ANALYTICAL MODEL

Analytical Model

To understand the study done it's important to know the basic notion of solar irradiance and solar altitude.

The amount of solar energy per unit area arriving on a surface at a particular angle is called irradiance which is measured in watts per square meter, W/m^2.

Solar altitude refers to the angle of the sun relative to the Earth's horizon.

From *PVGIS*, the total irradiation can be retrieved. When considered null slope, $G_{global} = G_{horizontal}$ is perpendicular to the earth. The following equation was used to obtain the $G_{panel} = \frac{G_{horiz} \sin(a+\beta)}{\sin(a)}$.

In order to have the maximum G possible, the addition of angle inclination and solar altitude has to be 90 degrees so that the surface can be perpendicular to the solar rays (a+ B =90).

Therefore, $\text{Gpanel} = \frac{G_{horiz}}{\sin(a)}$.

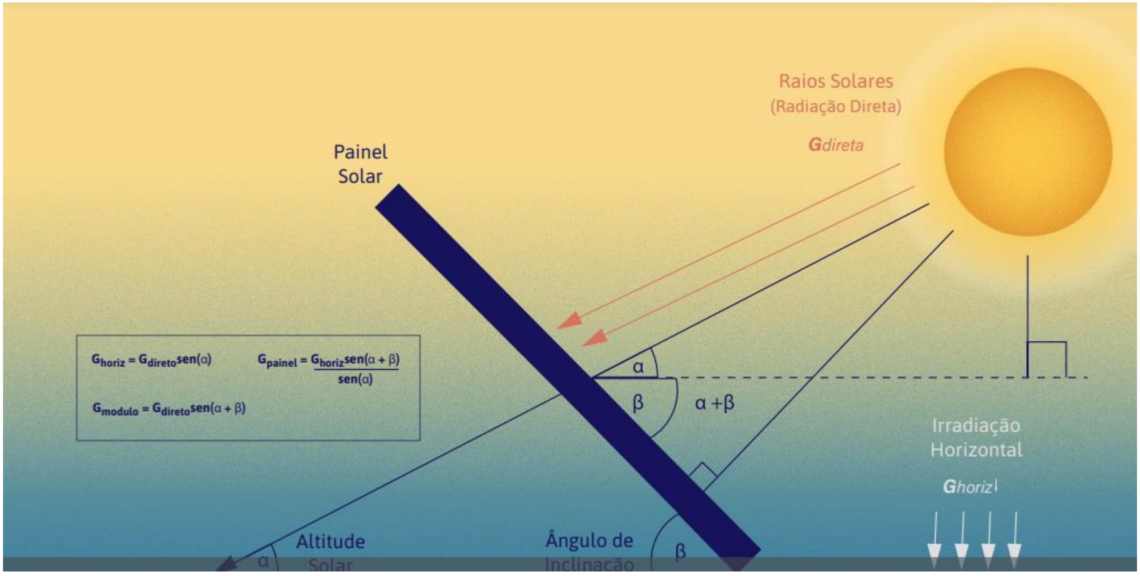

Fig. 1 – Drawing with solar irradiation and solar altitude

The azimuthal angle has also an impact on the production of energy. PVGIS considers the azimuth as the angle of the PV modules relative to the direction due South. As a result, the angle will be 0 degrees since our region should be south facing in order to produce more energy.

Our study was based on the data collected from PVGIS with null slope and azimuth.

This data had hourly temperature, total solar irradiation (Ghoriz as its null slope and azimuth), solar altitude, a parameter that certified that the values were obtained directly and are not reconstructed.

As there was no datasheet available for the cells we had asked, we found datasheets of another panel from the same company, and we used those values to determine the Nominal Operating Cell Temperature (NOCT), the temperature coefficient of the maximum (ap) power and the ambient temperature.

