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Study and Design of a Photovoltaic System on the TR10 Building's Roof in the Campus Terrassa of the UPC

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Abstract

The following thesis addresses the study, design, simulation and analysis of a photovoltaic system located on the roof of the TR10 building in the Campus Terrassa of the UPC.
The solar radiation and solar geometry are first introduced, and the working principle of a photovoltaic system is explained. A generic photovoltaic system has been studied and the different possible configurations and typologies are presented. The consumption of the specific building has been analysed. The typology, size and components have been chosen according to the logistic conditions, electrical constrains and economical criteria that is presented. A specific photovoltaic system located in Terrassa has been modelled and designed. A 2D and 3D design has been virtually made and the electrical scheme has been designed. The designed system has been simulated and analysed with the PVsyst software. The total production and economical predictions have been calculated, simulated, compared, exposed and analysed. Finally, the conclusions have been exposed and ideas for future studies are suggested.

Object and Motivation

The object of this work is to study, size, and define a preliminary design of a photovoltaic production installation on the roof of the TR10 building located in the Campus Terrassa of the Polytechnic University of Catalonia (UPC).

The motivation of this project comes from the desire to learn about a renewable energy, such as the photovoltaic energy, and to propose a detailed solution based on this energy.
Fortunately, the director of this project, Álvaro Luna, offered me the option to study the case of the roof of the TR10 building. The idea was to make use of an unused space, and take a profit in an ecological way, and a photovoltaic system was a suitable solution, because the roof is exposed to the solar radiation and the consumption of the building is relatively high, since it is dedicated to computer services and there is a great number of electronic devices that are connected to the buildings grid and consume electricity all the day long, but particularly during the day.

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Abbreviation's List

Abbreviation	Definition
b.c.	meaning “before christ”
e.g.	“exempli gratia” (from Latin), meaning “for example”
et al.	“et alia” (from Latin), meaning “and others”
etc.	“et cetera” (from Latin), meaning “and so on”
fig.	meaning “figure”
i.e.	“id est” (from Latin), meaning “That is”
p.a.	“per annum” (from Latin), meaning “Per year”

1 Introduction

1.1 Photovoltaic Energy

Solar energy is actually nothing new. People have used solar power as far back in history as the 7th century B.C. In its most primitive state, energy from the sun has been revered and put to use almost as long as man has walked the earth. The earliest uses of solar power included focusing the sun's energy through a magnifying glass to start fires for cooking. By the 3rd century B.C., Greeks and Romans bounced sunlight off of "burning mirrors" to light sacred torches for religious ceremonies.

In 1839, French physicist Edmond Becquerel discovered the photovoltaic effect while experimenting with a cell made of metal electrodes in a conducting solution. He noted that the cell produced more electricity when it was exposed to light.

Almost 50 years after the photovoltaic effect's discovery, in 1883, the American inventor Charles Fritz created the first working selenium solar cell. Though we use silicon in cells for modern solar panels, this solar cell was a major precursor to the technology used today. [1]

1.2 Solar Radiation

Solar radiation, often called the solar resource or just sunlight, is a general term for the electromagnetic radiation emitted by the sun.

The Solar radiation is composed of photons, i.e. elemental particles. These particles contain an energy value (E), which depends on the radiation's wave longitude (λ). Its value can be calculated as follows:

$$E = \frac{h \cdot c}{\lambda}$$

Where h is the Planck constant and c is the speed of light.
This radiation can be captured and transformed into useful forms of energy such as electricity or heat. The amount of solar radiation that reaches any surface varies according to the geographic location, time of day, season, local landscape and local weather. [2]

The solar irradiation can be defined as the energy per unit of time and surface that reaches a specific surface. It can be expressed with W/m^2.

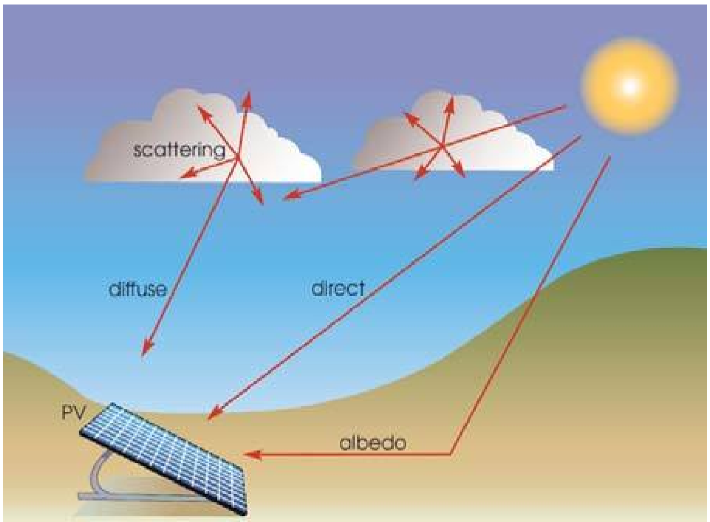
1.2.1 Diffuse and Direct Solar Radiations and Ground Reflected or "Albedo" Radiation

The diffuse solar radiation is defined as the sunlight that passes through the atmosphere and is partially absorbed, scattered and reflected by: Air molecules, water vapor, clouds, dust, pollutants, forest fires, etc.
One way to estimate the diffuse solar component is to study the regression between the global and the diffuse solar radiation at locations where appropriate data are available, establishing models which may be used to predict the diffuse solar radiation.

Direct solar radiation is defined as the sunlight that has reached a surface without being diffused, i.e. being partially absorbed by any of the previously mentioned factors. The sum of the diffuse and the direct solar radiations is called global solar radiation.

On the other hand, Albedo radiation is the amount of sunlight (solar radiation) reflected by a surface, and is usually expressed as a percentage or a decimal value, with 1 being a perfect reflector and 0 absorbing all incoming light. When talking about albedo, the surface is almost always the surface of a planet like Earth. [3]

Figure 1: Types of Solar Radiation



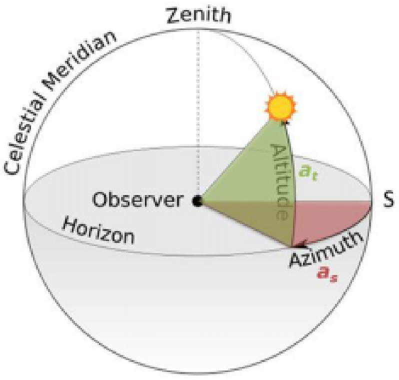
1.3 Solar Geometry

It is highly important to understand the solar geometry, how it influences on the performance of a photovoltaic system and how to structure an installation to take the maximum profit of the solar energy.

1.3.1 Solar Angles

The figure 2 represents the position of the sun in relation with the observer's position.

Figure 2: Solar Angles from the Observer's Position



These are some of the solar geometry angles that should be understood and determined, intending to determine the optimal tilt angle and orientation of the solar panels:

The declination angle (δ): It is the angle between the line extending from the center of earth to the center of Sun and the projection of this line over the equatorial plane. [4] The declination angle (δ) in degrees can be approximated by the equation:

$$\delta = 23.45{\cdot}sin((\frac{360}{365}){\cdot}(n + 284)$$

Where n is the day of the year.
The declination angle has the range $-23.5° \leq \delta \leq 23.5°$ during its year cycle. That is so because the equatorial plane makes an angle of 23.5º with the plane of the Earth's orbit.

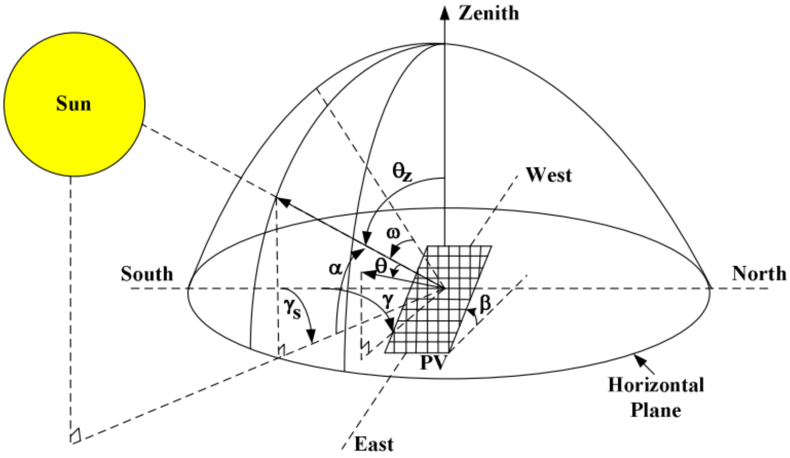
The hour angle (ω): The solar hour angle (ω) for any point on the surface of the earth is described as the angle by which the earth must rotate to position the meridian of the point directly aligned with the sun. [5] It can also be described as the angle between the longitude of sun rays and the longitude of the location. Its value is zero degrees at midday (mean the sun reaches its highest position) and 180 degrees at the end of the day (at 00:00h). The hour angle (ω) can be calculated as followed:

$$\omega = 15{\cdot}(12 - LST)$$

$$LST = OT - \epsilon + \frac{ET}{60} + \frac{\lambda_m - \lambda}{15}$$

Where LST is the Local Solar Time.

Figure 3: Solar Angles



The Altitude angle (α): It is the angle between the horizon's horizontal plane and the sun's position, measured on a plane that is perpendicular to the horizon. It is also called the solar elevation angle. This angle (α) can be calculated as:

$$sin(\alpha) = sin(\delta){\cdot}sin(\phi) + cos(\delta){\cdot}cos(\omega){\cdot}cos(\phi)$$

Where ϕ is the latitude of the specified location.
At sunrise and sunset, the altitude angle is 0°.

The Azimuth angle(γ): It is the angle between the sun's vertical projection and the South measured on the horizon's plane. This angle (γ) can be calculated as:

$$cos(\gamma) = sec(\alpha){\cdot}(cos(\phi){\cdot}sin(\delta) - cos(\delta){\cdot}sin(\phi){\cdot}cos(\omega))$$

The Zenith angle (θ_z): It is the angle between the line of the sun and the vertical axis, and it can be calculated with the following formulas.

$$cos(\theta_z) = sin(\delta)\cdot cos(\phi) + cos(\delta)\cdot cos(\omega)\cdot cos(\phi)$$

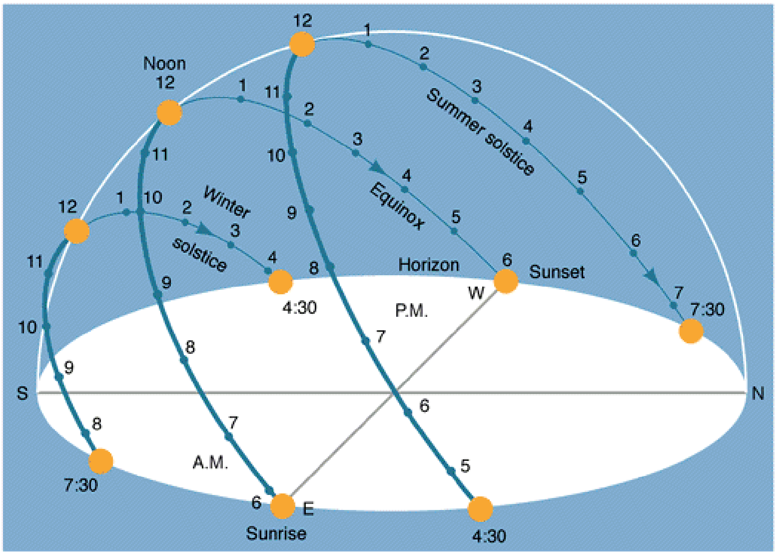
$$\theta_z = (90 - \alpha)$$

1.3.2 Summer and Winter Solstices

On the occasion of the summer solstice, usually the 21st of June, the sun shines down most directly on the Northern Tropic in the northern hemisphere, making an angle equal to + 23.5 degrees with the equatorial plane.

On the day of the winter solstice, usually the 21st of December, the smallest portion of the northern hemisphere is exposed to the sun and the sun is above the horizon for the shortest period of time there. The sun declination angle is – 23.5 degrees on the winter solstice.

Figure 4: Solar Position depending on the Solstice



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The sun declination angle has the range: $-23.5 \leq \delta \leq +23.5$ during its yearly cycle .

2 Study of a Photovoltaic System

2.1 PV-Module's Working Principle

A photovoltaic module, also named solar panel, is a device that absorbs the solar radiation, intending to subsequently generate usable electricity.

A standard solar panel consists of a layer of silicon cells, a metal frame, a glass casing, and various wiring to allow current to flow from the silicon cells. Silicon is a nonmetal with conductive properties that allow it to absorb and convert sunlight into electricity. When light interacts with a silicon cell, it causes electrons to be set into motion, which initiates a flow of electric current. This is known as the "photovoltaic effect" and it describes the general functionality of solar panel technology. [6]

The process of generating electricity can be divided into three general and simple steps:

- 1. The silicon photovoltaic solar cell absorbs solar radiation
- 2. When the sun's rays interact with the silicon cell, electrons begin to move, creating a flow of electric current
- 3. Wires capture and feed this direct current (DC) electricity to a solar inverter to be converted to alternating current (AC) electricity

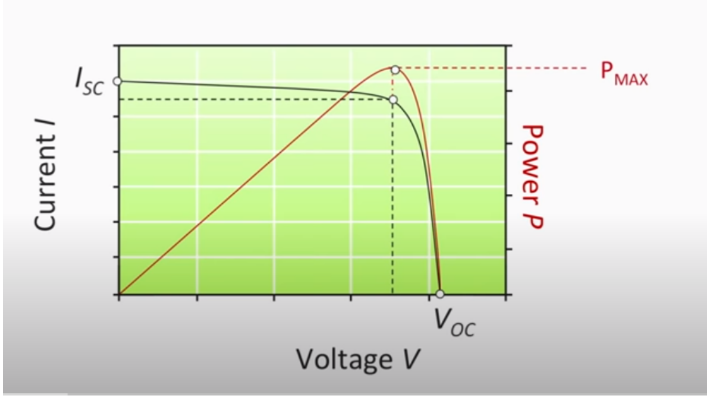
2.2 The Inverter and the Maximum Power Point Tracker (MPPT)

The electricity obtained by a solar panel is generated as direct current (DC). Therefore, a conversion to AC is needed.

The inverter in a photovoltaic system is an electronic device used to convert the obtained variable direct current (DC) that provides the solar module, into the usable alternating current (AC). This allows its feed into a commercial or local electrical power grid.

Solar inverters use maximum power point tracking (MPPT) to get the maximum possible power from the PV array. The MPPT is a characteristic point of the V-I curve of a solar module or a modules array, i.e a curve that shows the relationship between the voltage across the devices and the current flowing through them. The V-I curve is different for each temperature and irradiation, therefore the MPP is also different. That is the main reason why a tracker of this point is required intending to keep the generated power at its maximum value at each moment.

Figure 5: V-I Curve and Maximum Power Point



A MPPT device is essentially a hardware implementation of a MPPT algorithm, which continuously calculates the maximum power point of the solar modules array.

2.3 Three types of panel positioning configurations

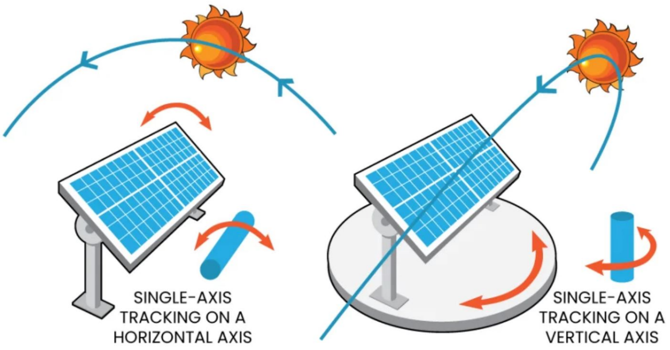
2.3.1 Solar tracking systems

These systems are the most efficient ones. They are formed by electronic sensors and actuators that adapt the orientation and tilt angle of the panel to follow the position of the sun and collect the highest amount of solar energy at each moment. They are also the most expensive ones, for they demand a big initial investment, constant supervision and regular maintenance. Their regular movement makes them suitable for location where it snows, since the movement of the panel would remove the snow from the panel. Otherwise not much energy would be collected. We can find 3 general types of Solar Tracking Systems:

- Single axis tilt tracking systems
- Single axis orientation tracking systems
- Dual axis tracking systems

In the single axis tilt tracking systems, the sun's path is tracked by the movement of the tilt angle only, while the orientation angle is fixed at an optimal value.
In the single axis orientation tracking systems, the sun's path is tracked by the movement of the orientation angle only, while the tilt angle is fixed at an optimal value.
In the dual axis tracking systems, the path of the sun is tracked by the movement of both the tilt and the orientation angles of the solar panel, to pursue the peak value of irradiation at each moment.
A single axis tracking system can increase production between 25 and 35%. A dual axis tracking system can increase energy production by 40%.

Figure 6: Single Axis Tracking (from sinovoltaics.com



2.3.2 Adjustable tilt angle systems

These systems try to simulate the solar tracking idea, but renounce the electronics. They are formed by a support structure that can be manually adjusted to one tilt angle or another. They usually have 12 different configurations, one for each month, and require a monthly manual adjustment. On the one hand, they demand much less maintenance than the solar tracking systems, are considerably cheaper and slightly increase the power production compared with the fixed systems. On the other hand, they require a monthly manual adjustment, whereas the fixed system don't.

2.3.3 Fixed systems

The fixed systems are the most affordable ones. They only require a simple block to hold the solar panel at the desired tilt angle and protect it from the wind that may impact. They are also the least efficient ones, since its tilt angle will be more optimally adjusted for some months than other ones. Therefore, it is normally calculated, via mathematical methods or simulated with specific software, which tilt angle would obtain the highest total power output throughout the whole year. Intending to do that, it must be considered, not only the amount of electricity that can be collected by the solar panels, but also the consumption demand that is trying to be satisfied over a period of time.

2.4 Types of Photovoltaic Systems

There are two main types of photovoltaic systems: the grid-tied PV systems and the isolated PV systems.

2.4.1 Grid-Tied Photovoltaic Systems

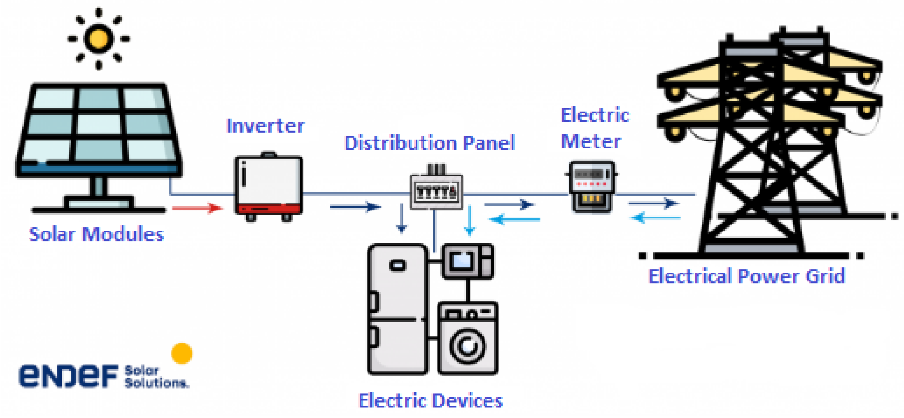
These systems are connected to the electrical power grid. It is a distributed energy generation model. They prioritise the self-consumption using the energy of the PV system as long as it is possible. Otherwise they obtain the energy from the electrical power grid.

There are three different types of grid-tied photovoltaic systems, the distinction is made depending on how they use the surpluses:

- Self-consumption PV System with Compensation

  This system uses its surpluses to capitalize the non used energy generated by the PV system. These surpluses are injected into the electrical power grid and it is received an economic compensation as exchange. [7]

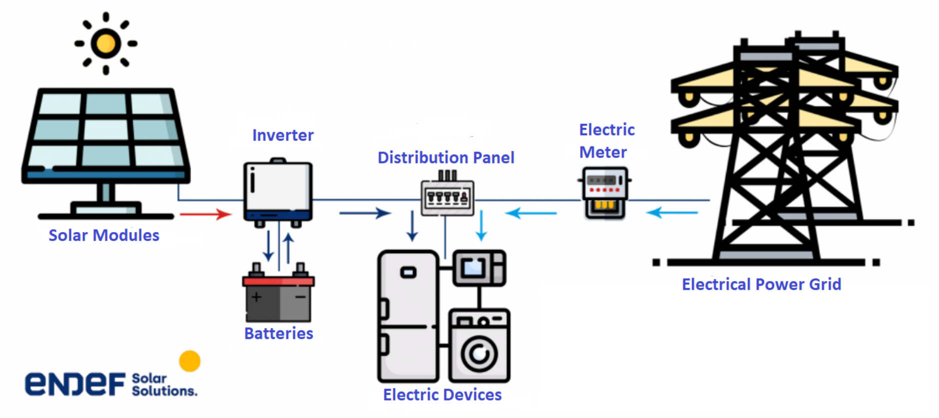
Figure 7: Self-consumption PV System with Compensation (from ENDEF Solar Solution)



- Self-consumption PV System with Batteries

This system uses batteries to store the surpluses, which can later be used, during the day hours when there is not enough solar radiation, e.g. during the night. Nevertheless, the system is still connected to the electrical power grid, so that in case that the batteries have no battery left, the system will obtain the energy from the electrical power grid. [7]

Figure 8: Self-consumption PV System with Batteries (from ENDEF Solar Solution)

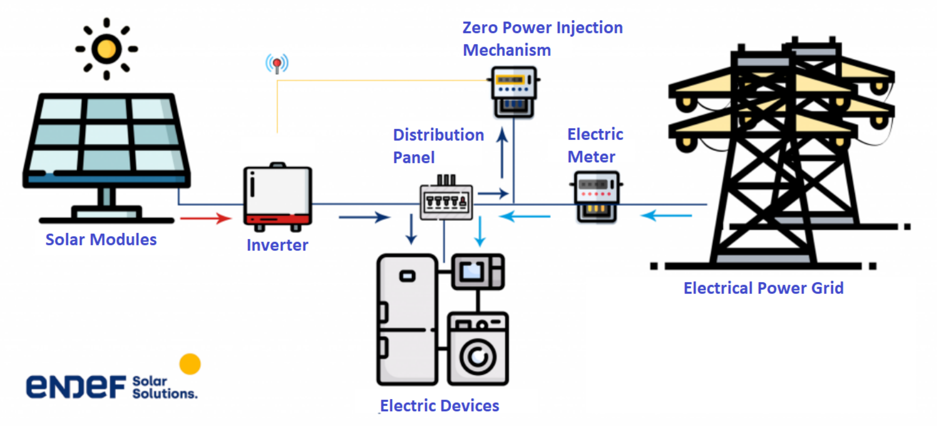


- Self-consumption PV System without Surpluses

This system does not inject power to the grid, however, it obtains the energy from it when it is required, i.e. when the electrical power demand is greater than the energy provided by the solar modules.

It is similar to the other system, but in this case it is used a mechanism to ensure that the power injection is zero. This mechanism mechanism communicates directly with the inverter, to restrict that the generated energy is not greater than the consumed energy. [7]

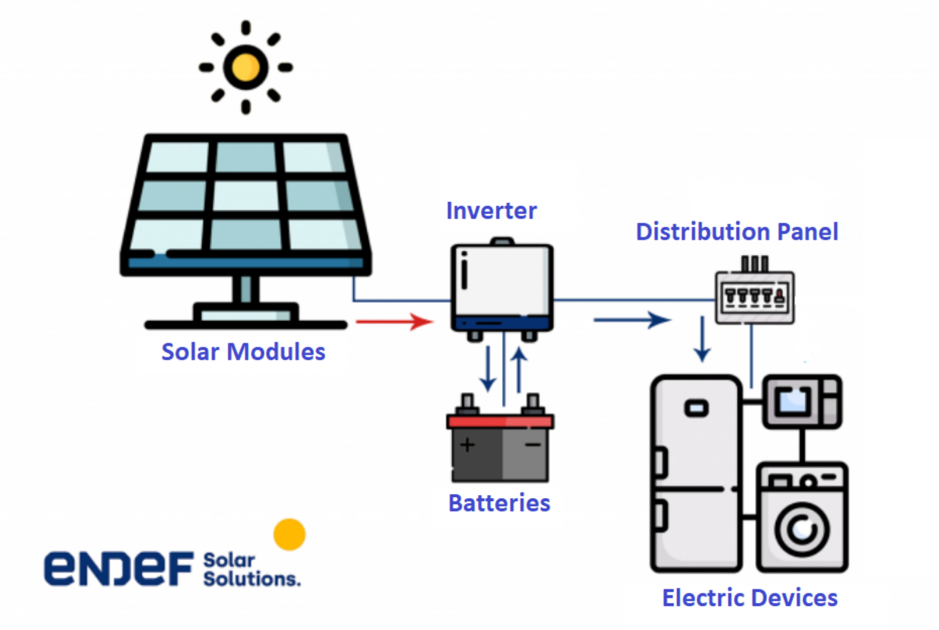
Figure 9: Self-consumption PV System without Surpluses (from ENDEF Solar Solution)



2.4.2 Isolated Photovoltaic Systems

In contrast with the previously explained PV system, the isolated PV system or off-grid PV system is not connected to the electrical power grid. It has batteries which store the produced energy. This energy will be used when there is not enough solar radiation. The project design of this system must calculated ensuring that the produced and stored energy make it possible to go through some days without solar radiation.
This option is especially appropriate for farms or houses from where it is not possible to connect to the electrical power grid. [7]

Figure 10: Isolated Photovoltaic System (from ENDEF Solar Solution)



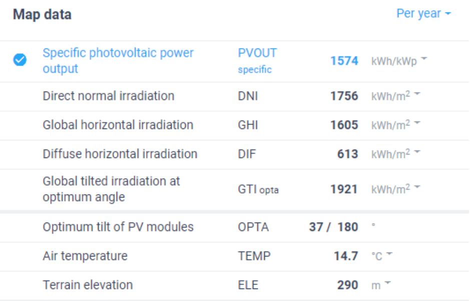
3 Design and Simulation of the Photovoltaic System

3.1 Solar Irradiation of the Specified Location

The coordinates of the specified location are 41°33’49.9”N 2°01’10.0”E.
Latitude = 41.563852 or 41°33’49.9”N
Longitude = 2.021948 or 2°01’10.0”E

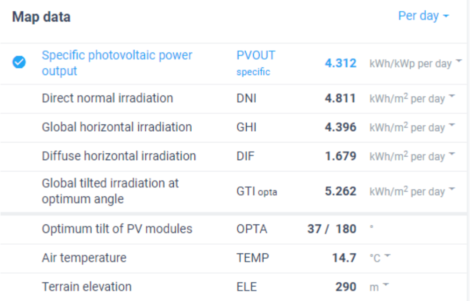
Figure 11: Irradiation map of the specified location

Figure 12: Irradiation table (per year values)



Map data			Per year
Specific photovoltaic power output	PVOUT specific	1574	kWh/kWp
Direct normal irradiation	DNI	1756	kWh/m²
Global horizontal irradiation	GHI	1605	kWh/m²
Diffuse horizontal irradiation	DIF	613	kWh/m²
Global tilted irradiation at optimum angle	GTI opta	1921	kWh/m²
Optimum tilt of PV modules	OPTA	37 / 180	°
Air temperature	TEMP	14.7	°C
Terrain elevation	ELE	290	m

Figure 13: Irradiation table (per day values)



Map data			Per day
Specific photovoltaic power output	PVOUT specific	4.312	kWh/kWp per day
Direct normal irradiation	DNI	4.811	kWh/m² per day
Global horizontal irradiation	GHI	4.396	kWh/m² per day
Diffuse horizontal irradiation	DIF	1.679	kWh/m² per day
Global tilted irradiation at optimum angle	GTI opta	5.262	kWh/m² per day
Optimum tilt of PV modules	OPTA	37 / 180	°
Air temperature	TEMP	14.7	°C
Terrain elevation	ELE	290	m

The location coordinates have been obtained from Google Earth Pro software, and the irradiation data has been extracted from the Global Atlas website. Global Atlas is an online platform, provided by The World Bank and the International Finance Corporation.

3.2 Chosen Typology and Legal Framework

For this project, the typology Self-consumption PV System with Compensation has been chosen. With this system type the surpluses are injected into the electrical grid and the marketer gives an economical compensation in return.

In Spain, there are some legal conditions to use this system. These conditions can be found in the IDAE official website. IDAE is the Institute for the Diversification and Conservation of

Energy (Instituto por la Diversificación y Ahorro de la Energía).

The 9th of October of 2015 a new legislation was established in Spain. This legislation was called "Real Decreto del impuesto al sol" which basically imposed taxes to the energy generated with photovoltaic panels. In 2018 this legislation was abolished and another new legislation was created. Finally, in 2019 the current legislation was established. This legislation is called " Real Decreto 244/2019, de 5 de abril" and regulates the technical, administrative and economic conditions of the self-consumption and the distribution of the surpluses of photovoltaic systems. The same legislation simplifies the bureaucratic processes to legalize the installation. [8]

According to the current legislation, the total power of the PV system must be lower or equal to 100kW in an installation of self consumption with compensation.

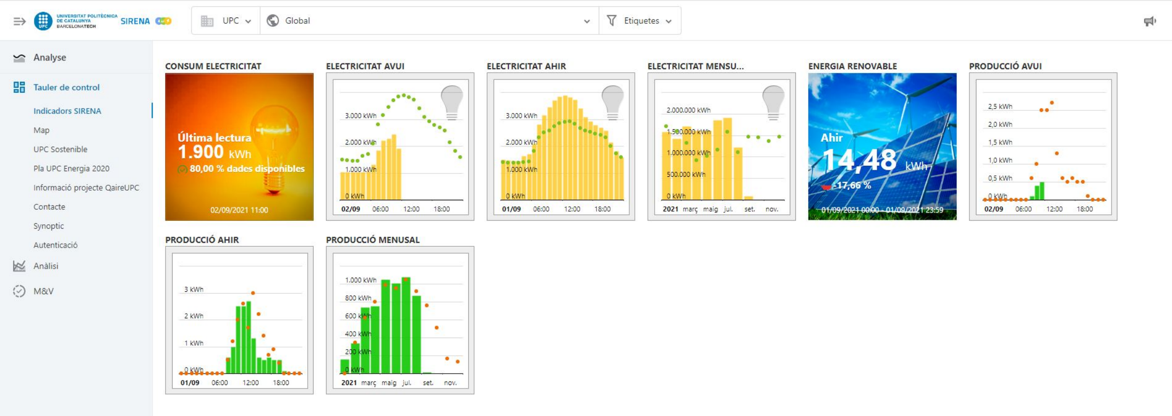
$$P_{total} \leq 100kW$$

3.3 Consumption Analysis of the TR10 Building with SirenaUPC

The analysed data has been extracted from SirenaUPC. SirenaUPC is an application developed by UPC students and professors that tracks and displays data related with the energy consumption and production of the UPC buildings, not only in Terrassa, but also in Barcelona's Campus, Manresa, Vilanova i la Geltrú, etc. Among this data, it can be found electrical consumption, gas consumption, energy costs, interior air quality, water consumption and produced electricity for some of the buildings that already have a photovoltaic system, e.g. the Gaia building in the Terrassa Campus.

All this data is sorted and structured in a "user-friendly " way with drop-downs, colored labels and illustrative and dynamic charts. This allows the user to easily find it and understand it.

Figure 14: SirenaUPC Website



In this project, it is required to consider the electrical consumption and energy costs of the TR10 building, which will be shown and explained.

In order to represent the hourly electricity and gas consumption of the building, the data of two specific days has been extracted. These two dates are the 21st of December and 21st of June, that have been used as reference because they are the days with the least and the most hours of sun of the year, respectively.

3.3.1 Electrical Consumption

The electrical consumption of the building varies depending on the time of the day, as well as the day of the year. Therefore, total and average values have been used for most of the calculations subsequently made.

Figure 15: Monthly Electrical Consumption TR10 [kWh]. Source: Self-made

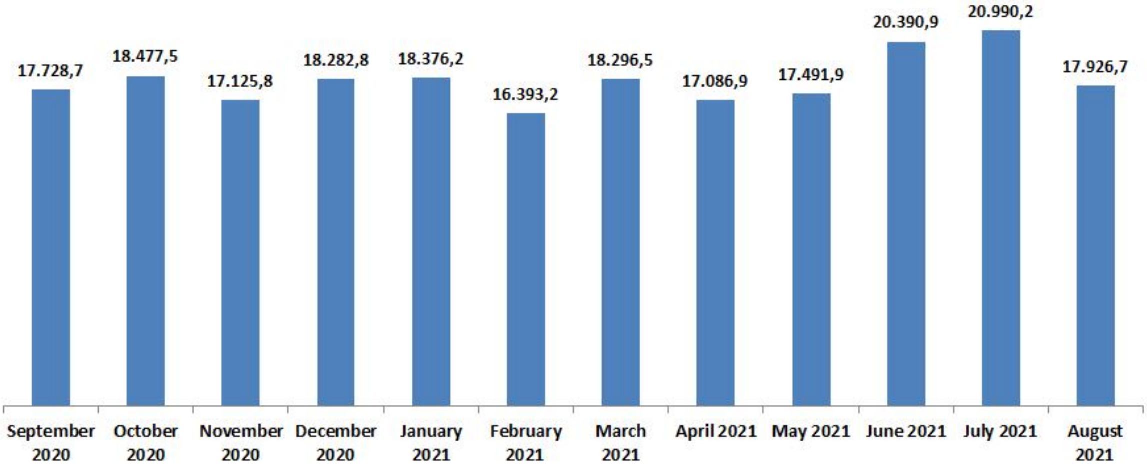
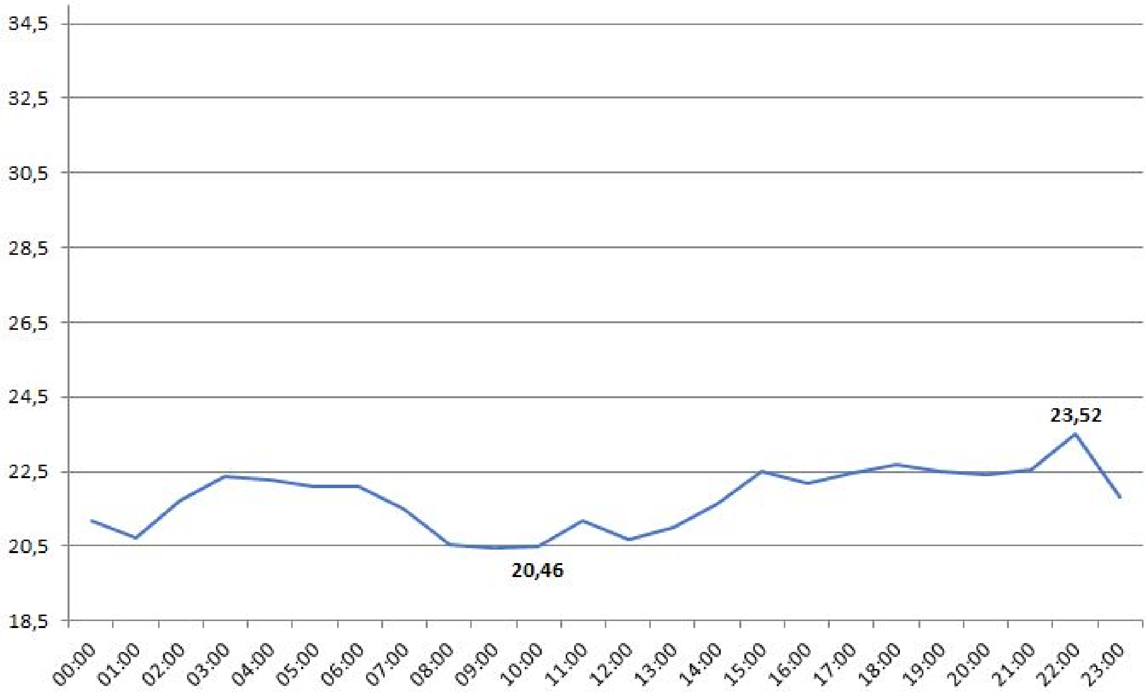


Figure 16: Electrical Consumption TR10 General Data Table

Average Daily Electrical Consumption TR10 (kWh/day)	576
Average Monthly Electrical Consumption TR10 (kWh/month)	17572
Year 2020 Total Electrical Consumption TR10 (kWh)	210858

Figure 17: TR10 Hourly Electrical Consumption on 21/06/2020 [kWh]



On 21/06/2020, the maximum electrical consumption value was reached at 22:00, while the minimum consumption was made at 9:00.

Figure 18: TR10 Hourly Electrical Consumption on 21/12/2020 [kWh]

On 21/06/2020, the maximum electrical consumption value was reached at 11:00, while the minimum consumption was made at 23:00.

As it can be seen in the previous diagrams, the hourly consumption is different on the winter solstice than on the summer solstice, reaching a maximum value of 31,05kWh during the winter day and 23,52kWh during the summer day. Furthermore, during the winter the consumption is higher during the morning and midday, whereas in summer is higher during the afternoon and night.

This indicates that the system, if possible, should be designed to produce 31,05kWh per day in the winter, although this would mean that there would be an overproduction during the summer days, since the peak solar hours are greater during summer. The overproduction would not be wasted as long as the system's typology includes surpluses compensation or batteries.

Another factor worth considering is the evolution of the electric consumption of the building through the years. This is useful to predict the consumption in the following years. Down below it is plotted the monthly and yearly consumption of the TR10 building between 2015 and 2020.

Figure 19: TR10 Monthly Electrical Consumption 2015-2020 [kWh]

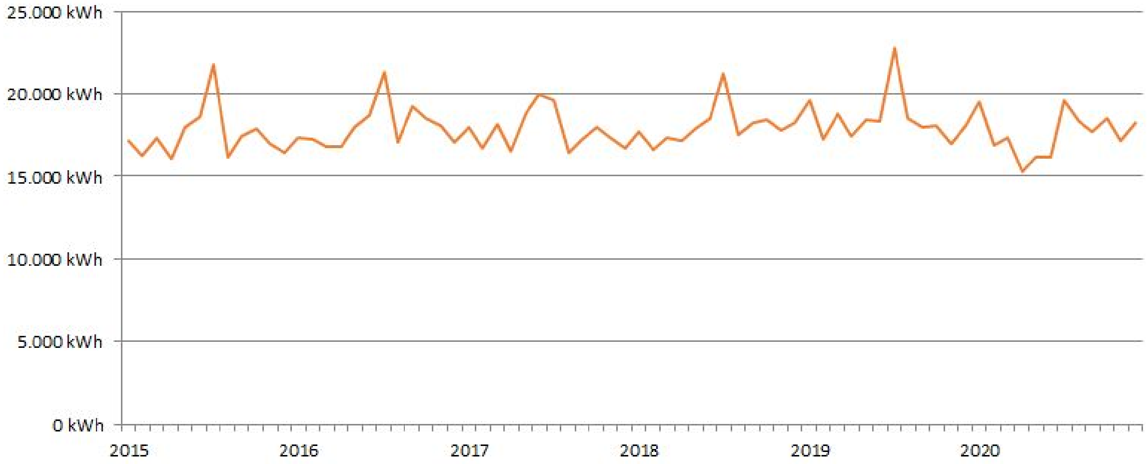
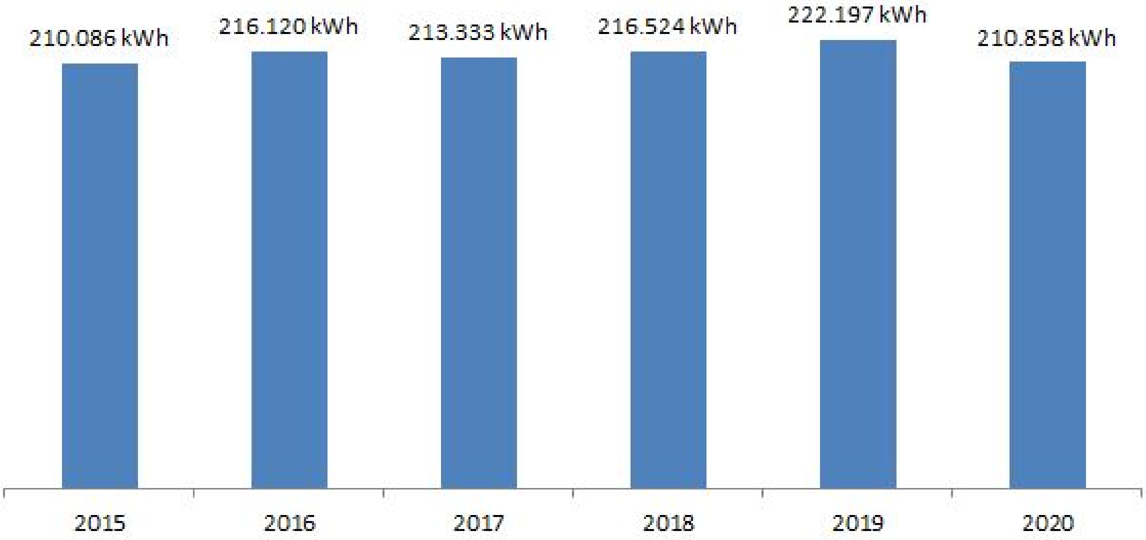


Figure 20: TR10 Yearly Electrical Consumption 2015-2020 [kWh]



As it can be seen in the previous diagrams, the electrical consumption of the building does not show an increasing or decreasing tendency, therefore it is safe to consider that in the near future the consumption will be similar to the consumption during 2020.

