Cracow University of Technology
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ERASMUS STUDIES

Diploma Dissertation

BATCHELOR OF SCIENCE

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Study of the energy reconditioning of a single-family home from wind and solar photovoltaic energy.

Estudio del reacondicionamiento energético de una vivienda unifamiliar a partir de energía eólica y solar fotovoltáica.

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1- WORK EXPLANATION

The present work consists in the energy reconditioning of a single-family home based in using renewable energy resources as solar photovoltaic plates and wind power generators.

The house is placed in a village called Bétera 18 km away of the city of Valencia, Spain. It is a big house of about 400 square meters with a significant energy expenditure, which will be covered with a wind power generator and thirty solar photovoltaic plates in addition to the energy provided by the electricity network.

Figure 2.1- Aerial photo of the house

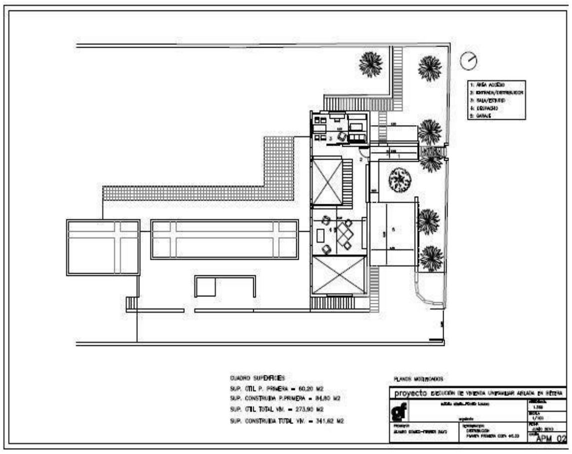


Figure 1.2- Floor plan of the house

Figure 1.3- Map of Spain with Bétera highlighted

As we see in the photograph the plates will be situated on the roof top which has an area of 100 square meters more than enough to our plates which occupy 60 square meters.

In the next sections we sill study how the wind turbines and the solar photovoltaic plates work, then we will make an analysis of the energy demand of the house, to continue we will choose the photovoltaic plates and the wind turbine which will cover our necessities and also the distribution which will have, to finish we will make the budget of making all the installation and we will analyse the money recovery and the benefit of installing all the plates and turbine.

2-INTRODUCTION TO SOLAR PHOTOVOLTAIC ENERGY [1][2]

In order to understand solar energy we need to define some parameters. First of all we will consider the different types of solar radiation. Solar radiation is made up of sets of electromagnetic waves with different frequencies and thus with different energies. The representation of the radiation energy depending on the wavelength, or frequency, is called a spectrum.

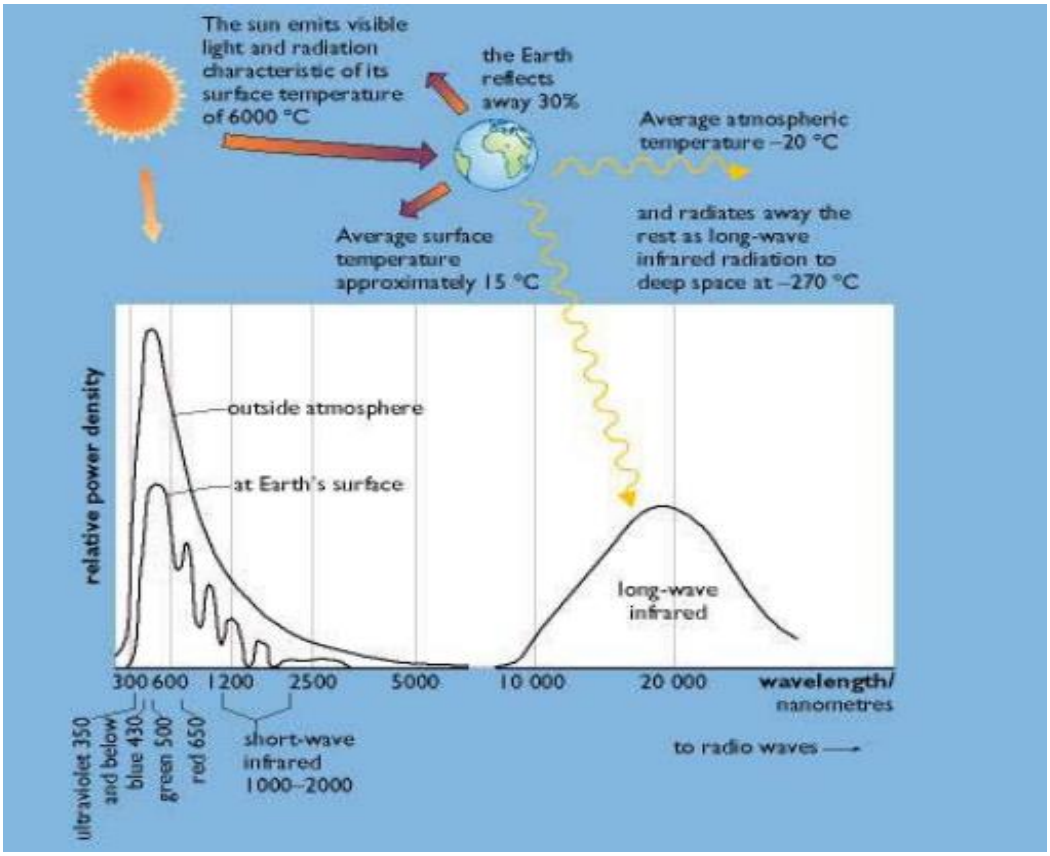


Figure 2.1- Relative power density vs Wavelength[3]

We are interested only in three kinds of radiation, visible range (57%), part of the ultraviolet radiation (3%) and part of the infrared (40%), between 300nm and 1500nm, since in this interval the amount of radiation spectrum is sufficiently large to be captured and used, and the energy of this radiation is capable of interacting with the materials used in the collectors.

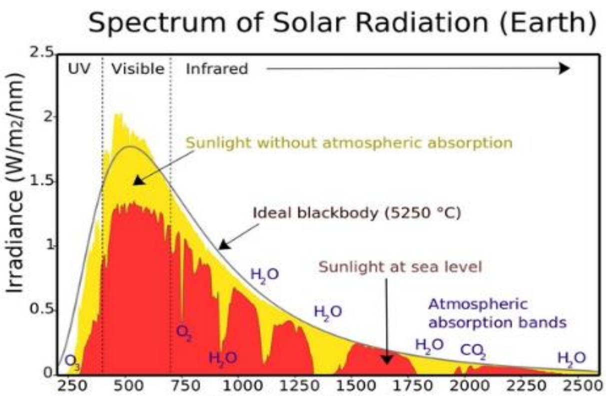


Figure 2.2- Irradiance vs Wavelength

We will need to study the solar incidence in our plates. In order to do this we will have to consider some parameters, as the **solar constant**, which is the intensity received in the form of solar radiation per unit time and unit area, measured on the outside of the atmosphere in a plane perpendicular to the rays.

According to the World Radiation Center (WRC), it takes the value of Gsc= 1367 W/m2. But the actual intensity available at the surface is lower than the solar constant due to absorption and scattering of radiation originated from photons interacting with the atmosphere (approx. 900 W/m2).

We also need to define **solar irradiance** which is the radiant power per unit area incident on a given plane measured in (W/m2) and **irradiation** which is the incident energy per unit area on a given plane, obtained by integration of the irradiance for a given time interval, typically one hour or one day. It is expressed in (MJ/m2) or (kWh/m2).

On average only 53% of the radiation incident on the outer layer of the atmosphere (exosphere) reaches the earth's surface (global radiation). It is divided in three types:
-**Direct radiation** has a track uninterrupted. We can distinguish it because it produces the shadows.
-The **diffuse radiation** comes from the rest of the sky and is a result of phenomena of reflection and refraction of radiation by atmospheric components.
-**Albedo,** radiation reaching by shocking in adjacent elements, especially sea or snow.

Global radiation it is obtained by sum of all the radiations. The next graphic expresses the radiations obtained in Spain by a study of the potential solar energy.

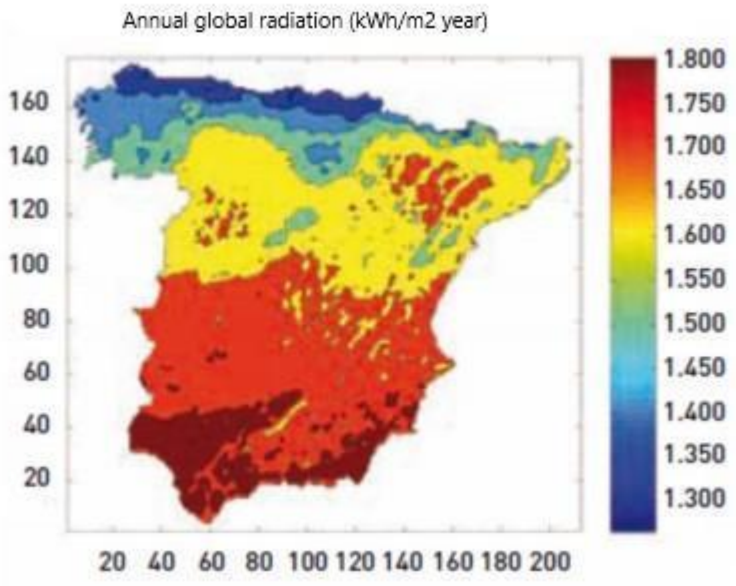


Figure 2.3- Annual global radiation per year in Spain

And the following one represents the different radiations including the global one at the Valencia Airport which is near Bétera, where the subject of study is located.

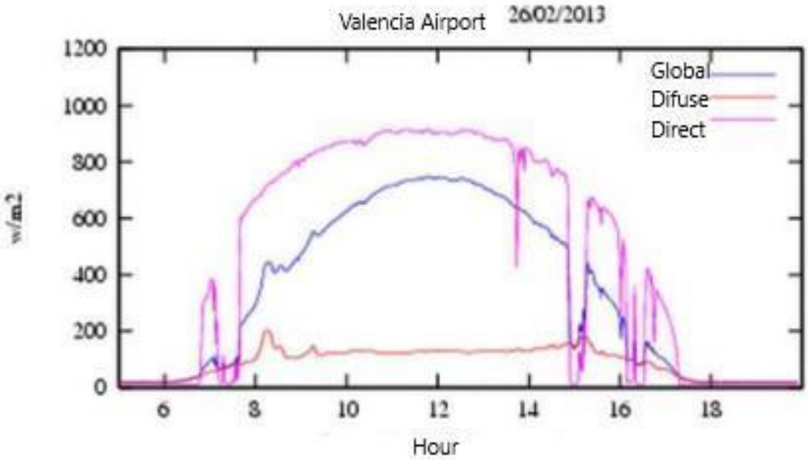


Figure 2.4- Types of radiation at the airport of Valencia

It is also very important to figure out the number of hours of sun in the place of study. For doing so, we can use the same study from the first map which shows the number of hours in each region of Spain.

Figure 2.5- Incident energy and hours of sunshine at Spain

The upper value is the incident energy, in kWh/m2-horizontal surface, in one year. In our region 1550 kWh/m2.
The lower value is the number of hours of sunshine in a year (HSP-peak sunshine hours). In our region 2630 hours.

Between the two options of solar energy (thermal solar energy and photovoltaic energy), we will choose, based on the necessities of our house, the photovoltaic energy which provide us of electricity.

Photovoltaic generation consists of energy production from the interaction of light on a certain material, so that the influence of sunlight on it produces a current of electrons. This effect, called photoelectric, transforms both direct and diffuse radiation in electric current. The most suitable materials are semiconductors, especially silicon (monocrystalline silicon, polycrystalline silicon and amorphous silicon).

Silicon atoms have an atomic valence of 4, whereby a covalent bond with each of the silicon adjacent atoms is formed. When the glass is at ambient temperature, some electrons can (absorbing the required energy from solar photons) jump to the conduction band, leaving the corresponding hole in the valence band. The required energies at ambient temperature are 1.12 eV and 0.67 eV for silicon and germanium, respectively.

In practice, impurities (doping) are added to the semiconductor crystal to increase the number of electrons or holes. Each photovoltaic cell is composed of two sheets of silicon PN. A layer is doped with elements less valence electrons (with excess positive charge) than silicon, called P (eg. boron), and the other layer elements with more electrons than the silicon atoms, referred to N (eg. phosphorus).

Photons (having an adequate energy) incident on the surface of the N layer and interacting with the material, release electrons of the silicon atoms which, pass through the semiconductor layer, but can not return. The N layer acquires a potential difference to P. The electric field established by the creation of the p-n junction creates a diode that allows current flow in one direction through the union. Electrons can pass side n-type into the p side, and holes may pass from the p-type side to the n-type side. The p-n junction acting as a diode, especially sensitive to radiation in the visible spectrum, generating electrical current when a load connected to the cell.

The following image it is a good simplification of the process.

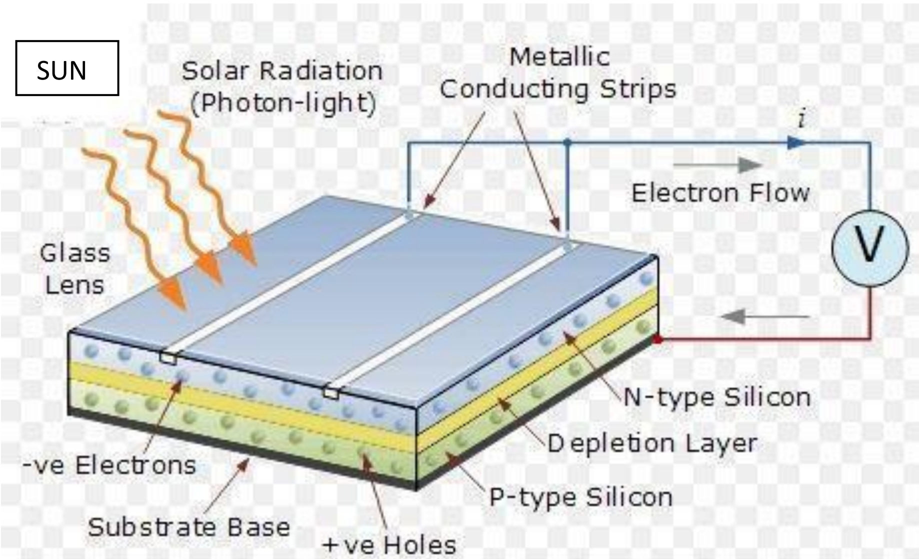


Figure 2.6- Operating detail of a photovoltaic solar panel [3]

We will continue the explanation by learning about the characterization curves of solar photovoltaic plates.

