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Bachelor Thesis

"SOLAR INTEGRATION IN A DISTRICT HEATING AND COOLING NETWORK"

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ABSTRACT

The purpose of this project is to perform an analysis of the feasibility of integrating solar energy into a district network, that supplies the demand of the domestic hot water, space heating and cooling.

The project is divided into two main parts: the first part makes an exposition of the district networks, their situation in Spain, as well as the main solar heating and cooling systems and their components. The second part is the case of study where the district network is defined and the performance of the solar installation model are analysed, as well as the most significant elements that make up the system are presented.

Key words: district networks; solar heating and cooling; renewables energies; solar collectors.

GRATITUDE

I want to express my gratitude to all those who have accompanied and helped me during the preparation of this work and my course in the university, particularly to my family for putting up with me and supporting me, my friends for always being there and my career colleagues, for sharing with me these years and for teaching me so much in so little. I dedicate this work to all of them

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1 INTRODUCTION

The data provided by the International Energy Agency in its "Renewables 2020" report[1] can be of great help to describe the current situation of heat production worldwide. Heat account for half of global final energy consumption, standing as the largest energy end-use ahead of electricity (20%) and transport (30%). About 50% of total heat consumed in 2020 is used for industrial process, another 47% is consumed in buildings and the rest is used in agriculture. Figure 1 shows the primary sources of energy consumption and the different distribution by sector.

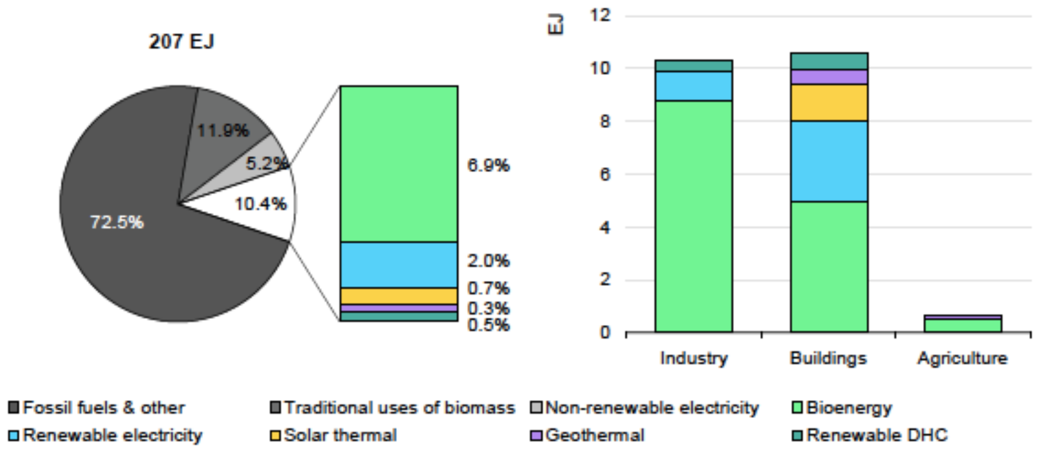

FIGURE 1 Global renewable heat consumption by fuel and technology [1]

The heat sector remains heavily fossil-fuel dependent with renewables meeting only 11% of global heat demand in 2019. In buildings, bioenergy is by far the largest renewable heat source followed by renewable electricity. In the last stages we can find thermal, renewable district heating and cooling (DHC) and geothermal as renewable heat source.

Because the vast majority of this energy is produced by fossil fuels, heat supplies contributed 40% of global energy-related CO_2 emissions in 2019, a share that has remained unchanged for the past decade.

Finally analysing this IEA data, we can surely say that the building sector is an important contributor to greenhouse gas emissions, air pollution and related to health effects, which are major concerns specially cities around the world. According to the IRENA in its

"Integrating low-temperature renewables in district energy systems: Guideline for policy makers" report[2]. About half (55%) of the people in the world live in urban areas, this percentage is expected to increase in the following years, risen up to a 68% in 2050. For this reason, it is essential to take urgent action in heating and cooling in order to decrease emissions.

The European Commission[3] has proposed in the Climate Target Plan 2030 to cut net greenhouse gas emissions in the EU by at least 55% by 2030 compared to 1990. To achieve this objective the EU should reduce buildings' greenhouse gas emissions by 60%, their final energy consumption by 14% and energy consumption for heating and cooling by 18%, compared to 2015 levels.

Multiple ways are possible to decarbonise the heating and cooling supply systems. This could be achieved by many routes, and compromise a combination of measures, not only on the demand side, by reducing the demand in buildings, but also in the supply side.

One way is by transitioning to district heating and cooling networks in urban areas. This option increases energy efficiency as the energy is produce in a single location. The idea of district networks is even more attractive when the use of renewable energy sources such as biomass, geothermal, waste heat or solar thermal is introduced. This way, district networks would also help to reduce the use of fossil fuels in the heat sector.

The integration of solar energy, as the renewable energy, in district networks to provide heat and cold, is the aim of this project.

2 DISTRICT HEATING AND COOLING NETWORKS

According to the information provided in the district heating and cooling guides[4][5], district heating produces thermal energy in centralized facilities and distributes it in the form of hot water or steam to residential, commercial or industrial consumer. In the case of district cooling the distribution of thermal energy is in the form of chilled water. Therefore, the heating or cooling effect comes from a distribution medium rather than being generated individually on site at each facility.

FIGURE 2 Schematic of a centralized heating system[7]

Figure 2 shows a schematic of a centralized district heating system. The systems based on district networks for the distribution of cold and/or heat aim to offer space heating and cooling and domestic hot water service to the occupants of the different buildings in a determined area. As mentioned before, end users can be of any kind: residents, company buildings, equipment buildings (schools, hospitals) or public administrations.

2.1 Benefits

The district heating guide[6] details the economic and environmental benefits of a district network, with respect individual production devices. A summary has been made with some of the points detailed in this guide

2.1.1 Environmental benefits

Generating the thermal energy in a central plant and distributing it to several users is normally more efficient than using in-building equipment and, therefore, the environmental impacts are generally reduced.

Greater efficiencies appear due to the large equipment and the possibility to design the equipment to nearly match the load demand, remaining within the equipment range of highest efficiency. District network systems take advantage of the diversity of demand across all users in the system and may also implement technologies such as thermal storage more easily than individual building heating systems.

Emissions are easier to control than those from individual plant, control technologies that are not technically or economically viable for small scale devices, can be used in centralized plants.

District-scale system provides fuel flexibility for the future, offering the possibility to use fuels that would not be feasible to use on an individual building scale. This is the case of new renewable sources with low carbon dioxide emissions, such as: the thermal energy from municipal wastes, biomass, geothermal or other type of renewable resources.

In conclusion, from an emissions and efficiency point of view, generating heat and/or cold in a central plant has the additional advantage of higher quality of equipment, higher seasonal efficiency due to demand diversity and less system heat loss.
District grids can reduce global fossil energy consumption by more than 50% and this is important in countries energy dependent like ours.

2.1.2 Economic benefits

Despite the fact that the initial capital investment for the construction of a district heating and cooling system is very high, consumers can realize benefits for the economies of scale in the long term.
Equipment maintenance is very reduced, since the equipment for individual users is reduced or even eliminated. Reducing the equipment also increases the usable space in

the buildings. Finally, more efficient energy systems, provide more energy at the same or even lower price.

2.2 Components of a district network

The main elements of district heating and cooling are: the central plant, distribution pipes lines and the substations.

After having analyzed several sources of information, the most relevant information that has been found on the components of the district networks is given by the “Guia Basica de redes calor y frio” [7] and “Guia técnica de enrgia solar térmica”[8]. A detailed summary of the information from these sources has been made.

2.2.1 Central plant or production source.

Where the thermal energy is produced. They are designed in order to provide the total heating and cooling demand.

Boilers and cogeneration are mainly used in these facilities. There is always the possibility of integration of solar energy, independently of the technology used.

For cooling, the most common technology will be cooling machines. It also exits the possibility of using absorption system feed with hot sources.

2.2.2 Distribution pipe network

The correct dimensioning of the distribution network is essential to guarantee the economic viability of urban air conditioning projects and to avoid thermal losses as much as possible. The most common is to use insulated steel or plastic pipes.

In a pipe network, it is possible to distinguish different parts, the trunk network, the main and secondary branches and the connection pipes for the service connections to users.

A pumping system is needed to drive and regulate the flow that circulates through the pipes of the distribution networks. The selection of pumps depends on many factors, among which the type of flow rates, the cost of the installation, the efficiency and the speed necessary for operating maneuvers stand out.

Apart from the sources detailed above, for the study of the distribution system configuration, valuable information from a report of the “Instituto para la Diversificación y Ahorro de Energía”[9] has also been taken into account. The configuration of the piping system depends on the type of demand to which it will be supplied. In the event that there is a demand for heat and cold, there are several options:

- Two-tube systems, one for heat and one for cold. In this case the demands for heat and cold cannot be provided simultaneously.
- Three tubes systems: one for cold, another for heat and a common return. It saves on investment of pipes, but energy efficiency decreases by mixing both fluids.
- Four-tubes systems: Allow the simultaneous supply of heating and cooling demands. Two circuits (impulsion and return) for each (heat and cold).
- Six or eight pipes systems: they are used when different temperatures, flow rates and periods of use of heat and cold are required, as occurs when domestic hot water application are introduced.

2.2.3 Substations or customer interconnection

The connection with client and the substation consists of the joining together of the energy distribution system and the consumers. The objective of the substations is to adequate the pressure and the temperature to the consumption conditions of the building.
Hot water, steam or chilled water may be used directly by the building system or isolated by the heat exchanger.
Those with direct connection in which there is no separation between the network circuit and that of the user are not recommended and are used less and less. The most used are indirect connection where a heat exchanger is needed to separate the network and the indoor installation.

3 DISTRICT HEATING AND COOLING NETWORKS IN SPAIN

In order to state a general image of the current situation of the district networks in Spain, the data provided by the "Asociación de empresas de Redes de Calor y Frio "(ADHAC) in their report "Censo de redes 2020"[10] have been considered. After analyzing the data from this source, the most relevant point for the study have been highlighted below.
The number of networks in Spain this last year has increased by a 13% compared to the previous one, with a total of 468 networks in 2020. Installed power has also increased by 2%, reaching 1,610 MW in the last year. The increase in networks and installed power can be seen in the figure 3 and figure 4 respectively.

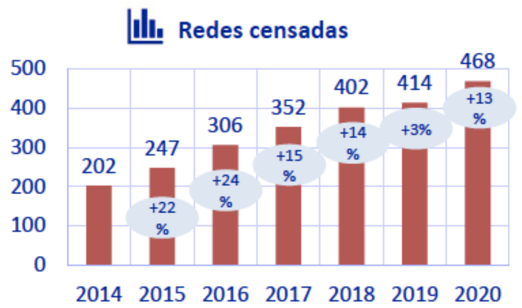

FIGURE 3 Registered networks [10]

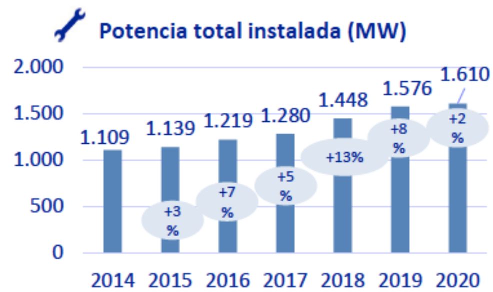

FIGURE 4 Total installed power [10]

The community with the highest number of networks is Cataluña with a total of 171 networks, followed by Castilla y Leon with 65. Regarding installed power, Catalonia follows the first with 550 MW of power, followed by Madrid and Navara. These three communities constitute 70% of the total installed power. The distribution of installed power depending on the community is shown in figure 5 and figure 6.

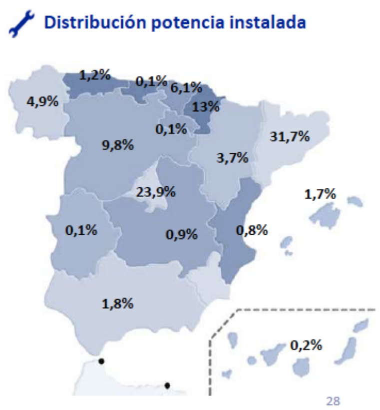

FIGURE 5 Installed power distribution [10]

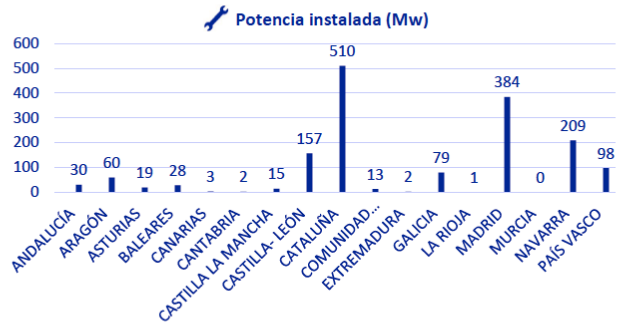

FIGURE 6 Installed power (MW) [10]

As it is indicated in figure 7, 91% of existing networks supply heat. In installed power this is translated into a 75% power entirely for heat generation. As show in figure just 1% of the district networks supply just cold.

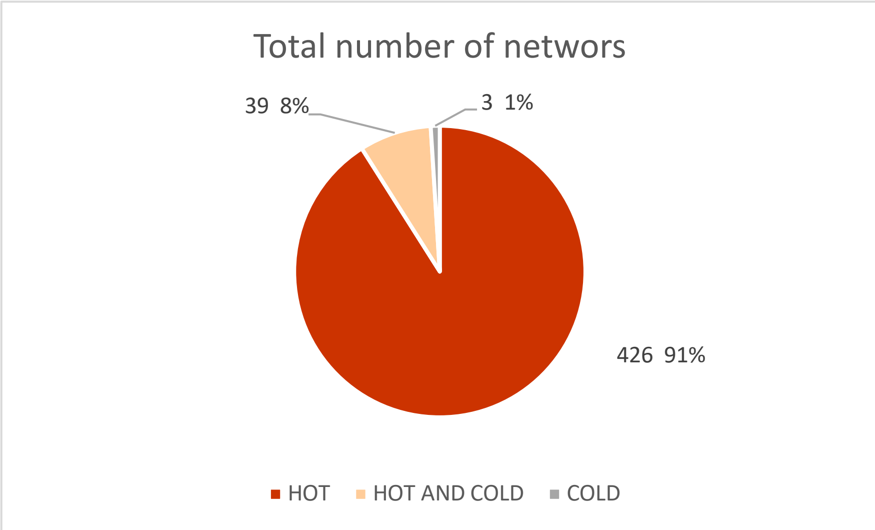

FIGURE 7 Total number of networks depending on what they supply [10]

Referring to the type of customers, the tertiary sector represents 54% of installed power. Although the number of networks destined for the housing sector is higher than the one for the industrial sector with 25% versus 8%, the installed power for the industrial sector is slightly higher, a 6% higher in the industrial sector. This information can be seen in figure 8.

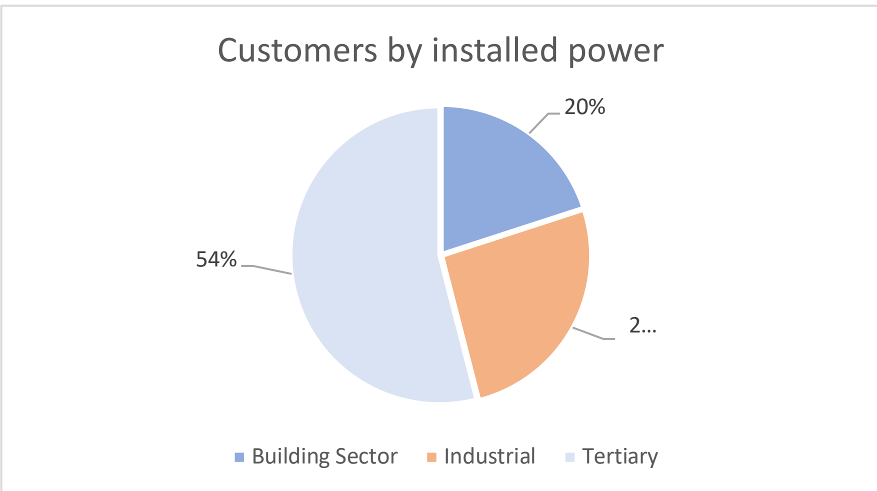

FIGURE 8 Customers by installed power [10]

If we look at the energy sources that supply the district networks. We can see in figure 9 that 80% of the networks include renewable energies in their energy mix.

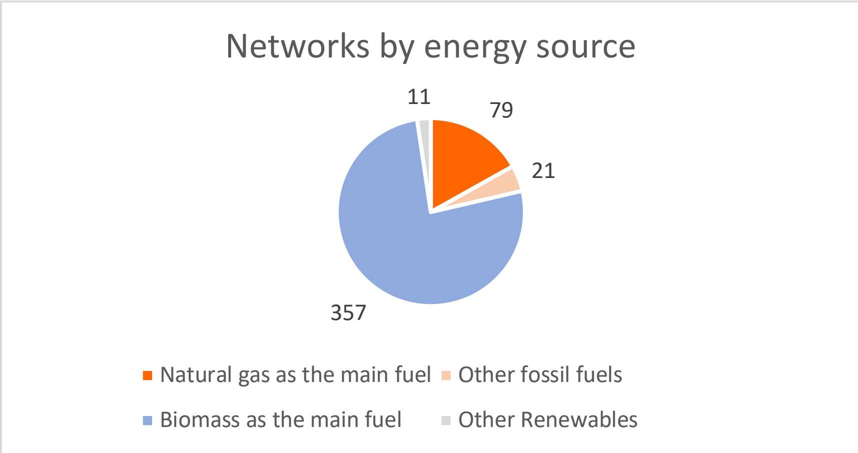

FIGURE 9 Networks by energy source [10]

Regarding installed power, natural gas is the main source of energy with 58%, followed by biomass with 38%. the share of the rest of the renewable energies is very low, 2%.

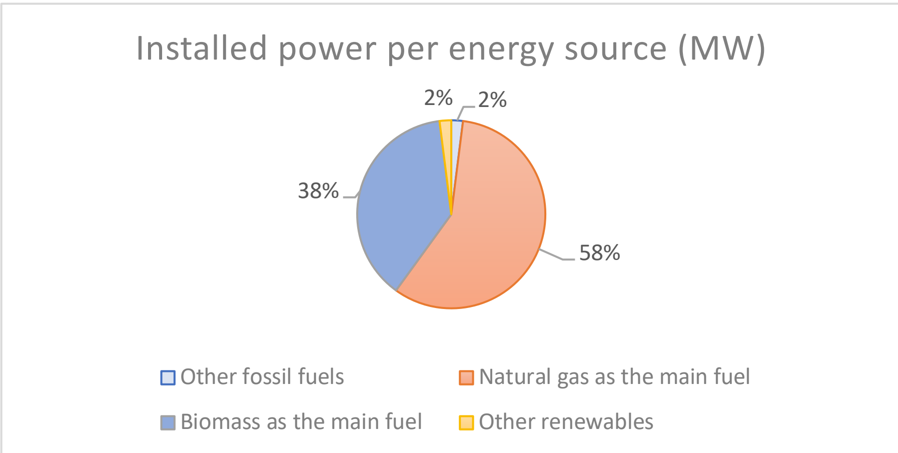

FIGURE 10 Installed power per energy source (MW) [10]

Finally, it is important to mention this last year 2020, a total amount 333.300 tones of CO_2 have been avoided thanks to the use of district networks.

Despite the fact that the number of networks in our country has increased considerably since 2013. The average number of networks in Europe is much higher than in Spain. The main problems for the expansion of urban air conditioning are related to the lack of long-term energy and urban planning[8]

4 RENEWABLE DISTRICT HEATING AND COOLING

District networks are capable of utilizing different energy sources, as seen in figure 11, they are not tied to a single type of supply. The energy sources used in a district heating and cooling include fossil fuels, nuclear power, cogenerated heat, waste heat, geothermal, solar thermal and biomass. District heating and cooling (DHC) systems utilize mainly fossil fuels, while renewable energy's overall share in district heating and cooling is marginal, it was less than 8%[2].

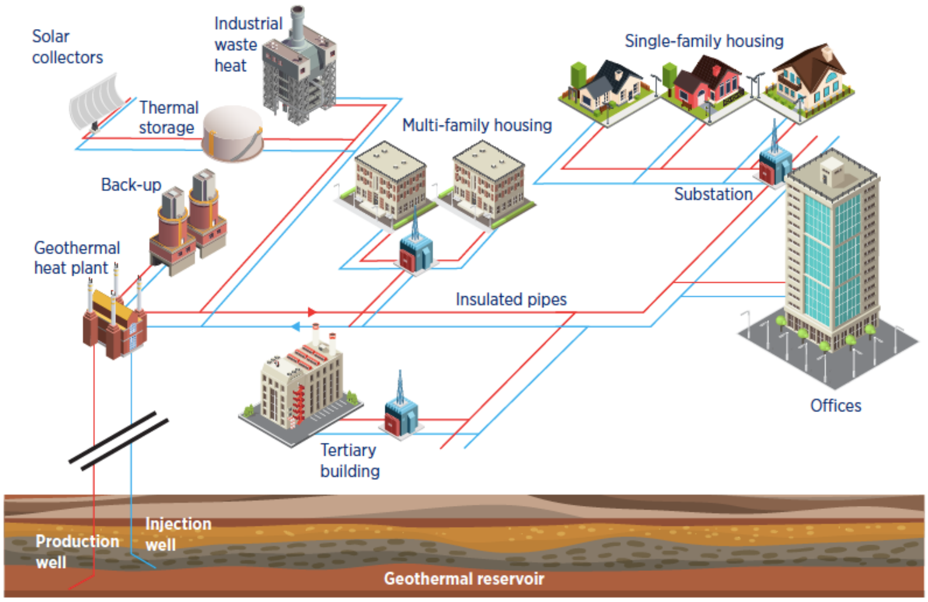

FIGURE 11 Schematic diagram of a district heating system using multiple energy sources [2]

Technology innovation and current trends towards more energy efficient buildings are forcing the development of new generations of DHC systems. New generations will enable the use of low temperature renewable energy sources such as geothermal, solar thermal or waste heat from industrial processes.

As shown in figure 12, the development of DHC technologies has resulted in improved efficiency and the use of lower supply technologies. The different DHC generation are well explained by the IRENA[2] and the article "Analysis of district heating and cooling in Spain"[11]. Next, the conclusion that has been drawn from these two sources is written. First generation technologies (1GDHC) were based mainly on steam transport, but steam at high temperature produces a large amount of heat losses. In the second generation

(2GDHC), steam was replaced by hot water under pressure, which allowed fuel savings but showed inability to control the heat demand. Then the third generation was developed, where pressurized water is still the heat transfer fluid, but temperatures can be lower, below 100 ºC. At present the fourth generation is deployed, and it works with even lower temperatures, below 50-60 ºC[12]. This trend paves the way for better utilization of renewables and recycled low-temperature heat.

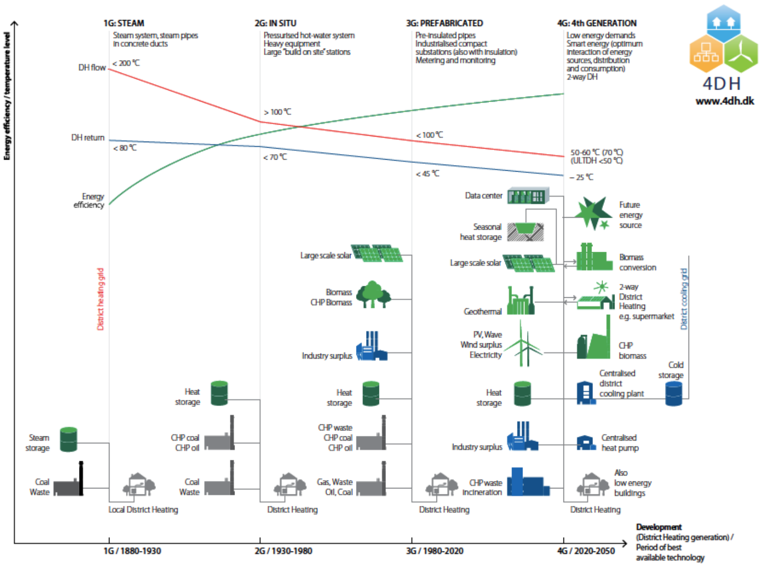

FIGURE 12 Evolution of district energy technologies, their operating temperatures and examples of energy sources [2]

Many local renewables sources can be used in DHC system the most commonly used are: geothermal, waste heat, biomass and solar thermal. The following summary of them has been developed based on the information given in the IRENA report[2] .

4.1 Geothermal

Built in locations above large geothermal sources, typically those with naturally occurring hot springs, geyser and aquifers. Advantages provider year around low-cost heating and cooling. Disadvantages geologically limited and usually only efficient in moderate temperature zones.

4.2 Waste heat

Excess heat or waste heat from industrial processes such as refineries, cement production or steel mills, that cannot be recovered for the process itself, can be used for district networks.

This renewable source produce temperatures high enough to directly supply heat to the network. In addition, waste heat can also supply cold through sorption chillers.

4.3 Biomass

Biomass is the by far the largest source of renewable heat. Biomass for district heating includes fresh wood, energy waste, agricultural residue, food waste, industrial waste and co-products of manufacturing, and biogas. This option represents a reliable supply in district networks.

4.4 Solar thermal

Solar collectors are used to supply heat and/or cold to a district network.

The integration of solar energy in district networks can be differentiated in centralized and decentralized.

- Centralized solar district networks, where a huge collector field feeds a production central at a sole location.
- Decentralized solar district networks, where the solar collectors are distributed in many locations of the district network. This option is common in places where there is no enough place available to install a massive collector field, for example in urban areas, in this case the cost reduction, due to a centralized installation, are decreased.

This renewable source is a good option for district networks. since it can be combined with many other energy sources, including fossil fuels. In addition, solar technology is also suitable to supply cold, using absorption chillers.