3.3.2 Energy Costs

It is going to be taken a standard established cost for the electricity equal to 0,14€ per kWh. In the next figure it is shown the monthly and yearly costs for electricity.

Figure 21: Yearly Electrical Consumption Costs 2015-2020 (left). Monthly Electrical Consumption Costs 2020 (right)

Year	Electrical Consumption [kWh]	Cost
2015	210086,13	29.412,06 €
2016	216120,45	30.256,86 €
2017	213332,81	29.866,59 €
2018	216524,03	30.313,36 €
2019	222196,63	31.107,53 €
2020	210858,13	29.520,14 €

2020		
Month	Electrical Consumption [kWh]	Cost
January	19.473,46	2.726,28 €
February	16.867,54	2.361,46 €
March	17.338,03	2.427,32 €
April	15.280,40	2.139,26 €
May	16.150,98	2.261,14 €
June	16.183,47	2.265,69 €
July	19.620,79	2.746,91 €
August	18.328,67	2.566,01 €
September	17.728,69	2.482,02 €
October	18.477,53	2.586,85 €
November	17.125,79	2.397,61 €
December	18.282,78	2.559,59 €

3.3.3 Energy Production Requirements

In order to satisfy all the energy production requirements of the building, the production of the system has to cover the consumption of the building. To calculate the approximate dimensions of a system, capable to satisfy these requirements, the average consume values are used. Furthermore, the next assumptions have been made:

- The average daily electrical consumption [figure 16] is equal to 576 kWh/day.
- Every day has an standard average of 5,4 peak solar hours, i.e. hours when the solar radiation is most optimal.
- The system has an efficiency of 0.8.
- The solar panels have a power of 450W and size of 1090x2090mm i.e. 2,28 m^2.

$$RequiredPower = \frac{C_d}{h_p * \eta}$$

Where C_d is the average daily consumption, h_p is the peak solar hours and η is the efficiency of the system.

$$RequiredPower = \frac{576kWh/day}{5,4 * 0,8} = 133,34kWh$$

The number of solar modules and space required is also calculated:

$$n_{modules} = \frac{RequiredPower}{PowerSolarModule} = \frac{133.340Wh}{450W} = 297modules$$

$$SpaceRequired = n_{modules} * Modulesize = 297 * 2,28m^2 = 677m^2$$

The required space to install all the modules is 677 m^2, which is much greater than the real free space on the building's roof. Therefore, it is assumed that the consumption will not be totally covered, but only a proportion of it.

3.4 Optimal Solar Panels Position Determination

The position of the solar panels is decisive and has a great influence into the performance of the final installation. The following factors are being taken into account to determine the optimal final position of the panels:

- Optimal tilt angle
- Optimal orientation angle
- TR10 building's roof geometry
- Self-Shading by the panels arrays
- Shading caused by the adjacent buildings
- Obstruction caused by the objects on the roof
- Shading caused by the objects on the roof

3.4.1 Optimal Orientation Angle Determination

The orientation angle of a solar panel is the angle made by the incident solar ray and the panel. The optimal value of orientation angle correspond to the peak value of irradiation obtained at the certain orientation angle.

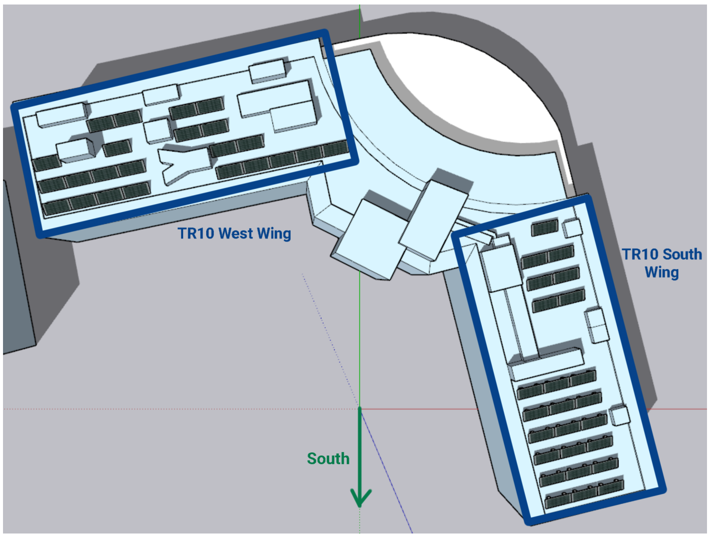
Since the specified location is in the northern hemisphere, the solar collectors are oriented towards the south. In the case the location was in the southern hemisphere, the panels would be oriented towards north. [4] That is because the sun normally shines over the Equator over the year, and by facing the panels towards south the exposure to sunlight is maximized.

In their article [4] Akif Karafi et.al. conclude that $\gamma = 0$ and $\omega = 0$ are the optimal values and therefore it is confirmed that the optimal orientation of a solar panel located in the northern hemisphere is toward South, where the solar hour angle at solar noon must be zero, as it is defined in [9].

To achieve the optimal orientation at every time of the day, the trajectory of the sun would be tracked by keeping the orientation equal to the solar azimuth angle, but to do that a solar tracking system would be required, which increases the initial costs and the maintenance required.

However, the solar panels of this projects are not positioned towards South exactly. The reason is the geometry of the building.
In the figure, the TR10 roof can be vertically seen. As it is drawn, the solar panels will be distributed on the two wings of the building, the south wing and the west wing.

Figure 22: South Wing and West Wing of the TR10 Building



The panels of each wing have been positioned this way, i.e. parallel to the roof's edges, pursuing to take the maximum profit of the free space and to be able to install the maximum number of solar panels.
The solar panels on the south wing have an azimuth angle equal to -14.2° and the solar panels on the west wing have an azimuth angle of -11.8°.

3.4.2 Optimal Tilt Angle Determination

The tilt angle of a solar panel is the angle made by the solar panel and the surface where it is placed on. It's commonly named the inclination of the panel. The optimal value of tilt angle correspond to the peak value of irradiation obtained at the certain tilt angle.

In order to maximize the output energy of the solar panels, the surface of the panel is required to be perpendicular to the direction of the solar ray, therefore, its value should be equal to the zenith angle of the sun.
Various factors must be taken into account in order to determine the optimal tilt angle. These factors are time, season and location.
It is known that a geographical location point can be defined with two variables: latitude and longitude. In this case, the latitude is very important, since it describes the inclination of the surface, which has to be considered in order to design a photovoltaic system.

As Charles R. Landau explains in his publication [10], some formulas have been developed through the years so that an optimum fixed tilt angle for your location can be easily and directly calculated. As Charles explains, if the latitude is between 25° and 50°, the tilt angle can be fixed as 0.76 times the latitude, plus 3.1°.

$$\beta = 0,76 \cdot \phi + 3,1$$

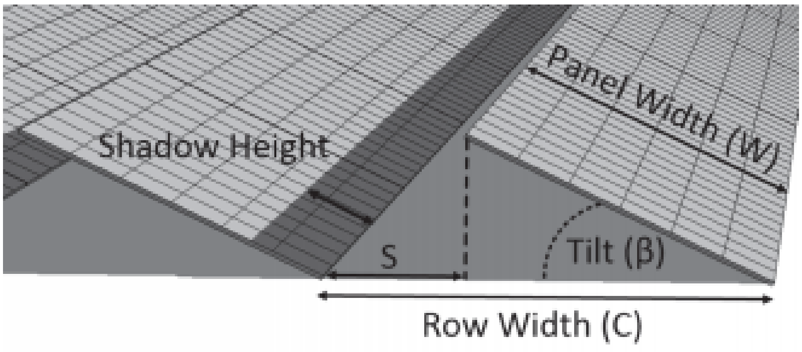
Given this equation, it is calculated a fixed tilt angle equal to 34.6885°.

Intending to calculate the amount of energy that can be collected through the year, it must be acknowledged that it will be a maximum of 71% compared to a solar tracking system, which is the most effective system.

3.4.3 Solar Panel Array's Distance to avoid Self-Shading

In big-scale arrays, parallel rows of solar panels can shade adjacent rows, causing effects known as self-shading and diffuse masking and consequently reducing the energy production [11].

Figure 23: Tilt angle and panels array self-shading (from [11])

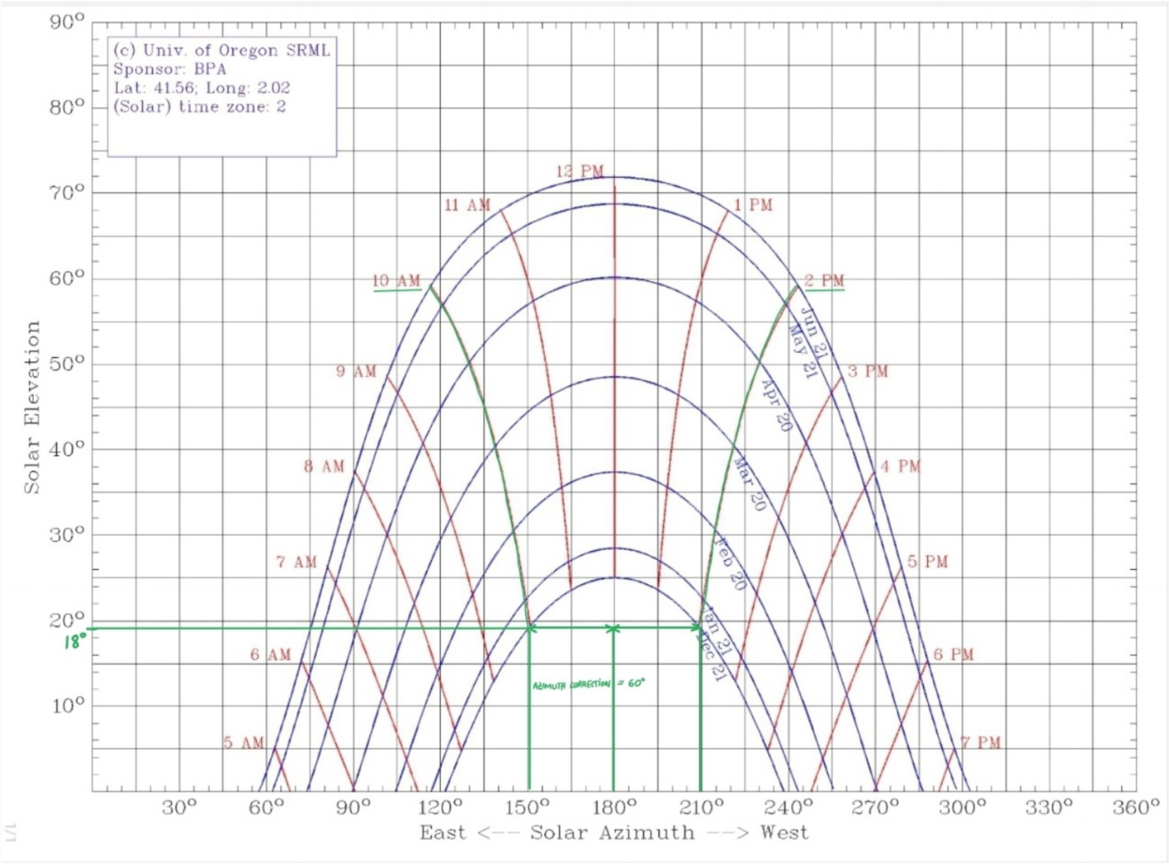


Large row spacing (S) and low tilt angles (β) decrease shading effects but negatively influence yearly energy output since fewer panels are employed.

As it is explained in the article [12] written by Adam Diehl published in the CED Greentech website, some simple steps and formulas can be used, in order to determine the minimum module inter-row spacing.

First of all, it is needed a chart that shows the Sun Elevation Angle of the location during the day on different days of the year. This chart has been obtained using the tool developed by the University of Oregon, which allows the creation of a specific sun path chart by specifying the location coordinates in their website. The figure 24 shows the obtained chart.

Figure 24: Solar Elevation Chart for the Specific Location in Terrassa



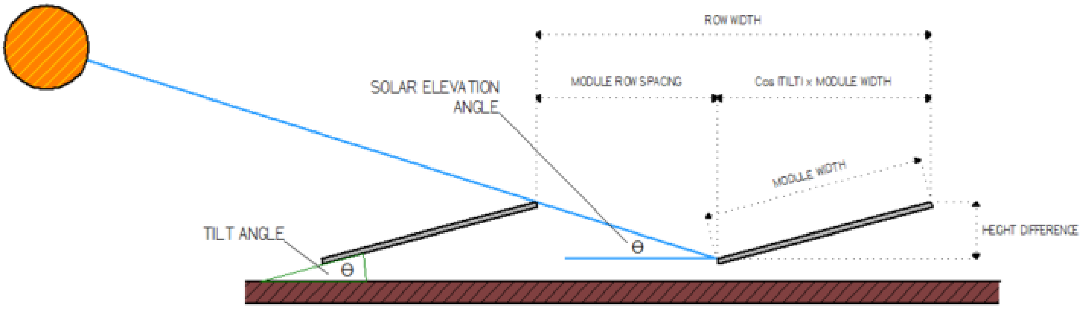
In this case, it has been chosen a 9AM to 3PM window during the winter solstice for the worst case scenario. A horizontal line has been drawn to mark the sun elevation at those times. An 18º angle has been estimated, which will next be used to determine the module row spacing using the formula below.

$$ModuleRowSpacing = \frac{HeightDifference}{Tan(SunElevationAngle)}$$

Where Height Difference=0,5664m and Sun Elevation Angle=18º.

Given these values, a Module Row Spacing equal to 1,743m is calculated.

Figure 25: Minimum Inter Row Spacing Between Solar Panels Rows



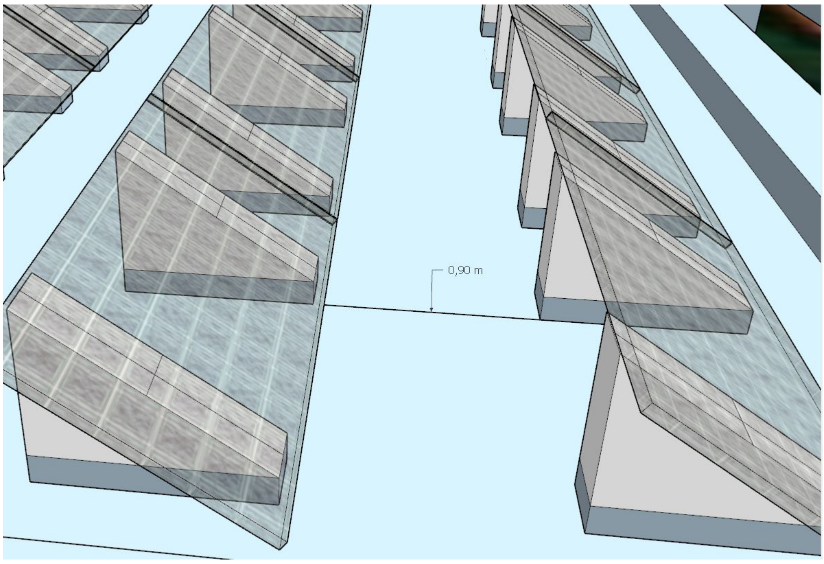
Nevertheless, this value can be optimized, i.e. reduced, in order to potentially increase the system size. A new value, named Minimum Module Row Spacing will be determined.
To do that, it must be accounted for the Azimuth Angle. As it can be seen in the sun elevation chart, two vertical reference lines have been drawn down from each time reference. The difference between these lines is 60º and it is used in the formula below to determine the Minimum Module Row spacing.

$$MinimumModuleRowSpacing = cos(AzimuthCorrectionAngle) \cdot ModuleRowSpacing$$

Where the Module Row Spacing=1,743m and the the Azimuth Correction Angle=60º as it can be seen in the figure sun elevation chart.

From this formula and these values, it is determined a Minimum Module Row Spacing equal to 0,8715m, rounded to 0,9m.This can be seen in the design of the figure 26.

Figure 26: Module Row Spacing Designed with SketchUp



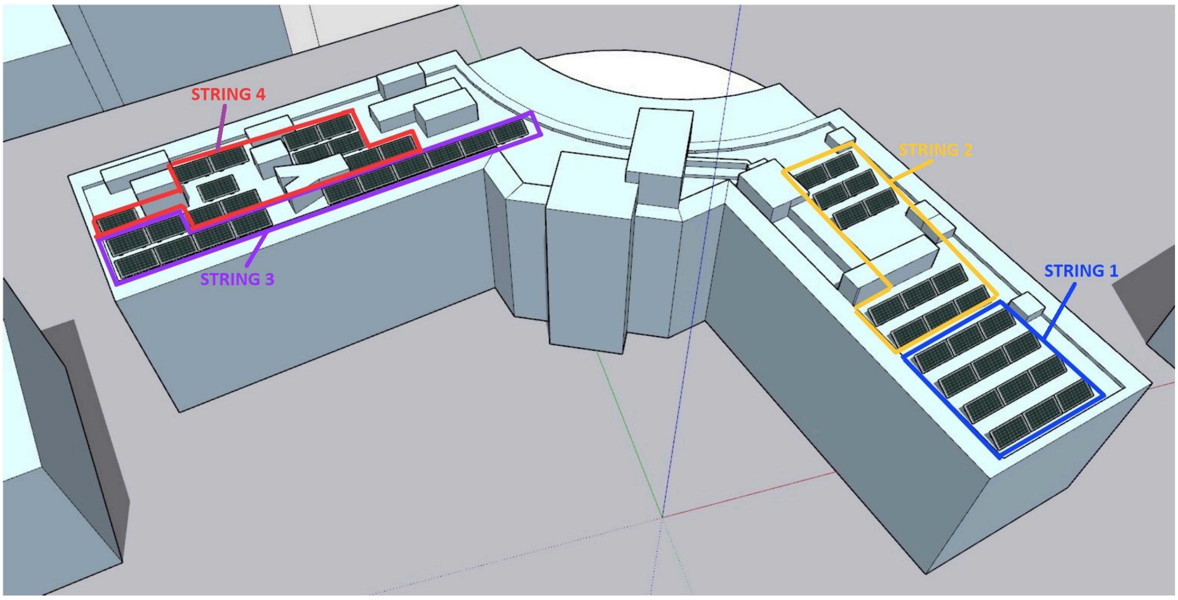
This same formula is used to determine the optimum distance between an obstacle and a solar panel behind it. The south-faced wing of the building has an obstacle with a height of 1,75m and a height difference equal to 1,61m. Therefore, the minimum module row spacing must be 2,5m. In the same wing, there is an obstacle with a height difference of 0,61m, which demands a minimum module row spacing equal to 0,95m.

3.4.4 Strings Distribution of the Solar Panel Arrays

A string in solar energy is defined as various solar modules connected in series.
The number and distribution of the strings of solar modules is very important and will have a strong influence in the overall power production and efficiency of the system. It is directly dependent on the solar modules power, the number of inverters, its inputs and MPPTs.

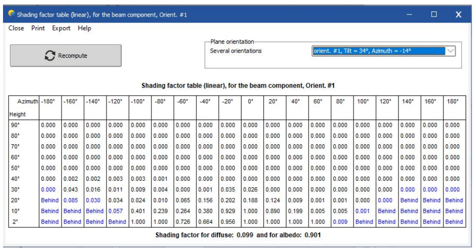
It should also be considered that the system has two different orientations, since the west wing has an azimuth angle equal to -11.8º, whereas the south wing has an azimuth angle equal to -14.2º. In order to simplify the system and its functioning, each string will be composed by solar modules with the same orientation. Therefore, each wing is divided by 2 strings. This simplifies the design and the simulation with the PVsyst software.

Figure 27: Distribution of the Strings



As it can be observed in the figure, there are 4 different strings identified by labels. The strings 1 and 2 have got one orientation, while the strings 3 and 4 have got a different one. This orientation difference and the different positions of the strings cause that the shading effects vary for each one, meaning that each one has its own efficiency, i.e. the strings 4 and 2 are more negatively affected by the shading effects caused by the obstacles on the roof of the building. This 3D model has been imported and simulated in the PVsyst software, from where the following tables have been obtained.

Figure 28: Shading Factor Table of the String 1



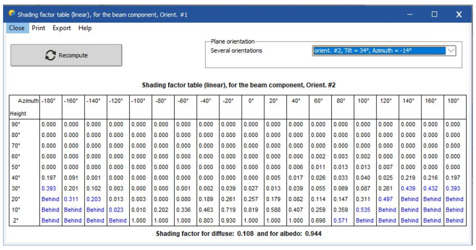
Plane orientation: Several orientations — orient. #1, Tilt = 34°, Azimuth = -14°

Shading factor table (linear), for the beam component, Orient. #1

Azimuth / Height	-180°	-160°	-140°	-120°	-100°	-80°	-60°	-40°	-20°	0°	20°	40°	60°	80°	100°	120°	140°	160°	180°
90°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
70°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40°	0.000	0.002	0.002	0.003	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30°	0.000	0.043	0.016	0.011	0.009	0.004	0.000	0.001	0.035	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20°	Behind	0.085	0.030	0.034	0.024	0.010	0.065	0.156	0.202	0.188	0.124	0.009	0.001	0.001	0.000	0.000	Behind	Behind	Behind
10°	Behind	Behind	Behind	0.057	0.401	0.239	0.264	0.380	0.929	1.000	0.890	0.199	0.005	0.005	0.001	Behind	Behind	Behind	Behind
2°	Behind	Behind	Behind	Behind	1.000	1.000	0.726	0.664	0.956	1.000	1.000	1.000	1.000	0.009	Behind	Behind	Behind	Behind	Behind

Shading factor for diffuse: 0.099 and for albedo: 0.901

Figure 29: Shading Factor Table of the String 2



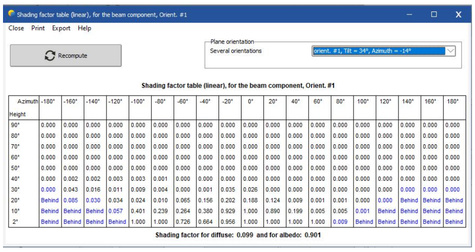
Plane orientation: Several orientations — orient. #2, Tilt = 34°, Azimuth = -14°

Shading factor table (linear), for the beam component, Orient. #2

Azimuth / Height	-180°	-160°	-140°	-120°	-100°	-80°	-60°	-40°	-20°	0°	20°	40°	60°	80°	100°	120°	140°	160°	180°
90°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
70°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.003	0.002	0.000	0.000	0.000	0.000
50°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.011	0.013	0.013	0.007	0.000	0.000	0.000
40°	0.197	0.091	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.017	0.026	0.033	0.040	0.025	0.219	0.216	0.197
30°	0.393	0.201	0.102	0.003	0.000	0.000	0.001	0.002	0.039	0.027	0.013	0.039	0.055	0.069	0.087	0.261	0.439	0.432	0.393
20°	Behind	0.311	0.203	0.013	0.003	0.000	0.080	0.189	0.261	0.257	0.179	0.082	0.114	0.147	0.311	0.497	Behind	Behind	Behind
10°	Behind	Behind	Behind	0.023	0.010	0.202	0.336	0.463	0.719	0.819	0.588	0.407	0.259	0.359	0.535	Behind	Behind	Behind	Behind
2°	Behind	Behind	Behind	Behind	1.000	1.000	1.000	0.803	0.930	1.000	1.000	1.000	0.698	0.571	Behind	Behind	Behind	Behind	Behind

Shading factor for diffuse: 0.108 and for albedo: 0.944

Figure 30: Shading Factor Table of the String 3



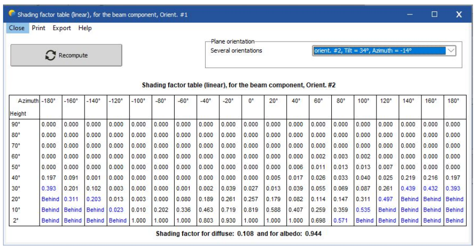
Plane orientation: Several orientations — orient. #1, Tilt = 34°, Azimuth = -14°

Shading factor table (linear), for the beam component, Orient. #1

Azimuth / Height	-180°	-160°	-140°	-120°	-100°	-80°	-60°	-40°	-20°	0°	20°	40°	60°	80°	100°	120°	140°	160°	180°
90°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
70°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40°	0.000	0.002	0.002	0.003	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30°	0.000	0.043	0.016	0.011	0.009	0.004	0.000	0.001	0.035	0.026	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20°	Behind	0.085	0.030	0.034	0.024	0.010	0.065	0.156	0.202	0.188	0.124	0.009	0.001	0.001	0.000	0.000	Behind	Behind	Behind
10°	Behind	Behind	Behind	0.057	0.401	0.239	0.264	0.380	0.929	1.000	0.890	0.199	0.005	0.005	0.001	Behind	Behind	Behind	Behind
2°	Behind	Behind	Behind	Behind	1.000	1.000	0.726	0.664	0.956	1.000	1.000	1.000	1.000	0.009	Behind	Behind	Behind	Behind	Behind

Shading factor for diffuse: 0.099 and for albedo: 0.901

Figure 31: Shading Factor Table of the String 4



Plane orientation: Several orientations — orient. #2, Tilt = 34°, Azimuth = -14°

Shading factor table (linear), for the beam component, Orient. #2

Azimuth / Height	-180°	-160°	-140°	-120°	-100°	-80°	-60°	-40°	-20°	0°	20°	40°	60°	80°	100°	120°	140°	160°	180°
90°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
70°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.003	0.002	0.000	0.000	0.000	0.000
50°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.011	0.013	0.013	0.007	0.000	0.000	0.000
40°	0.197	0.091	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.017	0.026	0.033	0.040	0.025	0.219	0.216	0.197
30°	0.393	0.201	0.102	0.003	0.000	0.000	0.001	0.002	0.039	0.027	0.013	0.039	0.055	0.069	0.087	0.261	0.439	0.432	0.393
20°	Behind	0.311	0.203	0.013	0.003	0.000	0.080	0.189	0.261	0.257	0.179	0.082	0.114	0.147	0.311	0.497	Behind	Behind	Behind
10°	Behind	Behind	Behind	0.023	0.010	0.202	0.336	0.463	0.719	0.819	0.588	0.407	0.259	0.359	0.535	Behind	Behind	Behind	Behind
2°	Behind	Behind	Behind	Behind	1.000	1.000	1.000	0.803	0.930	1.000	1.000	1.000	0.698	0.571	Behind	Behind	Behind	Behind	Behind

Shading factor for diffuse: 0.108 and for albedo: 0.944

These tables show that each string has a different shading factor for diffuse and for albedo radiation.

- String 1: Shading factor for diffuse: 0.099 and for albedo 0.901

- String 2: Shading factor for diffuse: 0.108 and for albedo 0.944
- String 3: Shading factor for diffuse: 0.078 and for albedo 0.927
- String 4: Shading factor for diffuse: 0.162 and for albedo 0.982

As it can be appreciated, the strings 1 and 3 have a lower shading factor than the strings 2 and 4. This means that the strings 1 and 3 will generally produce more energy than the strings 2 and 4.

3.5 TR10 Building and Surrounding's Designs

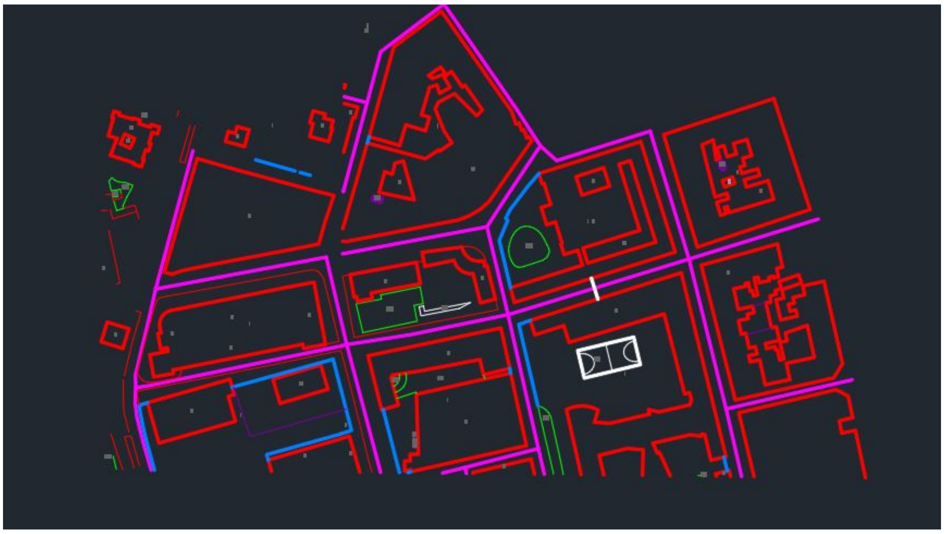
3.5.1 2D Design with Vissir3 and AutoCAD

The catalan geographic mapping service Vissir3 [13] has been used to obtain a 2D model of the location. Vissir3 is a digital tool developed by the Cartographic and Geologic Institute of Catalonia (ICGC), that provides accurate map files of most of the locations around Catalonia.

Figure 32: 2D Design of the location extracted from the Vissir3 website

A ".dwg" file containing the 2D map of the specific location has been downloaded and later converted to a ".cad" file, using the AutoCAD software, so it can be used in SketchUp, which is the software that has been used to develop the 3D model of the location.

Figure 33: 2D Design of the location as a CAD file



3.5.2 3D Design with SketchUp and Skelion

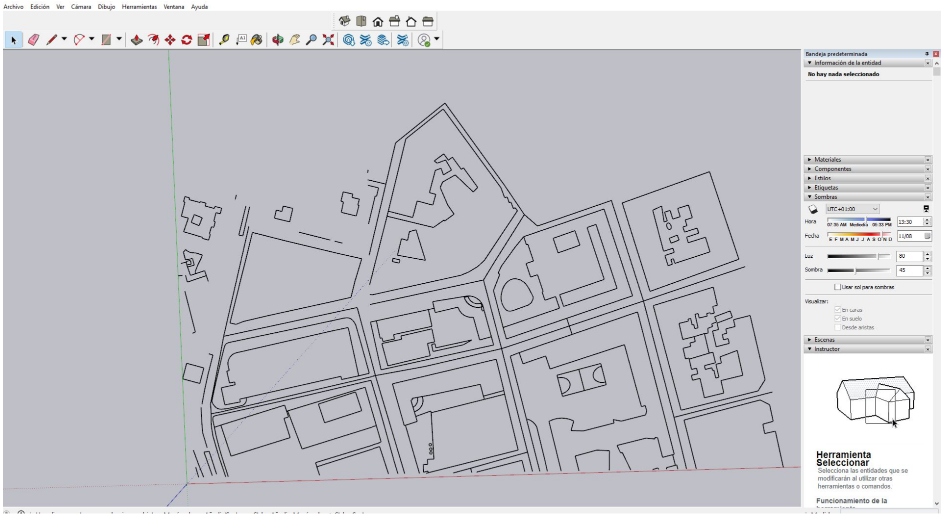
In order to perform the modelling and simulation of the photovoltaic system, a 3D model of the TR10 building and its surroundings has been designed using the google's software Sketchup Pro 2021.

Sketchup Pro is a software developed by Trimble, used to do 2D and 3D designs. The software has a free testing license period of one month, but the student license has been purchased for this project.

Down below are explained the steps that have been followed to design the 3D model.

First of all, the AutoCAD file containing the 2D model of the TR10 building and its surroundings has been uploaded on Sketchup.

Figure 34: First Step in the 3D Design with SketchUp



No hay nada seleccionado

UTC+01:00

Hora 07:35 AM Mediodía 05:33 PM 13:30

Fecha E F M A M J J A S O N D 11/08

Luz 80

Sombra 45

☐ Usar sol para sombras

☑ En caras

☑ En suelo

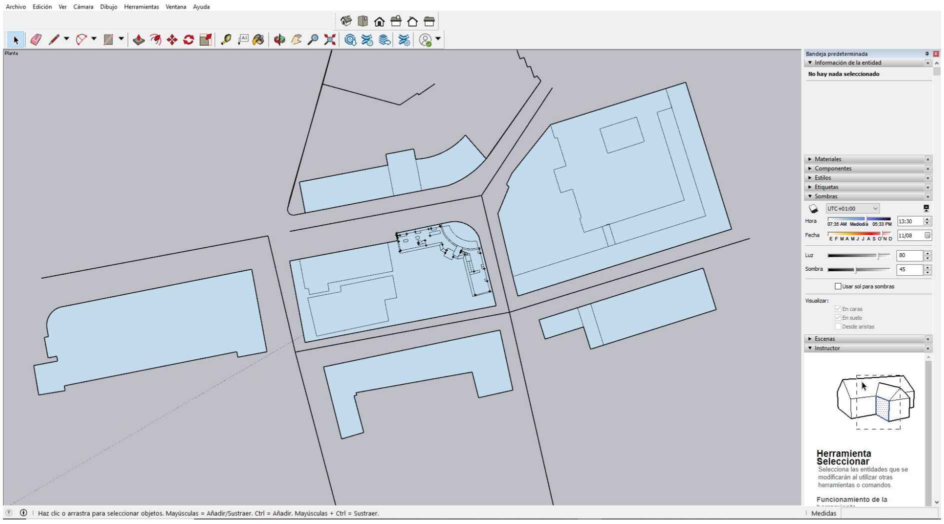
☐ Desde aristas

Herramienta Seleccionar

Selecciona las entidades que se modificarán al utilizar otras herramientas o comandos.

Secondly, the TR10 building and the other ones have been redrawn and selected, so they are ready to be extruded.

Figure 35: Second Step in the 3D Design with SketchUp



No hay nada seleccionado

UTC+01:00

Hora 07:35 AM Mediodía 05:33 PM 13:30

Fecha E F M A M J J A S O N D 11/08

Luz 80

Sombra 45

☐ Usar sol para sombras

Visualizar:

☑ En caras

☑ En suelo

☐ Desde aristas

Herramienta Seleccionar

Selecciona las entidades que se modificarán al utilizar otras herramientas o comandos.

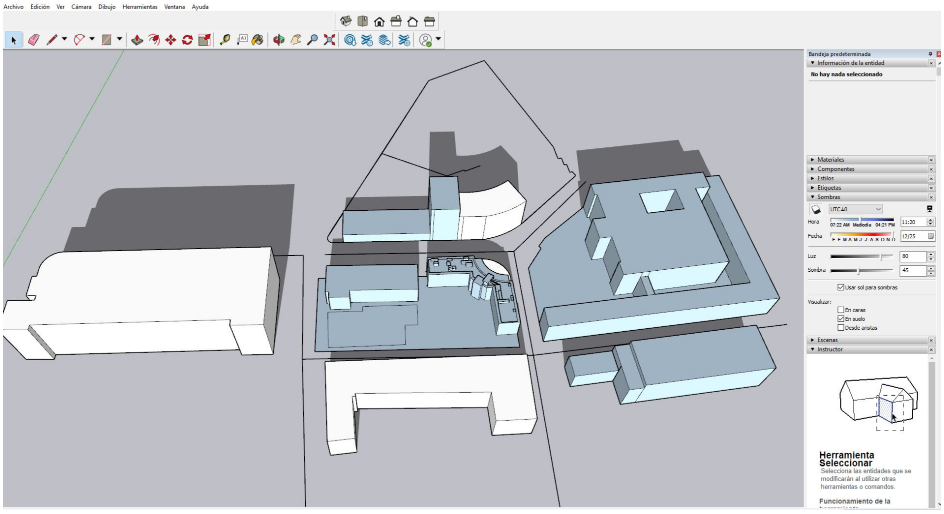
Funcionamiento de la

Haz clic o arrastra para seleccionar objetos. Mayúsculas = Añadir/Sustraer. Ctrl = Añadir. Mayúsculas + Ctrl = Sustraer.

The objective of including the surrounding buildings is to take into account the shading effects that these buildings have on the energy production of the solar panels. Depending on the day and the hour, these buildings, specially the ones located at the south of the TR10 building, will negatively affect the production of energy. These losses should be considered if it is intended to execute realistic simulations.

The measurements of the heights of all the buildings have been made with the google's software Google Earth Pro and its specific tool that makes it possible to measure any distance in 3D.

Figure 36: Extrusion of the 3D Design with SketchUp



No hay nada seleccionado

UTC±0

Hora 07:22 AM Mediodía 04:21 PM 11:20

Fecha E F M A M J J A S O N D 12/25

Luz 80

Sombra 45

☑ Usar sol para sombras

Visualizar:

☐ En caras

☑ En suelo

☐ Desde aristas

Herramienta Seleccionar

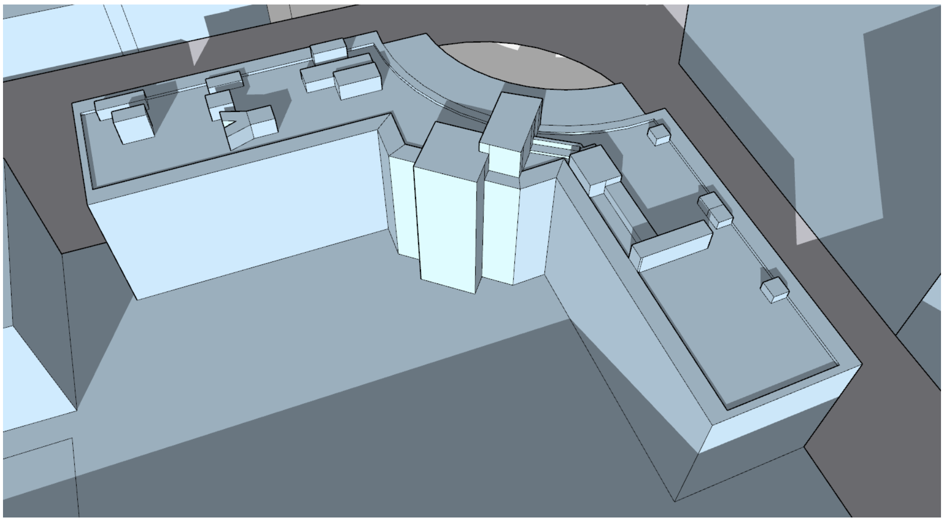
Selecciona las entidades que se modificarán al utilizar otras herramientas o comandos.

Funcionamiento de la

For the same reason that the surroundings buildings have been included, the objects on the roof must be included too, since they also produce shading. Furthermore, these objects obstruct a significant part of the surface. Consequently, they must be considered in the design in order to know exactly the amount of free space and to decide the exact location of each solar panel.
The exactitude of the dimensions of these objects is a key factor, because it will determine how many solar panels can be installed. Therefore, these measurements have been per-

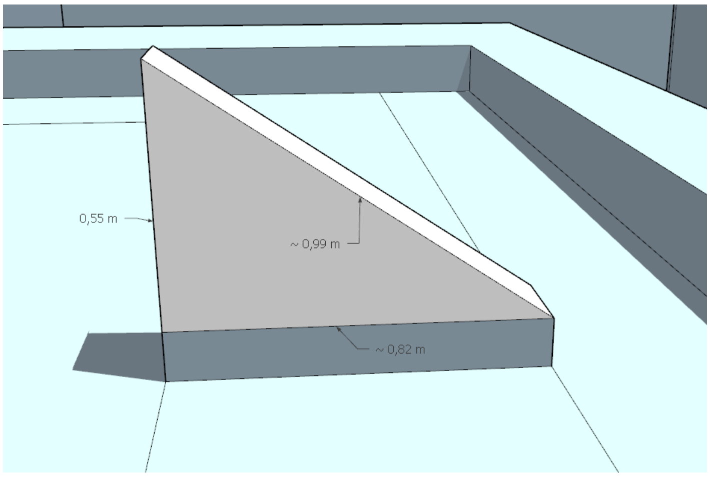
sonally made in-situ by using a laser distance meter and with the help of the director, Alvaro Luna, and a friend, Oscar Rodriguez.

Figure 37: TR10 3D Design with SketchUp



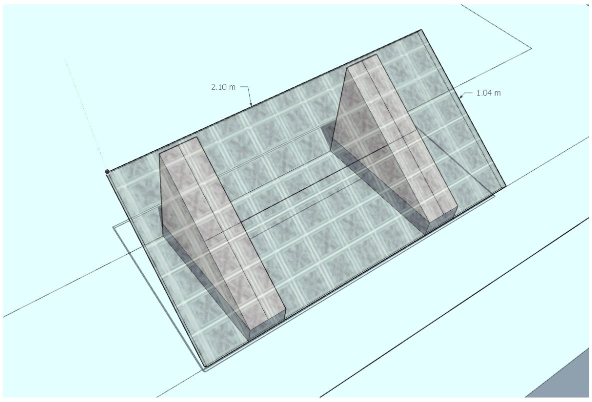
The solar block that has been designed with Sketchup does not have the exact shape of the real product, since the real structure has a triangular hole inside. However, the external dimensions are correct and this allows a correct simulation, which is the main objective of the design.

