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STUDY AND DESIGN OF A PHOTOVOLTAIC SOLAR INSTALLATION ON A HOTEL IN KRAKOW

MASTER THESIS

MASTER'S DEGREE IN INDUSTRIAL ENGINEERING

(POLYTECHNIC UNIVERSITY OF VALENCIA)

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1. Summary and purpose of the project

The main object of this work is the design, calculation and verification of a photovoltaic solar installation on the roof of an existing building, with 1500 m2 of useful space and a gable roof, located near Akademia Górniczo-Hutnicza in Krakow and whose specific use is a hotel.

As a description of the current situation, it is desired to create an installation of a set of photovoltaic solar panels on the roof of the building in order to decrease the costs associated with the electrical consumption. In this way, the current market must be explored taking into account the current costs of the elements that are necessary for a photovoltaic installation. It will be used specialized software in the field.

It will be important to analyze the different configurations and technologies in photovoltaics to choose the optimal one for this case. Moreover, the economic profitability study of the designed installation will be opened taking into account the current electricity market and the taxes to be paid. In this way, the number of years that must pass for the project to become profitable will be indicated.

Finally, the results obtained will be analyzed and the appropriate conclusions will be reached on the real possibility of carrying out the project.

2. Energy generation

2.1. Introduction

The current model of economic development and the intensive use of fossil fuels cause negative environmental impacts and socioeconomic unbalances that make it necessary to define a new model of sustainable development. Sustainable development can be defined as development that satisfies the needs of the present without compromising the ability of future generations to meet their own needs. In short, sustainable development tries to guarantee three main objectives simultaneously: economic growth, social progress and rational use of resources.

Conversely, the current level of consumption in developed countries does not allow securing future energy supplies or facilitating access to energy for countries in development. Among the policies that can be articulated to ensure the sustainability of the model, the policy of promoting renewable energy is among the main ones. To ensure this and sustainable development, a framework agreement on climate change brought to the development of the Kyoto Protocol, which has three objectives; to achieve emission reductions at the lowest cost to make it easier for developed countries to meet their commitments to reduce emissions and support the sustainable development of developing countries through of clean technology transfer. Subsequently, it has recently been endorsed with the Paris Agreement, where it was agreed to reduce carbon emissions as soon as possible and to do everything possible to keep global warming below 2°C.

2.2. Renewable energies

Renewable energies have made up a large part of the energy used by humans since the beginning of time, notably solar energy, wind energy and hydraulic energy. Wind and water mills are some of the examples.

With the invention of the steam engine by James Watt, these forms of exploitation were gradually abandoned and thermal and electric motors began to be used, at a time when the relatively low consumption did not predict a depletion of the sources or other environmental problems that later would be presenting. By the 1970s, renewable energies were considered an alternative to the traditional energies, both because of their present and future availability as well as by its minor environmental impact. Currently many of these energies are a reality, not an alternative, so the name of alternatives should no longer be used.

The main advantage of these types of energy is that they are environmentally friendly, very different from fossil fuels or nuclear power plants because of their diversity and abundance. It is assumed that the sun will supply these energy sources (solar radiation, wind, rain, etc.) for the next four billion years. The first advantage of a certain amount of renewable energy sources is that they do not produce greenhouse gases or other emissions, contrary to what happens with fossil fuels. Some renewable sources do not emit additional carbon dioxide, except for those required for their construction and operation, and do not present any additional risk, such as nuclear risk.

However, these energies also have drawbacks including their diffuse nature, some renewable energy sources provide relatively low intensity energy, distributed over large areas, and new types of plants are needed to convert them into usable sources. Another disadvantage is the irregularity, the production of permanent electrical energy requires reliable power sources or storage mediums. In fact, due to the high cost of energy storage, a small independent system is rarely economical, except in isolated situations, such as when connection to the energy network involves higher costs.

2.3. Solar photovoltaic energy

Photovoltaic is the direct conversion of solar radiation into electricity. This transformation takes place in devices called photovoltaic panels, surfaces formed by semiconductor materials, in most cases silicon, and covered by a transparent glass that allows solar radiation to pass through and minimizes losses. In photovoltaic panels, solar radiation excites the electrons in a semiconductor device generating a small potential difference.

The cells are grouped into modules for integration into photovoltaic systems. The modules have an estimated life of 30 years and their efficiency after 25 years is close to 80 %. The series connection of these devices allows for greater potential differences to be obtained.

There is no need for a direct light flow, electricity is produced even on cloudy days or nightfall. The photovoltaic modules generate direct current and are converted to alternating current through an electrical device called inverter. Subsequently, the electrical energy produced passes through a transformation centre where is adapted to the conditions of voltage and current of the transmission lines for consumption.

Although the photovoltaic effect was known since the 19th century, it was in the 1950s that photovoltaic panels began to undergo significant development. Initially used to supply electricity to geostationary communication satellites, today their modular aspect is one of their main virtues, and they can be built from huge photovoltaic plants on the ground to small panels for traffic lights.

Photovoltaic solar energy allows for a large number of applications, as it can supply energy in locations isolated from the network (isolated homes, lighthouses, SOS posts, pumping stations, telecommunications repeaters, etc.) or through installations connected to the electricity network, which can be small as installations in individual homes or very large plants.

An important point to note is that each kWh generated with photovoltaic solar energy avoids the emission of approximately 1 kg of CO_2 into the atmosphere, in the case of comparison with coal-fired electricity generation, or approximately 4 kg of CO_2 in the case of comparison with natural gas-fired electricity generation. This is of great help for the reduction of emissions proposed in the Kyoto Protocol and the Paris Climate Agreement cited above.

These are some of its main advantages summarized:

- It is a clean, renewable, infinite and silent source of energy.
- It does not consume fuel or generate waste.

- Possibility of selling surplus power.
- It requires little maintenance.
- The panels have a long life and are resistant to adverse weather conditions.
- The panels can be placed on roofs, industrial covers... without occupying useful space and without architectural impact.
- It is an increasingly affordable technology.

2.4. World situation

At the end of 2018, the installed solar photovoltaic energy in the world reached 500 GW for the first time and became the first source of electrical energy in terms of capacity deployed at a global level, data from the Photovoltaic Energy Systems Program of the International Energy Agency (IEA PVPS). According to the North American consulting firm IHS Market, the world will install around 142,000 megawatts of new photovoltaic solar power in 2020, seven times more than it installed in 2010. In addition, "strong growth trends are expected both in terms of total capacity and geographical coverage". In 2020 there will be 14% more photovoltaic power than in 2019.

While in 2010 there were only seven countries with more than 1,000 megawatts installed (most of them in Europe), 2020 will close with more than 43 nations above that level. China will continue to be the undisputed global market leader with nearly half of the world's installed capacity, but its dominance will decline over the next few years as other markets gain in strength.

3. Photovoltaics

3.1. Semiconductor characteristics and solar cells

In most of solar cells, the absorption of photons takes place in semiconductor materials, resulting in the generation of the charge carriers and the subsequent separation of the photogenerated charge carries. Therefore, semiconductor layers are the most important parts of a solar cell.

A solar cell is a device that converts the energy of sunlight directly into electricity by the photovoltaic effect. Although there are many kinds of solar cells developed by using different semiconductor materials, the operating principle is very similar. The most commonly known solar cell is configured as a large-area p-n junction made from silicon.

When a piece of p-type silicon is placed in intimate contact with a piece of n-type silicon, a diffusion of electrons occurs from the region of high electron concentration (the n-type side) into the region of low electron concentration (p-type side). Similarly, holes flow in the opposite direction by diffusion. This forms a diffusion current I_D from the p-side to the n-side, as shown in the next figure.

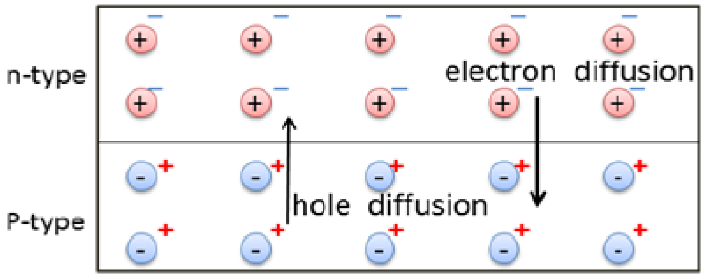

Fig. 1. Diffusion current I_D from the p-side to the n-side.[From: Solar Photovoltaic Energy Generation and Conversion]

When the electrons diffuse across the p-n junction, they recombine with holes on the p-type side. The diffusion of carriers does not happen indefinitely because of an electric field which is created by the imbalance of charge immediately on either side of the junction which this diffusion creates. The electric field established across the p-n junction generates a diode that promotes charge flow, known as drift current I_S, that opposes and eventually balances out the diffusion current I_D. The region where electrons and holes have diffused across the junction is called the depletion zone.

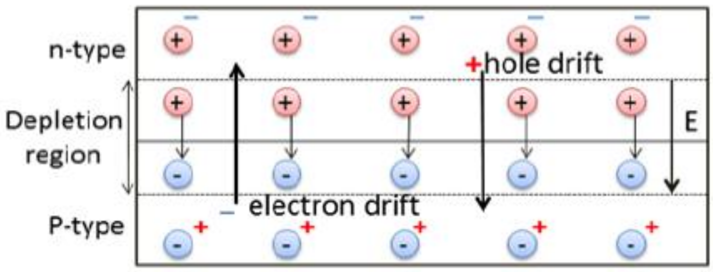

Fig. 2. Drift current I_S from the n-side to the p-side and the depletion zone. [From: Solar Photovoltaic Energy Generation and Conversion]

3.2. Photogenerated Current and Voltage

When a visible light photon with energy above the band-gap energy strikes a solar cell and is absorbed by the solar cell, it excites an electron from the valence band. With this newfound energy transferred from the photon, the electron escapes from its normal position associated with its atom, leaving a localized "hole" behind.

When those mobile charge carriers reach the vicinity of the depletion zone, the electric field sweeps the holes into the p-side and pushes the electrons into the n-side, creating a photogenerated drift current. Thus, the p-side accumulates holes and the n-side accumulates electrons (Fig. 3), which creates a voltage that can be used to deliver the photogenerated current to a load.

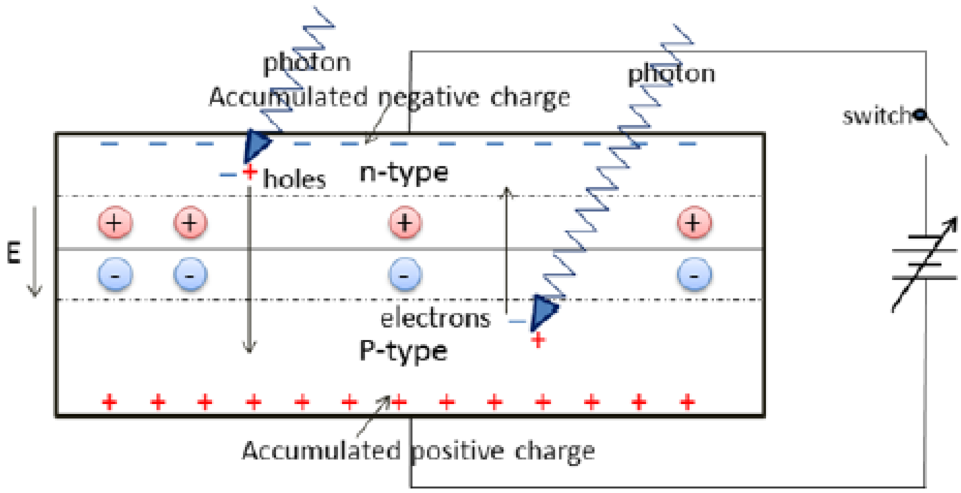

Fig. 3. Photogenerated current and voltage. [From: Solar Photovoltaic Energy Generation and Conversion]

At the same time, the voltage built up through the photovoltaic effect shrinks the size of the depletion region of the p-n junction diode resulting in an increased diffusion current through the depletion zone. Hence, if the solar cell is not connected to an external circuit (switch in the open position in Fig. 3), the rise of the photogenerated voltage eventually causes the diffusion current I_D balancing out the drift current I_S until a new equilibrium state is reached inside a solar cell.

3.3. Equivalent model of a Solar Cell

When a solar cell is connected to an external circuit (i.e., switch in the close position in Fig. 4, the photogenerated current then travels from the p-type semiconductor-metal contact, through the wire, powers the load, and continues through the wire until it reaches the n-type semiconductor-metal contact.

Under a certain sunlight illumination, the current passed to the load from a solar cell depends on the external voltage applied to the solar cell normally through a power electronic converter for a grid-connected PV system. If the applied external voltage is low, only a low photogenerated voltage is needed to make the current flow from the solar cell to the external system. Nevertheless, if the external voltage is high, a high photogenerated voltage must be built up to push the current flowing from the solar cell to the external system.

