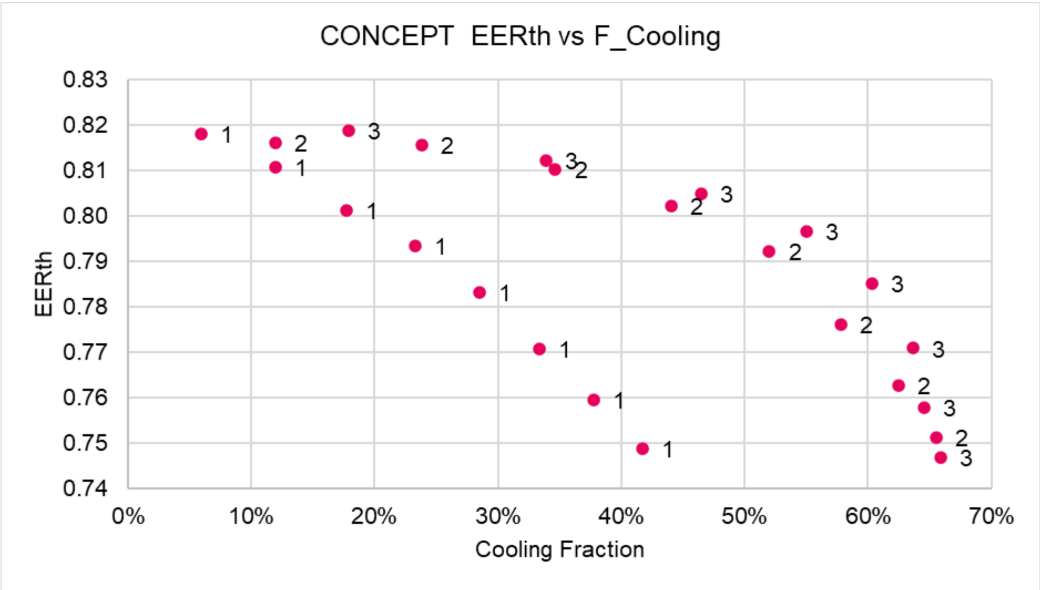

Figure 3-70. CONCEPT EERth vs Cooling Fraction

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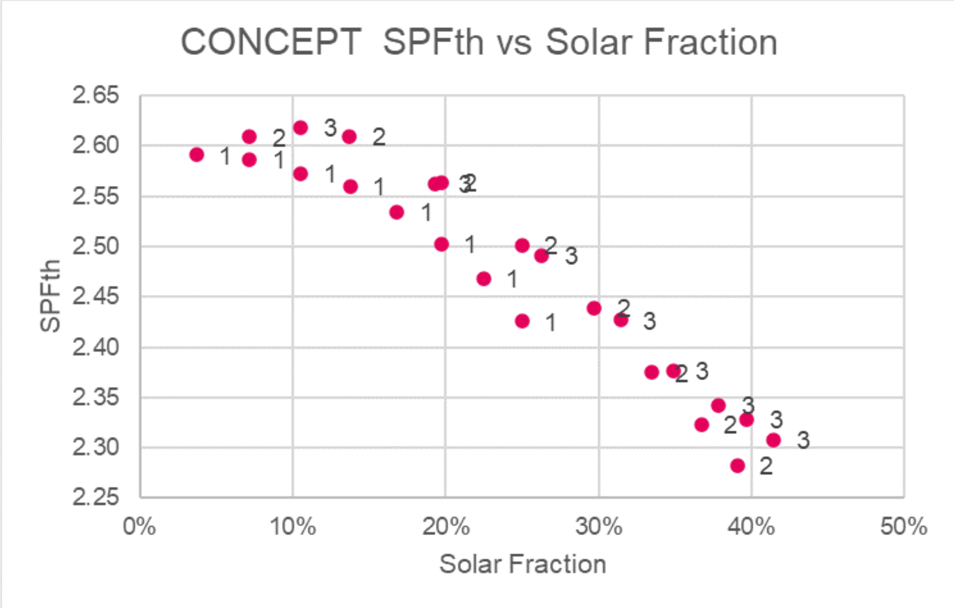

Figure 3-71. CONCEPT SPFth vs Solar Fraction

On the other hand, the following graphs show how both the heating and cooling fraction reach a saturation point with increasing solar area, showing a stagnation in the increase of the fraction due again to the AHPHR power not being able to take advantage of the heat generated by WESSUN, implying the inefficiency of a system with a very large solar area. The same result can be observed for both solar fraction and renewable energy fraction.

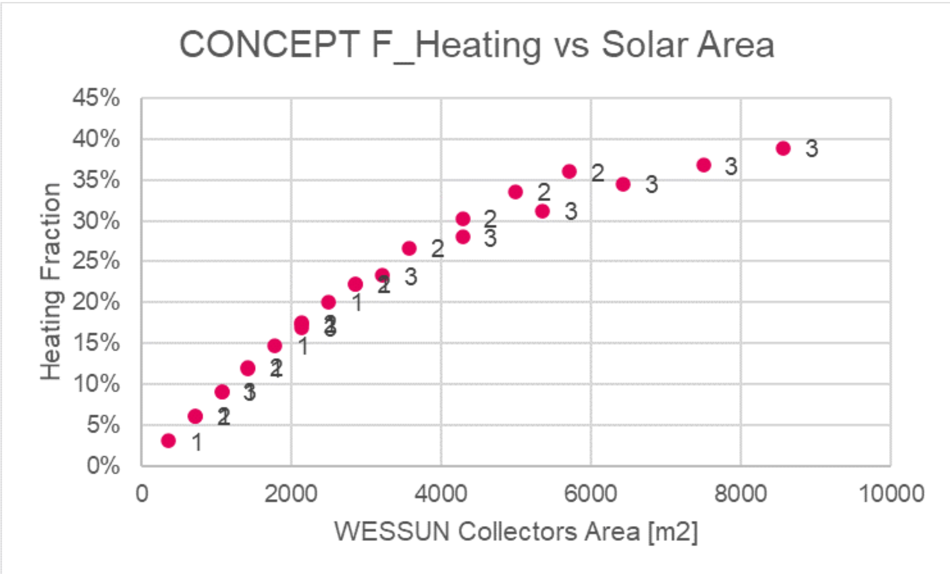

Figure 3-72.Heating Fraction vs Solar Fraction

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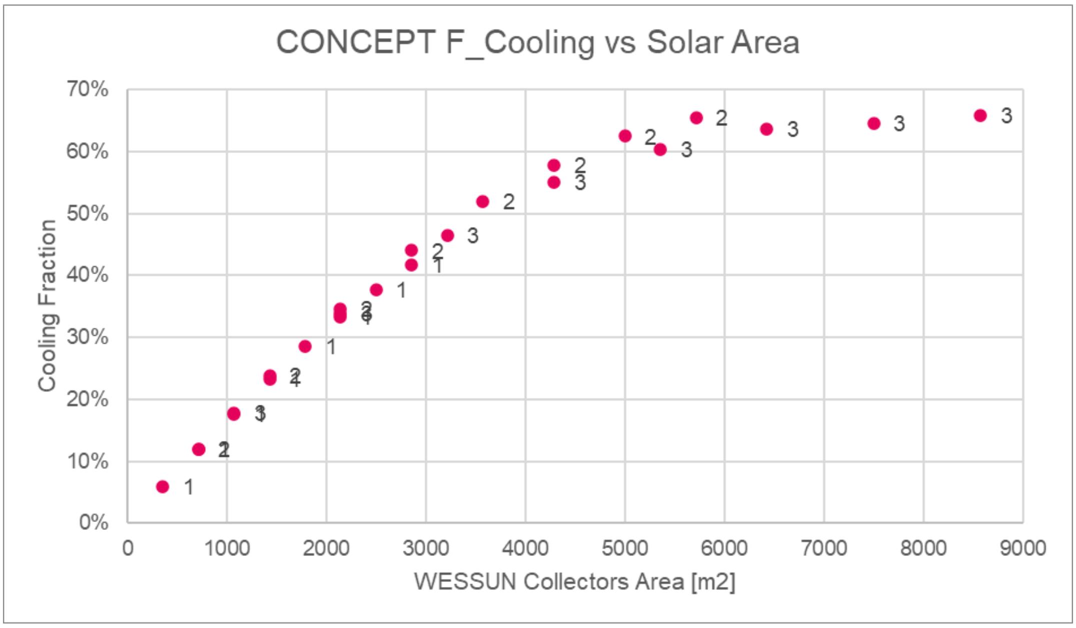

Figure 3-73. Cooling Fraction vs WESSUN Collectors Area

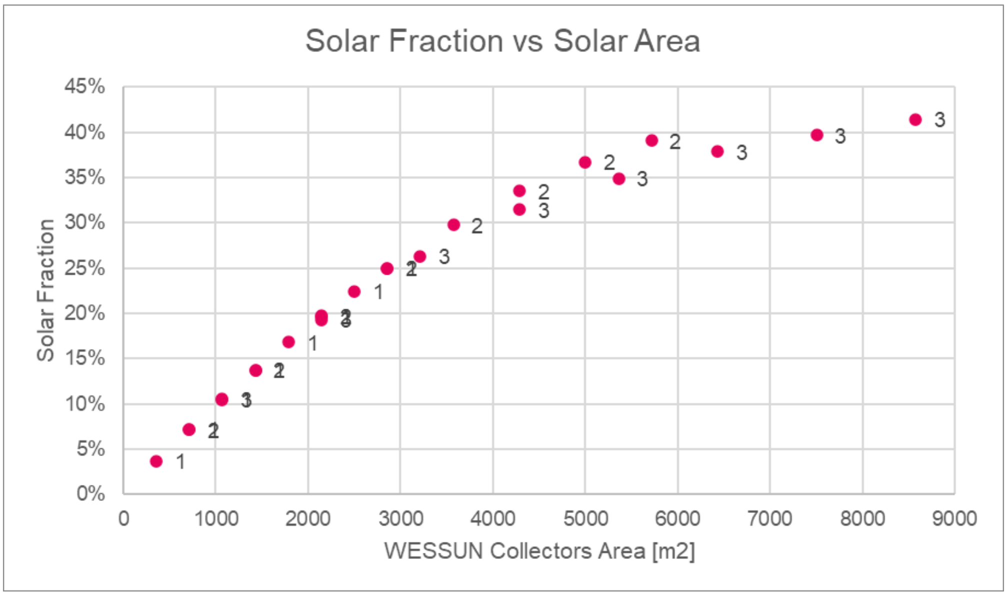

Figure 3-74. Solar Fraction vs WESSUN Collectors Area

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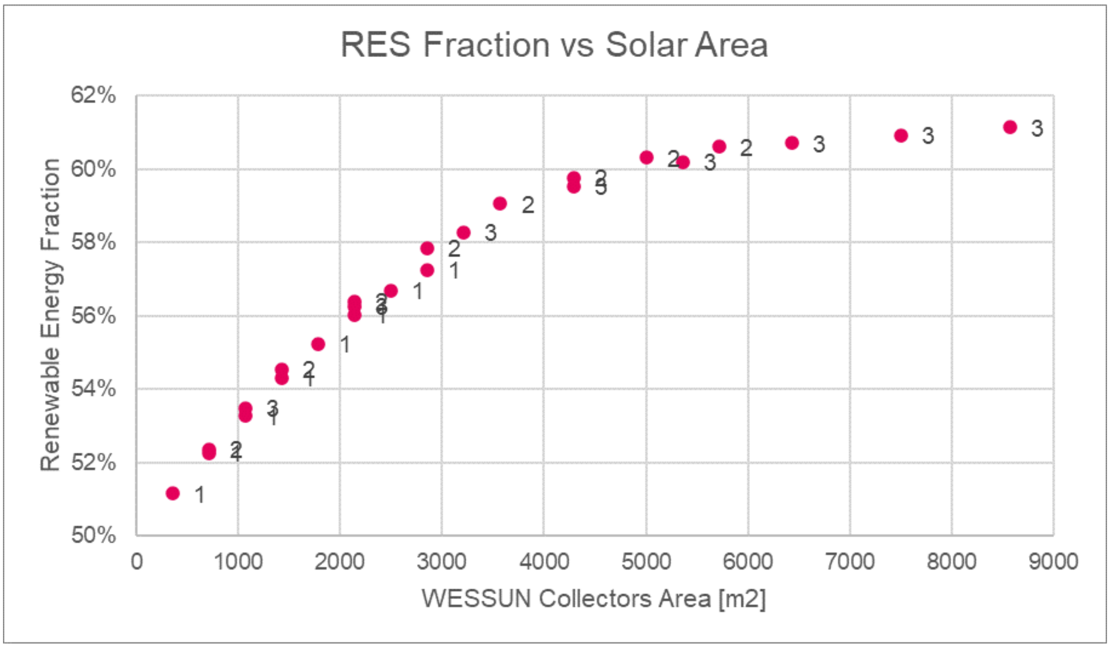

Figure 3-75. Renewable Energy Fraction vs WESSUN Collectors Area

System Performance

The graphs in Figure 3-76, Figure 3-77 and Figure 3-78 show the system performance. It can be observed that the electric COP of the system behaves in exactly the opposite way to the electric EER. However, it can be observed that with a maximum heat fraction of almost 40% a good COP can be obtained while maintaining an EER almost equal to 6, which would still imply a good overall system performance.

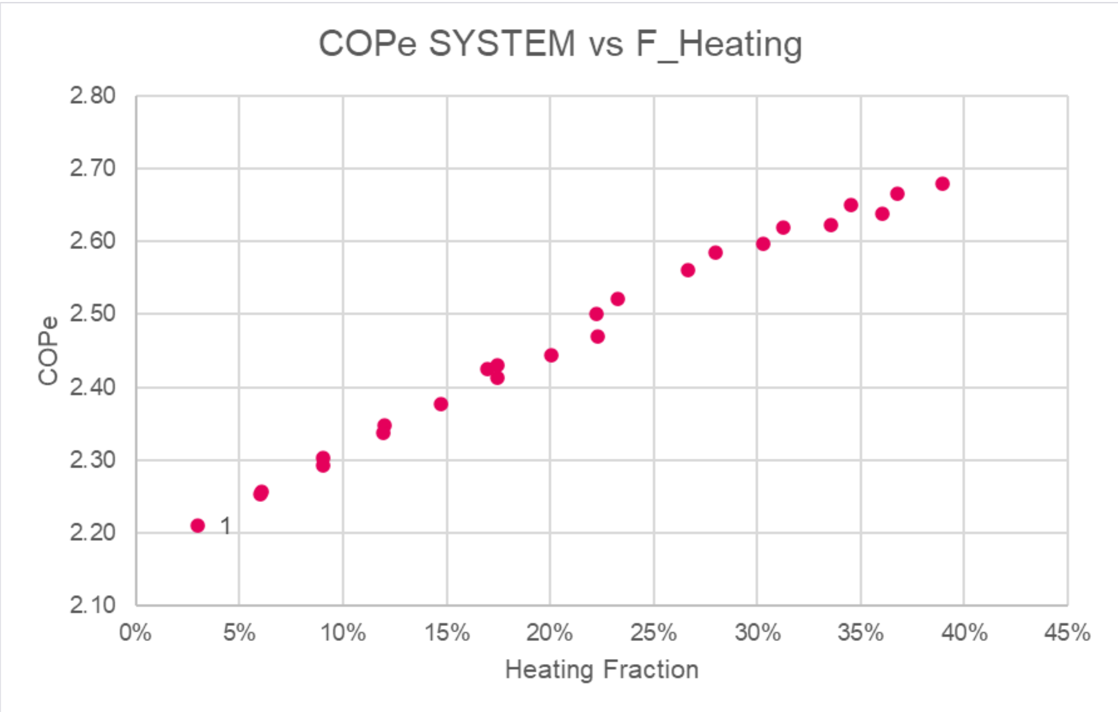

Figure 3-76. COPe System vs Heating Fraction

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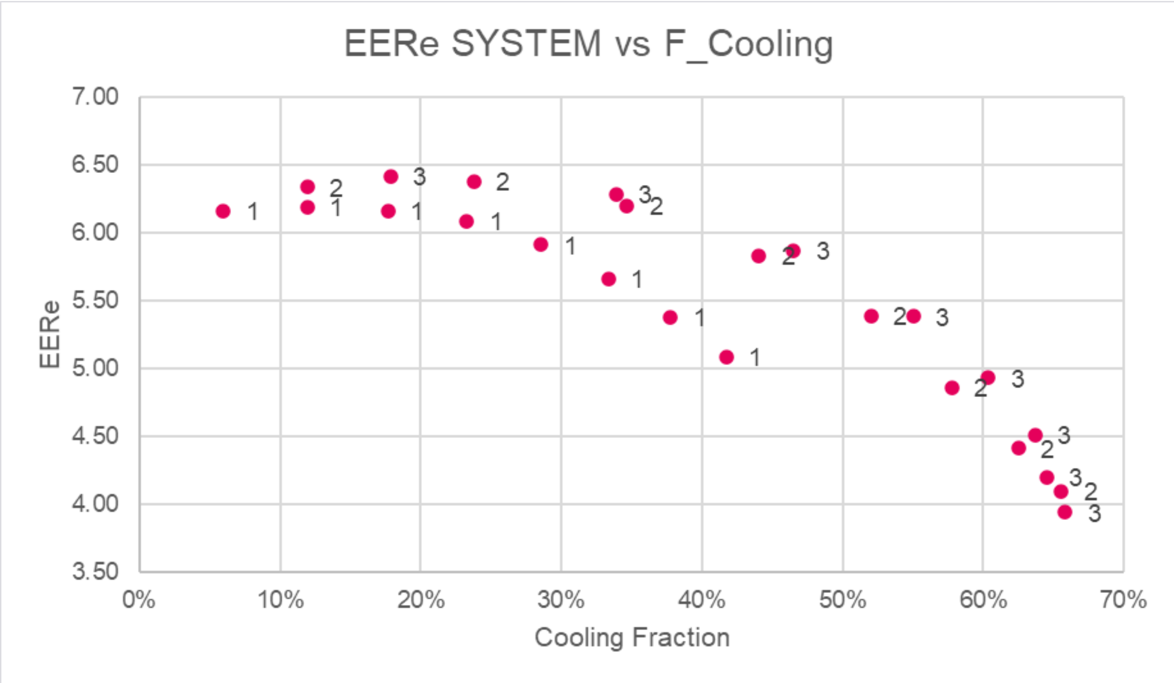

Figure 3-77. EERe System vs Cooling Fraction

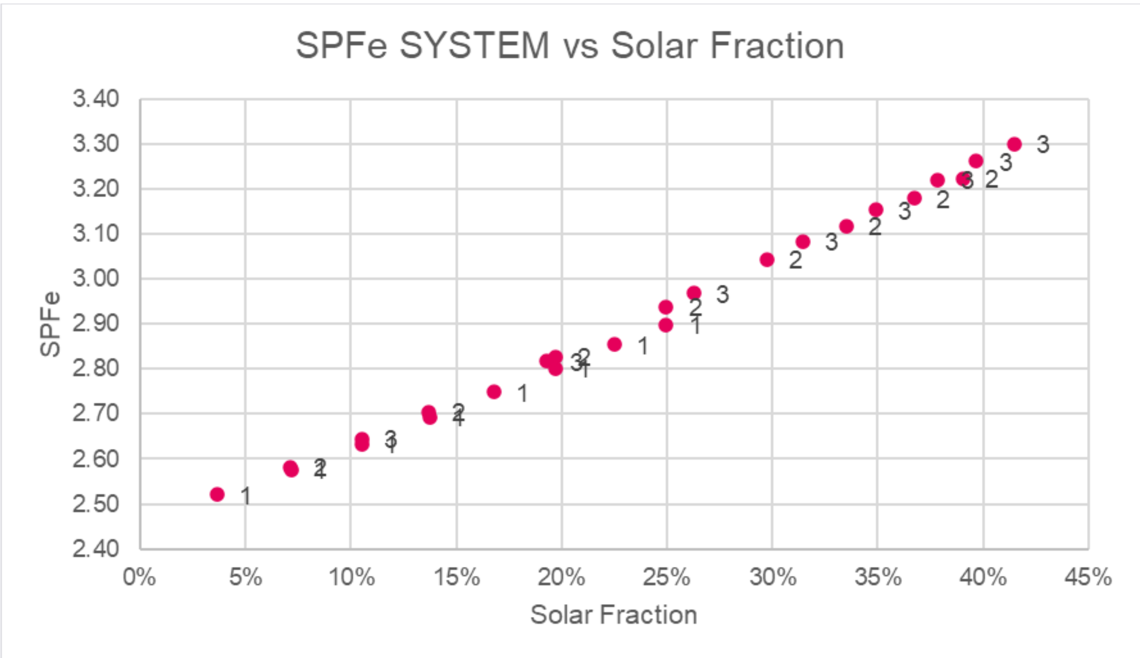

Figure 3-78. SPFe System vs Solar Fraction

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3.3.3.2 ECONOMIC ANALYZE

The following graphs show the economic analysis of the system. The IRR and CO2 emissions have been chosen as indicators of system feasibility.

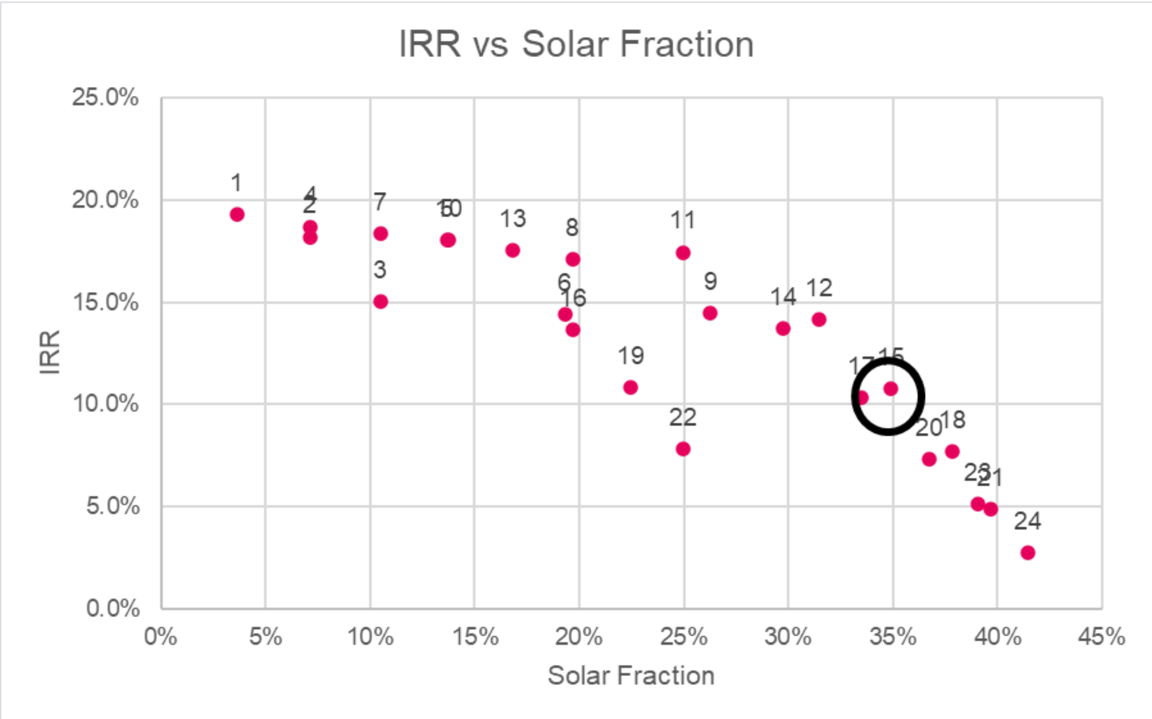

Figure 3-79. IRR vs Solar Fraction

It can be observed from the graph in Figure 3-79 that the IRR decreases with the increase of the solar fraction. From the technical results it could be noted that the energy generated does not increase steadily with the solar area, and therefore with the solar fraction, reaching a saturation point. If the energy generated does not increase steadily, the savings produced by the system also reach a saturation point, while the installation costs continue to increase, which implies a decrease in the IRR. It can be noted that the maximum solar fraction that allows reaching a competitive IRR (of 10%) is 35%. This result is achieved with the configuration of case number 15 of the parametric analysis.

From Figure 3-80 can be observed that the case 15 is the case with the maximum RES fraction that allows a competitive IRR too.

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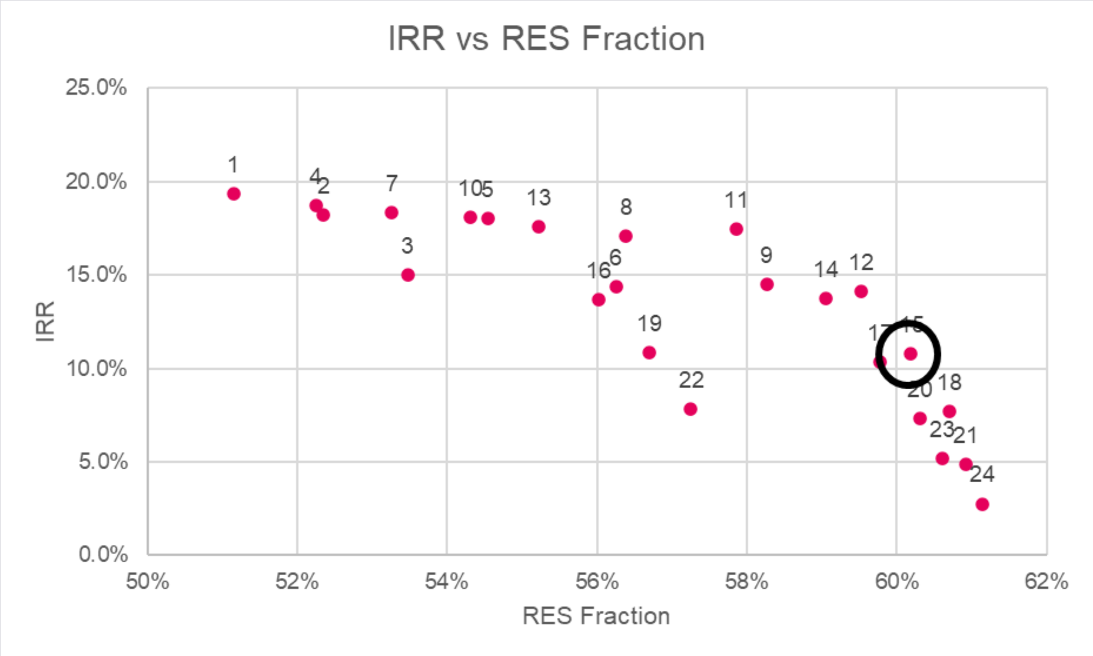

Figure 3-80. IRR vs Renewable Energy Fraction

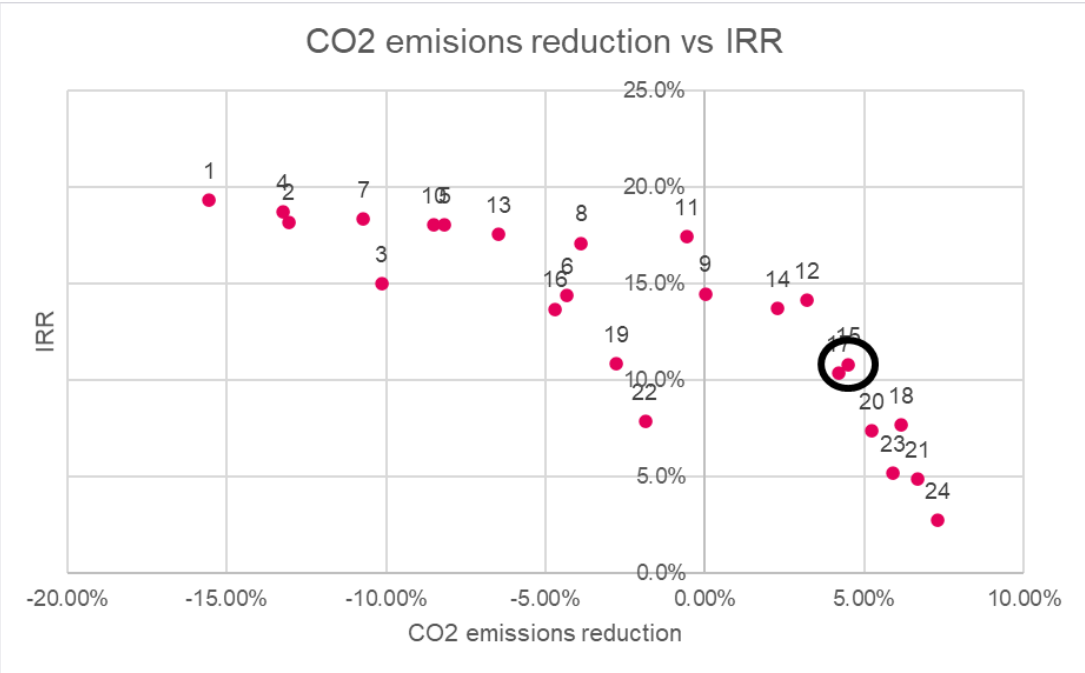

Figure 3-81. CO2 Emissions Reduction vs IRR

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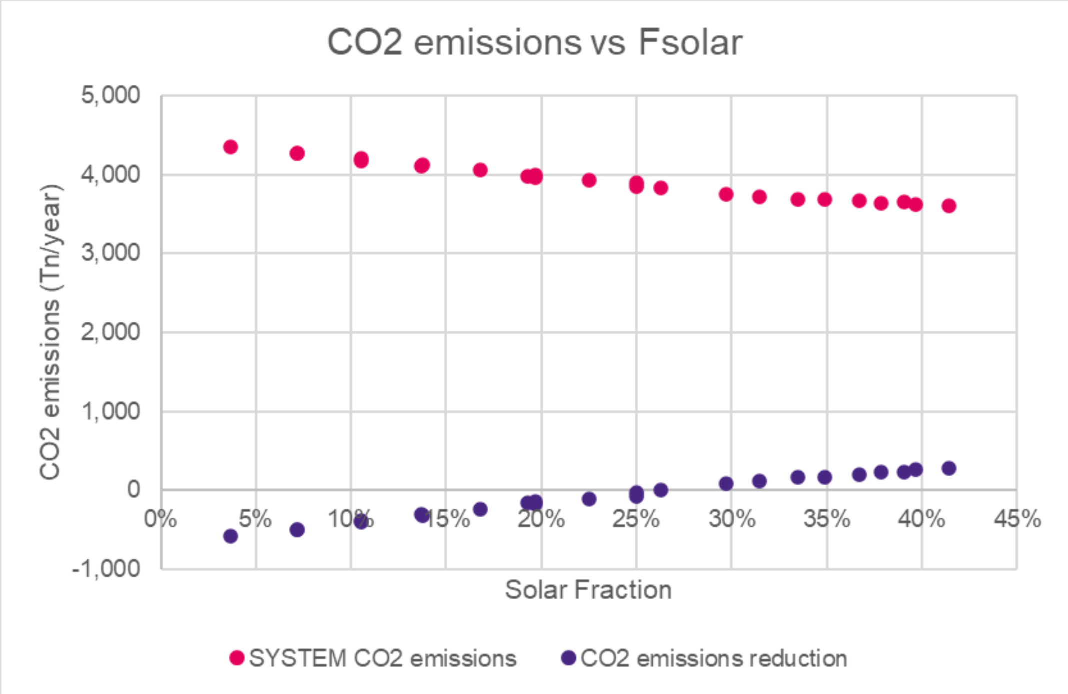

Figure 3-82. Total System CO2 Emissions and CO2 Emissions Savings vs Solar Fraction

Finally, from Figure 3-81 can be observed that definitely the case 15 is the one with the best configuration as this case also reach the maximum CO2 emissions savings while maintaining a competitive IRR.

3.3.4 CONCLUSIONS

The results obtained from the parametric analysis allow us to choose a case of technological configuration that may be of interest (case 15). The case chosen allows to conclude that the DHC system is economically feasible, and with the Wessun Concept reaches high levels of RES share with good profitability.

The proposal is to develop a 35% solar fraction system with a 11% IRR, based on a 4th generation DHC network, with the parameters and results shown in Table 3-28.

Table 3-28 Parameters of Selected Case

Parameter	Unity	Value
AAC Capacity	*kW*	1.250,00
Wessun Area	*m2*	5.357,14
Solar Multiple	-	3,00
Net Specific Solar Yield (after storage)	*kWh/m2*	596,34
COPe_ext CONCEPT		8,80
EERe_ext CONCEPT		4,34
SPFe_ext CONCEPT		13,15
CONCEPT F_Heating		31%
CONCEPT F_Cooling		60%

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Parameter	Unity	Value
SYSTEM F_SOLAR		35%
SYSTEM F_RES		60%
COPe SYSTEM		2,62
EERe SYSTEM		4,93
SPFe SYSTEM		3,15
IRR CONCEPT		13%
IRR SYSTEM		11%
SYSTEM CO2 emissions	*tonCO2eq*	3.689,87
SYSTEM CO2 emissions	*tonCO2eq/MWh*	0,20
CO2 emissions reduction	*tonCO2eq*	172,97
CO2 emissions reduction		4,48%

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3.4TecnoAlcalá (Alcalá de Henares – Spain)

3.4.1 GENERAL DESCRIPTION

In April 2003, at the hands of the Community of Madrid, the TECNOALCALÁ Scientific and Technological Park was established. Its main mission is to create a cluster where the priority is to support innovation and the transfer of technology and knowledge, offering quality flooring for the installation of innovative companies. The Park is developed on a 370,705m2 plot, located on the campus of the University of Alcalá.

It was mainly created to promote the innovative process of the companies and the transfer of technology and knowledge from the University, it constitutes a fundamental element that allows the strengthening of relations between the academic and business fields. Tecnoalcalá Park encompasses companies from different sectors, the most representative of which is Information Technology, healthcare and industry. Currently, the Park has more than 40 companies that represents 92% of the available surface area.

Within WEDISTRICT project, one of the main demosites is located in this area, where a big solar laboratory supported by biomass will be deployed in order to evaluate different WEDISTRICT technologies for heat and cold generation. This demosite will supply heating and cooling needs to a building through a new heat and cold network, which will operate following the advanced digitalization system developed in the frame of the project. Tecnoalcalá demo-follower will explore the possibility of having a whole Technology Park covered by a DHC (District Heating and Cooling) network.

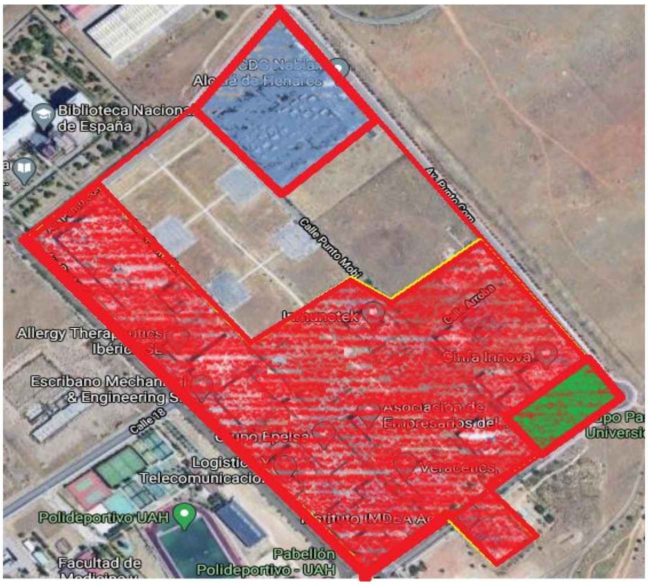

Figure 3-83. Areas use in Tecnoalcalá demo-follower (green: WEDISTRICT demosite; blue: Data center building:

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3.4.1.1 REFERENCE CASE MODEL

The picture below introduces the scheme of the reference case of TecnoAlcalá site simulated in TRNSYS software.
Main elements are:

- Meteorological data (M0100),
- Biomass boiler (M3100) and its heating distribution (M7300 and M8100),
- Compression chiller (M4300) and its cooling distribution (M7200 and M8200).

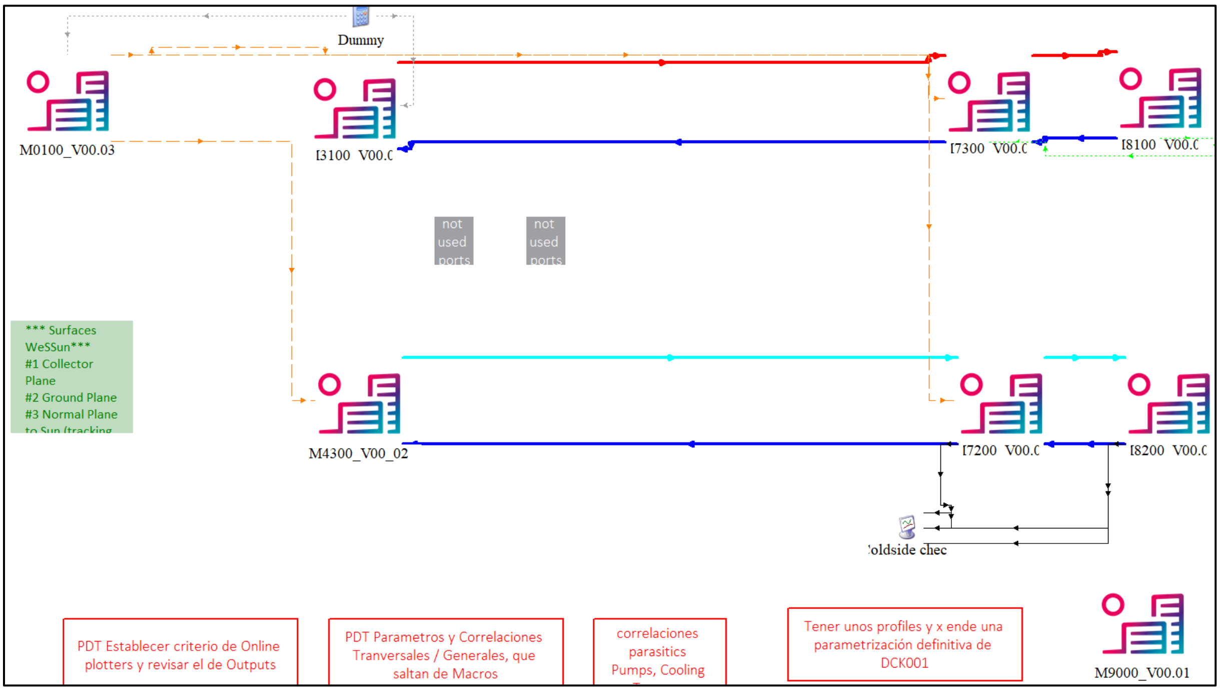

Figure 3-84 Simulation model of TecnoAlcala's virtual demo.

To simulate the heating and cooling district, the following values have been run. They have been assessed thanks to ratios from Alcala demo-site data.

Parameters	Value	Unit
Heating Power	7500	kW
Cooling Power	7500	kW
Network Length	2100	m

Temperature	Heating	Cooling
Supply	95º	7º
Return	75º	12º

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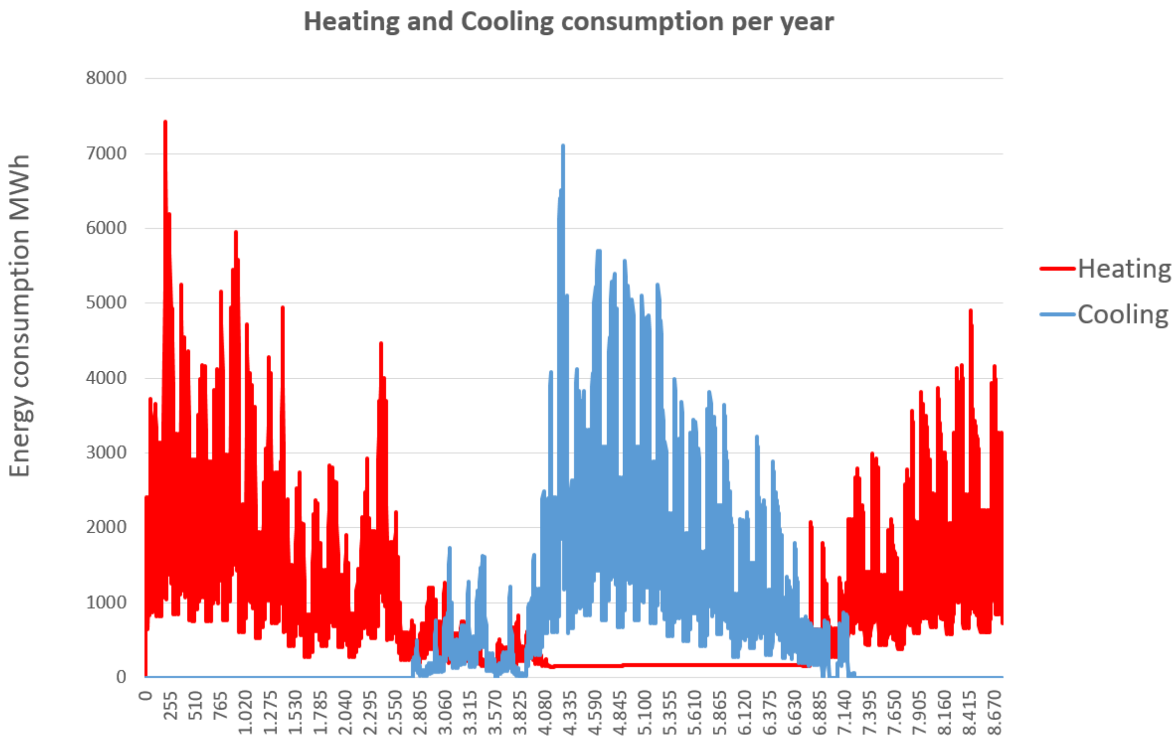
3.4.1.2 FIRST RESULTS

In a first approach, we analyse results from TRNSYS simulation about energy consumption, renewable energy ratio (RER), emissions of CO2.

Reference case	Heating	Cooling
Consumption (MWh/year)	8 953	6 175
RER	82%	30%
Emissions (kCO2/MWh.year)	137	164
Energy density	2,13	1,47

The graph of heating and cooling consumption during the year can be built thanks to TRNSYS simulation. It distinguishes clearly heating (winter) and cooling (summer) periods.



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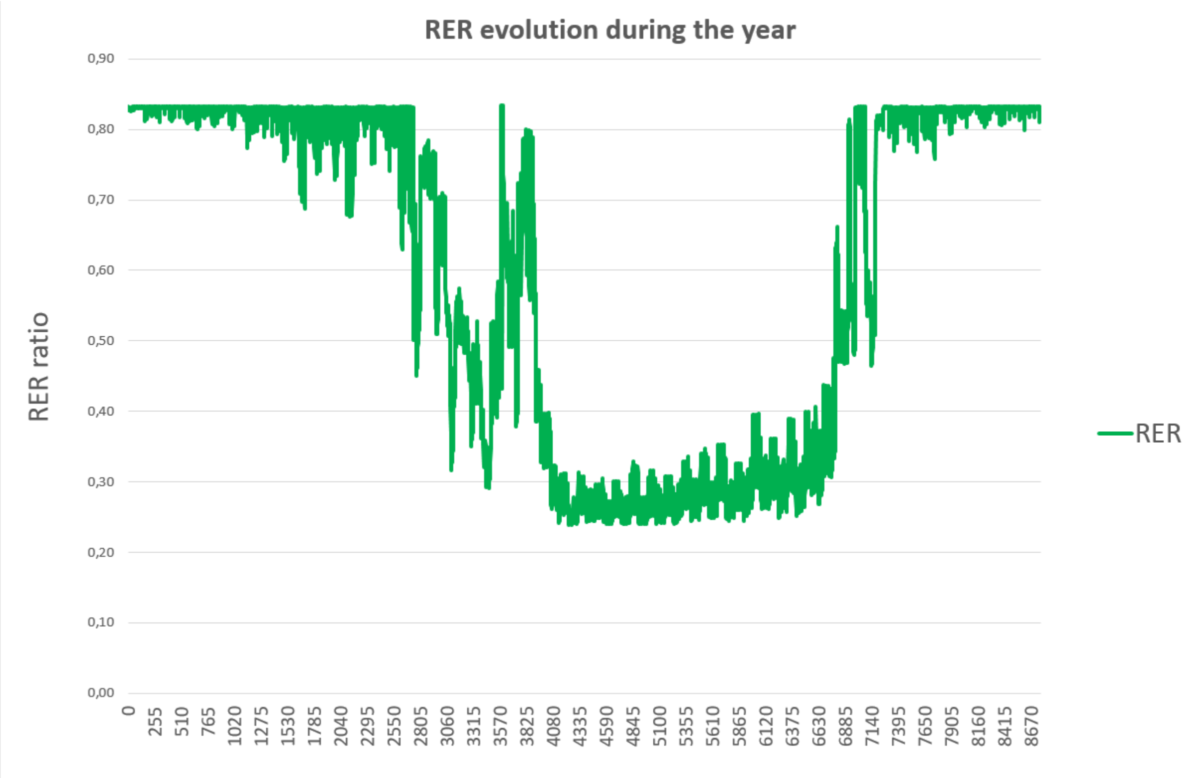
The RER result is different according to heating or cooling period. The following graph shows clearly the difference during a year.



Heating RER (82%) is higher than cooling RER (30%) thanks to biomass, which only 1/6 is considered as non-renewable. Whereas electricity is almost non-renewable.

The TRNSYS simulation is coherent with TecnoAlcalá data since the deviation between those and results is less than 10%.

Table 3-29 Comparison between data and simulation results of annual Heating and Cooling demand.

	Data [MWh]	Simulation [MWh]	Deviation [%]
Heating	8 383	8 953	6,8
Cooling	5 900	6 175	4,7

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A quick comparison between Alcala demo-site and TecnoAlcalá virtual demo can be made to evaluate if TecnoAlcalá extension would be relevant.

Parameters	TecnoAlcalá	Alcalá demo	Unit
Heating	8 953	1 330	MWh/year
Cooling	6 175	720	MWh/year
kCO2 Heating	137	33	kg/MWh.year
kCO2 Cooling	164	356	kg/MWh.year
RER Heating	82%	86%	
RER Cooling	30%	47%	
Heating density	2,13	2,66	MWh/m
Cooling density	1,47	1,44	MWh/m

An economic comparison is made to evaluate if TecnoAlcalá extension is relevant.

Coste	Type	Price
Extension investment	District	368.000 €
	Substations	840.000 €
	Total	*1.208.000 €*
Heating exploitation	Biomass	34 €/MWh
	Sell energy price	55 €/MWh
	Profit	160.091 €
Cooling exploitation	Electricity price	25 €/MWh
	Sell energy price	53 €/MWh
	Profit	174.115 €
Return of investment (year)		**3,6**

For the moment, this first draft does not enable to conclude for its relevance since many data have to be confirmed.

3.4.2 FEASIBILITY STUDY

3.4.2.1 SCENARIOS SELECTED

From this reference case simulation, other scenarios simulations are developed to improve energy efficiency, to reduce CO_2 emissions or to lower costs of energy production.

Table 3-30 Summary of technologies proposed for Tecnoalcalá demo-follower.

Technologies proposed	By means of
Biomass	Biomass boilers installation for covering peak loads or energy not covered by solar collectors.
Geothermal wate/water pump	This solution has great efficiency and benefits from geothermal renewable energy. Its bad point is its significant investment.
Waste heat recovery from data centres	Waste heat recovery from the chiller condenser for pre-heating.
PV	PV panels integrated for covering electricity consumption from the thermal station (and equipment installed).
Water storage	Optimized water storage sized for acting as solar buffer.

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The combination of the different technologies generates three main solutions which will be studied in the next step (other solutions might arise during the activity):

Table 3-31 Preliminary solutions proposed for Tecnoalcalá demo-follower

Solutions proposed overall description	
Combination code	TECNOALCALÁ – Scenario1
Justification	The first solution proposed consists in a combination of gas and biomass boiler. Gas boilers are often said to have very low LCOE in comparation with other heating solution, and biomass boiler is a renewable solution with low CO2 coefficient emission.
Expected impact	• Evaluate heating costs • Evaluate impact of CO2 emissions from heating

Combination code	TECNOALCALÁ – Scenario 2
Justification	The second solution aims to evaluate integration of heat recovery from datacenter thanks to fuel cell solution. The idea is to pre-heat water by this heat recovery. It is considered as free recovered energy to reduce heating consumption and CO2 emissions.
Expected impact	• Evaluate heating costs • Evaluate impact of CO2 emissions from heating

Table 3-32 Economic data for solutions proposed (Focsani demo follower).

Specific capital cost of biomass boiler	250 €/kW
Specific capital cost of natural gas boiler	80 €/kW
Specific capital cost of thermal energy storage	260 €/m^3
Specific capital cost of fresnel collectors	190 €/m^2
Specific capital cost of advanced absorption chiller	600 €/kW
Specific capital costs of A/W compression chiller	196 €/kW
Specific capital costs geothermal vertical HX	65 €/m
Specific capital cost of W/W heat pump	950 €/kW
Natural gas price	43.7€/MWh
Electricity price	129.3 €/MWh
Biomass price	43.2 €/MWh
Lifetime	25 year
Discount rate	7%
Fixed OM	3 %

Table 3-33 Primary energy factor and CO2 emission coefficient for solutions proposed (Focsani demo follower).

Energy Vector	Primary energy factor Non renewable	Primary energy factor Renewable	Primary energy factor Total	CO2 emissions coefficient [kg/MWh]
Natural gas	1.17	0	1.17	205
Biomass	0.28	0.8	1.08	39
Electricity	2.62	0	2.62	299

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3.4.2.2 SCENARIO 1

The design of this scenario is introduced by the scheme below.

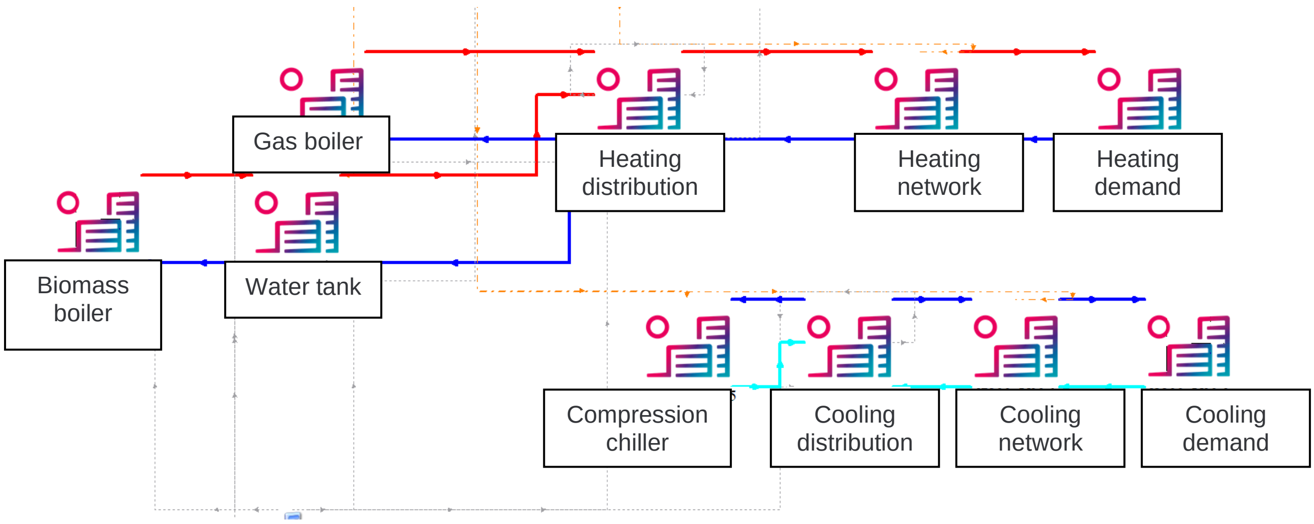

Figure 3-85. S1 design for TecnoAlcalá

The main parameters used in simulations are reported on Table 3-34. The heating capacity has been set at 30000 kW. The biomass boiler has been varied from 20000 kW to 30000 kW. The gas boiler capacity is the difference between the total capacity and the biomass boiler capacity in each case. The volume of the thermal storage is calculated to cover the nominal power of the biomass boiler for an amount of operating hours. The number of hours has been varied from 3 to 12. The cooling capacity has been set at 9000 kW. Three capacities (1000 kW, 2000 kW and 3000 kW) of the advanced absorption chiller have been considered. The compression chiller capacity is calculated as the difference between the total cooling capacity and the advanced absorption chiller capacity in each case.

Table 3-34 Main parameters of scenario S1 (TecnoAlcalá).

Biomass boiler capacity [kW]	Gas boiler capacity [kW]	Compression chiller [kW]
20000-30000	0-10000	7 500

Figure 3-86 compares the CO_2 emission coefficient and LCOE for each advanced absorption chiller capacity. As can be observed, the minimum CO_2 emission coefficient and LCOE are achieved by the cases with the minimum capacity of the advanced absorption chiller.

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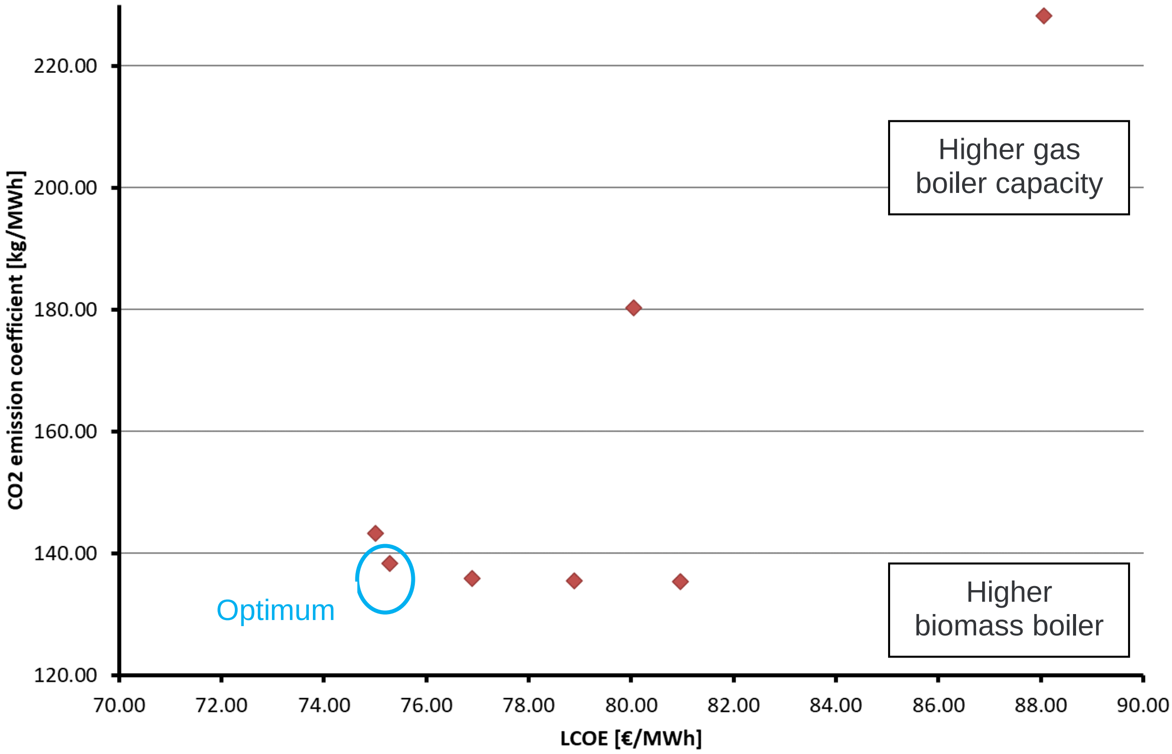
Figure 3-86. Simulation results of S1



A clear optimum between gas and biomass boiler capacities appears to get both low CO2 coefficient emission and LCOE. The worst results correspond to higher gas boiler capacity.

The lowest results for CO2 coefficient emission correspond to highest biomass boiler capacities than gas boiler capacity. But this kind of design is not enough to get both optimised CO2 coefficient emission and LCOE.

To understand these trends, it is necessary to focus on the fact that even if gas boiler CAPEX is lower than biomass boiler one, the higher costs of gas does not balance LCOE anymore when a large part of heating demand is covered by gas. Therefore, an optimise solution of S1 is the one indicated in the following table.

Table 3-35. Optimised solution for S1

Scenario	Biomass boiler capacity [kW]	Gas boiler capacity [kW]	Compression chiller [kW]	CO2 coefficient emission [kg/MWh]	LCOE [€/MWh]
S1	3 250	4 250	7 500	138,3	75,2

This is the optimise combination of CO2 emissions and LCOE found, according to the hypothesis taken. Obviously, as nowadays the price of gas is uncertain and can vary higher, this conclusion may evolve.

This optimise solution is only higher for 2% with the lower result simulation of CO2 coefficient emission. This trend can be true as biomass boiler is the priority boiler to provide heating.

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3.4.2.3 SCENARIO 2

Fuel cell powered data centre with waste heat recovery for district heating is innovative concept for reducing the overall environmental impact and increase profitability of data centres.

The data centre power needs are covered by fuel cells consuming renewably produced hydrogen or biogas, hence minimizing the greenhouse gasses emissions and environmental impact. In order to increase the feasibility of the concept, fuel cells with high operation temperatures are used (such as SOFC, 600-900 ºC) for allowing waste heat recovery to district heating network. Moreover, the heat output of the fuel cell is increased by using the heat generated in the data centre server room for preheating the fuel and air input streams, consequently, reducing the fuel cell internal reheating of input gasses with flue gasses.

Waste heat recovery consists of reusing the excess heat of different sources and processes. DHC is a great system for utilizing the excess heat from different heat sinks, the most common being heating and cooling buildings. This allows for better overall energy efficiency and reduced environmental impact. As the nature of the heat sources is diverse, it presents challenges, such as temperature levels, fluid characteristics, and availability. WEDISTRICT focuses on data centres, a high electricity consuming and heat generating industry. The challenges are to reduce the environmental impact of DC and reuse the waste heat.

The waste heat recovery concept considered in WEDISTRICT consists of integration of fuel cell powered data centres with waste heat recovery to district heating (DC+FC+WHR). The first goal is to supply the DC with power from the FC. However, FC are a CHP system that also provide heat, which is not useful for the data centre. To improve the overall energy efficiency of the DC, the heat is recovered for DH purposes.

This alternative solution of reference scenario considers that the Datacentre of TecnoAlcalá waste heat is recovered in order to preheat the fuel cell inlet air with the possibility of enhancing the thermal output of the FC system. The air-cooled data center, the DC heat recovery is performed in the condensing loop of the chiller. This configuration allows, even if in a very small amount due to the temperature levels of the system, reducing a bit the consumption of the air-cooling unit.

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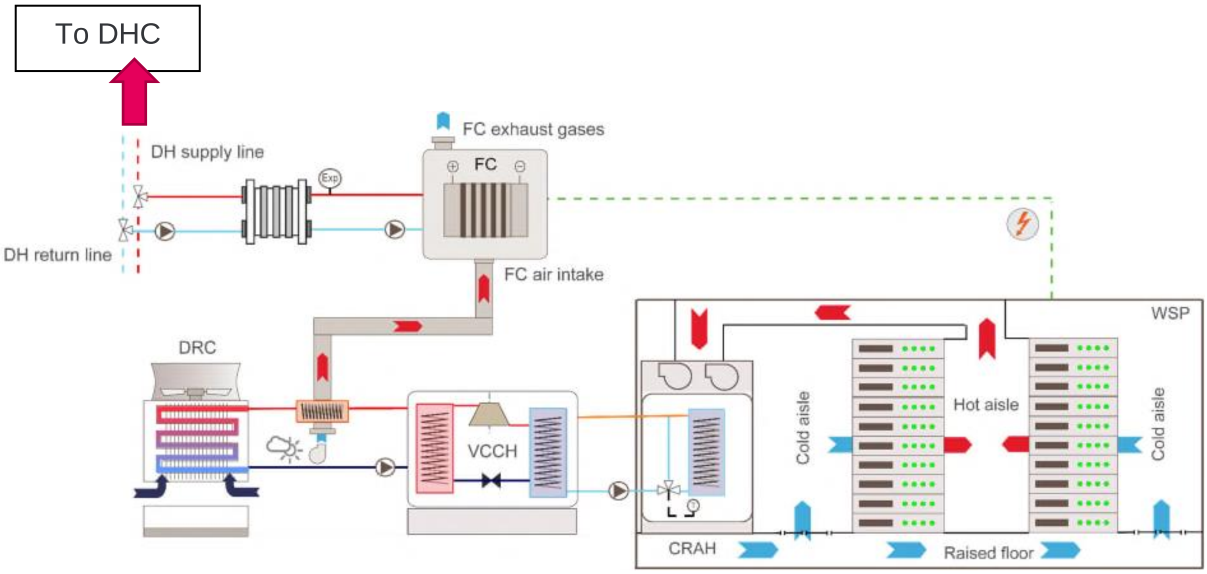
Figure 3-87. Waste heat recovery with fuel cells design



The most common equipment used to provide chilled water to the CRAH is a vapor compression chiller (VCCH). CRAH is Computer Room Air Handler and DRC Dry cooler.

The most promising concept of waste heat recovery for fuel cell powered data centre is identified as cascade heat recovery and air preheating in cooling loop. Here the water from the district heating is first pre-heated with the cooling loop in the data centre and then raise to the supply temperature with the fuel cell waste heat recovery heat exchanger. Additionally, the inlet air for the fuel cell is pre-heated with the water in the data centre cooling loop. This slightly reduces the cooling load of the dry cooler, while on the same time increasing the fuel cell thermal output, as it needs to use less internal heat to raise the air temperature.

In the case of TecnoAlcalá, the idea is to pre-heat water at 60ºC, and biomass boilers are in charge to up temperature to 90ºC which is the temperature of heat water supply in the DHC.

The parameters of this solution utilized in the simulation are introduced in the following table.

Table 3-36 Main parameters of scenario S2

Electrical installed capacity [kW]	Heat capacity for Fuel cell at 60ºC [W]	Number of Fuel cell module
50 000	330	150

Heat capacity of Fuel cell depends directly on the operating temperature. Electrical installed capacity corresponds to the electrical power used in TecnoAlcalá data centre. So, 150 modules of Fuel Cell are required to fit with this electrical capacity.

In this case, the pre-heating obtained is about 338 MWh. It is a very low part of TecnoAlcalá DHC heating need, only 4%.

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3.4.3 CONCLUSIONS

Finally, the solution studied in scenario 2 is not relevant for this kind of DHC. It has a low impact on energy efficiency and on CO2 emission reduction. It may fit more with low heating application. For the economic part, it is not relevant at all: in scenario 2, CAPEX would be 200 million of euros.

The optimize solution for S1 indicated is to optimize both CO2 coefficient emission and LCOE. Nowadays, all new projects are thought to maximize the reduction of CO2 coefficient emission for political decisions. So, this optimize S1 would not be developed in the future but preferably a 100% biomass solution.

3.5 Independencia/Recoleta (Santiago – Chile)

3.5.1 GENERAL DESCRIPTION

Independencia/Recoleta demo-follower consists of a new District Heating and Cooling system with the advanced absorption chiller technology as primary generation technology.

Independencia and Recoleta are two of Santiago's boroughs chosen to receive technical assistance that allows their management to identify and pursue the development of district energy related projects. Preliminary studies have shown promising results for populated areas and key infrastructure like health and educational buildings, including heating and cooling loads. In addition, both Municipalities have worked together before, facilitating the administrative and legal aspects to be dealt with.

The study considers the results of a preliminary assessment that showed promising results in some areas of Independencia and Recoleta in Santiago de Chile. The following map shows the locations of said areas.