Figure 38: Solar Block 3D Design with SketchUp



The solar panel that has been used for the design has the same dimensions than the LONGi Solar Module LR4-72HPH-450, i.e. a length of 2,09m, a width of 1,04m and a thickness of 0,03m. The LONGi Solar Module is the one chosen for this project.

Figure 39: Solar Panel 3D Design with SketchUp with the size of the LONGi Solar Panel



Here under, it can bee seen how the 48 solar modules have been distributed on the roof. Twenty-four modules have been positioned on each wing of the roof.

Figure 40: Photovoltaic Installation on the South-Wing of the TR10 Building 3D Design with SketchUp

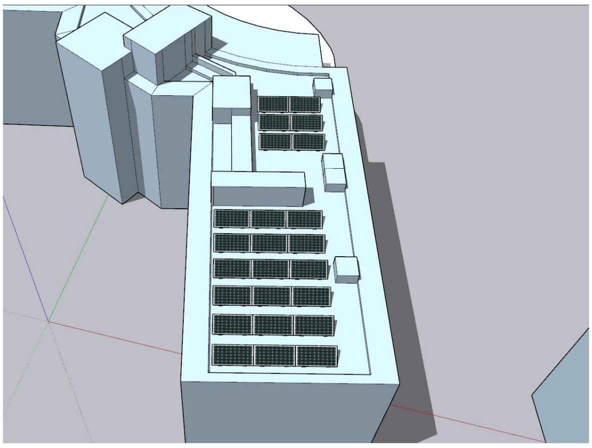
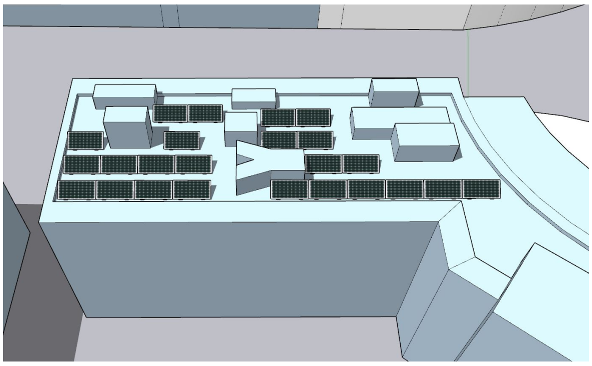
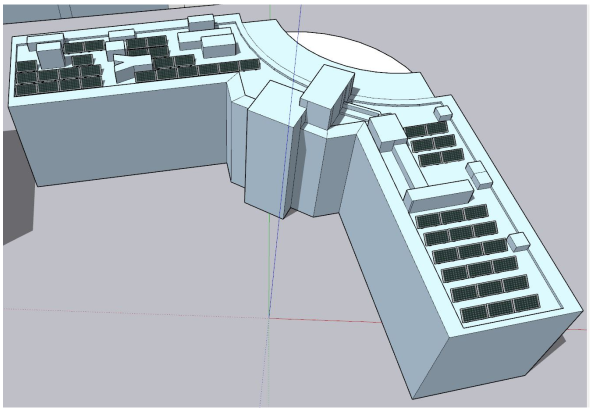


Figure 41: Photovoltaic Installation on the West-Wing of the TR10 Building 3D Design with SketchUp



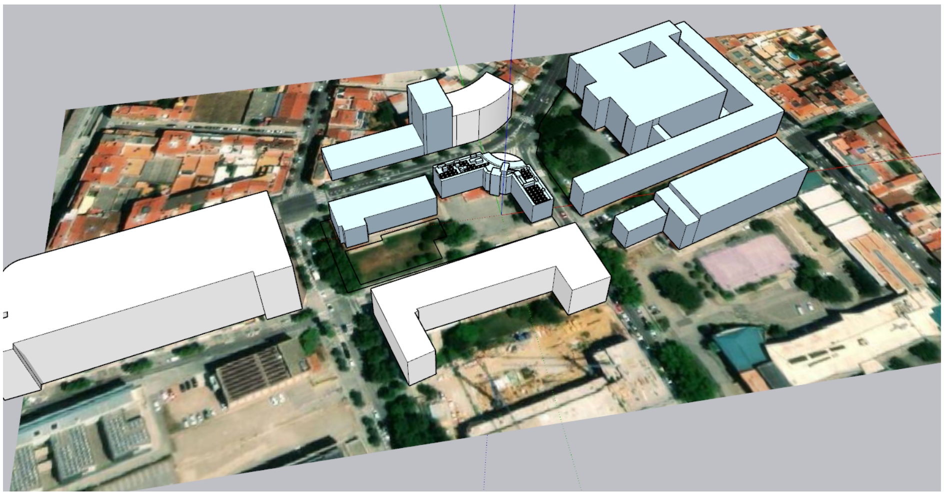
As it can be appreciated, there is still free space where more solar modules would fit. However, the left space is critical because it is very negatively affected by the shading effect caused by the objects around it. Therefore, this space has not been used.

Figure 42: Photovoltaic Installation on the TR10 Building 3D Design with SketchUp



Finally, the google maps view has been added to the design. As it can be seen, the measures fit perfectly, which indicates that the 2D model was correct and it has been correctly imported to the Sketchup Pro.

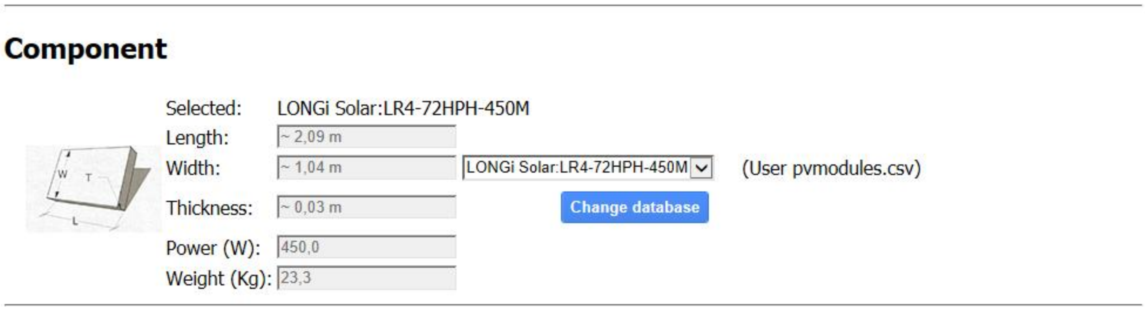
Figure 43: Google Maps View of the Photovoltaic Installation on the TR10 Building 3D Design with SketchUp



Once the 3D model has been correctly modelled, it is needed to switch the generic photovoltaic modules for specific ones. This is important because otherwise the software used for the simulation, i.e. PVsyst, will not detect the solar panels.

To create and specify these modules, the Sketchup extension Skelion has been installed and used. A free trial of this extension has been used. Skelion allows the user to create photovoltaic modules with custom technical specifications. In this case, the official technical specific data of the previously selected solar panel, i.e. the 450W LONGiSolar module, has been defined in Skelion.

Figure 44: Technical Data of the Solar Module specified with Skelion



Component

Selected: LONGi Solar:LR4-72HPH-450M
Length: ~ 2,09 m
Width: ~ 1,04 m
Thickness: ~ 0,03 m
Power (W): 450,0
Weight (Kg): 23,3

The electrical and performance data of the modules will be defined in the PVsyst software, which is the tool used to redefine and simulate all the system, as well as calculate the generated power, efficiencies, losses and analyse other data.

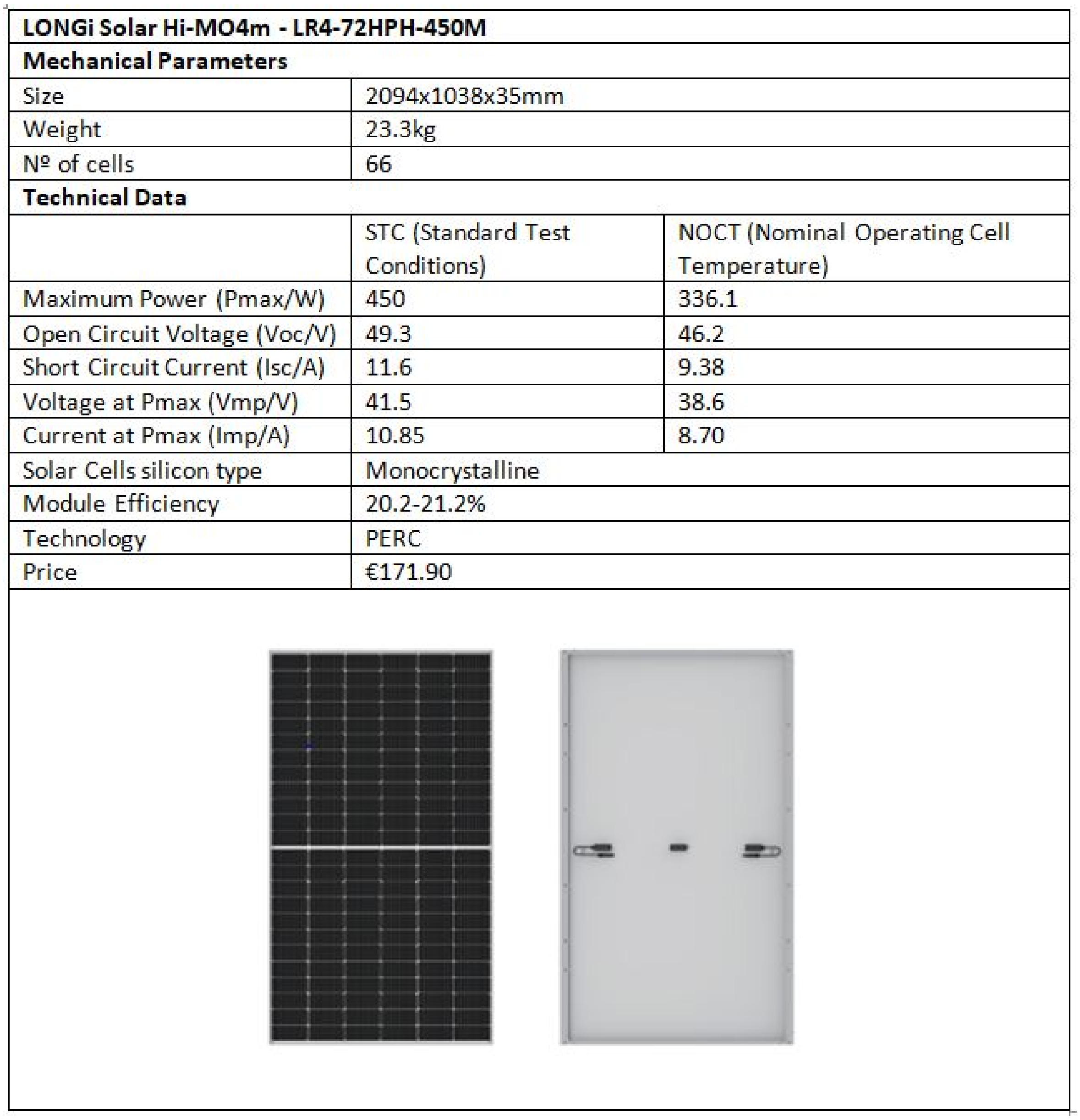
3.6 Components Characteristics

3.6.1 Solar Module

The solar module is one of the the most important component of a solar system, if not the most important one. Its size, power, number and distribution will determine the total production, efficiency and costs of the PV system. Therefore, it is crucial to choose and adequate model, with the adequate size and power. The higher the power is, the greater the size is too.

LONGi Solar is a world known leading mono-crystalline solar module manufacturer for achieving best LCOE (levelled cost of energy) solutions. The solar panel Hi-MO4 LR4-72HPH-450 has been chosen and it has an standard power equal to 450W.

Figure 45: Solar Module LONGi Solar



LONGi Solar Hi-MO4m - LR4-72HPH-450M		
Mechanical Parameters		
Size	2094x1038x35mm	
Weight	23.3kg	
Nº of cells	66	
Technical Data		
	STC (Standard Test Conditions)	NOCT (Nominal Operating Cell Temperature)
Maximum Power (Pmax/W)	450	336.1
Open Circuit Voltage (Voc/V)	49.3	46.2
Short Circuit Current (Isc/A)	11.6	9.38
Voltage at Pmax (Vmp/V)	41.5	38.6
Current at Pmax (Imp/A)	10.85	8.70
Solar Cells silicon type	Monocrystalline	
Module Efficiency	20.2-21.2%	
Technology	PERC	
Price	€171.90	

This solar module offers a very good reliability and a 12 years warranty. The solar panels designed in Sketchup and Skelion have been given the mechanical and electrical characteristics of this solar module LR4-72HPH-450M.

3.6.2 Inverter

The inverter is the device that converts the direct current provided by the solar panels into alternating current. In order to choose a suitable inverter for our photovoltaic plant, the following parameters of the device shall be considered:

- Input DC voltage
- Output AC voltage
- Frequency
- Circuitry

- Optional Accessories
- Stout Features (Resistance to heat, cold, wind, rain, humidity...)
- Cooling System
- Warranties

The inverter is a crucial part of the solar system. Therefore, it is recommended to select an inverter developed by an affirmed company with a good technical service and purchase it in a official shop.

There are various types of inverters, but for this specific application only the 'String Solar Inverters' will be considered. These inverters are wired to a string of solar panels linked together in series. Nevertheless, other inverter types, such as Hybrid or Micro Inverters, may be considered for hypothetical variations of the specified application on the TR10 building.

The optimal power of the inverter must be calculated and it depends on the total power of the solar modules that are connected to the device. In this case, it is desired to connect the panels in series forming strings of 12 modules.

Down below are exposed some of the characteristics of the solar panel, which will be taken into account in order to select an optimal inverter.
Solar panel data:

$$Vmp = 38.6VDC$$

$$Voc = 49.3VDC$$

$$Pmax = 450W(STC), 336.1W(NOCT)$$

Where Vmp is the maximum power voltage of a single solar panel, Vo is the open circuit voltage of a single solar p and $Pmax$ is the maximum power of a single solar panel.

To ensure that the voltage input limits of the inverter are respected, two constraints must be satisfied.
First of all, the minimum input voltage of the inverter must be exceeded, which means that the total maximum power voltage of the group of panels that compose the string must be higher. Here under the formula to calculate the total maximum power voltage of the string and the constraint that must be satisfied.

$$Vmp * n/1.25 > IIVmin$$

Where n is the number of solar panels connected in series in a string, 1.25 is a security factor and $IIVmin$ is the Inverter Minimum Input Voltage.
Secondly, the total open circuit voltage of the string must not exceed the maximum input voltage of the inverter.

$$IIVmax > Voc * n$$

Where n is the number of solar panels connected in series in a string and $IIVmax$ is the Inverter Maximum Input Voltage.

$$IIVmin < 38.6 * n/1.25$$

$$IIVmax > 49.3 * n$$

Therefore, the minimum input voltage of the inverter must be lower than 371VDC , and the maximum input voltage of the inverter must be higher than 592VDC.

The most differential characteristic of the inverter is its power. In this case, the approximated desired power of the inverter can be easily calculated by this formula:

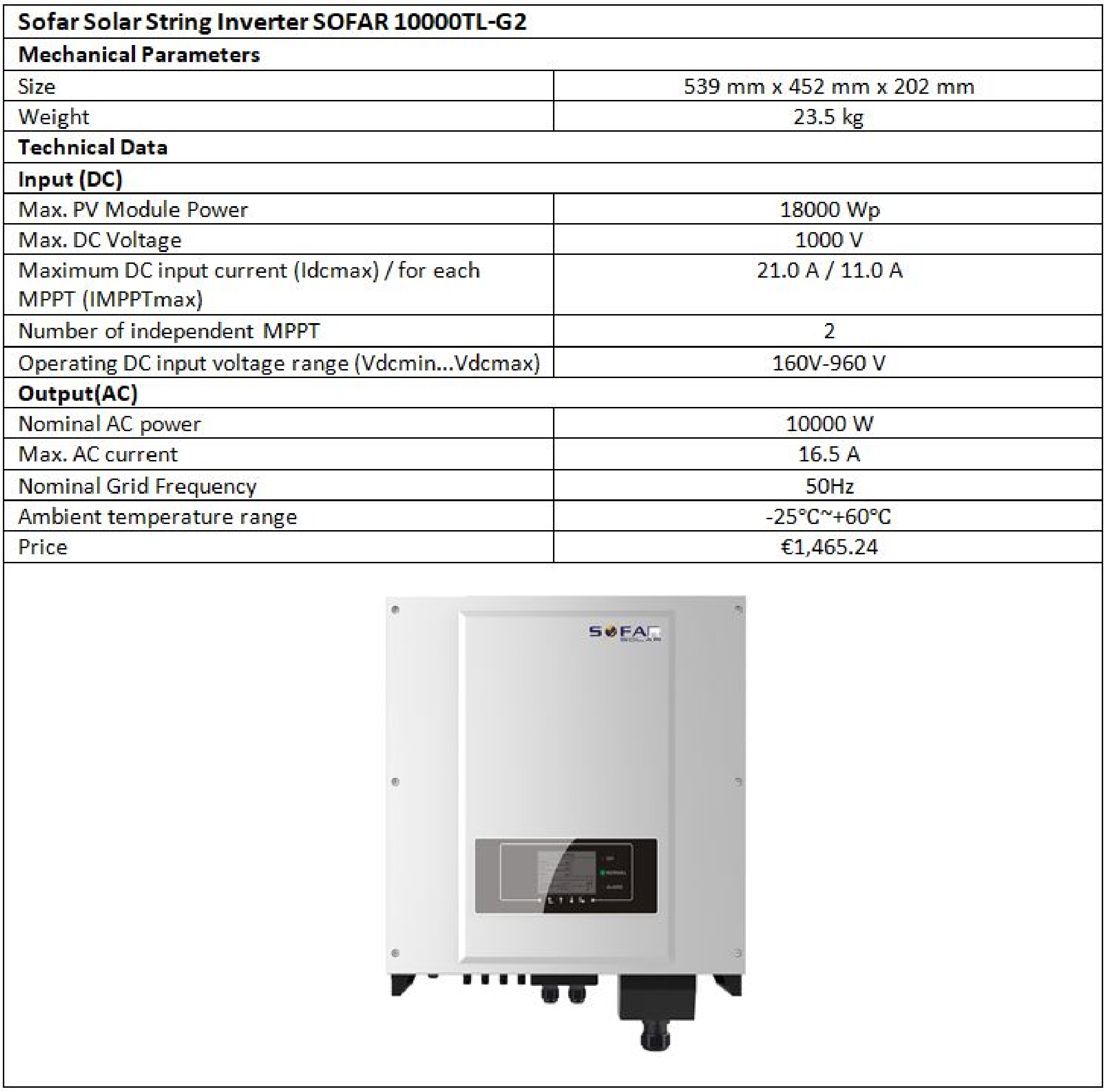
$$P_{Inverter} \approx P_{max(SolarModule)} * ns * nm$$

Where ns is the number of strings that are connected to the inverter and nm is the number of solar modules that compose each string.

It is recommended to use the P_{max} at the Standard Test Conditions (STC), since its the maximum power that the module would reach. Nevertheless, this power is hardly reached, therefore it is often recommended to select an inverter with a power slightly lower.
Using the previously mentioned formula, it is calculated a desired inverter power equal to 10.8kW.

Considering this power and the voltage input constraints, the SOFARSOLAR String Inverter SOFAR 10000TL-G2 with a power of 10.0kW is selected.
SOFARSOLAR is a technology company, established in 2013 in China and specialized in the Research and Development, production, and sales of a wide range of inverters, including grid-tied inverters (1kW-255kW) and hybrid inverters (3kW-20kW), energy storage systems and Electric Vehicles charging.

Figure 46: String Inverter SOFARSOLAR



Sofar Solar String Inverter SOFAR 10000TL-G2	
Mechanical Parameters	
Size	539 mm x 452 mm x 202 mm
Weight	23.5 kg
Technical Data	
Input (DC)	
Max. PV Module Power	18000 Wp
Max. DC Voltage	1000 V
Maximum DC input current (Idcmax) / for each MPPT (IMPPTmax)	21.0 A / 11.0 A
Number of independent MPPT	2
Operating DC input voltage range (Vdcmin...Vdcmax)	160V-960 V
Output(AC)	
Nominal AC power	10000 W
Max. AC current	16.5 A
Nominal Grid Frequency	50Hz
Ambient temperature range	-25°C~+60°C
Price	€1,465.24

Two units of this inverter are required. One unit will be connected to the strings 1 and 3, while the other unit will be connected with the strings 2 and 4.
The standard warranty period of this inverter is 60 months (5 years), but there is also the option to choose 7 or 10 years of warranty.

3.6.3 Support Structure: Solar Blocks

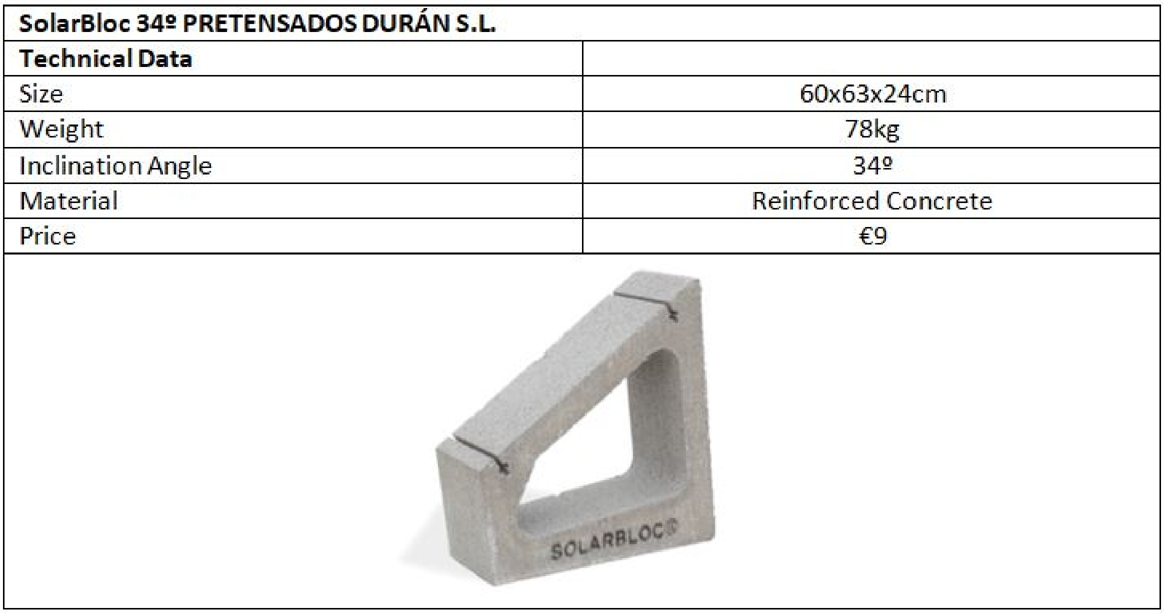
A fixed system is to be designed. Therefore, a fixed mount or structure has to be installed. This mount has to fulfill the following requirements:

- Keep the solar panel at an optimal inclination i.e. the tilt angle previously calculated and determined
- Hold the solar panel and keep it steady at any weather condition

For this component, the SOLARBLOC from the company PRETENSADOS DURÁN S.L. has been chosen due to various factors. First of all, it has already been purchased in other UPC projects. Secondly, the product is reliable, relatively cheap and requires an easy installation, since it avoids the process of drilling and anchoring on the roof. However, it will be necessary to hire a crane to place all the blocks on the roof, since their weight is 78kg each unit and they are too heavy to be carried to the roof.

PRETENSADOS DURÁN S.L. is a Spanish company founded in 1991 and has consolidated as a referent company in the construction sector.

Figure 47: Solar Bloc PRETENSADOS DURÁN S.L. Technical Data

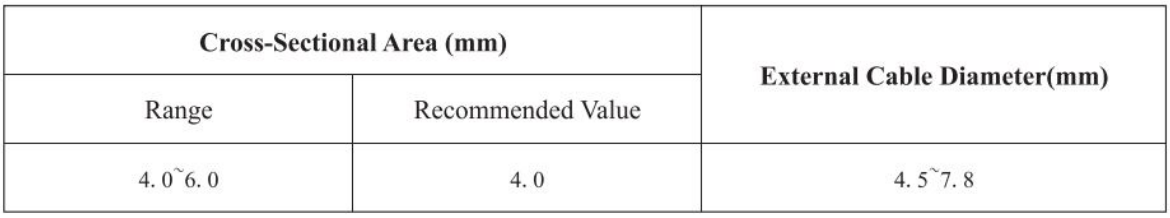


SolarBloc 34º PRETENSADOS DURÁN S.L.	
Technical Data	
Size	60x63x24cm
Weight	78kg
Inclination Angle	34º
Material	Reinforced Concrete
Price	€9

3.6.4 DC Wiring/Circuitry

In the installation manual of the inverter, which can be found in the annexes, the recommended DC input cable specifications can be found. They are shown in the table below.

Figure 48: Recommended DC Input Cable Specifications



Cross-Sectional Area (mm)		**External Cable Diameter(mm)**
Range	Recommended Value	
4. 0˜6. 0	4. 0	4. 5˜7. 8

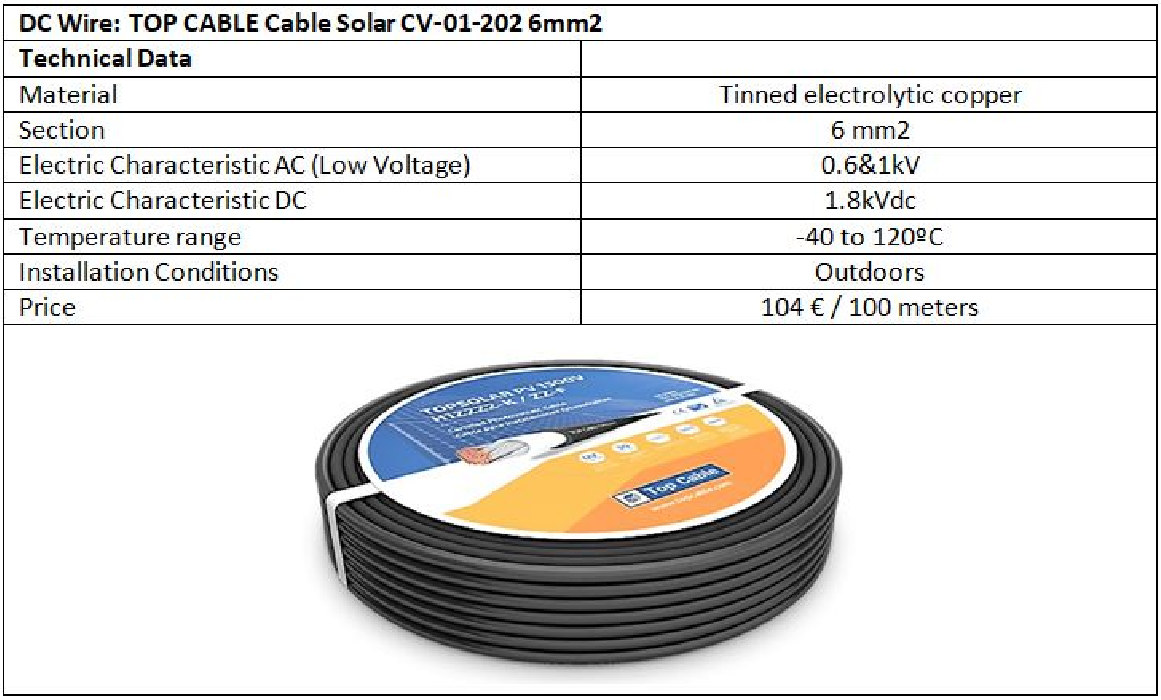
Furthermore, the specifications of the solar panel must also be checked. As it is written in the installation manual of the LONGi solar panel, ”The installer can only use single-wire cable, 2.5-16mm2, 90 ºC, with proper insulation capability to withstand the maximum open circuit voltage (such as EN50618 approval). Need to select appropriate wire specifications to reduce voltage drop.” The installation manual of the solar panel can be found in the annexes.

Now, the appropriate section of the cable can be calculated from the maximum current that will hold. In this system, the maximum current of each string is calculated multiplying it by 2.25 to add a security factor of 125%.

$$I_{max(string)} * 2.25 = 9.38 * 2.25 = 21.1A$$

Given these results and all these specifications, the single-wire CV-01-202 6mm2 cable from TOP CABLE has been selected, which satisfies the calculations and the constraints established by the manufacturers.

Figure 49: DC Wire Cable Solar CV-01-202 6mm2



DC Wire: TOP CABLE Cable Solar CV-01-202 6mm2	
Technical Data	
Material	Tinned electrolytic copper
Section	6 mm2
Electric Characteristic AC (Low Voltage)	0.6&1kV
Electric Characteristic DC	1.8kVdc
Temperature range	-40 to 120ºC
Installation Conditions	Outdoors
Price	104 € / 100 meters

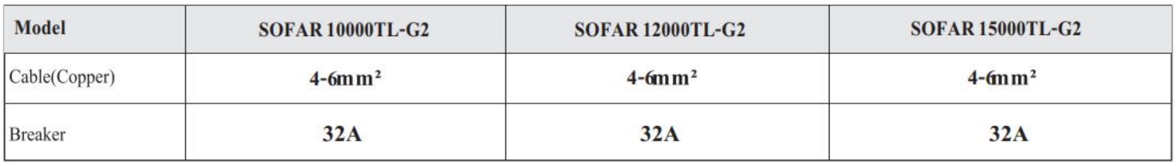
This tinned electrolytic copper cable ensures good conductivity as well as a good isolation that improves the resistance to harsh weather conditions at the outside. It is also halogens free, which is important to avoid fire accidents. This cable is specifically fabricated for photovoltaic installations and presumes to have a longer lifespan.

The LONGi solar panel includes 120cm of cable, which will be used to connect most of the solar modules between them to form the string. The distance between the first solar module and the inverter will be covered by the cable specified below.

3.6.5 AC Wiring/Circuitry

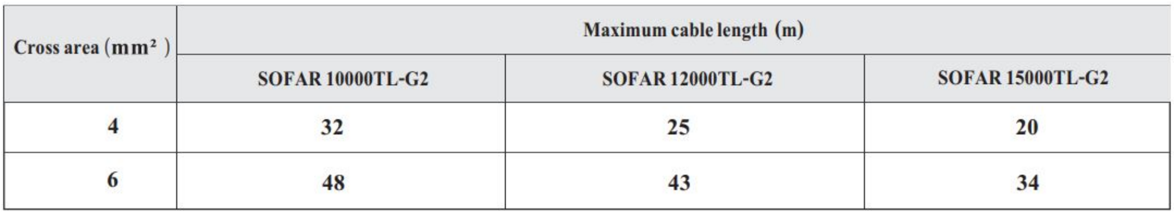
In the installation manual of the inverter, which can be found in the annexes, there are the recommended AC output cable specifications. These are shown in the tables below.

Figure 50: Recommended AC Output Cable Specifications



Model	**SOFAR 10000TL-G2**	**SOFAR 12000TL-G2**	**SOFAR 15000TL-G2**
Cable(Copper)	**4-6mm²**	**4-6mm²**	**4-6mm²**
Breaker	**32A**	**32A**	**32A**

Figure 51: Recommended AC Output Cable Specifications

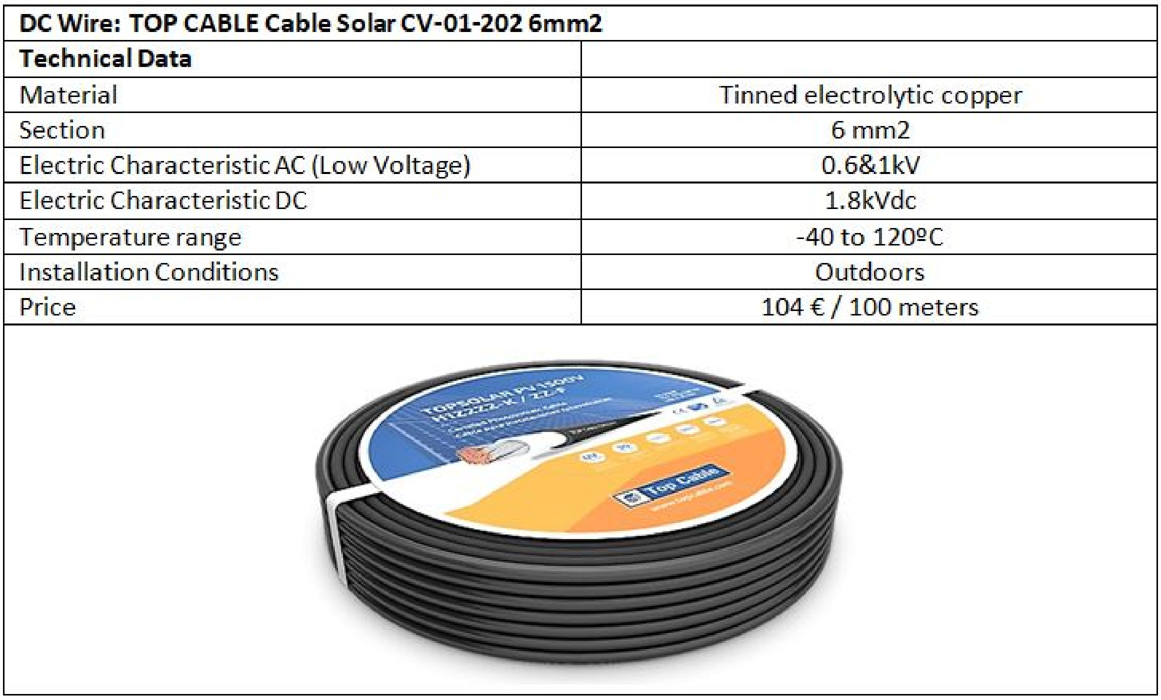


Cross area (mm²)	Maximum cable length (m)		
	SOFAR 10000TL-G2	SOFAR 12000TL-G2	SOFAR 15000TL-G2
4	32	25	20
6	48	43	34

It is also mentioned that the leakage current of breaker should be higher than 100mA and lower than 300mA.

For this purpose, the cable used will be the same CV-01-202 with a section of 6mm2, which will allow a maximum cable length equal to 48m.

Figure 52: AC Wire Cable Solar CV-01-202 6mm2



DC Wire: TOP CABLE Cable Solar CV-01-202 6mm2	
Technical Data	
Material	Tinned electrolytic copper
Section	6 mm2
Electric Characteristic AC (Low Voltage)	0.6&1kV
Electric Characteristic DC	1.8kVdc
Temperature range	-40 to 120ºC
Installation Conditions	Outdoors
Price	104 € / 100 meters

3.6.6 Protections

The protection used in the DC part is composed by fuses.
The fuses are devices that protect the photovoltaic installation, reducing the fire or destruction risk of other elements of the system, as well as enabling the flow of electric current until reaching the maximum value that the device, in this case the inverter, requires.

In this installation, the maximum current between the solar panels and the inverter is equal to 9.38A. Therefore, a 10A fuse has been selected. See the table below.

Figure 53: DC Protection. Fuse 10A Mersen

Protistor Cylindrical Fuse Mersen 10A	
Technical Data	
Size	10x38 mm
Weight (max)	10 g
Rated Voltage	690 V
Nominal Current	10 A
Breaking Capacity @ Rated Voltage	160 kA
Price	€7.24

The installation of fuses usually requires of fuse holders. For this purpose, fuse holders with the same size and from the same manufacturer have been selected. See the table below.

Figure 54: DC Protection. Fuse Holder Mersen

Fuse Holder Mersen Modulostar CUS10	
Technical Data	
Size	10x38 mm
UL ratings DC	1000 VDC, 32 A, 100 kA
Voltage Range DC	690 ... 1000 VDC
Mounting	Installation on to DIN rails to EN 60715
Conventional free air thermal current with fuse links	32 A
Price	€6.46

The protections used in the AC part, i.e. between the inverter and the buildings grid, can be divided into magneto-thermic and differential protections. Basically, the magneto-thermic protections protect the circuitry and devices from shortcircuits and overloads, whereas the differential protections protect the circuitry and devices from derivations and most important protect the persons from indirect contacts.

The maximum current in the AC part is 16.5 A, as it can be seen in the inverters data table. Given this value, a differential automatic switch has been selected. This switch has a rated current equal to 20 A and a rated fault current equal to 30 mA, which is the standard value for a medium size installation.

Figure 55: AC Protection. Magnetothermic Switch

Magnetothermic Automatic Switch iC60N 10A 4P SCHNEIDER	
Technical Data	
Pole thickness	18 mm
Number of poles	4
Curve	C
Intensity	20 A
Shortcut power	6 kA
Price	€26.90

Figure 56: AC Protection. Differential Switch

Industrial Differential Switch MAXGE 4P-30mA-Clase AC-10kA	
Technical Data	
Number of poles	4
Nominal Voltage	230-400V AC
Intensity	25 A
Shortcut power	10 kA
Price	€39.95

3.7 Electric Installation

The electric installation of all the components is divided in two parts: The direct current (DC) section and the alternating current (AC) section.

The DC section is composed by all the components from the solar modules to the inverter's input.
The AC section is composed by everything else, i.e. all the components from the inverter to the electrical power grid of the TR10 building.

3.7.1 Direct Current Section

The overall system is formed by 48 solar panels, which are divided in 4 strings. There are 2 inverters, each one with 2 inputs and 2 MPPT. This means that every string will be connected to one input and controlled by one MPPT.

Figure 57: AutoCAD DC Section Scheme. Strings 1 and 3

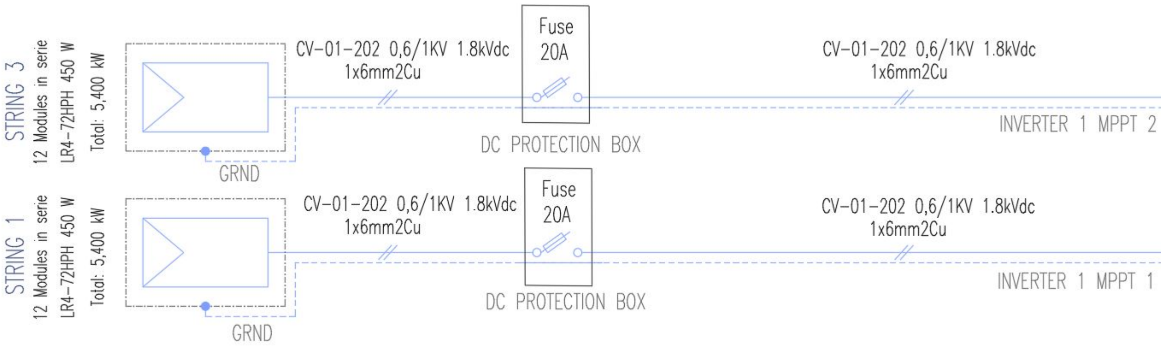
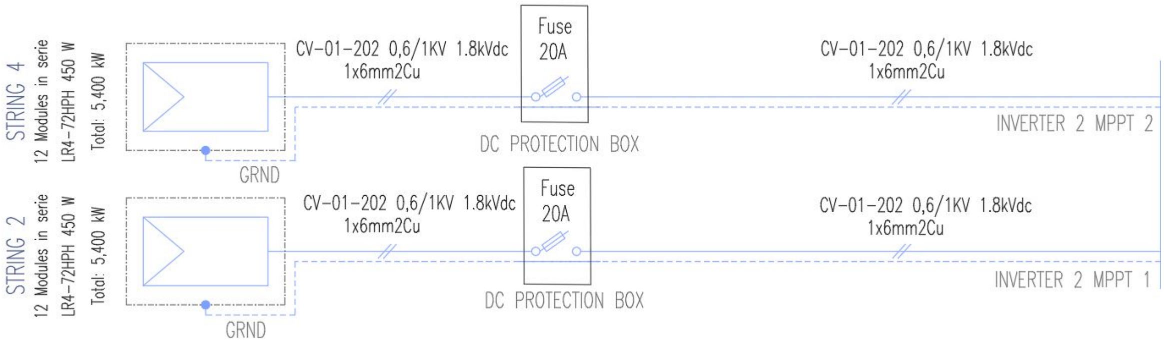


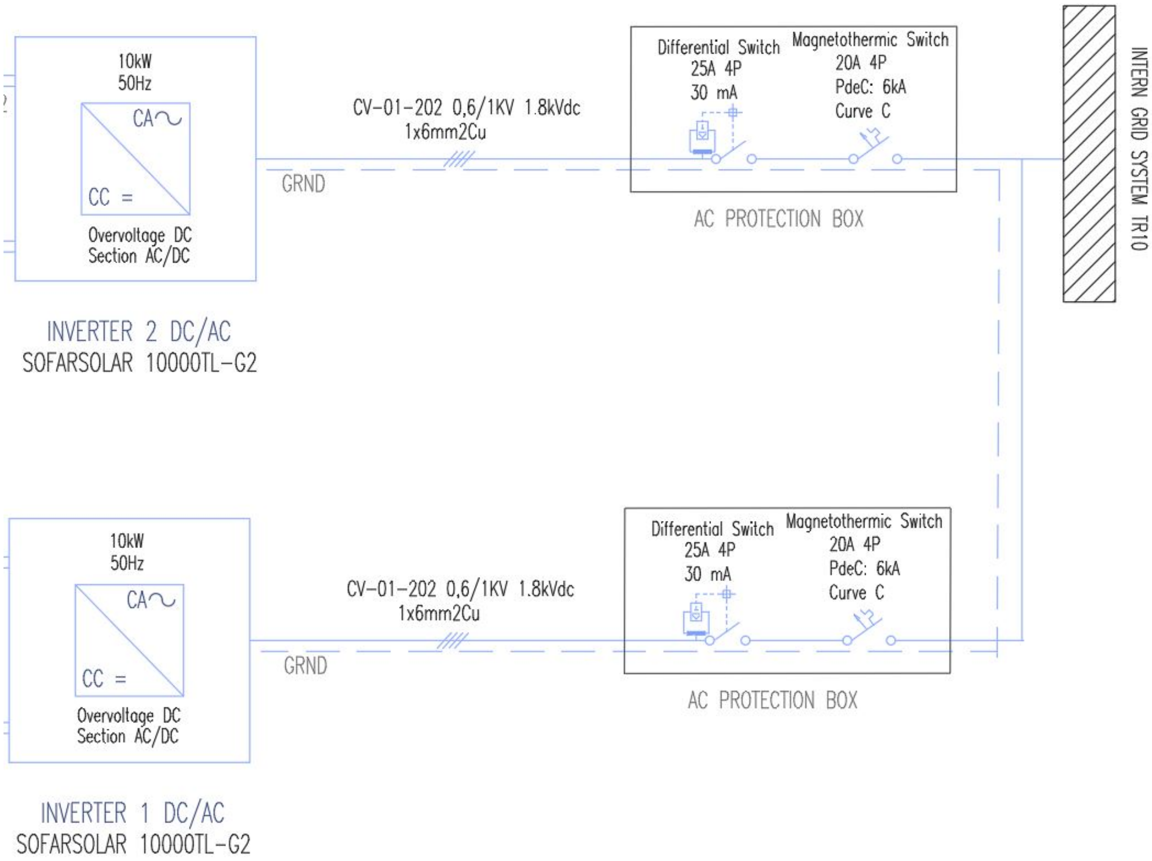
Figure 58: AutoCAD DC Section Scheme. Strings 2 and 4



3.7.2 Alternating Current Section

The 10000TL-G2 is a three phase output inverter and it complies with related on-grid standard and safety requirements.

