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Treball Final de Grau

Design of the necessary installations to make a home independent in terms of energy

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“If you believe that the economy is more important than the environment, try holding your breath while you count your money”

Guy Mcpheraon

Quisiera agradecer al tutor del presente trabajo de fin de grado, el Dr. Ricard Torres i Castillo, todo el apoyo, dedicación y compromiso mostrado durante los meses de trabajo. También quisiera agradecer a Víctor Canela su participación cediendo los planos de su vivienda para realizar el proyecto. Finalmente, a mi familia y amigos por ayudarme y respaldarme en todo momento.

Gracias.

CONTENTS

SUMMARY

In the present work, the preliminary design of the necessary installations to satisfy the energy demand of an already built house, located in the municipality of *el Perelló*, is carried out, in order to make it independent from the electricity network. In other words, turning the house into a self-sufficient accommodation through the use of renewable energies and with a minimum environmental impact, in order to promote a responsible house with the environment.

The demand for electrical energy is supplied by wind energy, while the demand for thermal energy for the domestic hot water will be supplied by solar thermal energy. The energy demand of the home, both electrical and thermal, is estimated by means of domestic appliances, electrical heating, lighting and domestic hot water consumption. To estimate the consumption of the electrical heating, a thermal study is done to determine the heat losses generated.

A wind study and a solar study are carried out on the site of the home to determine the wind and solar radiation resources available. These data, together with the hypotheses of daily electricity consumption and domestic hot water consumption, are used to choose the model and the number of wind turbines and solar thermal panels needed to satisfy the house's energy demand. The final design is carried out by comparing different models on the market, choosing the one that suits the expected needs the best. In addition, a model of batteries is also chosen for energy storage in order to satisfy the demand on days with adverse weather conditions. Once the project has been completed, the detailed engineering project for the entire installation is left for future work.

Keywords: Energy, Dimensioning, Installations, Self-sufficiency, Renewable, Wind, Solar, Wind turbine, Solar panel, Battery, Conduction, Convection.

RESUMEN

En el presente trabajo se realiza el diseño preliminar de las instalaciones necesarias para satisfacer la demanda energética de una vivienda ya construida, situada en el municipio de el Perelló, y así independizarla de la red eléctrica. Es decir, conseguir convertir la vivienda en un alojamiento autosuficiente mediante el uso de energías renovables y con un mínimo impacto ambiental, con la finalidad de promover un hogar responsable con el medio ambiente.

La demanda de energía eléctrica se suple a partir de energía eólica mientras que, la demanda de energía térmica para el ACS se suplirá mediante energía solar térmica. A partir de los electrodomésticos, calefacción eléctrica, iluminación y consumo de agua caliente sanitaria se estima la demanda energética tanto eléctrica como térmica del hogar. Para estimar el consumo de calefacción eléctrica se realiza un estudio térmico para determinar las pérdidas de calor que se generan.

Se realiza un estudio eólico y un estudio solar en el emplazamiento de la vivienda para determinar los recursos de viento e irradiación solar disponibles. Estos datos, junto a las hipótesis de consumo eléctrico y consumo de agua caliente sanitaria diarios, sirven para escoger el modelo y el número de aerogeneradores y paneles solares térmicos necesarios para satisfacer la demanda energética de la vivienda. El diseño final se realiza comparando diferentes modelos existentes en el mercado, escogiendo aquél que más se ajusta a las necesidades previstas. Además, se escoge también un modelo de baterías para el almacenaje de la energía con el propósito de poder satisfacer la demanda en días de condiciones climáticas adversas. Una vez concluido el proyecto, se deja para un trabajo futuro el proyecto de ingeniería de detalle de toda la instalación.

Palabras clave: Energía, Dimensionado, Instalaciones, Autosuficiencia, Renovable, Eólica, Solar, Aerogenerador, Panel, Batería, Conducción, Convección.

1. INTRODUCTION

1.1. HISTORY OF SELF-SUFFICIENT HOUSING

Decades ago, housing ceased to be just a place to have a shelter and thus guarantee the productivity of workers and became highly valued for the development of human beings, making it necessary for them to be healthy and comfortable. In this way, humanity launched into massive housing construction without considering global warming and the consequent climate change that follows it. Tons of CO_2, as well as many other pollutants, are being released into the atmosphere every day.

Facing this uncontrollable situation, in 1987 the concept of sustainable development was conceived in a report, headed by the Norwegian minister Gro Harlem Brundtland and written by several nations, for the ONU. In this report it was pointed out: *“It is up to humanity to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs".* (Our common future., 1987, ref. 6). Based on this report and the necessity to change, the concept of self-sufficient housing was born.

The self-sufficient houses are designed to be completely independent from the electricity grid, municipal systems, sewage treatment systems, storm drains, communication services and some public roads. These buildings obtain their energy through mini-wind, solar thermal, solar photovoltaic and other installations. The materials used to build them are respectful with the environment as they are obtained in an ecological way and come from nearby places, generally from the same town.

Another aspect that must be considered in this type of housing is the behaviour of the tenant, he or she must be responsible with the environment, an example would be the management and separation of domestic and recyclable waste or the treatment of the house's wastewater.

In this way, a self-sufficient and sustainable house can be built.

1.2. APLICABLE LEGISLATION

The regulations applying to the project are:

For self-consumption regulation: (*Real Decreto* 244/2019, 2019, ref. 13).

For the electrical installation: (*Reglamento Electrotécnico de Baja Tensión*, 2002, ref. 37). Specifically, *REBT ITC-BT-19* and *REBT ITC-BT-25* which refer to indoor or reception installations.

For domestic hot water (DHW): (*Código Técnico de la Edificación*, 2006, ref. 9). Specifically, CTE DB HE-4 which refers to the minimum solar contribution for domestic hot water.

For urban planning and house adaptation: (*Pla d'ordenació urbanística municipal del Perelló*, 2017, ref. 12).

1.3. ENERGY SAVING

As mentioned above, there are different ways of exploiting the resources offered by the environment. This section is an introduction to the different systems needed to ensure that the energy demand of the house, is covered by wind and solar thermal energy.

1.3.1. Solar thermal energy

Solar thermal energy is based on the use of energy from the sun to produce heat through collectors or solar thermal panels. Its main use is heating domestic water. It should be noted that thermal solar energy does not produce electricity, but rather accumulates heat that is subsequently used. It is a clean, renewable energy that contributes to reducing CO_2 emissions. Furthermore, the installations take up small space, are easy to install, require low maintenance and do not generate noise emissions.

There are two ways to capture, convert and distribute solar energy: actively or passively. Passive solar energy is the one that directly uses the energy coming from the sun without needing to process it, whereas active solar energy is the one that does require an energy transformation.

Both photovoltaic and thermal solar energy are active solar energies, but they must not be confused since the purpose of photovoltaic is to transform solar energy into electrical energy.

1.3.1.1. Solar energy origin

El The Sun generates a large amount of energy thanks to its electromagnetic radiation, however, all this energy does not reach the Earth's surface since, as it passes through the atmosphere, the solar radiation loses intensity due to atmospheric and geographical factors.

Regardless of the decrease in intensity, the amount of solar energy that the Earth receives is ten thousand times higher than all the energy that is consumed daily on the entire planet, which is why, in addition of being inexhaustible, it is an abundant resource. (Neha, H., Gugri, S., Mishra S., & Dubey, G., 2013, ref. 35).

The solar radiation that reaches the Earth has been used by human since ancient times, through different technologies that have been evolving. The first civilizations already created techniques to take profit of the solar energy in a passive way, later techniques were developed to take benefit of the thermal solar energy, and later photovoltaic solar energy was added.

1.3.1.2. Use of solar thermal energy

The process is based on capturing the sun's rays by panels where water or any other fluid circulates. This heat absorbed is exchanged with the circulating fluid and subsequently used or stored. Installations to collect solar thermal energy require the following systems:

- Solar radiation collector system: As shown in *Illustration 1*, it is made up of panels or collectors connected and are used to transform the captured solar radiation into thermal energy or heat. There are different types of solar collectors but the most common for domestic use to heat water and the house, is the flat solar collector (*Instituto para la Diversificación y Ahorro de la Energía,* 2006, ref. 30).

These collectors are made up with a cover in charge of minimizing losses by convection or radiation, an absorbent plate in charge of absorbing the solar energy and transferring it to the fluid that circulates through the pipes that are touching the plate, an air channel that separates the absorbent plate from the cover and, finally, an insulating layer that covers the system.

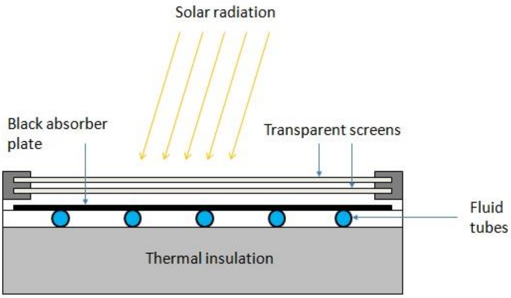

Illustration 1. Flat plate solar collector (Kalogirou, S.A., 2009, ref. 32)

The solar collectors' efficiency will be determined by their yield, which allows us to know how much energy we will be able to use depending on the situation.

- Solar thermal energy storage system: Consists of hot water tanks that store the calorific energy obtained for subsequent use as domestic hot water or for heating.

- Solar thermal energy distribution system: Responsible for the transport of the fluid that has been heated in the collectors to the point of consumption. It is distributed by stainless steel pipes covered with a thermal insulator to prevent heat loss. There are different circulation systems:

  Open-circuit systems: As shown in *Illustration 2*, they transfer the hot water from the collector directly to the accumulator. The water is moved upwards by the increase of temperature until it reaches the accumulator, at that moment, the accumulator empties an equivalent amount of cold water that is directed to the collector.

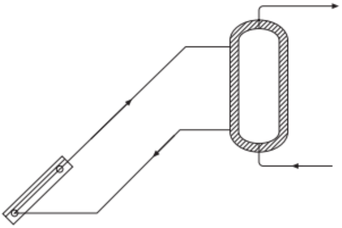

Illustration 2. Diagram of an open-circuit system (*Instituto para la Diversificación y Ahorro de la Energía*, 2006, ref. 30)

Closed-circuit systems: This consists of two circuits as shown in *Illustration 3*. The first is responsible for taking the hot fluid from the collectors to the accumulator and exchanging the heat with the water inside the accumulator by using a heat exchanger, avoiding any mixing. In this way, an anti-freeze component can be added to the liquid in the collector to allow it to be used in areas with temperatures below 0 ºC.

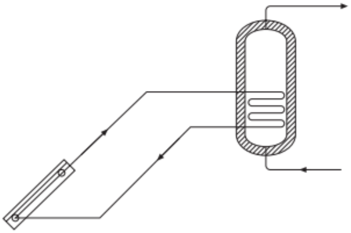

Illustration 3. Diagram of a closed-circuit system (*Instituto para la Diversificación y Ahorro de la Energía*, 2006, ref. 30)

Moreover, the liquids can circulate either by forced or natural circulation. Forced circulation has the advantage of using a boost pump moved by an external supply of electrical energy, making the circulating fluid transfer faster in order to prevent loss of calories in the distribution and avoids the circulation of the liquid in the collectors if it is below the temperature of the water in the tank. On the other hand, natural circulation, as mentioned above, is based on the upward circulation of hot water due to the difference of temperatures. *Illustration 4* shows a basic diagram of this type of installation.

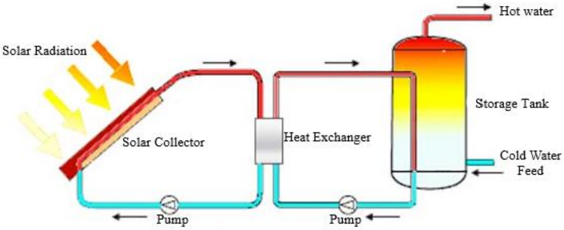

Illustration 3. Basic diagram of a closed-circuit and forced-circulation solar thermal system (Suelo Solar Corporation, ref. 44)

1.3.2. Wind and mini wind energy

Wind power is about exploiting the energy generated by the wind. It has been used since long ago and is one of the oldest since, apart from being able to be transformed into electrical energy, it can also be used directly. Over the years, it has been used to pump water, move boats by using sails and even to grind grain in mills.

Like most renewable energies, wind energy is inexhaustible, does not pollute and does not generate emissions of toxic substances that could aggravate the greenhouse effect and the climate change that it causes (Berry, J. E., M. R. Holland, P. R. Watkiss, R. Boyd y W. Stephenson, 1998, ref. 3). Furthermore, by using it, we reduce the consumption of fossil fuels and give them time to regenerate.

In this section a short introduction to wind and mini wind energy and the factors that must be considered to obtain it will be given. Mini wind energy is defined as energy that exploits wind resources by using power generators of less than 100 kW whose blades do not cover an area greater than 200 m². It is a form of self-consumption of electricity, because the energy obtained from these small wind turbines is usually used, not commercially, but to cover domestic needs, although it is also used to supply radio systems, road monitoring or urban road lighting.

1.3.2.1. Wind energy origin

The Sun is the original source of the renewable energy contained in the Earth's wind resource. The global winds are the cause of the pressure differences across the earth's surface due to the uneven heating of the earth's surface by solar radiation. This radiation is absorbed in greater quantity at the equators than at the Earth's poles.