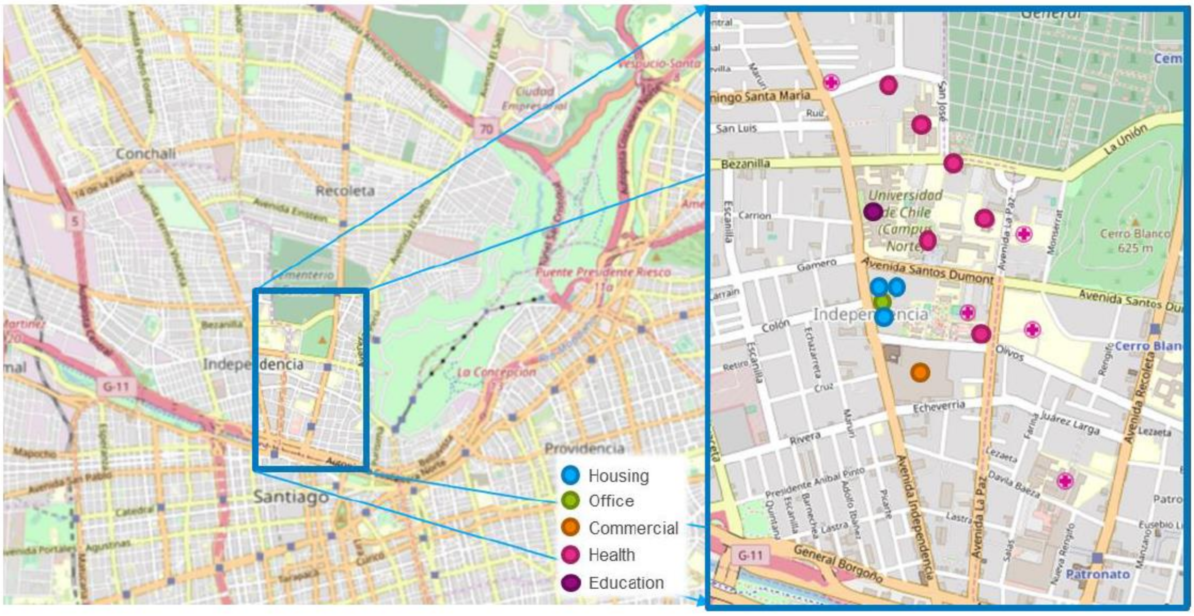

Figure 3-88. Location of Independencia. Google Maps

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Regarding the description of the buildings, not enough information could be obtained from the previous assessment, so contact was sought with each building (old or new) to assess their interest and willingness to participate in the project and provide the necessary information. Based in this analysis, the following buildings were finally considered.

Table 3-37 Summary connected buildings - Base case and extension case

Client	Sector	Area [m^2]	Existing generation systems[9]
Universidad de Chile Clinical Hospital	Health	65,214	NG boiler, Diesel boiler, Chiller, individual systems[10]
Dental Clinic	Health	4,068	GN boiler, disused diesel boiler, chiller, individual hot and cold systems.
Dental Clinic – Administrative	Administrative	5,308	NG boiler, disused diesel boiler Chiller, individual hot and cold systems
Dental Clinic – Laboratory	Education	4,046	NG boiler, Disused diesel boiler, Chiller, individual systems
Public Library	Administrative	1,320	Does not have
Municipality	Administrative	6,800	Heat pump, LPG boiler and individual hot and cold systems
School of Medicine	Education	73,518	NEITHER[11]
Roberto del Rio Hospital	Health	23,520	GN and LPG boiler, chiller, individual systems
San Jose Hospital	Health	36,350	NEITHER
National Cancer Institute	Health	13,057	GN boiler, chiller, heat pump, individual systems
Faculty of Chemistry and Pharmacy	Education	7,592	Diesel boiler, Heat pump, individual systems
Psychiatric Clinic	Health	5,154	NEITHER
José Horwitz Psychiatric Institute	Health	21,852	GN condensing boilers, solar thermal collectors, steam boiler, chiller

The following image shows the location of each building within the area.

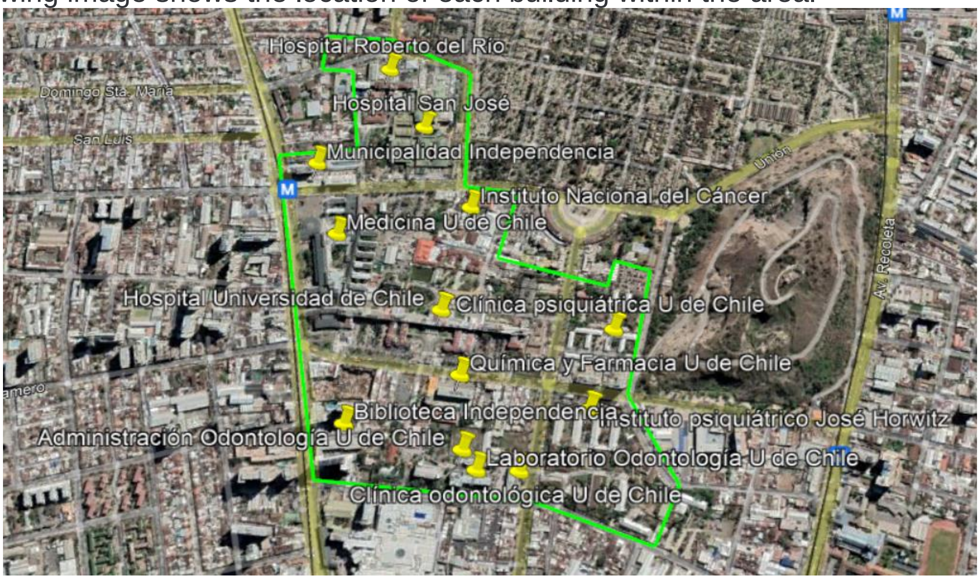

Figure 3-89. Location of the buildings being considered

[9]There may be other systems in addition to those indicated. Those shown in the table are those indicated in the information provided or observed during the visit.
[10]The individual systems consist of split systems installed by enclosures, and in some cases, heating systems such as gas stoves, among others.
[11]N/I refers to no information. This may be because they did not provide this specific information, or they did not provide information and secondary sources were used to estimate demand.

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To determine the energy demand of the study area, those buildings from which information could be collected in the information gathering stage were simulated. The simulations were carried out in the DesignBuilder v5.5 software that allows modelling the energy behaviour of the buildings under the climatic conditions of the locality under study.

The software allows geometrically modelling any building typology and assigning the technical characteristics of any constructive solution to its properties in order to quantify its energy performance dynamically for the hourly variations of the climatic conditions where the building is simulated. The calculation engine used by the software is that of ENERGYPLUS, which is today one of the benchmarks in the world for the energy simulation of buildings. Figure 1 shows the REF _Ref11315619 \h DesignBuilder simulation environment as an example.

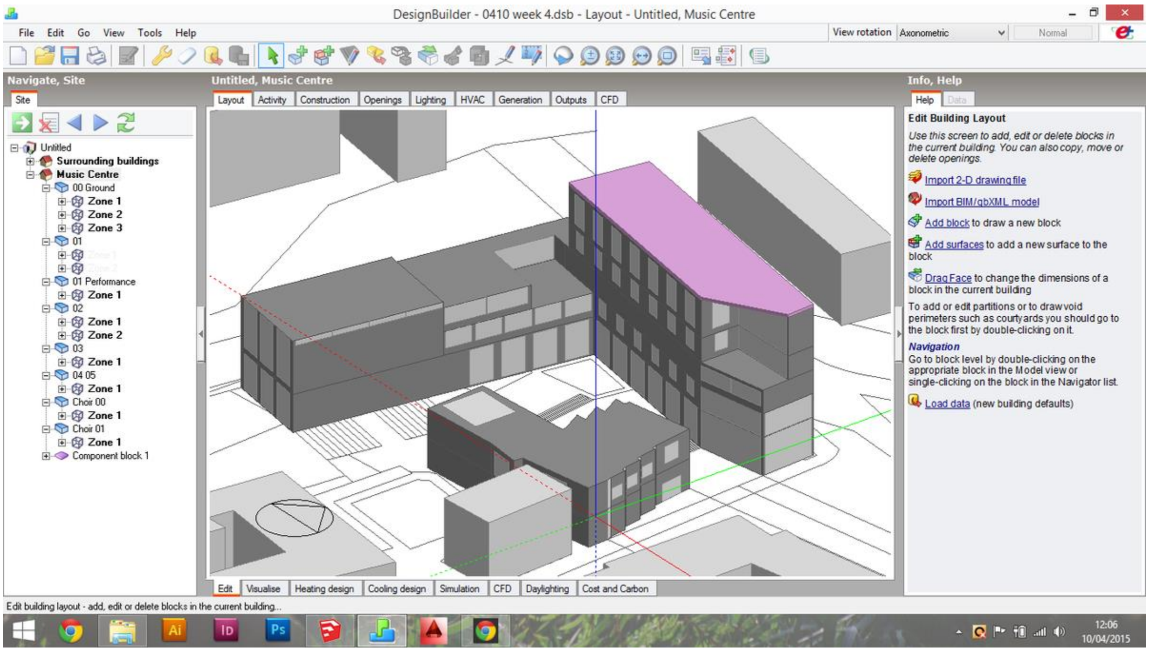

Figure 3-90. DesignBuilder Simulation Environment

For the simulation of the climate of the communes of Independencia and Recoleta, the database of the simulation software was considered, since there is a climatic file with data from the commune of Pudahuel in the city of Santiago, for which it was considered that the data of the file adjusts to what is required for the communes under study. Figure 3-91 shows the general characteristics of the existing climatic file for the commune of Pudahuel.

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General	
Name	PUDAHUEL
Country	CHILE
Source	ASHRAE/IWEC
WMO	855740
ASHRAE climate zone	3C
Koppen classification	Csb
Latitude (°)	-33,38
Longitude (°)	-70,78
Elevation (m)	474,0
Standard pressure (kPa)	95,8
Time and Daylight Saving	
Time zone	(GMT-04:00) Santiago
Start of Winter	Apr
End of Winter	Sep
Start of summer	Oct
End of summer	Mar
Energy Codes	
Legislative region	CHILE
Heating 99.6%	
Outside design temperature (°C)	-1,1
Wind speed (m/s)	7,3
Wind direction (°)	0,0
Heating 99%	
Outside design temperature (°C)	0,0
Wind speed (m/s)	6,2
Wind direction (°)	0,0

Figure 3-91. General Characteristics of the Climate File used for the simulations

The study contemplated the simulation of the following buildings, from which it was possible to collect enough information to generate a model.

1. Clinical Hospital University of Chile
2. Dentistry University of Chile - Clinic
3. Dentistry University of Chile – Administrative
4. Dentistry University of Chile - Laboratories
5. library
6. Municipality
7. Roberto del Rio Hospital
8. San jose hospital
9. José Horwitz Psychiatric Institute
10. National Cancer Institute

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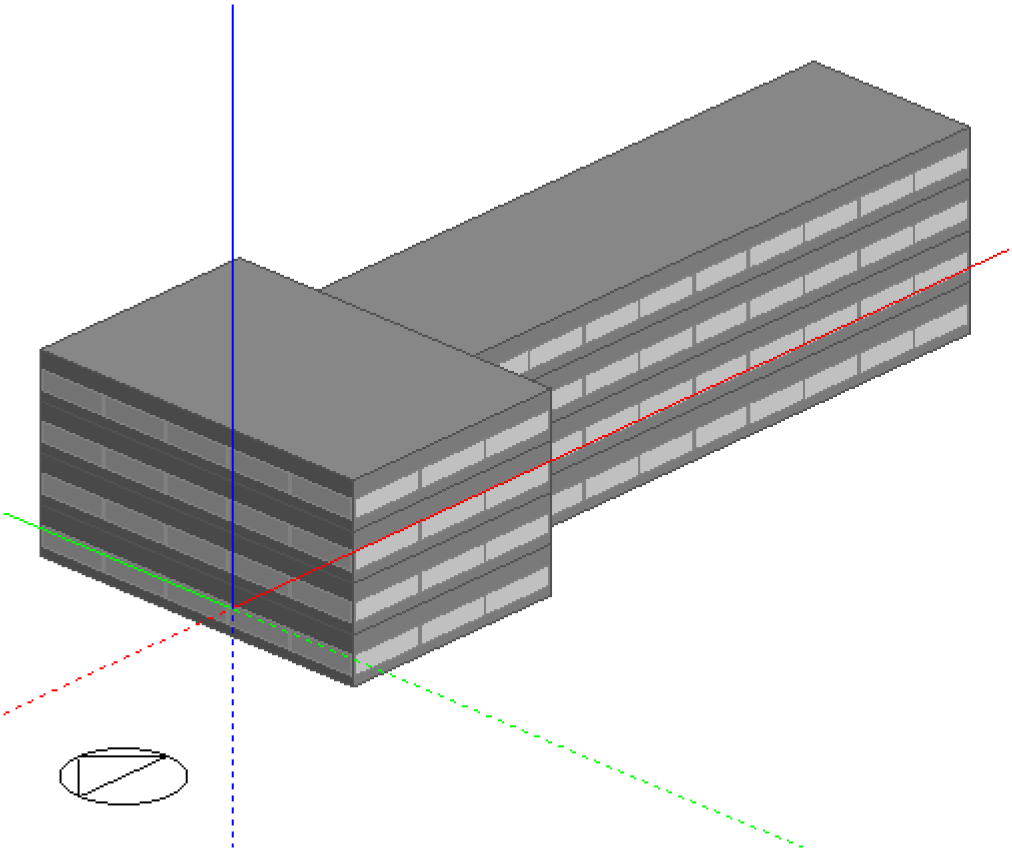

Figure 3-92. Geometric model Administrative Building of Dentistry

To determine the consumption of domestic hot water, the reference consumption is taken as that indicated by the current Chilean law, which considers, for different types of building use, different volumes of consumption.
Table 3-38 below shows daily consumption volumes for some of the types of use in the buildings in this study.

Table 3-38 Daily consumption of DHW for building typology

Building Type	Unit consumption (litres/ pers.day
Residential	40.0
Hospitals and clinics	80.0
Ambulatory and health center	60.0
school with showers	30.0
Small Business and Offices	3.0
Hotel /Hostel/ Aparthotel	50.0
Restaurants	12.0

The calculation developed with the Table 3-38 data was carried out using the following equation:

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$$DE_{ACS}=Q_{ACS}(T_u)\cdot\rho\cdot Cp\cdot(T_u\text{-}T_{AF})$$

Where:

DE_{ACS} = DHW energy requirement
Q_{ACS} = Volumetric flow rate considered at needed temperature
ρ = Water density
Cp = Specific heat capacity of water
T_u = Temperature requirement (45°C)
T_{AF} = Temperature of drinking water supplied

The consumption data were obtained from those recommended by the Technical Standard approved in Res Ex No. 502, of September 30, 2010, of the Ministry of Energy. The temperature considered for the drinking water supplied is that indicated in the same standard and which is summarized below for the city of Santiago.

Table 3-39 Drinking water temperatures considered. SOURCE: Chilean Law 20,365

Month	Network temperature [ºC]
JANUARY	17.5
FEBRUARY	16.0
MARCH	16.0
APRIL	14.0
MAY	12.0
JUNE	11.0
JULY	11.0
AUGUST	11.7
SEPTEMBER	12.5
OCTOBER	14.4
NOVEMBER	15.5
DECEMBER	17.0
AVERAGE	14.1

To calculate the DHW power required for each of the types of buildings in Independencia and Recoleta, it is necessary to know the hourly energy demand profiles for DHW. To do this, daily and weekly usage profiles are built, to then generate hourly profiles for the entire year for each of the typologies.

The graph in Figure 3-93 shows the profile of daily use of the DHW in a typical hospital or health center. It can be seen that some peaks in demand are generated during the day, which are produced by use at different times for patient showers, cooking, instrument sterilization, etc. As for the profile throughout the week, it is assumed to be constant for every day, given the type of use of a hospital-type building.

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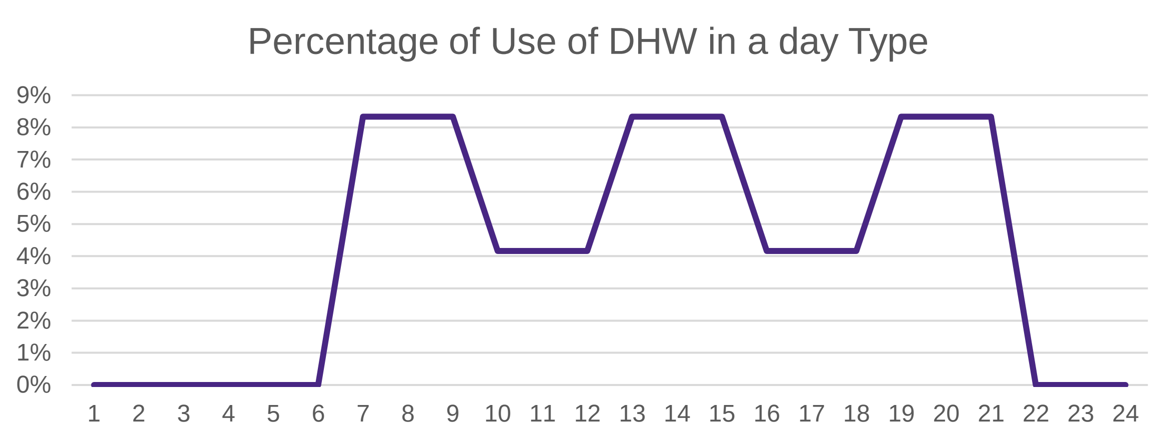

Figure 3-93. Daily profile of use of DHW in Hospitals and Health Centers

This profile is used to perform the distribution of energy in the year, in order to identify peaks in demand.

The tables below summarize the results of heating, DHW and cooling demands and powers for each of the buildings in the study area.

Table 3-40 Summary of heating and cooling energy loads for buildings in Independencia and Recoleta

Building	Heating [MWh/year]	DHW [MWh/year]	Cooling [MWh/year]
Universidad de Chile Clinical Hospital	2,533	3,427	3,600
Dental Clinic	156	214	220
Dental Clinic – Administrative	92	-	205
Dental Clinic – Laboratory	129	-	372
Public Library	25	-	63
Municipality	159	-	63
School of Medicine	2,590	-	819
Roberto del Rio Hospital	1,409	1,236	2,246
San Jose Hospital	2,435	1910	3,867
National Cancer Institute	981	686	1,389
Faculty of Chemistry and Pharmacy	268	-	189
Psychiatric Clinic	505	-	333
José Horwitz Psychiatric Institute	1,018	1,148	1,170
TOTAL	**12,300**	**8,621**	**14,536**

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Table 3-41 Summary of heating and cooling powers for buildings in Independencia and Recoleta

Building	Heating [MW]	DHW [MW]	Cooling [MW]
Universidad de Chile Clinical Hospital	2.9	0.9	5.4
Dental Clinic	0.4	0.1	0.4
Dental Clinic – Administrative	0.5	-	0.4
Dental Clinic – Laboratory	0.5	-	0.7
Public Library	0.0	-	0.1
Municipality	0.4	-	0.2
School of Medicine	4.2	-	2.8
Roberto del Rio Hospital	1.5	0.3	3.1
San Jose Hospital	2.6	0.5	5.4
National Cancer Institute	1.1	0.2	1.9
Faculty of Chemistry and Pharmacy	0.5	-	0.5
Psychiatric Clinic	0.3	-	0.4
José Horwitz Psychiatric Institute	1.2	0.3	1.8
TOTAL	**16.1**	**2.3**	**23.1**

3.5.2 REFERENCE CASE DESIGN DEVELOPMENT

To begin with the selection of technologies and design of the generation system for the base case, it is necessary to start by considering the energy sources that must be considered.

There are established natural gas networks, however, it is clear that the use of natural gas for heat generation contributes to the emission of polluting gases, a situation that should be avoided if possible.

In this sense, the use of electrical energy is contemplated, which in Santiago is produced from hydroelectric, biomass and solar sources, among others.

The energy demand of this study has the form indicated by the graph in the image below. The graph shows that there is a basal demand for heat throughout the year, mainly due to the demand for DHW by health buildings. The demand for cold, on the other hand, is intense during the summer months, decreasing significantly during the winter months. However, the cold demand of the system does not completely disappear in the months outside of summer, with cold demand still existing in the months of May, June and July.

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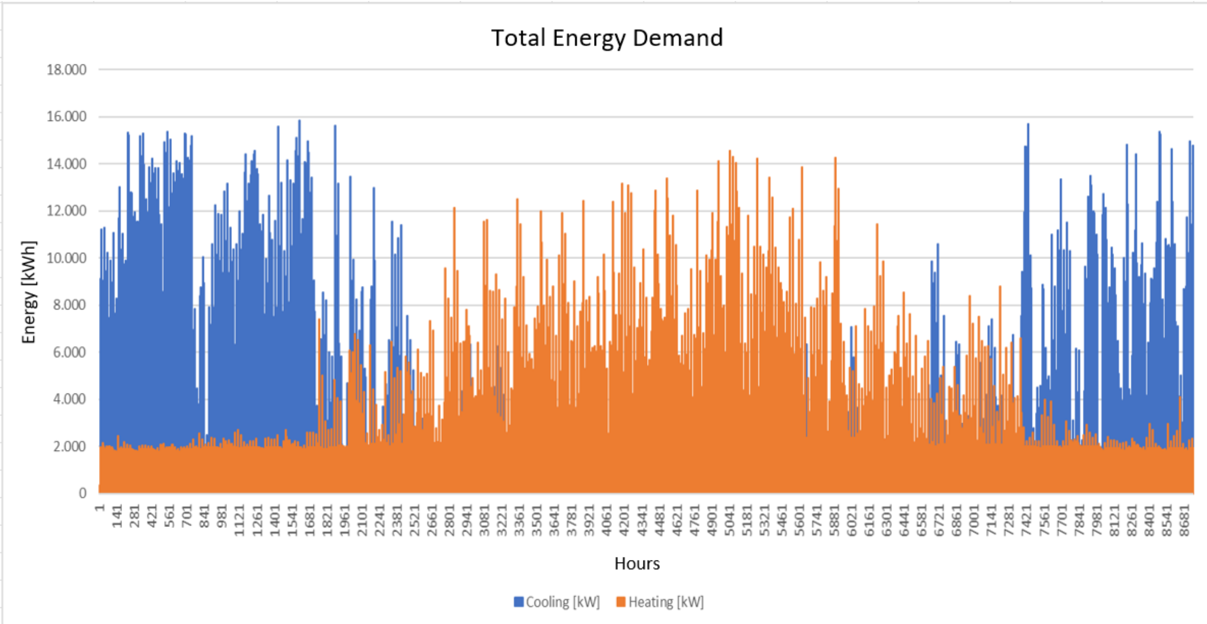

Figure 3-94. Total Energy Demand. Source: Study for Independencia and Recoleta,

According to the particular form of heat and cold demands, the use of simultaneous production heat pumps is opted for as basic equipment with equipment dedicated to the production of heat and cold as support to cover power peaks. The diagram of Figure 3-95 shows the operation and the equipment that forms part of the system. The main equipment is a simultaneous heat pump, which is connected to support heat and cold systems, in addition to connection to a cooling tower for dissipation purposes. The left side of the diagram shows the support equipment for the cold demand, consisting of a cold accumulator and support chillers

On the heat generation side, a heat accumulator and conventional electric heat pumps are also used as support.

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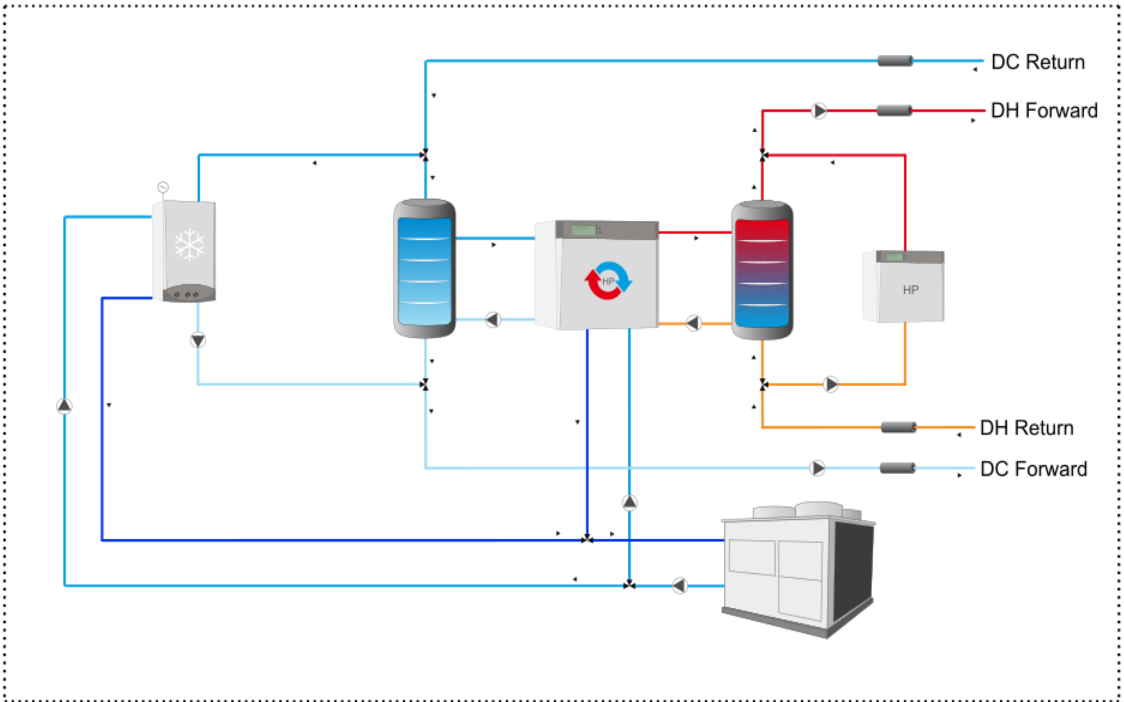

Figure 3-95. Diagram of operation of the generation system design. Source: Study for Independencia and Recoleta,

For the sizing of each of the equipment, firstly, the relationship between the power of the generating equipment and the accumulation volume is analysed, with the aim of covering 99.5% of the demand, both for the demand for heat as for cooling. It can be seen that the series of blue dots in both graphs shows the decrease in the accumulation volume as the power of the heat pump increases. An interesting conclusion is that the accumulation volume grows rapidly for pump powers of less than 4.5 MW in the case of heating, and less than 6.5 MW in the case of cooling. In turn, this aggressive growth of the accumulation volume is reflected in the initial investment level as shown by the series of orange dots.

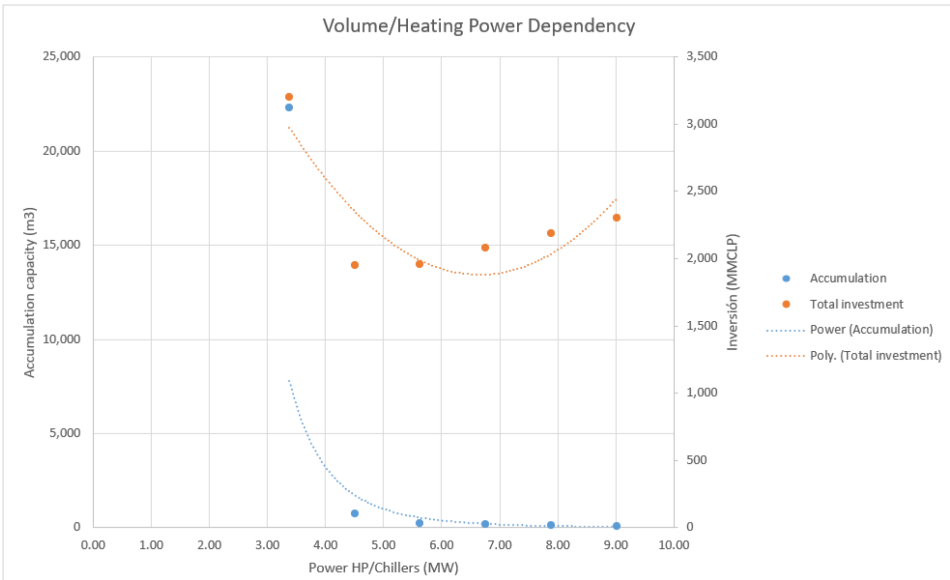

Figure 3-96. Relationship between heat pump power and accumulation volume, for heat production. Source: Study for Independencia and Recoleta,

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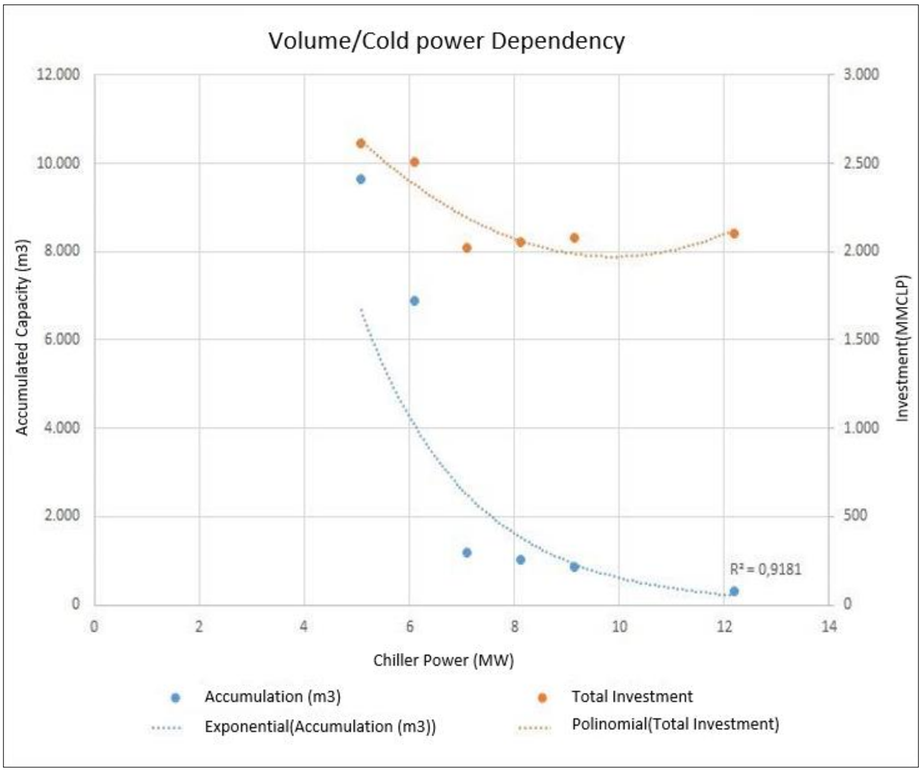

Figure 3-97. Relationship between heat pump power and storage volume, for cooling production. Source: Study for Independencia and Recoleta,

Knowing then that there is a minimum level of power in relation to the accumulation that allows to cover 99.5% of both demands, it is now possible to analyse the optimization of the size of the pump with the aim of achieving the best performance of the system (the one that finally it will result in the consumption of the system and finally in the rate that should be charged to potential clients) in relation to the level of investment and the possible energy rate.

From the graph in the image below, it can be seen that the global performance curve (SPF, *Seasonal Performance Factor*) presents a maximum around a power slightly lower than 7 MW, while approximately around the same power there is a minimum in the investment, indicating the presence of an optimum of size in the design.

This behaviour is also displayed in the behaviour of the bill, which also decreases around this power, clearly due to the improvement in system performance.

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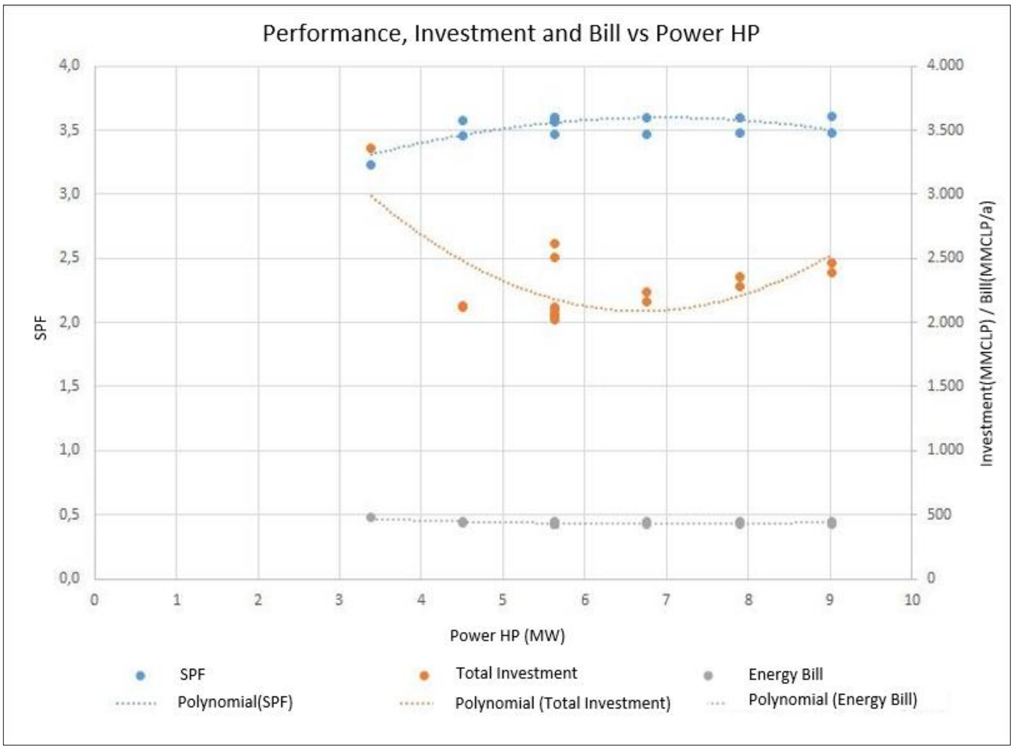

Figure 3-98. Relationship between heat pump power and overall system performance, investment level and energy bill. Source: Study for Independencia and Recoleta,

The final optimization of the sizes of the equipment is generated in relation specifically to the energy bill of the clients at 15 years. In the attached report you can see the graphs for each team.

Finally, Table 3-42 summarizes the main parameters of the proposed design, together with the system performance results.

Table 3-42 Summary of design parameters and main results.

Parameter	Unit	Value
Simultaneous HP	*MW*	0.47
Chiller Capacity	*MW*	7.11
Heat pump Capacity	*MW*	5.64
Heat Accumulator	*m3*	228
Cold Accumulator	*m3*	1,171
Cold Compliance		99.45%
Compliance Heat		99.53%
Dissipated energy	*MWh*	4,182

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Electricity consumption	*MWh*	10,149
Gas consumption	*MWh*	0
Total consumption	*MWh*	10,149
TER HPS		3.18
EER Chiler		3.14
COP HP		4.30
SPF		3.59

As an understanding of the proposed design, the graphs below show the distribution of powers and contributions to the total energy of the system.

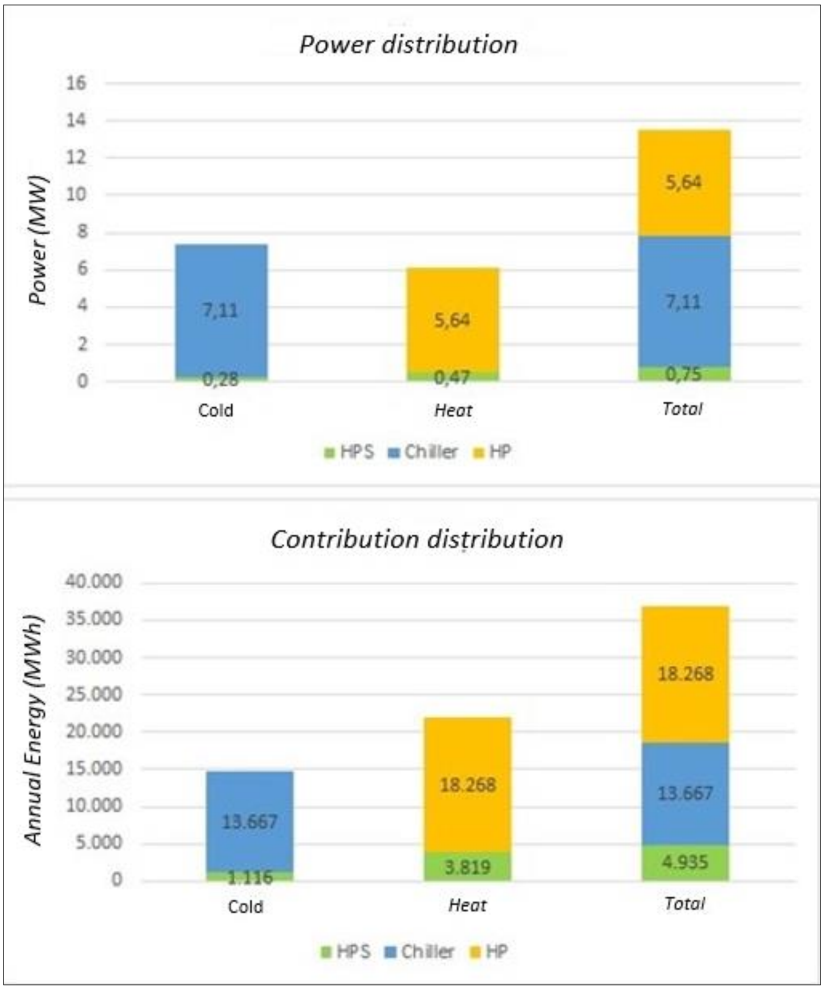

Figure 3-99. Power and Energy distribution for each technology. Source: Study for Independencia.

3.5.2.1 WEDSITRICT TECHNOLOGIES SYSTEM AND TRNSYS MODEL

In addition to the reference case mentioned, it has been generated a base case using advanced technologies such as AHPHR and WESSUN.

The diagram for the proposed system design is shown in Figure 3-100. The diagram shows that the main generation equipment, both for cooling and heating, is the absorption heat pump

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with heat recovery (AHPHR) coupled with WESSUN solar technology. The operation of the system consists of the following:

- The AHPHR transforms the high temperature stream from the WESSUN solar system into medium and low temperature streams that are both exploited in this system thanks to an Add-On heat pump integrated with the AHPHR Absorber output (low temp)
- An aerothermal heat pump supports the AHPHR capacity working at the same temperature is serial connected through another storage tank.
- At this point, the heat that is being generated is distributed through pipes to each building.
- For cooling generation, the main equipment is the AHPHR with a supply temperature of 12°C. This equipment is supported by a conventional chiller.

In summary, with this design it is possible to work with greater efficiency in the AHPHR when working at its optimum temperature. Since the system requires high temperatures due to the distribution systems required by the buildings, other efficient systems such as WESSUN are coupled to raise the temperature throughout the circuit. It is important to note that the project within the WeDistrict approach does not consider the analysis over the pipes and substation system.

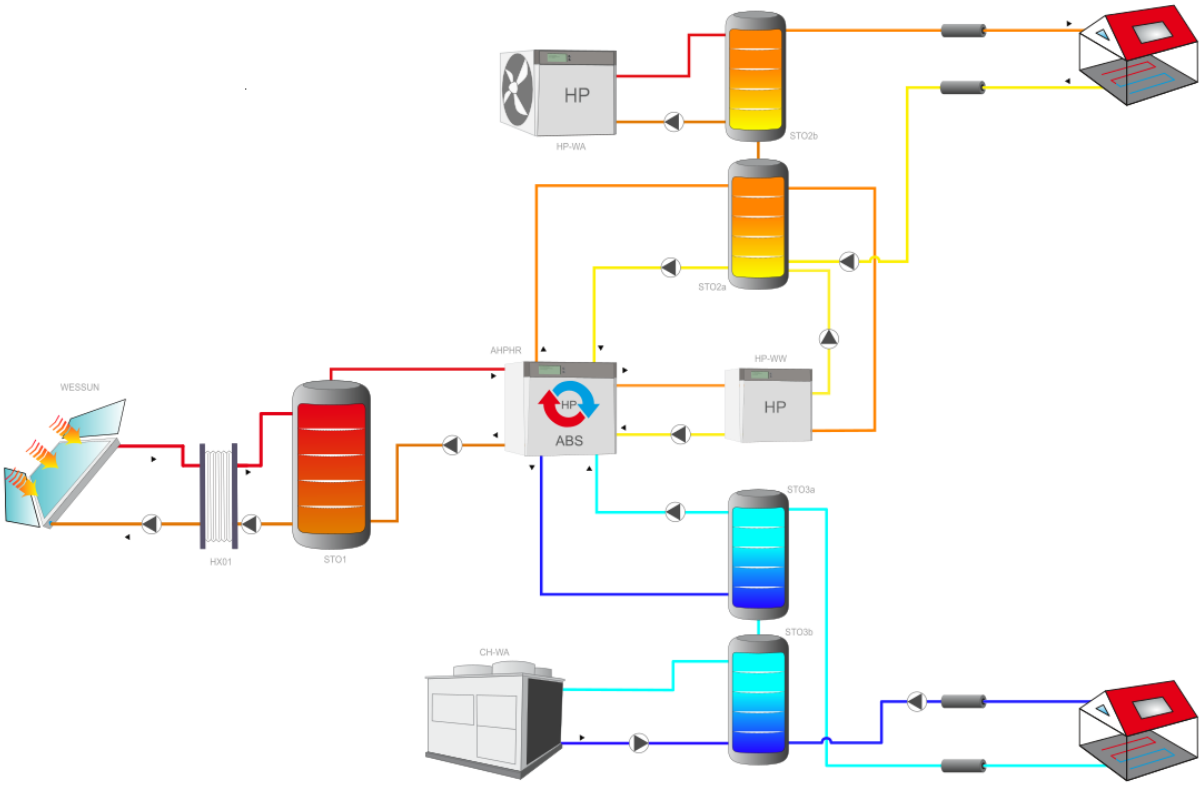

Figure 3-100. Wedistrict technologies system design for Independencia demo-follower.

The TRNSYS model is as shown below, showing the TRNSYS Macros that were considered.

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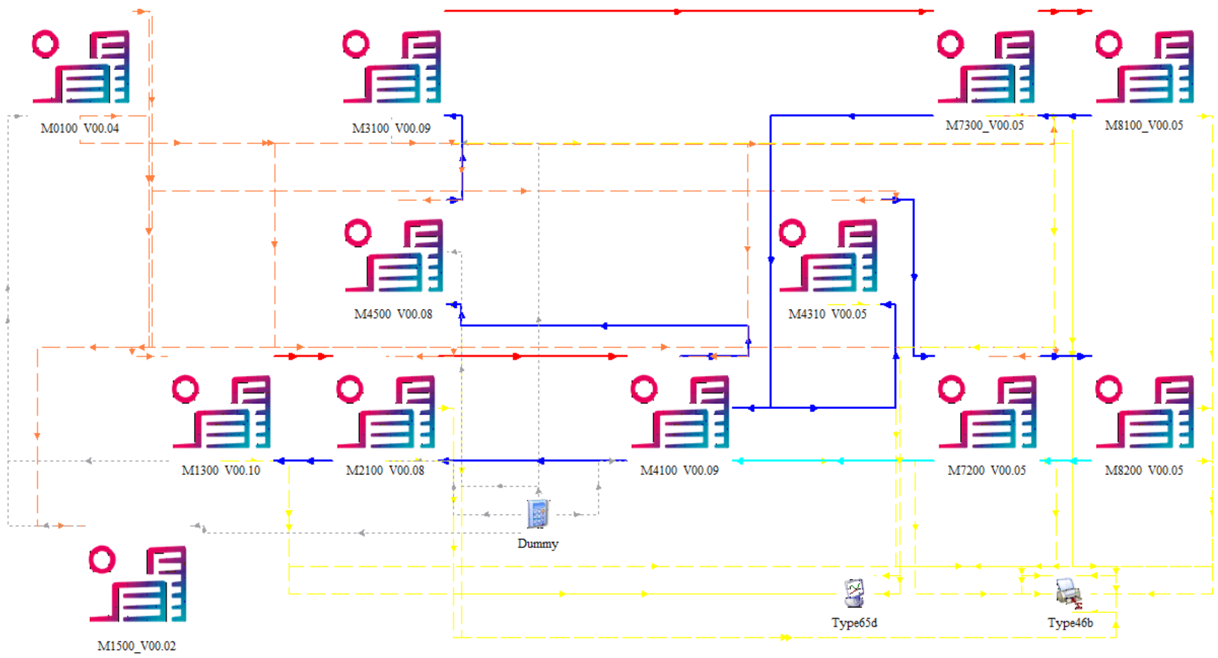

Figure 3-101. Wedistrict TRNSYS model

The macros used in the TRNSYS model are as follows:

- M0100: Weather conditions
- M1300: WESSUN Technology
- M2100: Hot water Storage
- M4100: Advanced absorption chiller
- M4310: Conventional chiller
- M4500: Heat pump
- M7200: Cold distribution
- M7300: Heat distribution
- M8100: Heat Load
- M8200: Cold load

The parameters used in the TRNSYS model are shown in Table 3-43.

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Table 3-43 Summary of design parameters for TRNSYS model

Parameter	Unit	Value
AHPHR Nom Cap	*MW*	1.4
Chiller Nom Cap	*MW*	15,9
Hp Nom Cap	*MW*	1,4
Total Volume Heat Storage	*m3*	228
Total Volume Cool Storage	*m3*	1,171
Cold Compliance		99.45%
Compliance Heat		99.53%
Electricity consumption	*MWh*	10,149
Gas consumption	*MWh*	0
Total consumption	*MWh*	10,149
TER HPS		3.18
EER Chiler		3.14
COP HP		4.30
SPF		3.59

3.5.2.2 RESULTS

Based on the simulation in TRNSYS, Table 3-44 shows the main results obtained, where CONCEPT refers to the system composed of the WESSUN technology and the advanced absorption chiller.

Table 3-44 Main results of TRNSYS simulation

Parameter	Value	Unit
Total Heat Generation	27,641,715	kWhth/year
CONCEPT Heating Fraction	0.27	
Total Cooling Generation	14,604,181	kWhth/year
CONCEPT F_Cooling	0.13	
SYSTEM F_SOLAR	0.18	
SYSTEM F_RES	0.47	
SYSTEM Total Heating Econs	11,710,793	kWhe/year
SYSTEM Total Cooling Econs	3,996,113	kWhe/year
SYSTEM Total Econs	14,620,513	kWhe/year

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COPe SYSTEM	2.36	
EERe SYSTEM	3.65	
SPFe SYSTEM	2.89	

3.5.3 FEASIBILITY STUDY

3.5.3.1 SCENARIOS SIMULATIONS

Based on the results obtained from the TRNSYS simulation, a parametric analysis was developed. The different simulation scenarios were chosen based on the performance of both the AHPHR system and the entire generation system. In this sense, we were interested in knowing different configurations of two of the most sensitive parameters in terms of system performance and capacity to meet demand. Different sizes of both the AHPHR and the solar area of the WESSUN collectors were considered, considering the ratio factor between the two.

For the performance analysis, KPIs such as IRR, CO2 emissions to the environment in tons per year and renewable fraction were chosen. Simulations of the different scenarios were developed on the reference case using a model parameterization using softwares like JEPlus and TRNEdit and a data mining model.

Table 3-45 Configurations for scenarios simulations

AAC CAP GEN [kW]c	Solar Area [m2]
250	357
250	714
250	1,071
500	714
500	1,429
500	2,143
750	1,071
750	2,143
750	3,214
1000	1,429
1000	2,857
1000	4,286
1250	1,786
1250	3,571
1250	5,357
1500	2,143
1500	4,286
1500	6,429

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AAC CAP GEN [kW]c	Solar Area [m2]
1750	2,500
1750	5,000
1750	7,500
2000	2,857
2000	5,714
2000	8,571

3.5.3.2 RESULTS

Based on the results obtained from the TRNSYS simulation, the following graphs show the results of the parametric analysis where the numbers next to the dots correspond to solar multiple of each case.

Solar Yield

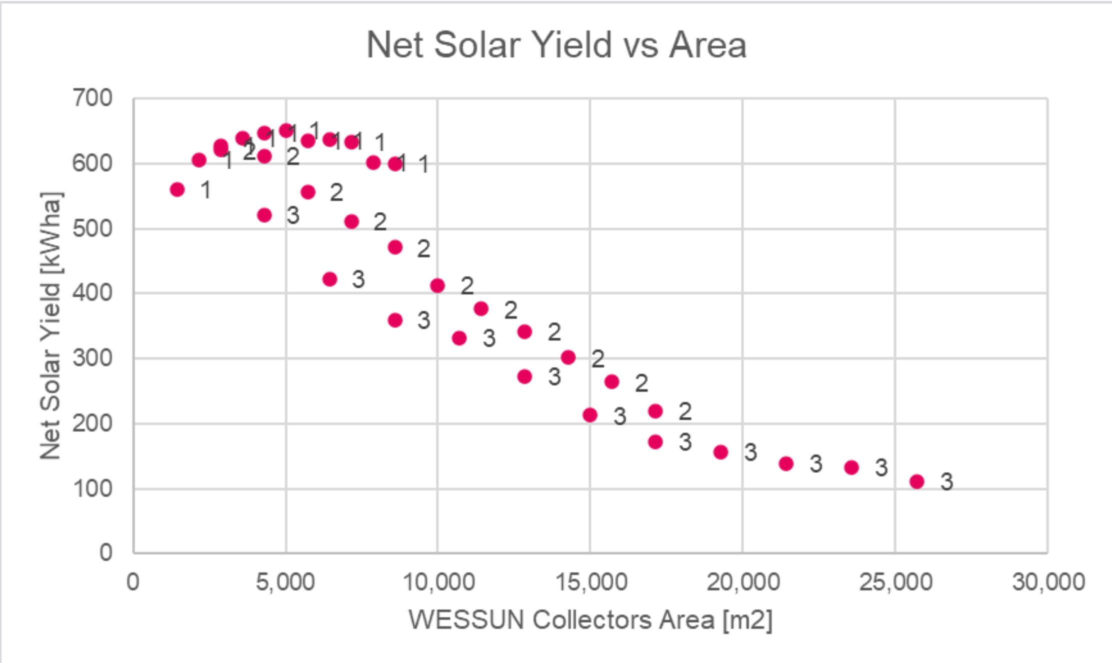

Figure 3-102. Net Solar Yield vs Area

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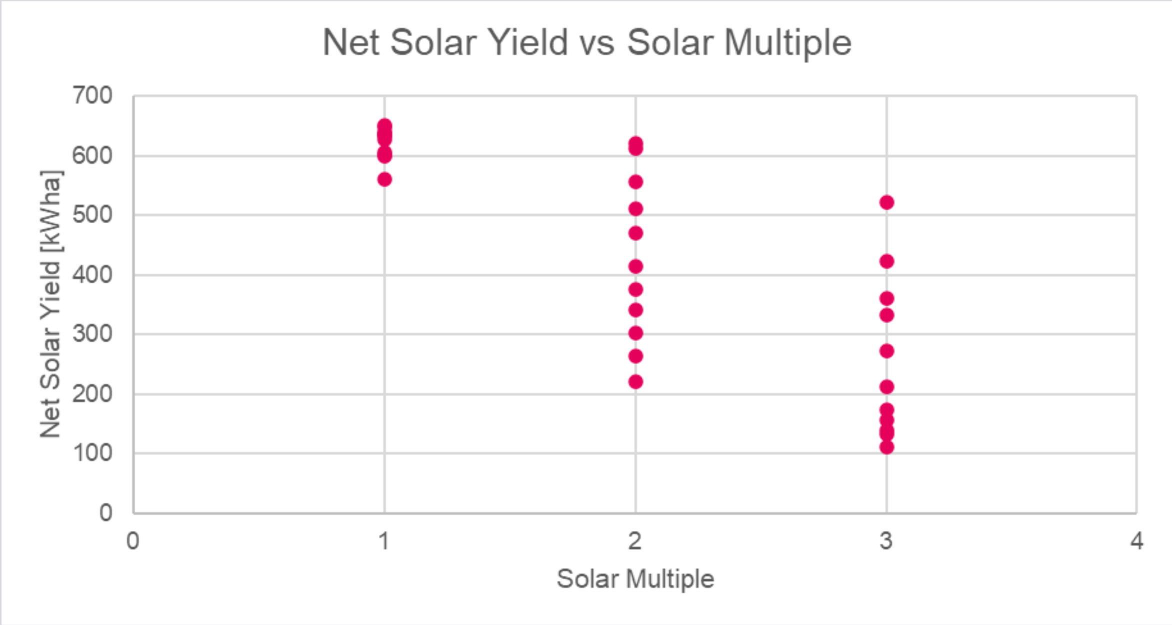

Figure 3-103. Net Solar Yield vs Solar Multiple

First, as can be seen from the graphs in Figure 3-102 and Figure 3-103 the Net Solar Yield decreases as the WESSUN collector area increases. This occurs because the power capacity of the AHPHR does not increase at the same rate as the collector area, limiting its ability to harness the solar energy produced by the WESSUN system.

Concept Performance

The graphs in Figure 3-104, Figure 3-105 and Figure 3-106 show the behaviour of the performance indicators with respect to variables that account for the amount of heat and cold generated respect to total energy generated by the system. This allows to know the total performance of the system in relation to the energy generated by both the condenser and the evaporator of the AHPHR.

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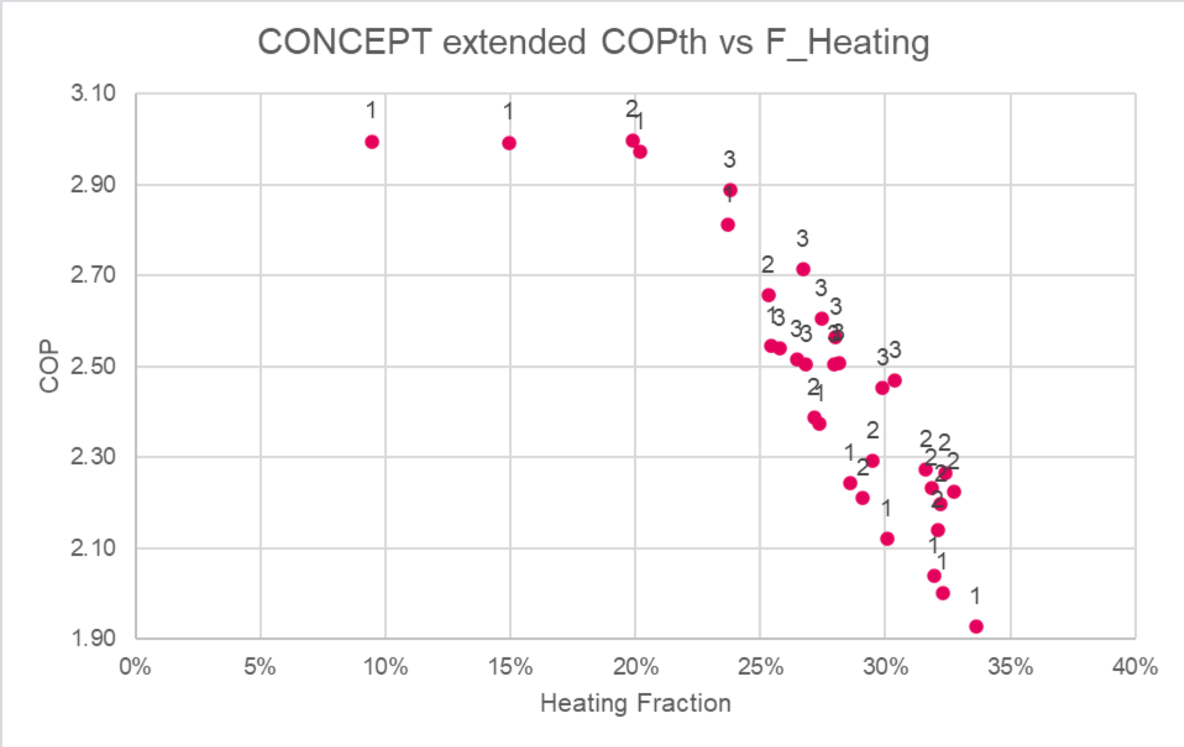

Figure 3-104. Extended CONCEPT COPth vs Heating Fraction

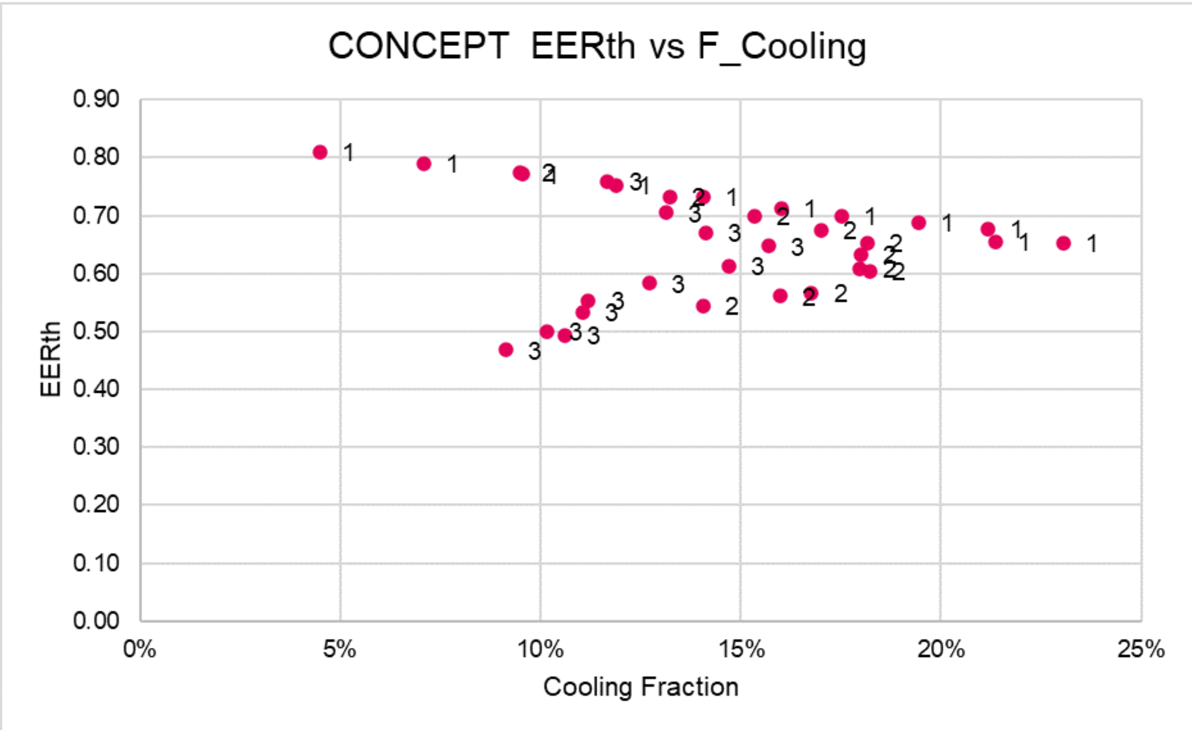

Figure 3-105. CONCEPT EERth vs Cooling Fraction

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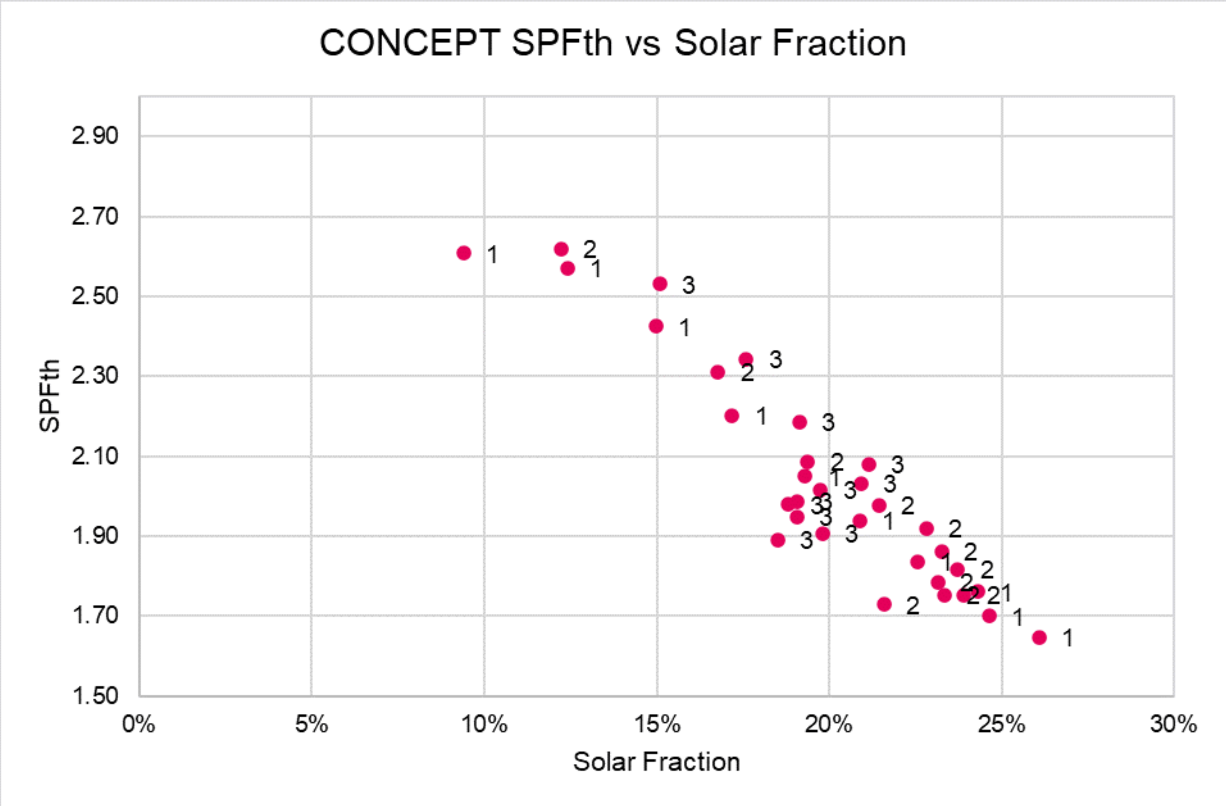

Figure 3-106. CONCEPT SPFth vs Solar Fraction

The following graphs show how both the heating and cooling fraction reach a saturation point with increasing solar area, showing a stagnation in the increase of the fraction due again to the AHPHR power not being able to take advantage of the heat generated by WESSUN, implying the inefficiency of a system with a very large solar area. The same result can be observed for both solar fraction and renewable energy fraction.

