DESIGN OF A SOLAR WATER HEATING SYSTEM IN A RESIDENTIAL BUILDING

Daniel Sánchez Herranz

June 2009

Master’s Thesis in Energy Systems
Preface

First of all, I would like to thank my family, especially my parents who made possible that I could spend a whole year studying abroad, and more especially to my brother and my sister, who supported me in the difficult decision of leaving my home town.

Thanks also to my home university, Universidad de Zaragoza, Högskolan i Gävle, and Yvonne Martensson who considered my application after the deadline.

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Finally, thanks to all neighborhood students with who I had spent this great year, which will be unforgettable.

June 2009

Daniel Sánchez Herranz
Abstract

One way to reduce CO$_2$ emissions, help to the global sustainable development and reduce the global warming is the use of clean and renewable energies. One of them is the solar energy, in fact this is one of the natural sources with more energetic potential. Due to this several prestigious entities and governments are promoting and improving the development and use of this kind of energy. For example, the Spanish government approved a law in March of 2006, named “Código Técnico de la Edificación”. This regulation is mandatory, and set the minimum quality requirements that residential buildings must have. One of them forces that new and renovated buildings have to produce part the energy demand for heating water by means of a solar thermal system.

The project is going to be carried out in an old building which is being renovated. The aim of this thesis is to design and calculate the installation of a solar system for covering part of the sanitary hot water in a residential building placed in Zaragoza, Spain.

The calculation includes dimension the system, to select the components and to obtain the solar annual coverage. After this, check that the obtained solar annual coverage is greater than the minimum one set by the law. The obtained results are the energy, fuel and money saves, as well as the initial investment and the payback of the installation.

The system can be divided in main and secondary elements, this thesis is only focused in calculate and dimension the main ones. The size of the elements and the selected components are the following ones:

- 34 flat plate collectors, model Vitosol 300F with 2,3 m2 of absorbent surface.
- 7 accumulators, model Vitocell 100V with capacity for 1000 liters.
- 1 natural gas boiler, model Vitogas 200F with a power of 29 KW.

Installing these elements the results obtained are quite satisfactory, the obtained solar annual coverage, 66,22% is greater than the minimum needed in this project, 65%. The energy and fuel saves reach a value of 66,23%. This carries a money saves of 55,95%, equivalent to 2.846,31 €/year. The CO$_2$ emissions reduction is also quite serious, 13.783,21 Kg/year.
The total initial investment cost of the installation, including main and secondary equipment and the installation of the system, is 62,160 €. This amount is divided between the sixty six flats of the building, therefore each flat is paying 941,82 €.

Finally, the payback of the installation is 21,83 years, more or less the life period of the system. So the initial investment money is returning back along the life period, predicted and guaranteed by manufactures between twenty and twenty five years.
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1. INTRODUCTION

Nowadays, in Spain exists a law called “Código Técnico de la Edificación” which means “Technical Building Manual”, henceforth on it will be referred as CTE. This regulation is composed by the main document, CTE, and a document of conditions and data for calculations, this second part is named “Pliego de Condiciones” and it will be referred as CTE PC. This law was written in March of 2006, and since then, its compliance is mandatory.

The CTE is a law which regulates the minimum quality requirements that the buildings must have. Some of those requirements are in the energy survey way. One of these energy survey requirements is the production of Sanitary Hot Water by mean of solar systems. It is worth mentioning that this project will be focused on the later part.

This requirement of CTE is applied to new buildings and to buildings that are renovated, independent of the use of the building always that they need sanitary hot water. Among these uses are included, residential buildings, private offices buildings, public buildings and shopping malls.

For the Sanitary Hot Water requirement, the CTE fix the minimum percentage of sanitary hot water that has to be produced by solar systems. This minimum percentage will be called minimum solar coverage, and depends on three parameters. The first one is the sanitary hot water demand per day in the building. The second one is the geographic position of the building, due to this position is directly related to the solar radiation. And the third one is the type of auxiliary energy source.

The mentioned percentage, minimum solar coverage, is proposed to be calculated by the CTE with the f-chart method. This practical method is used for dimensioning the optimal size of Sanitary Hot Water Systems heated by solar energy. In this project there is section that explain this method in a development way.

The CTE fix the minimum value for solar coverage, but it can be greater if the engineer who writes the project consider that it could be better, or if the previous data of the project set a higher value for the solar coverage.
### 1. INTRODUCTION

#### 1.1. Background

##### 1.1.1. Renewable Energy

The world energy consumption increases continuously, especially in countries which are developing themselves and has a huge population like China or India. Nevertheless it is known that nowadays the fossil fuels are increasing in prices day by day, and it is also known that in a near future will be lack of this kind of fuels. To overcome this problem, researches and governments are looking for new energy sources, known as the renewable energies. These energies are: bio-fuel, biomass, solar energy, wind energy, hydro energy, wave energy, tidal energy and geothermal energy. The development of renewable energies during the last years is shown in the following figure.

![Figure 1: Average annual growth rates of renewable energy capacity, 2002-2006.](image)

Almost all of these energies, solar, wind, hydro, wave and tidal energy, can be considered that come directly or indirectly from the sun. Only solar energy comes directly from the solar radiation, the rest come from solar energy in an indirect way. Wind energy will not exist if the sun does not heat the air and creates difference of pressure between air masses what produces air flows and wind, from this wind the energy is obtained by mean of wind mills. Hydro energy is possible because the solar heat evaporates the water forming clouds which are moved by means of wind energy, and after, the water accumulated in the clouds come back to the ground in form of rain...
or snow. When those precipitations take place in rivers, water flows and lakes are formed and hydro energy is obtained from them in hydro-powers stations. Wave energy obtains the energy from the wave’s propagation in wave farms by “Pelamis Wave Energy Converters”. Finally, Tidal energy is not produced only by the sun, tides currents are produced by the moon and the sun in combination with the Earth’s rotation movement, and the energy is produced in water turbines.

So why not use solar energy directly? These is the reason because of the solar energy use is being increased all over the world, especially in countries where there is a high solar irradiation.

This is the case of Spain, the most sunshine country of Europe, the average irradiation per day goes from 2.5 KWh/m\(^2\) in the northern regions of Spain, when the climate is more humid and cloudy, so there is less solar radiation, to more than 5.5 KWh/m\(^2\) in the south of the country. The solar irradiation in Spain is shown in the following figure.

![Average daily Horizontal Solar Irradiation in Spain, in KWh/m\(^2\).](image)

This power is enough for heating the hot water used in a common house. Because of that, the Spanish Government created a new law, called “Código Técnico de la Edificación”, which has already been explained.

### 1.1.2. Solar Energy Uses

Solar Energy can be used in many different ways, since some applications in the countryside like green houses in agriculture, to many different applications in the
residential buildings such as, lighting, water heating, space heating, space cooling, ventilation, water treatment and electricity generation, even it also can be used in some engineering fields, for example, solar vehicles or solar chemical, which uses solar energy to drive chemical reactions.

Nowadays, the most important for industry and residential buildings are only two of them, one for producing electricity, photovoltaic solar energy and the other one for heating water, thermal solar energy. The CTE only makes reference to these two applications. In this project only will be calculated the solar heating water system, due to this system is more interesting and complex.

1.1.3. Sanitary Hot Water heated by Solar Energy

First of all, it is important to define clearly what sanitary hot water is exactly. Sanitary Hot Water is the potable hot water doomed to human consumption. In the human consumption are included the activities that need water and are realized at home, such as human hygiene, cooking, washing, cleaning and so on. The temperature for this hot water consumption is 60 ºC.

The installation of this kind of system used to be easy. If the system is properly designed the energy saved are quite important, what is synonym of quite important money saving. Hence, these installations have a short payback, what produces that this installation were very interesting for a medium-long period.

1.1.4. f-chart Method

As it was said in the introduction, the CTE propose the f-chart method for calculating the minimum solar coverage percentage. In this part, the f-chart method is going to be explained.

The f - Chart is a method designed to determine the optimal size of solar water heating systems. This method has been studied, checked, tested and explained by many prestigious entities, such as NASA, University of Wisconsin, University of Texas, and so on. So it is better to explain this method with some of their studies or explanations, they can be seen in the next references.

“The Smithsonian/NASA Astrophysics Data System: Solar heating design, by the f-chart method.
Beckman, W. A.; Klein, S. A.; Duffie, J. A.

A practical technique for determining the optimal size of solar space and water heating system is presented. The technique, particularly suited to small systems, provides an optimization of solar collectors, storage tanks and heat exchangers; liquid or air may be the heat transfer agent. Detailed computer simulations correlating important dimensionless variables of solar heating systems with performance are presented in graphical and equation form. These charts, when used in conjunction with monthly average meteorological data and material costs, permit estimation of the long-term thermal performance of a solar heating system as a function of design parameters." [3]

“The Smithsonian/NASA Astrophysics Data System: A correction factor to f-chart predictions of active solar fraction in active-passive heating systems.

Evans, B. L.; Beckman, W. A.; Duffie, J. A.; Mitchell, J. W.; Klein, S. A.

