Wrocław University of Technology

Faculty of Mechanical Engineering

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Thesis

"Dimension of a solar power station for sanitary hot water"

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Introduction

The use of renewable energies is an inevitable requirement, both from a social and technical point of view. The exponential increase in energy consumption, related to the technological development of post-industrial societies and the environmental conditions that it entails, with the new regulations that limit CO2 emissions, lead to the search for non-polluting energy, and especially those that Take advantage of the natural cycle of our planet and do not interfere in it.

The demand for electrical energy in Spain is higher each year that passes. We also have a high dependence on energy from abroad, since Spain imports more than 80% of the primary energy it uses compared to 50% on average in the European Union. To all this, we also have to add the existing concern to carry out a significant reduction in pollutant emissions. All this contributes to the need to promote new energy actions.

One of the actions promoted is the use of solar thermal energy as a means to reduce energy consumption from non-renewable sources and thus reduce, as far as possible, energy dependence from outside.

The technical code of the building, approved by the Royal Decree 314/206, obliges the buildings of new construction, as well as the buildings that carry out works of extension, modification reform or rehabilitation to the installation of solar thermal systems.

Another reason that drives the development of these renewable energies is that the main cause of air pollution is the energy of fossil origin. 80% of the energy consumed worldwide comes from fossil fuels, being only 4% from renewable sources.

The use of solar radiation for power generation is by no means a novel technology. Placing a container with water in the sun to warm it up is a practice that is lost in history.

Is not need to be very smart to realize that renewable energies are the future. In a world where emissions of polluting gases are becoming more visible in climatology, there is no other choice but to invest in "clean" energies that, apart from providing the necessary energy, are environmentally friendly.
Spain is in a climatological zone beneficial for the use of solar thermal energy, but unfortunately, this has not been a fundamental factor when boosting this technology. Countries with the worst weather conditions give us a big advantage in this field.

Solar energy

Most of the energy that reaches our planet comes from the Sun, in the form of electromagnetic radiation. Solar energy is the energy obtained directly from the Sun. The solar radiation incident on Earth can be exploited, by its ability to heat, or directly, through the use of radiation in optical or other devices. It is a type of renewable and clean energy, which is known as green energy, which can be transformed into thermal or electrical energy.

Solar energy is one of the most developed renewable energy sources in the last years and with greater expectations for the future. Each year the sun throws on the earth four thousand times more energy than the one consumed, which shows that this energy source is still undervalued and above all little exploited in relation to its possibilities. The use of solar energy consists of capturing through different technologies the radiation of the sun that reaches the earth in order to use that energy for different uses, such as heating water, generating electricity, etc.

The power of the radiation varies according to the time of day, the atmospheric conditions that cushion it and the latitude. It can be assumed that in good irradiation conditions the value is approximately 1000 W / m2 on the earth's surface. This power is known as irradiance.

The idea is to concentrate the energy supplied by the sun and transform it into heat that can be used for multiple applications, such as hot water collection, low temperature heating, swimming pool air conditioning or air conditioning by means of absorption machines.

The development of solar energy is still very limited in Spain, despite being one of the European countries with Greece, Italy or Portugal with greater solar radiation. Some of the causes of the low implementation of this type of energy are the lack of ecological awareness and the need to make a high initial investment that not everyone is willing to assume. However, in recent years the costs have been significantly reduced and, in addition, solar facilities have substantial subsidies from institutions to try to promote their consumption.

The advantages of solar energy are numerous compared to conventional energies. First is the energy formula more respectful with the environment and its resources are inexhaustible, so it reduces the energy dependence of fossil fuels and pollutants such as oil. Finally, it facilitates the self-sufficiency and allows to generate energy near where it is needed without needing expensive infrastructures for its transport.

Project

The installation proposed in the thesis is a low-temperature thermos-solar system designed for supplying a single house, for four inhabitants, with 3 rooms, of sanitary hot water.

The energy of the Sun is a huge source of thermal power, that can replace the ancients and pollutant fossil sources, or the expensive electricity.

Location of the project

The selected building is placed in Valencia, Spain, near the city center, in Albacete street.

Picture 1. Screen- shot of the area chosen.

The location has not been selected randomly , this building has a huge free area in its roof, perfect for placed the installation, furthermore, there is not high building surrounded, in this way, there will not be problems with shadows in the collectors. The collectors must be oriented through south side, because the chosen city is in the north hemispheric.

Previous data

The first step to begin the design of the installation is to collect all the data related with the weather, water's temperature and hours of sunlight in the roof of the building.

Meteorological data

The weather in Valencia, is ideal for this kind of thermos-solar installations. Valencia has a huge amount hours of sunlight, a regular Mediterranean weather, and a medium average temperature. In this table is shown the numbers of sun hours, the average of the ambient temperature and the temperature of the water network.

Average temperature (Cº)			Hours of sun		
2011		18,7	2011		2678
2012		18,7	2012		2929
2013		18,7	2013		2731
2014		19,2	2014		2726
2015		**19,2**	2015		**2826**
	January	12,5		January	221
	February	12,3		February	161
	March	15,2		March	206
	April	16,7		April	242
	May	21		May	299
	June	23,8		June	298
	July	27,7		July	289
	August	27,1		August	265
	September	23,1		September	210
	October	19,9		October	264
	November	16,6		November	224
	December	14,1		December	147

Table1.Average temperature in Valencia and hours of Sun (2011-2015).

As it can be seen the annual temperature is around 20° with light winters, that means that in winter will not be necessary a huge device for supplying hot water when the weather will not be favorable.

On the other hand, is also necessary previous data of the average temperature of the water network in the city for beginning the project, collected in the following table:

Month	Network Temperature [ºC]
January	8
February	9
March	11
April	13
May	14
June	15
July	16
August	15
September	14
October	14
November	11
December	8
AVERAGE	12,33

Table 2. Temperature of the water per month and annual average.

The difference between the annual average temperature of the water and the wanted temperature (60ºC) is around 48ºC, this is difference will be assumed for the installation, in general, without any convectional energy support. However, as is known, the energy produced depends on the climate, so an small support must be needed, at the end of the project the most favorable one will be chosen for the installation, when the Sun power will not be enough for supplying the wish temperature.

Incident radiation

Solar radiation is the energy flow that is received from the Sun in the form of electromagnetic waves of different frequencies (visible light, infrared and ultraviolet). Approximately half of them, between 0.4 μm and 0.7 μm, can be detected by the human eye, constituting what is called visible light.

Approximately, half of the rest are located in the infrared part and a small part in the ultraviolet.

There are three types of radiation that reach the surface of the Earth:

- Direct radiation: it comes to Earth in a straight line from the solar circle, without having undergone any change in its direction. This type of radiation is characterized by projecting a definite shadow of opaque objects that intercept.
- Diffuse radiation: it diffuses and disperses when it collides with the atmosphere. It goes in all directions as a result of the reflections and absorptions of clouds and particles of atmospheric dust, mountains, trees, buildings, the soil itself, and so on.
- Albedo radiation: comes from nearby bodies. The amount of radiation of this type depends on the reflection coefficient of the surface, called albedo. It is generally not considered for calculation purposes because of the difficulties in determining its value, as it depends on the objects visible by the solar collectors above the horizon line.

The sum of these three types of radiation is called global radiation.

The radiation usually refers to a horizontal plane, since the instruments of measurement and valuation are positioned horizontally.

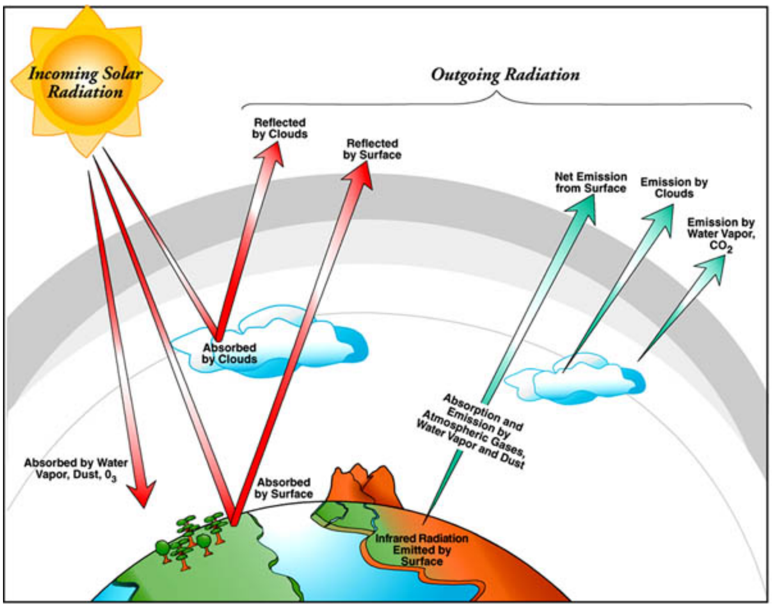
The incident radiation energy data is related to the amount of energy that can be obtained from the installation and it is essential to calculate the number of collectors needed to raise the temperature of the mains water to the water supply.

The solar flow radiation must cross a huge distance between the beginning of the atmosphere until it arrives to the Earth. During the way, and because of the physical phenomenon of reflection, absorption and diffusion, this flow loose power per area unit (clouds, powder, smokes…).

Other point to take into account is the reflection of the same Earth. The Earth reflects the 30% of the Sun power that enters inside the atmosphere giving it back to the deep space.

Besides, the intensity of the solar effect increase as long as more close is from the poles. This takes place because the distance from the atmosphere to the Earth is bigger in those latitude.

This picture shows a diagram of how the solar energy is distributed once arrives to the Earth.



Picture 2. Diagram of Earth energy budget.

The data related to the incident energy shown below, are referred to a typical day of each month of the city of Valencia:

Angle	Jan.	Feb.	March	Apr.	May.	Jun.	Jul.	Ag.	Sep.	Oct.	Nov.	Dec.	Annual rad.	Winter
0	8,65	11,16	15,97	22,02	22,4	24,2	24,7	21,7	18	12,9	9,2	7,3		
20	12,9	14,7	18,9	21,2	22,1	23,2	24	22,3	20,3	16,4	13,2	11	6602	2624
25	13,7	15,3	19,3	21,2	21,8	22,6	23,5	22,2	20,5	17	14	11,8	6694	2750
30	14,5	15,9	19,7	21,1	21,3	22	22,9	21,9	20,7	17,5	14,7	12,5	6748	2858
35	15,2	16,4	19,9	20,9	20,7	21,3	22,2	21,5	20,8	18	15,4	13,2	6763	2948
40	15,8	16,7	20	20,6	20,1	20,5	21,4	21	20,7	18,3	15,9	13,7	6740	3020
45	16,3	17	19,9	20,1	19,3	19,5	20,5	20,4	20,5	18,5	16,3	14,2	6679	2072
50	16,7	17,2	19,8	19,5	18,5	18,5	19,5	19,7	20,2	18,6	1,6	14,6	6580	3105
55	16,9	17,2	19,5	18,8	17,6	17,5	18,5	18,9	19,7	18,5	16,9	14,8	6444	3119
60	17,1	17,2	19,1	18,1	16,5	16,3	17,3	18	19,2	18,4	17	15	6272	3112
65	17,1	17	18,6	17,2	15,5	15,1	16,1	16,9	18,5	18,1	17	15,1	6065	3086
70	17,1	16,7	18	16,2	14,3	13,9	14,8	15,9	17,7	17,8	16,8	15	5827	3040

Table 3. Solar radiation in Valencia [MJ/m^2, per day].

Using the above table for an inclination of 25 °, inclination chosen by recommendation of the manufacturer, (i=latitude $\pm$15°, where the latitude of Valencia is over 40°), is possible to calculate the average radiation that will be produced in the solar plates.

$$I_{diary} = 18{,}575 \frac{MJ}{m^2}$$

The last step to collect data for choose the collectors are shown in the following table can be seen the global radiation produced in Valencia monthly and annually:

	I (MJ/m2)	Hour of Sun	It (W/m2 per day)
January	13,7	8	475,69
Ferbuary	15,3	9	531,25
March	19,3	9	670,14
April	21,2	9,5	736,111
May	21,8	9,5	756,94
June	22,6	9,5	784,72
July	23,5	9,5	815,97
August	22,2	9,5	770,83
September	20,5	9	711,81
November	17	9	590,28
October	14	8	486,11
December	11,8	7,5	409,72
ANNUAL	18,575	8,9	644,97

Table 4. Diary solar intensity received for a collector with a 25° of inclination.

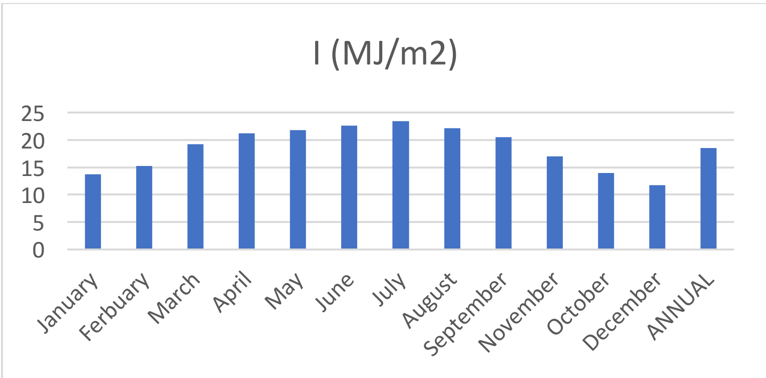
As it can be seen in the table, the daily solar intensity that occurs in the city of Valencia varies depending on the hours of sunshine found in each month of the year.

The value of the average annual intensity obtained in the table is found taking into account that the average solar radiation occurs throughout the year in 8.9 hours.

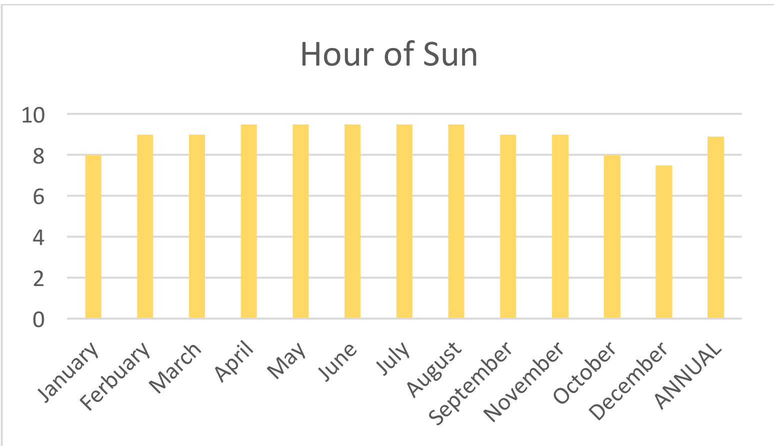
From the same reference, the useful average intensity (It) is obtained, in an average day of each month measured in W / m2. The previous values have already taken into account the useful period of the day in terms of the possibility of using solar energy, that is, the energy incident in the first and last moments of the day has been deducted, in which the obliquity of the rays is very large and does not take advantage of such energy.

One important fact to consider in the subsequent dimensioning of the installation is to realize that in the winter months the solar radiation decreases quite considerably, being in the summer months and more concretely in the month of July when it occurs The maximum solar radiation to which our solar collectors are exposed.

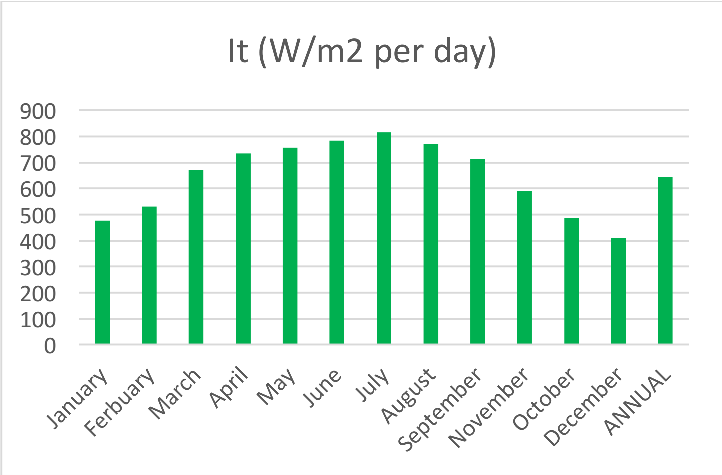
In the following graphic, the difference between months Is clear distinguished:



Graphic 1. Intensity per month and annual.



Graphic 2. Hours of Sun per month and annual.



Graphic 3. Total intensity of radiation per month and annual.

Calculation of energy demand

Initial considerations

Once is known the climatological factors that will affect the size of our facility, we will calculate the average monthly hot water needs of the homes for each of the months of the year.

It is especially important to explain in this section that the subsequent dimensioning of the installation will be done for an average annual case and these calculations will be repeated for the average monthly cases.

To make this calculation with complete accuracy, the number of people that inhabit each house as shown in the next section must be known.

Monthly average needs

In this section will be calculated the energy demand in the city of Valencia in each month of the year. For this, the data contemplated in the Technical Building Code (CTE) is very useful.

- Number of occupants of the dwelling: In this case, is need to supply sanitary hot water to one single-family. To calculate the total number of inhabitants of these houses, the Technical Building Code (CTE) establishes the following relation:

Number of bedrooms	1	2	3	4	5
Number of people	1,5	3	4	6	7

Table 5. Number of people living in the house related number of bedrooms.

In the case is studied, the house has got 3 bedrooms, so our number of people will be:

$$Number\ of\ people = 4$$

- Average daily consumption per person and day: The Ordinance of the City of Valencia says that the minimum consumption will be 26 liters per person and day at a temperature of 60 ° and the CTE establish this amount in 22 liters per person and day to a Temperature of 60 ° for multifamily dwellings, which is the case that occupies us since we will supply of ACS to the house to which the present study refers, the Ordinance of the City of Valencia is ignored since it establishes a more restrictive assumption .

Calculation of the consumption of sanitary hot water

The amount of sanitary hot water depends on the consumption as can be seen in the normalized table of the Technical Building Code:

BUILDING	LITERS OF SHW PER DAY AT 60º	
Unifamiliar house	30	per person
Multifamiliar house	22	per person
Hotel ****	70	per bed
Hotel ***	55	per bed
Camping	40	per tent
Dorm	55	per bed
School	3	per student
Industry	15	per person
Gym	22	per costumer

Table 6. Amount of SHT (CTE).

The house chosen is built to host four people, so the necessary amount of sanitary hot water will be:

$$V_{SHT} = 4\,[people] * 22\left[\frac{l}{day * person}\right] = 88\left[\frac{l}{day}\right] = \frac{88}{1000}\left[\frac{m^3}{day}\right]$$

Ec. 1. Volume of water per day in cube meters.

This consumption can increase or decrease depending on the month in which we are, since factors such as housing may not be occupied in any of the months or that there are too hot months and, therefore, not so much water is needed hot.

- Network water temperature: The average water temperature of the network for the city of Valencia is expressed in the following table, collected from the city council of Valencia.

January	February	March	April	May	June	July	August	September	October	November	December	ANNUAL
8	9	11	13	14	15	16	15	14	13	11	8	12,25

Table 7. Temperature of water network in Valencia.

With the data indicated above, we can carry out the calculation of the energy demand of hot water that is needed in the home.

In order to calculate the energy demand corresponding to the heating of the mains water up to the consumption temperature of 60 ° C we will use the following expression:

$$Q_{SHT}[MJ] = V[m^3] * \rho[\frac{kg}{m^3}] * C_p\left[\frac{J}{kg * K}\right] * (T_f - T_0)[K]$$

Ec. 2. Amount of energy in mega joules.

Where:

$$Q_{SHT} = Amount\ of\ energy\ to\ supply\ SHT\ ;$$

$$V = Consumption\ of\ water;$$

$$\rho = Water\ density\ \left(1000\left[\frac{kg}{m^3}\right]\right);$$

$$C_p = Speficic\ heat\ of\ the\ water\ \left(4187\ \left[\frac{J}{kg * K}\right]\right);$$

$$T_f = Water\ temperature\ (60ºC);$$

$$T_0 = Water\ temperture\ of\ the\ netwrok;$$

The following step is to make a table with the data of the energy that is needed to supply the house:

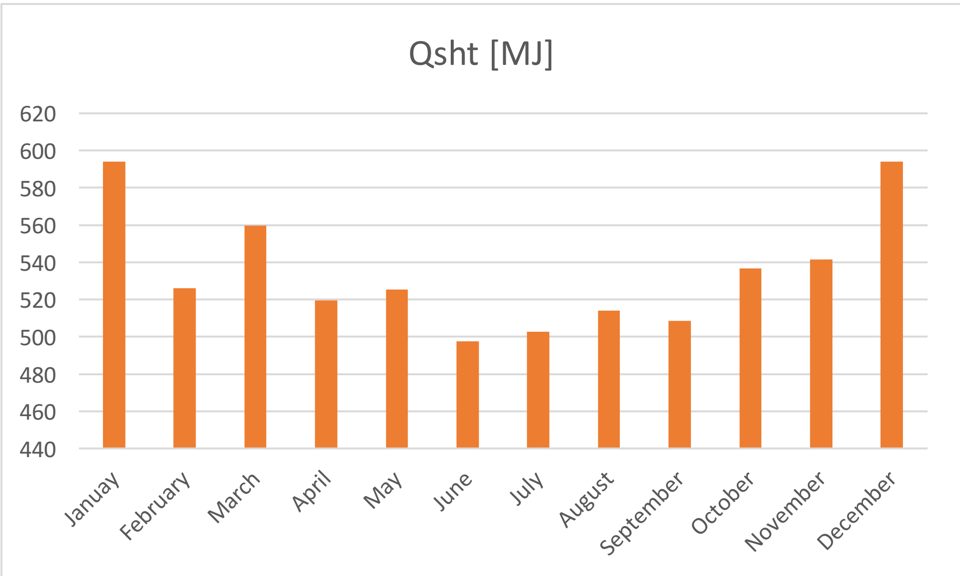
Month	Days	Cosumption [m^3/day]	Total [m^3]	T0 [℃]	Tf [℃]	ΔT [°C]	Qsht [MJ]
Januay	31	0,088	2,728	8	60	52	**593,95**
February	28		2,464	9		51	**526,16**
March	31		2,728	11		49	**559,68**
April	30		2,64	13		47	**519,52**
May	31		2,728	14		46	**525,42**
June	30		2,64	15		45	**497,42**
July	31		2,728	16		44	**502,57**
August	31		2,728	15		45	**514,00**
September	30		2,64	14		46	**508,47**
October	31		2,728	13		47	**536,84**
November	30		2,64	11		49	**541,63**
December	31		2,728	8		52	**593,95**

Table 8. Amount of energy [MJ].

From this table is possible to know the average of $\Delta T[°\mathrm{C}] = 47{,}75$; the average of $Q_{SHT'}[MJ] = 534{,}97$ and the average of $Total\ cosumption\ \left[\frac{m^3}{month}\right] = 2{,}68$.

The annual amount of energy will be the sum of each month:

$$Q_{SHT} = 6419{,}61\ MJ$$



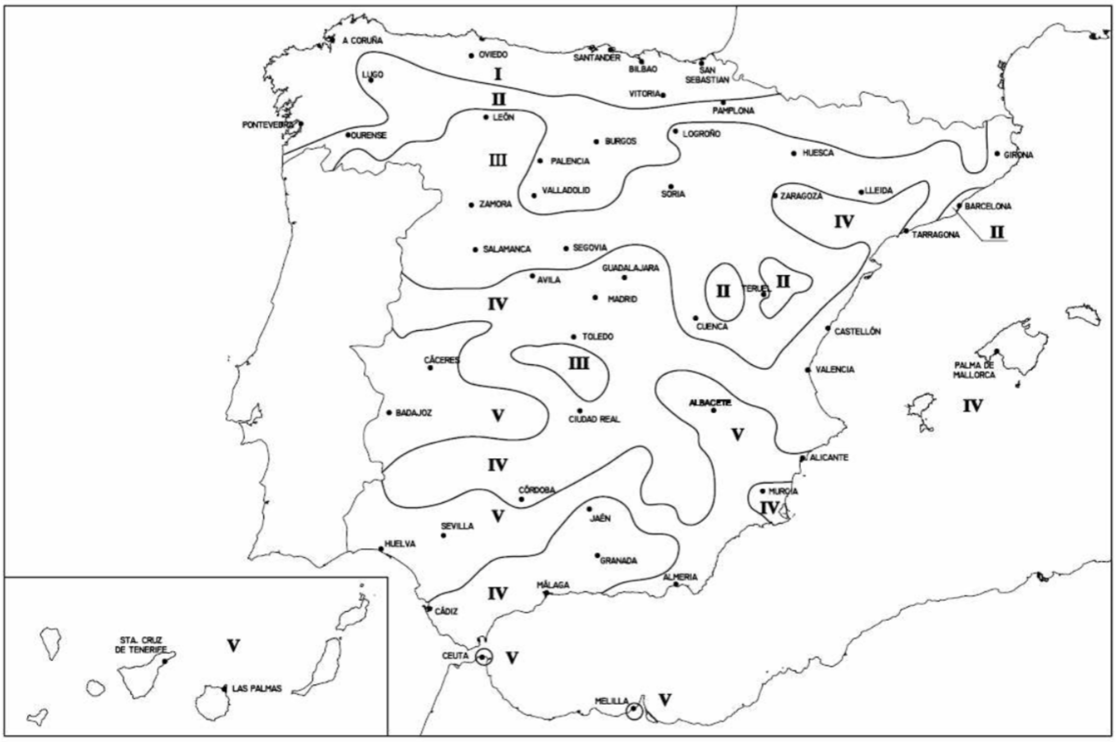
Graphic 4. Quantity of energy per month.

In the graphic is easy to observe than in winter months (January and December), logically, more energy is needed.

Minimum solar contribution

The annual minimum solar contribution is the fraction between the annual values of the required solar energy demanded and the annual energy demand, obtained from the monthly values. The following table indicates, for each climatic zone and different levels of hot water demand, the annual minimum solar contribution.

The following figure shows the climatic zones that occur in each of the Spanish cities.



Picture 3. Climatic zones in Spain.

Total demand for Sanitary Hot Water in the building	I	II	III	IV	V
50-5000	30	30	50	60	70
5000-6000	30	30	55	65	70
6000-7000	30	35	61	70	70
7000-8000	30	45	63	70	70
8000-9000	30	52	65	70	70
9000-10000	30	55	7070	70	70
10000-12500	30	65	70	70	70
12500-15000	30	70	70	70	70
150000-17500	35	70	70	70	70
17500-20000	45	70	70	70	70
>20000	52	70	70	70	70

Table 9. Minimum solar contribution.

As can be seen, and making use of the above tables, the house belongs to the city of Valencia (climate zone IV) will have a minimum solar contribution of 60%.

The size of the installation will be limited by compliance with the condition that in no month of the year the energy produced by the installation may exceed 110% of the energy demand and in no more than three months 100% as it is written in the CTE (technical code of construction).

$$f = 60\%$$

Solar collector

Once all the parameters related to the energetic consumption and volume of water have been obtained, the minimum heat that the selected solar collector should provide is calculated.

To do this, a preliminary study of the daily sunshine hours per month must be made. These measures are taken for a type collector oriented to the south and with a slope very close to the latitude of its location, as recommended by the manufacturer, the following table normalized by the CTE collects the mentioned hours in Valencia.

Latitude (+25º to +45º)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	ANNUAL
Hours	8	9	9	9,5	9,5	9,5	9,5	9,5	9,5	9	8	7,5	8,96

Table 10. Number of usable hours of Sun per day per month.

With annual average of number of usable hours of light of Sun, is possible to calculate an estimation of the heat needed with the average of $\Delta T[°C]$ (47,75) and the average of consumption of water of the house (0,088 m^3per day).

$$Q_t[kW] = \dot{m}\left[\frac{kg}{s}\right] * C_p\left[\frac{J}{kg * K}\right] * \Delta T_{average}[°C]$$

$$= 0{,}088 * \left(\frac{1000}{8{,}96 * 3600}\right) * 4187 * 47{,}75 = 0{,}545\ kW$$

Ec. 3. Average of annual necessary heat.

So, the minimum heat that is needed from the collector will be:

$$Q_{min}[kW] = Q_t * f = 0{,}545 * 0{,}6 = 0{,}327$$

Ec. 4. Minimum heat needed from the collector.

For this parameter, the chosen one has been: "BERSOLAR OPS-V250" with the following characteristics:

Model		OPS_V250
Collector	**Units**	**Values**
measurement	mm	105x70
Area	m^2	0,75
Cover thickness	mm	4
Pipes		11
Diameter of pipes	mm	8
Distance between pipes	mm	100
Weight (empty)	kg	50
Absorver		
Losses coeficient k1	W/m^2*K	3,556
Losses coeficient k2	W/m^2*K	0,17
Insulation thickness (outside/inside)	mm	25/40
Hidraulics		
Volume of heat liquiid	l	1,64
Working pressure	bar	10
Recommended flow	l/hm^2	50

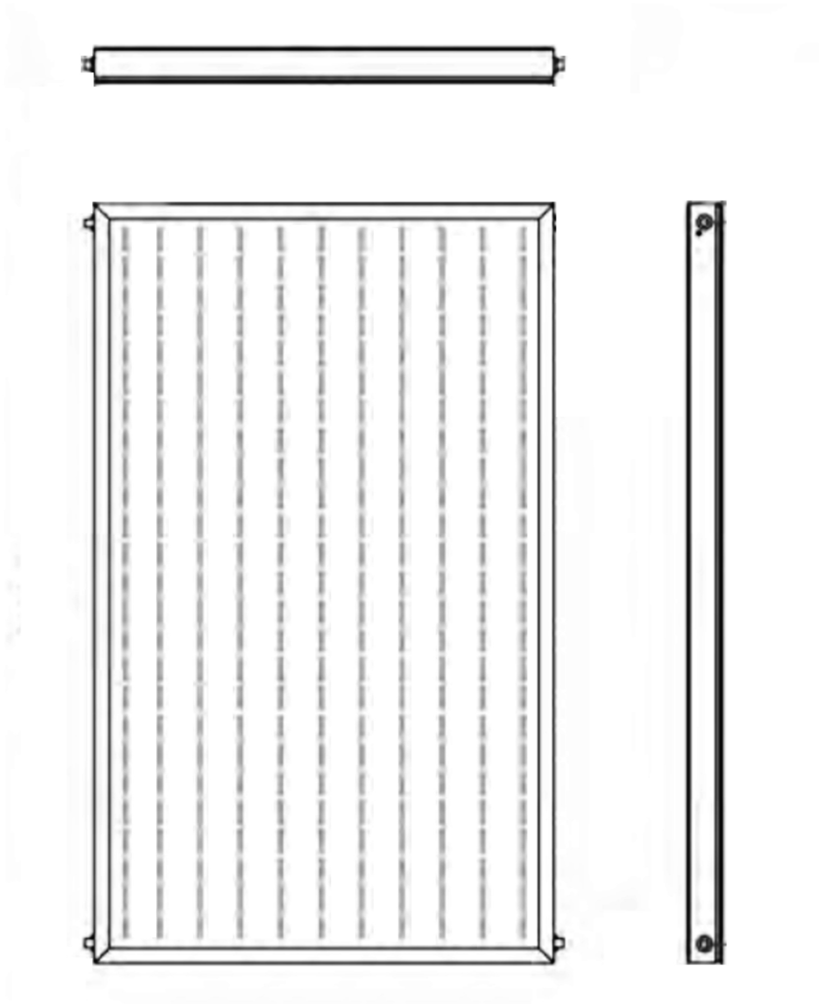
Table 11. Characteristics of the collector.

Average of temperature in Valencia: 18,83 ºC.

Temperature of outlet: 60 ºC.

Average of daily radiation: 18,575 MJ/m^2.

In the following image, obtained from the manufacturer's catalogue are attached the drawings with the dimensions (in mm) of the manifold:



Picture 4. Drawings of the collector (in mm).

Dimensioning of the installation

Calculation procedure

F-Chart

For the dimensioning of solar thermal installations, the f-Chart method is suggested, which allows the calculation of the coverage of a solar system, its contribution to the total required heat input to cover the thermal loads, and their average performance over a long period of time.

Widely accepted as a sufficiently accurate calculation process for long estimates, it should not be applied for weekly or daily rate estimates.

To develop it, monthly data are used meteorological means, and it is perfectly valid to determine the performance or factor of solar coverage in heating installations, in all types of buildings, by means of solar collectors flat.

Its systematic application is to identify the dimensionless variables of the solar heating system and to use computer simulation, to measure the correlations between these variables and the average performance of the system for an extended period of time.

The equation used in this method can be seen in the following formula:

$$f = 1{,}029 \cdot D_1 - 0{,}065 \cdot D_2 - 0{,}245 \cdot D_1^2 + 0{,}0018 \cdot D_2^2 + 0{,}215 \cdot D_1^3$$

Ec. 4. Equation used for the f-Chart method.

The sequence that is usually followed in the calculation is as follows:

1. Assessment of heat loads for heating water intended for the production of A.C.S. or heating.
2. Assessment of incident solar radiation on the inclined surface of the sensor or sensors.
3. Calculation of parameter D1.
4. Calculation of parameter D2.
5. Determination of the graph f.
6. Assessment of monthly solar coverage.
7. Assessment of annual solar coverage and formation of tables.

The parameter D1 expresses the relationship between the energy absorbed by the plate collector plate and the total heating charge for one month.

D1 = Energy absorbed by the sensor / Monthly heat load

The energy absorbed by the sensor is given by the following expression:

$$E_a = S_c \cdot F_r' \cdot (\tau \cdot \alpha) \cdot I_t \cdot N$$

Ec. 5. Energy absorbed by the collector.

Where:

$$S_c = Collector's\ area\ [m^2];$$

$$I_1 = Daily\ average\ monthly\ radiation\ incident\ on\ the\ catchment\ area\ per\ unit\ of\ area\ \left[\frac{kJ}{m^2}\right];$$

$$N = Number\ of\ days\ in\ each\ month;$$

$$F_r'(\tau \cdot \alpha) = Factor\ given\ by\ the\ following\ expresision\ ;$$

$$F_r'(\tau \cdot \alpha) = F_r(\tau \cdot \alpha)_n \left[\frac{(\tau \cdot \alpha)}{(\tau \cdot \alpha)_n}\right] \cdot \left[\frac{F_r'}{F_r}\right]$$

Ec. 6. Dimensional factor for the correlation.

Where:

$$F_r(\tau \cdot \alpha)_n = Factor\ of\ optical\ efficiency\ of\ the\ sensor,$$
$$y - intercept\ of\ the\ characteristic\ curve\ of\ the\ collector\ [0{,}745];$$

$$\left[\frac{(\tau \cdot \alpha)}{(\tau \cdot \alpha)_n}\right] = Incident\ angle\ modifier\ constant: [0{,}96](simple\ surface);$$

$$\frac{F_r'}{F_r} = Factor\ of\ the\ collector - acumullator\ [0{,}95];$$

Parameter D_2, expresses the relation between the energy losses in the collector, for a given temperature, and the heating charge for one month:

$$D_2 = \frac{Losses\ of\ energy\ in\ the\ collector}{Monthly\ heat\ load}$$

The energy lost by the sensor is given by the following expression:

$$E_p = S_c \cdot F_r' \cdot U_L \cdot (100 - t_a) \cdot \Delta t \cdot K_1 \cdot K_2$$

Ec. 7. Energy lost in the collector.

Where:

$$S_c = Area\ cof\ the\ collector\ [m^2];$$

$$t_a = Average\ of\ the\ temperature\ per\ moth;$$

$$\Delta t = Time\ period\ consider\ [s];$$

$$K_1 = Correlation\ factor\ during\ the\ storage;$$

$$K_1 = \left[\frac{V}{75 \cdot S_c}\right]^{-0{,}25}$$

Ec. 8. Factor K_1.

Where:

$$V = Tank\ volume\ [l];$$

$$F_r' \cdot U_L = F_r \cdot U_L \cdot \left(\frac{F_r'}{F_r}\right);$$

Ec. 9. Dimensional factor for the correlation.

Where:

$$F_r \cdot U_L = The\ charecteristic\ curve\ of\ the\ collector\ \left(3{,}556\ \left[\frac{W}{m^2 \cdot {}^{\circ}C}\right]\right);$$

$$t_a = Average\ of\ the\ temperature\ per\ moth;$$

$$\Delta t = Average\ of\ useful\ time\ per\ day\ [s];$$

$$K_2 = Correlation\ factor\ for\ SHT, wich\ join\ the\ min.\ temperture\ of\ SHT, the\ temperature\ of\ the\ water\ netwrok\ and\ the\ average\ of\ the\ environment\ temperature.$$

$$K_2 = \frac{11{,}6 + 1{,}18 \cdot t_{ac} + 3{,}86 \cdot t_n - 2{,}32 t_a}{100 - t_a}$$

Ec. 10. Correction factor K_2.

Where:

$$t_{ac} = Min.\ temperaturo\ of\ SHT;$$

$$t_n = Network's\ temperature;$$

$$t_a = Average\ of\ the\ temperature\ per\ month;$$

After obtaining D_1 and D_2, applying the initial equation, the fraction of the monthly heat load contributed by the solar energy system is calculated.

In this way, the useful energy collected each month, Q_u, has the value:

$$Q_u = f \cdot Q_a$$

Ec. 11. Useful energy collected per month.

Where:

$$Q_a = Heat\ load\ of\ SHT\ per\ month;$$

Through the same operating process that developed for a month, will operate for all months of the year. The relationship between the sum of the monthly coverage and the sum of the heat loads, or monthly heat requirements, will determine the annual coverage of the system:

$$Annual\ solar\ cover = \sum_{u=1}^{u=12} Q_u \Big/ \sum_{u=1}^{u=12} Q_a$$

Ec. 12. Annual solar cover.

Calculation of solar fraction

In this point, the solar fraction (f) is calculated based on the data included on the section of 'Previous data', the F-Chart method is used.

As has been written, the first step is to calculate the D_1 parameter.

	$(\tau\alpha)/(\tau\alpha)_n$	Fr'/Fr	$Fr(\tau\alpha)_n$	$Fr'(\tau\alpha)$	$S_c[m^2]$	N	$I_t[MJ/m^2]$	$E_a[MJ]$	$Q_{SHT}[MJ]$	D_1
January	0,96	0,95	0,75	0,68	0,75	31,00	13,70	216,42	593,95	**0,36**
February	0,96	0,95	0,75	0,68	0,75	28,00	15,30	218,30	526,16	**0,41**
March	0,96	0,95	0,75	0,68	0,75	31,00	19,30	304,88	559,68	**0,54**
April	0,96	0,95	0,75	0,68	0,75	30,00	21,20	324,09	519,52	**0,62**
May	0,96	0,95	0,75	0,68	0,75	31,00	21,80	344,37	525,42	**0,66**
June	0,96	0,95	0,75	0,68	0,75	30,00	22,60	345,50	497,42	**0,69**
July	0,96	0,95	0,75	0,68	0,75	31,00	23,50	371,23	502,57	**0,74**
August	0,96	0,95	0,75	0,68	0,75	31,00	22,20	350,69	514,00	**0,68**
September	0,96	0,95	0,75	0,68	0,75	30,00	20,50	313,39	508,47	**0,62**
October	0,96	0,95	0,75	0,68	0,75	31,00	17,00	268,55	536,84	**0,50**
November	0,96	0,95	0,75	0,68	0,75	30,00	14,00	214,02	541,63	**0,40**
December	0,96	0,95	0,75	0,68	0,75	31,00	11,80	186,40	593,95	**0,31**

Table 12. Calculation of D_1 parameter.

Once the first parameter is found out, the second one (D_2) is calculated, but before the correction factors $(K_1\ y\ K_2)$:

On the recommendation of the manufacturer, for a solar panel of the chosen area (0,6 m^2), the corresponding tank will be 300 litters, checking that is inside the regulations (CTE):

$$50 < \frac{V}{A} < 180;$$

$$50 < 130{,}43 < 180$$

Ec. 13. Regulation of the CTE for the tank volume.

Where:

$$V = Volume\ of\ the\ tank\ [l];$$

$$A = Solar\ collector's\ area\ [m^2];$$

$$K_1 = \left[\frac{V}{75 \cdot S_c}\right]^{-0,25} = \left[\frac{300}{75 \cdot 0,75}\right]^{-0,25} = 0,87$$

Ec. 14. Correction factor K_1.

The other correction factor (K_2), associate the minimum temperature of the STH, with the network's temperature and the environment's temperature, in the following table is showed the factor for each month and its corresponding D_2 parameter:

$$K_2 = \frac{11,6 + 1,18 \cdot t_n + 3,86 \cdot t_n - 2,32 \cdot t_{ac}}{100 - t_{ac}} = \frac{11,6 + 11,8 \cdot 60 + 3,86 \cdot 8 - 2,32 \cdot 12}{100 - 12}$$

Ec. 15. K_2 correction factor for January.

Once is known K_1 and K_2 is possible to build the table with the rest of values:

	Sc [m²]	F_rU_l	Fr'/Fr	$F_r'U_l$	t_{ac} [ºC]	t_n[ºC]	t_n [ºC]	Δt (h)	K_1	K_2	N	Q_{SHT} (MJ)	Ep (MJ)	D_2
January	0,75	3,56	0,95	3,38	12	60	8	8	0,658	0,971	31	593,95	2621,05	**4,41**
February	0,75	3,56	0,95	3,38	13	60	9	9	0,658	1,000	28	526,16	3001,83	**5,71**
March	0,75	3,56	0,95	3,38	15	60	11	9	0,658	1,060	31	559,68	3108,13	**5,55**
April	0,75	3,56	0,95	3,38	17	60	13	9,5	0,658	1,122	30	519,52	3393,01	**6,53**
May	0,75	3,56	0,95	3,38	20	60	14	9,5	0,658	1,126	31	525,42	3280,08	**6,24**
June	0,75	3,56	0,95	3,38	23	60	15	9,5	0,658	1,129	30	497,42	3167,15	**6,37**
July	0,75	3,56	0,95	3,38	26	60	16	9,5	0,658	1,133	31	502,57	3054,22	**6,08**
August	0,75	3,56	0,95	3,38	27	60	15	9,5	0,658	1,064	31	514,00	2829,08	**5,50**
September	0,75	3,56	0,95	3,38	24	60	14	9	0,658	1,063	30	508,47	2787,17	**5,48**
October	0,75	3,56	0,95	3,38	20	60	13	9	0,658	1,077	31	536,84	2974,22	**5,54**
November	0,75	3,56	0,95	3,38	16	60	11	8	0,658	1,045	30	541,63	2691,61	**4,97**
December	0,75	3,56	0,95	3,38	13	60	8	7,5	0,658	0,955	31	593,95	2390,52	**4,02**

Table 13. Calculation of the D_2 parameter.

With the parameters D_1 and D_2 calculated, the solar fraction for the collector will be:

$$f = 1{,}029D_1 - 0{,}065D_2 - 0{,}245D_1^2 + 0{,}0018D_2^2 + 0{,}0215D_1^3$$

Table 14. Final results of the D_1 and D_2 and the solar fraction per month.

As can be seen, the catchment area reaches the limits established by the necessary solar fraction established by the Valencian community in that there must be a minimum solar fraction of 60%.

Annual solar fraction

The annual solar fraction is calculated as the ratio between the sum of monthly solar contributions and the sum of the energy demands of each month:

$$Annual\ solar\ cover = \sum_{u=1}^{u=12} Q_u \,/ \sum_{u=1}^{u=12} Q_a$$

Ec. 16. Calculation of the annual solar cover or fraction.

Where:

$$Q_u = useful\ energy\ supplied\ by\ the\ instalation\ for\ SHT;$$

$$Q_U = f \cdot Q_a;$$

Ec. 17. Calculation of the useful energy.

$$Q_a = amount\ of\ energy;$$

Following the previous equations is possible to calculate the final solar fraction:

	f	u (QSHT) [M	Q_a [MJ]
January	0,41	593,95	241,82
February	0,60	526,16	316,40
March	0,69	559,68	383,64
April	0,90	519,52	465,00
May	0,87	525,42	457,62
June	0,92	497,42	457,43
July	0,90	502,57	454,74
August	0,78	514,00	402,15
September	0,73	508,47	371,55
October	0,65	536,84	348,15
November	0,49	541,63	266,04
December	0,33	593,95	195,67
		6419,61	**4360,21**

Table 14. Amount of energy

Therefore, the solar fraction for the installation will be:

$$f = \frac{\sum_{u=1}^{u=12} Q_u}{\sum_{u=1}^{u=12} Q_a} = \left(\frac{4360{,}31[MJ]}{6419{,}61[MJ]}\right) = 0{,}68$$

Ec. 18. Solar fraction.

$$f = 68\%$$

The solar coverage in our homes complies with the Ordinance of the City of Valencia in an appropriate manner, since it imposes that the minimum solar contribution, as we saw above, should be 60%.

Conclusion

After the complete study of the installation of solar collectors for the supply of domestic hot water for the city of Valencia proceed with a few short conclusions:

- In this final project, a study has been carried out on the installation of solar collectors for the supply of domestic hot water in the city of Valencia.
- The method was used to calculate the number of necessary collectors and solar fraction, F-CHART method.
- It is intended to supply sanitary hot water to single-family homes whose demand amounts to 88 L / day.
- One solar collector has been used to obtain an average annual solar fraction of 0.68 compared to 0.6 required by the CTE for the city of Valencia.
- Therefore, we will conclude by saying that the project carried out meets both economic and environmental expectations, being the same a way to promote renewable energy over conventional ones, helping to avoid pollution of the planet.

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