The most important one is the Current-Voltage curve.

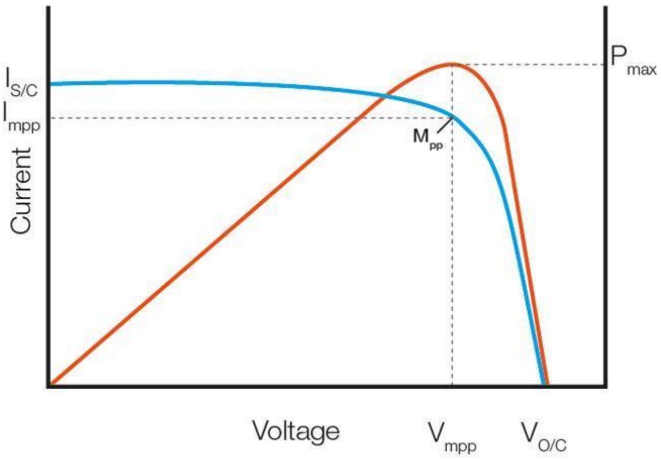


Figure 2.7- Current vs Voltage of a solar photovoltaic plate

-The **Mpp** point shows the maximum power of the cell.

-The **Form Factor** (FF) is a measure of the quality of the union and the internal resistance of the cell. Due to losses occurring in the cell, mainly parallel resistance and serial resistance, curve defining the actual cell is not exactly a rectangle. The bigger is FF the higher is the maximum power.

-**Energy conversion performance η**: is defined as the ratio between the maximum electrical power that can be delivered to the load and the power of incident radiation on the device PL.

$$\eta = \frac{Pmax}{Pl} = \frac{FF \times Isc \times Voc}{Pl} \tag{1}$$

$$Pmax = Voc \times Isc \times FF \tag{2}$$

$$FF = \frac{Vmp \times Imp}{Voc \times Isc} \tag{3}$$

The section of a photovoltaic plate:

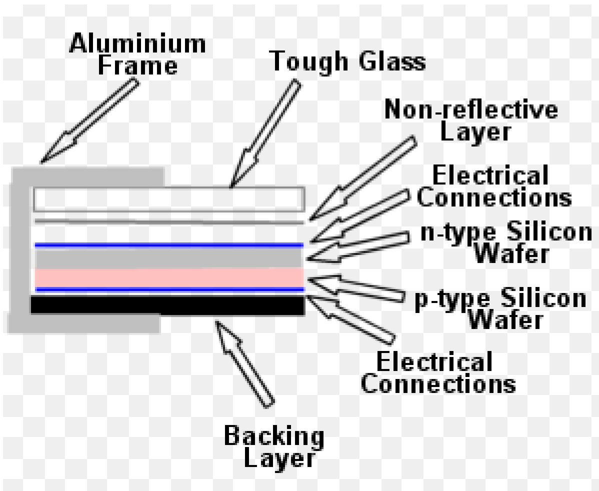


Figure 2.8- Section of photovoltaic plate [(3)]

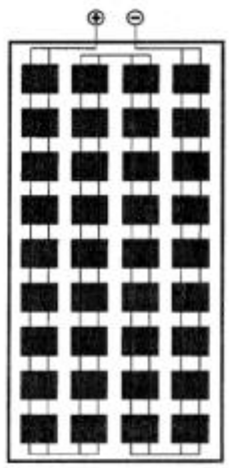


Figure 2.9- Detail of photovoltaic plate [(3)]

In order to obtain a considerable amount of voltage we make unions between cells. The way to connect the cells in series to increase the voltage is via a flat tinned copper wire joining the "positive" of a cell with the "negative" of the next cell. Welding between cells (36, 72, etc) is carried by a tinned flat copper ribbon, so that the "circuit" is formed.

The photovoltaic cells have different structures depending on manufacturers, the common parts are:

Outer Cover: It has a protective function as it is the one to suffer the action of atmospheric agents. Tempered glass has some qualities that give the photovoltaic module great advantages over other materials, because it has a good impact protection while having excellent transmission to radiation of the solar spectrum.

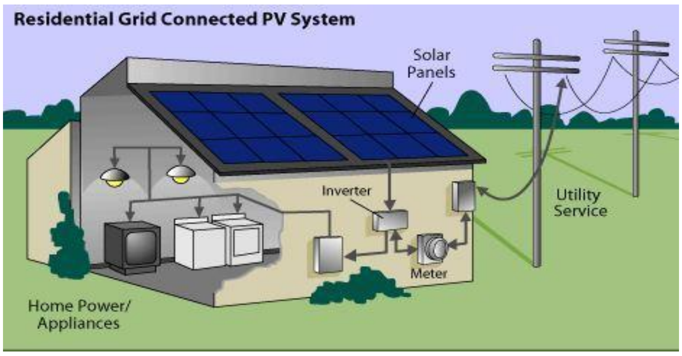
Encapsulating layers: They are responsible for protecting solar cells and interconnecting contacts. The materials used must have excellent transmission of solar radiation and no degradation against ultraviolet radiation, because if not, may decrease the performance of the module. Above EVA encapsulant (Ethylene-Vinyl-acetylene). Fix the cells, seal and protect the circuit against input humidities. It should allow maximum radiation transmission and not be degraded by the effect of ultraviolet rays, as it can be opaque and prevent the entry of photons in the cells.

Support frame: Provides mechanical rigidity and allows the integration into structures that grouped more modules. The frame is usually made of anodized aluminium or stainless steel, and can apply special treatment to make it more resistant to marine environment.

Electrical contacts: Usually arranged in one or two connection boxes outdoors. Contacts accessible via screw connector or any other form of reliable electrical contact. The weatherproof protection connection box is the most reliable and durable in time, in addition to incorporating therein certain protective elements as bypass diodes, which would prevent the damage from partial shading option.

To finish the theoretical introduction we need to know which type of installation we are going to use:
-**Isolated system**: A configuration of this type means that the PV array must be dimensioned so as to allow, during the hours of sunlight, the power load and recharge the batteries of accumulation. This could be a good option for residences far from the grid (>3km) and with low expenses (<10kwh), but as our house is near the power grid and has higher power necessities we will use a grid-connected system which does not need an accumulator the component that increases the price substantially.

-**Grid-connected system**: The grid-networked systems do not incorporate storage systems because the energy produced during the hours of sunlight is transferred in-line to the electrical grid. It needs to connect with distribution lines, meeting the requirements demanded by the power company. In this system we have to take in account this components; photovoltaic modules (plates), inverter DC-AC, exchange device with the electric grid, bidirectional counter.
The last component, bidirectional counter allow us to sell our excess of energy to the grid, which will make much cheaper the electric bill.



This is a simplified model, which shows us what will look like the grid-connected system.

Figure 2.10- Residential grid connected PV System (3)

3-INTRODUCTION TO WIND POWER ENERGY [4][5]

Power wind depends on temperature difference due to solar radiation (we have more wind during the day), and Coriolis force due to rotation of the earth, also it is very important the altitude (less altitude, higher density of the air, higher power to move the generators, more energy obtained), and the orography of the terrain, it is not the same to put the generator in a city with buildings, than in the mountain or the sea.

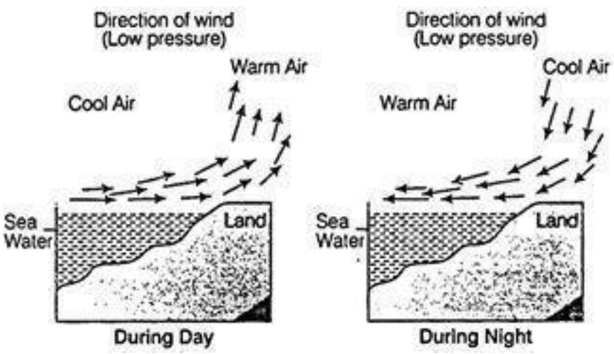


Figure 4.1- Wind movement detail [6]

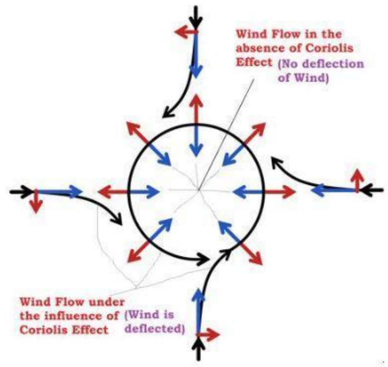


Figure 3.2- Wind flow under Coriolis effect [6]

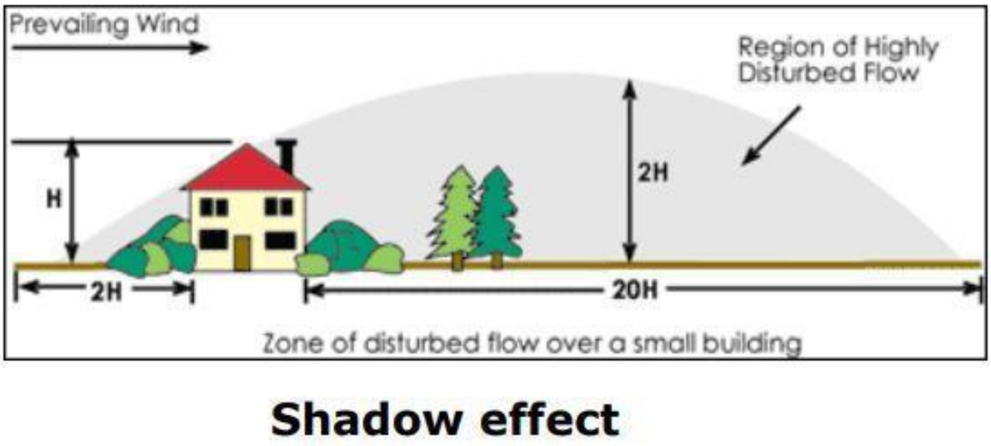


Figure 3.3- Shadow effect detail [6]

The wind speed increases its value with the height and thus the power produced by the wind turbine, the equations that make this relations are the following:

$$V_2 = V_1 \times \frac{\ln({}^{Z_2}/_{Z_0})}{\ln({}^{Z_1}/_{Z_0})} \quad (4)$$

$$V_h = V_{10} \times (\frac{h}{10})^a \quad (5)$$

The symbol α represents the Hellman coefficient that varies with the roughness of the terrain.

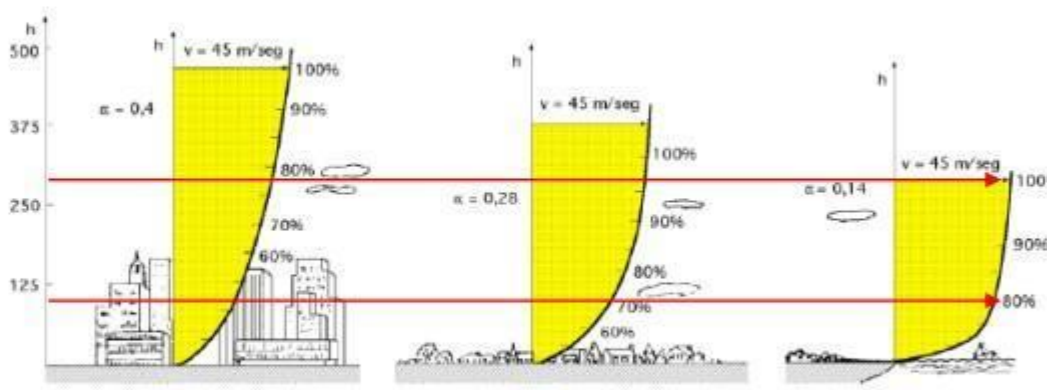


Figure 3.4- Detail of Hellman coefficient depending on roughness [6]

The variables that define the wind are the speed and the direction; the graphics of the velocity distribution curve, and the rose of the winds represent these variables.