At that point, we created several VBA scripts in Excel so that we could calculate the parameters needed for our analysis: power and temperature, using the formulas below:

$$T_{panel} = T_{amb} + G \frac{(NOCT - 20)}{800} \qquad P = P_{STC} \cdot \frac{G}{1000} \cdot \left(1 + \alpha_p \left(T_{panel} - 25\right)\right)$$

We studied 3 different scenarios to evaluate the power generated from solar cells: firstly, with just one solar cell; secondly, with five solar cells; and finally, to mimic solar blinds, with a set consisting of a 15x10 solar cells. For the power in Standard Test Conditions, we considered the power that was indicated in the solar cell datasheet and then multiplied by the number of cells noted in each case. Furthermore, for each case, the power in NOCT conditions (which means to replace the solar panel temperature with the NOCT temperature in the power formula) was noted. For the power of the cell, the values were calculated hourly (which is the interval in which the PVGIS gives data about the solar irradiance) and then added together to get the daily energy produced (Fig. 2).

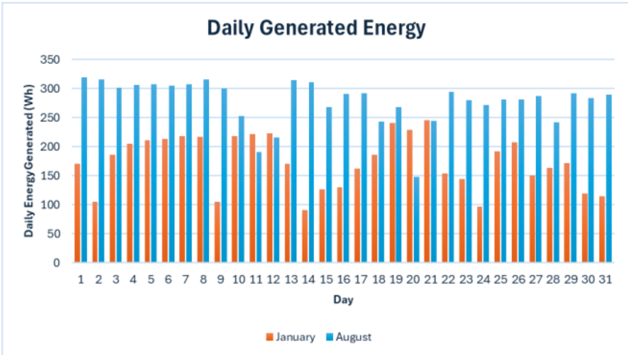

Fig. 2 – Daily Energy Produced by the Solar Panel (15 x10 cells) in the months of January and August

In addition, we drew graphics, not only to facilitate the visualization of the data previously organized/calculated but also to allow comparations particularly between a winter month (specifically January) and a summer month (we chose August).

Firstly, we drew a graph of the evolution of the air Temperature within the several hours of the day for January and August. (Fig. 3) The observations were as expected: the ambient temperature increased until about two or three in the afternoon, getting a decrease after four or five in the afternoon. Also, the average air temperature of January was about 10 degrees Celsius inferior to the average ambient temperature of August.

We also drew the same graph for the solar panel temperature, obtaining the same conclusions, although, given that the average solar panel temperatures are relatively higher than the ambient temperatures, the difference between January and August is intensified into almost twenty degrees Celsius of temperature at noon (it is still higher in August, as expected). (Fig. 4)

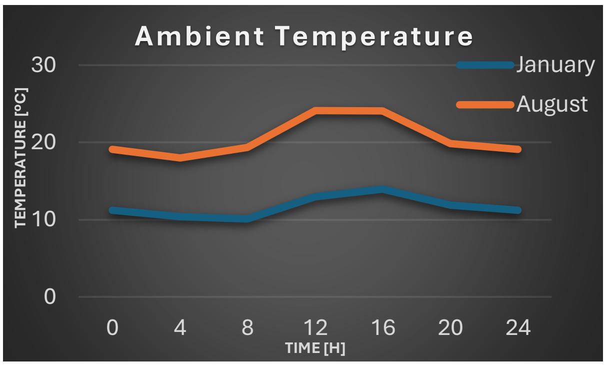

Fig. 3 – Ambient Temperature in a day in January and August

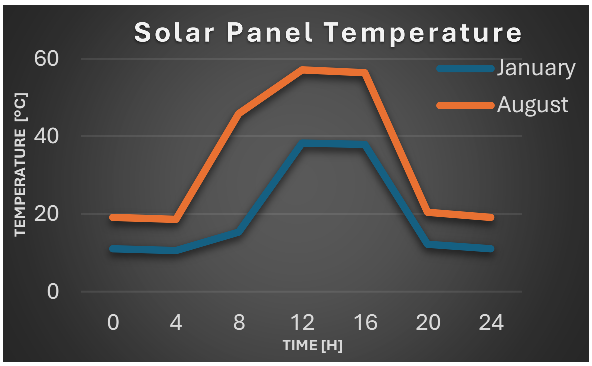

Fig. 4 – Solar Panel Temperature in a day in January and August

We also drew two graphs which compare the solar panel and ambient temperatures for these two different months. (Fig. 5 & Fig. 6)