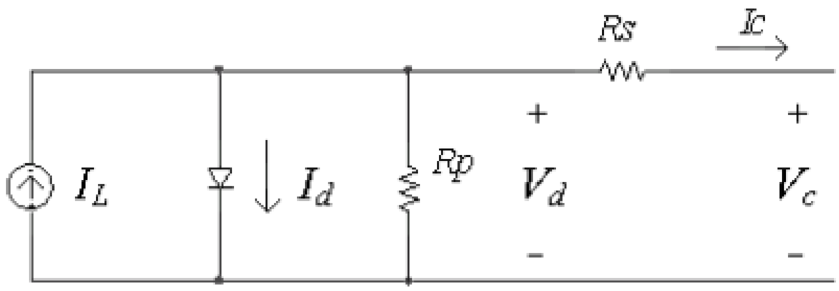

Fig. 4. Solar cell equivalent circuit model. [From: Solar Photovoltaic Energy Generation and Conversion]

To analyze the behavior of a solar cell, it is useful to create a model which is electrically equivalent. An ideal solar cell can be modeled by a current source, representing the photogenerated current I_L, in parallel with a diode, representing the p-n junction of a solar cell. In a real solar cell, there exist other effects, not accounted for by the ideal model. Those effects influence the external behavior of a solar cell, which is particularly critical for integrated solar array study. Two of these extrinsic effects include:

1. Current leaks proportional to the terminal voltage of a solar cell
2. Losses of semiconductor itself and of the metal contacts with the semiconductor.

The first is characterized by a parallel resistance accounting for current leakage through the cell, around the edge of the device, and between contacts of different polarity (Fig. 2.3). The second is characterized by a series resistance *Rs*, which causes an extra voltage drop between the junction voltage and the terminal voltage of the solar cell for the same flow of current.

The mathematical model of a solar cell is described by

$$I_C = I_L - I_0\left(e^{\frac{qV_d}{mkT}} - 1\right) - \frac{V_d}{R_p}, \qquad V_c = V_d - I_c \cdot R_s$$

where I_L is proportional to the sunlight illumination intensity, m is the diode ideality factor (1 for an ideal diode), the diode reverse saturation current I_0 depends on temperature, q is the elementary charge, k is the Boltzmann's constant, and T is the absolute temperature.

Characteristics of a solar cell can either be simulated using a circuit simulation tool based on the equivalent circuit model or computed directly by using MatLab based on the equations. Important characteristics for a solar cell consist of output current I_c and power P_c versus output voltage V_c characteristics. Figure 5 shows typical I-V and P-V characteristics of a solar cell under ideal condition and with the consideration of parallel and series resistance.

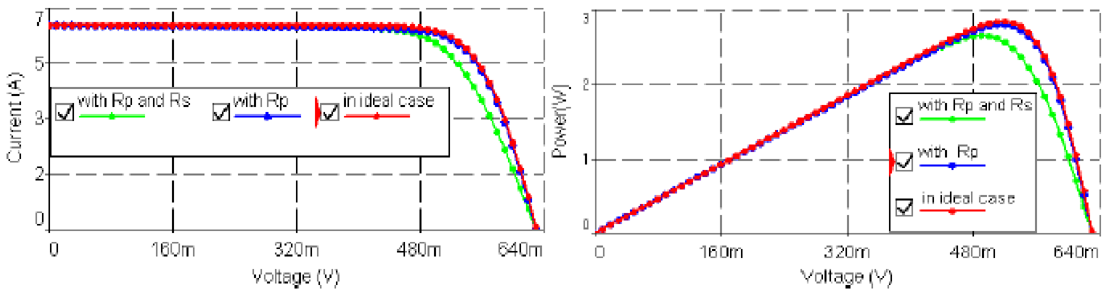

Fig. 5. I-V and P-V characteristics. [From: Solar Photovoltaic Energy Generation and Conversion]

As it can be seen from the Figure, if the external voltage applied to the solar cell is low, the net output current of the solar cell, depending primarily on the photogenerated current, is almost constant. Therefore, as the external voltage increases, more power is outputted from the solar cell. But, if the external voltage is around the forward conduction voltage of the p-n junction diode, the net output current drops significantly and the output power reduces.

3.4. Types of solar panels

A solar panel system is an inter-connected assembly of photovoltaic solar cells that capture energy emanating from the sun in the form of photons and transform that solar energy directly into electricity. The amount of electricity produced, as measured in volts or watts, varies according to the system and the type of solar cell.

Each individual solar panel in the array consists of a group of solar cells packaged together in a metal frame. There are typically 60, 72 or 96 solar cells in a single solar panel.

To convert the direct current (DC) electricity produced into the alternating current (AC) used in your home, every solar cell system contains an inverter. The inverter may be large and centralized. It will be analized in the next section.

The three most famous types of photovoltaic cells are monocrystalline, polycrystalline and thin film cells.

Monocrystalline solar panels

- Average efficiency range: 15-24%
- How it’s made: Wafers are cut from a block of a single crystal of highly pure silicon.
- Appearance: Monocrystalline solar cells have a uniform appearance, and the cells form a distinctive shape, small black squares with notched corners. Solar panels made with these solar cells typically have either a white or black back sheet.
- Features: These panels conduct electricity more efficiently and perform better in high temperatures and shaded conditions, enabling them to generate more solar power than other panels of the same size. That makes them ideal for smaller rooftops. Because this type of technology is the most established, it also has a proven track record of durability.

However, these are the most expensive panels and generate more waste in the manufacturing process.

Polycrystalline (or multicrystalline) solar panels

- Average efficiency range: 12-16%
- How it's made: Fragments from multiple silicon crystals are heated, melted, and pressed together to form a large solar cell.
- Appearance: These solar cells have a multifaceted, non-uniform, gem-like surface and are typically blue in color.
- Features: Polycrystalline solar panels are composed of polycrystalline solar cells. They are less efficient but are less expensive. There is less silicon waste in the manufacturing process. These are the most prevalent solar panels globally, primarily due to a production boom in China over the last few years.

Thin film solar panels

- Average efficiency range: 7-13%
- How it's made: A thin layer of photovoltaic material or combination of materials such as non-crystalline amorphous silicon, Cadmium Telluride, or copper indium gallium selenite is deposited onto a surface like glass, plastic, or metal.
- Appearance: Thin film silicon panels are generally larger and have a uniform, solid black appearance.
- Features: This is a commercially available but newer technology that makes sense where space is not an issue. Thin film solar panels are low cost, easy to produce, flexible, portable and lightweight. They are expected to be less durable and to have a shorter lifespan.

The following Table summarizes the most important features that can help choosing the most appropriate solar panel for each case.

Silicon Cell Types	Efficiency	Key Advantages	Key Disadvantages
Monocrystalline	15-24%	Most efficiency Durable Proven Aesthetically pleasing	Highest cost
Polycrystalline	12-16%	Lower cost Improving efficiencies	Lower efficiency Poorer aesthetics
Thin film	7-13%	Low cost Easy to make Best aesthetics	Low efficiency Less proven

Table 1. Silicon Cell Types

3.5. Inverter

The power conditioning and control system is constituted by an inverter that converts direct current to alternating current and controls the quality of the output power to be delivered to the grid, also by means of an L-C filter inside the inverter itself. Figure 6 shows the principle scheme of an inverter. The transistors, used as static switches, are controlled by an opening-closing signal which, in the simplest mode, would result in an output square waveform.

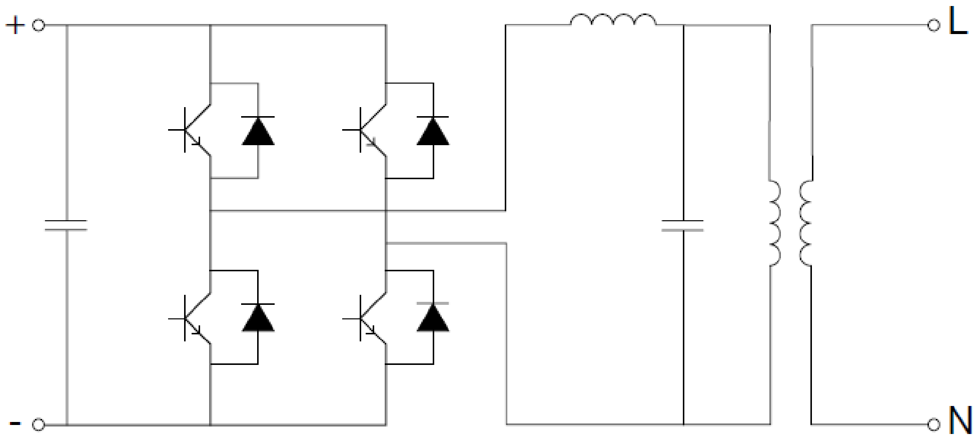

Fig. 6. Principle scheme of a single-phase inverter. [From: Technical Application Papers No.10 Photovoltaic plants. ABB]

The power delivered by a PV generator depends on the point where it operates. In order to maximize the energy supply by the plant, the generator shall adapt to the load, so that the operating point always corresponds to the maximum power point.

To this purpose, a controlled chopper called Maximum Power Point Tracker (MPPT) is used inside the inverter. The MPPT calculates instant by instant the pair of values "voltage-current" of the generator at which the maximum available power is produced. Figure 7 shows the I-V curve of the PV generator.

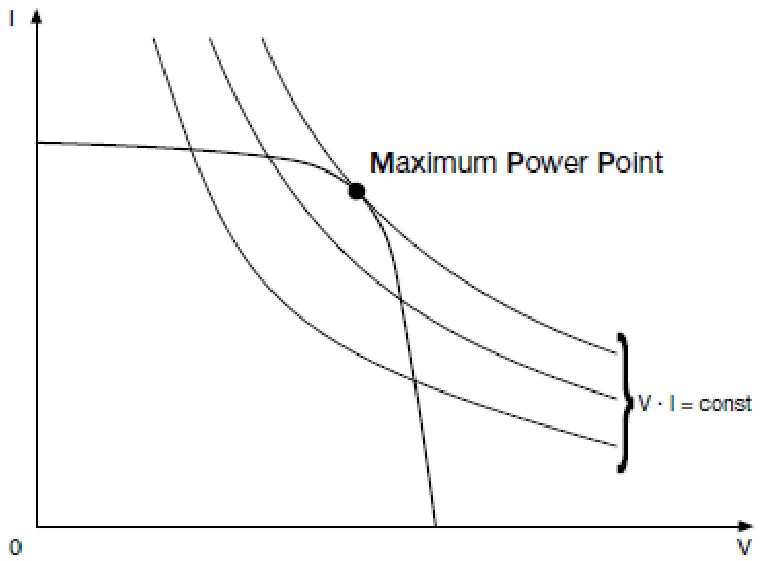

Fig. 7. Maximum Power Point (MPP) for a photovoltaic generator. [From: Technical Application Papers No.10 Photovoltaic plants. ABB]

The maximum point of power transfer corresponds to the point of tangency between the I-V characteristic for a given value of solar radiation and the hyperbola of equation VI = const. The MPPT systems commercially used identify the maximum power point on the characteristic curve of the generator by causing, at regular intervals, small variations of loads which determine deviations of the voltage-current values and evaluating if the new product I-V is higher or lower then the previous one. In case of a rise, the load conditions are kept varying in the considered direction.

Otherwise, the conditions are modified in the opposite direction. Due to the characteristics of the required performances the inverters for stand-alone plants and for grid-connected plants shall have different characteristics:

- In the stand-alone plants the inverters shall be able to supply a voltage AC side as constant as possible at the varying of the production of the generator and of the load demand
- In the grid-connected plants the inverters shall reproduce, as exactly as possible, the network voltage and at the same time try to optimize and maximize the energy output of the PV panels.

3.7. Advantages of solar panels in the hotel sector

1. Sustainable hotels. Efficient hotels and rural houses help build a more sustainable society.

2. Natural energy source. The sun is the main source of energy in solar panels, a natural, clean and renewable energy. Thanks to solar panels we can produce heat and electricity without using fossil combustion and avoiding polluting emissions.

3. Energy saving. Solar energy allows hotels to save up to 50% more on heating and electricity with photovoltaic self-consumption systems.

4. Minimum maintenance. Solar panels are durable parts (about 30 years of useful life according to manufacturer) and require very little maintenance. Unlike other photovoltaic self-consumption systems, once installed in the hotel, it is not practically necessary to worry about the panels again.

5. Subsidies for the tourism sector. The main problem with the installation of photovoltaic panels is that your initial investment is high, a problem that we can reduce thanks to subsidies for the tourism sector.

6. The value of the property is increased. After all, creating a photovoltaic system is an investment for the building that will raise the price of a future sale.

3.8. Environmental considerations

Putting in place truly alternative energy systems to fossil fuels, which are environmentally efficient through the use of renewable energy, must be a priority in global energy development approaches. Solar energy, both thermal and photovoltaic, is a substantial part of this alternative.

Some of the environmental improvements generated by a PV installation are:

- Small or no environmental space in its use.
- They do not emit CO_2 into the atmosphere and therefore avoid the process of global warming as a consequence of the greenhouse effect.
- It does not contribute to the formation of acid rain.
- They do not give rise to the formation of Nox.
- Allows areas with a low level of economic and social development to evolve.
- It improves the living conditions of developing communities.

Sustainable environmental development is one of the premises on which the most developed countries base their policies at present trying to reduce the deterioration produced by the emissions of CO_2 and other gases and the destruction of the ozone layer, which are having a direct impact on the health of our planet. The balance that is sought between consumption and development is the basis of this policy, which finds great obstacles in the energy demand of developing countries and in the multinational companies that control the planet's energy resources.