This uneven heating is greatly influenced by the effects of the Earth's rotation turning at a speed of approximately 1 670 kilometers per hour at the equator and decreasing to zero at the poles.

Warm air is less dense, and this makes it tend to rise, creating low pressure zones. On the other hand, in the cold areas, the cold air is denser and thus generates zones of higher pressure. This pressure difference makes the air circulate from high pressure to lower pressure zones, creating the winds (see *Illustration 5*).

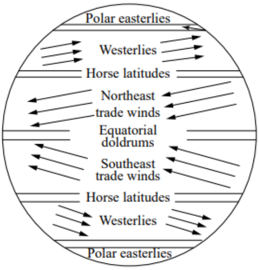

Illustration 4. Surface winds of worldwide circulation pattern (Hiester, T. R. and Pennell, W.T., 1981, ref. 25)

The current's movement is often unpredictable since there are many factors that affect it. Two important would be:

- The Coriolis effect (Coriolis, 1835, ref. 15) which considers the rotation of the planet and the inertia generated by it. The presence of high and low pressure zones causes the isobars to be curved, creating a centrifugal force.
- Another factor to consider is the surface of the Earth, this makes a horizontal force on the moving air, the effect is to slow down the flow and divert it slightly.

1.3.2.2. Wind variability

The wind speed is always changing, so the energy content in the wind is also changing continuously. This variation depends on both climatic conditions and the surface conditions and obstacles.

Another variation of the wind is that it blows stronger during the day than at night. This variation is mainly due to the fact that the temperature differences between the sea surface and the land surface are higher during the day than at night. The wind is also more turbulent and tends to change direction more quickly during the day.

It is very important for the wind industry to be able to describe the variability of the wind and to know its speed profile in order to maximize the capacity to obtain wind energy.

The wind speed profile can be known with a significant number of air speed records over a long period of time or by the statistical method of Weibull distribution (Weibull, 1951, ref. 52), which is able to estimate the probability density of a certain wind speed profile at a particular location. In this way, the viability, production and performance of a wind turbine system can be predicted.

1.3.2.3. Wind energy obtention

Wind energy is the one that takes profit of the wind force (air mass) to produce electricity via aerogenerators, devices composed of blades, shafts and generators.

These is exploited by converting the movement of the blades of a wind turbine into electrical energy. An aerogenerator is an electric generator moved by a turbine powered by the wind; its predecessors are the windmills.

The energy scheme that follows is the transformation of kinetic energy into mechanical energy through the force of the wind that causes a pressure difference on the two sides of the blade and causes them to move. The rotor transfers the energy to the generator, which converts the mechanical energy into electrical energy.

Not all the kinetic energy from the wind is transformed into electrical energy. This is because, as much kinetic energy is extracted from the wind, more wind speed is reduced by the wind turbine. Therefore, if we extract all the energy from the wind, the wind speed at the output would be zero. Following Betz's law, we see that in ideal conditions only 59.26 % of the energy is used, converting less than 16/27 of the kinetic energy into mechanical energy (Betz, 1966, ref. 4).

The electrical energy produced is direct current, which is directed to a charge regulator and then to a converter placed in the base. This converter will transform the direct current into alternate current and the energy will be distributed through the electrical network. In the wind farms, the wind turbines are connected by underground lines that take the energy to a transformer substation in charge of raising the voltage, so it is possible to distribute the electricity with the least losses through high voltage lines.

1.3.2.4. Wind turbines

There are different types of wind turbines and they are mainly classified according to the orientation of the rotor axis, vertical or horizontal axis wind turbines.

Those with a vertical axis stand out because they do not need an orientation mechanism and the electric generator can be placed on the ground, on the other hand they are not very effective and are very expensive.

Horizontal axis wind turbines are the most widely used, as they are more energy efficient and achieve higher rotation speeds, and therefore require a gearbox with a lower rotation multiplication ratio. Furthermore, thanks to their construction on top of the tower, they take greater advantage of the increased wind speed.

When designing horizontal axis wind turbines, it must be taken into account that increasing the number of blades means a higher cost. The advantage lies in producing much more energy with less wind speed. Regardless of the type of wind turbine used, the internal mechanism of wind turbines follows the same scheme (see Illustration 6).

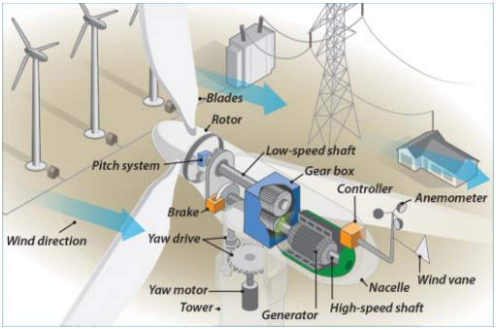

Illustration 5. Wind turbine mechanism (US. Department of Energy, ref. 51)

The rotor consists of the blades, responsible of capturing the wind energy, and of the hub that connects the blades with the low-speed shaft. The low-speed shaft connects to the gear box or multiplier which, by using a gear system, makes the high-speed output shaft rotate at a frequency between 50 and 80 times faster. The high speed shaft rotates at approximately 1 500 revolutions per minute, which allows the generator to work.

The generator is responsible of converting mechanical energy into electrical energy. The electricity produced in the generator is conducted to the base of the tower, where the transformer reduces the intensity and increases the voltage to 20 kW. Finally, it is sent to the network. Normally, an asynchronous or induction type generator is used.

The orientation mechanism has the function of facing the wind turbine in a direction perpendicular to the wind. This circular movement is achieved with motors and gearboxes fixed to the gondola. In mini wind turbines, thanks to its low weight, the same vane faces the wind turbine thanks to the force of the air on it.

The pitch system is used as a security system that allows the blades to turn on themselves when the wind speed exceeds 100 km/h and this prevents damage to the wind turbine as the rotor stops turning. The wind turbine also has a control system (Controller) which is responsible for monitoring the conditions of the wind turbine, collecting statistics on its operation and regulating switches, hydraulic pumps, valves and other elements of the wind turbine.

1.3.2.5. The power curve

The power curve is a characteristic graphic of every wind turbine that shows the electrical power available in the turbine at different wind speeds. The curve is obtained from measurements made by an anemometer located on a mast relatively close to the wind turbine. As the wind fluctuates continuously, to obtain the curve an average of the different measurements must be taken for each wind speed, and the graph must be drawn with these averages.

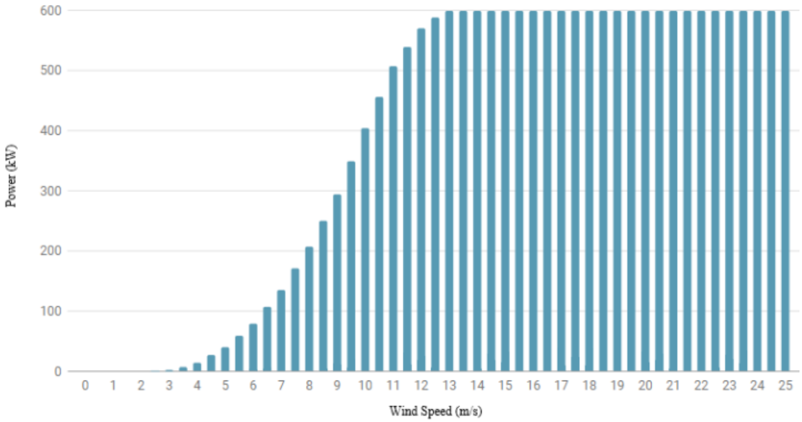

Illustration 7. Power curve of a 600 kW wind turbine (The Wind Power, ref. 47)

Illustration 7 shows a power curve of a 600 kW wind turbine[1]. It can be seen that for wind speeds below 3 m/s there is no electricity production. The cut-in speed is the speed necessary to activate the generator, from where the power production increases until the nominal power of the wind turbine is reached. When the cut-out speed is reached, the turbines have to stop for safety reasons.

The power coefficient shows how efficiently the wind turbine converts wind energy into electricity. It is obtained by making the quotient of the available power per m^2 of rotor area (obtained from the power curve) respect to the amount of power available in the wind per m^2. Therefore, it depends both on the design of the wind turbine and on the wind speed (*Illustration 8*).

Energy efficiency is not an aim in itself since, in this case, the energy is free and inexhaustible, so there is no need to save it. What really matters is the cost of obtaining the energy from the wind (in kWh).

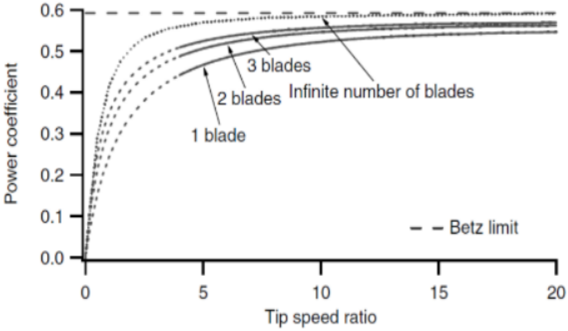

Illustration 6. Power coefficient as a function of the number of blades and specific speed

(James F.Manwell, Jon G. McGowan, Anthony L. Rogers. , 2009, ref. 31)

The optimal power coefficient corresponds to the Betz limit and is defined according to Betz's Law. As mentioned above, no turbine will be able to absorb more than 16/27 parts of the kinetic energy of the wind (Betz, 1966, ref. 4).

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[1] Power curve of a 3-blade wind turbine manufactured by Enercon

1.3.3. Energy storage and batteries

As mentioned above, one disadvantage of wind energy is the variability and unpredictability of the wind. Therefore, many times, due to the inexistence or low speed of the wind, the cut-in speed, necessary to start the generator and produce energy, is not reached. The prevention of these cases must be ensured with the previous storage of enough energy to cover the energy demand during a certain period. Energy storage includes methods for conserving, as much as possible, a certain amount of energy through different forms:

- Thermal: Consists of heating and storing water in insulated tanks.
- Mechanical: It consists of pumping water to a tank at a certain height and then using the potential energy.
- Electrical: By electric capacitors.
- Chemical: Consists of direct accumulation in different types of batteries.

However, the most common method of storing electrical energy for domestic use is through an electrolytic process in lead-acid batteries (accumulators) due to their good price to energy ratio.

Batteries are a set of electrochemical cells that store electrical energy in the form of chemical energy through electrochemical reactions and can subsequently convert it into electrical current. Each electrochemical cell in the battery consists of an anode, a cathode and an electrolyte which is normally formed by a solution of water and sulfuric acid which allows the ions to move between the electrodes, via redox-type reactions, allowing the current to flow out of the battery to carry out its function, to supply an electrical circuit (see *Illustration 9*).

In these cases, the batteries have to provide energy over a relatively long time and are often discharged to lower levels, so they are called deep cycle batteries. They have thick layers of lead and are composed of 2 volt cells. The voltage they reach depends on the number of cells connected in series so that values of 12 V, 24 V, or more are reached, depending on the model of the battery.

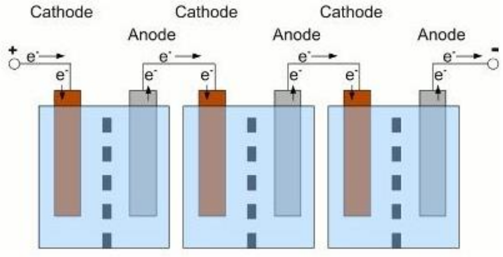

Illustration 7. Diagram of a series cell battery (*Área Tecnología*, ref. 2)

When the lead or lead dioxide is consumed, the battery is exhausted and to recharge it an electric current is passed from the positive to the negative plate via an alternator or dynamo so that the lead sulphate decomposes back into lead on the negative plate and into lead dioxide on the positive plate.

1.3.3.1. Battery characteristics

Despite the different types of batteries that exist, they can all be characterized by a series of particularities that are defined below:

- Internal resistance: Formed by the ohmic resistance of its components and by a resistance that varies according to the state of charge and the different polarizations and concentrations. It increases with low temperatures, with battery discharge and with age.
- Yield: This is the ratio between the energy supplied during the discharge and the energy required to fully charge the battery. Losses are due to the production of heat energy in chemical processes.
- Charging and discharging speed: Time it takes to discharge and charge completely.
- Lifetime: Number of charging and discharging cycles it is able to perform.
- Capacity: It is the most important feature and is measured in Ampere-hours. It is the amount of electrical charge that circulates through the section of a conductor where a current of one Ampere passes for one hour. The capacity of a battery varies with: temperature (a rise in temperature increases the capacity due to the increase of chemical processes), the discharge

rate (the capacity increases as the discharge is slower) and ageing (the more charge and discharge cycles it takes, the less capacity it has).

The energy capacity that will be stored and the depth of discharge to be set are the key factors that will be taken into account in the design of the battery and the lifetime of the battery will depend on them.

2. OBJECTIVES

The world is constantly changing, and we must adapt to it. Climate change is no longer a warning for the future, it is a concrete reality, which implies a need of action. We have the responsibility to preserve our environment and to improve it as much as possible for future generations. Energy-related activities (extraction, production, transformation, transport and use) are key to climate change mitigation, accounting for 79 % of EU greenhouse gas emissions such as carbon dioxide and methane (EU Court of Auditors, 2017, ref 49). This is how it is conceived that one of the ways to solve this situation is by renewable energies. This work focuses specifically on sustainable energy self-sufficiency.