Forecast for the future are positive as the share of renewable energy in district heating is expected to a 77% in 2050, figure 13. Based on this scenario 5% of the total final energy consumption could be delivered by DHC systems in 2050 compared to the 3% in 2017[2].

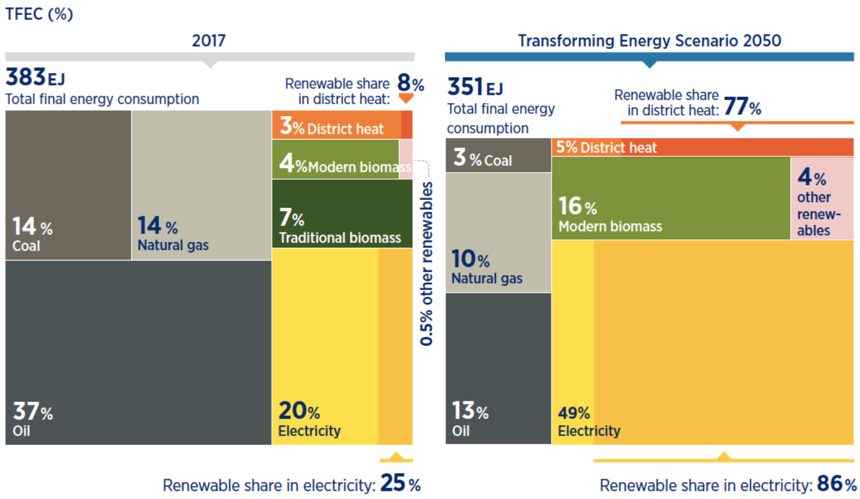

FIGURE 13 Breakdown of total final energy consumption by energy carrier in 2017 and in the Transforming Energy Scenario2050 (EJ) [2]

5 COMPONENTS OF SOLAR THERMAL ENERGY

Main components of these systems and the ones explained in this project are: the solar collectors, the storage tank, the auxiliary energy, the distribution pipelines and the working fluid and the heat exchanger.

5.1 Solar collectors

Solar collectors act as heat exchangers that transforms solar radiant energy into heat. However solar collectors differ from conventional heat exchangers in the sense that the energy transfer is from a distant source, the incoming solar radiation, to a fluid that can be air, water or oil, flowing inside the collector.
This energy can be used for different applications such as, hot water or space conditioning equipment.

5.1.1 Solar angles

Before beginning to explain the different solar collector technologies, it is important to make a brief summary of the solar angles and the equations to calculate them. Solar angles make possible to predict accurately where the sun will be in the sky at a given time of day and year. For solar application this will be essential in order to calculate the performance and operation of the solar collector.
Of all the sources that have been found on this subject, the most recurrent information and data, which are repeated in numerous studies, are those provided by the books "Solar Energy Engineering" and "Solar Engineering of Thermal Processes" in their chapters 2[13] and 1[14] respectively. Based on these sources, a review has been carried out with the most relevant information and equations for our study.

5.1.1.1 Latitude L

The angular position north or south of the equator, south negative; $-90° \leq L \leq 90°$

5.1.1.2 Solar declination δ

Declination angle is the angle between the sun–earth centerline and the projection of this line on the equatorial plane. Declinations north with respect the equator are positive, and those souths are negative. The declination ranges from 0° at the spring equinox to +23.45° at the summer solstice, 0° at the fall equinox, and −23.45° at the winter solstice. Declination angle reaches its maximum in the months between May and July[13].
Declination depends on the day of the year and can be calculated approximately with the following formula:

$$\delta = 23{,}45 \times \sin\left(\frac{360}{365} \times (284 + N)\right) \qquad (1)$$

5.1.1.3 Hour angle h

The hour angle is the angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15° per hour; morning negative, afternoon positive. The hour angle can also be obtained from the apparent solar time (AST); that is, the corrected local solar time:

$$h = (AST - 12) \times 15 \qquad (2)$$

At local solar noon, AST = 12 and h = 0°

5.1.1.4 Zenith angle Φ

The zenith angle is the angle between the vertical and the line to the sun, that is, the angle of incidence beam radiation in a horizontal plane.

5.1.1.5 Solar altitude angle α

The solar altitude is the angle between the horizontal and the line to the sun. it is the complement of the zenith angle.

$$\Phi + \alpha = 90° \qquad (3)$$

$$\sin(\alpha) = \cos(\Phi) = \sin(L)\sin(\delta) + \cos(L)\cos(\delta)\cos(h) \qquad (4)$$

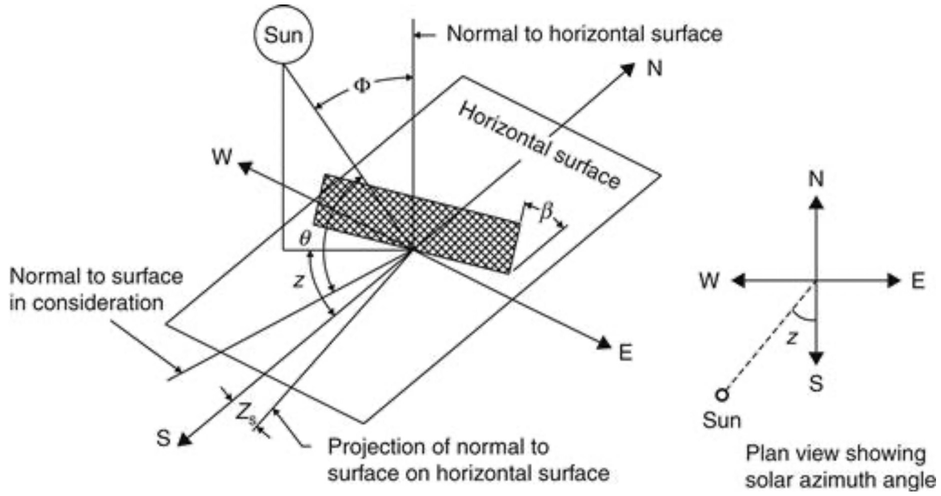

FIGURE 14 Solar angles diagram[13]

5.1.1.6 Slope or tilted angle β

The surface tilted angle is the angle between the plane of the surface, collector, and the horizonal. $0° \leq \beta \leq 180°$. The different solar angles with respect a tilted angle are shown in figure 13.

5.1.1.7 Solar azimuth angle z

Solar azimuth angle is the angular displacement from south of the projection of beam radiation on the horizontal plane. Displacement east of south are negative and west of south are positive. The mathematical expression for the solar azimuth angle is:

$$\sin(z) = \frac{\cos(\delta) \times \sin(h)}{\cos(\alpha)} \qquad (5)$$

5.1.1.8 Surface azimuth angle.

Surface azimuth angle is the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due south, east negative, and west positive, $-180 \leq Z_s \leq 180$

For a south-facing tilted surface in the Northern Hemisphere, Z_s = 0°

For a north-facing tilted surface in the Southern Hemisphere, Z_s = 180°

5.1.1.9 Solar incidence angle θ

The solar incidence angle, θ, is the angle between the sun's rays, beam radiation, and the normal to the surface. For a horizontal plane, the incidence angle, θ, and the zenith angle, Φ, are the same. The general expression to determine this angle is:

$$\begin{aligned}\cos(\theta) = {} & \sin(L)\sin(\delta)\cos(\beta) - \cos(L)\sin(\delta)\sin(\beta)\cos(Z_s) \\ & + \cos(L)\cos(\delta)\cos(h)\cos(\beta) \\ & + \sin(L)\cos(\delta)\cos(h)\sin(\beta)\cos(Z_s) \\ & + \cos(\delta)\sin(h)\sin(\beta)\sin(Z_s) \qquad (6)\end{aligned}$$

5.1.1.10 Angles for sun tracking surfaces

Some collectors move in different ways in order to track the sun, with the objective of minimizing the incidence angle of direct radiation on their surfaces and thus maximize the incident beam radiation. The angles of incidence and the surface azimuth angles are needed for the radiation and power calculations of these collectors[14].

Tracking systems are classified by their motions. Rotation can be about a single axis or it can be about two axes. In the case of a single-axis mode rotation could have any orientation but which in practice is usually horizontal east-west or north-south, vertical, or parallel to the earth's axis. The different tracking modes are represented in figure 15.

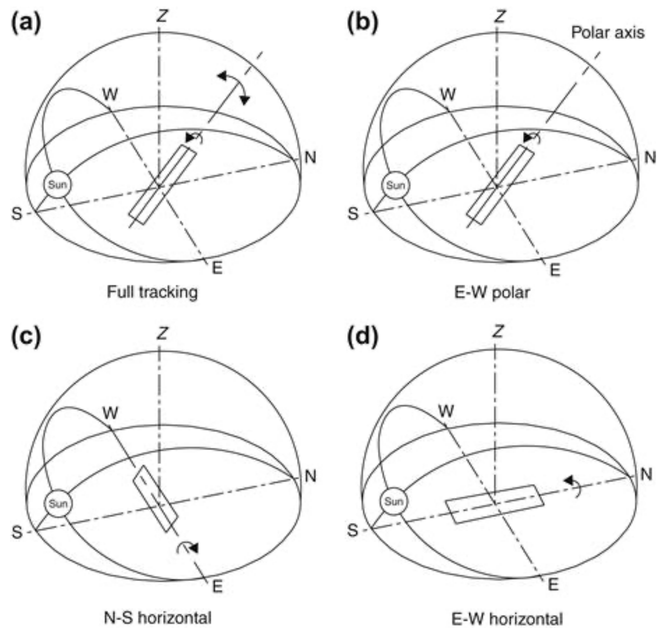

FIGURE 15 Collector geometry for various modes of tracking [13]

It is clear that tracking can significantly change the time distribution of incident beam radiation as it can be seen in figure 16. In this figure it can be seen a comparative of the solar radiation flux depending on the collector's orientation and on the period of time. Three cases are plot, figure 16: a fixed surface with tilted angle equal to the latitude, 45 degrees, and two surfaces that track the sun about a horizontal north-south or east-west axis. The plot refers to two different time periods: one is the summer solstice, continuous lines, and the other the winter solstice, dotted line.

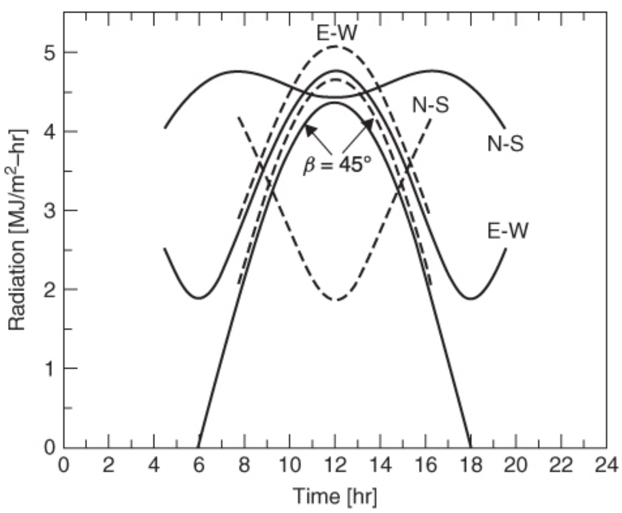

FIGURE 16 Extraterrestrial solar radiation for different tracking modes in both winter(dotted line) and summer(solid line) solstices[14]

Many conclusions can be drawn from this figure:

- Tracking does not always mean an increase on beam radiation. As it is shown in the picture in the winter solstice an orientation north south represents a significantly less incidence radiation than in a fixed surface.
- An east west orientation result on a similar radiation wave in both summer and winter solstice. The incident radiation is higher in the middle hours of the day and lower early in the morning or late in the night.
- In the summer solstice a north south orientation results on a lower radiation in the middle hours of the day and a higher radiation in the early and late hours of the day.

Different formulas are given in order to calculate the incidence angle of this tracking surface:

- <u>Full tracking or two-axis tracking</u>

  This mechanism manages to keep the surface continuously oriented facing the sun at all times. Its incidence angle is equal to zero. Of course, this depends on the accuracy of the mechanism. Generally speaking, the full tracking configuration collects the maximum possible sunshine[13].

- <u>Horizontal east-west axis with north south tracking:</u>

  For a plane rotated about a horizontal east-west axis with continuous adjustment to minimize the angle of incidence[14].

$$\cos(\theta) = \sqrt{1 - cos^2(\delta) sin^2(h)} \qquad (7)$$

- <u>Horizontal north-south axis with east-west tracking:</u>

  For a plane rotated about a horizontal north-south axis with continuous adjustment to minimize the angle of incidence[14].

$$\cos(\theta) = \sqrt{cos^2(\Phi) + cos^2(\delta) sin^2(h)} \qquad (8)$$

5.1.2 Solar collectors types

Solar collectors can be differentiated mainly in two types: stationary and concentrating or sun-tracking collectors:

5.1.2.1 Stationary solar collectors

These collectors are permanently fixed in position and do not track the sun. A non-concentrating collector has the same area for intercepting and absorbing solar radiation.

Three main types of collectors fall into this category: Flat-plate collector, stationary compound parabolic collector (CPC), evacuated tube collector (ETC).
As seen in figure 17[15] the most common ones in thermal application are the evacuated tube collector and the flat plate collector, these are the one that are going to be detailed in this section.

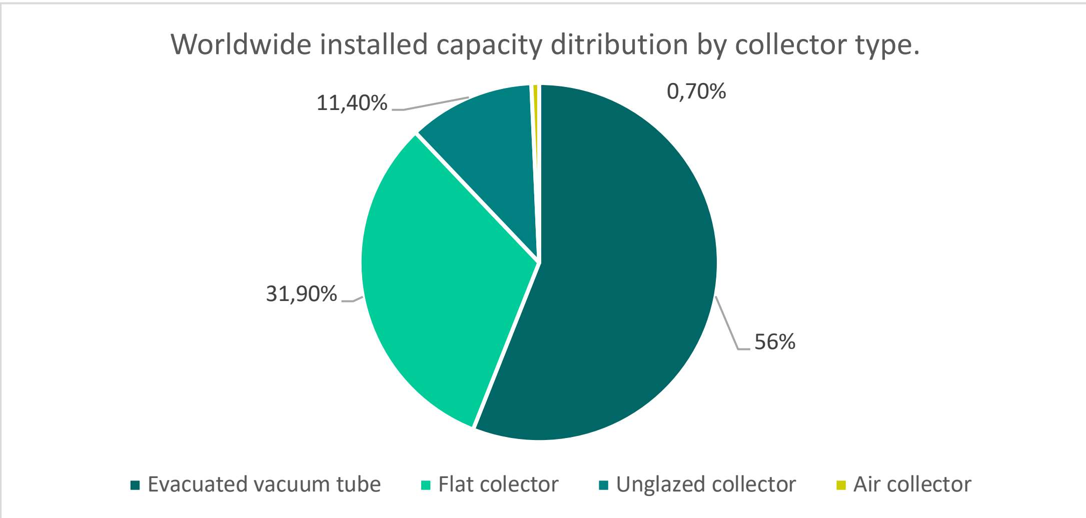

FIGURE 17 Worldwide installed capacity distribution by collector type [15]

5.1.2.1.1 Flat plate collector

In order to give a correct overview of the characteristics and operation of the flat collector technologies, different sources of information have been considered. The most relevant and recurring are the chapter of the books[16] and [17] and the article[18]

The functioning of a solar flat plate collector (FPC) is simple. Solar radiation passes through a transparent cover and heat up a dark flat surface, the absorber plate, which converts the solar radiation energy into heat energy. This heat is then transferred to the fluid flowing through the pipes attached to the absorber sheet.

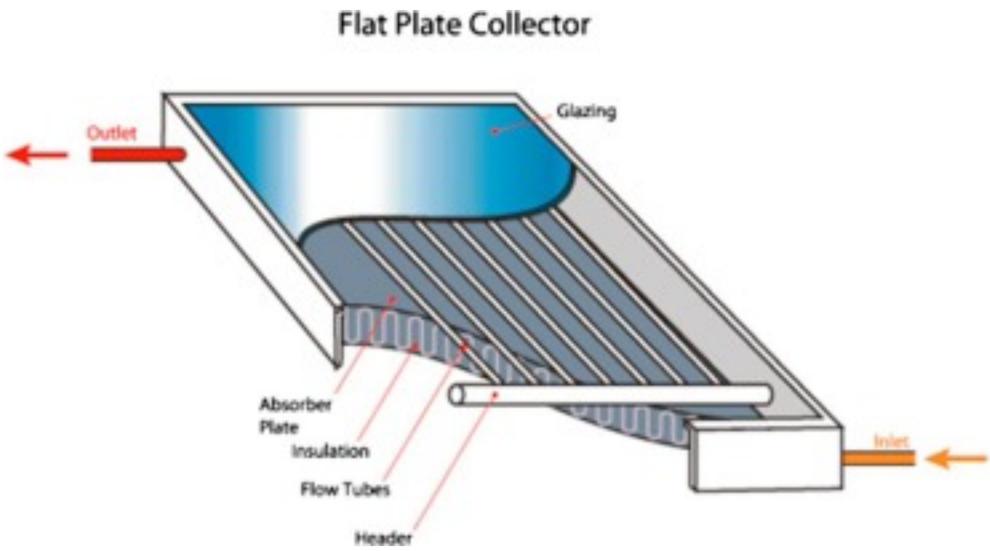

FIGURE 18 Schematic of a typical flat collector [19]

The absorber plate is made up of high thermal conductivity metals such as copper, aluminum steel and are painted with selective coatings to maximize the absorption of incident solar radiation. The underside and the two sides of the absorber are well insulated to reduce conduction heat losses[18].

The tubes or ducts carrying the fluid are either integral or attached to the absorber sheets. The liquid tubes, called riser tubes, are connected at both ends by large-diameter header tubes. The header and riser tubes collector are the typical design configuration for flat-plate collectors.
Cover sheets, also known as glazing, are used to reduce convection losses as they prohibit surrounding air from enter in touch with the absorber plate. They also reduce radiation losses, as they allow the high frequency solar rays to pass through and reach the absorber plate but prevents the low frequency rays in the absorber plate from escaping. Material commonly used for this purpose is glass. Some plastic materials can also be used since they are cheaper and have higher transmittance, however they are not as durable[18].

Generally flat-plate collectors can be designed for applications requiring energy delivery at low temperatures, with these collectors' good efficiencies can be obtained up to temperatures about 100 ºC[17].

The main advantages of these collectors are that they can collect both beam and diffuse solar radiation, do not require tracking of the sun, and require little maintenance. As they are fixed, their manufacturing is simpler, as they do not require sophisticated positioning or mounting. A liquid (water or oil) or air can be used in these collectors. Water is usually the best choice due to its high availability, large specific heat capacity, and high mass density. The problem with water is that it can freeze during periods of low temperatures and cause damage in the collector. For this reason, antifreeze mixtures are commonly used.

Flat plate collectors are commonly used in the residential sector to provide the domestic hot water demand. They can also be used for building space heating and cooling, and industrial process.

5.1.2.1.2 Evacuated tube collector

To give a clear idea of the main features and the operation of this type of collector, it has been used the information given by the references in the chapter of the book[16] and the article[19].

FPC were designed to work in sunny climates, however when the weather conditions are unfavorable, their performance is highly decreased. Evacuated tube collectors (ETC) have a different way of operation, so they performance better even in cold, cloudy and rainy weather conditions.

ETC are composed of a copper heat pipe, consisting of a thermal conductor, placed inside a vacuum-sealed tube, arranged in parallel rows with many other identical tubes. Vacuum-sealed glass tubes are set into a horizontal manifold placed at the top of the collector. The pipe is then attached to a dark absorber coating. Projecting from the top of each tube is a metal tip attached to the sealed pipe, called the condenser.

The functioning of these collectors is the following: inside the heat fluid there is a heat transfer fluid, as the fluid receives heat, it evaporates and the vapor goes up to the top of the heat pipe, where it condensates and releases heat. The collected heat is transferred to Water, glycol or oil flows that goes through the manifold. The condensed fluid goes down the solar collector and the process is then repeated.

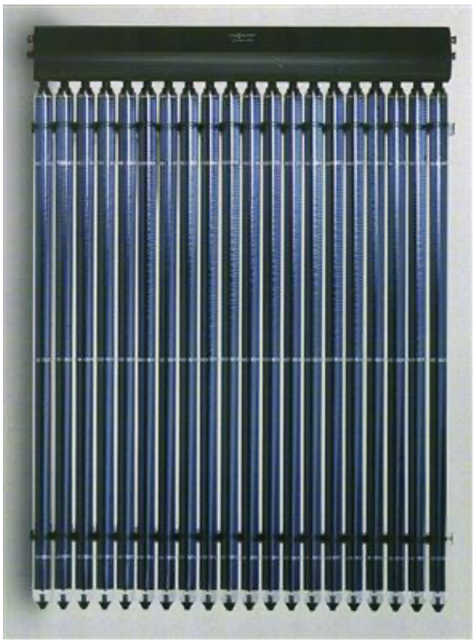

FIGURE 20 Actual ETC installation [16]

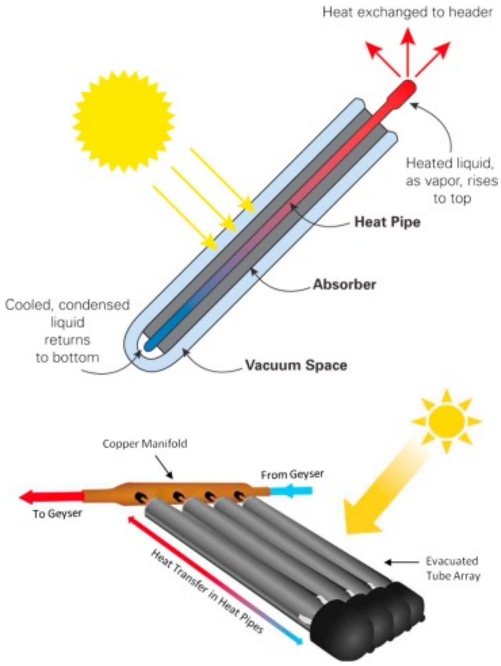

FIGURE 19 Schematic diagram and operating principle of an ETC [19]

The vacuum envelope reduces the heat losses by convection and conduction, thus these collectors operate at higher temperatures than FPC, up to 150ºC. ETC collects the beam and diffuse radiation as well, but their efficiency is better at low incidence angle, so they are better than FPC in terms of performance along the day.

Figure 19 shows a schematic of an ETC operation while in figure 20, it can be seen a picture of a real evacuated tube collector.

5.1.2.2 Concentrating solar collectors

A summary with the main features, advantages and disadvantage of concentrating collectors has been written with the information provide in[16] and [20]

Frequently it is convenient to deliver energy at temperatures higher than those obtained with stationary collectors. Higher temperatures can be achieved by reducing the area from which heat losses occur. This is done by interposing an optical device between the source of radiation and the energy-absorbing surface. The small absorber will have less heat losses than conventional flat-plate, at the same absorber temperature[20].

In these concentrating systems a device, formed by mirrors or lenses, concentrate the solar radiation, reflecting or refracting it, into a receiver that is placed in the focal line, increasing the energy flux in that line.

These collectors have two main components: the receiver where the radiation is absorbed and converted to heat; its components are: the absorber, covers, and insulation. The concentrator, is the part of the collector that focus the radiation onto the receiver. The aperture of the concentrator is the area through which the incident radiation enters the concentrator.

The definition of concentration ratio, used here, is the area concentration ratio, the ratio of the area of aperture to the area of the receiver. The ratios and temperatures at which energy can be delivered increase proportionally as well as optical requirements.

The main advantages of these types of collector are[16]:

- Higher temperatures are achieved in the working fluid, for this reason a higher thermal efficiency can be achieved.
- The thermal efficiency is greater because of the small heat loss area relative to the receiver area.
- Reflecting mirrors require less material and are structurally simpler than FPCs. Then the cost per unit area of the solar-collecting surface of concentrating collectors is lower than that of a flat-plate collector.
- Smaller area of the receiver reduces heat losses and improve collector efficiency.

However, sun-tracking collectors have also some disadvantages with respect stationary collectors:

- Concentrator systems hardly collect diffuse radiation. Except at low concentration ratios they can use only the direct component of solar radiation, because the diffuse component cannot be concentrated by most types.
- Cleaning and refurbishing requirements for maintenance are needed, particularly to retain the quality of optical systems for long periods of time in the presence of dirt, weather, and oxidizing or other corrosive atmospheric components.

The combination of operating problems and collector cost has restricted the utility of concentrating collectors.

This type of collector should follow the movement of the sun in order to be focused so that the incident beam radiation will be reflected to the receiver. The sun's motion can be tracked by two methods. The first is the two-axis tracking, which requires the tracking device to move in both altitude and azimuth directions, when performed properly, this method enables the concentrator to follow the sun perfectly. The second method is one-axis tracking, in which the collector tracks the sun in only one direction, either from north to south or from east to west.

The collectors falling into this category are: Parabolic trough collector (PTC); Linear Fresnel reflector (LFR); Parabolic dish reflector (PDR); Heliostat field collector (HFC). The one that are going to be detailed in this section are going to be the first two.

5.1.2.2.1 Parabolic through collector

Different sources of information have been used to give a general idea of the component, features and functioning of this type of collectors. The most relevant information has been provided by the sources[16], [21] and [22], using those documents a summary has been written.

Parabolic through collectors (PTC) belong to the line focusing systems with a one axis tracking mechanism. A schematic of a PTC can be seen in figure 21[23].