4. Literature review

In this section it will be described the most important articles, projects, thesis and other documents that have been analyzed to create this photovoltaic project. All of them were obtained after an exhaustive Internet search always selecting those who have a scientific basis or have been published by people specialized in the field.

Analysis of solar energy resources in southern Poland for photovoltaic applications. By: Tadeusz Rodziewicz, Janusz Teneta, Aleksander Zaremba and Maria Wacławek.

The article presents an analysis of the resources and the structure of the solar energy in the area of Southern Poland on the basis of complete meteorological data from the AGH University of Science and Technology in Krakow in 2009. An analysis attempt of its use for photovoltaic conversion using different modules with different spectral characteristics of absorbers was made. These latest methods for characterizing the structure of solar energy resources such as: distributions throughout the year: sky clearness or cloudiness indexes, the average values of photon energy (APE) and the contents of the useful fraction of the solar spectrum, are not yet widely known and used as in Poland and in other EU countries, despite the fact that most accurately determine the spectral matching factor for the chosen photovoltaic module. Due to the need for very expensive measuring equipment, are used only by a few laboratories in the European Union, such as CREST (Centre for Renewable Energy Systems Technology) in the UK. The article presents - developed and used in the Opole University - a new low-cost method for determining of the spectrum with the use of above-mentioned indexes, including APE and UF, without buying an expensive spectroradiometer, which gives comparable results.

Application of Building Integrated Photovoltaic: Design Strategies for Optimization of Renewable Energy Through Envelope and Daylight Harvesting. Shazia Ahmad (University of Washington).

Buildings account for roughly 39% of the atmospheric carbon dioxide produced in the United States. To mitigate the impact of our buildings on the environment, our buildings need to take advantage of the abundance of sunlight that falls on them.

Despite recent advances in photovoltaic technology, building integration of photovoltaic falls short of its potential. This thesis proposes design strategies for optimization of renewable energy from sunlight through building integrated photovoltaic, and incorporating daylight harvesting as an additional means to decrease buildings' energy use.

Design of Photovoltaic Systems Using Computer Software. Paweł Kut, Krzysztof Nowak (Journal of Ecological Engineering).

Renewable energy sources such as solar, wind and hydroelectric power plants are an inexhaustible and clean source of electricity and heat. The development of civilization, resulting in a constant increase in the demand for electricity and the prospect of fossil fuels depletion, including coal and oil, forces us to seek new sources of energy and invest in the renewable energy sources. The development of technology and the policy of the European Union have a positive impact on the development of renewable energy sources and the increase in the installed capacity. One of the ways of obtaining electricity from renewable sources is through the photovoltaic cells. Computer software is becoming helpful in designing the photovoltaic installations. Simulations enable conducting the economic analysis and selection of the best possible installation parameters. This enables the best use of the available conditions to obtain the largest production of electricity. The article presents a project of a photovoltaic installation for a single-family building using the BlueSol Design software.

Performance simulation of grid-connected rooftop solar PV system for small households: A case study of Ujjain, India. Elsevier Journal.

Solar rooftop PV system is an attractive alternate electricity source for households. The potential of solar PV at a given site can be evaluated through software simulation tools. This study is done to assess the feasibility of grid-connected rooftop solar photovoltaic system for a household building in holy city Ujjain, India. The study focuses on the use of various simulation software, PV*SOL, PVGIS, SolarGIS and SISIFO to analyze the performance of a grid-connected rooftop solar photovoltaic system. The study assesses the energy generation, performance ratio and solar fraction for performance prediction of this solar power plant. PV*SOL demonstrates to be easy, fast, and reliable software tool for the simulation of a solar PV system.

Photovoltaic System Integrated Into the Noise Barrier - Energy Performance and Life Cycle Assessment. Agata Zdyb, Agnieszka Żelazna, Ewelina Krawczak (Journal of Ecological Engineering)

The presented work is devoted to the analysis of the performance of an installation comprising photovoltaic modules (3.56 kWp) integrated into a noise barrier under temperate climate. The application of the DDS-Cad software enables to estimate the amount of electricity produced annually. The use of LCA (Life Cycle Assessment) method, based on the material and energy balance of the system, allows the ecological evaluation of the analyzed solution. The designed installation, in which the thin film cadmium telluride modules were applied, can produce 3390 kWh of electric energy per year. This kind of photovoltaic system can be multiplied depending on the available number of acoustic panels oriented at the desired azimuth along the highway or railway.

Solar Photovoltaic Energy Generation and Conversion. From Devices to Grid Integration.

Solar photovoltaic energy is becoming an increasingly important part of the world’s renewable energy. In order for effective energy extraction from a solar PV system, this research investigates solar PV energy generation and conversion from devices to grid integration. First of all, this dissertation focuses on I–V and P–V characteristics of PV modules and arrays, especially under uneven shading conditions, and considers both the physics and electrical characteristics of a solar PV system in the model development. The dissertation examines how different bypass diode arrangements could affect maximum power extraction characteristics of a solar PV module or array. Secondly, in order to develop competent technology for efficient energy extraction from a solar PV system, this research investigates typical maximum power point tracking (MPPT) control strategies used in solar PV industry, and proposes an adaptive and close-loop MPPT strategy for fast and reliable extraction of solar PV power. Thirdly, in order to develop efficient and reliable energy conversion technologies, this dissertation compares the energy extraction characteristics of a PV system for different converter configurations. Lastly, the development of coordinated control tools for next-generation PV installations, provides flexibility to distribution system operators. The objective of the control of this hybrid PV and energy storage system is to supply the desired active and reactive power to the grid and at the same time to maintain the stability of the dc-link voltage of the PV and energy storage system through coordinated control of power electronic converters.

Photovoltaic Installation Design of a Rural Hotel. La Laguna University.

This project aims to design and analyze the photovoltaic system of a rural hotel located in the province of Santa Cruz de Tenerife. The installation is in the self-consumption regime, although the possibility of the installation of excess energy accumulation system has been studied as well. First, it has been made a prediction of the consumption's profile that will have the hotel from the luminaires, appliances, televisions, computer, printer and small electrical appliances that could be connected to the power points. A power peak of 12.21 kW has been obtained. Then, the design of the necessary photovoltaic system is carried out in order to be able to supply the expected consumption. Among the possible proposals studied, it will finally be necessary a total of 39 photovoltaic modules of 315 W and an inverter able to supply up to 15 KW. Once these elements have been selected and all the necessary checks and calculations have been made, such as determining the orientation and inclination of the modules or the compatibility of the inverter, the wiring, the corresponding protections and all possible losses has been dimensioned in order to calculate the total energy generated by the installation. The budget has been determined with the selected material being able to verify the profitability that this installation has.

Amortization of Photovoltaic Installations in Self-Consumption Regime. International University of Andalusia.

This Master Thesis develops a simulation tool that allows evaluating the payback period of photovoltaic installations operating in the self-consumption mode, under four predominant consumption profiles in the urban environment, the residential profile, the retail, office and SME profile, the restaurant profile and the hotel profile. The study is oriented towards small and medium sized installations mainly on roofs and ceilings. To simulate the solar radiation conditions of the locations, a model of hourly solar radiation is developed with a variable daily behaviour for each month, based on the model of hourly radiation based on the average day of each month. Given the current state of uncertainty of the economic regime that will be applicable to self-consumption, the calculation of possible scenarios includes options for backup tolls, hourly, daily, weekly, monthly and annual netting, for all the low-voltage tariffs currently in force. It is also provides for the possible commercialisation of surplus energy from generation. The result of the simulations allows the behaviour of the parameter economic DPBT (Discount Pay Back Time) or Discounted Recovery Time against the yield and against the installation cost.

Study of Photovoltaic System. The Ohio State University.

The main aim of this work is to analyze the interface of photovoltaic system to the load, the power electronics and the method to track the maximum power point (MPP) of the solar panel. The first chapter consists of an overview of the PV market and cost. It describes the application of the PV system, the energy storage and the different standard requirement when having grid-connected PV system. Then main emphasis is to be placed on the photovoltaic system, the modeling and simulation photovoltaic array, the MPP control and the DC/DC converter will be analyzed and evaluated.

Photovoltaic Solar Energy Systems Applied to Residential Homes in Urban Environments. International University of Andalusia.

This Master Thesis compares the different technologies existing in the market in terms of photovoltaic systems, applied to the use of residential houses in an urban environment, in which the limitation of space, the efficiency of the system and the energy management of the same are among the main elements that condition them. Being aware of the specific problems for this type of buildings, the possibilities and limitations of these applications are analyzed, as well as the influence of the different parameters that condition the electrical production in a photovoltaic system integrated in a residential building in an urban environment, since it is considered that the installations in rural environments as well as the installations in buildings of the Tertiary Sector, have been object of greater development and study.

5. Objective of the thesis and methodology

5.1. Objectives

The main objective of this analysis is to evaluate how a solar photovoltaic installation can help to cover the energy needs of a building, in this case a hotel. Thus, a project of a photovoltaic system is proposed, evaluating the technical and economic part and the context of the reality of this proposal. To do this, the available solar radiation in the city of Krakow, the architecture of the building and the positive and negative consequences of this type of project, and any other external or internal factors that may influence this analysis, must be analysed. For the modelling of the photovoltaic solar system, the specialised software in the field will be used. The aim is to make it possible to design a photovoltaic system that produces at least half of the energy required by the hotel on the southwest roof surface. A more environmentally friendly production of energy is also sought, making use of this renewable energy.

5.2. Software

The specialized software in the field used in this project will be Photovoltaic Geographical Information System (PVGIS) and PV*sol in its premium free trial version.

PVGIS makes it possible to estimate the average monthly and yearly energy production of a PV system connected to the electricity grid. The calculation takes into account the solar radiation, temperature, wind speed and type of PV module. The user can choose how the modules are mounted, whether integrated in a building with predefined angles of inclination or orientation, or on a free standing position where these angles can either be defined by the user, or the user can request PVGIS to calculate the optimum slope and orientation that maximizes the yearly energy production. The calculations are made with the full temporal coverage of the solar radiation database selected.

PV*sol premium is a dynamic simulation program with 3D visualization and detailed shading analysis for the calculation of photovoltaic systems in combination with appliances, battery systems and electric vehicles. With PV*sol premium, the industry standard for photovoltaic design programs, it is possible design and simulate all types of modern PV systems. From the small rooftop system with a few modules to medium-sized systems on commercial roofs to large solar parks. It supports you with numerous tools for design and simulation.

The unique 3D visualization is the highlight of PV*sol premium. It is possible to visualize all common types of systems in 3D, whether roof-integrated or roof-mounted, whether on small angled roofs, large industrial halls or open spaces. This enables to achieve the highest reliability for earnings forecast because for an accurate income calculation, a realistic representation of the shading from surrounding objects is essential. The detailed results provide information about the performance of your system at all times. Whether calculating self-consumption, designing battery storage or integrating electric vehicles with PV*sol you can implement and present all customer wishes in no time at all.

The extensive product database includes over 20,000 PV modules, 4,700 inverters, 1,400 battery systems and many other products such as electric vehicles and performance optimizers. It is updated regularly by the product manufacturers themselves, so that it is possible always work with the latest data. Moreover, it allows generating high-quality project reports that can be configured and edited as required. Circuit diagrams with the necessary safety devices can also be created, e.g. for submission to the relevant authorities.

The current feed-in tariffs are available in the database for the calculation of economic efficiency. Supplemented with the information on the system costs, it is possible to receive a detailed and meaningful economic analysis of the system over 20 years.

6. Case study

6.1. Present building and structure

The hotel where the installation will be designed is located in the vicinity of the Akademia Górniczo-Hutnicza in the city of Krakow. The coordinates of the plot are the next ones:

- Latitude: 50º 03' 55'' N
- Length: 19º 55' 02'' E
- Altitude: 216 meters above sea level.

Figure 8 shows the plan view of the building. Due to the height of the building and the absence of obstacles around it, the photovoltaic system will not have problems with shadows at any time of the day.

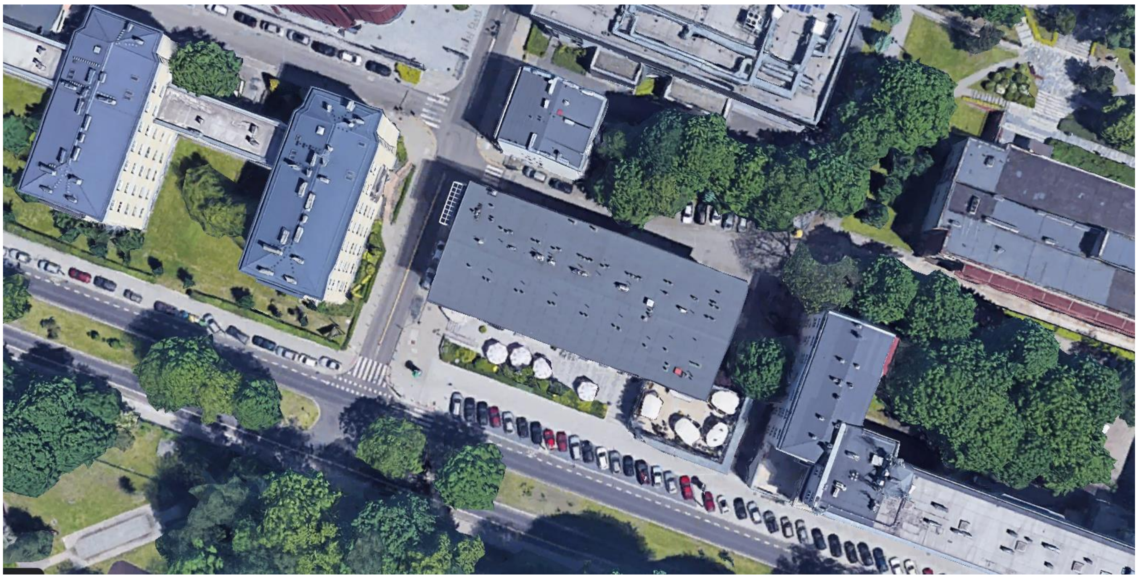

Fig. 8. Hotel location [From: Google Maps]

The address of the hotel is Reymonta Street 15 but it also faces Akademicka Street, which connects to the university. The hotel also has a terrace area and an attached restaurant which will not be taken into account for the calculations of this Project.