For this reason, apart from being a student of chemical engineering, being able to apply the knowledge acquired during the degree in subjects such as *Tecnologies pel medi Ambient*, *Transmissió de Calor* or *Circulació de Fluid*, to find solutions and work to solve this problem, is a personal motivation.

The objective of this project is to increase the sustainability of a house already built in *el Perelló*, minimizing their generation of greenhouse gases. This type of housing is presented as a fundamental way to reverse the effects of climate change. Specifically, it is proposed to make the house independent from the energy network to which it is currently connected. To achieve this objective, the selection and sizing of wind turbines and solar thermal panels will be carried out. As it is proposed to achieve total energy autonomy, independent of environmental conditions, the corresponding energy storage batteries will also have to be sized.

3. STARTING POINT OF THE HOUSE

The project's scope is based on the study of the energy demand and the dimensioning of the wind and solar thermal installation of an already built house located in the municipality of *el Perelló*. This house is currently used by a couple as a second holiday home and it is intended to start using it as a first residence. Therefore, the wind and solar thermal installation is described and designed, under the hypothetical energy demand of the family if they always lived in the house.

The living area of the house is 114.5 m^2 and is equipped with the necessary appliances for the family. A system for capturing solar thermal energy will be sized and installed on the roof of the house and it will also include, a general wind energy system to supply the electrical needs and a shed where the storage system for the wind energy produced by the wind turbines will be installed.

3.1. LOCATION

As mentioned above, the house is in the municipality of *el Perelló* (Tarragona). The coastal region of the *Baix Ebre* is located in the southern part of Catalonia, bordering on the north with *Baix Camp* and *Ribera d'Ebre*, on the west with *"Terra Alta"* and on the south with *Montsià*, with which it forms *Les Terres de l'Ebre*. The whole region is open to the sea and, despite the presence of the mountains of the pre-coastal mountain range, the mistral wind blows with intensity (*Servei Meteorològic de Catalunya*, ref. 39). In addition, the territory is characterized by a high level of solar radiation, which is essential to obtain profitability and efficiency from the energy installation.

3.1.1. Solar study

The solar study is made from the data corresponding to the solar irradiation in the municipality of *el Perelló*. The sizing and the amount of thermal solar panels will depend on the solar irradiation that is given and the energy demand of the house corresponding to the heating and consumption of the sanitary water.

The current design of the house will be used by installing the solar panels on the roof facing fully south, this orientation makes the house optimal to take benefit of the solar energy.

The European Union Photovoltaic Geographical Information System provides monthly solar irradiation data from 2005 to 2016, for any location and tilt. In addition, it shows the irradiation data for the optimal tilt.

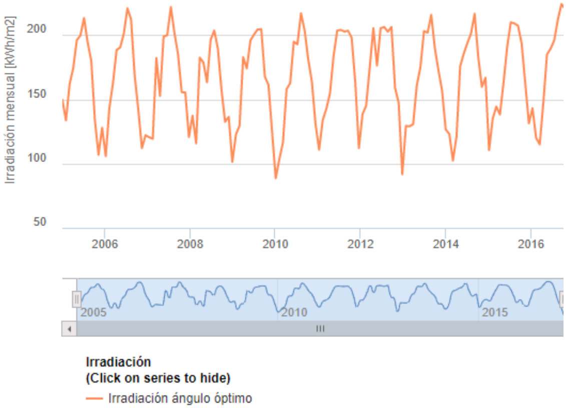

Illustration 8. *Solar radiation data at the house location for optimal inclination* [kWh/m^2] (Photovoltaic Geographical Information System, ref. 21)

Illustration 10 shows that the highest peaks occur in the summer months while the lowest are in December and January. The optimum degree of irradiation is at 38 º, so that will be the degree of irradiation of the plates that will be on the roof.

As self-sufficiency and the production of thermal solar energy for domestic use are the main objectives of the project, and not the large-scale production of solar energy for sale, only the irradiation values in the worst cases or conditions will be considered. In this way, the sizing will be able to cover the demand of thermal energy for all the periods of the year.

The minimum irradiation along the years studied is around 100 kWh/m^2 so in order to cover the demand of the house in any month of the year, a 10 %[2] less is taken as reference, this means, 90 kWh/m^2 as in this way it is assured that the demand will be covered without risk.

3.1.2. Wind study

The wind study is based on the study of the amount of power that can be extracted from the wind in the place where the house is located, based on the Specific Power that the wind has per meter squared for a determined speed (*Eq.1*) and the one that can really be extracted, called Mechanical Power.

It is necessary to have the largest amount of data on wind speeds, at the house location, registered by the weather station of *el Perelló* (*Servei Meteorològic de Catalunya*, ref. 49), and therefore, estimate more accurately the power that can be obtained. All wind speed registrations have been obtained for every half hour during the last two years. Specifically, from January 2018 to December 2019, that is a total of 35 036 data. The Mechanical Power that can be extracted will be calculated later using the Specific Power.

$$\text{Specific Power} = \frac{1}{2} \cdot \rho \cdot v^3 \;\; [\frac{W}{m^2}] \qquad (\text{Eq.1})$$

Where:

ρ = Air density [kg/m^3]

v = Wind speed [m/s]

The air density will be calculated taking as a reference a pressure of 1 atm considering that it is at sea level and with the annual average temperature of 16 ºC registered by *el Perelló* weather station from 2007 to 2016 (*Servei Meteoròlogic de Catalunya*, ref. 41). The air properties at 1 atm are consulted from ("*Mecánica de fluidos: Fundamentos y aplicaciones" 1ª edición*, 2006, ref. 53) where the following values are selected in *Table 1.*

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[2] Chosen by own criteria

Table 1. Air densities as a function of temperature at 1 atm (Own Elaboration)

Temperature [ºC]	Density [kg/m³]
15	1.225
20	1.204

To determine the air density at 16 ºC, the *Table 1* information is interpolated, and it is obtained that for a temperature of 16 ºC and 1 atm the air density is:

$$\frac{20 - 15}{1.204 - 1.225} = \frac{20 - 16}{1.204 - \rho}$$

$$\rho_{air} = 1.2208 \ [kg/m^3]$$

To calculate the specific power, the wind speed records of the last two years are used, ordered by 1 m/s intervals (*Table 2*) and their corresponding average speed. The specific energy obtained for each interval is obtained through:

- v.min and v.max = Minimum and maximum wind speeds for 1 m/s wind intervals.
- v.average = Average of the registered velocities that each interval includes.
- Frequency = Number of times a speed is repeated corresponding to an interval.
- Relative Frequency = Frequency of each interval divided by the number of data registered
- Hours/Day = Hours that would be given that interval in a full day. It is calculated as Relative Frequency · 24 hours.
- Specific Power = (Eq.1)
- Specific Energy = Specific Power · Hours / Day

Table 2. Register of speeds of 2018 and 2019 by intervals along their Specific Powers and Energies (Own Elaboration)

v.min [m/s]	v.max (m/s)	v.promedio [m/s]	Frecuency	Relative Frecuency	Hours/Day	Specific Power. [W/m^2]	Specific Energy [W·h/m^2]
0	0.9	0.489	6 487	0.185	4.444	0,071	0,317
1.0	1.9	1.475	5 417	0.155	3.711	1.959	7,269
2.0	2.9	2.499	4 928	0.141	3.376	9.526	32,157
3.0	3.9	3.488	4 571	0.130	3.131	25.903	81,106
4.0	4.9	4.475	3 500	0.100	2.398	54.701	131,147
5.0	5.9	5.477	2 560	0.073	1.754	100.287	175,865
6.0	6.9	6.485	1 792	0.051	1.228	166.473	204,352
7.0	7.9	7.481	1 400	0.040	0.959	255.560	245,086
8.0	8.9	8.489	1 196	0.034	0.819	373.408	305,923
9.0	9.9	9.477	841	0.024	0.576	519.550	299,309
10.0	10.9	10.100	699	0.020	0.479	628.896	301,129
11.0	11.9	11.482	493	0.014	0.338	923.990	312,040
12.0	12.9	12.496	364	0.010	0.249	1 191.043	296,979
13.0	13.9	13.494	269	0.008	0.184	1 499.811	276,367
14.0	14.9	14.496	197	0.006	0.135	1 859.341	250,912
15.0	15.9	15.445	122	0.003	0.084	2 248.942	187,947
16.0	16.9	16.461	80	0.002	0.055	2 722.596	149,200
17.0	17.9	17.466	53	0.002	0.036	3 252.332	118,078
18.0	18.9	18.420	30	0.001	0.021	3 814.902	78,397
19.0	19.9	19.423	26	0.001	0.018	4 472.635	79,659
20.0	20.9	20.300	5	0.000	0.003	5 106.257	17,489
21.0	21.9	21.500	4	0.000	0.003	6 066.384	16,622
22.0	22.9	22.100	1	0.000	0.001	6 588.573	4,513
23.0	23.9	23.200	1	0.000	0.001	7 622.167	5,221
			35 036	1	24		3577,085

Therefore, the ideal wind power in a day in the municipality of *el Perelló* is 3.58 kWh/m^2. For the calculation of the Mechanical Power in *Equation 2*, parameters that depend exclusively on the model of the turbine and determine the maximum usable wind power must be considered.

$$\text{Mechanical Power} = \frac{1}{2} \cdot \rho \cdot A \cdot v^3 \cdot Cp \ \ [W] \quad (\text{Eq. }2)$$

Where:

A = Rotor sweep area [m^2]

Cp = Power coefficient

The power coefficient is determined by Betz's Law (Betz, 1966, ref. 4) The power coefficient is determined by Betz's law, which determines the maximum power that can be extracted from the wind in open flow without considering the design of the wind turbine. The power coefficient is calculated using the undisturbed wind speed before passing through the wind turbine and the speed after passing through the wind turbine. In *Illustration 11* it can be seen how the air occupies a larger transverse section (diameter) behind the plane of the rotor. This increase in section is due to the fact that the rotor slows down the wind in order to capture its kinetic energy and following the law of conservation of matter (Lomonósov-Lavoisier, 1785, ref.33), the mass flow remains constant (*Eq.3*).

$$\text{Mass flow} = \rho \cdot A1 \cdot v1 = \rho \cdot A \cdot v = \rho \cdot A2 \cdot v2 \quad \left[\frac{Kg}{s}\right] \quad (\text{Eq.}3)$$

Where:

v1 = wind speed before passing through the wind turbine [m/s]

v2 = wind speed after passing through the wind turbine [m/s]

v = average speed between v1 and v2 [m/s]

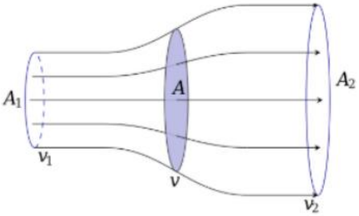

Illustration 9. Air behavior passing through the wind turbine area (*Sistemas eólicos de producción de energía eléctrica*, 2003, ref.1)

The value of the power coefficient is always less than 16/27 according to the Betz limit, so there is no turbine able to capture more than 59.3 % of the kinetic energy of the wind. It is calculated by *Equation 4*.

$$\mathrm{Cp} = \frac{\mathrm{P}}{\mathrm{Po}} = \frac{1}{2} \cdot \left(1 - \left(\frac{\mathrm{v2}}{\mathrm{v1}}\right)^2\right) \cdot \left(1 + \frac{\mathrm{v2}}{\mathrm{v1}}\right) \quad \text{(Eq.4)}$$

Where:

P = Available power per square meter of rotor area [W/m^2]

Po = Power available in the wind per square metre [W/m^2]

Illustration 12, based on (*Eq.4*), shows the maximum power coefficient that can be obtained as a function of wind speed, knowing that the value of the coefficient is between 0 and 1.

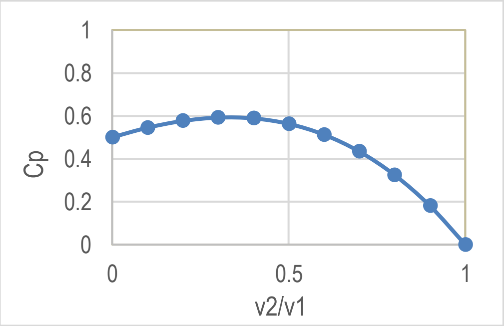

Illustration 10. Power coefficient as a function of v2/v1 (Own Elaboration)

As expected, the maximum power coefficient is 16/27, corresponding to the Betz limit. Currently, wind turbines used by electricity companies reach a maximum of 75-80 % of the Betz limit due to power losses generated by the tower's shadow, the orientation, or the deterioration of the blades, among others. So, a common Cp corresponds to:

$$\mathrm{Cp} = 0.75 \cdot \text{Ideal Cp} = 0{,}44$$

Once the Mechanical Power is obtained, the electrical power that the wind turbine is able to provide is calculated from the efficiency of the turbine rotor (*Eq.5*).

$$\text{Electrical Power} = 12 \cdot \rho \cdot A \cdot v^3 \cdot \mathrm{Cp} \cdot \eta \;\; [\mathrm{W}] \quad \text{(Eq.5)}$$

Where:

η = rotor yield

3.2. HOUSE DETAILS

The house is located in the municipality of *el Perelló*, in the region of *Baix Ebre*. The total surface area of the house is 114.5 m^2, which includes 18.45 m^2 of a porch and another 24.5 m^2 of a garage attached to the house[3]. The house is able to accommodate the couple and a guest as it has a bed-couch in the living room. The property has:

Table 3. Volumes and surfaces of the rooms in the house (Own Elaboration)

Room	Surface [m^2]	Volume [m^3]
Kitchen	9	21.6
Bathroom	3.2	7.68
Bedroom	10.38	24.91
Living room	35.28	174.63
Garage	21.44	51.45

From the volumes and surfaces of Table 3, it is calculated that the rooms are 3.9 m high. The exterior walls are made of *Tochana* (28x13.5x9 cm), covered with an air chamber of 10 cm and then a thermal insulation of 3 cm thick made of polystyrene and solid brick (27x13x5 cm). The windows of the house are double-glazed, each glass is 6 mm and the air chamber that separates them is 16 mm.