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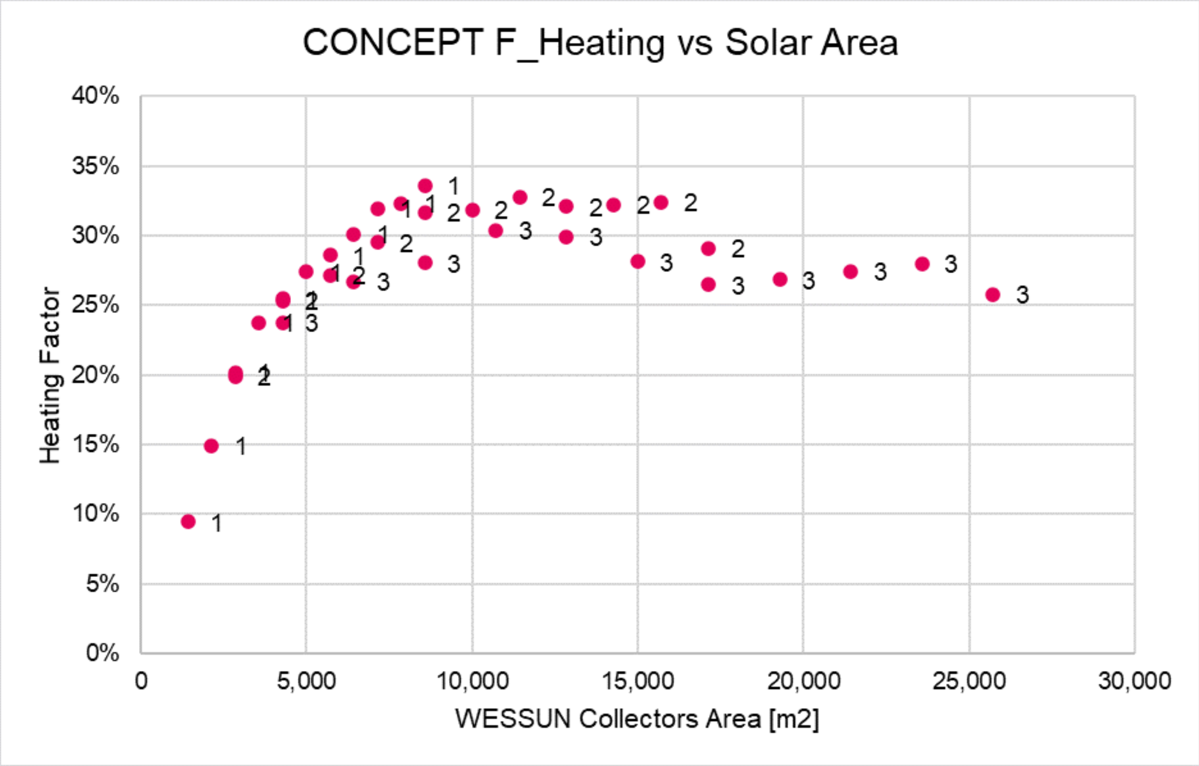

Figure 3-107. Heating Fraction vs Solar Fraction

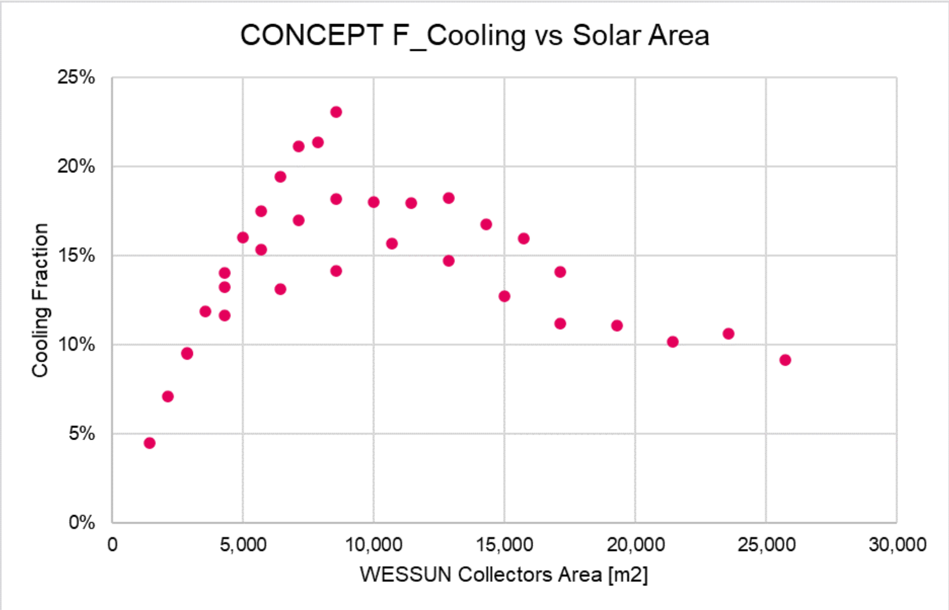

Figure 3-108. Cooling Fraction vs WESSUN Collectors Area

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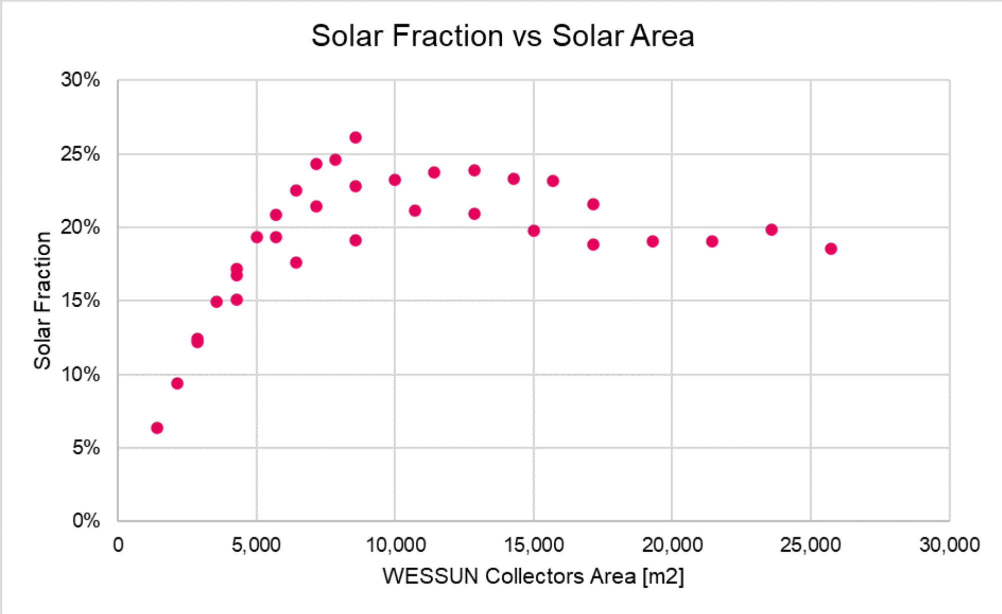
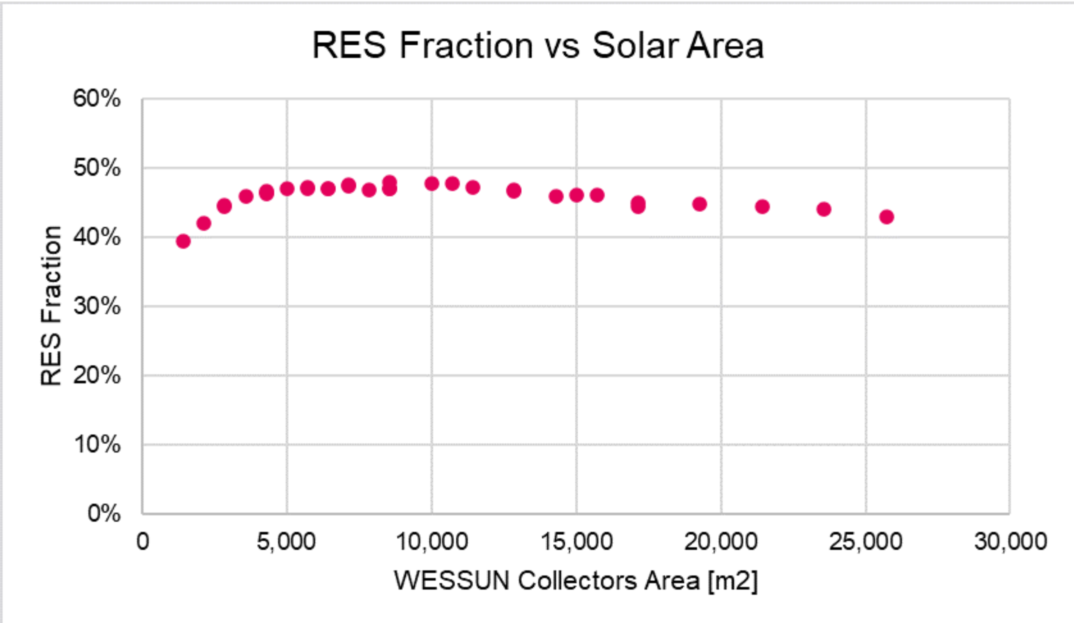


Figure 3-109. Solar Fraction vs WESSUN Collectors Area



System Performance

The graphs in Figure 3-110, Figure 3-111 and Figure 3-112 show the system performance. It can be observed that the electric COP of the system behaves very differently to the electric EER. The COP has a set of results that range from 2.2 to 2.35 with heating fractions of 25% to 35%. On the other hand, the EER decreases with the increase of cooling factor even though with factors of 10% to 15% it can be observed some increase.

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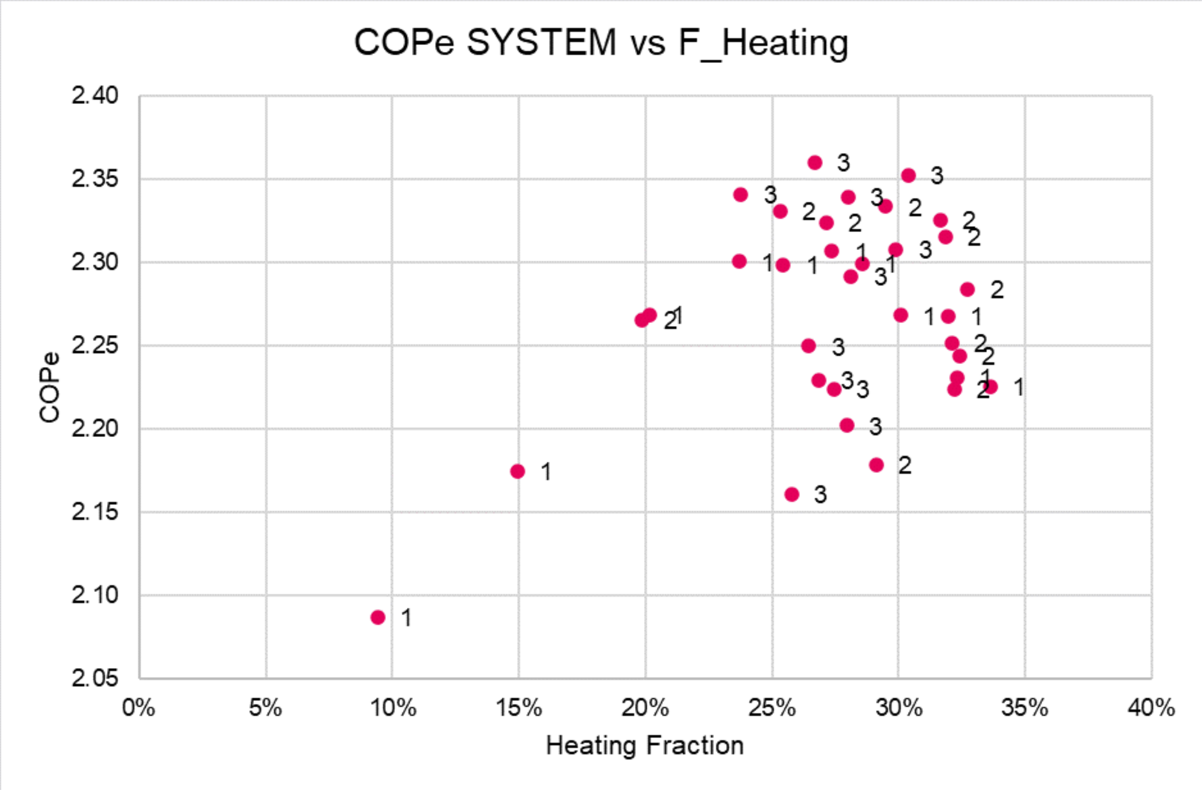

Figure 3-110. COPe System vs Heating Fraction

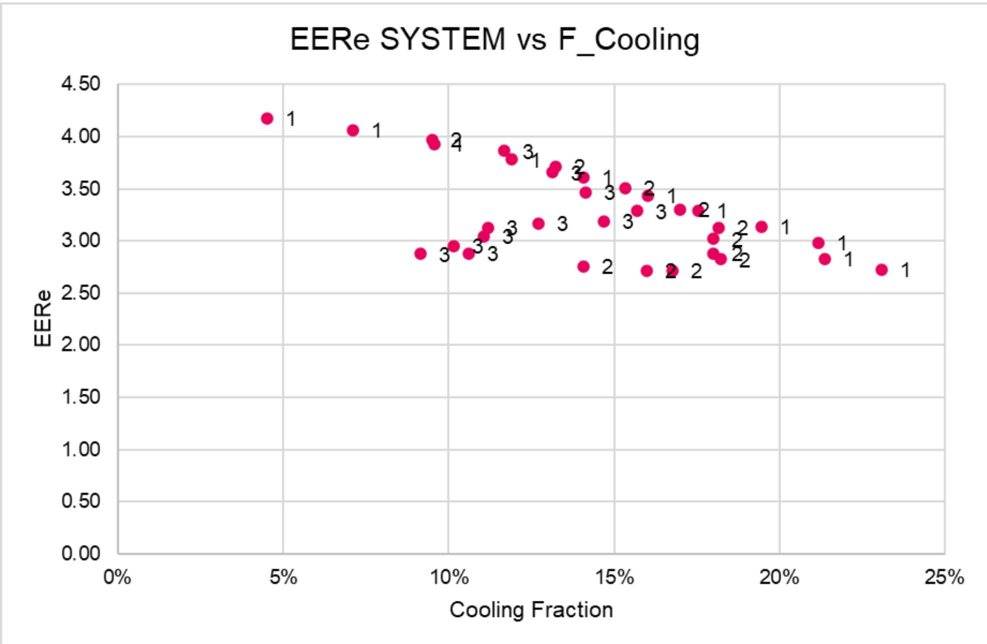

Figure 3-111. EERe System vs Cooling Fraction

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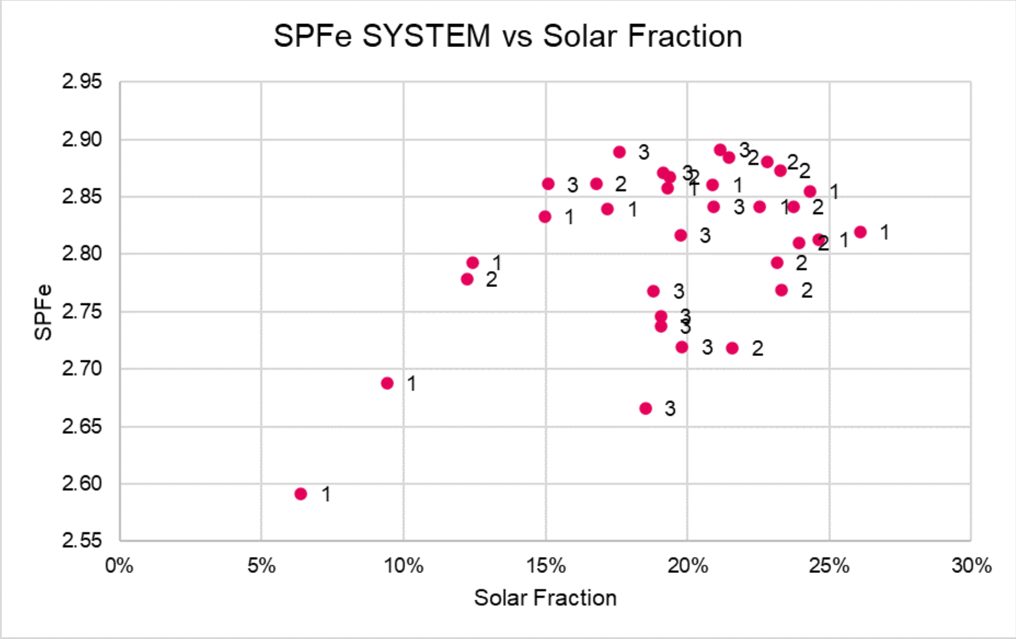

Figure 3-112. SPFe System vs Solar Fraction

The graph in Figure 3-112 shows that it can be obtained a relatively high SPFe with solar fractions ranging from 15% to 25%, with high solar multiples like 3.0.

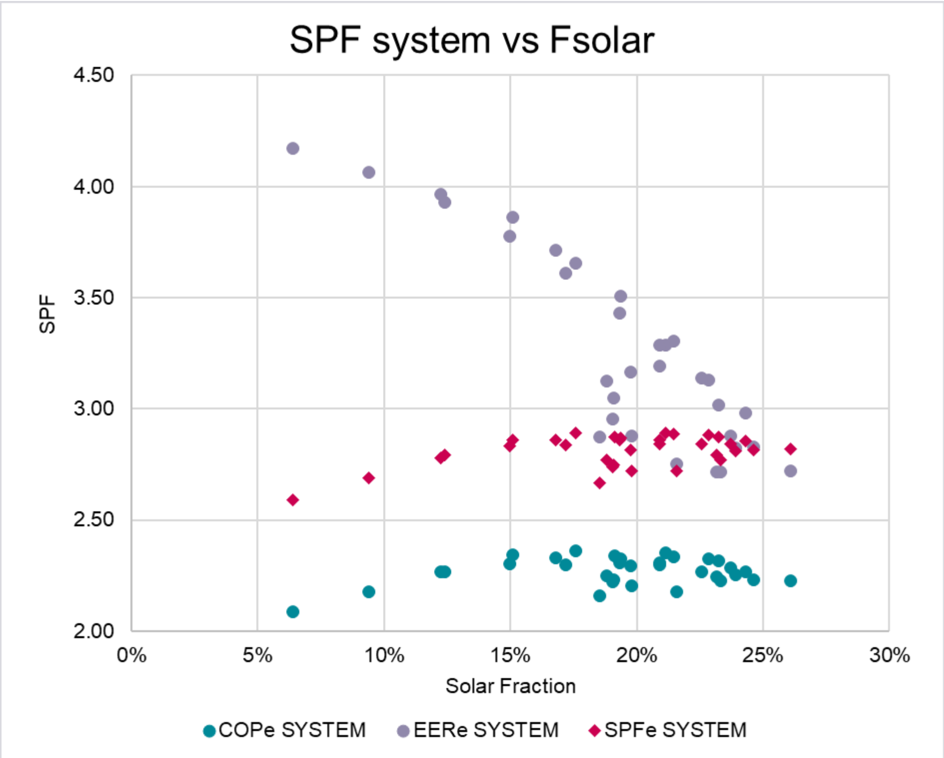

Figure 3-113. SPF System vs Solar Fraction

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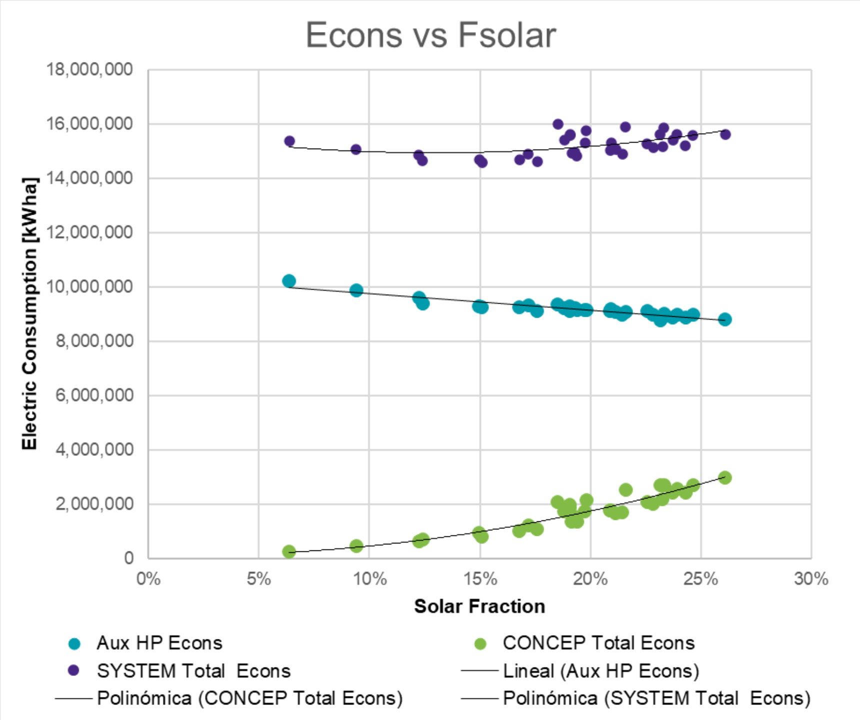

Figure 3-114. Electric Consumption vs Solar Fraction

3.5.3.3 ECONOMIC ANALYZE

The following graphs show the economic analysis of the system. The IRR and CO2 emissions have been chosen as indicators of system feasibility.

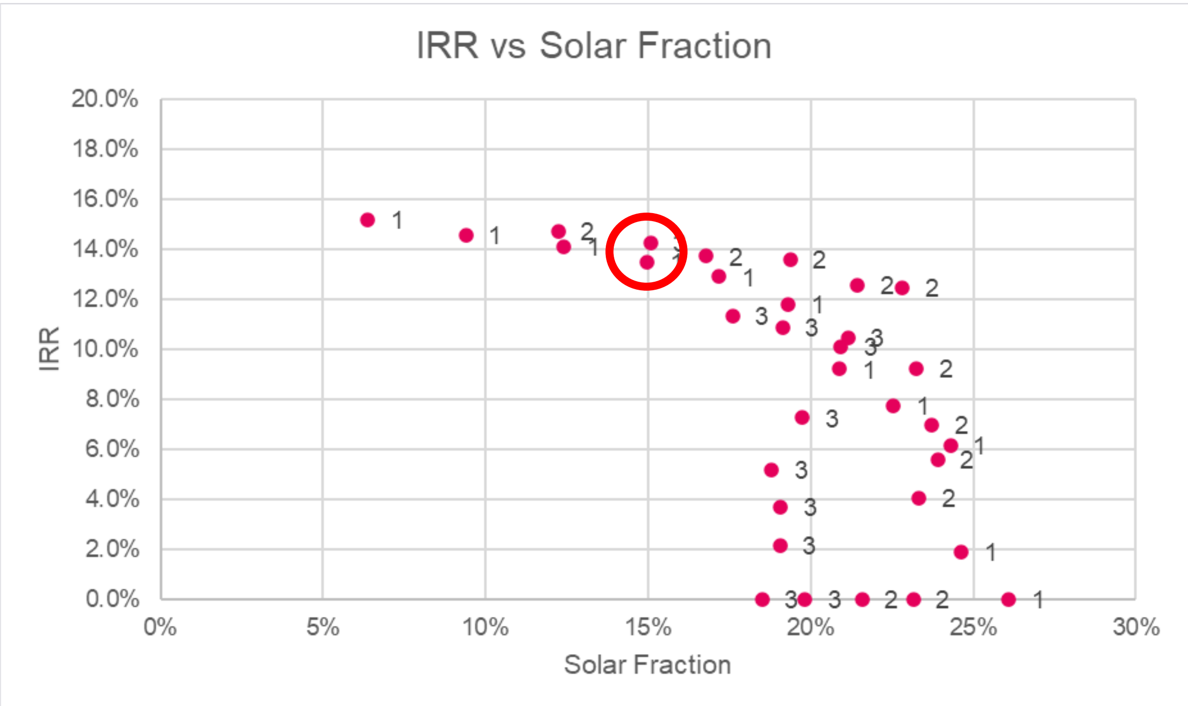

Figure 3-115. IRR vs Solar Fraction

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It can be observed from the graph in the figure above that the IRR decreases with the increase of the solar fraction. From the technical results it could be noted that the energy generated does not increase steadily with the solar area, and therefore with the solar fraction, reaching a saturation point. If the energy generated does not increase steadily, the savings produced by the system also reach a saturation point, while the installation costs continue to increase, which implies a decrease in the IRR. It can be noted that the maximum solar fraction that allows reaching a highly competitive IRR (of 14%) is 15%.

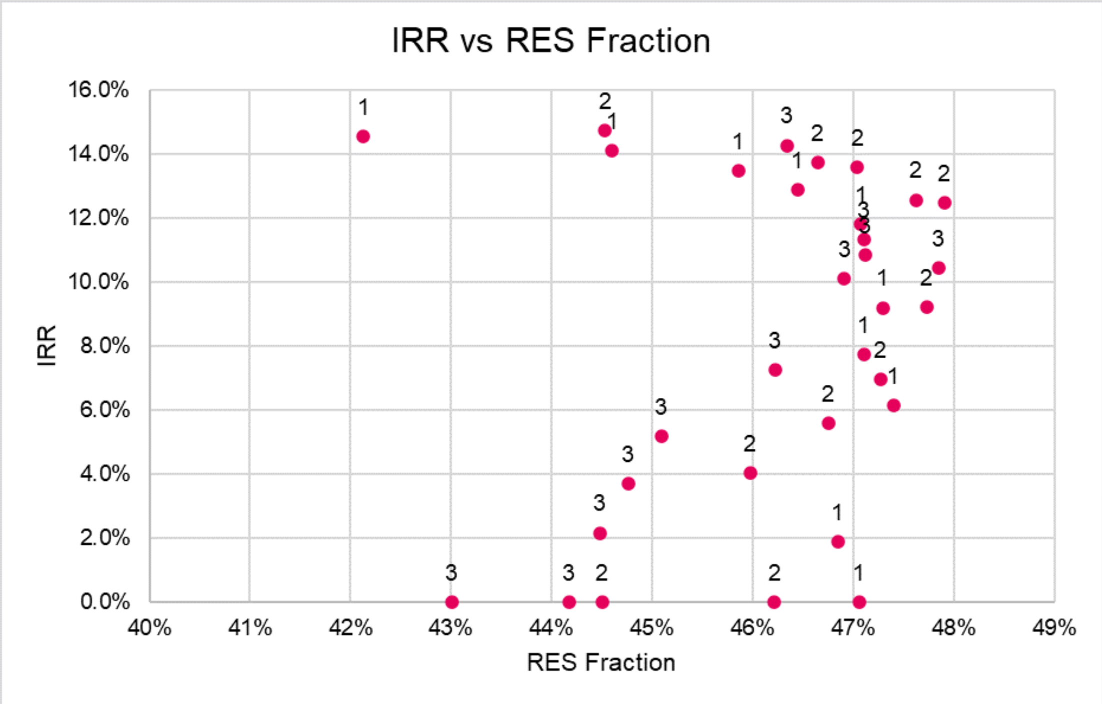

Figure 3-116. IRR vs Renewable Energy Fraction

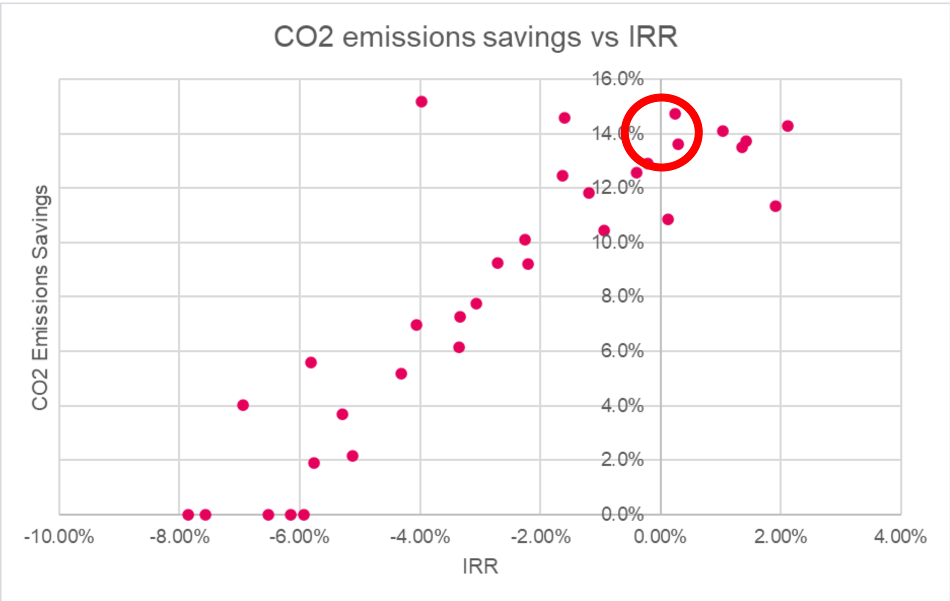

Figure 3-117. CO2 Emissions Savings vs IRR

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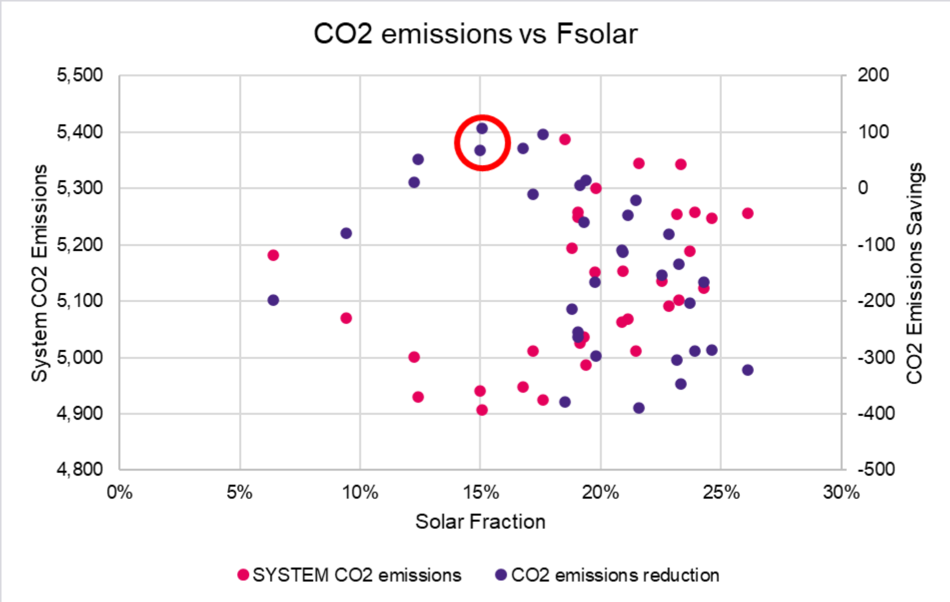

Figure 3-118. Total System CO2 Emissions and CO2 Emissions Savings vs Solar Fraction

3.5.4 CONCLUSIONS

The results obtained from the parametric analysis allow us to choose a case of technological configuration that may be of interest. The case chosen allows to conclude that the DHC system is economically feasible, and with the Wessun Concept reaches high levels of RES share with good profitability.

The proposal is to develop a 15% solar fraction system with a 14% IRR, based on a 4th generation DHC network, with the parameters and results shown in Table 3-46.

Table 3-46 Parameters of Selected Case

Parameter	Unit	Value
AHPHR Capacity	*kW*	1.000
Wessun Area	*m2*	4.285,7
Solar Multiple	-	3,00
Net Specific Solar Yield (after storage)	*kWh/m2*	521,52
Concept Extended COPe		8,14
Concept Extended EERe		2,14
Concept Extended SHPe		10,27
Heating Fraction Concept		24%
Cooling Fraction Concept		12%
SYSTEM F_SOLAR		15%
SYSTEM F_RES		46%

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Parameter	Unit	Value
COPe SYSTEM		2,34
EERe SYSTEM		3,86
SPFe SYSTEM		2,86
IRR CONCEPT		17,3%
IRR SYSTEM		14,3%
SYSTEM CO2 emissions	*tonCO2eq*	4.907
CO2 emissions reduction	*tonCO2eq*	106
SYSTEM CO2 emissions	*tonCO2eq/MWh*	0,13
CO2 emissions reduction		2,12%

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4 Retrofitting DH/C demo-followers

4.1 Parc de l’Alba (Barcelona – Spain)

4.1.1 GENERAL DESCRIPTION

The “Parc de l’ Alba” (also known as Directional Centre) is a new urban development located in Cerdanyola del Vallès, a city of 57,000 inhabitants in the Barcelona’s area. The park aims to become a model of sustainable growth; therefore, it has partially implemented a high efficiency energy system that produces electricity, heat and cold with a DHC network.

Figure 4-1: Parc de l’ Alba main generation plant (foreground) and Synchrotron (background)

Currently there are two data centres and three office buildings connected, although further services and industrial buildings are expected, and a residential development is planned. The most relevant feature of the development is the presence of the Alba Synchrotron, a facility with a characteristics demand profile. These building have a very high cooling and electricity demand that is the reason why the “Parc de l ’Alba“ is a cooling dominated network. As it is in a partial implementation stage, the “Parc de l’ Alba” is operating with a single generation plant (ST-04 in Figure 4-1). This supplies heating and cooling mainly with combined heat and power engines, backup gas boilers, absorption chillers, and compression chiller. This plant is ready to increase its capacity when the energy demand grows, with space available within the facility. Moreover, two more production plants are planned to be implemented according to the pace of the urban development (ST-05 and ST-07 in Figure 4-2).

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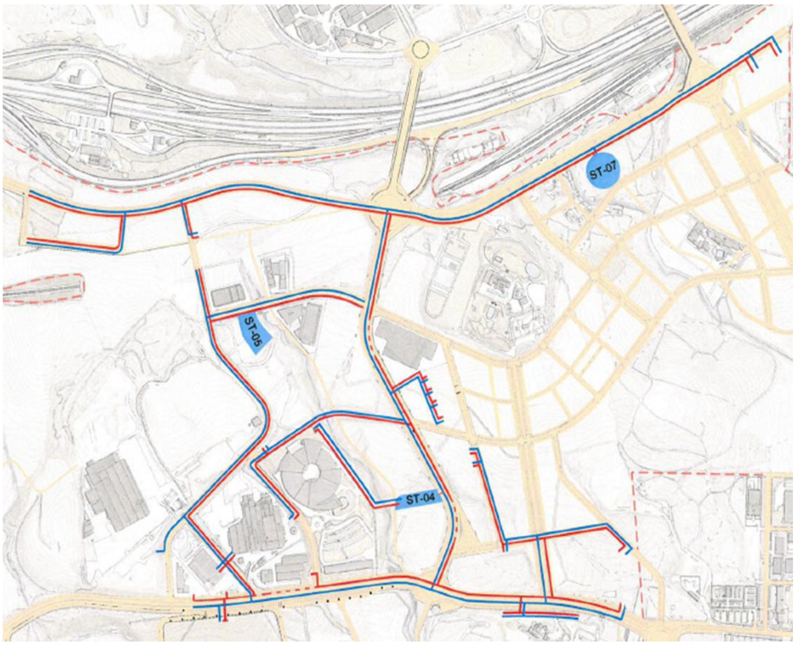

Figure 4-2: Parc de l' Alba current network layout

4.1.2 REFERENCE CASE MODEL AND VALIDATION

4.1.2.1 REFERENCE CASE HOURLY DEMAND GENERATION

Just like mentioned previously, Parc de l' Alba is composed by six buildings: 2 data centers, 3 office buildings and the Synchrotron light lab. There are three different simulation models used to describe the thermal and electrical demand of the reference case buildings:

- ***Air-cooled data centre model*** in TRNSYS. Data centre demand is calculated using a highly detailed model for air-cooled data centre. The energy model reproduces the thermal management of a typical data centre with compression chiller cooling and waste heat recovery from the condenser side of the chiller.

- **Reduced model for offices** in TRNSYS. The model is an improved and more detailed version of ISO 13790 resistances-capacitances model. The model uses two sets of parameters to calculate the demand depending on whether the indoor temperature drops below 24ºC, heating mode, or rises above 24ºC, cooling mode. The reduced model considers standard internal gains due to lighting, equipment, and occupancy.

- **Knowledge from previous projects** provided a detailed insight of the Synchrotron operation. This approach has been called “4+1”. It considers that the facility operates four weeks no stop with a stable 3.3 MW cooling consumption, and it stops one week, with no cooling consumption. Moreover, a stable heating consumption of 245 kW is considered.

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The hourly profiles estimated for the heating and cooling demands of the Parc are shown in Figure 4-3 and Figure 4-4.

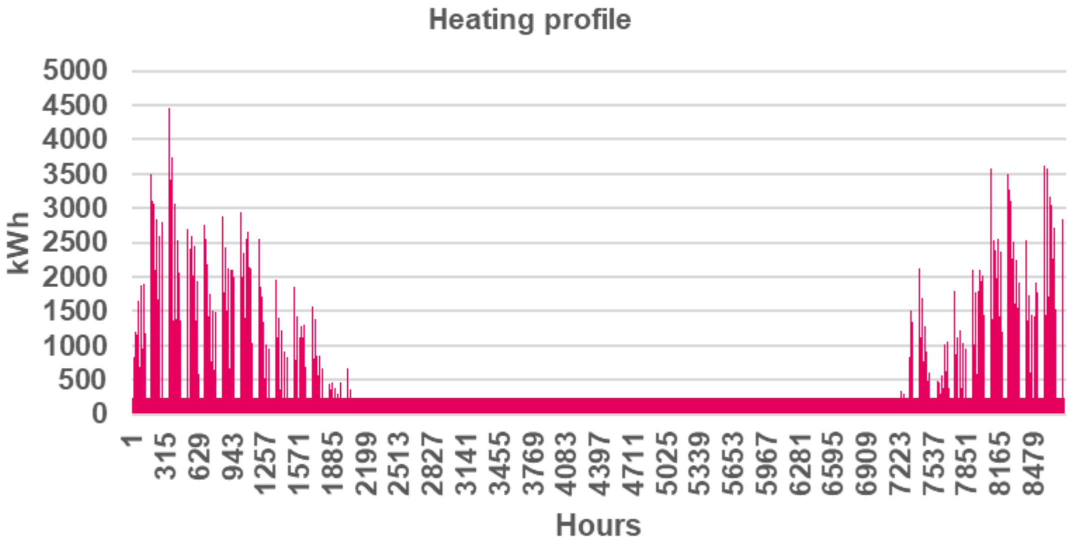

Figure 4-3: Heating hourly demand profile estimated

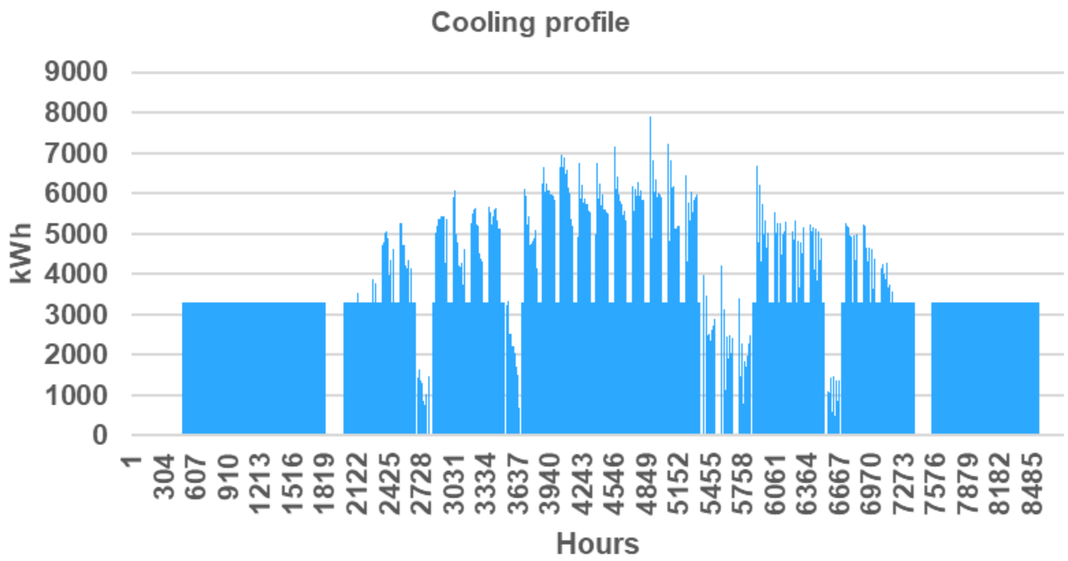

Figure 4-4: Cooling hourly demand profile estimated

4.1.2.2 REFERENCE CASE ENERGY MODEL

Reference case modelling focuses on the implementation of the ST-4 plant in the dynamic simulation environment of TRNSYS. As mentioned before, this plant supplies heating and cooling mainly with combined heat and power engines, backup gas boilers, absorption chillers, and a compression chiller (as shown in Figure 4-5):

- Three cogeneration engines (3 x 3.35 MW), Electrical efficiency = 44.9%

- Single effect absorption chiller (hot water at 90 C), 3MW, COP =0.7

- Double effect absorption chiller, 5MW, COP= 1.3

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- Natural gas boiler (back-up): 5MW
- Air-cooled chiller, 5MW, COP=5
- Cold water storage: 3750 m^3 (22 MWh)

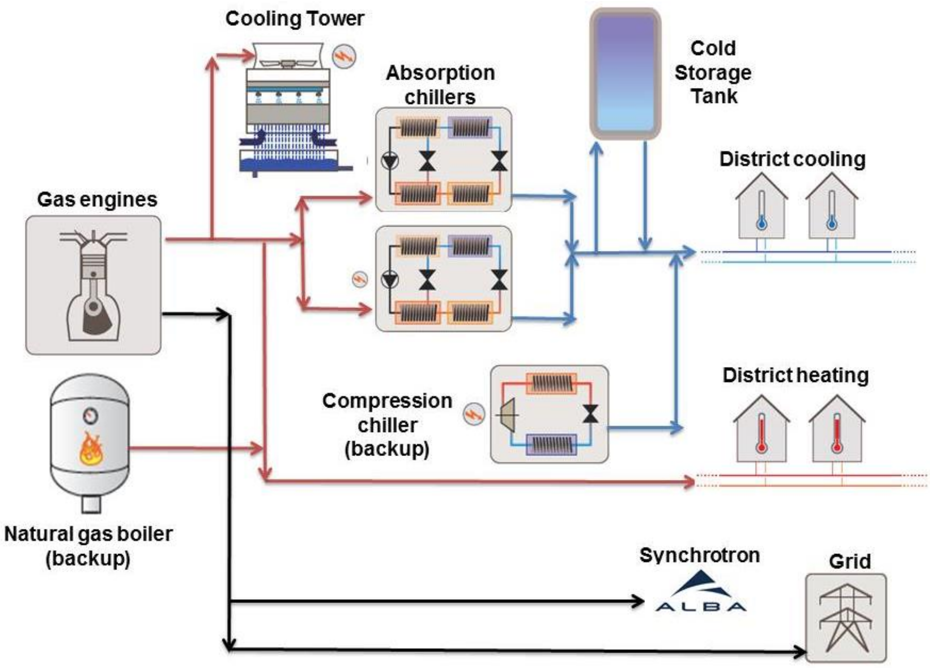

Figure 4-5: Layout of ST-4 plant

The ST-4 plant has been modelled in a detailed way in the TRNSYS environment. The energy model, shown in Figure 4-6, includes all the most important equipment of the plant as well as the operation strategy of the plant.

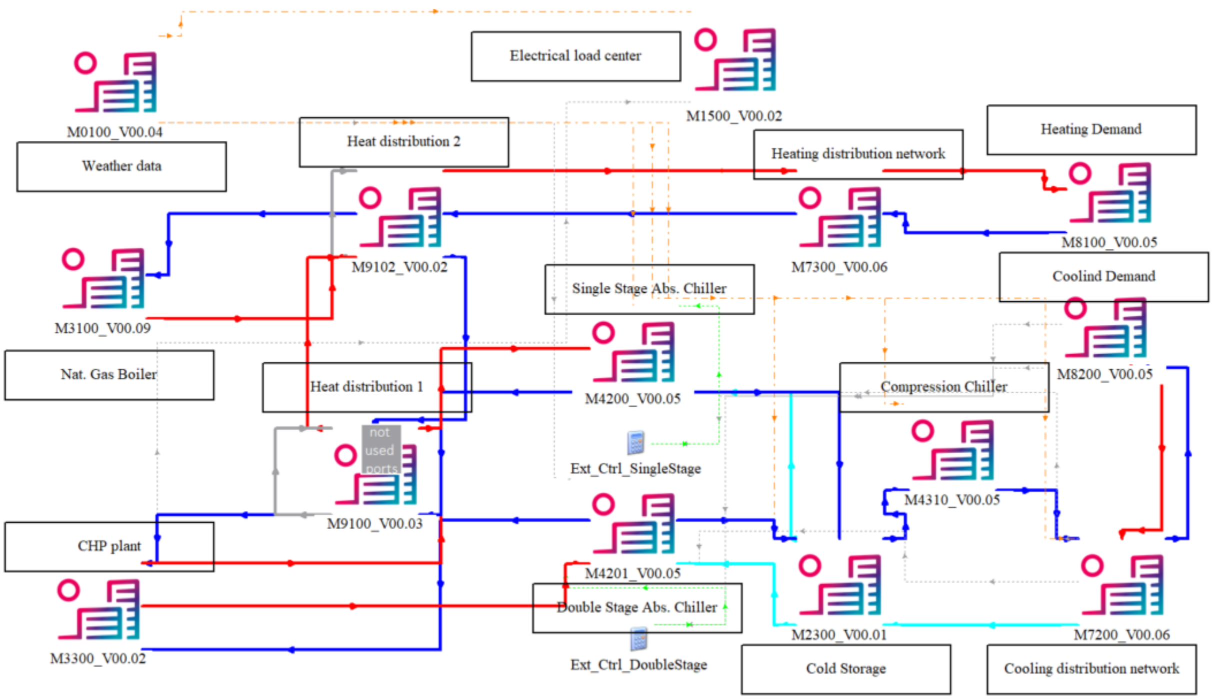

Figure 4-6: ST-4 plant modelled in TRNSYS environment

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Each of the “macros” programmed in TRNSYS represent a specific equipment of the system. As example, Figure 4-7 gives an insight of the sub-components (pumps, pipes, etc.) included in one of the macros implemented. It refers to a single stage absorption unit.

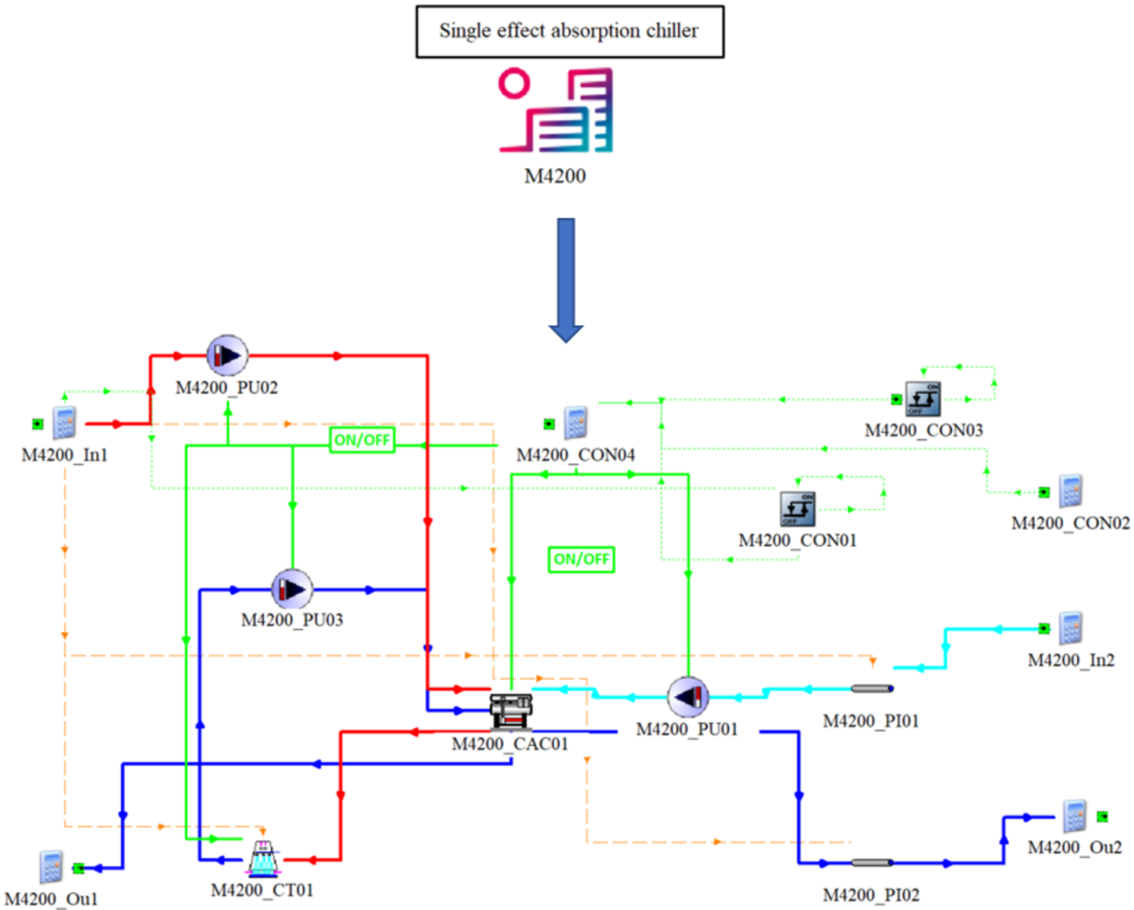

Figure 4-7: Insight of a TRNSYS macro used for the ST-4 modelling

4.1.2.3 Results

First, the work has been focused on the generation of the thermal demand hourly profiles required for the detailed dynamic simulation and on the reference plant modelling in the simulation environment. Figure 4-8 shows the comparison between the real office building thermal demand and the simulated one., the model is able to capture the monthly behaviour of the thermal demand. Yet, discrepancies are inevitable due to the lack of specific information regarding the building envelope and operation regimes.

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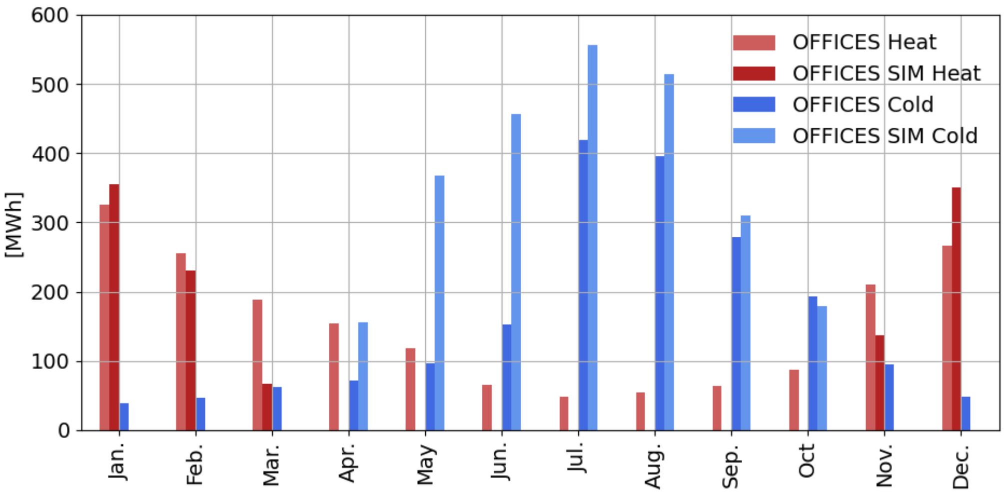

Figure 4-8: Real and simulated heating and cooling consumption of the office buildings

On the other hand, Figure 4-9 shows the comparison between the synchrotron real thermal demand and the simulated one. In this case the tuning of the model is really detailed, and the results shows that the simulated demand is perfectly in line with real data.

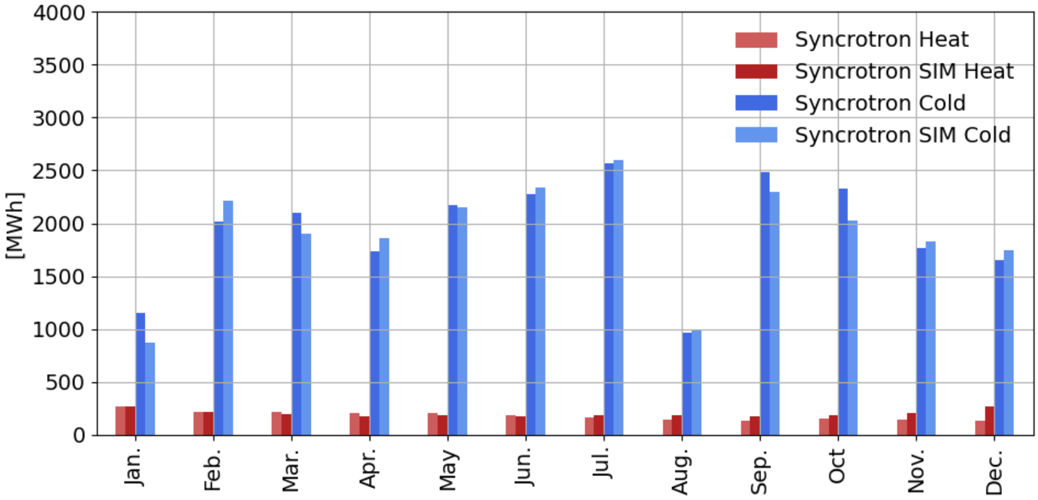

Figure 4-9: Real and simulated heating and cooling consumption of the Synchrotron

Regarding the reference case energy model, the aforementioned heating and cooling demand has been used as inputs for the TRNSYS model. Figure 4-10 shows, in a monthly basis, the heating and cooling demand covered by the system equipment.

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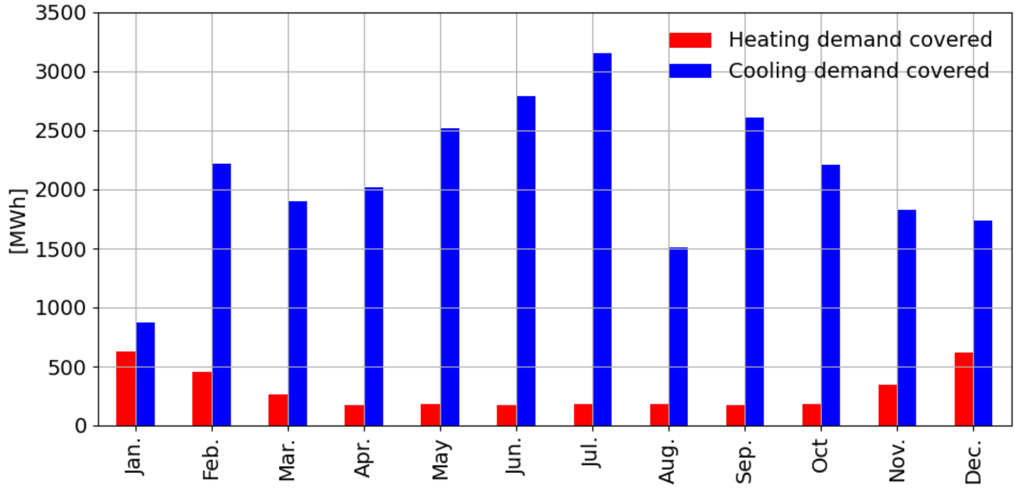

Figure 4-10: Yearly heating and cooling demand covered.

Finally, Figure 4-11 reports the monthly electrical energy generated by the simulated CHP plant. This electrical output has been simulated considering an ON-OFF signal for the CHP plant. In particular, the CHP is ON when the hourly spot price (of 2019) is higher than the average spot price of the year 2019 (47.7 €/MWh), shown in Figure 4-12.

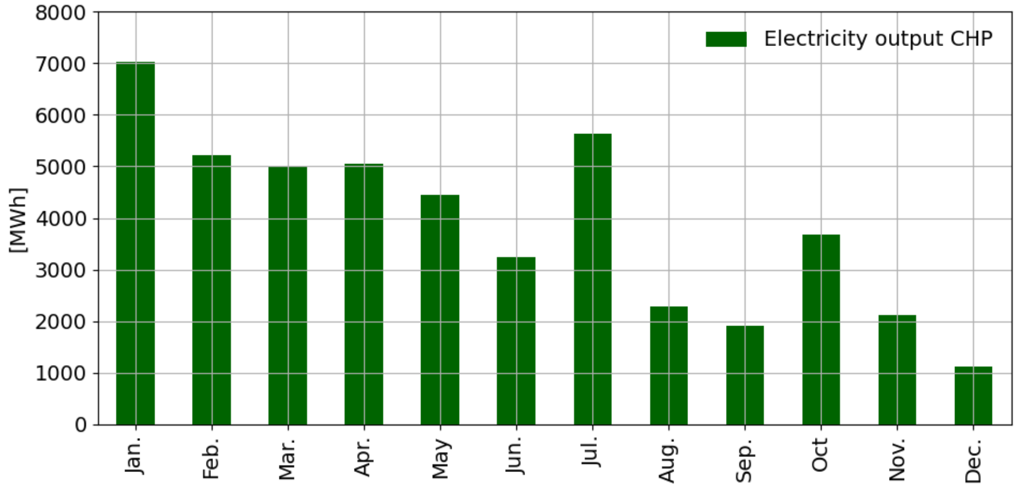

Figure 4-11: Monthly simulated electricity production of the CHP.

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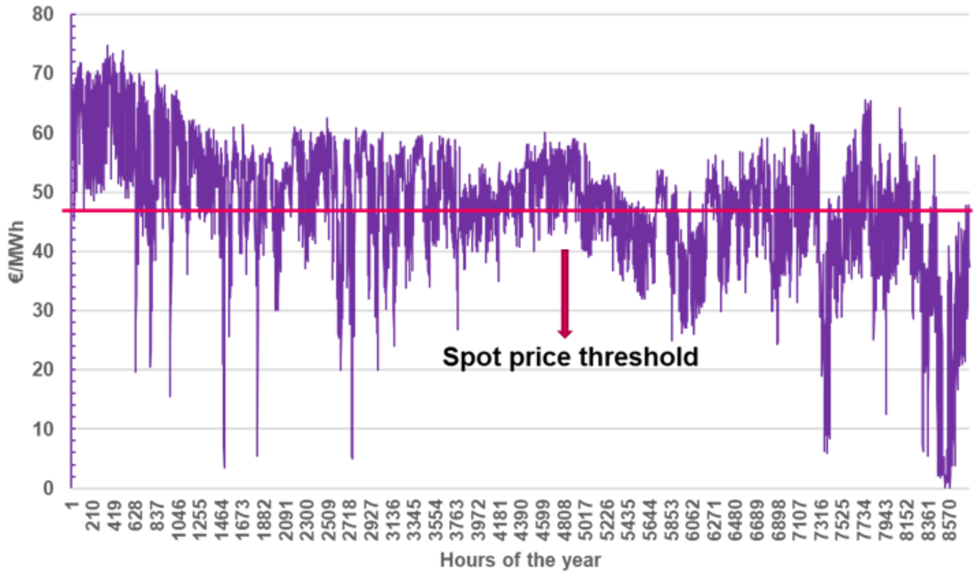

Figure 4-12: Electricity price signal activation for the simulated CHP plant based on 2019 spot price

Figure 4-13 represents the main energy fluxes of the system. *Q_CHP_input* is the energy content of the natural gas burned in the CHP plant which part is converted into electricity, part is recovered by the CHP heat recovery system and part is rejected to the environment. The heat recovered is used as heat source for the absorption chillers and for covering the heating demand. However, the system needs some backup/peak power to cover the heating demand (with a gas boiler) and the cooling demand (with a conventional chiller). The conventional chiller results to be operating for the 37% of the time, in good agreement with the typical operation of the plant up to now (< 40% depending on the years). The plant does not work at the expected nominal efficiency of 89% but on a yearly average of 69%. This is due to the high heat wasted from the CHP (*Q_CHP_wasted*) that can't recover the entire thermal dissipation of the engine since there's a clear lack of demand. This behaviour has been validated by the operator of the ST-4 plant and the ST-4 model seems to be very robust with a high potential as digital twin application.

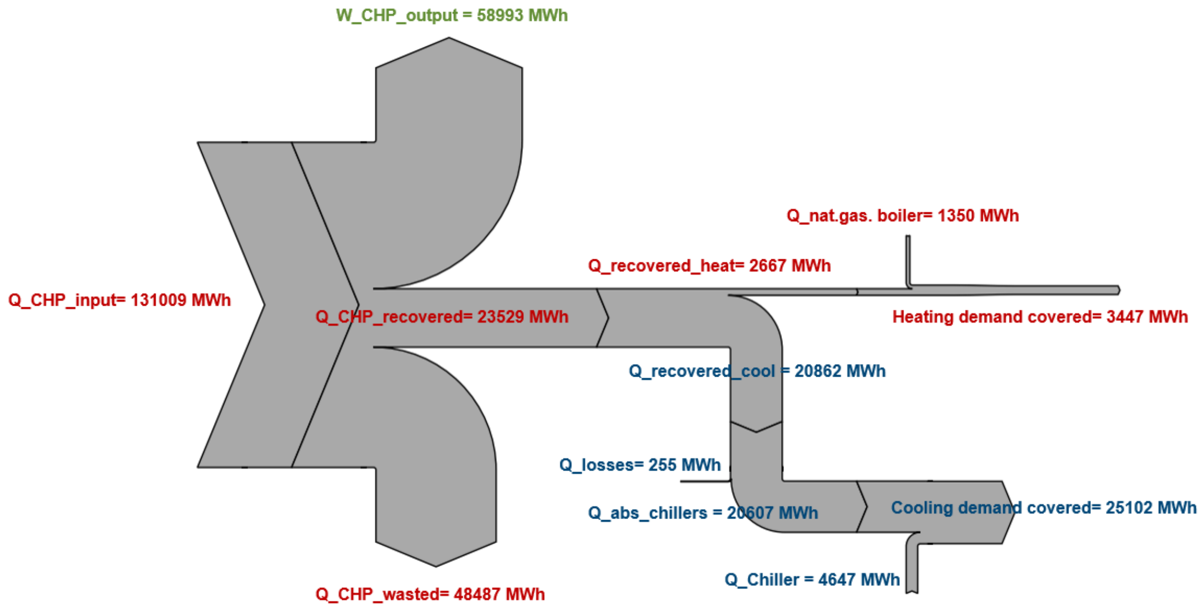

Figure 4-13: Sankey diagram for ST-4 simulated annual energy flow

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The system performance results evaluated in terms of KPI are presented in the table below:

- *Primary energy consumption*: it represents the energy consumption of the entire system taking into account the default primary energy conversion factors stated in the ISO-52000
- *CO_2 emissions:* it represents the amount of CO_2 emissions associated with system operation. Such as the primary energy factors, the emission coefficients are taken from the ISO-52000.
- *Renewable energy ratio (RER)*: The renewable energy ratio is the metric that allows calculating the share of renewable energy use in the system.
- *Cooling share (CS)*: a cooling share parameter is proposed for dividing the impact of the elements that are shared between the cooling and heating. It represents the ratio between the heat consumed to generate cooling (through absorption chillers) and the heating generated (with CHP and gas boiler).

Results for the first simulation are as follow:

Table 4-1: KPIs evaluated for ST-4

Key performance factors evaluated	
Cooling share [-]	0.87
Deviation Heating demand [%]	**-0.33**
Deviation Cooling demand [%]	-1.20
Heating renewable energy ratio [-]	**0.00**
Cooling renewable energy ratio [-]	0.04
Heating Non-renewable primary energy factor [-]	**4.55**
Cooling Non-renewable primary energy factor [-]	3.99
Heating service equivalent CO_2 emission coefficient [g/kWh]	**568.71**
Cooling service equivalent CO_2 emission coefficient [g/kWh]	730.44

4.1.3 FEASIBILITY STUDY

Considering the previous information, the technologies and solutions proposed for Parc de l'Alba study are the following.

Table 4-2: Technologies proposed

Technologies proposed	By means of
Waste heat recovery from data centres	Waste heat recovery from the chiller condenser with booster heat pump.
Absorption chiller	Main supply of cooling with solar driven heat.
Solar technologies	Main heat source of the generation plant for RES district heating.
Hot water storage	Optimized water storage sized for acting as solar buffer.
Biomass boiler	Biomass boilers installation for covering peak loads

Different plant layouts from the WEDISTRICT portfolio have been identified as interesting layouts for possible implementation in the different Parc de l'Alba scenarios. Figure 4-14 and Figure 4-15 show thermal plants that provide heat to a DH network by means of a biomass boiler and solar thermal panels. A gas boiler is used as backup. The layouts are the same as for Montegancedo Campus and lessons learned regarding the modelling approach from that demo-follower have been implemented here to reduce the number of simulations to perform.

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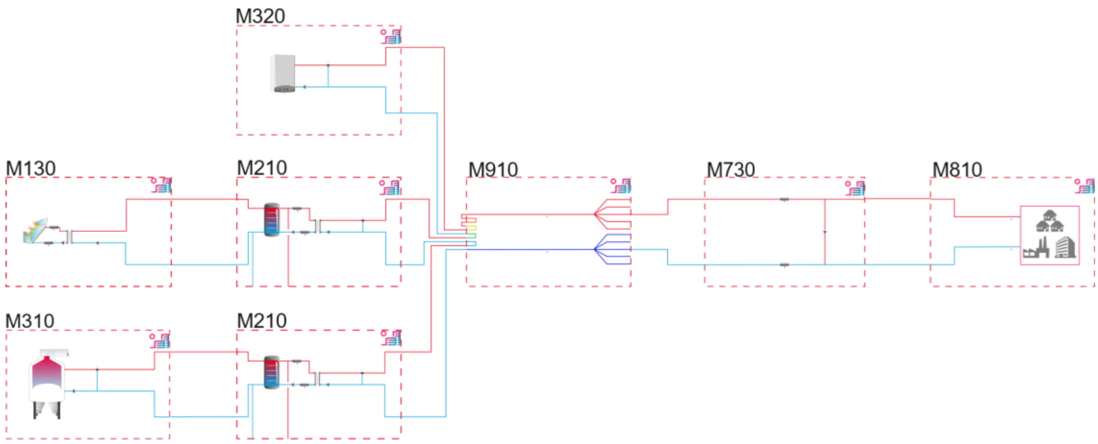

Figure 4-14: WEDISTRICT DECK 201- biomass boiler, solar field, and gas boiler

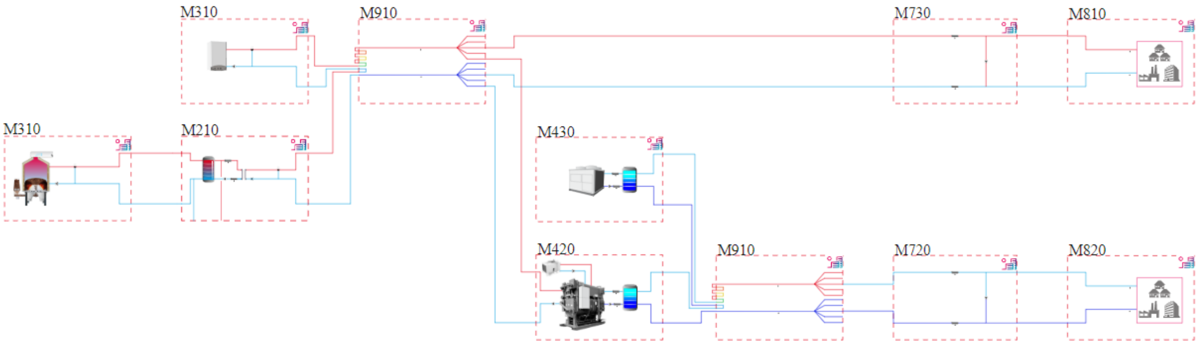

Figure 4-15: WEDISTRICT DECK 314- biomass boiler, and gas boiler, absorption and compression chiller

With a similar configuration, Figure 4-16 represent the same systems as before but with the addition of a cooling network for cold water production. Cooling is provided by an absorption chiller and by a conventional air-cooled chiller used as backup.