The extent to which a passive system degrades the performance of an active solar space heating system was investigated, and a correction factor to account for these interactions was developed. The transient system simulation program TRNSYS is used to simulate the hour-by-hour performance of combined active-passive (hybrid) space heating systems in order to compare the active system performance with simplified design method predictions. The TRNSYS simulations were compared to results obtained using the simplified design calculations of the f-Chart method. Comparisons of TRNSYS and f-Chart were used to establish the accuracy of the f-Charts for active systems. A correlation was then developed to correct the monthly loads input into the f-Chart method to account for controller deadbands in both hybrid and active only buildings. A general correction factor was generated to be applied to the f-Chart method to produce more accurate and useful results for hybrid systems.” [4]


Duffie, J. A.; Mitchell, J. W.

The level of accuracy of the f-chart method of predicting the annual performance of a solar heating system is tested against performance measurements, with consideration given to an enlarged initial data base. Implicit in the f-chart method are assumptions that the storage tank contains thoroughly mixed fluid and that heat can be delivered to load as long as the tank water is 20 C higher than the room temperature. Both liquid and air systems are considered, and month-by-month estimates of the solar contribution to
heating and cooling loads are calculated. Comparisons of predictions with performance
were made for a liquid system with liquid heat storage, an air system with pebble bed
storage, and a hot water only system, using data from nine U.S. system installation sites.
Generally good agreement was found, although a tendency was revealed to
underestimate the performance of air systems when using the f-chart method. The f-
chart is concluded to be valid for the systems for which it was designed, and only within
the ranges of design parameters.” [5]

Once the f-chart method has been explained, it is going to be used in the calculation part
in order to calculate and dimension Sanitary Hot Water System for the building where
the project is being carried out.

1.2. The aim of the project

The aim of this project is to design and calculate the installation of the solar system for
covering the demand of sanitary hot water in a residential building placed in Zaragoza,
Spain. After this, calculate the money saving because of the fuel consumption reduction
and the CO2 emissions reduction. In the economical aspect the objectives are two, to
know the initial investment cost and to determine the payback period.

The solar is system is installed with an auxiliary water heater, this water heater only
works if the solar energy is not enough to cover the energy demand. The auxiliary boiler
selected for this project works with natural gas, which fixes for the installation the
general design.

The installation will be carried out in an old building, this event has been taken into
account when the installation would be designed. Because of it is and old building, the
installation has to be adapted to the architecture and the existing elements of the
building.
1.3. Limitations

There are three main limitations, two of them are directly related with the project and the engineer but not the other one. The first one takes place in the design aspect, the second one in the input data. There are also secondary limitations that derive in this two main again. And the third one takes place in the economic field.

The most important limitation in the design aspect is the surface needed to install the solar panels. This can became an important problem if the surface that the installation needs, is greater than the free surface in the roof of the building. There are also more secondary limitations in this aspect but all of them can be solved increasing the absorbent surface.

This limitation can be solved changing some elements of the installation. The best way to do it is to change the solar panels and install other type or other model with a higher efficiency. Maybe this improvement is not enough, in this case vertical panels could be used in the lateral walls of the building, these panels would not have the highest efficiency due to its orientation and its inclination could not be chosen, but the total energy absorbed would be increased in order to rise up the minimum that the law set.

The second important limitation of the thesis is related with the input data. The problem is that all the climatologic data are based in statistical data. Then they are reliable for a long period of years, but it can happen that one year the real data were different than the statistical ones. The data affected are the next ones:

- Hot water demand
- Environment temperature
- Cold Water grid temperature
- Useful sunlight hours
- Irradiation

This problem is solved immediately because the system has an auxiliary natural gas boiler. The gas boiler, its size and power, is calculated as if the system works only with this boiler. Thus, if one day is totally clouded and there is not any radiation in panel surface or the system brakes down, the gas boiler will have enough power to heat the water for covering the hot water demand predicted.
Finally, the third limitation of the project is placed in the economical field. This one always appear in all projects and is not related directly with the design of the project, it depends more of the owner of the building and the neighbor community. Due to they are who have to pay the installation of the system and subsequently the maintenance costs. It could be a problem if the installation is not profitable enough or the pay back of the operation is very long. Solve this problem is quite difficult because the engineer could not modify the prices of the elements neither the salary of the installers. The best option for solving this limitation is trying of reducing the initial investment and reduce the payback period.
2. DESCRIPTION OF THE BUILDING

The project will be carried out in a residential building placed in Zaragoza, Aragón in the north-east of Spain. The position is marked in the following map of Spain with a red rectangle:

![Political Map of Spain](image)

This project is focused into reform an old building. The new design will include a sanitary hot water production system.

The calculation method is based in some input data that depends on the geographic position of the building, such as coverage percentage, irradiation, correction factors according to the latitude, environment temperature and so on.

Some of these parameters depend on the geographic position but according with the zone that place in the “Zone Map of Spain”. The Zone Map of Spain have been created.
dividing Spain in different zones according with the irradiation received in each point, the higher irradiation, the higher level zone. This map is shown in the following picture.

Figure 4: Irradiation Zone Map of Spain. [7]

According to this map, the city of study, Zaragoza, is placed in Zone IV. As the legend explains, Zaragoza has a high irradiation which means that the incident solar energy is high. Because of that it is quite interesting to carry out this project, because the energy and money saves can be quite important.

The exact geographic position, used to obtain the others parameters, can be taken from municipality’s documents or from satellite pictures. In this project, those geographical parameters have been obtained using the program Google Earth. The following picture is an aerial picture of the building where the project is being carried out. The main address of the building is:

- Country: Spain
- City: Zaragoza
2. DESCRIPTION OF THE BUILDING

- Address: Paseo de Cuellar 37
- Zip Code: 50.007
- Kind of building: Building with several flats

![Aerial picture of the building.](image)

As well, it can be seen the orientation of the building using the compass on the top right corner. The orientation is quite good due to the facade walls are almost alienated with the principal axis of the compass, thus this position is the optimal to place the solar panels extracting the maximum performance to the available surface in the roof of the building.
In the photo, the two relevant surfaces for the project have been drawn. On the one hand, the red line represents the total surface of the building including the surface destined to the housings, that of both interior terraces, and that of the principal terraces of the first floor, placed in the interior side of the building. On the other hand, the green line delimits the useful surface that is going to be able to be used to place elements of the installation, this surface is greater than $270 \, m^2$. Principally in the roof only solar panels are going to be installed, the other elements are not designed to be exposed to the sun, and it is possible they would be placed in some interior room. The surface that is delimited by the green line coincides with the surface occupied by flats in the floors below.

Now is time to describe the composition of the building, and the main uses of each one of its parts.

The building is composed by one basement of garages, another basement of junk rooms, a ground floor with the entrance and three commercial places, eleven floors of flats, and a plane roof in the top of the building.

The three commercial places of the ground floor are of particular property and they will not be included in the reform. The garages and the junk rooms are active parts of the building therefore they are considered in the project, but they do not consume any water to develop their natural functions, so they are not going to affect in the calculation process.

The main part of the building, in terms of the project, is the residential part, the building possesses eleven floors and in each floor there are six flats. The configuration is not the same in all the flats, and the number of rooms is also different. Four of these flats are formed by one living room, one kitchen, one bathroom and three rooms. And the other two are organized by one living room, one kitchen, one bathroom and two rooms.

The total demand of water of the building depends directly on the people who live in there. This value, number of people, is not constant along the time and it is difficult to determine. To settle this uncertainty the CTE specifies that the number of persons who live in a flat is directly dependent of the number of rooms that the above mentioned flat possesses. According to this, the CTE sets in the page HE 4-4, the next relationship:
2. DESCRIPTION OF THE BUILDING

<table>
<thead>
<tr>
<th>Number of rooms</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>more than 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of persons</td>
<td>1.5</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>number of rooms</td>
</tr>
</tbody>
</table>

Along the project and the calculation process there are also many variables, like this one, with an unclear value, for all this variables the CTE set some rule in order to lead all the engineers and all the projects in the same way.
3. DESCRIPTION OF THE SANITARY HOT WATER SYSTEM

The main purpose of the system is to provide hot water to a residential building using solar energy. This objective is achieved by following the process described in the paragraph later, it will be easy to understand with the help of the diagram shown in the following picture.

![Sanitary Hot Water System Diagram](image)

*Figure 6: Sanitary Hot Water System Diagram.*

This diagram is very representative for understanding the case of the project. Although this diagram does not represent the real one which is going to be installed, the main
working process is the same than the real one. Due to this, it is good to have a look, to facilitate the comprehension of the process.

First, the solar energy in form of radiation is absorbed by the solar panels and transferred to the heat-transfer fluid. Then, this heat-transfer fluid flows inside the firstly circuit pipes. After, the fluid yields its energy in form of heat to the cold water storage in the accumulator, the heat-transmission is done across the interior coil pipe of the accumulator. This water is the one that will be used for the human consumption. Later, the water is stored till it is need in some supply point. Afterwards, when the hot water is needed it leaves the accumulator and goes through the auxiliary natural gas boiler. Now, the control system measures the temperature of the accumulator exit water, and switch on the auxiliary boiler if the water temperature is not high enough, under 60 ºC, or keep the auxiliary boiler off if the water temperature is right, 60 ºC. Finally, the water flows inside the deliver pipes until the supply point, that can be any device that needs water or some tap.

If the wished temperature of the water is not so high, less than 60 ºC, the user has to regulate it by himself mixing the hot water with water from the cold water grid.

It is worth mentioning that the water heating system is common for all the building, then the fuel consumption and delivery will be only for one client. The number of clients influence in the total fuel cost, due to the unitary fuel cost used to change depending on the total demand.