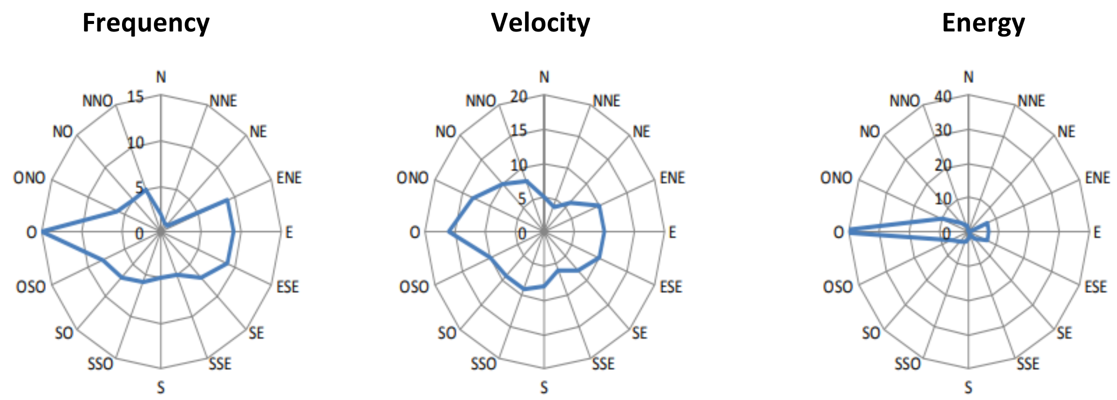


Figure 3.5- Rose of the winds of frequency, velocity and energy [6]

To estimate the energy produced by a wind turbine we will have to make the histogram of wind speeds for a certain period, as is not enough to know the average wind speed in one place.

$$P(V) = \frac{k}{A} \times \left(\frac{V}{A}\right)^{k-1} \times \exp\left(-\left(\frac{V}{A}\right)^{k}\right), V \geq 0 \quad (6)$$

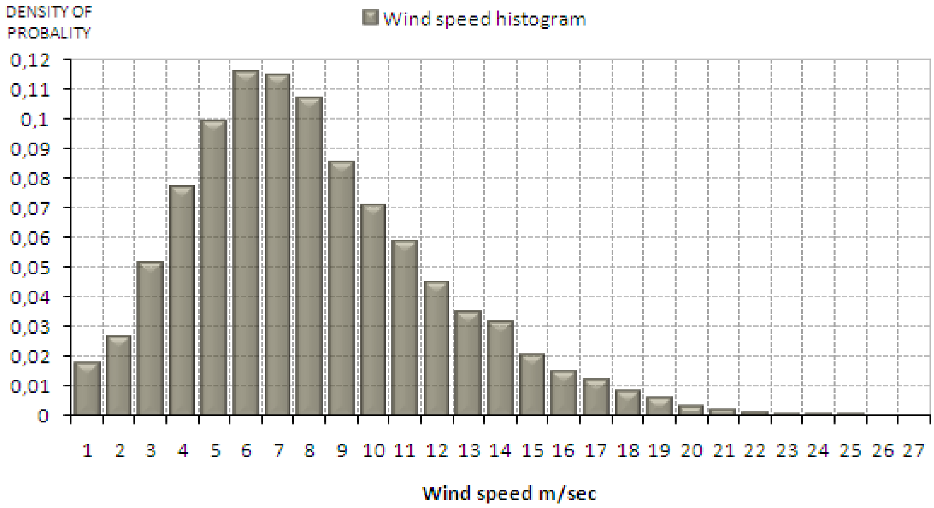


Figure 3.6- Weibull statistical distribution [(6)]

We use the Weibull statistical function to represent the temporal distribution of wind speeds of a place. Which is completely determined with only two parameters; the scaling factor **A** and the form factor **k**.

The scale factor, expressed in m/s, relates directly to the average speed.

The form factor, dimensionless, modifies the symmetry of distribution, low values (near to 1) correspond to very skewed distributions, high values (around 2-3) correspond to symmetric distributions similar to Gauss ones.

Hereafter we will observe the wind maps of Spain and specifically Valencia, where our subject of study is placed.

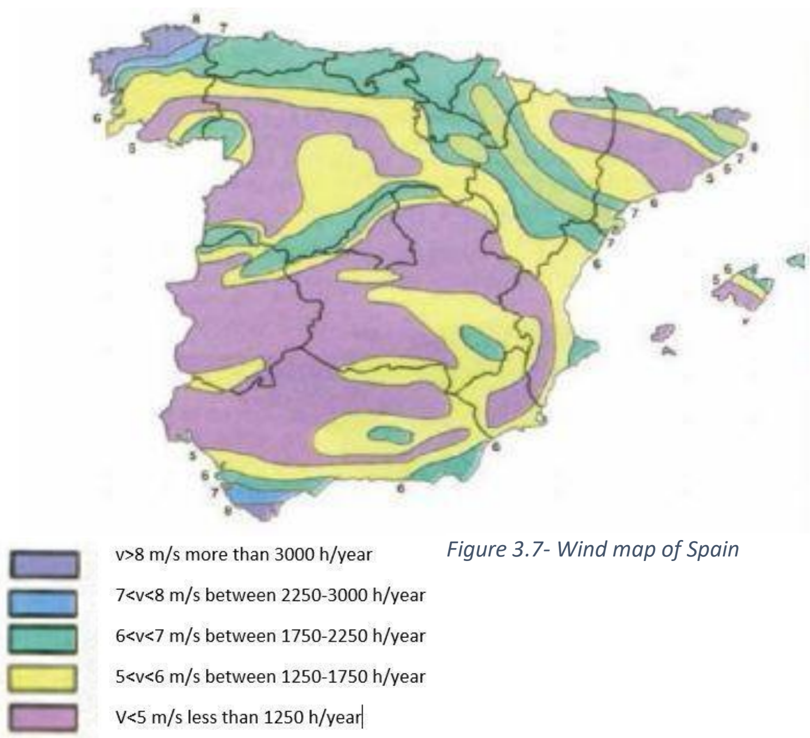


Figure 3.7- Wind map of Spain

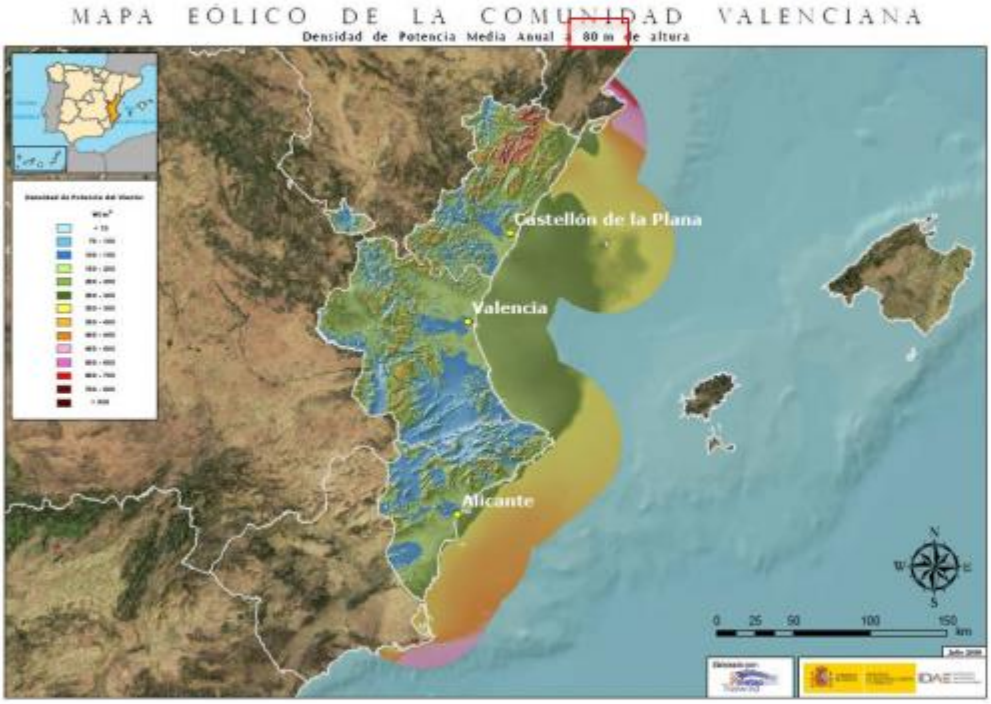


Figure 3.8- Wind map of Valencia

Finally we arrive to the calculation of the available power in the wind, generically the power available in the wind flowing through a cylindrical control volume (blades) is:

$$P = \frac{1}{2} \times \rho \times A \times v^3 \quad (7)$$

-ρ is de density of air, with a standard value of 1.225 kg/m3, depends on the height and the temperature.

-A is the surface swept by wind turbine blades.

-v represents the wind speed.

We add at the end of the formula the **Cp** (power coefficient) to know which amount of the stored energy can be extracted, takes the maximum value of 0,593 by the Betz law. It depends on the wind turbine, losses by friction deviation of the wind direction from the optimum, turbulence…

Tip-Speed ratio (TSR) - Specific speed is also important:

$$TSR = \frac{r \times w}{v} \quad (8)$$

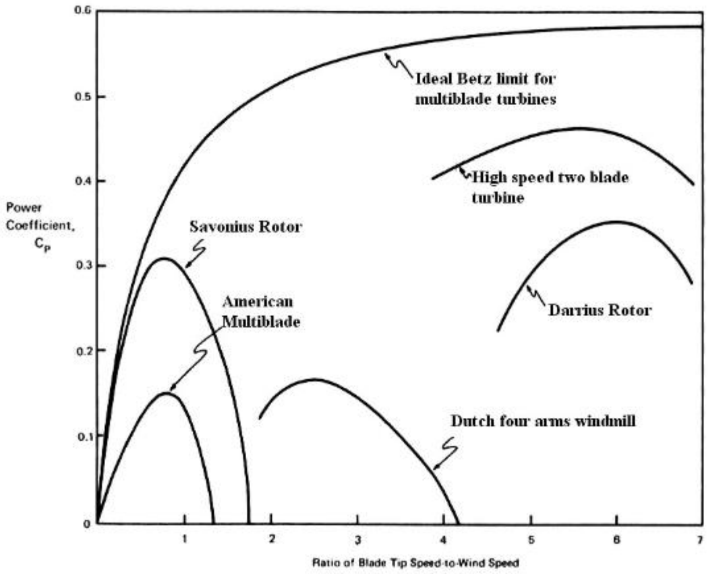


Figure 3.9- Power coefficient vs Tip-Speed ratio (6)

Now we will have to decide which type of wind turbine do we prefer to install.

First of all decision between vertical axis turbine or horizontal axis, usually to make big amounts of energy the easy decision will be the horizontal axis wind turbine with three blades, but for lower amounts of energy it is reasonable to take in account the horizontal axis turbines as the Savonius, Darrieus and Darrieus Savonius which is the combination of the two others.

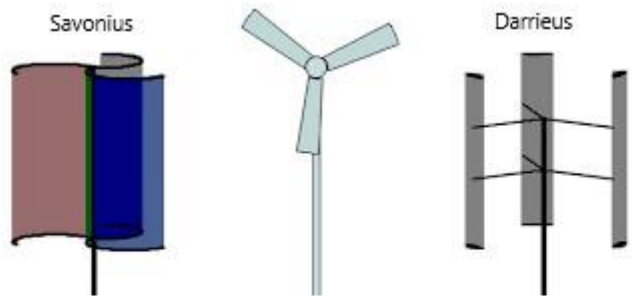


Figure 3.10- Types of wind turbines (6)

The decision of buying one or another is explicated in the next section. Now I am going to make a brief explanation between each generator.

Savonius: Simplest model of wind turbine, with two or four vertical plates, it is called wind turbine resistance as the engine torque on the shaft is generated by the difference in resistance that symmetrically arranged about the axis vertical surfaces provide wind.

It is a slow wind turbine with low efficiency, usable with winds of low intensity and a limited range, it is needed a mechanical device for stopping, valid only for lower applications and a noisy.

Darrieus: Vertical axis wind turbines and “lift”, since the surfaces exposed to the wind present an air foil capable of generating a pressure distribution along the blade and a torque in the axis of rotation. Darrieus provides greater efficiency by having less friction losses than Savonius. It is unable to start rotating by itself therefore the turbine needs an auxiliary device.

Figure 3.11- Darrieus-Savonius wind turbine [(6)]

Fast wind turbine with lower efficiency than horizontal axis turbines, capable of adapting to changes in wind direction, usable with winds of a low intensity and in a limited range, also needs a mechanical device to stop the turbine and suitable for high power applications.

Darrieus-Savonius: It has the advantage of having the starting torque provided by the wind turbine Savonius, which is located inside Darrieus.

Horizontal axis wind turbines: There are two main types of horizontal turbines; the so-called turbines windward because the wind is the rotor before the tower. They have a higher efficiency than downwind turbines; no longer having aerodynamic interference with the tower. They have the disadvantage of not aligned autonomously in relation to the wind. And downwind turbines accused the negative effects of tower rotor interaction, but they are aligned independently and they can use a flexible rotor to withstand strong winds.

Other difference between horizontal turbines is the number of blades, when there is one or two blades, it makes more noise but the generator is cheaper. The compromise between efficiency and noise is three blades. In addition two-bladed rotor is subjected to imbalances due to wind variation with height.

We could study the shape of big horizontal axis turbines but as we are going to install a very small one we won´t delve further.

To complete this section we will study the low power applications.

It has a lot of advantages as the accessibility for the users also it needs small civil works, and installation is simple, works with moderate winds and does not require complicated feasibility studies.

