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Comparison of photovoltaic systems in Brno, Czech Republic and Gandía, Spain

TRABAJO FINAL DE GRADO

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Resumen

El principal objetivo del estudio es obtener información con respecto al uso de sistemas fotovoltaicos (FV) en dos localizaciones Europeas con distintas condiciones, no sólo climáticas sino también económicas. La localización se ha hecho en Gandía, costa este de España, con clima Mediterráneo y un elevado número de horas solares por año; y Brno, situada en el Este de la República Checa, con clima húmedo continental y un valor de horas solares menor. El estudio se realizará en dos viviendas similares con el mismo número de habitantes y equipamiento. Se tendrán en cuenta las diferencias en precio de electricidad y tasas de los dos países, con la intención de estimar si es viable la utilización de sistemas fotovoltaicos no sólo en zonas con clima favorable sino también en Europa central donde el número de horas solares está más limitado y el clima es más estricto. Ésta viabilidad estará afectada principalmente por la prima añadida a la electricidad generada con el sistema y se estudiarán cuatro modos de operación para estimar qué porcentaje de la electricidad producida se debería utilizar y que porcentaje vender.

Palabras clave

Sistema fotovoltaico, producción eléctrica, consumo.

Summary

The main objective of the study is to obtain data concerning the use of photovoltaic (PV) systems in two European locations with distinct conditions, not only climatic but also economic. This locations have been set as Gandía, east coast of Spain, with Mediterranean climate and high amount of solar hours per year, and Brno, east of Czech Republic, with a humid continental climate and less amount of solar hours. The study will be held in two similar households with the same inhabitants and equipment. There will be taken into account differences in prices of electricity and taxes of this two different countries, with the goal to see if its viable the adoption of photovoltaic solar systems into buildings, not only in areas with favourable weather but in central Europe in which the solar hours are more limited and the weather is more strict. This viability will be affected primarily by the bonus added to electricity generated with photovoltaic systems. In addition, four modes of operation will be studied to see the how much percentage of the electricity produced should be used and how much sold.

Key words

Photovoltaic system, electricity production, consumption.

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Abstract

The main objective of the study is to obtain data concerning the use of photovoltaic (PV) systems in two European locations with distinct conditions, not only climatic but also economic. This locations have been set as Gandía, east coast of Spain, with Mediterranean climate and high amount of solar hours per year, and Brno, east of Czech Republic, with a humid continental climate and less amount of solar hours. The study will be held in two similar households with the same inhabitants and equipment. There will be taken into account differences in prices of electricity and taxes of this two different countries, with the goal to see if its viable the adoption of photovoltaic solar systems into buildings, not only in areas with favourable weather but in central Europe in which the solar hours are more limited and the weather is more strict. This viability will be affected primarily by the bonus added to electricity generated with photovoltaic systems. In addition, four modes of operation will be studied to see the how much percentage of the electricity produced should be used and how much sold.

Key words

Photovoltaic system, Gandía, Brno, electricity production, electricity consumption, economic savings.

1. Introduction

People has been dependant of the sun since ancient times, some cultures even worshiped it as a god. As people's lives revolt around the sun, in the era of technology came to their minds a way of using the energy received from the sun as a source of useful energy. This energy can be thermic energy or in form of radiation. The one that interests us in this project is the energy transformed from radiation and this is possible thanks to the invention of the solar cells. The first cells where used by Daryl Chapin, Calvin Souther Fuller and Gerald Pearson in 1954 at Bell Laboratories. They were made using silicon and reaching an efficiency of 6%. This cells work on the principle of photoelectric effect. This effect is produced when a light shines upon a metal and electrons are emitted (discovered by Hertz and Hallwachs in 1887). (Physics 2000. *Photoelectric effect*, University of Colorado, Boulder, Colorado)

From this effect take the name the technology, named photovoltaic, from the Greek "photos" meaning light, and volt, which is the unit of electro-motive force, named after Alessandro Volta. Nowadays, using photovoltaic systems, it's possible to produce electricity, which is the form of energy that is more used around the world and is the energy which is used in all common appliances. Photovoltaic systems use energy directly from the sun, a renewable and inexhaustible source of energy, which means that the load in fossil fuels will be lower using this type of systems. The problematic of fossil fuels have made people realize that maybe searching for alternative energies will be the best solution for their energy problems in the future and that reason is why this project is being considered. (John Perlin, (1999). *From Space to Earth: the story of solar electricity*, Earthscan).

2. Main objective

The main goal of this project is, adding an alternative type of energy non-dependant from fossil fuels to feed the actual energetic necessities of the people in two regions of Europe with different climates, geographic locations and elevations over the sea level but inside a range of latitude with comparable specs. This two regions will be represented by Gandía from Spain with a Mediterranean climate and a latitude of 38º N and Brno from Czech Republic with a humid continental climate and a latitude of 49º N.

After describing the areas of the study and how a photovoltaic system works, there will be presented the chosen photovoltaic system from the selected company and its specifications.

From this point, the study and comparison of the two cities with the same system will be done and in the end will be presented the results. In this results will be attach an economic comparison of the system output and the viability study of the system in the two locations.

3. Site description, Gandía

3.1. Geographic location

The city of Gandía is located cartographically speaking, 0º 10' 38" West of Greenwich and 38º 58' 06" North. Its UTM coordinates are X = 744522 Y = 4315859 Z = 31.

The municipality is situated in the east coast of Spain, in the south part of the Valencian province, 63 Km from the capital, being part of the region called "La Safor", region that constitutes the south-east end of the province. In the next figure can be seen the localisation of Gandía where the star is.

Figure 1. Geographic location of Gandía.

3.2. Area

The surface area is about 61.45 Km^2, which means the 0.2636% of the total area of the province. The altitude of the area goes from the sea level up to 840 meters at Montdúver peak, located at the North – West end of the municipality. The mean altitude of the urban area is 22 meters. The municipality borders with the municipalities of "Xeraco" and "Xeresa" on the North, the Mediterranean Sea and the municipalities of “Daimús”, “Guardamar de la Safor” and “Miramar” at the East, the municipalities of “Barx”, “Pinet” and “Lluxent” at the West and “Ador”, “Palma de Gandía” and “Real de Gandía” at South. Also inside the municipality there is a minor municipality called “Benirredrá” with an area of 40 hectares (0.4 Km^2). (Ajuntament de Gandía, *Agenda 21 Gandía*, Provisional release)

3.3. Population

Gandía’s population in 2013, based on the National Institute of Statistics (INE) in Spain, is 78,543 people, but the floating population is estimated in 120,000 people due to being the capital of the region and people from the surrounding towns coming to work. It’s the seventh most populated city in all Valencia and one of the most important ones, not only because of its long history but also because it’s situated in the border of the Valencian province and Alicante province. Gandía is a touristic city and one of the principal touristic places of Spanish population. Mainly in summer and Easter the population of Gandía grows up to 400,000 people.

The city is divided in eleven districts:

- Beniopa.
- El raval.
- Corea.
- Benipeixcar.
- Historic centre.
- Santa Ana.
- Marchuquera.
- Roís de Corella, hospital and adjacents.
- Gandía’s beach.
- Elliptic square and Argentine Republic neighbourhood.
- Grao, Venice and Rafalcaïd.

3.4. Climatology

The municipality of Gandía belongs to a humid Mediterranean climate, but its localisation and altitude above the sea level, make temperatures in winter and summer to be soft. The annual average temperature is 18ºC with 9-11ºC in winter and 25-26º in summer. The annual precipitation is 700-800 L/m^2 being distributed between 66 days of rain, 9 days of storms and 1.06 days of hails. The rainiest months are October and November in autumn and April in spring, the driest month is July. January is the coldest month with 11ºC and the hottest is August with 26ºC average from historic data, 2013 has been one of the hottest years bringing maximum temperatures up to 40ºC in summer and in the past winter the minimum temperatures never dropped 9ºC, which is a 4ºC difference. The average amount of sunshine hours per year is 2,700 h, with the sunniest months being July and August with over 300 monthly hours of sun and the darkest months January and December with 120 and 140 monthly hours of sun. (Perez Cueva, Alejandro J. *Atlas climático de la Comunidad Valenciana*, 1994, Conselleria d'Urbanisme, Obres Públiques i Transports)

3.5. Orography

Gandía its characteristic for having a relief with violent contrasts, without intermediate transition forms. It has only two relief categories, separated with a well-defined trace: the mountain area and the alluvial plain.

3.5.1. The mountain area

The highest mountain of the municipality is called Montdúver and goes in NW-SE direction and across the West and South-West borders of the municipality. In relationship with the municipality the mountain areas are called occidental, oriental, and central.

The occidental area it's an abrupt area with over 30% slopes and few plain spots in isolated places. In this area is where the highest peak of these mountains is located up to 840m.