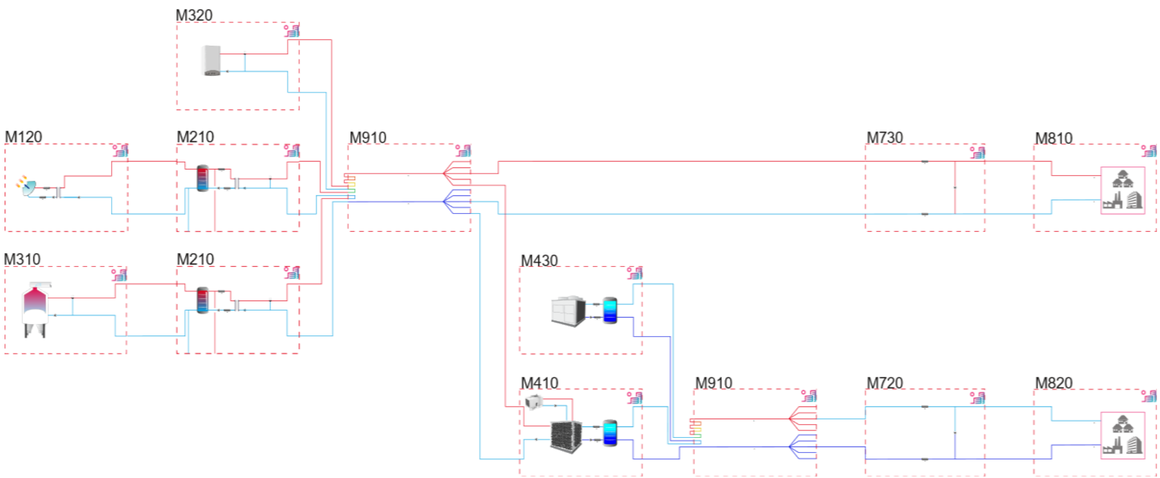

Figure 4-16: WEDISTRICT DECK 321: biomass boiler, solar field, and gas boiler, abs. and conv. chillers

In the specific case of Parc de l' Alba, scenarios proposed assume different scenarios of forecasted increase in the heating and cooling demand of the urban development. However, the existing ST-4 plant is not currently running at full capacity and it is foreseen that it would also cover part of the new demands. These demands have been evaluated through dynamic modelling. Different data centres are operating in the Parc and are considered in the cooling demand. However, it the scenarios analysis, special attention is given to the future facilitiy foreseen to have 42MW capacity.

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Table 4-3: Summary of solutions proposed for Parc de l'Alba

Solutions proposed overall description	
Combination code	PARC DE L'ALBA– S1
Justification and plants description	This combination integrates the operation of a new plant (biomass and gas boiler with a thermal storage for the heating part and absorption and conventional chiller for cooling) to the existing ST-4 plant to cover the current demand plus the forecasted increase due to the construction of a shopping mall.
Expected impact	• Assess the preliminary design of a new district heating and cooling network that will work in parallel to the ST-4. • Evaluate the capability of the ST-4 to also cover part of the increased load.
DHC layout temperature regime, and demand profile	• Four-pipe network (DCK321) working at high temperature (90 °C supply – 70 °C return). Increased Demand (Current demand + Mall own plant)
Data centre cooling	• 42MW Data centre cooling not considered
Combination code	PARC DE L'ALBA – S2
Justification and plants description	This combination integrates the operation of a new plant (biomass and gas boiler with a thermal storage) to the existing ST-4 to cover current load and increase expected for the construction of different new specific buildings and a residential neighbourhood.
Expected impact	• Assess the preliminary design of a new district heating network that will work in parallel to the ST-4. • Evaluate the capability of the ST-4 to also cover part of the increased load. • Assess the feasibility to avoid a four-pipe network by providing cooling with RACUs units.
DHC layout temperature regime, and demand profile	• Two-pipe network (DCK201) working at high temperature (90 °C supply – 70 °C return). Increased demand (Residential without cooling + buildings services: Auditorium, Primary care centre and school)
Data centre cooling	• No district cooling network. 42MW Data centre cooling not considered
Combination code	PARC DE L'ALBA – S3
Justification and plants description	This combination integrates to ST-4 a big central power plant based on gas boilers and biomass boilers and solar field as renewable heating generation. Absorption chillers and conventional air-cooled chillers as cooling equipment. .
Expected impact	• Assess the preliminary design of a new district heating and cooling network that will work in parallel to the ST-4 and having the 42MW data centre as cooling consumer.
DHC layout temperature regime, and demand profile	• Four-pipe network (DCK321) working at high temperature (90 °C supply – 70 °C return). Increased demand (Residential without cooling + buildings services: Auditorium, Primary care centre and school) + 42MW data centre cooling
Data centre cooling	• 42MW Data centre as consumer of the district cooling network.

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The aim of the study is to investigate scenarios where the heating and cooling demands increase, and a new generation plant will be needed. However, it seems reasonable that ST-4 plant would be able to cover at least part of the new demand. To simulate the simultaneous operation of two plants in WEDISTRICT simulation environment the following approach has been considered:

1. ST- 4 is simulated with the total demand of the scenario (e.g.: current demand + Mall demand) but shutting down peak equipment (gas boiler). In this way we calculate the fraction of the new demand is covered by the old plant running only with the CHP. The CHP runs under electricity price control. It turns on when the spot price reaches 47.7 Euro/MWh.
2. With the results of this first simulation, we know how much of the demand is left and must be covered by a new generation plant. The new generation plant has WEDISTRICT technologies and peak equipment of the ST-4. This reflects in generation priority like:
    - ST-4 CHP cover part of the demand while running under electricity price control.
    - Low emission WEDISTRICT technologies try to cover what is left.
    - ST-4 peak equipment covers the peaks and additional peak capacity is added if necessary.
3. KPIs are evaluated individually for the new plant. CO_2 emissions and OPEX are accounted for the new plant operation and ST-4 peaks coverage. CAPEX only considers the new plant equipment.

4.1.3.1 SCENARIO #1 (S1)

The aim of S1 is to evaluate the feasibility of building a plant which will serve to cover the heating and cooling needs of a new mall. As mentioned before, the first step is to simulate the ST-4 plant with the increased estimated demand (current + mall) to see how much can be covered by the existing plant. Figure 4-17 shows the estimated total heating and cooling demand (hourly monotone profiles) for this Scenario (solid line) and the fraction to be covered by the new plant (dotted line).

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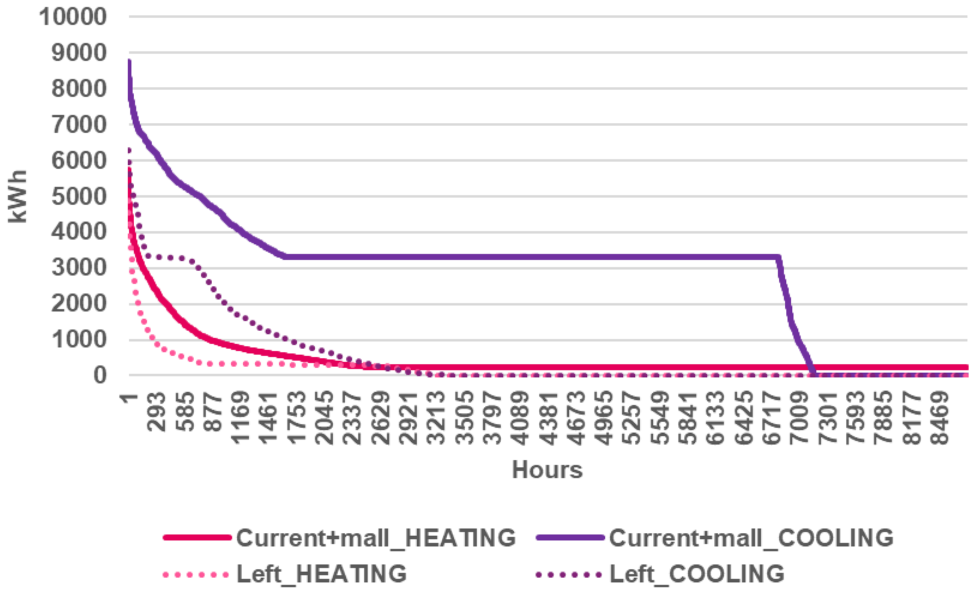

Figure 4-17: Current + mall demand and left demand

- With the estimated increase in demand, the left demand that should be covered by the new plant can be covered by the peak equipment of the ST-4.
- However, with the idea that peak equipment should behave as back up for the two plants, biomass boilers can be installed.

For the last reason, a WEDISTRICT plant layout (DCK314) has been considered and simulated with the heating and cooling demand left to be covered. Table 4-4 shows the parameters considered in the parametric analysis. Notice that the heating equipment have been oversized (respect the heating demand curve) to try to operate the absorption chiller.

Table 4-4: Range of parameters considered in Parc de l'Alba S1 parametric study of the new plant

Biomass Boiler capacity [kW]	Gas Boiler capacity [kW]	TES capacity [m3]	Absorption chiller capacity [kW]	Conventional chiller capacity [kW]	Solar collectors field area [m2]
400-1200	ST-4	50-250	50-150	ST-4	-

Figure 4-18 shows the results obtained from this parametric analysis where biomass boiler capacity, thermal storage capacity, and chillers capacity have been investigated. The resulting LCOE is very low because the back-up equipment cost has not been considered (the ST-4 equipment is used as back up and are already installed). Three cluster of results are clearly noticeable, each characterized by three different sizes of the absorption chiller. One general result of the cooling plant layout modelled is that the lower absorption chiller capacity, the better KPIs are achieved for both environmental and economical. This behaviour must be further investigated but it is strictly related to the high parasitic electrical consumptions (circulation pumps mainly) modelled in this technology. Moreover, it is clear the impact of the biomass boiler capacity on the LCOE.

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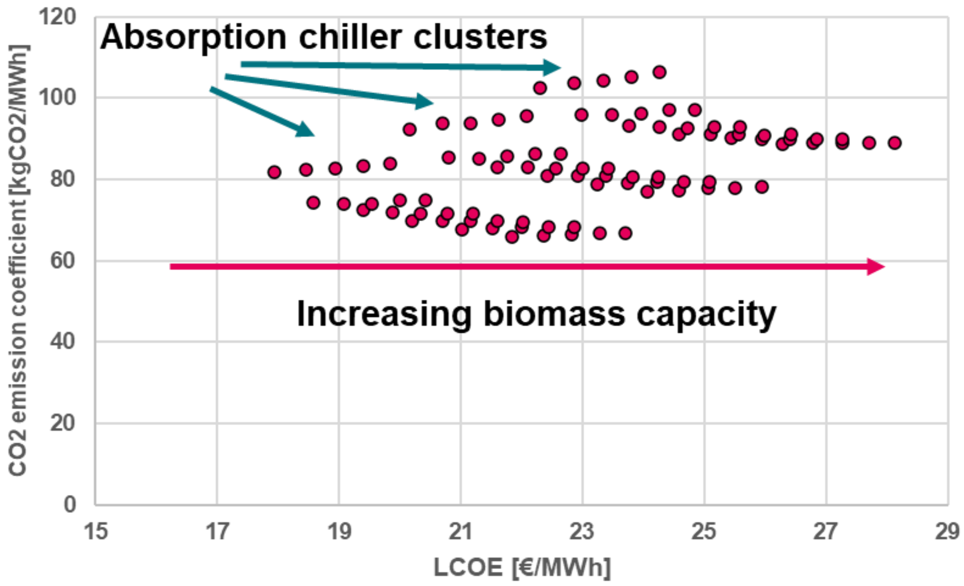

Figure 4-18: Parametric analysis results of Parc de l'Alba S1

4.1.3.2 SCENARIO#2 (S2)

The aim of S2 is investigating an increase in demand considering heating and cooling demand of three specific buildings (a school, a primary health centre and an auditorium) and only the heating demand of a new residential neighbourhood. The goal is to avoid building a four-pipe district network (which will increase a lot the cost) but at the same time providing cooling locally by mean of a WEDISTRICT technology. This technology is called renewable air-cooling unit (R-ACU) and can generate cooling from a heat source at 90 ºC. Moreover, it is worth to mention that the R-ACU will also serve as air treatment equipment since it has temperature, humidity, and CO_2 controls. The equipment is very promising but, since it is in a first development stage, the cost is estimated for the WEDISTRICT prototype, which results in a high price that challenges the economical evaluation of this study. For this reason, the present study considers a R-ACU investment cost per kW comparable to mature cooling technologies. Price that it is supposed to be reached in a commercial stage of the equipment and with large scale production. Another drawback of the current prototype is its footprint, which has room for improvement. Indeed, a 10kW unit occupies almost 10m^2. As shown in Figure 4-19, S2 considers that R-ACUs units withdraw hot water from the district heating supply line. Individual simulations for the three buildings (school, primary care centre and auditorium) have been performed to address the number of units needed to cover the cooling needs of these buildings. Results tell that 120 units are needed to cover the 290 MWh of cooling energy required by only these three buildings. Notice that R-ACU units have only been considered for use in tertiary buildings, disregarding the use in the residential buildings. However, it has been identified the potential for use of R-ACU in small commercial premises placed in the ground floors of residential building connected to DH only.

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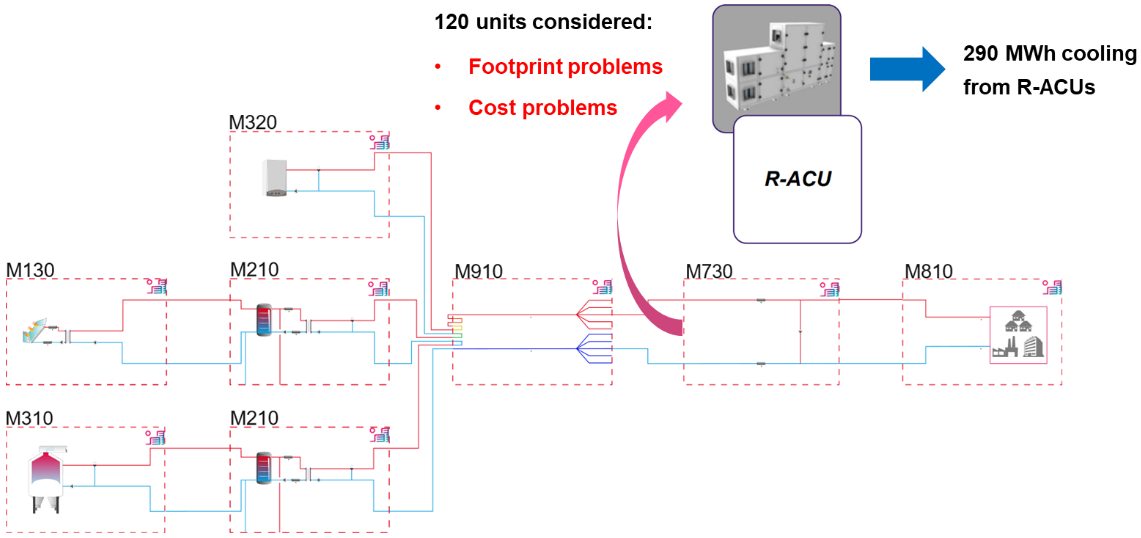

Figure 4-19: Proposed layout with integration of RACU

From a demand point of view, it is interesting how the heating needed by the R-ACU equipment contribute to shape the heating profile. Notice in Figure 4-20 the unusual summer heating peaks occurring during weekdays. This increase in the total heat demand as well as in the time when heat demand is required is an opportunity to expand the operation hours of the heat generation equipment. This will increase the economic performance of the heating equipment and the distribution network, as the same investment cost will result in more operation hours. This aspect is especially relevant in southern Europe climates, where the thermal demand has a clear seasonal pattern.

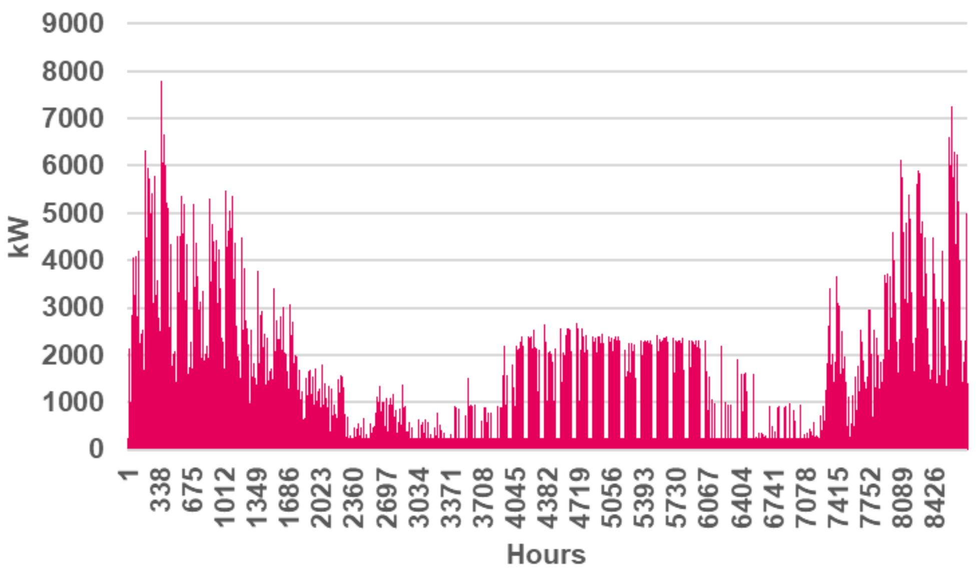

Figure 4-20: Heating demand profile of Parc de l'Alba S2

As for the previous scenario, the increased demand (in this case only heating since it is a two pipes network), has been simulated in the ST-4 plant. Figure 4-21 shows the new demand monotone profile created (Increased 2) and the demand left for the new plant. Respect to S1, the heating demand increases enough that a new generation plant becomes mandatory. Table 4-5 shows the parameters considered in the parametric analysis.

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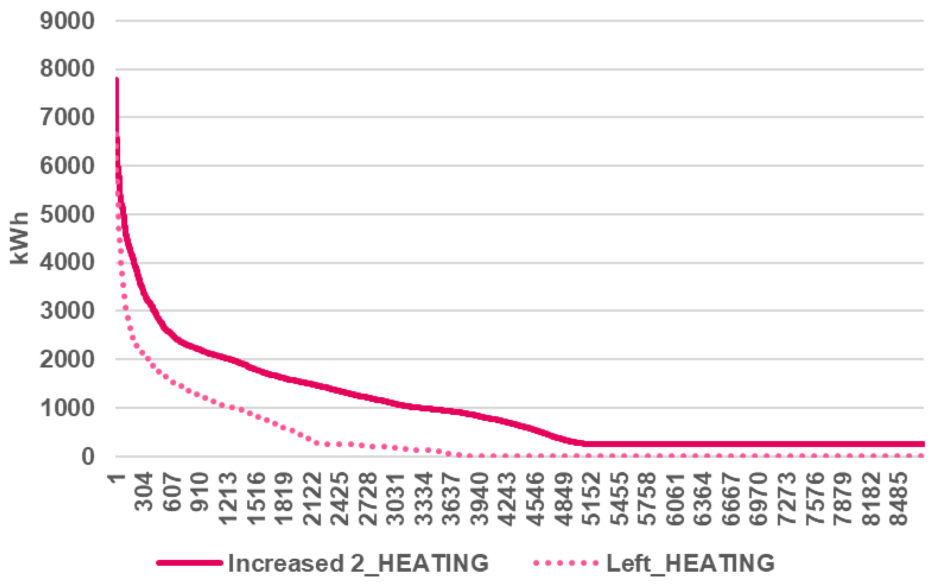

Figure 4-21 : Increased S2 demand and left demand

Table 4-5: Range of parameters considered in Parc de l'Alba S2 parametric study of the new plant.

Biomass Boiler capacity [kW]	Gas Boiler capacity [kW]	TES capacity [m3]	Absorption chiller capacity [kW]	Conventional chiller capacity [kW]	Solar collectors field area [m2]
500-3000	ST-4	170-700	-	-	500-1500

Figure 4-22 shows the results of the parametric analysis conducted for S2. Results are characterized by the Pareto optimality where there is no unique optimum solution. The higher the LCOE the lower CO_2 emissions (high investment cost of solar Fresnel collectors). Four clusters are identified that corresponds to the solar areas investigated. The graph shows one of the limitations of the parametric approach. Notice that more feasible results are provided for larger area. This is due to the combinations of storage volumes and solar area investigated. However, results are competitive respect to conventional technologies (considering the assumption on R-ACUs units).

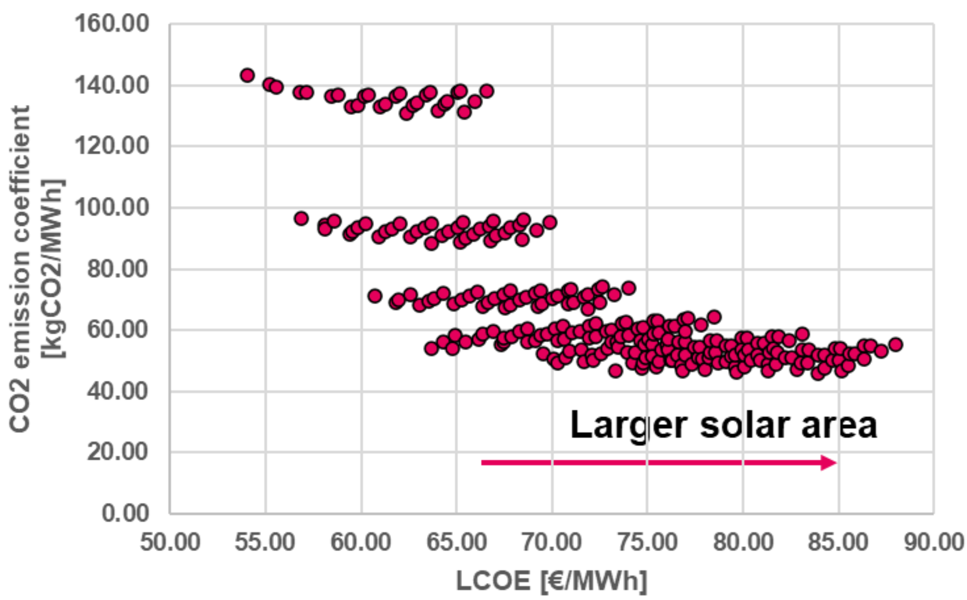

Figure 4-22: Parametric analysis results of Parc de l'Alba S2

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4.1.3.3 SCENARIO #3 (S3)

The aim of S3 is investigating the same demand increase of S2 but also adding as district cooling consumer a 42MW data centre that will be built in Parc de l'Alba. There will be a lot of heat that can be recovered but not enough demand where to supply it. Figure 4-23 shows how the thermal demand of the plant will be drastically shaped by the data centre cooling consumption. Considering a typical average 75% of IT workload of the DC, the cooling demand of the Parc will be around 30MW during all the year. The cooling peak demand is expected to be almost 4.25 times higher (from 8 to 34 MW) while the yearly cooling demand 10 times higher than current operation, see Figure 4-24.

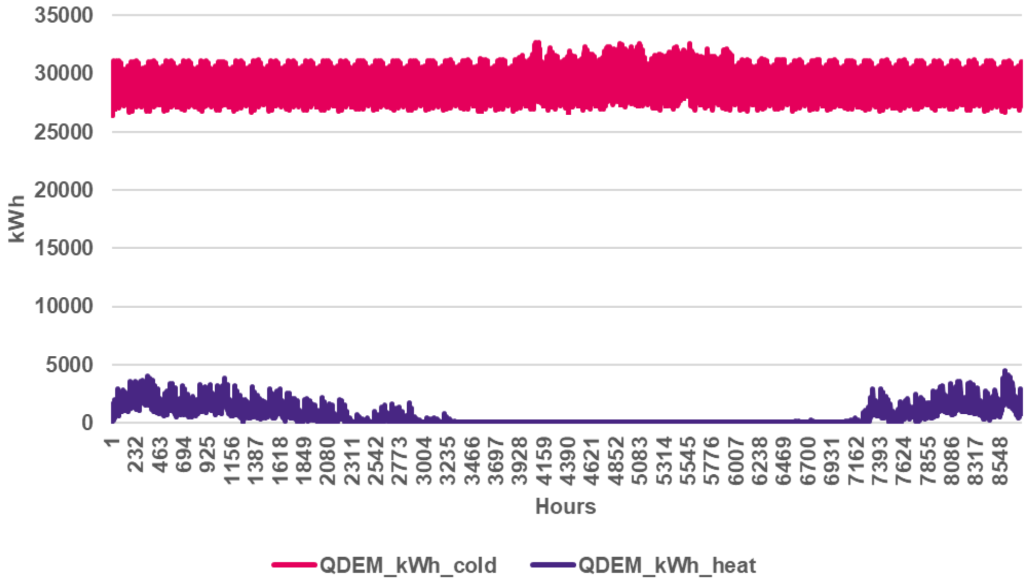

Figure 4-23: Heating and cooling demand profile of Parc de l'Alba S3

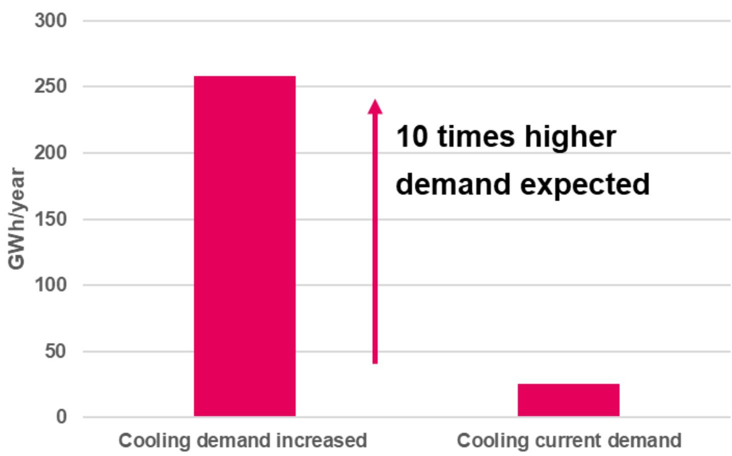

Figure 4-24: Comparison between the hourly cooling demand estimated for S3 and current scenario

Table 4-6 shows the parameters considered in the parametric analysis. From previous simulations with cooling plant layouts, it was clear that considering absorption chillers lead to worst results compared to conventional compression chillers. This is due by a not optimized absorption chillers behaviour but also to the very good performance (COP=5) of the compression chiller considered. For this reason, the parametric analysis does not concern the use of absorption chillers and cooling is provided only by compression chillers.

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Table 4-6: Range of parameters considered in Parc de l'Alba S3 parametric for the new plant.

Biomass Boiler capacity [kW]	Gas Boiler capacity [kW]	TES capacity [m3]	Absorption chiller capacity [kW]	Conventional chiller capacity [kW]	Solar collectors field area [m2]
500-4500	ST-4	250-600	-	42000	1000-4000

Figure 4-25 shows the results for the parametric analysis of S3. Notice that axis values in this case are really close to them and results are almost equal. This is due to the CAPEX and OPEX of the 42 MW compression chiller that represents almost the entire cost and operation of this plant.
Looking at these results, it is not clear the advantage of building a huge cooling network rather than provide cooling locally to the data centre

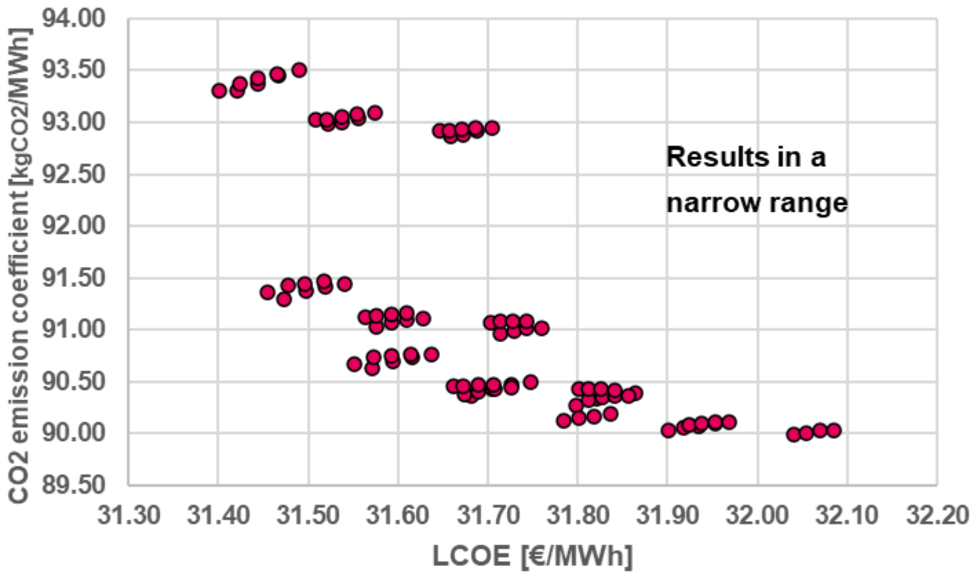

Figure 4-25: Results for the parametric analysis of S3

Notice that the data centre has been considered only as consumer and not as “prosumer” (as it would be with the implementation of waste heat recovery solution). The data centre would have the potential to provide 1319 TWh/year of heat to the district heating, but the demand is forecasted to be 4361 MWh/year. This means that only a small part of the DC waste heat can be recovered, maybe implementing a modular solution.

4.1.3.4 SCENARIOS COMPARISON

Tables below present two sets of parameters for each Scenario. The cases with minimum CO_2 emission coefficient (S1-CO2) and minimum LCOE (S1-ECO) are reported. KPIs are individually evaluated for the new generation plant but the overall integration comprehends ST-4 equipment working in parallel with the new plant.

Table 4-7: ST-4 already installed equipment to couple with new plant.

ST-4	Biomass boiler [kW]	Gas boiler [kW]	Heat storage vol. [m3]	Solar Area [m2]	Abs chiller cap. [kW]	Conv. Chiller cap. [kW]	Cold storage vol. [m3]
Equipment already installed	-	5000	-	-	8000	5000	3750

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Table 4-8: Parc de l'Alba S1 Optimum results.

SCENARIO #1	Biomass boiler [kW]	Gas boiler [kW]	Heat storage vol. [m3]	Solar Area [m2]	Abs chiller cap. [kW]	Conv. Chiller cap. [kW]	Cold storage vol. [m3]
S1-ECO	200	-	50	-	-	-	15
S1-CO2	1200	-	50	-	-	-	15

Best LCOE = 17.90 €/MWh, Best kCO2 = 65.68 kg/MWh

Table 4-9: Parc de l'Alba S2 Optimum results

SCENARIO #2	Biomass boiler [kW]	Gas boiler [kW]	Heat storage vol. [m3]	Solar Area [m2]	Abs chiller cap. [kW]	Conv. Chiller cap. [kW]	Cold storage vol. [m3]
S2-ECO	500	-	170	500	-	-	-
S2-CO2	3000	-	870	1500	-	-	-

Best LCOE = 69.19 €/MWh, Best kCO2 = 45.94 kg/MWh

Table 4-10: Parc de l'Alba S3 Optimum results

SCENARIO #3	Biomass boiler [kW]	Gas boiler [kW]	Heat storage vol. [m3]	Solar Area [m2]	Abs chiller cap. [kW]	Conv. Chiller cap. [kW]	Cold storage vol. [m3]
S3-ECO	500	-	250	1000	-	41950	3000
S3-CO2	4500		250	4000	-	41950	3000

Best LCOE = 31.4 €/MWh, Best kCO2 = 89.99 kg/MWh

4.1.3.5 SCENARIO TO BE DEVELOPED

The timeline for the extension of Parc de l'Alba is still uncertain and probably some years would be needed to have a clear picture of the final situation. For this reason, there would be time to perform more studies about the feasibility of the solutions proposed. The recovery of waste heat from data centres as well as the two pipes configuration with cooling equipment in the consumption points need to be studied further in detail.

4.1.4 CONCLUSIONS

Results of this preliminary feasibility study highlight a special interest in the R-ACUs technology that could be able to provide local cooling without the need of building a four-pipe network. However, this technology must step in a commercial phase to cut investment cost and becoming an attractive solution. Another result is that it seems not feasible, considering the plant layouts proposed in the framework of WEDISTRICT, that the new 42MW data centre would be connected to the district cooling networks. Local air-cooled chillers seem to be the easiest and most convenient solution to adopt, together with partial waste heat recovery.

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4.1.4.1 Extended studies proposal

The following three extensions of the study are proposed:

1) ST-4 plant TRNSYS model, further improved and validated, could serve as digital twin of the real ST-4. This digital twin can be used to perform simulation on plant optimization and control strategies.
2) It is interesting to consider the heat recovery capability of the new data centre that will be built (but also of the already existing ones). In the present study this heat recovery has not been investigated since the heating demand estimated for the campus is too low respect the data centre capacity. When more details about the data centre facility (e.g.: cooling technology adopted, final IT capacity installed) will be known it would be possible to investigate in the specific this situation and adopt a modular modelling approach to recover only a part of the waste heat.
3) Future trends on district heating and cooling networks point to reduce the supply and return temperature of the network. However, the expectation in Parc de l' Alba is to continue working in a high temperature regime. A further study could investigate different network temperature regimes and how they could be optimized considering the heat recovery from the CHP plant.
4) The extension of the network with a two pipes configuration should be studied more in detail. The cost and energy implication of implementation of cooling generation equipment at the tertiary buildings, reducing the need of four pipes but requiring additional decentralized equipment should be considered. The further development f the RACU technology but also absorption chiller should be accounted. Note that this will require the grid to supply heat at high temperature, at least while cooling demand exists. This clashes with the trend to reduce the temperature of DH networks. A concept of variable temperature network could be considered, with high temperature in summer (to run the absorption chillers) and low temperature in winter (to reduce losses).

4.2 University of Cyprus (Nicosia – Cyprus)

4.2.1 GENERAL DESCRIPTION

University of Cyprus (UCY) is a retrofitting DHC demo-follower. Its DHC was built in 1999, and so far, two expansions have been completed in 2007 and 2010. The next expansion is planned in 2022. Figure 4-26shows the most updated aerial photograph of the UCY Campus.

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Figure 4-26. University of Cyprus – Aerial campus photograph.

The UCY has three types of energy demands:

- Cooling of 17 buildings, in total an area of 91,422 m^2 (excl. student residences)
- Heating of 29 buildings, in total an area of 98,520 m^2 (incl. student residences)
- Domestic hot water

For the 2022 expansion, the following technologies are planned to be installed at UCY:

- A 5 MWp PV plant with a 2.35 MWh capacity electric battery
- Various heating and cooling storage systems

In a previous report, "*WEDISTRICT_WP2_D2.3 District Heating and Cooling stock at EU level"*, the distribution of energy sources used to satisfy the heat demand in the residential section (2017) for Cyprus is listed as N/A. However, the Sankey diagram in Figure 4-27 illustrates the energy flows for heating purposes (data from 2015).

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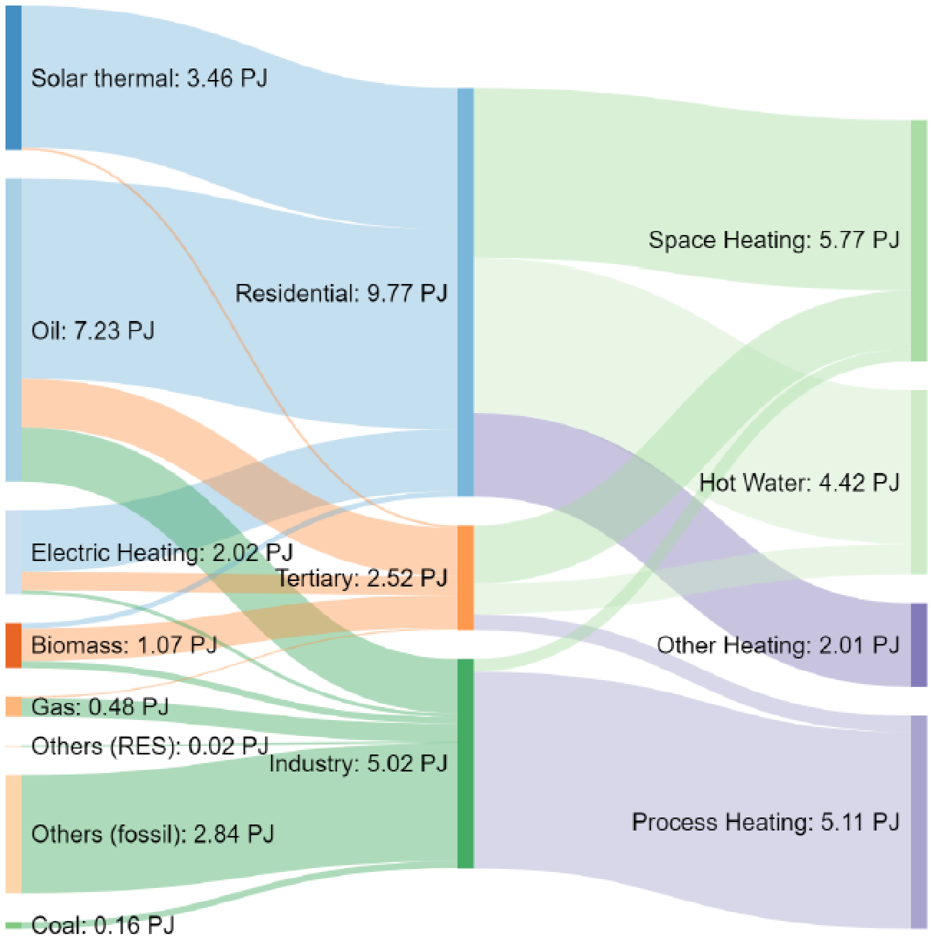

Figure 4-27. Sankey diagram of energy flows for heating purposes in Cyprus in 2015.

In the following figures, respectively, the overall energy consumption and average CO_2 emission in Cyprus are listed for a given time period (2009-2017). From the data available, it is noted that the energy consumed in Cyprus mainly comes from oil- and petroleum products, while both electricity and heat (e.g., space heating, hot water etc.) emits a noticeable amount of CO_2 (according to the data available in Ref. *WEDISTRICT_WP2_D2.3 District Heating and Cooling stock at EU level*). In addition, it is noted that, apart from University of Cyprus (UCY), no other district heating systems exist in the island of Cyprus.

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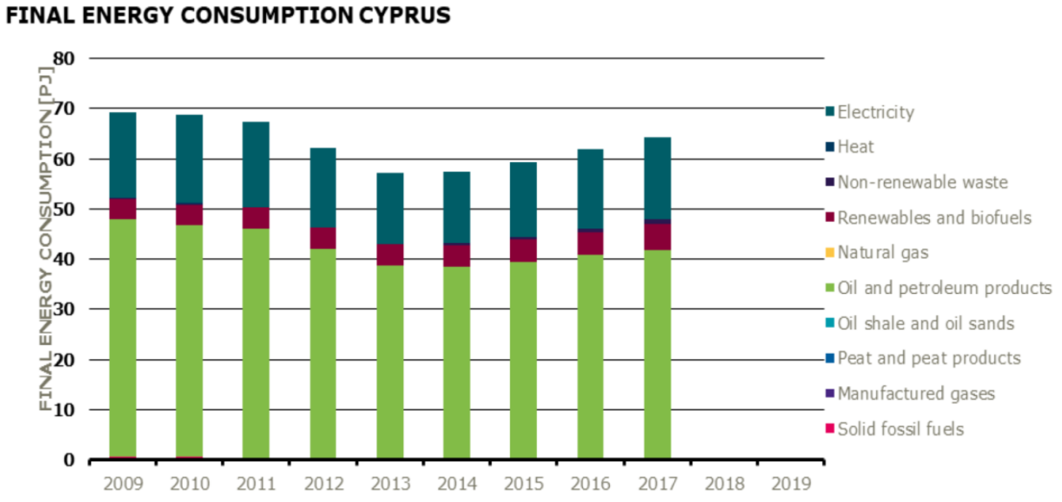

Figure 4-28. Final energy consumption by fuel and year in Cyprus. Data from extracted from Euroheat & Power.

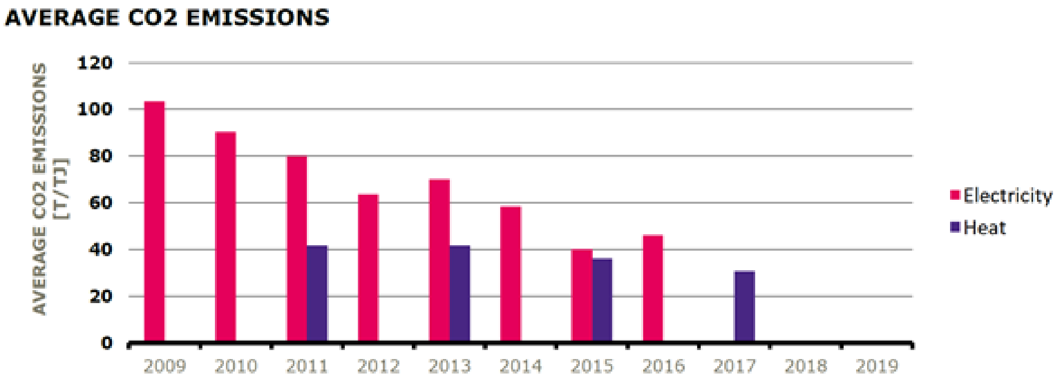

Figure 4-29. Average CO2 emissions in Cyprus. Data extracted from Heat Roadmap Europe and EEA.

Month	H_Gh	H_Dh	H_Bn	Ta
	[kWh/m2]	[kWh/m2]	[kWh/m2]	[°C]
January	80	36	103	10,6
February	95	43	106	10,6
March	144	59	143	13,1
April	171	73	150	17,1
May	205	78	187	22,3
June	217	74	204	26,9
July	217	78	201	29,7
August	217	63	224	29,4
September	162	59	164	26,2
October	129	44	159	22,3
November	91	36	119	16,3
December	76	29	118	12,0
Year	1802	672	1878	19,7

H_Gh: Irradiation of global radiation horizontal
H_Dh: Irradiation of diffuse radiation horizontal
H_Bn: Irradiation of beam
Ta: Air temperature

Figure 4-30. Solar radiation potential in Nicosia, Cyprus. Data extracted from Meteonorm 7.

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In Cyprus, the annual solar radiation potential is in the range of 1878 kWh/m²/year. It is a relatively high radiation representing a great potential for solar power as well as solar heating applications. The data shows an intense solar radiation peak in the summertime. This peak is expected to trigger a certain need for cooling. Therefore, thermal energy storage solutions are considered great assets in Cyprus, e.g., potentially storing heat (and cooling) during the summer to deliver heat in wintertime.

4.2.2 REFERENCE CASE MODEL AND VALIDATION

A first layout of the reference case model was set up in order to simulate the current DHC system at UCY in alignment with all the data that has been shared for the past year.

Solution S0 consists of a gas-fuelled boiler that can provide heat and domestic hot water, and a "conventional" heat pump to provide cooling. During the 1st workshop, it was noted, that by default, also PV panels were also included in this case model (thus, a new reference case will be simulated primo 2022, since PV panels should be introduced in S1 instead).

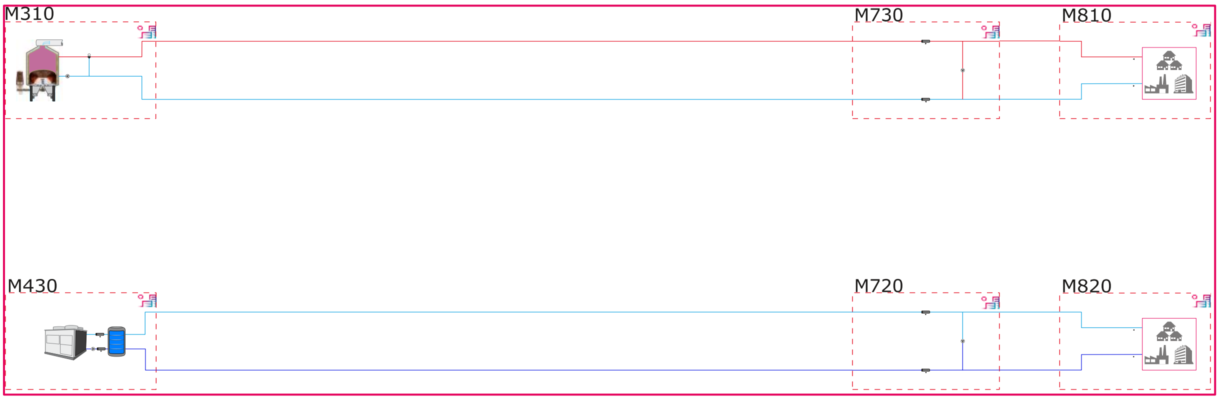

Figure 4-31. Illustration of DCK308.

In the illustration given in Figure 4-31, the gas-fuelled boiler (M310) and the heat pump (M430) is seen to the right, delivering energy to the Heat and Cooling Loads (M810 and M820, respectively) through the distribution macros (M720 and M730).

The boiler is laid out to provide heating during the winter and domestic hot water all year round, while the heat pump can assist with heating during winter and provide cooling during summertime.

PV solar collectors (M150), added by default (as an optional technology) to all decks, is not visible in this illustration, yet results of this macro is, for now, included in the first results. As mentioned above, a new reference case will be simulated primo 2022, since PV panels should be introduced in S1 instead once the PV panels optional setup is finalized.

The baseline case, Solution 0, was set up based on actual measured data (electricity consumption and purchased heating oil) provided by UCY, on a monthly as well as hourly resolution (for some data only). The comparison of measured data and output simulation is further described in the following section (First results).

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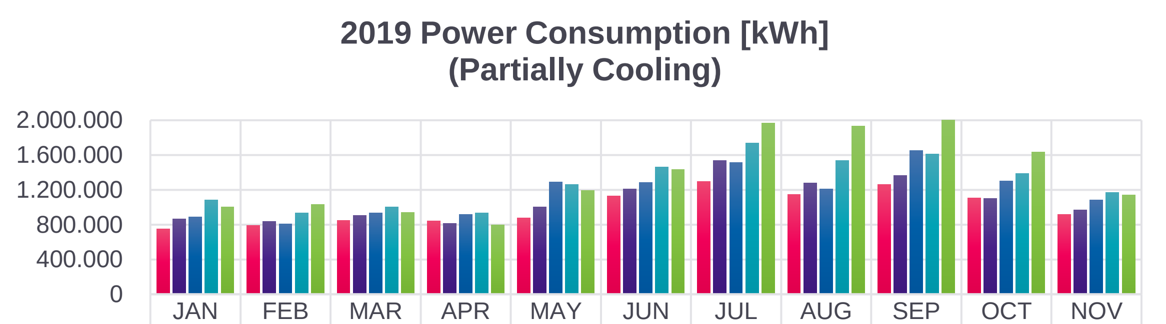
A first set of results, based on the measured heating and electricity demands, was presented during the 1st workshop. Simulations were based on the demand profiles, as provided, as well as data extrapolation, to some extent. The selected reference year for the simulation was chosen to be the year 2019.

For the demand profiles, the following notes apply:

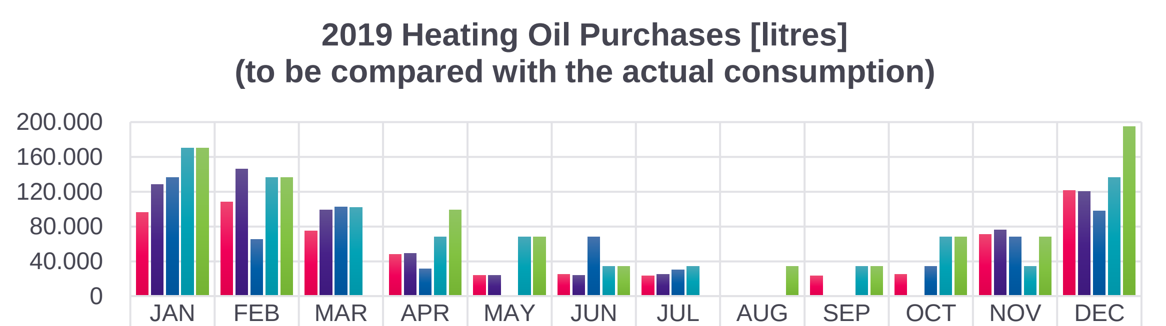
- For the electric power consumption, hourly data sets were available for 2019-2020, and historical (monthly) data sets were available for 2010-2020.
- For the heating oil purchases (in a monthly resolution), the 90.000 litres storage tank was taken into account, and data extrapolation were done, to estimate the hourly consumption.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
2016	751.30	793.20	849.50	842.70	877.30	1.130.	1.298.	1.145.	1.259.	1.109.	919.00
2017	868.60	836.60	906.40	813.20	1.004.	1.210.	1.540.	1.281.	1.364.	1.102.	970.28
2018	890.76	806.21	932.22	917.85	1.289.	1.285.	1.516.	1.210.	1.652.	1.302.	1.082.
2019	1.081.	935.88	1.005.	937.22	1.264.	1.463.	1.739.	1.536.	1.613.	1.388.	1.167.
2020	1.001.	1.033.	938.02	797.41	1.194.	1.435.	1.969.	1.930.	2.111.	1.636.	1.144.

2016 2017 2018 2019 2020

Figure 4-32. UCY Electricity consumption (in kWh) for the years 2016-2020, partially used for cooling applications.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2016	96.112	108.12	75.176	48.023	24.053	25.010	23.018	0	23.018	25.011	71.058	121.14
2017	128.17	146.14	99.181	49.045	24.024	24.012	25.057	0	0	0	76.081	120.10
2018	136.18	65.098	102.20	31.078	0	68.052	30.065	0	0	34.025	68.062	98.090
2019	170.24	136.09	102.12	68.085	68.054	34.078	34.026	0	34.070	68.092	34.012	136.07
2020	170.21	136.11	4	99.035	67.997	34.001	0	33.998	33.999	68.001	68.005	195.00

2016 2017 2018 2019 2020

Figure 4-33. UCY Heating oil purchases (in litres) for the years 2016-2020.

During the workshop, the process of data extrapolation was thoroughly discussed and approved by UCY for further work. Some results of the data extrapolation made is shown below in Figure 4-34 and Figure 4-35.

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A daily energy demand profile is estimated, based on the data set shown in Figure 4-33 (Heating oil used, hourly, for year 2019). Data is shown for Dec-Jan-Feb-Mar, and an average profile is highlighted in bold red. The profile shows a peak demand around 8:00 in the morning, and a smaller spike around 19:00.

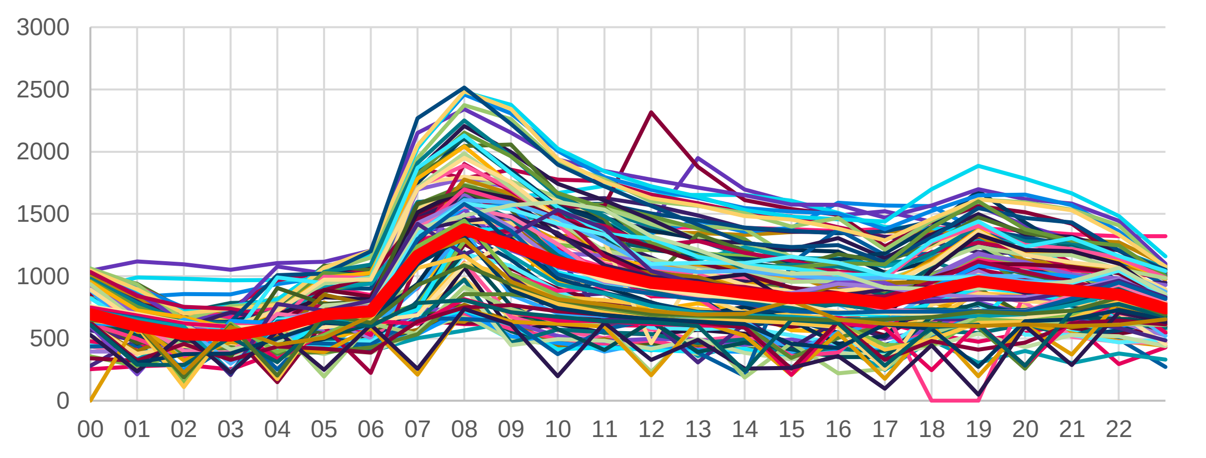

Figure 4-34. Heat consumption profile used to estimate the heating demand.

The same data set is plotted in three dimensions, here shown with days on the x-axis, hours on the y-axis, and energy demand on the z-axis. Again, a spike is found around 8:00 in the morning. From the plot, it is visible that the weekend demand is significantly smaller than the demand during the weekdays, and the increase in demand during end of January-beginning of February marks the transition from exam period to semester start at the university.

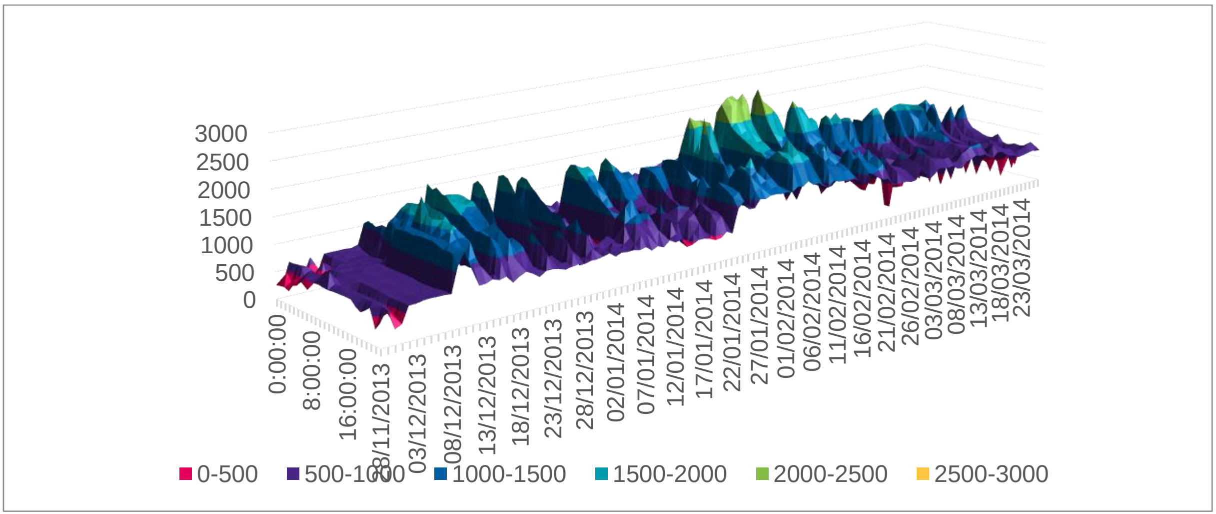

Figure 4-35. Heat consumption profile used to estimate the difference between weekdays and weekends.

Selected results from the TRNSYS DCK308 energy load and production are shown below. Figure 4-36(a) shows the boiler heat production profile, which follows the Heat demand estimated based on Figure 4-34 and Figure 4-35 (weekday/weekend distribution).

Figure 4-36(b) shows the absorption chiller (CHA) cooling production, and in Figure 4-36(c), it is seen that the distribution (Simulation) follows the load (Data), as predicted (see Figure 4-31, M720/M820). The main KPIs achieved have yet to be addressed.

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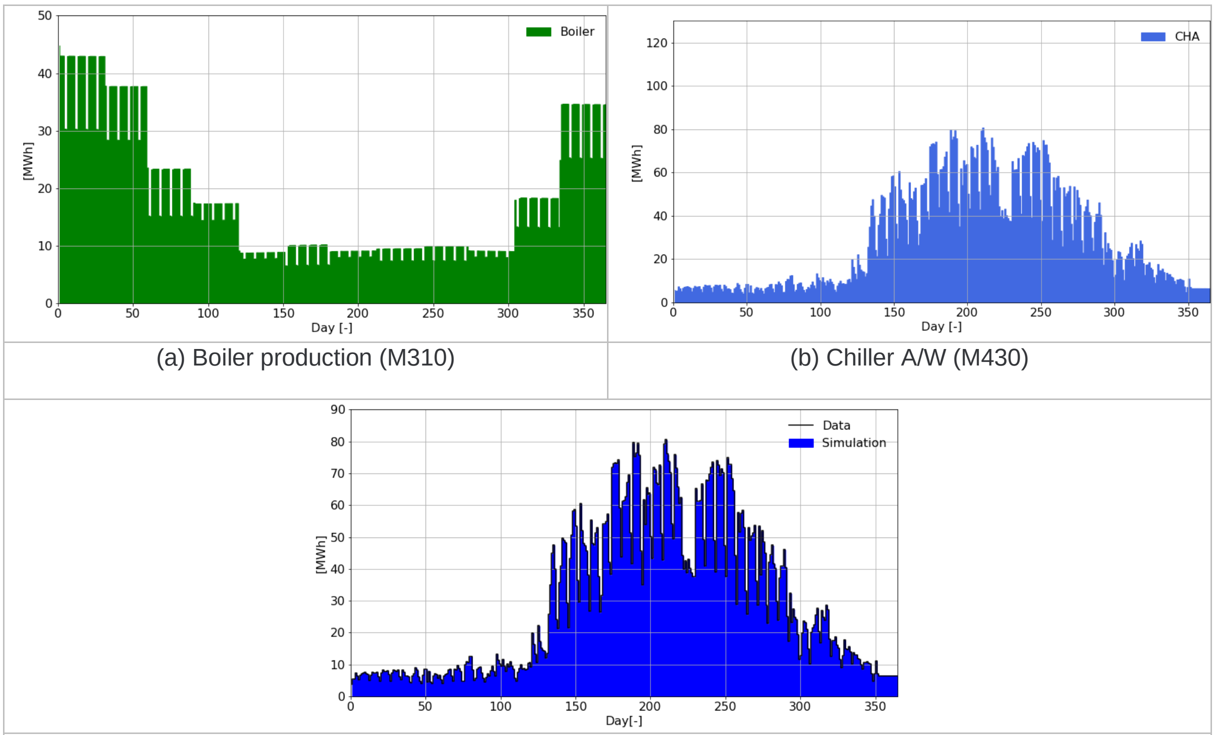

(a) Boiler production (M310)

(b) Chiller A/W (M430)

(c) Cooling load (M720) and distribution (M820).

Figure 4-36. Selected results from the TRNSYS DCK308 first results (S0 – Current system simulation).

The skewed histogram seen in Figure 4-37 shows the hourly district heating demands sorted from the hour with the highest district heating demand to the hour with the lowest district heating demand.

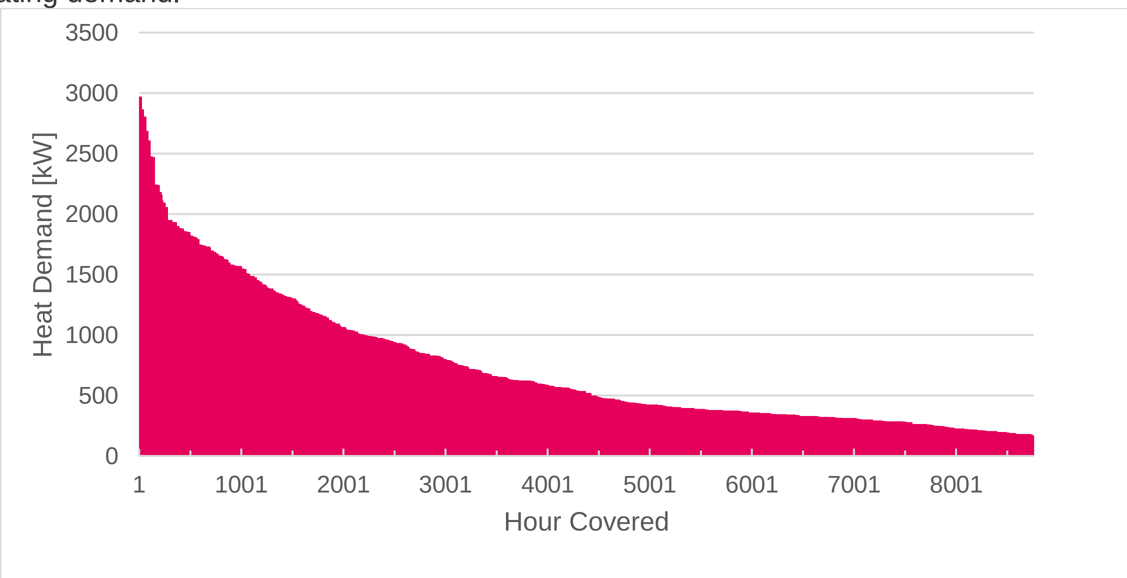

Figure 4-37 Unyversity of Cyprus Skewed Histogram of the Heat Demand

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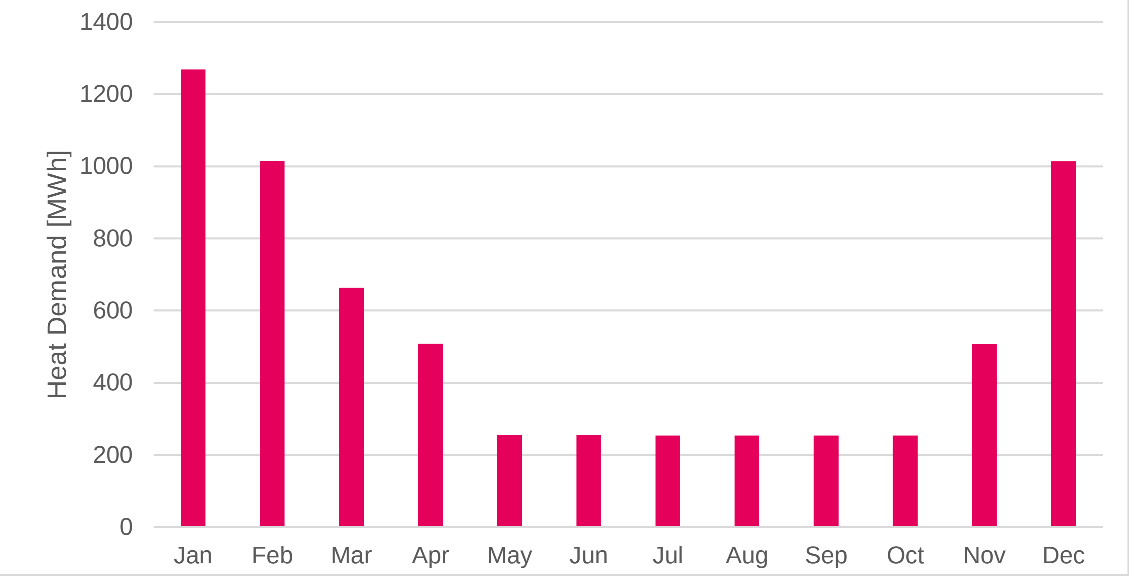

Figure 4-38 University of Cyprus Monthly Heat Demand Diagram

The district heating demand summed up for each month can be seen in Figure 4-38, above.