Furthermore, it is important to comment that for greater facility it will be supposed that the superior cover of the building is flat without any type of obstacle for the incorporation of solar panels.

6.2. Building specifications

The building in question is a rectangular structure with the following measurements:

- Large: 60 m
- Width: 25 m
- Roof height: 14 m
- Maximum height: 15 m
- Useful area of construction: 1,500 m^2

The roof is gabled at an angle of 4.6° to the horizontal.

Fig. 9. General view of the hotel. [From: Google Maps]

Studying the literature review and taking into account the size of the hotel (27 rooms), it is assumed that the hotel needs 150,000 kWh/year to meet the demand of lights, HVAC equipment and other utilities. With the implementation of the photovoltaic installation, the aim is to cover at least 50% of the hotel's energy demand.

6.3. Climate conditions in Krakow

Table 2 summarizes the average monthly values of the energy of radiation on the horizontal plane in AGH-Krakow area originating from a global and a diffused component of solar radiation.

Month	Global irradiation E_0 [kWh/m^2]	Diffused irradiation E_S [kWh/m^2]	$k_{S/0}$
January	22.1	15.4	0.70
February	33.3	27.6	0.83
March	57	40.6	0.71
April	157.8	52.9	0.33
May	163.4	69.6	0.43
June	137.6	72.8	0.53
July	188.7	74.3	0.39
August	146.1	57.3	0.39
September	103.2	47.6	0.46
October	41.9	29.0	0.69
November	29.7	16.3	0.55
December	13.3	10.4	0.78
2009	1094.2	513.7	0.47

Table 2. Summary of monthly values of the solar radiation energy: total (global) and diffused component content index, AGH Krakow area. [From: Analysis of Solar Energy Resources in Southern Poland for Photovoltaic Applications]

However, histogram of the daily values of irradiation, AGH Krakow area is shown in Figure 2. The histogram shows that the test area was characterized by the presence of a large number of cloudy days with insolation not exceeding 800 Wh/m^2, which accounted for more than 24.5% of the monitoring period. They are mostly a day MIMT (Medium Irradiation, High Temperature) or even LILT (Low Irradiation, Low Temperature) [2, 3] for the period of autumn and winter. During the six months only 18% of the annual energy radiation reaches the module.

Then they are very difficult conditions for photovoltaic energy conversion, and energy needs increased (the need of heating, lighting for a long time because of the short days and frequent heavy overcast and reheating the water from the lower temperature). In addition, during the monitoring period were 35.9% of cloudy days with irradiation in the range of 800 to 3,200 Wh/m2. These are the days of the typical weather failures occurring in the entire period of spring and autumn. Then median exceeds 1.6 kWh/m2, in which typical modern PV inverter already operates with an efficiency of up to 98% of its maximum efficiency [4-6], and a typical PV system already exceeds 75% of its nominal performance [7, 8].

To different category can be classified so-called sunny and very sunny days, which are respectively 18.6 and 21% of the days monitored. They occur during the spring and summer, in which are the ideal conditions for the operation of photovoltaic systems. Since the number of these days largely depends the value of generated energy in the PV system [7].

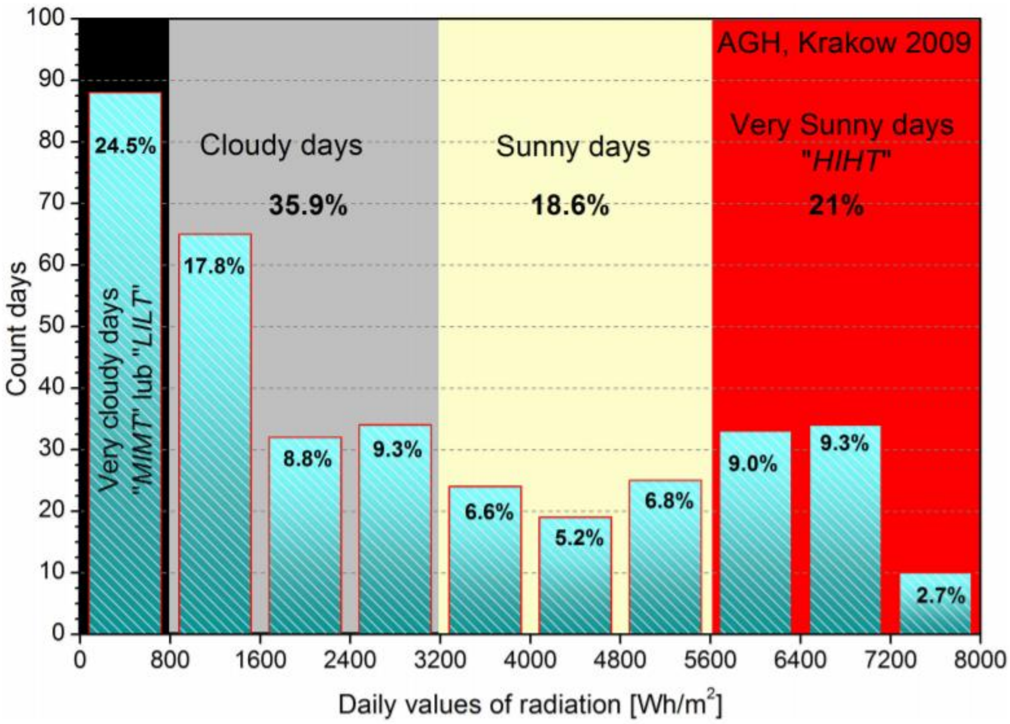

Fig. 10. Histogram of the daily values of irradiation, AGH Krakow area. [From: Analysis of Solar Energy Resources in Southern Poland for Photovoltaic Applications]

Figure 11a shows the distribution of average ambient temperatures for the area of Krakow. One may notice the lack of symmetry of hourly temperature distribution. In summer days are characteristic cooler mornings and significant warming in the afternoon and evening hours.

However, Figure 11b shows the distribution of intensity of solar radiation on the horizon surface at the testing site. Note the wide range of changes in both the intensity of the radiation, as well as the time of solar radiation. The data are the basis to determine the so-called insolation of area, i.e. determine the average number of hours of daily activity of the Sun in different months of the year, enough to operate the PV system.

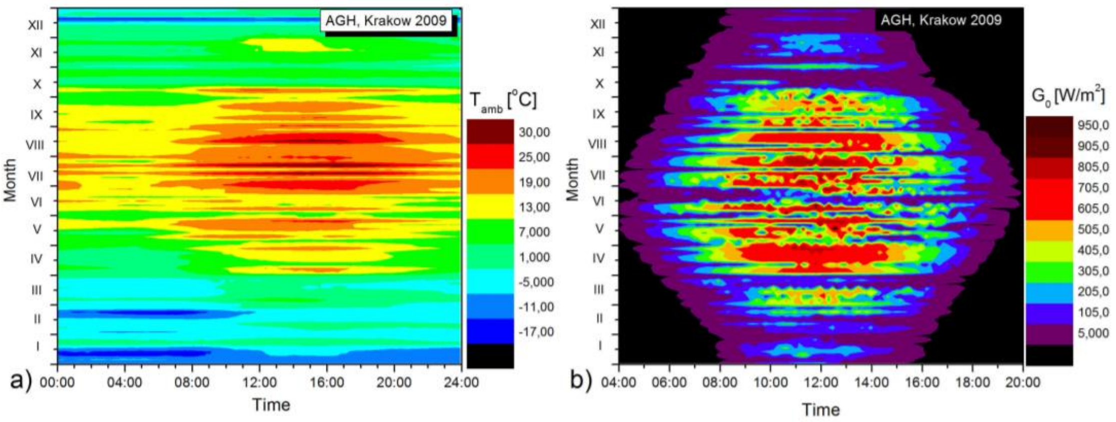

Fig. 11. Distribution of daily values of: a) ambient temperature and b) intensity of solar radiation occurring in the AGH in Krakow. [From: Analysis of Solar Energy Resources in Southern Poland for Photovoltaic Applications]

A system that will meet future user needs, not only in summer but also in the other seasons of work, and the system for which the performance factor will be the best for our geographical and climatic conditions.

6.4. Develop of the system

6.4.1. Type of photovoltaic installation

According to the type of installation and depending on the purpose, it is possible to differentiate: on-grid or grid-tied solar power system and off-grid solar power system.

In on-grid or grid-tied type of solar system, the solar power generation system is connected to the electric utility grid. When the consumption of power generated from solar exceeds that of produced solar electricity, home owners can then use traditional utility power source or the grid. When solar power production is more than the consumption, then the excess solar electricity can be sold back to the utility company, thus making profit from selling the power. This process is called as net-metering. This is completely an automated system, and switching between the power supplies hardly takes any time and neither the user has to bother about. Some advantages of this configurations are that it generates passive income through the facility to export excess electricity to the utility company and they are easier solar installation and ensure electricity even with lower solar power generation capacity.

In the off-grid solar power system type, the PV system is completely disconnected from the utility power grid. Storage batteries are required to generate and store power from sun and use when required. The excess power generated is only stored in the batteries and cannot be transported back to the utility companies like the grid connection. For prolonged excess power demand, electricity generators can be used as a power source to match up with the requirements. Some benefits of off-grid solar power installation are the possibility of bringing power to the remote areas, where traditional grid connection is not reachable and the uninterrupted power supply, even during power cuts.

Furthermore, there is another type of solar installations called hybrid systems. Modern hybrid systems combine solar and battery storage and are now available in many different forms and configurations. Due to the decreasing cost of battery storage, systems that are already connected to the electricity grid can start taking advantage of battery storage as well. This means being able to store solar energy that is generated during the day and using it at night. When the stored energy is depleted, the grid is there as a backup, allowing consumers to have the best of both worlds. Hybrid systems are also able to charge the batteries using cheap off-peak electricity (usually after midnight to 6am).

In this project, the option of a grid-connected photovoltaic system has been selected having reviewed the above considerations. In this way, the system will be investigated under net metering conditions.

6.4.2. Incident solar radiation. Optimum inclination

The first step is to determine the best tilt angle for the photovoltaic panels to obtain maximum performance from them. To find out, it will be used the Photovoltaic Geographical Information System (PVGIS), where it is introduced the location and an estimated system loss of 20%. In addition, the azimuth is 20º.

Provided inputs:	
Location [Lat/Lon]:	50.065, 19.917
Horizon:	Calculated
Database used:	PVGIS-SARAH
PV technology:	Crystalline silicon
PV installed [kWp]:	1
System loss [%]:	20

Simulation outputs:	
Slope angle [°]:	38 (opt)
Azimuth angle [°]:	20
Yearly PV energy production [kWh]:	956.63
Yearly in-plane irradiation [kWh/m^2]:	1288.22
Year-to-year variability [kWh]:	50.34
Changes in output due to:	
Angle of incidence [%]:	-2.95
Spectral effects [%]:	1.69
Temperature and low irradiance [%]:	-5.94
Total loss [%]:	-25.74

Fig. 12. Summary of inputs and outputs. [From: PVGIS]

The slope angle provided by the program is 38º relative to the horizontal. The yearly PV energy production is 956.63 kWh/year per each unit of kWp, as expected taking into account the location of the building. Other information the software provides is the monthly energy output and the monthly in-plane irradiation, shown in Figures 13 and 14.