The oriental area has a softer relief and eroded and short forms, and although it's slopes are over 30%, the highest part of them have a shape of a hill with great plains or areas with low or inexistent slope. In this area the highest points are at Xeresa's peak (267m), el Plá Gran (220m), Santa Anna mount (108m) and mount Bayren (108m).

The central area it's composed by Falconera mountain range which emerges from the alluvial plain with its biggest axis in NW-SE direction. It has an abrupt relief similar to occidental area, mostly in the West part with slopes bigger than 30%. The most characteristic landforms are Molló de la Creu (454m), the Crag of the Yedra (332m) and its East spur is known as Mount of Saint Anthony.

3.5.2. The alluvial plain

The other big category of the relief is extended at the oriental part of the territory and contains the area of the alluvial grounds with deposits from erosion of the avenues, rivers and canyons which have compacted the lateral alluvial fans.

The area of the alluvial plain is divided in five areas with very specific geomorphologic character.

- High Marxuquera, it's the area situated west of the municipality. Limited by the occidental and central mountain areas and the municipalities of Ador and Palma de Gandía.
- Low Marxuquera, it's the area situated in the central-west part of the municipality.
- The plain, it's the area situated in the central-south oriental part of the territory and it's limited from the west by the Falconera mountain range, low Marxuquera, mount of Santa Anna and Mount Bayren. From the north it's limited by the king's gutter and the national road N-337. From the east it's the Mediterranean coast and the municipalities of Daimús, Guardamar de la Safor and Miramar and from the south the municipalities of Real de Gandía, Benirredrá, Almoines and Bellreguard. In this area is where the principal urban area is situated.
- The Marsh, it's the northern area of the territory, limited by the national road N-332 from the west, the municipality of Xeresa from north, the national road N-337 from the south and the Mediterranean coast from the east.
- The coast, it's the eastern part of the territory and has a variable width of 600 to 850 meters and 7,800 meters long.

(Ajuntament de Gandía, *Agenda 21 Gandía*, Provisional release)

3.6. Hydrology

The municipality of Gandía its part of the Serpis river basin and its tributary river Vernisa. The city lies in between this two rivers plains at 3 kilometres far from the Mediterranean Sea, up to the river mouth of both the rivers. Due to the irregularity in the precipitations in that area the rivers have a torrential character.

3.6.1. The Serpis River

It's the most important river in the area and the source of fresh water that gets stored in the marsh and in the underground water reservoir. Its river bed flows from the south and borders the city from the east, separating it from the municipality of Daimús. The river mouth it's situated south of Gandía's harbour.

3.6.2. Marxuquera's ravine

This ravine reaches the city and separates the district Beniopa from the rest of the city. It comes from the mountains of the west territory bringing the rainfall from that area. As it travels changes its name, at the river birth it's called Marxuquera's ravine, when it reaches the city is called Beniopa's ravine or avenue and when it reaches the harbour it's called Saint Nicholas' ravine.

3.6.3. Dams and ditches

The water from the Serpis River it's stored in two principal dams, Villalonga dam and en March dam. From Villalonga dam the water is divided in seven water lines, two of them go together to the north part of the municipality and the other five get divided and become the Common drain of Gandía and Oliva.

(Ajuntament de Gandía, *Agenda 21 Gandía*, Provisional release)

3.7. Economy

The economy of the municipality lies basically in the service sector, being the most important city of the region, having big malls and residential and holidays housing areas. The percentage of distribution of the economy is as it follows:

- Services 78.3%
- Construction 14.8%
- Industry 4.2%
- Agricultural 2.7%

This data is extracted from INE for 2008.

4. Site description, Brno

4.1. Geographic location

The city of Brno is located cartographically speaking, 16º 38' 0" East of Greenwich and 49º 12' 0" North. Its UTM coordinates are X= 573142, Y= 5427937, Z= 33. The city area is situated in the south east part of the Czech Republic, in the Moravian Region, 200 km far from the capital of the country, Prague. The next figure shows where Brno is situated inside Czech Republic with a star.

Figure 2. Geographic situation of Brno.

4.2. Localization

Brno is situated at the crossroads of the ancient trade routes as a part of the Danube basin region. The city is connected with Vienna, which is 110 km south. Brno is located in the south-east part of the Czech Republic, at the confluence of the Svitava and Svratka rivers, and there are also several brooks flowing through it including the Veverka, Ponávka and Říčka. The Svratka River flws through the city for about 29 km, the Svitava River cuts a 13 km path through the city. The length of Brno is 21 km measured from the east to the west, and its overall area is 230 km^2. Inside the city limits there is the Brno Dam Lake, several ponds and other standing bodies of water, like the reservoirs in the Marian Valley or the Žebětín Pond. Brno is surrounded by woody hills from three sides, a significant part of the area of the city is forest, reaching 6,479 ha or what is the same, 28% of the area. Due to being located between the Bohemian-Moravian Highlands and the Southern Moravian lowlands, Brno has a moderate climate, compared to other cities in the country with a very high air quality thanks to the good natural air circulation. (Filip, Aleš (2006). *Brno – city guide*. Brno: K-Public).

4.3. Climatic conditions

The climatic conditions of Brno are mild but diverse throughout the whole year. This diversity of the climate is influenced by several factors, where one of the most important ones is the influence of elevation above the sea level. With the elevation, the air temperature slopes goes down, being in Czech Republic approximately 0.6 ºC per 100 meters and rainfall increases. The region has the rainiest places situated in the highest mountain ranges in the slopes towards north-west and the driest places can be found in south-east Moravia. In this last region is where Brno is situated. The highest monthly rainfall totals can be measured in summer, while February and March are the driest. (Homolková, Jana, Ondroušková, Zdenka, *Závěrečná zpráva z terénního cvičení Brno ţivotní podmínky*, 2011 Masaryk University of Brno).

The city of Brno is situated in the so called area A3 in the warm area A of Moravia. According to the wide and diverse natural base, the city belongs to the warmer areas of the Czech Republic, where the rainfall totals are smaller. The city of Brno is immersed in a microclimate thanks to the segmenting landscape, the air temperature, the rain and the wind. Under the Köppen climate classification, Brno has a borderline oceanic climate (Cfb) and a humid continental climate (Dfb) with cold winters and warm, mild summers. The average annual temperature ranges 7ºC to 11ºC being January the coldest month with an average minimum temperature of -5.2ºC and July being the hottest month of the year with an average of maximum temperature of 24.5ºC. Controversially, the driest month of the year doesn’t correspond to the hottest, but to February and March with a precipitation of 23.8 and 24.4 mm each. The rainiest months are June and July with a rainfall of 72.2 and 63.7 mm respectively. The average annual precipitation is between 400 and 600 mm being around 500 in the last years. The average number of precipitation days is 150, the average cold days with the minimum temperature below 0ºC is approximately 100-120 and 25-40 days where the maximum temperature doesn’t reach 0ºC. In summer, the minimal temperature is around 14-16ºC and the maximum temperature is 25ºC. The amount of summer days is around 60 but more commonly 50-55 days.

The city of Brno belongs to one of the warmest areas of Czech Republic with the highest concentration of sunshine. There are approximately 50-250 hours of sunshine per month, reaching an average of 1,770 hours of sunshine per year. The sunniest months in the year are June and July, corresponding to summer and reaching up to 345 solar hours per month. The darkest months of the year are December and January with 31 to 45 hours of sun in the entire month. (World meteorological organization).

4.4. Orography

Brno elevation above the sea level varies from 190 m to 425 m and the highest point in the area is the Kopeček Hill. There are dozens of legally protected areas which are protected because of their ecological or natural values, like the Moravian Karst, Stránská Skála, and others.

4.5. Demography

Brno is the former capital city of Moravia and the political and cultural hub of the South Moravian Region. The city has over 400 thousand residents. Its urban agglomeration has approximately 450 thousand residents and its larger urban zone has a population of about 730 thousand while its greater metropolitan area is home to more than 800 thousand people out of the 1.2 million people that live in the South Moravian Region. (Adresy v České republice: Brno. Ministry of the interior of the Czech Republic. Retrieved 23 January 2011).

The city itself form a separate district, the Brno-City District, surrounded by the Brno-Country District. Brno is divided into 29 administrative divisions or city districts, and consists of 48 cadastral areas. The city districts of Brno vary in their size of population and area. The most populated city district of Brno is the Brno-Centre which has over 91 thousand residents and the less populated are Brno-Ořešín and Brno-Útěchov with 500 residents. By its area, the largest one is Brno-Bystrc with 27.24 square kilometres and the smallest is Brno-Nový Lískovec with 1.66 square kilometres. The districts names are Bohunice, Bosonohy, Bystrc, Brno Centre, Cernovice, Chrlice, Ivanovice, Jehnice, Jundrov, Kníničky, Kohoutovice, Komín, Královo Pole, Lesná, Líšeň, Maloměřice and Obřany, Medlánky, Brno North, Nový Lískovec, Ořešín, Rečkovice and Mokrá Hora, Slatina, Brno South, Starý Lískovec, Tuřany, Utěchov, Vinohrady, Zabovřesky, Zebětín and Zidenice. (Homolková, Jana, Ondroušková, Zdenka, *Závěrečná zpráva z terénního cvičení Brno ţivotní podmínky*, 2011 Masaryk University of Brno).