The roof has a 5 cm layer of polyurethane foam under the 12 mm tile. In addition, under the polyurethane foam there is a 10 cm thermal insulator made of glass wool placed on top of a 20 cm layer of concrete. The floor of the entire house is covered with 10 mm thick ceramic tiles and a 20 cm layer of concrete that insulates it thermally from the ground. All the walls facing the interior of the house, including the ceiling, are covered with a thin layer of 1.2 cm plaster.

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[3] The house plan is shown in Appendix 1

3.3. THERMAL STUDY

The house's thermal study consists of calculating the heat loss through the exterior walls[4], windows, roof and floor in order to know the energy consumption of the heating system necessary to maintain the temperature inside the house at 21 ºC. For the thermal study, only the places wanted to be kept at 21 ºC will be considered, so the garage is excluded from the study.

Since the minimum temperature registered in the municipality in 2019 was 3 [ºC] (*Servei Meteoròlogic de Catalunya*, ref. 41), the losses will be calculated as if the outside temperature were this one throughout the year[5]. In this way, the solar panel system will become oversized. *Illustrations 13, 14, 15 and 16* show, by means of a scheme of the thicknesses of the different materials that insulate the house, the layers that the heat passes through.

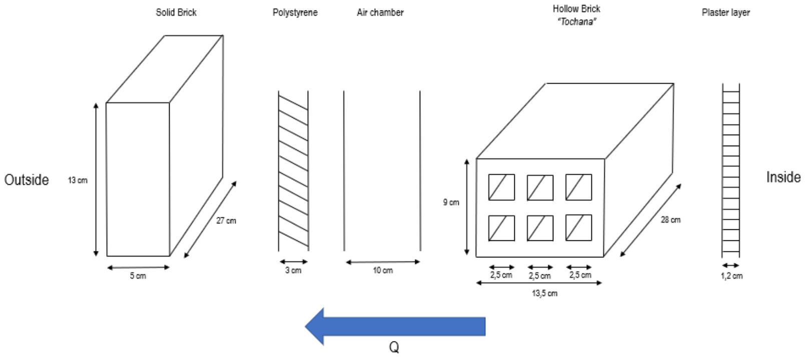

Illustration 11. Scheme of the wall layers (Own Elaboration)

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[4] All exterior walls are master walls as there are no beams in the house

[5] Temperature chosen by own criteria in order to oversize

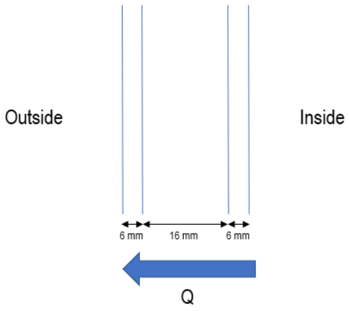

Illustration 12. Scheme of layers of double-glazed windows (Own Elaboration)

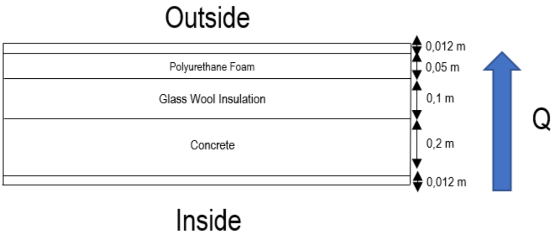

Illustration 15. Scheme of the roof layers (Own elaboration)

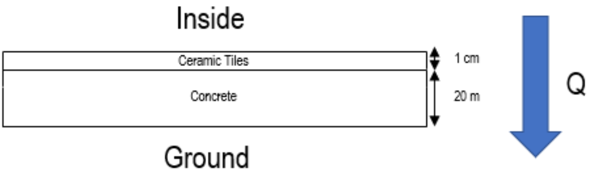

Illustration 13. Scheme of floor layers (Own Elaboration)

In *Table 4* we can see the area covered by the different layers of materials to be studied.

Table 4. Surfaces that the heat passes through (Own Elaboration)

Zone	Surface [m²]
Walls	58.4
Windows	7.7
Roof	71.55
Floor	71.55

(a) As no information is available on the House pla, a 1.1 m height of the windows is chosen

Losses are produced through heat transmission by conduction and convection[6].

Heat conduction is the mechanism of heat transmission in solids and fluids in repose and is represented by Fourier's Law (*Eq.6*).

$$q = -\, k \, \nabla T \left[\frac{W}{m^2}\right] \quad (\text{Eq.6})$$

Where:

q = Heat flux density [W/m²]

k = Thermal conductivity of each material [W/(K·m)]

∇T = Temperature gradient [K]

In order to calculate the heat loss by conduction through the different layers of thermal insulation, knowing that it is stationary and ignoring the contact resistance[7], we have that applying the microscopic energy balance and the Fourier law to each thickness and conductivity layer, *Equation 7* results.

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[6] All the theory, equations and suppositions in this section have been extracted and consulted in the notes of (*Asignatura Transmisión de Calor*, ref. 48)

[7] Thermal resistance at the interface of two solids in contact

$$Q = \frac{T_0 - T_N}{\sum_{i=1}^{N}(\frac{e}{k \cdot A})_i} = \frac{T_0 - T_N}{\sum_{i=1}^{N} R_i} \ [W] \quad (Eq. 7)$$

Where:

Q = Heat flux [W]

T_0 = Temperature of the layer facing the inside of the house [K]

T_N = Temperature of the layer facing the outside of the house [K]

R_i = Thermal resistance of each layer [K/W]

e_i = Thickness of each layer [m]

k_i = Thermal conductivity of each material [W/(K·m)]

A_i = Area through which heat flows [m^2]

Then, in Table 5, the Ri of each material is calculated using *Equation 7* and with the values of thickness, area that the heat passes through (*Table 4*) and the thermal conductivity consulted in (*Instituto Eduardo Torroja de ciencias de la construcción*, 2010, ref. 26) for each material.

Table 5. Thermal resistance calculated for each material (Own Elaboration)

Place	Material	K [W/(K·m)]	Thickness [m]	R_i [K/W]
Walls	Plaster	0.30	0.012	0.0007
	"Tochana"	0.32	0.135	0.0072
	Air at 15.5 [ºC]	0.03	0.100	0.0685
	Polystyrene	0.04	0.030	0.0143
	Solid Brick	0.85	0.050	0.0010
Windows	Glass	0.80	0.006	0.0010
	Air	0.03	0.016	0.0831
	Glass	0.80	0.006	0.0010
Floor	Ceramic Tiles	1.63	0.010	0.0001
	Concrete	0.32	0.200	0.0087
Roof	Ceramic Tile	0.29	0.012	0.0006
	Polyurethane Foam	0.03	0.050	0.0250
	Concrete	0.32	0.200	0.0087
	Plaster	0.30	0.012	0.0006

(a) The air in the air chamber is estimated to be at an average temperature between the inside and outside of the house

Convection, on the other hand, consists of the transport of energy due to its own material movement inside a system. Solving the microscopic balances of energy, matter and quantity of movement gives us *Equation 8* to calculate it.

$$Q = h \cdot A \cdot \Delta T \; [W] \quad (Eq.8)$$

Where:

Q = Heat flux [W]

h = Individual heat transmission coefficient [$W/(m^2 \cdot K)$]

A = Contact area between fluid and solid [m^2]

ΔT = Temperature difference between air and wall [K]

As the temperature of the walls is not known, a wall temperature is chosen with a difference of 1/4, both inside and outside, from the inside and outside temperature respectively. The individual coefficient of heat transmission will have different values depending on the area studied, so there will be:

- $h_{\text{outside-walls}}$: h of the outside air in contact with the brick wall layer.
- $h_{\text{inside-walls}}$: h of the inside air of the house in contact with the plaster layer of the walls.
- $h_{\text{outside-windows}}$: h of the outside air in contact with the windows.
- $h_{\text{inside-windows}}$: h of the inside air of the house in contact with the windows.
- $h_{\text{outside-roof}}$: h of the outside air in contact with the roof tiles.
- $h_{\text{inside-roof}}$: h of the inside air of the house in contact with the plaster layer of the ceiling.
- $h_{\text{inside-floor}}$: h of the inside air of the house in contact with the ceramic tile floor.
- h_{ground}: h of the ground in contact with the concrete of the house floor.

The equations from which the value of the individual transfer coefficient will be solved are shown below. The properties of air at 1 atm are extracted from ("*Mecánica de fluidos: Fundamentos y aplicaciones" 1ª edición*, 2006, ref. 53)[8].

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[8] Air properties at the average temperature between the air and the wall in contact with it

$$\mathrm{Nu} = \frac{\mathrm{h} \cdot \mathrm{L}}{\mathrm{k}} \quad (\mathrm{Eq.}\,9)$$

$$\mathrm{Pr} = \frac{\mathrm{Cp} \cdot \mu}{\mathrm{k}} \quad (\mathrm{Eq.}\,10)$$

$$\mathrm{Gr} = \frac{\mathrm{L}^3 \cdot \rho^2 \cdot \mathrm{g} \cdot \beta \cdot \Delta\mathrm{T}}{\mu^2} \quad (\mathrm{Eq.}\,11)$$

$$\mathrm{Ra} = \mathrm{Pr} \cdot \mathrm{Gr} \quad (\mathrm{Eq.}\,12)$$

Where:

k = Thermal conductivity of air [W/(K·m)]

Cp = Specific heat of air [J/(kg·K)]

μ = Air viscosity [kg/(m·s)]

ρ = Air density [kg/m^3]

β = Thermal expansion coefficient of air [K^{-1}] ≈ $\frac{1}{T\ air}$[9]

ΔT = Temperature difference between air and wall [K]

Nu = Nusselt number

Pr = Prant number

Gr = Grashof number

Ra = Rayleigh number

L = Characteristic length (depending on the area studied)

The Nusselt number estimation is different depending on the studied zone:

For horizontal surfaces it is used the Nusselt equation *(Eq.13).*

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[9] It is considered an ideal gas to estimate the coefficient

$$\mathrm{Nu} = \mathrm{a} \cdot (\mathrm{Pr} \cdot \mathrm{Gr})^{\,\mathrm{m}} \quad (\mathrm{Eq.\,13})$$

Where:

Pr = Prant number

Gr = Grashof number

a and m = Experimental values

Table 6 will be followed to select the corresponding a and m values. The roof and floor of the house will be considered as horizontal planes with a 33.9 m of perimeter.

Table 6. Experimental values of a and m according to the geometric configuration (*Asignatura Transmisión de Calor*, ref.48)

Geometric configuration	Characteristic length (L)	Rayleigh number (Ra)	a	m
Horizontal plane face-up	Area/Perimeter	$10^5 < \mathrm{Ra} < 2\cdot10^7$	0.54	1/4
	Area/Perimeter	$2\cdot10^7 < \mathrm{Ra} < 3\cdot10^{10}$	0.14	1/3
Horizontal plane face-down	Area/Perimeter	$3\cdot10^5 < \mathrm{Ra} < 3\cdot10^{10}$	0.27	1/4

For walls and windows, as they are considered large vertical surfaces, the characteristic length becomes the height of the wall or window and the Nusselt number is estimated by *Equation 14* ("Correlating Equations for Laminar and Turbulent Free Convection fom a Vertical Plate", 1975, ref. 8).

$$\mathrm{Nu} = \left(0{,}825 + \frac{0.387 \cdot \mathrm{Ra}^{\frac{1}{6}}}{\left[1 + \left(\frac{0.492}{\mathrm{Pr}}\right)^{\frac{9}{16}}\right]^{\frac{8}{27}}} \right)^{2} \quad (\mathrm{Eq.\,14})$$

Finally, the estimation of the h required to calculate the conduction resistance through surfaces in contact with the ground, is calculated in a completely different way by resembling the house to a rectangular surface and following *Equation 15* (Heat Loss from a Solid Ground Floor, 1993, ref. 17).

$$h_{ground} \cdot A = \frac{2 \cdot (L+B)}{\pi} \left(\ln \left[\frac{\sqrt{\left(1+\frac{2}{x}\right)+1}}{\sqrt{\left(1+\frac{2}{x}\right)-1}} \right] + 0.091 \cdot \pi \right) \cdot k_{ground} \qquad \text{(Eq.15)}$$

$$x = \frac{(L \cdot B)}{W \cdot (L \cdot B)}$$

Where:

A = Ground contact area with the concrete = (L·B) [m^2]

k_{ground} = Thermal conductivity of the ground [W/(K·m)]

L = Length of the house [m]

B = House width [m]

W = Master wall thickness [m]

Values of the individual heat transmission coefficients mentioned are estimated in order to calculate the thermal resistances relating to heat transmission by convection.