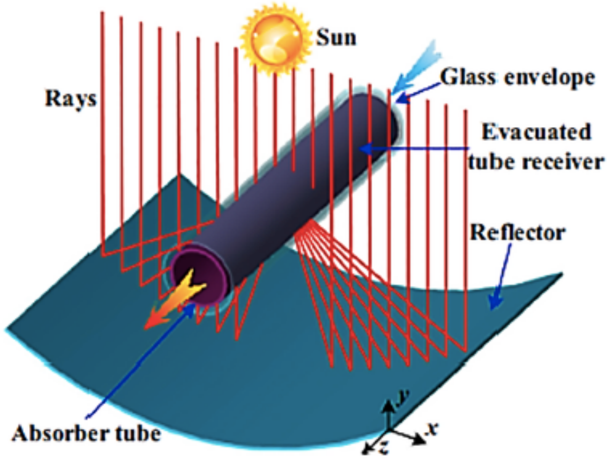

FIGURE 21 Concentration of the solar energy at the focal point of a parabolic trough collector [23]

PTC consist of an absorber, a concentric transparent cover and a parabolic reflector plate. The absorber consists of a black metal tube fixed permanently at the focus of the parabolic concentrator. The surface of the receiver is typically covered with a selective coating that has a high absorptance for solar radiation but a low emittance for thermal radiation loss, this way heat losses are reduced.

The concentric glass cover tube is usually placed around the receiver tube to reduce the convective heat loss from the receiver, thereby further reducing the heat loss coefficient.

A disadvantage of the glass cover tube is that the reflected light from the concentrator must pass through the glass to reach the absorber, adding a transmittance loss even when the glass is clean. The glass envelope usually has an antireflective coating to improve transmissivity. In addition, a vacuum pressure is obtained between cover and absorber. One way to reduce convective loss from the receiver tube and thereby increase the performance of the collector, is to evacuate the space between the glass cover tube and the receiver[16].

The parabolic concentrator is made by bending a reflective material into a parabolic shape. It is placed in a rigid structure and the solar tracking mechanism is installed in the rigid structure to track the solar radiation by the parabolic concentrator.

The idea behind these collectors is the following, when the parabola is pointed towards the sun, sun rays arrive to the reflector are reflected onto the receiver tube. The concentrated radiation reaching the receiver tube heats the fluid that circulates through it, transforming the solar radiation into useful heat.

FIGURE 22 An industrial Solar Technology collector [16]

5.1.2.2.2 Linear Fresnel reflector

A schematic of a Linear Fresnel Reflector (LFR) can be seen in figure 23. These collectors consist of an array of mirror reflectors that focus the sunlight onto a fixed linear receiver located at the common focal line of all the mirrors. Another parabolic mirror is placed at the top of the absorber tube to further focus of beam radiation reflected from the reflectors to the receiver. The concentrated heat is then transfer to a fluid that flows inside the absorber tube. These collectors operate at high temperatures, in the range of 60-250 ºC.
Flat or elastically curved reflectors are cheaper than parabolic glass reflectors, this is an advantage of these collectors with respect PTC. Additionally, these are mounted close to the ground, thus minimizing structural requirements and costs.

One problem of the LFR technology is the shading and blocking between bordering reflectors that leads to a reduction of the performance. The solution is to increase the space between reflectors and the height of the absorber towers, but this increases cost[16].

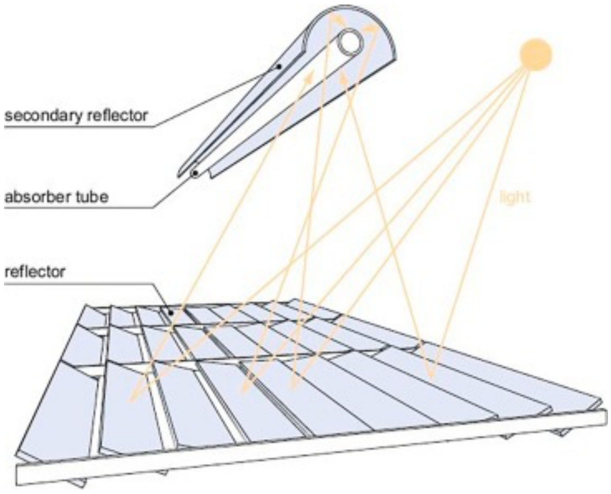

FIGURE 23 Schematic representation of a Linear Fresnel collector [19]

5.2 Auxiliary energy

Information about the auxiliary energy and where its configuration in a solar system has been taken from the [24] in the section auxiliary energy.

Sometimes just solar energy is not enough to supply all the required demand, therefore auxiliary energy systems are needed to ensure the supply of the demand and a high reliability of the system. Also, the auxiliary systems prevent the oversizing of the solar collector field.
Auxiliary energy can be located in three different ways, all the configurations are shown in figure 24:

- Energy is supplied to the tank. A thermostat is placed at the top of the storage tank and the auxiliary system maintains the temperature at a certain setpoint.
  This is a very simple configuration and the least expensive. However, there is a possibility of increasing the temperature of the tank at the bottom and thus the collector inlet temperature increase, reducing the solar system performance.
- Energy is supplied to the water leaving the storage tank. This configuration requires a heater in series and apart from the solar tank, this heater may have a storage device of its own, which implies certain heat loss. Temperate at the outlet of the auxiliary heater is controlled this way. This method allows the use of the

maximum solar energy from the tank, since it does not vary the tank's temperature directly and does not affect the collector performance.

- Energy is supplied directly to the incoming water using a bypass system. This method has the disadvantage that either auxiliary water flow or the solar heated flow must have a temperature above the setpoint so when both water streams get mixed, the desired setpoint temperature is achieved. If the heated water coming from the collectors is too low, the auxiliary heated water should be considerably higher than the set temperature, this could lead to several problems in the system.

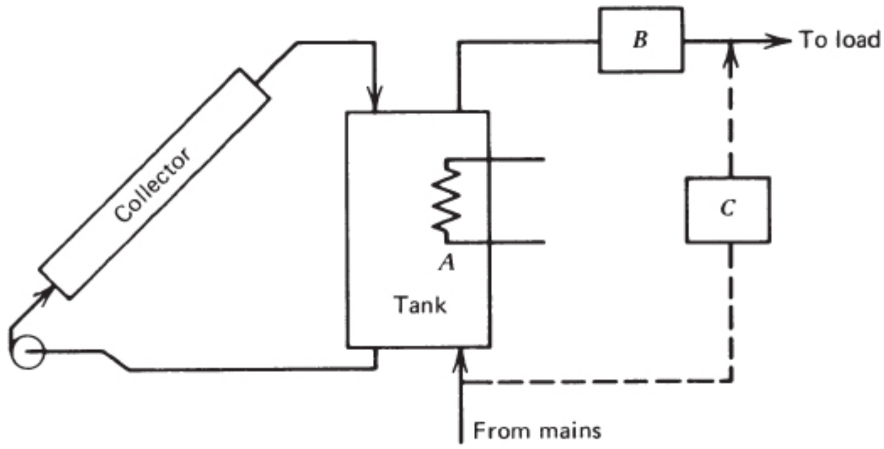

Figure 24 Schematic of alternative location for auxiliary energy supply to a one-tank forced-circulation solar water heater: A, in tank; B, in line to load; C, in a bypass around tank. [24]

5.3 Storage system

Information about the storage system and the types of solar accumulation has been taken from the Chapter 8 of the book "Solar Engineering of thermal processes" [25]

Solar energy is a time-dependent energy resource. Because of this storage tanks should be considered in any solar process system. Its main function is to accumulate excess energy, that is generated when the production is greater than demand, or when supply temperatures are not valid to be introduce into the system.

The use of a storage system undoubtedly affects the solar system performance. The temperature deliver to the load clearly differs from the temperature going out of the collectors. The reason for this is the heat losses produced because of the used of a storage system. At the end, the temperature at which the heat is used is lower than the temperature of the collector.

Energy storage may adapt different forms, the most common and highlighted in this section are the accumulation of sensible heat contained in a liquid or solid material, or as heat of fusion in chemical systems.

5.3.1 Water storage

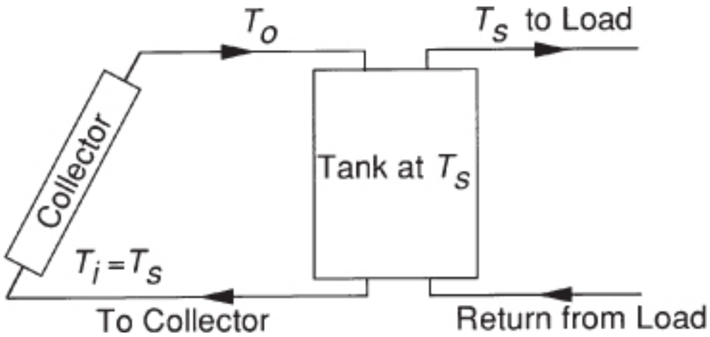

FIGURE 25 A typical system using water tank storage, with water circulation through collector to add energy and through the load to remove energy. [25]

This type of storage is ideal for water heating. Energy can be added and removed from this type of storage simultaneously. Heat is transported by the storage medium itself so the temperature drop between the transport fluid and the storage medium is eliminated.
A simple schematic of a water storage is shown in figure 25.
Due to density differences caused by differences in temperature, stratification usually occurs in water storage tanks. This effect will cause the temperature at the top of the storage tank to be higher than at the bottom. Stratified tank model can be divided in two categories: multimode approach, in which the tank is divided into a number of sections, and an energy balance is defined for each of the sections, and plug flow approach, in which segment of the liquid at various temperature move along the tank, and the model try to define the size, temperature, and position of the segments at any time.
The degree of stratification will depend on various features: the design of the tank; the size, and configuration of the flow rates of the entering and leaving the tank.

5.3.2 Pebble bed storage

A packed-bed storage uses the heat capacity of a bed of packed solid particulates to store energy. A fluid, mainly air, is circulated through the bed to add or remove energy. Many solids may be used, rock is typically used.

This type of storage unit is represented in figure 26. This method consists of a container, a screen to support the bed, and inlet and outlet ducts.

The flow inside the bed is maintained in only one direction for addition of heat and in the opposite direction for removal of heat. So, this system is not able of adding and removing heat simultaneously. This is a disadvantage compared to water storage systems.

Pebble bed storage have many features desirable for solar energy applications. The main advantage is its high level of stratification, caused by the high heat transfer coefficient between the air and the solid. Entering air rapidly losses its energy transferring it to the pebbles. The pebbles near the entrance are heated, however the temperature of the pebbles near the exit remains the same and the exit air temperature remains very close to the initial bed temperature. As time progresses a temperature front passes through the bed. In addition, cost for this type of storage material and container are low[25].

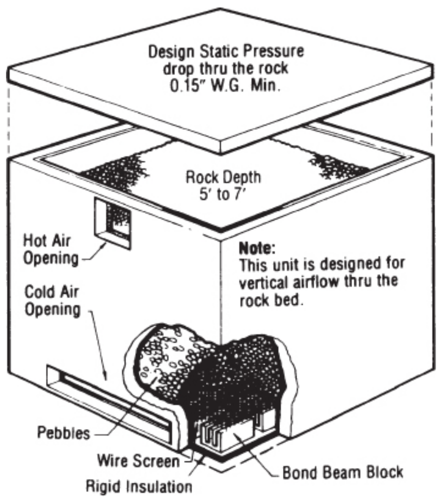

Figure 26 A packed-bed storage unit [25].

5.3.3 Seasonal storage

In addition to the information mentioned before, the accumulation can also be divided into short-term storage and seasonal storage.

In the short-term accumulation the mismatch between the production and the demand is of hours or day, while in the case of seasonal accumulation the difference period is of the order of one year. For this reason, seasonal storage unit has a higher capacity. The objective of the seasonal storage is to store the excess summer energy in order to use it later at winter.

5.4 Working fluid

Information for the working fluid have been taken from the sources [9] and [26]
As working fluid of the primary circuit or the collector circuit, various materials can be used, such as mains water, demineralized water or water with additives, depending on the climatic characteristics of the place, one option or another will be chosen.
Water is a good option since it does not involve a high cost, it has a high specific heat, it is not flammable, nor toxic and it hardly requires maintenance. However, the water can freeze if the outside temperatures are below 0ºC. Furthermore, at high temperatures it is corrosive and its pressure increases a lot when working at temperatures above 100ºC, so it is preferable to limit its use to a temperature close to 150ºC or 200ºC to be able to work at valid pressures.

Water with additives is presented as a good option. the most common additives are antifreeze, although anticorrosive additives can also be used. As antifreezes, products may be used alone or mixed with water, so that their freezing temperature is lower than 0ºC. It is desirable that an auxiliary tank that is responsible for replenishing the fluid in the circuits in case of losses.

5.5 Pipelines

Obviously, heat losses occur in the connection pipes, when the fluid is transported between the generation plant and the solar installation surface.

Thermal losses per meter of pipe increase as the required implantation surface decreases, due to the fact that pipes with a smaller section have a greater exchange surface with the outside per unit of volume contained than pipes with a larger section.

In order to avoid thermal losses, the length of the system pipes should be as short as possible, avoiding elbows and general pressure losses as much as possible.

5.6 Heat exchanger

Information for the working fluid have been taken from the sources [9] and [8]. These documents have been useful to elaborate a quick review of this device.

It is the device where heat transfer occurs between two circuits.
The heat transferred in the exchanger is given by the equation [9]:

$$Q = U \times A \times \Delta T \qquad (9)$$

U = global heat transfer coefficient; A: area of the exchange surface; ΔT: temperature difference between primary and secondary circuits.
The difference in temperatures between the primary and secondary circuits must be as low as possible, in order to achieve greater collector performance, therefore it is necessary that the transmission coefficient (U · A) be the maximum possible.
AT = 0; TI = T2 corresponds to the efficiency of the collector without exchanger, this is equivalent to considering an exchanger with 100% efficiency, which is not a real case.

The configuration of the exchange system in the solar installation may be independent or incorporated into the accumulator and also centralized or distributed.
External heat exchangers should also be protected from freezing. They are used in large installations and should be complemented with: shut-off valves in all the exchanger ports; elements necessary for its disassembly and cleaning: purge and drain valves; manometric bridges in primary and secondary; thermometers on all four connections.
A schematic of a heat exchanger outside the storage tanks can be seen in figure 27.

The heat exchanger inside the solar accumulator will be located in the lower part of the tank and may be a submerged or a double-enclosed type. The submerged exchanger may be a coil or a tube bundle.

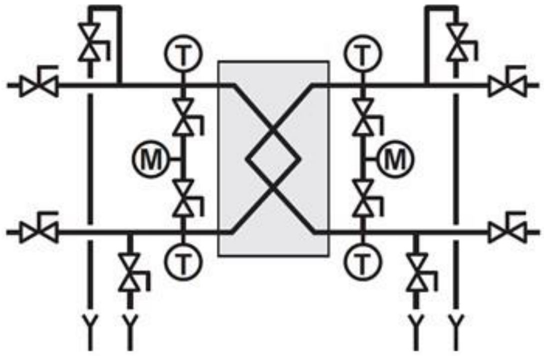

FIGURE 27 Schematic of a heat exchanger [8]

6 SOLAR HEATING AND COOLING SYSTEMS

This section will address the different solar heating and cooling systems. This category includes: water heating, space heating and space cooling.

6.1 Solar water heating:

The information sources that have been considered to carry out a review of the solar water heating system, that contains the most relevant information are [27],[24] and [28]. Taking these documents as a reference the following summary about solar heated water has been performed.

Surely the most popular application of solar systems is for domestic water heating. This category of solar systems belongs to the low-temperature heat applications.
The operation of a solar water heater is simple the solar collector array absorbs solar radiation and converts it to heat. This heat is then absorbed by a heat transfer fluid, that passes through the collector. This heat can then be stored or used directly.
Because solar collectors are exposed to weather conditions, solar energy systems must be protected from freezing and overheating.

Based on the driven forces that produce the working fluid circulation within the system, solar water heating systems are divided into two categories: passive and active systems.

6.1.1 Passive systems

Passive or natural circulation systems can be divided in two categories: thermosiphon and integrated collector storage.

6.1.1.1 Thermosiphon

Information for thermosiphon system has been taken mainly from the reference [28]
The circulation of the fluid is done by density difference. In these systems the working fluid is heated in the collector, increasing its temperature, thus it becomes less dense and automatically goes up, where the storage tank is placed. In the storage tanks the hot water is replaced by the cooler water that is introduced at the bottom of the tank, from which it flows down the collector.
In order to prevent heat losses, connecting pipelines must be well insulated
The advantages of thermosiphon systems are the following:

- They do not require pumps or controllers; thus, they are more reliable, and have a longer operational life than forced circulation systems.
- They do not require an electrical supply to operate, as they do not need pump or fans to transport the fluid.
- Whenever solar radiation exists, there is going to be a temperature difference. The flow rate is a function of the useful gain of the collector which produces the temperature difference. Considering this, these systems are self-modulated.

However, this system also has disadvantages. Its main disadvantage is that because the water tank should be above the collector the unit are relatively tall, which makes them less operative and malleable.
Other problem of the system is linked to the quality of the water used. Because the system is open, overly hard or acidic water can cause scale deposits that may cause corrosion in the absorber fluid passages.

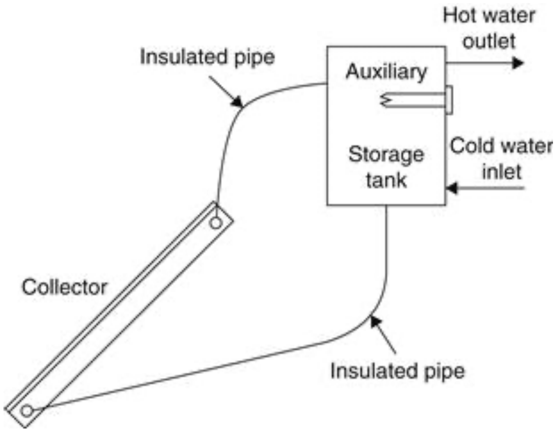

FIGURE 28 Schematic diagram of a thermosiphon solar water heater [28]


FIGURE 29 Thermosiphon system [28]

6.1.1.2 Integrated collector storage systems

Integrated collector storage solar water heating systems are simple and less costly compare with others.

In such systems, a single unit functions as both absorber and storage at the same time, the hot water storage tank is used as part of the collector since the collector absorber is placed in the storage tank surface.
As in any system, to improve stratification, the hot water is extracted from the top of the tank and cold water enters the bottom of the tank on the opposite direction. The storage tank surface is coated to avoid heat loss.
The main disadvantage of the ICS systems is that it suffers from high thermal losses from the accumulation tank to the surroundings, since most of the surface area of the storage tank cannot be thermally insulated, as it is supposed to be exposed to be able to absorb solar radiation. Especially, heat losses are larger during the night, cloudy hours and days of low ambient temperatures. Due to these losses, the water temperature drops substantially during night time, especially during the winter, producing a reduction in the system overall efficiency[28].

6.1.2 Active systems

Active or forced circulation systems use pumps or fans to circulate the heat transfer fluid from tank to solar collector**.** Differential thermostats control the pump, measuring and

comparing the collector outlet temperature and the storage tank and activates the pump whenever a specified temperature difference exists.
These are more expensive and less efficient than passive systems, especially when antifreeze actions are required. Four types of systems that belong in this category, are going to be mentioned in this section: direct circulation systems and indirect water-heating systems.

6.1.2.1 Direct active water heating systems

In these systems potable water is directly heated in the collector. A part from the references mentioned before for water heating systems[28], information for the direct type is taken from the article “Solar thermal collectors and applications”[29].

A pump is used to circulate potable water from storage to the collectors when there is enough available solar energy to increase its temperature and then return the heated water to the storage tank until it is needed[29].

Direct heating systems can be operated with a flow supplied from cold-water accumulation tank or directly connected to the city water mains. In this last scenario, valves and pressure relief valves are required to reduce the pressure whenever the city water pressure is greater than the working pressure of the collectors[29].

It is not recommended to use direct systems in areas where the water is extremely hard or acidic, because scale deposits may obstruct or corrode the collectors.

6.1.2.2 Indirect active water heating system

This system is divided into two independent loops to realize heating, one is collector loop and another is water tank loop, connected through a heat exchanger. The pump, that operates with a thermostat, forces the heat transfer fluid to circulated through the closed collector loop to a heat exchanger, where the heat collected is transferred to the potable water in the storage tank. The collector loop is closed; therefore, an expansion vessel and a pressure relief valve are needed, to prevent from over pressure differences that could damage the system. In the closed loop antifreeze solutions can be used.

Air systems are considered indirect circulation systems too, because air is circulated through air collectors and then directed to an air-to-water heat exchanger. In the heat exchanger, heat is transferred to the potable water, and from there it is returned to the storage tank.

6.2 Solar space heating.

Many information sources have been analyzed to generate a clear overview of the solar space heating systems. The most significant information has been found in [30],[31],[27] and [32] this document has serve to write a summary of the different solar space heating technologies

Space heating can be supplied by solar energy too. These systems are very similar to those for water heating, described previously as the same considerations apply for use of an auxiliary energy, storage system, collector design, freezing temperatures and thermostat controls.
Solar space heating systems can be also can be distinguished in passive and active systems. Passive systems are related with the building design.

Active systems use solar collector to supply the desired demand. There are two main types of active solar heating systems: those that use liquid-based collectors, and those that use air collectors.

Both systems absorb and collect solar radiation to heat either a liquid or air and then they transfer this heat directly to a building space or to a storage tank from which the heat can be distributed.

6.2.1.1 Water systems

These types of systems can be used for both solar space heating and domestic hot water. Their functioning and configurations are similar to the solar water heaters explained previously.

When used for both applications, the system is able to control the solar accumulation and storage load loops independently. This is mainly because heated water can be added at the same time that hot water is removed from the tank.

Control of the system is done with two thermostats: one that measure the collector and main storage tanks temperature difference and another one that measure the room ambient temperature. These control thermostats work as follows: when the room temperature is lower than a predetermined value, the thermostat send an activation signal to the load pump, connected to the main storage, and the heated water flows from the tank to the load heat exchange to meet the heating demand. If the energy accumulated in the tank in not enough to meet the load demand, the thermostat activates the auxiliary system to cover the rest of the heating requirements[30].

Usually, three-way valves can be used in the system, so that the water flows only through the auxiliary system whenever the storage tank is empty. In the system illustrated, figure 30[30], a bypass around the storage tank is provided to avoid heating the storage tank with auxiliary energy

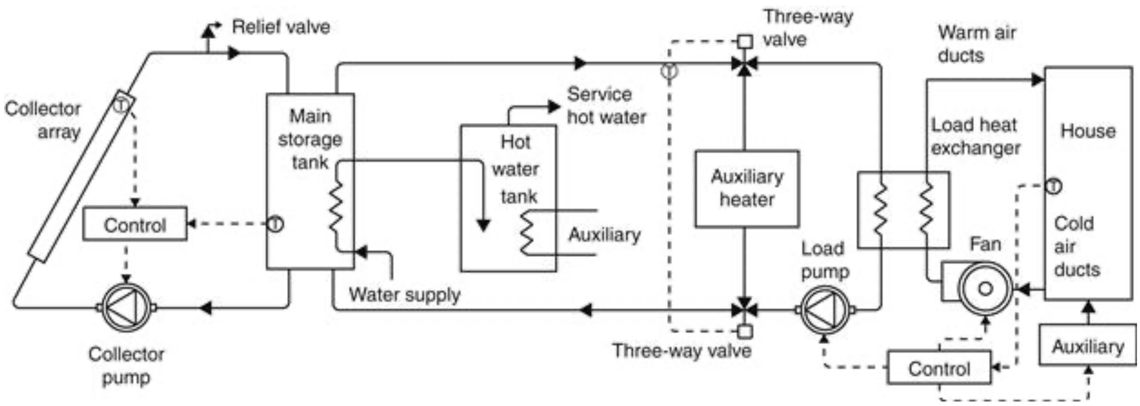

FIGURE 30 Schematic diagram of a solar space-heating and hot water system. [30]

The solar heating system design shown before is only valid for use in non-freezing climates. If the system is placed in a climate with abundant sub-freezing temperatures, the use of antifreeze solution in a closed collector loop is necessary. A detailed schematic of such a liquid-based system is shown in figure 31

It is important to note that a heat exchanger between the collector and the storage tank is also needed, to prevent the antifreeze solution and the potable water from mixing and for the heat transfer to occur.

Relief valves in the collector loop are also required to dump excess heat if over-temperature conditions exist.

As in the previous system auxiliary energy is required, in cases where the energy demand is not fulfilled by the solar energy.

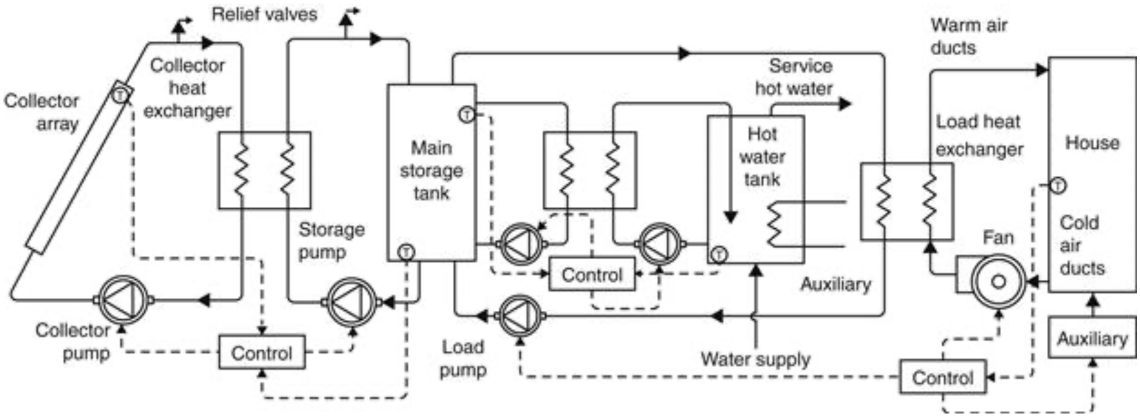

FIGURE 31 Detailed schematic diagram of a solar space-heating and hot water system with antifreeze solution [30].

A load heat exchanger is also installed in the system, to transfer the energy from storage tank to the heating spaces.

The main benefits of liquid heating systems, among other things, are the high heat removal factor of the collector, the moderate storage volume requirement, and the simple combination with solar cooling devices, like absorption chillers.

6.2.1.2 Air systems

Some devices and configurations for air systems are similar to the ones used in liquid systems. This is the case of the auxiliary energy and bypass system, used to top off the energy coming from the solar collector, by increasing the air temperature to meet the load demand.