4.6. Administration

Brno is a statutory city, it consists of 29 city districts or administrative divisions. The highest body of its self-government is the Assembly of the City of Brno. The city is headed by the Lord Mayor and has the right to use the mayor insignia to represent the city outwards. The executive body is the city Council and local councils of the city districts. The City Council has 11 members including the Lord Mayor and his four deputies. The head of the Assembly of the City of Brno in personal matters is the Chief Executive who, according to certain special regulations, carries out the function of employer of the other members of the city management. The Chief Executive is directly responsible to the Lord Mayor. Brno is the home of the highest courts in the Czech judiciary. The Supreme Court is on Burešova Street, the Supreme Administrative Court is on Moravské náměstí, the Constitutional Court is on Joštova Street and the Supreme Public Prosecutor's Office of the Czech Republic is on Jezuitská Street. (Filip, Aleš (2006). *Brno – city guide*. Brno: K-Public).

5. Photovoltaic systems description and specifications

Solar photovoltaic energy it's a technology that generates direct current, potency measured in watts or kilowatts, via semiconductor materials when they are illuminated with a beam of photons. The basic and individual element is called photovoltaic cell and when solar light shines upon it, electric power is generated, when the light disappears the electricity disappears also. This photovoltaic cells don't need to be charged like batteries and its utility life goes from twenty to thirty years.

Solar photovoltaic energy has advantages and disadvantages both technical and non-technical. When used in power plants this energy has disadvantages and advantages completely opposite to conventional non-renewable power plants. This energy has the technical advantages of not producing any dangerous waste or emissions for the environment, its cost comes determined by the inversion and it doesn't grow over time. As for the disadvantages, the energy produced it's very difficult to store. (Intelec Ingeniería, *Estimación de la energía generada por un sistema fotovoltaico conectado a la red*, 2011)

As for non-technical advantages and disadvantages, referred to economical or infrastructure, can be compensate thanks to the acceptation of the public and the benefits for the environment.

Table 1. (Colegio oficial de ingenieros de telecomunicación, *Energía solar fotovoltaica*, Madrid.)

Advantages	Disadvantages
Clean, renewable, infinite, silent	Big initial inversion
Bonuses to the price when sold to the grid	Manufacture process of modules expensive and complex
Subsidy	Difficult storage
Short pay-back of the energy	Low competitiveness with the actual energy
Without moving parts and modular	Not stable production depending of the climatology and time of the year.

5.1. Basic physical concepts about photovoltaic conversion

The solar cells are made from semiconductor materials, which contain weakly bound electrons occupying a band of energy called valence band. When a quantum of energy over certain value is applied to an electron of valence, the bond is broken and the electron goes to a new band of energy called conduction band. Through a selective contact, this electrons can be transported to an external circuit and realize a useful work, losing its energy captured and returning towards the initial valence band through another contact.

This electron flow in the external circuit is called cell current and its product, generated by the voltage produced when electrons are set free by the selective contacts, establish the power generated. Heat is not required in this process because all of this occurs at ambient temperature and without moving parts, because the solar cells which convert only a part of the energy from the photons into electricity only get heated 25 – 30 ºC over the ambient temperature.

In the application of photovoltaic energy this cells are interconnected and enclosed inside photovoltaic modules, which is the product that the consumer is going to buy. This modules produce direct current (DC) and gets transformed into alternate current (AC), which is more useful, by the means of an electronic dispositive called invertor. This invertor, the rechargeable batteries, in case of storage needed, the structures needed to mount and orient the modules and other basic elements needed to build a photovoltaic system (PVS) are called BOS, Balance of System. (Endecon Engineering, *A guide to photovoltaic system design and installation*, 2001, California Energy Comission).

The principal semiconductor used in the fabrication of photovoltaic cells is silicon, and this is because it's the second most abundant material in the Earth crust and for the previous knowledge of the material attained by its use in microelectronics. From the point of view of photovoltaic, the value of its gap band (1.1 eV) is very adequate for the conversion of solar light into electricity. Thanks to being a semiconductor with an indirect band, a notorious thickness is needed, around 100 microns, to absorb the light, but its fragility determines that the solar cells are being built into wafers of 300 microns.

In order to not let the elevated electrons to the conduction band don't come back to the band of valence before we can get some useful work out of them, the material has to be of high purity and have a high structural perfection. That is why a material with microelectronic quality is used and made into monocrystalline wafers.

This solar cells are then connected electrically and encapsulated as a module. This modules have often a sheet of glass on the front side, allowing light to pass while protecting the semiconductor wafers from abrasion and impact of wind-driven debris, rain or hail, etc. solar cells are usually connected in series in modules, creating additive voltage. Connecting cells in parallel will yield a higher current, however, very significant problems exist with parallel connections. If for example, shadow effects such as tree branches or buildings can shut down the weaker or less illuminated parallel string (a number of cells connected in series) causing substantial power loss and even damaging the weaker string because of the excessive revers bias applied to the shadowed cells by their illuminated partners. Strings of series cells are usually handled independently and not connected in parallel. Although modules can be interconnected to create an array with the desired peak DC voltage and loading current capacity, using independent MPPTs (maximum power point trackers) provides a better solution. In the absence of paralleling circuits, shunt diodes can be used to reduce the power loss due to shadowing in arrays with series/parallel connected cells. This modules are joint together into photovoltaic panels, which are arrays of modules connected summing up the unitary voltage of every module. (Endecon Engineering, *A guide to photovoltaic system design and installation*, 2001, California Energy Commission).

5.2. Photovoltaic system components.

The photovoltaic systems can be used, apart from producing electricity in big facilities, to produce electricity in a house. Usually this houses are connected to the grid and the photovoltaic system is used to supply a part of the electrical consumption of the house. This system can be also connected to the grid and inject the excess of the electricity produced in order to sell it to the distributors gaining that way an extra income. The basic components are:

- PV Array: A PV Array is made up of photovoltaic modules, which are environmentally-sealed collections of photovoltaic cells. The most common photovoltaic module that is 0.46 to 2.30 m^2 in size and weighs about 1.3-1.8 kg/m^2. Often sets of four or more smaller modules are framed or attached together by struts in panels so it is easier to handle them on a roof. This allows some assembly and wiring functions to be done on the ground if called for by the installation instructions.
- Balance of system equipment (BOS): BOS includes mounting systems and wiring systems used to integrate the solar modules into the structural and electrical systems of the home. The wiring systems include disconnects for the dc and ac sides of the inverter, ground-fault protection, and overcurrent protection for the solar modules. Most systems include a combiner board of some kind since most modules require fusing each module source circuit. Some inverters include this fusing and combining within the inverter enclosure.
- DA-AC inverter: this is the device that takes the DC power from the photovoltaic array and converts it into standard AC power used by the house appliances.
- Metering: this includes meters to provide indication of system performance. Some meters can indicate home energy usage.
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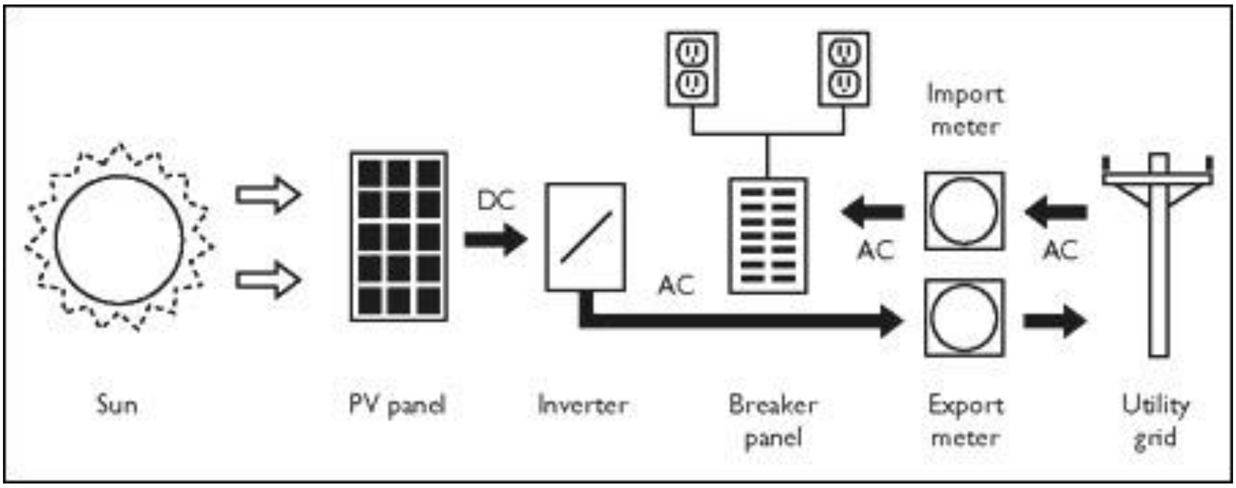