Table 7. Air properties at 1 atm and at different temperatures (Own Elaboration)

	T inside average 18.38 [ºC]	T outside average 3.75 [ºC]
k [W/(K·m)]	0.249	0.239
Cp [J/(kg·K)]	1007	1006
μ [Kg/(m·s)]	$1.81 \cdot 10^{-5}$	$1.74 \cdot 10^{-5}$
ρ [Kg/m³]	1.21	1.27

Table 7 shows the air properties at the average temperature between the air temperature and the temperature of the solid in contact with it[10]. Instead, β is calculated at the temperature of the fluid and as mentioned above, is the inverse of the temperature expressed in K so, for an air temperature of 21 ºC, β is 0.034 K^{-1} while for an inside temperature of 3 ºC it is 0.036 K^{-1}. Based

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[10] It is estimated a difference of ¼ of the temperature of the air in contact with

on these data, *Table 8* shows the estimated values of h calculated from *Equations 9,10,11 and 12* by estimating the number of Nusselt from *Equation 13*.

Table 8. Estimation of heat transmission coefficients for horizontal surfaces (Own Elaboration)

Zone	Geometric configuration	Characteristic length [m]	Nu	h [W/(m²·K)]
Inside-Roof	Horizontal plane face-down	2.11	41.09	4.85
Outside-Roof	Horizontal plane face-up	2.11	94.38	10.69
Inside-Floor	Horizontal plane face-up	2.11	113.80	13.43

Therefore:

$h_{\text{inside-roof}} = 4.85\ W/(m^2·K)$

$h_{\text{outside-roof}} = 10.69\ W/(m^2·K)$

$h_{\text{inside-floor}} = 13.43\ W/(m^2·K)$

Table 9. Estimation of heat transmission coefficients for vertical surfaces (Own Elaboration)

Zone	Characteristic length [m]	Nu	h [W/(m²·K)]
Inside-Walls	3,9	117.31	7.49
Outside-Walls	3,9	99.05	6.07
Inside-Windows	1,1	36.93	8.36
Outside-Windows	1,1	32.26	7.01

Therefore:

$h_{\text{inside-walls}} = 7.49\ W/(m^2·K)$

$h_{\text{outside-walls}} = 6.07\ W/(m^2·K)$

$h_{\text{inside-windows}} = 8.36\ W/(m^2·K)$

$h_{\text{outside-windows}} = 7.01\ W/(m^2·K)$

In order to calculate the heat transmission coefficient of the ground, a temperature of 2.5 ºC and a thermal conductivity of 1.39 W/(m²·K), both extracted from (Asignatura Transmisión de

Calor, ref. 48) .h $_{ground}$ is calculated using *Equation 15*, where: the thickness of the master walls is 0.33 m and the dimensions of the surface area of the house in contact with the ground of (9x7.95 m).

In this way it is obtained:

$h_{ground} = 0.18\ W/(m^2 \cdot K)$

Once the thermal resistances and heat transmission coefficients have been determined, *Table 10* shows the heat losses through the different areas of the house, following *Equations 7 and 8.*

Table 10. Heat losses through the different areas of the house (Own Elaboration)

Place	Transfer area [m^2]	Q [W]
Walls	58.4	114
Windows	7.7	92
Floor	71.55	93
Roof	71.55	255

As expected, the surfaces with the highest heat losses are the roof and the windows. The total heat loss of the house will be the sum of those calculated in *Table 10.*

$$Qtotal = Qwalls + Qwindows + Qfloor + Qroof = 554\ W$$

4. DOMESTIC ENERGY CONSUMPTION

The study of the energy demand of the house is essential since the design and sizing of both the solar panels and the wind turbines are based on it. The energy demand is based on the annual consumption of the house and two types of demand can be distinguished:

- Electricity demand: Supplied by wind turbines and refers to the consumption generated by the illumination, the water pump, the domestic appliances and the electric heating.
- Thermal energy demand: Supplied by solar panels and referring to the consumption of domestic hot water[11].

Due to the impossibility of obtaining actual data on energy consumption by homeowners, an estimate will be made based on values corresponding to average consumption in single-family homes.

4.1. ELECTRICAL ENERGY DEMAND

The demand study will consist of the total power required by the appliances, water pump, illumination and electric heating based on an estimate of the daily use of each one. *Table 11* shows the consumption per hour of use generated by the domestic appliances along with the lighting. The values have been taken from a study carried out from 2010 to 2018 (*Instituto para la Diversicación y el Ahorro de la Energía*, 2018, ref. 28).

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[11] The house's kitchen is electric

Table 11. Electrical consumption by domestic appliances and lighting *(Instituto para la Diversicación y el Ahorro de la Energía*, 2018, ref. 28)

Consumption Item	Quantity	Average annual consumption per house in Spain [kW·h]	Average daily consumption [W·h]
Lighting	-	410	1123.28
Refrigerator	1	655	1794.52
Washing machine	1	254	695.89
Dishwasher	1	245	671.23
Oven	1	231	632.87
Tv	1	263	720.54
Computer	1	172	471.23
Standby	-	231	632.87
Total daily consumption [W·h]			6 742.43

(a) The Standby term refers to the average consumption of all domestic appliances while they are not in use

Table 12 shows the data regarding to the daily consumption of the glass-ceramic, microwave, toaster, iron and water pump because there are not conclusive studies. The values of daily consumption have been calculated from an estimation of the power of each one by means of an online power calculator (*Empresa Municipal d'Energia Electrica de Torre del Segre*, ref. 18) and an estimate of the hours of daily use, taking into account that they are not used every day.

Table 12. Estimated electricity consumption for certain domestic appliances and the water pump (Own Elaboration)

Consumption Item	Quantity	Power [W]	Use time per day [h]	Daily use [W·h]
Glass-ceramic	1	2 000	0.5	1 000
Microwave	1	800	0.2	160
Iron	1	1 500	0.5	750
Toaster	1	400	0.2	80
Water Pump	1	1 000	0.20	200
Total daily consumption [W·h]				2 190

(a) The daily consumption is calculated as the product of the power multiplied with the time of daily use

(b) The estimated time of use of the water pump is detailed below

To estimate the time that the water pump supplies water[12], the simultaneous flow of cold water and the total domestic water consumption need to be evaluated.

The average water consumption per habitant in Spain is 136 liters per day (*Instituto Nacional de Estadística*, 2018, ref. 27). Knowing that the house studied is inhabited by 2 persons, the total consumption of domestic water will be:

$$136\ \left[\frac{\mathrm{L}}{\mathrm{hab}\cdot\mathrm{day}}\right]\cdot 2\ \mathrm{hab} = 272\left[\frac{\mathrm{L}}{\mathrm{day}}\right] = 0.272\ \left[\frac{\mathrm{m}^3}{\mathrm{day}}\right]$$

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[12] Flow used to size the different sections of the installation

The simultaneous flow of cold water is calculated from the sum of minimum instantaneous flows[13], so *Table 13* shows the minimum water supply conditions (COAATC, ref. 11).

Table 13. Minimum instantaneous flow for each type of appliance (COAATC, ref. 11)

Appliance	Minimum instantaneous cold water flow [dm^3/s]	Minimum instantaneous cold water flow [m^3/h]
Handwasher	0.05	0.18
Shower	0.2	0.72
Toilet with tank	0.1	0.36
Sink	0.2	0.72
Dishwasher	0.15	0.54
Washing machine	0.2	0.72
Total minimum instantaneous cold water flow [m^3/h]		3.24

The total flow obtained corresponds to the simultaneous use of all the appliances, as the probability of this situation is very low, the simultaneity coefficient is applied, a corrective factor that adjusts the value to reality.

$$\mathrm{Qs}^* = \mathrm{Qs} \cdot \mathrm{Kv} \quad \text{being} \quad \mathrm{Kv} = \frac{1}{\sqrt{\mathrm{n}-1}} \qquad (\mathrm{Eq.}\,16)$$

Where:

Kv = Simultaneity coefficient for a house

n = Number of appliances inside the house that consume water

Qs = Total simultaneous flow [m^3/h]

Qs* = Corrected total simultaneous flow [m^3/h]

The number of appliances is 6, so there is a corrected total simultaneous flow of 1.32 m^3/h (*Eq.16*). Dividing the total domestic water consumption of 0.272 m^3 per day by the corrected

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[13] Minimum flow that must be supplied to a sanitary appliance so that it can be used correctly regardless of its good condition

simultaneous flow calculated, the estimate operating hours of 0.20 hours used in *Table 12* is obtained.

On the other hand, heating consumption is determined by the heat losses of 554.22 W [14]. As the house needs to be kept at 21 ºC all the time and the energy demand is oversized to ensure that the house is energy supplied at any time of the year, the heating time is estimated as it is working 24 hours a day in order to oversize the system. Therefore, the daily energy consumption by the heating system is:

$$\mathrm{E = Qtotal \cdot 24\ h} \qquad \left[\frac{\mathrm{kW \cdot h}}{\mathrm{day}}\right]$$

$$\mathrm{E} = 554\ \mathrm{W} \cdot \frac{1\ \mathrm{kW}}{1000\ \mathrm{W}} \cdot 24\ \mathrm{h} = 13.3\ \ \frac{\mathrm{kW \cdot h}}{\mathrm{day}}$$

Where:

Q total = Total heat losses [W]

The sum of the daily consumptions of all the elements gives a daily electricity consumption of:

$$\mathrm{D.e.c.} = (6\,742\ \mathrm{Wh} + 2\,190\ \mathrm{Wh}) \cdot \frac{1\ \mathrm{kWh}}{1000\ \mathrm{Wh}} + 13.3\ \mathrm{kWh}\ = 22.23\ \mathrm{kWh}$$

In addition to the estimated electricity consumption, for the adjustment and design of the wind turbines, it is also necessary to know the expected power of the house, which is the maximum electrical power available and its value is equal or higher than the contracted power. In this case, as the house is becoming independent from the electrical grid, no power is contracted, so the value could be estimated by adding the installed power of each consumption element multiplied by the corresponding simultaneity coefficients[15]. It is not possible to do it in this way since the determination of the simultaneity coefficients is responsibility of the designer, requiring a detailed knowledge of the installation and the conditions in which each load is exploited.

In this way, it is chosen to set an expected power following ITC-BT-10 (*Reglamento Electrotécnico de Baja Tensión*, 2002, ref. 37). The document mentions that the owner of the

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[14] Calculated in the Thermal Study, section 3.3

[15] The simultaneity coefficient represents the degree of diversity corresponding to the demands of a system, since the simultaneous operation of all of them never occurs.

house, together with the electricity supply company, are responsible for setting the power to be provided and in no case will be less than 5.75 kW in new construction, this value will be taken as an estimation for the house. In this way, the expected power of the house is set at 5.75 kW.

Table 14 shows the sum of the installed powers for each of the consumption elements, considering 12 energy-saving bulbs of 50 W each for the lighting. To estimate the global simultaneity coefficient (*Eq.12*), the fixed expected power of 5.75 kW will be divided by total installed power. This coefficient of simultaneity indicates the amount of power that the house can consume at the same time, in other words, the number of appliances that can operate at the same time.

Table 14. Total installed power in the house (Own Elaboration)

Consumption Element	Power [W]
Energy-saving bulbs x12	600
Refrigerator	300
Washing Machine	2 000
Dishwasher	2 000
Oven	1 500
Tv	250
Computer	150
Glass-ceramics	2 000
Microwave	800
Iron	1 500
Toaster	400
Water pump	1000
Electric heating	554
Total installed power	13 054

$$\mathrm{fs} = \frac{\text{Expected power [kW]}}{\text{Total installed power [kW]}} = \frac{5.75}{13.05} = 0{,}44 \quad (\text{Eq. } 12)$$

Where:

fs = Global simultaneity coefficient

4.2. THERMAL ENERGY DEMAND

The demand for thermal energy will be supplied by solar panels and is determined by the consumption of DHW (domestic hot water). To determine the consumption of DHW, the HE document concerning to the minimum contribution of renewable energy to cover the demand of domestic hot water should be consulted (*Codigo Técnico de la Edificación*, 2019, ref. 10). This document provides the estimations of daily consumption of domestic hot water at 60 ºC per person for different possible buildings. In the case of buildings for private residential use as would be the case of the house studied, the daily average consumption is 28 liters per person. It should be noted that this estimate is different to that of 136 liters per habitant[16] (*Instituto Nacional de Estadística*, 2018, ref. 27). In this way, and being the residence place for 2 people:

$$28\left[\frac{\mathrm{L}}{\mathrm{day}\cdot\mathrm{person}}\right]\cdot 2\ \mathrm{persons} = 56\ \left[\frac{\mathrm{L}}{\mathrm{day}}\right]$$

To determine the energy that will be consumed, it is necessary to know the temperature of the water supplied. In the same HE document mentioned in the previous paragraph (*Codigo Técnico de la Edificación*, 2019, ref. 10), the monthly average of daily temperature of the cold water supplied, it is shown for each provincial capital in Spain[17]. The following is an exclusive list of data for the province capital of Tarragona, where the home is located (*Table 15*).