3.1. Description in detail of the main elements

Now, once that the system’s work process has been told, the main elements of the installation are going to be explained in detail.

3.1.1. Solar Panel, Flat Plate Collector

The type of solar panel selected for the project is a flat plane collector

“Solar collectors are the key component of active solar-heating systems. Solar collectors gather the sun's energy, transform its radiation into heat, then, it transfers that heat to water, solar fluid, or air. The solar thermal energy can be used in solar water-heating
systems, solar pool heaters, and solar space-heating systems. There are several types of solar collectors:

- Flat-plate collectors
- Evacuated-tube collectors
- Integral collector-storage systems

Residential and commercial building applications that require temperatures below 200°F typically use flat-plate collectors, whereas those requiring temperatures higher than 200°F use evacuated-tube collectors.

“Flat-plate collectors are the most common solar collector for solar water-heating systems in homes and solar space heating. A typical flat-plate collector is an insulated metal box with a glass or plastic cover (called the glazing) and a dark-colored absorber plate. These collectors heat liquid or air at temperatures less than 180°F.”

“Liquid flat-plate collector’s heat liquid as it flows through tubes in or adjacent to the absorber plate. The simplest liquid systems use potable household water, which is heated as it passes directly through the collector and then flows to the house. Solar pool heating also uses liquid flat-plate collector technology, but the collectors are typically unglazed as in figure below.” [11]

![Flat Plate Collector](image)

*Figure 7: Solar Panel, Flat Plate Collector.* [12]
The flat plane collector selected for our project is of the Viessmann Company, model Vitosol 300F. For achieving the minimum coverage set by the CTE, the absorbent surface needed is 74.89 m², which is equivalent to 34 solar panels Vitosol 300F. The principal characteristics of this element are shown in the following figure. More details of this product can be checked in the references.

### Vitosol 300-F, type SH3, SV3 (cont.)

#### 5.2 Specification

<table>
<thead>
<tr>
<th>Type</th>
<th>SV3</th>
<th>SH3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross area</td>
<td>m²</td>
<td>2.61</td>
</tr>
<tr>
<td>(required when applying for subsidies)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absorber area</td>
<td>m²</td>
<td>2.30</td>
</tr>
<tr>
<td>Aperture area</td>
<td>m²</td>
<td>2.32</td>
</tr>
<tr>
<td>Dimensions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width</td>
<td>mm</td>
<td>1056</td>
</tr>
<tr>
<td>Height</td>
<td>mm</td>
<td>2380</td>
</tr>
<tr>
<td>Depth</td>
<td>mm</td>
<td>80</td>
</tr>
<tr>
<td>The following values apply to the absorber area:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>— Optical efficiency</td>
<td>%</td>
<td>84</td>
</tr>
<tr>
<td>— Thermal loss correction value $\alpha_1$</td>
<td>W/(m² · K)</td>
<td>3.86</td>
</tr>
<tr>
<td>— Thermal loss correction value $\alpha_2$</td>
<td>W/(m² · K)</td>
<td>0.0130</td>
</tr>
<tr>
<td>Thermal capacity</td>
<td>kJ/(m² · K)</td>
<td>6.4</td>
</tr>
<tr>
<td>Weight</td>
<td>kg</td>
<td>52</td>
</tr>
<tr>
<td>Liquid content</td>
<td>l/m²</td>
<td>1.83</td>
</tr>
<tr>
<td>(heat transfer medium)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permissible operating pressure (see chapter &quot;Solar expansion vessel&quot;)</td>
<td>bar</td>
<td>6</td>
</tr>
<tr>
<td>Max. idle temperature</td>
<td>°C</td>
<td>210</td>
</tr>
<tr>
<td>Connection</td>
<td>Φ mm</td>
<td>22</td>
</tr>
</tbody>
</table>

**Figure 8:** Viessmann, Vitosol 300F Technical Data.[13]

### 3.1.2. Heat-Transfer Fluid

This fluid always works in liquid state. This liquid is the manager of the heat transports from the solar panel up to the deposit accumulator.

This liquid should have not very variable properties with the temperature, due to its working range is wide and have to be efficiency in all this range. Sometimes these installations are placed in cold regions and the environment temperature could be very low, to avoid the liquid frozen it has an especial composition. Most of the time, this composition is water mixed with alcohol, or other substance with a low solidification temperature.

The heat-transfer fluid used in this project is Tyfocor L, from Tyfo. Its main characteristics are shown in the following figure. More details of this product can be checked in the references.
Tyfocor L

<table>
<thead>
<tr>
<th>Properties</th>
<th>Appearance</th>
<th>clear, colourless liquid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling point</td>
<td>&gt; 150 °C</td>
<td>ASTM D 1120</td>
</tr>
<tr>
<td>Pour point</td>
<td>&lt;= -50 °C</td>
<td>DIN ISO 3016</td>
</tr>
<tr>
<td>Density (20 °C)</td>
<td>1.054 - 1.058 g/cm³</td>
<td>DIN 51757/ASTM D 4052</td>
</tr>
<tr>
<td>Viscosity (20 °C)</td>
<td>68 - 72 mm²/s</td>
<td>DIN 51582</td>
</tr>
<tr>
<td>Refractive index nD20</td>
<td>1.435 - 1.437</td>
<td>DIN 51423</td>
</tr>
<tr>
<td>pH of concentrate</td>
<td>6.5 - 8.0</td>
<td>ASTM D 1287</td>
</tr>
<tr>
<td>pH of 1:2 dilution with water</td>
<td>7.5 - 8.5</td>
<td>ASTM D 1287</td>
</tr>
<tr>
<td>Water content</td>
<td>&lt;= 4 % w/w</td>
<td>ASTM D 1123/DIN 51777</td>
</tr>
<tr>
<td>Flash point</td>
<td>&gt; 100 °C</td>
<td>DIN 51758</td>
</tr>
<tr>
<td>Alkali reserve</td>
<td>&gt; 10-13 ml 0.1 n HCl</td>
<td>ASTM D 1121</td>
</tr>
</tbody>
</table>

Figure 9: Tyfo, Tyfocor L Technical Data. \(^{14}\)

### 3.1.3. Accumulator

The accumulator is the device which stores the hot water while there is not hot water demand. An accumulator has three main characteristics. The first one is high effective thermal insulation, it is important because sometimes water is storage for a long period of time and in this period the energy lost ought to be the minimal. The second one, it should have big and long interior coil pipes in order to make easier and increase the heat transfer from the heat-transfer fluid to the water inside the deposit. And the third one, the capacity of the accumulator, this characteristic depends on each case of study, for small houses would be required a small accumulator, and for building would be required a big accumulator or even some of them working in parallel.

The accumulator selected for this project is Vitocell 100V 1.000 liters, of the Viessmann Company. It would be installed seven of these accumulators, because the storage volume needed is 7.038 liters. The design, the structure and the components can be seen in the following picture.
3. DESCRIPTION OF THE SANITARY HOT WATER SYSTEM

Figure 10: Viessmann, Vitocell 100V Design and Structure. \(^{151}\)

In the next figure are shown the main characteristics of the accumulator selected. More details of this product can be checked in the references.
3. DESCRIPTION OF THE SANITARY HOT WATER SYSTEM

3.1.4. Auxiliary Natural Gas Boiler

“A boiler is a device for generating steam for power, processing, or heating purposes or for producing hot water for heating purposes or hot water supply. Heat from an external combustion source is transmitted to a fluid contained within the tubes in the boiler shell. This fluid is delivered to an end-use at a desired pressure, temperature, and quality.” [17]

The purpose of the auxiliary gas boiler is to heat the water when the solar energy is not enough to heat it till the demand temperature.

In the boiler selection there are three characteristics more important than the rest ones. The first one is the power of the boiler, it means the heating capacity, the water which is able to heat per unit of time. The power is selected according to the heat energy demand predicted, the bigger the installation is the more powerful is the boiler. The second
important characteristic is the efficiency, due to this will determine the fuel consumption also depending on the heat demand. This characteristic includes the thermal insulation in order to do not have loses of heat, and good heat transfer from the fuel to the water. Finally, the third one is the kind of fuel used, it is important to consider not only its prices also the availability in the region. The most common fuels for gas boilers are natural gas, propane gas (GLP), kerosene, coal and electricity.

The auxiliary gas boiler selected for our project is Vitogas 200F, of the Viessmann Company. This model works with natural gas and its power is from 11 KW to 60 KW, in our installation it only will work until 29 KW. The design, the structure and the components can be seen in the following picture.

![Viessmann, Vitogas 200F Design and Structure](image)

In the next figure are shown the main characteristics of the natural gas boiler selected. More details of this product can be checked in the references.
3. DESCRIPTION OF THE SANITARY HOT WATER SYSTEM
4. DESIGN PROCESS

In this part, design process, all the steps follows in the calculation process are going to be explained in detail, this steps are going to be cleared with data, tables and graphics. This part is very important and should be made carefully, due to this results will determine if the installation is well dimension and useful for its propose.

4.1. Hot Water Demand

First, it is necessary to know the hot water demand per month in the building. This demand will depend on the people that live in the building and in the consumption per person. These two variables have a very wide range of possibilities and they change constantly, so they are difficult to fix.