Figure 4-39 shows the district cooling demand sorted from the highest to the lowest district cooling demand in a skewed histogram,

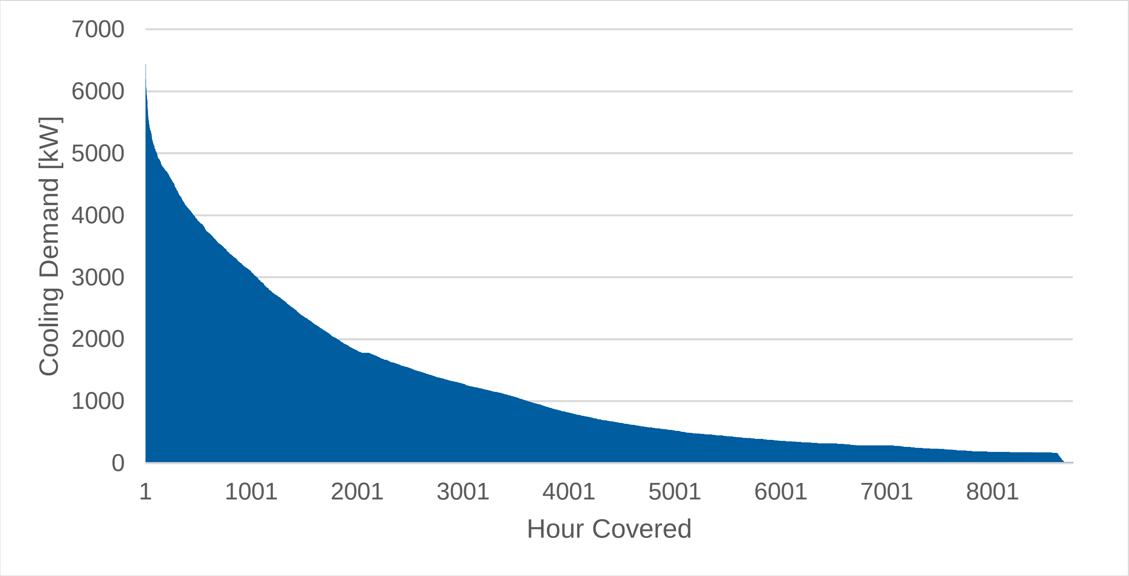

Figure 4-39 Cooling Demand Skewed Histogram for the University of Cyprus

The sum of district cooling demand for each month can be seen in Figure 4-40, below.

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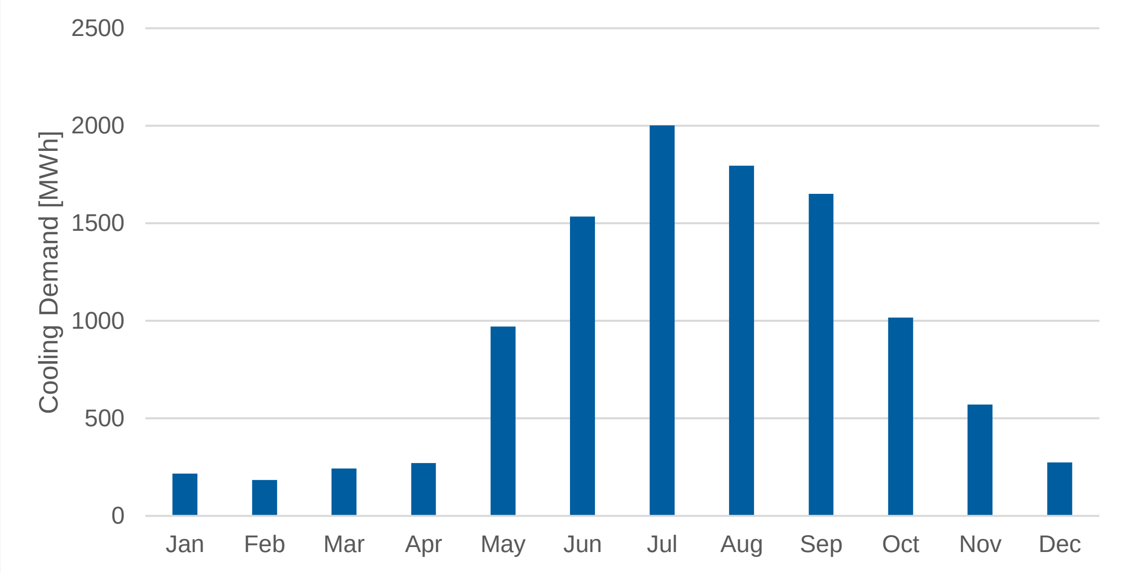

Figure 4-40 Monthly Cooling Demand for the University of Cyprus

The current heating and cooling producing plant at the University of Cyprus concists of 4 boilers with a thermal capacity of 1.75 MW each and 8 air heated chillers which each has a nominal cooling capacity of 1 MW.

4.2.2.1 FIRST RESULTS

The current district heating and cooling plant has been used to set up a deck in the launcher. In the launcher they were set up as one 7 MW oil fired boiler and one 8 MW chiller.

Parameters	Value	Unit
Oil Boilers	4x1.75	MWth
Chillers	8x1	MW Cooling

Figure 4-41 Current District Heating and Cooling Plant at the University of Cyprus

The deck was then set to try to match the temperatures of the University of Cyprus district heating and cooling networks given the hourly heating and cooling demands and the environmental factors such as ambient temperature, wind and humidity. The results of the district heating part of the simulation can be seen in Figure 4-42 and Figure 4-43.

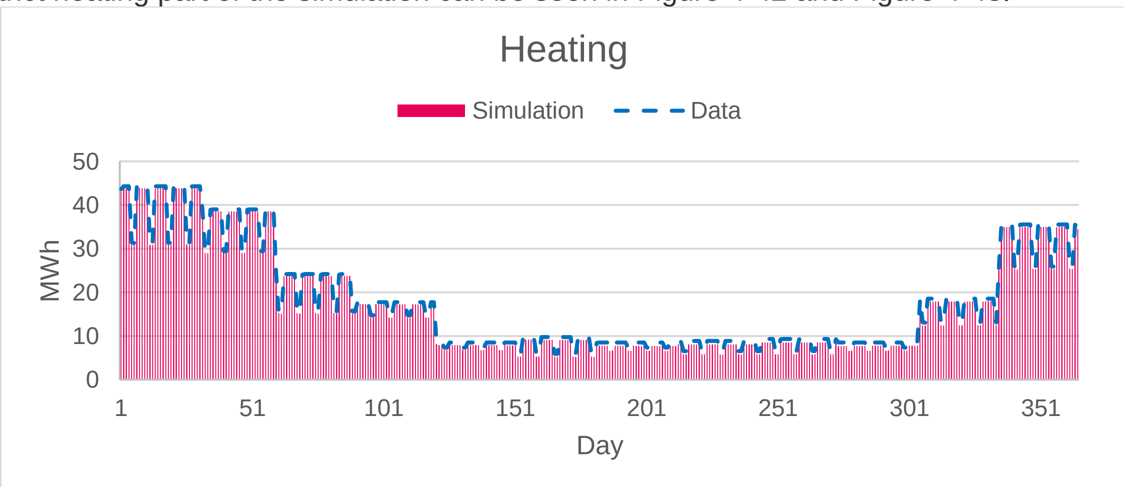

Figure 4-42 Simulated District Heating Held Against the Heating Demand

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As it can be seen in Figure 4-42 and Figure 4-46 the district heating produced per the simulation results. Comparing the simulation results to the demand gives relatively small deviation of 3.41% of the annual district heating demand which is within the uncertainty of the simulation model. This means that the district heating result is a reasonable result.

	Heating
Heating Non-renewable primary energy factor [-]	1.33 (1)
CO2 emission coefficient [kg/MWh]	350.18
LCOE [€/MWh]	70.28

Figure 4-43 District Heating KPI results

The district heating KPIs for the reference model are shown in Figure 4-43. The non-renewable primary energy factor seems a little high in that it should not be possible to be more than 1. The CO_2 emissions and the LCOE for oil fuelled boilers with thermal efficiencies of approximately 80% seem reasonable.

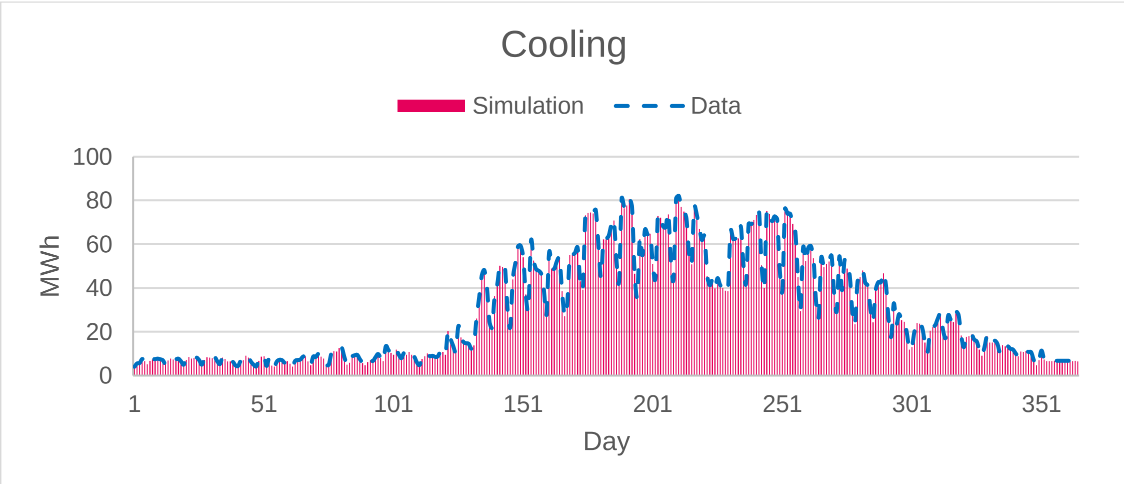

Figure 4-44 Simulated District Cooling Held Against the Cooling Demand

Figure 4-44 and Figure 4-46 show the district cooling produced per the simulation results. Comparing the simulation results to the district cooling demand results in a deviation of 0.51% which is quite low and well within the uncertainty of the simulation model.

	Cooling
Cooling Non-renewable primary energy factor [-]	0.00 (0.92)
CO2 emission coefficient [kg/MWh]	0.05 (168)
LCOE [€/MWh]	17.02 (48)

Figure 4-45 District Cooling KPI results

The KPI results for district cooling shown in Figure 4-45. The non-renewable energy factor could be too low given that a factor of 0 implies that the power for the chillers comes entirely from renewable sources. Most of the cooling energy will come from a renewable source i.e., the ambient air but the compressor and pump power must come from the electricity grid which may come from entirely renewable sources but probably does not. As stated, before most of

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the cooling energy produced by the chillers come from the air and therefore will not cause CO_2 emissions but some of the cooling and the pumping energy must come from the grid which probably will not come from an entirely carbon free source. The cooling LCOE for the cooling system also seems low which could point to a fault in the setup of the results template.

	Boiler		
	Simulation	Data	Deviation [%]
Heat generated	6278	6499	-3.41
	Chiller		
	Simulation	Data	Deviation [%]
Cooling generated	10736	10681	-0.51

Figure 4-46 Simulation Validation Results

	System
Non-renewable primary energy factor [-]	0.49 (0.95)
CO2 emission coefficient [kg/MWh]	126.67 (236.92)
LCOE [€/MWh]	36.74 (56.43)

Figure 4-47 Overall System KPIs

The overall system KPIs overall seem low which is due to the low KPIs for the cooling system.

4.2.3 FEASIBILITY STUDY

A next step would be to run the simulations as presented in the previous section – however without the PV option enabled – and confirm that the same results are obtained for heating and cooling. This will then be the Solution 0 to represent the current system in UCY to be used as reference case.

Subsequently, S1 (already planned by UCY), S2, and S3 can be simulated and compared to S0. In addition, UCY has shown interest in simulations based on increased heating, cooling, and power demands (+30% and +60%), compared to the reference.

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TECHNOLOGIES PROPOSED	BY MEANS OF
Solar Heating Technologies; TF-FTC	Investigation of integration of WEDISTRICT solar thermal panels (TC-FTC, Tracking Concentrator for Fixed Tilt Collector) to cover the heating load of the Campus; utilization of the high solar radiation potential in Cyprus.
PV / PV-Thermal (PVT)	Investigation of PV for electricity generation. UCY informs that their plans of expansion include a PV field to produce electricity to Campus (5 MWe initially, later to be upgraded to 10 MWe). Comparison of possible PV and PVT solutions (possibly with tracking mirrors) to investigate the possibility of increasing the electrical and thermal outputs. The WEDISTRICT PV-geothermal hybrid will also be considered.
Geothermal System	Investigation of the option of a geothermal system layout as well as the WEDISTRICT PV-geothermal hybrid solution.
Heat Pump	Investigation of the performance and operation of an absorption heat pump compared to a (conventional) compression heat pump (several WEDISTRICT thermocycle technologies are available for comparison).
Advanced Absorption Chiller	Investigation of the performance and operation of the WEDISTRICT advanced absorption chiller, compared to the planned air-cooled chillers.
Renewable Air-Cooling Unit (RACU)	Investigation of the option of integrating RACUs in the buildings to deliver cooling instead of the chiller solution(s).
Biomass Boiler (back-up)	Low-emission biomass boiler as a back-up solution for the coverage of peak loads. The biomass performance is to be compared to the performance of the planned oil-fired boilers, included in the Energy Center.
Energy Storage	Investigation of various energy storage solutions including: • Utilization of an optimized water storage sized for acting as solar buffer • Utilization of ice (cooling) storage solution(s) • Utilization of an electric battery (2.35 MWh capacity already planned)

Table 4-11. Proposed technologies for the investigated UCY solutions.

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The combination of the different technologies generates three main solutions which will be studied in the next step (other solutions might arise during the activity):

SOLUTIONS PROPOSED AFTER PRELIMINARY ASSESSMENT			
WEDISTRICT Technologies	**S1**	**S2**	**S3**
TF-FTC	x	x	x
PV / PVT	x	(x)	(x)
PV-Geothermal Hybrid		x	
Heat pump (A-W or A-A)	x	x	x
RACU		x	(x)
Advanced Absorption Chiller		x	(x)
Biomass			x
OTHER Technologies – *to be considered*			
Energy storage, in general	x	x	x
Tri-generation (CCHP*), in general	x	x	x
Air-cooled chillers	x		
Oil-fired boilers	x		

Table 4-12. Solutions proposed for UCY after preliminary assessment.

SOLUTIONS PROPOSED OVERALL DESCRIPTION	
Combination code	UNIVERSITY OF CYPRUS – S1
Justification	The proposed solution S1 reflects the solution planned for DHC at UCY after the expansion and refurbishment in 2022. This is intended to be used as a benchmark solution. Thereby solution S1 integrates and combines the technologies of FTC, PV, Heat pumps, Energy storage, CCHP and Air-cooled chillers as well as oil- or biomass fired boilers for backup. This solution is suitable for UCY since it includes the technologies that are being considered for the production of District Heating, (fixed tilt solar collectors, geothermal system), district cooling (Air-to-water or Air-to-air heat pumps, Ice (i.e., cold) storage and Air-cooled chillers) and power production (Photovoltaics) – all three (trigeneration; in the form of a combined cooling, heating, and power plant), which are in scope for 29 buildings, including student residences.
Expected impact	• Investigation of the installation of the new DHC equipment / plant capacity to cover the expected DHC and electricity demands of the new Campus buildings. • Investigation of the possible improvements of the WEDISTRICT solar thermal panels (TC-FTC), compared to traditional solar heating technologies. • Investigation of the possible improvements reg. PV or PV-T system layouts. • Investigation of the installation of Heat pump technologies. • General advising on energy equipment planning of the expansion of the UCY Campus buildings.
Combination code	UNIVERSITY OF CYPRUS – S2
Justification	The proposed solution S2 is a variation of the planned setup using RACU and/or Advanced Absorption Chilling instead of the planned Air-cooled chillers to deliver cooling. In addition, part of the heating will be covered by Geothermal heating instead of the planned Oil-fired boilers. Note that FTC, PV, HP, Energy Storage and Trigeneration are still in this configuration.

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Expected impact	• Investigation of the possible improvements related to district cooling from RACU and/or Advanced Absorption Chillers, as opposed to Air-cooled chillers. • Investigation of the impact of geothermal heating to cover peak load heating as opposed to using Oil-fired boilers. • Investigation of the possible improvements reg. PV or PV-T system layouts in combination with the WEDISTRICT Geothermal Hybrid. • General advising on planning of buildings' energy equipment alternatives.
Combination code	UNIVERSITY OF CYPRUS – S3
Justification	The proposed solution S3 is a variation the planned setup using RACU, and/or Advanced Absorption Chilling, instead of Air-cooled chillers for cooling. In addition, the option of the WEDISTRICT Low-Emission Biomass Boiler technology is investigated for the purpose of heat provision, instead of the proposed geothermal (hybrid) heating in S2. Note that FTC, PV, HP, Energy Storage and Trigeneration are still in this configuration.
Expected impact	• Investigation of the improvement related to district cooling from Advanced absorption chillers as opposed to air-cooled chillers (considering results from S2). • Investigation of the impact of using biomass boilers to cover peak load heating as opposed to geothermal heating or heating from oil-fired boilers. • General advising on planning of buildings' energy equipment alternatives.

Table 4-13. Overall description of proposed solutions for UCY (justifications and expected impacts).

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4.2.3.1 Scenario 1

The scenario 1 model for the University of Cyprus is a very complex model. The model contains four technologies that generate heat. The solar thermal (TC-FTC), the boiler, the CHP and the Heat pump. There are three cooling generating technologies the absorption chiller, the chiller and the heat pump. And finally, there is thermal energy storage which can store heat for a while. The absorption chiller will require heat from one of the heat generating technologies in order to generate cooling. The model also contains a photo voltaic solar power field which will generate electric power to the university as well as the district heating and cooling technologies.

TF-FTC area [m²]	TES volume [m³]	Oil boiler [kW]	CHP [kW]	CAC capacity [kW]	Chiller A/W capacity [kW]	HP A/W heating capacity [kW]	HP A/W cooling capacity [kW]
4200-5040	420-504	800-1000	1080-1200	900-1100	3000	2700-3300	2025-2475

Figure 4-48 Scenario 1 simulation parameters

In the parametric simulation the volume of the TES is bound to the area of the solar thermal field this was done to limit the number of independent parameters in order to save time when running the simulation and the main function of the TES is to store heat from the solar field since the boiler and the CHP come with their own dedicated TESs whose volumes are tied to their respective peak flows. The heat pumps cooling capacity is tied to the heat pump's heating capacity this is because the that is the way a heat pump works. For an air to water heat pump in heating mode will extract heat from the relatively cold ambient air by evaporating a liquid at a temperature lower than the ambient air the vapours will then be compressed and lead to a heat exchanger where the vapours will be condensed releasing heat to the district heating water. When running the heat pump in cooling mode the fluid is evaporated in the water heat exchanger thereby cooling the district cooling water and the compressed vapours are condensed in the ambient air heat exchanger where the heat is released. In both cases the heat released by the condensing vapours is equal to the heat extracted by the evaporating liquid and the heat generated from the mechanical work of the compressor. This means that there is a very specific relationship between the heating and cooling capacity of a heat pump. For the parametric simulation the chiller was kept at a constant capacity in order to keep the simulation time down. The chiller is a simple and relatively inexpensive so letting it handle a significant portion of the cooling will not affect the study on the viability of the heat pump and the absorption chiller too much.
The photo voltaic solar power field was kept constant to limit the simulation time. The photo voltaic technology will not provide district heating or cooling directly but will affect the LCOE and emissions.

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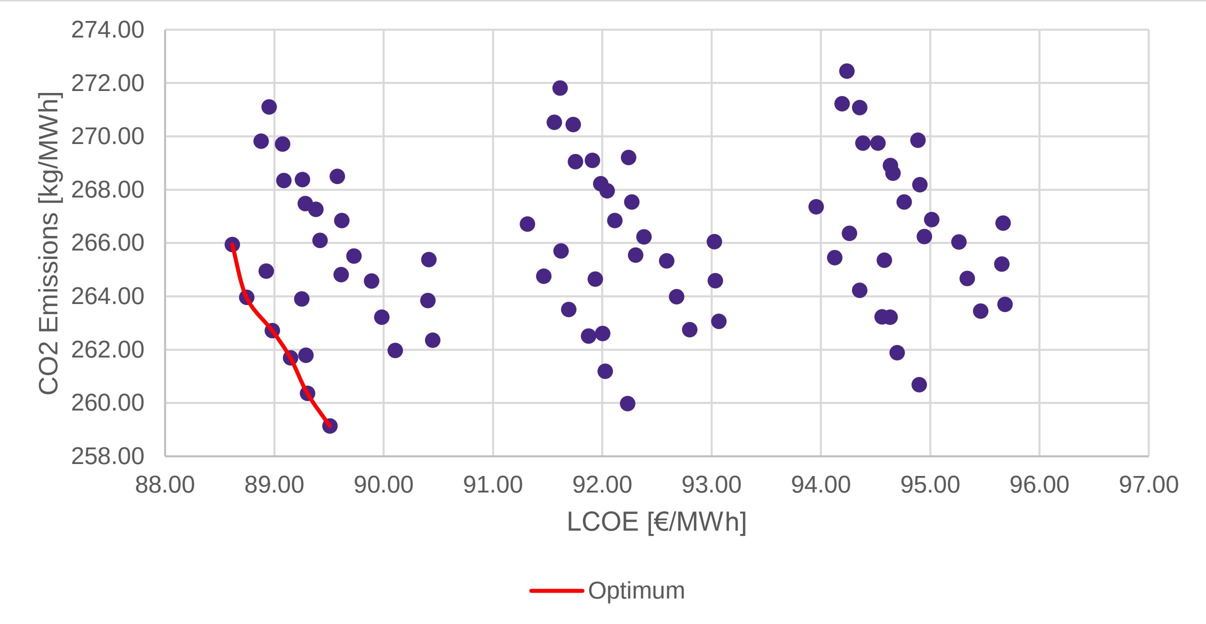

Figure 4-49 Scenario 1 parametric simulation results

Analysing the results of the parametric simulation reveal that increasing the size of the solar thermal collector field increases the LCOE while decreasing the CO_2 emissions, increasing the boiler decreases the LCOE slightly while increasing emissions significantly. If the size of capacity of the absorption chiller is increased the LCOE increases and so does the CO_2 emissions. When the capacity of the heat pump is increased the LCOE is increased as well while the emissions are not affected or only to a negligible degree.

Given these tendencies minimizing the solar thermal field, the heat pump and the absorption chiller will minimize the LCOE. While minimizing the boiler and the absorption chiller will minimize the emissions.

The absorption chiller needs to take heat from either solar thermal field or the boiler to generate cooling.

So, minimizing the absorption chiller will minimize both the LCOE and the emissions but this will in turn require a larger heat pump in order to cover the cooling demand which will push the LCOE up because the combined cooling capacity of the absorption chiller, the chiller and the heat pump on cooling mode must be able to cover the cooling demand.
Depending on the value of the emissions versus the LCOE the minimizing the either the solar field or the boiler will be the approach or finding the right balance between the two.

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University of Cyprus Scenario 1 Optima

Case	TF-FTC Area M1300 [m²]	TES capacity M2100 [m³]	Boiler capacity M3100 [kW]	CHP capacity M3300 [kW]	CAC Generator Power Nominal Capacity M4200 [kW]	HP A/W heating capacity M4500 [kW]	HP A/W cooling capacity M4500 [kW]	LCOE [€/MWh]	CO2 emission coefficient [kg/MWh]
Emissions	5040	504	800	1080	900	2700	2025	89.58	259.14
Economical	4200	420	1000	1080	900	2700	2025	88.61	265.95

Figure 4-50 Scenario 1 Optima

As it can be seen in Figure 4-49 and Figure 4-50 the difference in the LCOE at the extremes of the pareto front is lower than the extremes of the emissions meaning that there is a relatively low trade of in price per MWh heating and cooling to minimize the CO_2 emissions. The question will be if it makes sense to increase the LCOE by 1.1% to lower the emissions by 2.6%.

4.2.3.2 Scenario 2

The model for the University of Cyprus scenario 2 contains two technologies for heat production a solar thermal collector field and an air to water heat pump. The heat pump also can provide cooling where it supports the absorption chiller. The absorption chiller will require heat generated by the solar field or the thermal energy storage to provide cooling. The TES will store heat produced during the day and store it to the night or the following days. The model also has a photo voltaic power plant.

TF-FTC area [m²]	TES volume [m³]	CAC capacity [kW]	HP A/W heating capacity [kW]	HP A/W cooling capacity [kW]
20000-25000	2000-2850	3000-6000	5675-7500	4275-5625

Figure 4-51 Scenario 2 simulation parameters

The cooling capacity of the heat pump is tied to the heating capacity of the heat pump for the parametric simulation. This because it is the way the heat pump practically works. The photo voltaic solar power plant is kept at a constant size to keep the simulation time down and to remove noise from non-district heating and cooling equipment.

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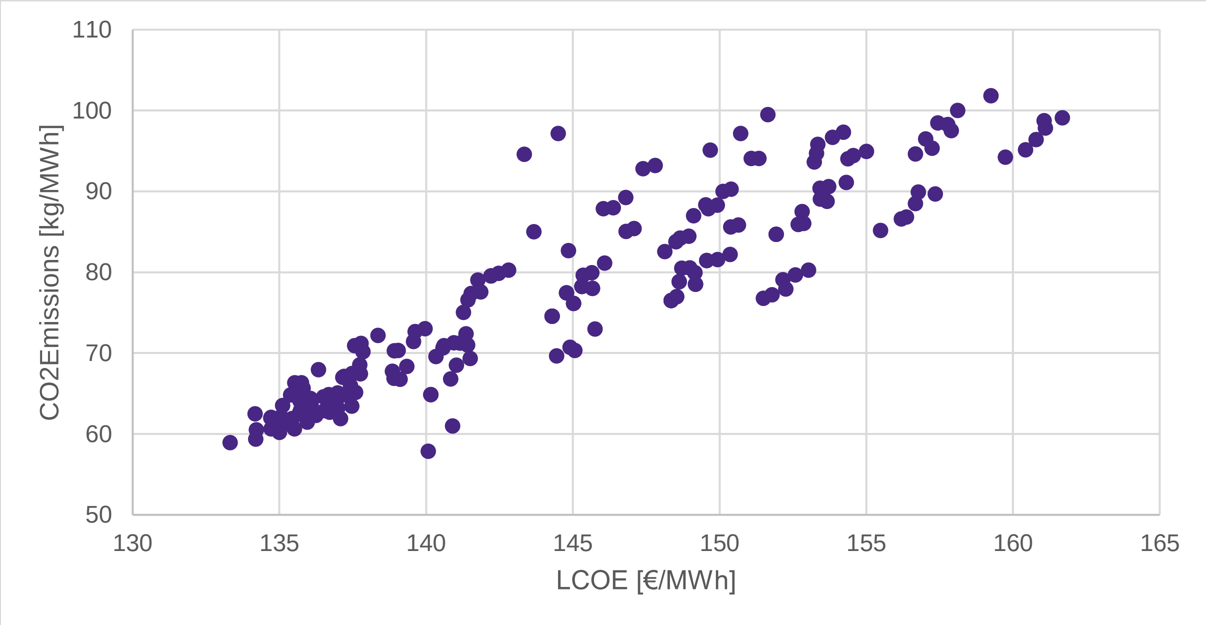

Figure 4-52 Scenario 2 parametric simulation results

The parametric simulation for scenario 2 had more "results" than are shown in Figure 4-52. Those "results" are not shown because their deviations were too big and therefore would not be part of the set of "realistic" results.

When examining the results of the parametric simulation, increasing the solar thermal field area results in decreasing LCOE and emissions. Increasing the TES volume increases the LCOE and the emissions, increasing the absorption chiller capacity will increase the emissions while it may lower the LCOE. If the heat pump capacity is increased the LCOE will be increased but the emissions will get lowered.

Case	TF-FTC Area M1300 [m²]	PV capacity M1500 [kW]	TES capacity M2100 [m³]	CAC Generator Power Nominal Capacity M4200 [kW]	HP A/W heating capacity M4500 [kW]	HP A/W cppling capacity M4500 [kW]	LCOE [€/MWh]	CO2 emission coefficient [kg/MWh]
Optimum	23600	4000	2750	5675	6500	4875	133.31	58.93

Figure 4-53 Scenario 2 optimum

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The results of the parametric simulation for scenario 2 reveal an apparent singular optimum. The optimal solution is generally between the limits of the parametric simulation. The optimal solution has a relatively big solar thermal collector field, absorption chiller, heat pump and TES tank. The heat pump and the absorption chiller can cover most of the cooling demand on their own, but neither can cover the peak cooling demand on their own. The solar field should cover most of the district heating demand using the TES to store heat from daytime to night-time. The heat pump can easily cover the heating demand on alone but cannot provide heating and cooling at the same time.

The relatively big technology components push up the LCOE but because all technologies have a high renewable energy factor which keeps the emissions low.

4.2.3.3 Scenario 3

The model used to simulate scenario 3 has three technologies that can generate district heating namely a solar thermal collector field, a boiler and a water-to-water heat pump. The model also three technologies that can provide district cooling which are a chiller, and absorption chiller and the water-to-water heat pump. The model also has a thermal energy storage and a photo voltaic solar power field.

TF-FTC area [m²]	TES volume [m³]	Boiler Capacity [kW]	Chiller A/W capacity [kW]	AAC capacity [kW]	HP W/W Heating capacity [kW]	HP W/W Cooling capacity [kW]
11000-28000	1080-3360	1500-5000	3000-5000	375-2500	1625-8000	1220-6000

Figure 4-54 Scenario 3 parametric simulation parameters

In the parametric simulation the heat pumps cooling capacity it tied to the heat pumps heating capacity because that is how the heat pump functions. To limit the calculation time of the parametric simulation the photo voltaic solar power plant is kept at a constant peak power capacity this will also remove the impact of changing the PV power on the LCOE and emissions. Considering that the PV plant is a non-district heating and cooling equipment its contribution can be seen as noise (a disturbance on the DHC results).

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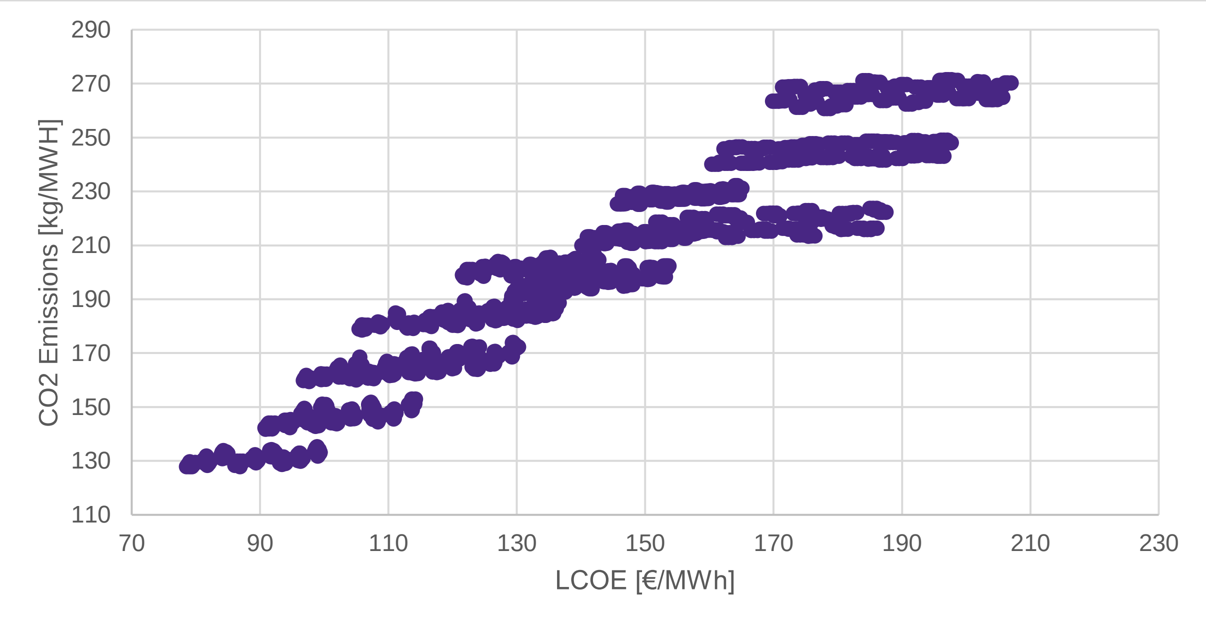

Figure 4-55 Scenario 3 parametric simulation results

Analysing the parametric simulation results reveals that as the size of the solar thermal collector field goes up so does the LCOE and the emissions. Increasing the boiler capacity lowers the LCOE and increase the emissions. If the chiller capacity is increased so is the LCOE and the emissions. For the absorption chiller the tendency is clear both LCOE and emissions increase with increasing capacity. Increasing the heat pumps capacity impacts the LCOE more than the emissions but both are increased.

Case	TF-FTC Area M1300 [m²]	PV capacity M1500 [kW]	TES capacity M2100 [m³]	Boiler capacity M3100 [kW]	AAC Generator Power Nominal Capacity M4100 [kW]	Air chiller capacity M4310 [kW]	HP A/W Heating capacity M4500 [kW]	HP A/W Cooling capacity M4500 [kW]	LCOE [€/MWh]	CO2 emission coefficient [kg/MWh]
Optimum	11000	4000	1080	2000	375	3750	1625	1219	78.50	127.86

Figure 4-56 Scenario 3 optimum

From the results of the parametric simulation of scenario 3 there can be seen an apparent optimum. The apparent optimal configuration consists of a minimized solar thermal collector field, a minimized TES, a boiler in the lower end of the search, an absorption chiller that has been minimized, a chiller which is close to midrange, and a heat pump whose capacity has been minimized.

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4.2.3.4 Discussion

From these three scenarios certain tendencies seem to appear. The absorption chillers tend to increase both LCOE and emissions and they do not seem too viable without a relatively big heat source that can provide a relatively high-quality heat. Establishing a big heat source just to power an absorption chiller like a solar thermal collector field does not seem too viable when compared to the results of installing a photo voltaic solar power plant and using that to power a conventional chiller. The PV collectors may be less efficient than the solar thermal collectors, but the absorption chiller is even less efficient than the conventional chiller and at the same the absorption is at least twice as expensive as the conventional chiller. The solar thermal collectors may not be significantly more expensive than the PV panels, but the PV panels need less auxiliary equipment. Battery packs and inverters add to the cost but so does a hot water tank, pumps, valves heat exchangers elaborate control systems and frequency converters. So, unless there is a vast heat source of high-quality heat and no other use for said heat the absorption chiller does not seem a too viable solution.

Solar thermal collectors are one of the cheapest ways to generate district heating. The trouble is that the FTC will invariably generate most when the requirement for heat is low or non-existent. This can in part be remedied by adding a thermal energy storage which of course adds to the plant cost and thereby the LCOE of the heating.

Air to water heat pumps have a similar problem to FTCs even though the heat pump may be set up in such a way that it can generate heating and cooling, although not at the same time, or it can but, not optimally for both demands. The air to water heat pump is more efficient at generating heat when the ambient air is warmer, and it is more efficient at generating cooling when the air is colder. This is because when the heat pump generates heat it is cooling the air and when it is generating cooling it heats the air. Water to water heat pumps work like air to water heat pumps the only difference is that water is used as a source instead of air.

There is a potential synergy between the three technologies FTC, TES and water to water HP. If solar collectors are used to heat cold water to lukewarm water which is, then either cooled by a heat pump or stored in a TES to be cooled later or both. Then the heat pump cools the water back down to use said heat to heat district heating water. By letting the solar collectors heat cold water to a midrange temperature the efficiency of the solar panels is increased because the temperature difference between the water in the panels and the ambient air is minimized. Cooling lukewarm water in the heat pump to heat district heating water increases the efficiency of the heat pump because it minimizes the temperature difference between the evaporator and condenser units of the heat pump. This synergy seems to only exist in the cold or heating period of the year. It may still be interesting to attempt to simulate a system where this is attempted.

4.2.3.5 Economics

Parameter	Value
Electricity price	120 €/MWh
Fuel Oil Price	57.2 €/MWh
Life time	25 yr
Discount rate	7 %

Figure 4-57 LCOE parameters

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Scenario	LCOE [€/MWh]
UCY S1-ECO	88.61
UCY S1-CO2	89.58
UCY S2	133.31
UCY S3	78.5

Figure 4-58 University of Cyprus LCOEs

Scenario	LCOE [€/MWh]	CO2 emission coefficient [kg/MWh]
UCY S0	36.79 (56.43)	126.67 (236.92)
UCY S1-ECO	88.61	265.95
UCY S1-CO2	89.58	259.14
UCY S2	133.31	58.93
UCY S3	78.50	127.86

Figure 4-59 University of Cyprus Optima

As it can be seen in Figure 4-59 the apparent cheapest solution is the reference scenario or status quo this is not a viable solution since the current boilers need to be replaced and the University is planning to increase their campus and therefore expand the district heating and cooling networks and demands. The most environmentally friendly solution is Scenario 2 but increasing the LCOE to a level that is more than a 100% increase is probably not viable especially when considering that a large group of DHC users are students and the rest is the University itself, and the University would probably prefer to spend the least amount possible on heating and cooling so that there is more room in the budget for education and research. The most reasonable solution would be scenario 3 it has the lowest LCOE after scenario 0 and the lowest CO_2 after scenario 2.

4.2.4 CONCLUSIONS

Based on the studies on the three scenarios the most viable scenario is scenario 3 the LCOE may not be as low as the base case LCOE and the emissions may be higher than the emissions of scenario 2 but as explained the base case is not possible in the future and the LCOE of scenario 2 is just too high.

It might be possible to improve the results by removing the absorption chiller. There might also be something in combiniing the solar thermal and the PV in a PV thermal solar solution.
It could be interesting to see if the synergy between the solar thermal, the TES and the water to water heat pump can help optimize these three technologies but also how much it would do to minimize the boiler.

In a future study it would be interesting increasing the heating and cooling demands to see if the future expansions to the University will cause the balance between the technologies to shift.

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4.3 Żyrardów (Żyrardów – Poland)

4.3.1 GENERAL DESCRIPTION AND PRELIMINARY ASSESSMENT

4.3.1.1 GENERAL DESCRIPTION

Żyrardów is a town in central Poland with approximately 41,400 inhabitants. Żyrardów has almost 200 years of history. The town was developed during the 19th century into a significant textile mill town in Poland.

Regarding the targets related to the energy sector, Poland has established an objective of 21% of renewable energy on the final energy consumption by 2030. This aims at achieving a more sustainable energy sector in Poland. Moreover, 70% of all households in the country are to be connected to DH networks by 2030.[12] District Heating is one of the best solutions to increase the share of renewable energies regarding the heat sector.

The next figure shows the predominance of the fossil fuels in the heat production field.

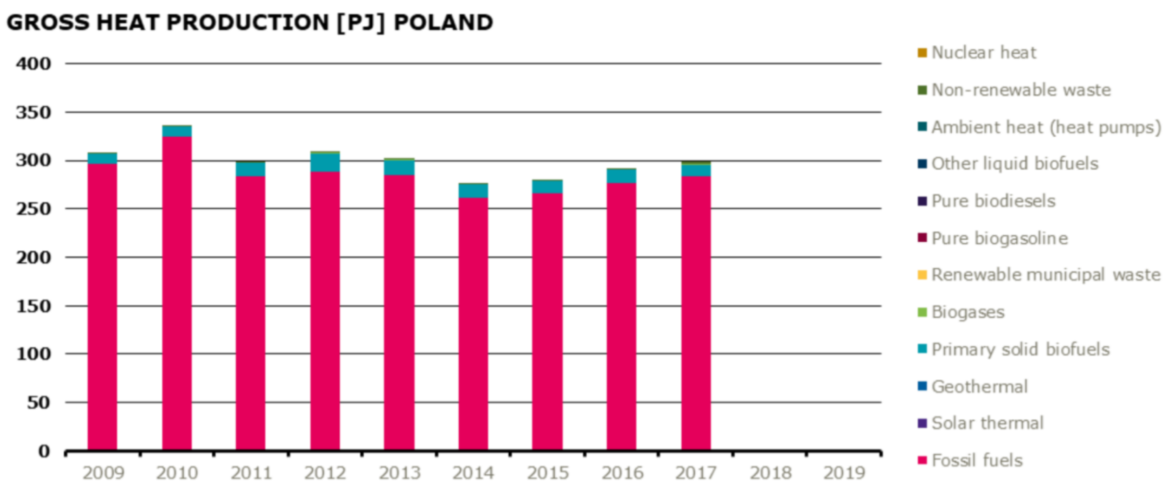

Figure 4-60. Gross heat production by fuel and year in Poland.

Regarding the installed heating capacity, the individual boilers represent a 64% of the total power, followed by the 25% of DHs with boilers (mainly based on fossil fuels) and 10% of DHs with CHP as can be seen in Figure 4-61.

[12] *WEDISTRICT - Deliverable D2.3 "District Heating and Cooling Stock at EU level"*

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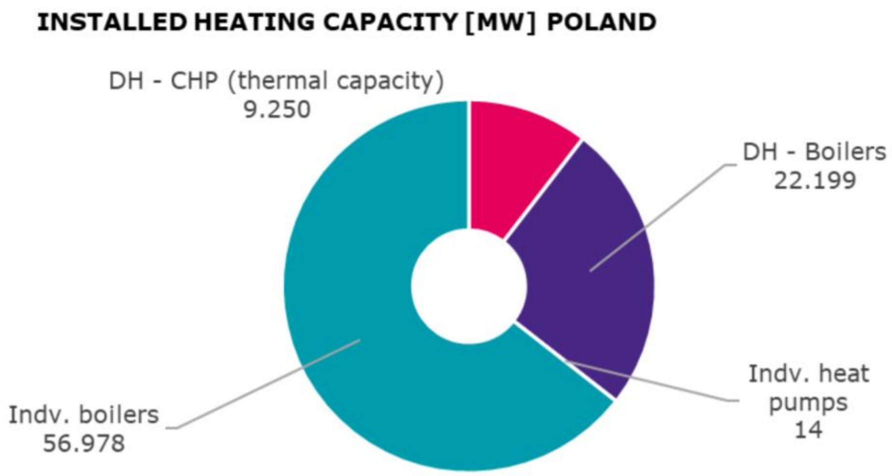

Figure 4-61. Installed heating capacity installed in Poland in 2015.

In case of Żyrardów the district heating system covers around half of the city and is still developing. There are two thermal plants in Żyrardów. One hard coal fired with water boilers (around 63 MW in fuel) which belongs to PEC "Żyrardów" company, and one 10 MW gas fired boiler which belongs to other company Geotermia S.A. located around 2 km from the main heat plant.

In the map the area in red circle is the 63 MW power plant driven by coal boilers. The blue circle represents the location of the smaller 10 MW power plant. The district heating system supplies energy in all the green marked area.

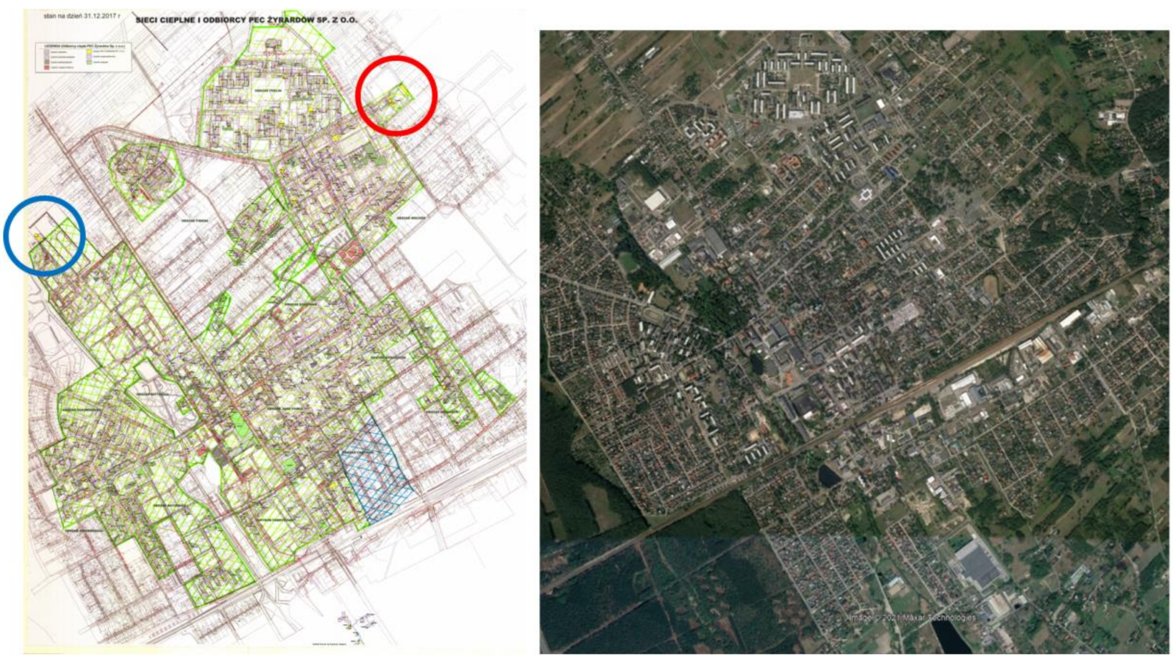

Figure 4-62. Left - Żyrardów District Heating map. Right - View of Żyrardów

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The DH network has a length of around 43.km. In 2013-2016 almost all sections of DH made in "traditional technology" were replaced by pre-insulated pipes (currently 99,9% of the network is made in pre-insulated technology). The energy losses in the network represent around 13-14% of the produced energy. The district heating was also expanded by so called "rings" which reduced markedly the electric energy consumption.

Figure 4-63. Żyrardów District Heating installation

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4.3.1.2 PRELIMINARY ASSESSMENT

Supply/Return temperatures

The supply temperature varies seasonally depending on the outdoor temperature. In winter it can reach almost 122°C when the outdoor temperature is -20°C while in summer the supply temperature is quite constant around 70ºC.

The return temperature is between 60-70ºC during the winter, and 45-55°C during the summer. The graphs in Figure 4-64 and Figure 4-65 show the seasonal trend of supply and return temperatures.

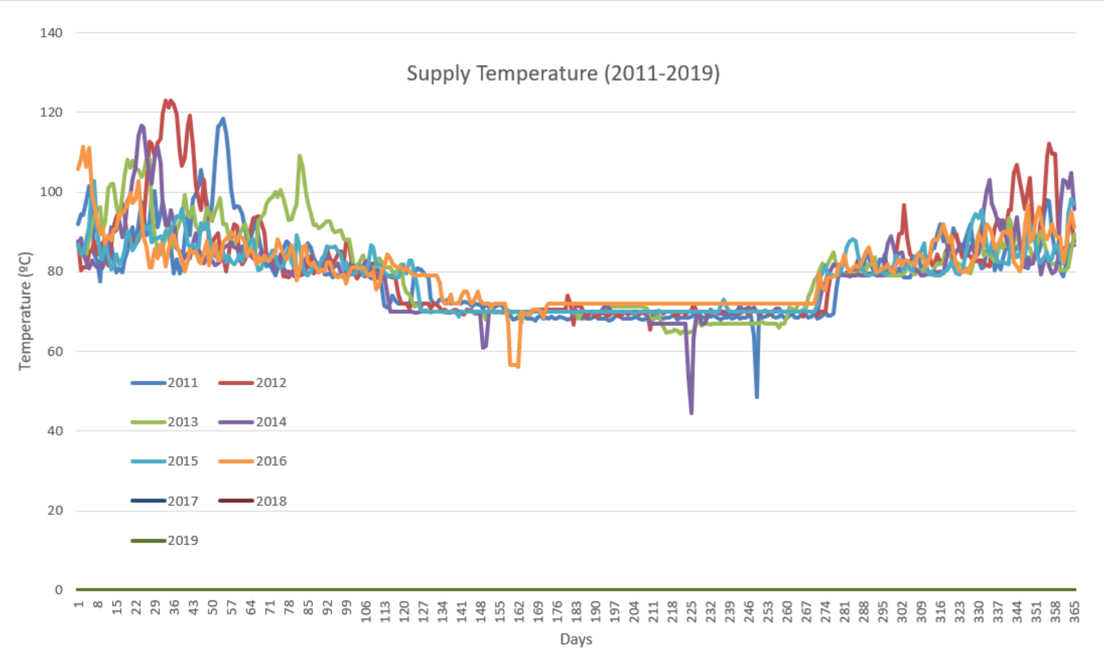

Figure 4-64. DH supply temperature

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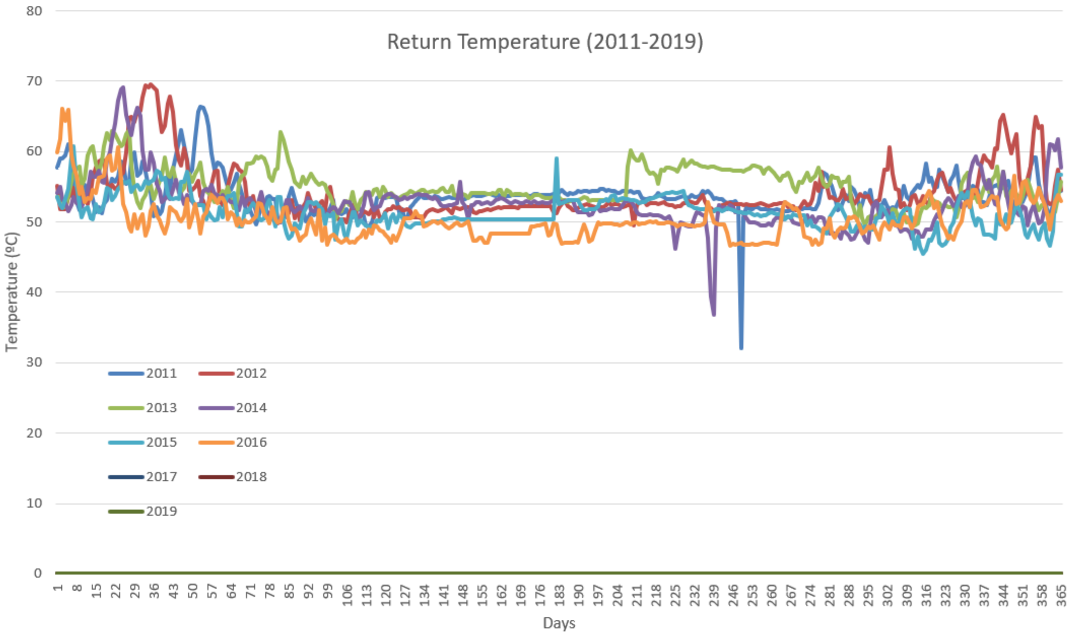

Figure 4-65. DH return temperature

Produced thermal energy

To obtain the thermal energy production curves, we worked with the data sent from the thermal power plants. The data is in hourly format per day for both the gas plant and the coal plant, but only for some days of some months of each year, from 2015 to 2019. Due to this, work was done to obtain a profile annual schedule from the data obtained, through data extrapolations under the following assumptions.

- If, given a certain month, there is data for 2019, this year is used as the base.
- If the above is not true, the corresponding month is searched one year backwards.
- To determine the monthly hourly profile, it is assumed that, for each hour for which there are no data, it is calculated as the average of the same hours of the same month, of the days that do have data.
- All days for which data exist, these were not altered.

These calculations led to the graph that is shown in Figure 4-66.

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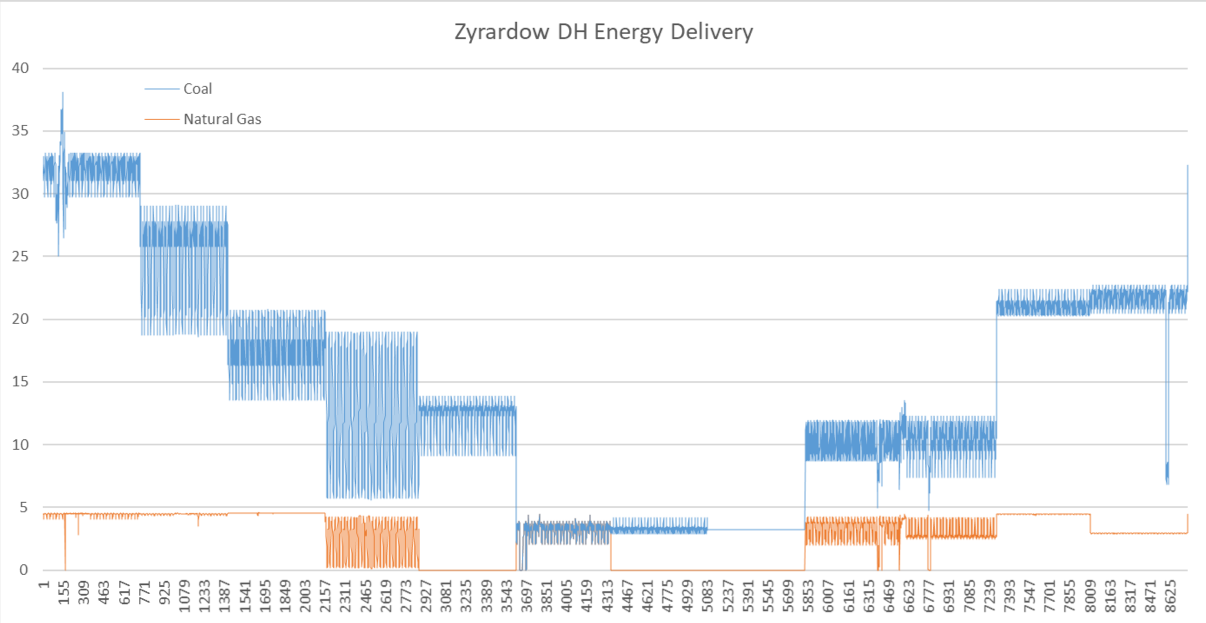

Figure 4-66. Produced thermal energy

The graph above shows very interesting information. First, it is observed that at no time is the system completely off, which makes sense considering that the system must deliver DHW. However, a significant drop in the energy generated in summer can be observed, which means that for some months only the coal-fired plant can be operated or only the gas-fired plant, omitting simultaneity.

It can also be seen that the peak of generated energy is found in winter, specifically in January, a month in which there is also an oscillation in power of about 5 MW.

Heat load

The load curves that appear in Figure 4-67, Figure 4-68 and Figure 4-69 are not very precise, since the data that was gathered is a daily average heat power, so the hourly peaks are not registered here.
DHECO had access to hourly data for some days and we have seen that between the daily average value and the peak power there could be a difference of 10% to 30%. Therefore, 46 MW peak power could be “converted” into almost 60 MW, which is more realistic when compared it with the installed power. Recently (February 20201), which is not shown in the graph, the peak demand exceeded 50 MW due to longer periods of outdoor temperature below -10 C. Thus, it might be assumed that for longer periods with temperature below -20C, 60 MW peak might be reached once per 10 years for instance.

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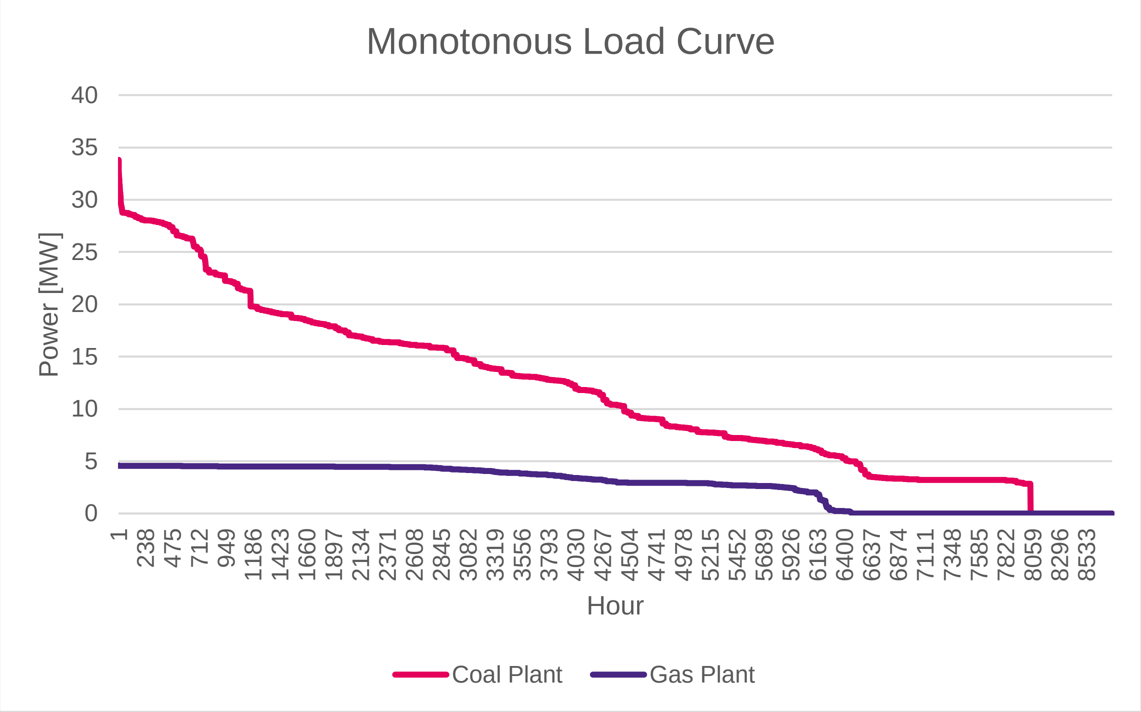

Figure 4-67. Monotonous load curve

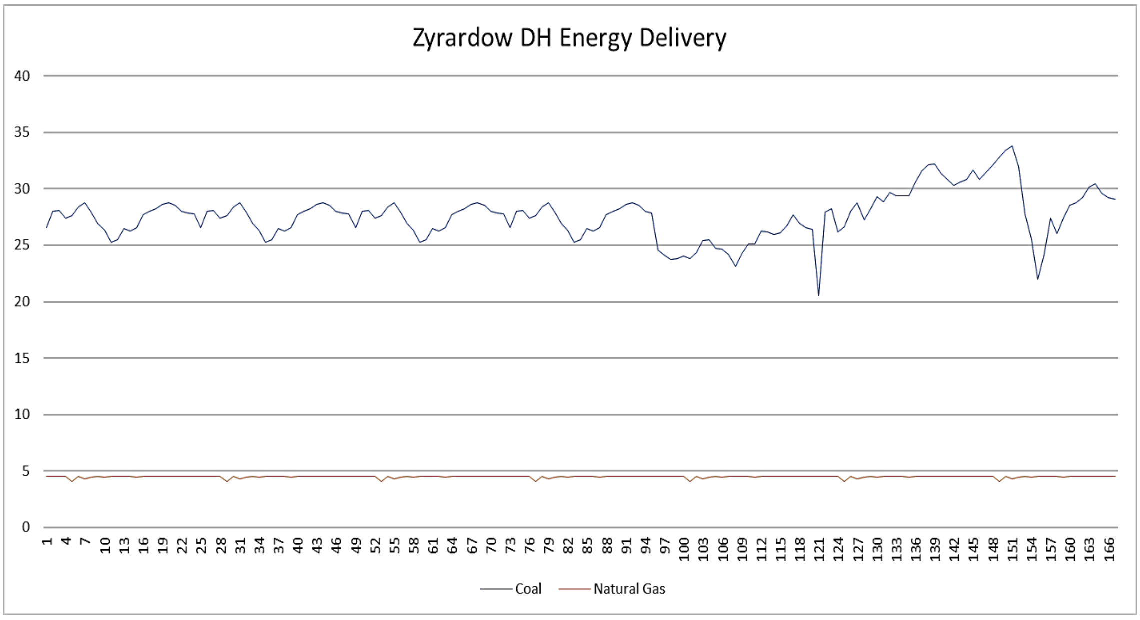

Figure 4-68. Weekly Delivered Energy in a week of January

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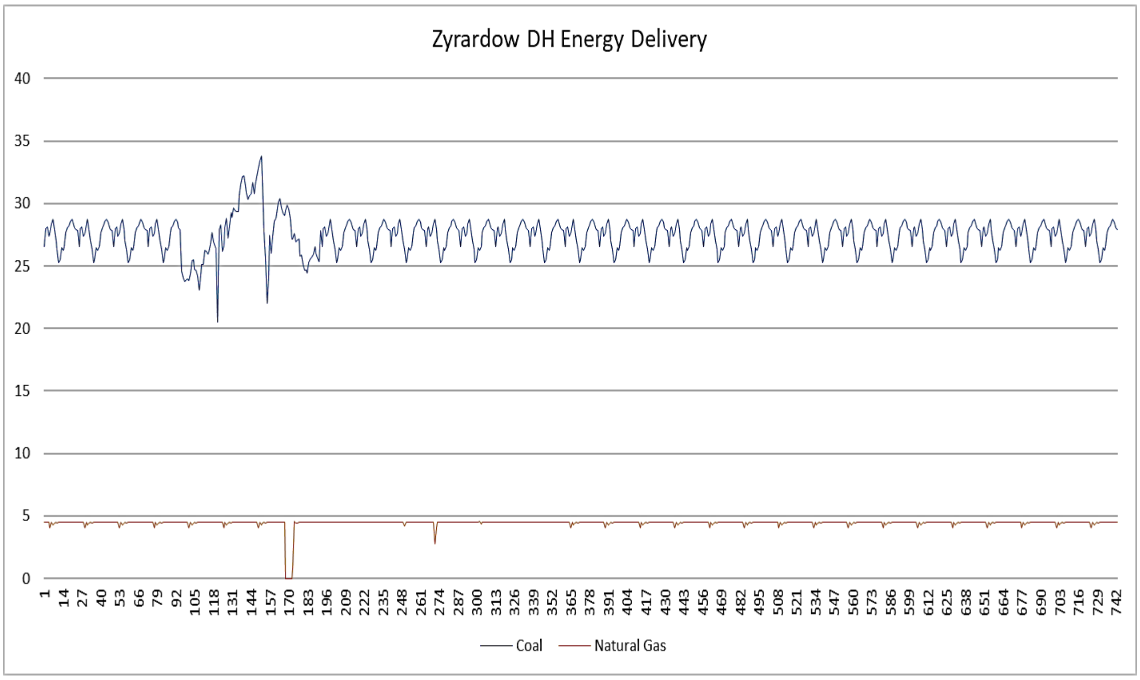

Figure 4-69. Monthly Energy Delivered for January

Considering the previous information, the technologies and solutions proposed to be studied in Zyrardow demo-follower are the technologies described in Table 4-14, Table 4-15 and Table 4-16

Table 4-14 Solutions proposed after the preliminary assessment for Zyrardow demo-follower.

Technology	S1	S2
PTC	x	
Fresnel	x	
TF-FTC	x	
Biomass		
Molten Salts		
Hybrid PV-Geothermal		x
Advanced Absorption Chiller		
RACU		
FC-WHR		
CHP		x
Gas boilers	x	

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Table 4-15 Conceptual descriptions of solutions proposed after the preliminary assessment for Zyrardow demo-follower.

Technologies proposed	By means of
Solar technologies	Integration of solar panels in the central stations to cover extra heating load.
Biomass boiler	Biomass boilers installation for replacing partially or totally the existing fossil fuel fired boilers
Hot water & Molten salt storage	Optimized water and molten salt storage for acting as solar buffer and to maximize the biomass boiler energy production.
Geothermal	Integrate Geothermal heat pumps as a renewable energy source. The PV installation coupled with these HPs will be analyzed.
CHP	Three 1 MWe gas engines (3 x 2,5 MW in fuel) located in different places in Żyrardów.
Peak gas boilers	Gas boilers installation to cover peaks from November to March

Table 4-16 Overall description and justification of solutions proposed after the preliminary assessment for Zyrardow demo-follower.

Solutions proposed overall description	
Combination code	ZYRARDOW – S1
Justification	This combination integrates biomass boilers and the installation of new gas boilers to cover the heating peak demands.
Expected impact	• Increase at 90% the thermal production by renewable energies. • Evaluate tech-economic feasibility of the proposed solutions. • Evaluate availability of biomass. Analyze the biomass sector in Poland. • Maximise biomass boiler energy production.
Combination code	ZYRARDOW – S2
Justification	This combination integrates solar technologies and thermal storage systems based on hot water and molten salts. Besides, the existing coal fired boilers are replaced by gas boilers.
Expected impact	• Increase at 30% the thermal production by renewable energies. • Increase energy efficiency of current installation. • Evaluate tech-economic feasibility of the proposed solutions. • Evaluate space requirements for the solar panels. • Evaluate the optimized combination of the chosen technologies.
Combination code	ZYRARDOW – S3
Justification	This combination integrates biomass boilers, geothermal heat pump system (coupled with PV system) and CHP.
Expected impact	• Increase at 90% the thermal production by renewable energies. • Evaluate tech-economic feasibility of the proposed solutions. • Maximise geothermal heat pump system for DHW in summer. • Evaluate the operation strategy modes.