Figure 3. PV system components. (http://www.cmhc-schl.gc.ca/en/co/grho/grho_009.cfm)

Depending if the system is a stand-alone or have a battery backup in order to store the energy before releasing it to the grid or using it in afterhours it will need other components. This type of system incorporates energy storage in form of a battery to keep “critical load” circuits in the house operating during utility outage. When an outage occurs the unit disconnects from the utility and powers specific circuits in the home. These critical load circuits are wired from a subpanel that is separate from the rest of the electrical circuits. If the outage occurs during daylight hours, the photovoltaic array is able to assist the battery in supplying the house loads. If the outage occurs at night, the battery supplies the load. The amount of time critical loads can operate depends on the amount of power they consume and the energy stored in the battery system. A typical backup battery system may provide about 8 kWh of energy storage at an 8-hour discharge rate, which means that the battery will operate at 1 kW load for 8 hours. A 1 kW load is the average usage for a home when not running air conditioner. (Colegio oficial de ingenieros de telecomunicación, *Energía solar fotovoltaica,* Madrid.)

A system with backup batteries incorporates apart from the basic components, batteries and battery enclosures, battery charge controller and separate subpanel for critical load circuits.

Charge controllers: is the most important component in photovoltaic systems which use batteries. It is the brain of the system, responsible for performance, durability and functions. Charge controller or solar regulator coordinate the main components of any off-grid or battery dependent system: photovoltaic generator, batteries and loads. The common voltages are 12/24V and 48V, which means the voltage of system batteries. The two main types of charge controller are pulse-width-modulation (PWM) and maximum power point tracking (MPPT). The main difference comes from the charging mode. (Endecon Engineering, *A guide to photovoltaic system design and installation,* 2001, California Energy Commission).

PWM charge controller reduces the voltage from the photovoltaic module to that of the battery, resulting in a decrease in efficiency. This charge controller works based on 1/2/3 or 4-stage charging method. Switching between constant stages according to the occurring PV voltage and current. PWM charge controllers are less expensive than MPPT charge controllers and are an ideal solution for smaller photovoltaic systems where the price can be a critical point or where the maximum efficiency and additional power is not really needed.

MPPT charge controllers have two fundamental advantages over PWM, system efficiency and applicable for big photovoltaic panels. The MPPT charge controllers allow photovoltaic modules to operate at their higher optimum voltage in varying light conditions: summer, winter, morning, noon, cloudy, etc. This charge controller takes the voltage output of the solar panels and compares it to the battery voltage. It figures out what is the best voltage to get the maximum current into the battery. Or said in another way, the MPPT charge controller tracks the best voltage level and then down converts it to the voltage of batteries. It calculates in real-time the optimal charging parameters, continuously by its internal algorithm. This tracking of the optimal power point improves performance by as much as 30% in annual energy production compared with the PWM charge controller.

In cold weather, cloudy or hazy days as in fall, winter or spring, and in low temperature conditions, this system works with more efficiency. A photovoltaic module works better at low temperatures and MPPT is utilized to extract the maximum power available from the module.

Wiring and voltage management: connecting several photovoltaic modules in string, the system voltage can be minimized by parallel connection. In series connection the voltage will be added up. Connecting panels in parallel, the voltage will remain the same, and it’s very important in off-grid systems, where the max photovoltaic voltage may have a significant influence on system efficiency and system design and cannot be exceeded. While in off-grid systems parallel connections are typical, in grid-connected systems are a waste of potential because there is no need to control the voltage in order to maintain the batteries with health. (Endecon Engineering, *A guide to photovoltaic system design and installation*, 2001, California Energy Commission).

Batteries: there are two basic types of batteries that are available for use in a standard solar energy production system: sealed batteries and flooded lead acid batteries. Sealed batteries require only little maintenance in order to keep them working properly but the flooded lead acid batteries have longer lifespan.

The working process of a solar battery is measured in cycles. This means when the battery is discharged and then recharged back to its full level and how much is the battery discharged is called the depth of discharge. Deep solar batteries are designed to be repeatedly discharged and recharged in cycles, where up to 80% of the battery capacity is used up. Deep solar batteries are dedicated for solar photovoltaic systems and in systems above approximately 200Ah capacity. A shallow cycle battery is when 20% or less of the battery capacity is discharged and recharged. This batteries are designed to give up lots of power over a short period of time and are used in cars and vehicles and are less suited for photovoltaic systems. (Endecon Engineering, *A guide to photovoltaic system design and installation*, 2001, California Energy Commission).

5.3. Mounting options

The photovoltaic system requires an open space without shades, stable and flat. Most photovoltaic systems produce 15 to 45 Watts per square meter of array area. A typical 2 kW photovoltaic system will need 20 to 40 square meters approximately of unobstructed area to site the system. Consideration will be given to accessibility to the system in order to attach it or repair it and can add up to 20% more area needed to the mounting area.

5.3.1. Roof mount

Often the most convenient and appropriate place to put the photovoltaic array is on the roof of the building. It’s the place in which the photovoltaic array will have no shade and it has a big unused area. The photovoltaic array may be mounted above and parallel to the roof surface with a standoff of several centimetres for cooling purposes. This is not necessary in northern countries because the modules don’t reach amounts of heat enough to decrease the performance. Sometimes in flat roofs, a separate structure with a more optimal tilt angle is mounted in order to attain the maximum efficiency of the system.

Particular attention must be paid to the roof structure and the weather sealing of the roof perforations. For new construction, support brackets are usually mounted after the decking is applied and before the roofing materials are installed.

Masonry roofs are often structurally designed near the limit of their weight-bearing capacity. In this case, the roof structure must either be enhanced to handle the additional weight of the photovoltaic array system or the masonry roof transitioned to composition shingles in the area where the photovoltaic array is to be mounted. By transitioning to a lighter roofing product, there is no need to reinforce the roof structure since the combined weight of composite shingles and photovoltaic array is usually less than the displaced masonry product.

Figure 4. Roof mounted photovoltaic panels.
(http://www.acclaimimages.com/_gallery/_image_pages/0480-1009-1811-1819.html)

5.3.2. Shade structure

An alternative to roof mounting is to mount the system as a shade structure. A shade structure may be a patio cover or deck shade trellis where the photovoltaic array becomes the shade. These shade systems can support a small to large photovoltaic systems. The construction cost with a photovoltaic system is no different than for a standard patio cover, especially if the photovoltaic array acts as part of the entire shade roof. If the photovoltaic array is mounted at a steeper angle than a typical shade structure, additional structural enhancements may be necessary to handle the additional wind loads. The weight of the photovoltaic array is 5 to 7 kg/m^2, which is well within structural limits of most shade support structures. The avoided cost of installing roof brackets and the associated labour could be counted towards the cost of a fully constructed patio cover. The overall cost of this option will likely be higher than roof mounting, but the value of the shade often offsets the additional costs. Building a shade mounted photovoltaic array is not always possible and it needs some considerations to have into account. The access to the array for maintenance will be simplified and if the roof is a terrace will leave more open space for other activities but the module wiring has to be concealed to keep the installation safe and aesthetically pleasing, when the roof mounting photovoltaic array doesn’t have any need to conceal wiring. It is not possible to grow vines or if possible it has to be done very carefully and trimmed back from the modules and wiring in order to prevent fires and malfunction.

Figure 5. Shade mounted photovoltaic panels. (http://www.solar-installation-pros.com/solar-carport.php)

5.3.3. Building-integrated photovoltaic array (BIPV)

It’s another type of system that displaces the conventional roof mounting products with building-integrated photovoltaic modules. Commercially available products currently include roof slates, similar to masonry roofing, and standing seam metal roofing products. Special attention must be paid to ensure that these products are installed properly and carry the necessary fire ratings. The inclusion of this type of arrays need to be done in new buildings and its construction has to be approved in the plans of the building. One advantage that this photovoltaic array have is that the initial inversion can be offset by reducing the amount spent on building materials and labour that would normally be used to construct the part of the building that the building-integrated photovoltaic modules replace.

The most widely installed building-integrated system to date is a thin film solar cell integrated to a flexible polymer roofing membrane. Pitched roofs use modules shaped like multiple roof tiles, using solar shingles. This shingles are modules designed to look and act like regular shingles, while incorporating a flexible thin film cell. This pitched roof extends the normal roof life by protecting the insulation material and membranes from ultraviolet rays and water degradation by eliminating condensation thanks to the dew point being kept above the roofing membrane. Another type of building-integrated system can be installed in facades and can be installed on existing buildings, not only new ones, giving old buildings a new look and valorisation. These modules are mounted on the facade of the building, over the existing structure. Other type can be used in glazing, using semi-transparent modules to replace architectural elements commonly made with glass or similar materials, such as windows and skylights.