Air systems have many advantages compared to those liquid-based. Problems of freezing and boiling in the collectors are eliminated and corrosion problems are reduced. The pebble bed storage allows a high degree of stratification, which leads to lower collector inlet fluid temperatures [31]. Air-heating systems are commonly used in the building services sector.

However, these types of system also have some disadvantages. As they are not arranged to simultaneously add and remove energy from the tank, relatively large volumes of storage, which leads to higher storage costs. They are difficult to adapt with solar air conditioning systems. Air systems can have significant energy losses due to an air leakage from the pipes. Air collectors operate with lower values of heat removal factor than are liquid heating collectors.

Air space heating collectors usually operate at fixed airflow rates, this means that collector outlet temperatures are variable through the day. Although it is also possible for them to operate at fixed outlet temperature, by varying the flow rate along the day, at low flow rates, heat removal factor is reduced and thus collector performance decrease[29].

6.3 Solar space cooling

Solar cooling of buildings is an attractive idea because the cooling loads and availability of solar radiation are in phase.

Solar energy can be used to produce a cooling effect via either electricity-driven or thermally-driven cooling processes[33] An scheme of the different technologies for both processes can be seen in figure 33[19]

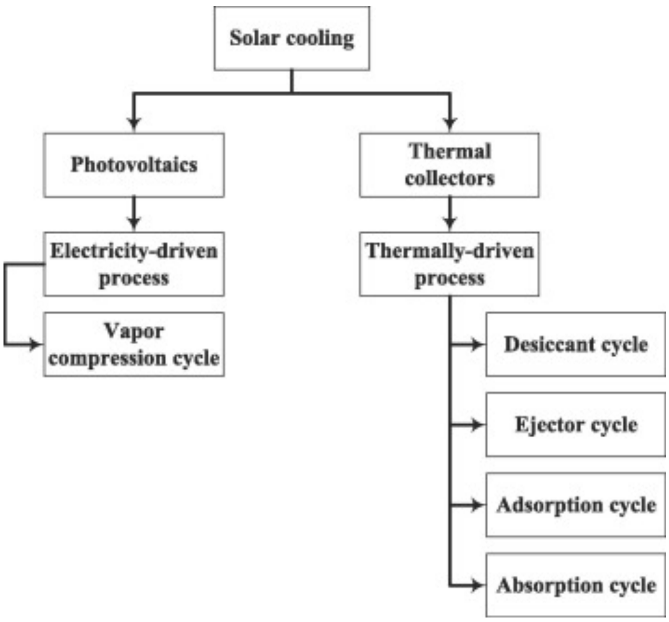

FIGURE 32 Classification of main solar cooling technologies [19].

6.3.1 Electricity driven

The most common solar electricity-driven technology in based on high COP vapor compression chillers connected to solar PV.

6.3.1.1 Vapor compression refrigeration systems

Information about the vapor compression refrigeration system, has been found in[33]. This system uses a liquid refrigerant sealed in the system and it is circulated through various components of the system. A schematic of the vapor compression cycle is given in figure 33. Components of the system are the compressor the condenser, an expansion valve and an evaporator where the cooling effect is produced

On the market for air conditioning, electricity driven vapor compression systems are the most widely used method because of their high COPs. However, this technology has a significant problem, the high cost of battery storage, that has limited PV-driven cooling production to sunny hours[19]. Without batteries, a separate storage system may be required to cover the imbalance between available solar electricity gains and building loads.

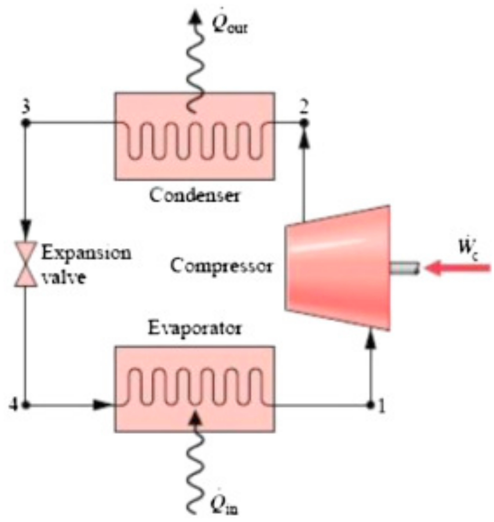

FIGURE 33 Vapor compression system [33].

6.3.2 Thermally driven

Thermally-driven cooling systems, compared to electrical vapor compression chillers, have a lower COP (0.6–1.8) but higher collector efficiency (35–70%)[19].

The available technologies on the market for thermally driven cooling systems are the following: solid and liquid desiccant cooling systems, ejector refrigeration cycles, adsorption and absorption chillers[33]. Absorption chillers are commonly used widely and are considered as the most desirable method for utilizing solar thermal energy due to their reliability, and higher efficiency.

6.3.2.1 Desiccant cooling

Sorbents are materials with the ability to attract and hold other gases or liquids. Desiccants are sorbents that have a particular affinity for water. The process of attracting and holding moisture is described as either absorption or adsorption, depending on whether the desiccant undergoes a chemical change as it takes on moisture[30].

After seeing various sources of information on the subject analyzed. the most relevant and complete for our study are [33] and [30], with them a brief summary of the desiccant cooling systems.
This system is based on open cycle dehumidification-humidification processes.

The process is the following: The air from the outside is passed through a liquid or solid desiccant wheel, where it is dehumidified. Its temperature is increased since adsorption and absorption of vapor water is an exothermic reaction. Its temperature is then decreased by exchange of sensible heat in a heat wheel. Heat wheel can be used in combination with vapor compression system if required cooling is not supplied. Finally, evaporative cooling is applied to reach the desired comfort state.
A schematic of a desiccant cooling can be seen in figure 34[34] In this picture is showed the different stage the air has to pass in this process. From state 7 to 8, the desiccant is regenerated by using a heater, in order to provide the required high temperatures. The purpose of this heater could be done by solar energy.

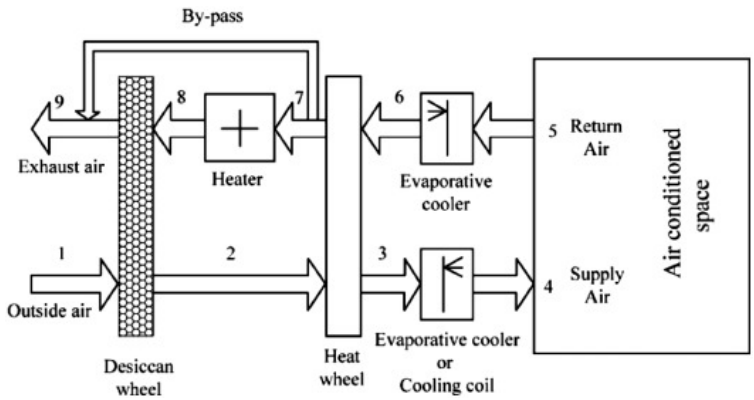

FIGURE 34 Desiccant dehumidification associate with evaporative. [34]

Because desiccant systems are based on the handling of latent heat, the energy demand for vapor compression systems is reduced. And also, energy savings may reach up to 80% for dry climates since the desiccant cooling system's performance is strongly linked to weather conditions.

6.3.2.2 Ejector cooling

In an ejector refrigeration system, the compressor from the vapor compression cycle, is replaced by a boiler, an ejector and a pump. These systems have a COP 0,3 lower than vapor compressor systems. However, they are simpler, have no moving parts and the cost for installation and operation is low[33].

6.3.2.3 Adsorption chillers

As it is mentioned in the reference [33], the interest in adsorption systems has started because of the ecological problems that are produce with the release of refrigerants such as CFC, HCFC into the atmosphere. These refrigerants are contributors to the ozone layer destruction.

Adsorption refrigeration systems mainly differ from absorption system by absence of a pump and a rectifier. Because of this the electricity consumption in adsorption systems is minimal. The pressure difference inside the system is the result of the transfer of a substance from one phase (vapor) followed by condensation on the surface[33].

One of the biggest advantages with respect absorption chillers is that working pairs such as: zeolite–water, zeolite–methanol, and activated carbon–methanol can be used in adsorption systems. These pairs perform better and are more environmentally friendly than for example ammonia[30].

6.3.2.4 Absorption chillers

In comparison with an ordinary vapor-compression system, the idea of an absorption system is to avoid compression work. This is done by using a suitable working pair: a refrigerant and an absorbent. In general, an evaporating refrigerant is absorbed by an absorbent on the low-pressure side.

An absorber, pump, expansion valve and generator are the main parts of the absorption mechanism. The components of the absorption mechanism may change with the used working fluid in the system.

The cycle is divided into high pressure zone and low-pressure zone, as it can be seen in figure 35[35]. The pressure in the condenser and generator is fixed by the condenser fluid coolant temperature. The pressure in the evaporator and absorber is fixed by the temperature of the cooling fluid to the absorber

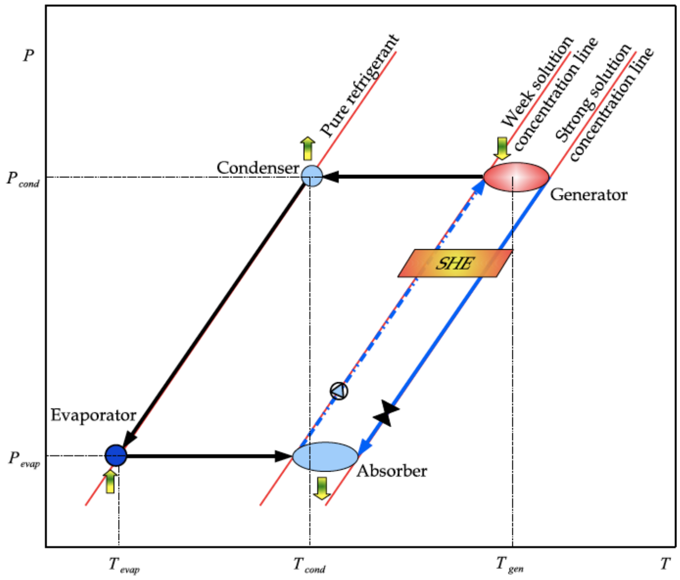

FIGURE 35 A P-T-X diagram of a single effect absorption system. [35]

The information about the operation of the absorption chiller have been found[35]. The system can be set to start at the generator where heat from the solar collector is added, to the refrigerant-absorbent mixture, and separate the refrigerant fluid and the absorbent. The refrigerant vapor is sent to the condenser and the concentrated absorbent solution is sent to the absorber. Once in the condenser the steam gives up heat and condenses. Normally the condensation is produced thanks to another stream of water, said stream absorbs heat, therefore it must be sent to a cooling tower to release that energy. After the refrigerant reaches the evaporator, it passes through an expansion valve to reduce its pressure as necessary. After reducing its pressure, the refrigerant reaches the evaporator, the refrigerant evaporates by absorbing heat from another stream that circulates on the side of the tubes, producing the cooling effect and achieving a chilled water stream. From there the refrigerant is directed to the absorber. In the absorber the refrigerant and the absorbent come into contact. The absorbent in the generator duty passes through a pressure-relief valve and a heat exchanger that is used for internal heat recovery to preheat the solution leaving the absorber with the hot concentrated solution leaving the generator in order to improve the system's performance. A schematic of the simpler system can be seen in figure 36.

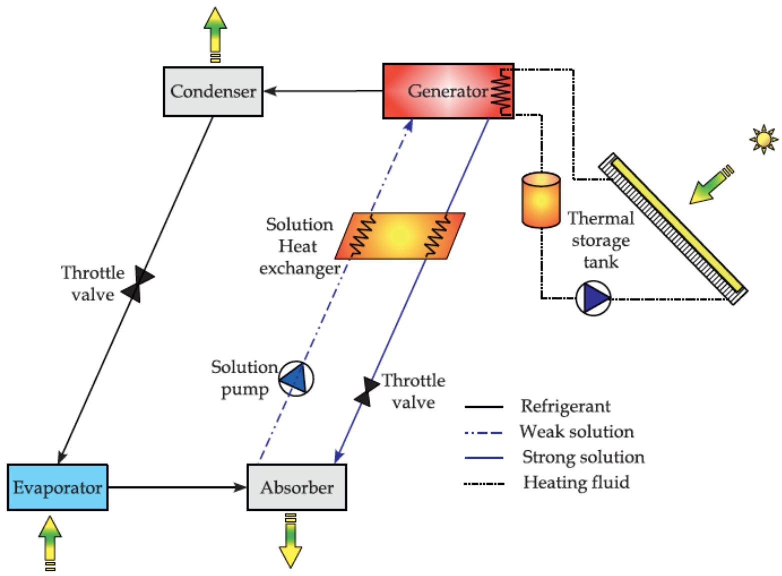

FIGURE 36 A schematic diagram for the basic single effect solar absorption cooling system.[35]

The pump is the only part that needs electric work input, in order to increase the pressure of a liquid in the absorption refrigeration cycle. And this work input is very small compared to the compressor in the vapor compression cycle system. Work from the pump can be negligible, for this reason the thermal coefficient of performance COP of these systems, is defined as the ratio of energy into the evaporator energy to the energy into the generator[36]. This means that the refrigerant power provided by an absorption chiller will be equal to the heat source power multiply by the COP of the machine.

$$COP = \frac{Q_{EVAP}}{Q_{GEN}} \qquad (10)$$

The most used working pairs are: lithium bromide–water (LiBr–H_2O), where water vapor is the refrigerant, and ammonia–water (NH_3–H_2O) systems, where ammonia is the refrigerant.

6.3.2.4.1 Lithium bromide–water vs ammonia–water working pair

The LiBr–H_2O working pair operates at a generator temperature in the range of 70–95 °C, with water used as a coolant in the absorber and condenser, and has a COP higher than the NH_3–H_2O systems. The COP of this system is between 0.6 and 0.8. A disadvantage

of the LiBr–H_2O systems is that their evaporator cannot operate at temperatures much below 5 °C, since the refrigerant is water vapor[30]. Commercially available absorption chillers for air-conditioning applications usually operate with a solution of lithium bromide in water and use steam or hot water as the heat source.
Since the freezing point of NH3 is -77ºC, water/NH3 systems are feasible for low temperature applications[33].

Water/NH3 absorption refrigeration cycle. Apart from the components mentioned above, a rectifier is used in the absorption cooling system for this configuration. The rectifier provides separation of water vaporous from the NH3 since water is highly volatile. The water vaporously freezes and accumulate in the evaporator without a rectifier; hence the system performance would decrease[33].

Two types of chillers are available on the market: the single effect and the double effect.

6.3.2.4.2 Single-effect absorption chiller vs double-effect absorption chiller

After studying many information sources, it has been seen that many of them rely in the article "Solar air conditioning in Europe—an overview"[37]. The following information is based on the data provided in this article.

Most solar-powered absorption cooling projects to-date have utilized single-effect systems, with low-temperature solar collectors.

Single-effect absorption systems are limited in COP to about 0.7 for LiBr-Water and to 0.6 for ammonia-water. This COP are low compared to a vapor compression cycle.
However, when considered, the cost for investment absorption refrigeration system is more expensive than the vapor compression system, and absorption chillers are heavier than the conventional vapor compression chillers.

The single-effect system operates in the temperature range 80–100ºC and allow temperature between 6-7 ºC for the chilled water.
For supply temperature higher than 100ºC, it is worth switching to a double effect system.

Double-effect systems have a COP near the range 1.0–1.2. The double-effect absorption chiller has two stages of generation to separate the refrigerant from the absorbent. Therefore, the temperature of the heat source needed to drive the high-stage generator is essentially higher than that needed for the single-effect machine until 160ºC.
Although double-effect chillers are more efficient than the single-effect machines, they are obviously more expensive to purchase.

Triple-effect and quadruple-effect absorption chiller are still underdevelopment and will provide COPs of about 1,7 and 2 respectively. These systems may be adapted to and employed in a solar-powered installation with high temperature solar collectors.
Performance comparison of several multi-effect chillers, can be seen in figure 37. The COP as a function of the heat supply temperature for a single, double and triple effect chiller is shown

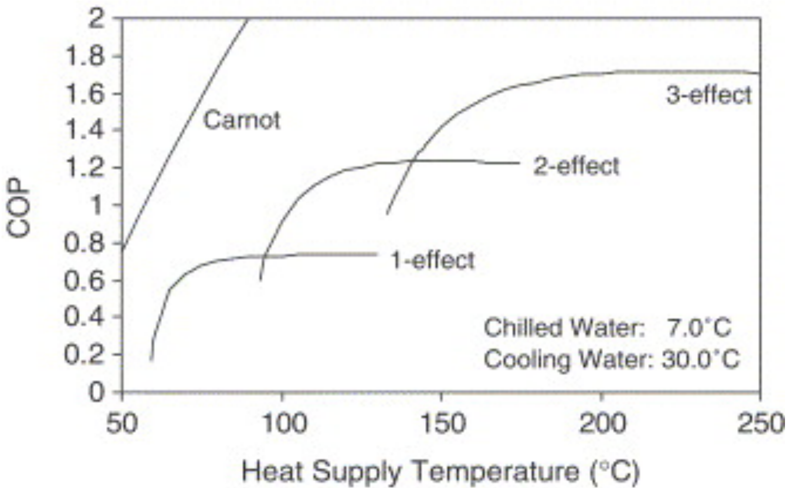

FIGURE 37 Coefficient of Performance (COP) as a function of solar heat supply temperature for single-, double- and triple-effect LiBr–water absorption chillers.[37]

7 CASE OF STUDY

7.1 Object

The objective of this work is to carry out a experimental study on the feasibility of integrating solar energy in a district network that supplies the demand for domestic hot water, space heating and cooling.

The combination of cooling and heating offers a better scenario for using solar energy than just for heating. In the case that the cold demand is supplied, there would be no need for seasonal accumulation, since the network itself would act as an accumulator, consuming the energy at the time. In addition, this produces an increase in the solar fraction and therefore a better use of the renewable resource.

The same collector field will provide both space-heating and cooling. In our case the domestic heat water needs would be covered 100%, those for cold partially and those for heat partially or totally. This combination of modes will be possible by the use of thermostats, these devices will allow to combine applications and operate in more than one application at a time.
The solar installation will be connected in parallel with the biomass boilers that will act as the auxiliary energy system.

The cold production for this case will be done through absorption chillers. So, the demand of the network will be supplied with the biomass boiler and the solar field,
supplying heat to have sanitary hot water, heating and cooling.

7.2 Methodology

- Estimation of the energy demand for cooling and heating for the study network. To calculate the theoretical demand of the district network, a hypothesis made by the IDAE in its study "Ánalisis de potencial y oportunidades de integración de energía solar térmica en redes de climatización. Energía solar de concentración en una red de calor y frío en Jaén"[9] has been used.

- Obtaining data on solar radiation and average temperature in Spain in a typical year. The data has been obtained from the spreadsheet data provided by the Photovoltaic Geographical Information System (PVGIS)
- Selection of solar collector technologies as well as their optimal placement and orientation.
- Analysis of the performance of the solar installation, for both cases with or without solar accumulation. The equations that have been considered for the calculation of the collector field power output are given by the article "Analysis and validation of a quasi-dynamic model for a solar collector field with flat plate collectors and parabolic trough collectors in series for district heating "[38]
- Selection of the significant elements for the central production: auxiliary energy and refrigeration machines.

7.3 Input data

The buildings that are being considered in this study are: a university center, a set of 19 identical apartments and an elderly residence, which is in the construction process.
These buildings are located in Madrid, Spain, latitude 40.45, altitude above sea level 582.

These are buildings whose demand profiles are different and can complement each other. This operating scenario is ideal for a network since it is not obligated to stop and start continuously, being able to work in a constant and predictable way for long periods of time.

The figure 38 shows the layout of both buildings and the areas to be considered as a catchment area and a production center.
The different quadrants indicated in the figure represent the different components of the network. The yellow square represents the university; the green is the plot where the elderly home is being built, it is still not on Google earth, since the construction started recently; the black display the 19 apartments; and finally, the orange shows the plot that has been chosen for the installation of the solar field.
As it can be seen, the elements of the chosen network are very close to each other, thus reducing distribution and civil engineering costs.

FIGURE 38 Layout of the different component of the district network

The input data of all the building is detailed in the tables 1,2,3.

The university is formed by 5 floors:

- Ground floor: The teaching activity on this floor is centered on seven classrooms where postgraduate programs will be taught and thirteen work rooms that support the classrooms and will be used for group work. The ground floor incorporates the cafeteria and outdoor terraces.
- First floor: it integrates the reception and administration spaces, the great hall, the oratory, work rooms, toilets and an atrium connected to the rest of the floors
- The second floor: incorporate the activity of the teaching staff mainly, attention to students and researchers, in addition to other student activities such as the computer room and seminars
- Penthouse: The attic floor houses the most managerial functions and reception spaces and teacher relations, with offices, council room, living space, dining room and meeting room, mainly, apart from the general toilets and service areas.

TABLE 1 INPUT DATA UNIVERSITY BUILDING

UNIVERSITY CENTER	
Heat production	3 boilers of 350 kW each. Operative boiler temperature (85-65ºC)
Cold production	2 coolers of 450 kW each and another cooler of 150 kW. Production of cold water at temperature 6ºC
Total Heating Power (kW)	1050
Total Cooling Power (kW)	1050
Built Surface (considering garage) (m2)	8.928,51
Number of floors	5 (one garage not climatized)
Orientation	North-south

Figure 39 shows a schematic of the university building.

FIGURE 39 Schematic of the university

The nursing home is made up of 100 rooms for mostly individual use, distributed from the first to the third floor, and 7 apartments for double use. On each floor there is a dining room. The ground floor also has a cafeteria, a hairdresser, a gym and a nursing room. they also incorporate a chapel. Figure 40 shows a schematic of the elderly residence building.

TABLE 2 INPUT DATA ELDERLY HOME

ELDERLY RESIDENCE	
Heat production	2 air heat pumps: one of 497,6 kW and the other one of 163,5 kW. In addition, it is installed a water heat pump of 178 kW to provide the domestic heat water.
Cold production	2 air heat pumps: one of 455 kW and the other one of 160,1 kW.
Total Heating Power (kW)	839,1
Total Cooling Power (kW)	615,1
Built Surface (considering garage) (m2)	14.847,20
Number of floors	7 (two garages not climatized)
Orientation	The building is shaped as a block in the shape of a "U", in such a way that its central zone develops in an east-west direction and its lateral "arms" advance in South direction (really South-East and South-West),

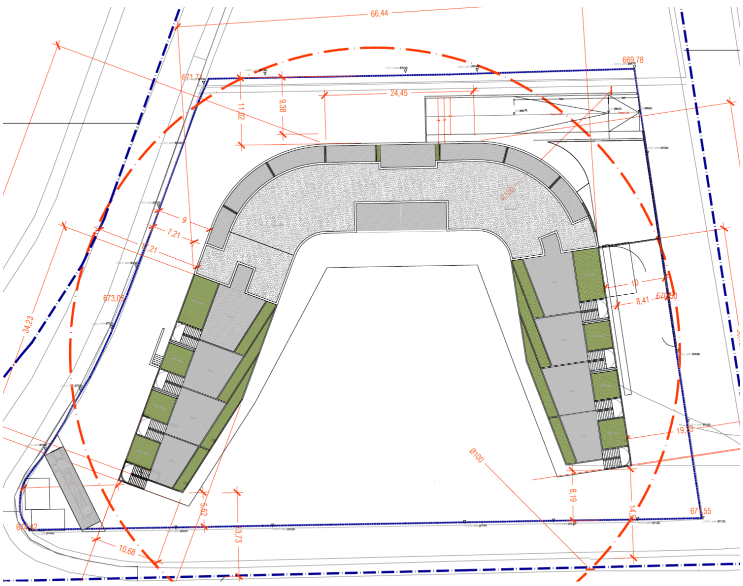

FIGURE 40 Schematic of the elderly house

The 19 apartments consist of: first floor with dinning room, kitchen and a bathroom; the second floor 2 bedroom each with a bathroom and a third floor with 1 bedroom with its bathroom and a hall.

TABLE 3 INPUT DATA APARTMENTS

19 APARTMENTS	
Heat production	Natural gas condensing boiler. 24 kW for each apartment
Cold production	Multizone cold-only duct equipment. 15,5 kW for each apartment
Total Heating Power (kW)	456
Total Cooling Power (kW)	294,5
Surface (with garages) (m2)	3.958,327 (total of the apartments)
Number of floors	4 (one garage not climatized)
Orientation	The orientation of the streets that allow access to each of the plots is, sensibly north-south, so that the main facades of the projected blocks are oriented to the west and east

Blueprints of the apartments were not provided.

7.4 Estimated demand

To carry out the implementation of a solar system it is necessary to know, or at least be able to estimate, the characteristics of the annual energy demand for heating, cooling, DHW

We have the maximum heat and cold demands of the buildings. The production centers will be designed around these conditions, since they are assumed to be the most unfavorable to which the system must be designed.

Since the object of this study is not to obtain the energy demand of the network, in a precise and detailed way. To find the annual demand of the two buildings we are going to consider a hypothesis used by the IDAE, at their report "Ánalisis de potencial y oportunidades de integración de energía solar térmica en redes de climatización. Energía solar de concentración en una red de calor y frío en Jaén"[9]

The starting hypothesis to obtain the estimated demand of the network considers:

- the demand for domestic hot water is constant throughout the year. This demand is to be considered included within the estimated total heat demand.
- Since the cooling demand is going to be covered by absorption machines, the cooling demand is going to be represented by an equivalent heat demand that will be supplied by a single source of energy that also supplies the heating.

  In order to define the relationship between the cooling demand and the equivalent heat demand, the coefficient of performance of the refrigeration machines will be used. To size the collector field, a COP value of 0.7 is normally taken as a reference, however later in the chapter 7.8 a more detailed explanation of the choice of the cold production absorption machine will be made

Although, the periods of operation of the network studied in the IDAE report differ from our reference network, this will not imply a change in the way in which the demand will be calculated.

The thermal demand will vary depending on the occupancy of the buildings.