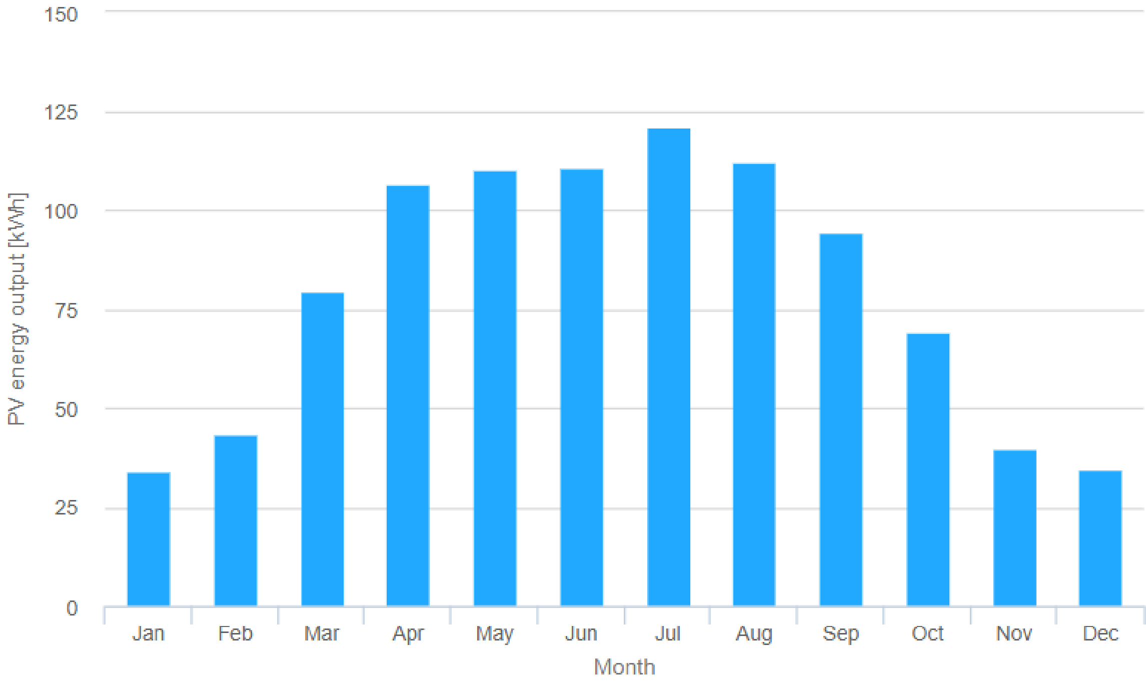

Fig. 13. Monthly energy output. [From: PVGIS]

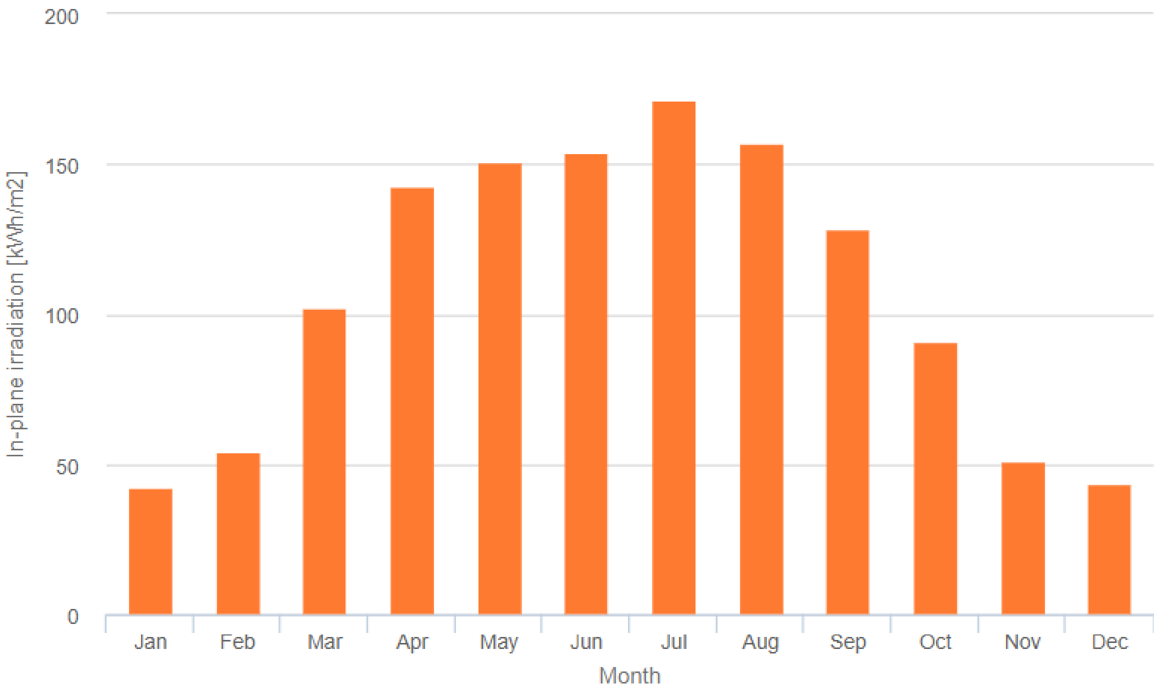

Fig. 14. Monthly in-plane irradiation. [From: PVGIS]

6.5. Simulation. Different configurations and technologies

6.5.1. Starter specifications

First of all, it is important to analyze the energy requirements. As it was studied, the hotel needs 150,000 kWh/year to meet the demand of lights, HVAC equipment and other utilities.

At this phase, it is necessary to start using the PV*sol software. Next values and characteristics have been considerated and introduced for the simulation.

- Main voltage between phase and neutral: 230 V
- Number of phases: 3-phase
- Type of system: Grid-connected PV System
- Displacement power factor (cos φ): 1
- Specific CO_2 saving through the use of PV energy: 470 g/kWh
- Power losses resulting from a drop in voltage at the bypass diodes: 0.5%
- Power losses resulting from mismatching or reduced yield: 2%
- Power losses resulting from ground reflection (albedo): 20% (constant every month of the year)
- Output losses due to soiling of the PV modules: 0%

Taking into account that the inclination of mounting surface, β_1, is 4.6º and the resulting module inclination is 38º, the resulting mount angle β_r turns out to be 33.4º. Furthermore, the orientation to mounting face α_r is assumed to be 0º for ease of installation. All the details are reported in Figure 15.

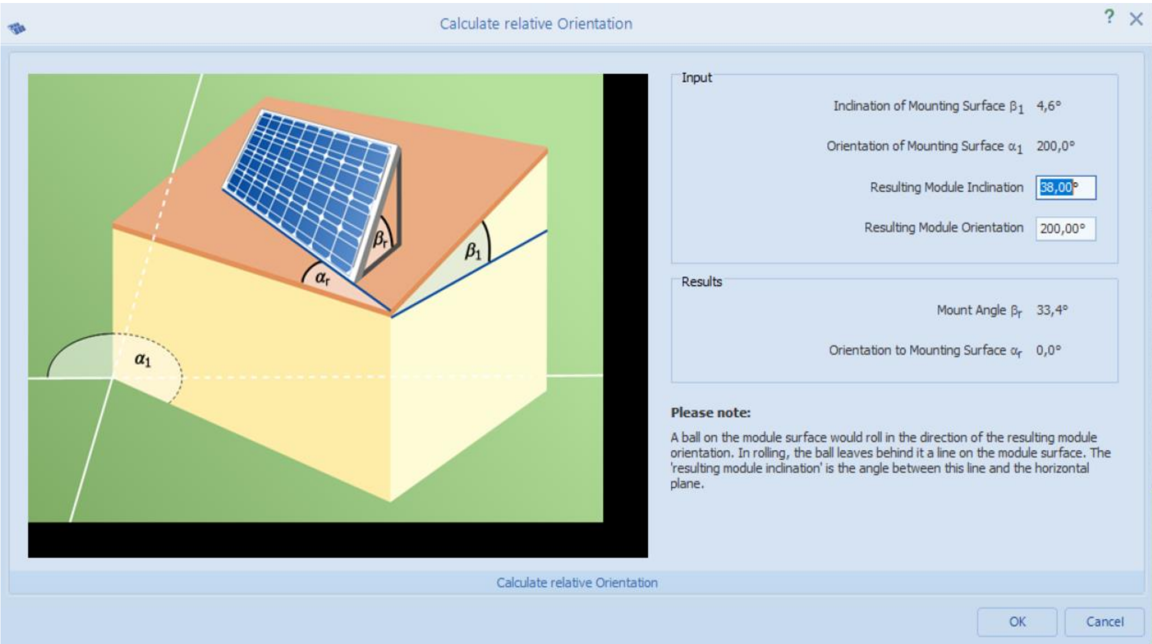

Fig. 15. Relative orientation of the modules [From: PV*sol]

6.5.2. Selection of the solar panel

Regarding the selection of the photovoltaic panel and the inverter/s, the way to proceed will be to simulate with the PV*sol software with different brands and check the results in terms of energy produced and performance.

On the one hand, for the solar panels, it will be tested with different models of the best brands in the field. When the panel has been chosen, a list of the most recognized brands worldwide will be introduced in the software so that the simulation will recommend the best ones for our case. The first results will be evaluated to know which will give better performance to the installation.

Table 3 shows the result of the simulation with various brands of solar panels with 350 W of power. The high quality brands chosen were Canadian Solar, SunPower, LG, JA Solar and Hanwha Q Cells. The aim was to profit the south-west roof surface, as maximum energy production is desired. As it is possible to appreciate in the third column, the number of panels changes because it is sought to create an installation with the maximum nuber of them that they fit.

Company	Model	Number of panels	Power (kWp)	Energy produced (kWh/year)
Canadian Solar	CS3U-350P	236	82.6	76,491
SunPower	SPR-MAX2-350	224	78.4	77,476
LG	LG350Q1K-V5	232	81.2	79,305
Hanwha Q Cells	Q.PEAK DU8-G8.2 350 Rev1	228	79.8	79,356
JA Solar	JAM 72D00-350/PR 350W	236	82.6	77,730

Table 3. Solar panels tested with PV*sol

The values of energy produced have been obtained with the same type of inverter. Several panels are valid for this case, but the one that gave the best result was the model **Q.PEAK DU8-G8.2 350 Rev1** of **Hanwha Q Cells**, one of the top brands in the market. All the details of this type of solar panel are included in the Appendix 1. Moreover, it is important to comment that the selected distance between rows of solar panels was 1,5 meters looking to make the most of the space.

Figure 16 illustrates the arrangement of the solar panels on the hotel roof. As it can be analyzed in Figures 8 and 9, surrounding buildings and trees are not considered because they do not have relevant importance in this case.

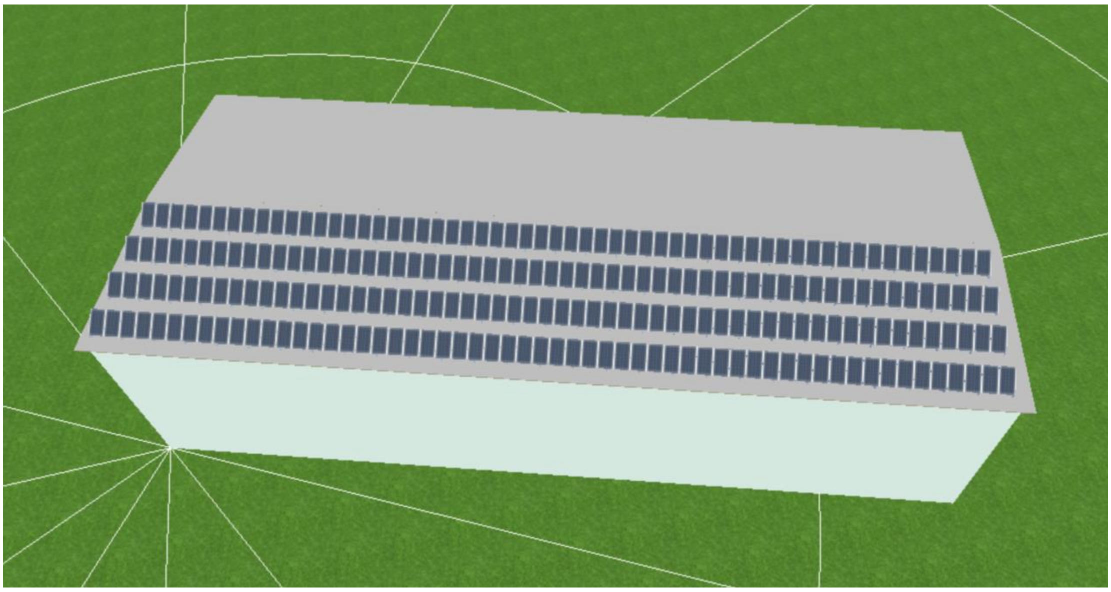

Fig. 16. Arrangement of solar panels [From: PV*sol]

6.5.3. Selection of the inverter

Regarding the selection of the inverter, the market has been studied to select a list of the best quality brands. All inverters of the following brands with at least 20 kW have been selected.

- Fronius Internacional
- Danfoss Solar Inverters
- GoodWe Solar Inverter
- GROWATT New Energy Co.
- Huawei Technologies
- Ingeteam S.A.
- KACO new energy
- Kostal
- SMA Solar Technology AG
- SolarEdge
- SolaX Power Co.

The result of the simulation shows that the three options with better quality of connection are shown in Figure 17.