Figure 6. BIPV (http://www.tomshardware.com/reviews/technical-foundations-diy-solar-powered-pc,1680-5.html)

5.4. System output

Photovoltaic systems produce power in proportion to the intensity of sunlight striking the solar array surface. The intensity of light on a surface varies throughout a day, as well as day to day, so the actual output of a solar power system can vary substantially. There are other factors that affect the output of a solar power system and have to be taken into account when the system is going to be designed. These factors need to be understood so that the expectations match the reality of the project for an overall system output and economic benefits under variable weather conditions over time. (Intelec Ingeniería, *Estimación de la energía generada por un sistema fotovoltaico conectado a la red*, 2011).

5.4.1. Factors affecting the output

Standard Test Conditions: solar modules produce DC electricity and this DC output is rated by manufacturers under Standard Test conditions or STC. These conditions are easily recreated in a factory, and allow for consistent comparisons of products but need to be modified to estimate output under common outdoor operating conditions. STC conditions are: solar cell temperature = 25ºC, solar irradiance or intensity =1000 W/m^2 which is often referred to as peak sunlight intensity, comparable to clear summer noon time intensity and solar spectrum as filtered by passing through 1.5 thickness of atmosphere.

Temperature: the output power of the module gets reduced as the temperature of the module increases. When operating on a roof, a solar module will heat up substantially, reaching inner temperatures of 50- 75ºC. For crystalline modules, a typical temperature reduction factor is 89% or 0.89. So if the module is a 100-watt module it will have a decreased performance of 11% in the middle of a spring or fall day, under full sunlight conditions.

Dirt and dust: dirt and dust can accumulate on the solar module surface, blocking some of the sunlight and reducing the output. If the place of the installation has rainy seasons the typical dirt and dust will be cleaned off during every rainy season but it’s not realistic to assume that all the dirt and dust will be gone so it is necessary to apply another factor to better estimate the output.

Mismatch and wiring losses: the maximum output of the total photovoltaic array is always less than the sum of the maximum output of the individual modules. The difference is a result of slight inconsistences in performance from one module to the next and is called module mismatch and amounts to at least 2% loss in system power. Power is also lost to resistance in the system wiring. These losses should be kept to a minimum but it is difficult to keep these losses below 3% for the whole system.

Dc to AC conversion losses: the DC power generated by the solar module must be converted into common household AC power using an inverter. Some power is lost in the conversion process, and there are additional losses in the wires from the rooftop array down to the inverter and out to the house panel. Modern inverters commonly used in residential photovoltaic power systems have peak efficiencies of 92-94% indicated by their manufacturers, but these again are measured under well-controlled factory conditions. (Intelec Ingeniería, *Estimación de la energía generada por un sistema fotovoltaico conectado a la red*, 2011).

5.4.2. System energy output:

During the course of the day, the angle of sunlight striking the solar module will change, which will affect the power output. The output will rise from zero gradually during dawn hours and increase with the sun angle to its peak output at midday, and then gradually decrease into the afternoon and back down to zero at night. While this variation is due in part to the changing intensity of the sun, the changing sun angle, relative to the modules, also has an effect.

The pitch of the roof will affect the sun angle on the module surface, as will the East-West orientation of the roof. For the northern hemisphere, the optimal roof direction is south while north is the worst roof direction. In case of having north faced roof it is recommended to alternatively mount the photovoltaic array in shade or walls facing south. If the roof is flat, an additional structure is needed to reach the desired angle. This structure can be made to be adjustable in order to gain more power through the year. Usually in houses the panels are fixed, because is cheaper to install and maintain and the initial inversion can be too high for a normal home and the improvement won't make it worth it. If to this disadvantages are added the difficulty of repairs due to being roof mounted or the extra weight, the addition of mobile parts can be considered a luxury not necessary.

Often the books and articles on solar energy give the advice that the tilt should be equal to the latitude of the site, plus 15 degrees in winter or minus 15 degrees in summer. Because the sun is higher in the summer and lower in the winter, the energy captured won't be the same during the whole year if the tilt is fixed. The tilt can be fixed as 2 seasons, 4 seasons or 2-axis tracker. Changing the tilt in two seasons means adjusting it in summer and winter, which are the seasons that change most the sun's angle. Changing the tilt in four seasons means adjusting it every season, which means only a small improvement and it is not worth in Europe. Tracking the sun with a 2-axis system means having the modules facing directly the sun at any time of the day and the year having the maximum output. From the fixed tilt to the 2 seasons adjustment tilt, the improvement of performance will be approximately of 4% (National Renewable Energy Laboratory), adjusting it 4 seasons will improve the performance less than 1% from the 2 season adjustment, which means that the boost of energy output will improve meaningfully in the 2 season adjustment but not worth the 4 season.

Adjusting the tilt twice a year will be made, in the northern hemisphere, on March 30 to adjust the summer angle and on September 12 to adjust the winter angle in order to get the full season with the optimal angle. The formula to calculate the best tilt is 0.93 times the latitude minus 21 degrees for summer and 0.875 times the latitude plus 19.2 degrees for winter in the range of 25º-50º latitude.

If the photovoltaic panels will have a fixed tilt angle, it will depend of what are the energy demands of the house over the whole year. Normally, for a latitude between 25º and 50º the formula is 0.76 times the latitude plus 3.1 degrees. If the highest energy demands are required in winter, it is better to adjust the tilt angle to capture the highest energy in this season. It will be relatively efficient, capturing 81-88% of the energy compared to optimum tracking. In spring and autumn the efficiency will be lower and in summer will be the lowest due to the bigger difference in angle and because the sun travels more area in the sky in this season. The energy produced during the other seasons will be enough while producing more energy in the needed season. For southern and central Europe latitudes, this setting will be recommended due to the high performance. In latitudes close to 50º the amount of isolation that the panels will receive in the other seasons will be over 150% of the winter isolation, which means, that they will produce more energy than needed even with the winter setting. (Landau, Charles R., Optimum tilt of solar panels, 2014, http://www.solarpaneltilt.com/).

6. Chosen photovoltaic system

The system chosen for the study will be a pre-arranged system that the company Techno sun offers in their price list of products. This pre-arranged system includes all necessary complements for the photovoltaic modules to work and it will ensure that all the components are compatible and the losses are kept to a minimum. This pre-arranged system is Auto Sun System DANFOSS DLX2.0/STP250 (flat cover) - TECHNO SUN with 2.0 kW of power and serial number of 711-DLX2-STP250P. (Techno Sun, Specialized Solar Energy Company, http://www.technosun.com/uk/index.htm).

The system includes an inverter with 2kW of reactive power without fuses, 10 monocrystalline silicon modules of 250W each from SUNTECH manufacturer, 6 aluminium rails, 24 clamps and 4 unions, 14 grounding connectors and 24 adjustable legs. The total price of the system is 4,125.28 € (113,321.44 Czk).The serial numbers, prices and components prices are described in the following table with unitary prices.

Table 2. System components, serial number and prices.

Serial number	Pcs	Description	Price (€/Czk)
711-DLX2-STP250P	2.0 kW	Auto Sun System DANFOSS DLX2.0/STP250 (Flat Cover) – TECHNO SUN	4,125.28 / 113,321.44
305.02.01.DLX2.0	x1	Red Inverter 2.0kW reactive power, without fusses DLX2.0kW - DANFOSS	704.88 / 19,363.05
619.01.01.STP250	x10	Monocrystalline module 250W – STP250S-20/Wd(T) - SUNTECH	295.40 / 8,114.63
659.08.01.RAIL4200	x4	Aluminium rail for PV 4.20m – TECHNO SUN	32.77 / 900.19
659-RAIL-210	x2	Aluminium rail for PV 2.10m – TECHNO SUN	15.91 / 437.04
659.08.01.ENDF50	x8	End fixation for panel 50mm – TECHNO SUN	1.07 / 29.39
659.08.01.INTERF50	x16	Fixation in T between panels 50mm – TECHNO SUN	1.07 / 29.39
659.08.01.SPLICE	x4	Rail union – TECHNO SUN	4.29 / 117.84
659.08.01.JUMPER	x4	Grounding connector between rails – TECHNO SUN	3.90 / 107.133
659.08.01.GRNDCLIP	x8	Grounding clip between panels under rails – TECHNO SUN	0.29 / 7.96
659.08.01.GRNDLUG	x2	Grounding connector between panels and cable – TECHNO SUN	1.37 / 37.63
659-RL30-60	x12	Structure rear leg adjustable tilt 30/60º - TECHNO SUN	15.71 / 431.55
659.08.01.FRONTLEG	x12	Structure front leg adjustable tilt - TECHNO SUN	4.29 / 117.84

The system will be grid-connected, with no auxiliary battery system. The 10 module array will be mounted on top of the roof and the tilt will be adjusted with the adjustable legs. The tilt will be fixed in both cases because it's the simplest system and there won't be any need for any additional inversion.