In this case, it will be considered that the occupation in the buildings of the nursing home and the apartments will always be the maximum and the same, since there is occupation during all hours of the day, when dealing with housing. For these buildings there will be no reduction in demand in any hour.

However, in the university, it is going to be considered that the period of occupation decreases drastically from eight o'clock in the afternoon to six o'clock in the morning, since it is approximately the closing time of this type of centers. In order to do this, the demand in these hours will be reduced by 10% of what it would be in the situation of maximum production. Despite the fact that the demand for this building is reduced during those hours, in no case will it be reset, since this would damage the start-up of the building's system, as it has been turned off during certain hours. Although the demand is minimal, there is always a certain amount when necessary.

The process to estimate demand is as follows:

1. Obtaining hourly ambient temperatures of a typical year, for this study the temperatures have been obtained using PVGIS.
2. Definition of the summer and winter comfort temperatures based on the interior design temperatures established in the "Reglamento de instalaciones térmicas" RITE. It is possible to choose any temperature between the values shown in table 4 for both seasons. For this hypothesis they have chosen the limit 23ºC.

TABLE 4 INSIDE BUILDINGS DESIGN CONDITIONS

Season	Operative temperature (ºC)	Relative humidity (%)
Summer	23-25	45-60
Winter	21-23	40-50

3. Calculation of the hourly thermal jump between the room temperature and the selected comfort temperatures. If the same interior design temperature is defined for both stations, the demand will never be canceled except in the case in which the ambient conditions coincide with those of the design.
4. Obtaining the maximum thermal jump in summer and in winter respectively.
5. Percentage estimation of heat and cold needs from the relationship between the hourly thermal jump and the maximum thermal jump for both seasons. in this way, a thermal jump coinciding with the maximum supposes a need for 100% of the peak power demanded.
6. To establish the energy demands of heat and cold for each hour, the previous percentages are applied to the peak power of heat and equivalent heat. adding

both values the total heat demand required for each hour of network operation is obtained.

The previous steps can be outlined in the table 5:

TABLE 5 DEMAND CALCULATION

ESTIMATED DEMAND CALCULATION	
Winter design temperature (ºC)	$T_{d,winter}$
Summer design temperature (ºC)	$T_{d,summer}$
Peak heat power (kW)	2345,1
Peak equivalent cold power (kW)	1959,6 / 0,7 = 2799,43
Ambient temperature (ºC)	$T_{ambient}$
Hourly thermal jump in winter	$\Delta T_{winter} = T_{d,winter} - T_{ambient}$
Hourly thermal jump in summer	$\Delta T_{summer} = T_{ambient} - T_{d,summer}$
Maximum hourly thermal jump in winter	max (ΔT_{winter})
Maximum hourly thermal jump in summer	max (ΔT_{summer})
% Heat peak power (%H)	$\Delta T_{winter} > 0;\ \%H = \frac{\Delta T_{winter}}{\max(\Delta T_{winter})}$
	$\Delta T_{winter} < 0;\ \%H = 0$
% Cold peak power (%C)	$\Delta T_{summer} > 0;\ \%C = \frac{\Delta T_{summer}}{\max(\Delta T_{summer})}$
	$\Delta T_{winter} < 0;\ \%C = 0$
Hourly heat power (kW)	$\%H \times heat\ peak\ power$
Hourly cold power (equivalent heat) (kW)	$\%C \times equivalent\ cold\ peak\ power$
Estimated demand	Hourly heat power + Hourly equivalent cold power (kW)

Finally, the graph of the demand is plot in the following figures. Figure 41 represents the heating demand. As can be seen, the demand for heating is much higher in the winter months. However, there are always certain heat requirements even in summer, this makes sense, since within the heat demand is the demand for domestic hot water, that must exist during all the months of the year.

Figure 42 shows the cooling demand, that mostly exist only in the summer periods. It is also important to mention that the cooling demand reach higher values than the heating demand, this is mainly produced because of the transformation of the cooling demand to an equivalent heating demand through the coefficient of performance of the absorption chiller. Finally figure 43 represent the total estimated demand during the year, the one has to be covered by our installation.

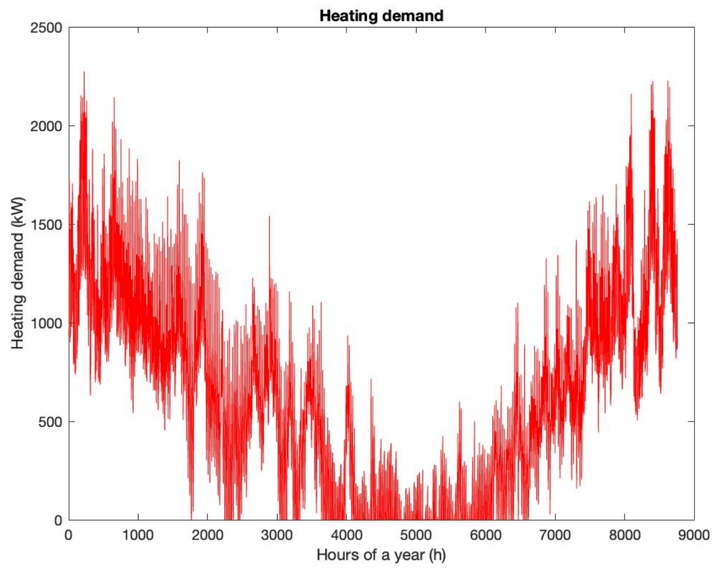

FIGURE 41 Heating demand

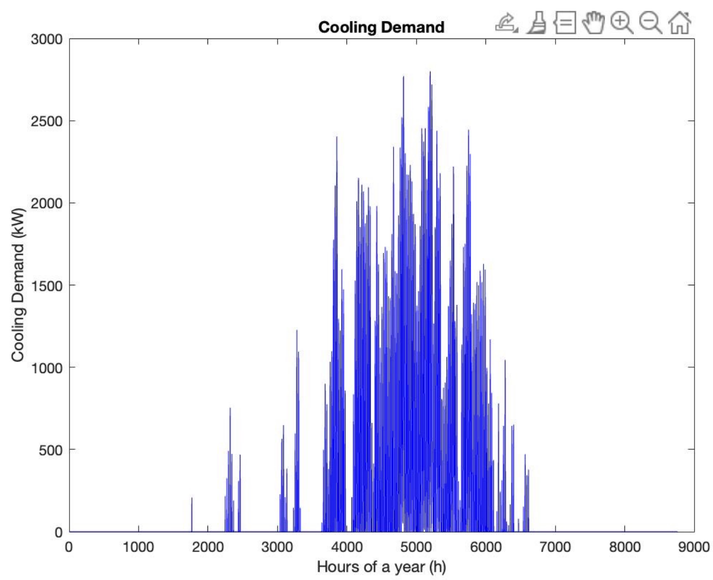

FIGURE 42 Cooling demand (equivalent heat)

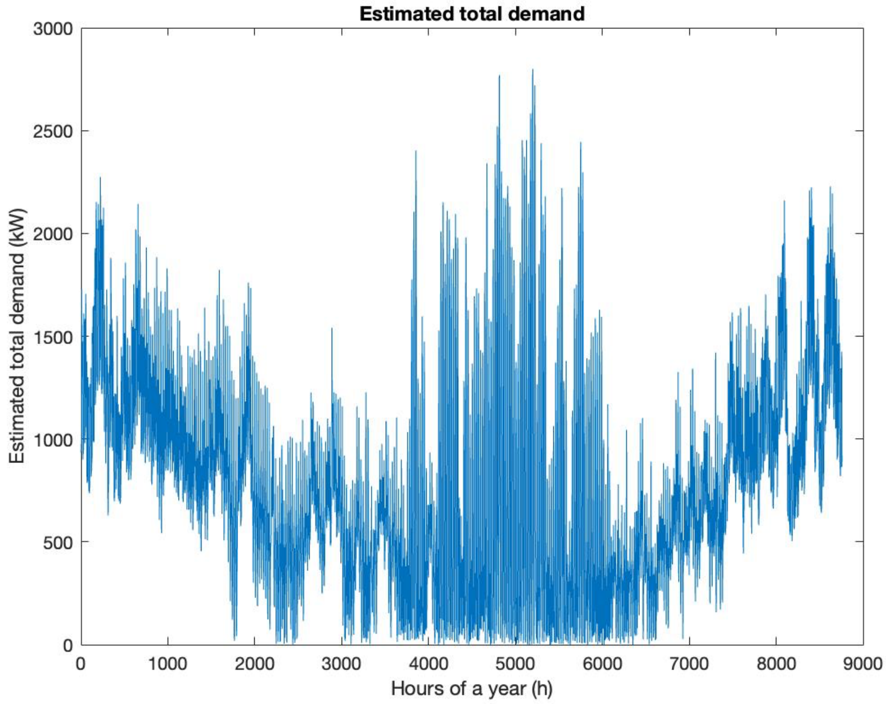

FIGURE 43Total Estimated Demand

The table 6 shows the total estimated demand, the estimated heat demand and the estimated equivalent heat demand, coming from the cold demand, in a year.

TABLE 6 ESTIMATED DEMAND

	Total demand	Heat demand	Equivalent heat demand
Annual demand (MWh year)	6.716,2	5.308,5	1.407,8

7.5 Radiation data

Radiation data in Spain are high compared to the European average.

Radiation data in Madrid for a typical year have been provided by the PVGIS platform, from the tool TMY, Typical Meteorological Year. The most relevant data that we have obtained are those of beam and diffuse irradiance (W / m2) and those of average temperature.

Next, in the figure 44 a plot of these data is shown.

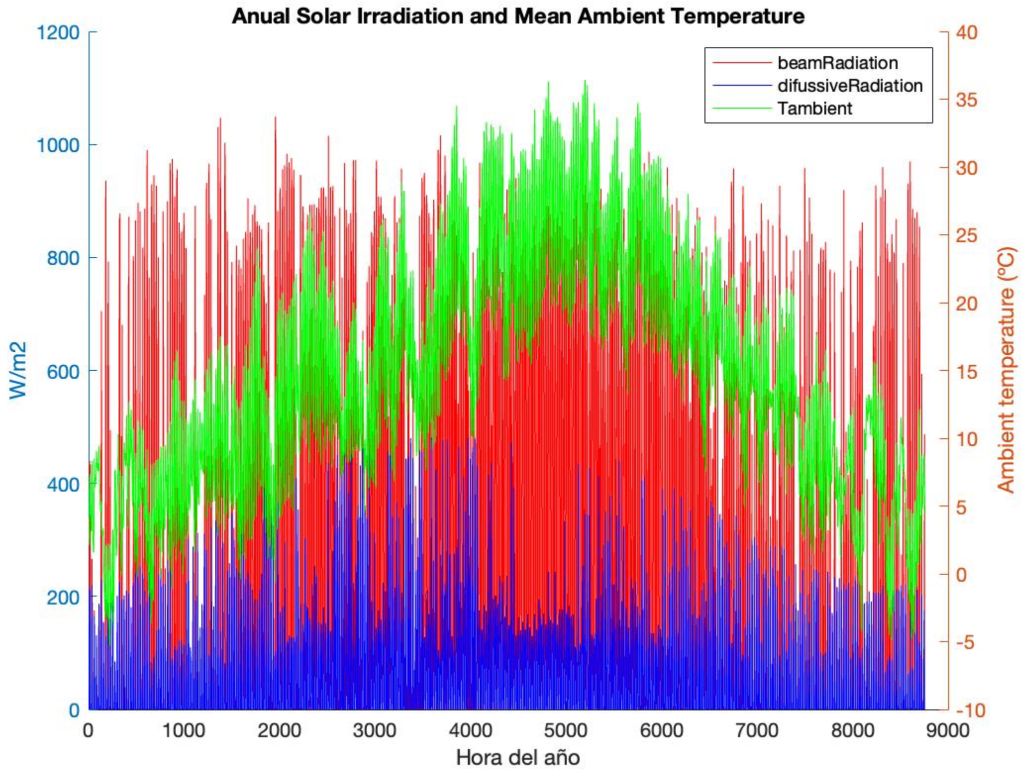

FIGURE 44 Solar radiation and ambient temperature

The radiation data in Madrid is very favorable, reaching 2064,6 kWh/m2 year in beam and 567,1 kWh/m2 year on diffuse radiation.

Temperature are very high is the summer season almost reaching 40°C and low in winter months even sub-freezing temperatures.

7.6 Collector field

7.6.1 Type of collectors choosen

For the design of our collector field, a combination of flat plate collectors (FPC) with parabolic trough collectors (PTC) has been chosen. This combination of collectors is already operating in a solar installation in Taars Varmevaerk, Denmark, that supplies the demand for heating, and is offering good performance in that location. Figure 45 shows the solar installation itself, this image has been taken from [39]
This installation has been taken as a reference for the configuration of the collector field, the calculation of the performance collectors, operating temperatures and flow rates.

Aalborg CSP A/S in their brochure "Project introduction- 6,8 MWth solar district heating plant (CSP + flat panels)"[40] explain that the combination of flat and parabolic technologies enables greater efficiency thereby lowering energy costs to a large extend.
The mix of these two solar-thermal technologies is an optimal combination as both systems deliver exactly what they do best: flat collectors have a higher performance at lower temperatures and produce more heat around midday, whereas CSP is most efficient at higher temperatures and provides a more balanced heat production throughout the day. Furthermore, flat plate collector can absorb the diffuse radiation while parabolic through collectors are not able.
This installation provides a larger solar energy share achieved compared to a conventional plant consisting of flat panels only. Even if the cost per m^2 of PTC is higher, it shows cost-effectiveness and the overall system is cost-competitive to present natural gas boiler heat production costs.

FIGURE 45 Taars Varmevaerk, Denmark, Solar district heating installation[38]

The collectors used in the Denmark installation are provided by Aalborg CSP A/S. From this source it is easy to find the technical sheet[41] of the collectors used.
The technical sheet and a diagram of the flat plate collector can be seen in the figure 47 and figure 46 respectively. The flat plate collector that was selected in Denmark's solar field and that we will therefore consider for this study is also the GK3133 / GK3133-S.
From the technical sheet we can highlight several values, table 7, that will be useful in future calculations. the dimensions of the collector, the working fluid to be used and the aperture area.

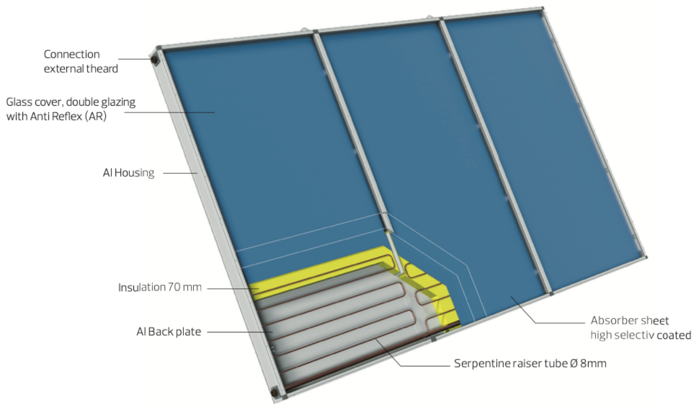

FIGURE 46 Schematic of the solar flat plate collector [40]

Technical data	GK3133 / GK3133-S	GK3803 / GK3803-S
Collector type	Large-size collector	
Overall area [m²]	13.17	7.91
Absorber area [m²]	12.37	7.42
Aperture area [m²]	12.35	7.41
L x W x H [mm]	5.920 x 2.224 x 135	3.557 x 2.224 x 135
Weight [kg]	333	202
Weight [kg] - GK/S	232	141
Absorber capacity [l]	11.35	6.81
Housing	Al-frame	
Surface	Al-natural	
Back plate	Al-sheet	
Absorber	Al, high selective vacuum coating	
Absorption [%]	95	
Emission [%]	5	
Ø manifold [mm]	28	
Ø risers [mm]	8	
Connections	1¼ " external thread	
Glass	3.2 mm tempered solar safety glass (double glazing)	
Transmittance of glass [%]	95 - AR glass	
Insulation	70 mm mineral wool plate	
Max. stagnation temperature	218 °C under norm conditions	
Max. operating pressure	10 bar	
Heat transfer medium	Polypropylene glycol / water mixture	
Packaging	for truck and container optimized	

FIGURE 47 Technical sheet of the solar flat plate collector [40]

The technical sheet and a diagram of the parabolic through collector[42] can be seen in the figure 48 . From the technical sheet we can highlight several values, table 7, that will be useful in future calculations. the dimensions of the collector, the working fluid to be used and the aperture area.

DESIGN SPECIFICATONS - SINGLE TROUGH	
Dimensions	L: 12m, W: 5.77m, H: 3.4m
Construction	Rotating torsional body and wing design
Weight	2,930 kg
Parabolic mirrors	28 pcs 67.3 m²
Receiver tube	ø70mm or ø80mm Stainless Steel pipes surrounded by a special glass vacuum tube
Heat loss in receiver tube	≤10% at 400 °C ≤1% at 100 °C
Heat transfer media	Water Thermal oil
Corrosion surface class	C3 as standard
Component class	IP66
Type of drive system	Hydraulic or electrical
Trough rotation speed	Tracking 1.8° / min Fast 7° / min
Trough rotation angle	220° (appr. 16 min hydraulic and 10 min electrical)

PERFORMANCE	
Design temperature	≤400 °C
Design pressure	≤40 barg
Max performance	540 KW
Optical efficiency	≤77%
Max wind speed (operation)	15m/s (54 km/h) mean wind speed
Max wind speed (operation with 3 sec gust)	20m/s (72 km/h) mean wind speed with 3 sec gust
Max wind speed (stow)	40 m/s (146 km/t) wind speed
Design criteria for wind speed	40 m/s
Operation mode	Automatic operation Remote control Local control
System safety	Automatic defocus using hydraulic pressure or electrical defocus using battery back-up
System lifetime	25 years

ROW DIMENSIONS	
Max troughs / row	12 pcs
Dimensions	L: 150m, W: 5.77m, H: 6.58m
Max aperture area	809 m²

APPLICATION	
District heating	District heating / hot water ≤95 °C
Process industries	Steam ≤180 °C ≤36 bar Heat transfer fluid ≤400 °C

FIGURE 48 Technical sheet parabolic trough collector[41]

TABLE 7 COLLECTORS TECHNICAL SPECIFICATIONS

	Flat plate collector	Parabolic through collector
Dimensions (LxWxH) (m)	5,92x2,224x0,135	12x5,77x3,4
Aperture area (m^2)	12,35	69,24
Maximum collectors per row	22	12
Working fluid	Polypropylene glycol/water mixture	Water

7.6.2 Orientation of the collectors

7.6.2.1 Flat collectors

According to [26]the South direction is considered as the optimal orientation and the best inclination, β_{opt}, depending on the period of use, one of the following values: Constant annual consumption: geographical latitude, preferential consumption in winter: geographical latitude + 10 ° and preferential consumption in summer: geographical latitude - 10 °.

As in this particular case the solar installation is aimed to supply the demand for space heating and cooling and domestic hot water demand the best selection for the tilted angle is the one that is going to provide an optimal performance of the collector for the whole year, so the selection is going to be:

$$\beta_{opt} = Location\ latitude \approx 40°$$

7.6.2.2 Parabolic through collectors

As has already been seen in the chapter 5.1.1. The collector can be oriented in an east–west direction, tracking the sun from north to south, or in a north–south direction, tracking the sun from east to west.
In the east-west orientation, the collector performance during the early and late hours of the day is greatly reduced, due to large incidence angles.
On the other hand, north–south orientation has their highest cosine loss at noon and the lowest in the mornings and evenings, when the sun is due east or due west[16].

If an annual period is evaluated, a horizontal north–south through field usually collects more energy than a horizontal east–west one. However, the north–south field collects a lot of energy in summer and much less in winter while the east–west field collects more energy in winter than a north–south field and less in summer, providing a more constant annual output[16].

Therefore, the choice of orientation will usually depend on the application and whether the energy demand is higher in summer or winter.
If we take a look at our thermal demand, it can be easily seen that the demand is significantly higher on summer, this is when the greatest energy supply will be needed. For this reason, in our particular case, a north-south orientation will be the best choice.

7.6.3 Collector field area

The plot designated for the solar installation has previously been shown. Being an urban area and in the process of urban growth, the chosen plot is close to homes, high-altitude buildings, protected parks, and heavily populated areas. It is convenient to reduce the designated area to a smaller quadrant, which is away from the edges of the plot. This will avoid possible shadows produced by other buildings, and serve as protection for the installation. The area of this plot, figure 49 has been obtained via Google Earth.

FIGURE 49 Collector field area

TABLE 8 AREAS

Total Collector Surface (m2)	Flat Collectors' surface (m2)	Parabolic Collectors Surface (m2)
5.592,85	2.992,07,33	2.287,73

It has been considered 8 meters between the installation of the flat collectors and the parabolic ones, to facilitate mobility between the facilities and avoid creating shadows between both collectors.

7.6.4 Number of collectors and aperture area

The collectors will be mounted on the ground, this choice depends on two aspects: the costs, which are lower than those roof mounted, and the space that exists on the roofs of the buildings that would limit the number of collectors and therefore the installed power. As we are going to use a model in which shadows from the solar collectors for both collectors' subfields have been simulated, it is important to use the same row distances that have been used in the model situation, in order to avoid shadows and blocks between collectors and get the desirable results. Although the inclination of the flat collectors has been modified in our case with respect to the reference model, this does not influence the necessary distance since the angle of inclination is smaller, and should create less shadow, therefore that of the model is valid in this case.

The given row distance for the parabolic trough and flat plate collector field are 12,6 m and 5,67 m respectively.

Considering the orientations, the surface dedicated to each technology, the dimensions of both collectors, table and the necessary distances between rows, it is possible to obtain the number of rows per type of collectors and the number of collectors per row.

TABLE 9 NUMBER OF COLLECTORS

	Nº of rows	Nº of collectors per row.
Flat plate collector	6	12
Parabolic Through collector (N-S orientation E-W tracking)	3	4

Aperture area of each collector technology is showed in table 10 . Considering the number of each type of collector, the total aperture area can be calculated. The results are shown in table

TABLE 10 APERTURE AREA

Total Collectors Aperture Surface (m2)	Flat Collectors' aperture Surface (m2)	Parabolic Collectors aperture Surface (m2)
1.720,08	889,2	830,88

7.6.5 Temperature y volumetric flow

Many of the machines used in air conditioning systems work best at constant supplied temperatures. This is the case of absorption machines, this equipment require a minimum temperature of the fluid that enters the generator for its operation and its production regime will be linked to the amount of energy that is contributed, ceasing to produce cold if the thermal level of the heating fluid falls below the minimum required[8]. For this reason, it is convenient that the outlet temperature of our collectors is constant as much as possible.

For our study we have considered that the outlet temperatures of our collectors are constant. The working fluid will enter the flat collectors at 40°C and will go out at 75°C. From this temperature it will enter at the parabolic trough collectors from which it will go out at 95°C. A schematic of the reference installation in Denmark is showed in figure 50 [39], as it can be seen a heat exchanger is needed to combine the two collector fields.

Due to this, the volumetric flow of the system will vary your value to accommodate the temperature to that fixed value.

Lower flow rates mean a higher fluid outlet temperature and large flows lower the outlet temperature mean the use of larger diameter pipes.

The collector circuit can use variable flow to achieve certain working temperatures depending on the irradiation conditions and ambient temperature and in the secondary circuit to avoid breaking stratification in the accumulation tank.

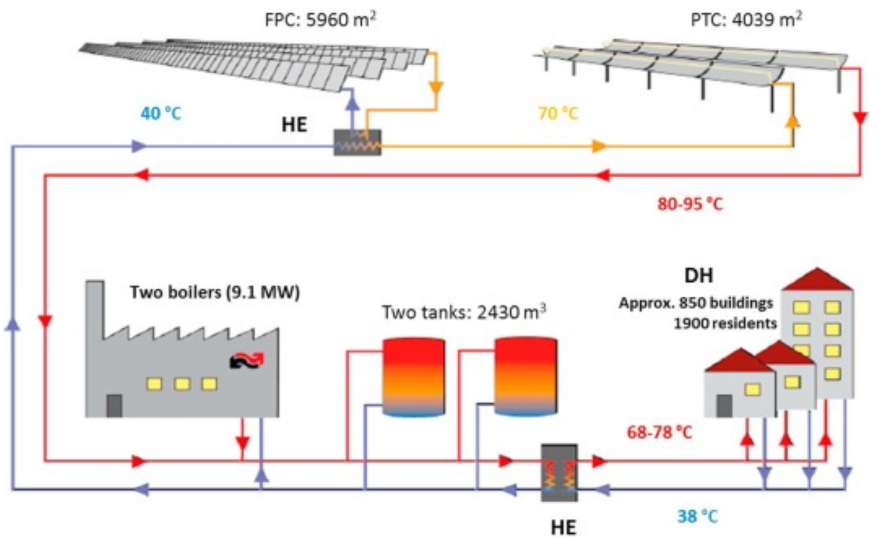

FIGURE 50 Schematic of the operation of the reference solar district heating network [39]

7.6.6 Performance of the collector field

In order to calculate the thermal performance of the collector field, a validated TRNSYS model of a hybrid solar heating plant, provided in the article [38] is going to be used. This model simulates thermal performance of both parabolic trough collector and flat plate collector field. The solar collector model is given as follows:

$$\frac{Q}{A} = \eta K_{\theta b}(\theta)G_b + \eta K_{\theta d}(\theta)G_d - c1(T_m - T_a) - c2(T_m - T_a)^2 - c3\frac{dT_m}{dt} \quad (11)$$

$$K_{\theta b}(\theta) = 1 - b_0\left(\frac{1}{\cos(\theta)} - 1\right) - b_1\left(\frac{1}{\cos(\theta)} - 1\right)^2 \; \theta \leq 60° \quad (12)$$

G_b is the beam radiation (W/m^2) and G_d is the diffuse radiation (W/m^2).
$K_{\theta b}$ represents the incidence angle modifier for the beam radiation and depends on the incidence angle. When the incidence angle is higher than 60° the incidence angle modifier is linearized from the value at 60° to a value of zero at 90°.
The incidence angle is calculated in two different ways, one for the flat plate collector, using equation 6 and the other for the parabolic trough collector, using equation 8 for being north-south oriented.
$K_{\theta d}$ is the incidence angle modifier of the diffuse radiation and it is a constant.
T_m is the mean fluid temperature(ºC) and T_a is the ambient temperature(ºC). The rest of the variables of the equation are constants, their values can be found in figure 51.
With the purpose of simplify the calculations, in our particular case flat plate collectors will be of the type HEATboost 35/10, without the FEP foil, only those values are going to be considered for the calculation of the flat place collectors' performance.