To overcome this uncertainty the CTE set that the people who live in a flat is directly dependent of the number of rooms. According to this, the CTE sets in the page HE 4-4, the next relationship:

<table>
<thead>
<tr>
<th>Number of rooms</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>more than 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of persons</td>
<td>1.5</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>number of rooms</td>
</tr>
</tbody>
</table>

The consumption per person is also set according to the type of building, for the type of this project, building with several flats, the CTE consider 22 liters per person and day, in the page CTE HE 4-4, Table 3.1. The regulation does not make difference between winter and summer months.

The composition of the building has already been explained in one previous part of this project, Description of the building. Anyway, in the next table is recompiled the main information about the building design.
Table 3: Building design characteristics.

<table>
<thead>
<tr>
<th>Number of floors:</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of houses:</td>
<td>2 rooms houses</td>
</tr>
<tr>
<td>Number of houses per floor:</td>
<td>2</td>
</tr>
<tr>
<td>People per house:</td>
<td>3</td>
</tr>
</tbody>
</table>

Now, the total people per floor, and in the whole building are going to be estimated.

\[
\text{People per floor} = (2 \cdot 3) + (4 \cdot 4) = 22 \text{ persons per floor}
\]

\[
\text{Total people in the building} = 22 \frac{\text{persons}}{\text{floor}} \cdot 11 \text{ floors} = 242 \text{ persons in the building}
\]

After obtaining the total people in the building and with the estimated hot water demand per person and day, they can be calculated, first the total hot water demand per day and second the total hot water demand per month.

\[
\text{Demand per day} \left[ \frac{l}{\text{day}} \right] = HWD_d = 242 \text{ persons} \cdot 22 \frac{\text{liters}}{\text{day} \cdot \text{person}} = 5324 \frac{\text{liters}}{\text{day}}
\]

\[
\text{Demand per month} \left[ \frac{l}{\text{month}} \right] = HWD_m = HWD_d \cdot n(\text{Number of days})
\]

The result of this last calculation is shown in the table of the next section.

According to this demand per day, to the irradiation zone where the building is placed, Zone IV, explained in the section: Description of the building, and the auxiliary energy source, general (natural gas), explained in the section: Introduction, The aim of the project. According to these three parameters, the CTE sets the minimum solar coverage in the following table:
4. DESIGN PROCESS

Figure 14: Minimum Solar Coverage. \(^{[21]}\)

The minimum allowed coverage for this project is 65%. It means that the 65% of the total hot water demand per year has to be heated by solar energy, is the same than say, that the 65% of the energy used to heat up water has to be provided by a solar system. The real coverage will be calculated with the f-chart method. After, this real coverage will be compared with the minimum one, and the real has to be greater than the minimum in order to compliance the regulation.

### 4.2. Energy Demand

The water demanded should be heated up till the accumulation temperature, also called demand temperature \((T_{\text{Demand}})\), this temperature is 60 °C. The energy needed to increase the water temperature depends on the amount of water and the difference of temperatures between the inlet and the outlet.

The outlet temperature is the demand temperature which has already been fixed and is constant during all the months of the year, 60 °C. And the inlet temperature is the temperature of the cold water System of Zaragoza \((T_{\text{CWS}})\) measures in °C, this temperature varies along the month of the year being lower in winter months and hotter in summer months. The monthly values for the cold water system are obtained from the CTE PC page 50.

<table>
<thead>
<tr>
<th>Demanda total de ACS del edificio (l/d)</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.000-6.000</td>
<td>30</td>
<td>30</td>
<td>60</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>6.000-7.000</td>
<td>30</td>
<td>30</td>
<td>55</td>
<td>65</td>
<td>70</td>
</tr>
<tr>
<td>7.000-8.000</td>
<td>30</td>
<td>30</td>
<td>55</td>
<td>65</td>
<td>70</td>
</tr>
<tr>
<td>8.000-9.000</td>
<td>30</td>
<td>55</td>
<td>65</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>9.000-10.000</td>
<td>30</td>
<td>55</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>10.000-12.500</td>
<td>30</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>12.500-15.000</td>
<td>30</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>15.000-17.500</td>
<td>30</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>17.500-20.000</td>
<td>30</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>&gt; 20.000</td>
<td>52</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
</tbody>
</table>
4. DESIGN PROCESS

Then, the energy demand per month (EDm) and the power demand per month (PDm) can be obtained with the next expressions. They are measure in MJ/month and MWh/month, respectively.

\[
EDm \left[ \frac{MJ}{month} \right] = \frac{HWDm \cdot \rho_{H_2O} \cdot (T_{Demand} \cdot T_{CWS}) \cdot c_{p H_2O}}{1000}
\]

\[
PDm \left[ \frac{MWh}{month} \right] = \frac{EDm}{3600}
\]

Being:

\(\rho_{H_2O} = \text{Density of water} = 0,994 \text{ Kg/l}\)

\(C_{p H_2O} = \text{Specific heat capacity of water} = 4,184 \text{ KJ/Kg.ºC}\)

The energy demand per year, EDy, and the power demand per year, PDy, is the sum up of the twelve energy or power demand per month. Their results are the next ones:

\[
EDy \left[ \frac{MJ}{year} \right] = \sum_{m=1}^{12} EDm = 410,024,858 \text{ MJ/year}
\]

\[
PDy \left[ \frac{MWh}{year} \right] = \sum_{m=1}^{12} PDm = 113,896 \text{ MWh/year}
\]

These are the total demand of energy and power per year, but the coverage is only the 65% of this amount of energy. This new two variables are called, covered energy per year (ECy) and covered power per year (PCy), measure in the same units than the previous ones.

In the next table are shown all results of the previous section, in order to be observed in a global view.
4. DESIGN PROCESS

Table 4: Energy and Power Demands.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>165.044</td>
<td>5</td>
<td>37.752,05</td>
<td>24.538,83</td>
<td>10,49</td>
<td>6,82</td>
</tr>
<tr>
<td>February</td>
<td>149.072</td>
<td>6</td>
<td>33.478,65</td>
<td>21.761,12</td>
<td>9,30</td>
<td>6,04</td>
</tr>
<tr>
<td>March</td>
<td>165.044</td>
<td>8</td>
<td>35.692,84</td>
<td>23.200,35</td>
<td>9,91</td>
<td>6,44</td>
</tr>
<tr>
<td>April</td>
<td>159.720</td>
<td>10</td>
<td>33.212,94</td>
<td>21.588,41</td>
<td>9,23</td>
<td>6,00</td>
</tr>
<tr>
<td>May</td>
<td>165.044</td>
<td>11</td>
<td>33.633,64</td>
<td>21.861,87</td>
<td>9,34</td>
<td>6,07</td>
</tr>
<tr>
<td>June</td>
<td>159.720</td>
<td>12</td>
<td>31.884,43</td>
<td>20.724,88</td>
<td>8,86</td>
<td>5,76</td>
</tr>
<tr>
<td>July</td>
<td>165.044</td>
<td>13</td>
<td>32.260,84</td>
<td>20.969,55</td>
<td>8,96</td>
<td>5,82</td>
</tr>
<tr>
<td>August</td>
<td>165.044</td>
<td>12</td>
<td>32.947,24</td>
<td>21.415,71</td>
<td>9,15</td>
<td>5,95</td>
</tr>
<tr>
<td>September</td>
<td>159.720</td>
<td>11</td>
<td>32.548,68</td>
<td>21.156,64</td>
<td>9,04</td>
<td>5,88</td>
</tr>
<tr>
<td>October</td>
<td>165.044</td>
<td>10</td>
<td>34.320,04</td>
<td>22.308,03</td>
<td>9,53</td>
<td>6,20</td>
</tr>
<tr>
<td>November</td>
<td>159.720</td>
<td>8</td>
<td>34.541,46</td>
<td>22.451,95</td>
<td>9,59</td>
<td>6,24</td>
</tr>
<tr>
<td>December</td>
<td>165.044</td>
<td>5</td>
<td>37.752,05</td>
<td>24.538,83</td>
<td>10,49</td>
<td>6,82</td>
</tr>
<tr>
<td>Total</td>
<td>1.943.260</td>
<td></td>
<td><strong>410.024,86</strong></td>
<td><strong>266.516,16</strong></td>
<td><strong>113,90</strong></td>
<td><strong>74,03</strong></td>
</tr>
</tbody>
</table>

The annual results are remarkeit with color. In yellow color are the energy and power demanded, and in green one the energy and power that have to be covered with solar energy.

4.3. Solar Energy

The system works with solar energy, therefore this energy has to be quantified in order to determinate the size of the installation. The more energy absorbed per surface unit, the less surface necessary for obtaining the same amount of energy.

First, the incident solar energy in the absorbent surface of the flat plate collector, also named radiation, is going to be obtained. Radiation per day is not necessary to be calculated due to it can be taken from climatologic stations, the radiation that this stations measure is in horizontal plane and per day ($R_{day}(0°)$), measures in MJ/(m$^2$-day). The radiation varies with the inclination of the incident surface, being the maximum when the radiation is perpendicular to the incident surface. Radiation in an inclined
surface \( (R_{\text{day}}(\text{angle}^\circ)) \) is calculated multiplying the horizontal radiation by a correction factor \((k_{\text{angle}})\). Correction factors vary along the months of the year because the sun inclination also varies. The value of the horizontal plane radiation in different cities, Zaragoza in this project, can be obtained from the CTE PC page 100. And the corrections factors for inclined surfaces are also register in the CTE PC pages 102 - 108, depending on the latitude.