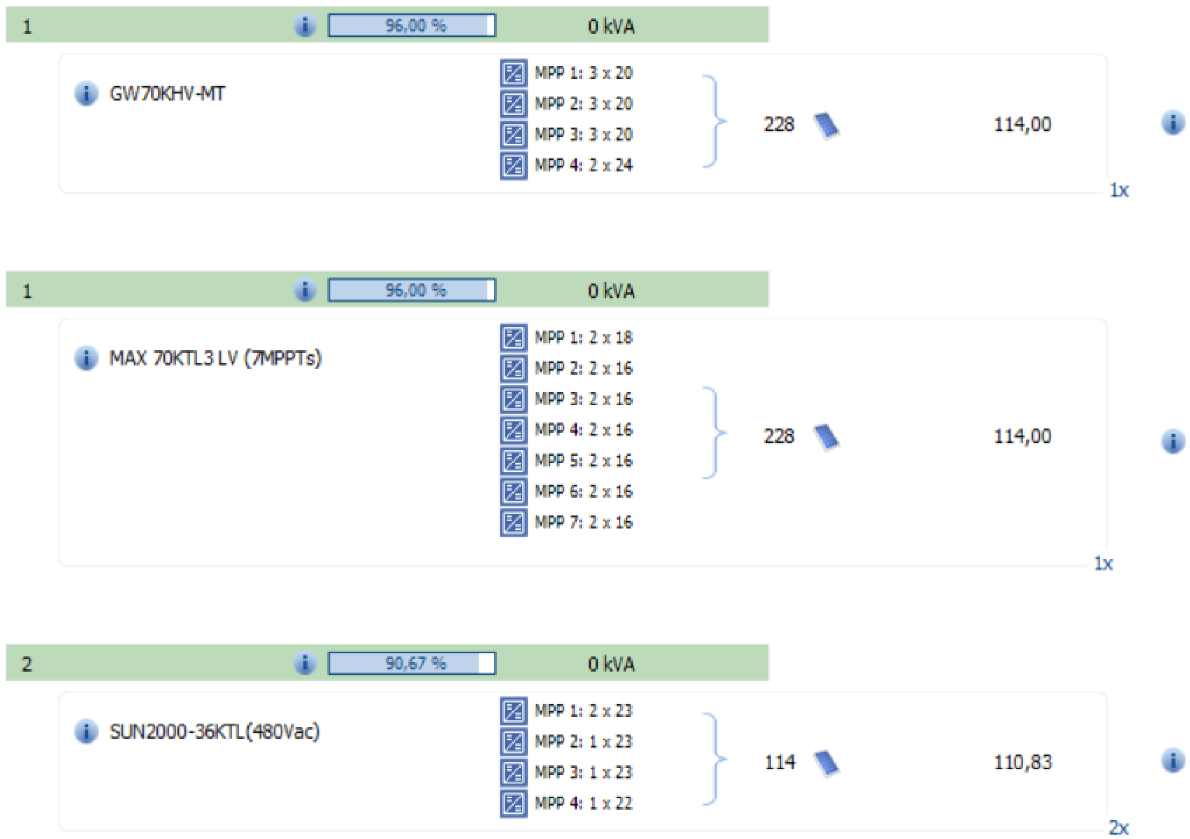

Fig. 17. Selection of the inverter [From: PV*sol]

Table 4 shows the comparison between energy produced using each type of inverter. In the first two cases, the entire system would be covered with 70 kW inverters while the third option relies on two 36 kW inverters.

Company	Model	Energy produced (kWh/year)
GoodWe Solar Inverter	GW70KHV-MT	79,311
GROWATT New Energy Co.	MAX 70KTL3 LV (7MPPTs)	79,610
Huawei Technologies	2x SUN2000-36KTL (480Vac)	80,194

Table 4. Inverters tested with PV*sol

As it can be seen, the option that produces more energy is the third one, where two inverters **SUN2000-36KTL** of the well-known Chinese brand **Huawei Technologies** would supply the necessary power for the installation. The amount of energy generated will be 80,194 kWh/year, covering more than half of the energy consumption needed in the hotel and meeting the objective proposed in this project. So, the energy provided by PV*sol per kWp installed is 1,004.94 kWh. The data sheet and all specifications of the selected inverter can be found in Appendix 2.

7. Results

This section will summarize the most important results of the project simulation. The final circuit diagram of the installation is shown in Figure 18. Both inverters cover the different module arrays in a 3-phase system. The losses of connection has been approximated to zero for this project.

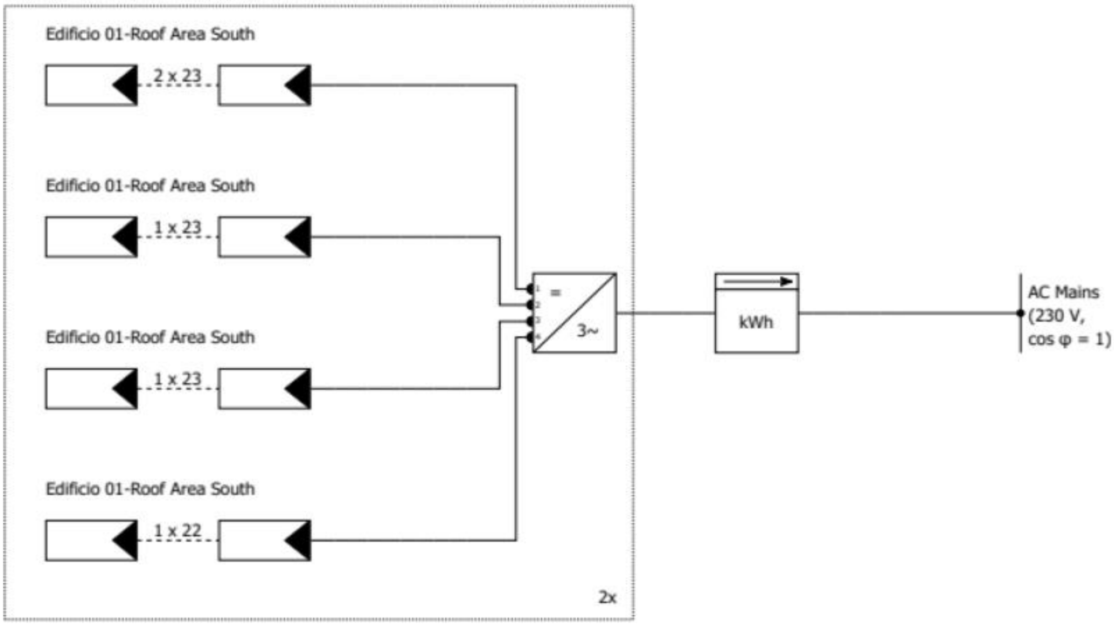

Fig. 18. Circuit Diagram [From: PV*sol]

First of all, it is possible to observe in Figure 19 a summary of the most important data from the simulation. Both the energy and economic results will be discussed below. The graph represents the energy production in kWh throughout the months of the year. At least 8 of them exceed 5000 kWh, which is a positive indicator.

Fig. 19. Results overview [From: PV*sol]

The energy balance shows how the radiation is transformed step by step into useful energy that will later be used as electrical energy. All losses are listed in order in Table 5. First the Global Radiation is estimated horizontally and then the Radiation in each module is calculated. Multiplying by the useful surface the Global Radiation of the system is obtained. Once we have got this, we subtract all relevant losses for the energy obtained from the system in DC. Finally, the losses produced by the inverters must be included to know the energy in AC that will be used by the user.

Global radiation - horizontal	**1.059,95**	**kWh/m²**	
Deviation from standard spectrum	-10,60	kWh/m²	-1,00 %
Ground Reflection (Albedo)	18,98	kWh/m²	1,81 %
Orientation and inclination of the module surface	102,61	kWh/m²	9,60 %
Module-independent shading	0,00	kWh/m²	0,00 %
Reflection on the Module Interface	0,00	kWh/m²	0,00 %
Global Radiation at the Module	**1.170,94**	**kWh/m²**	
	1.170,94	kWh/m²	
	x 408,622	m²	
	= 478.472,02	kWh	
Global PV Radiation	**478.472,02**	**kWh**	
Soiling	0,00	kWh	0,00 %
STC Conversion (Rated Efficiency of Module 19,53 %)	-385.048,82	kWh	-80,47 %
Rated PV Energy	**93.423,20**	**kWh**	
Module-specific Partial Shading	-5.289,13	kWh	-5,66 %
Low-light performance	-2.022,15	kWh	-2,29 %
Deviation from the nominal module temperature	-1.443,70	kWh	-1,68 %
Diodes	-31,38	kWh	-0,04 %
Mismatch (Manufacturer Information)	-1.692,74	kWh	-2,00 %
Mismatch (Configuration/Shading)	-840,91	kWh	-1,01 %
PV Energy (DC) without inverter down-regulation	**82.103,18**	**kWh**	
Failing to reach the DC start output	-16,27	kWh	-0,02 %
Down-regulation on account of the MPP Voltage Range	-1,37	kWh	0,00 %
Down-regulation on account of the max. DC Current	0,00	kWh	0,00 %
Down-regulation on account of the max. DC Power	0,00	kWh	0,00 %
Down-regulation on account of the max. AC Power/cos phi	-46,68	kWh	-0,06 %
MPP Matching	-59,56	kWh	-0,07 %
PV energy (DC)	**81.979,30**	**kWh**	
Energy at the Inverter Input	**81.979,30**	**kWh**	
Input voltage deviates from rated voltage	-92,81	kWh	-0,11 %
DC/AC Conversion	-1.692,00	kWh	-2,07 %
Standby Consumption (Inverter)	-27,91	kWh	-0,03 %
Total Cable Losses	0,00	kWh	0,00 %
PV energy (AC) minus standby use	**80.166,57**	**kWh**	
Grid Feed-in	**80.194,48**	**kWh**	

Table 5. PV system energy balance [From: PV*sol]

Furthermore, it is important to note that the implementation of this renewable energy system will achieve a reduction in CO_2 emissions of 37.691 kg/year.

The irradiance and temperature per module area are detailed in the Figures 20 and 21. The first distinguishes between irradiance onto horizontal plane and irradiance onto tilted surface while the second differentiates between outside temperature module temperature. As expected, higher values are recorded in the summer months on both graphs.

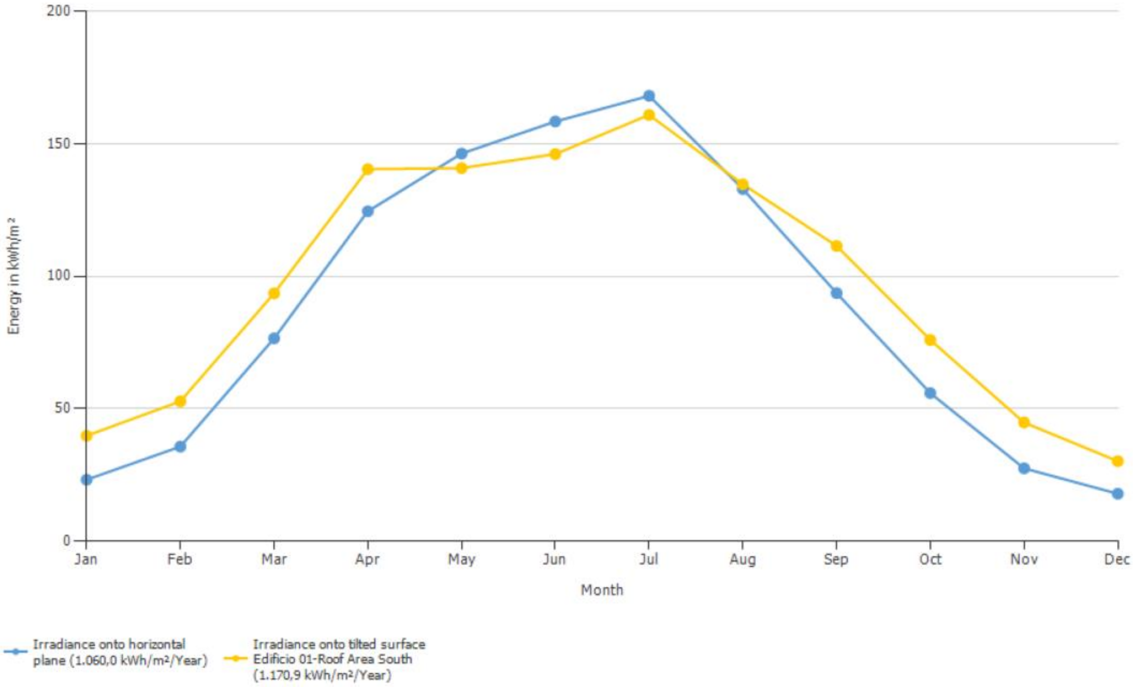

Fig. 20. Irradiance per module area [From: PV*sol]

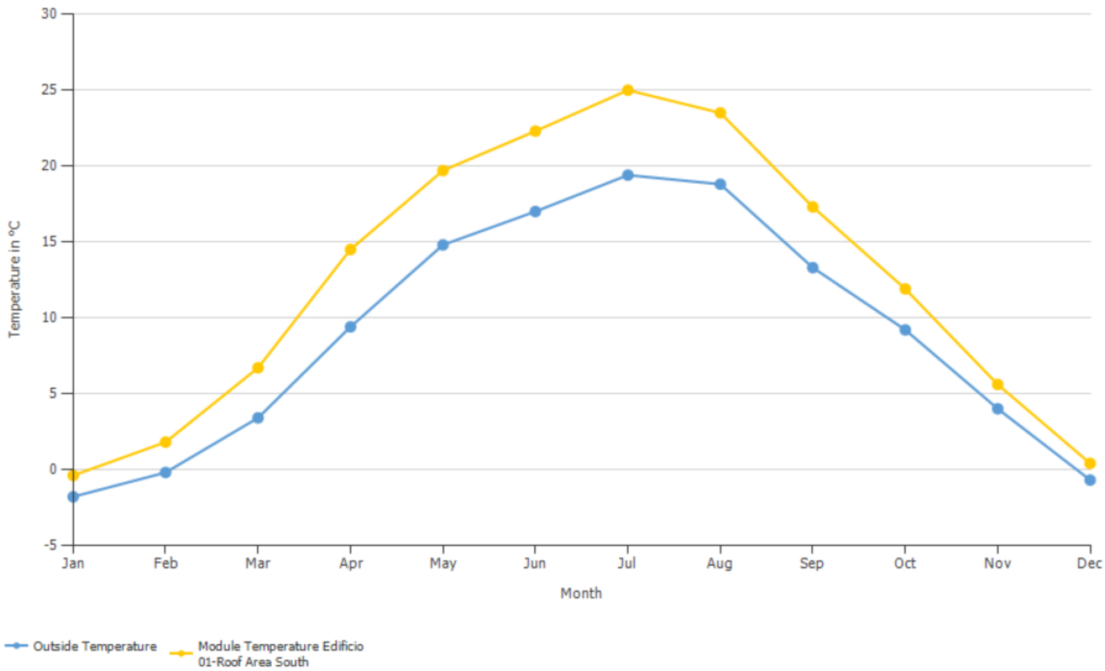

Fig. 21. Temperature per module area [From: PV*sol]

In addition, it is possible to see the production forecast and the performance ratio (PR) per inverter in Figures 22 and 23. The graphs compare both inverters. Values are quite higher in the first inverter because it embraces a larger number of modules.