η_0	b_0	b_1	$K_{\theta d}$	c_1 [W/(m$^2\cdot$K)]	c_2 [W/(m$^2\cdot$K^2)]	c_3 [kJ/(m$^2\cdot$K)]	
0.779	0.1	0	0.98	2.410	0.015	6.798	HEATboost 35/10
0.745	0.1	0	0.93	2.067	0.009	7.313	HEATstore 35/10
0.75	0.27	0	0.038	0.04	0	4	PTC collector

FIGURE 51 Variables values for each type of collector

7.6.6.1 Flat plate collector field

As it can be seen in figure 52 the maximum power output of flat collector field does not reach 800 W/m2. The collector field performs clearly different depending on the season of the year, figure 53. In summer it can be seen that the output power is much more constant through all the hours an almost reach the maximum value. A similar result can be observed in spring, with some discontinuities on some specific days. The image changes a lot in the autumn and winter months, in which there are several discontinuities of the power output, in addition its value barely exceeds 600 W / m2 on repeated occasions. Figure 54 show the output power of the FPC field in kW.

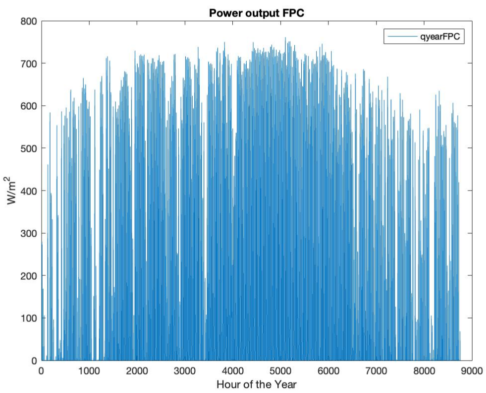

FIGURE 52 Power output FPC (W/m2)

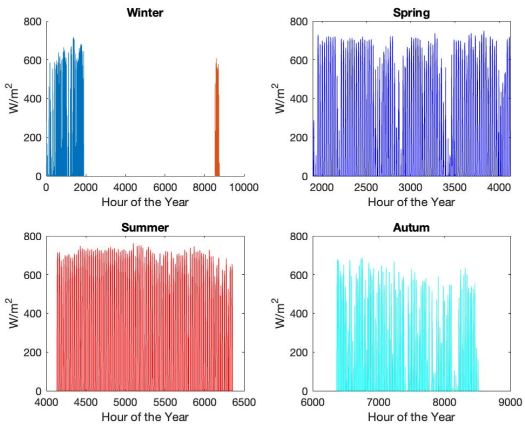

FIGURE 53 Power output (W/m2) each season

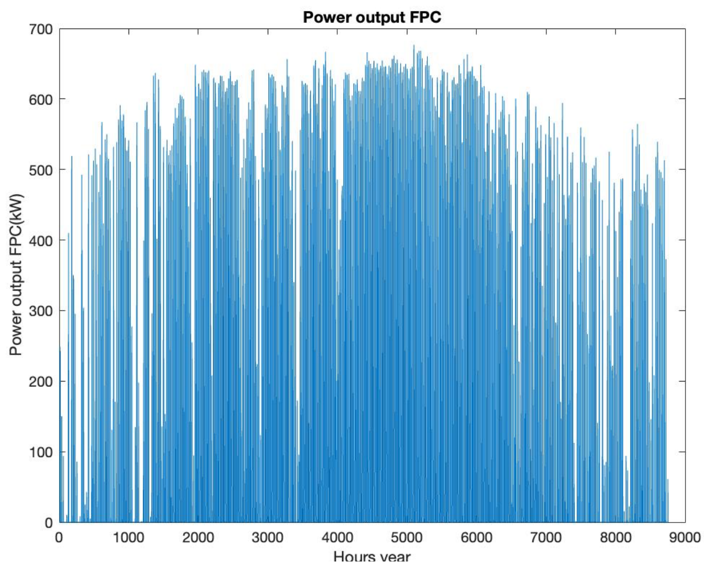

FIGURE 54 Power output FPC (kW)

7.6.6.2 Parabolic trough collector field

The behavior of the parabolic trough collector field is very similar to that of the flat collector with some small differences. The collector field clearly collects more radiation in summer as previously explained. In the other months, there are certain discontinuities in the power output and their value is lower than in the summer months.

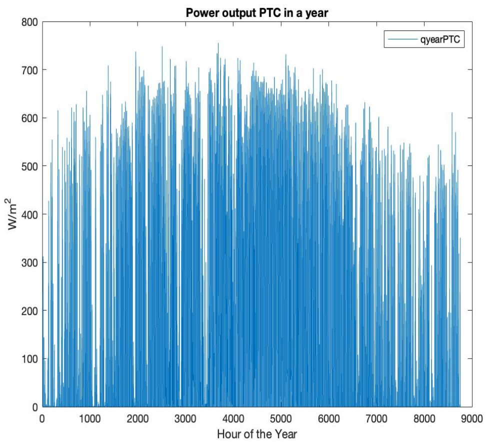

FIGURE 56 Power output PTC (W/m2)

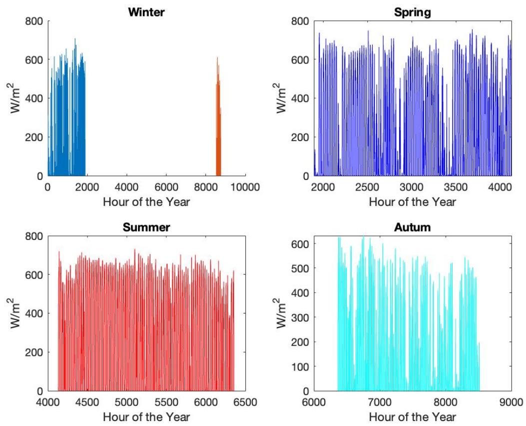

FIGURE 55 Power output (W/m2) by season

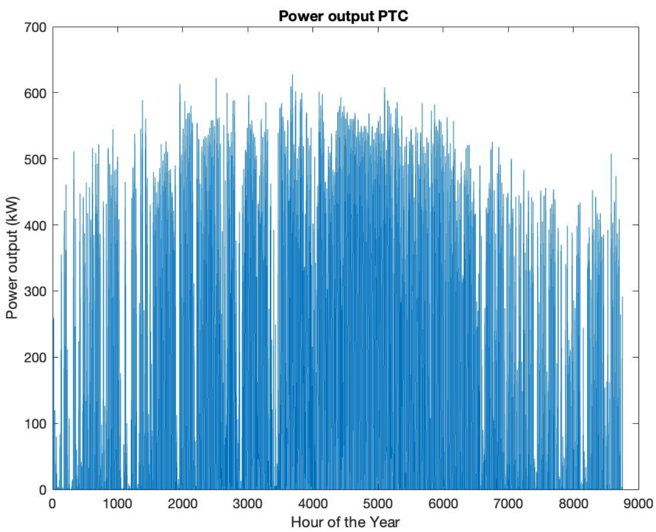

FIGURE 57 Power output PTC (kW)

7.6.6.3 Total collector field

The power output collector field has been calculated by summing up the power output of the flat plate and parabolic trough collector fields. The results are as expected, figure 58, the collector field will produce more power in the summer month, with a maximum of approximately 1200 kW

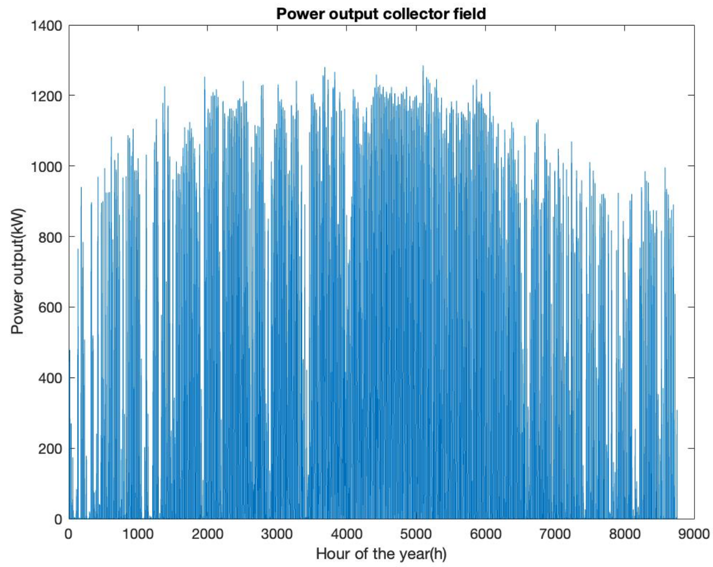

FIGURE 58 Power output collector field

Figure 59 shows the output power of the collector field, indicating the seasons of the year.

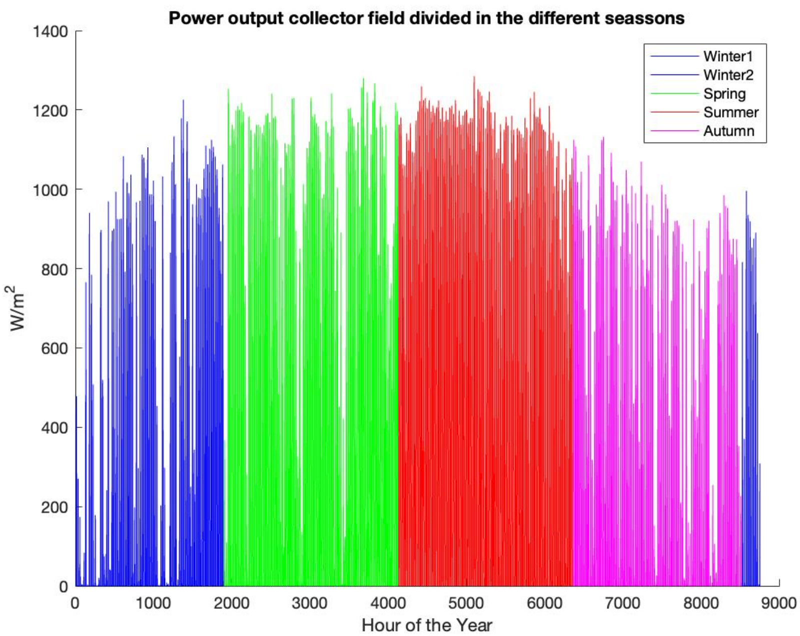

FIGURE 59 Power output collector field by each season

The table 11 shows the thermal performance of the collector field

TABLE 11 COLLECTOR FIELD ANNUAL PRODUCED ENERGY

Annual flat plate collector field	1.343,5 kWh/m^2 year
	1.194,7 MWh year
Annual parabolic trough collector field	1.472,8 kWh/m^2 year
	1.223,7 MWh year
Annual total field	2.418,4 MWh year

7.7 Solar accumulation

As previously mentioned, a seasonal accumulation in this case is not necessary, since solar production in summer will be directed to cover the cooling demand of the network. However, short-term storage can offer many advantages for the integration of solar energy in the study network. It allows better use of the solar resource, also provides more reliability to the installation, since the accumulated energy can be used at times when production and demand are not in phase. Furthermore, in the case of cold production, it is usually necessary to require a certain volume of accumulation so that the absorption machines or chillers can function correctly.

The most commonly used accumulation systems are usually for sensible heat storage through water or oil tanks. The use of molten salts or in solids storage is not justified, since the temperatures of use do not require it. For this specific case, the correct thing to do would be to use a water storage tank.

As it is a short-term accumulation, the volume of the tank must be as low as possible to allow the maximum use of solar energy. For air conditioning installations, the accumulation volume will be dimensioned so that the energy needs demanded are covered for at least one hour. In any case, it is recommended to use a V/A ratio between 25 l/m2 and 50 l/m2[23].
By looking at the demand figure, an average demand of 1000kWh can be determined as a reference

Table 12 has been built by changing the accumulation data in our facility. In order to find the storage volume, in m^3, the following equation is used:

$$V = \frac{Energy\ accumulated \times 3600 \times t}{Density \times Specific\ heat \times \Delta T} \qquad (13)$$

The density of the water is assumed to be 1000 kg/m^3 and the specific heat 4,1813 kJ/kgK. The ΔT represent the temperature different, in this case it will be (95-40) =55 K. The variable t represents the number of hours of desired storage.
The accumulation ratios (storage volume l / collector area m2) and solar production, and therefore the solar fraction, evolve proportionally. So, if the ratio is increased, the fraction is increased.

TABLE 12 ACCUMULATION

Accumulation (kWh)	Accumulation (L)	Accumulation ratio (l/m2)	Solar fraction (%)
1000	15.658,98	9,1	58,34
1500	23.488,47	13,65	61,78
2000	31.317,96	18,2	69,20
2500	39.147,45	22,76	79,81

Considering all this information, the choice of accumulation volume will depend on costs, performance, and the overlap of production and demand.
If our installation is analyzed, it can be seen, that the accumulation is only used and is useful during the summer months approximately, in which the solar production is greater, an excessive accumulation would also bring losses. During the first months of the year and the last, hardly any energy is accumulated, so the tanks are not useful.

For this reason, in this particular case, a minimum value of accumulation, to cover one hour of the demand, is used 1000kWh. The volume will be 15.658,98 liters.

When it is necessary for the accumulation system to consist of several tanks, these will be connected in inverted series in the consumption circuit or in parallel with the balanced primary and secondary circuits[26] as shown in figure 60.

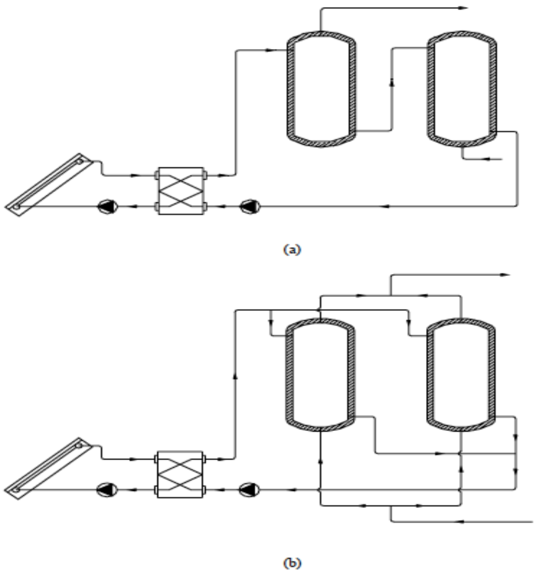

FIGURE 60 Storage tanks configuration

In the case of the domestic hot water (DHW) accumulator, this is independent of the previous calculation. In the case of the DHW, the energy that the solar field provides during a day must be considered.
For this application the accumulation ratio will be of the order

$$50 < V/A < 180$$

Its recommended value is approximately the daily consumption load[26].
For this study, the calculation of the domestic hot water tank will not be considered, since there will be a different one for each building that constitute the network. The reason is that the domestic hot water needs a specific treatment and temperatures to avoid bacteria and legionella problems. These problems are difficult to solve from the central plants and more so if they are used for other applications (heating and cooling). In addition, the distribution of domestic hot water from the plant to the substations is not adequate, due to the previously mentioned requirements. Therefore, the heat will arrive from the plant to the substations, where the temperature and regulated specifications required for the DHW production will be controlled.

7.8 Cold production

For the production of cold from the plant, the best option to combine with solar energy are absorption chillers, information about the configuration of this machines has been found[8].

If the production of cold is carried out exclusively by absorption equipment, it is recommended, in addition to the solar installation, a heat generator as an auxiliary energy system that can use any source of energy and that must provide the necessary power and temperature. to activate the absorption process.

The output power and the performance of the absorption equipment is highly dependent on the temperatures. The great importance of the hot water inlet temperature to the generator. Normally the equipment has a minimum operating value of 75ºC; the nominal regime is established for a value of the order of 90ºC, although it can operate at higher temperatures by increasing the useful power supplied.
The dependence on the outlet temperature of the chilled water from the evaporator is also very significant. Normally the nominal value is 7ºC which is the most used in conventional refrigeration systems.

For the operation temperatures used in this particular case the most adequate absorption chiller is a single effect one, as the temperatures are below 100 ºC, as mentioned before the COP of these machines is limited to 0,7-0,6 depending on the working pair used.

When sizing the absorption machine, the maximum cooling power of the network must be considered, this is a total refrigerant power of 1959,6 kW.

7.9 Auxiliary energy

As it has been previously mentioned in this project, the solar resource can be combined with other energy sources to supply thermal energy to a district network. This will provide more reliability to the system, as this auxiliary energy will supply the demand in periods where the solar installation is not able.

Solar thermal energy can be combined with many different technologies including conventional fossil fuels sources. For this particular case, it has been selected the biomass boiler technology as the auxiliary energy combined with the solar collectors.
According to [43] this type of fuel does not contribute to the increase of CO2 in the atmosphere, because its emissions are within the natural cycle of this greenhouse gas.
In addition, it is a renewable technology from which you can have a certain control of fuel availability, although in some cases it may have a certain seasonality

According to "Solar district heating guidelines"[44] there are two technical aspects to take into account when biomass and solar are combined:

- The biomass boiler has a minimum load limit. That means, that the boiler has to be run on/off, if the solar fraction is too high but no high enough to turn the biomass boiler off for longer periods. Therefore, the solar fraction has to be near 100% in the summer period.
- If the biomass system is with flue gas condenser the biomass boiler and the solar collectors has to be in parallel to optimize the efficiency.

With respect the configuration of the biomass boiler and the solar installation, there exist many specifications indicated in [26]:

- The connection of an auxiliary system in the solar accumulator is not allowed, since this may reduce the possibilities of the solar installation to provide the energy benefits that are intended to be obtained with this type of installation.
- The use of auxiliary energy systems in the collector primary circuit is prohibited.

Analysing the case study and considering what is mentioned in the section and the specific requirement, it has been decided that the biomass boiler is connected in parallel with the solar installation through a pipe collector. A three ways valve will be needed to control the contribution of the boiler to the system. Example of solar and biomass in parallel is showed in figure 61.

For systems with auxiliary power in parallel and especially in air conditioning applications, industrial uses and other applications in that temperature range, a system for regulating the water heated by the solar and auxiliary system is necessary in order to make the most of solar energy[26].

To size the biomass boiler, the maximum deficit value during the year will be taken into account. Deficit refers to the power demand that could not be covered by the solar installation plus accumulation. the production plants are sized according to the worst case, the maximum. In this case the maximum deficit is approximately 2.3 MW. so, the boiler should cover at least that power.

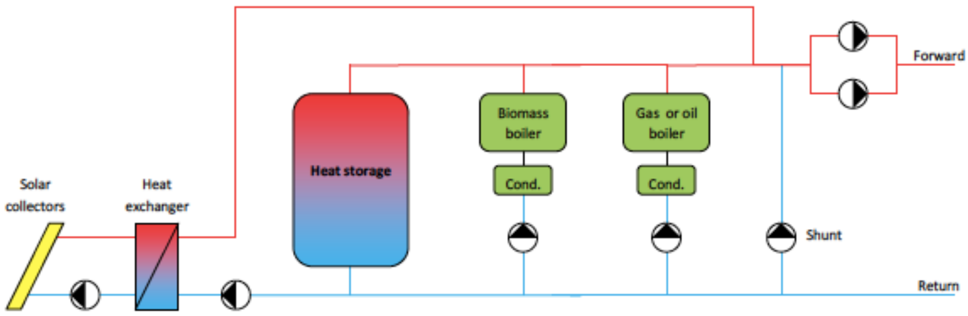

FIGURE 61 Example of combined solar and biomass in parallel configuration[44]

7.10 Results

7.10.1 Solar fraction

The solar fraction is the percentage of demand that is supplied with solar energy.

$$SF(\%) = \frac{Supplied\ solar\ energy}{Energy\ demand} \times 100 \qquad (14)$$

The annual solar fraction must be such that there is no excessive surplus of solar energy during any of the months of the year.

Oversizing of the installation would mean a surplus of energy production during the months of lower demand, this surplus, would be lost. Although the aim of achieving the highest annual solar coverage is very important to correctly size the solar to be efficient.

To check if our collector field is well dimensioned, it must be calculated the monthly solar fraction. The table 13 shows the results obtained:

TABLE 13 MONTHLY SOLAR FRACTION

Month	Solar fraction (%)
January	9,52
February	17,5
March	36,21
April	58,11
May	64,31
June	66,57
July	64,96
August	57,47
September	84,56
October	34,77
November	15,76
December	12,15

According to [26] the basic dimensioning of an installation, for any application, must be carried out in such a way that, in no month of the year the energy produced by the solar installation exceeds 110% of the consumption demand and not more than three months in a row 100%.

Our solar field satisfies both of these requirements, so it can be said that a correct dimensioning of the installation has been carried out.

The annual solar fraction will be 36.01 %. This annual solar fraction and the previous monthly solar fractions are calculated only considering the solar field of the installation.

If solar accumulation is considered the results are significantly different.

In the monthly scope, there will be months in which the solar production combined with the accumulation exceeds the demand, so the excess energy will dissipate. This excess given in punctual months can be assumed as certain loss of energy in the accumulation.

At annual level, the solar fraction is clearly benefited by the use of solar accumulation, amounting to a value of 58,34%. In this way, it can be demonstrated that solar accumulation contributes to an improvement in the use of the solar resource.

7.10.2 Behavior of the installation

In the figure 62 the overlap of demand and annual solar production is observed. It can also be seen the evolution of the accumulation and the solar fraction. A more detailed analysis of the behavior of the installation is made below.

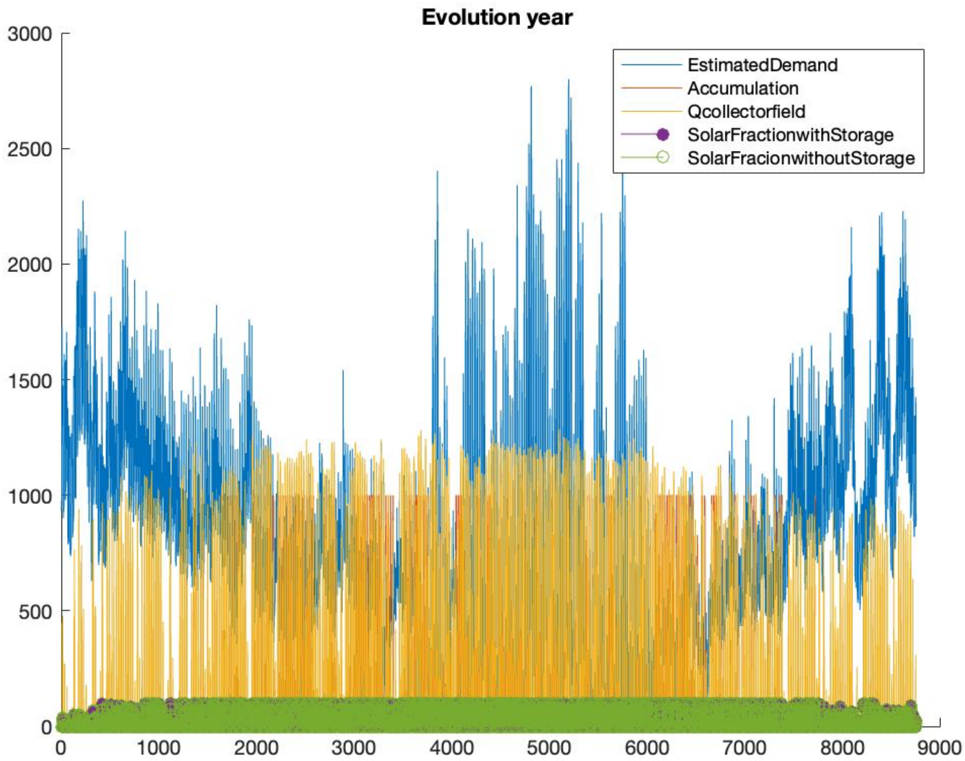

FIGURE 62 Yearly evolution

From figures 63 to 66, it can be observed, the disposition of the demand and the production during the different seasons of the year. It should be noted, the winter situation in which production almost never meets the needs of demand, also solar accumulation is almost non-existent, there is a gap between production and demand. solar fractions are low especially at the beginning of the year.

The situation in spring changes, production begins to be more constant, and even in many cases greater than demand. solar accumulation becomes important. a high solar fraction is achieved.