It is possible to install the solar panels in horizontal position, but it is not the best option because their efficiency increase when the radiation is perpendicular. The CTE suggest that the optimal inclination is the value of the latitude of the place, 0 may bit higher than those. According to this, in our project the inclination is 45º.

The solar energy has to cross the glass cover of the flat plate collector, this produce losses of energy. The percentage of energy that the glass cover lets go inside the collector is named Correction factor due to the optical performance of the collector \((k_{\text{op}})\). The correction factor due to optical performance of the flat plate with glass cover, is 0.95. It means that only the solar energy is lost in the glass cover. With this variables, it is able to calculate the incident solar energy per day \( (R_{\text{day}}(45^\circ)) \) and the incident solar energy per month \( (R_{\text{month}}(45^\circ)) \) in the case of sturdy, using the following expressions, the measuring units are shown in the expressions.

\[
R_{\text{day}}(45^\circ) \left[ \frac{MJ}{m^2 \cdot \text{day}} \right] = R_{\text{day}}(0^\circ) \cdot k_{45^\circ} \cdot k_{\text{op}}
\]

\[
R_{\text{month}}(45^\circ) \left[ \frac{MJ}{m^2 \cdot \text{month}} \right] = R_{\text{day}}(45^\circ) \cdot n
\]

Radiation is already obtained, but the f-chart method and the expression to calculate the collector efficiency use irradiation \( (G) \) instead of radiation. The difference between them are the way to be expressed, radiation is energy per surface and time, MJ/(m²·day), and irradiation is power per surface, W/m². The transformation from radiation to irradiation is just dividing inclined surface radiation per day by the useful radiation time per day. The useful radiation time depends on the useful sunlight hours per day \( (h_{\text{day}}) \), measures in hours/day. It is easy to understand looking the next expression.
The calculations of this section are shown in the following table.

**Table 5: Solar Radiation and Solar Irradiation in Zaragoza.**

<table>
<thead>
<tr>
<th>Month</th>
<th>$R_{\text{day}} (0^\circ)$ [MJ/m$^2$·day]</th>
<th>$k_{45}$</th>
<th>$R_{\text{day}} (45^\circ)$ [MJ/m$^2$·day]</th>
<th>$R_{\text{month}} (45^\circ)$ [MJ/m$^2$·month]</th>
<th>hd [h/day]</th>
<th>$G (45^\circ)$ [W/m$^2$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>6,3</td>
<td>1,42</td>
<td>8,50</td>
<td>263,46</td>
<td>8</td>
<td>295,09</td>
</tr>
<tr>
<td>February</td>
<td>9,8</td>
<td>1,3</td>
<td>12,10</td>
<td>338,88</td>
<td>9</td>
<td>373,55</td>
</tr>
<tr>
<td>March</td>
<td>15,2</td>
<td>1,16</td>
<td>16,75</td>
<td>519,26</td>
<td>9</td>
<td>516,99</td>
</tr>
<tr>
<td>April</td>
<td>18,3</td>
<td>1,03</td>
<td>17,91</td>
<td>537,20</td>
<td>9,5</td>
<td>523,58</td>
</tr>
<tr>
<td>May</td>
<td>21,8</td>
<td>0,93</td>
<td>19,26</td>
<td>597,07</td>
<td>9,5</td>
<td>563,17</td>
</tr>
<tr>
<td>June</td>
<td>24,2</td>
<td>0,89</td>
<td>20,46</td>
<td>613,83</td>
<td>9,5</td>
<td>598,28</td>
</tr>
<tr>
<td>July</td>
<td>25,1</td>
<td>0,93</td>
<td>22,18</td>
<td>687,45</td>
<td>9,5</td>
<td>648,42</td>
</tr>
<tr>
<td>August</td>
<td>23,4</td>
<td>1,04</td>
<td>23,12</td>
<td>716,70</td>
<td>9,5</td>
<td>676,00</td>
</tr>
<tr>
<td>September</td>
<td>18,3</td>
<td>1,21</td>
<td>21,04</td>
<td>631,08</td>
<td>9</td>
<td>649,25</td>
</tr>
<tr>
<td>October</td>
<td>12,1</td>
<td>1,41</td>
<td>16,21</td>
<td>502,45</td>
<td>9</td>
<td>500,25</td>
</tr>
<tr>
<td>November</td>
<td>7,4</td>
<td>1,55</td>
<td>10,90</td>
<td>326,90</td>
<td>8</td>
<td>378,35</td>
</tr>
<tr>
<td>December</td>
<td>5,7</td>
<td>1,52</td>
<td>8,23</td>
<td>255,15</td>
<td>7,5</td>
<td>304,84</td>
</tr>
<tr>
<td>Average</td>
<td><strong>15,63</strong></td>
<td><strong>16,39</strong></td>
<td><strong>499,12</strong></td>
<td><strong>502,31</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It can be seen that the average radiation increases slightly when the surface is inclined $45^\circ$. The increasing in not very important, but the most important consequence of inclined the solar collector is that, the difference between the maximum and the minimum radiation is reduce, therefore irradiation difference is reduced too. This improvement is quite important because it makes that the size of the installation will be smaller, and also because the efficiency of the system will be more regular.
4.4. Number of Collectors and Accumulators

4.4.1. Absorbent area and number of collectors

These two elements, collector and accumulator, are very important elements in the system. They have to be calculated together because the size of the collector depends on the efficiency of both, and the size of the accumulator depends on the collector’s size.

Collector is important because transforms the solar radiation into heat, the better efficiency the collector has the bigger energy is obtained from the same solar energy. Solar panel installed is Vitosol 300F, of Viessmann Company, it is a flat plate collector. Flat plate collectors have been selected because they work very well in water heater systems, actually nowadays most of the systems has this type of solar collector.

As all engineering device this one also has energy loses due to its efficiency is not 100%. These devices have been development in the last years, and their efficiency has been increased too much. The collector’s efficiency ($\eta_{\text{coll}}$) depends on several variables. Three constant that owns to the collector, and three climatologic variables, cold water system temperature ($T_{\text{CWS}}$) measures in °C, environment temperature ($T_e$) in °C, and irradiation ($G$) in W/m$^2$, and it is determined by the next expression.

$$
\eta_{\text{coll}} = \eta_o - k_1 \frac{T_m - T_e}{G} - k_2 \cdot G \left( \frac{T_m - T_e}{G} \right)^2
$$

Being:

$\eta_o$ = Optical efficiency of the collector = 0.84

$k_1$ = Lineal thermal loss correction value = 3.86 W/(m$^2$·K)

$k_2$ = Square thermal loss correction value = 0.0139 W/(m$^2$·K$^2$)

$T_m$ [°C] = Medium temperature of the collector = $(T_{\text{out}} - T_{\text{in}})/2$

$T_{\text{out}}$ = Outlet water temperature from the collector = 60 °C

$T_{\text{in}}$ [°C] = Inlet water to the collector = $T_{\text{CWS}}$

Accumulator is also important because is the place where the water is storage. The energy losses in this element are quite difficult to calculate, because they depend on
directly on the time the water is storage. This time is almost impossible to know certainly, so the losses have to be assumed. In this project the efficiency of the accumulator ($\eta_{\text{accu}}$) will be assumed as 85%, therefore $\eta_{\text{accu}} = 0.85$.

Once the collector’s efficiency and accumulator’s efficiency have been obtained, the supplied energy per month ($ES_m$), and the supplied energy per year ($ES_y$) can be calculated. The expressions used to calculate the supplied energies per month and per year are the next ones respectively.

$$ES_m \left[ \frac{MJ}{m^2 \cdot \text{month}} \right] = R_{\text{month}} (45^\circ) \cdot \eta_{\text{coll}} \cdot \eta_{\text{accu}}$$

$$ES_y \left[ \frac{MJ}{m^2 \cdot \text{year}} \right] = \sum_{m=1}^{12} ES_m$$

The efficiencies of both elements and the supplied energy are shown in the following table.