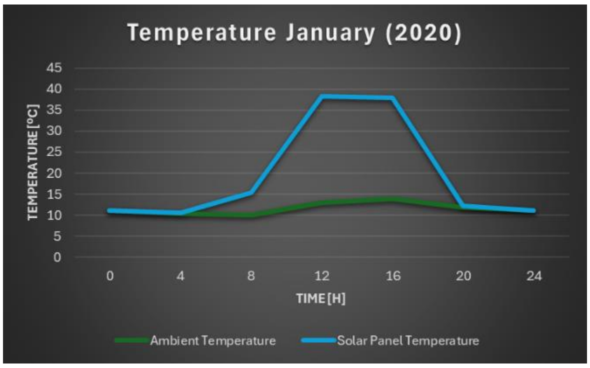

Fig. 5 – Ambient and Solar Panel Temperature in a day in January

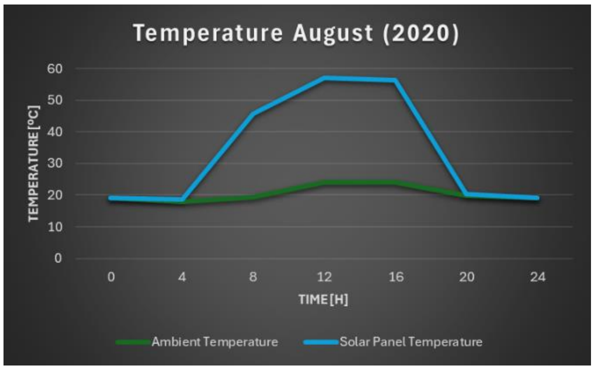

Fig. 6 – Ambient and Solar Panel Temperature in a day in August

Then, we drew two graphs which represent the evolution of the Solar Irradiance (Fig. 7) and the average Maximum Power generated (Fig. 8) (in the solar blind, which means, in 15x10 solar cells) over every hour for the two months referred previously. We can observe that these two characteristics possess a correlation with temperature –higher the temperature (more highlighted by the graph that showcases the solar irradiation and temperature over a year Fig. 9), higher the solar irradiance and the maximum power generated.