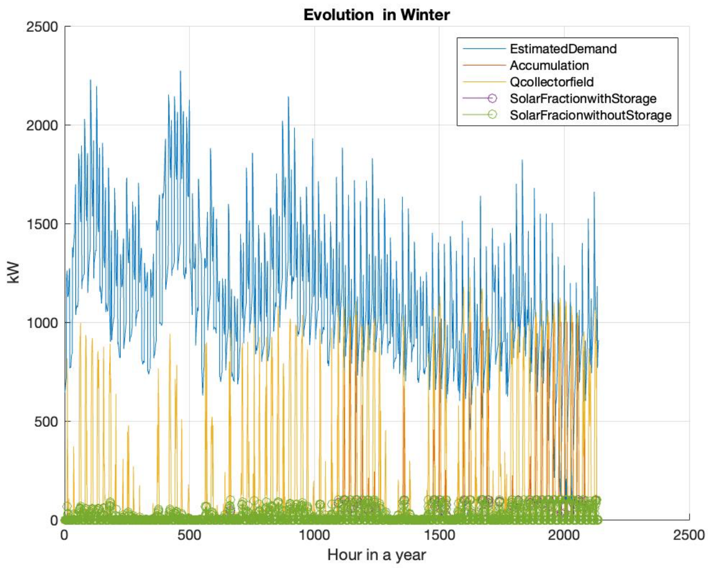

FIGURE 64 Winter evolution

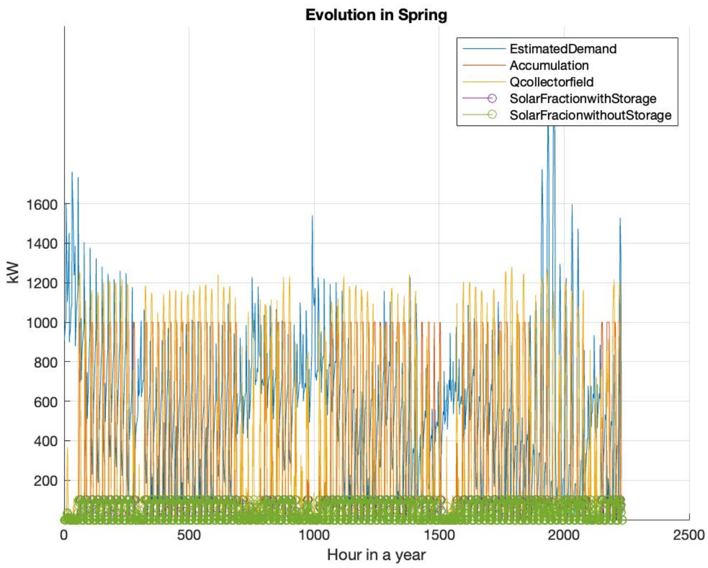

FIGURE 63 Spring evolution

In summer the production is very favorable, it is very constant throughout the period. Although demand is higher, production plus accumulation are able to cover it on many occasions, achieving a high solar fraction in these months. demand and production can be said to be mostly in phase.

In autumn the situation changes again. In the last months of this season, production is very low and demand rises, so the solar fractions are low and the solar accumulation is zero.

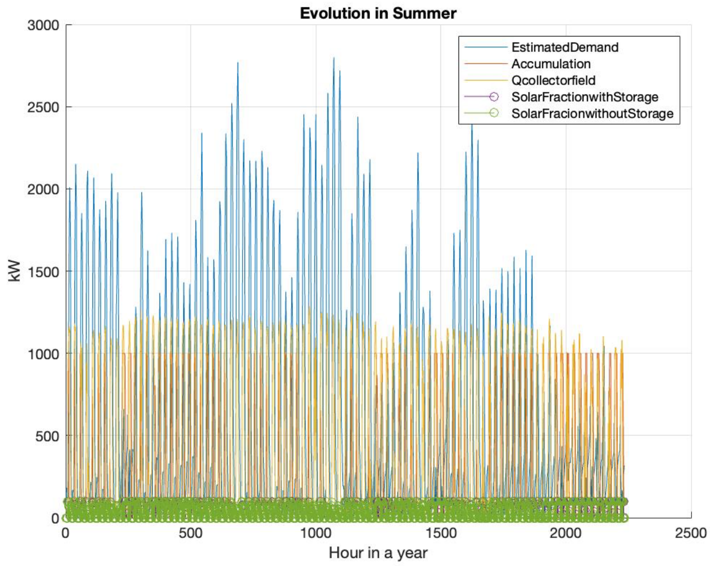

FIGURE 65 Summer evolution

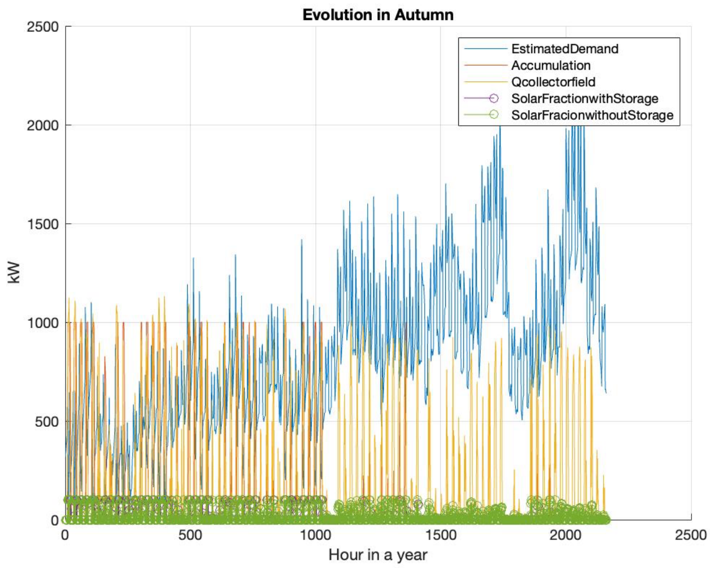

FIGURE 66 Autumn evolution

From figure 67 to 70 the evolution of demand, solar production, deficit, accumulation and solar fraction are observed during the 24 hours of a day. Four days have been chosen, one for each of the four seasons of the year, to have more variety and a more generalized image.

All days share a feature, the first and last hours of the day there is no solar production, this is produced by the lack of solar radiation. Related to this, it is observed that the days in summer are longer, the hours in which exist solar radiation are higher, thus the production. In summer and spring high production values are reached.

In the winter day, the production is less than the demand, the deficit is high, and the solar fractions low. energy is never stored, since excess production never occurs.

In the rest of the days, accumulation can be observed, how it grows when there is a surplus of production and how it decreases when it is being consumed by the network. And how the accumulation reaches its limit in many occasions. These days, it can be seen the difference in the coverage of the demand with and without accumulation.

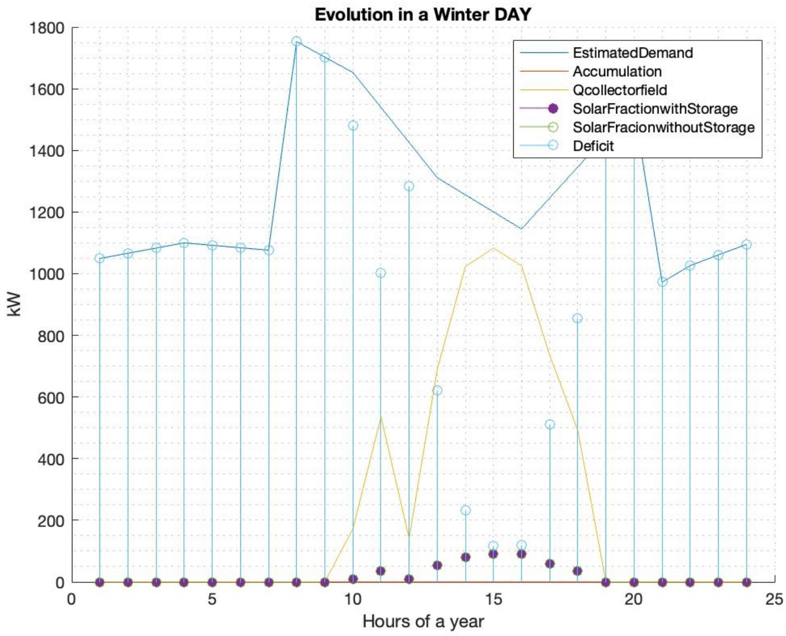

FIGURE 67 Winter day evolution

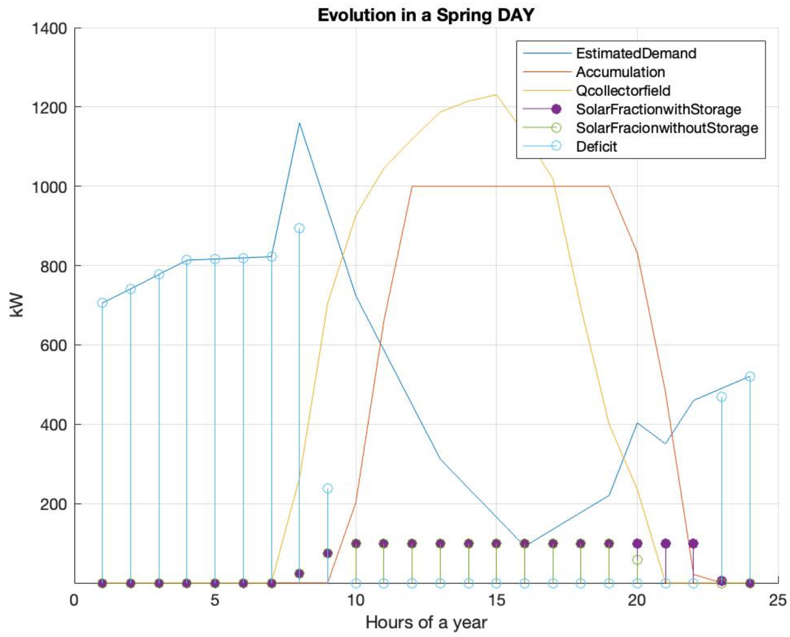

FIGURE 68 Spring day evolution

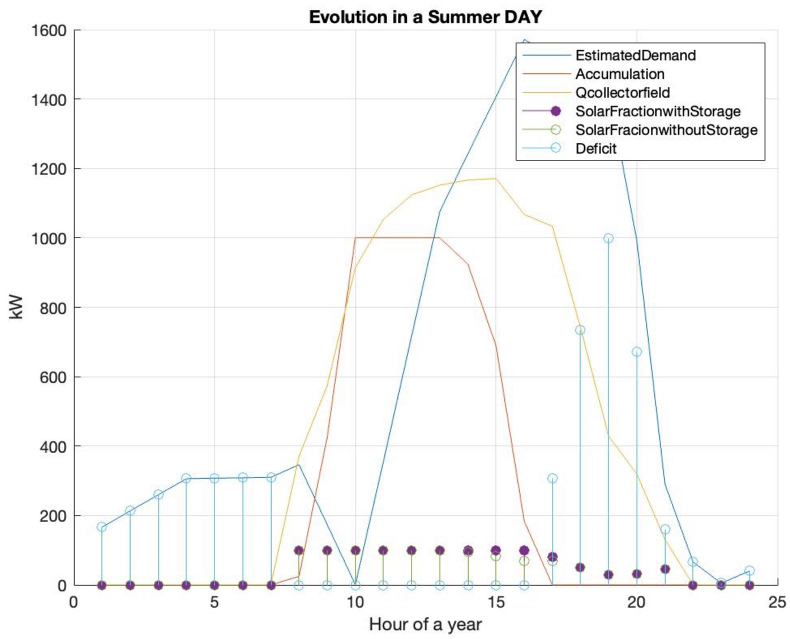

FIGURE 69 Summer day evolution

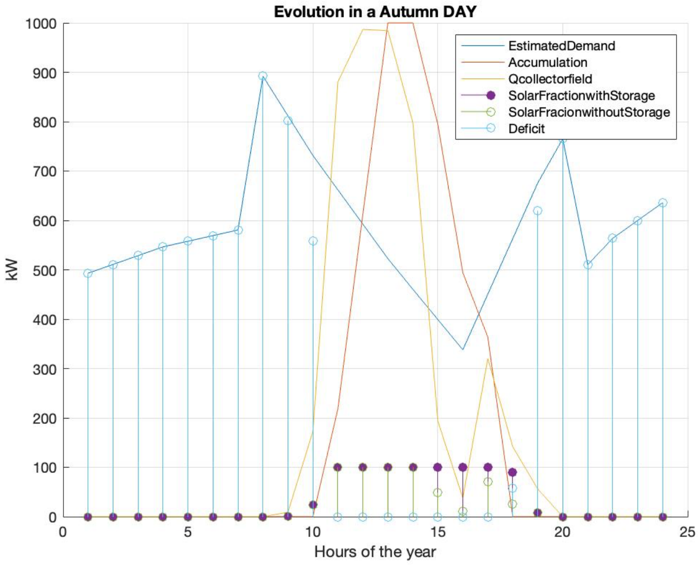

FIGURE 70 Autumn day evolution

The final results of the solar installation can be seen in table 14.

TABLE 14 FINAL RESULTS

YEARLY RESULTS	
Total collector field area	5.592,85 m2
Aperture area	1.720,08 m2
Number of collectors	72 PTC+12 PTC
Volume de accumulation	15.658,98 L
Yearly estimated demand	6.716,2 MWh year
Yearly Collector field output	2.418,4 MWh year
Yearly accumulation	1.499,6 MWh year
Solar fraction without accumulation	36,01 %
Solar fraction with accumulation	58,34 %

8 SOCIO-ECONOMIC ANALYSIS

8.1 Socio-economic impact

The applications of this project affect the air conditioning and building sector.

On March 23, 2021, the update of the "Reglamento de instalaciones térmicas (RITE)" was approved. This standard partially transcends the European framework and complements the CTE DB-HE of 2019 so that nearly zero energy buildings are more real every day. The information about the new changes in the RITE are obtain from[45]

In this new RITE, urban air conditioning networks and the use of renewable energies gain importance. A summary of the changes in the RITE 2021, related to the case study, which will also be mandatory for all projects that are requesting a license as of July 1, 2021.

1. It is updated to the European legal framework: eco-design criteria and labeling.
2. It reinforces the weight of renewables as required by the European framework: when referred to energy efficiency, it is also added "renewable and residual energies".

   The increase in renewables, is encourage by requiring the submission of technical, environmental and economic feasibility studies for alternative high-efficiency facilities, which are mandatory in all new buildings and, according to feasibility, also in renovations.
3. Regulates urban heat and cold networks: defines their design and control, and provides for the creation of maps of heat networks and installed renewable systems.

Considering these changes in the regulation of thermal installations, which every building project in our country must comply with, it can be assumed that the new regulation is committed to renewable energy, zero emissions, more efficient air conditioning installations, including urban networks.

It can be forecasted that the district networks are going to have significant growth in Spain in the next few years.

Although the initial investment of these installations is very high, they hardly require maintenance costs and their high efficiency makes them a safe offer in the long term. Finally, as we have already seen, there are direct orders from Europe to reduce emissions and create clean cities of pollution, district networks and more those that integrate renewable energy are key to this change.

Referring to the solar resource, Spain is one of the countries in Europe with the most solar radiation during the year. However, solar energy has not yet been exploited in the sector of solar heating and cooling in Spain, its application is reduced to supply the domestic hot water demand.

Although the mean radiation data in Europe is much lower than in Spain, solar district heating installations are very common in countries like Denmark. Germany and Austria[46], while in Spain they are isolated cases.

8.1.1 Annual savings

For this study is also relevant to carry out a quick calculation, in order to highlight the annual savings in natural gas that the use of collectors entails. Natural gas data can be shown in table

TABLE 15 NATURAL GAS DATA

NATURAL GAS	
PCI (kWh/Nm^3)	10,83
PCS (kWh/Nm^3)	11,98
PCI/PCS (%)	90,4
Density (kg/ Nm^3)	0,83
grCO_2/kWh (PCI)	204

The data has been obtained from the “Guía técnica: Diseño de centrales de calor eficiente”[47]

Nm3 (Normal m3) is the gas contained in 1 m3 at 0 ° C and atmospheric pressure.

PCI represent the lower calorific value, that is the heat that can be obtained in the complete combustion of the fuel unit. Part of the heat generated in oxidation is used to evaporate the water and therefore this heat is not used.

PCS represents the higher calorific value, that is the heat generated when water appears in liquid form in the combustion products; in other words, all the heat of oxidation of the fuel components is used.

The value grCO_2/kWh represent the CO2 produced in complete combustion per unit of energy (kWh)

The buildings that use natural gas boilers for heating, are the university and the apartments. It has been calculated the annual heat demand of these buildings and it has given us a result of 2,86x10^6 kWh year.

With this and the PCI we obtain the Nm3 of natural gas that would save with the use of the urban network. This value can be obtained in kg using the density of the fuel.

It is also important to realize how many emissions have been avoided with the use of the urban network with renewable integration, the parameter grCO_2/kWh is used. It should be noted that these savings, will be produce in the case that the district network system produce zero emission which is not really true, this is just an estimation to generate a general idea of the CO_2 emission that are saved by using the district network.

TABLE 16 ANNUAL SAVINGS

Avoided natural gas (Nm3)	264.118,19
Avoided natural gas (kg)	219.218,09
Avoided emission (tonnes CO_2)	583,52

Approximately 583,52 tonnes are avoided by the use of the studied district network.

8.2 Budget

To prepare an estimated budget on the integration of a solar installation in a district network, only the part that corresponds to the solar installation in an existing network will be considered. This means that the construction of the production plant will not be considered, nor the distribution network to the building of the network, which would involve a large amount of civil works, nor the construction of the substation. Within the installation, only the most significant items will be taken into account, and in an estimated way, since this is not an economic analysis as such but an estimate, in order to have an approximate idea of the prices of each component and the total.

The estimated prices have been obtained from the central database of the “Colegio Oficial de Aparejadores, Arquitectos Técnicos e Ingenieros de Edificación de Guadalajara”[48] and the CYPE database[49].

In order to mount the solar collectors on the ground, a certain civil work is necessary. Within this item, the following have been taken into account: the clearing and cleaning of the land by machine, the excavation of disaggregated land, the transport to the landfill and the beam of concrete.

For the collector field, a battery of flat collectors of approximately the size of the reference has been considered. To estimate the parabolic collectors' price different websites have been found, finally a price of 5,050 euros for 1 set has been taken.

Our solar accumulation is approximately 15,000 liters. A price has been found in the database, for an accumulator of 3000 liters, so it would take between 5 accumulators of this type.

It has been decided that it is going to be used an indirect solar system, so an external heat exchanger is necessary, between the collector loop and the accumulation tank. Its power is obtained from the following [26], in our case approximately 860 kW. An approximation has been considered.

Being an indirect system, the primary circuit (of collectors) is closed, for this reason overpressures are produced, which must be solved by installing an expansion vessel. A bleeder has also been included to release air from the circuit.

For the pipelines between collectors a 180 m of pipe have been considered.

The working fluid (glycol) and a reservoir for the working fluid have also been included.

Referring to auxiliary energy, the prices of biomass boilers have been reviewed, the price of a 250 kW boiler has been indicated. Although the power required in our installation is much higher, it has been taken this into account just one, as an order of magnitude. The heat collector pipe has also been included.

Finally, a study has been made of the price of the absorption chiller. An offer has been requested to the supplier Carrier for one of its 844 kW power absorption chiller, and the price has been obtained. As for the boiler, the price of only one chiller has been indicated in the budget, despite the fact that the required power would require at least two machines.

As mentioned before, these prices serve only to get an idea of the installation budget, they are not the real ones, there are many items and elements that have not been taken into account, if considered the final budget will be so much higher. Despite this, it allows us to draw conclusions and an approximate idea of the installation costs.

Código	Nat	Ud	Resumen	Comentario	N	Longitud	Anchura	Altura	Cantidad	CanPres	Pres	ImpPres
01	Capitulo		CIVIL ENGINEERING							1	227.219,81	227.219,81
01.01	Partida	m2	CLEARING AND CLEANING OF THE LANDS							5.592,00	0,65	3.634,80
				square meters					5.592,00			
									Total 01.01	5.592,00	0,65	3.634,80
01.02	Partida	m3	MANUAL DRAINING EXCAVATION OF DISGREGATED LAND <2 m ON THE EDGE							5.592,00	21,43	119.836,56
				square meters					5.592,00			
									Total 01.02	5.592,00	21,43	119.836,56
01.03	Partida	m3	LANDFILL TRANSPORT <10 km CHARGING MANUAL							202,50	42,61	8.628,53
					1,5	30,00	30,00	0,15	202,50			
									Total 01.03	202,50	42,61	8.628,53
01.04	Partida	m2	REINFORCED CONCRETE FLOOR HA-25 / B / 20 / IIa # 150x150x6 mm VERT. MANUAL e = 15 cm							5.592,00	17,01	95.119,92
				square meters					5.592,00			
									Total 01.04	5.592,00	17,01	95.119,92
									Total 01	1	227.219,81	227.219,81
02	Capitulo		COLLECTOR FIELD							1	218.157,35	218.157,35
02.01	Partida	u	BATTERY 2 SOLAR COLLECTORS 2.80 m2 FLAT COVER							72,00	1.571,27	113.131,44
				ud					72,00			
									Total 02.01	72,00	1.571,27	113.131,44
02.02	Partida	u	PARABOLIC THERMAL SOLAR COLLECTOR							12,00	5.439,10	65.269,20
				ud	12,0	0,00	0,00	0,00	12,00			
									Total 02.02	12,00	5.439,10	65.269,20
02.03	Partida	u	INERTIAL ACCUMULATOR CARBON STEEL 3000 l							5,00	6.059,32	30.296,60
				ud					5,00			
									Total 02.03	5,00	6.059,32	30.296,60
02.04	Partida	u	SOLAR-ACS HEAT WELDED PLATE EXCHANGER 48 kW							2,00	857,85	1.715,70
									2,00			
									Total 02.04	2,00	857,85	1.715,70
02.05	Partida	u	SOLAR EXPANSION VESSEL 100 l							1,00	316,49	316,49
					1,0	0,00	0,00	0,00	1,00			
									Total 02.05	1,00	316,49	316,49
02.06	Partida	m	DOUBLE PIPE ANNEALED COPPER INSULATED 14 mm 2x18 mm SOLAR							180,00	32,36	5.824,80
				conection lines	6,0	30,00	0,00	0,00	180,00			
									Total 02.06	180,00	32,36	5.824,80
02.07	Partida	u	3-WAY VALVE TYPE ZONE 1 "							3,00	69,53	208,59
				circuits	3,0	0,00	0,00	0,00	3,00			
									Total 02.07	3,00	69,53	208,59
02.08	Partida	u	SOLAR ENERGY AUTOMATIC BLEEDER							6,00	49,75	298,50
					6,0	0,00	0,00	0,00	6,00			
									Total 02.08	6,00	49,75	298,50
02.09	Partida	u	WORKING FLUID TANK 100 l							1,00	360,03	360,03
					1,0	0,00	0,00	0,00	1,00			
									Total 02.09	1,00	360,03	360,03
02.10	Partida	l	SOLAR WORKING FLUID							200,00	3,68	736,00
				estimado	200,0	0,00	0,00	0,00	200,00			
									Total 02.10	200,00	3,68	736,00
									Total 02	1	218.157,35	218.157,35
03	Capítulo		ENERGIA AUXILIAR							1	35.918,55	35.918,55
03.01	Partida	u	BIOMASS BOILER OF PELLET STEEL TRADEPELLET AUTOMATIC 250 kW							1,00	34.948,55	34.948,55
					1,0	0,00	0,00	0,00	1,00			
									Total 03.01	1,00	34.948,55	34.948,55
03.02	Partida	u	COLLECTOR PIPE (COPPER)							2,00	485,00	970,00
					2,0	0,00	0,00	0,00	2,00			
									Total 03.02	2,00	485,00	970,00
									Total 03	1	35.918,55	35.918,55
04	Capítulo		PRODUCCION DE FRIO							1	150.000,00	150.000,00
04.01	Partida	u	ABSORPTION CHILLER							1,00	150.000,00	150.000,00
					1,0	0,00	0,00	0,00	1,00			
									Total 04.01	1,00	150.000,00	150.000,00
									Total 04	1	150.000,00	150.000,00
									Total 0	1	631.295,71	631.295,71

Figure 71 Estimated budget

9 REGULATORY FRAMEWORK

Any thermal installation in our country is conditioned to comply with the “Reglamento de Instalaciones Térmicas (RITE)”.

For thermal solar installations, there exist the “Pliego de Condiciones Técnicas de Instalaciones de Baja Temperatura”. The objective of this document is to establish the minimum technical conditions that solar thermal installations for liquid heating must meet.

It also exists “Guía Técnica de Energía Solar Térmica” in which recommendations are collected based on the experience given by the number of solar thermal installations already in operation.

In the “Código Técnico de la Edificación CTE” in the “Documento Básico de ahorro de energía DB-HE” in its section HE4 “Contribución mínima de energía renovable para cubrir la demanda de agua caliente sanitaria”. The minimum contribution of energy from renewable sources will cover at least 70% of the annual energy demand for DHW and for pool heating, obtained from the monthly values, and including the thermal losses due to distribution, accumulation and recirculation. This minimum contribution may be reduced to 60% when DHW demand is less than 5000 l / d. During past year this renewable energy has been referred to the minimum solar contribution mostly. It varies depending on the climate zone, although the majority is 70%.

Still there are still no specific rules that regulate solar air conditioning, its design or its contribution to the demand.

10 CONCLUSIONS

After analysing the obtained results, several conclusions can be drawn from the present study:

- The feasibility of integrating a solar installation in a district network is highlighted.
- Being the objective of the district networks to achieve a minimum level of CO_2 emissions and to reduce dependence on fossil fuels, the integration of renewable energy sources in the energy production system of the district network studied is justified.
- The existence of an auxiliary energy that supports the solar installation is essential, since there are periods of hours during the day or even days in which the solar production is not enough to cover the whole demand.
- the biomass boiler must guarantee supply at all times. The solar plant will reduce the consumption of the boiler, but the installed power must provide the demand in the most unfavourable cases
- Solar thermal and biomass have no impact on CO_2 emissions into the atmosphere, with the exception of the electrical self-consumption of certain devices necessary to transport the fluids. Therefore, its inclusion in the generation system can significantly reduce the gr CO_2 / kWh t ratio, minimizing the environmental impact of the system.
- Although seasonal accumulation is not needed for this case, short-term accumulation is essential in order to increase the reliability of the solar system. The use of a shot-term storage system increases considerably the annual solar fraction of the installation.
- The solar installation has its highest capacity in the summer periods, so it is optimal for the system to provide the cooling demand that is generated in this season. Providing heat and cold to the network, will result in a better use of the solar resource.
- As it is a district heating and cooling, the need for seasonal accumulation is dispensed with, thus considerably reducing the cost of the system.
- Despite dispensing with seasonal accumulation, long-term accumulation is essential, which increases the reliability of the solar system.