**Table 6:** Collector’s Efficiency, Accumulator’s Efficiency and Supplied Energy.

<table>
<thead>
<tr>
<th>Month</th>
<th>$T_m$ [°C]</th>
<th>$T_e$ [°C]</th>
<th>$G (45^\circ)$ [W/m$^2$]</th>
<th>$\eta_{\text{coll}}$</th>
<th>$\eta_{\text{accu}}$</th>
<th>$R_{\text{month}} (45^\circ)$ [MJ/m$^2$-month]</th>
<th>$ES_m$ [MJ/m$^2$-month]</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>32.5</td>
<td>8</td>
<td>295.09</td>
<td>0.4913</td>
<td>0.85</td>
<td>263.46</td>
<td>110.01</td>
</tr>
<tr>
<td>February</td>
<td>33</td>
<td>10</td>
<td>373.55</td>
<td>0.5826</td>
<td>0.85</td>
<td>338.88</td>
<td>167.83</td>
</tr>
<tr>
<td>March</td>
<td>34</td>
<td>13</td>
<td>516.99</td>
<td>0.6714</td>
<td>0.85</td>
<td>519.26</td>
<td>296.32</td>
</tr>
<tr>
<td>April</td>
<td>35</td>
<td>16</td>
<td>523.58</td>
<td>0.6903</td>
<td>0.85</td>
<td>537.20</td>
<td>315.22</td>
</tr>
<tr>
<td>May</td>
<td>35.5</td>
<td>19</td>
<td>563.17</td>
<td>0.7202</td>
<td>0.85</td>
<td>597.07</td>
<td>365.50</td>
</tr>
<tr>
<td>June</td>
<td>36</td>
<td>23</td>
<td>598.28</td>
<td>0.7522</td>
<td>0.85</td>
<td>613.83</td>
<td>392.47</td>
</tr>
<tr>
<td>July</td>
<td>36.5</td>
<td>26</td>
<td>648.42</td>
<td>0.7751</td>
<td>0.85</td>
<td>687.45</td>
<td>452.93</td>
</tr>
<tr>
<td>August</td>
<td>36</td>
<td>26</td>
<td>676.00</td>
<td>0.7808</td>
<td>0.85</td>
<td>716.70</td>
<td>475.68</td>
</tr>
<tr>
<td>September</td>
<td>35.5</td>
<td>23</td>
<td>649.25</td>
<td>0.7623</td>
<td>0.85</td>
<td>631.08</td>
<td>408.93</td>
</tr>
<tr>
<td>October</td>
<td>35</td>
<td>17</td>
<td>500.25</td>
<td>0.6921</td>
<td>0.85</td>
<td>502.45</td>
<td>295.58</td>
</tr>
<tr>
<td>November</td>
<td>34</td>
<td>12</td>
<td>378.35</td>
<td>0.5978</td>
<td>0.85</td>
<td>326.90</td>
<td>166.10</td>
</tr>
<tr>
<td>December</td>
<td>32.5</td>
<td>9</td>
<td>304.84</td>
<td>0.5173</td>
<td>0.85</td>
<td>255.15</td>
<td>112.18</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>31</strong></td>
<td><strong>9</strong></td>
<td><strong>304.84</strong></td>
<td><strong>0.5173</strong></td>
<td><strong>0.85</strong></td>
<td><strong>255.15</strong></td>
<td><strong>112.18</strong></td>
</tr>
</tbody>
</table>
It can be seen that the collector’s efficiency has a wide range of work, with a difference of almost 30% between the minimum and the maximum. Although the minimum is 50%, the average efficiency is 66.94%, quite a high value, a bit more than two thirds. The minimum efficiency is in January, and it coincides with the minimum irradiation and with the maximum difference between working and environmental temperatures. For against, the maximum efficiency is in August when the irradiation is the maximal and the difference of temperatures is the minimal. Summing up the supplied energies per months, the supplied energy per year (ESy) is obtained, $ESy = 3.558.76 \text{MJ/(m}^2\cdot\text{year)}$.

Comparing the supplied energy per year (ESy) with the needed energy to heat up the covered water demand predicted, covered energy per year (ECy), the necessary absorber area needed ($A'_{\text{abs}}$) for taking this amount of energy will be calculated, and fix in a number of solar panels ($n_{\text{coll}}$).

$$A'_{\text{abs}} \left[ \text{m}^2 \right] = \frac{ECy \left[ \frac{\text{MJ}}{\text{year}} \right]}{ESy \left[ \frac{\text{MJ}}{\text{m}^2 \cdot \text{year}} \right]} = \frac{65\% \ \text{EDy} \left[ \frac{\text{MJ}}{\text{year}} \right]}{3558.76 \left[ \frac{\text{MJ}}{\text{m}^2 \cdot \text{year}} \right]} \Rightarrow A'_{\text{abs}} = 74.89 \text{m}^2$$

The absorbent surface per panel is 2.3 m$^2$, it is disposed in the technical of our flat plate collector, Vitosol 300F. Hence it is necessary to install several panels, the number of them can obtained dividing the total absorbent area needed by the absorbent area per panel (aap).

$$n'_{\text{coll}} = \frac{A'_{\text{abs}}}{\text{absorbent area per panel}} = \frac{74.89 \text{m}^2}{2.3 \text{m}^2} = 32.56 \Rightarrow n_{\text{coll}} = 34 \text{ solar panels}$$

The number of collectors has to be a full number, so the result is round to a greater one, in our case 34 solar panels. In the f-chart method, the real absorbent area ($A_{\text{abs}}$) is used for calculating, and it is obtained multiplying the number of panels by the absorbent area of one.
Now, the size of the solar panels is determined. If the f-chart result sentence that the solar coverage is lower than the minimum set by CTE, the change to improve this result, will be increase the absorbent area

4.4.2. Accumulation volume and number of accumulators

The total accumulation volume \( V_{\text{accu}} \) also depends on the total absorbent area. This relationship is fixed by the regulation, CTE, and it can be gotten in the page CTE HE 4-12, \( 50 < \frac{V_{\text{accu}}}{A_{\text{abs}}} < 180 \).

The selected one for this project is 90, due to the building is not very big and with the accumulation volume gotten will be enough to satisfy the necessities of residents. After, this volume has to be converted in the equivalent number of accumulators. The model of the accumulator selected, Vitocell 100V, has capacity for 1000 liters. The process to calculate them is similar to the one for the collectors. Then, the necessary accumulation volume \( V'_{\text{accu}} \), the number of accumulators \( n_{\text{accu}} \) and the total installed accumulation volume \( V_{\text{accu}} \) will be.

\[
V'_{\text{accu}} = 90 \cdot A_{\text{abs}} = 90 \cdot 78.2 = 7038 l
\]

\[
\frac{V'_{\text{accu}}}{\text{one accumulator volume}} = \frac{7,038}{1000} = 7,038 \Rightarrow n_{\text{accu}} = 7 \text{ accumulators}
\]

\[
V_{\text{accu}} = n_{\text{accu}} \cdot \text{one accumulator volume} = 7 \cdot 1000 \Rightarrow V_{\text{accu}} = 1000 \text{ liters}
\]

As this accumulation volume depends on the absorbent surface, if the absorbent surface changes because the f-char result is not correct, the accumulation volume will change.

Finally, if the f-chart is correct these calculations are valid.
4. DESIGN PROCESS

4.5. f-chart calculation

The method and how it works have already been explained in a section before, just say that the result of the f-chart method is a percentage for each month. Then these percentages are applied to the energy demand per month (EDm) and the useful energy taken per month (EUm) is obtained. Finally, solar annual coverage is calculated.

The result of the solar annual coverage will determine if all the previous work and calculations are valid. The previous calculations are correct if the solar annual coverage is greater than the minimum percentage of covered energy set by the regulation CTE. This minimum coverage is 65% in this project.

The way of calculating by this method is just follow the equations step by step. The f-chart result is obtained with the next expression.

\[ f = 1.029 \cdot D_1 - 0.065 \cdot D_2 - 0.245 \cdot D_1^2 + 0.0018 \cdot D_2^2 + 0.0215 \cdot D_1^3 \]

Where D1 and D2 are two dimensionless parameters of calculation and can be obtained with these expressions.

\[
D_1 = \frac{Absorbed\ energy\ by\ the\ captator\ per\ month}{Energy\ demand\ per\ month}\left[\frac{MJ}{month}\right]
\]

\[
D_2 = \frac{Lost\ energy\ in\ the\ captator\ per\ month}{Energy\ demand\ per\ month}\left[\frac{MJ}{month}\right]
\]

All the intermediate calculations can be obtained with expressions explained, but here only the important results. The following table is a summary of the whole method.
Table 7: f-chart calculation method results.

<table>
<thead>
<tr>
<th>Month</th>
<th>D1</th>
<th>D2</th>
<th>f</th>
<th>EDM [MJ/month]</th>
<th>EUm [MJ/month]</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>0,41808</td>
<td>0,63796</td>
<td>0,34821</td>
<td>37.752,05</td>
<td>13.145,75</td>
</tr>
<tr>
<td>February</td>
<td>0,60641</td>
<td>0,72414</td>
<td>0,49257</td>
<td>33.478,65</td>
<td>16.490,52</td>
</tr>
<tr>
<td>March</td>
<td>0,87154</td>
<td>0,75893</td>
<td>0,67666</td>
<td>35.692,84</td>
<td>24.151,77</td>
</tr>
<tr>
<td>April</td>
<td>0,96896</td>
<td>0,84075</td>
<td>0,73322</td>
<td>33.212,94</td>
<td>24.352,31</td>
</tr>
<tr>
<td>May</td>
<td>1,06349</td>
<td>0,82620</td>
<td>0,79062</td>
<td>33.633,64</td>
<td>26.591,33</td>
</tr>
<tr>
<td>June</td>
<td>1,15333</td>
<td>0,78683</td>
<td>0,84384</td>
<td>31.884,43</td>
<td>26.905,28</td>
</tr>
<tr>
<td>July</td>
<td>1,27658</td>
<td>0,77051</td>
<td>0,91005</td>
<td>32.260,84</td>
<td>29.358,89</td>
</tr>
<tr>
<td>August</td>
<td>1,30316</td>
<td>0,71416</td>
<td>0,92696</td>
<td>32.947,24</td>
<td>30.540,86</td>
</tr>
<tr>
<td>September</td>
<td>1,16153</td>
<td>0,69280</td>
<td>0,85419</td>
<td>32.548,68</td>
<td>27.802,88</td>
</tr>
<tr>
<td>October</td>
<td>0,87705</td>
<td>0,77447</td>
<td>0,67927</td>
<td>34.320,04</td>
<td>23.312,51</td>
</tr>
<tr>
<td>November</td>
<td>0,56695</td>
<td>0,69343</td>
<td>0,46435</td>
<td>34.541,46</td>
<td>16.039,50</td>
</tr>
<tr>
<td>December</td>
<td>0,40490</td>
<td>0,58140</td>
<td>0,34072</td>
<td>37.752,05</td>
<td>12.862,79</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>410.024,86</td>
<td>271.554,39</td>
</tr>
</tbody>
</table>

The yellow cell is the energy dead per year (EDy) and the green one is the useful energy taken per year (EUy). With these two values it is possible to calculate the solar annual coverage, just dividing them.

\[
\text{Solar annual coverage} = \frac{EU_y}{ED_y} = \frac{271.554,39 \text{ MJ/year}}{410.024,86 \text{ MJ/year}} = 0.6622 \Rightarrow 
\]

\[
\Rightarrow \text{Solar annual coverage} = 66,22\% 
\]

It is possible to realize that the solar annual coverage is slightly greater than the minimum obeyed. Therefore this result confirms that the previous calculations are correct and useful, because the installation satisfies and obeys the regulation.
4. DESIGN PROCESS

4.6. Auxiliary Natural Gas Boiler Power

Finally, the last element that has to be dimensioned is the auxiliary boiler.