7. Energy production simulation and comparison

The energy comparison has been made using the online application PVGIS from the Joint Research Centre of the Institute for Energy and Transport (IET) from the European Commission. (http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php).

With this application is possible to obtain accurate data from every place in Europe using Google Maps and the radiation data base Climate-SAF which has been highly tested and has less than a 5% error in all places. The houses of the simulation will be located in Gandía, Spain, 38º 58' 44" N, 0º 10' 13" W and in Brno, Czech Republic, 49º 12' 38" N, 16º 37' 7" E. Both houses will have south oriented roofs and the photovoltaic array will be mounted in it.

After the input of the basic data in the application, there have to be selected the specifications of the system, which are crystalline silicon, 2 kWp of the system, the estimated losses, the optimum slope and azimuth and the type of system, which in this case is free standing and without tracking. The data obtained is the following:

Table 3. Basic system data output.

	Gandía	Brno
Latitude	38°58'44" North	49°12'38" North
Longitude	0°10'13" West	16°37'7" East
Nominal power of the PV system	2kWp	
Inclination of modules	35º	
Orientation (azimuth)	0º	-2º

The inclination and orientation of the modules has been optimized and the difference is minimal. That is because the difference in latitude is 10° which affects more the hours of sun than the angle of irradiation that will affect the place.

As per daily and monthly average radiation it goes as it follows in graphs 1 and 2:

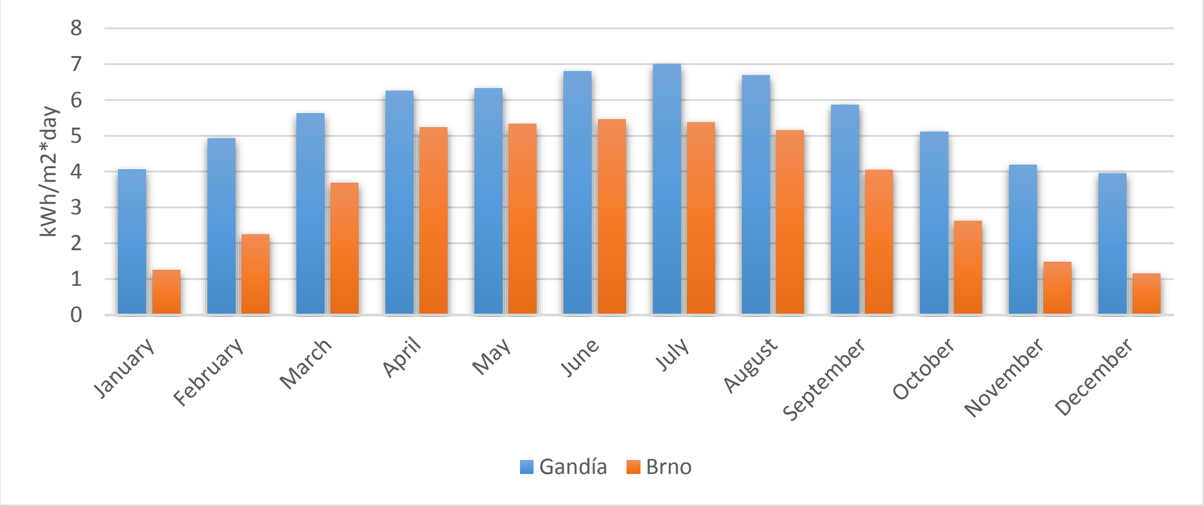

Figure 7. Daily average radiation.

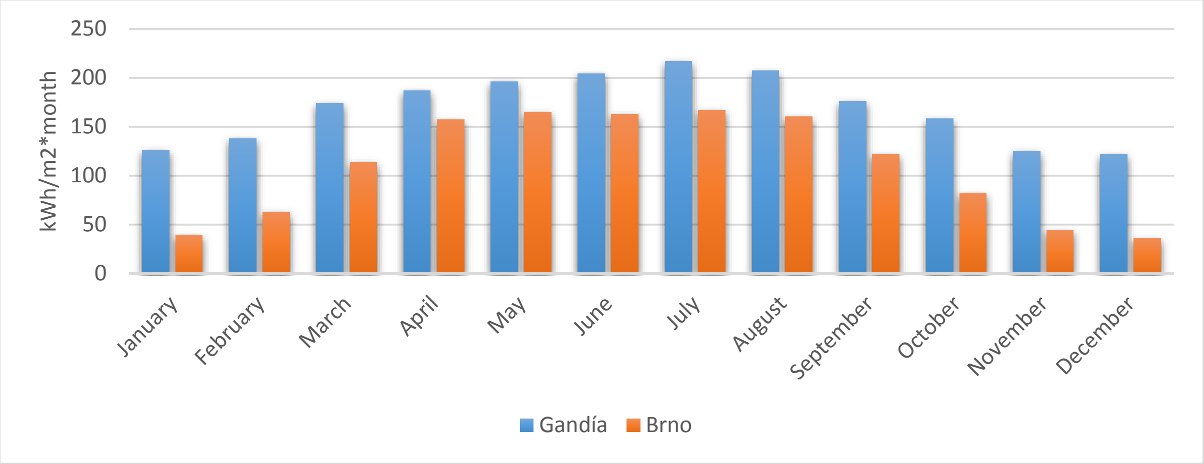

Figure 8. Average monthly radiation.

Here it can be seen the difference of latitude. This difference is greater in winter months when the irradiation of the modules doesn’t vary that much in Gandía but in Brno it decreases to less than half the summer value. In summer, early autumn and late spring, the difference in daily irradiation is less than 2 points difference while in winter it can be almost 3 points difference. With this differences is expected to see more production in Gandía than Brno because of the amount of irradiation received by the modules and the average sunshine hours of both places. While Gandía has 2,700 average sunshine hours, Brno has 1,770, meaning one thousand more hours of sun a year, mostly in winter. In the graphs above this difference is made clear.

The average electricity consumption in Gandía has been estimated as 3,850 kWh/year while in Brno has been estimated as 2,346 kWh/year, which is the average for 4 person household. This difference can be misleading, but considering that in an average household of Czech Republic the heating, cooker and boiler will be gas powered makes sense. Also for Gandía, while the cooker will be electric, the boiler will be gas powered and the house doesn’t have air conditioner installed.

The graphs 3 and 4 display the average amount of electricity produced by the given system as per daily basis and monthly basis.

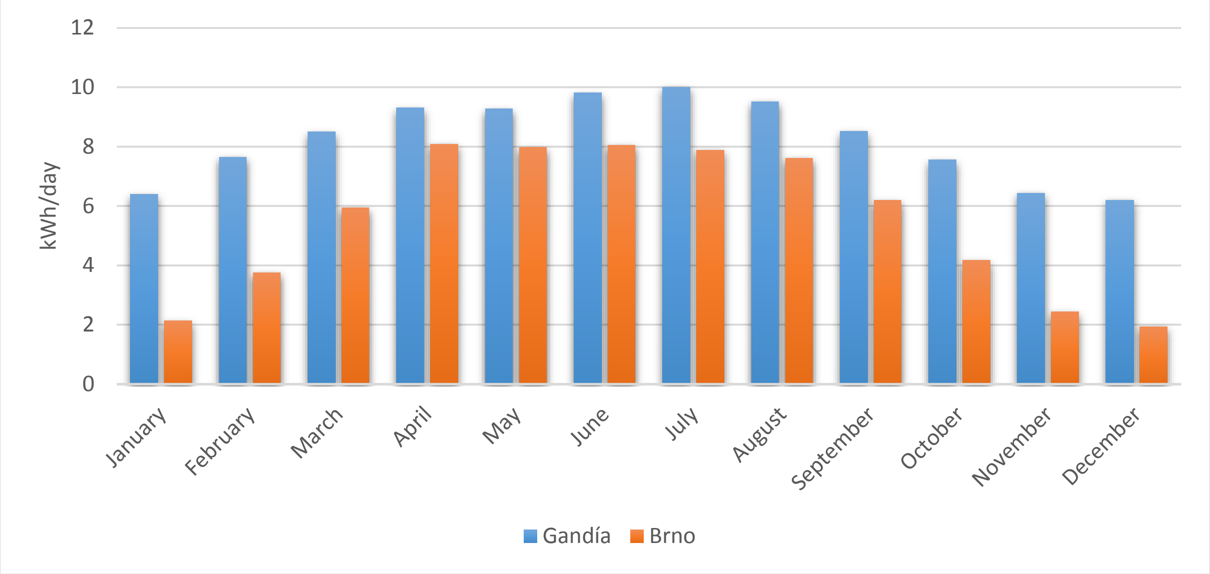

Figure 9. Average daily electricity production.