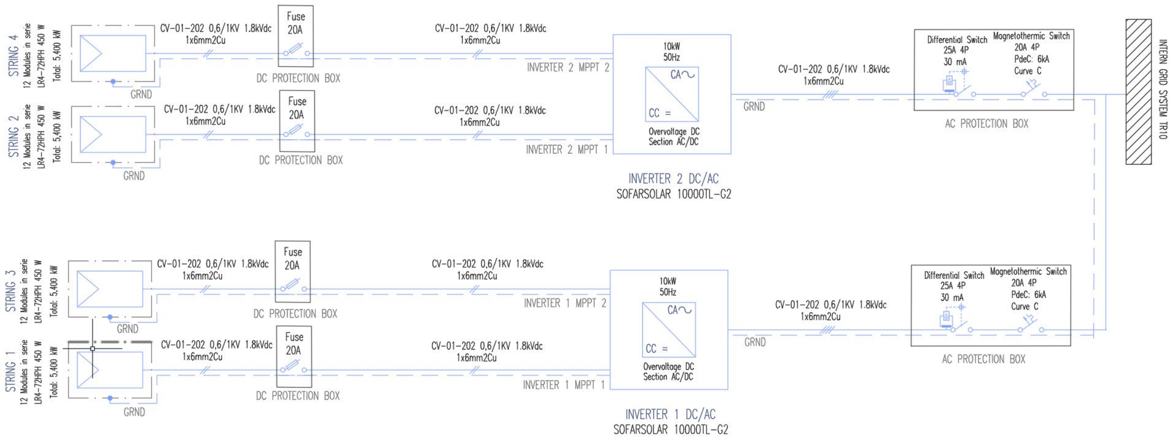
Figure 59: AutoCAD AC Section Scheme



3.7.3 Global System’s Electric Scheme

The following diagram represents the scheme of the whole photovoltaic system.

Figure 60: AUTOCAD System’s Electric Scheme



3.8 Monitoring System. SolarMAN Mobile App

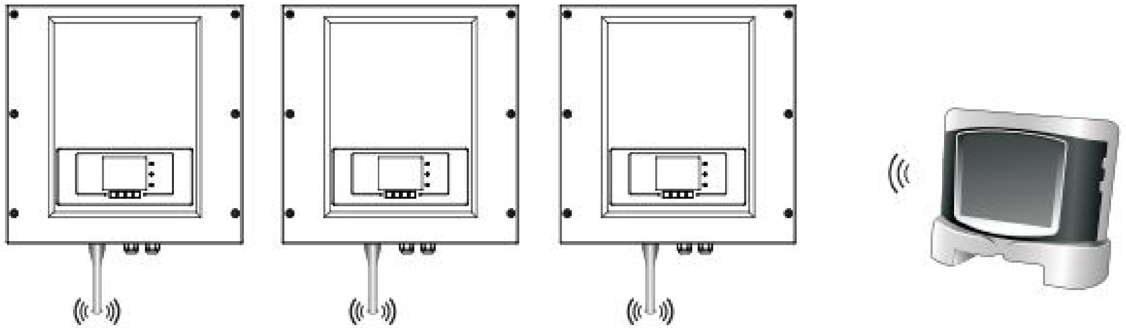
Once the photovoltaic installation has been made, it is very important to track its performance continuously and check if there is any singularity or if it is functioning as it was expected. This way, it will be easier to detect breakdowns and malfunctions, as well as predict the future production.

For this purpose, a monitoring system has to be used. In this case, the inverter's manufacturer, SOFAR Solar, has developed SolarMAN.

SolarMAN is a free smartphone application that enables monitoring of the PV system easier and quicker. It displays both real-time and historical data, as well as CO2 savings and weather conditions. The application supports both local and remote mode. With remote mode, all data can be viewed in the SolarMAN Portal. With local mode, the user can get direct access to the web server of SolarMAN monitoring device via WiFi.

The application requests the serial number of the specific inverter, as well as other data e.g. the WiFi where the inverters are connected to, the location coordinates, address, capacity, etc. The user can connect the Inverters to the WiFi through the user's interface i.e. the screen that has the inverter.

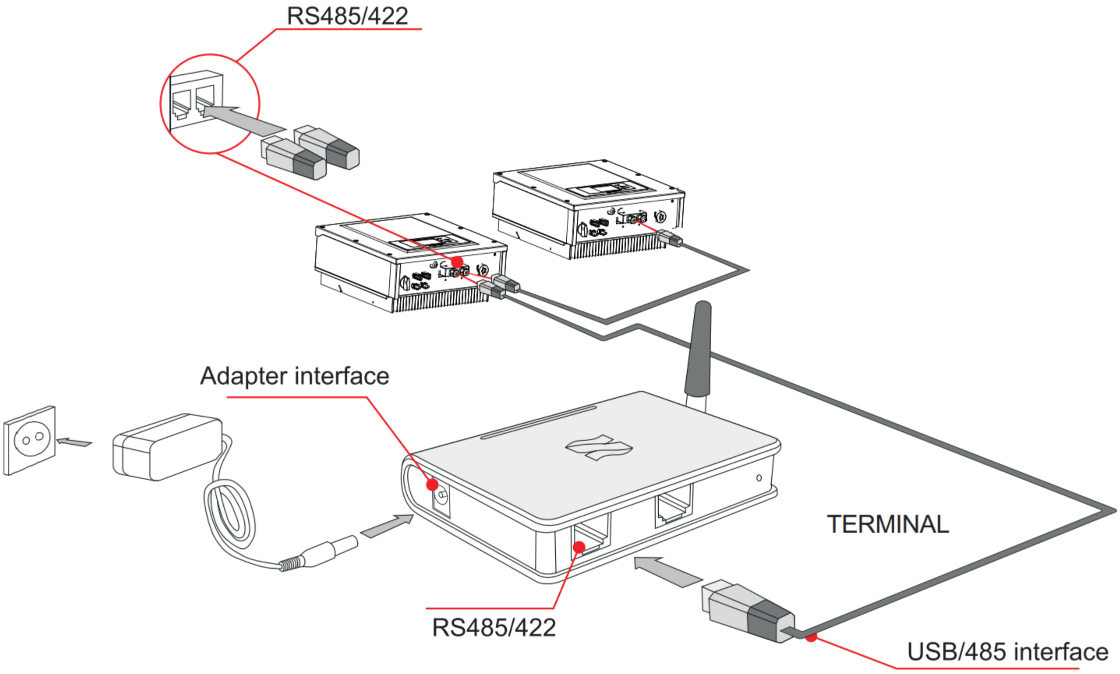
Figure 61: Connection of the Inverter to a Wireless Router



The functioning of the interface is explained in the inverter user's manual, which has been attached in the Annexes.

In order to obtain the information from the inverter the user can also do the connection with cables. To do that, it is necessary to connect the inverter to a communication equipment. In this case, it can be connected to a PC terminal with a USB connector, and from the PC the obtained data can be used.

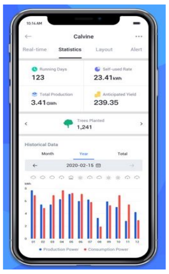
Figure 62: Multi Sofar 10KTL-G2 Connecting Communication



The cable used for this connection has to be the RS485 with USB connector and the other connector is the RJ45. The data-sheets of both components can be found in the Annexes.

The following figures are examples of how the monitoring can be displayed in the smartphone application and in the web portal.

Figure 63: Solarman App Display



Running Days 123

Self-used Rate 23.41 kWh

Total Production 3.41 GWh

Anticipated Yield 239.35

Trees Planted 1,241

2020-02-15

Figure 64: Solarman Web Portal Display

trevor.larkum@fuelincluded.com

TL Northampton

04/03 light rain 7.58-8.58 °C | 04/04 light rain 3.34-10.2 °C | 04/05 clear sky 2.3-9.7 °C

Alerts: 12 items

Trees Planted 0.10 trees

Carbon Offset 0.04 ton

Income £17.08

Power Now	Today's Energy	Monthly Energy	Yearly Energy	Total Energy
-1690.00 W	11.05 kWh	22.29 kWh	35.59 kWh	35.59 kWh

Site Profile

System Size: 7.00 kW

Installer: Fuel Included

Peak Power: 0.61 kW

Efficiency: 1.01 kWh/kW/day

Commission Date: 30/03/2018

Last Update Time:

3.9 Simulation and Analysis with the PVsyst Software

The software PVsyst 7.2 has been purchased and used to simulate and analyse the grid-connected photovoltaic system designed in this project.

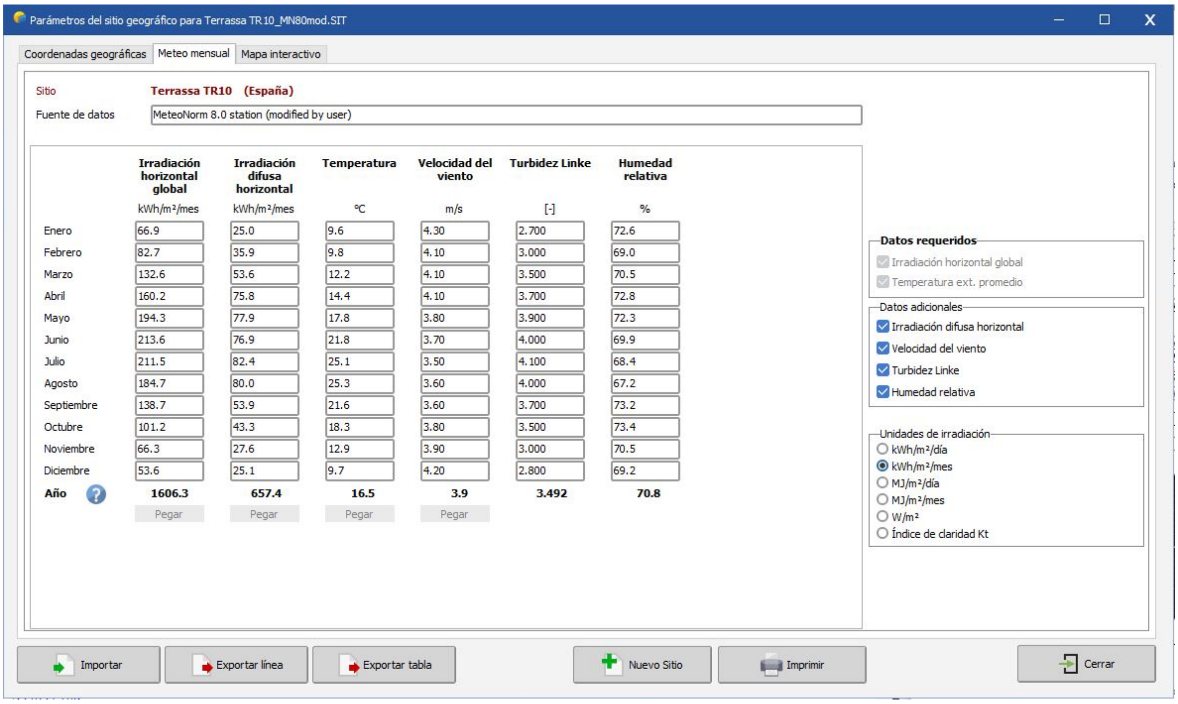
PVsyst 7.2 is a PC software package for the study, sizing and data analysis of complete PV systems. It deals with grid-connected, stand-alone, pumping and DC-grid (public transportation) PV systems, and includes extensive meteorological data and PV systems components databases, as well as general solar energy tools. This software is geared to the needs of architects, engineers, researchers and others. It is also very helpful for educational training.

3.9.1 Definition of the Project in PVsyst

In this case, two projects have been created, each one for one inverter. The projects characteristics and the process to create the projects are all the same and only differ in the active solar panels. The distributions of the strings has been previously shown.

The first step has been the definition of the meteorological data. Fortunately, PVsyst has a wide meteorological database and it is only needed to insert the location coordinates.

Figure 65: Meteorological Data of the Location in the PVsyst's Database



Sitio: **Terrassa TR10 (España)**

Fuente de datos: MeteoNorm 8.0 station (modified by user)

	Irradiación horizontal global kWh/m²/mes	**Irradiación difusa horizontal** kWh/m²/mes	**Temperatura** °C	**Velocidad del viento** m/s	**Turbidez Linke** [-]	**Humedad relativa** %
Enero	66.9	25.0	9.6	4.30	2.700	72.6
Febrero	82.7	35.9	9.8	4.10	3.000	69.0
Marzo	132.6	53.6	12.2	4.10	3.500	70.5
Abril	160.2	75.8	14.4	4.10	3.700	72.8
Mayo	194.3	77.9	17.8	3.80	3.900	72.3
Junio	213.6	76.9	21.8	3.70	4.000	69.9
Julio	211.5	82.4	25.1	3.50	4.100	68.4
Agosto	184.7	80.0	25.3	3.60	4.000	67.2
Septiembre	138.7	53.9	21.6	3.60	3.700	73.2
Octubre	101.2	43.3	18.3	3.80	3.500	73.4
Noviembre	66.3	27.6	12.9	3.90	3.000	70.5
Diciembre	53.6	25.1	9.7	4.20	2.800	69.2
Año	**1606.3**	**657.4**	**16.5**	**3.9**	**3.492**	**70.8**

Datos requeridos
- ☑ Irradiación horizontal global
- ☑ Temperatura ext. promedio

Datos adicionales
- ☑ Irradiación difusa horizontal
- ☑ Velocidad del viento
- ☑ Turbidez Linke
- ☑ Humedad relativa

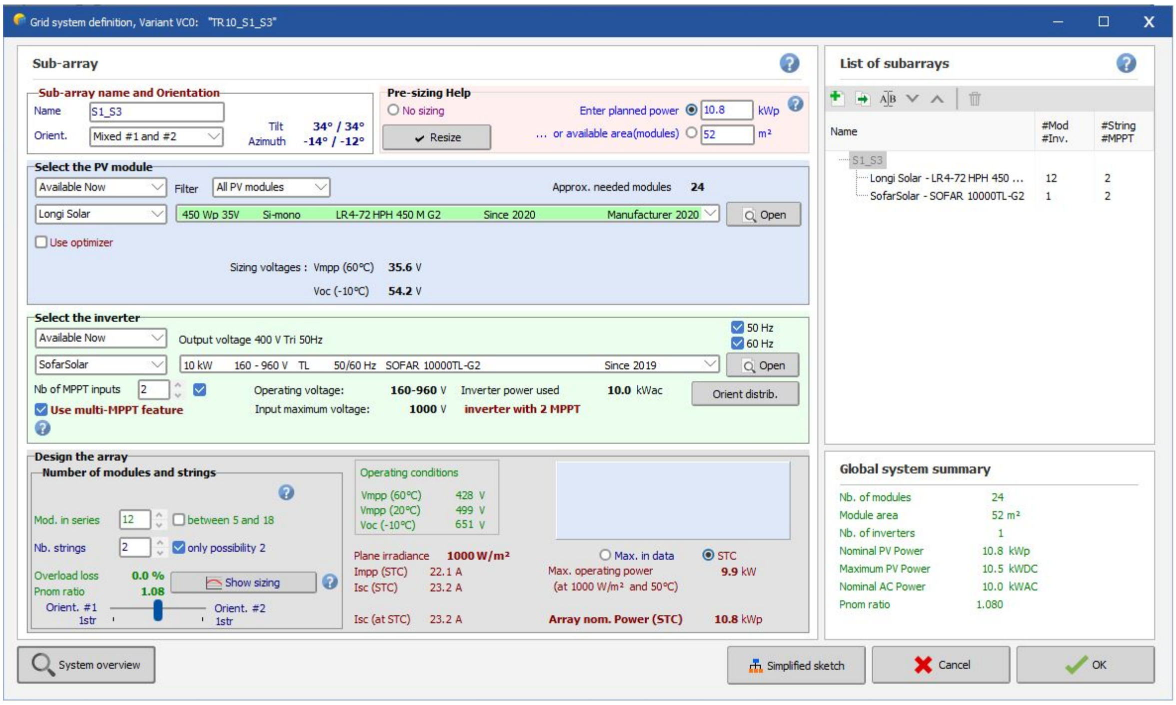
Unidades de irradiación
- ○ kWh/m²/día
- ● kWh/m²/mes
- ○ MJ/m²/día
- ○ MJ/m²/mes
- ○ W/m²
- ○ Índice de claridad Kt

The data has been contrasted with the data obtained in the Global Solar Atlas website and proved to be reliable.

Then, the main system components are defined. Firstly, the solar module's manufacturer and models is selected from the database and the planned power is entered. In this case, the 450W LONGi solar modules have been used and a total power of 21.6kW is planned, however, this project is only for two strings and they have a maximum output power equal to 10.8kW.

Secondly, the inverter manufacturer and model are selected, in this case, the 10kW SOFAR Solar inverter with 2 inputs and 2 MPPTs.

Figure 66: System's Data Definition in PVsyst



Sub-array name and Orientation

Name: S1_S3

Orient.: Mixed #1 and #2

Tilt 34° / 34°

Azimuth -14° / -12°

Pre-sizing Help

○ No sizing

Enter planned power ● 10.8 kWp

… or available area(modules) ○ 52 m²

Select the PV module

Available Now; Filter: All PV modules

Approx. needed modules 24

Longi Solar: 450 Wp 35V Si-mono LR4-72 HPH 450 M G2 Since 2020 Manufacturer 2020

☐ Use optimizer

Sizing voltages : Vmpp (60°C) 35.6 V

Voc (-10°C) 54.2 V

Select the inverter

☑ 50 Hz

☑ 60 Hz

Available Now; Output voltage 400 V Tri 50Hz

SofarSolar: 10 kW 160 - 960 V TL 50/60 Hz SOFAR 10000TL-G2 Since 2019

Nb of MPPT inputs 2 ☑

Operating voltage: 160-960 V

Input maximum voltage: 1000 V

Inverter power used 10.0 kWac

inverter with 2 MPPT

☑ Use multi-MPPT feature

Design the array

Number of modules and strings

Mod. in series 12 ☐ between 5 and 18

Nb. strings 2 ☑ only possibility 2

Overload loss 0.0 %

Pnom ratio 1.08

Orient. #1 1str — Orient. #2 1str

Operating conditions

Vmpp (60°C)	428 V
Vmpp (20°C)	499 V
Voc (-10°C)	651 V

Plane irradiance 1000 W/m²

Impp (STC) 22.1 A

Isc (STC) 23.2 A

Isc (at STC) 23.2 A

○ Max. in data ● STC

Max. operating power (at 1000 W/m² and 50°C) 9.9 kW

Array nom. Power (STC) 10.8 kWp

List of subarrays

Name	#Mod #Inv.	#String #MPPT
S1_S3		
Longi Solar - LR4-72 HPH 450 ...	12	2
SofarSolar - SOFAR 10000TL-G2	1	2

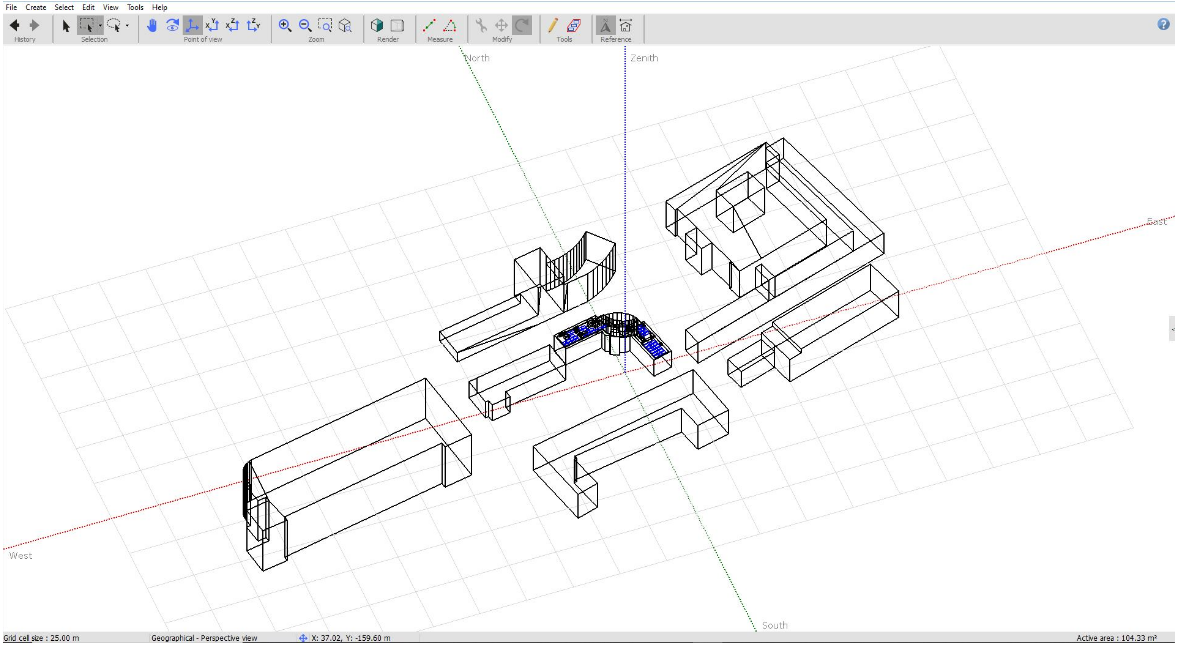
Global system summary

Nb. of modules	24
Module area	52 m²
Nb. of inverters	1
Nominal PV Power	10.8 kWp
Maximum PV Power	10.5 kWDC
Nominal AC Power	10.0 kWAC
Pnom ratio	1.080

As it can be seen in the figure, there are two different orientations, because each string is located on a different section of the roof. These orientations have been automatically detected by the software because the 3D model has been correctly imported and the active solar modules have been defined.

has The import of the 3D model is highly important because it allows the software to calculate all the shading effects and perform a realistic simulation.
In order to import the 3D scene, the Sketchup file of the 3D model has been exported to a ".3ds" file. Now, the project detects the solar modules defined with the Skelion software.

Figure 67: 3D Shading Scene in PVsyst



Grid cell size : 25.00 m

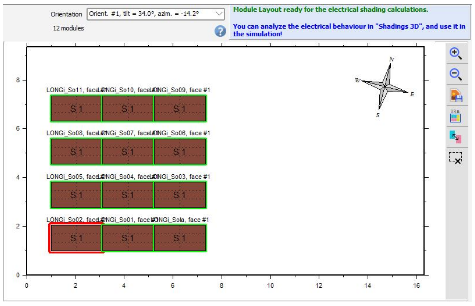
Geographical - Perspective view

X: 37.02, Y: -159.60 m

Active area : 104.33 m²

Next, it has to be defined which solar panels compose each string, and which strings are connected to each inverter. As it has been explained before, the strings 1 and 3 are connected to one inverter and the strings 2 and 4 are connected to the other one. Both inverters are the same. This must be defined in the Module Layout section.

Figure 68: String 1



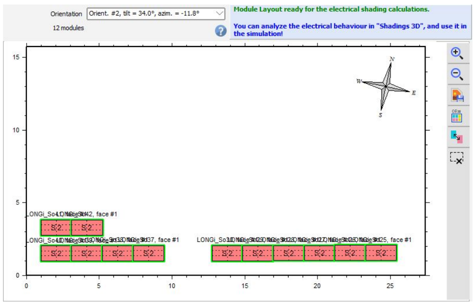
Orientation: Orient. #1, tilt = 34.0°, azim. = -14.2°

12 modules

Module Layout ready for the electrical shading calculations.

You can analyze the electrical behaviour in "Shadings 3D", and use it in the simulation!

Figure 69: String 3



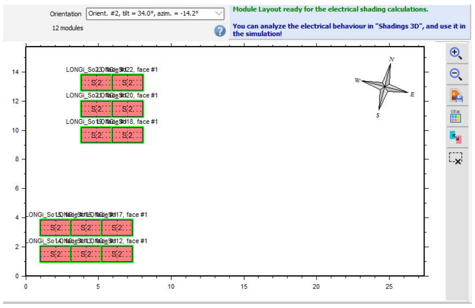
Orientation: Orient. #2, tilt = 34.0°, azim. = -11.8°

12 modules

Module Layout ready for the electrical shading calculations.

You can analyze the electrical behaviour in "Shadings 3D", and use it in the simulation!

Figure 70: String 2



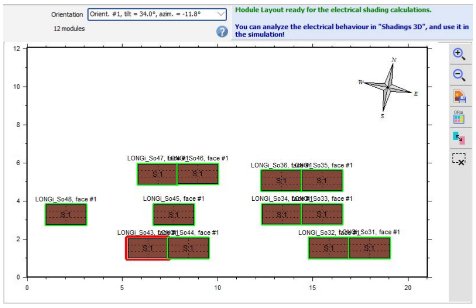
Orientation: Orient. #2, tilt = 34.0°, azim. = -14.2°

12 modules

Module Layout ready for the electrical shading calculations.

You can analyze the electrical behaviour in "Shadings 3D", and use it in the simulation!

Figure 71: String 4



Orientation: Orient. #1, tilt = 34.0°, azim. = -11.8°

12 modules

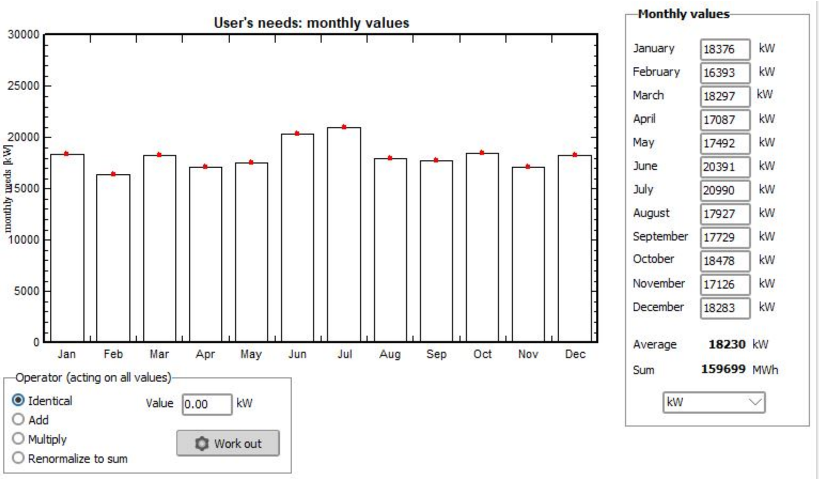
Module Layout ready for the electrical shading calculations.

You can analyze the electrical behaviour in "Shadings 3D", and use it in the simulation!

Hereafter, the physical part of the system has already been designed, but before the simulation, other data, such as the self-consumption expectations and economic costs can also be defined. By defining this parameters, the software will perform a higher quality analysis.

The self-consumption data that has been entered in PVsyst has been extracted from SirenaUPC and explained in the Consumption's Analysis section.

Figure 72: TR10 Monthly Energy Needs in PVsyst



● Identical
○ Add
○ Multiply
○ Renormalize to sum

Value 0.00 kW

January	18376	kW
February	16393	kW
March	18297	kW
April	17087	kW
May	17492	kW
June	20391	kW
July	20990	kW
August	17927	kW
September	17729	kW
October	18478	kW
November	17126	kW
December	18283	kW
Average	**18230**	kW
Sum	**159699**	MWh

kW

The economic costs of the components have been extracted from the manufacturers websites and exposed in the Components Characteristics section. The costs for the installation, transportation and other services is exposed in the Project's Budget section.

3.9.2 Analysis and Results of the Simulation in PVsyst

First of all, the estimated power production is manually calculated. This way it is possible to detect failures and incoherence in the simulation, or correct the calculations.

$$EstimatedPowerProductionPerYear = P_{Total} * 5,4 * n_{year} * \eta$$

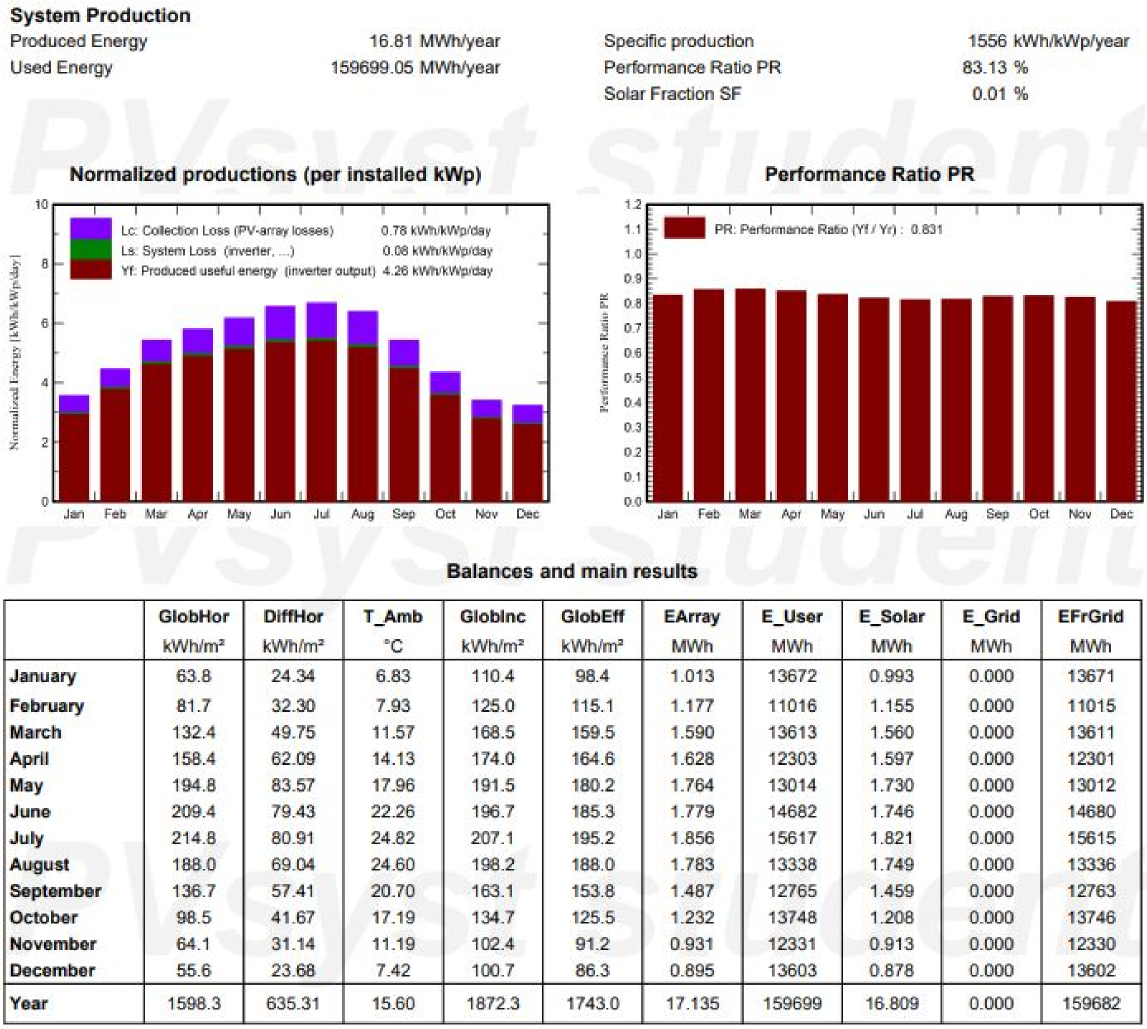
Where P_{Total} is the total peak power of the system, n is the number of days in a year and η is the expected efficiency of the system.

$$EstimatedPowerProductionperYear = 21,6kWp * 5,4 * 365days * 0,8 = 34.000kWh$$

The calculated estimated power production through a year is 34.000kWh.

Back again to PVsyst, once all the data has been included in the software, the system is simulated. After the simulation is completed, the software generates an extensive report with the results.

Figure 73: Simulation's Main Results of Strings 1 and 3 in PVsyst



System Production

Produced Energy	16.81 MWh/year	Specific production	1556 kWh/kWp/year
Used Energy	159699.05 MWh/year	Performance Ratio PR	83.13 %
		Solar Fraction SF	0.01 %

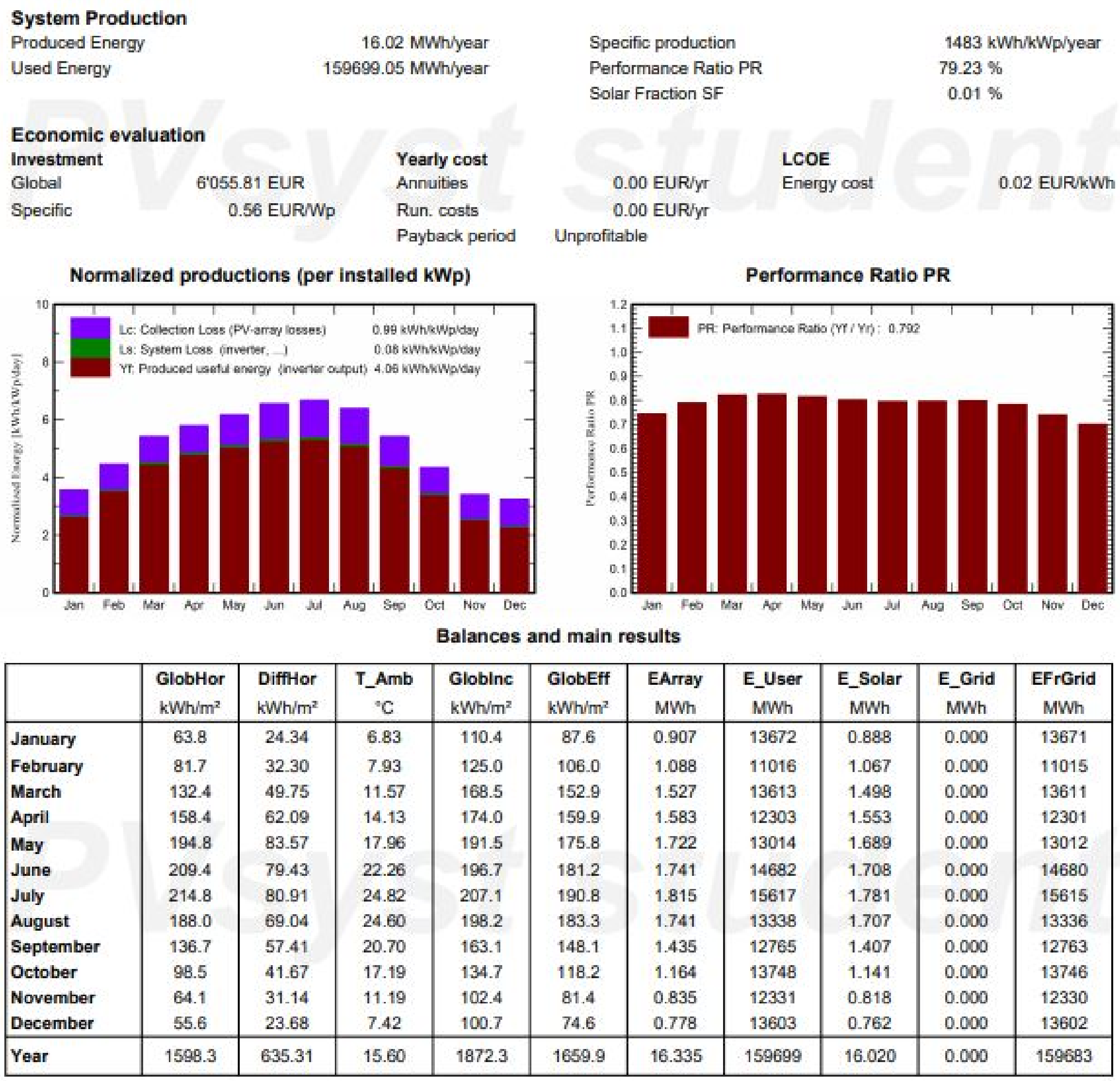
Normalized productions (per installed kWp)

Performance Ratio PR

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_User MWh	E_Solar MWh	E_Grid MWh	EFrGrid MWh
January	63.8	24.34	6.83	110.4	98.4	1.013	13672	0.993	0.000	13671
February	81.7	32.30	7.93	125.0	115.1	1.177	11016	1.155	0.000	11015
March	132.4	49.75	11.57	168.5	159.5	1.590	13613	1.560	0.000	13611
April	158.4	62.09	14.13	174.0	164.6	1.628	12303	1.597	0.000	12301
May	194.8	83.57	17.96	191.5	180.2	1.764	13014	1.730	0.000	13012
June	209.4	79.43	22.26	196.7	185.3	1.779	14682	1.746	0.000	14680
July	214.8	80.91	24.82	207.1	195.2	1.856	15617	1.821	0.000	15615
August	188.0	69.04	24.60	198.2	188.0	1.783	13338	1.749	0.000	13336
September	136.7	57.41	20.70	163.1	153.8	1.487	12765	1.459	0.000	12763
October	98.5	41.67	17.19	134.7	125.5	1.232	13748	1.208	0.000	13746
November	64.1	31.14	11.19	102.4	91.2	0.931	12331	0.913	0.000	12330
December	55.6	23.68	7.42	100.7	86.3	0.895	13603	0.878	0.000	13602
Year	1598.3	635.31	15.60	1872.3	1743.0	17.135	159699	16.809	0.000	159682

Figure 74: Simulation’s Main Results of Strings 2 and 4 in PVsyst



System Production

Produced Energy	16.02 MWh/year	Specific production	1483 kWh/kWp/year
Used Energy	159699.05 MWh/year	Performance Ratio PR	79.23 %
		Solar Fraction SF	0.01 %

Economic evaluation

Investment		**Yearly cost**		**LCOE**	
Global	6'055.81 EUR	Annuities	0.00 EUR/yr	Energy cost	0.02 EUR/kWh
Specific	0.56 EUR/Wp	Run. costs	0.00 EUR/yr		
		Payback period	Unprofitable		

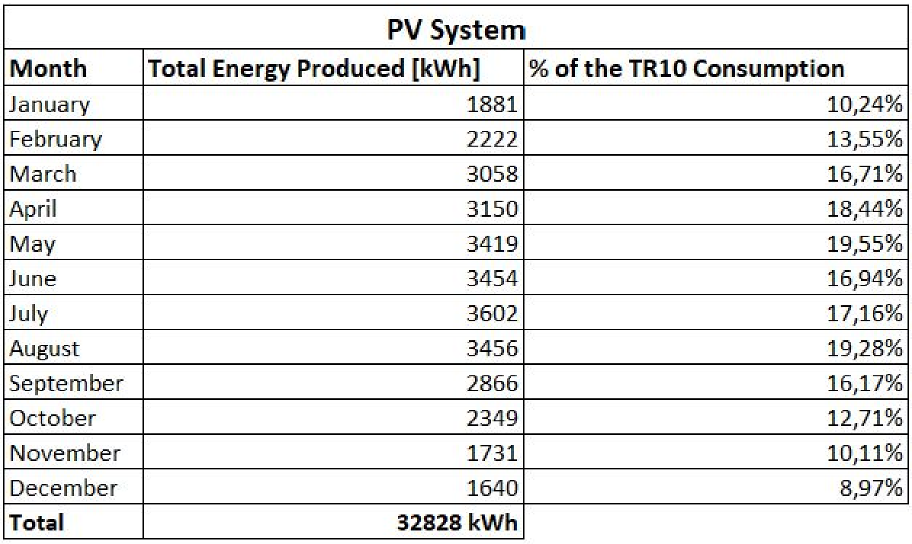
Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_User MWh	E_Solar MWh	E_Grid MWh	EFrGrid MWh
January	63.8	24.34	6.83	110.4	87.6	0.907	13672	0.888	0.000	13671
February	81.7	32.30	7.93	125.0	106.0	1.088	11016	1.067	0.000	11015
March	132.4	49.75	11.57	168.5	152.9	1.527	13613	1.498	0.000	13611
April	158.4	62.09	14.13	174.0	159.9	1.583	12303	1.553	0.000	12301
May	194.8	83.57	17.96	191.5	175.8	1.722	13014	1.689	0.000	13012
June	209.4	79.43	22.26	196.7	181.2	1.741	14682	1.708	0.000	14680
July	214.8	80.91	24.82	207.1	190.8	1.815	15617	1.781	0.000	15615
August	188.0	69.04	24.60	198.2	183.3	1.741	13338	1.707	0.000	13336
September	136.7	57.41	20.70	163.1	148.1	1.435	12765	1.407	0.000	12763
October	98.5	41.67	17.19	134.7	118.2	1.164	13748	1.141	0.000	13746
November	64.1	31.14	11.19	102.4	81.4	0.835	12331	0.818	0.000	12330
December	55.6	23.68	7.42	100.7	74.6	0.778	13603	0.762	0.000	13602
Year	1598.3	635.31	15.60	1872.3	1659.9	16.335	159699	16.020	0.000	159683

The complete reports have been included in the annexes.