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CONCLUSION

There are no renewable energy systems in Zyrardow District Heating. The property is thinking about retrofitting the power plant using biomass and gas, and removing the coal fired boilers. They are also considering the cogeneration and geothermal systems for the DH.Cooling technologies are not considered since there is no cooling demand.

Solar installations as Fresnel, parabolic trough collectors and low concentration flat collectors might encounter limitations, for instance low irradiation, lack of space and high costs. Therefore, the property has not considered this kind of renewable sources. However, an energy-economic analysis should be done in order to find the most suitable solution in a hypothetical retrofitting solution.

4.3.2 REFERENCE CASE MODEL AND BOUNDARY CONDITIONS

For the case of the Zyrardow demo follower, a reference case has not been generated, since there is no viable base case similar to what currently exists. This is because the existing system must be changed by external conditions and certain restrictions that are discussed here.
The existing thermal power plant in Zyrardow is composed, as mentioned, of a 9 MW gas-fired power plant and a 60 MW coal-fired power plant. As a first approximation, it would be desirable to increase the installed power of the gas plant, however, this is not possible because the existing distribution network is dimensioned to transport only up to 9 MW of gas. In this way, this is the first restriction to take into account in the design of the plant. Notwithstanding the foregoing, due to public policy issues, thermal power plants with installed power greater than 20 MW must be composed at least of 50% renewable energy by 2025.

In the case of the use of biomass, this fuel is quite expensive and is mainly marketed informally or in poorly regulated markets. It is so expensive that it is more profitable for thermal power plants to continue operating with coal and pay the fees associated with this fuel.
It can be concluded that, in general, there are several restrictions to generate a base case that does not involve the conversion to renewable energies, for this reason, it is decided to generate a direct Wedistrict case and perform an optimization of this design.

Finally, another aspect to consider as a boundary condition is that there is currently a pilot project for the construction of geothermal wells and for the extraction of heat from them. This pilot project could extract approximately 2.3 MW of usable heat for every 10°C of associated thermal jump, considering a flow of about 200 m3/hr that was reported to us. It must be considered that this pilot project is in the pipeline to be developed and has a cost of about 5 million euros, for wells about 2,700 meters deep.

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4.3.2.1 WEDISTRICT TECHNOLOGIES SYSTEM MODEL AND CASE MODEL

The diagram for the proposed design system is shown in Figure 4-70 while Figure 3-100 shows the system TRNSYS model. Regarding the technologies, since the main restriction is related to the possibility of reaching the peak capacity without using the coal boiler, but seasonal (like solar) and continuous medium capacity resources (like natural gas and geothermal) are available and enough from the energetic point of view, the proposal is focussed on using seasonal storage to integrate a multisource system able to deliver 100% of capacity under any circumstances. This kind of system, taking also advantage of the ring architecture of the heating network, will allow a progressive transition to 100% RES system.

The first approach is to build a large underground Pit Storage, powered by medium temperature solar thermal panels and the geothermal system. In parallel, gas-based technologies, boilers and CHP will also be taken into account. Since summer load (DHW) will be largely covered by solar system, natural gas capacity in summer may be lost. To avoid this, all sources are needed the first years, CHP will also be considered, instead of using boilers, at least in summer. Since CHP heat should be stored for winter, one important subject is to decide if CHP (and gas pipeline) may be installed close to the seasonal storage or if another (quite less profitable) seasonal should be build, just for CHP.

To make this concept work, thumb rule numbers lead to the following configuration for baseline case:

- 400.000 m3 seasonal storage
- 1.500 m3 storage
- 40.000 m2 of solar collectors
- 5 MWth geothermal energy
- 8 MWe CHP
- 9 MWth gas boiler

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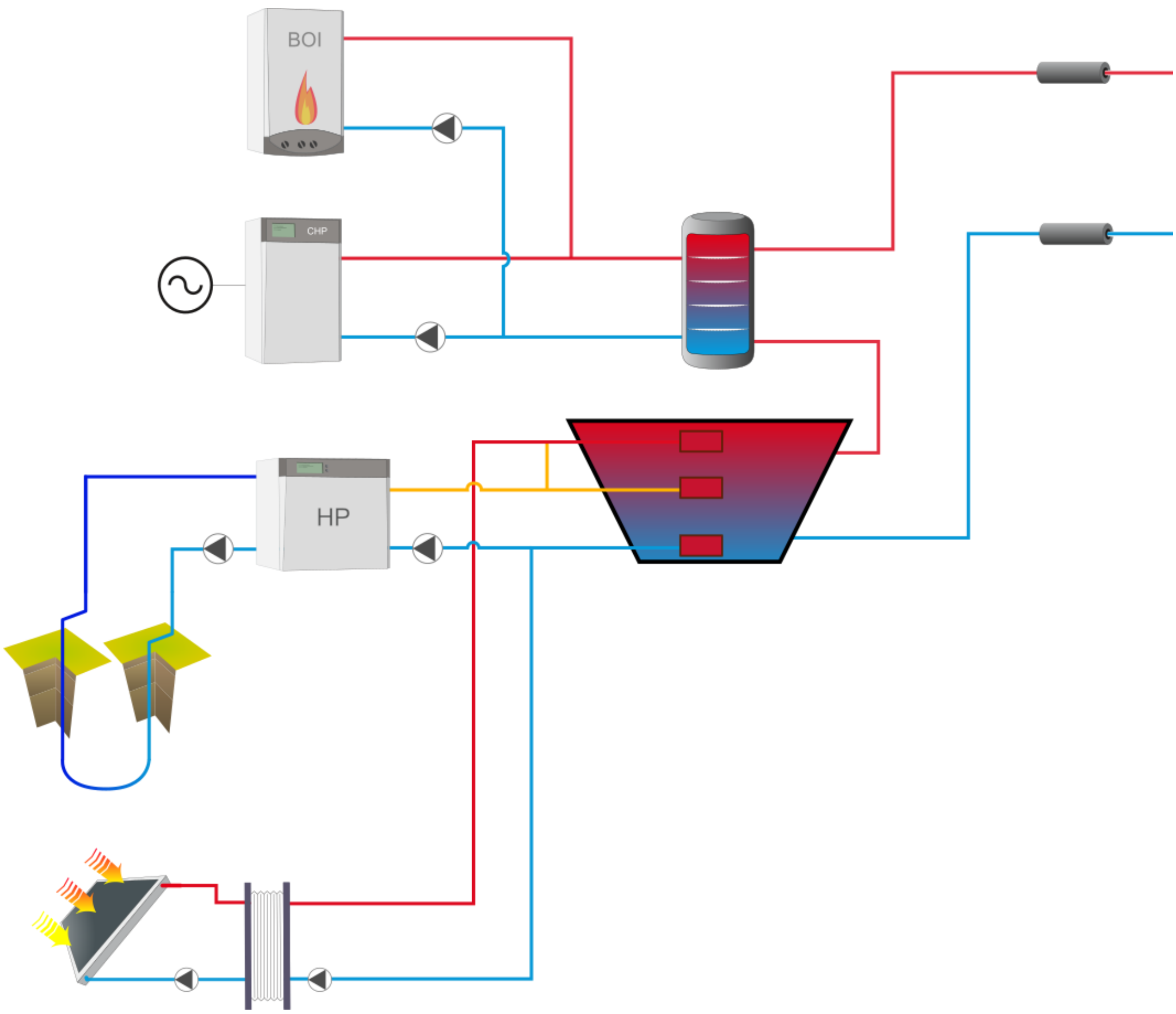

Figure 4-70. Wedistrict technology system for Zyrardow demo-follower

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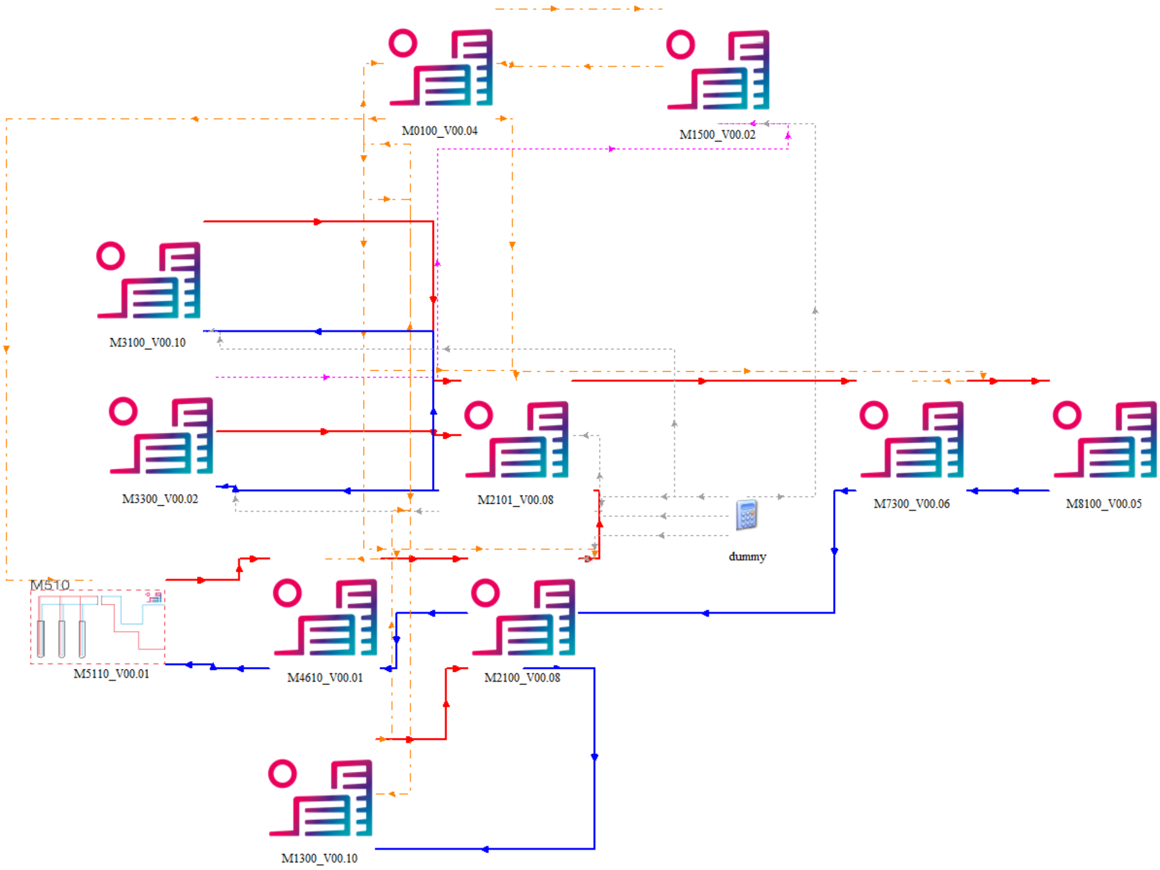

Figure 4-71. Wedistrict TRNSYS model

The macros used in the TRNSYS model are as follows:

- M0100: Weather conditions
- M1300: WESSUN Technology
- M2100: Hot water Storage and PTES water Storage
- M3300: Cogeneration
- M5110: Geothermal vertical HX
- M4610: Heat Pump W/W
- M7300: Heat distribution
- M8100: Heat Load

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TRNSYS MODEL

The parameters used in the TRNSYS model are shown in Table 4-17.

Table 4-17 Summary of design parameters for TRNSYS model

Parameter	Unit	Value
Seasonal Storage Volume	m3	400.000
Storage Volume	m3	1.500
Solar Area	m2	40.000
Geothermal Powe	MWth	5
CHP Power	MWe	8
Gas Boilers Power	MWth	9

4.3.2.2 RESULTS

Based on the simulation in TRNSYS, Table 3-44 following table shows the main results obtained, where can immediately be noted that the energy load cannot be meet. Considering these results, it is imperative to develop a parametric analysis of the system configuration.

Table 4-18 Main results of TRNSYS simulation

Variable	Value	Unit
Total Heat Generation	93.432	MWhth/year
Total Heat Load	123.933	
Compliance Energy Demand	75%	kWhth/year

4.3.3 FEASIBILITY STUDY

Based on the results obtained from the TRNSYS simulation, a parametric analysis was developed. The different simulation scenarios were chosen based on the performance of both the GHP system and the entire generation system. In this sense, we were interested in knowing different configurations of two of the most sensitive parameters in terms of system performance and capacity to meet demand. Different sizes of both the GHP and the solar area of the WESSUN collectors were considered. It is important to mention that prior to this parametric study, an analysis of the results obtained with the base case was carried out, concluding that one of the problems of the case is the excessively large size of the seasonal storage. Basically, the excessive size implies that for several months the heat pump is not able to supply the energy needed to meet the demand and keep the heat in storage unless the pump grows in capacity to inconvenient sizes. Thus, we test setting smaller storage sizes, and decide to parameterize the size of the heat pump and the solar collector area with the objective of meet demand.

For the performance analysis, KPIs such as IRR and LEC were chosen as indicators of feasibility. Simulations of the different scenarios were developed on the reference case using a model parameterization using softwares like JEPlus and TRNEdit and a data mining model.

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Table 4-19 Configurations for scenarios simulations

AAC CAP GEN [kW]	Solar Area [m2]
10000	20000
10000	40000
10000	60000
10000	80000
10000	100000
20000	20000
20000	40000
20000	60000
20000	80000
20000	100000
30000	20000
30000	40000
30000	60000
30000	80000
30000	100000

4.3.3.1 RESULTS

Based on the results obtained from the TRNSYS simulation, the following graphs show the results of the parametric analysis.

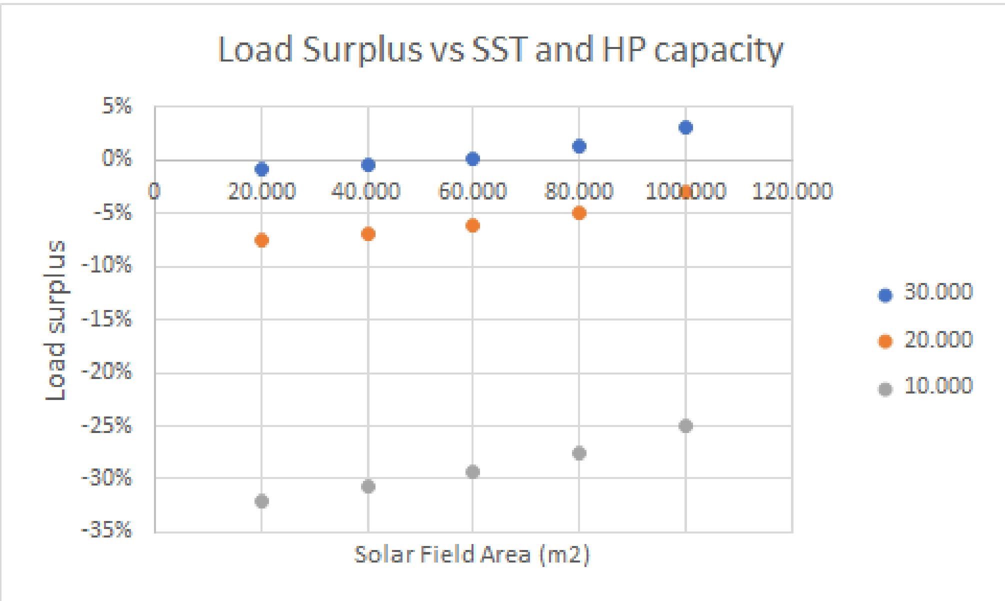

Figure 4-72. Load Surplus vs SST and HP Capacity

It can be observed that the load surplus of the system shows an increase as both the capacity of the heat pump and the solar collector area increase. Logically this is an expected behaviour because with a larger solar collector area the energy produced by the solar system increases

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as this energy can be stored. The heat pump also increases its production as it grows in capacity, contributing to the total increase in production.

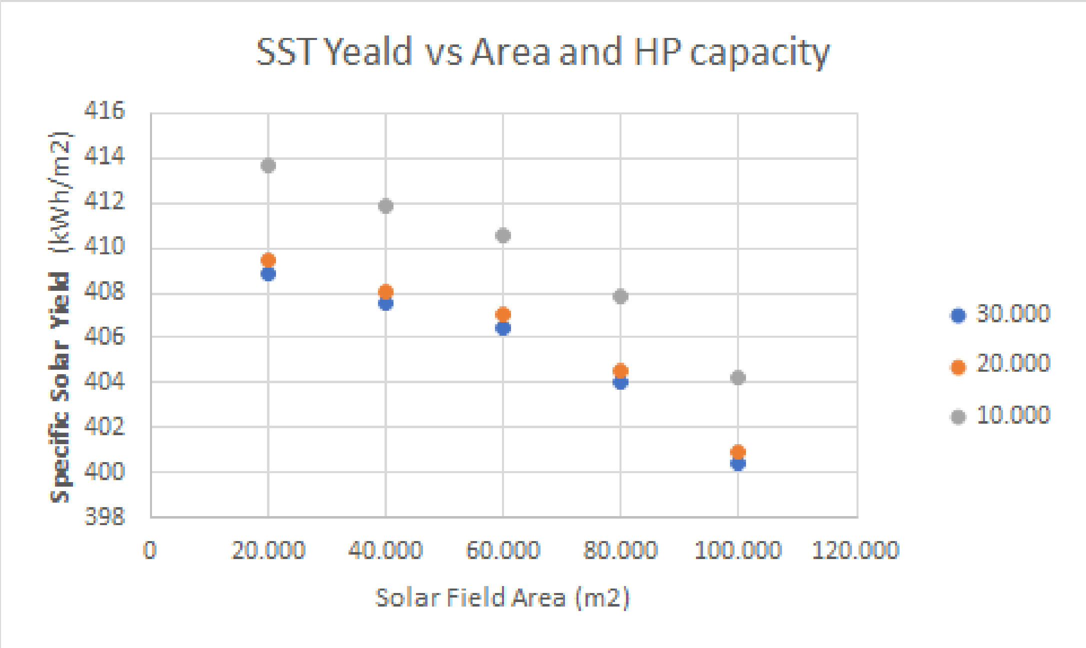

Figure 4-73. Solar yield vs Solar Area and HP Capacity

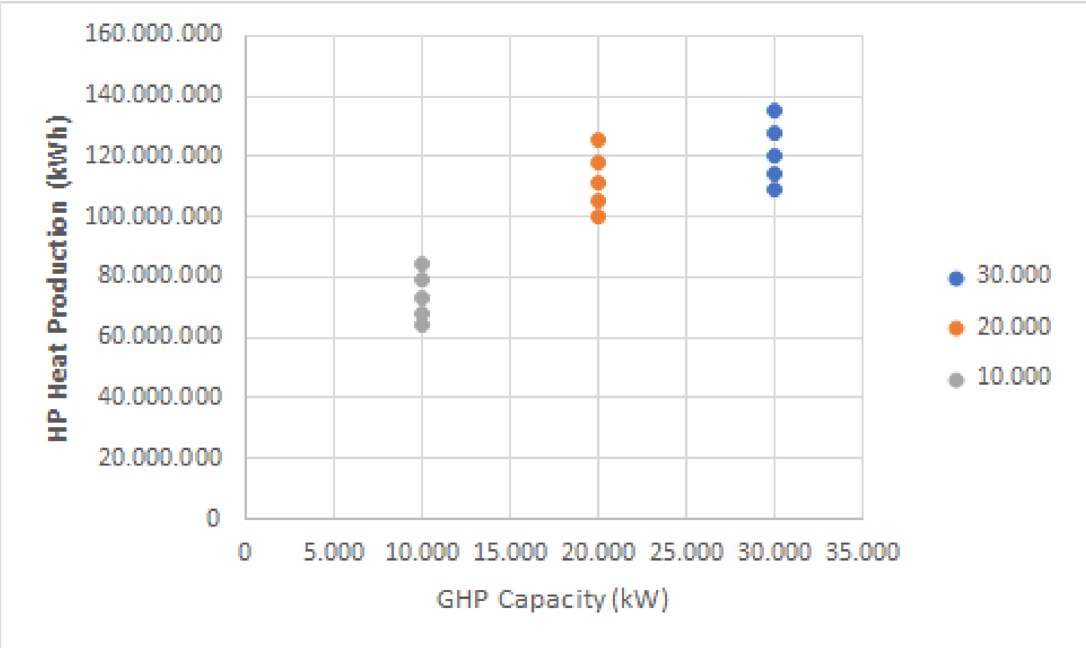

Figure 4-74. Heat pump production vs GHP Capacity

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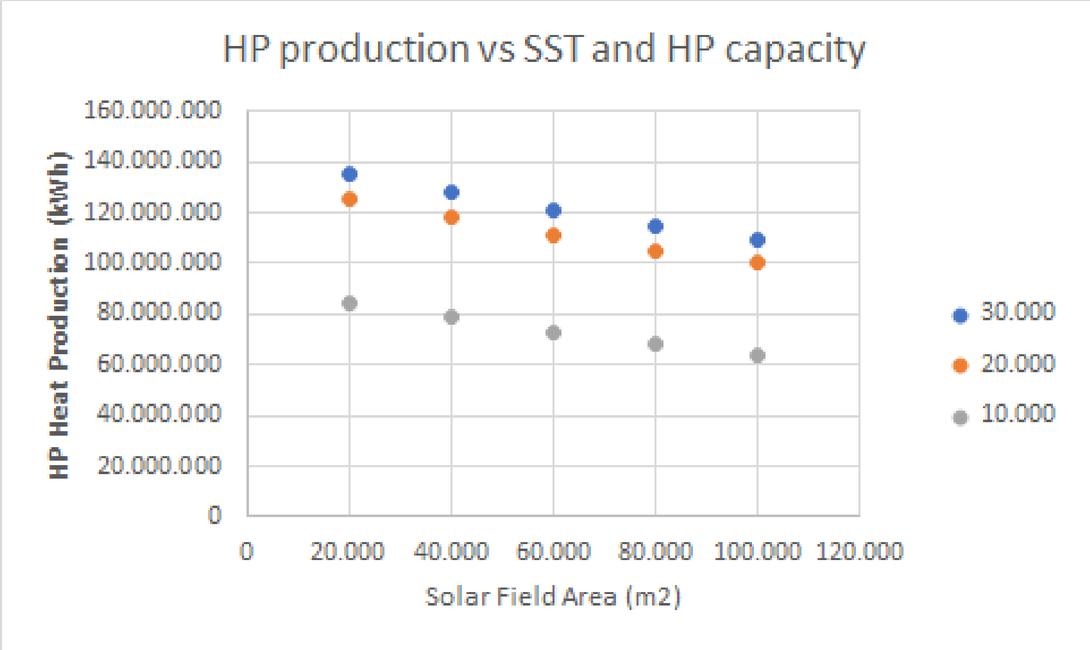

Figure 4-75. Heat Pump production vs Solar Area and HP Capacity

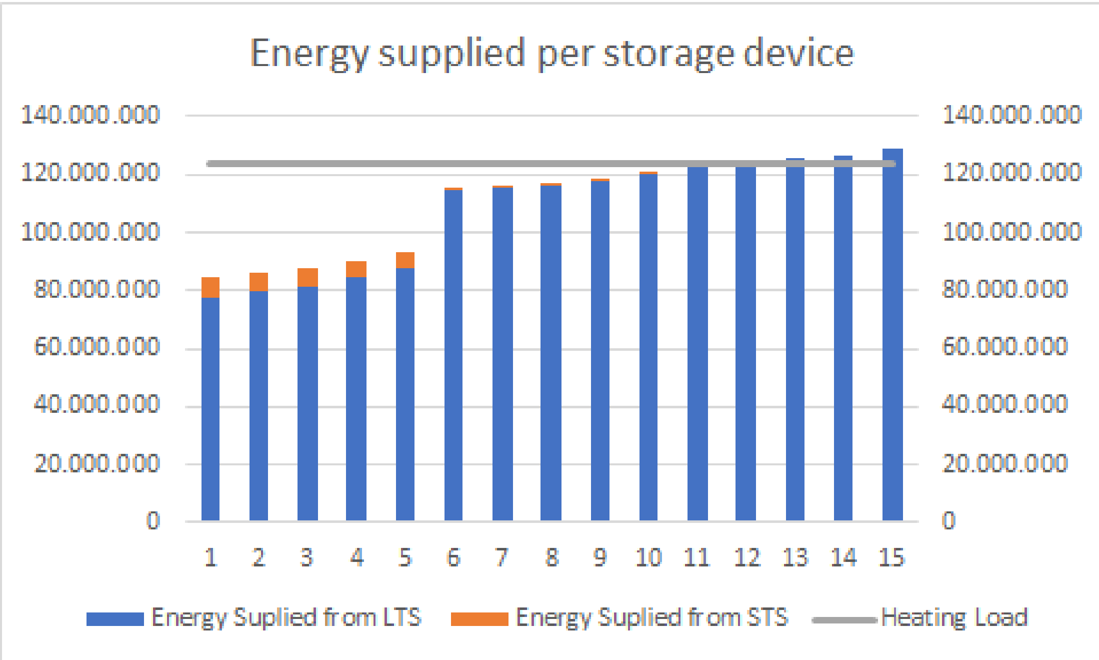

Figure 4-76. Energy Supplied per Storage Device

From the graphs in Figure 4-76 and Figure 4-77 it can be noted that only in a few cases the total energy demand is totally meet or even surpassed. These cases are those in which the GHP has the bigger capacity, with a large solar area too.

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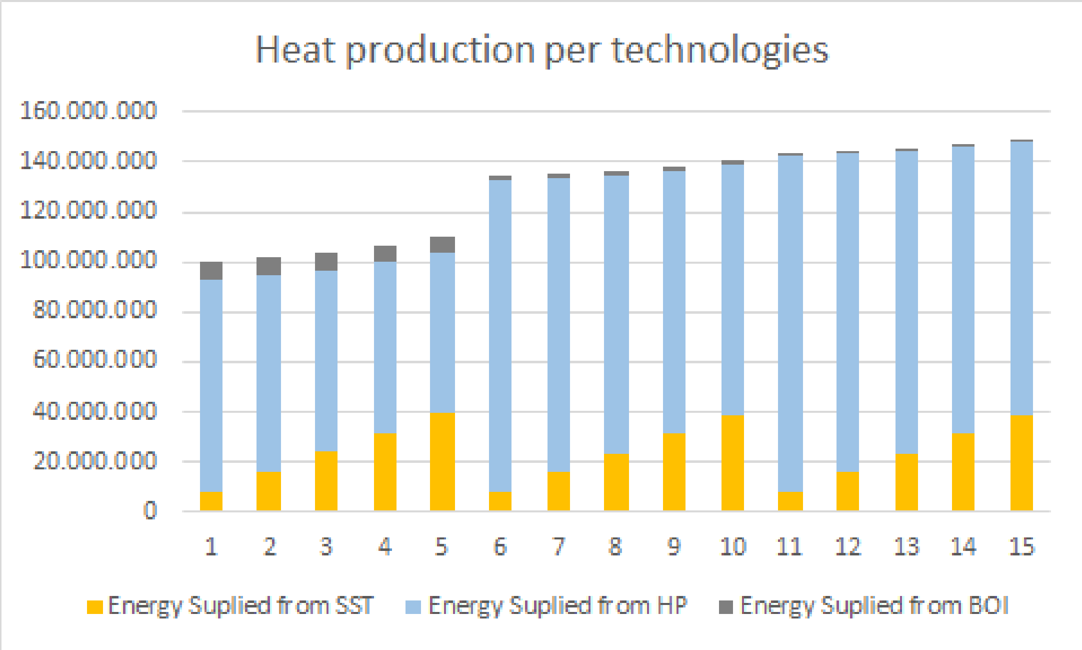

Figure 4-77. Heat production per technology

4.3.3.2 ECONOMIC ANALYZE

The following graphs show the economic analysis of the system. The IRR and LEC have been chosen as indicators of system feasibility.

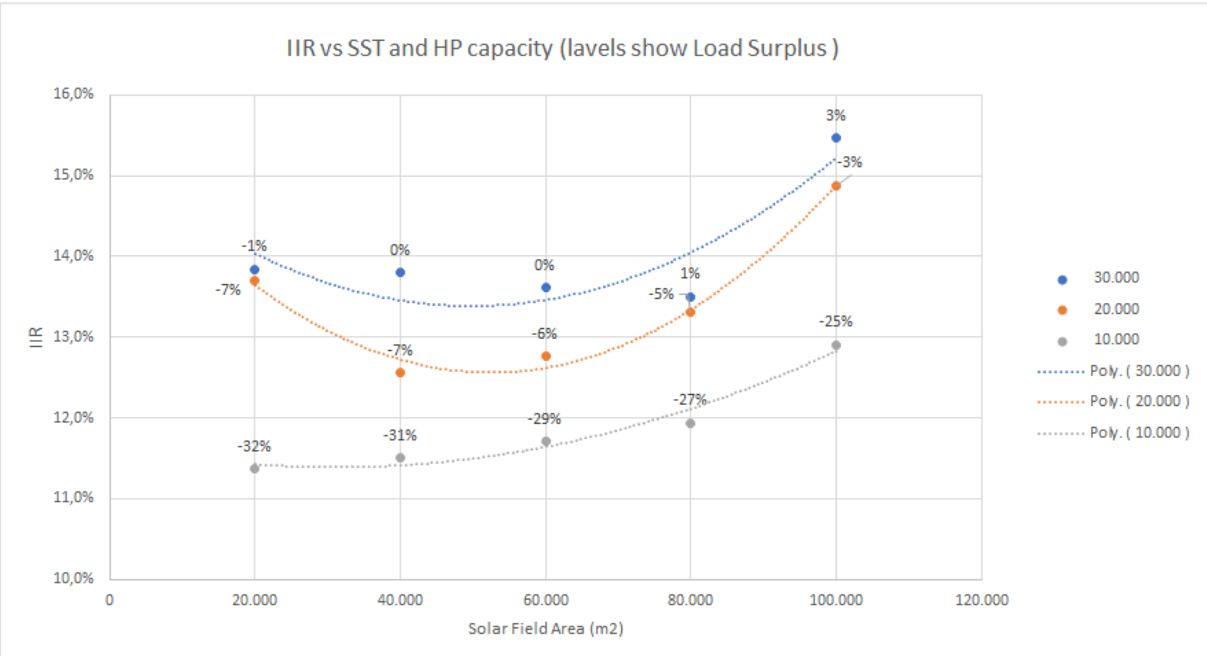

Figure 4-78. IRR vs SST and HP Capacity

From the graphs in Figure 4-78 and Figure 4-79 can be observed that exists one case in which the maximum IRR is reached with a positive load surplus. This case corresponds to the one that has a higher GHP capacity with a larger solar area too. It is observed that the LEC behaves in a similar way, in fact, the exact same case reaches a low LEC while maintaining a positive load surplus.

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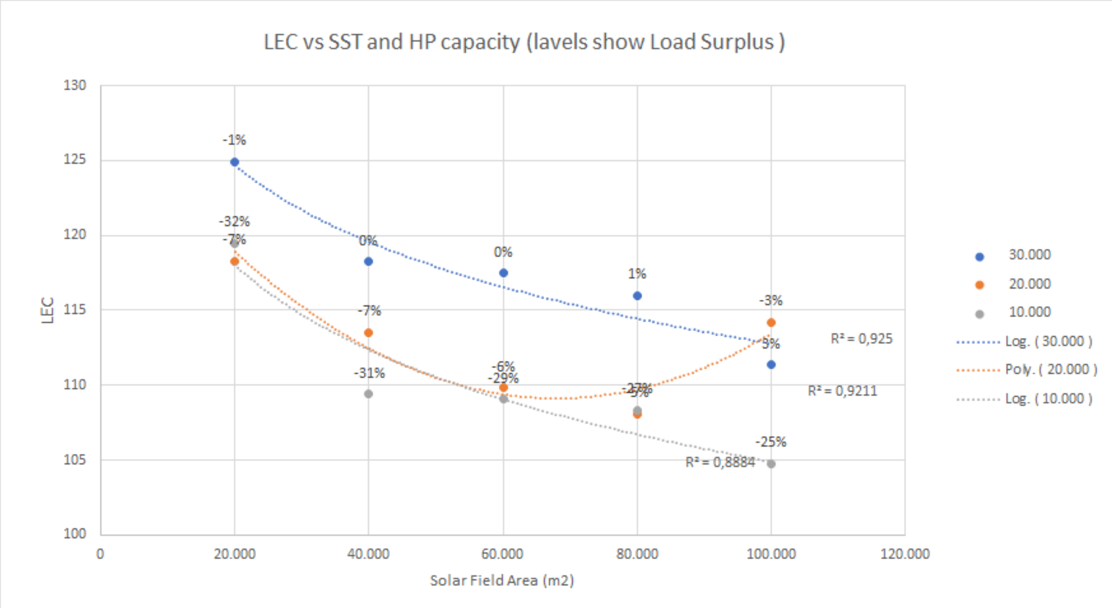

Figure 4-79. LEC vs SST and HP capacity

4.3.4 CONCLUSIONS

The results obtained from the parametric analysis allow us to choose a case of technological configuration that may be of interest. The case chosen allows to conclude that the DHC system is economically feasible with almost total compliance with energy demand.

The proposal is to develop a 30 MW geothermal heat pump system with a 15,5% IRR, based on a 4th generation DHC network, with the parameters and results shown before. The graphs in Figure 4-80 and Figure 4-81 show the monthly behavior of the system in terms of energy balance, highlighting the dominant technology and storage device in each season.

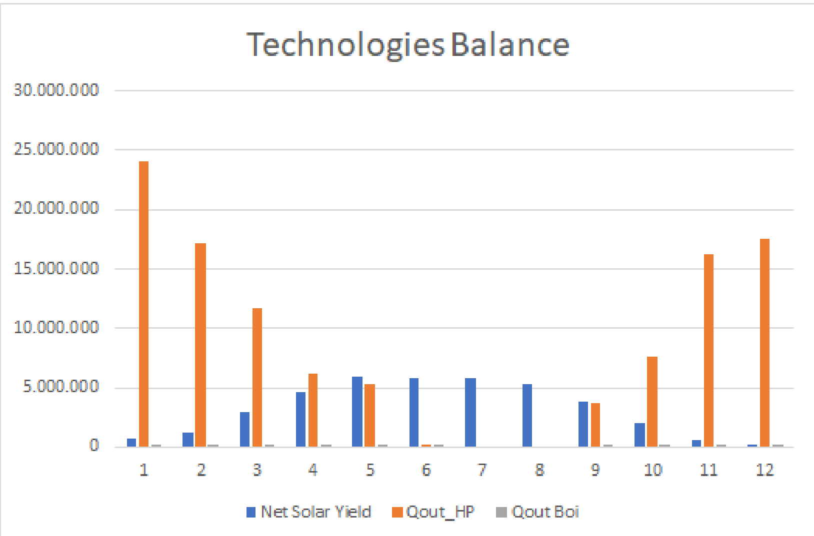

Figure 4-80. Technologies Balance

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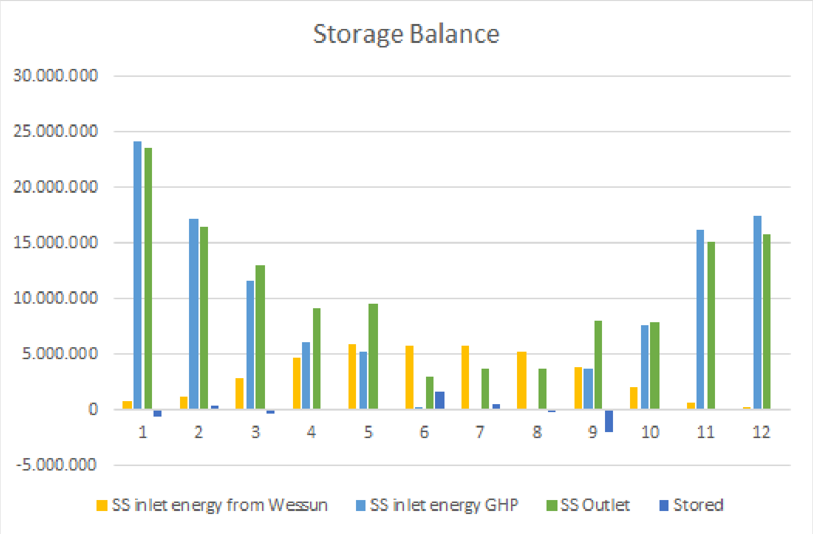

Figure 4-81. Storage Balance

Table 4-20 Parameters of Selected Case

Parameter	Unit	Value
HP Capacity	*kW*	30.000
Wessun Area	*m2*	10.000
Total heat Supplied	*MWha*	127.772
Net Solar Yield	*MWha*	38.886
Total HP Production	*MWha*	109.421
Total Boiler Production	*MWha*	209

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4.4 Valladolid (Valladolid – Spain)

4.4.1 GENERAL DESCRIPTION

Valladolid demo-follower consists of an existing District Heating biomass-based (100% renewable energy). It was built in 2016 and operates since 2018. It is managed by SOMACYL, a public entity of Castile and Leon.

The demo-follower is located in the urban area of Valladolid, administrative capital of autonomous region of Castile and Leon at 250 km northwest of Madrid. Valladolid has a total population of 299,300 approx. (in 2020) making it north-western Spain's biggest city. The city lies along the Pisuerga River, the demo-follower and the connected buildings are located near that river.

Figure 4-82. Location, layout and current view of Valladolid Central Station (biomass-based)

Valladolid DH installations are composed of two biomass boilers of 3.48 MW each, having a peak power capacity of 6.96 MW. The district heating provides only heating to the connected buildings. DHW and cooling are not covered by Valladolid district heating network.

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The District Heating network is being developed in 5 phases. Currently, it is at phase 3 serving eight buildings: two public buildings used as offices for public administrations, two high educational buildings and four housing communities.

The current layout has been considered as the Base Case for the present study and it will be used as a basis for comparison of results between future scenarios.

The Extension case adds the Phase 4, which considers three additional buildings and the corresponding extension of the network, as it is shown in the Table 4-21.

Table 4-21 Connected buildings – Base case & Extension case.

	No.	Building	Type of building
Base Case (Phase 1, 2, 3)	1	Arquitectura 1	High educational building
	2	Arquitectura 2	High educational building
	3	Consejería Economía y Hacienda	Public building - offices
	4	Consejería Fomento y MA	Public building - offices
	5	CP Avda Salamanca 16	Residential
	6	CP Gloria Fuertes 21	Residential
	7	CP Balago	Residential
	8	CP Joaquin Velasco Martin1	Residential
Extension Case (Phase 4)	9	Residencia	Social building
	10	Colegio	Educational building
	11	CP SAN JOSE ARTESANO	Residential

4.4.2 REFERENCE CASE MODEL AND VALIDATION

A base case model has been developed in order to serve as a reference for the simulation and comparison of other hypothetical scenarios. The KPIs calculated for the base case will be the baseline for assessing the effect of the proposed scenarios, which will allow evaluating the suitability of the proposed solutions per scenario and obtaining relevant conclusions.

The simulation model has been built on TRNSYS 18 software based on the macros and the configuration developed by the Simulation-Working Group of WEDISTRICT Project. The model includes the following elements:

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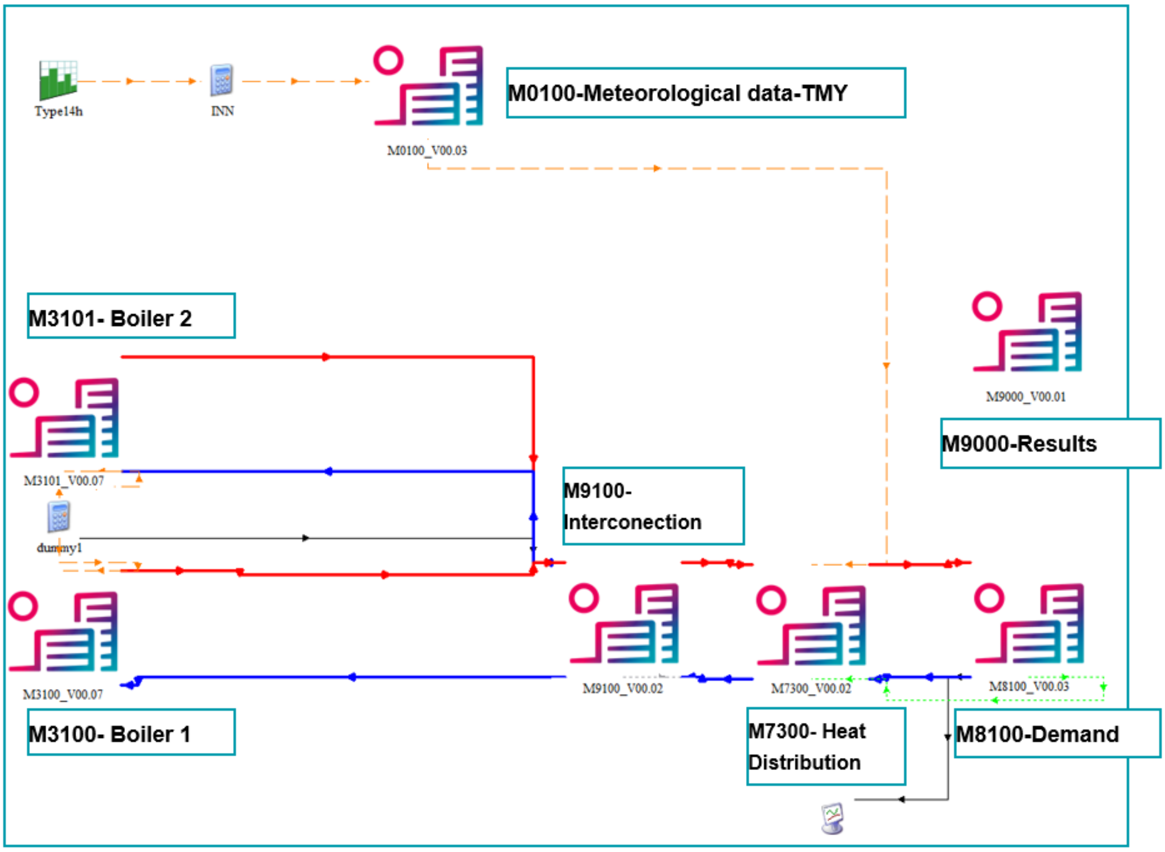

Figure 4-83. Simulation model of Valladolid Base Case on TRNSYS environment.

The operation of the simulation model is the following:

- The biomass boilers (macros M3100 and M3101) generate heat in accordance with the demand (macro M8100), temperature set-points of the facility and the meteorological conditions (macro M0100). Boiler 1 (macro 3100) acts as the main boiler and works in continuous operation to deliver the demanded heat, whereas the Boiler 2 (macro 3101) acts as back-up boiler, and only operates when the heat demand exceeds the nominal capacity of the main boiler.
- The thermal energy generated on the boilers is transferred to the heated water network (M7300), which distributes the heat to the connected buildings (Demand – M8100). This operation is regulated by the interconnection macro M9100.
- Macro M9000 shows all the results of the model and provides the values of the defined KPIs.

For this first workshop, only the Base case and the Extension case have been created.

As mentioned above, the Base case includes eight buildings of different size and typology, and a total network length of 2.100 meters. The Extension case considers eleven buildings and a total length of 2.400 meters (300-meter extension). No additional heating and/or cooling technologies have been considered for the extension case in this first workshop.

The Valladolid DH managers have provided the following data to feed the Trnsys model:

- Nominal power of each boiler: 3.48 MW
- Temperature supply: 95 ºC
- Temperature return: 75ºC
- Heat Demand consumption of connected buildings for 2019, 2020 and 2021, which has been used to estimate the consumption energy profile per month, as shown below:

Consumption													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
MWh Base	940.8	561.8	580.7	374.7	161.9	0.0	0.0	4.5	10.5	151.4	480.2	474.3	**3,740.7**
MWh Extension	2,348.0	1,402.1	1,449.1	935.0	403.9	0.0	0.0	11.2	26.2	377.9	1,198.4	1,183.7	**9,335.7**

Other data used for the study:

- Biomass cost: 34 EUR/MWh
- Heating selling price: 55 EUR/MWh
- Heating value of biomass: 3.8 kWh/kg

4.4.2.1 FIRST RESULTS

Based on the model in TRNSYS and the basic data of the demo site, a preliminary set of results has been obtained. First, the base case has been tested with the objective of evaluating the reliability of the model compared with the real situation. Once the model has been calibrated, the extension case has been built.

Technical assessment

The technical assessment is based on the values of the previously defined KPIs.

KPIs used for the evaluation of the results are:

- **Heat energy distributed in the network (MWh/year)**
- **Renewable Energy Ratio (RER)**
- **Emissions of CO_2 (kg/MWh total year)**

Results obtained were the following:

	KPI	Value Base case	Value Extension case	Unit
Energy	Q dist_heating	4030.0	9537.9	MWh/year
	RER heating*	90%	90%	% average year
Emissions	kCO_2 heating	49	43	kg/MWh total year

*Note that the RER includes both, the fuel to generate the heat in the boilers, in this case, biomass; and the electricity grid to power the equipment (boilers and pumps mainly).

These are the annual average results for each KPI. The extension case is considered more efficient as the plant generates more than twice as much energy as the base case, while optimising primary energy renewable sources and reducing CO2 emissions.

The following graphs show the results over the whole year duration and compare the base case and extension case for each one of the KPIs defined above.

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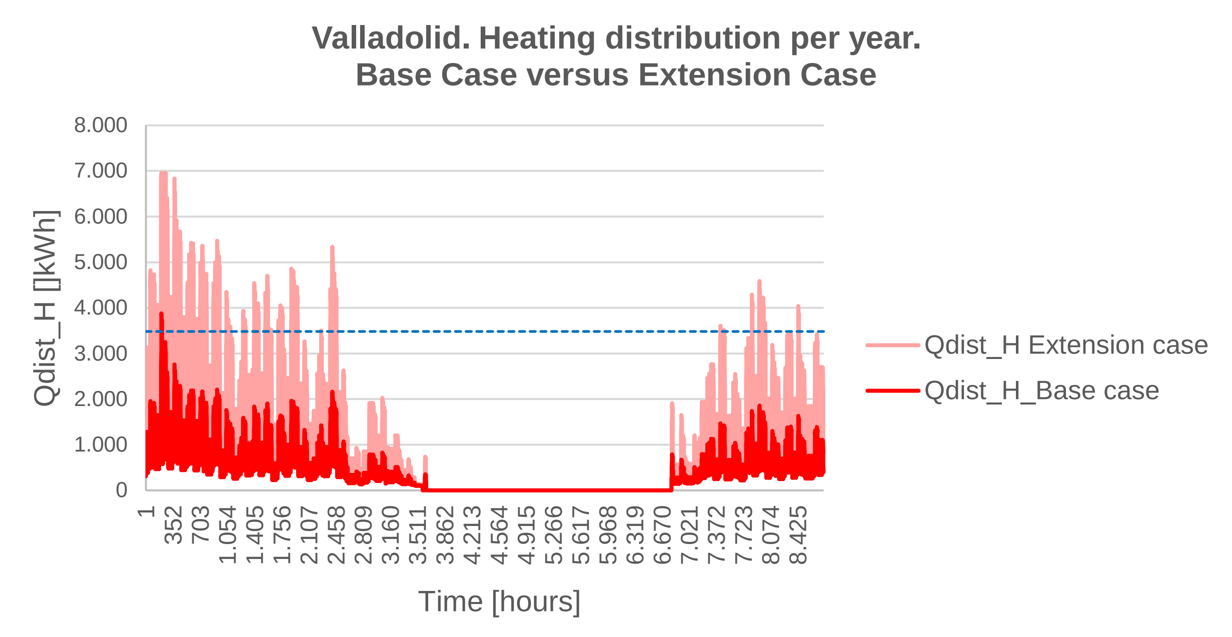

Figure 4-84. Heating distribution per year. Base case vs Extension case

Figure 4-84 shows the heating energy distributed in the network, from the DH plant to the buildings. The dotted blue line indicates the maximum power capacity of the main biomass boiler (3.48 MW) and then marks the point when the second boiler starts working.

As can be seen in the graph, the plant is continuously working at variable capacity almost all the year, apart from the months from June to September when the DH plant is not operative at all, as there is no heating demand.

In the Base case, the Qdist is very low in comparison with the installed heating capacity of the plant (6.96 MW), and therefore, only the main boiler is operative during almost the whole heating season, with the exception of the first weeks of January when the maximum capacity of the main boiler is exceeded. The main boiler is working most of the time to respond to a heating demand of 2 MWh, well below its nominal capacity, which is not very efficient. This situation is accentuated in May and October, when the Qdist lies below one MWh.

In the Extension case, nonetheless, the main boiler is working at nominal capacity during the coldest months of the year (January and February) and changing from nominal to partial loads during March, April, November and December. The back-up boiler is also activated in a continuous way during the coldest months (January and mid-February) reaching nominal capacity some days of January, and in an intermittent way the rest of the year except for May and October, when no back-up is needed. Again, the months of May and October are the least efficient and only the main boiler is operating at low capacity.

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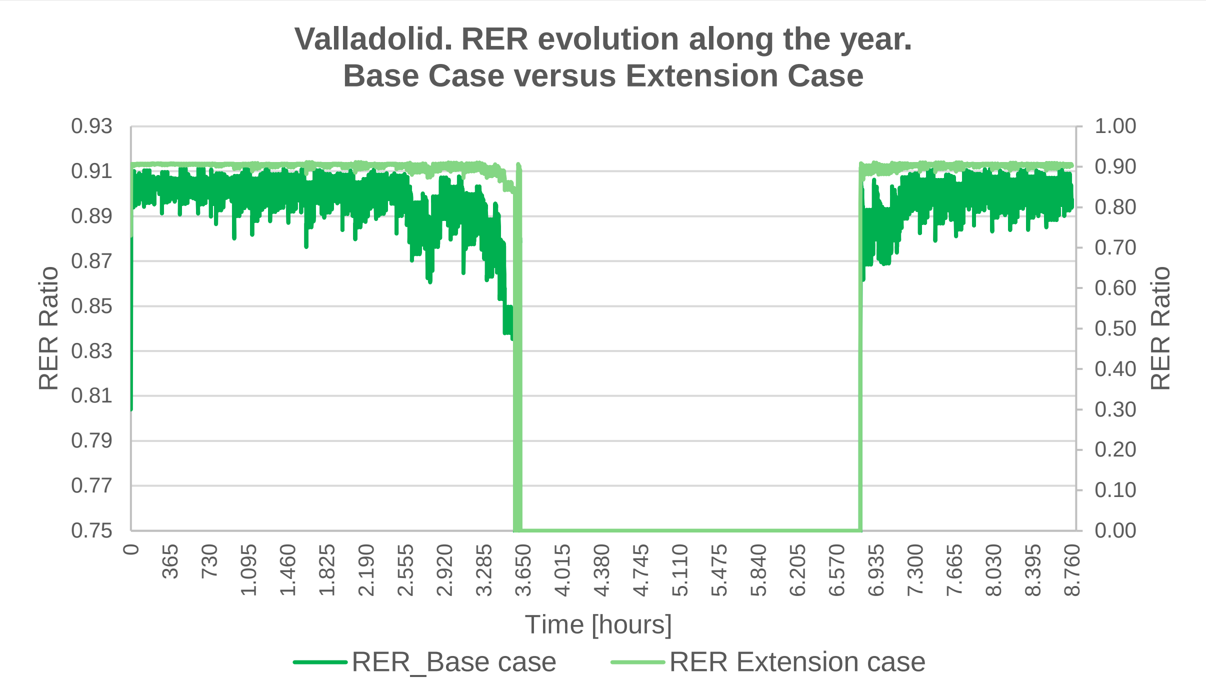

Figure 4-85. RER. Base case vs Extension case

The RER parameter refers to the ratio of renewable energy source used for generating heating. Although it is a plant based on biomass boilers, there is a percentage of non-renewable energy source coming from the electricity consumed to operate the plant.

In both cases, the average RER is 90%, but Figure 4-85 shows that Extension case is more efficient as the plant is working nearer its nominal capacity. Likewise, it can be seen that in the months of May and October, when demand is lower, the RER drops, so does the performance of the DH plant. This is especially remarkable in the Base case. This means that the thermal plant is using electricity (with a percentage of non-renewable energy) almost at the same level when the plant is working at full or partial capacities, and therefore the closer the nominal capacity (6.98 MW) the more efficient the performance and RER of the plant.

In addition, it has also been analysed the Heating density for the extension. This parameter refers to the amount of energy (Qdist) per unit of installed network (in meters). It could be a useful parameter to evaluate options for extending the network.

	Value Base case	Value Extension case	Only new branches (+3 buildings)	Unit
Heating density	0.96	1.99	9.18	MWh/m

The higher the heating density the more profitable and efficient is the network, as the investment for one meter of network results in the distribution of higher amount of energy. In this case, the heating energy of the extension is particularly high as the extension entailed the construction of only three secondary branches with a total length of 300 meters, to distribute more than double heating energy (from 4030 MWh/year in the base case to 9538 MWh/year in the extension case).

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Financial assessment

A financial estimation of the connection to the new buildings considered in the extension case has also been performed, considering the CAPEX and OPEX required for extending the network.

The investment costs (CAPEX) for the extension consider: (i) cost of extending the network (construction of new branches) and (ii) cost of the substation located at each new building. Unit costs vary for each building based on the diameter of the pipeline and the thermal capacity of the substation. The construction investment costs considered for this study are:

	CP San Jose Artesano	Residencia	Colegio
Extension length (m)	160	30	110
Unit cost network (EUR/m)	300	150	240
Cost extended network (EUR)	48,000	4,500	26,400
Cost Substation (EUR)	40,000	18,000	32,000
Total investment cost (EUR)	88,000	22,500	58,400
CAPEX (EUR)	**168,900**		

The exploitation costs (OPEX) due to the extended network are estimated based on the increase of distributed heating-Qdis (from 4030 MWh/year in the base case to 9538 MWh/year in the extension case) and the heat energy price of biomass.

Exploitation cost Extension	Increase Qdis	5,507.89	MWh
	Heat energy price_Biomass	34.00	EUR/MWh
	OPEX _Biomass	**187,268.52**	**EUR/year**

The heating selling price is set on 55 EUR/MWh and so the annual profit of the extension would result in 115,665.9 EUR/year. As a result, the payback (without considering inflation) is 1.5 years, which is considered acceptable and a profitable investment.

Exploitation finances	Heating selling price	55.00	EUR/MWh
	Total sales	302,934.4	EUR/year
	Profit	**115,665.9**	**EUR/year**
	Payback (without inflation)	**1.5**	**year**

In conclusion, this preliminary study demonstrates that the DH plant is currently operating below its nominal capacity and consequently efficiency could be greatly improved (the closer the plant gets to its nominal capacity, the higher its energy efficiency). The addition of further buildings (new customers) as well as the implementation of other technologies and solutions have the potential to improve its energy performance, resulting in a more efficient, more sustainable and more cost-effective district heating.

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4.4.3 FEASIBILITY STUDY

4.4.3.1 SCENARIOS SELECTED

From this reference case simulation, other scenarios simulations are developed and analysed to improve energy efficiency, to reduce CO2 emissions or to lower costs.

The tables below summarise the technical solutions that could be assessed by WEDISTRICT simulations:

Table 4-22 Summary of technologies for Valladolid demo-follower.

Technologies proposed	By means of
Economizer/ flue gas heat recovery system	Increase efficiency of existing biomass boilers by recovering the heat (partially or totally) in the flue gas released to the atmosphere
Solar technologies	Integration of solar thermal panels in a nearby land to cover heating load or cooling load of new customers. This technology is still to be accepted due to the lack of space in the closer area to Valladolid thermal plant or it may be considered only to reproduce the results in other DHC managed by SOMACYL.
PV panels	Integrate PV panels in the roof to cover electricity needs of the thermal plant (or even sell electricity to the central grid).
Hot water storage	Optimized water storage sized for acting as buffer for added new renewable technologies (new solar or biomass). There is no space for this technology in Valladolid, so it may be simulated to understand the effects of storage, to extrapolate results to other DHC managed by SOMACYL.
Absorption chiller	Add WEDISTRICT absorption chiller to the current/extended thermal plant to allow cooling in summer (now there is only district heating available). Compare its performance with other type of chiller
Compression chiller	Conventional air/water type of chiller. Reference solution to compare other more efficient cooling solution.
Geothermal wate/water pump	This solution has great efficiency and benefits from geothermal renewable energy. Its bad point is its significant investment.

No more heating solution are studied since the DH ever integrates optimized biomass boilers.

The combination of the different technologies generates three main solutions, which will be studied in the next step (other solutions might arise during the activity):

1. First scenario S1: Biomass boiler for heating with combined absorption and compressions chillers for cooling.
2. Second scenario S2: Geothermal water/water pump for heating and cooling with biomass boiler auxiliary

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Table 4-23 Solutions proposed for Valladolid demo-follower.

Solutions proposed overall description	
Combination code	VALLADOLID – Scenario1
Justification	The first solution proposed consists in the creation of cooling branch, to integrate in the DH. Valladolid climate is very hot in summer and consequently, the use of individual air conditioner systems to reach comfort conditions in buildings is a general practice in summer, especially in public buildings, where offices and other public services are placed. A combination of absorption and compression chillers is studied to assess the performance of such installation.
Expected impact	• Increase generation plant capacity to cover new building development. • Include DHW demand, currently not covered, if necessary • Evaluate cooling costs • Evaluate impact of CO2 emissions from cooling

Combination code	VALLADOLID – Scenario 2
Justification	The second solution is the integration of lower deep geothermal boreholes including heat exchanger, and water/water heat pump generating heating and cooling. Auxiliary biomass boiler is included too. This kind of solution may be a great alternative to cooling chillers. For other part, geothermal heating resource is freer but more expensive.
Expected impact	• Increase generation plant capacity to cover new building development. • Include DHW demand, currently not covered, if necessary • Evaluate cooling costs • Evaluate impact of CO2 emissions from heating

The following tables indicate hypothesis considered for simulation analysis

Table 4-24 Economic data for solutions proposed

Specific capital cost of biomass boiler	250 €/kW
Specific capital cost of natural gas boiler	80 €/kW
Specific capital cost of thermal energy storage	260 €/m^3
Specific capital cost of absorption chiller	400 €/kW
Specific capital costs of A/W compression chiller	196 €/kW
Specific capital costs geothermal vertical HX	65 €/m
Specific capital cost of W/W heat pump	950 €/kW
Natural gas price	60 €/MWh
Electricity price	120 €/MWh
Biomass price	25 €/MWh
Lifetime	25 year
Discount rate	7%
Fixed OM	3 %

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Table 4-25. Primary energy factor and CO2 emission coefficient for solutions proposed

Energy Vector	Primary energy factor Non-renewable	Primary energy factor Renewable	Primary energy factor Total	CO2 emissions coefficient [kg/MWh]
Natural gas	1.17	0	1.17	205
Biomass	0.28	0.8	1.08	39
Electricity	2.62	0	2.62	299

4.4.3.2 SCENARIO 1

The following figure represents the simulation model proposed for scenario S1. The boilers generate heating to provide to heating distribution and to fit the demand. For other part, there are the chillers providing cooling in the cooling distribution.

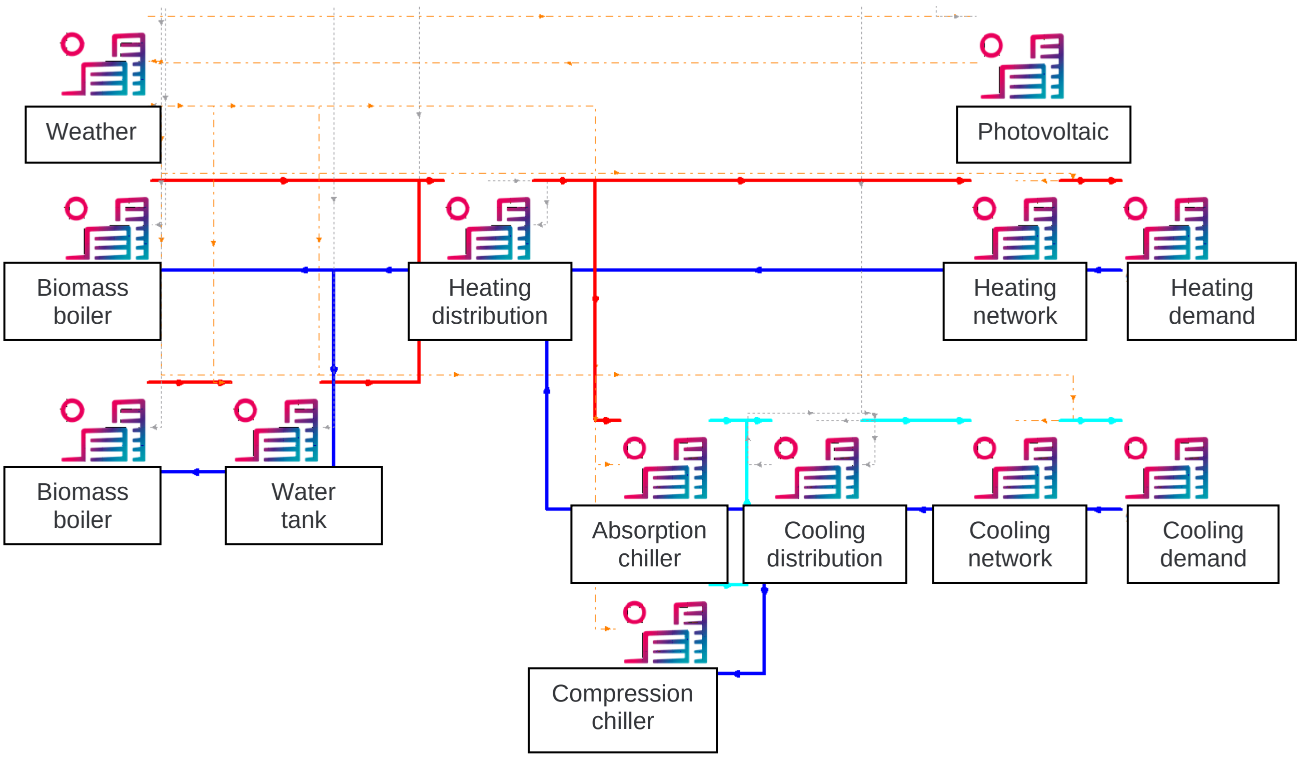

Figure 4-86 - Simulation model for S1 (Valladolid)

The following table introduces the main parameters used in simulations. The total heating capacity is 10 000 kW generated by biomass boilers. The total cooling capacity is 4.500 kW, generated by both absorption and compression chillers. Their capacity is varying in the simulations between 500 and 4 000 kW. Capacity of water tank varies too in the simulations.

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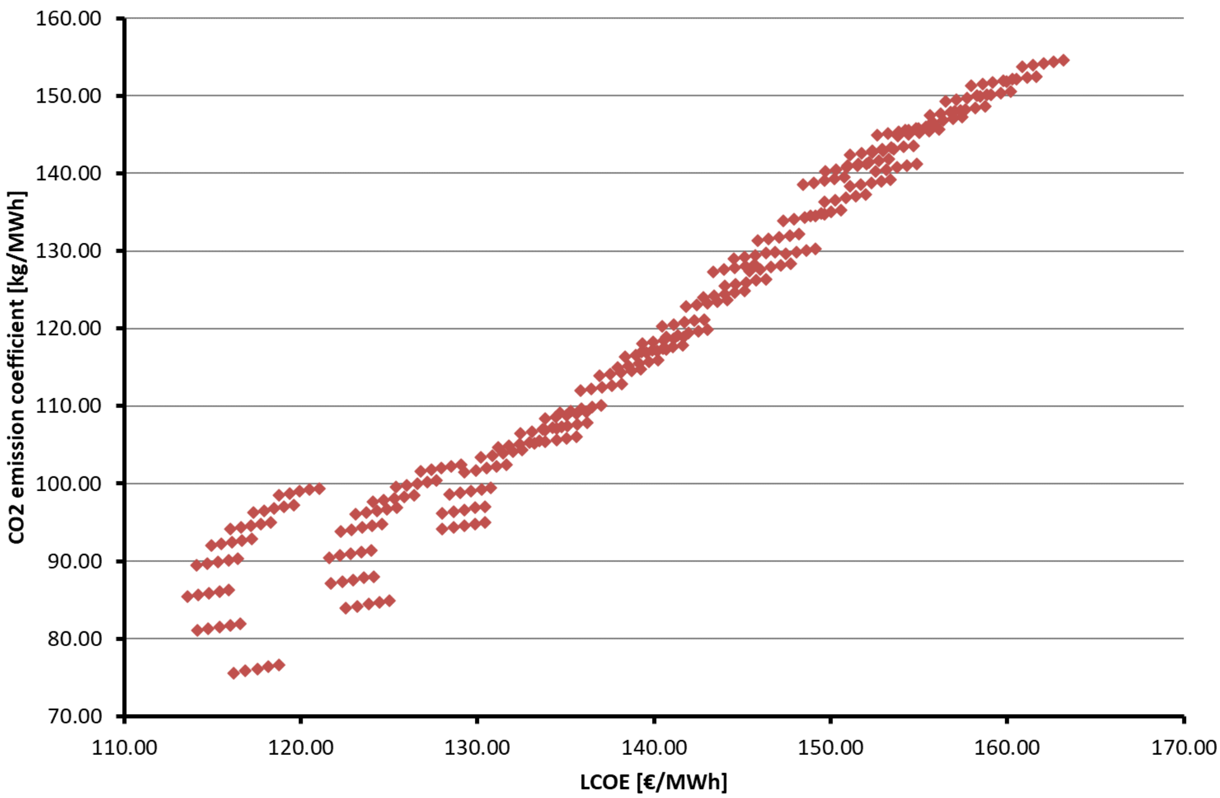
Table 4-26 - Scenario 1, parameters simulation

Water tank capacity [m^3]	Biomass Boilers capacity [kW]	CAC capacity M4200 [kW]	Air Chiller capacity M4310 [kW]
100 - 500	10000	500 – 4000	500 – 4000

Figure 4-87introduces simulations results, comparing CO2 emissions coefficient and LCOE for each design of variable parameter (water tank, absorption chiller and compression chiller capacities).