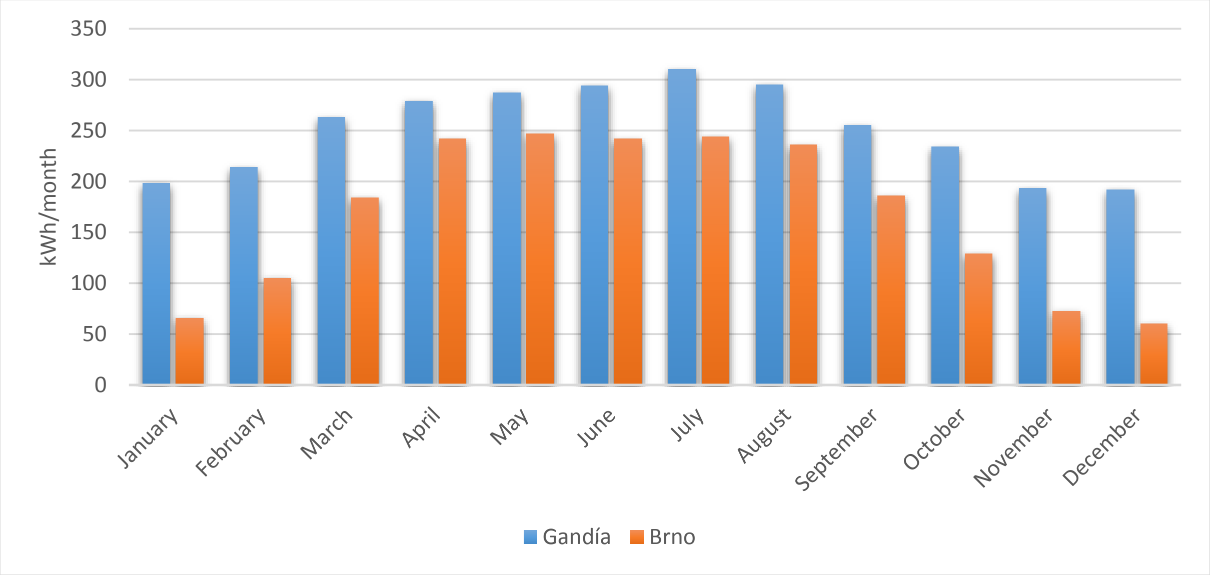

Figure 10. Average monthly electricity production.

In this graphs the difference of production is greater in winter months where in Gandía reaches almost 200 kWh and in Brno a bit more than 50 kWh. The total production of the system is as it follows:

Table 4. Yearly and total production and irradiation values.

	Gandía	Brno
Average daily production (kWh)	8.26	5.52
Average monthly production (kWh)	251	168
Total production (kWh)	3,014.0	2,013.8
Average daily irradiation (kWh/m2)	5.57	3.59
Average monthly irradiation (kWh/m2)	169	109
Total irradiation (kWh/m2)	2,030.0	1,311.3

As expected from the data seen in the graphs, the yearly average in Gandía is slightly higher than in Brno. This numbers are not strange given the differences in weather and climate but despite the differences they are quite similar. The production of this photovoltaic system will have 33.18% less production in Brno than in Gandía receiving a 35.40% less total irradiation. Comparing the systems only with production data, the same system installed in Gandía will produce more electricity than if installed in Brno but to compare a system completely, economic comparison is needed.

8. Electricity and economic savings

A photovoltaic system installed in a house is more complicated than one installed in a power plant. The scale is smaller but more things have to be taken into account. For example a household can decide if they want to sell all the electricity produced to an electricity supplier company and buy directly from the same company or use a certain percentage of the electricity produced and buy the rest.

This electricity produced with photovoltaic resources is being charged differently than normal electricity. In the electricity bill will appear two kinds of prices, one for the bought electricity and one for the sold electricity. In order to get accurate results in this case economic data from 2013 will be used, being the tariff as it follows:

Table 5. Electricity tariffs of Czech Republic and Spain.

	Spain	Czech Republic	
	€	€	Czk
Regular electricity tariff	0.14	0.20	5.50
Alternative electricity tariff	0.33	0.09	2.48

This tariffs are taken from the Energy Regulatory Office from Czech Republic, Decision No. 4/2013 of 27th November 2013 in case of Czech Republic and from Ministry of Industry, Energy and Tourism, Official Newspaper from the State (BOE) 1st October 2013 in the case of Spain. The conversion to Euros is made at 27.4 Czech crowns per Euro.

The price in Spain is more favourable than in Czech Republic in 2013, where it can be seen that selling energy produced with photovoltaic systems has bonus over the regular price. In Czech Republic it was the same up until 2012 when the government no longer gave bonus and the electricity generated this way had a smaller tariff until 2013 when it is less than half the price of regular electricity. To consider different situations have been added four modes of operating the system. The first one is selling all the electricity produced to the grid, buying the full consumption from the provider. The second is using 40% and selling the rest, where the household still will buy 60% of the consumption. The third one is using 60% of the electricity produced and selling 40% while the last is using all energy produced and buying the rest from the provider. In the table 6 can be seen the numbers of kilowatts of every mode:

Table 6. Modes of operation in kWh/year.

	Gandía	Brno
Consumption	3,850.0	2,346.0
0% utilization	0.0	0.0
40% utilization	1,205.6	805.5
60% utilization	1,808.4	1,208.3
100% utilization	3,014.0	2,013.8

In table 7 are the amount of kilowatts that the two households will have to buy from the provider in the four modes described. Because the production is lower than the consumption there will be always the need to buy electricity from the provider but the main idea is to contrast with the different prices how much is the amount of savings that can be attained.

Table 7. kWh/year needed to buy in each mode.

	0%	40%	60%	100%
Gandía	3,850.0	2,644.4	2,041.6	836.0
Brno	2,346.0	1,540.5	1,137.7	332.2

Table 8 shows the amount of money utilized by the households in each mode. This electricity will be bought with the price of 0.14 € in the case of Gandía and 5.5 Czk (0.2€) in the case of Brno.

Table 8. Price of electricity bought.

	Gandía (€)	Brno (€/Czk)
0% utilization	539.0	470.9 / 12,903.0
40% utilization	370.2	309.2 / 8,472.7
60% utilization	285.8	228.3 / 6,257.3
100% utilization	117.0	66.7 / 1,827.1

The counterpart of this amount of money used every year with the operation of the photovoltaic system is shown in table 9, which will be sold at a 0.33 € in Gandía and 2.48 Czk in Brno:

Table 9. Price of the kWh sold.

	Gandía (€)	Brno (€/Czk)
0% utilization	994.6	182.2 / 4,992.2
40% utilization	596.8	109.7 / 2,995.7
60% utilization	397.8	72.5 / 1,996.5
100% utilization	0.0	0.0

The balance of electricity sold and bought will be as it shows in table 10. In Gandía can be seen a decrease in the income the more electricity produced is used. This is because the electricity produced is more expensive than the electricity bought. In Brno happens the opposite effect, the balance becomes more favourable the more electricity is used.

Table 10. Balance of expenses (electricity bought/electricity sold).

	Gandía (€)	Brno (€/Czk)
0% utilization	455.6	-288.7 / -7,910.8
40% utilization	226.6	-199.5 / -5,477.4
60% utilization	112.0	-155.8 / -4,260.5
100% utilization	-117.0	-66.7 / -1,787.1

9. Viability of the installation

The viability of the installation is measured in the amount of time in years that will take to return the money invested in the system. This time is calculated from the difference between the amount of money that the household would pay without the system and the amount that is paying with it and divided by the investment. In table 11 are displayed the amount of years that will take for the four modes of operation and the two cities.

Table 11. Years to return the investment.

Utilization	0%	40%	60%	100%
Gandía (years)	9.27	5.52	6.49	10.01
Brno (years)	23.19	15.59	13.40	10.45

In theory, the amount of years to return the investment has to, at least, leave a quarter of the life expectancy of the system generating benefits. For photovoltaic systems is around 20-25 years, although they can last until 30 years. In the graph below can be seen better the variation through the modes.