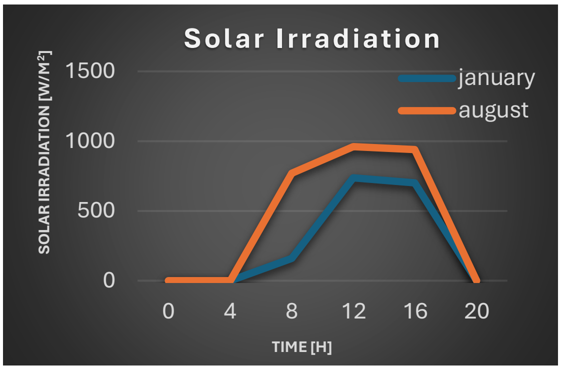

Fig. 7 – Solar Irradiation in a day in January and August

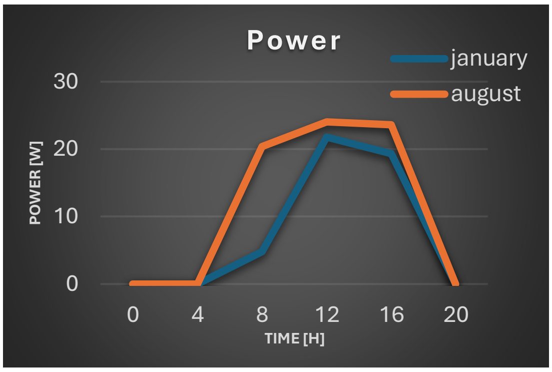

Fig. 8 – Power in a day in January and August

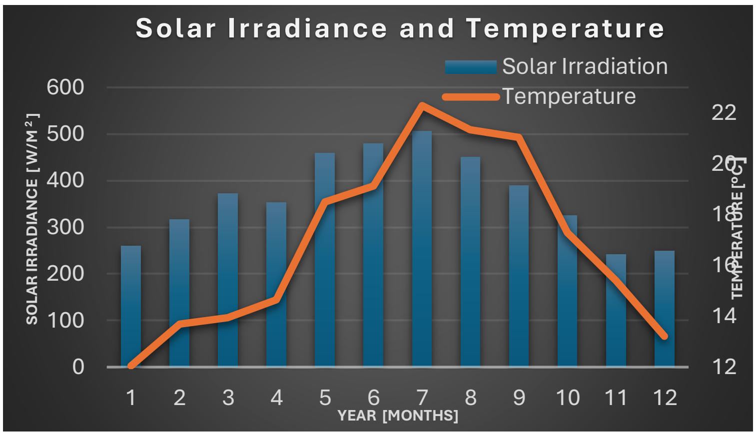

Fig. 9 – Solar Irradiation and Temperature in 2020

We also did a graph for the energy (in Wh) produced by the solar blinds monthly in the year 2020 (Fig. 10). It is important to note that not only is it perceptible the correlation explained previously (higher the temperature, higher the energy produced by the solar blinds), but we can also verify that even in the coldest months on average (December, January) the energy generated is still about 50% of the energy generated in July (the month with the highest production of energy).

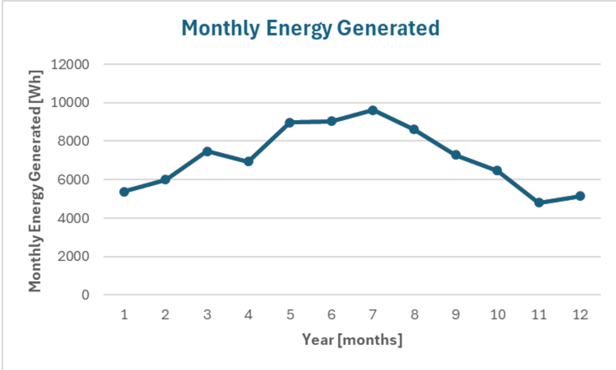

Fig. 10 – Energy generated in 2020

Lastly, given that PVGIS only possesses data up until 2020 for hourly solar irradiance and solar altitude, although by experience we expect that the difference in time is negligible in this past four years, we wanted to confirm if that was really the case: so, we collected data from the past five years (2016 to 2020) in which PVGIS has information and compared the total energy generated by the solar blinds (the set of 15x10 solar cells) yearly (Fig. 11).

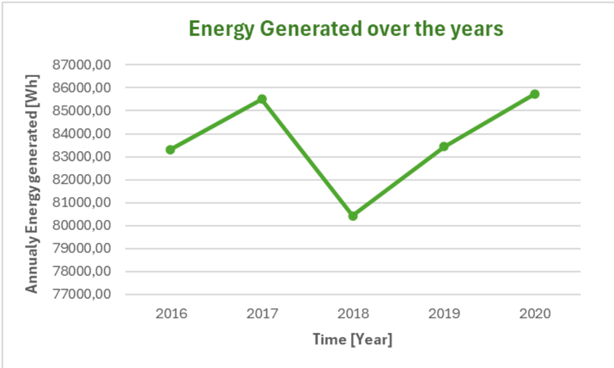

Fig. 11 – Energy Generated over the years

We observed that, in fact, the variation in energy was small (the values varied between 80 kWh and 86 kWh) and, therefore, we concluded that the variation should also be small between 2020 and the present (and also the near future) giving reasons to believe that by utilizing the data from 2020 (as we did in the past formulas and graphs described previously) we built a model that would be general enough to be applied in the present and in the (near) future.