Figure 4-87 - Simulations results for S1



Each red point represents a simulation result of KPIs. Group of 5 ones represents a couple of chillers capacity for 5 different water tank capacity (100-500 m3). As those 5 points in each group are very close, the water tank capacity has a very low impact on CO2 emission coefficient and a low impact on LCOE.

The groups more at left represent simulations for lowest capacity of absorption chiller and compression chiller, and more at right highest capacity. Capacity chillers higher, more LCOE

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high, which is logical with technology cost. But with this graph, it is not possible to know which type of chiller increase more CO2 emission coefficient.

To understand better the impact of each type of chillers on CO2 emissions coefficient and LCOE, each KPi is analysed separately with a water tank fixed to 300 m3.

Figure 4-88 shows the evolution of CO2 emission coefficient according to the increase of capacity of one type of chiller and fixing capacity of the other one.

Figure 4-89 shows the evolution of LCOE according to the increase of capacity of one type of chiller and fixing capacity of the other one.

Figure 4-88 - CO2 emission coefficient for chillers in S1 (Valladolid)

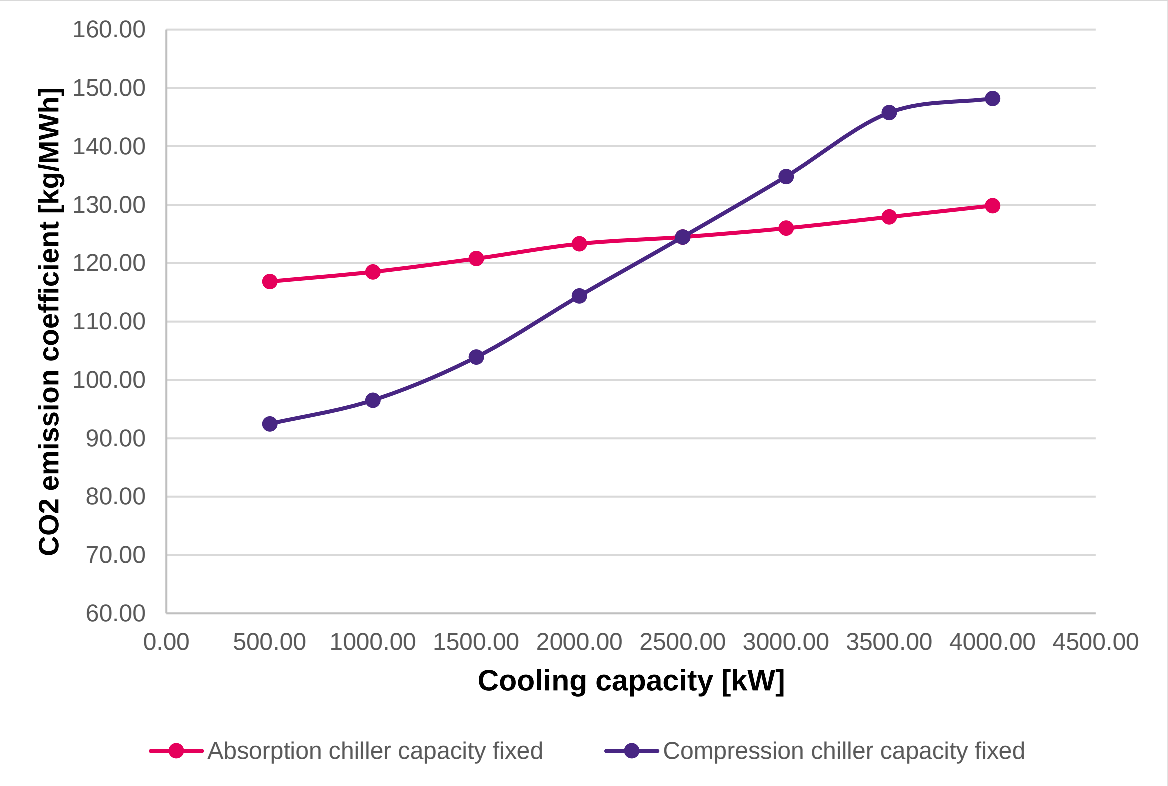

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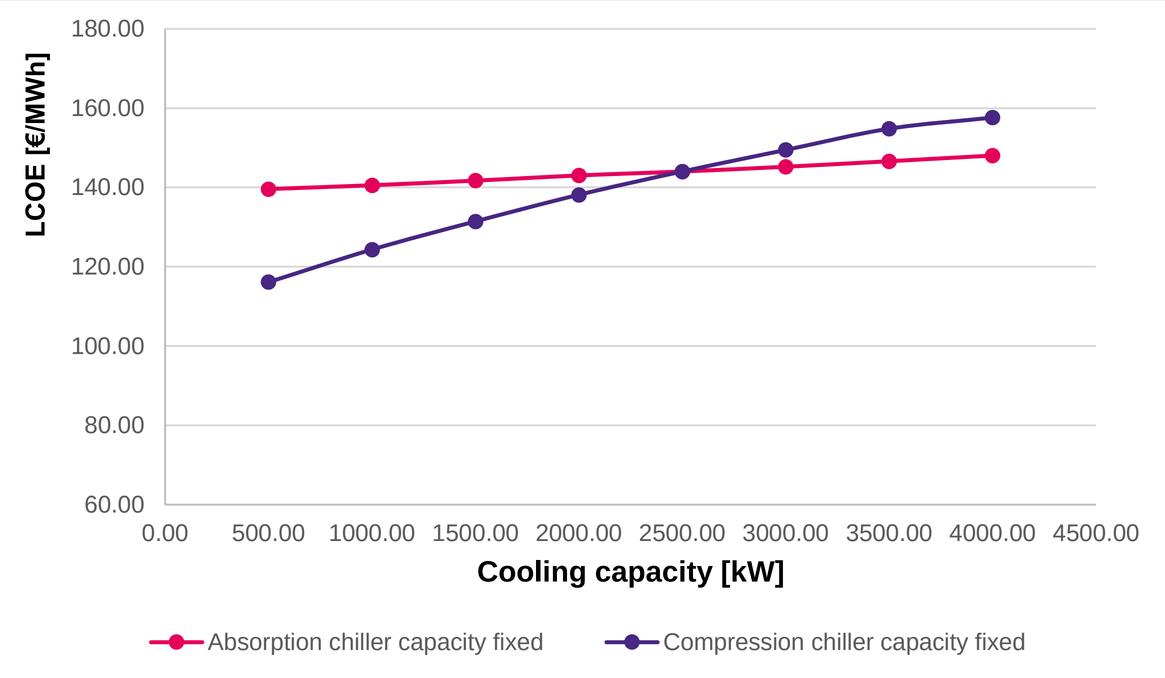
Figure 4-89 - CO2 emission coefficient for chillers in S1 (Valladolid)



For pink curve, the capacity of the absorption chiller is fixed to 2500 kW and the capacity of compression chiller is varying from 500 kW to 400 kW. For purple curve, the capacity of the compression chiller is fixed to 2500 kW and the capacity of absorption chiller is varying from 500 kW to 400 kW.

The curves show that for both KPis the impact is worse when absorption chiller capacity is lower than the fixed capacity of 2500 kW, and worse when compression chiller is higher than the fixed capacity.

So, the trend is to design installation with lower absorption chiller than compression chiller in a combination of the 2 types. An optimized design is:

Table 4-27 - S1 optimized (Valladolid)

Optimized design	Water tank capacity [m3]	Biomass Boilers capacity [kW]	Absorption chiller capacity [kW]	Compression chiller capacity [kW]	CO2 emission [kg/MWh]	LCOE [€/MWh]
S1 - optimized	100	10 000	2 000	2 500	114,14	137,54

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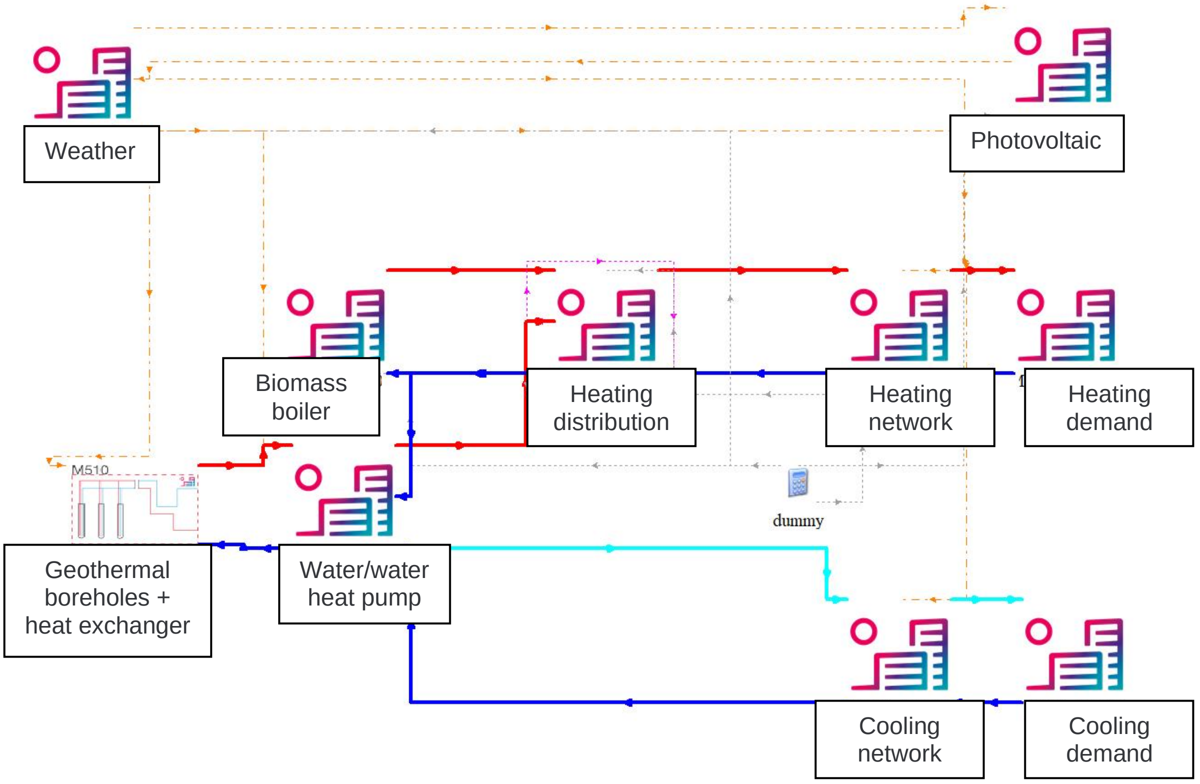
4.4.3.3 SCENARIO 2

The design of this scenario is introduced by the scheme below. The combination of geothermal boreholes and heat pump (water/water type) generates heating and cooling. Auxiliary biomass boiler is also installed. Photovoltaic panels help to cover a part of electrical consumption.

Figure 4-90 - S2 scheme design



The total heating capacity is still 10 000 kW installed. The total cooling capacity is 4.500 kW. The geothermal heating capacity is varying from 1000 kW to 9000 kW by step of 500 kW. The biomass boiler capacity is the difference between the total capacity and the geothermal heating capacity in each case.

Table 4-28 - Scenario 2 parameters (Valladolid)

Biomass Boilers capacity [kW]	W/W Heat Pump heating capacity [kW]	W/W Heat Pump cooling capacity [kW]
500 - 9500	1000 – 9000	4500

Figure 4-92 introduces the graph of the simulation results of CO2 coefficient emission and LCOE.

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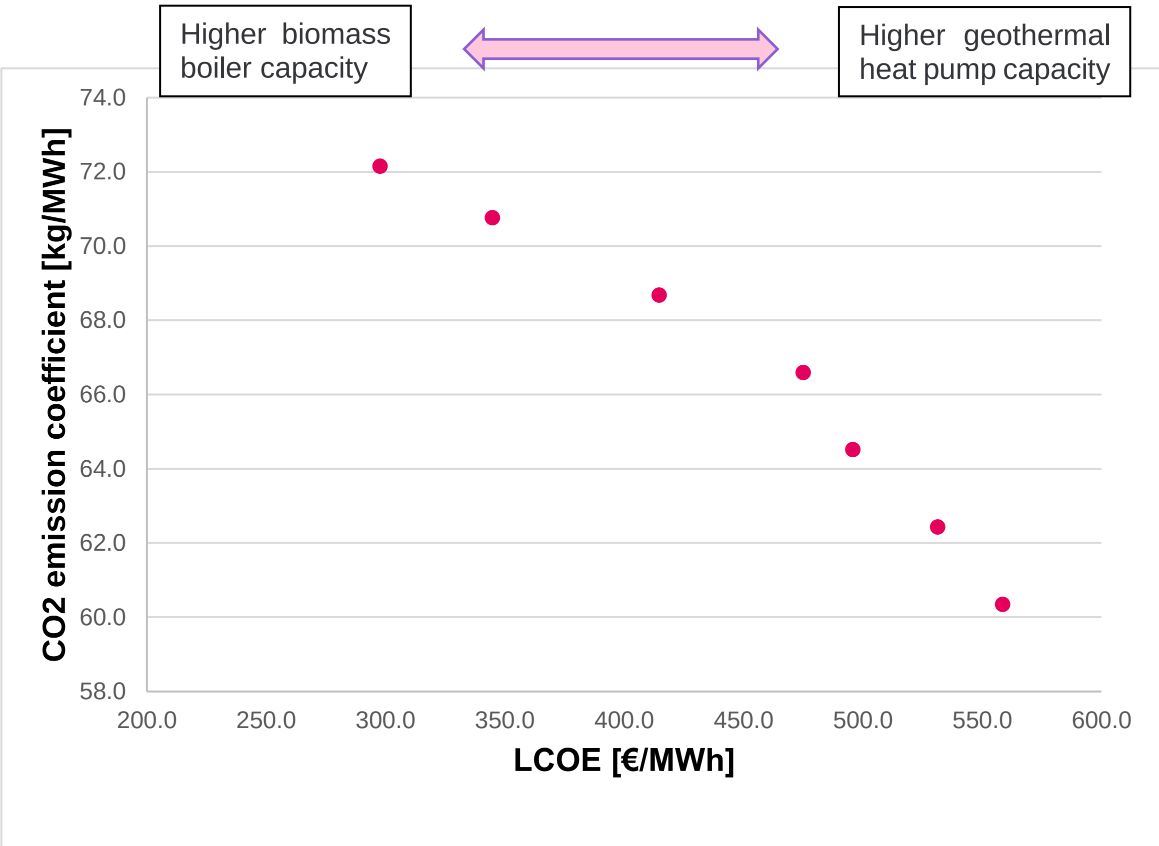
Figure 4-91. CO2 coefficient emission according to LCOE for S2



This graph shows that, when biomass boiler is higher than geothermal capacity, the CO2 coefficient emission is higher but LCOE lower. Otherwise, when geothermal capacity is lower, the CO2 coefficient emission is lower but LCOE higher.

An optimized scenario of this design depends on the ambient and economic objectives. Varying heating capacity has more impact on LCOE (9%) than on CO2 coefficient emission (3%).

In case of the invertor does not want to pay more than 450 €/MWh for LCOE, an optimized design may be:

Table 4-29. Optimized design for S2

Optimized design	Biomass Boilers capacity [kW]	W/W Heat Pump heating capacity [kW]	W/W Heat Pump cooling capacity [kW]	CO2 emission [kg/MWh]	LCOE [€/MWh]
S2 - optimized	7 000	3 000	4 500	68,7	414,7

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4.4.3.4 SCENARIO COMPARISON

Table 4-30. Optimized design for S2

Optimized design	CO2 emission [kg/MWh]	LCOE [€/MWh]
Reference scenario	53,8	95,3
S1 - optimized	114,14	137,54
S2 - optimized	68,7	414,7

The optimised scenarios present higher CO2 coefficient emission and LCOE than the reference scenario because of the extension of cooling added.

CO2 coefficient emission is 112% higher for optimized S1 and 28% higher for optimized S2 in comparison with the reference scenario.

LCOE is 44% higher for optimized S1 and 335% higher for optimized S2 in comparison with the reference scenario.

4.4.4 CONCLUSIONS

According to DHC Valladolid employees, LCOE may be a more important criteria than CO2 coefficient emission. Indeed, both optimized scenarios have better CO2 coefficient emission than common DHC, for which it is higher than 300 kg/MWh. So, the optimized scenario preferred would be optimized S1 to develop, integrating absorption and compression chiller.

4.5 Focsani (Focsani – Romania)

4.2.1 GENERAL DESCRIPTION

Focşani is the capital city of Vrancea County in Romania on the shores of the Milcov River with around 98 000 inhabitants. The Municipality of Focşani is the legal owner of the DH Company ENET SA, which is the operator of the cogeneration and heating plants, the transmission (23.21 trench km), the distribution network (60.93 trench km), and the DHW system (6.093 km trench including recirculation) in Focsani.

The main problem is the high rate of disconnection of flats from the DH network with an average 650 flats per year within the period 2013-2018 but considered a longer period between 2005 and 2018 it was around 850 flats per year. Only 55% of the apartments where a district heating connection would be possible are currently supplied with district heating. Flats not connected to DHC systems have individual gas heating systems, which is the most common practice in the country[39]. There has been seen a cut in district heating facilities and number of

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users in the last past years have. The retrofitting of existing facilities is one of the actions to be taken to improve the competitiveness of district heating services versus individual boilers.

The reason for the low connection rate is the low amount of energy delivered per heating line length of the DH system with approx 1.02 GWh/km trench, which is far below the international DH benchmark of 2 GWh/km trench. This low value is due to the high DH losses of 36.9% (2018).

For that reason, the Focsani municipality has planned and started the modernization and rehabilitation of the heating networks and heating sub-stations. Based on the Master Plan developed in 2009, the municipality has already successfully rehabilitated the DH system including substations and the facilities with the installation of 2 x 6.8 MWe gas engines and a 50 Gcal/h gas boiler.

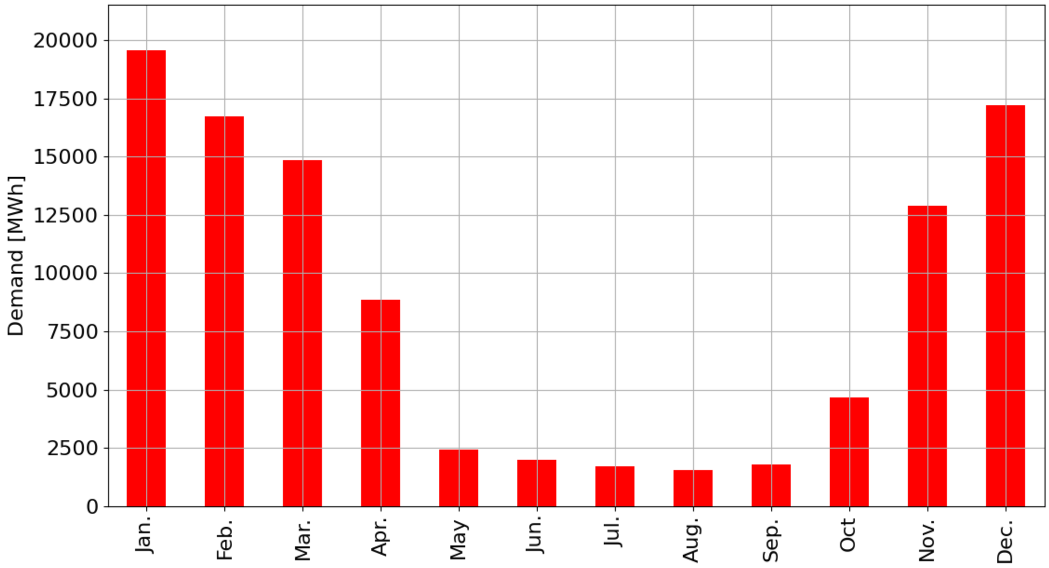

Figure 4-92 Monthly heating demand profile (Focsani demo follower).

The monthly heating demand profile is represented on the Figure 4-92. The annual demand is 104440 MWh/year. Boilers cover 49.5 % of the demand and its fuel consumption represents the 23.9%. Boilers are switched off from May to September. Cogeneration unit covers 50.5 % of the demand and its fuel consumption represents the 76.1%of the total. Cogeneration supplies 7683 MWh of electric power. Figure 4-93 Figure 4-93 shows the annual load duration curve of heating for Focsani. The peak demand is 40125 kW. An installed capacity of 30 MW covers the demand 97% of the time.

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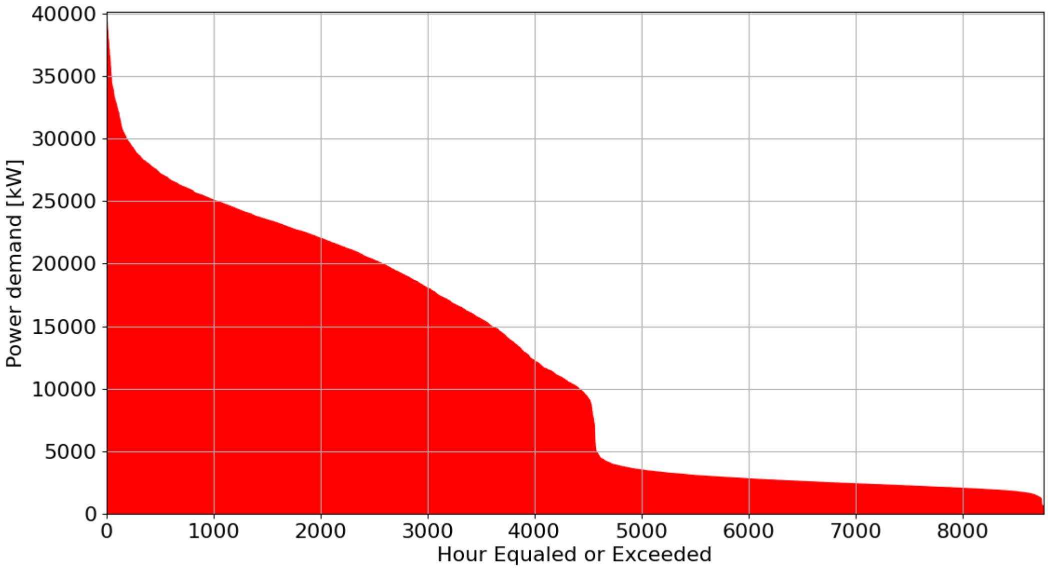

Figure 4-93 Annual demand duration curve of heating (Focsani demo follower).

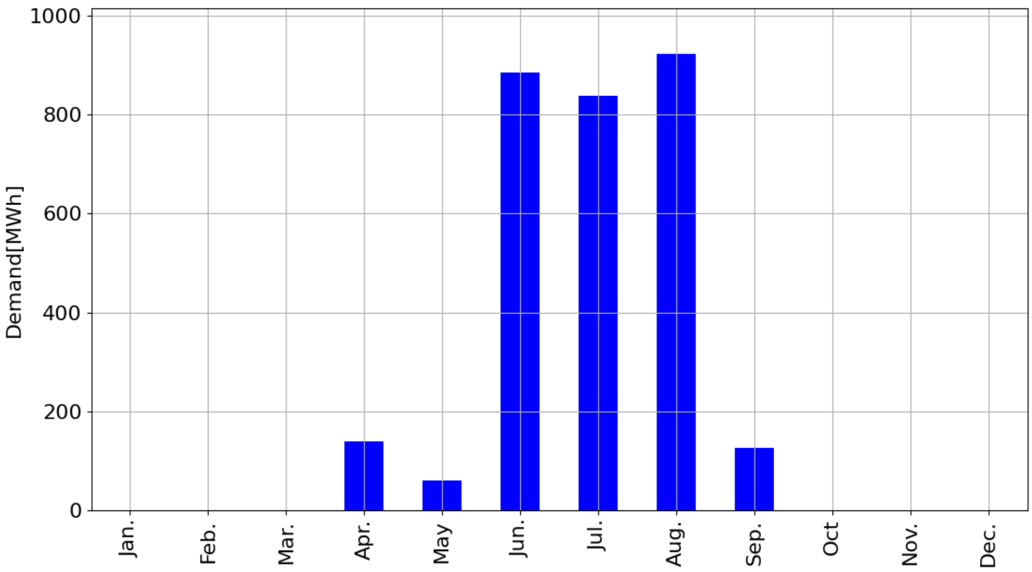

Figure 4-94 Monthly cooling demand profile (Focsani demo follower).

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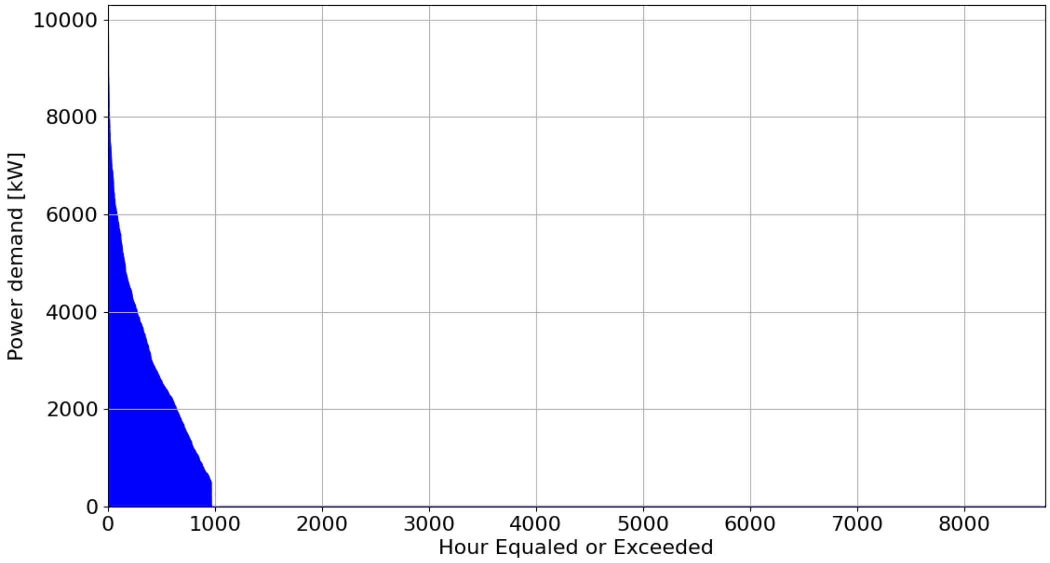

Figure 4-95 Annual demand duration curve of cooling (Focsani demo follower).

The hourly cooling demand (Figure 4-94) has been estimated from the heating demand and weather data. The annual cooling demand is 2973 MWh/year with a peak of 10.3 MW. Rhe cooling demand is less than 9 MW for 97% of operating hours (Figure 4-95).

4.5.1 REFERENCE CASE MODEL AND VALIDATION

Figure 4-96 shows the simulation model for the reference case. This model consists in:

- Two ICE cogeneration with a nominal capacity of 6 MW_e/ 7 MW_{th} each
- A gas boiler with a capacity of 58.15 MW

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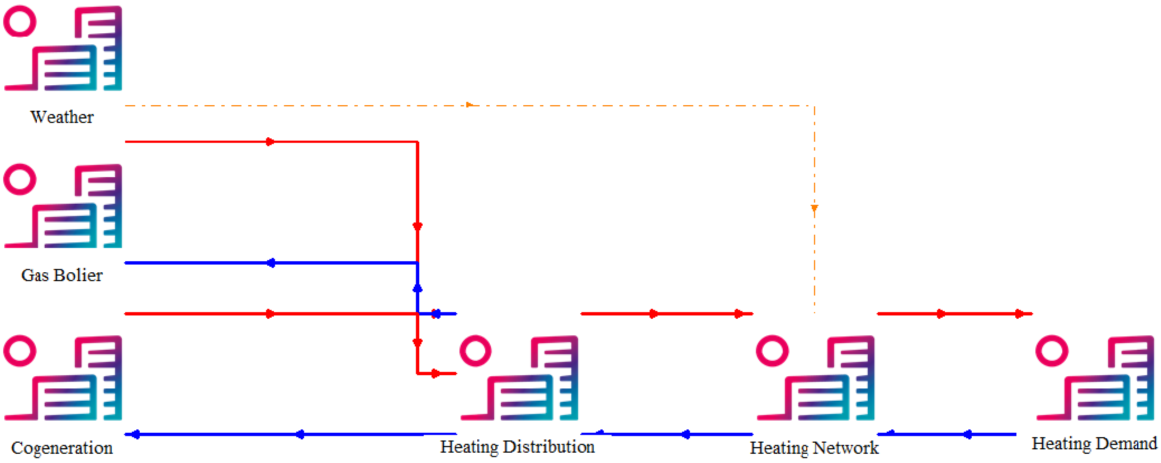

Figure 4-96. Simulation model for reference case (Focsani demo follower).

Figure 4-97 compares the daily generation profile provided by the simulation and the data. The result of the simulation is 104392 MWh while the data is 104440 MWh. The deviation is -0.042 %. Table 4-31 and Table 4-32 include the individual validation of the cogeneration and the boiler respectively.

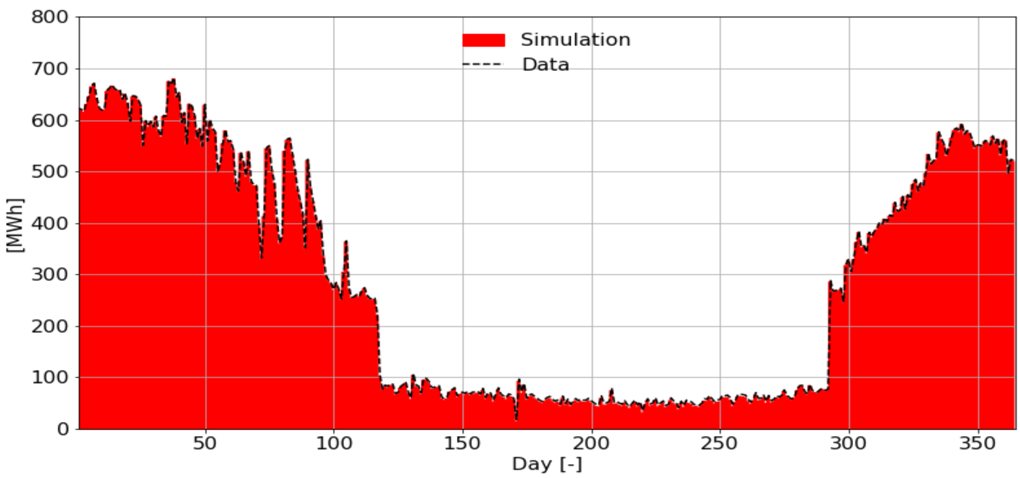

Figure 4-97 Comparison between daily generation profile provided by the simulation and the data (Focsani demo follower).

Table 4-31 Comparison between simulation results and data for cogeneration.

Parameter	Simulation [MWh]	Data [MWh]	Deviation [%]
Energy generated	52596	52733	-0.26
Fuel consumption	195588	196434	-4.33
Electricity generated	76502	76832	-0.43

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Table 4-32 Comparison between simulation results and data for boiler.

arameter	Simulation [MWh]	Data [MWh]	Deviation [%]
Energy generated	51796	51703	0.18
Fuel consumption	61884	61743	2.11

The key parameters have been calculated from these results are included in Table 4-33. The CO_2 emission coefficient is 335.35 $kgCO_2/kWh$ and non-renewable primary energy factor is 1.91. The LCOE is 99.47 €/MWh. Table 4-34 and Table 4-35 include the economic data and primary energy factor and CO_2 emission coefficient used to calculate these key parameters.

Table 4-33 Key parameters for the reference case (Focsani demo follower).

CO2 emission coefficient [kg/MWh]	Heating Non-renewable primary energy factor [-]	LCOE Heating [€/MWh]
335.35	1.91	99.47

Table 4-34 Economic data for the reference case (Focsani demo follower).

Specific capital cost of cogeneration unit	1500 €/kW
Specific capital cost of natural gas boiler	80 €/kW
Natural gas price	43.7
Electricity price	129.3 €/MWh
Lifetime	25 year
Discount rate	7%
Fixed OM	3 %

Table 4-35 Primary energy factor and CO2 emission coefficient for the reference case (Focsani demo follower).

Energy Vector	Primary energy factor Non renewable	Primary energy factor Renewable	Primary energy factor Total	CO2 emissions coefficient [kg/MWh]
Natural gas	1.17	0	1.17	205
Electricity	2.62	0	2.62	299

4.5.2 FEASIBILITY STUDY

The main impacts of the proposed alternative solution might be:

- Diversification and combination of additional energy sources, giving an alternative to extend the operation of all installations to the whole year, avoiding their shutdown in winter or summer periods, or oversizing.
- Extension of the facilities to develop cooling services

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Considering the previous information, the technologies and solutions proposed to be studied in Focsani demo-follower are included on Table 4-36 and Table 4-37.

Table 4-36 Summary of preliminary technologies proposed (Focsani demo follower).

Solution proposed after preliminary assessment			
Technology	**FOCSANI S1**	**FOCSANI F2**	**FOSCANI F3**
Fresnel		x	
TF-FTC			
Biomass boiler	x	x	x
Gas boiler	x	x	
Advanced Absorption Chiller	x	x	
Free cooling			
Thermal storage	x	x	
Hybrid PV-Geothermal-Heat Pump			x
A/W Compression chiller	x	x	

Table 4-37 Preliminary solutions proposed (Focsani demo follower).

Solutions proposed overall description	
Combination code	FOCSANI – S1
Justification	This combination integrates biomass and gas boiler with a thermal storage to analyse the upgrade to existing systems. Advanced Absorption Chiller and compression chiller technologies are included to add cooling capabilities to the system.
Expected impact	• Reduce CO_2 emissions • Add cooling capabilities to the system
Combination code	FOCSANI – S2
Justification	This combination is similar to S1 including Fresnel Collectors with the corresponding thermal storage
Expected impact	• Reduce CO_2 emissions • Add cooling capabilities to the system • Evaluate the possibility of additional solar thermal capabilities to the district heating and cooling.
Combination code	FOCSANI – S3
Justification	This combination integrates hybrid PV and geothermal heat pump and biomass boiler technologies to analyse the upgrade to district heating and cooling.
Expected impact	• Add cooling capabilities to the system • Evaluate the possibility of additional low-enthalpy geothermal sources and PV system for thermal and electric balance.

The economic data and primary energy factor and CO_2 emission coefficient emissions considered to calculate the key parameters are included in Table 4-38 and Table *4-39*.

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Table 4-38 Economic data for solutions proposed (Focsani demo follower).

Specific capital cost of biomass boiler	250 €/kW
Specific capital cost of natural gas boiler	80 €/kW
Specific capital cost of thermal energy storage	260 €/m^3
Specific capital cost of fresnel collectors	190 €/m^2
Specific capital cost of advanced absorption chiller	600 €/kW
Specific capital costs of A/W compression chiller	196 €/kW
Specific capital costs geothermal vertical HX	65 €/m
Specific capital cost of photovoltaic collectors	1000 €/kW
Specific capital cost of W/W heat pump	950 €/kW
Natural gas price	43.7€/MWh
Electricity price	129.3 €/MWh
Biomass price	43.2 €/MWh
Lifetime	25 year
Discount rate	7%
Fixed OM	3 %

Table 4-39 Primary energy factor and CO2 emission coefficient for solutions proposed (Focsani demo follower).

Energy Vector	Primary energy factor Non renewable	Primary energy factor Renewable	Primary energy factor Total	CO2 emissions coefficient [kg/MWh]
Natural gas	1.17	0	1.17	205
Biomass	0.28	0.8	1.08	39
Electricity	2.62	0	2.62	299

4.5.2.1 SCENARIO 1

Figure 4-98 represents the simulation model proposed for scenario S1. The operation of the simulation model is the following:

- The biomass boiler transfers thermal energy in the thermal storage when this uncharged.
- The thermal storage transfers thermal energy to the heated water network and the advanced absorption chiller at the temperature set points of the facility. If the energy stored does not cover the demand, the gas boiler is turned on.
- The advanced absorption chillers and compression chiller supply the cold network connected in series The connection is made in such a way that the demand is to be covered with the advanced absorption chillers first and, if this not sufficient, compression chiller would be turned on.

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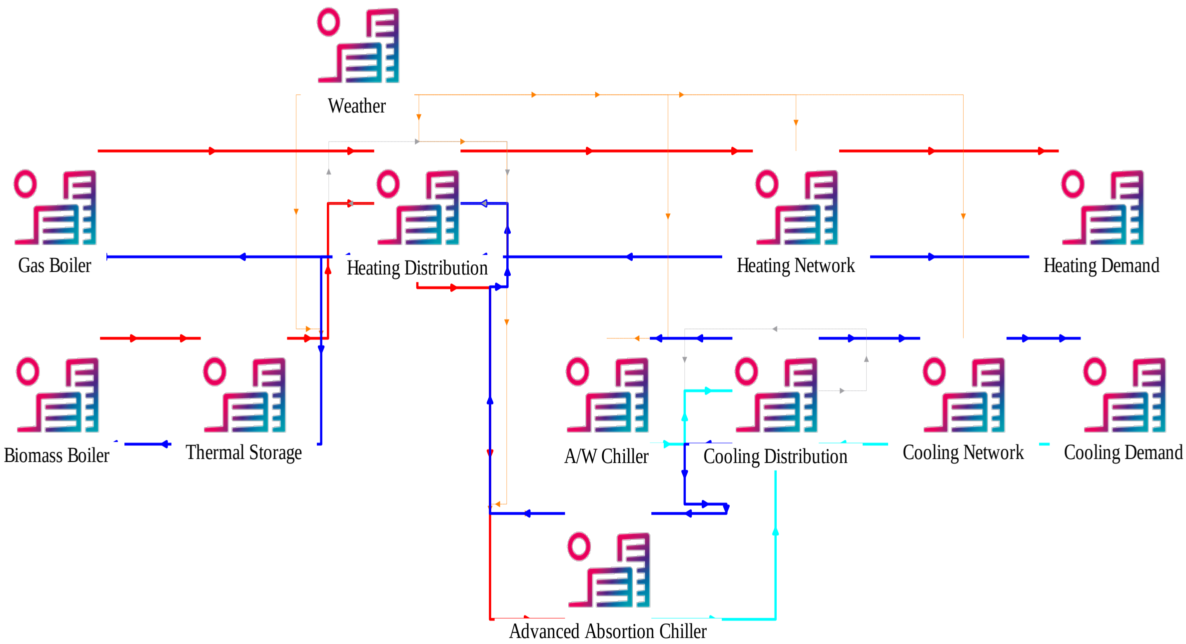

Figure 4-98 Simulation model of scenario S1 (Foscani demo follower).

The main parameters used in simulations are reported on Table 4-40. The heating capacity has been set at 30000 kW. The biomass boiler has been varied from 20000 kW to 30000 kW. The gas boiler capacity is the difference between the total capacity and the biomass boiler capacity in each case. The volume of the thermal storage is calculated to cover the nominal power of the biomass boiler for an amount of operating hours. The number of hours has been varied from 3 to 12. The cooling capacity has been set at 9000 kW. Three capacities (1000 kW, 2000 kW and 3000 kW) of the advanced absorption chiller have been considered. The compression chiller capacity is calculated as the difference between the total cooling capacity and the advanced absorption chiller capacity in each case.

Table 4-40 Main parameters of scenario S1 (Focsani demo follower).

Biomass boiler capacity [kW]	Gas boiler capacity [kW]	TES capacity [h]	AAC capacity [kW]	Chiller A/W capacity [kW]
20000-30000	0-10000	3-12	1000-3000	6000-8000

Figure 4-99 compares the CO2 emission coefficient and LCOE for each advanced absorption chiller capacity. As can be observed, the minimum CO2 emission coefficient and LCOE are achieved by the cases with the minimum capacity of the advanced absorption chiller.

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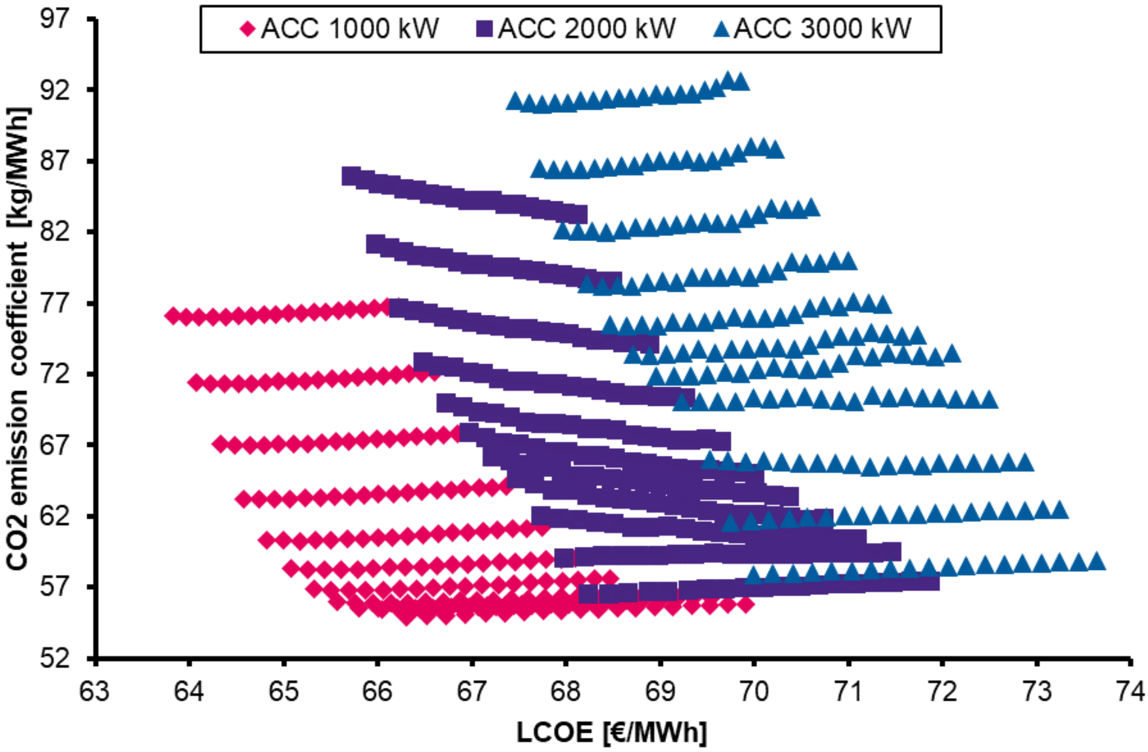

Figure 4-99 Comparison between absorption chiller capacity for scenario S1 (Foscani demo follower)

Figure 4-100 shows the CO2 emission coefficient and LCOE for the minimum size of ACC. For a given capacity of biomass and gas boiler, the CO2 and LCOE are minimized when the thermal storage is minimum (3 hours). Also, if the capacity of the biomass boiler is reduced, the capacity of the gas boiler is increased to cover the demand. This causes the LCOE decreases, and the CO2 emission factor increases. The cases with minimum CO2 emission coefficient (S1-CO2) and LCOE (S1-ECO) are summarized on Table 4-41. The CO2 emissions are lower for the case S1-CO2 owing to a lower gas consumption. The LCOE for both cases are very similar.

Table 4-41 Optimum cases of scenario S1 (Focsani demo follower).

	Biomass boiler capacity [kW]	Gas boiler capacity [kW]	TES capacity [h]	AAC capacity [kW]	Chiller A/W capacity [kW]	LCOE [€/MWh]	CO2 emission coefficient [kg/MWh]
S1-CO2	30000	-	3	1000	8000	66.30	54.91
S1-ECO	20000	10000	3	1000	8000	63.82	76.08

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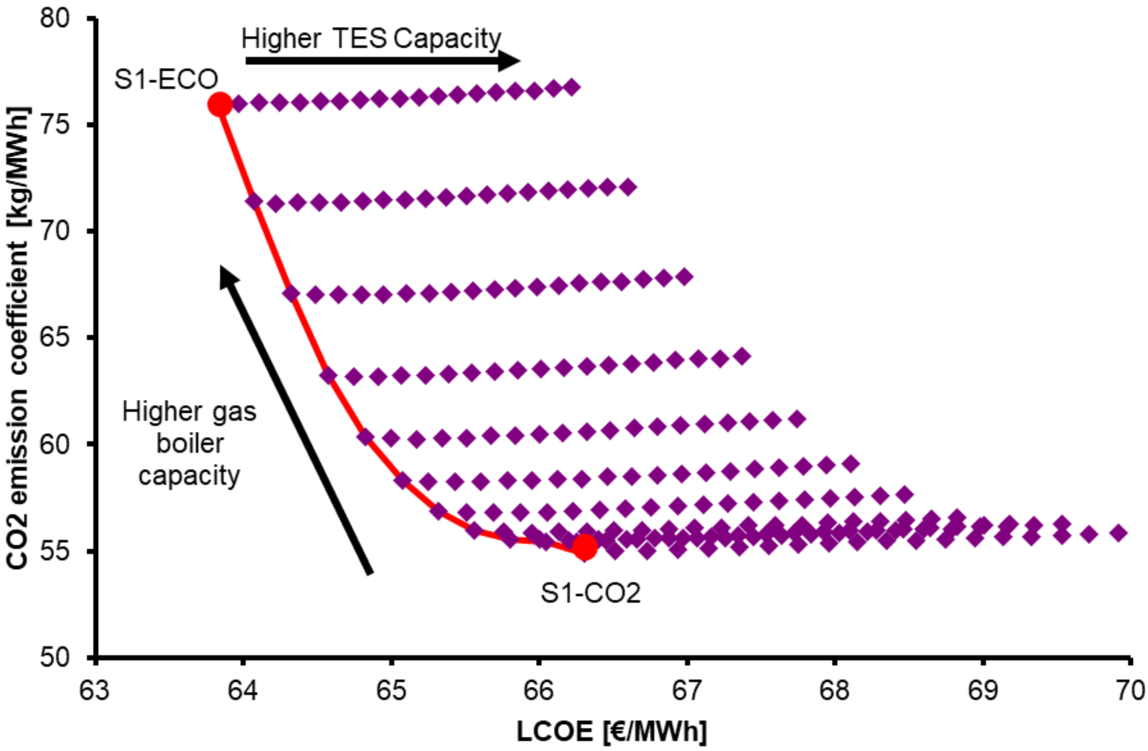

Figure 4-100 CO2 emission coefficient and LCOE of scenario S1 (Foscani demo follower).

Finally, the results of the cooling network are analyzing (Figure 4-101). The cases present the same shape as the heating network (Figure 4-99). However, the emissions and LCOE values are quite high owing to the shape of the cooling demand (Figure 4-95). The cooling equipment operates few hours with a very variable capacity. This causes low performance. Additionally, the absorption chiller is an expensive system that is operating few hours.

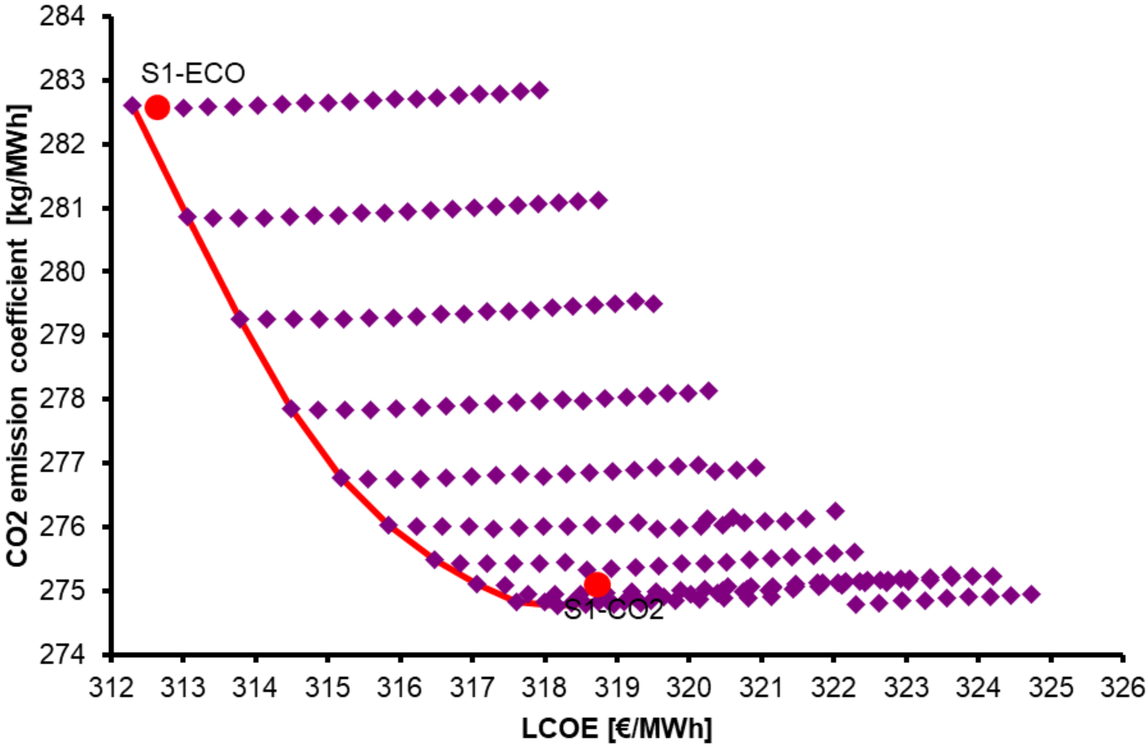

Figure 4-101 CO_2 emission coefficient and LCOE of scenario S1 (Foscani demo follower)

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4.5.2.2 SCENARIO 2

Figure 4-102 represents the simulation model of scenario S2. The operation of the simulation model is the following:

- The Fresnel collectors captures the solar radiation of the site and transforms it into thermal energy, which is stored in the thermal energy storage 1.
- The biomass boiler transfers thermal energy in the thermal storage 2 when this uncharged.
- The thermal energy storage 1 transfers energy to the heated water network the advanced absorption chiller at the temperature set points of the facility. If the energy stored does not cover the demand, the thermal energy storage 2 is used. If both thermal storages do not cover the demand the gas boiler is turned on
- The thermal storage transfers thermal energy to the heated water network and the advanced absorption chiller at the temperature set points of the facility. If the energy stored does not cover the demand, the gas boiler is turned on.
- The advanced absorption chillers and compression chiller supply the cold network connected in series. The connection is made in such a way that the demand is to be covered with the advanced absorption chillers first and, if this not sufficient, compression chiller would be turned on.

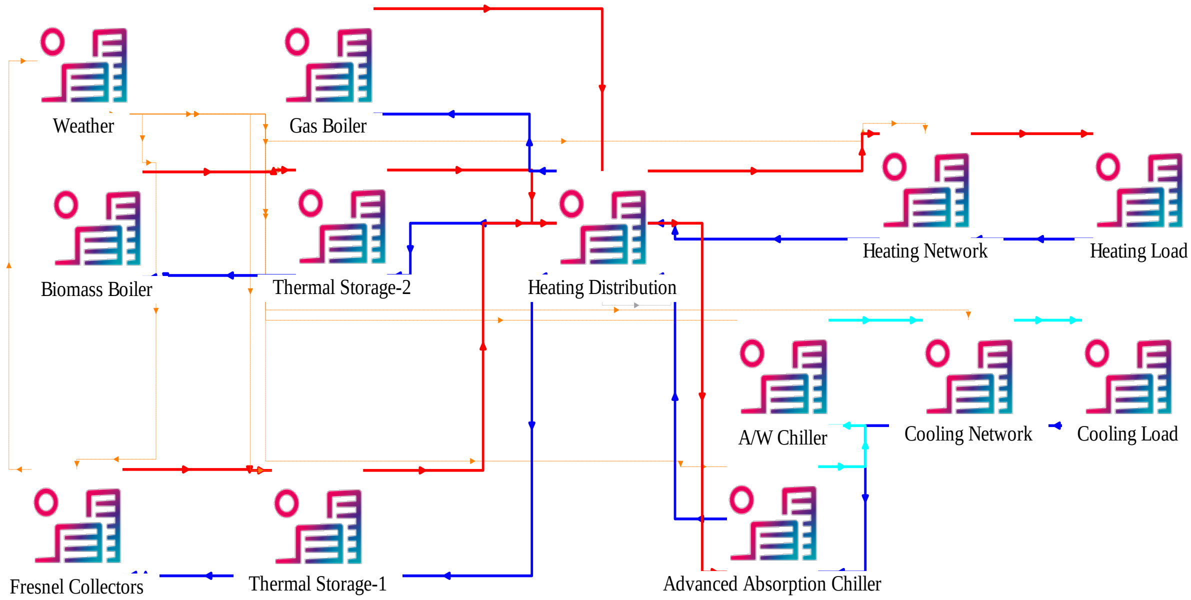

Figure 4-102 Simulation model of scenario S2 (Foscani demo follower).

The main parameters used in simulations are reported on Table 4-42. The total heating capacity has been set at 30000 kW. The biomass boiler has been varied from 20000 kW to 30000 kW. The gas boiler capacity is the difference between the total capacity and the biomass boiler capacity in each case. The area of the solar collectors has been varied from 8000 to 20000 m^2. The volume of the thermal energy storage 2 has been varied from 100 to 1500 m^3. From the results of the scenario 1, the thermal energy storage 1, the AAC capacity and the compression chiller capacity have been fixed.

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Table 4-42 Parametrization of scenario S2 (Focsani demo follower).

Biomass boiler capacity [kW]	Gas boiler capacity [kW]	TES 1 capacity [h]	Collector area [m²]	TES 2 volume [m³]	AAC capacity [kW]	Chiller A/W [kW]
20000-30000	0-10000	3	8000-20000	1000-3000	1000	8000

Figure 4-103 shows simulation the CO_2 emission coefficient and LCOE for scenario 2. For a given capacity of biomass and gas boilers, the minimum collector area (8000 m^2) with the minimum volume of thermal energy storage 2 (100 m^3) optimizes LCOE. The CO_2 coefficient is lightly improved increasing the collector's area but the LCOE is increased. If the capacity of the biomass boiler is reduced, the capacity of the gas boiler is increased to guarantee the covert of the demand. This causes that the LCOE decreases and the CO2 emission factor increases. The cases with minimum CO_2 emission coefficient and LCOE are included on Table 4-43. The CO_2 emissions are lower for the case S2-CO2 owing to a lower gas consumption. The LCOE for both cases are very similar.

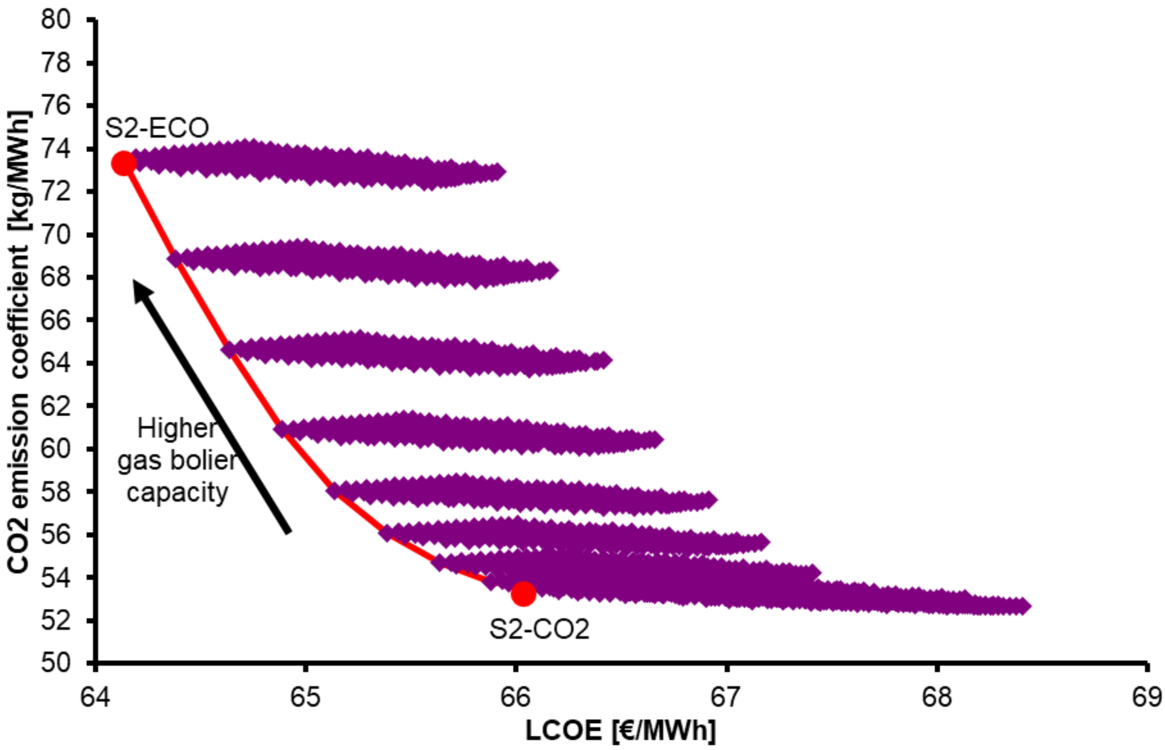

Figure 4-103 CO2 emission coefficient and LCOE of scenario S2 (Foscani demo-follower).

Table 4-43 Optimum cases of scenario S2 (Focsani demo follower).

	Biomass boiler capacity [kW]	Gas boiler capacity [kW]	Collector area [m²]	TES volume [m³]	LCOE [€/MWh]	CO2 emission coefficient [kg/MWh]
S2-CO2	28000	2000	8000	100	66.12	53.51
S2-ECO	20000	10000	8000	100	64.13	73.49

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4.5.2.3 SCENARIO 3

Figure 4-104 represents the simulation model of scenario S3. The operation of the simulation model is the following:

- In winter, the geothermal heat pump and the biomass boiler cover the heating demand.
- In summer, the geothermal heat pump covers the cooling demand and the biomass boiler covers the heating demand.
- The photovoltaic collectors supply electricity to the heat pump. If there is an excess of the electricity production, it is fed into the grid.

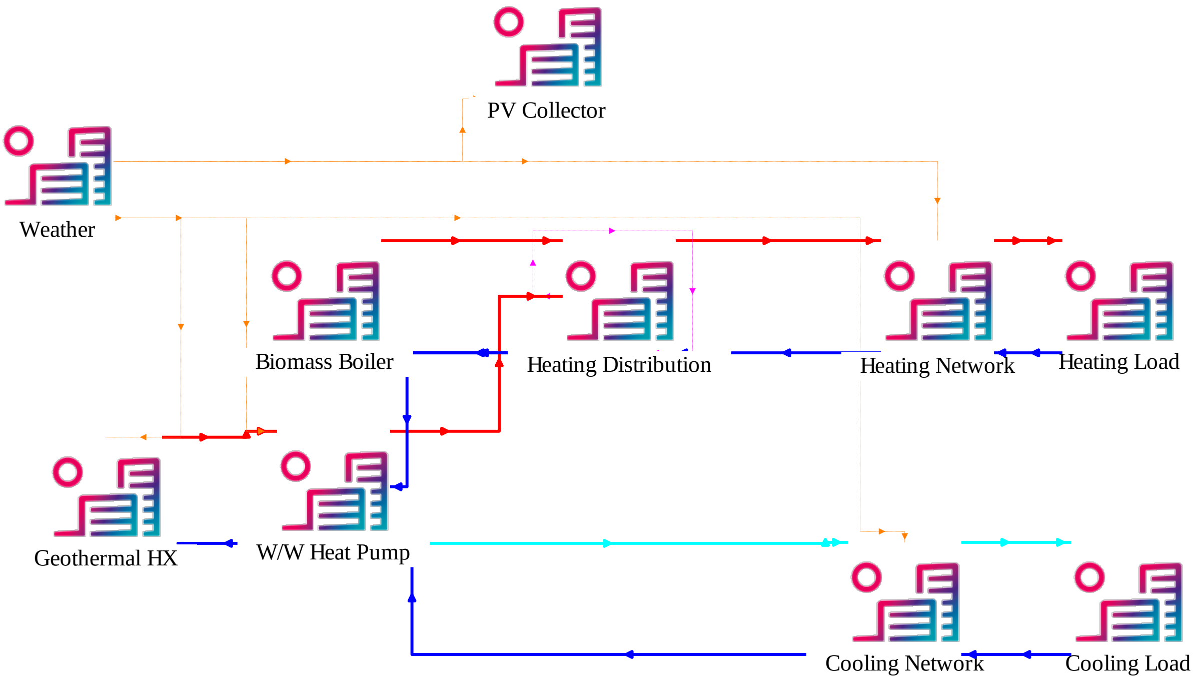

Figure 4-104 Simulation model of scenario S3 (Foscani demo follower).

The values of the main parameters used on the simulations are included on Table 4-44. The biomass boiler has been varied from 10000 kW to 25000 kW. The heat pump cooling capacity haven been varied from 7000 to 10000 kW. The ratio between cooling and heating capacity of heat pump is 0.75. The photovoltaic capacity calculates to provide the nominal electric consumption of the heat pump.

Table 4-44 Parametrization of scenario S3 (Focsani demo follower).

PV capacity [kW]	Biomass boiler capacity [kW]	HP W/W heating capacity [kW]	HP W/W cooling capacity [kW]
Nominal electric consumption HP	10000-25000	0.75* cooling capacity	7000-10000

Figure 4-105 shows CO_2 emission coefficient and LCOE for the scenario S3. For a given capacity of heat pump, the minimum CO_2 emissions coefficient and LCOE are achieved when the biomass boiler is the minimum that covers the demand properly. On this scenario, there is a unique case that minimize CO_2 emission coefficient and LCOE simultaneously (Table 4-45).

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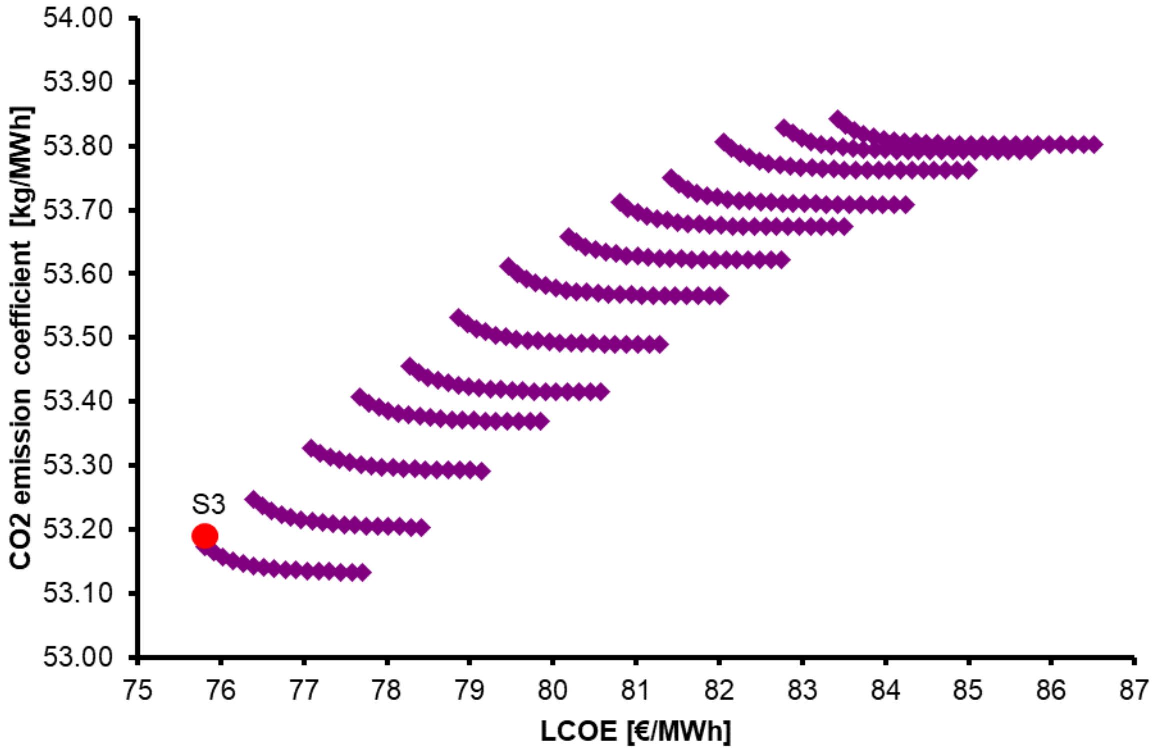

Figure 4-105 CO2 emission coefficient and LCOE of scenario S3 (Foscani demo follower)

Table 4-45 Optimum cases of scenario S3 (Focsani demo follower).

	PV capacity [kW]	Biomass boiler capacity [kW]	HP W/W heating [kW]	HP W/W cooling [kW]	LCOE [€/MWh]	CO2 emission coefficient [kg/MWh]
S3	2800	17500	9333	7000	75.81	53.17

Finally, the results of the cooling network are analyzing (Figure 4-106). In summer, the heat pump operates few hours because there is low cooling demand. The electric consumption of the heat pump is very small. So that, the electrical energy produced by the photovoltaic collectors is mainly transferred to the grid. The CO_2 emission coefficient and the LCOE are reduced because the model assumes that the electrical energy transferred to the grid represents savings in emissions and costs. The extreme situation occurs for the highest capacity heat pump. In this case, the emissions saved by the sale of electricity offset those produced by the operation of the heat pump. This is not a realistic situation because the heat pump is clearly oversized.

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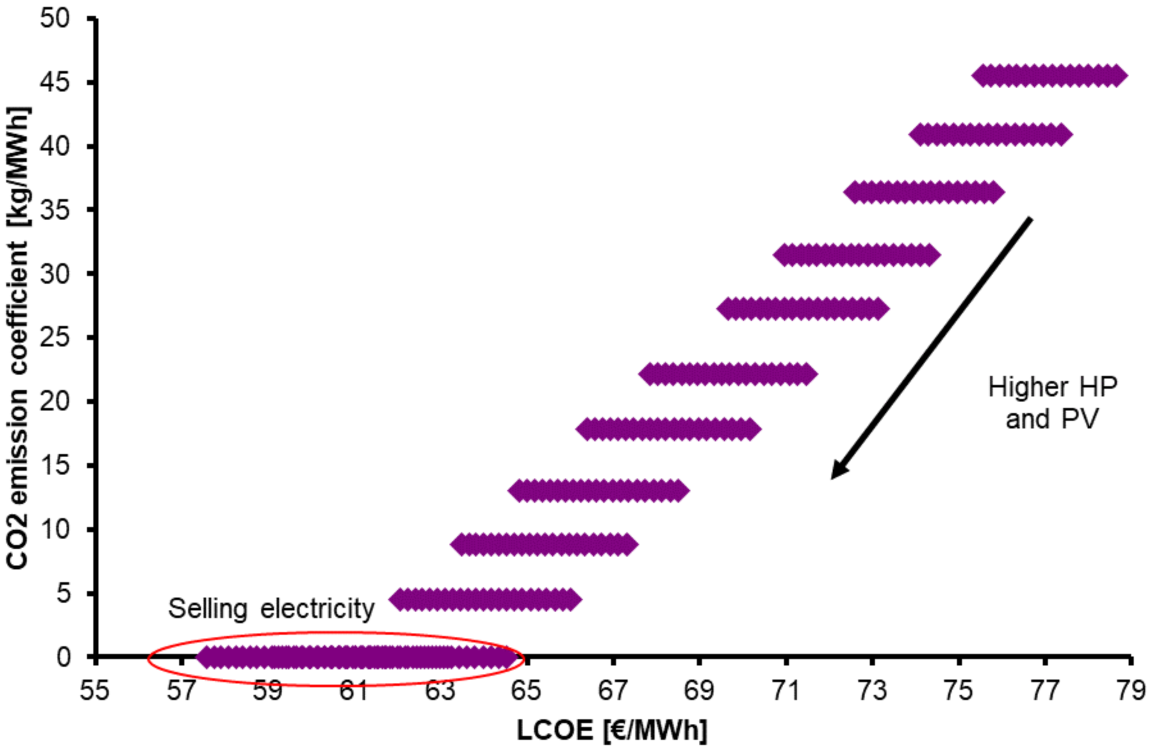

Figure 4-106 CO2 emission coefficient and LCOE of scenario S3 for Foscani demo-follower

4.5.2.4 SCENARIOS COMPARISON

Table 4-46 summarizes the results of the reference case and the selected cases for each scenario. All cases present lower CO_2 emission coefficient and LCOE than reference case because the gas is partially or totally replacing by renewable technologies. The reduction on CO2 emission coefficient is almost the 80 % (Figure 4-108). The reduction on LCOE is between from 24 % to 36 % (
Figure 4-109). The reduction on the LCOE is owing to the equipment on the reference case is oversized.

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Figure 4-123

Figure 4-107. Economic comparison of optimal scenarios

Table 4-46 LCOE and CO2 emission coefficient (Focsani demo follower)

	LCOE [€/MWh]	CO2 emission coefficient [kg/MWh]
S0	99.47	335.35
S1-ECO	63.82	76.08
S1-CO2	66.30	54.91
S2-ECO	64.13	74.91
S2-CO2	66.12	53.51
S3	75.81	53.17

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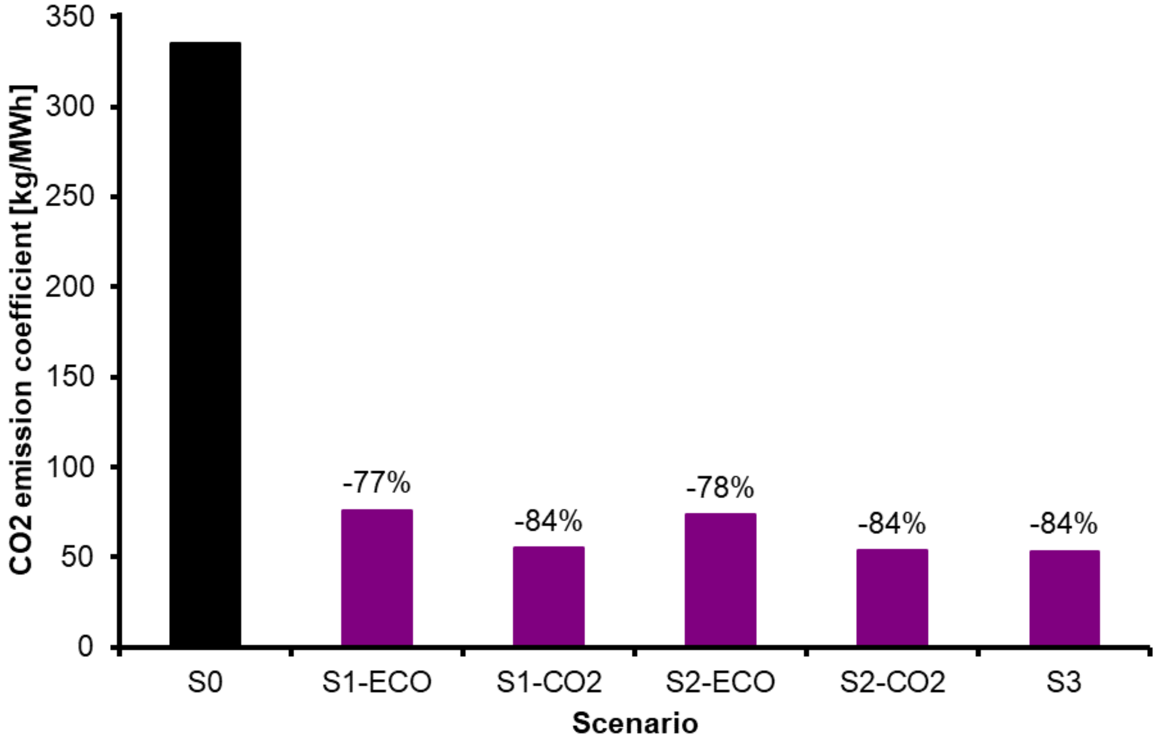

Figure 4-108 Comparison of the CO_2 emission coefficient (Focsani demo follower).

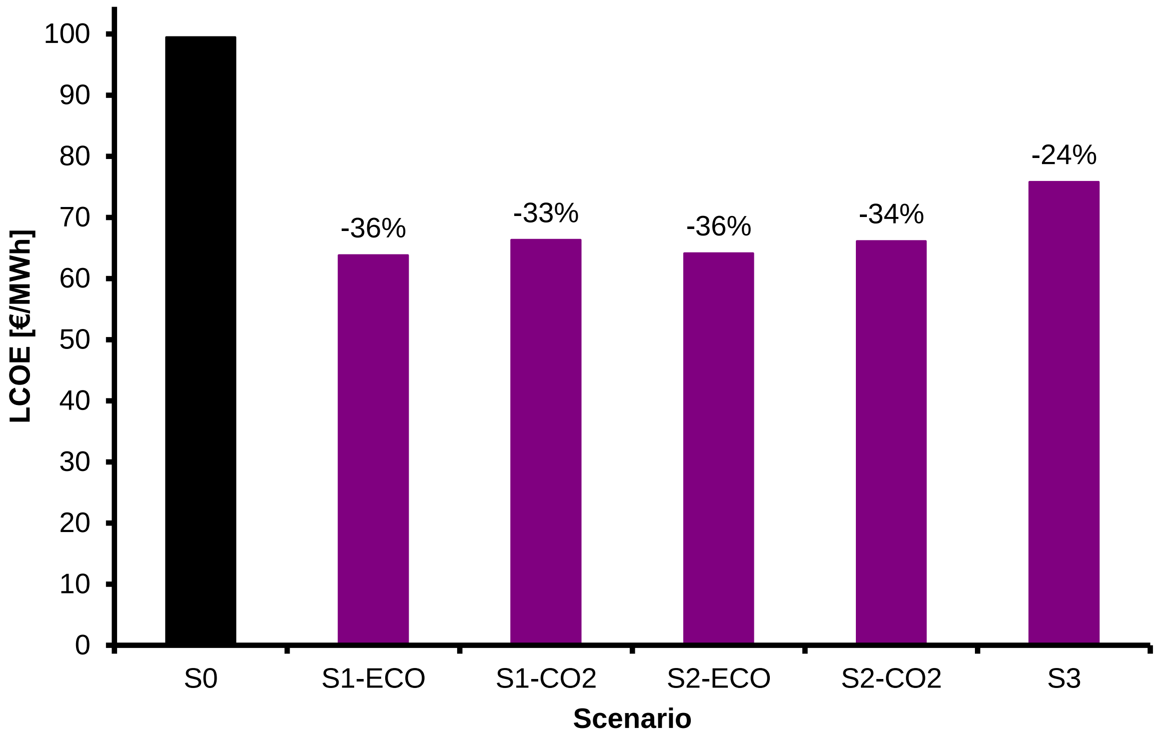

Figure 4-109 Comparison of the LCOE (Focsani demo follower).

Figure 4-110 shows LCOE breakdown by CAPEX, fixed OM and variable OM. On scenarios 1 and 2, the variable OM represents the 80 % of the LCOE owing to the biomass consumption.

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On scenario 3, the heat pump reduces the biomass consumption. In this scenario, the CAPEX is higher while variable OM are lower

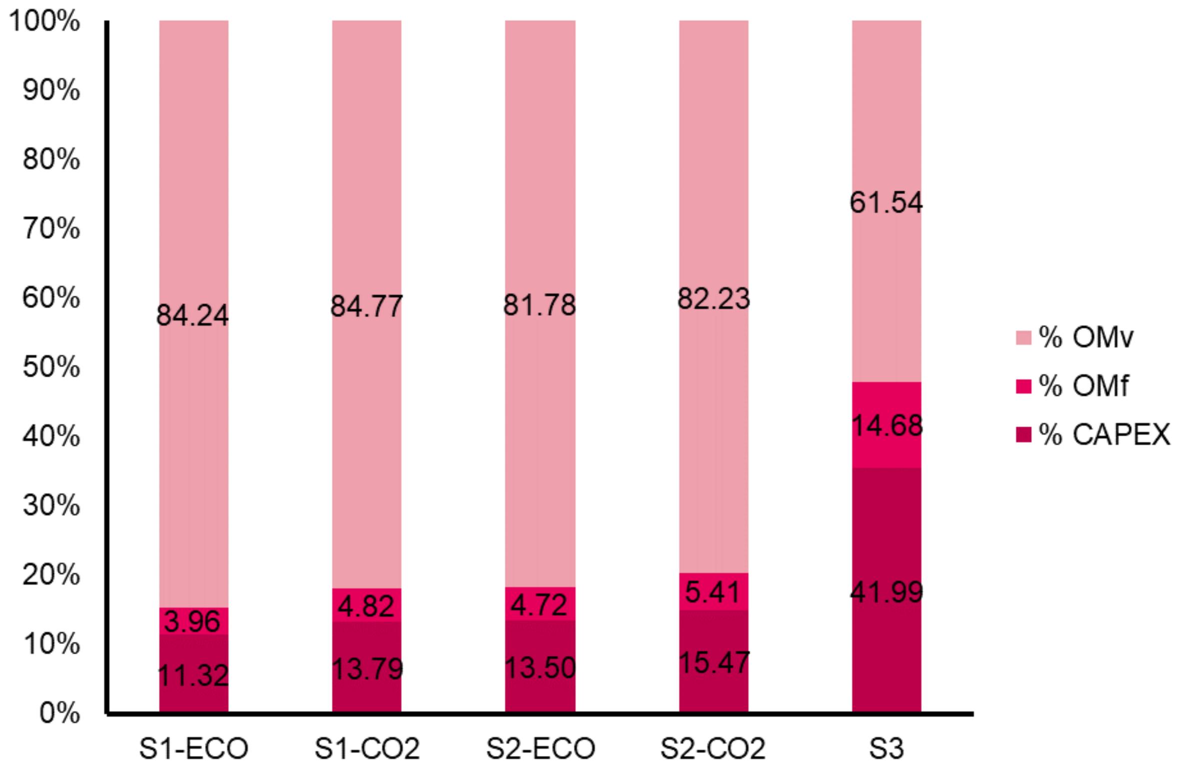

Figure 4-110 Comparison between the LCOE breakdown (Focsani demo follower).

4.5.2.5 SCENARIO TO BE DEVELOPED

The selected scenario is the scenario 3. In this scenario the consumption of fossil fuels is lower than in other scenarios. This causes the LCOE to be less dependent on fuel prices. Furthermore, there is no gas consumption. In addition, the photovoltaic system reduces the consumption electricity of the heat pump.

Additionally, the cooling demand is covered with a low CO_2 coefficient emission factor and LCOE. The LCOE for cooling is lower than in other scenarios because the same equipment is used for heating and cooling.

4.5.3 CONCLUSIONS

The main conclusion drawn from this study is that replacing the use of natural gas with biomass significantly reduces CO_2 emissions. From the economic point of view, the price of the fuels influences strongly the LCOE. The use of solar energy is not recommended because the solar resource is not enough to reduce CO_2 emissions in a significant way. The best alternative to cooling is a geothermal photovoltaic hybrid heat pump. The system is used for heating and

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cooling. Accordingly, the capacity factor of the equipment is higher than alternatives that use specific cooling equipment.

4.6 Mrągowo (Mrągowo – Poland)

4.6.1 GENERAL DESCRIPTION

The heating demand of the Mrągowo municipality is covered in a 70% by district heating by the company Miejska Energetyka Cieplna Spółka zoo. The city hospital, the city hall, the town hall and primary and secondary schools, for instance, are heated by the district heating based on boilers WR-10, and WR-5, with a total power of 40.7 MW (3 boilers of aprox. 10 MW and 3 boilers of aprox. 5 MW), with hard coal. The total number of buildings connected is 247, covering an area of around 416,000 m^2. The system is under retrofitting, initiating the process for the substitution of part of the production by biomass technologies.

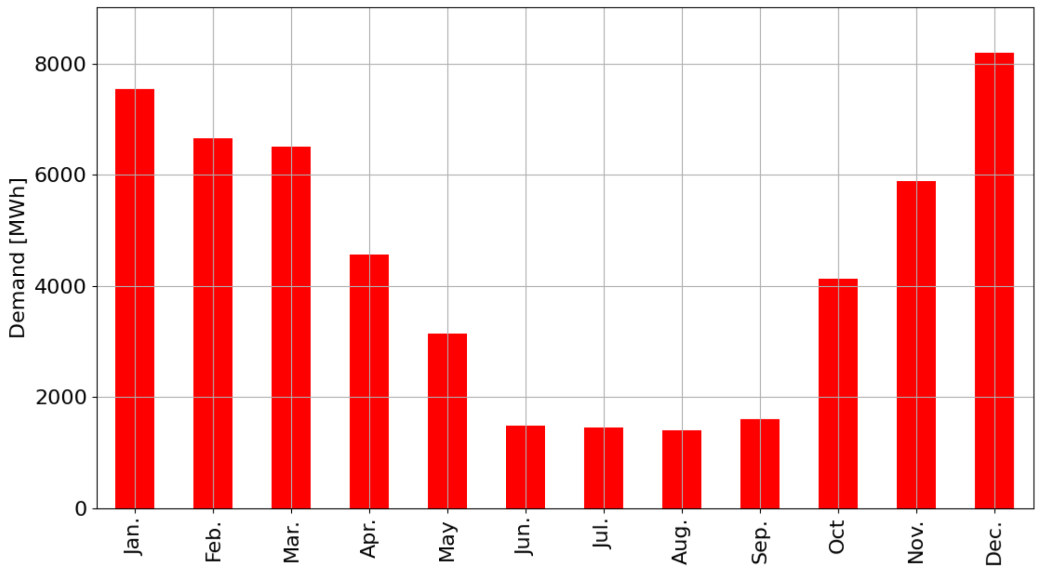

Figure 4-111 Monthly heating demand profile (Mrągowo demo follower).

Figure 4-111 shows the monthly heating demand profile. The annual demand of the district heating is 53112 MWh/year. The peak demand is 15 MW while, the demand is less 3.5 MW in summer period (Figure 4-112).

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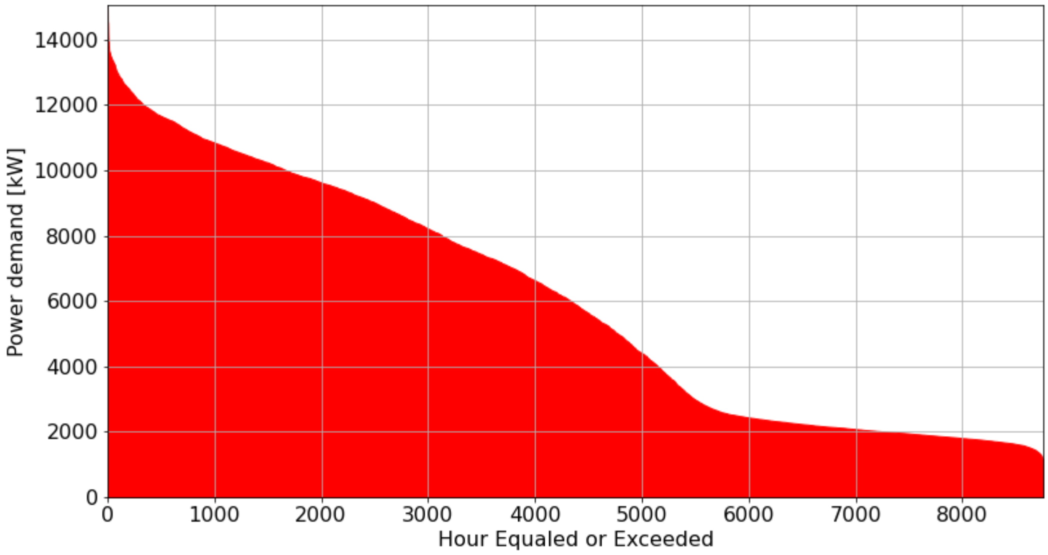

Figure 4-112 Annual demand duration curve of heating (Mrągowo demo follower).

4.6.2 REFERENCE CASE MODEL AND VALIDATION

Figure 4-113 shows the simulation model for the reference case. This model consists in two coal boilers. The first boiler has a nominal capacity of 11.6 MW. This boiler operates as base demand in winter and is switched off in summer. The second coal boiler has a nominal capacity of 5 MW. This boiler operates at peak demand in winter. In summer, this boiler covers the demand completely.

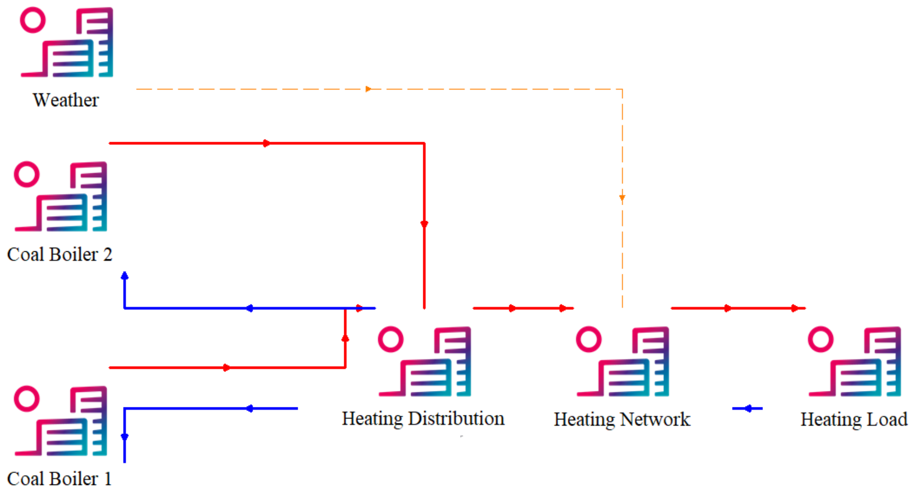

Figure 4-113 Simulation model for the reference case (Mrągowo demo follower)

The model is validated with real data of the energy generated. Figure 4-114 shows a comparison of the daily demand data and results given by the simulation. The result of the simulation is 3452.45 MWh while the data is 3452.37 MWh. The deviation is -0.015 %.

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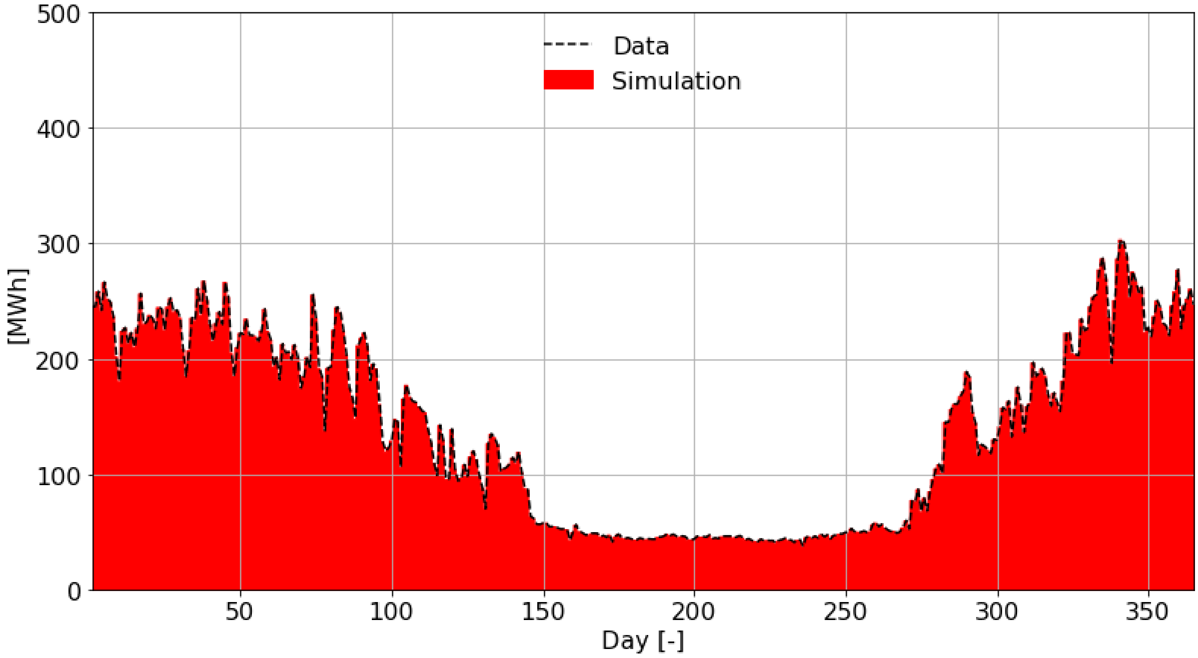

Figure 4-114 Comparison between simulation results and data (Mrągowo demo follower).

The key parameters calculated from these results are included in Table 4-47. The CO_2 emission coefficient is 400.55 $kgCO_2$/kWh and non-renewable primary energy factor is 1.29. The LCOE is 21.12.69 €/MWh. Table 4-48 and Table 4-49 include the economic data and primary energy factor and CO_2 emission coefficient used to calculate these key parameters.

Table 4-47 Key parameters for the reference case (Mrągowo demo follower).

CO2 emission coefficient [kg/MWh]	Heating Non-renewable primary energy factor [-]	LCOE Heating [€/MWh]
400.55	1.29	21.12

Table 4-48 Economic data for the reference case (Mrągowo demo follower).

Specific capital cost of coal boiler	300 €/kW
Coal price	8.63
Electricity price	110.4 €/MWh
Lifetime	25 year
Discount rate	7%
Fixed OM	3 %

Table 4-49 Primary energy factor and CO_2 emission coefficient for the reference case *(Mrągowo demo follower).*

Energy Vector	Primary energy factor Non renewable	Primary energy factor Renewable	Primary energy factor Total	CO2 emissions coefficient [kg/MWh]
Coal	1.1	0	1.1	342
Electricity	2.62	0	2.62	765

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4.6.3 FEASIBILITY STUDY

A preliminary assessment of Mrągowo district heating led to the following proposals:

- Replacing the coal boiler by biomass boilers.
- Studying the possibility to include thermal energy storage.
- Studying the possibility to use solar thermal technologies in summer periods.

Considering the previous information, the technologies and solutions proposed to be studied in Mrągowo demo follower are included on Table 4-50 and Table 4-51.

Table 4-50 Summary of preliminary technologies proposed (Mrągowo demo follower).

Solution proposed after preliminary assessment			
Technology	**FOCSANI S1**	**FOCSANI F2**	**FOSCANI F3**
TF-FTC		x	
Biomass boiler	x	x	x
Gas boiler	x	x	x
Thermal storage		x	x

Table 4-51 Preliminary solutions proposed (Mrągowo demo-follower).

Solutions proposed overall description	
Combination code	Mrągowo – S1
Justification	This combination integrates a biomass and gas boiler to analyze the upgrade to district heating
Expected impact	• Lower significatively CO_2 emissions.
Combination code	Mrągowo – S2
Justification	This combination integrates scenario 1 and solar thermal technologies the upgrade to district heating.
Expected impact	• Lower significatively CO_2 emissions. • Reduce biomass and gas consumptions
Combination code	Mrągowo – S3
Justification	This combination integrates a biomass and gas boiler with a thermal storage to analyze the upgrade to district heating
Expected impact	• Lower significatively CO_2 emissions. • Increase the utilization factor of boilers. • Reduce installed capacity

The economic data and primary energy factor and CO_2 emission coefficient emissions considered to calculate the key parameters are included in Table 4-52 and Table 4-53.

Table 4-52 Economic data for solutions proposed (Mrągowo demo follower).

Specific capital cost of coal boiler	300 €/kW
Specific capital cost of natural gas boiler	80 €/kW
Specific capital cost of biomass boiler	250 €/kW
Specific capital cost of WESSUN collectors	163.8 €/m^2
Specific capital cost of thermal energy storage	260 €/m^3
Coal price	8.63 €/MWh

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Biomass price	43.2 €/MWh
Natural gas price	41.2 €/MWh
Electricity price	110.4 €/MWh
Lifetime	25 year
Discount rate	7%
Fixed OM	3 %

Table 4-53 Primary energy factor and CO_2 emission coefficient for solutions proposed (Mrągowo demo follower).

Energy Vector	Primary energy factor Non renewable	Primary energy factor Renewable	Primary energy factor Total	CO2 emissions coefficient [kg/MWh]
Coal	1.1	0	1.1	342
Electricity	2.62	0	2.62	765
Natural gas	1.1	0	1.1	200
Biomass	0.2	0.8	1	39

4.6.3.1 SCENARIO 1

Figure 4-115 represents the simulation model of scenario S1. The operation of the simulation model is the following:

- The biomass boiler operates as base demand in winter and is switched off in summer months.
- The gas boiler operates as peak demand in winter and covers the demand in summer.

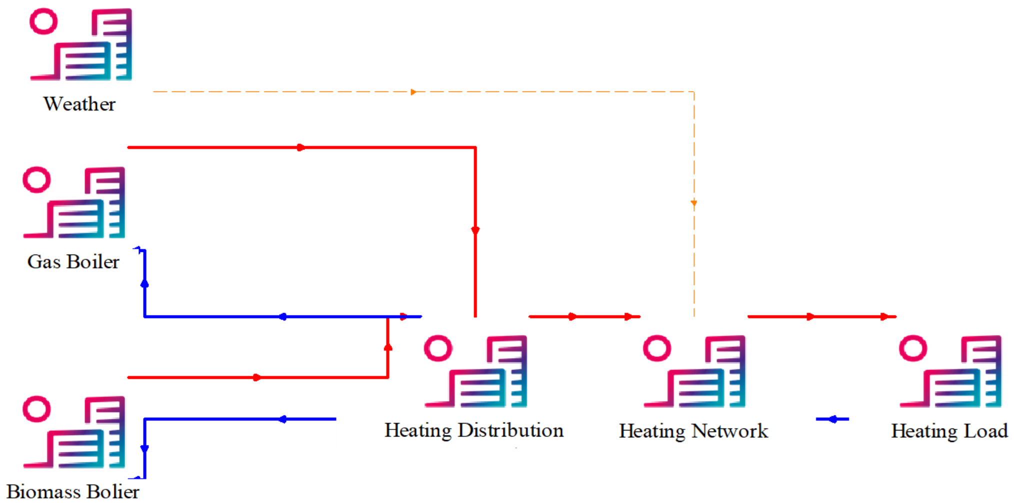

Figure 4-115 Simulation model of scenario S1 (Mrągowo demo follower)

The values of the main parameters used on the simulations are listed on Table 4-54. Biomass boiler capacity has been varied from 7000 kW to 13500 kW. Gas boiler capacity has been varied from 3500 kW to 6500 kW.

Table 4-54 Parametrization of scenario S1 (Mrągowo demo follower).

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Biomass boiler capacity [kW]	Gas boiler capacity [kW]
7000-13500	3500-6500

Figure 4-116 shows CO_2 emission coefficient and LCOE for each case. Optimum solutions are achieved by different capacities of biomass and gas boilers. Two different regions are observed:

- From point S1-CO2 to S1-ECO: The gas boiler has a fixed capacity of 3500 kW and the capacity of the biomass boiler varies from 8750 to 13500 kW. The gas boiler operates at nominal capacity in summer period. In winter, the gas consumption is increased when the capacity of the biomass boiler is reduced.
- Above point S1-ECO: The gas boiler capacity is higher than 3500 kW and biomass boiler is lower than 8750 kW. The gas boiler is oversized to cover during the summer period. This oversize allows reducing the capacity of biomass boiler below 8750 kW in winter period.

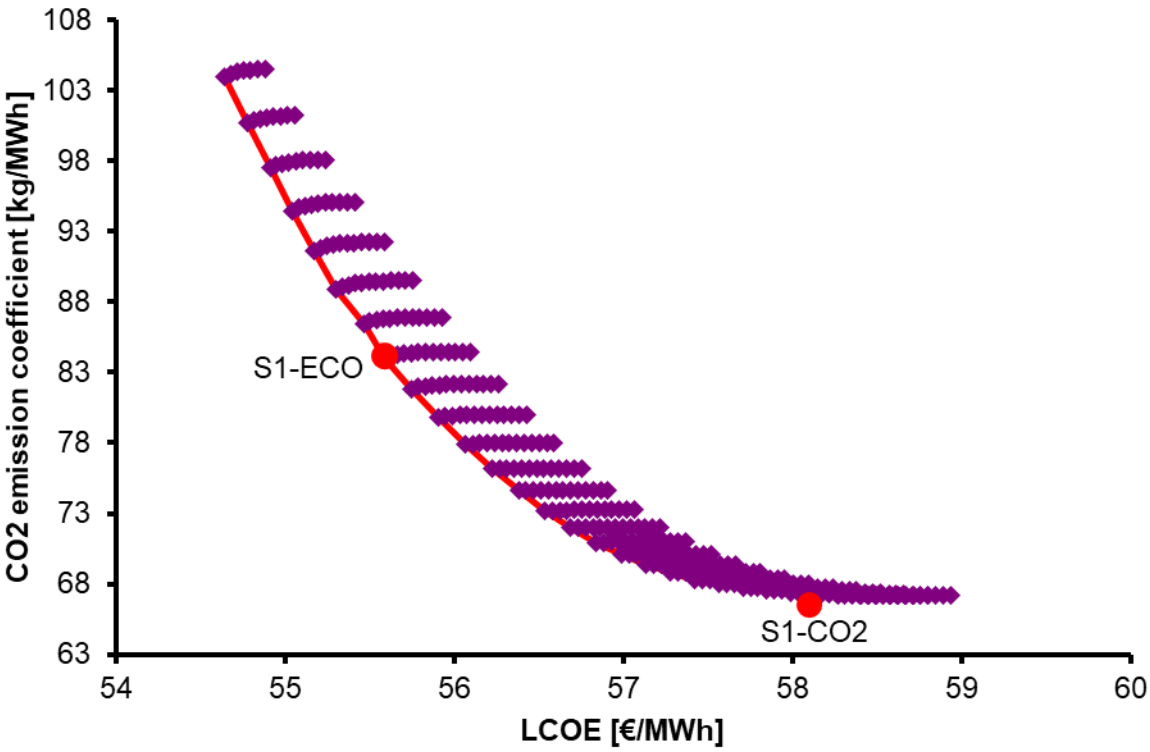

Figure 4-116 CO_2 emission coefficient and LCOE of scenario S1 for Mrągowo demo-follower.

Table 4-55 summarizes optimum cases selected for this scenario. The higher biomass capacity minimizes the CO_2 emission coefficient while lower biomass capacity minimizes the LCOE. The cases with an oversized biomass boiler have been discarded. The LCOE are very similar while the CO_2 emission coefficients values present an appreciable difference.

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Table 4-55 Optimum cases of scenario S1 (Mrągowo demo follower).

	Biomass boiler capacity [kW]	Gas boiler capacity [kW]	LCOE [€/MWh]	CO2 emission coefficient [kg/MWh]
S2-CO2	13000	3500	58.13	67.27
S2-ECO	8750	3500	55.59	83.99

4.6.3.2 SCENARIO 2

Figure 4-117 represents the simulation model of scenario S2. The operation of the simulation model is as follows:

- WESSUN collectors capture the solar radiation of the site and transforms it into thermal energy, which is stored in the water tank.
- Water tank transfers thermal energy to the heated water network (M7300) at the temperature set points of the facility. If the energy stored does not cover the demand, the boiler is turned on.
- Biomass boiler operates as base demand in winter and is switched off in summer months. Gas boiler operates as peak demand in winter and cover the demand in summer.

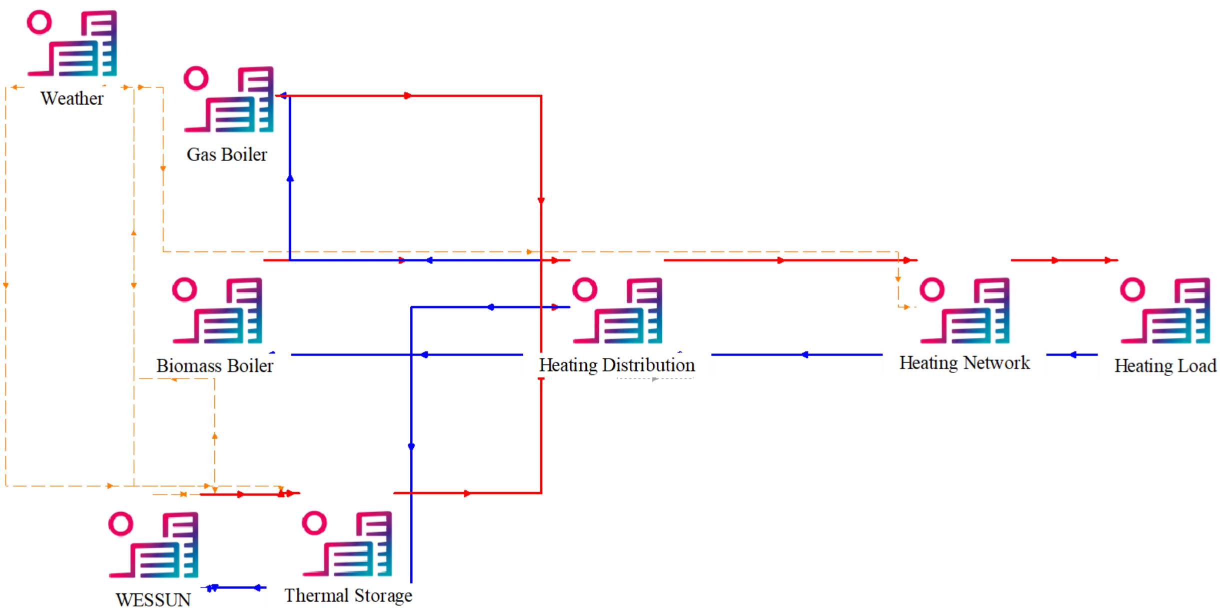

Figure 4-117 Simulation model of scenario S2 (Mrągowo demo follower)

The values of the main parameters used on the simulations are listed on Table 4-56. The biomass boiler capacity has been varied from 8500 kW to 13500 kW. The gas boiler capacity has been set to 3500 kW. The area of the WESSUN collectors has been varied from 4000 m^2 to 14000m^2. The volume of the thermal energy storage has been varied from 100 m^3 to 1000 m^3.

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Table 4-56 Parametrization of scenario S2 (Mrągowo demo follower).

Biomass boiler capacity [kW]	Gas boiler capacity [kW]	TES Volume [m³]	WESSUN area [m²]
8500-13500	3500	100-1000	4000-14000

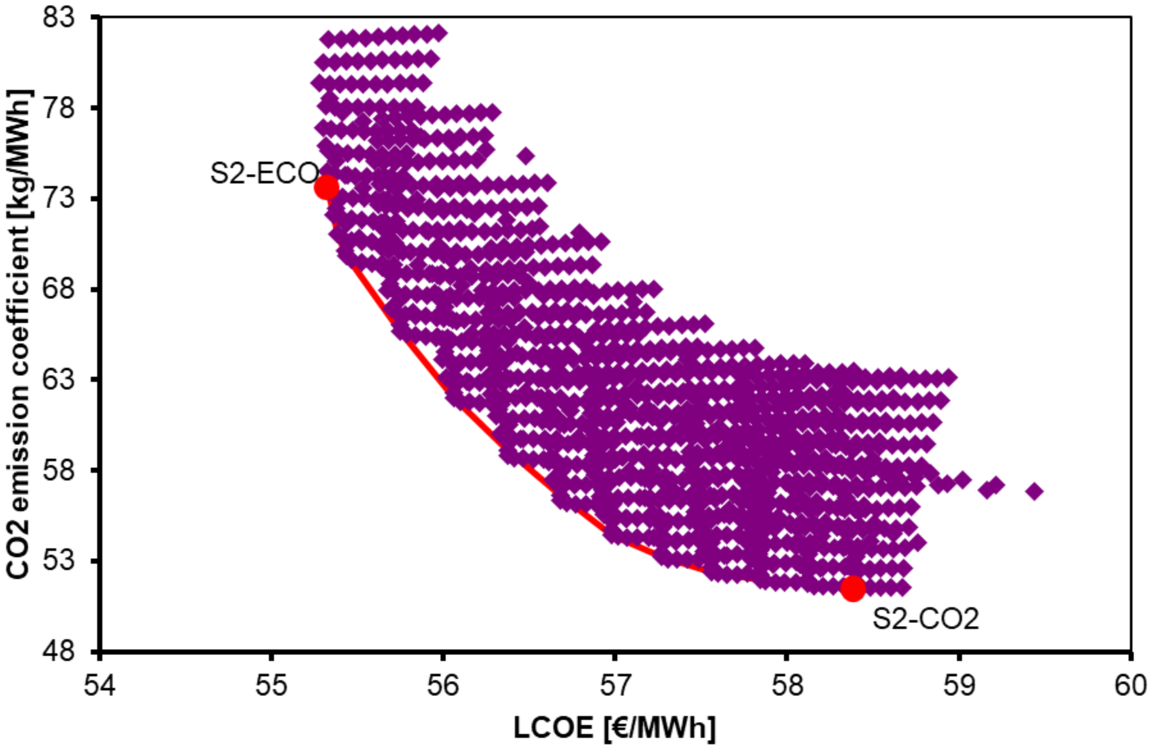

Figure 4-118 shows the CO_2 emission coefficient and LCOE for each case. For every given biomass boiler capacity, the optimum is achieved by a solar collector area between 11000-14000 m^2 and a thermal energy storage between 300-500 m^3. Table 4-57 summarizes the optimum cases selected for this scenario. The LCOE values are very similar while the CO_2 emission coefficients values present an appreciable difference owing to the reduction on the gas consumption.

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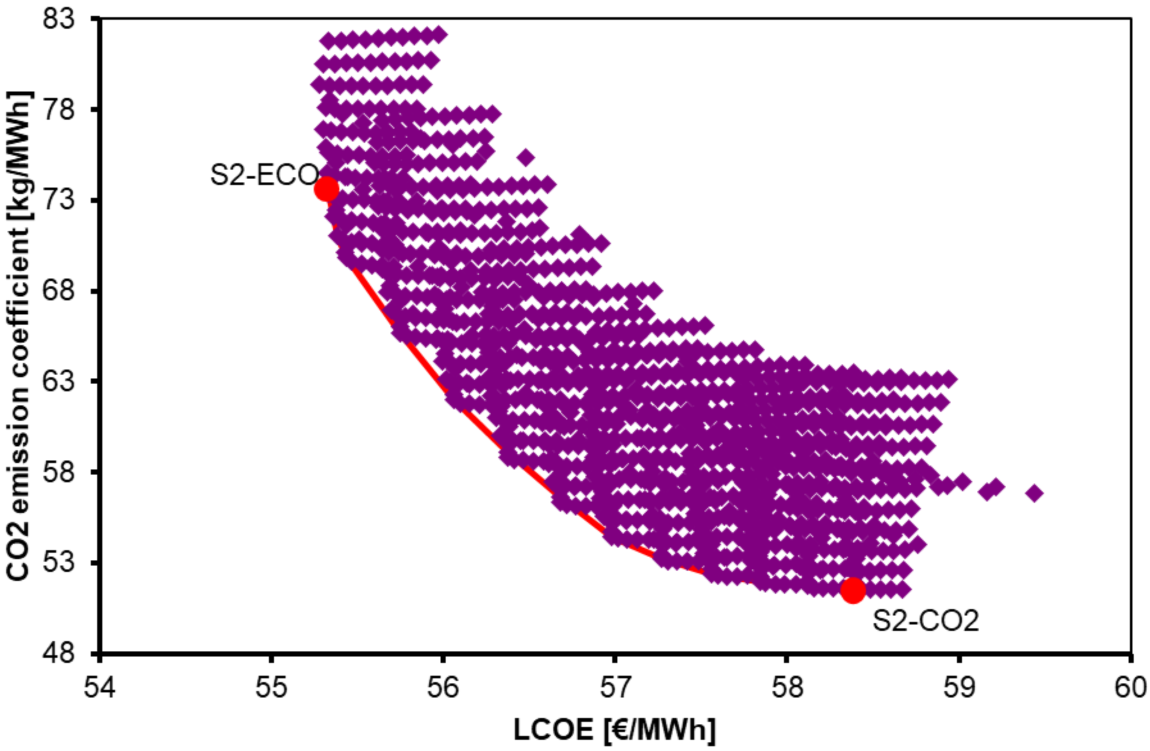

Figure 4-118 CO_2 emission coefficient and LCOE of scenario S2 (Mrągowo demo follower).

Table 4-57 Optimum cases of scenario S2 (Mrągowo demo follower).

	Biomass boiler capacity [kW]	Gas boiler capacity [kW]	TES Volume [m^3]	WESSUN area [m^2]	LCOE [€/MWh]	CO2 emission coefficient [kg/MWh]
S2-CO2	13000	3500	500	14000	58.12	51.72
S2-ECO	11000	3500	300	11000	55.33	73.39

4.6.3.3 SCENARIO 3

Figure 4-119 represents the simulation model of scenario S3. The operation of the simulation model is as follows:

- The biomass boiler stores thermal energy in the water tank. This boiler is turned off when the tank is full.
- The water tank transfers thermal energy to the heated water network and the at the temperature set points of the facility. If the energy stored does not cover the demand, the gas boiler is turned on.

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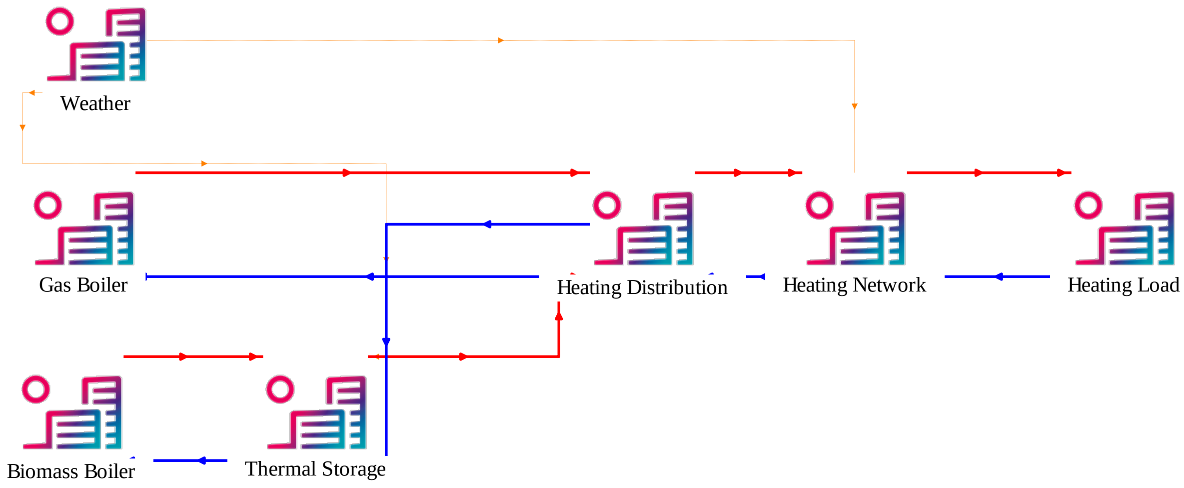

Figure 4-119 Simulation model of scenario S3 (Mrągowo demo follower)

The values of the main parameters used on the simulations are listed on Table 4-58. Biomass boiler capacity has been varied from 6000 kW to 11750 kW. Thermal storage capacity has been calculated to provide the nominal capacity of the biomass boiler for a number of hours. This parameter has been varied from 4 h to 12 h. The capacity of the gas boiler has been calculated to achieve a total installed capacity of 11750 kW.

Table 4-58 Parametrization of scenario S3 (Mrągowo demo follower).

Biomass boiler capacity [kW]	Gas boiler capacity [kW]	TES Capacity [h]
6000-11750	0-5750	4-12

Figure 4-120 shows the CO_2 emission coefficient and LCOE for each case. For a given biomass boiler capacity, the CO_2 emission coefficient is minimum when the thermal energy storage is minimum. Table 4-59 summarizes the optimum cases selected for this scenario. The higher biomass capacity minimizes the CO_2 emission coefficient while lower biomass capacity minimizes the LCOE. The LCOE values are very similar while the CO_2 emission coefficients values present an appreciable difference. The case with a minimum CO_2 emission coefficient is achieved by a case with only a biomass boiler.

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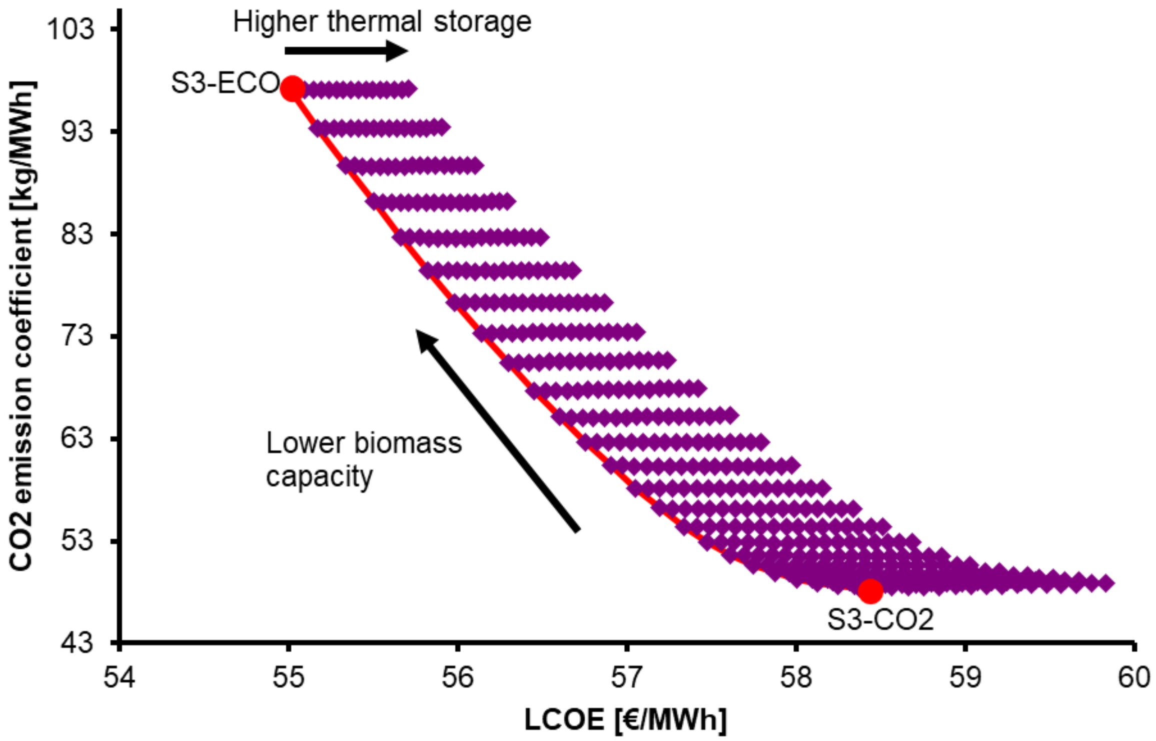

Figure 4-120 CO2 emission coefficient and LCOE of scenario S3 (Mrągowo demo follower)

Table 4-59 Optimum cases of scenario S3 (Mrągowo demo follower).

	Biomass boiler capacity [kW]	Gas boiler capacity [kW]	TES Volume [m^3]	LCOE [€/MWh]	CO2 emission coefficient [kg/MWh]
S3-CO2	11750	0	808	58.38	48.37
S3-ECO	6000	5750	412	55.01	97.15

4.6.3.4 SCENARIOS COMPARISON

Table 4-60 summarizes the results of the reference case and the selected cases for each scenario. All cases present lower CO_2 emission coefficient then reference case because the coal boiler is replaced by less polluting technologies (Figure 4-121). The difference between cases is owing to the gas consumption. The cases with lower gas consumption have lower emission coefficient.

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Table 4-60 LCOE and CO2 emission coefficient (Mrągowo demo follower)

	LCOE [€/MWh]	CO2 emission coefficient [kg/MWh]
S0	21.12	400.55
S1-ECO	55.59	83.99
S1-CO2	58.13	67.27
S2-ECO	55.33	73.39
S2-CO2	58.12	51.72
S3-ECO	55.01	97.15
S3-CO2	58.31	48.37

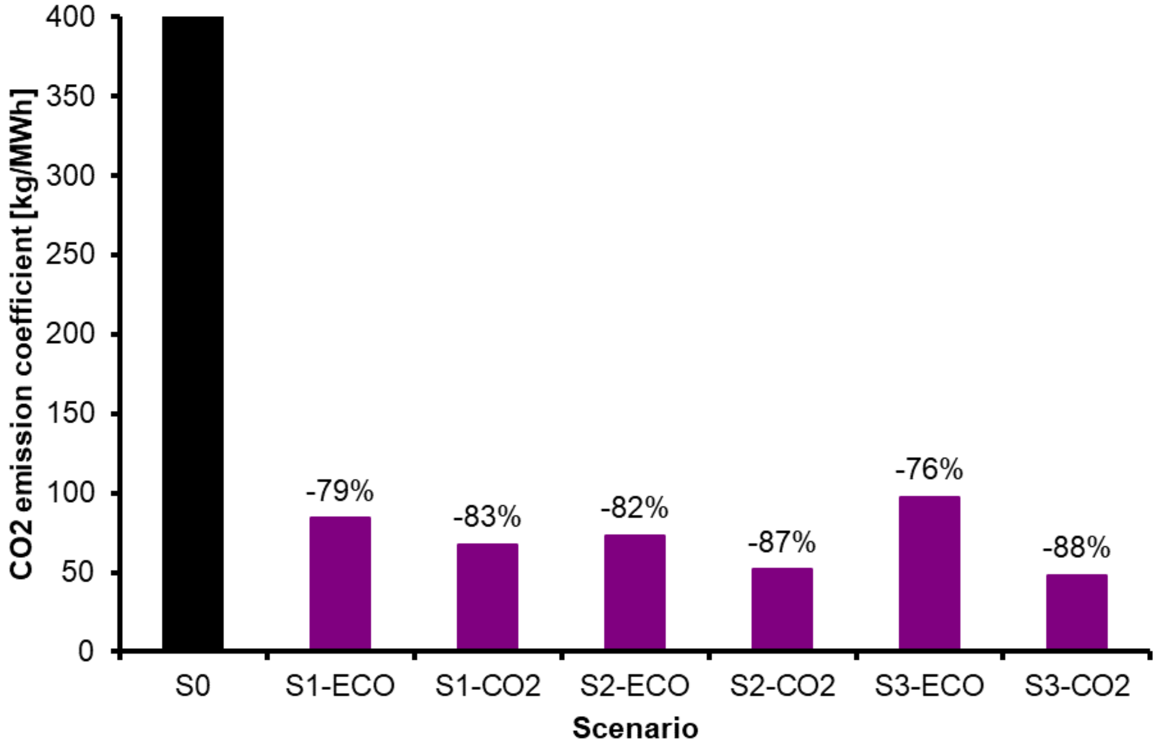

Figure 4-121 Comparison of the CO2 emission coefficient (Mrągowo demo follower).

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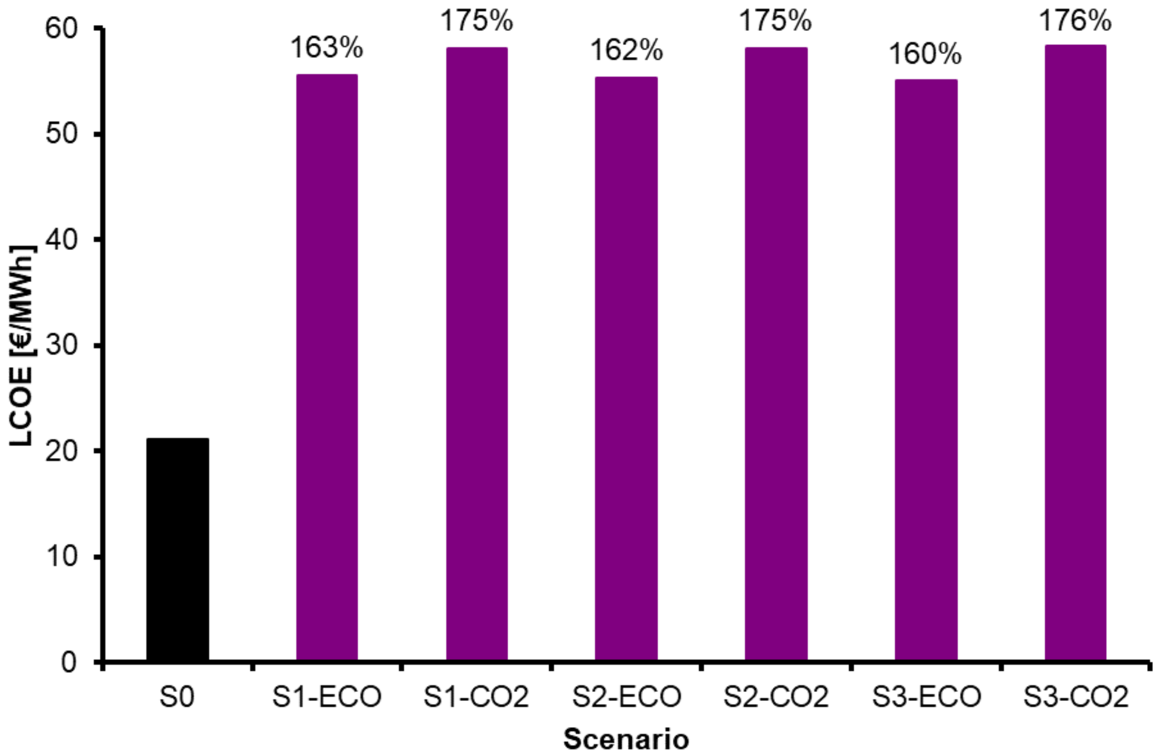

Figure 4-122 Comparison of the LCOE (Mrągowo demo follower).

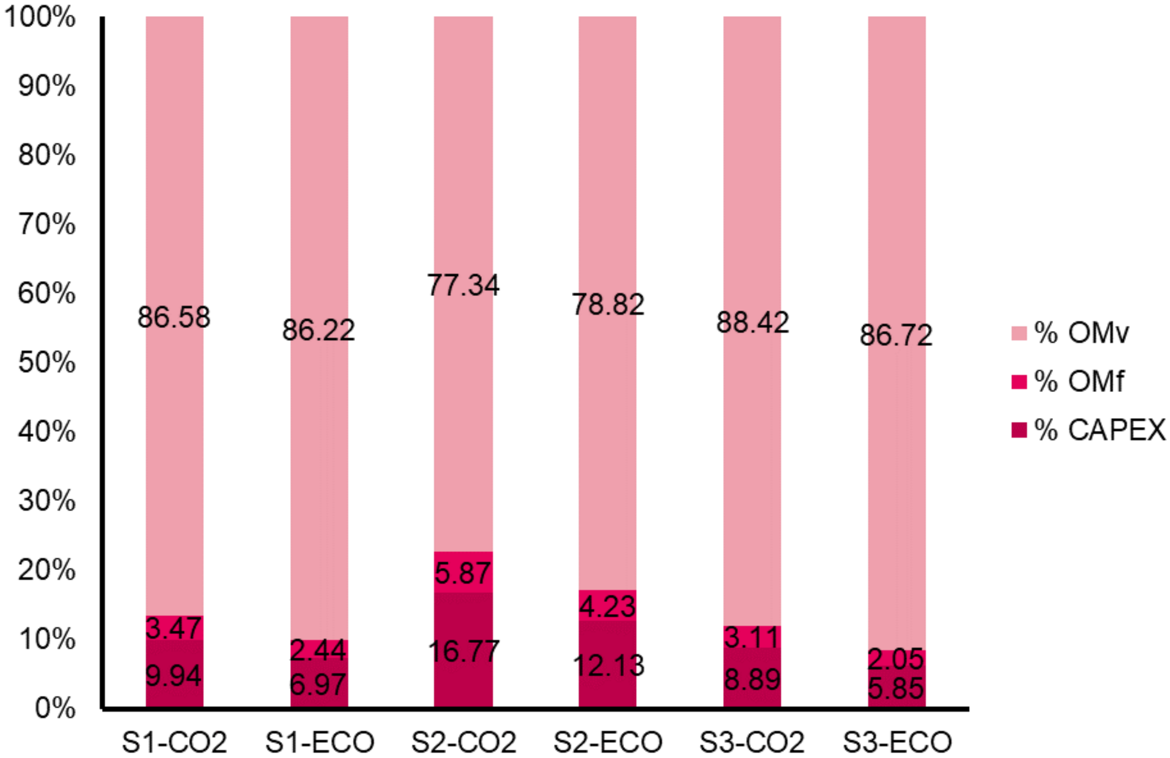

Figure 4-123 Comparison between the LCOE breakdown (Mrągowo demo follower).

All cases present a higher LCOE than reference case (Figure 4-122) because the price of the coal is lower than the price of the biomass and gas.

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Figure 4-123 shows LCOE breakdown by CAPEX, fixed OM and variable OM. In all cases, the higher contribution is owing to the variable OM. This indicates that the LCOE is highly influenced by the cost of fuel (biomass and gas). In scenario 2, the contribution of this cost is lower because the fuel consumption is reduced by the solar technology. Therefore, the LCOE will be less dependent on fuel prices.

4.6.3.5 SCENARIO TO BE DEVELOPED

The scenario to be developed is scenario 2. The use of solar technology together with the storage system reduces the fuel consumption (gas and biomass). This allows reducing the CO2 emissions coefficient and reducing the dependence of the price of fuels. Within this scenario, the case with minimum emissions is selected (S2-CO2). The reduction in the emissions coefficient is more significant than the increase in the LCOE.

4.6.4 CONCLUSIONS

This study analyzes the substitution of carbon by biomass and natural gas in a Mrągowo district heating network. In addition, the use of solar energy and storage have been analyzed to reduce dependence on fossil resources. The results show that the CO2 emissions could be strongly reduced. However, the LCOE is not reduced due to the difference between fuel prices.

The use of solar energy with thermal storage is recommended because the solar resource allows reducing fuel consumption and, consequently, CO2 emissions. The size of the collector area and the thermal energy storage should be optimized in function of the biomass and gas boiler capacity.

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5 GENERAL FEEDBACK FROM DEMO-FOLLOWERS

For Simulation work Team, it has been a pleasure to work with representants of real case of DHC site. It helps a lot to make simulation parametrization fit with real needs for demo-followers helping them to decide for potential development of future DHC construction.

This kind of feedback has been very profitable at each step of simulation work, 1st and 2nd workshop. It helps to identify relevant scenarios for the site. And their collaboration helps us to give more significant sense to KPIs analyse.

The debates concerning technologies or design is the kind of feedback that make simulations results more relevant. We are very grateful for their participation and hope WEDISTRICT collaboration helps them in DHC development.

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6 GENERAL CONCLUSIONS AND TRENDS

All simulation work helps to point out general trends of optimizing WEDISTRICT technologies and conventional solutions to make DHC more efficient in energy consumption, CO2 emission reduction and economic rentability.

Absorption chillers work efficiently in some specific situation as indicated in Canarias virtual demo. Primary circuit must be designed for high water temperature and secondary circuit with low water temperature. Another important criterion is into equivalent simultaneous heating and cooling consumption.

Waste heat recovery based on fuel cell from date centre is not a solution adapted for DHC. A limited energy efficiency and high investment make this solution not relevant for it as it has been analysed for SeiMilano and TecnoAlcalá virtual demos

RACU technology is energetically efficient. But it is limited by its expensive cost and in high humidity environment.

Geothermal energy storage is not the most relevant solution for DHC. A better alternative would be the use of ground water as energy source.

WESSUN has demonstrated In Playa del Inglés virtual demo a high level of renewable energy source use and makes it as a relevant solution for DHC. It fits well with 4th generation DHC, as seen in Independencia virtual demo.

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