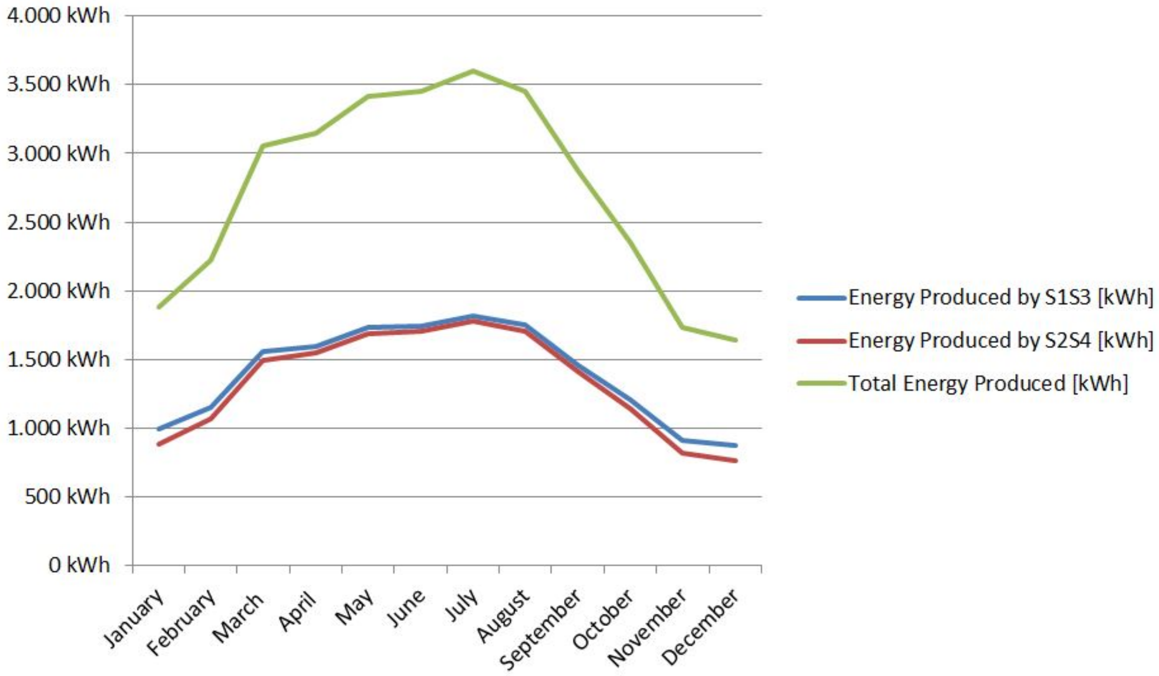
By adding both systems, the global results are obtained. In the table here under it is shown the total production per month of the designed system and the percentage of the building’s consumption that would be covered.

Figure 75: Total Production of the Simulated System in PVsyst



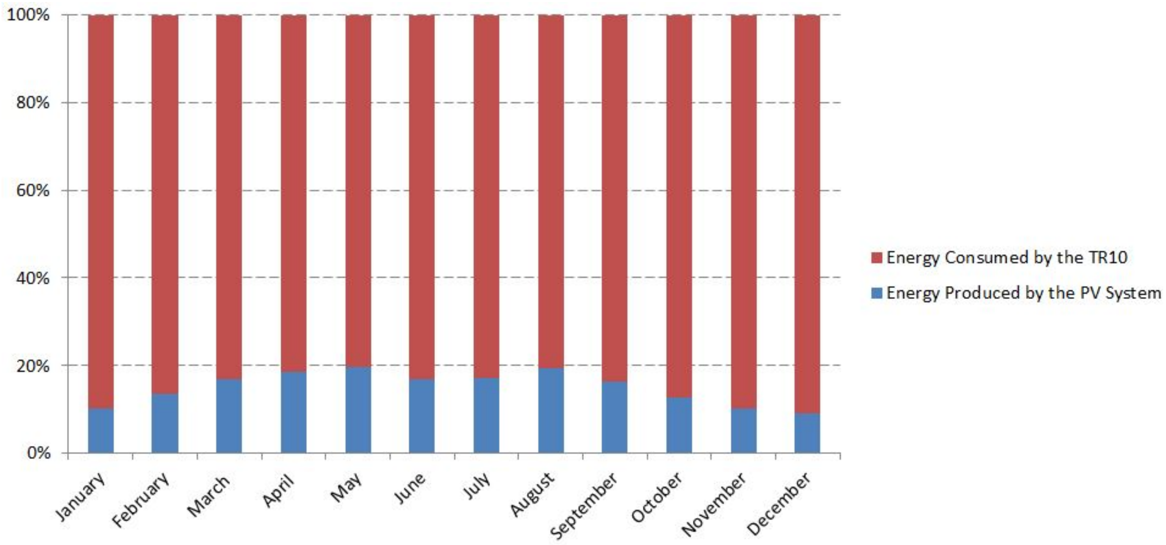
PV System		
Month	**Total Energy Produced [kWh]**	**% of the TR10 Consumption**
January	1881	10,24%
February	2222	13,55%
March	3058	16,71%
April	3150	18,44%
May	3419	19,55%
June	3454	16,94%
July	3602	17,16%
August	3456	19,28%
September	2866	16,17%
October	2349	12,71%
November	1731	10,11%
December	1640	8,97%
Total	**32828 kWh**	

Figure 76: Total Production of the Simulated System in PVsyst



As it can be seen, the total production p.a. (32.282 kWh/year) matches with the initial calculations. This reinforces the idea that the simulation has been correctly done and the simulated system performs as it should. One possible reason for the difference between the results is that PVsyst consider shading losses and other losses that are not considered in the calculations.

Figure 77: Relation Between Produced and Consumed Energy



The PVsyst software provides us with a great amount of analysed data, that can be useful to conduct studies and comparatives in the future. The complete reports of both simulations have been attached in the Annexes in a pdf format. The PVsyst files of the projects have also been attached, but they require the software installations and the license.

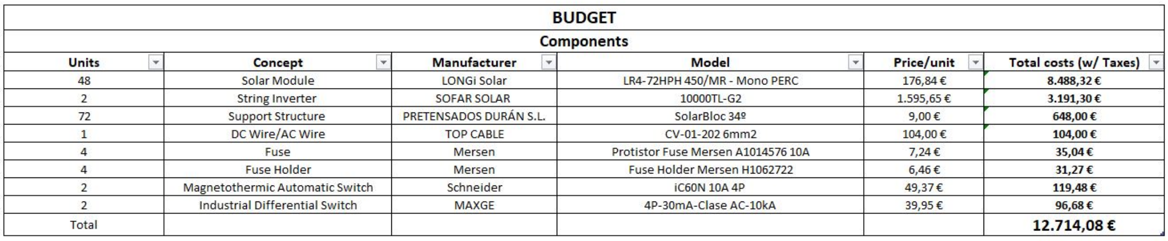
3.10 Economic Results

3.10.1 Project's Budget

The project's budget has been calculated with the prices that the manufacturer's establish, including the taxes and the transportation costs, in case they are not already included in the product's price.

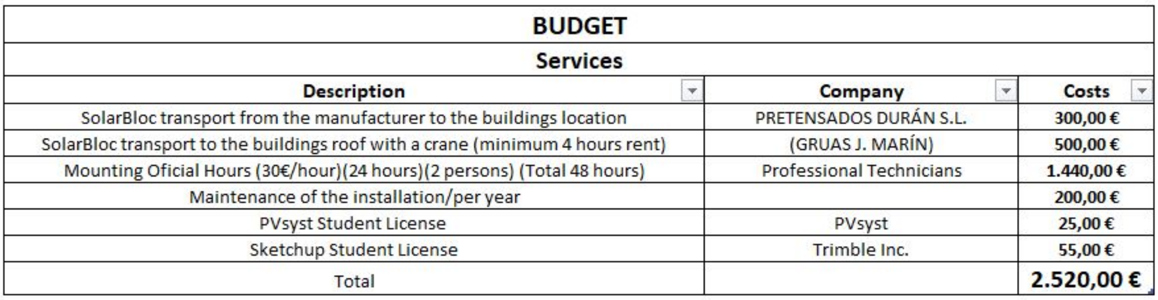
Two tables have been made, one for the products required to install the PV system, and the other one for the services that must be hired in order to do the installation.

Figure 78: Component's Budget



BUDGET					
Components					
Units	**Concept**	**Manufacturer**	**Model**	**Price/unit**	**Total costs (w/ Taxes)**
48	Solar Module	LONGi Solar	LR4-72HPH 450/MR - Mono PERC	176,84 €	**8.488,32 €**
2	String Inverter	SOFAR SOLAR	10000TL-G2	1.595,65 €	**3.191,30 €**
72	Support Structure	PRETENSADOS DURÁN S.L.	SolarBloc 34º	9,00 €	**648,00 €**
1	DC Wire/AC Wire	TOP CABLE	CV-01-202 6mm2	104,00 €	**104,00 €**
4	Fuse	Mersen	Protistor Fuse Mersen A1014576 10A	7,24 €	**35,04 €**
4	Fuse Holder	Mersen	Fuse Holder Mersen H1062722	6,46 €	**31,27 €**
2	Magnetothermic Automatic Switch	Schneider	iC60N 10A 4P	49,37 €	**119,48 €**
2	Industrial Differential Switch	MAXGE	4P-30mA-Clase AC-10kA	39,95 €	**96,68 €**
Total					**12.714,08 €**

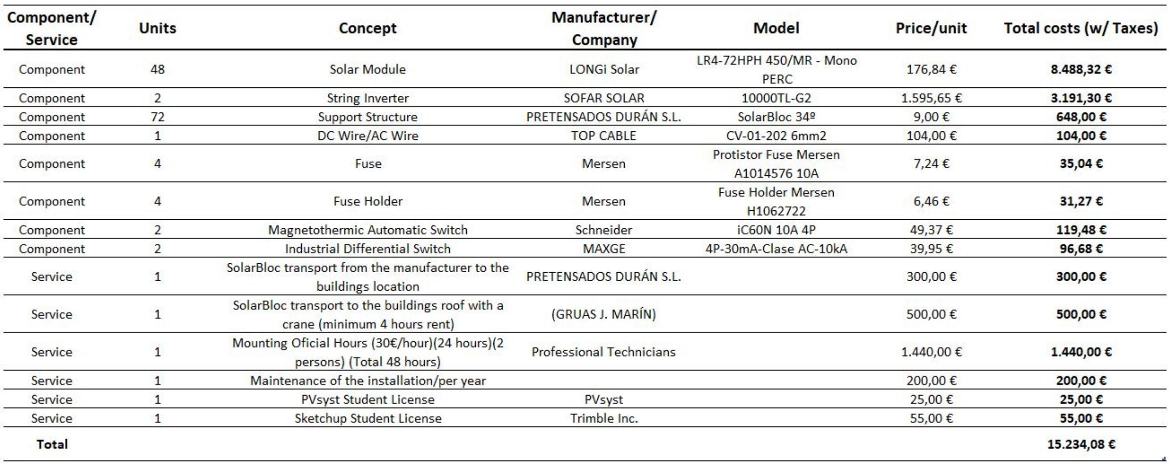
Figure 79: Service's Budget



BUDGET		
Services		
Description	**Company**	**Costs**
SolarBloc transport from the manufacturer to the buildings location	PRETENSADOS DURÁN S.L.	**300,00 €**
SolarBloc transport to the buildings roof with a crane (minimum 4 hours rent)	(GRUAS J. MARÍN)	**500,00 €**
Mounting Oficial Hours (30€/hour)(24 hours)(2 persons) (Total 48 hours)	Professional Technicians	**1.440,00 €**
Maintenance of the installation/per year		**200,00 €**
PVsyst Student License	PVsyst	**25,00 €**
Sketchup Student License	Trimble Inc.	**55,00 €**
Total		**2.520,00 €**

The total cost of the installation is 15.234,08 €.

Figure 80: Total Budget



Component/ Service	Units	Concept	Manufacturer/ Company	Model	Price/unit	Total costs (w/ Taxes)
Component	48	Solar Module	LONGi Solar	LR4-72HPH 450/MR - Mono PERC	176,84 €	**8.488,32 €**
Component	2	String Inverter	SOFAR SOLAR	10000TL-G2	1.595,65 €	**3.191,30 €**
Component	72	Support Structure	PRETENSADOS DURÁN S.L.	SolarBloc 34º	9,00 €	**648,00 €**
Component	1	DC Wire/AC Wire	TOP CABLE	CV-01-202 6mm2	104,00 €	**104,00 €**
Component	4	Fuse	Mersen	Protistor Fuse Mersen A1014576 10A	7,24 €	**35,04 €**
Component	4	Fuse Holder	Mersen	Fuse Holder Mersen H1062722	6,46 €	**31,27 €**
Component	2	Magnetothermic Automatic Switch	Schneider	iC60N 10A 4P	49,37 €	**119,48 €**
Component	2	Industrial Differential Switch	MAXGE	4P-30mA-Clase AC-10kA	39,95 €	**96,68 €**
Service	1	SolarBloc transport from the manufacturer to the buildings location	PRETENSADOS DURÁN S.L.		300,00 €	**300,00 €**
Service	1	SolarBloc transport to the buildings roof with a crane (minimum 4 hours rent)	(GRUAS J. MARÍN)		500,00 €	**500,00 €**
Service	1	Mounting Oficial Hours (30€/hour)(24 hours)(2 persons) (Total 48 hours)	Professional Technicians		1.440,00 €	**1.440,00 €**
Service	1	Maintenance of the installation/per year			200,00 €	**200,00 €**
Service	1	PVsyst Student License	PVsyst		25,00 €	**25,00 €**
Service	1	Sketchup Student License	Trimble Inc.		55,00 €	**55,00 €**
Total						**15.234,08 €**

Considering that the peak production of the 48 solar modules is 21,6 kWp, it can be calculated an estimated cost equal to 0,71 € / Wp.

3.10.2 Amortisation

First of all, it is considered that the 100 % of the produced energy is consumed. There will not be any income by compensation, but all the energy produced will be considered as a saving.

To calculate the amortisation of the project, it is necessary to consider the price of the electricity that is paid. This value can be approximated to 0,14 € / kWh.

With the PVsyst software it was calculated a total year production equal to 32.828 kWh.

$$TotalYearProduction = 32.828kWh/year$$

$$TotalDailyProduction = \frac{32.828}{365} = 90kWh/day$$

This means an average daily production equal to 90kWh approximately. Considering the electricity price, every day the system produces the energy equivalent to 12,6 €.

$$DailySaving = 90kWh/day * 0,14EUR/kWh = 12,6EUR/day$$

With this average production, and considering the total budget is equal to 15.234,08 €, the repayment period of this PV system is 1210 days, i.e. 3 years, 3 months and 22 days.
It is appropriate to take into account the maintenance too. It has been predicted a yearly maintenance cost of 200 €. The time required to save this amount can be calculated and is equal to 16 days.

$$MaintenanceCost(EUR) = 200EUR/year$$

$$DaysOfProductionToCoverTheMaintenanceCost = 200/12,6 = 16days/year$$

This means that the realistic repayment period is 48 days longer, which means a period of 3 years, 5 months and 8 days.

On the other hand, PVsyst also provides an economic evaluation of the system. All the data of the calculated budget in the previous section has been inserted in to the PVsyst project. Both projects have been economically evaluated and here under it can be seen a resume of the obtained results.
As it is shown, the results obtained in PVsyst match perfectly with the calculations previously made.

The repayment period is 3 years and 4 months and the total cumulative profit after 20 years is 73.578 €, which is slightly more optimistic that the calculations, but is not a significant difference, therefore, it is considered that both economic evaluations are correctly calculated.

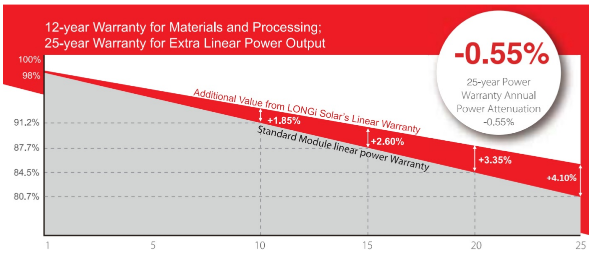
Furthermore, PVsyst provides extra economic data such as the percentage of amortisation. In this case it is approximately a + 586.3%.

3.10.3 Economical Efficiency

In order to calculate the economic efficiency, the yearly production data obtained with PVsyst will be used. It is considered that the average useful life span of a photovoltaic system like this is 20-25 years.

The most important devices in the system are the solar modules and the inverters, due to their high prices and their relevance in the system. The solar module's manufacturer, LONGi Solar, ensures a low loss of efficiency through the years and a 12 years warranty.

Figure 81: LONGi Solar Modules Warranty



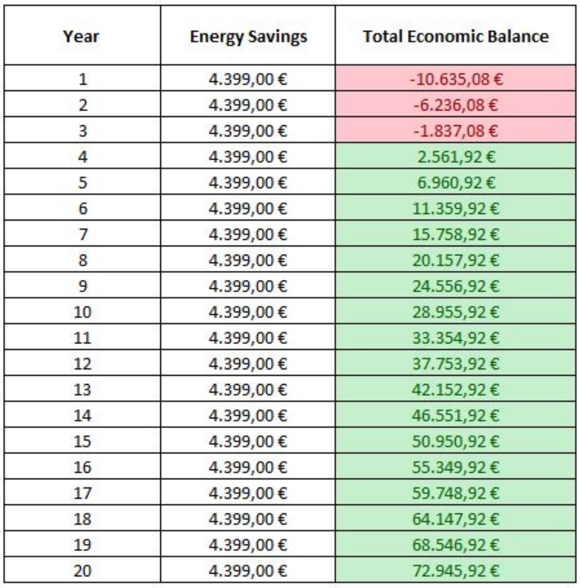
In the other hand, the standard SOFARSOLAR inverter's warranty is 5, 7, or 10 years, also ensuring low efficiency losses through the years.

The efficiency losses have been considered by PVsyst software to calculate the overall production.

Here under they energy savings are shown in a table. This savings have been calculated considering the standard electricity price, the initial investment, the yearly maintenance and the data obtained from the simulation.

$$EnergySavingsperYear = (12,6EUR/day * 365days) - 200EUR = 4399EUR/year$$

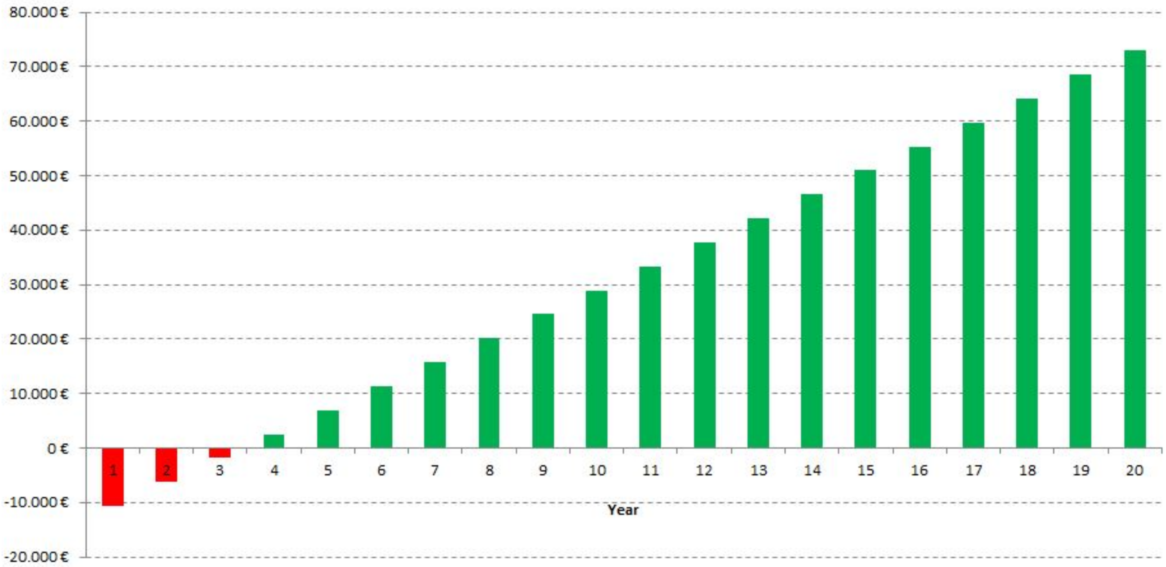
Figure 82: Economic Balance in the next 20 Years



Year	Energy Savings	Total Economic Balance
1	4.399,00 €	-10.635,08 €
2	4.399,00 €	-6.236,08 €
3	4.399,00 €	-1.837,08 €
4	4.399,00 €	2.561,92 €
5	4.399,00 €	6.960,92 €
6	4.399,00 €	11.359,92 €
7	4.399,00 €	15.758,92 €
8	4.399,00 €	20.157,92 €
9	4.399,00 €	24.556,92 €
10	4.399,00 €	28.955,92 €
11	4.399,00 €	33.354,92 €
12	4.399,00 €	37.753,92 €
13	4.399,00 €	42.152,92 €
14	4.399,00 €	46.551,92 €
15	4.399,00 €	50.950,92 €
16	4.399,00 €	55.349,92 €
17	4.399,00 €	59.748,92 €
18	4.399,00 €	64.147,92 €
19	4.399,00 €	68.546,92 €
20	4.399,00 €	72.945,92 €

The first year with real profit is the 4th year, with a positive balance of 2.561,92€. In 20 years, which is typically considered as the life span of an installation like this, the savings ascend to 72.945,92€.

Figure 83: Cumulative Profit in the next 20 Years



4 Conclusions

The fundamental conclusion obtained is that the designed system is a viable alternative, technologically and economically, particularly at present, given the continuous increase of the price of the electric energy and the continuous restrictions regarding the level of emissions.

This study also enhances the energetic transition that the UPC University is experiencing, since it has been achieved to design a feasible solution to produce energy for a facility of the UPC in a sustainable way.

The typology that has been chosen is the self-consumption with compensation. This typology has been selected due to its versatility and simplicity. It prevents the possible situation in which the consumption is lower than the production, and ensures that the surpluses are always leveraged.

One of the objectives of this study was to create a detailed model of the location and take in to account all the losing effects. The model has been successfully created and the losses have been considered. One of the main causes of these losses is the shading effect, which has been accurately considered.

The sizing of the installation has been adjusted to the available space of the building's roof, which has been an important constraint regarding the design. Nevertheless, the size of the system has been designed to exploit all the available space, avoiding the most critical areas where the production would not be cost-efficient due to the shading effects. This way, the costs are optimized and the production maximized.

The economic viability is achieved due to the relatively low initial costs and fast amortization. In fact, this design implies an initial investment of 15.234€ and ensures a repayment period of 3 years and 5 months. Moreover, it predicts a total saving of almost 73.000€ in 20 years.

With regard to a possible future project or a widening of this study, there are many possibilities and ideas that could be implemented. For instance, this study can be defined as a project and executed and implemented following all the required steps, i.e. plan a timeline, acquire the UPC permissions and budgets, acquire the legal allowances, purchase all the components, hire the required services, materialize the installation and test and track the photovoltaic installation.

Other studies can also be done, e.g. an study of the viability of the same system with a different configurations, different tracking system, such as a Solar Tracking system, and different typology, such as a Self-consumption with Batteries system.

Furthermore, the same kind of study could be done but using a different simulation software, such as Homero Pro, pvPlanner or Solar Pro.

Another possibility would be to do a similar study but for the contiguous building, the UPC Library of the Campus Terrassa. For this, it would be required to do another model, analyse other consumption data and adapt the design to other conditions.

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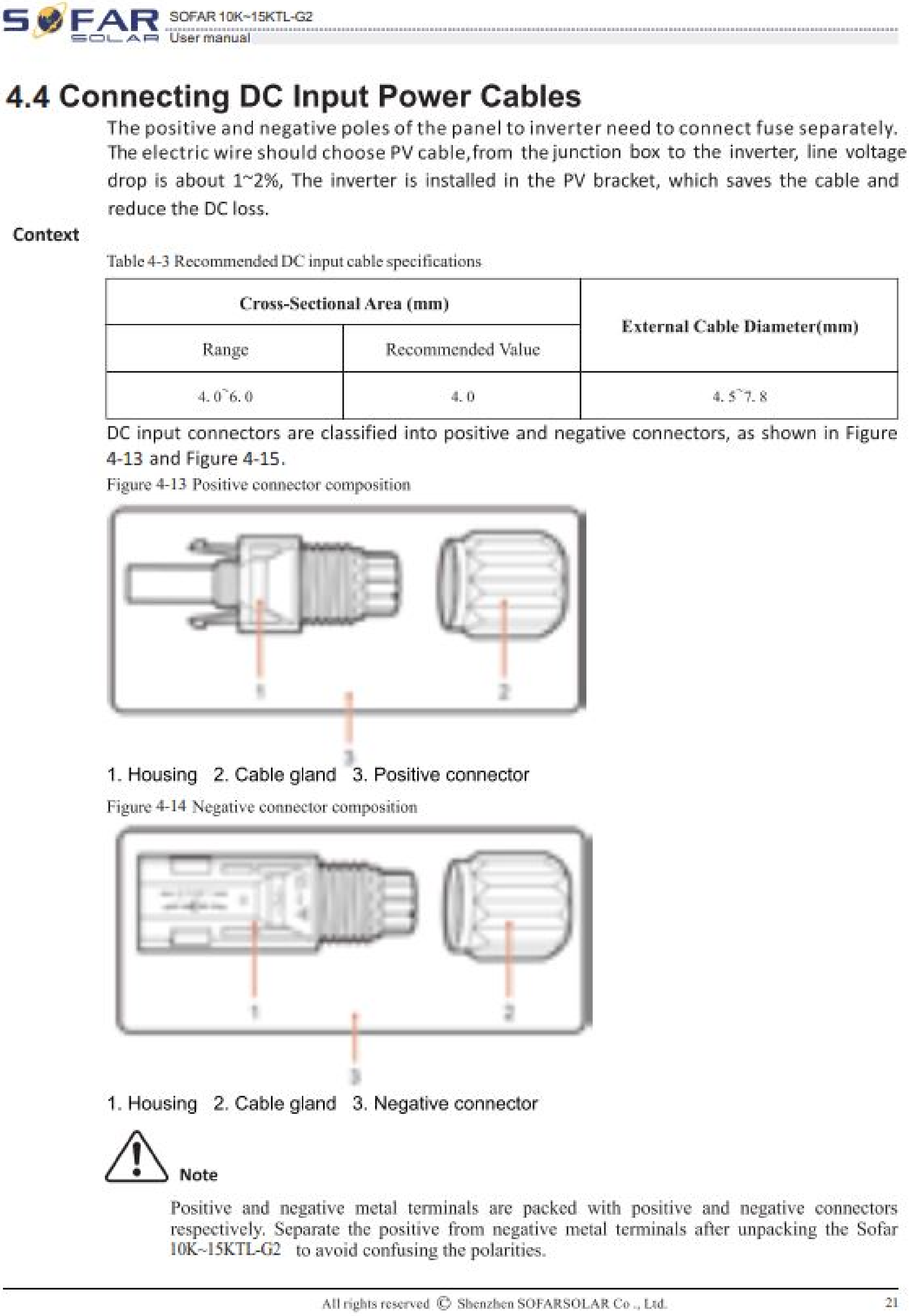
Appendices

A SOFAR 10K-G2 Inverter Installation Manual

Figure 84: SOFAR 10K-G2 Inverter Installation Manual DC Cable Specifications p.1



4.4 Connecting DC Input Power Cables

The positive and negative poles of the panel to inverter need to connect fuse separately. The electric wire should choose PV cable,from the junction box to the inverter, line voltage drop is about 1~2%, The inverter is installed in the PV bracket, which saves the cable and reduce the DC loss.

Context

Table 4-3 Recommended DC input cable specifications

Cross-Sectional Area (mm)		External Cable Diameter(mm)
Range	Recommended Value	
4.0~6.0	4.0	4.5~7.8

DC input connectors are classified into positive and negative connectors, as shown in Figure 4-13 and Figure 4-15.

Figure 4-13 Positive connector composition

1. Housing 2. Cable gland 3. Positive connector

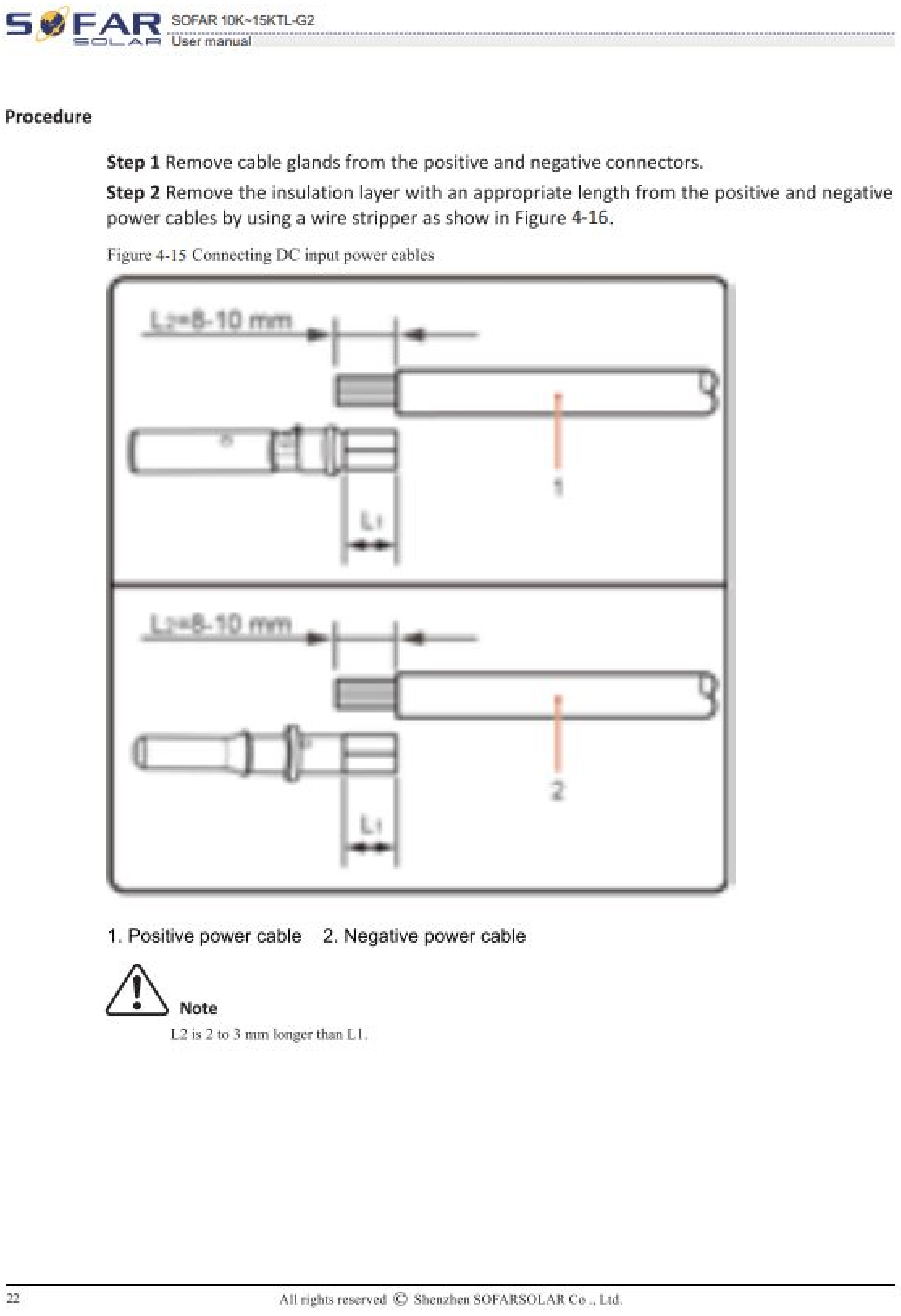
Figure 4-14 Negative connector composition

1. Housing 2. Cable gland 3. Negative connector

Note

Positive and negative metal terminals are packed with positive and negative connectors respectively. Separate the positive from negative metal terminals after unpacking the Sofar 10K~15KTL-G2 to avoid confusing the polarities.

Figure 85: SOFAR 10K-G2 Inverter Installation Manual DC Cable Specifications p.2



Procedure

Step 1 Remove cable glands from the positive and negative connectors.

Step 2 Remove the insulation layer with an appropriate length from the positive and negative power cables by using a wire stripper as show in Figure 4-16.

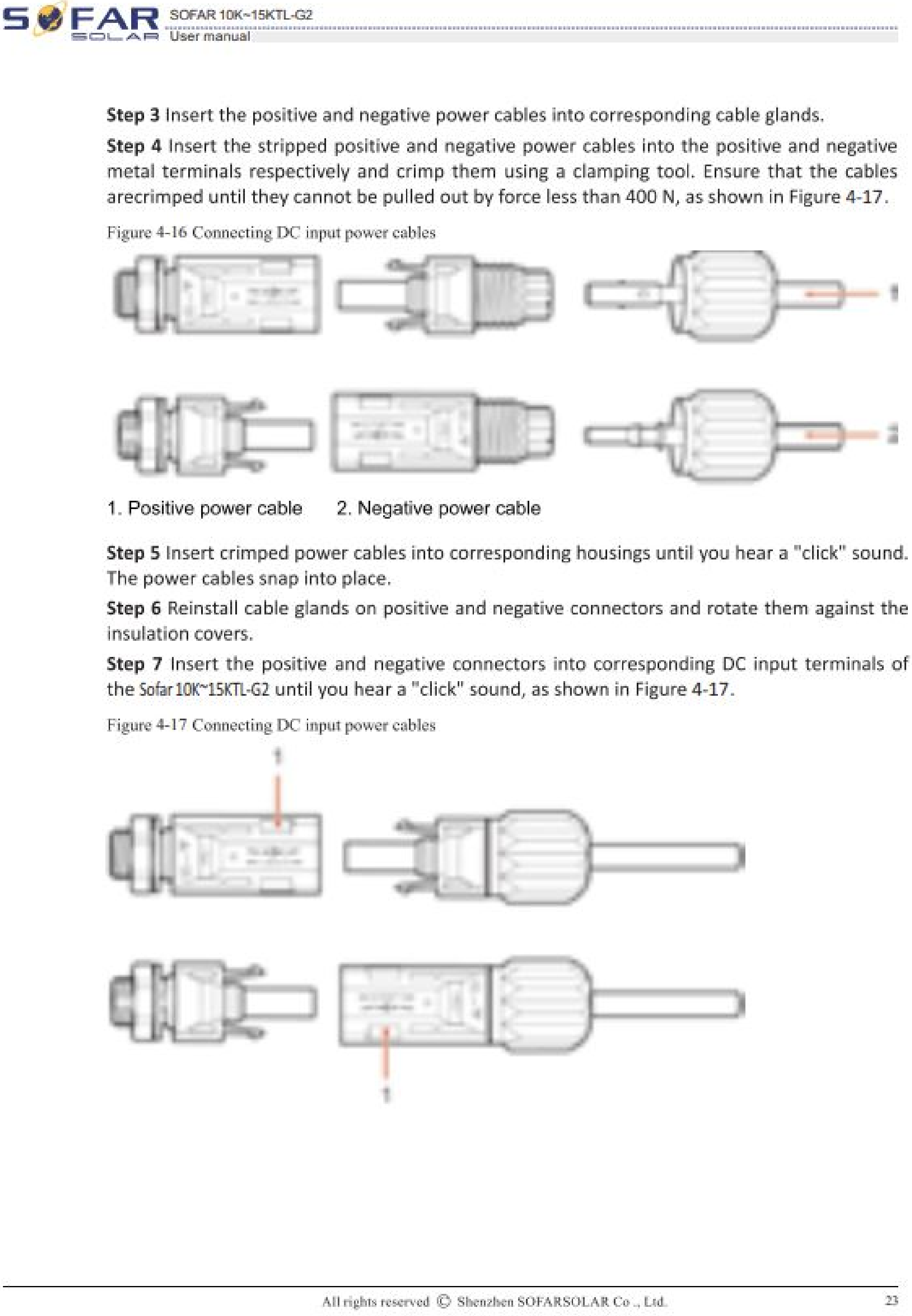
Figure 4-15 Connecting DC input power cables

1. Positive power cable 2. Negative power cable

Note

L2 is 2 to 3 mm longer than L1.

Figure 86: SOFAR 10K-G2 Inverter Installation Manual DC Cable Specifications p.3



Step 3 Insert the positive and negative power cables into corresponding cable glands.

Step 4 Insert the stripped positive and negative power cables into the positive and negative metal terminals respectively and crimp them using a clamping tool. Ensure that the cables arecrimped until they cannot be pulled out by force less than 400 N, as shown in Figure 4-17.

Figure 4-16 Connecting DC input power cables

1. Positive power cable 2. Negative power cable

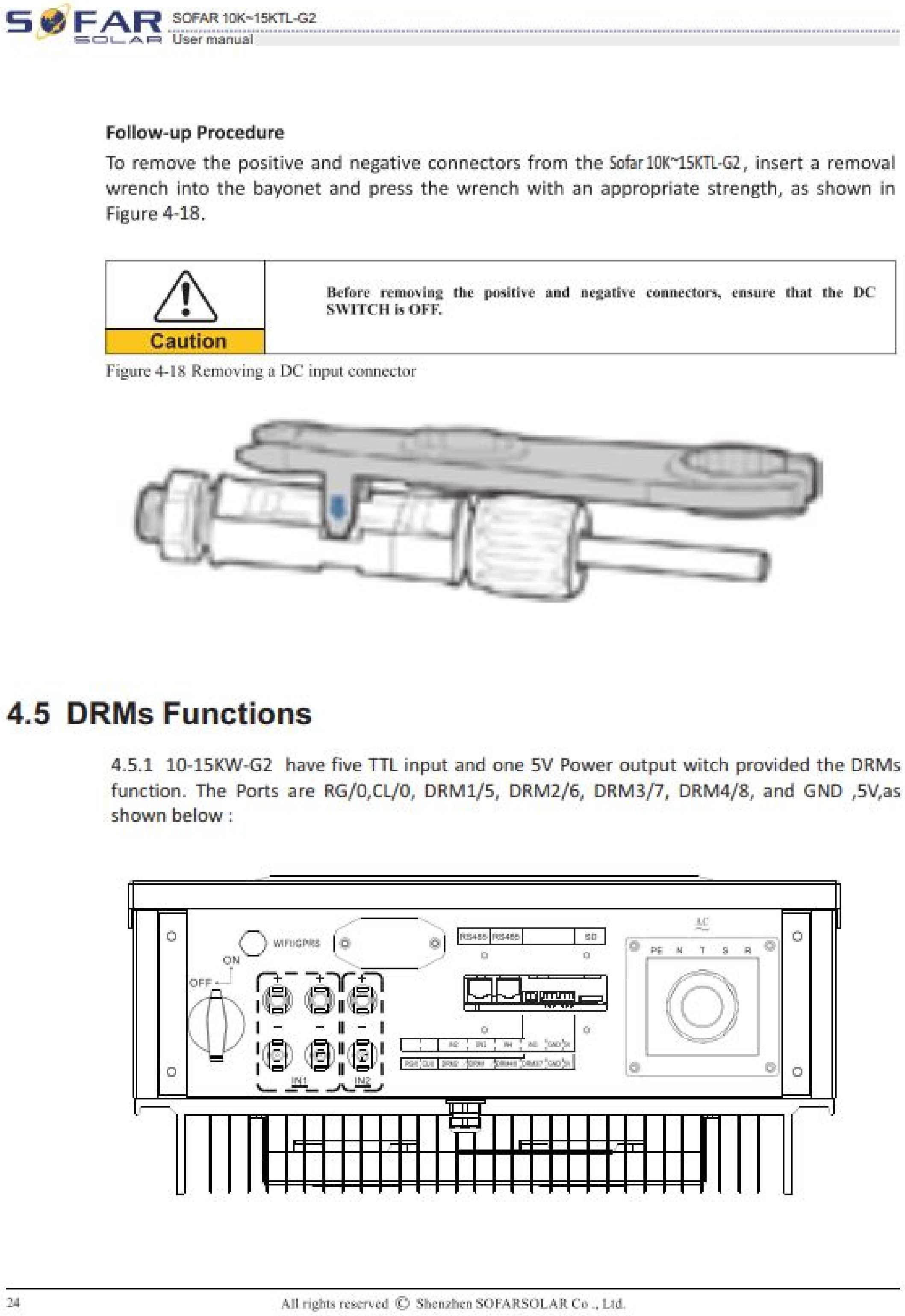
Step 5 Insert crimped power cables into corresponding housings until you hear a "click" sound. The power cables snap into place.