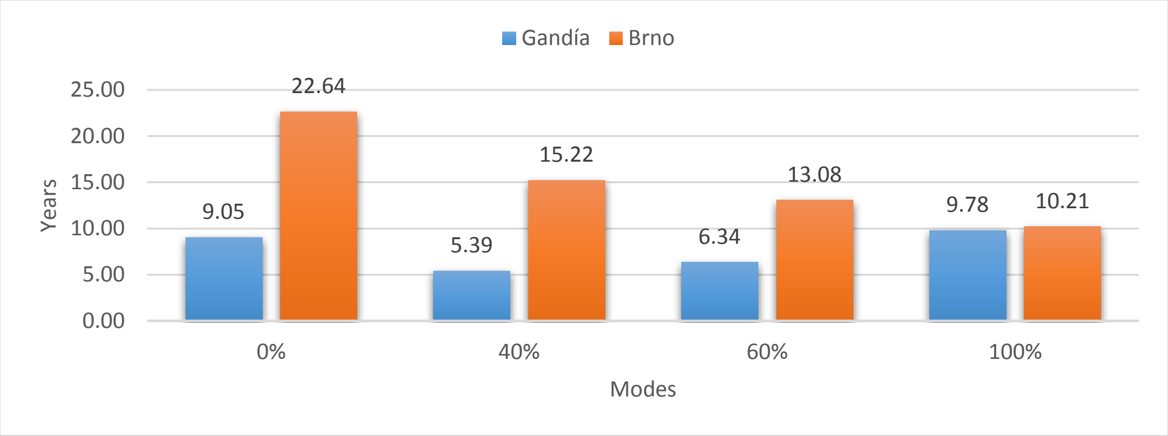

Figure 11. Years to return the investment number 1.

Here can be see the progression of Brno very clearly, the inversion will be more viable if all the electricity produced is used to supply the household consumption. On the other hand, in Gandía, as it has better prices for the photovoltaic electricity, it should sound logic to sell all the electricity and supply all the electricity consumption from the grid. The graph shows that this statement is not true and the best situation for Gandía is to use 40% of the electricity produced and sell the surplus. This is produced because using that amount of electricity, the price of the sold and bought will equalize, creating a situation of zero electric expenses and the household will change from paying 539 € every year to earning 226 €, making a difference of 765 €. In Brno the situation is more favourable when the totality of the electricity is used, because from the low price of selling, the produced electricity is better being used.

In the next graph has been pictured the same situation but adding a fee of 100 € (2,740 Czk) to the annual expenses in order to get maintenance. This slight change added makes the situation more realistic. In Brno won't be viable the system unless at least 60% of the production is consumed in the household.

Table 12. Years to return the investment with maintenance.

Utilization	0%	40%	60%	100%
Gandía (years)	11.60	6.20	6.34	12.81
Brno (years)	50.19	24.12	13.08	13.56

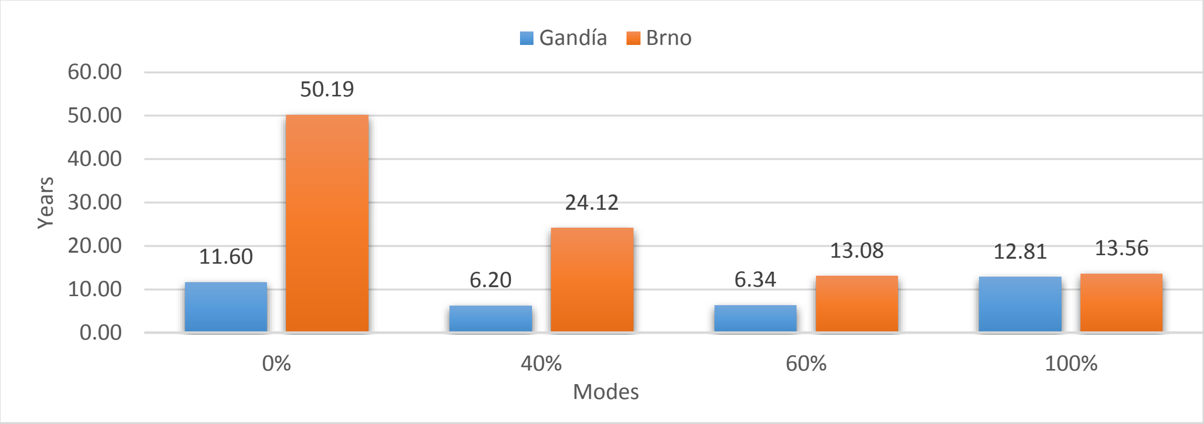

Figure 12. Years to return the investment number 2.

10. Conclusions

With the results obtained, this 2kWp photovoltaic system will work in better conditions and will produce more electricity in Gandía than Brno. To relate the modes into real life, the 100% utilization mode wouldn't be possible without batteries in a normal household, because the majority of the production is made during the day, when people goes to work, school and is not in the house. The most realistic mode would be 40% utilization. That will be the electricity used early in the mornings and in the afternoon, which in Gandía is the best mode of operation. The 60% utilization mode can be related if we take into account a bigger use of electricity in weekends and households with people staying more hours than normal during the day.

The operation mode for an optimum display in Gandía will be using a percentage of the electricity near 40% and selling the surplus paying off the debt in less than 7 years and having 13-18 years of the lifespan of the system generating benefits.

For Brno as it is impossible to use the full electricity produced with this system, it should be considered to add a set of batteries and store the electricity while connected to the grid in order to store the surplus of electricity not used during the highest producing hours of the day and using it in the highest consuming hours of the day. This will add more money to the inversion and a full study of viability should be done to ensure the pay off.

Another possibility is adding more power to the system. For example, using a 2.9 kWp or 3.8 kWp will add a lot of production and the most important part, the price won't double, because the structure is the same, instead of 4,125 € (113,312 Czk), it will cost 4,800-5,400 € (131,520-147,960 Czk).

11. Annex

Table 13. Average Daily Electricity Production.

Month	Gandía	Brno
January	6.39	2.13
February	7.64	3.75
March	8.49	5.94
April	9.3	8.08
May	9.27	7.98
June	9.81	8.05
July	10	7.88
August	9.52	7.61
September	8.51	6.19
October	7.56	4.17
November	6.43	2.43
December	6.2	1.94

Table 15. Average Daily Irradiation.

Month	Gandía	Brno
January	4.06	1.25
February	4.93	2.25
March	5.62	3.68
April	6.25	5.23
May	6.32	5.33
June	6.8	5.45
July	7	5.38
August	6.69	5.16
September	5.86	4.05
October	5.11	2.63
November	4.18	1.47
December	3.95	1.15

Table 14. Average Monthly Electricity Production.

Month	Gandía	Brno
January	198	65.9
February	214	105
March	263	184
April	279	242
May	287	247
June	294	242
July	310	244
August	295	236
September	255	186
October	234	129
November	193	72.8
December	192	60.1

Table 16. Average Monthly Irradiation.

Month	Gandía	Brno
January	126	38.8
February	138	63
March	174	114
April	187	157
May	196	165
June	204	163
July	217	167
August	207	160
September	176	122
October	158	81.6
November	125	44.1
December	122	35.8

12. Bibliography

- Ajuntament de Gandía, *Agenda 21 Gandía*, Provisional release.
- BOE Thursday 1 de October 2013 number 235. Section I. p. 79087-79093.
- Colegio oficial de ingenieros de telecomunicación, *Energía solar fotovoltaica*, Madrid. 2007.
- Endecon Engineering, *A guide to photovoltaic (PV) system design and installation*. California energy Commission. 2001, p.5-7.
- Energy Regulatory Office's Price Decision No. 4/2013 of 27th November 2013. (Last consultation 22-05-2014) http://www.eru.cz/en/-/cenove-rozhodnuti-c-4-2013.
- Homolková, Jana, Ondroušková, Zdenka. Závěrečná zpráva z terénního cvičení Brno ţivotní podmínky 2011-2012.
- Instituto Nacional de Estadística. Data from 2008.
- Intelec Ingeniería. *Estimación de la Energía Generada por un Sistema Fotovoltaico Conectado a la Red*. Pvs in bloom. 2010.
- John Perlin (1999). *From Space to Earth: the story of solar electricity*, Earthscan.
- Joint Research Centre of the Institute for Energy and Transport (IET) from the European Commission. (http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php).
- Landau, Charles R., *Optimum tilt of solar panels*, 2014, http://www.solarpaneltilt.com/
- National Renewable Energy Laboratory. (NREL). (Last consultation 23-03-2014) http://www.nrel.gov/rredc/solar_resource.html.
- Perez Cueva, Alejandro J. *Atlas Climático de la Comunidad Valenciana*, 1994, Conselleria d'Urbanisme, Obres Públiques i Transports.
- Philip, Aleš (2006). *Brno – city guide*. Brno: K-Public.
- Photovoltaic Geographical Information System. (Last consultation 26-05-2014). http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php#.
- Physics 2000. *Photoelectric effect*, University of Colorado, Boulder, Colorado.
- Sancho Ávila, J.M.,Riesco Martín, J, Sánchez de Cos Escuin, M, Montero Cadalso, J y López Bartolomé, M. *Atlas de Radiación Solar en España utilizando datos del SAF de Clima de EUMETSAT*, 24-04-2012.

- South Moravia region portal. (Last consultation 20-04-2014) http://www.kr-jihomoravsky.cz/default.aspx/Default.aspx?ID=961&TypeID=1.
- Techno Sun. (Last consultation 25-05-2014) http://www.technosun.com/es/index.php.
- World meteorological organization (Last consultation 20-04-2014) http://www.wmo.int/pages/index_en.html.