Table 15. Monthly average daily temperature of cold water [ºC] supplied in Tarragona (*Codigo Técnico de la Edificación*, 2019, ref. 10)

Provincial Capital	Altitude [m]	JA	FE	MA	AP	MY	JN	JL	AG	SE	OC	NO	DI
Tarragona	69	10	11	12	14	16	18	20	20	19	16	12	11

The average values corresponding to the province of Tarragona are used. On the other hand, an average value for each month will not be used, but rather the minimum value corresponding to 10 ºC in January will be chosen in order to oversize and ensure the capacity to

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[16] Estimation used in section 4.1 for the time of use of the water pump and which refers to the total average of water consumed

[17] The whole Table is shown in Appendix 2

supply hot water in any month of the year. *Equation 13* shows the calculation of the energy required to increase the water temperature from 10 ºC to 60 ºC.

$$\mathrm{E} = \mathrm{C_{DHW}} \cdot \mathrm{Cp} \cdot \Delta\mathrm{T} \quad \left[\frac{\mathrm{kW \cdot h}}{\mathrm{day}}\right] \quad (\mathrm{Eq.\,13})$$

$$\mathrm{E} = 56\,\frac{\mathrm{L}}{\mathrm{day}} \cdot 1.16\,\frac{\mathrm{W \cdot h}}{\mathrm{ºC \cdot L}} \cdot (60 - 10)\ \mathrm{ºC} = 3.248\,\frac{\mathrm{kW \cdot h}}{\mathrm{day}}$$

Where:

C_{DHW} = DHW Consumption

Cp = Specific heat of water[18]

ΔT = Temperature increase

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[18] It is considered constant over the entire heating interval

5. DESIGN OF THE ENERGY INSTALLATION

Once the climatic conditions of the place where the house is located have been studied and an estimate of the energy consumption required by the house has been made, the design, number of wind turbines and solar panels necessary to cover the energy demand of the house are chosen [19].

5.1. WIND TURBINES SIZING

The basic sizing requirement for wind turbines is being able to produce the same or more electrical energy than the daily demand of the home, while the nominal power of the turbine must be equal or higher than the expected power.

In this case, the total installed nominal power of the wind turbines must be at least 5.75 kW and the energy to be produced must be higher than 22.23 kWh corresponding to the daily electricity consumption of the home. In the possibility of an energy demand excess, there is a tolerance range of 15 %[20] in both requirements. Therefore, the two requirements for sizing are:

- Minimum daily energy produced = 25.57 [kWh]
- Minimum installed nominal power = 6.04 [kW]

Table 16 below shows the differences between the main models of domestic wind turbines. Due to the confidentiality agreements present in the companies, it has been impossible to study in detail and extract relevant information from most of them. However, the technical data sheets for wind turbines are available on the websites of Spanish companies (Enair, ref. 19) and (Bornay, ref. 5).

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[19] Calculated in the study of electricity demand, section 4.1

[20] Chosen by own criteria considering that, the consumption by the electric heating system has already been oversized

Table 16. Characteristics of the possible wind turbines (Own Elaboration)

	Enair		Bornay		
Model	E30 Pro	E70 Pro	Wind 13 +	Wind 25.2+	Wind 25.3+
Axis Type	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal
Diameter [m]	3.8	4.3	2.86	4.05	4.05
Nº Propellers	3	3	2	2	3
Cut in [m/s]	2	2	3.5	3.5	3.5
Cut out [m/s]	60	60	30	30	30
V.Nominal [m/s]	11	11	12	12	12
Nominal Power [kW]	1.9	4	1,5	3	5
Price [€]	8 000	9 800	4 225	5 725	8 175

By means of the same confidentiality agreement, the companies do not show the exact values of efficiency and power coefficient. Therefore, following *Equation 5*, by isolating and using the values of power and nominal speed, an approximate value of Cp and efficiency of the rotor can be established.

$$\text{Electrical power} = 12 \cdot \rho \cdot A \cdot v^3 \cdot Cp \cdot \text{ŋ} \quad (\text{Eq.5})$$

$$Cp \cdot \text{ŋ} = \frac{P_N}{12 \cdot \rho \cdot A \cdot v_n^3 \cdot Cp \cdot \text{ŋ}}$$

$$A = \pi \cdot \left(\frac{d}{2}\right)^2$$

Where:

Cp·ŋ = Power coefficient · Rotor yield

P_N = Nominal Power [W]

V_N = Nominal Speed [m/s]

A = Rotor sweeping area [m^2]

d = Diameter [m]

In this way, from the total specific energy of 3.58 kWh/m^2 [21] we have obtained the total daily energy that each wind turbine would produce, represented in *Table 17*.

Table 17. Daily energy obtained for each wind turbine studied (Own Elaboration)

	Area [m^2]	Cp·η	Daily energy produced [kWh]
E30 Pro	11.34	0.21	8.37
E70 Pro	14.52	0.34	17.62
Wind 13 +	6.42	0.22	5.09
Wind 25.2+	12.88	0.22	10.18
Wind 25.3+	12.88	0.37	16.97

Where:

Daily energy produced = Sweeping area · Power coefficient · Rotor yield · Total specific power

The sizing of the wind turbines will be determined by the number of turbines needed to satisfy the minimum necessary energy of 25.57 kWh and subsequently the total installed nominal power, which must be higher than the 6.038 kW mentioned above. In *Table 18* the most relevant data for each wind turbine can be seen, as it is a project carried out for a familiar house, the economic variable is chosen as a determining factor for the selection.

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[21] Calculated in section 3.2.1, in Table 2

Table 18. Comparison of the most relevant data for each wind turbine model (Own Elaboration)

	Enair		Bornay		
Model	E30 Pro	E70 Pro	Wind 13 +	Wind 25.2+	Wind 25.3+
Cp·ŋ	0.21	0.34	0.22	0.22	0.37
Sweeping area [m^2]	11.34	14.52	6.42	12.88	12.88
Nominal power per turbine [kW]	1.9	4	1.5	2	5
Daily energy per turbine [KWh]	8.37	17.62	5.09	3.5	16.97
Price per turbine [€]	8 000	9 800	4 225	30	8 175
Number of turbines	4	2	6	12	2
Total nominal power [kW]	7.6	8	9	3	10
Total daily energy [kWh]	33.48	35.25	30.54	5725	33.94
Total price [€]	32 000	19 600	21 125	17 175	16 350

After the analysis of the calculated values, the wind turbine Wind 25.3+ of the manufacturer Bornay is chosen as the model that best fits the electricity demand of the house[22]. Nevertheless, it can be seen that all models exceed the minimum daily energy production by up to 20 %. The Wind 25.3+ model is not only the cheapest, it also provides the highest value of installed nominal power. In this way, the two turbines will be able to satisfy the power demand in moments where there is a high level of simultaneous use of domestic appliances. Finally, even though it has the second largest diameter, this model is compensated by having the fewest wind turbines required, minimizing the visual impact. *Illustration 17* shows an image of the Wind 25.3+ wind turbine. The orientation rudder of the wind turbine can be observed and is capable of directing the rotor to a position perpendicular to the wind regardless of the direction the wind is blowing.

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[22] Wind 25.3+ wind turbine technical sheet in Appendix 3

Illustration 14. Bornay Wind Turbine Wind 25.3+ (Bornay, ref. 5)

The installation of the wind turbines will be carried out at the back of the house, as space is not a problem since the plot has approximately 10 km^2 of terrain, a distance of 7 times the diameter of the rotor is left between the two wind turbines (*Instituto para la Diversificación y Ahorro de Energía*, ref. 19) to avoid interferences and turbulences that could affect the speed and direction of the wind. Therefore, the wind turbines will be separated by a distance equal to 28.3 m.

5.2. SIZING OF SOLAR PANELS

The solar panels are sized based on a monthly solar irradiation value of 90 kWh/m^2 [23] and a daily thermal energy demand of 3.25 kWh [24]. In order to compare both values, the monthly solar irradiation is converted into daily solar irradiation:

$$\text{Daily solar irradiation} = 90\ \frac{\text{kWh}}{\text{m}^2 \cdot \text{month}} \cdot \frac{1\ \text{month}}{30\ \text{day}} = 3\ \frac{\text{kWh}}{\text{m}^2 \cdot \text{day}}$$

To obtain the total m^2 of solar panels required, it is only necessary to divide the daily energy demand by the daily solar radiation that could be captured.

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[23] Calculated in section 3.1.1, Solar Study

[24] Calculated in section 4.2, Thermal energy demand

$$\text{Panel surface} = \frac{3.248\ \frac{\text{kWh}}{\text{day}}}{3\ \frac{\text{kWh}}{\text{m}^2 \cdot \text{day}}} = 1.08\ \text{m}^2$$

Therefore, the two requirements for the design of the solar thermal installation are:

- Minimum of 1.08 m^2 of solar panel.
- Tank with a minimum capacity of 56 liters to cover the daily demand for DHW.

A thermosiphon closed circuit system is chosen, as it is easy to install, in most cases more economical and does not require forced circulation, so there is no need for an additional pump which would mean more electricity consumption. In addition, it is the best system for handling low quantities of water.

As with the choice of wind turbines, there is not enough information available regarding to the characteristics of the accumulators and solar collectors due to the confidentiality agreements between manufacturers. Nevertheless, it has been possible to obtain information from the data sheets of the manufacturer (Teican, ref. 45). *Table 19* shows the models studied with their determining characteristics. This manufacturer offers thermosiphon kits that incorporate all the necessary elements for their interconnection. These kits include:

- Horizontal solar accumulator of 150, 200 or 300 liters
- Solar collector
- Anodized aluminum roof structure
- Assembly tool kit
- Solar anti-freeze fluid
- Insulated stainless steel flexible hoses

Table 19. Comparison of the most relevant data for each thermosiphon system (Own Elaboration)

Kit reference	Solar collector model	Number of panels required	Solar collection area [m^2]	Storage tank volume [L]	Kit Price [€]
AS-150 H	Termocan 1.8 A	1	1.77	145	1 838
AS-200 H	Termocan 2.0 A	1	2	192	1 989
AS-300 H	Termocan 1.8 A	2	3.54	280	2 838
FR 150 L	TS350	1	1,7	150	1 725
FR 300 L	TS350	2	3.4	300	2 700
AS-200 DB	Termocan 2.0 A	1	2	200	3 091
AS-300 DB	Termocan 1.8 A	2	3.6	300	3 992
AS-200 V	Termocan 2.0 A	1	2	200	3 135
AS-300 V	Termocan 1.8 A	2	3.6	300	4 049

Considering that the estimates in the solar study and in the thermal energy demand have been made in the case of worst conditions, an excessive panel surface could oversize the system and cause damage to it, so the model with the smallest collection area is chosen.

The FR 150 L model, with more than the 1.08 m^2 required, has the smallest collection area and is also the most economical, which is why it is chosen[25]. This model consists of a 150 liters accumulator and a TS350 solar panel with a solar collection area of 1.7 m^2. The system will be installed on a structure that provides the 38 º tilt fully focused to the south to optimize the collection of solar energy and the accumulator will be coupled on top of the panels. *Illustration 18* shows a picture of the chosen model with the accumulator coupled at the top.

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[25] FR 150 L technical sheet in Appendix 4

Illustration 15. Thermosiphonic kit with TS350 collector and 150 L storage tank (Teican, ref. 46)

5.3. STORAGE BATTERY SIZING

The batteries are designed to cover the energy consumption of the home for a full day. Therefore, the amount of energy that is stored corresponds to the demand for electrical energy in a day with a margin of 15 %[26].

$$\text{Total storage capacity} = 25.565\ \text{kWh}$$

To select the appropriate model, the capacity that each battery would store in Ampere-hours [Ah] must be calculated by the following *Equation 14*.

$$\text{Minimum capacity per battery [Ah]} = \frac{\text{Total capacity [Wh]}}{\sum \text{Voltages [V]}} \quad (\text{Eq. } 14)$$

A storage system consisting of 3 batteries of 24 V is chosen, according to the recommendations of the manufacturer of the Bornay wind turbine. These batteries are connected in series, since in this way, the current is only allowed to pass through when there is consumption and when there is no consumption, the batteries are maintained in rest. Therefore, the minimum capacity per battery will be:

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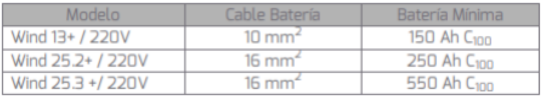
[26] Chosen by own criteria to oversize because everything is already highly dimensioned

$$\text{Minimum capacity per battery} = \frac{25.565\ \text{kWh} \cdot \frac{1\,000\ \text{Wh}}{1\ \text{kWh}}}{3 \cdot 24\ \text{V}} = 355.07\ \text{Ah}$$

A depth of discharge per battery of 60 % is set as this will satisfy the specifications of a minimum battery of 550 Ah as shown in *Illustration 19.*



Modelo	Cable Batería	Batería Mínima
Wind 13+ / 220V	10 mm^2	150 Ah C_{100}
Wind 25.2+ / 220V	16 mm^2	250 Ah C_{100}
Wind 25.3 +/ 220V	16 mm^2	550 Ah C_{100}

Illustration 16. Recommendations of the manufacturer Bornay according to wind turbine model (Bornay, ref. 5)

In this way, following *Equation 15*:

$$\text{Necessary capacity per battery [Ah]} = \frac{\text{Minimum capacity per battery}}{\text{Discharge depth}} \quad \text{(Eq. 15)}$$

$$\text{Necessary capacity per battery} = \frac{355.07\ \text{Ah}}{0.6} = 591.78\ \text{Ah}$$

Once the necessary capacity per battery has been established, the shop's battery catalogue is consulted (Solar Bex, ref. 42). The cheapest 24 V battery with a capacity of more than 591.78 Ah, capable of supporting a discharge depth of more than 60 %, is chosen (*Table 20*).