Step 6 Reinstall cable glands on positive and negative connectors and rotate them against the insulation covers.

Step 7 Insert the positive and negative connectors into corresponding DC input terminals of the Sofar 10K~15KTL-G2 until you hear a "click" sound, as shown in Figure 4-17.

Figure 4-17 Connecting DC input power cables

Figure 87: SOFAR 10K-G2 Inverter Installation Manual DC Cable Specifications p.4



Follow-up Procedure

To remove the positive and negative connectors from the Sofar 10K~15KTL-G2, insert a removal wrench into the bayonet and press the wrench with an appropriate strength, as shown in Figure 4-18.

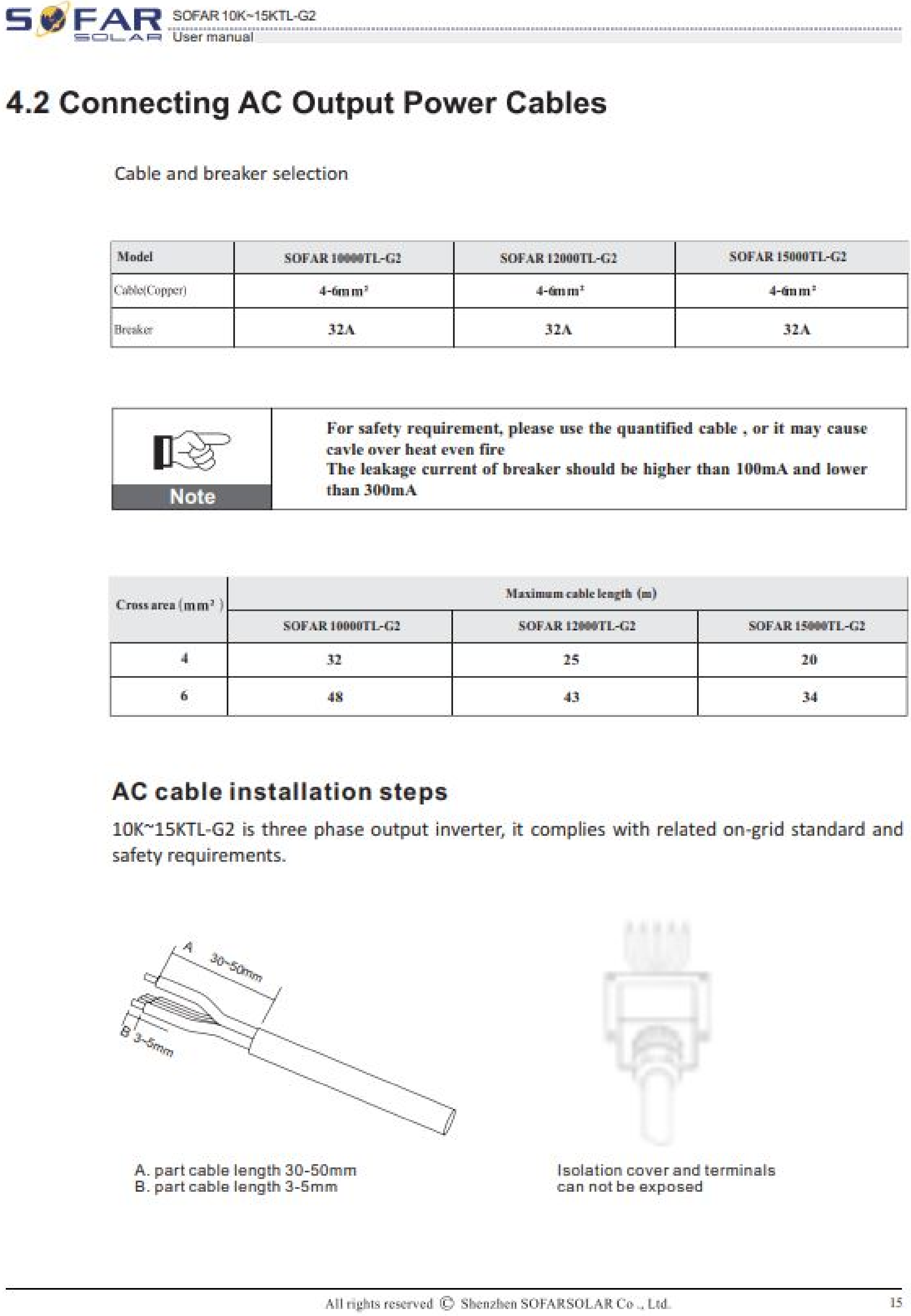
Caution	Before removing the positive and negative connectors, ensure that the DC SWITCH is OFF.

Figure 4-18 Removing a DC input connector

4.5 DRMs Functions

4.5.1 10-15KW-G2 have five TTL input and one 5V Power output witch provided the DRMs function. The Ports are RG/0,CL/0, DRM1/5, DRM2/6, DRM3/7, DRM4/8, and GND ,5V,as shown below :

Figure 88: SOFAR 10K-G2 Inverter Installation Manual AC Cable Specifications p.1



SOFAR 10K~15KTL-G2
User manual

4.2 Connecting AC Output Power Cables

Cable and breaker selection

Model	SOFAR 10000TL-G2	SOFAR 12000TL-G2	SOFAR 15000TL-G2
Cable(Copper)	4-6mm²	4-6mm²	4-6mm²
Breaker	32A	32A	32A

Note

For safety requirement, please use the quantified cable , or it may cause cavle over heat even fire
The leakage current of breaker should be higher than 100mA and lower than 300mA

Cross area (mm²)	Maximum cable length (m)		
	SOFAR 10000TL-G2	SOFAR 12000TL-G2	SOFAR 15000TL-G2
4	32	25	20
6	48	43	34

AC cable installation steps

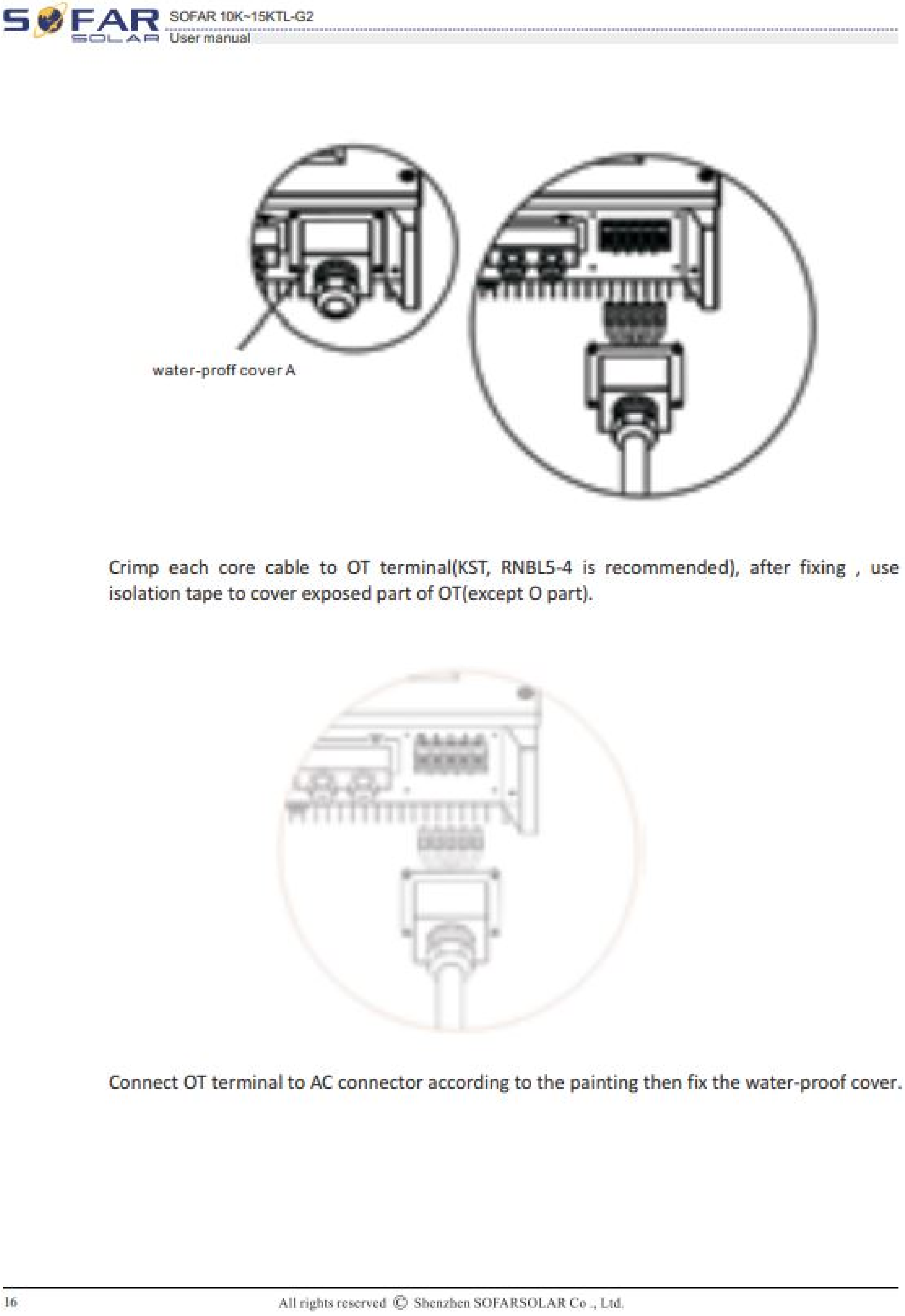
10K~15KTL-G2 is three phase output inverter, it complies with related on-grid standard and safety requirements.

A. part cable length 30-50mm
B. part cable length 3-5mm

Isolation cover and terminals
can not be exposed

15

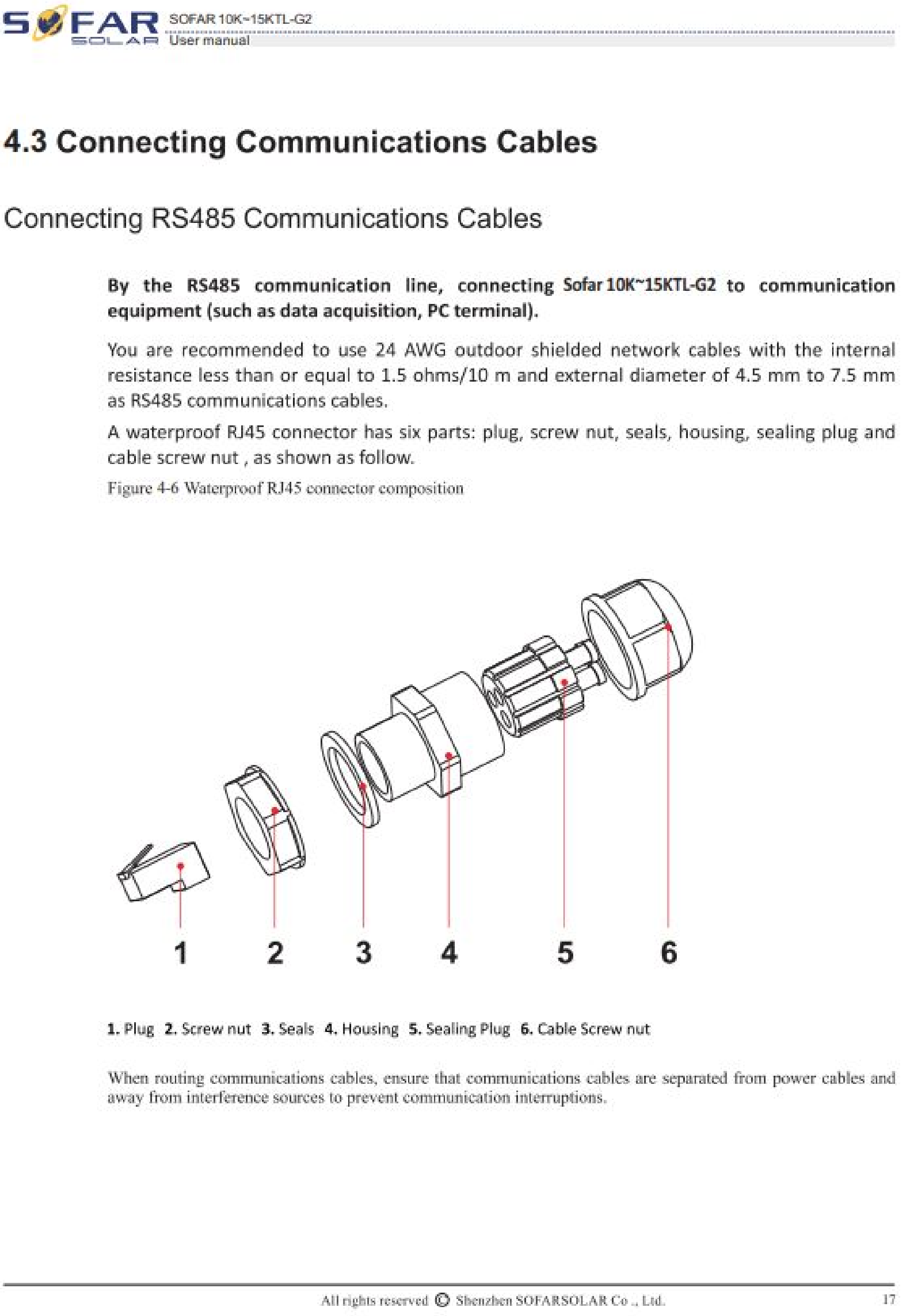
Figure 89: SOFAR 10K-G2 Inverter Installation Manual AC Cable Specifications p.2



Crimp each core cable to OT terminal(KST, RNBL5-4 is recommended), after fixing , use isolation tape to cover exposed part of OT(except O part).

Connect OT terminal to AC connector according to the painting then fix the water-proof cover.

Figure 90: SOFAR 10K-G2 Inverter Installation Manual Monitoring System p.1



SOFAR 10K~15KTL-G2
User manual

4.3 Connecting Communications Cables

Connecting RS485 Communications Cables

By the RS485 communication line, connecting Sofar 10K~15KTL-G2 to communication equipment (such as data acquisition, PC terminal).

You are recommended to use 24 AWG outdoor shielded network cables with the internal resistance less than or equal to 1.5 ohms/10 m and external diameter of 4.5 mm to 7.5 mm as RS485 communications cables.

A waterproof RJ45 connector has six parts: plug, screw nut, seals, housing, sealing plug and cable screw nut , as shown as follow.

Figure 4-6 Waterproof RJ45 connector composition

1. Plug **2.** Screw nut **3.** Seals **4.** Housing **5.** Sealing Plug **6.** Cable Screw nut

When routing communications cables, ensure that communications cables are separated from power cables and away from interference sources to prevent communication interruptions.

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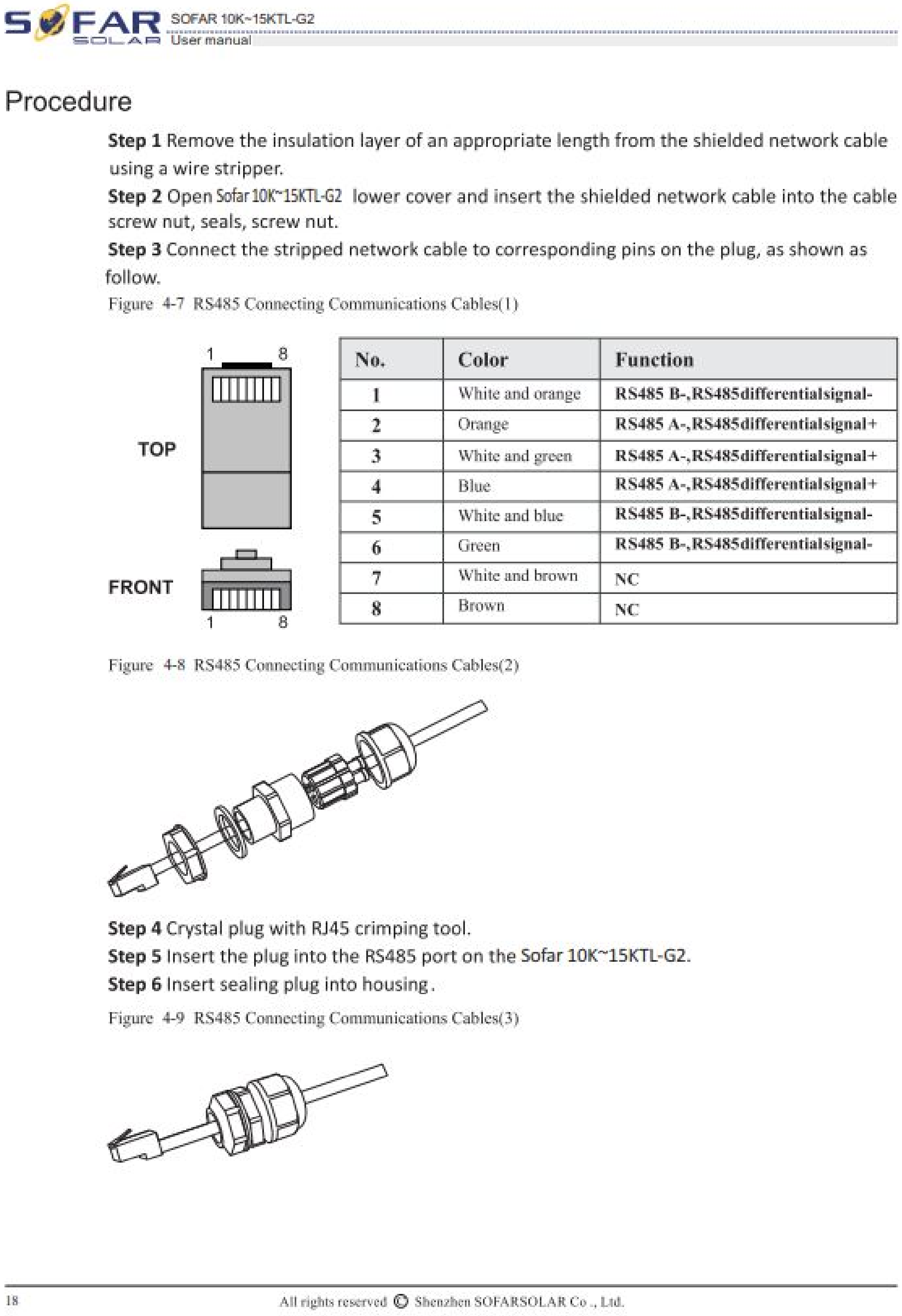
Figure 91: SOFAR 10K-G2 Inverter Installation Manual Monitoring System p.2



SOFAR 10K~15KTL-G2
User manual

Procedure

Step 1 Remove the insulation layer of an appropriate length from the shielded network cable using a wire stripper.

Step 2 Open Sofar 10K~15KTL-G2 lower cover and insert the shielded network cable into the cable screw nut, seals, screw nut.

Step 3 Connect the stripped network cable to corresponding pins on the plug, as shown as follow.

Figure 4-7 RS485 Connecting Communications Cables(1)

No.	Color	Function
1	White and orange	RS485 B-,RS485differentialsignal-
2	Orange	RS485 A-,RS485differentialsignal+
3	White and green	RS485 A-,RS485differentialsignal+
4	Blue	RS485 A-,RS485differentialsignal+
5	White and blue	RS485 B-,RS485differentialsignal-
6	Green	RS485 B-,RS485differentialsignal-
7	White and brown	NC
8	Brown	NC

Figure 4-8 RS485 Connecting Communications Cables(2)

Step 4 Crystal plug with RJ45 crimping tool.

Step 5 Insert the plug into the RS485 port on the Sofar 10K~15KTL-G2.

Step 6 Insert sealing plug into housing.

Figure 4-9 RS485 Connecting Communications Cables(3)

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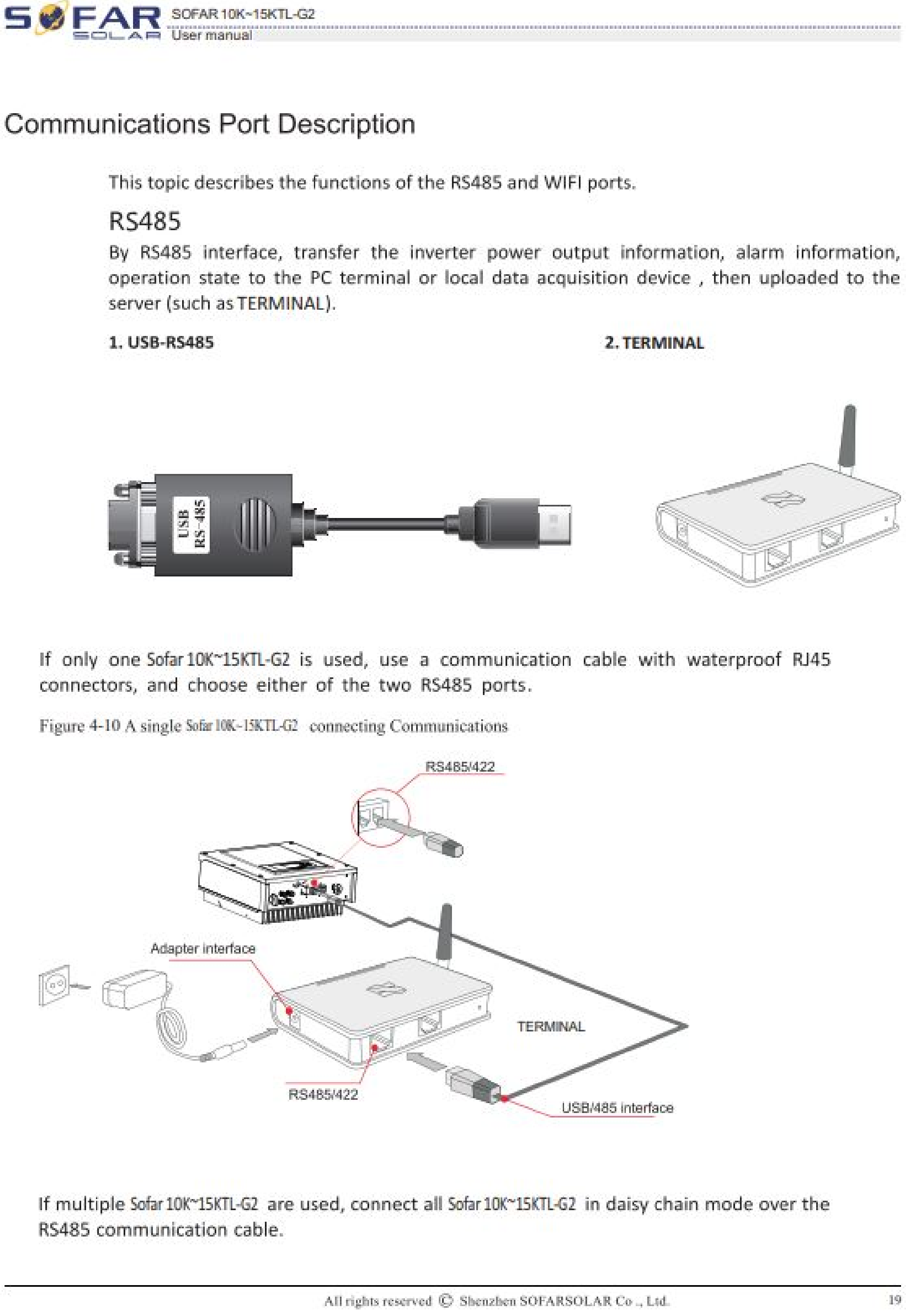
Figure 92: SOFAR 10K-G2 Inverter Installation Manual Monitoring System p.3



SOFAR 10K~15KTL-G2
User manual

Communications Port Description

This topic describes the functions of the RS485 and WIFI ports.

RS485

By RS485 interface, transfer the inverter power output information, alarm information, operation state to the PC terminal or local data acquisition device , then uploaded to the server (such as TERMINAL).

1. USB-RS485 **2. TERMINAL**

If only one Sofar 10K~15KTL-G2 is used, use a communication cable with waterproof RJ45 connectors, and choose either of the two RS485 ports.

Figure 4-10 A single Sofar 10K~15KTL-G2 connecting Communications

If multiple Sofar 10K~15KTL-G2 are used, connect all Sofar 10K~15KTL-G2 in daisy chain mode over the RS485 communication cable.

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Figure 93: SOFAR 10K-G2 Inverter Installation Manual Monitoring System p.4

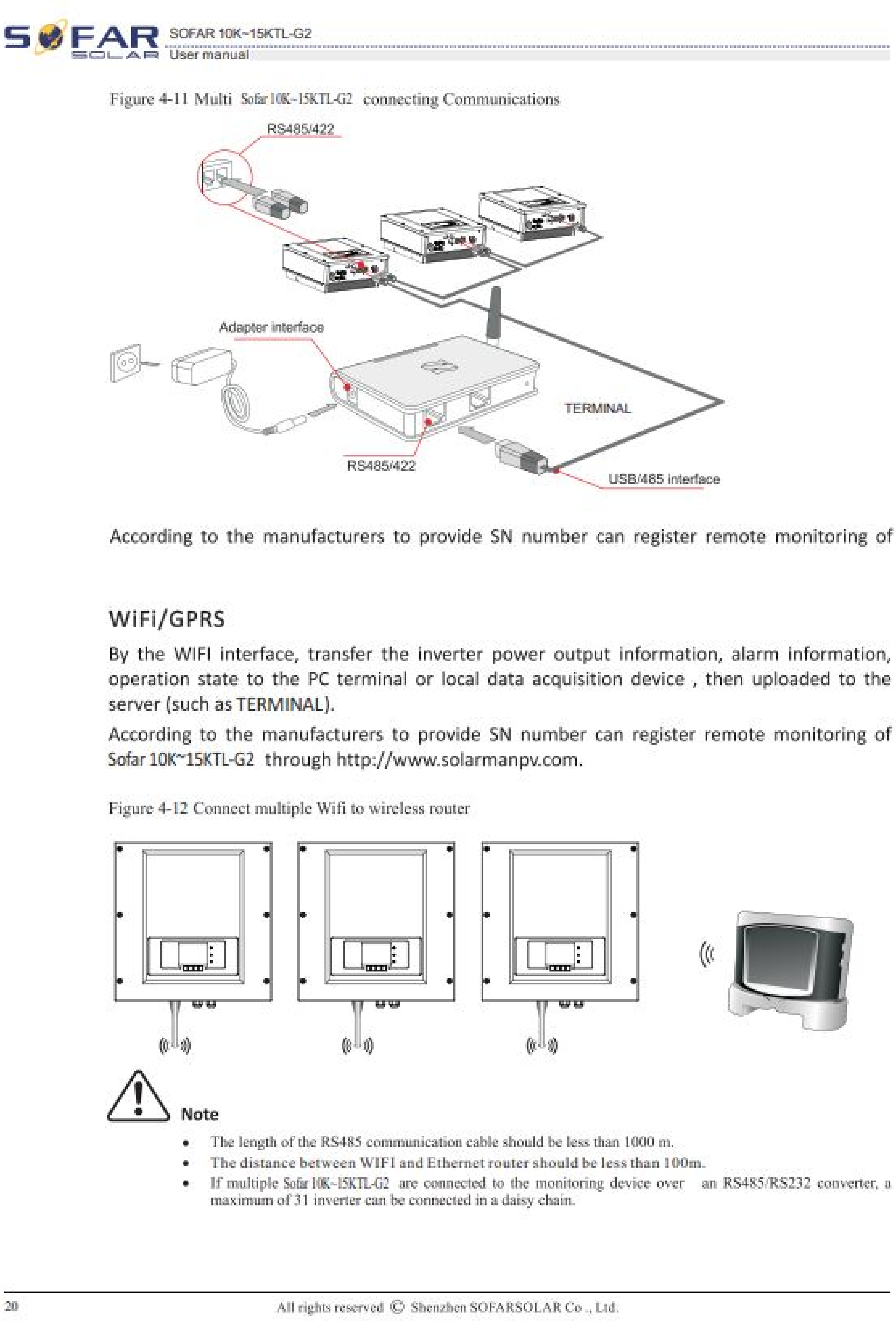


Figure 4-11 Multi Sofar 10K~15KTL-G2 connecting Communications

According to the manufacturers to provide SN number can register remote monitoring of

WiFi/GPRS

By the WIFI interface, transfer the inverter power output information, alarm information, operation state to the PC terminal or local data acquisition device , then uploaded to the server (such as TERMINAL).

According to the manufacturers to provide SN number can register remote monitoring of Sofar 10K~15KTL-G2 through http://www.solarmanpv.com.

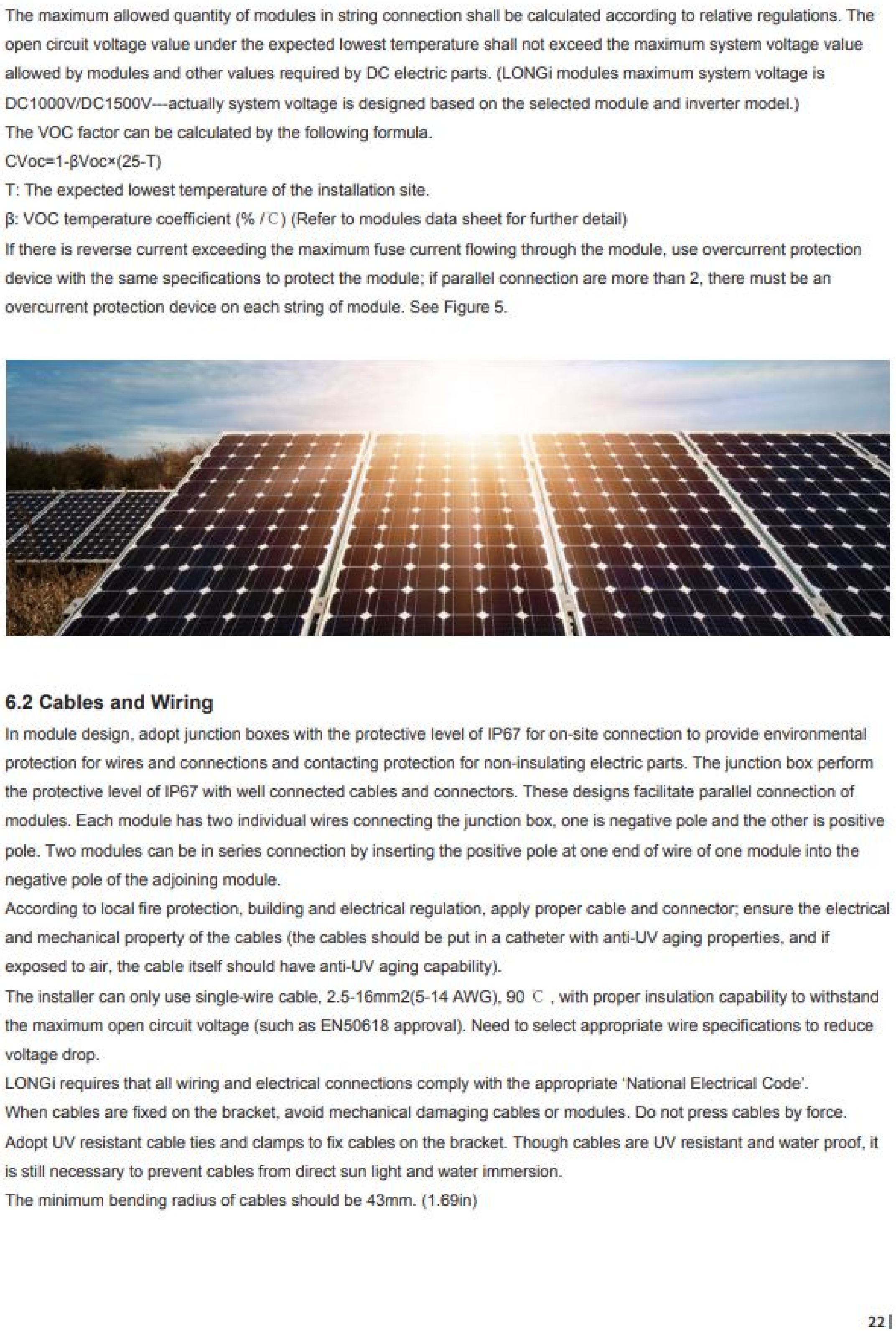
Figure 4-12 Connect multiple Wifi to wireless router

Note

- The length of the RS485 communication cable should be less than 1000 m.
- The distance between WIFI and Ethernet router should be less than 100m.
- If multiple Sofar 10K~15KTL-G2 are connected to the monitoring device over an RS485/RS232 converter, a maximum of 31 inverter can be connected in a daisy chain.

B LR4-72HPH-450M Solar Panel Installation Manual

Figure 94: LR4-72HPH-450M Solar Panel Installation Manual DC Cable Specifications



The maximum allowed quantity of modules in string connection shall be calculated according to relative regulations. The open circuit voltage value under the expected lowest temperature shall not exceed the maximum system voltage value allowed by modules and other values required by DC electric parts. (LONGi modules maximum system voltage is DC1000V/DC1500V---actually system voltage is designed based on the selected module and inverter model.)

The VOC factor can be calculated by the following formula.

CVoc=1-βVoc×(25-T)

T: The expected lowest temperature of the installation site.

β: VOC temperature coefficient (% /℃) (Refer to modules data sheet for further detail)

If there is reverse current exceeding the maximum fuse current flowing through the module, use overcurrent protection device with the same specifications to protect the module; if parallel connection are more than 2, there must be an overcurrent protection device on each string of module. See Figure 5.

6.2 Cables and Wiring

In module design, adopt junction boxes with the protective level of IP67 for on-site connection to provide environmental protection for wires and connections and contacting protection for non-insulating electric parts. The junction box perform the protective level of IP67 with well connected cables and connectors. These designs facilitate parallel connection of modules. Each module has two individual wires connecting the junction box, one is negative pole and the other is positive pole. Two modules can be in series connection by inserting the positive pole at one end of wire of one module into the negative pole of the adjoining module.

According to local fire protection, building and electrical regulation, apply proper cable and connector; ensure the electrical and mechanical property of the cables (the cables should be put in a catheter with anti-UV aging properties, and if exposed to air, the cable itself should have anti-UV aging capability).

The installer can only use single-wire cable, 2.5-16mm2(5-14 AWG), 90 ℃ , with proper insulation capability to withstand the maximum open circuit voltage (such as EN50618 approval). Need to select appropriate wire specifications to reduce voltage drop.

LONGi requires that all wiring and electrical connections comply with the appropriate 'National Electrical Code'.

When cables are fixed on the bracket, avoid mechanical damaging cables or modules. Do not press cables by force.

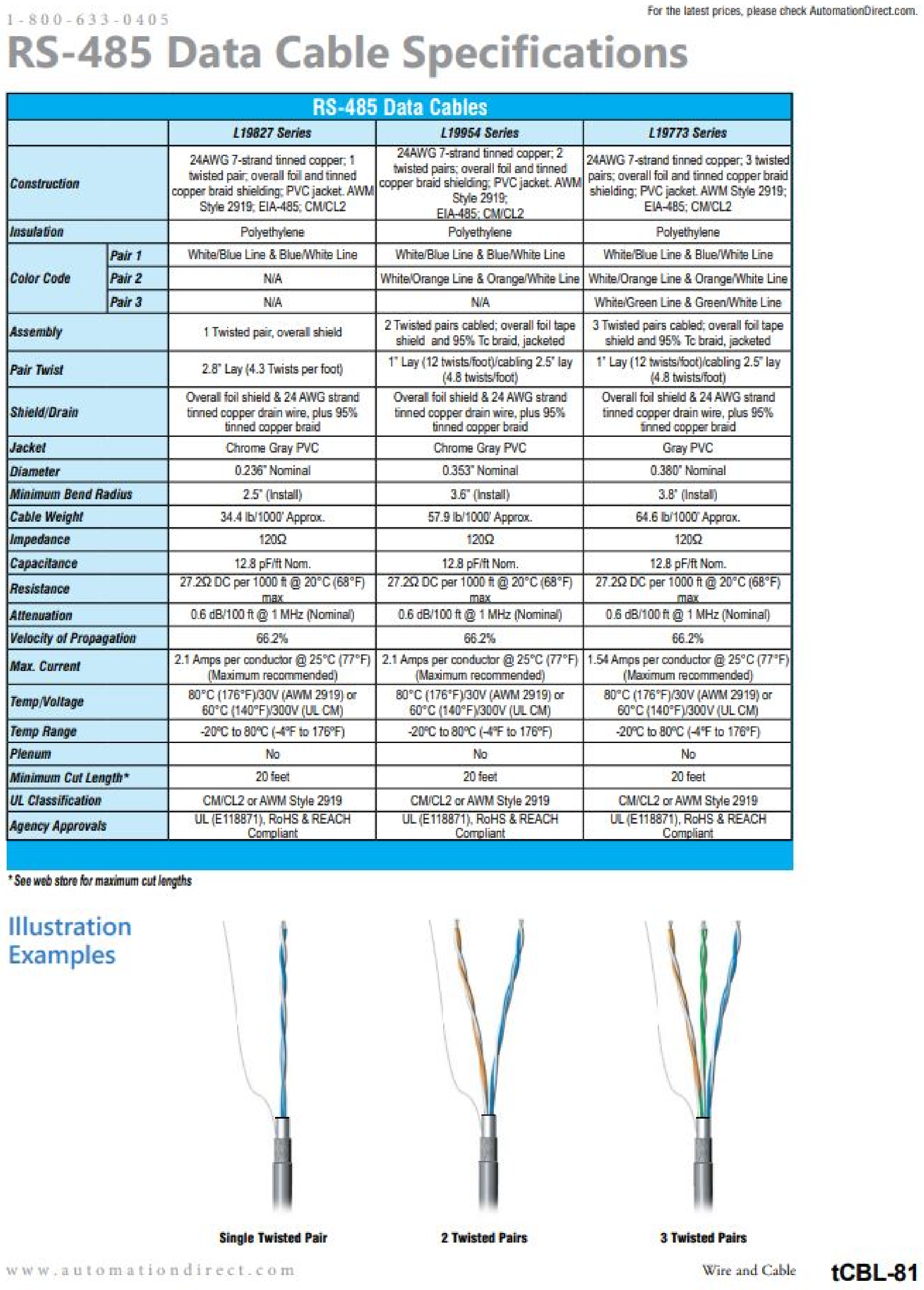
Adopt UV resistant cable ties and clamps to fix cables on the bracket. Though cables are UV resistant and water proof, it is still necessary to prevent cables from direct sun light and water immersion.

The minimum bending radius of cables should be 43mm. (1.69in)

22 |

C RS485 Datasheet

Figure 95: RS485 Datasheet



1-800-633-0405

For the latest prices, please check AutomationDirect.com.