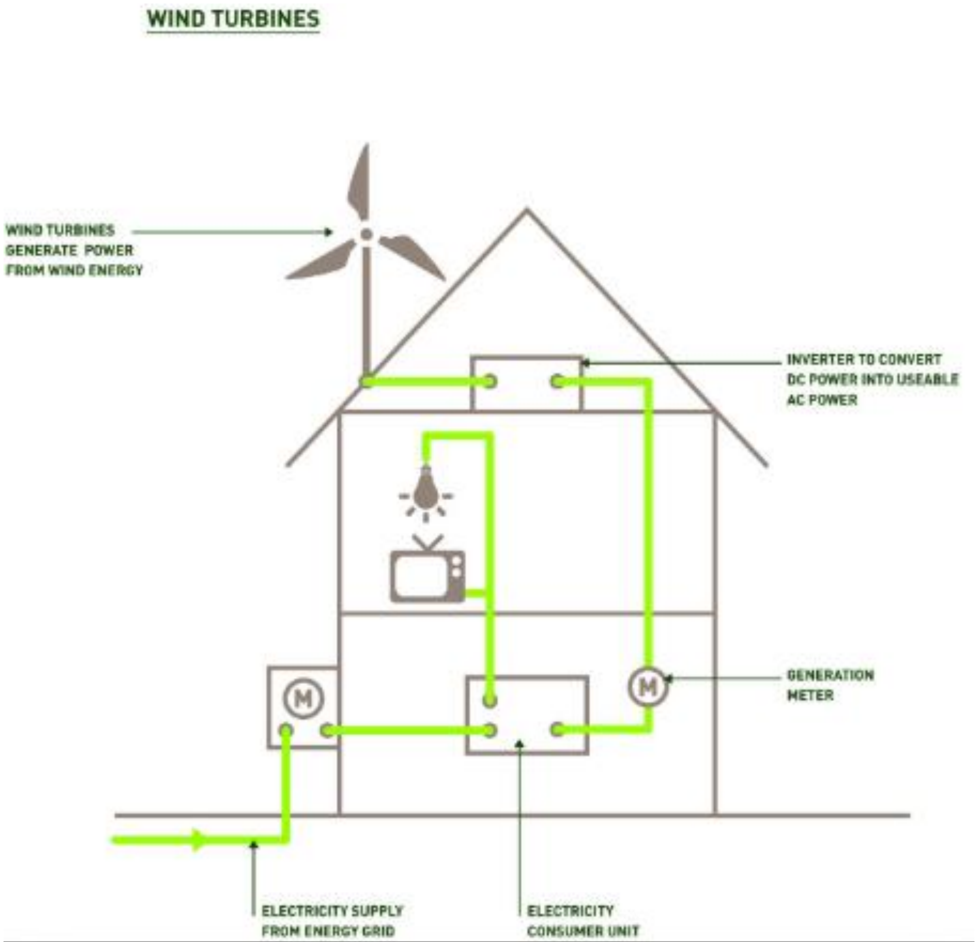


Figure 3.12- Grid connected system with wind turbine [6]

With this scheme of the grid-connected system installation very similar to the solar photovoltaic one, we finish this section and we start with the selection of the solar plates and the wind generator by analysing the necessities of the house.

4-ANALYSIS OF ENERGY DEMAND

In this section we will analyse the power demands of the house by summing all the devices, which require energy as illumination, furniture, electric boiler… We will also use the electric bills to make an estimation of the use of each element along the year.

I will start with the illumination; here is a map with the number of lights and its types:

Figure 4.1- Plant of detailed number and type of lights

Figure 4.2- Kap 105 (16 W)

Figure 4.3- Easy Kap (Max 50 W)

Figure 4.4- Kap Surface (11 W)

17x16W=272W   45xMax50W=2,25KW   2x11W=22W

Figure 4.5- Led downlight (1 W)

3x1W=3W

10x16W=160W

Figure 4.6- Pure 1 Spot (16 W)

Figure 4.7- Duplo Incasso (35 W)

2x35W=70W

Total power expend at maximum demand of light:

272+2250+22+3+160+70=2,777kW

Now we will proceed with the calculus of the furniture power demand:

Figure 4.8- Whirlpool dishwasher

Figure 4.9- Siemens induction plaque

WHIRLPOOL dishwasher ADG 9999

Power= 2kW

SIEMENS Induction plaque EH651MD21 E

Power= 6,8kW

Figure 4.10- Falmec extractor hood

Figure 4.11- De Dietrich refrigerator

FALMECextractor Hood Lumen Isla

Power= 280W

DE DIETRICH refrigerator DRS 1137I

Power= 90W

WHIRLPOOL oven AKPM 756 IX

Power= 2550W

Figure 4.12- Whirlpool oven

MITSUBISHI Air Conditioner PEAD-RP71JAQ

Power= 10kW

Figure 4.13- Mitsubishi air conditioner

The house also counts with a radiating floor which demands quite an amount of energy, we have to keep in mind the temperature in the village is not very cold and it only needs to be switched on freezing days of winter, the structure of the radiating floor is represented on this scheme:

ROOM	Area (m^2)	Red PVC150+ Red WLFH140																				Pot. (KW)
		PVC1.5	PVC2	PVC3	PVC4	PVC5	PVC6	PVC7	PVC8	PVC9	PVC10	WLFH1.5	WLFH2	WLFH3	WLFH4	WLFH5	WLFH6	WLFH7	WLFH8	WLFH9	WLFH10	
Corridor	43.95									2	2											5.70
Bedroom	18.40																		2			2.24
Bathroom	3.70													1								0.42
Bedroom	11.20																				1	1.40
Bathroom	3.80													1								0.42
Bathroom	3.80													1								0.42
Bedroom	11.20																				1	1.40
Laundry	8.10																1					0.84
Kitchen	26.57																				2	2.80
Bathroom	2.05											1										0.21
Hall	20.65																			2		2.52
Dinning room	28.65																		3			3.36
Distributor (P1)	21.65																			2		2.52
Room (P1)	19.40																		2			2.24
Room (P1)	15.75																	2				1.96
TOTAL	238.47																					28.45

Figure 4.14- Structure detail of the radiating floor

As we see the installed power its 28,45kW, which represents almost the sum of all the other elements on the house. In the annexed we can find the detail of the distribution.

With all this information we could make a graphic, which shows us the energy expenditure each month. This is just an approximation but in addition to the electric bills we have, it will allow us to know the exact energy demands of the house.

Table 1- Energy consumption estimation on warm months

SUMMER	Power (kW)	Day (h)	Month (h)	Energy (kWh)
Illumination	2,77	4	120	332,4
Dishwasher	2	3	90	180
Induction	6,8	1	30	204
Extractor	0,28	1	30	8,4
Refrigerator	0,09	24	720	64,8
Oven	2,55	0,5	15	38,25
Air conditioning	10	3	90	900
			TOTAL	1727,85

Table 2- Energy consumption estimation on cold months

WINTER	Power (kW)	Day (h)	Month (h)	Energy (kWh)
Illumination	2,77	5	150	415,5
Dishwasher	2	3	90	180
Induction	6,8	1	30	204
Extractor	0,28	1	30	8,4
Refrigerator	0,09	24	720	64,8
Oven	2,55	0,5	15	38,25
Radiating Floor	14,4	2	60	864
			TOTAL	1774,95

This are just estimations about how many hours each element is used every day in the house. There are few differences between summer (warm months), and winter (cold months). We see that in summer the most expensive element is the air conditioning, as it is a big house with a lot of glass it has many loses so we have to use a very big machine to cold out the place. Similar situation occurs in winter with the radiating floor. I have made a media of the expend of the radiating floor because it is very rare to have the whole floor switched on, and I increase one hour the use of illumination because the long nights of winter.

Now I will show the real expenses of the house with the electric bills in order to have a magnitude order to define the solar photovoltaic plates and wind turbine necessities.

ENERGÍA			
Potencia facturada	PP 22,5 kW x 40 días x 0,123151 €/kW día		110,84 €
	PLL 28,5 kW x 40 días x 0,076581 €/kW día		87,30 €
	PV 22,5 kW x 40 días x 0,054666 €/kW día		49,20 €
Total importe potencia hasta 27/05/2019		**247,34 €**	
Energía facturada	P 310 kWh x 0,202335 €/kWh		62,72 €
	LL 982 kWh x 0,171824 €/kWh		168,73 €
	V 757 kWh x 0,141613 €/kWh		107,20 €
Total 2.049 kWh hasta 27/05/2019		338,65 €	
Impuesto sobre electricidad	5,11269632% s/585,99 €		29,96 €
TOTAL ENERGÍA			615,95 €
SERVICIOS Y OTROS CONCEPTOS			
Alquiler equipos medida	40 días x 0,197918 €/día		7,92 €
TOTAL SERVICIOS Y OTROS CONCEPTOS			7,92 €
IMPORTE TOTAL			**623,87 €**
IVA	**21% s/623,87 €**		**131,01 €**
TOTAL IMPORTE FACTURA			**754,88 €**

This is a bill from spring (17/04-27/05), we see that is a really big amount of energy (2049 kWh) but we have to take in account that this shows us the bill from 40 days, not from 30.

Figure 4.15- Energy bill from spring

ENERGÍA			
Potencia facturada	PP 15,001 kW x 34 días x 0,123151 €/kW día		62,81 €
	PLL 15,001 kW x 34 días x 0,076581 €/kW día		39,06 €
	PV 15,001 kW x 34 días x 0,054666 €/kW día		27,88 €
Total importe potencia hasta 22/08/2018		**129,75 €**	
Energía facturada	P 332 kWh x 0,19258 €/kWh		63,94 €
	LL 1.051 kWh x 0,159378 €/kWh		167,51 €
	V 723 kWh x 0,129379 €/kWh		93,54 €
Total 2.106 kWh hasta 22/08/2018		324,99 €	
Impuesto sobre electricidad	5,11269632% s/454,74 €		23,25 €
TOTAL ENERGÍA			477,99 €
SERVICIOS Y OTROS CONCEPTOS			
Alquiler equipos medida	34 días x 0,394521 €/día		13,41 €
TOTAL SERVICIOS Y OTROS CONCEPTOS			13,41 €
IMPORTE TOTAL			491,40 €
IVA	21% s/491,4 €		103,19 €
TOTAL IMPORTE FACTURA			594,59 €

This one is from summer (19/07-22/08), it is one more time a big amount (2106 kWh), but in this one the limit of hired potency (15 kW) is not overcome so the bill is cheaper than the other one using more energy.

Figure 4.16- Energy bill from summer

ENERGÍA			
Potencia facturada	PP 25,5 kW x 30 días x 0,123151 €/kW día		94,21 €
	PLL 19,5 kW x 30 días x 0,076581 €/kW día		44,80 €
	PV 15,001 kW x 30 días x 0,054666 €/kW día		24,60 €
Total importe potencia hasta 21/11/2018		**163,61 €**	
Energía facturada	P 252 kWh x 0,19258 €/kWh		48,53 €
	LL 633 kWh x 0,159378 €/kWh		100,89 €
	V 320 kWh x 0,129379 €/kWh		41,40 €
Total 1.205 kWh hasta 21/11/2018		**190,82 €**	
Impuesto sobre electricidad	5,11269632% s/354,43 €		18,12 €
TOTAL ENERGÍA			**372,55 €**
SERVICIOS Y OTROS CONCEPTOS			
Alquiler equipos medida	30 días x 0,394521 €/día		11,84 €
TOTAL SERVICIOS Y OTROS CONCEPTOS			**11,84 €**
IMPORTE TOTAL			384,39 €
IVA	**21% s/384,39 €**		80,72 €
TOTAL IMPORTE FACTURA			**465,11 €**

Here we have a winter bill (22/10-21/11), with a lower expend (1205 kWh) but with the overcome of the hired potency this is probably caused by the radiating floor which makes high demand peaks.

Figure 4.17- Energy bill from winter

With the information provided by the bills we can make some conclusions. The energy expenditure is higher on the warm months, which can be better and easier to solve with our generators, as they produce more energy in the month with more sun. And, we also learn that is very important to have control on the power expenditure; we have to try not to overcome our contracted limit power because this will make the bill much more expensive.

5- SELECTION OF PHOTOVOLTAIC PLATE AND WIND TURBINE

As we have seen the energy demand of the house is quite big, so the decision about which turbine and plate we have to use is difficult.

As there are not many types of domestic wind turbines which are big enough to produce a remarkable amount of energy, after many calculations, taking in account the wind velocity average of Bétera I decided to use only one turbine but much bigger than the simple ones of 1kW, the company **ENAIR** provides turbines with a power generation of 3 and 5 kW, with a bigger installation costs but including the grid connection with the inverter, resistance and battery regulator.

The chosen turbine is the 3 kW one, this decision will be justified after explaining which photovoltaic plate we are going to use.

For the photovoltaic plate we see that there are not big plates which produce 1 kW or more, there are specially plates which produce 330 W or less power, so what we have to do is buy a lot of individual plates and make a net on the roof top, as I needed many plates I seek for packs on the internet and I found an offer in Leroy Merlin of a pack of 30 polycrystalline photovoltaic solar panels with a maximum power of 330W making a sum of 9,9 kW and occupying a surface of around 60 square meters.

Now we will see the justification of this selection and we will observe the energy provided by the entire grid. After this in the next section we will analyse the price of making this arrangements and the benefit, which will provide to the economy.

Figure 5.1- E30PRO Wind generator [9]

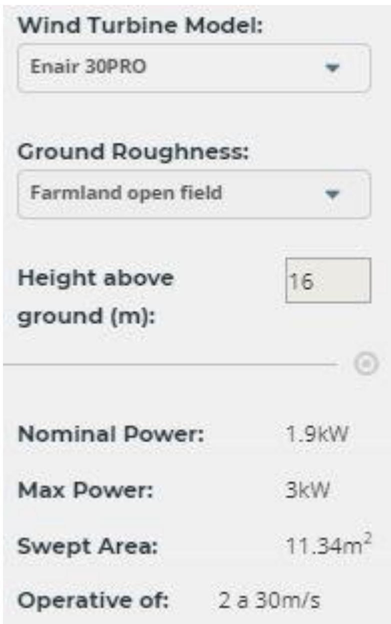


Figure 5.2- E30PRO working details [9]

Here we have the wind turbine **E30PRO**. It is the smallest one of the turbines, which sells ENAIR. As we see in the image its maximum power is 3 kW with a nominal power of 1.9 kW, we have all the specifications in the annexed, but just to have an idea I will expose some of the most important ones; it has a diameter of 3.8 meter, with a weight of 125 kg, a length of 3.4 meters and we are going to use a 12 meter tower, it has three blades as we see in the photo and emits little noise (48 dB). Also a very important characteristic is its resistance, is made by glass fiber with resins and polyurethane core with an anti-corrosion protection made by an epoxy paint.