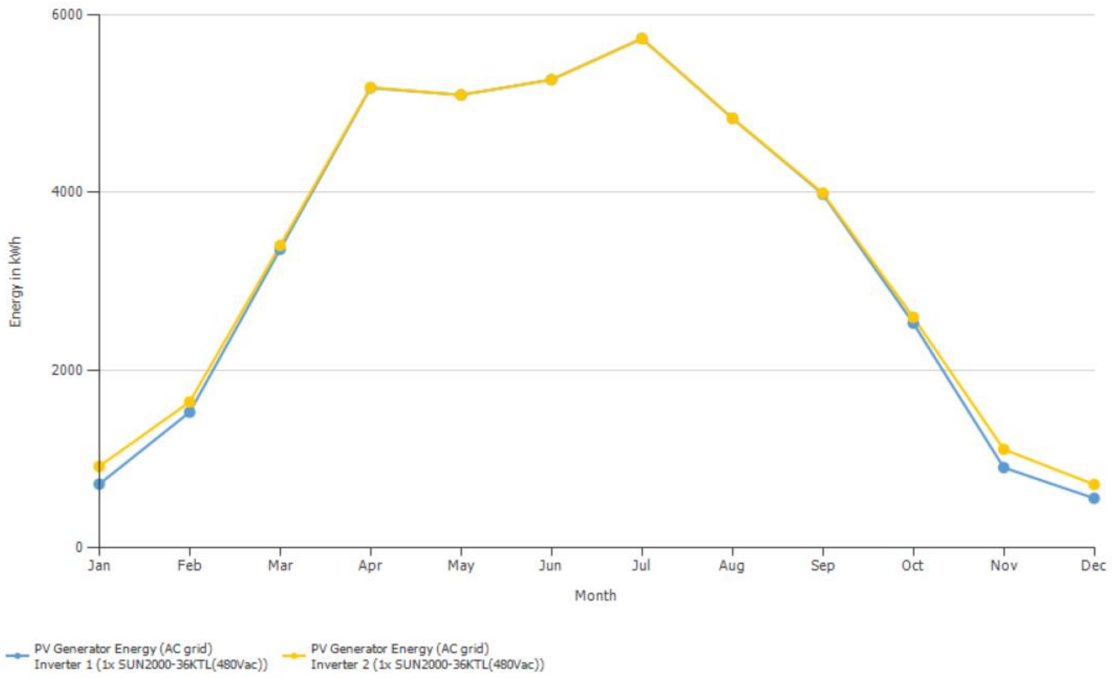

Fig. 22. Production Forecast per inverter [From: PV*sol]

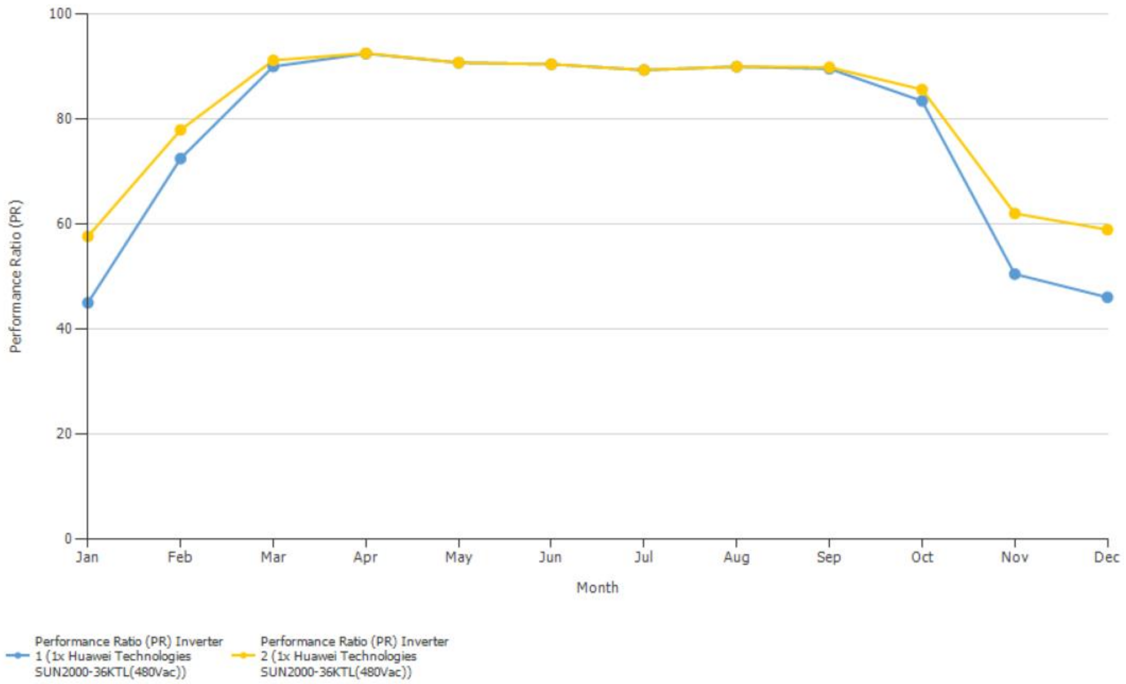

Fig. 23. Performance Ratio (PR) per inverter [From: PV*sol]

8. Economic analysis

In this section, an economic evaluation of the project will be carried out in order to analyse the viability of the photovoltaic installation in the hotel. An assessment period of 20 years and 1% of interest capital have been defined to perform the simulation looking at the literature review.

System Data		
Grid Feed-in in the first year (incl. module degradation)	80.194	kWh/Year
PV Generator Output	79,8	kWp
Start of Operation of the System	25/05/2020	
Assessment Period	20	Years
Interest on Capital	1	%
Economic Parameters		
Return on Assets	7,87	%
Accrued Cash Flow (Cash Balance)	105.960,93	€
Amortization Period	10,6	Years
Electricity Production Costs	0,08	€/kWh

Table 6. Financial analysis [From: PV*sol]

The most important value that it is possible to appreciate is the amortization period. The simulation indicates that it will be **10.6 years**. Apart from this, the price of electricity sold to grid has been determined to be 0.15 €/kWh. This leads to a remuneration value of 12,029.17 €/year, as seen in Table 7.

Remuneration and Savings		
Total Payment from Utility in First Year	12.029,17	€/Year
Remuneration of Electricity sold to Third Party		
Price of Electricity sold to Third Party	0,15	€/kWh
Remuneration of Electricity sold to Third Party	12.029,17	€/Year

Table 7. Remuneration and saving [From: PV*sol]

The next step is to analyze the Cash Flow Table (Table 8) where it can be seen the change in cash balance from negative to positive in year 11. This is consistent with what was previously obtained.

Moreover, the software also offers a graphical view for better visualization that it is shown in Figure 24.

	Year 1	Year 2	Year 3	Year 4	Year 5
Investments	-119.700,00 €	0,00 €	0,00 €	0,00 €	0,00 €
Feed-in / Export Tariff	10.737,10 €	11.792,15 €	11.675,40 €	11.559,80 €	11.445,34 €
Annual Cash Flow	**-108.962,90 €**	**11.792,15 €**	**11.675,40 €**	**11.559,80 €**	**11.445,34 €**
Accrued Cash Flow (Cash Balance)	-108.962,90 €	-97.170,75 €	-85.495,35 €	-73.935,56 €	-62.490,21 €
	Year 6	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Investments	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
Feed-in / Export Tariff	11.332,02 €	11.219,83 €	11.108,74 €	10.998,75 €	10.889,85 €
Annual Cash Flow	**11.332,02 €**	**11.219,83 €**	**11.108,74 €**	**10.998,75 €**	**10.889,85 €**
Accrued Cash Flow (Cash Balance)	-51.158,19 €	-39.938,36 €	-28.829,62 €	-17.830,87 €	-6.941,02 €
	Year 11	**Year 12**	**Year 13**	**Year 14**	**Year 15**
Investments	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
Feed-in / Export Tariff	10.782,03 €	10.675,28 €	10.569,58 €	10.464,93 €	10.361,32 €
Annual Cash Flow	**10.782,03 €**	**10.675,28 €**	**10.569,58 €**	**10.464,93 €**	**10.361,32 €**
Accrued Cash Flow (Cash Balance)	3.841,01 €	14.516,29 €	25.085,88 €	35.550,81 €	45.912,13 €
	Year 16	**Year 17**	**Year 18**	**Year 19**	**Year 20**
Investments	0,00 €	0,00 €	0,00 €	0,00 €	0,00 €
Feed-in / Export Tariff	10.258,73 €	10.157,16 €	10.056,60 €	9.957,03 €	9.858,44 €
Annual Cash Flow	**10.258,73 €**	**10.157,16 €**	**10.056,60 €**	**9.957,03 €**	**9.858,44 €**
Accrued Cash Flow (Cash Balance)	56.170,87 €	66.328,03 €	76.384,63 €	86.341,65 €	96.200,09 €
	Year 21				
Investments	0,00 €				
Feed-in / Export Tariff	9.760,83 €				
Annual Cash Flow	**9.760,83 €**				
Accrued Cash Flow (Cash Balance)	105.960,93 €				

Table 8. Cash Flow Table [From: PV*sol]

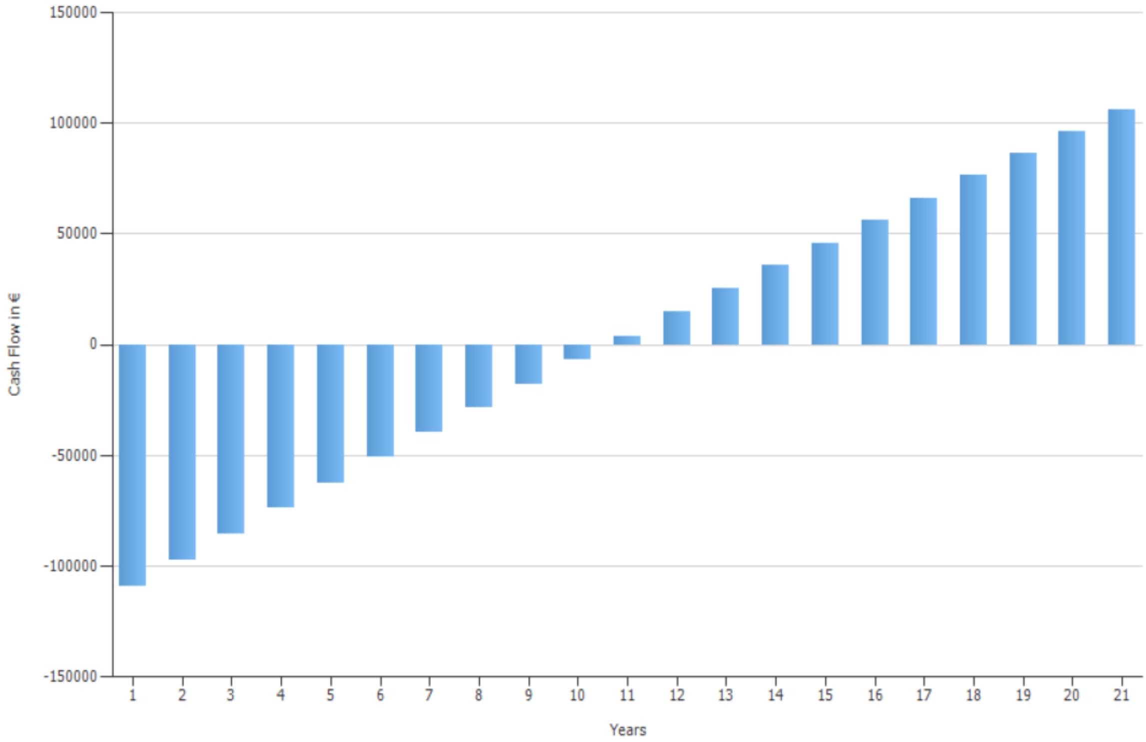

Fig. 24. Accrued Cash Flow (Cash Balance) [From: PV*sol]

9. Conclusions

The generation of renewable energy is one of the solutions for energy saving and sustainable development of our society. It is important for the whole of Poland to promote the use and development of renewable energy technology, both for industry and for the tertiary sector.