RS-485 Data Cable Specifications

RS-485 Data Cables

		L19827 Series	L19954 Series	L19773 Series
Construction		24AWG 7-strand tinned copper; 1 twisted pair; overall foil and tinned copper braid shielding; PVC jacket. AWM Style 2919; EIA-485; CM/CL2	24AWG 7-strand tinned copper; 2 twisted pairs; overall foil and tinned copper braid shielding; PVC jacket. AWM Style 2919; EIA-485; CM/CL2	24AWG 7-strand tinned copper; 3 twisted pairs; overall foil and tinned copper braid shielding; PVC jacket. AWM Style 2919; EIA-485; CM/CL2
Insulation		Polyethylene	Polyethylene	Polyethylene
Color Code	Pair 1	White/Blue Line & Blue/White Line	White/Blue Line & Blue/White Line	White/Blue Line & Blue/White Line
	Pair 2	N/A	White/Orange Line & Orange/White Line	White/Orange Line & Orange/White Line
	Pair 3	N/A	N/A	White/Green Line & Green/White Line
Assembly		1 Twisted pair, overall shield	2 Twisted pairs cabled; overall foil tape shield and 95% Tc braid, jacketed	3 Twisted pairs cabled; overall foil tape shield and 95% Tc braid, jacketed
Pair Twist		2.8" Lay (4.3 Twists per foot)	1" Lay (12 twists/foot)/cabling 2.5" lay (4.8 twists/foot)	1" Lay (12 twists/foot)/cabling 2.5" lay (4.8 twists/foot)
Shield/Drain		Overall foil shield & 24 AWG strand tinned copper drain wire, plus 95% tinned copper braid	Overall foil shield & 24 AWG strand tinned copper drain wire, plus 95% tinned copper braid	Overall foil shield & 24 AWG strand tinned copper drain wire, plus 95% tinned copper braid
Jacket		Chrome Gray PVC	Chrome Gray PVC	Gray PVC
Diameter		0.236" Nominal	0.353" Nominal	0.380" Nominal
Minimum Bend Radius		2.5" (Install)	3.6" (Install)	3.8" (Install)
Cable Weight		34.4 lb/1000' Approx.	57.9 lb/1000' Approx.	64.6 lb/1000' Approx.
Impedance		120Ω	120Ω	120Ω
Capacitance		12.8 pF/ft Nom.	12.8 pF/ft Nom.	12.8 pF/ft Nom.
Resistance		27.2Ω DC per 1000 ft @ 20°C (68°F) max	27.2Ω DC per 1000 ft @ 20°C (68°F) max	27.2Ω DC per 1000 ft @ 20°C (68°F) max
Attenuation		0.6 dB/100 ft @ 1 MHz (Nominal)	0.6 dB/100 ft @ 1 MHz (Nominal)	0.6 dB/100 ft @ 1 MHz (Nominal)
Velocity of Propagation		66.2%	66.2%	66.2%
Max. Current		2.1 Amps per conductor @ 25°C (77°F) (Maximum recommended)	2.1 Amps per conductor @ 25°C (77°F) (Maximum recommended)	1.54 Amps per conductor @ 25°C (77°F) (Maximum recommended)
Temp/Voltage		80°C (176°F)/30V (AWM 2919) or 60°C (140°F)/300V (UL CM)	80°C (176°F)/30V (AWM 2919) or 60°C (140°F)/300V (UL CM)	80°C (176°F)/30V (AWM 2919) or 60°C (140°F)/300V (UL CM)
Temp Range		-20°C to 80°C (-4°F to 176°F)	-20°C to 80°C (-4°F to 176°F)	-20°C to 80°C (-4°F to 176°F)
Plenum		No	No	No
Minimum Cut Length*		20 feet	20 feet	20 feet
UL Classification		CM/CL2 or AWM Style 2919	CM/CL2 or AWM Style 2919	CM/CL2 or AWM Style 2919
Agency Approvals		UL (E118871), RoHS & REACH Compliant	UL (E118871), RoHS & REACH Compliant	UL (E118871), RoHS & REACH Compliant

* See web store for maximum cut lengths

Illustration Examples

Single Twisted Pair

2 Twisted Pairs

3 Twisted Pairs

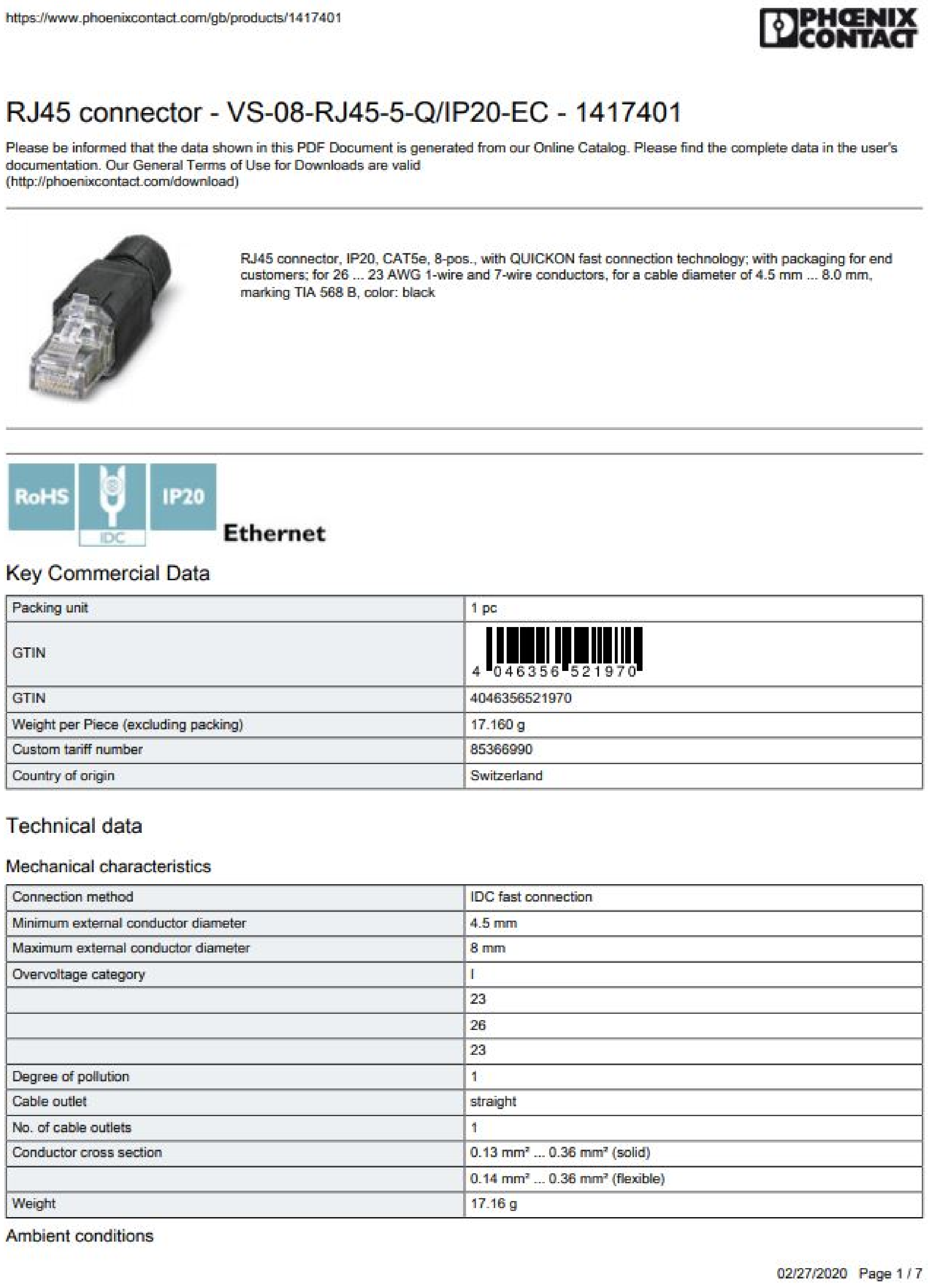
www.automationdirect.com

Wire and Cable

tCBL-81

D RJ45 Datasheet

Figure 96: RJ45 Datasheet



https://www.phoenixcontact.com/gb/products/1417401

RJ45 connector - VS-08-RJ45-5-Q/IP20-EC - 1417401

Please be informed that the data shown in this PDF Document is generated from our Online Catalog. Please find the complete data in the user's documentation. Our General Terms of Use for Downloads are valid (http://phoenixcontact.com/download)

RJ45 connector, IP20, CAT5e, 8-pos., with QUICKON fast connection technology; with packaging for end customers; for 26 ... 23 AWG 1-wire and 7-wire conductors, for a cable diameter of 4.5 mm ... 8.0 mm, marking TIA 568 B, color: black

RoHS IDC IP20 Ethernet

Key Commercial Data

Packing unit	1 pc
GTIN	4 046356 521970
GTIN	4046356521970
Weight per Piece (excluding packing)	17.160 g
Custom tariff number	85366990
Country of origin	Switzerland

Technical data

Mechanical characteristics

Connection method	IDC fast connection
Minimum external conductor diameter	4.5 mm
Maximum external conductor diameter	8 mm
Overvoltage category	I
	23
	26
	23
Degree of pollution	1
Cable outlet	straight
No. of cable outlets	1
Conductor cross section	0.13 mm² ... 0.36 mm² (solid)
	0.14 mm² ... 0.36 mm² (flexible)
Weight	17.16 g

Ambient conditions

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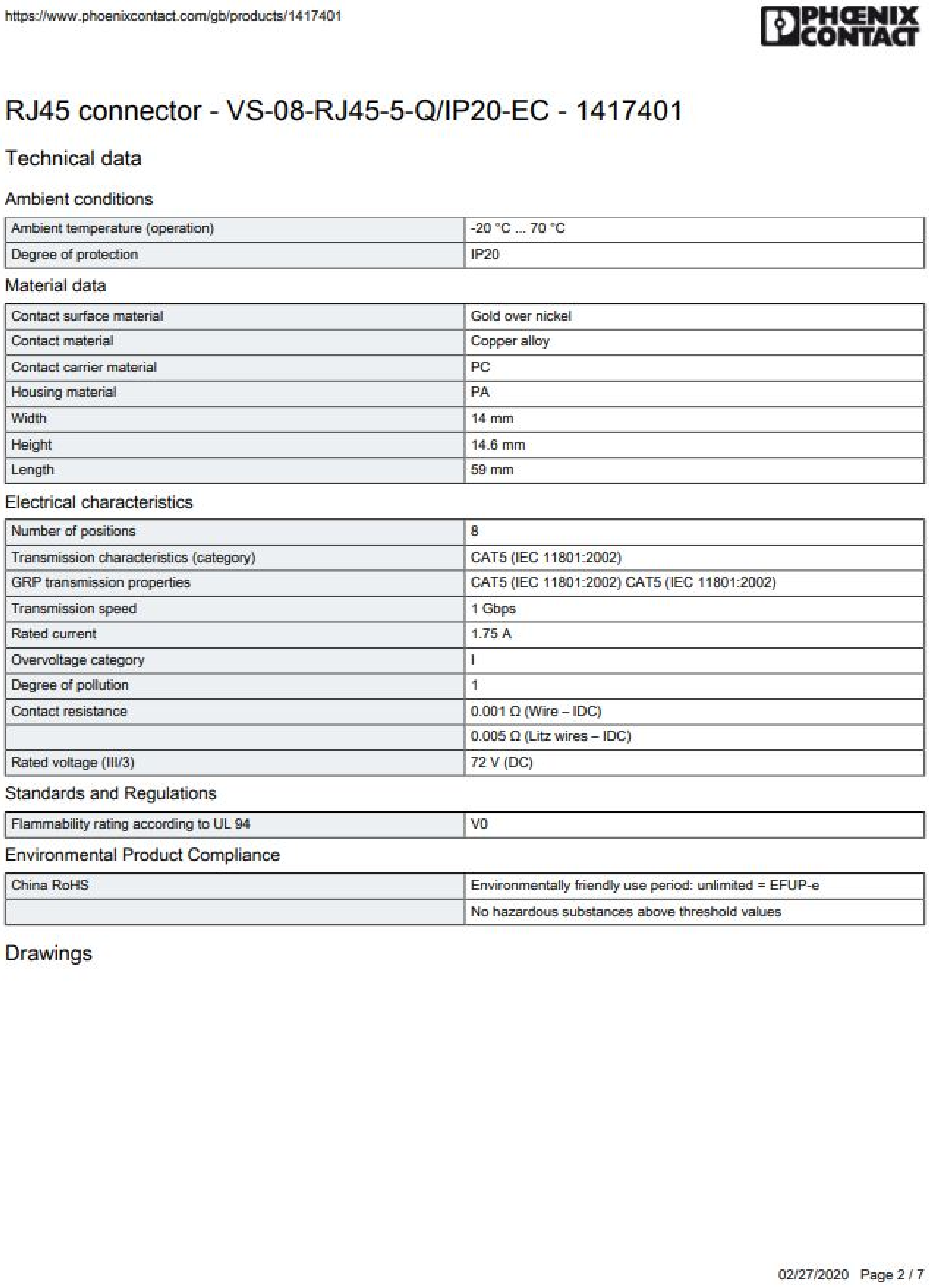
Figure 97: RJ45 Datasheet p.2



https://www.phoenixcontact.com/gb/products/1417401

RJ45 connector - VS-08-RJ45-5-Q/IP20-EC - 1417401

Technical data

Ambient conditions

Ambient temperature (operation)	-20 °C ... 70 °C
Degree of protection	IP20

Material data

Contact surface material	Gold over nickel
Contact material	Copper alloy
Contact carrier material	PC
Housing material	PA
Width	14 mm
Height	14.6 mm
Length	59 mm

Electrical characteristics

Number of positions	8
Transmission characteristics (category)	CAT5 (IEC 11801:2002)
GRP transmission properties	CAT5 (IEC 11801:2002) CAT5 (IEC 11801:2002)
Transmission speed	1 Gbps
Rated current	1.75 A
Overvoltage category	I
Degree of pollution	1
Contact resistance	0.001 Ω (Wire – IDC)
	0.005 Ω (Litz wires – IDC)
Rated voltage (III/3)	72 V (DC)

Standards and Regulations

Flammability rating according to UL 94	V0

Environmental Product Compliance

China RoHS	Environmentally friendly use period: unlimited = EFUP-e
	No hazardous substances above threshold values

Drawings

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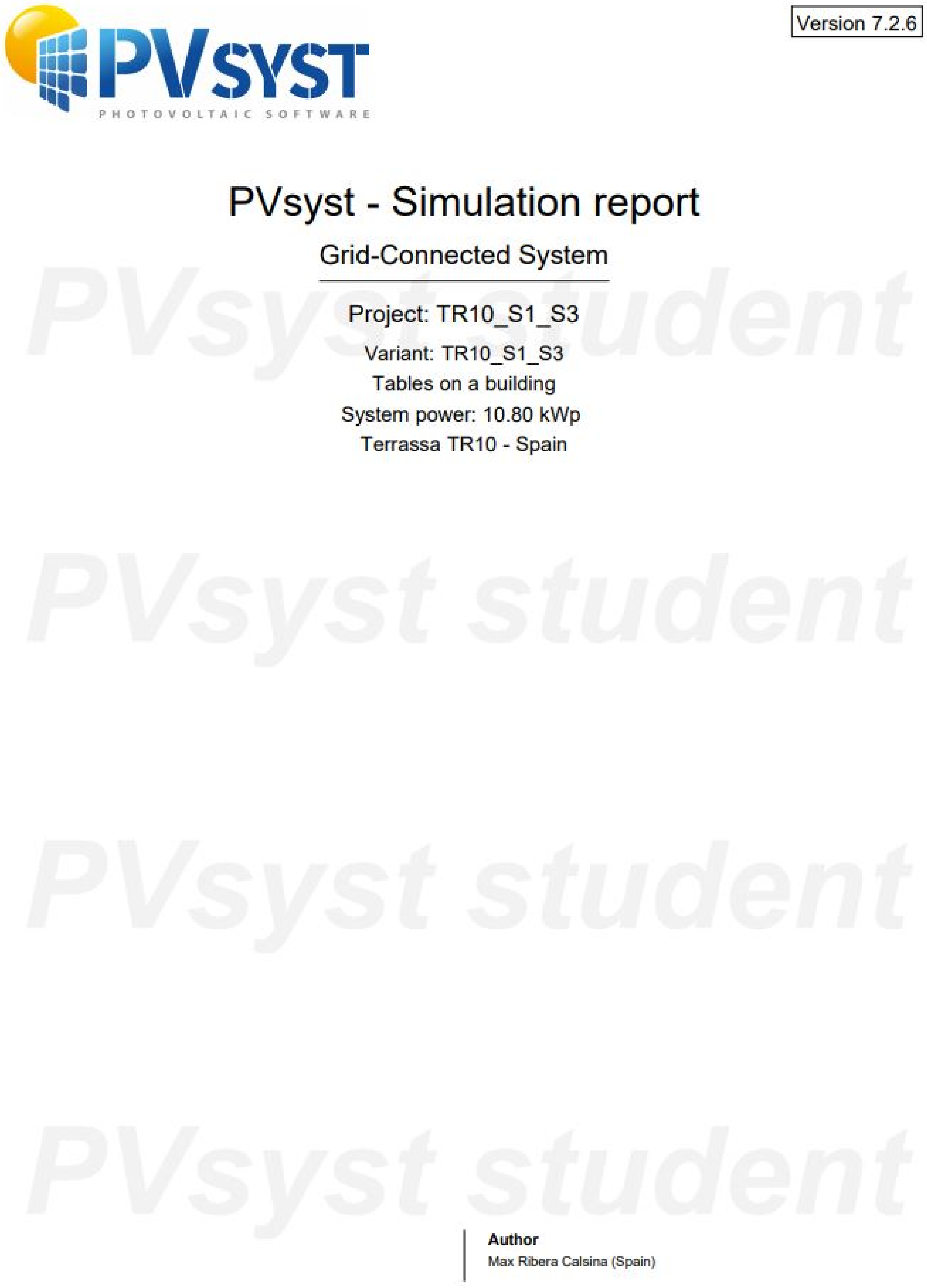
E PVsyst Reports

Figure 98: PVsyst Simulation Report



Version 7.2.6

PVsyst - Simulation report

Grid-Connected System

Project: TR10_S1_S3
Variant: TR10_S1_S3
Tables on a building
System power: 10.80 kWp
Terrassa TR10 - Spain

Author
Max Ribera Calsina (Spain)

Project summary

Geographical Site		**Situation**		**Project settings**	
Terrassa TR10		Latitude	41.56 °N	Albedo	0.20
Spain		Longitude	2.02 °E		
		Altitude	286 m		
		Time zone	UTC+1		

Meteo data
Terrassa TR10
Meteonorm 8.0 (1996-2015), Sat=100% - Sintético

System summary

Grid-Connected System — **Tables on a building**

PV Field Orientation		**Near Shadings**	**User's needs**
Fixed planes	2 orientations	Linear shadings	Monthly values
Tilts/azimuths	34 / -14 °		
	34 / -12 °		

System information

PV Array		**Inverters**	
Nb. of modules	24 units	Nb. of units	1 Unit
Pnom total	10.80 kWp	Pnom total	10.00 kWac
		Pnom ratio	1.080

Results summary

Produced Energy	16.81 MWh/year	Specific production	1556 kWh/kWp/year	Perf. Ratio PR	83.26 %
Used Energy	159699.11 MWh/year			Solar Fraction SF	0.01 %

Table of contents

General parameters

Grid-Connected System

Tables on a building

PV Field Orientation

Orientation

Fixed planes	2 orientations
Tilts/azimuths	34 / -14 °
	34 / -12 °

Sheds configuration

Nb. of sheds	24 units
Identical arrays	

Sizes

Sheds spacing	1.77 m
Collector width	1.04 m
Ground Cov. Ratio (GCR)	58.6 %

Shading limit angle

Limit profile angle	32.5 °

Models used

Transposition	Perez
Diffuse	Perez, Meteonorm
Circumsolar	separate

Horizon

Free Horizon

Near Shadings

Linear shadings

User's needs

Monthly values

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
13672	11016	13613	12303	13014	14682	15617	13338	12765	13748	12331	13603	159699	MWh

PV Array Characteristics

PV module

Manufacturer	Generic
Model	LR4-72 HPH 450 M G2
(Original PVsyst database)	
Unit Nom. Power	450 Wp
Number of PV modules	24 units
Nominal (STC)	10.80 kWp
Modules	2 Strings x 12 In series

At operating cond. (50°C)

Pmpp	9.88 kWp
U mpp	446 V
I mpp	22 A

Inverter

Manufacturer	Generic
Model	SOFAR 10000TL-G2
(Original PVsyst database)	
Unit Nom. Power	10.00 kWac
Number of inverters	2 * MPPT 50% 1 unit
Total power	10.0 kWac
Operating voltage	160-960 V
Pnom ratio (DC:AC)	1.08

Total PV power

Nominal (STC)	11 kWp
Total	24 modules
Module area	52.2 m²
Cell area	47.6 m²

Total inverter power

Total power	10 kWac
Nb. of inverters	1 Unit
Pnom ratio	1.08

Array losses

Thermal Loss factor

Module temperature according to irradiance

Uc (const)	20.0 W/m²K
Uv (wind)	0.0 W/m²K/m/s

DC wiring losses

Global array res.	333 mΩ
Loss Fraction	1.5 % at STC

Module Quality Loss

Loss Fraction	-0.4 %

Module mismatch losses

Loss Fraction	2.0 % at MPP

Strings Mismatch loss

Loss Fraction	0.1 %

Array losses

IAM loss factor

Incidence effect (IAM): User defined profile

0°	25°	45°	60°	65°	70°	75°	80°	90°
1.000	1.000	0.995	0.962	0.936	0.903	0.851	0.754	0.000

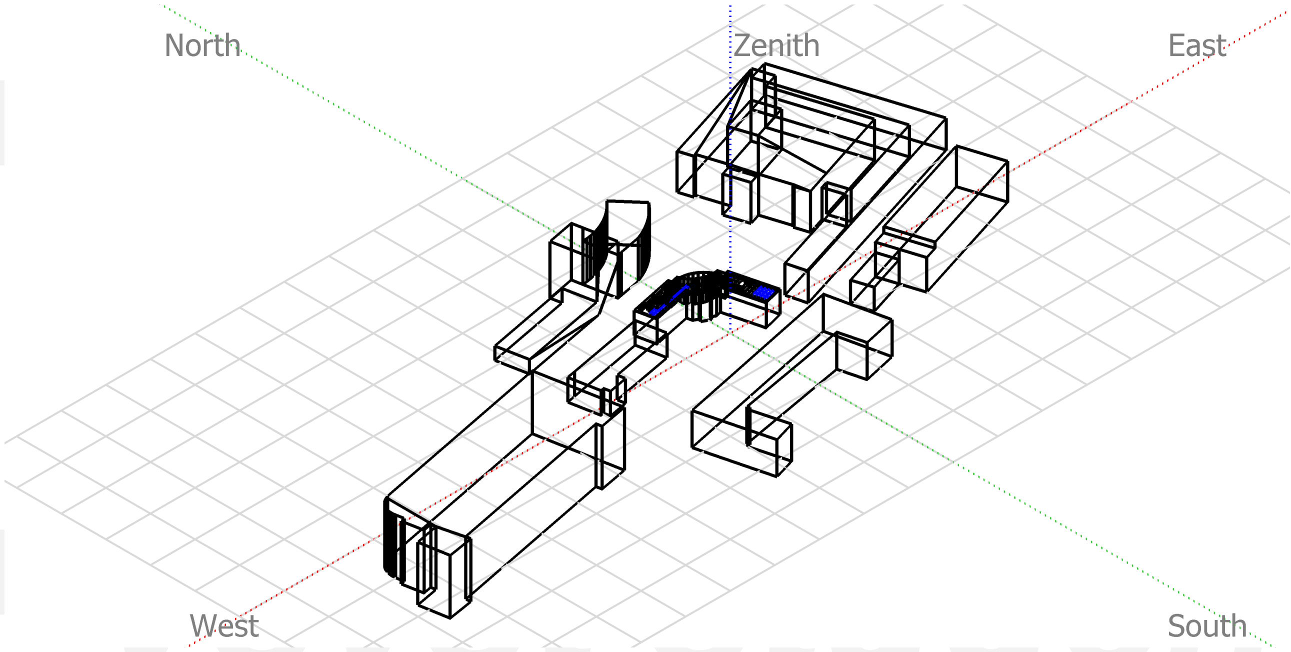
Project: TR10_S1_S3

Variant: TR10_S1_S3

Max Ribera Calsina (Spain)

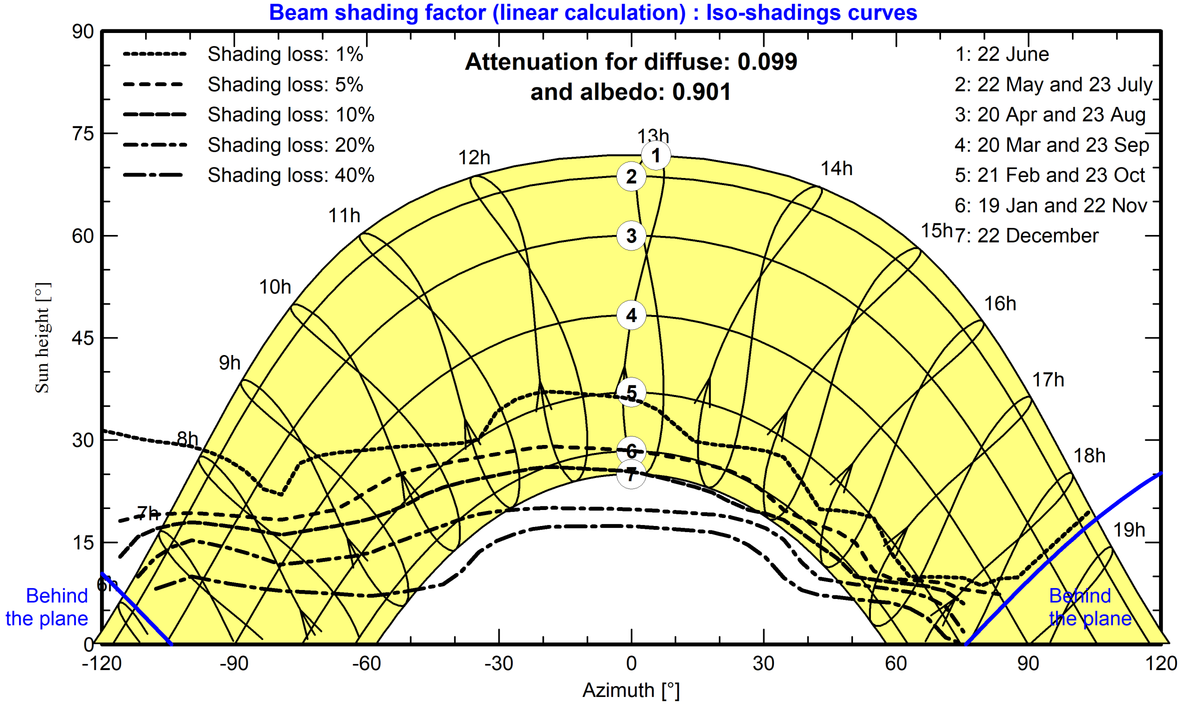
Near shadings parameter

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

TR10_S1_S3 - Legal Time



Main results

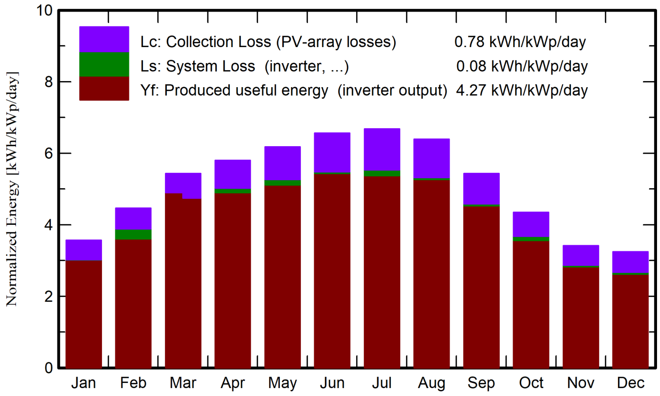
System Production

Produced Energy	16.81 MWh/year	Specific production	1556 kWh/kWp/year
Used Energy	159699.11 MWh/year	Performance Ratio PR	83.26 %
		Solar Fraction SF	0.01 %

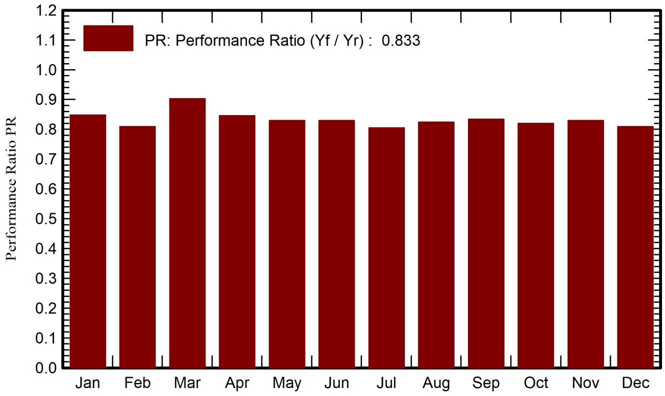
Economic evaluation

Investment		**Yearly cost**		**LCOE**	
Global	7'427.31 EUR	Annuities	0.00 EUR/yr	Energy cost	0.03 EUR/kWh
Specific	0.69 EUR/Wp	Run. costs	100.00 EUR/yr		
		Payback period	3.3 years		

Normalized productions (per installed kWp)



Performance Ratio PR



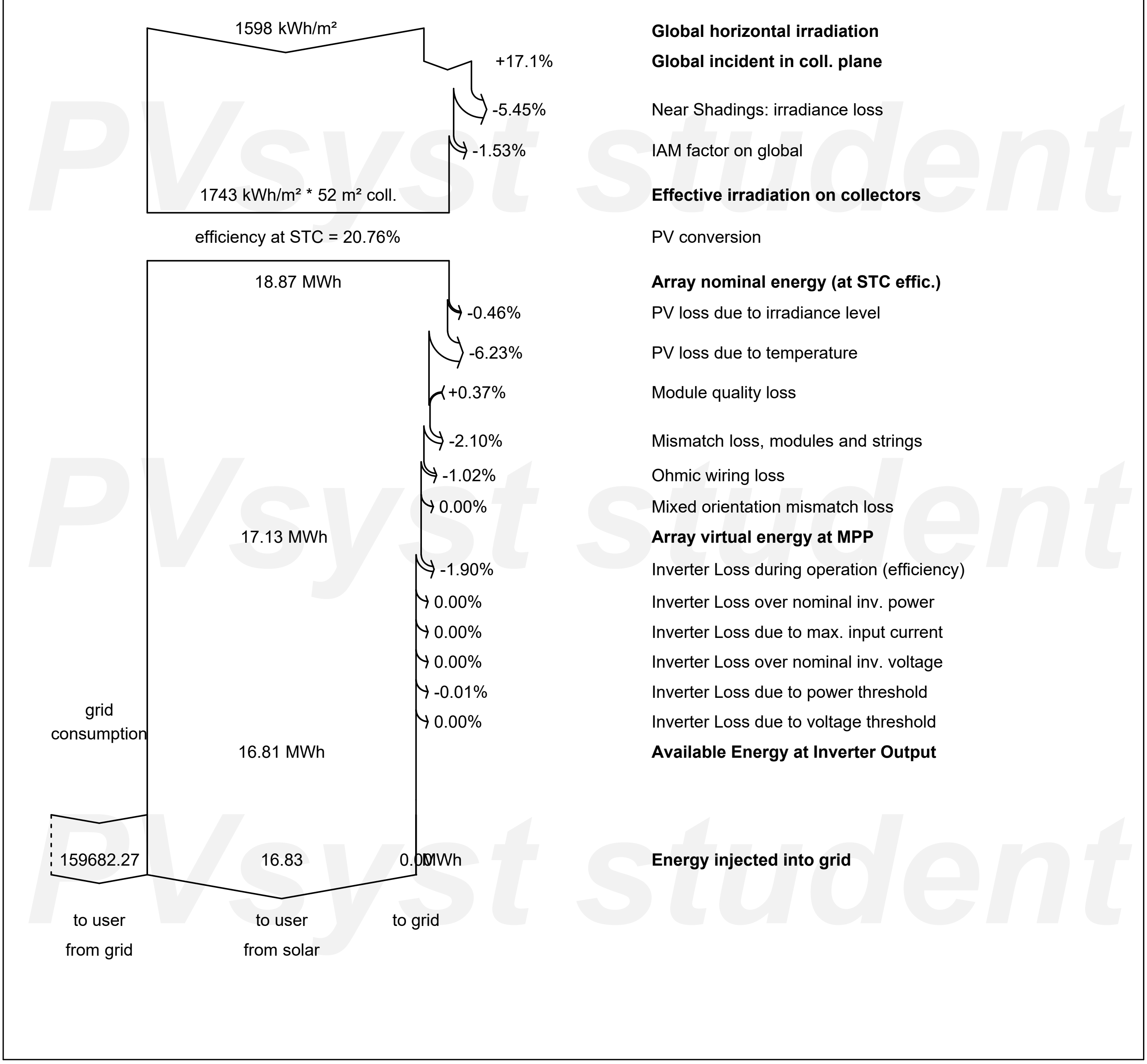
Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_User	E_Solar	E_Grid	EFrGrid
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	MWh	MWh	MWh	MWh	MWh
January	63.8	24.34	6.83	110.4	98.4	1.013	13672	1.010	0.000	13671
February	81.7	32.30	7.93	125.0	115.1	1.177	11016	1.093	0.000	11015
March	132.4	49.75	11.57	168.5	159.5	1.590	13613	1.643	0.000	13611
April	158.4	62.09	14.13	174.0	164.6	1.628	12303	1.588	0.000	12301
May	194.8	83.57	17.96	191.5	180.2	1.764	13014	1.715	0.000	13012
June	209.4	79.43	22.26	196.7	185.3	1.779	14682	1.762	0.000	14680
July	214.8	80.91	24.82	207.1	195.2	1.856	15617	1.800	0.000	15615
August	188.0	69.04	24.60	198.2	188.0	1.783	13338	1.765	0.000	13336
September	136.7	57.41	20.70	163.1	153.8	1.487	12765	1.469	0.000	12763
October	98.5	41.67	17.19	134.7	125.5	1.232	13748	1.193	0.000	13746
November	64.1	31.14	11.19	102.4	91.2	0.931	12331	0.917	0.000	12330
December	55.6	23.68	7.42	100.7	86.3	0.895	13603	0.880	0.000	13602
Year	1598.3	635.31	15.60	1872.3	1743.0	17.135	159699	16.835	0.000	159682

Legends

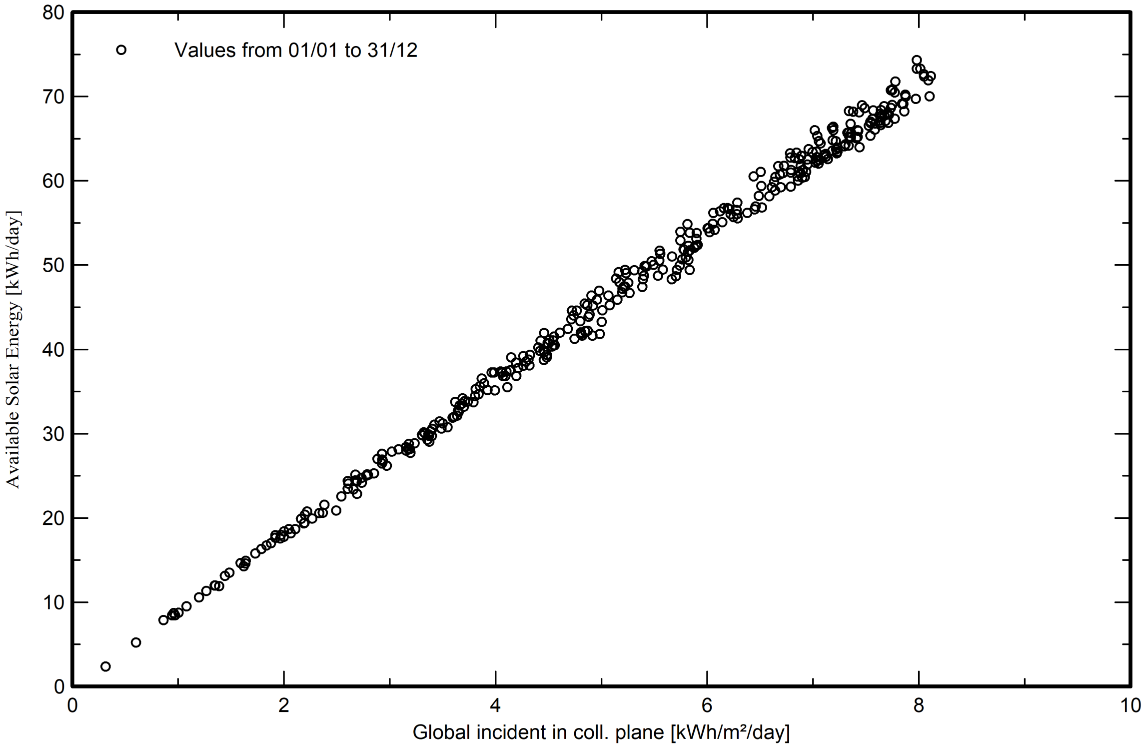
GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_User	Energy supplied to the user
T_Amb	Ambient Temperature	E_Solar	Energy from the sun
GlobInc	Global incident in coll. plane	E_Grid	Energy injected into grid
GlobEff	Effective Global, corr. for IAM and shadings	EFrGrid	Energy from the grid

Loss diagram

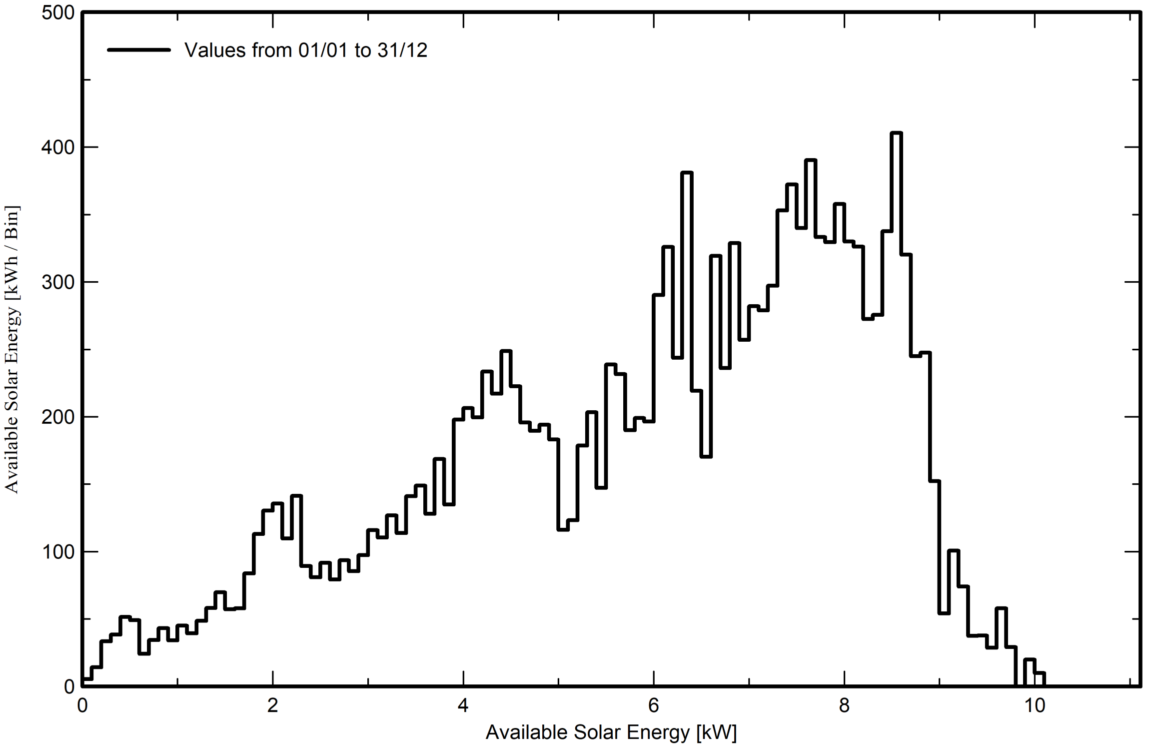


Special graphs

Daily Input/Output diagram



System Output Power Distribution



Cost of the system

Installation costs

Item	Quantity units	Cost EUR	Total EUR
PV modules			
LR4-72 HPH 450 M G2	24	176.84	4'244.16
Supports for modules	36	9.00	324.00
Inverters			
SOFAR 10000TL-G2	1	1'595.65	1'595.65
Other components			
Wiring	1	52.00	52.00
Combiner box	1	51.50	51.50
Studies and analysis			
Engineering	1	40.00	40.00
Installation			
Global installation cost per module	24	30.00	720.00
Transport	1	400.00	400.00
Total			7'427.31
Depreciable asset			6'163.81

Operating costs

Item	Total EUR/year
Maintenance	
Repairs	100.00
Total (OPEX)	100.00

System summary

Total installation cost	7'427.31 EUR
Operating costs	100.00 EUR/year
Produced Energy	16.8 MWh/year
Cost of produced energy (LCOE)	0.028 EUR/kWh

Financial analysis

Simulation period

Project lifetime	20 years	Start year	2022

Income variation over time

Inflation	0.00 %/year
Production variation (aging)	0.00 %/year
Discount rate	0.00 %/year

Income dependent expenses

Income tax rate	0.00 %/year
Other income tax	0.00 %/year
Dividends	0.00 %/year

Financing

Own funds	7'427.31 EUR

Electricity sale

Feed-in tariff	0.14 EUR/kWh
Duration of tariff warranty	20 years
Annual connection tax	0.00 EUR/kWh
Annual tariff variation	0.0 %/year
Feed-in tariff decrease after warranty	50.00 %