The power of the auxiliary boiler has to be calculated as if it was the only energy source of the building. It is the same than say that it has to be calculated with the energy demand (ED), and not with the part of the energy that is not covered with solar energy. The reason of that is because the auxiliary boiler needs to have power enough to cover the whole demand if the solar system breaks down.

In order to get a suitable power, neither very big nor small, it is assumed that the whole demand of energy per day becomes exhausted during twelve hours in a uniform way. The chosen time for calculating is only twelve hours because there are a lot time when there is not hot water consume, for example during the night. Then, the minimum boiler power needed per hour each month is obtained with the next expression.

\[
\text{Minimum boiler power per hour} = \frac{EDm \left( \frac{MJ}{month} \right) \cdot 10^3 \left[ KJ/MJ \right]}{3.600 \left[ KJ/KWh \right] \cdot n \left( \frac{days}{month} \right) \cdot 12 \left[ hours/day \right]}
\]

With this the minimum boiler power per day is obtained for each month, and the selected one has to be maximum of all of them. Applying this procedure the minimal power obtained is 28.19 KWh.

The selected boiler for this project is Vitogas 200F, of Viessmann company, which works with natural gas. This model has the option for choosing the power, the greater one to the minimal needed is 29 KWh.
5. RESULTS

In this section the final result of the project are going to be obtained and studied. These results include five parts. The first one is a short summary of the energies and efficiencies of the system. The second one is the energy, fuel and money saves. The third one is the CO$_2$ emissions reduction. The forth is the initial investment of the installation. And the fifth one is the payback period of the system.

5.1. Summary of the forms of energy and efficiencies of the system

The best form for seeing and comparing easily all the forms of energy and efficiencies is representing them in a graph according to the twelve months. The energies that it is interesting to compare are the energy demand, the irradiation received and the solar energy produced. The two last one, have been calculated per square meter, but it is necessary to know the total per month with the absorbent area installed.
The numerical results are shown in the next table.

**Table 8: Summary of the efficiencies and energy forms.**

<table>
<thead>
<tr>
<th>Month</th>
<th>Collector’s Efficiency, $\eta_{\text{coll}}$</th>
<th>$f$</th>
<th>Energy Demand per Month, EDm [MJ/month]</th>
<th>Incident Solar Energy per Month, $R_{\text{month}}$ (45º) [MJ/month]</th>
<th>Useful Energy Taken per Month, EUm [MJ/month]</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>0.4913</td>
<td>0.34821</td>
<td>37.752,05</td>
<td>20.602,55</td>
<td>13.145,75</td>
</tr>
<tr>
<td>February</td>
<td>0.5826</td>
<td>0.49257</td>
<td>33.478,65</td>
<td>26.500,73</td>
<td>16.490,52</td>
</tr>
<tr>
<td>March</td>
<td>0.6714</td>
<td>0.67666</td>
<td>35.692,84</td>
<td>40.606,32</td>
<td>24.151,77</td>
</tr>
<tr>
<td>April</td>
<td>0.6903</td>
<td>0.73322</td>
<td>33.212,94</td>
<td>42.008,77</td>
<td>24.352,31</td>
</tr>
<tr>
<td>May</td>
<td>0.7202</td>
<td>0.79062</td>
<td>33.633,64</td>
<td>46.690,82</td>
<td>26.591,33</td>
</tr>
<tr>
<td>June</td>
<td>0.7522</td>
<td>0.84384</td>
<td>31.884,43</td>
<td>48.001,74</td>
<td>26.905,28</td>
</tr>
<tr>
<td>July</td>
<td>0.7751</td>
<td>0.91005</td>
<td>32.260,84</td>
<td>53.758,70</td>
<td>29.358,89</td>
</tr>
<tr>
<td>August</td>
<td>0.7808</td>
<td>0.92696</td>
<td>32.947,24</td>
<td>56.045,56</td>
<td>30.540,86</td>
</tr>
<tr>
<td>September</td>
<td>0.7623</td>
<td>0.85419</td>
<td>32.548,68</td>
<td>49.350,10</td>
<td>27.802,88</td>
</tr>
<tr>
<td>October</td>
<td>0.6921</td>
<td>0.67927</td>
<td>34.320,04</td>
<td>39.291,31</td>
<td>23.312,51</td>
</tr>
<tr>
<td>November</td>
<td>0.5978</td>
<td>0.46435</td>
<td>34.541,46</td>
<td>25.563,19</td>
<td>16.039,50</td>
</tr>
<tr>
<td>December</td>
<td>0.5173</td>
<td>0.34072</td>
<td>37.752,05</td>
<td>19.953,11</td>
<td>12.862,79</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>0.6695</strong></td>
<td></td>
<td><strong>34.168,74</strong></td>
<td><strong>39.031,07</strong></td>
<td><strong>22.629,53</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>410.024,86</strong></td>
<td><strong>468.372,89</strong></td>
<td><strong>271.554,39</strong></td>
</tr>
</tbody>
</table>

And now, these results are represented in a graphical way.

![Solar Coverage and Collector's efficiency](image-url)
Looking to the graphs it can be appreciated many details of the system. The energy demand is almost constant, the small variation that it has is due to months have different number of days. The incident solar energy per month is superior to the energy demand during the eight middle months of the year. And the higher the incident energy is, the higher solar coverage is, and the higher the useful energy taken is. As it is logical, when incident solar energy is lower than demand energy, the solar coverage and in addition the useful energy taken have very low values.

A very interesting detail is that the solar coverage has a quite similar shape to the incident energy. Then if it was found some method for increasing the solar irradiation, the solar coverage will also be increased.

The solar coverage during July, August and September is round 90%, and more than 80% in May and June, quite high values. Then it can be predicted that the energy consumption and the fuel cost are going to be very small.

\[\text{Figure 16: Energy forms.}\]
5.2. Energy, fuel and money saves

To calculate the mentioned saves, have been done similar calculations. One, calculating the auxiliary boiler energy, the fuel volume necessary to obtain this energy, and the money that costs this fuel without considering the solar system. In this case all the energy demand is covered by the natural gas boiler. And the second calculation, the same parameters have been obtained but this time considering the solar system. Hence, the energy covered by fuel in this case is the part that the solar system can not supply.

These three variables are directly dependent, so the evolution along the year is the same for all of them. And the relation between the two calculations is also the same for the three parameters. Then, it is enough represent only one, auxiliary boiler energy for example, and shown the numerical results of the three.

As it was announced in the previous part the energy consumption between May and September is very low. The maximum consumptions are in January and December, this is because are the coldest months and it coincide with the lowest incident solar energy.

The natural gas price is regulated by the government, and is published in the official bulletin of the government. The price is different depend on the consumption, there are four different prices. The price is divided in two parts, a constant cost per month and
client, and the variable cost dependent of the natural gas consumed. These prices are shown in the next figure.

**Figure 18:** Natural gas prices in Spain. \(^{[22]}\)

The water heating system is a common system for all the building, so the agreement with the gas company is only for one client. Before the reform, the building is subscribed to the T4 tariff, because the annual power consumption is greater than 100,000 KWh. And after the reform, the building will be still subscribed to the T4 tariff, because, although the power consumption is much smaller, it should be able to cover all the energy demand with the auxiliary boiler.

\[
\text{Power consumption before the reform} = \frac{410,024.86 \text{[MJ/year]}}{3.6 \text{[MJ/KWh]}} = 113,895.79 \text{[KWh/year]}
\]

\[
\text{Power consumption after the reform} = \frac{138,470.46 \text{[MJ/year]}}{3.6 \text{[MJ/KWh]}} = 38,464.02 \text{[KWh/year]}
\]

In the following table are the numerical results or the three variables, and the total saves, called also reduction.
5. RESULTS

Table 9: Numerical results for the energy, fuel and money saves.

<table>
<thead>
<tr>
<th></th>
<th>Without Solar System</th>
<th>With Solar System</th>
<th>Reduction</th>
<th>Reduction Percentage [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Auxiliary Boiler</strong></td>
<td>410.024,86</td>
<td>138.470,46</td>
<td>271.554,39</td>
<td>66,23</td>
</tr>
<tr>
<td><strong>Energy [MJ/year]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Natural Gas</strong></td>
<td>10.594,96</td>
<td>3.578,05</td>
<td>7.016,91</td>
<td>66,23</td>
</tr>
<tr>
<td><strong>Volume [m3/year]</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Money [€/year]</strong></td>
<td>5.086,94</td>
<td>2.240,63</td>
<td>2.846,31</td>
<td>55,95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the table it can be checked that the auxiliary boiler energy and natural gas volume are directly dependent due to the reduction percentage is the same. It should be mentioned too, that the reduction percentage is quite high, more than two thirds.

The reduction of the money is a bit lower than the other two. It happens because the natural gas price has one part of the price that is constant, and this one is not reduced. Then the reduction is less because only the variable part related to the consumption is reduced.

5.3. CO$_2$ emissions reduction

The CO$_2$ analysis is something really important nowadays. Our society is facing a global warming due to the CO$_2$ emissions and the authorities are doing a special effort to reduce them. For this reason, the CO$_2$ emissions resulting of all the industrial processes should be studied. At the same time, all the technologies that are avoiding these emissions should be developed and improves, and the most of them are also supported by different entities and governments.

The natural gas composition influences in the CO$_2$ generation. It is composed by 90 - 95 % of methane, 5 - 8 % of ethane, and the rest < 2 - 3 % of other gases. To simplify the calculations, just for having a general idea of the CO$_2$ emissions, it is assumed that all the gas natural is composed by methane, with this assumption we can equilibrate the chemical equation of the methane combustion.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$
Therefore, one mol of natural gas will produce one mol of CO$_2$, what is the same than one liter of CO$_2$ for one liter of natural gas. The volume of natural gas necessary with and without solar system has already been calculated.

The CO$_2$ is liberated to the atmosphere, in that moment the gas is in a thermodynamic state between normal conditions, 1 atmosphere and 25 ºC, and standard conditions, 1 atmosphere and 0 ºC. One mol of gas in normal conditions occupies a volume of 24,43 liters, and one mol in standard conditions occupies a volume of 22,38 liters. The difference will be despicable between choosing one or the other one. Maybe the final condition would be closer to the standard one because during the cold months is when the natural gas demand is bigger. Then, it will be assumed that one mol of CO$_2$ occupy 22,4 liters when it is liberated to the atmosphere. The expression to calculate the amount of kilograms of CO$_2$ is the next one.

\[
m_{CO_2}[Kg] = V_{CO_2}[m^3] \cdot 1.000 \left[ \frac{l}{m^3} \right] \cdot 22.4 \left[ \frac{l}{mol} \right] \cdot PM_{CO_2} \left[ \frac{g}{mol} \right] \cdot 1.000 \left[ \frac{g}{Kg} \right]
\]

Being:

PM CO$_2$ = Molar weight of CO$_2$ = 44 g/mol

The emissions per month and the total kilograms produced per year are shown in the following table and graph.

![Figure 19: CO$_2$ emissions reduction.](image-url)
5. RESULTS

Table 10: CO\textsubscript{2} emissions distribution.

<table>
<thead>
<tr>
<th>Month</th>
<th>CO\textsubscript{2} Emissions [Kg/month]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without Solar System</td>
</tr>
<tr>
<td>January</td>
<td>1916,17</td>
</tr>
<tr>
<td>February</td>
<td>1699,27</td>
</tr>
<tr>
<td>March</td>
<td>1811,65</td>
</tr>
<tr>
<td>April</td>
<td>1685,78</td>
</tr>
<tr>
<td>May</td>
<td>1707,13</td>
</tr>
<tr>
<td>June</td>
<td>1618,35</td>
</tr>
<tr>
<td>July</td>
<td>1637,45</td>
</tr>
<tr>
<td>August</td>
<td>1672,29</td>
</tr>
<tr>
<td>September</td>
<td>1652,07</td>
</tr>
<tr>
<td>October</td>
<td>1741,97</td>
</tr>
<tr>
<td>November</td>
<td>1753,21</td>
</tr>
<tr>
<td>December</td>
<td>1916,17</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>20811,52</strong></td>
</tr>
</tbody>
</table>

The CO\textsubscript{2} is produced by the natural gas combustion, and they are directly proportional. It can be noticed in the distribution, that is the same to the natural gas volume consumption mentioned in the previous part. The reduction percentage of emissions is also going to be the same.

\[
\text{CO}_2 \text{ emissions reduction} = \frac{20.811,52 - 7.028,31}{20.811,52} \cdot 100 = 66,23\%
\]

This reduction is very high, 13.783,21 Kg CO\textsubscript{2}/year, and has to be a point of bearing in mind at the moment of taking the final decision about the installation of the solar system.

5.4. Investment Cost of the Installation

The investment cost is the total initial cost of the installation including elements and installation. The prices of the elements have been taken from other projects, hence these prices are quite reliable.
There are three main elements, the ones that have been carefully studied and calculated. Besides, there are some secondary elements, such as pipes, supports of fixation and positioning, control systems, and so on. The cost of all these secondary elements is considered to be the fifteen per cent of the three main elements cost. And the cost of the installation is the five per cent of the three main elements cost. These percentages have been verified in many previous projects.

In the next table are the prices considered and the total investment.

<table>
<thead>
<tr>
<th>Element</th>
<th>Unitary cost [€ / unit]</th>
<th>Number of Units [unit]</th>
<th>Element cost [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar panel: Vitosol 300F</td>
<td>850</td>
<td>34</td>
<td>28.900</td>
</tr>
<tr>
<td>Accumulator: Vitocell 100V</td>
<td>3100</td>
<td>7</td>
<td>21.700</td>
</tr>
<tr>
<td>Natural Gas Boiler: Vitogas 200F</td>
<td>1200</td>
<td>1</td>
<td>1.200</td>
</tr>
<tr>
<td>Secondary elements (15% of the three main elements cost)</td>
<td></td>
<td></td>
<td>7.770</td>
</tr>
<tr>
<td>Installation (5% of the three main elements cost)</td>
<td></td>
<td></td>
<td>2.590</td>
</tr>
<tr>
<td><strong>Total Installation Cost [€]:</strong></td>
<td></td>
<td></td>
<td><strong>62.160</strong></td>
</tr>
</tbody>
</table>

The initial investment of the installation ascends to 62.160 €. This cost is being paid for all the owners of the building, then this cost should be divided into the 66 flats which composed the building. Therefore the cost per flat will be 941.82 €.

### 5.5. Payback

The payback of one project is the period to get back the initial money invested, this return back of the money is thanks to the annual money saves which the installation is followed.

The way to calculate is it is very easy and the result show how many years are necessary to amortize the installation. The expression to calculate the payback is the next one.
The payback is slightly high, similar to the predicted life period of the most of the elements of the installation, between twenty and twenty five years. It has to be look from a positive approach. The installation is mandatory, there is not choice about install or not, then it is a very good result if all the initial costs are recovered during the life period of the installation. And maybe some profits will be gained in the last years.

Even more, it is known that natural gas is increasing its price year by year. If its price continues increasing the money save per year will also increase and the payback period will be reduced, making the system more profitable.

Finally, all the objectives of the project have been calculated and studied carefully,
6. CONCLUSIONS

The whole planet is suffering now the consequences of its own development. The global warming, due to greenhouse effect, and the Antarctic ozone layer hole are increasing and suppose a very grievous problem for the environment and the development of the world. The humanity has to evolve towards a better life, but always without neglecting the care of the planet in which they live.

The aim of this thesis is calculate the size and the necessary equipment for a solar water heating system. The installation of this system is followed by a few consequences that are necessary to know and quantify in advance. These consequences can be looked from different points of view, the two principal ones are the environmental and the economical.

On one hand, in the environmental aspect, it has to be considered the reduction of energy produced by fossils fuels. This is equivalent to a reduction of fossils fuels consumption, which also means a reduction in the greenhouse gases emissions, like carbon dioxide, methane nitrous oxide and so on. It is worth mentioning that the system calculated in this thesis makes a really good contribution to the environment. The traditional energy demand, and as a consequence the natural gas consumption, have been reduced a 66,23%. It means a reduction of 271.554,39 MJ/year and 7.016,91 m$^3$/year respectively. This reduction of fuel consumption avoids the emission of 13.783,21 Kg CO$_2$/year.

On the other hand, in the economical way, the amount of saved money for this building is quite important. Nowadays in Spain, the installation of Sanitary Hot Water Systems by means of solar energy is mandatory in new and renovated buildings. So, there is not choice about installing it or not. Two economical parameters have to be calculated, the first one is the initial investment cost, and the second one is the payback period. In this project both parameters have an acceptable value. The first one, the initial investment cost reaches the quantity of 62.160 €. This amount has to be paid between all the flats of the building, so each owner of a flat should pay 941,82 €. Finally, the payback obtained is 21,83 years. This time is approximately equal to the life’s period of the installation, between 20 and 25 years. Considering the increment in the price of natural gas year by year, the payback period could be considerably reduced. Hence, it is quite possible that
not only the initial investment money come back, but also could be additional profits during these last years of the installation’s life.

Sometimes, in order to get a better environment for our life, the economical profits should be considered as a secondary factor.
7. REFERENCES


In MCC Assoc., Inc. Proc. of the Passive and Hybrid Solar Energy Update p 9-14 (SEE N84-26125 16-44).


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