- The use of parabolic collectors allows the installation to reach higher temperatures. These temperatures are optimal for DHW and air conditioning applications, since certain machinery needs high temperatures to start its operation.
- As parabolic collectors are significantly more expensive than flat collectors, the combination of both makes the option economically viable

11 ANNEXES

Annex A

```
%%%FLAT PLATE COLLECTOR%%%

% Close all opened figures
close all

% Load the data in the workspace
load('BEAMYEAR.mat');
load('TEMPYEAR.mat');
load('DIFFUSEYEAR.mat');

% Convert table data type into array (allow math expression)
difussiveRadiation = table2array(DIFFUSE);
beamRadiation = table2array(BEAM);
Tambient = table2array(temperaturamediaanotipo20072016);

% plot radiation data
figure
hold on
yyaxis left
plot(beamRadiation,'r')
plot(difussiveRadiation,'b-')
xlabel('Hora del a√±o')
ylabel('W/m2')

yyaxis right

plot(Tambient,'g')
ylabel('Ambient temperature (¬∫C)')

legend("beamRadiation","difussiveRadiation", "Tambient");
title("Anual Solar Irradiation and Mean Ambient Temperature");


% Vector Hours in a year of energy
hoursYearVector = 1:length(beamRadiation);
hoursInAYear = length(hoursYearVector);

% Constants
c1=2.41;
c2=0.015;
no=0.779;
bo=0.1;
b1=0;
Kd=0.98;
c3=6.78;
tilted = 40;
Tout=75;
Tin=38;
Tm=(Tout+Tin)/2;
ATM=0;

% Latitud madrid
latitude = 40.45;

% Preallocation
declination = zeros(1, hoursInAYear);
```

```
solarhour = zeros(1, hoursInAYear);

% Auxiliar counters
hourOfTheDay = 1;
dayOfTheYear = 1;



% For each hour of a year
for i = 1:hoursInAYear

    hourOfTheDay;
    %dayOfTheYear

        % Solar hours
        solarhour = (hourOfTheDay-12)*15;

        % Declination
        declination=23.45*sind((360/365)*(284+dayOfTheYear));

        % Incide Angle formula
        exp1 = sind(latitude) * sind(declination) * cosd(tilted);
        exp2 = cosd(latitude) * sind(declination) * sind(tilted);
        exp3 = cosd(latitude) * cosd(declination) * cosd(solarhour) *
cosd(tilted);
        exp4 = sind(latitude) * cosd(declination) * sind(tilted) *
cosd(solarhour);

        incidenceAngle = acosd( exp1 - exp2 + exp3 + exp4);

        % Incide Angle modifier Coefficient
        Kb=1-bo*((1./cosd(incidenceAngle))-1) -
b1*((1./cosd(incidenceAngle))-1).^2;

        % if incidenceAngle is bigger than 60
        if incidenceAngle > 60  && incidenceAngle < 90

            % Starting point is
             Kb60 = 1-bo*((1./cosd(60))-1) - b1*((1./cosd(60))-1).^2;
             Kb90 = 0;

            % Calculate incidenceAngle linearly
            m = -0.9/30;
            Kb = -0.03 * incidenceAngle + 2.7;

            elseif  incidenceAngle > 90
            % incidenceAngle cannot be > 90. If so, set it to 90
(kb=0)
                Kb = 0;
        end

        % Power emitted by collector in a year
        qyearFPC(i) = (no .* Kb .* beamRadiation(i)
)+(no.*Kd.*difussiveRadiation(i) ) - (c1.*(Tm - Tambient(i) ))-
(c2.*(Tm-Tambient(i)).^2)-(c3*ATM);

        % Update day hour
        hourOfTheDay = hourOfTheDay + 1;

        % Si nos encontramos en la ultima hora del dia (24)
```

```
        if hourOfTheDay == 25
            % Then we increase one the day of the year
            dayOfTheYear = dayOfTheYear + 1;
            % And we reinit the hour of the day
            hourOfTheDay = 1;
        end


end


for i=1:length(qyearFPC)

     if   qyearFPC(i)<0

         % Make null the negative values
        qyearFPC(i)=0;

    end
end

% Plot
figure
plot(qyearFPC)
ylabel("W/m^2");
xlabel("Hour of the Year");
title("Power output FPC")
legend("qyearFPC");

FPCenergyAnual=sum(qyearFPC,'omitnan')

% Plot the energy within the different weather estations
figure
hold on
plot((1:1896), qyearFPC(1:1896), 'b');
plot((8520:8760), qyearFPC(8520:8760), 'b');
plot(1896:4128,qyearFPC(1896:4128),'g');
plot(4128:6360,qyearFPC(4128:6360),'r');
plot(6360:8520, qyearFPC(6360:8520),'k');
ylabel("W/m^2");xlabel("Hour of the Year");title("Power output FPC
without negative values, divided in the different seassons")
legend("Winter1", "Winter2", "Spring", "Summer", "Autumn");


%% PLOTS
figure
subplot(221)
hold on
plot((1:1896), qyearFPC(1:1896));
plot((8520:8760), qyearFPC(8520:8760));
title("Winter");ylabel("W/m^2");xlabel("Hour of the Year");
subplot(222)
plot(1896:4128,qyearFPC(1896:4128),'b');
title("Spring");ylabel("W/m^2");xlabel("Hour of the Year");
subplot(223)
plot(4128:6360,qyearFPC(4128:6360),'r');
title("Summer");ylabel("W/m^2");xlabel("Hour of the Year");
subplot(224)
plot(6360:8520, qyearFPC(6360:8520),'c');
title("Autum");ylabel("W/m^2");xlabel("Hour of the Year");
```

```
aperturearea = 12.35;
numberofFPC=72;
TotalAperturearea=aperturearea*numberofFPC;

QoutFPC=(qyearFPC*TotalAperturearea)/1000;
figure
plot(QoutFPC);
title('Power output FPC'); %% TODO
xlabel('Hours year');
ylabel('Power output FPC(kW)');
FPCtotalenergyAnual=sum(QoutFPC,'omitnan')
```

Annex B

```
%%PTC%%

close all
%%DATOS GENERALES%%%%
load('BEAMYEAR.mat');
load('DIFFUSEYEAR.mat');
load('TEMPYEAR.mat');
year=(1:8760);
difussiveRadiation=table2array(DIFFUSE);
beamRadiation=table2array(BEAM);
Tambient=table2array(temperaturamediaanotipo20072016);
latitude=40.45;

hoursYearVector = 1:length(beamRadiation);
hoursInAYear = length(hoursYearVector);

%%DATOS PARABOLIC THROUGH COLLECTOR%%

c1=0.04;
c2=0;
no=0.75;
bo=0.27;
b1=0;
Kd=0.038;
c3=4;
Tout=95;
Tin=75;
Tm=(Tout+Tin)/2;
ATm=0;

declination = zeros(1, hoursInAYear);
solarhour = zeros(1, hoursInAYear);
qyearPTC = zeros(1, hoursInAYear);

% Auxiliar counters
hourOfTheDay = 1;
dayOfTheYear = 1;

% For each hour of a year
for i = 1:hoursInAYear

        % Solar hours
        solarhour = (hourOfTheDay-12)*15;

        % Declination
        declination=23.45*sind((360/365)*(284+dayOfTheYear));

        % Zenith angle formula

zenith=acosd(sind(latitude)*sind(declination)+cosd(latitude)*cosd(decl
ination)*cosd(solarhour));

incidenceAngle=acosd((cosd(zenith).^2+(cosd(declination)).^2*(sind(sol
arhour)).^2).^(1/2));

        % Incide Angle modifier Coefficient
        Kb=1-bo*((1./cosd(incidenceAngle))-1)-
b1*((1./cosd(incidenceAngle))-1).^2;
```

```
        % Power emitted by collector in a year
        qyearPTC(i) = (no .* Kb .* beamRadiation(i)
)+(no.*Kd.*difussiveRadiation(i) ) - (c1.*(Tm - Tambient(i) ))-
(c2.*(Tm-Tambient(i)).^2)-(c3*ATm);

        % Update day hour
        hourOfTheDay = hourOfTheDay + 1;

        % Si nos encontramos en la ultima hora del dia (24)
        if hourOfTheDay == 25
            % Then we increase one the day of the year
            dayOfTheYear = dayOfTheYear + 1;
            % And we reinit the hour of the day
            hourOfTheDay = 1;
        end


end

 for i = 1:hoursInAYear

      if   qyearPTC(i)<0

          % Make null the negative values
         qyearPTC(i)=0;

     end
 end

% Plot
figure
plot(qyearPTC)
ylabel("W/m^2");
xlabel("Hour of the Year");
title("Power output PTC in a year")
legend("qyearPTC");
PTCenergyAnual=sum(qyearPTC,'omitnan')

figure
subplot(221)
hold on
plot((1:1896), qyearPTC(1:1896));
plot((8520:8760), qyearPTC(8520:8760));
title("Winter");ylabel("W/m^2");xlabel("Hour of the Year");
subplot(222)
plot(1896:4128,qyearPTC(1896:4128),'b');
title("Spring");ylabel("W/m^2");xlabel("Hour of the Year");
subplot(223)
plot(4128:6360,qyearPTC(4128:6360),'r');
title("Summer");ylabel("W/m^2");xlabel("Hour of the Year");
subplot(224)
plot(6360:8520, qyearPTC(6360:8520),'c');
title("Autum");ylabel("W/m^2");xlabel("Hour of the Year");

% Calculo total del area
W=5.77;
L=12;
numberofPTC=12;
Aperturearea=W*L;
TotalAperturearea = numberofPTC*Aperturearea;
```

```
%%power output en W%%
QoutPTC=(qyearPTC*TotalAperturearea)/1000;

figure
plot(year,QoutPTC);
title('Power output PTC ');
ylabel('Power output (kW)');
xlabel('Hour of the Year');
PTCtotalenergyAnual=sum(QoutPTC,'omitnan')
```

Annex C

```
%%%%%DEMANDA TEORICA%%%%
load('TEMPYEAR.mat');

hoursofaYearvector=(1:1:8760);
hoursofaYear=length(hoursofaYearvector);
%%TEMPERATURE CONFORT INVIERNO====RITE%%%
Tci=23;
%%TEMPERATURE CONFORT VERANO====RITE%%%
Tcv=23;
%%POTENCIA PICO VERANO%%%
Qcalorequivalenteaulario=1050/0.7;
Qcalorequivalenteresidencia=615.1/0.7;
Qcalorequivalentechalets=294.5/0.7;
%%%POTENCIA PICO INVIERNO%%%%
Qcaloraulario=1050;
Qcalorresidencia=839.1;
Qcalorchalets=456;

Tmean = table2array(temperaturamediaanotipo20072016);
%%Salto t√©rmico horario invierno%%%
ATi=minus(Tci,Tmean);

%%Salto t√©rmico horario invierno%%%
ATv=Tmean-Tcv;

%%Salto t√©rmico maximo horario invierno%%%
ATimax=max(ATi);

%%Salto t√©rmico maximo horario verano%%%
ATvmax=max(ATv);

%%POTENCIA PUNTA CALOR%%%
C=zeros(8760,1);
l=length(ATi);

for i=1:length(ATi)
   if ATi(i)>0
C(i)=ATi(i)./ATimax;
else
    C(i)=0;
end
end
%%POTENCIA PUNTA FRIO%%%
F=zeros(8760,1);
for j=1:length(ATv)

if ATv(j)>0
F(j)=ATv(j)./ATvmax;
else
    F(j)=0;
end
end

%% DEMANDA ENERGETICA Aulario
DemandaCalorAulario=C*Qcaloraulario;
DemandaFrioAulario=F*Qcalorequivalenteaulario;
%%DEMANDA ENERGETICA Chalets
DemandaCalorChalets=C*Qcalorchalets;
```

```
DemandaFrioChalets=F*Qcalorequivalentechalets;
%% DEMANDA ENERGETICA Residencia
DemandaCalorResidencia=C*Qcalorresidencia;
DemandaFrioResidencia=F*Qcalorequivalenteresidencia;

%Crear vector posiciones que  comprendan todas las horas del a√±o
entre 6:00-20:00
vectHorasEnergiaReducidaAnt =[20:24 1:6];
vectHorasEnergiaReducida = [20:24 1:6];

for i = 1:364

    vectHorasEnergiaReducidaPost = vectHorasEnergiaReducidaAnt+24;
    vectHorasEnergiaReducida = [vectHorasEnergiaReducida
vectHorasEnergiaReducidaPost];
    vectHorasEnergiaReducidaAnt = vectHorasEnergiaReducidaPost;
end

%Aplicamos la reduccion de energia (a un 10%) a las horas del aulario
DemandaCalorAulario(vectHorasEnergiaReducida) = 0.1*
DemandaCalorAulario(vectHorasEnergiaReducida);
DemandaFrioAulario(vectHorasEnergiaReducida) = 0.1 *
DemandaFrioAulario(vectHorasEnergiaReducida);
% Suma dee energias demandadas
Demandacalor = DemandaCalorAulario + DemandaCalorResidencia +
DemandaCalorChalets;
Demandafrio = DemandaFrioAulario + DemandaFrioResidencia +
DemandaFrioChalets;

%%%%%POTENCIA EQUIVALENTE SUMA CALOR Y FRIO%%%%
Demandaestimada = zeros(1,hoursofaYear);

for i=1:hoursofaYear;

    Demandaestimada(i)=Demandacalor(i)+Demandafrio(i);

end

figure
plot(hoursofaYearvector,Demandacalor,'r');
title('Heating demand');
xlabel('Hours of a year (h)');
ylabel('Heating demand (kW)')

figure
plot(hoursofaYearvector,Demandafrio,'b')
title('Cooling Demand');
xlabel('Hours of a year (h)');
ylabel('Cooling Demand (kW)')

figure
plot(hoursofaYearvector,Demandaestimada);
title('Estimated total demand');
xlabel('Hours of a year (h)');
ylabel('Estimated total demand (kW)')

EnergiaDemandadaAnual=sum(Demandaestimada);
EnergiaDemandadaCalorAnual=sum(Demandacalor);
EnergiaDemandadaFrioAnual=sum(Demandafrio);
```

Annex D

```
%% RUN the script to create the variables
FPCYearTFG
PTCyearTFG
DemandaTFG

close all
%% Calculo de la fraccion solar

% Potencia recogida en el colector ()
Qcollectorfield= QoutPTC + QoutFPC;
figure
plot(Qcollectorfield);
title('Power output collector field');
ylabel('Power output(kW)');
xlabel('Hour of the year(h)');
figure
hold on
plot((1:1896), Qcollectorfield(1:1896), 'b');
plot((8520:8760), Qcollectorfield(8520:8760), 'b');
plot(1896:4128,Qcollectorfield(1896:4128),'g');
plot(4128:6360,Qcollectorfield(4128:6360),'r');
plot(6360:8520, Qcollectorfield(6360:8520),'m');
ylabel("W/m^2");xlabel("Hour of the Year");title("Power output
collector field divided in the different seassons")
legend("Winter1", "Winter2", "Spring", "Summer", "Autumn");


%% hoursYearVector
hoursYearVector =(1:length(QoutPTC));
hoursInAYear = length(QoutPTC);

energiaAcumulada = zeros(1,hoursInAYear);
energiaDeficit = zeros(1,hoursInAYear);
fraccionSolarwithStorage = zeros(1,hoursInAYear);
fraccionSolarwithoutStorage = zeros(1,hoursInAYear);

% Calculo de la hora uno
energiaAcumulada(1) = 0;
energiaDeficit(1) = Demandaestimada(1)- Qcollectorfield(1);

% Potencia acumulada
for i = 2:hoursInAYear

    % Si la demanda menos la potencia producida es positiva
    if Demandaestimada(i) - Qcollectorfield(i) > 0

        % Si tenemos potencia acumulada en el pasado
        if energiaAcumulada(i-1) > 0

            % La energia acumulada recalculada ser√° la potencia
generada
            % m√°s la accumulacion menos la demanda

            % La gastamos ahora (presente)
            energiaAcumulada(i) = energiaAcumulada(i-1) +
Qcollectorfield(i) - Demandaestimada(i);
                % Si la acumulada es negativa, se pone a cero
                if energiaAcumulada(i) <0
```

```
                    energiaAcumulada(i) = 0;
                end
            fprintf(" Energ√≠a acumulada gastada! Energ√≠a restante:
%d\n",  energiaAcumulada(i));

            % Si la demanda, menos la producida, menos la acumulada es
            % mayor a 0
        end

       if Demandaestimada(i) - Qcollectorfield(i) -
energiaAcumulada(i-1) > 0

                % Tenemos un deficit de energia
                energiaDeficit(i) = Demandaestimada(i) -
Qcollectorfield(i) - energiaAcumulada(i-1);
                fprintf(" Ha habido deficit de energ√≠a  %d\n",
energiaDeficit(i));
       end
%
    % Si la demanda, es menor a la producida
    elseif Demandaestimada(i) <  Qcollectorfield(i)
        % A√±adimos la potencia restante presente a la potencia
acumulada
        % del pasado
        energiaAcumulada(i) = energiaAcumulada(i-1) +
Qcollectorfield(i) - Demandaestimada(i);


        % Si la energia acumulada, super el tope limite (media de la
demanda), se queda en el
        % limite
        if  energiaAcumulada(i) > 1000
             energiaAcumulada(i) = 1000 ;
             fprintf("Storage energy has reached it limit,the rest of
the collector energy is dissipated\n");
        end

        fprintf(" Hay en total %d de energ√≠a acumulada \n",
energiaAcumulada(i));

    % sino (la potencia producida es igual a la demanda)
    else

        % No acumulamos (no hacemos nada)
        fprintf("No de hay demanda de energ√≠a \n");
    end

    % Calculo de la fraccion solar (producida + acumulada(pasada) /
demanda)

    fraccionSolarwithStorage(i) = ((Qcollectorfield(i) +
energiaAcumulada(i-1)) ./ Demandaestimada(i))*100;
    fraccionSolarwithoutStorage(i) =  (Qcollectorfield(i) /
Demandaestimada(i))*100;

    % Si mi fraccion solar es superior a 100%, ponla a 100%
    if fraccionSolarwithStorage(i) > 100

        fraccionSolarwithStorage(i) = 100;
```

```
     end
    if fraccionSolarwithoutStorage(i) > 100

        fraccionSolarwithoutStorage(i) = 100;


    end

end

    figure
    hold on
    title("Evolution year ");
    plot(Demandaestimada);
    plot(energiaAcumulada);
    plot(Qcollectorfield);
    hold on
    stem(fraccionSolarwithStorage,'filled');
    stem(fraccionSolarwithoutStorage);
   legend("EstimatedDemand","Accumulation",
"Qcollectorfield","SolarFractionwithStorage",
"SolarFracionwithoutStorage");

%Plot 4 days of the different seassons

% All hours of the day start at 1:00 AM (multiples of 24)
    % Winter
    vectorWinter = 600:623;
    % Spring
    vectorSpring = 3000:3023;
    % Summer
    vectorSummer = 4704:4727;
    % Autumn
    vectorAutumn = 6984:7007;
    % HourDayVector
    HourDayVector = 1:24;
figure

    hold on
    grid minor
    plot(HourDayVector,Demandaestimada(vectorWinter));
    plot(HourDayVector,energiaAcumulada(vectorWinter));
    plot(HourDayVector,Qcollectorfield(vectorWinter))

stem(HourDayVector,fraccionSolarwithStorage(vectorWinter),'filled');
        stem(HourDayVector,fraccionSolarwithoutStorage(vectorWinter));
    stem(HourDayVector,energiaDeficit(vectorWinter));

    xlabel('Hours of a year');ylabel('kW');

    legend("EstimatedDemand","Accumulation",
"Qcollectorfield","SolarFractionwithStorage",
"SolarFracionwithoutStorage","Deficit");
    title("Evolution in a Winter DAY");

   figure
    grid on
     hold on
    plot(HourDayVector,Demandaestimada(vectorSpring));
    plot(HourDayVector,energiaAcumulada(vectorSpring));
```

```
    plot(HourDayVector,Qcollectorfield(vectorSpring))
stem(HourDayVector,fraccionSolarwithStorage(vectorSpring),'filled');
    stem(HourDayVector,fraccionSolarwithoutStorage(vectorSpring));
    stem(HourDayVector,energiaDeficit(vectorSpring));

    legend("EstimatedDemand","Accumulation",
"Qcollectorfield","SolarFractionwithStorage",
"SolarFracionwithoutStorage","Deficit");
    title("Evolution in a Spring DAY");

%Mark the divisions of y axis
yticks([200 400 600 800 1000 1200 1400 1600 ])
    xlabel('Hours of a year');ylabel('kW');

   figure
     hold on
     grid on
    plot(HourDayVector, Demandaestimada(vectorSummer));
    plot(HourDayVector,energiaAcumulada(vectorSummer));
    plot(HourDayVector,Qcollectorfield(vectorSummer))

stem(HourDayVector,fraccionSolarwithStorage(vectorSummer),'filled');
    stem(HourDayVector,fraccionSolarwithoutStorage(vectorSummer));

     stem(HourDayVector,energiaDeficit(vectorSummer));

    legend("EstimatedDemand","Accumulation",
"Qcollectorfield","SolarFractionwithStorage",
"SolarFracionwithoutStorage","Deficit");
    title("Evolution in a Summer DAY");
    xlabel('Hour of a year');ylabel('kW');

    figure
    grid on
     hold on
    plot(HourDayVector, Demandaestimada(vectorAutumn));
    plot(HourDayVector,energiaAcumulada(vectorAutumn));
    plot(HourDayVector,Qcollectorfield(vectorAutumn))

stem(HourDayVector,fraccionSolarwithStorage(vectorAutumn),'filled');
    stem(HourDayVector,fraccionSolarwithoutStorage(vectorAutumn));

    stem(HourDayVector,energiaDeficit(vectorAutumn));
    legend("EstimatedDemand","Accumulation",
"Qcollectorfield","SolarFractionwithStorage",
"SolarFracionwithoutStorage","Deficit");
    title("Evolution in a Autumn DAY");
xlabel('Hours of the year');ylabel('kW');




%% Ploteo estaciones
    % Winter
    vectorWinter = cat(2, (8520:8760), (1:1896));
    % Spring
    vectorSpring = 1896:4128;
    % Summer
    vectorSummer = 4128:6360;
    % Autumn
    vectorAutumn = 6360:8520;
```

```
    figure

    hold on
    grid on
    plot(Demandaestimada(vectorWinter));
    plot(energiaAcumulada(vectorWinter));
    plot(Qcollectorfield(vectorWinter))
        stem(fraccionSolarwithStorage(vectorWinter));
        stem(fraccionSolarwithoutStorage(vectorWinter));
        %stem(fraccionSolarDifference(vectorWinter), '*r');
    %stem(energiaDeficit(vectorWinter));

    xlabel('Hour in a year');ylabel('kW');

     legend("EstimatedDemand","Accumulation",
"Qcollectorfield","SolarFractionwithStorage",
"SolarFracionwithoutStorage");
    title("Evolution  in Winter");

    figure
    grid on
     hold on
    plot(Demandaestimada(vectorSpring));
    plot(energiaAcumulada(vectorSpring));
    plot(Qcollectorfield(vectorSpring))
    stem(fraccionSolarwithStorage(vectorSpring));
    stem(fraccionSolarwithoutStorage(vectorSpring));
%     stem(fraccionSolarDifference(vectorSpring), '*r');
%     stem(energiaDeficit(vectorSpring));

 legend("EstimatedDemand","Accumulation",
"Qcollectorfield","SolarFractionwithStorage",
"SolarFracionwithoutStorage");
title("Evolution in Spring");
% Mark the divisions of y axis
yticks([200 400 600 800 1000 1200 1400 1600 ])
    xlabel('Hour in a year');ylabel('kW');

    figure
     hold on
     grid on
    plot(Demandaestimada(vectorSummer));
    plot(energiaAcumulada(vectorSummer));
    plot(Qcollectorfield(vectorSummer))
    stem(fraccionSolarwithStorage(vectorSummer));

    stem(fraccionSolarwithoutStorage(vectorSummer));
%      stem(fraccionSolarDifference(vectorSummer), '*r');
%      stem(energiaDeficit(vectorSummer));

     legend("EstimatedDemand","Accumulation",
"Qcollectorfield","SolarFractionwithStorage",
"SolarFracionwithoutStorage");
        title("Evolution in Summer");
    xlabel('Hour in a year');ylabel('kW');

    figure
    grid on
     hold on
    plot(Demandaestimada(vectorAutumn));
```

```
    plot(energiaAcumulada(vectorAutumn));
    plot(Qcollectorfield(vectorAutumn))
    stem(fraccionSolarwithStorage(vectorAutumn));
    stem(fraccionSolarwithoutStorage(vectorAutumn));
%     stem(fraccionSolarDifference(vectorAutumn), '*r');
%      stem(energiaDeficit(vectorAutumn));
     legend("EstimatedDemand","Accumulation",
"Qcollectorfield","SolarFractionwithStorage",
"SolarFracionwithoutStorage");
        title("Evolution in Autumn");
xlabel('Hour in a year');ylabel('kW');
%% CALCULO DE LA ENERGIA TOTAL DEMANDADA Y PRODUCIDA EN UN A√ëO
%Energia=sumatorio(potencia*tiempo(1hora))

%TOTAL DE ENERGIA DEMANDADA EN UN A√ëO (KWh/a√±o)
EnergiaDemandadaAnual=sum(Demandaestimada);
%TOTAL DE ENERGIA PRODUCIDA EN UN A√ëO (KWh/a√±o)
EnergiaProducidaColectoresAnual = sum(Qcollectorfield,'omitnan');
%TOTAL ENERG√çA ACUMULADA EN UN A√ëO (KWh/a√±o)
EnergiaAcumuladaAnual=sum(energiaAcumulada);
%FRACCION SOLAR ANUAL
FraccionsolarAnual=((EnergiaProducidaColectoresAnual+EnergiaAcumuladaA
nual)/EnergiaDemandadaAnual)*100;
FraccionsolarAnualWithoutStorage=(EnergiaProducidaColectoresAnual/Ener
giaDemandadaAnual)*100;
%MAX POTENCIA DEFICIT (KW)
energiaDeficitMax = max(energiaDeficit);
energiaDeficitAnual=sum(energiaDeficit);
```

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