Self-consumption

Consumption tariff	0.14 EUR/kWh
Tariff evolution	0.0 %/year

Return on investment

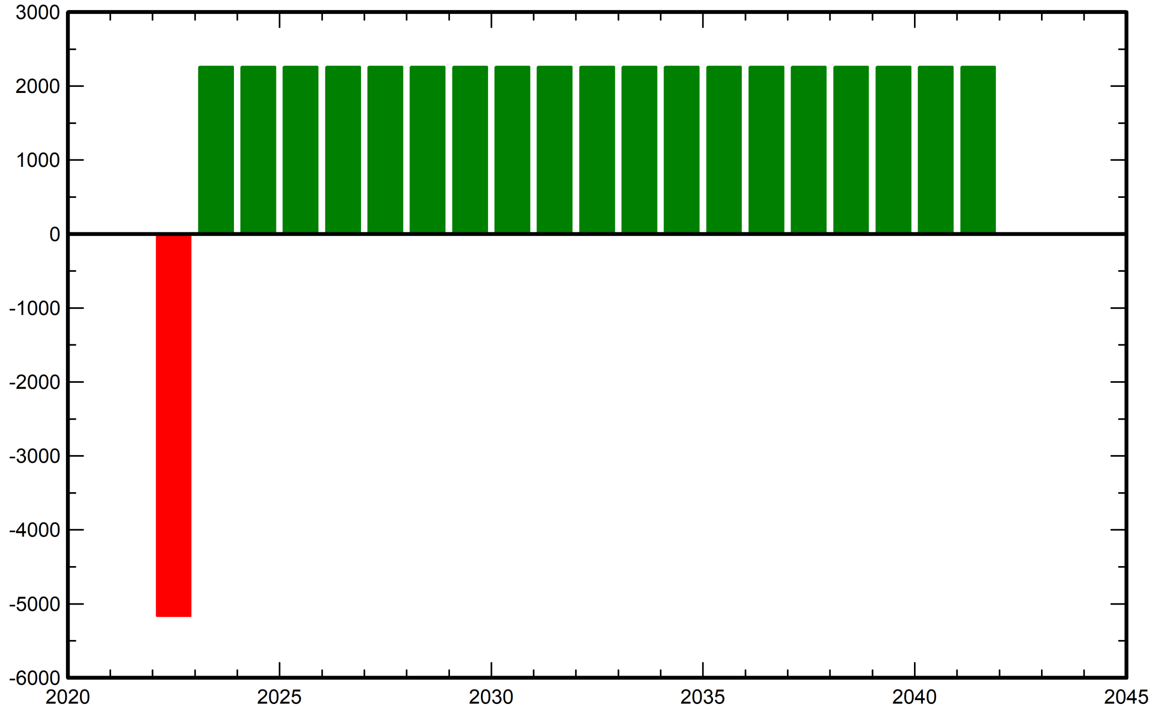
Payback period	3.3 years
Net present value (NPV)	37'801.47 EUR
Return on investment (ROI)	509.0 %

Detailed economic results (EUR)

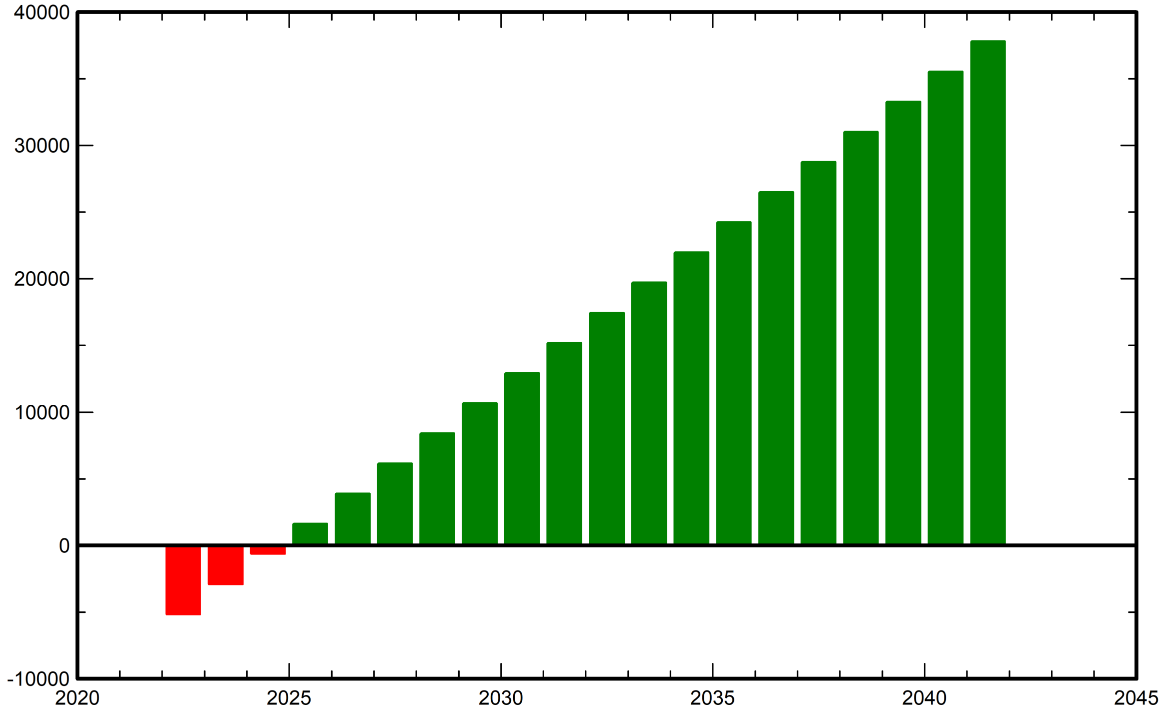
	Electricity sale	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Self-cons. saving	Cumul. profit	% amorti.
2022	0	100	0	0	0	-100	2'361	-5'166	30.4%
2023	0	100	0	0	0	-100	2'361	-2'904	60.9%
2024	0	100	0	0	0	-100	2'361	-643	91.3%
2025	0	100	0	0	0	-100	2'361	1'618	121.8%
2026	0	100	0	0	0	-100	2'361	3'880	152.2%
2027	0	100	0	0	0	-100	2'361	6'141	182.7%
2028	0	100	0	0	0	-100	2'361	8'403	213.1%
2029	0	100	0	0	0	-100	2'361	10'664	243.6%
2030	0	100	0	0	0	-100	2'361	12'926	274.0%
2031	0	100	0	0	0	-100	2'361	15'187	304.5%
2032	0	100	0	0	0	-100	2'361	17'449	334.9%
2033	0	100	0	0	0	-100	2'361	19'710	365.4%
2034	0	100	0	0	0	-100	2'361	21'971	395.8%
2035	0	100	0	0	0	-100	2'361	24'233	426.3%
2036	0	100	0	0	0	-100	2'361	26'494	456.7%
2037	0	100	0	0	0	-100	2'361	28'756	487.2%
2038	0	100	0	0	0	-100	2'361	31'017	517.6%
2039	0	100	0	0	0	-100	2'361	33'279	548.1%
2040	0	100	0	0	0	-100	2'361	35'540	578.5%
2041	0	100	0	0	0	-100	2'361	37'801	609.0%
Total	**0**	**2'000**	**0**	**0**	**0**	**-2'000**	**47'229**	**37'801**	**609.0%**

Financial analysis

Yearly net profit (EUR)



Cumulative cashflow (EUR)



CO_2 Emission Balance

Total:	68.7 tCO_2

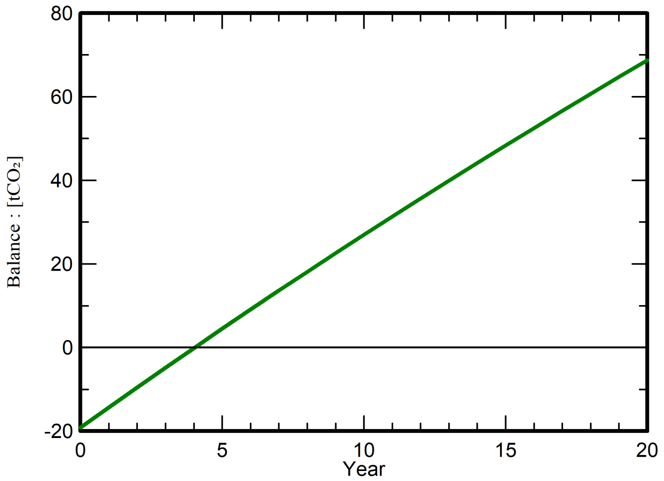
Generated emissions

Total:	19.15 tCO_2
Source:	Detailed calculation from table below:

Replaced Emissions

Total:	96.5 tCO_2
System production:	16.81 MWh/yr
Grid Lifecycle Emissions:	287 gCO_2/kWh
Source:	IEA List
Country:	Spain
Lifetime:	20 years
Annual degradation:	1.0 %

Saved CO_2 Emission vs. Time



System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[$kgCO_2$]
Modules	1713 kgCO2/kWp	10.8 kWp	18497
Supports	1.91 kgCO2/kg	240 kg	459
Inverters	190 kgCO2/units	1.00 units	190

Version 7.2.6

PVsyst - Simulation report

Grid-Connected System

Project: TR10_S2_S4

Variant: S2_S4
Tables on a building
System power: 10.80 kWp
Terrassa TR10 - Spain

Author
Max Ribera Calsina (Spain)

Project summary

Geographical Site
Terrassa TR10
Spain

Situation

Latitude	41.56 °N
Longitude	2.02 °E
Altitude	286 m
Time zone	UTC+1

Project settings

Albedo	0.20

Meteo data
Terrassa TR10
Meteonorm 8.0 (1996-2015), Sat=100% - Sintético

System summary

Grid-Connected System

Tables on a building

PV Field Orientation

Fixed planes	2 orientations
Tilts/azimuths	34 / -12 °
	34 / -14 °

Near Shadings
Linear shadings

User's needs
Monthly values

System information

PV Array

Nb. of modules	24 units
Pnom total	10.80 kWp

Inverters

Nb. of units	1 Unit
Pnom total	10.00 kWac
Pnom ratio	1.080

Results summary

Produced Energy	16.02 MWh/year	Specific production	1483 kWh/kWp/year	Perf. Ratio PR	79.23 %
Used Energy	159699.05 MWh/year			Solar Fraction SF	0.01 %

Table of contents

General parameters

Grid-Connected System **Tables on a building**

PV Field Orientation

Orientation

Fixed planes	2 orientations
Tilts/azimuths	34 / -12 °
	34 / -14 °

Sheds configuration

Nb. of sheds	24 units
Identical arrays	

Sizes

Sheds spacing	1.77 m
Collector width	1.04 m
Ground Cov. Ratio (GCR)	58.5 %

Shading limit angle

Limit profile angle	32.5 °

Models used

Transposition	Perez
Diffuse	Perez, Meteonorm
Circumsolar	separate

Horizon
Free Horizon

Near Shadings
Linear shadings

User's needs
Monthly values

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
13672	11016	13613	12303	13014	14682	15617	13338	12765	13748	12331	13603	159699	MWh

PV Array Characteristics

PV module

Manufacturer	Generic
Model	LR4-72 HPH 450 M G2
(Original PVsyst database)	
Unit Nom. Power	450 Wp
Number of PV modules	24 units
Nominal (STC)	10.80 kWp
Modules	2 Strings x 12 In series

At operating cond. (50°C)

Pmpp	9.88 kWp
U mpp	446 V
I mpp	22 A

Total PV power

Nominal (STC)	11 kWp
Total	24 modules
Module area	52.2 m²
Cell area	47.6 m²

Inverter

Manufacturer	Generic
Model	SOFAR 10000TL-G2
(Original PVsyst database)	
Unit Nom. Power	10.00 kWac
Number of inverters	2 * MPPT 50% 1 unit
Total power	10.0 kWac
Operating voltage	160-960 V
Pnom ratio (DC:AC)	1.08

Total inverter power

Total power	10 kWac
Nb. of inverters	1 Unit
Pnom ratio	1.08

Array losses

Thermal Loss factor

Module temperature according to irradiance

Uc (const)	20.0 W/m²K
Uv (wind)	0.0 W/m²K/m/s

DC wiring losses

Global array res.	333 mΩ
Loss Fraction	1.5 % at STC

Module Quality Loss

Loss Fraction	-0.4 %

Module mismatch losses

Loss Fraction	2.0 % at MPP

Strings Mismatch loss

Loss Fraction	0.1 %

Array losses

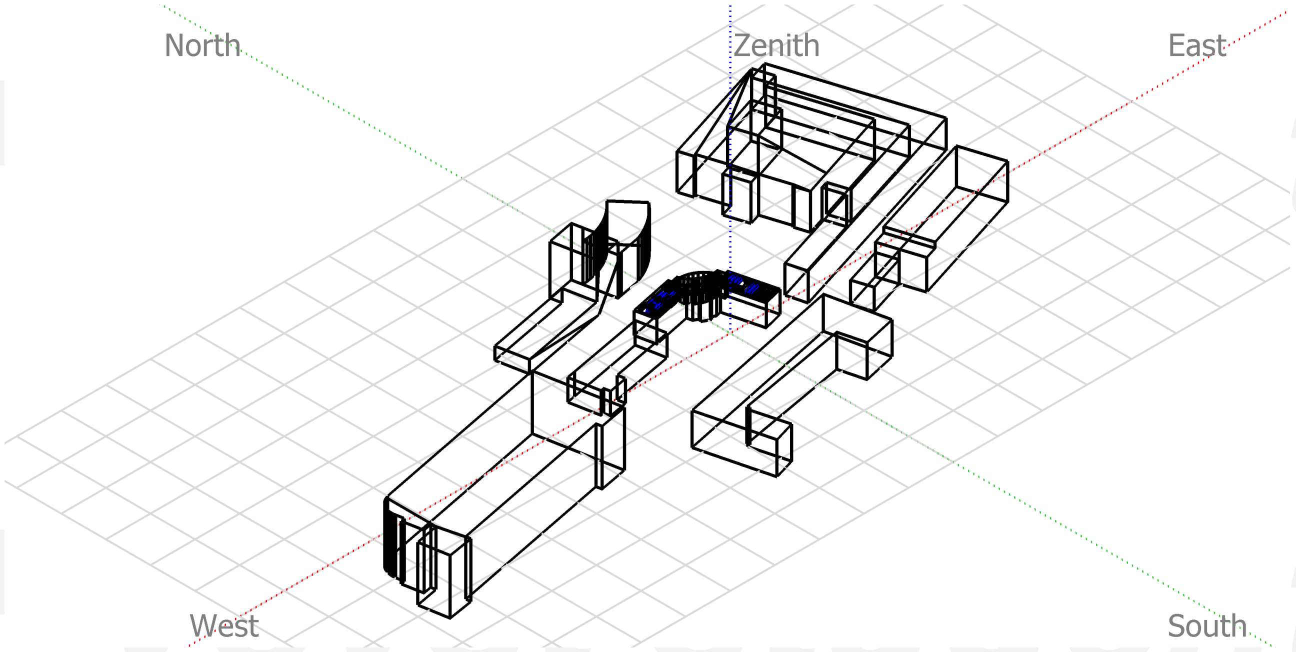
IAM loss factor

Incidence effect (IAM): User defined profile

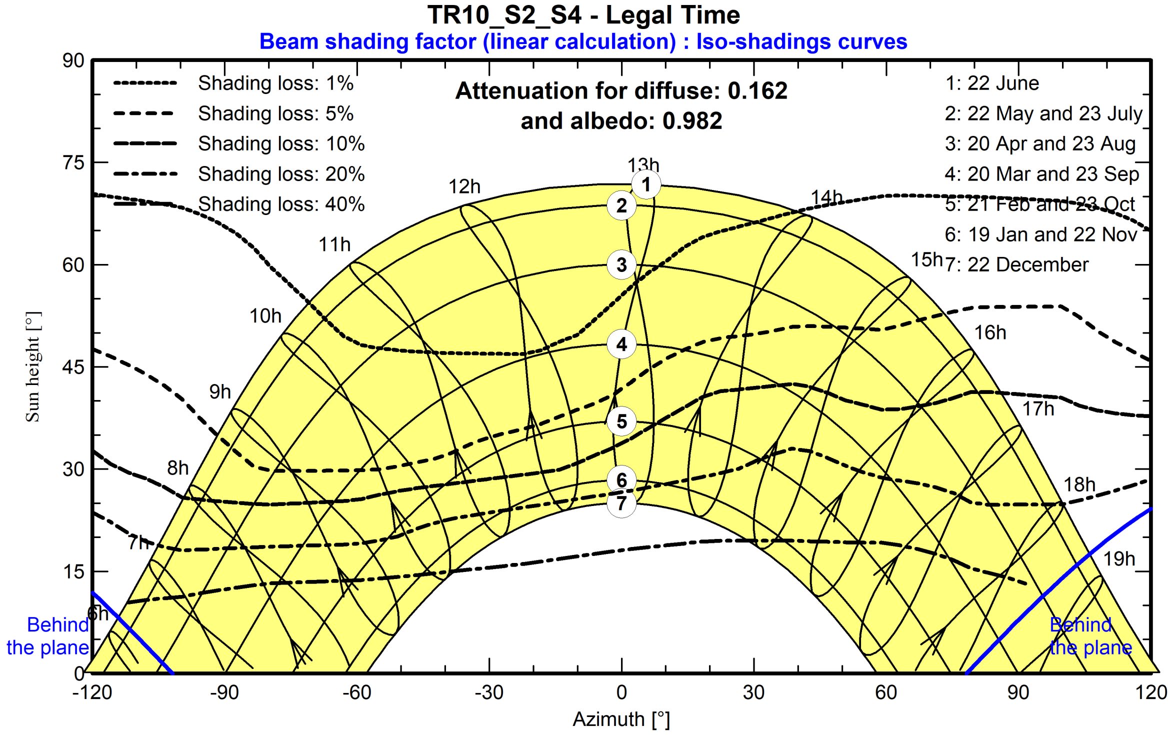
0°	25°	45°	60°	65°	70°	75°	80°	90°
1.000	1.000	0.995	0.962	0.936	0.903	0.851	0.754	0.000

Near shadings parameter

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram



Main results

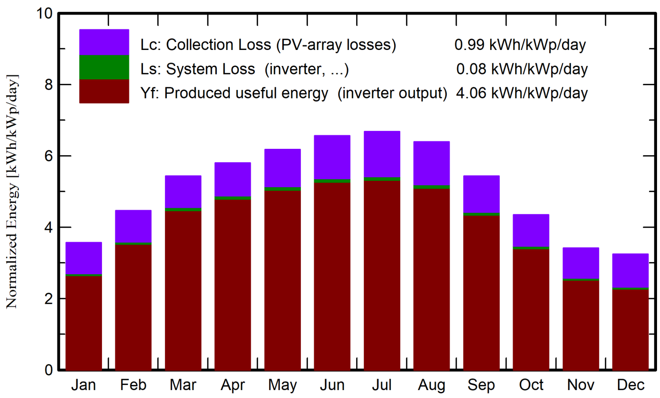
System Production

Produced Energy	16.02 MWh/year	Specific production	1483 kWh/kWp/year
Used Energy	159699.05 MWh/year	Performance Ratio PR	79.23 %
		Solar Fraction SF	0.01 %

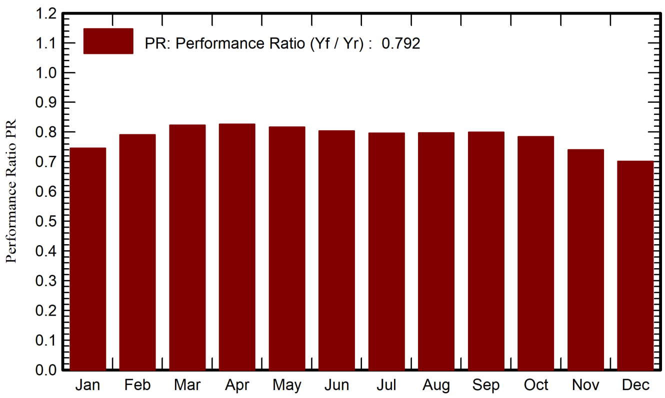
Economic evaluation

Investment		**Yearly cost**		**LCOE**	
Global	7'357.31 EUR	Annuities	0.00 EUR/yr	Energy cost	0.03 EUR/kWh
Specific	0.68 EUR/Wp	Run. costs	100.00 EUR/yr		
		Payback period	3.4 years		

Normalized productions (per installed kWp)



Performance Ratio PR



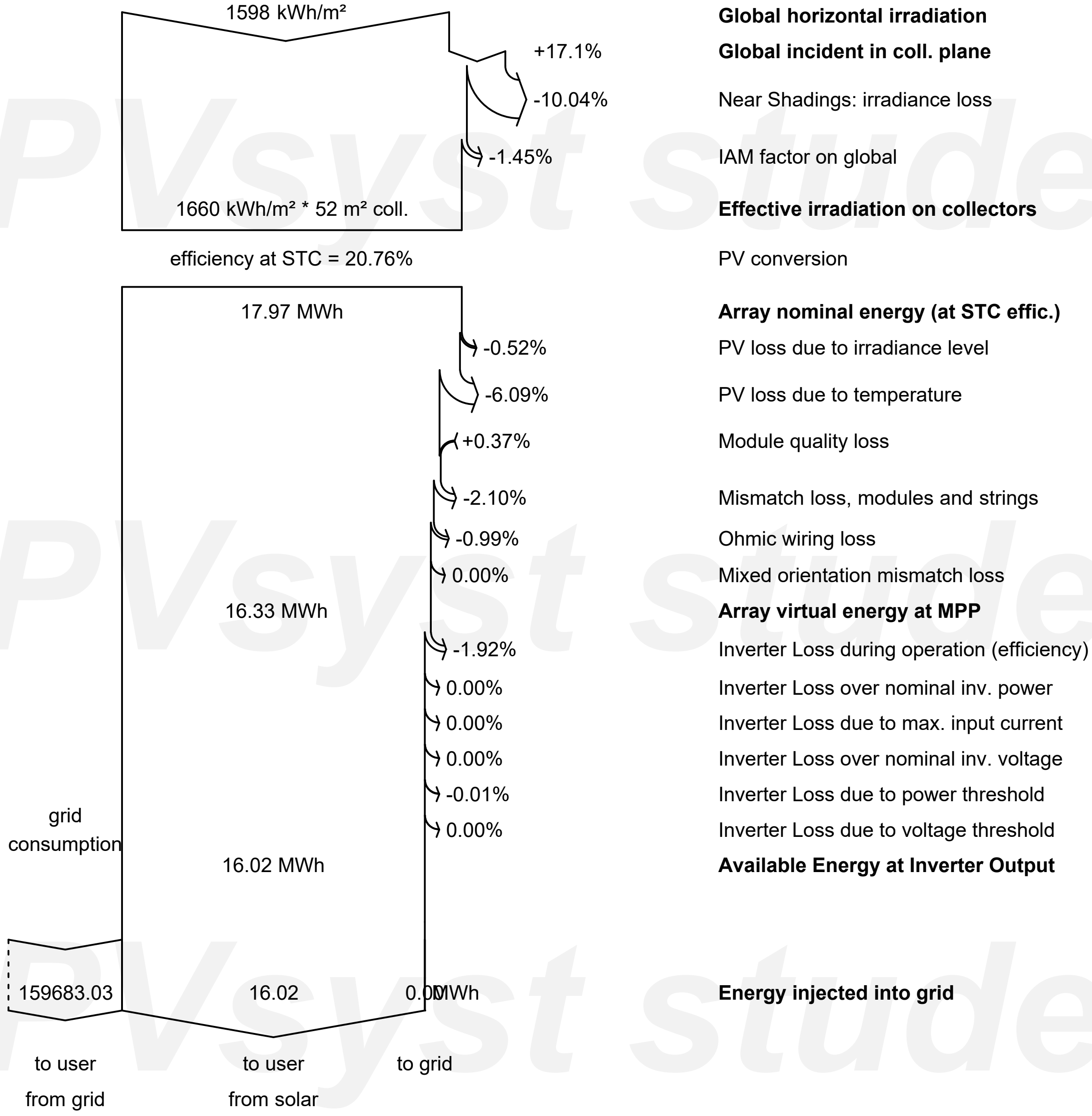
Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_User MWh	E_Solar MWh	E_Grid MWh	EFrGrid MWh
January	63.8	24.34	6.83	110.4	87.6	0.907	13672	0.888	0.000	13671
February	81.7	32.30	7.93	125.0	106.0	1.088	11016	1.067	0.000	11015
March	132.4	49.75	11.57	168.5	152.9	1.527	13613	1.498	0.000	13611
April	158.4	62.09	14.13	174.0	159.9	1.583	12303	1.553	0.000	12301
May	194.8	83.57	17.96	191.5	175.8	1.722	13014	1.689	0.000	13012
June	209.4	79.43	22.26	196.7	181.2	1.741	14682	1.708	0.000	14680
July	214.8	80.91	24.82	207.1	190.8	1.815	15617	1.781	0.000	15615
August	188.0	69.04	24.60	198.2	183.3	1.741	13338	1.707	0.000	13336
September	136.7	57.41	20.70	163.1	148.1	1.435	12765	1.407	0.000	12763
October	98.5	41.67	17.19	134.7	118.2	1.164	13748	1.141	0.000	13746
November	64.1	31.14	11.19	102.4	81.4	0.835	12331	0.818	0.000	12330
December	55.6	23.68	7.42	100.7	74.6	0.778	13603	0.762	0.000	13602
Year	1598.3	635.31	15.60	1872.3	1659.9	16.335	159699	16.020	0.000	159683

Legends

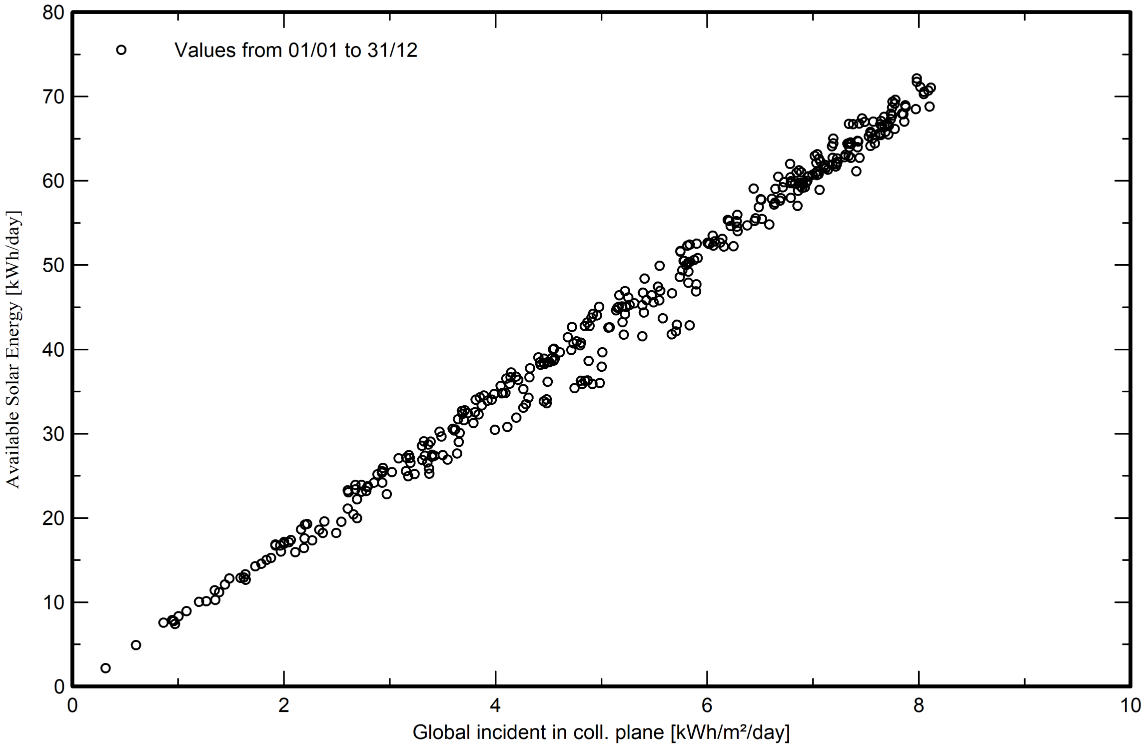
GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_User	Energy supplied to the user
T_Amb	Ambient Temperature	E_Solar	Energy from the sun
GlobInc	Global incident in coll. plane	E_Grid	Energy injected into grid
GlobEff	Effective Global, corr. for IAM and shadings	EFrGrid	Energy from the grid

Loss diagram

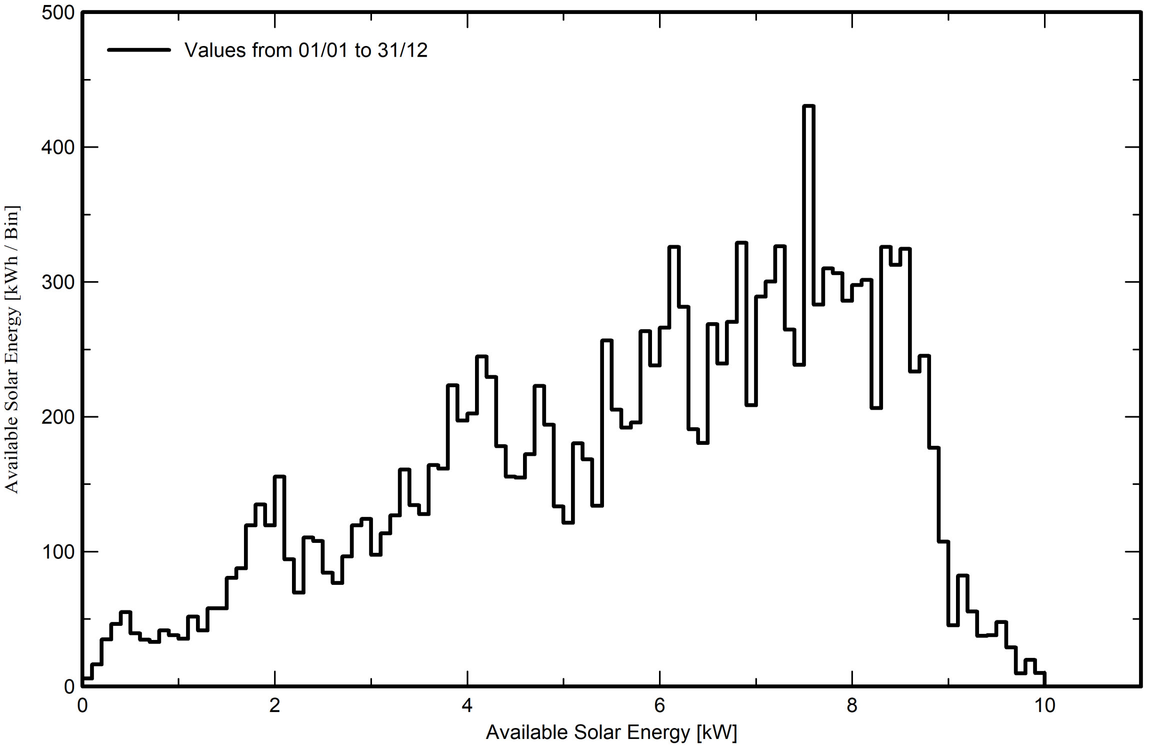


Special graphs

Daily Input/Output diagram



System Output Power Distribution



Cost of the system

Installation costs

Item	Quantity units	Cost EUR	Total EUR
PV modules			
LR4-72 HPH 450 M G2	24	176.84	4'244.16
Supports for modules	24	9.00	216.00
Inverters			
SOFAR 10000TL-G2	1	1'595.65	1'595.65
Other components			
Combiner box	1	141.50	141.50
Studies and analysis			
Engineering	1	40.00	40.00
Installation			
Global installation cost per module	24	30.00	720.00
Transport	1	400.00	400.00
Total			7'357.31
Depreciable asset			6'055.81

Operating costs

Item	Total EUR/year
Maintenance	
Salaries	100.00
Total (OPEX)	100.00

System summary

Total installation cost	7'357.31 EUR
Operating costs	100.00 EUR/year
Produced Energy	16.0 MWh/year
Cost of produced energy (LCOE)	0.029 EUR/kWh

Financial analysis

Simulation period

Project lifetime	20 years	Start year	2022

Income variation over time

Inflation	0.00 %/year
Production variation (aging)	0.00 %/year
Discount rate	0.00 %/year

Income dependent expenses

Income tax rate	0.00 %/year
Other income tax	0.00 %/year
Dividends	0.00 %/year

Financing

Own funds	7'357.31 EUR

Electricity sale

Feed-in tariff	0.14 EUR/kWh
Duration of tariff warranty	20 years
Annual connection tax	0.00 EUR/kWh
Annual tariff variation	0.0 %/year
Feed-in tariff decrease after warranty	50.00 %

Self-consumption

Consumption tariff	0.14 EUR/kWh
Tariff evolution	0.0 %/year

Return on investment

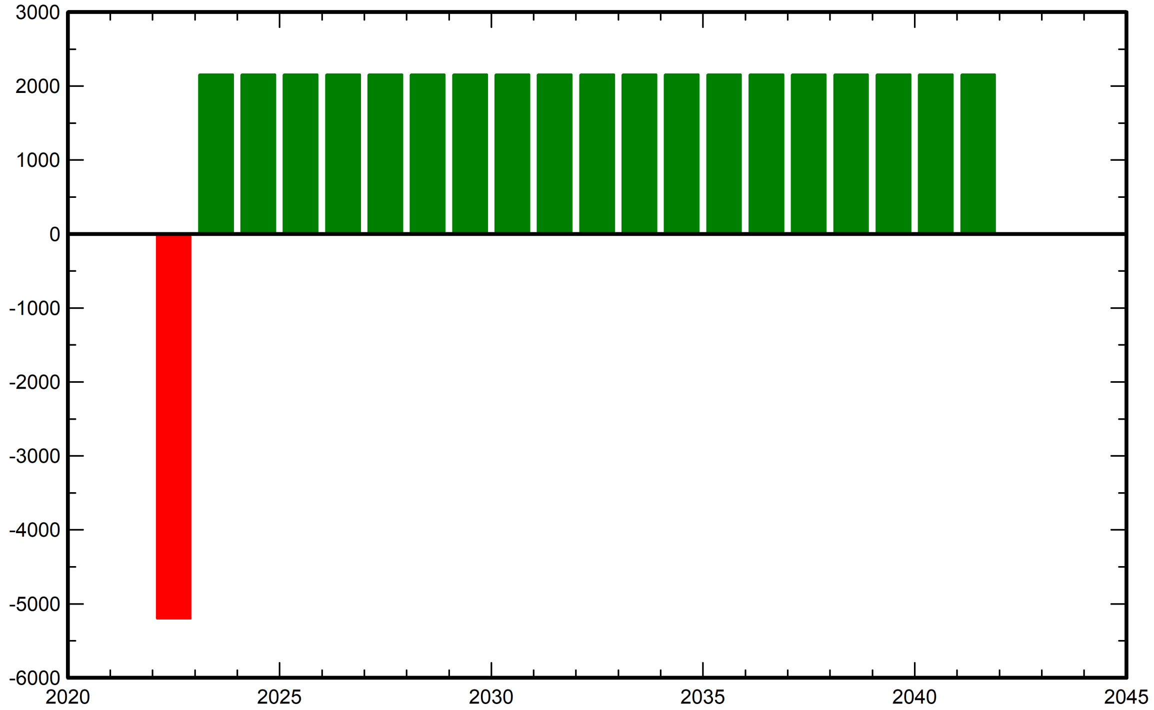
Payback period	3.4 years
Net present value (NPV)	35'777.21 EUR
Return on investment (ROI)	486.3 %

Detailed economic results (EUR)

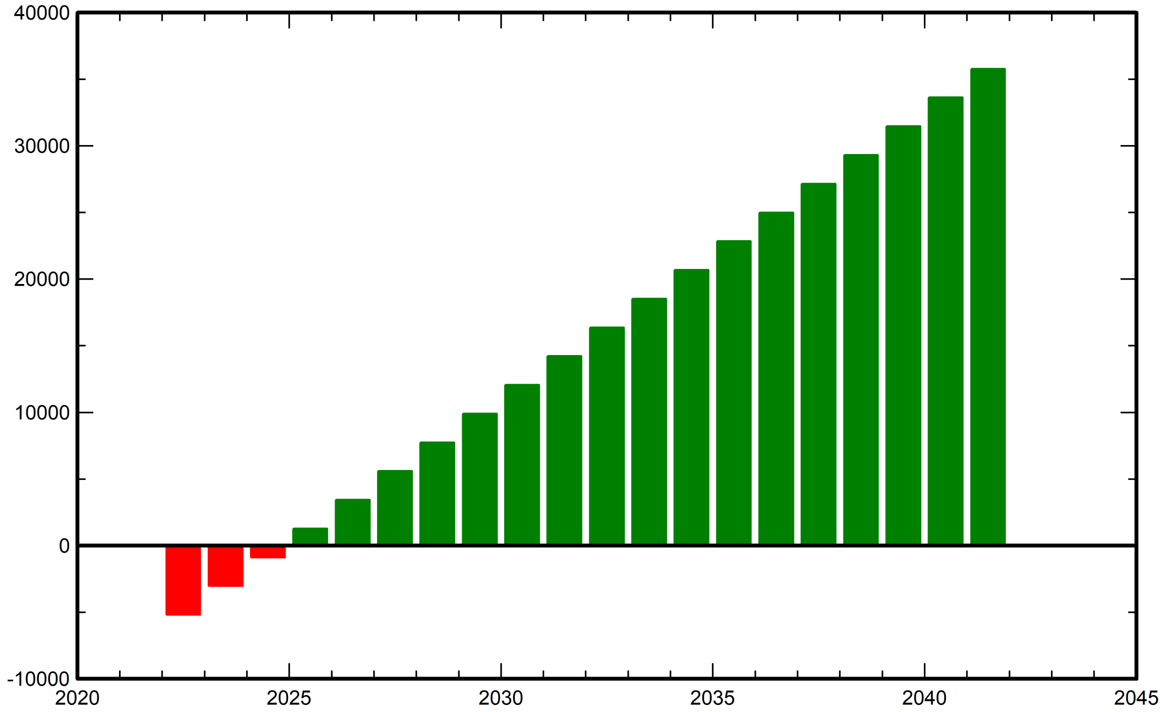
	Electricity sale	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Self-cons. saving	Cumul. profit	% amorti.
2022	0	100	0	0	0	-100	2'257	-5'201	29.3%
2023	0	100	0	0	0	-100	2'257	-3'044	58.6%
2024	0	100	0	0	0	-100	2'257	-887	87.9%
2025	0	100	0	0	0	-100	2'257	1'270	117.3%
2026	0	100	0	0	0	-100	2'257	3'426	146.6%
2027	0	100	0	0	0	-100	2'257	5'583	175.9%
2028	0	100	0	0	0	-100	2'257	7'740	205.2%
2029	0	100	0	0	0	-100	2'257	9'896	234.5%
2030	0	100	0	0	0	-100	2'257	12'053	263.8%
2031	0	100	0	0	0	-100	2'257	14'210	293.1%
2032	0	100	0	0	0	-100	2'257	16'367	322.5%
2033	0	100	0	0	0	-100	2'257	18'523	351.8%
2034	0	100	0	0	0	-100	2'257	20'680	381.1%
2035	0	100	0	0	0	-100	2'257	22'837	410.4%
2036	0	100	0	0	0	-100	2'257	24'994	439.7%
2037	0	100	0	0	0	-100	2'257	27'150	469.0%
2038	0	100	0	0	0	-100	2'257	29'307	498.3%
2039	0	100	0	0	0	-100	2'257	31'464	527.7%
2040	0	100	0	0	0	-100	2'257	33'620	557.0%
2041	0	100	0	0	0	-100	2'257	35'777	586.3%
Total	**0**	**2'000**	**0**	**0**	**0**	**-2'000**	**45'135**	**35'777**	**586.3%**

Financial analysis

Yearly net profit (EUR)



Cumulative cashflow (EUR)



CO_2 Emission Balance

Total:	100.5 tCO_2

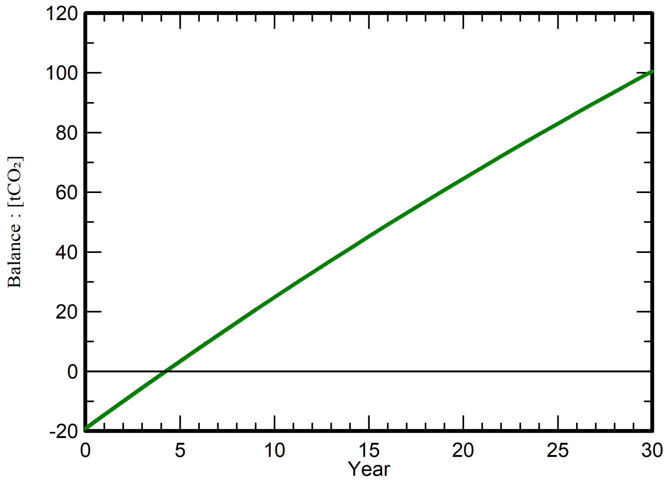
Generated emissions

Total:	19.15 tCO_2
Source:	Detailed calculation from table below:

Replaced Emissions

Total:	137.9 tCO_2
System production:	16.02 MWh/yr
Grid Lifecycle Emissions:	287 gCO_2/kWh
Source:	IEA List
Country:	Spain
Lifetime:	30 years
Annual degradation:	1.0 %

Saved CO_2 Emission vs. Time



System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[$kgCO_2$]
Modules	1713 kgCO2/kWp	10.8 kWp	18497
Supports	1.91 kgCO2/kg	240 kg	459
Inverters	190 kgCO2/	1.00	190