Table 20. Characteristics of the selected battery model (Own Elaboration)

Battery Model	Quantity	Capacity [Ah]	Lifetime [Years]	Discharge depth	Price [€]	Total Price [€]
SOPZS 24V 600Ah	3	600	15	80%	1 692	5 076

6. ECONOMIC STUDY

In the economic study, the necessary budget for the purchase of the energy installation will be calculated and an estimate will be made of the annual economic savings in relation to the cost of the electricity and natural gas.

6.1. BUDGET

The economic budget detailed in *Table 21*, includes the prices corresponding to the energy installations that will supply the house demand. Expenses equivalent to the installation, fees and maintenance of these installations are left out the budget as the necessary information is not available.

Table 21. Energy installations budget (Own Elaboration)

Installation	Price [€]	Quantity	Total Price [€]
Wind turbine Wind 25.3+	8 175	2	16 350
Thermosiphonic Kit FR 150 L	1 725	1	1 725
Battery SOPZS 24V 600Ah	1 692	3	5 076

The total budget without considering installation, fees and maintenance reaches 23 151 €.

6.2. ECONOMIC SAVINGS

Auto-consumption by means of renewable energy sources requires a high economic investment for the study, design, purchase and assembly of the energy installation, including the future cost of maintenance, therefore, economic savings are achieved over a long-term period. An estimate of the cost of the electricity and natural gas costs will be made in order to know how much money is saved annually. The price of the electricity bill is divided into three parts: the access fee (in this case at low voltage), the price per contracted power (which would correspond to the total nominal power of 10 kW installed by the wind turbines) and the price for consumption, giving rise to multiple tariffs. This is why the data recorded by Eurostat are used for both electricity and gas.

During the first half of 2019, the average price of electricity for domestic consumers in Spain (including price per contracted capacity, taxes and consumption) was 0.24 €/kWh (Eurostat, ref. 22). With an estimated daily consumption of 22.23 kWh.

$$\text{Electricity savings} = 0.24\ \frac{€}{\text{kWh}} \cdot 22.23\ \frac{\text{kWh}}{\text{day}} \cdot \frac{365\ \text{days}}{1\ \text{year}} = 1\ 949.78\ \frac{€}{\text{year}}$$

In the same half of 2019, the average price of natural gas was 0.07 €/kWh (Eurostat, ref. 22). For the estimated daily energy consumption for DHW of 3.248 kWh.

$$\text{Economic savings in gas} = 0.07\ \frac{€}{\text{kWh}} \cdot 3.248\ \frac{\text{kWh}}{\text{day}} \cdot \frac{365\ \text{days}}{1\ \text{year}} = 82.98\ \frac{€}{\text{year}}$$

The total annual economic savings after becoming energetically independent is 2 032.76 €.

Therefore, in approximately 12 years. Although, this value is quite inaccurate, because it does not take into account the cost for the installation, fees and maintenance. Furthermore, electricity prices are constantly changing, so the 12 year amortization period is significantly inaccurate.

7. REDUCTION OF CO_2 EMISSIONS

A distinction is made between the CO_2 emissions produced by the combustion of natural gas for the purpose of heating domestic water and the emissions related to the generation of electricity needed by the house. Depending on the type of fossil fuel used and the amount needed to obtain energy, determined CO_2 emissions are emitted, so the CO_2 emission factors in *Table 22* are used depending on the source of the energy used (*Ministerio para la Transición Ecológica y el Reto Demográfico*, ref. 34).

Table 22. Daily CO_2 emissions according to energy source (Own Elaboration)

Energy source	Energy to be produced [kWh/day]	Emission factors [Kg CO_2/kWh]	CO_2 Emissions [Kg/day]
Gas Natural	3.248	0.203	0.66
Electricidad	22.23	0.43	9.56

De esta manera, se consigue un ahorro anual de emisiones de CO_2 de:

$$\text{Reduction of } \mathrm{CO_2} \text{ emissions} = \left(0.66\ \frac{\mathrm{Kg}}{\mathrm{day}} + 9.56\ \frac{\mathrm{Kg}}{\mathrm{day}}\right) \cdot \frac{365 \text{ days}}{1 \text{ year}} = 3\,730.3 \frac{\mathrm{Kg}}{\mathrm{year}}$$

8. CONCLUSIONS

Once the project has been completed, it can be seen that there is not a single solution for the energy supply of a house, as there are several models of both panels and turbines that could satisfy energy needs in the same way. Likewise, other renewable energies could have been used to satisfy the energy demand of the home, such as: photovoltaic solar energy to produce electricity or biomass to generate heat from the forest residues.

It should be noted that in many cases the design has been carried out estimating values chosen by own criteria, this is due to the fact that these values are usually chosen by the project manager in order to oversize the system, but they are not defined anywhere and there is no correct one in particular. From this point on, and although a higher degree of deepening may be required, it can be seen that the project is viable.

One of the biggest drawbacks of this type of energy supply is the need for a high economic investment at the beginning that is not recovered for up to 12 years without taking into account the maintenance and installation costs. However, once the initial outlay has been recovered, 2 000 euros are saved annually. Aside from the economic issue, it is clear that self-sufficient housing is a real solution for the environmental problems, avoiding the emission of more than three tons per year of polluting particles in the case of the studied house.

This work is intended to be the starting-point for a detailed engineering project, such as a final master's project, to design even more precisely the entire thermal and wind energy installation in order to optimize energy production. As possible future work derived from this final degree work, it is proposed to carry out a study of a heating system fed by a biomass boiler or, failing that, a larger installation of solar panels. In addition, a possible reform of the house could be studied, such as a redistribution of the windows, the climate control system or adding more insulation, with the aim of obtaining more efficiency and energy conservation. Finally, a closer look at the electrical installation and its distribution and regulation for the house, as well as the design of the electrical switchgear and protection, both in the area of the wind turbines and batteries and inside the house.

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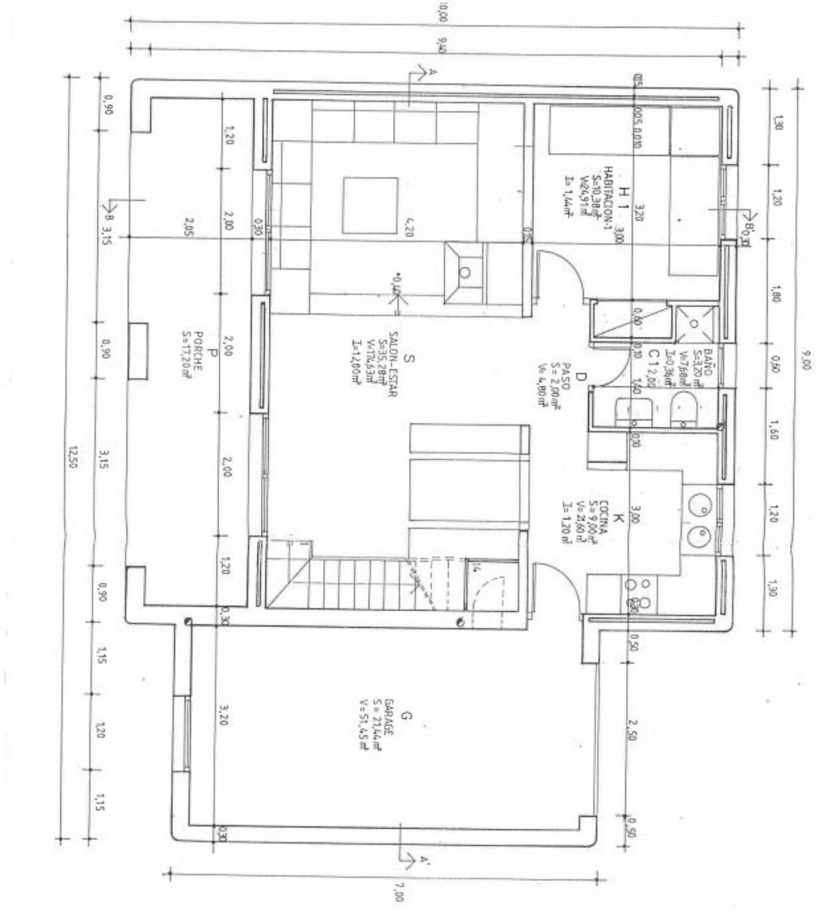
ACRONYMS

η	Rotor yield
ρ	Density
μ	Viscosity
β	Thermal expansion coefficient of air
Ah	Ampere-hour
Cp	Power coefficient
d	Diameter
DHW	Domestic hot water
D.e.c	Daily electricity consumption
Eq.	Equation
Ext.	Outside
fs	Global simultaneity coefficient
Gr	Grashof number
H	Individual heat transfer coefficient
hab.	Habitant
Int.	Inside
K	Thermal conductivity
P_N	Nominal power
Pr	Prant number
Q	Heat flux
Qs	Total simultaneous flow
Qs*	Corrected total simultaneous flow

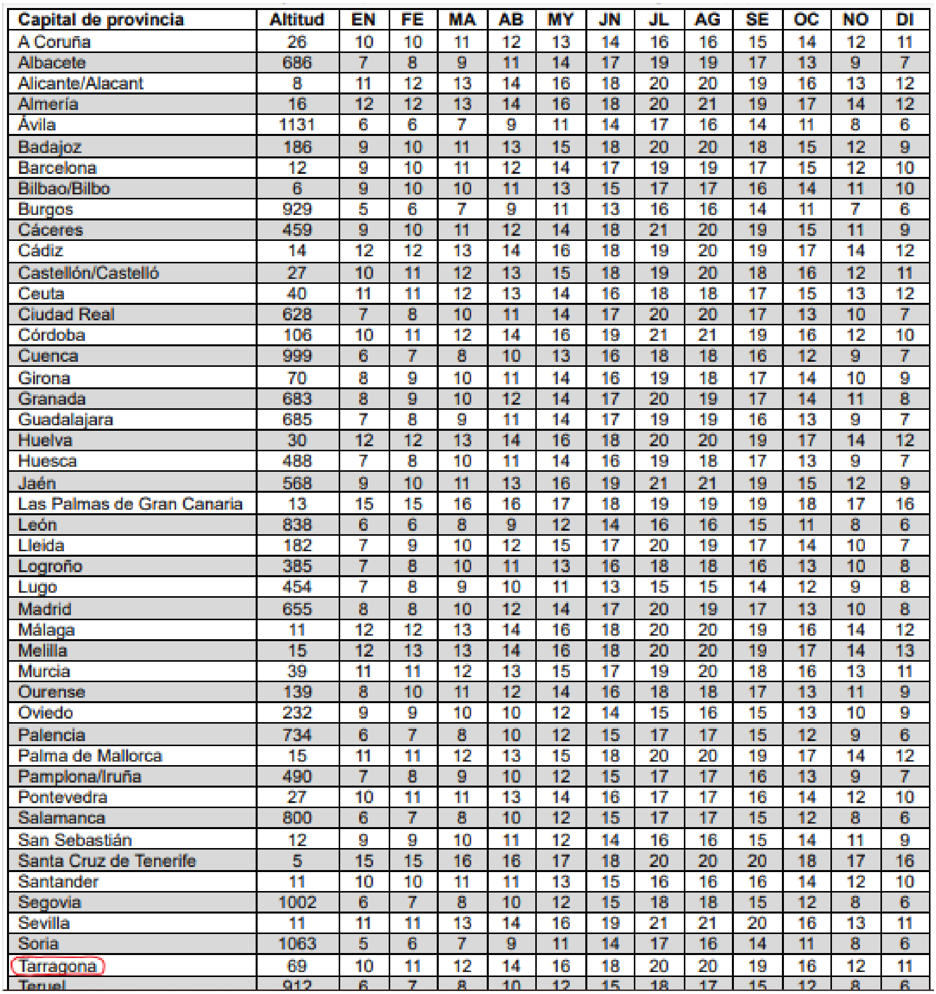
Ra	Rayleigh number
Ref.	Reference
Ri	Thermal resistance
T	Temperature
V	Volts
v	Speed
Wh	Watts-hour