In order to find the exactly winds at the house, I have used two different websites: one was the own **ENAIR** wind calculation website (www.enair.es/en/app)[9], and the other was **WindFinder** (es.windfinder.com)[7]. This were the obtained results:

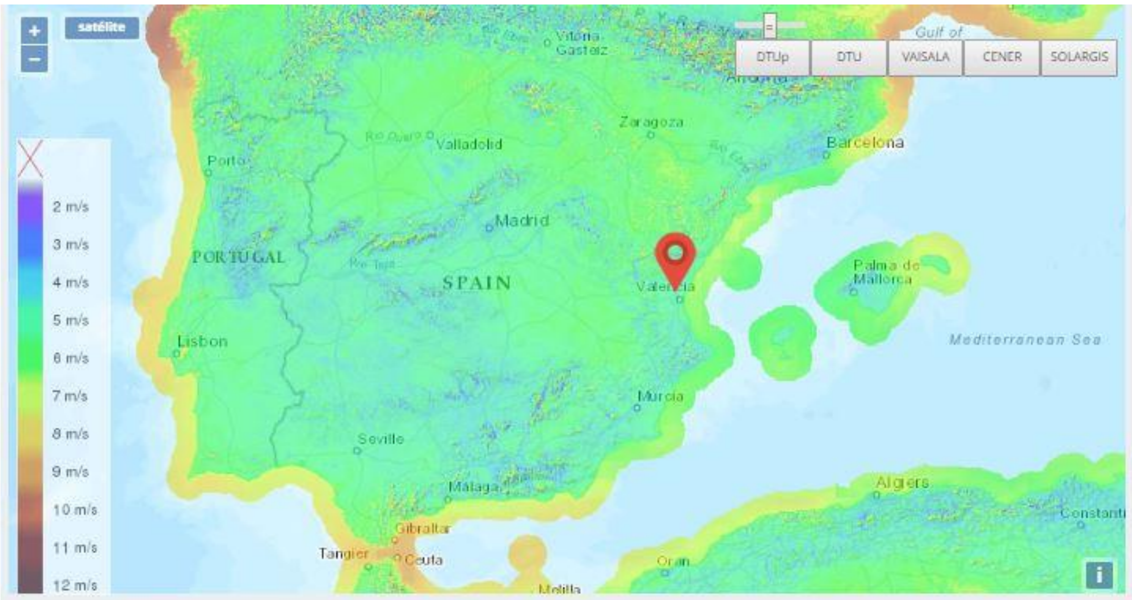
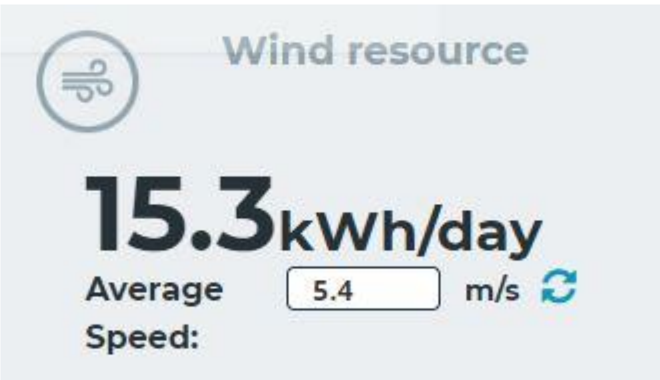


Figure 5.3- Wind velocity map of Spain [9]

The ENAIR website give us a yearly average speed of 5.4 m/s which give us an average energy generation of 15.3 kWh/day with the E30PRO turbine.

Month	ene 01	feb 02	mar 03	abr 04	may 05	jun 06	jul 07	ago 08	sep 09	oct 10	nov 11	dic 12	Año 1-12
Direction of the wind													
Probability	24	16	19	18	13	13	12	7	4	2	7	9	12
Average speed	7	7	7	8	7	8	8	7	6	5	5	5	6
Air Temperature	13	14	17	19	22	28	29	29	26	22	16	14	20

Figure 5.4- Average wind velocity in Bétera [7]



This result is the obtained with the windfinder website, which give us a yearly average wind speed of 6 m/s very similar to the calculated with ENAIR app.

Figure 5.5- Energy generated per day with wind generator [9]

This results give us the next rose of the winds which will allow us to know where we have to face the wind turbine. This could be useful to start it but we have to remember that our wind turbine has a system to orientate itself called passive system with steering rudder.

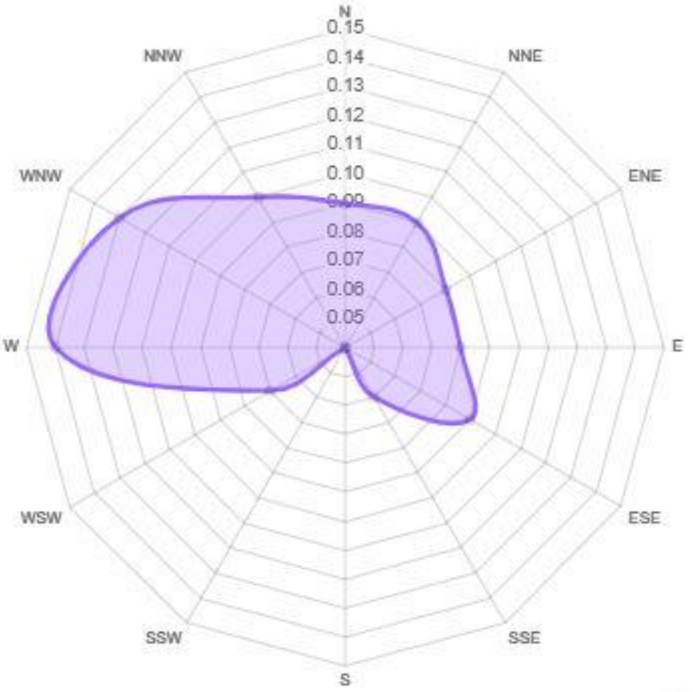


Figure 5.6- Rose of winds of Bétera [9]

With this information we realise that the wind turbine will face the West - West NorthWest.

Thanks to all this information which provides us the webpages we are able to find out the energy generated each month by the turbine. It is calculated by knowing the altitude (105 meters), that gives us the air density (105%) and the wind probabilities, which I provide after the resume of the energy generated each month on the next graphic.

	Wind production in kWh													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average	Anual
Wind speed (m/s)	5.6	5.9	5.9	6.0	5.3	5.1	5.3	5.2	4.8	5.0	5.2	5.5	**5.4**	
kWh/day	16.8	19.3	19.7	20.5	14.0	13.0	14.6	13.3	10.9	12.1	13.8	15.9	**15.3**	**5595 kWh/year**
kWh/month	521	546	610	615	433	389	453	413	327	375	413	492	**466**	

Figure 5.7- Energy generated each month by the wind turbine [9]

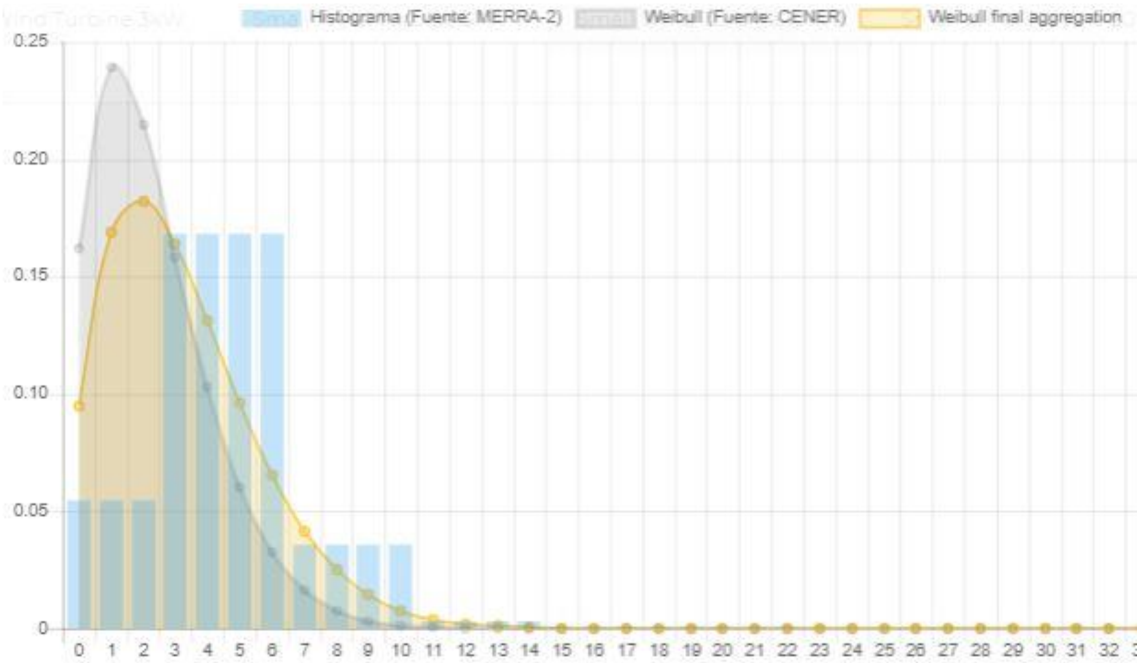


Figure 5.8- Weibull distribution of Bétera [9]

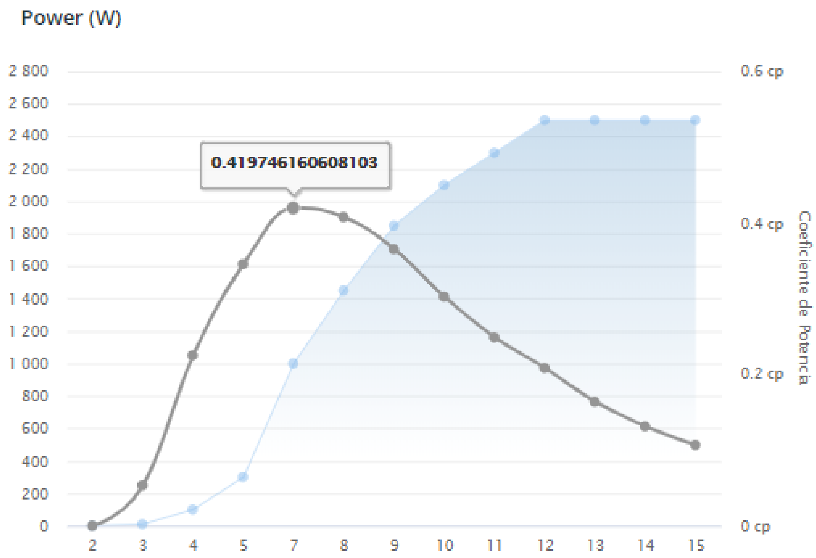
Data source	Hub height (m)	Average speed (m/s)	Degree of confidence	Dispersion zone (m/s)	Weibull C	Weibull K	Rose of winds	Monthly variation
PROPIA	50	4.7	5.0%	±	5.1918	1.6188		✔
DTU	50	4.9	80.0%	±0.21	5.4627	1.5313		
MERRA-2	50	4.5	50.0%	±0.51	5.1918	1.6188	✔	✔
VAISALA	ERROR: Servidor no responde o localización fuera de cobertura							
CENER	30	2.8	40.0%	±0.00	3.0859	1.5365		
Result	**50**	**4.36**	**--**	**±0.21**	**4.9125**	**1.6188**		

Figure 5.9- Weibull coefficients [9]

All of this calculations are made by using the formulas (7) and (8) of the theoretical introduction of the power provided using the Weibull charts.

It is also very important to find out the energy provided, to know the value of the power coefficient.

This value is provided by the company who has made the studies and knows how his wind turbine reacts to the different winds.



As we can see the maximum Cp is acquired at 7 m/s which is near to our average speed, so it is a good decision of wind turbine.

Figure 5.10- E30PRO Cp graphic detail [9]

Now that we know how many energy is provided by our wind generator we will study the energy provided by our 30 photovoltaic plates.

Figure 5.11- Pack of solar panels 330 W offer [10]

These are the photovoltaic plates showed before. The rest of the specifications are in the annexed, the most important ones are: the size, which is (1,956x0,992)=1,94 m2 ≈2 m2, which give us a surface of about 60 square meters which will be divided in the two roof tops of 50 and 50 square meters, the other important data is the power provided which is 330 W each, which give us 9,9 kW and the efficiency 17%.

Now we have to find out the amount of solar energy that impacts in our rooftop over the year, this can be searched in several web pages like the one I used to find the wind and the Weibull char. In this case one of the bests pages is the one of the NASA (power.larc.nasa.gov/data-access-viewer/), which give us a lot of information about the solar radiation over many years in the place we select, the following images are captures of the information provided by the website.

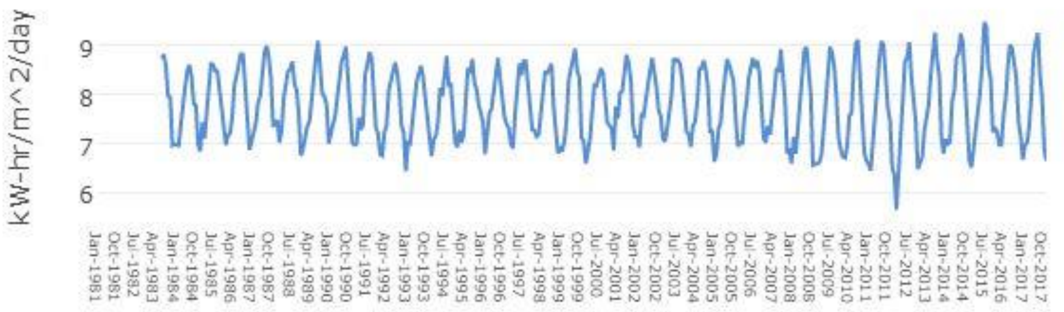


Figure 5.12- Solar radiation between 1981 and 2017 in Bétera [(8)]

This one show us the radiation since the year 1981, we see that the radiation has not changed much over the years, so in order to get more accuracy we will use the one which shows the past three years.