The need to be more competitive and to obtain a better quality of life for the inhabitants implies a better use of the available resources. The main objective of this project has been to cover at least half of the hotel's energy demand. To this end, specialized software in the field has been used.

On the one hand, through PVGIS, it has been determined that the optimal angle of inclination is 38º with respect to the horizontal. Since the hotel roof has a slope of 4.6°, the supports must be oriented 33.4°. In addition, the program shows that the annual production of photovoltaic energy will be 956.63 kWh per installed kW.

On the other hand, by means of PV*sol, several possibilities of solar panel brands have been analyzed concluding that the model Q.PEAK DU8-G8.2 350 of the Hanwha Q Cells brand provides the highest energy production. The implementation of 228 solar modules on the southern roof of the hotel will form a 79.8 kW solar photovoltaic installation. With regard to the inverters used, analysing the models of over 20 kW of the best quality brands, it has been concluded that two SUN2000-36KTL inverters of the Huawei Technologies brand generate the best performance from the installation. Thus, 80,194 kWh/year will be produced, exceeding half of the 150,000 kWh/year needed to meet the demand of lights, HVAC equipment and other utilities. Moreover, the annual production of energy provided by PV*sol is 1,004.94 kWh per installed kW, quite higher than the value given by PVGIS.

Eventually, for the economic study, it has been determined that the amortization period will be 10.6 years. This value indicates that the project is completely viable and that it could be started in a hypothetical case.

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A. Data Sheet Q.PEAK DUO-G8

powered by Q.ANTUM DUO

Q.PEAK DUO-G8
340-360
ENDURING HIGH PERFORMANCE

Q.ANTUM TECHNOLOGY: LOW LEVELISED COST OF ELECTRICITY
Higher yield per surface area, lower BOS costs, higher power classes, and an efficiency rate of up to 20.4 %.

INNOVATIVE ALL-WEATHER TECHNOLOGY
Optimal yields, whatever the weather with excellent low-light and temperature behaviour.

ENDURING HIGH PERFORMANCE
Long-term yield security with Anti LID Technology, Anti PID Technology[1], Hot-Spot Protect and Traceable Quality Tra.Q™.

EXTREME WEATHER RATING
High-tech aluminium alloy frame, certified for high snow (5400 Pa) and wind loads (4000 Pa).

A RELIABLE INVESTMENT
Inclusive 12-year product warranty and 25-year linear performance warranty[2].

STATE OF THE ART MODULE TECHNOLOGY
Q.ANTUM DUO combines cutting edge cell separation and innovative wiring with Q.ANTUM Technology.

[1] APT test conditions according to IEC/TS 62804-1:2015, method B (−1500 V, 168 h)
[2] See data sheet on rear for further information.

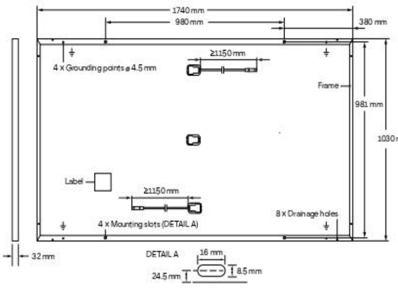
THE IDEAL SOLUTION FOR:
Rooftop arrays on residential buildings
Rooftop arrays on commercial / industrial buildings

Engineered in Germany

Q CELLS

MECHANICAL SPECIFICATION

Format	1740 mm × 1030 mm × 32 mm (including frame)
Weight	19.9 kg
Front Cover	3.2 mm thermally pre-stressed glass with anti-reflection technology
Back Cover	Composite film
Frame	Black anodised aluminium
Cell	6 × 20 monocrystalline Q.ANTUM solar half cells
Junction box	53-101 mm × 32-60 mm × 15-18 mm Protection class IP67, with bypass diodes
Cable	4 mm² Solar cable; (+) ≥1150 mm, (−) ≥1150 mm
Connector	Stäubli MC4, Hanwha Q CELLS HQC4; IP68

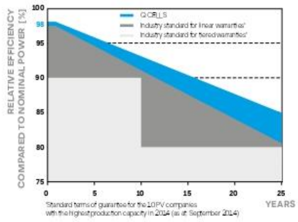


ELECTRICAL CHARACTERISTICS

POWER CLASS				340	345	350	355	360
MINIMUM PERFORMANCE AT STANDARD TEST CONDITIONS, STC[1] (POWER TOLERANCE +5 W / −0 W)								
Minimum	Power at MPP[1]	P_{MPP}	[W]	340	345	350	355	360
	Short Circuit Current[1]	I_{SC}	[A]	10.63	10.68	10.74	10.79	10.84
	Open Circuit Voltage[1]	V_{OC}	[V]	40.20	40.45	40.70	40.95	41.19
	Current at MPP	I_{MPP}	[A]	10.12	10.17	10.22	10.28	10.33
	Voltage at MPP	V_{MPP}	[V]	33.61	33.92	34.24	34.55	34.85
	Efficiency[1]	η	[%]	≥19.0	≥19.3	≥19.5	≥19.8	≥20.1
MINIMUM PERFORMANCE AT NORMAL OPERATING CONDITIONS, NMOT[2]								
Minimum	Power at MPP	P_{MPP}	[W]	254.6	258.4	262.1	265.9	269.6
	Short Circuit Current	I_{SC}	[A]	8.56	8.61	8.65	8.69	8.74
	Open Circuit Voltage	V_{OC}	[V]	37.91	38.14	38.38	38.61	38.85
	Current at MPP	I_{MPP}	[A]	7.96	8.00	8.05	8.09	8.13
	Voltage at MPP	V_{MPP}	[V]	31.98	32.28	32.57	32.87	33.16

[1]Measurement tolerances P_{MPP} ±3%; I_{SC}; V_{OC} ±5% at STC: 1000 W/m², 25±2 °C, AM 1.5 according to IEC 60904-3 • [2]800 W/m², NMOT, spectrum AM 1.5

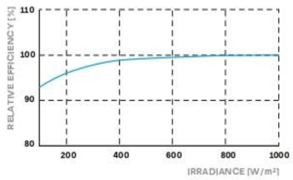
Q CELLS PERFORMANCE WARRANTY



At least 98% of nominal power during first year. Thereafter max. 0.54% degradation per year. At least 93.1% of nominal power up to 10 years. At least 85% of nominal power up to 25 years.

All data within measurement tolerances. Full warranties in accordance with the warranty terms of the Q CELLS sales organisation of your respective country.

PERFORMANCE AT LOW IRRADIANCE



Typical module performance under low irradiance conditions in comparison to STC conditions (25 °C, 1000 W/m²).

TEMPERATURE COEFFICIENTS

Temperature Coefficient of I_{SC}	α	[% / K]	+0.04	Temperature Coefficient of V_{OC}	β	[% / K]	−0.27
Temperature Coefficient of P_{MPP}	γ	[% / K]	−0.35	Nominal Module Operating Temperature	NMOT	[°C]	43±3

PROPERTIES FOR SYSTEM DESIGN

Maximum System Voltage	V_{SYS}	[V]	1000	PV module classification	Class II
Maximum Reverse Current	I_R	[A]	20	Fire Rating based on ANSI / UL 61730	C / TYPE 2
Max. Design Load, Push / Pull		[Pa]	3600 / 2667	Permitted Module Temperature on Continuous Duty	−40 °C - +85 °C
Max. Test Load, Push / Pull		[Pa]	5400 / 4000		

QUALIFICATIONS AND CERTIFICATES

VDE Quality Tested,
IEC 61215:2016;
IEC 61730:2016.
This data sheet complies with DIN EN 50380.

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PACKAGING INFORMATION

Horizontal packaging	1780 mm	1080 mm	1208 mm	673.8 kg	28 pallets	26 pallets	32 modules
Vertical packaging	1815 mm	1150 mm	1220 mm	683 kg	28 pallets	24 pallets	32 modules

Note: Installation instructions must be followed. See the installation and operating manual or contact our technical service department for further information on approved installation and use of this product. Q CELLS supplies solar modules in two different stacking methods, depending on the location of manufacture (modules are packed horizontally or vertically). You can find more detailed information in the document "Packaging and Transport Information", available from Q CELLS.

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Sonnenallee 17-21, 06766 Bitterfeld-Wolfen, Germany | **TEL** +49 (0)3494 66 99-23444 | **FAX** +49 (0)3494 66 99-23000 | **EMAIL** sales@q-cells.com | **WEB** www.q-cells.com

Engineered in Germany

B. Data Sheet SUN2000-36KTL

SUN2000-36KTL

Smart String Inverter

HUAWEI

Smart

8 strings intelligent monitoring

Efficient

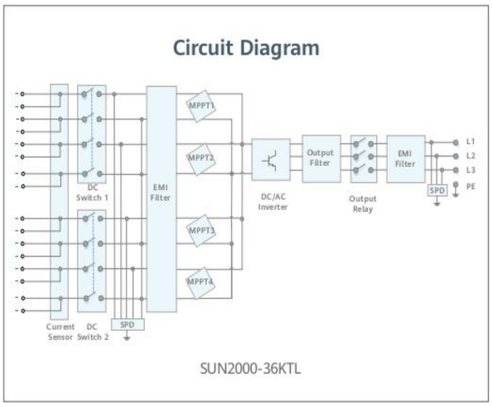
Max. efficiency 98.6%

Safe

Fuse free design

Reliable

Type II surge arresters for DC & AC



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SUN2000-36KTL

Technical Specification

Technical Specification	SUN2000-36KTL
Efficiency	
Max. Efficiency	98.8% @480 V; 98.6% @380 V / 400 V
European Efficiency	98.6% @480 V; 98.4% @380 V / 400 V
Input	
Max. Input Voltage [1]	1,100 V
Max. Current per MPPT	22 A
Max. Short Circuit Current per MPPT	30 A
Start Voltage	250 V
MPPT Operating Voltage Range [2]	200 V ~ 1,000 V
Rated Input Voltage	620 V @380 Vac / 400 Vac; 720 V @480 Vac
Number of MPP trackers	4
Max. number of inputs	8
Output	
Rated AC Active Power	36,000 W
Max. AC Apparent Power	40,000 VA
Max. AC Active Power (cosφ=1)	Default 40,000 W; 36,000 W optional in settings
Rated Output Voltage	220 V / 380 V, 230 V / 400 V, default 3W + N + PE; 3W + PE optional in settings 277 V / 480 V, 3W + PE
Rated AC Grid Frequency	50 Hz / 60 Hz
Rated Output Current	54.6 A @380 V, 52.2 A @400 V, 43.4 A @480 V
Max. Output Current	60.8 A @380 V, 57.8 A @400 V, 48.2 A @480 V
Adjustable Power Factor Range	0.8 leading... 0.8 lagging
Max. Total Harmonic Distortion	< 3%
Protection	
Input-side Disconnection Device	Yes
Anti-islanding Protection	Yes
AC Overcurrent Protection	Yes
DC Reverse-polarity Protection	Yes
PV-array String Fault Monitoring	Yes
DC Surge Arrester	Type II
AC Surge Arrester	Type II
DC Insulation Resistance Detection	Yes
Residual Current Monitoring Unit	Yes
Communication	
Display	LED indicators; WLAN adaptor + FusionSolar APP
RS485	Yes
USB	Yes
Monitoring BUS (MBUS)	Yes (isolation transformer required)
General Data	
Dimensions (W x H x D)	930 x 550 x 283 mm (36.6 x 21.7 x 11.1 inch)
Weight (with mounting plate)	62 kg (136.7 lb.)
Operating Temperature Range	-25°C ~ 60°C (-13°F ~ 140°F)
Cooling Method	Natural Convection
Max. Operating Altitude	4,000 m (13,123 ft.)
Relative Humidity	0 ~ 100%
DC Connector	Amphenol Helios H4
AC Connector	Waterproof PG Terminal + OT Connector
Protection Degree	IP65
Topology	Transformerless
Nighttime Power Consumption	< 2.5 W
Standard Compliance (more available upon request)	
Certificate	EN 62109-1/-2, IEC 62109-1/-2, EN 50530, IEC 62116, IEC 60068, IEC 61683
Grid Code	IEC 61727, VDE-AR-N4105, VDE 0126-1-1, BDEW, G59/3, UTE C 15-712-1, CEI 0-16, CEI 0-21, RD 661, RD 1699, P.O. 12.3,RD 413, EN-50438-Turkey, EN-50438-Ireland, C10/11, MEA, Resolution No.7, NRS 097-2-1, AS/NZS 4777.2

*1 The maximum input voltage is the upper limit of the DC voltage. Any higher input DC voltage would probably damage inverter.
*2 Any DC input voltage beyond the operating voltage range may result in inverter improper operating.

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