APPENDICES

APPENDIX 1: HOUSE PLAN

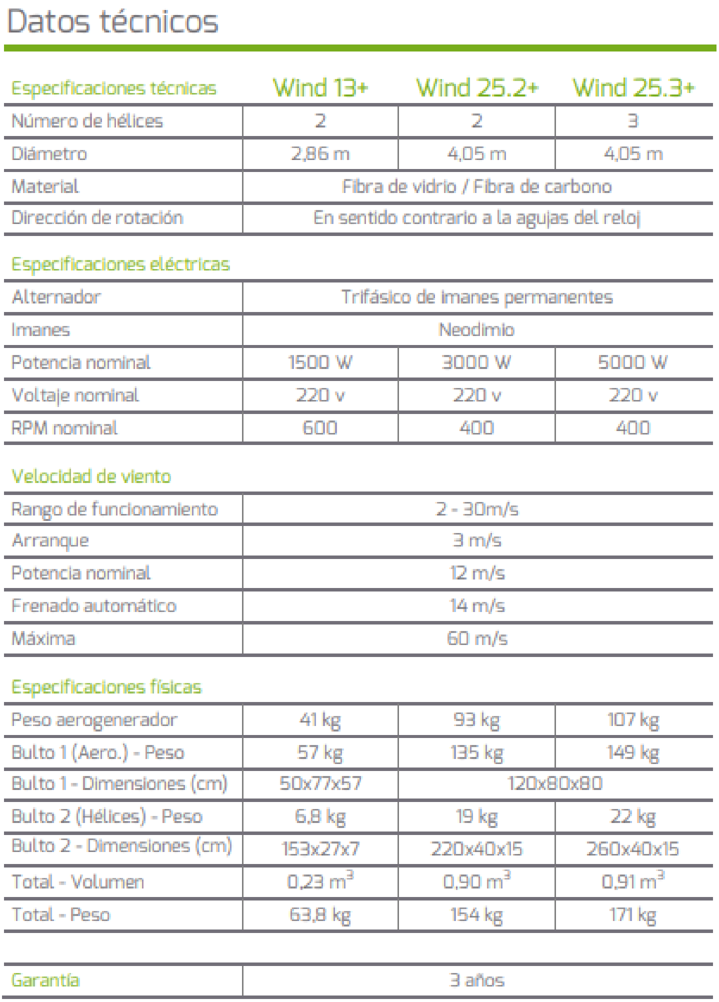


APPENDIX 2: AVERAGE MONTHLY TEMPERATURE



Capital de provincia	Altitud	EN	FE	MA	AB	MY	JN	JL	AG	SE	OC	NO	DI
A Coruña	26	10	10	11	12	13	14	16	16	15	14	12	11
Albacete	686	7	8	9	11	14	17	19	19	17	13	9	7
Alicante/Alacant	8	11	12	13	14	16	18	20	20	19	16	13	12
Almería	16	12	12	13	14	16	18	20	21	19	17	14	12
Ávila	1131	6	6	7	9	11	14	17	16	14	11	8	6
Badajoz	186	9	10	11	13	15	18	20	20	18	15	12	9
Barcelona	12	9	10	11	12	14	17	19	19	17	15	12	10
Bilbao/Bilbo	6	9	10	10	11	13	15	17	17	16	14	11	10
Burgos	929	5	6	7	9	11	13	16	16	14	11	7	6
Cáceres	459	9	10	11	12	14	18	21	20	19	15	11	9
Cádiz	14	12	12	13	14	16	18	19	20	19	17	14	12
Castellón/Castelló	27	10	11	12	13	15	18	19	20	18	16	12	11
Ceuta	40	11	11	12	13	14	16	18	18	17	15	13	12
Ciudad Real	628	7	8	10	11	14	17	20	20	17	13	10	7
Córdoba	106	10	11	12	14	16	19	21	21	19	16	12	10
Cuenca	999	6	7	8	10	13	16	18	18	16	12	9	7
Girona	70	8	9	10	11	14	16	19	18	17	14	10	9
Granada	683	8	9	10	12	14	17	20	19	17	14	11	8
Guadalajara	685	7	8	9	11	14	17	19	19	16	13	9	7
Huelva	30	12	12	13	14	16	18	20	20	19	17	14	12
Huesca	488	7	8	10	11	14	16	19	18	17	13	9	7
Jaén	568	9	10	11	13	16	19	21	21	19	15	12	9
Las Palmas de Gran Canaria	13	15	15	16	16	17	18	19	19	19	18	17	16
León	838	6	6	8	9	12	14	16	16	15	11	8	6
Lleida	182	7	9	10	12	15	17	20	19	17	14	10	7
Logroño	385	7	8	10	11	13	16	18	18	16	13	10	8
Lugo	454	7	8	9	10	11	13	15	15	14	12	9	8
Madrid	655	8	8	10	12	14	17	20	19	17	13	10	8
Málaga	11	12	12	13	14	16	18	20	20	19	16	14	12
Melilla	15	12	13	13	14	16	18	20	20	19	17	14	13
Murcia	39	11	11	12	13	15	17	19	20	18	16	13	11
Ourense	139	8	10	11	12	14	16	18	18	17	13	11	9
Oviedo	232	9	9	10	10	12	14	15	16	15	13	10	9
Palencia	734	6	7	8	10	12	15	17	17	15	12	9	6
Palma de Mallorca	15	11	11	12	13	15	18	20	20	19	17	14	12
Pamplona/Iruña	490	7	8	9	10	12	15	17	17	16	13	9	7
Pontevedra	27	10	11	11	13	14	16	17	17	16	14	12	10
Salamanca	800	6	7	8	10	12	15	17	17	15	12	8	6
San Sebastián	12	9	9	10	11	12	14	16	16	15	14	11	9
Santa Cruz de Tenerife	5	15	15	16	16	17	18	20	20	20	18	17	16
Santander	11	10	10	11	11	13	15	16	16	16	14	12	10
Segovia	1002	6	7	8	10	12	15	18	18	15	12	8	6
Sevilla	11	11	11	13	14	16	19	21	21	20	16	13	11
Soria	1063	5	6	7	9	11	14	17	16	14	11	8	6
Tarragona	69	10	11	12	14	16	18	20	20	19	16	12	11
Teruel	912	6	7	8	10	12	15	18	17	15	12	8	6

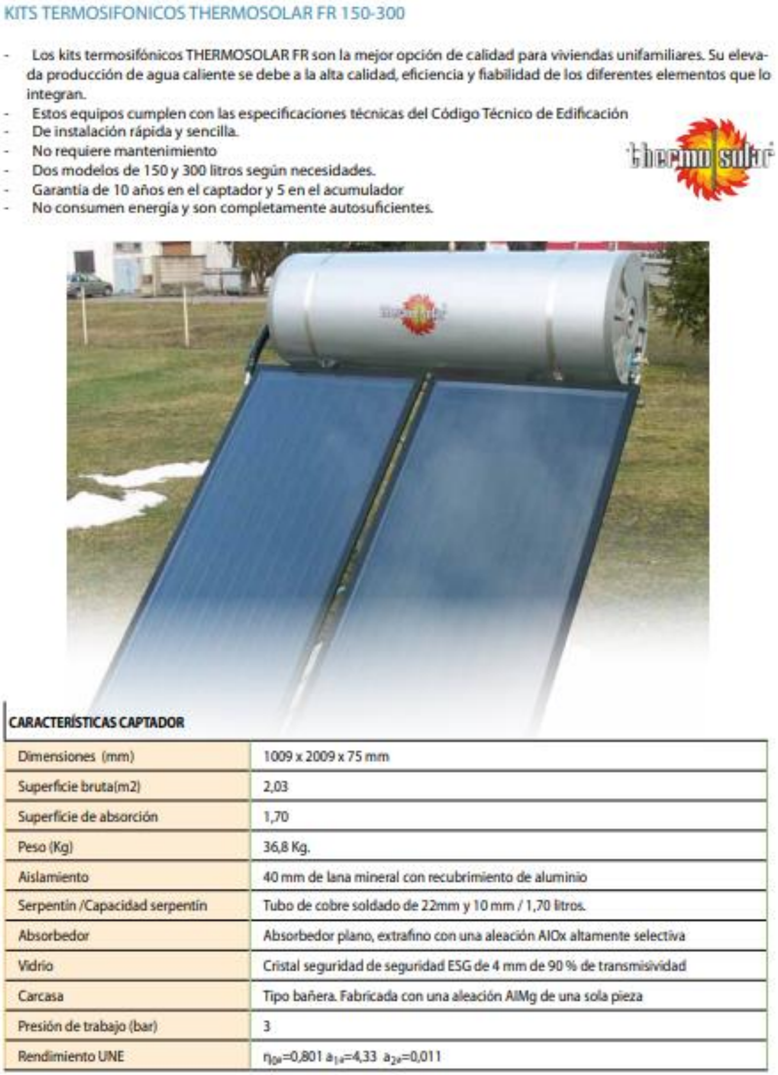
APPENDIX 3: TECHNICAL SPECIFICATIONS OF WIND+



Datos técnicos

Especificaciones técnicas	Wind 13+	Wind 25.2+	Wind 25.3+
Número de hélices	2	2	3
Diámetro	2,86 m	4,05 m	4,05 m
Material	Fibra de vidrio / Fibra de carbono		
Dirección de rotación	En sentido contrario a la agujas del reloj		
Especificaciones eléctricas			
Alternador	Trifásico de imanes permanentes		
Imanes	Neodimio		
Potencia nominal	1500 W	3000 W	5000 W
Voltaje nominal	220 v	220 v	220 v
RPM nominal	600	400	400
Velocidad de viento			
Rango de funcionamiento	2 - 30m/s		
Arranque	3 m/s		
Potencia nominal	12 m/s		
Frenado automático	14 m/s		
Máxima	60 m/s		
Especificaciones físicas			
Peso aerogenerador	41 kg	93 kg	107 kg
Bulto 1 (Aero.) - Peso	57 kg	135 kg	149 kg
Bulto 1 - Dimensiones (cm)	50x77x57	120x80x80	
Bulto 2 (Hélices) - Peso	6,8 kg	19 kg	22 kg
Bulto 2 - Dimensiones (cm)	153x27x7	220x40x15	260x40x15
Total - Volumen	0,23 m^3	0,90 m^3	0,91 m^3
Total - Peso	63,8 kg	154 kg	171 kg
Garantía	3 años		

APPENDIX 4: THERMOSIPHONIC KITS FR 150-300



KITS TERMOSIFONICOS THERMOSOLAR FR 150-300

- Los kits termosifónicos THERMOSOLAR FR son la mejor opción de calidad para viviendas unifamiliares. Su elevada producción de agua caliente se debe a la alta calidad, eficiencia y fiabilidad de los diferentes elementos que lo integran.
- Estos equipos cumplen con las especificaciones técnicas del Código Técnico de Edificación
- De instalación rápida y sencilla.
- No requiere mantenimiento
- Dos modelos de 150 y 300 litros según necesidades.
- Garantía de 10 años en el captador y 5 en el acumulador
- No consumen energía y son completamente autosuficientes.

CARACTERÍSTICAS CAPTADOR

Dimensiones (mm)	1009 x 2009 x 75 mm
Superficie bruta(m2)	2,03
Superficie de absorción	1,70
Peso (Kg)	36,8 Kg.
Aislamiento	40 mm de lana mineral con recubrimiento de aluminio
Serpentín /Capacidad serpentín	Tubo de cobre soldado de 22mm y 10 mm / 1,70 litros.
Absorbedor	Absorbedor plano, extrafino con una aleación AlOx altamente selectiva
Vidrio	Cristal seguridad de seguridad ESG de 4 mm de 90 % de transmisividad
Carcasa	Tipo bañera. Fabricada con una aleación AlMg de una sola pieza
Presión de trabajo (bar)	3
Rendimiento UNE	η_{0a}=0,801 a_{1a}=4,33 a_{2a}=0,011

KITS TERMOSIFONICOS THERMOSOLAR FR 150-300

CARACTERÍSTICAS ACUMULADOR	**150 L**	**300 L**
Cubierta exterior	Chapa galvanizada pintada	
Diámetro X Longitud (mm)	600 x 1400	600 x 1800
Material interior acumulador	Acero al carbono 2,5 mm	
Intercambiador	Acero al carbono 1,5 mm	
Tratamiento de tanque interior	Vitrificado 0,1 - 0,2 mm	
Protección catódica	Ánodo de magnesio de 30 cm	
Presión máx. tanque ACS (bar)	6	
Presión max. circuito primario (bar)	4	
Aislamiento	Espuma de poliuretano (42 Kg/m3) 50 mm	

ACCESORIOS INCLUIDOS	
Tuberias primario	Acero inox. Con coquilla elastomérica de 19 mm y funda enxterior anti UV
Valvulería	Vaso de expansión de 8L, válvula de seguridad de primario tarada a 5 bar, purgador, tapones, llave de llenado del primario, grupo de seguridad AFS (Válvula anti retrono y de seguridad)
Estructura de fijación	Sistema de fijación del conjunto para cubierta plana o inclinada en acero galvanizado de alta resistencia incluyendo tornilleria en acero inox. y guía de tubos.

REFERENCIA	**ARTÍCULO**
FR 150 L	Kit termosifónico con captador TS350 y depósito de 150 litros
FR 300 L	Kit termosifónico con 2 captadores TS350 y depósito de 300 litros