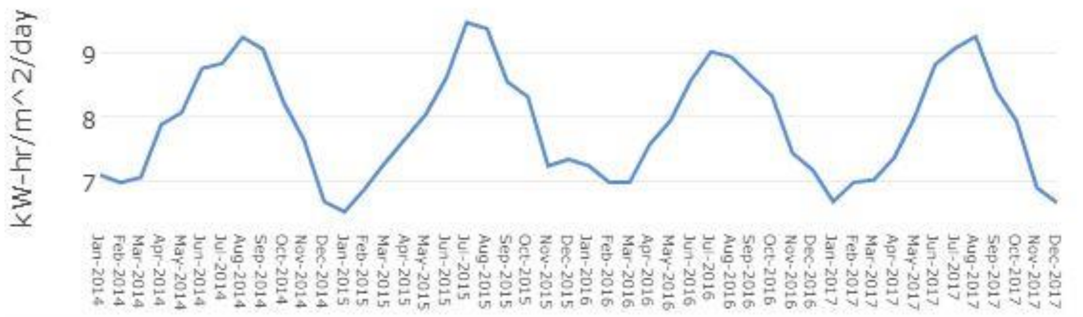


Figure 5.13- Solar radiation the past 4 years in Bétera [(8)]

With this information we may know find out the energy provided by our plates, using the formula E = I x V x PSH x PC representing each value:

$$E = I \times V \times PSH \times PC \times (\eta_{Inv}) \qquad (9)$$

I- Maximum plate current (8,73 A)

V- Maximum plate voltage (37,8 V)

PSH- Peak Sun Hours (Depends on the day)

PC- Performance Coefficient (It descends over the years, the detail of its value is in the technical sheet)

η_{Inv}- DC/AC Inverter coefficient (93%)

As we know the maximum voltage and current, and also the performance coefficient, the only thing we have to calculate are the peak sun hours. I have made an Excel showing the calculations.

Table 3- Calculation of solar photovoltaic plates energy generation

MONTH	DAY	DECLINE	OPT. INC. (β)	Gdm(0)	Gdm(0,β)	IF	PSH/DAY	ENERGY/DAY (KWh)	ENERGY/MONTH
january	15	-9,252666771	30,33510023	2,3	2,62268293	0,950378044	2,1858695	19,47574314	561,4856748
february	44	1,808402141	37,77936486	3	3,688657467	0,907396827	2,72219048	24,25427618	699,2507822
march	74	22,15962565	17,42814135	4	4,183741668	0,993378726	3,9735149	35,40337408	1020,679275
april	105	9,065490009	30,52227699	5,3	6,053506971	0,949460338	5,03213979	44,83555032	1292,608916
may	135	-23,21780811	16,36995889	6,2	6,45288933	0,995130835	6,16981118	54,97201807	1584,843281
june	166	-17,9394154	21,6483516	7	7,490032764	0,983717909	6,88602536	61,35337042	1768,817669
july	196	19,15383563	20,43393137	7,4	7,862315588	0,986935969	7,30332617	65,07145305	1876,009991
august	227	22,85566895	16,73209805	6,5	6,776325865	0,994561463	6,46464951	57,59897984	1660,578589
september	258	11,33689698	28,25087002	5,5	6,162984094	0,960028689	5,28015779	47,04535053	1356,317456
october	288	-22,72966023	16,85810677	4,2	4,381106219	0,994355965	4,17629505	37,21011235	1072,767539
november	319	-19,45835581	20,12941119	3,4	3,60626275	0,987687403	3,35813717	29,92045818	862,6068094
december	349	17,58918843	21,99857857	2	2,144541965	0,982724093	1,96544819	17,51182494	504,8659131
								TOTAL	14260,8319

Coordinates	39,587767	-0,458904
Inclination from surface	20	
Inclination from south	10	
Energy/day	E=I*V*PSH*PC	
Max power voltage (V)	37,8	
Max power current (A)	8,73	
PC (%)	90	

The calculations follow the next order:

First of all, we obtain the coordinates of the house, (39´587767, -0´458904) and decide the inclination of 20° from the horizontal, and 10° from the south of our plates. Then, we calculate the solar decline (°) in each day of the month equation 10, I choose the middle one to simplify the calculations.

$$\partial = 23{,}45 \times sen\left(360 \times \frac{284+\partial_n}{365}\right) \quad (10)$$

Next we obtain the optimal inclination of the plates by using this formulas: **β = ϕ – δ** In the summer solstice, and **β = ϕ + δ** In the winter solstice. The symbol (**ϕ**) represents the latitude and (**δ**) the solar declination.

To continue we find the horizontal global radiation with the NASA website.

Figure 5.14- Horizontal global radiation in Bétera [8]

And this radiation is used to find the optimum daily global radiation on a sloping surface with this formula:

$$FI = 1 - \left(1{,}2 \times 10^{-4} \times \left(\beta - \beta_{opt}\right)^2\right), \ \ \beta \leq 15° \quad (11)$$

Which uses the horizontal global radiation and the optimal inclination.

Now we find the irradiance factor which corrects the values of the irradiance for an angle of 10°. We use the lower formula, and then we finally obtain the peak sun hours by multiplying the Irradiance Factor and the optimum daily global radiation on a sloping surface.

Finally, we reach the formula to calculate the energy provided by the plates each day, it is the one showed before E = I x V x PSH x PC it is also important take in account the inverter efficiencies which is about 93% and multiply it to the energy provided, then we calculate multiplying by the days of each month the energy provided each month and each year.

We can observe that on summer we obtain a lot of energy which will cover almost all the demand of the house.

Before continue to the next section where we will see the budget of the installation and the benefits over the years, it is important to explain how is going to be the connection of the thirty solar panels and the wind turbine.

First we will see that the wind turbine doesn’t provide us such a big power amount so there is no need of using such a big AC/DC inverter, nevertheless we know that the solar plates will need quite a big inverter, so in order to make the installation easier and more homogenous we will use the same inverters for both installations.

The chosen inverter is the MUST solar 5kw inverter PV1800 PH1800 Series 4kW 5kW Hybrid Solar Inverter, we will use this one because of many reasons: it covers our power necessities as we will see in the following calculations, its good quality is proven and it is quite cheap, considering other inverters of this capacity.

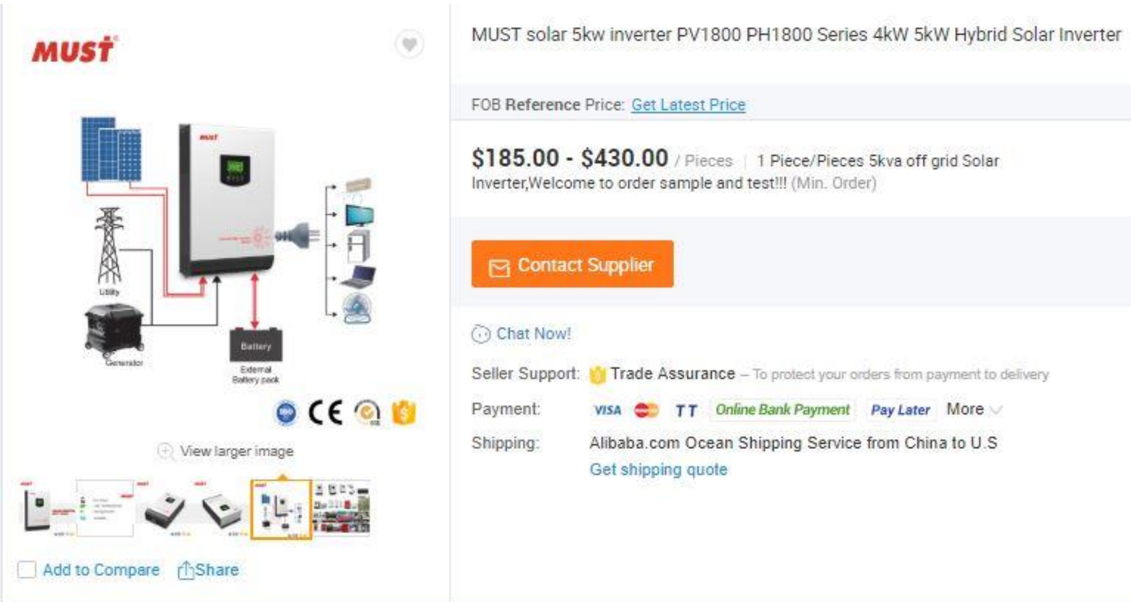


Figure 5.15- DC/AC Inverter MUST 5 kW [11]

This is the offer of the inverter, we will make the budget with the 430$=384,19€ in the following image we will see the specifications and then the distribution of the plates in order to not overcome the power, voltage and current limits of the inverter.

Product Parameter						
MODEL		PV18-1K MPK	PV18-2K MPK	PV18-3K MPK	PV18-4K MPK	PV18-5K MPK
Default Battery System Voltage		24VDC			48VDC	
INVERTER OUTPUT	Reted Power	1000VA/ 800W	2000VA/ 1600W	3000VA/ 2400W	4000VA/ 3200W	5000VA/ 4000W
	Surge Power	2000VA	4000VA	6000VA	8000VA	10000VA
	Waveform	Pure sine wave				
	AC Voltage Regulation (Batt.Mode)	230VAC±5%				
	Inverter Efficiency (Peak)	90%	93%			
	Transfer Time	10ms(For Personal Computers) 20ms(For Home Appliances)				
AC INPUT	Voltage	230VAC				
	Selectable Voltage Range	170~280VAC(For Personal Computers) 90~280VAC(For Home Appliances)				
	Frequency Range	50Hz/60Hz (Auto sensing)				
BATTERY	Nominal voltage	24VDC			48VDC	
	Floating Charge Voltage	27VDC			54VDC	
	Overcharge Protection	31VDC			60VDC	
SOLAR CHARGER & AC CHARGER	Maximum PV Array Open Circuit Voltage	75VDC			145VDC	
	PV Array MPPT Voltage Range	30 ~ 66VDC			60 ~115VDC	
	Standby Power Consumption	2W				
	Reted Power	600W			3000W	
	Maximum Solar Charge Current	25A			60A	
	Maximum Efficiency	98%				
	Maximum AC Charge Current	10A or 20A	20A or 30A		60A	
	Maximum Charge Current	25A	30A		120A	
MECHANICAL SPECIFICATIONS	Dimension,W*H*D(mm)	272*372*131			295*528*141	
	Net Weight(kg)	7.4	7.6	8.0	12.5	13.5
OTHER	Humidity	5% to 95% Relativ Humidity (Non-condensing)				
	Operating Temperature	0°C -55 °C				
	Storage Temperature	-15 °C -60 °C				

Figure 5.16- DC/AC Inverter specifications [11]

Our model is the PV18-5K MPK with the maximum PV Open circuit voltage of 145V, and maximum charge current of 120A.

The distribution used is:

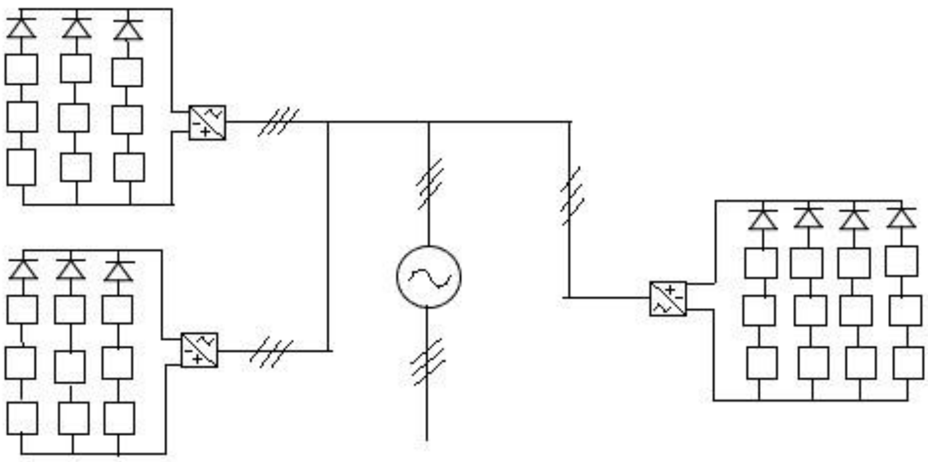


Figure 5.17- Connection scheme of the solar photovoltaic plates and the inverters

As we see, we have two grids of 3 connections in parallel with 3 panels in series and one grid with 4 connections in parallel with 3 panels in series. The bigger grid connection is the most critical one to the inverter, which gives to it:

I_{gen}=8,73x4=34,92A < 120A

V_{gen}=37,8x3=113,4V < 145V

P_{gen}=113,4x34,92= 3,96KW < 5KW

The only difference with the other grids is the generated current, which is lower so the power will be lower and there will be no problem.

It is also important to notice the fact that all the grids have diodes, which avoid the flow of current in the opposite direction, this is very useful to preserve the installation and enlarge it live.

To conclude we realise that we are going to generate, with the wind turbine of 3kW and the 30 solar plates of 330W: 14260 + 5203 = 19463 kWh/year using 4 current inverters of 5kW each.

In the next section we will analyse the budget and the benefits of the installation.

6- CALCULATION OF BUDGET AND BENEFITS OF THE INSTALLATION

In this section we will calculate the price of making all the installation, including the prices of the plates, wind turbine, materials and work forces.

I have made the calculations using an Excel, separating the installation in three work units, one installs the photovoltaic plates on the roof, other installs the wind turbine and the tower, and the last one makes all the wire connections of the installations and places the DC/AC inverters.

We can see the details in the next tables.

Table 4- Work Unit 1: Installation of photovoltaic plates

CODE	MAGNITUDE	DESCRIPTION	PERFORMANCE	MEASUREMENT	U. PRICE	AMOUNT
UW1		Installation of photovoltaic plates			4946,193	
WF1	h/m2	Ordinary construction peon	0,2	60	17,88	214,56
WF2	h/m2	Oficial electrician	0,2	60	20,5	246
M1	u	Photovoltaic plates	1	30	141,67	4250,1
	%	Complementary direct costs	0,05		4710,66	235,533

Table 5- Work Unit 2: Installation of wind turbine

CODE	MAGNITUDE	DESCRIPTION	PERFORMANCE	MEASUREMENT	U. PRICE	AMOUNT
UW2		Installation of wind turbine			6251,196	
WF1	h/u	Ordinary construction peon	4	1	17,88	71,52
WF2	h/u	Oficial electrician	4	1	20,5	82
M2	u	Wind turbine	1	1	4300	4300
M3	u	12 meter tower	1	1	1500	1500
	%	Complementary direct costs	0,05		5953,52	297,676

Table 6- Work Unit 3: Wire installation

CODE	MAGNITUDE	DESCRIPTION	PERFORMANCE	MEASUREMENT	U. PRICE	AMOUNT
UW3		Wire installation			3095,673	
WF2	h/m	Oficial electrician	0,067	120	20,5	164,82
WF3	h/m	Electrician helper	0,067	120	17	136,68
M4	m	Unipolar cable RZ1-K(AS)	1,05	120	7,5	945
M5	m	Flexible PVC tube DN 125 mm	1,1	120	1,25	165
M6	u	DC/AC Inverter 5 kW	1	4	384,19	1536,76
	%	Complementary direct costs	0,05		2948,26	147,413

We can see that each work unit has different work forces and materials, and everyone has in addition a percentage of complementary direct costs to correct possible errors.

In the first work unit, the installation of photovoltaic plates we use ordinary construction peon and an electrician which advance 5m2 per hour, that's why they have a performance of 0,2 which is multiplied by the 60 square meters that occupy all the plates added to the price per hour of both workers and the price of the photovoltaic plates, we obtain a price of installation of 4946,19€.

The second work unit show us the installation of the wind turbine in which also is needed a construction peon and an electrician, they expend 4 hour making the installation of the tower and the turbine, that's why they have a performance of 4 by unit, all the installation with the price of the tower and the turbine has a price of 6251,19€.

Finally we reach the third work unit, which represents the wire installation, in this section we need an electrician and an electrician helper, they will install a unipolar cable RZ1-K (AS) conductor copper 50 mm2 section with insulation crosslinked polyethylene, covered by a flexible PVC tube DN 125 mm, this wires will connect the 30 photovoltaic plates and the wind turbine with the DC/AC Inverters, the estimation of the distance of wire needed is of about 120 meters, which give us a price of 3095,73€.

The sum of the three work units adding a percentage of indirect costs that represent expenses of the whole work which we can't find out the origin is represented on the next table.

Table 7- Total price of the installation

CODE	DESCRIPTION	QUANTITY	U. PRICE	AMOUNT
TOTAL	Total price of the installation		14721,85386	
UW1	Installation of photovoltaic plates	1	4946,193	
UW2	Installation of wind turbine	1	6251,196	
UW3	Wire installation	1	3095,673	
	Indirect costs	0,03	14293,062	428,79186

We can see that with the addition of 3% of indirect costs we get a cost of all the installation of 14721,85€.

Now we will see the benefit obtained by the energy generation, and the analysis of money recovery.

First of all, it is important to know that the calculations of the benefit are made with the actual contract with the electric company, the prices per kilowatt-hour are maintained and we suppose that the energy sold to the grid has the same price as we buy it. So these calculations are only accurate suppositions.

The next table will show us the money saved per year having in account the energy generated in each period of hours at one day.

Table 8- Saved money per year

		TIMETABLE	HOURS GENERATING	ENERGY SUPPLIED	SAVED MONEY/DAY	SAVED MONEY/YEAR
Valley hours	0,129379	0:00-7:00	1	5,059465993	0,654588651	238,9248575
Flat hours	0,159378	7:00-18:00_22:00-00:00	8	40,47572795	6,450940569	2354,593308
Peak hours	0,19258	18:00-22:00	2	10,11893199	1,948703922	711,2769315
					TOTAL	3304,795097

In the left side of the table we see the prices of the energy at valley hours, flat hours and peak hours that give us the electric company, and the timetable of each price. Then we make an estimation about the hours that our generators are functioning each day. By looking on the internet, we find out that our house has a media of 10 hours of sun each day. The amount reaches 11 hours because we assume that the wind turbine can also generate by night although with a very low power, so we add one hour per day, which represents all the generation of the wind turbine in the night at maximum power.

Table 9- Energy per hour generated

ENERGY/HOUR	WIND ENERGY/MONTH	ENERGY/DAY
3,238794831	521	16,151
3,743661471	546	16,926
4,937579462	610	18,91
5,809140938	615	19,065
6,217728915	433	13,423
6,673851857	389	12,059
7,192223005	453	14,043
6,400179985	413	12,803
5,198395503	327	10,137
4,439555668	375	11,625
3,883950744	413	12,803
2,97852954	492	15,252
5,059465993		

The supplied energy per hour is the result of making the division of the energy provided each day and the hour in which we generate the energy, as I said 11 hours. This gives us the amount of energy per hour each month. Then, we can make an average of all the months and obtain the average energy generated each hour. Hence, we multiply it by the hours of each kind of bill (valley, flat and peak), and obtain the energy supplied. This gives us the saved money per day and finally per year.

We can see that these approximations give us a saved money per year of 3304€.

Now it is easy to calculate the money recovery and the benefits obtained in the future. The price of all the installation was 14721,85€ divided by the benefit of the energy generation each year of 3304€. We assume that the investment will be recovered in about 4,5 years. In 10 years we will be earning 18318€.

As this installation is supposed to have a 20 years lifelong, we can conclude that this is a very beneficial investment, not only economically but also for the environment.

7- LITERATURE REVIEW

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8- ANNEXED

In this section we can find the specifications of the solar photovoltaic plates, the wind turbine, and a detail of the distribution of the radiating floor.

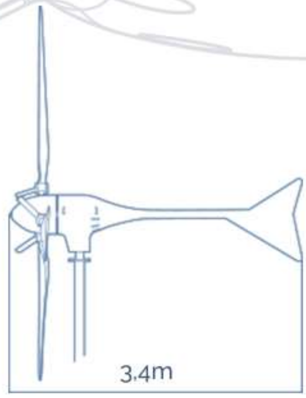
E30PRO

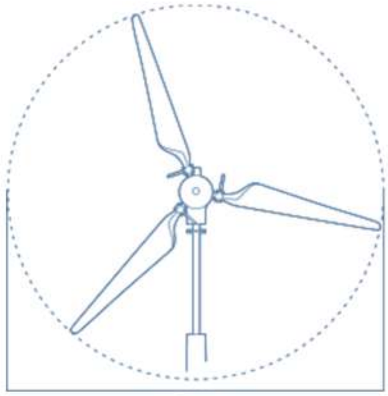
DATA SHEET

With average wind speed of 11m/s the model Enair 30PRO is capable of generating more than 30kWh/day

TECHNICAL, ELECTRICAL AND OPERATIONAL FEATURES

Number of Blades	3
Blades material	Fibreglass resins and polyurethane core
Generator	250rated rpm | neodymium magnets
Power	3000W
Rated powe curve	1900W (acording to IEC 61400-2)
Voltage	24/48/220V
Wind class	CLASS I-IEC 61400-2/NVNI-A
Diameter	4.30m
Turning sense	Clockwise
Swept area	$11.34 m^2$
Weight	125kg
Applications	Charging 24 or 48V batteries and grid connection
Wind to start	2m/s
Rated speed	11m/s
Speed regulation of pitch	12m/s
Survival speed	60m/s
Efficient generation range	From 2 to 60m/s
Type	Upwind horizontal rotor
Orientation	Variable passive centrifugal pitch system with 2 speeds
Power control	Sistema de paso variable pasivo centrifugo con dos vel.
Transmision	Direct
Brake	- Electromagnetic by short circuit - Mechanical (optional) - Aerodynamic through the pitch control - Manual or automatic tru wind or battery voltage
Controller	Grid connection and battery charging
Inverter	Eficiency 97%, MPPT algorithm
Noise	48dB | Reduction to a minimum, due to the design of the blades and the low revolutions, 1% more than ambient wind noise
Anti corrosive protection	Airtight, hight-temperature bake-drying epoxy painting, generating a plastic coating
Tower	Lattice, clip, tubular. Variable height axles can be folded





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+34 96 556 00 18 info@enair.es
www.enair.es

E30PRO Wind Turbine
DATA SHEET

PASSIVE VARIABLE PITCH 	Patented technology to maximize energy production. It is a mechanical system due to what the blades angle of attack of the blades is modied to obtain the maximum energy in each case and never exceeds its rotor rpms. It archieves: - Less noise - More ability to absorb high winds - More consistency in the generation - More energy with less wind
ELECTRONIC CONTROL 	System of intelligent energy management Batteries connection:: 7 types of programmable batteries (lithium, lead, gel, etc.) Charging shunt resistor pulses if overload. The excess which can't be charged is derived to protect the batteries Grid connection: Throught the MPPT inverters, which are programmed by the wind power curve that maximises energy production. Compatible with triphasic grids, monophasic and European and American systems

MORE ENERGY

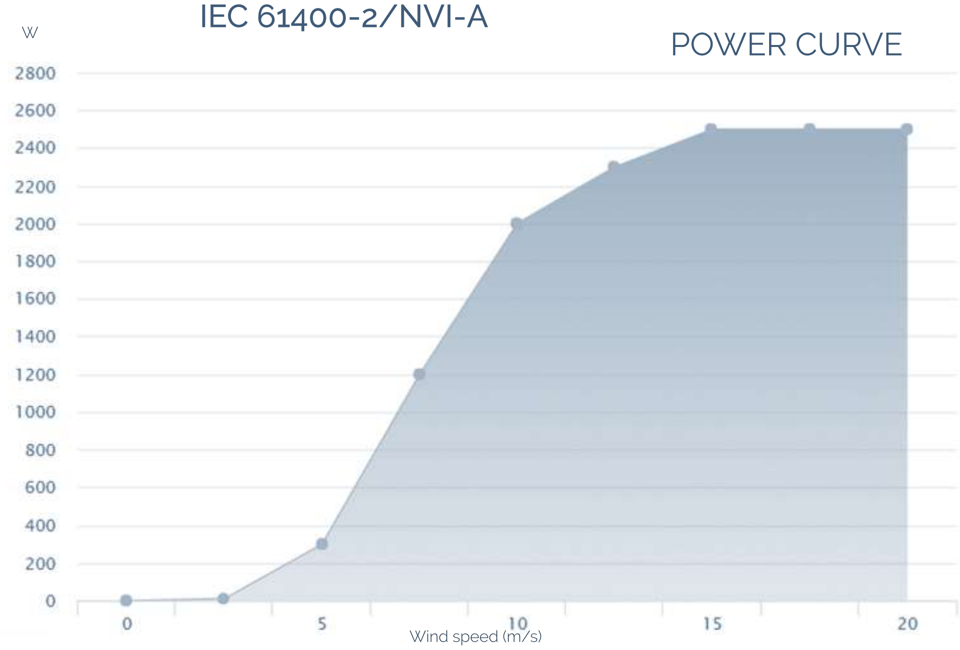
MORE EFFICIENTCY

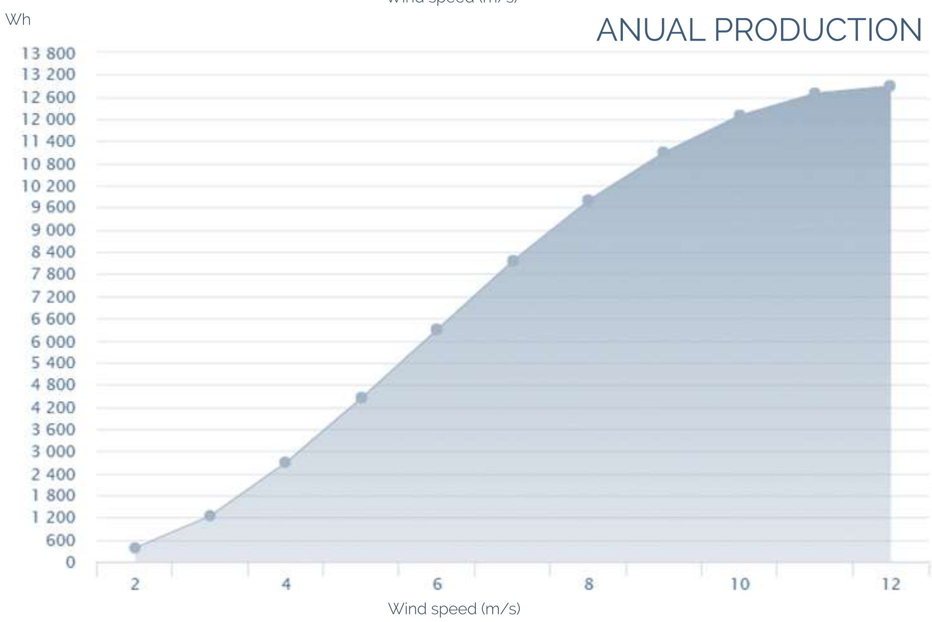
MORE STURDINESS

MORE SECURITY

CLASS I WIND TURBINE

IEC 61400-2/NVI-A





Minimum noise
The noise is around 1% above ambient noise, being invaluable to our ears

Safety-Brake
New mechanical safety system to the axle that guarantees braking under the most adverse conditions, for winds even greater then 70m/s

Anticorrosive
Epoxy painting, which becomes an covering anticorrosive and perfect for salt on islands and coasts

Anti-Icing and Hermetic
Structural resin acrylic urethane with an anti-ice chemical composition and maximum resistance for temperatures up to -50 ° C. Hermetically sealed

Storm-detection
Intelligent storm detection algorithm and safety lock of the fully automatic wind turbine combined with the Safety-Brake

Remote-Control
Combined control with the Victron Venus that allows the wind turbine to run/stop remotely

BBS (Battery Brake System)
Intelligent system that measures the level of battery charge and allows the wind turbine to stop when the battery reaches the setpoint voltage, resuming when the load level drops

GCL-P6/72

HIGH EFFICIENCY MULTICRYSTALLINE MODULE

GCL-P6/72 310-330 Watt

330 W
MAXIMUM POWER OUTPUT

17.0 %
MAXIMUM MODULE EFFICIENCY

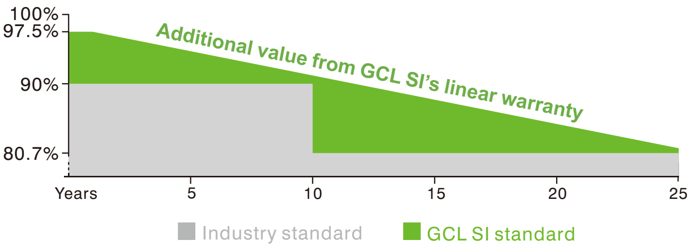
0~+5 W
POWER OUTPUT GUARANTEE

Trust GCL to Deliver Reliable Performance Over Time

- World- class manufacturer of crystalline silicon photovoltaic modules
- Fully automatic facility and world-class technology
- Rigorous quality control to meet the highest standard: ISO9001:2008, ISO 14001: 2004 and OHSAS: 18001 2007
- Tested for harsh environments (salt mist, ammonia corrosion and sand blowing test: IEC 61701, IEC 62716, DIN EN 60068-2- 68)
- Long term reliability tests
- 2*100% EL inspection ensuring defect-free modules

LINEAR PERFORMANCE WARRANTY

10 Years Product Warranty   25 Years Linear Power Warranty



- Ideal choice for large scale ground installation
- High conversion efficiency due to top quality wafer and advanced cell technology
- Selected encapsulating material and stringent production process control ensure product highly PID resistant and snail trails free
- Passed sand blowing test, salt mist test and ammonia test; flexible for harsh environments
- Optimized system performance by module level current sorting
- Special cell process ensures great performance in low irradiance environment
- Additional yield and easy maintenance with high transparent self-cleaning glass

Additional insurance backed by Swiss RE

According to UL 1703

GCL

Bringing Green Power to Life

GCL-P6/72

HIGH EFFICIENCY MULTICRYSTALLINE MODULE

ELECTRICAL SPECIFICATION (STC)

TYPE (STC)	GCL-P6/72 310	GCL-P6/72 315	GCL-P6/72 320	GCL-P6/72 325	GCL-P6/72 330
Maximum Power Pmax (W)	310	315	320	325	330
Maximum Power Voltage Vm(V)	37	37.2	37.4	37.6	37.8
Maximum Power Current Im(A)	8.38	8.47	8.56	8.64	8.73
Open Circuit Voltage Voc(V)	45.4	45.6	45.8	46	46.2
Short Circuit Current Isc(A)	8.99	9.08	9.17	9.24	9.33
Module Efficiency (%)	16.0	16.2	16.5	16.7	17.0
Power Output Tolerance Pm(W)	0~+5				

Values at Standard Test Conditions STC (Air Mass AM1.5, Irradiance 1000W/m², Cell Temperature 25°C).

ELECTRICAL DATA (NOCT)

Maximum Power Pmax (W)	224.45	227.14	231.2	234.61	237.71
Maximum Power Voltage Vm(V)	33.6	33.8	34.1	34.3	34.5
Maximum Power Current Im(A)	6.68	6.72	6.78	6.84	6.89
Open Circuit Voltage Voc(V)	42.2	42.4	42.5	42.7	42.9
Short Circuit Current Isc(A)	7.19	7.30	7.38	7.46	7.58

NOCT: Irradiance at 800W/m², Ambient Temperature 20°C, Wind Speed 1m/s.

MECHANICAL DATA

Solar Cells	Poly 156.75×156.75mm (6 inches)
Cell Orientation	72 Cells (6×12)
Module Dimensions	1956×992×35mm (77 × 39.05 × 1.38 inches)
Weight	22.2 kg
Glass	High transparency solar glass 3.2mm (0.13 inches)
Backsheet	White
Frame	Silver, anodized aluminium alloy
J-Box	IP68 Rated
Cables	4.0mm² (0.006 inches²), 1200mm (47.2 inches)
Connector	Original MC4 or Compatible
Wind Load/ Snow Load	2400Pa/6000Pa*

*For more details please check the installation manual of GCLSI

TEMPERATURE RATINGS

Nominal Operating Cell Temperature (NOCT)	45±2°C
Temperature Coefficient of P_{MAX}	-0.41%/°C
Temperature Coefficient of V_{oc}	-0.32%/°C
Temperature Coefficient of I_{sc}	+0.055%/°C

MAXIMUM RATINGS

Operational Temperature	-40~+85°C
Maximum System Voltage	1000V DC(IEC)
Max Series Fuse Rating	15A

WARRANTY

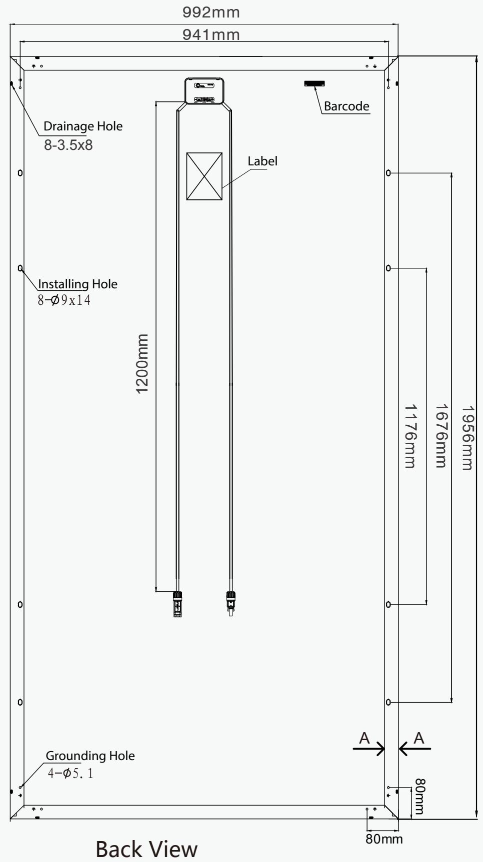
10 years Product Workmanship Warranty
25 years Linear Power Warranty

(Please refer to GCL standard warranty for details)

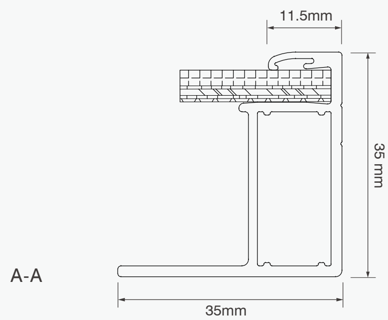
PACKAGING CONFIGURATION

Modules per box: 30 pieces
Modules per 40'HD container: 720 pieces

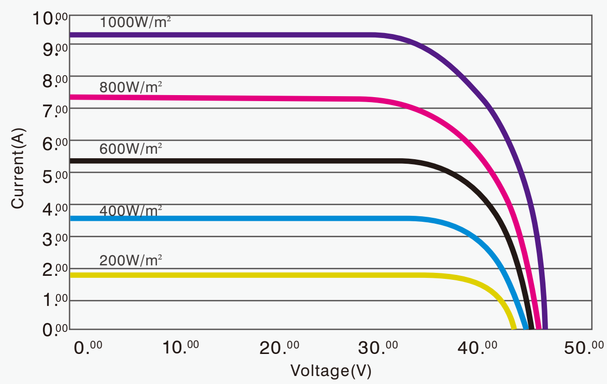
MODULE DIMENSION



Back View



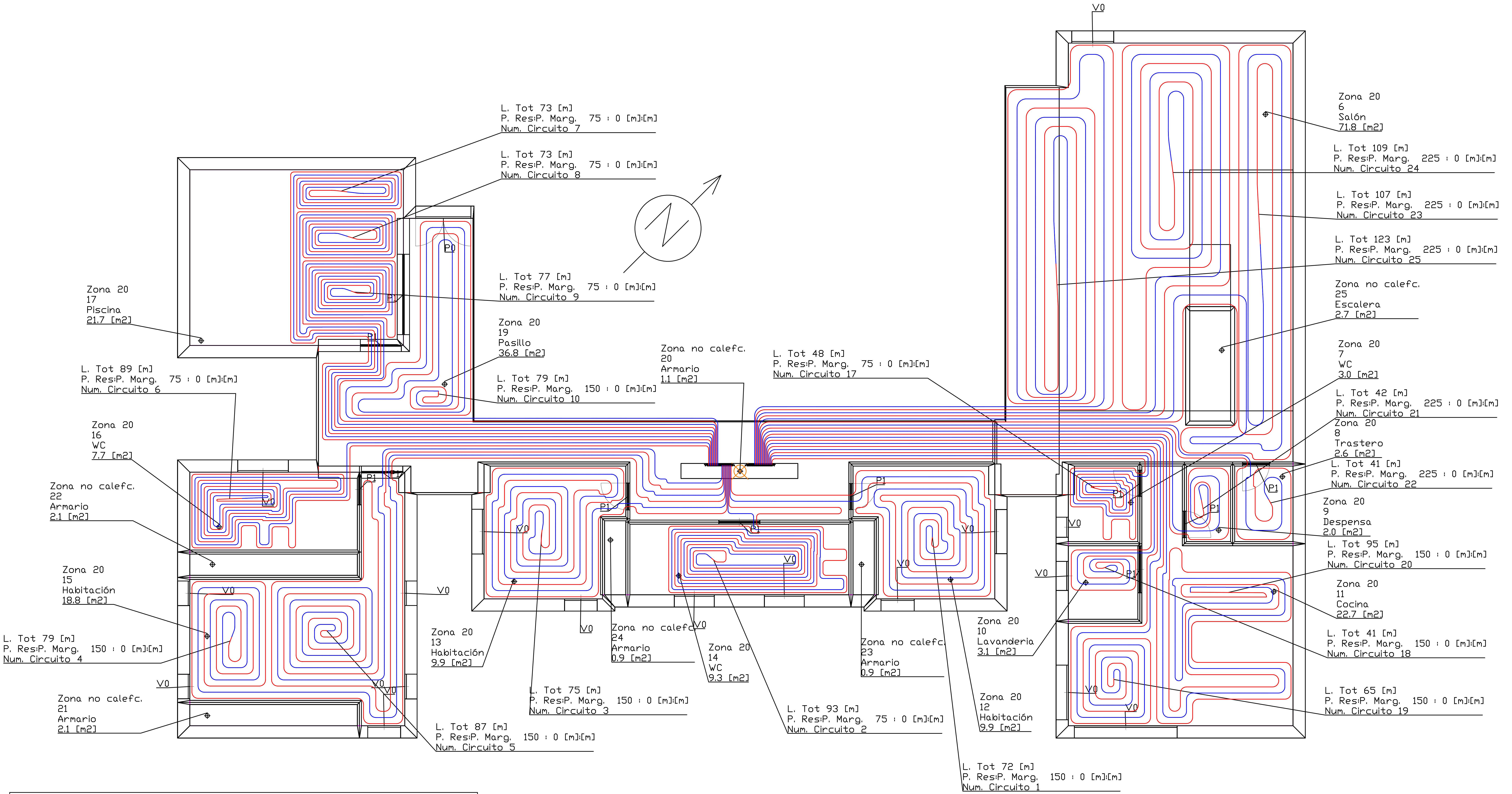
I-V CURVES OF MODULE(330W)



Excellent performance under weak light conditions: at an irradiation intensity of 200W/m² W/m(AM 1.5, 25 °C), 96.5% or higher of the STC eciency (1000 W/m²) is achieved

Bringing Green Power to Life
http://en.gclsi.com

GCL-EN-P6/72-2017-V1.0
CAUTION: READ INSTALLATION MANUAL BEFORE USING THE PRODUCT



Colector: C1

Espacios	Circuito	L.Tot.[m]	Caudal[l/h]	P.Res.:P.Marg.	Tarado
12-Habitación	1	72	94.6	150 : 0	0,5 v
13-Habitación	3	75	85.6	150 : 0	0,5 v
14-WC	2	93	102.8	75 : 0	0,5 v
15-Habitación	4	79	116.7	150 : 0	1 v
	5	87	136.5	150 : 0	1,5 v
16-WC	6	89	140.2	75 : 0	1,5 v
17-Piscina	7	73	219.6	75 : 0	3 v
	8	73	218.0	75 : 0	2,5 v
	9	77	227.9	75 : 0	Total
19-Pasillo	10	79	151.7	150 : 0	1,5 v

Colector: C1

Espacios	Circuito	L.Tot.[m]	Caudal[l/h]	P.Res.:P.Marg.	Tarado
6-Salón	23	107	141.9	225 : 0	2 v
	24	109	143.5	225 : 0	2 v
	25	123	152.8	225 : 0	Total
7-WC	17	48	36.7	75 : 0	0,5 v
8-Trastero	22	41	52.7	225 : 0	0,5 v
9-Despensa	21	42	48.5	225 : 0	0,5 v
10-Lavandería	18	41	41.3	150 : 0	0,5 v
11-Cocina	19	65	68.6	150 : 0	0,5 v
	20	95	100.2	150 : 0	1 v

-REVISION-	-FECHA-	-PROYECTADO-	-DIBUJADO-	-DESCRIPCION-
	07/07/2006	A.Aizpurua	I. Telleria	

-TAMAÑO-	-ESCALA-	-UNIDADES-
A2	15:1000	mm

DENOMINACION: *Proyecto de suelo radiante*

DESCRIPCION: *Distribución de tuberías en planta baja*

orkli lurbero

Nº PLANO: *L-060607*

REVISION: