Performance Analysis of the Solarus AB Power Collector

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Abstract— We live in a period where the sustainability of the natural resources is a recurring topic worldwide. Along with this thought, the relevance of clean energy production has grown bigger and it is affecting not only the industry sector but also each individual citizen. Inserted on this thematic the photovoltaic technology is one of the most spoken ways to produce electricity with a minimal impact to the environment. However, this type of systems is still way under its full potential. Not only their electrical efficiency is low but also much of the captured radiation is not converted into electrical energy, instead it is wasted as it transforms in heat. Some systems looked at this issue, tackled it by using the wasted heat, and use it as a thermal source of energy. Together with this idea, there are systems that add solar concentrators so that the photovoltaic area usage gets optimized, these are the so called CPVT.

Keywords— CPVT; Solar Concentration; Electrical Efficiency; Photovoltaic Cell.

I. Introduction

THIS paper's scope is related with the photovoltaic-thermal collector with solar concentration Figure-1 developed by the Swedish company Solarus AB. The objective is to study its electrical and thermal characteristics and relate them not only with the concentration effect but also regarding the location where it will be installed. For this Solarus provided one power collector and the needed materials for its installation, which was done in the Instituto Superior Técnico campus at Tagus Park.

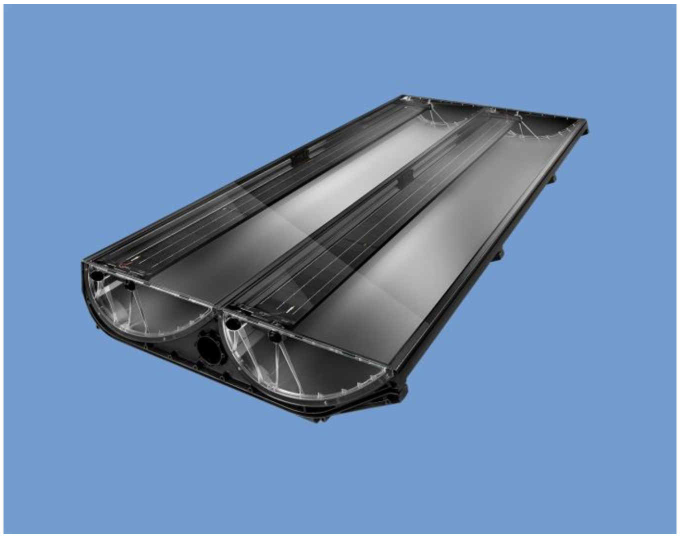

Figure-1. Solarus's Power Collector [1].

In order to study this device, several models were developed so that it could be possible to describe the power collector functioning: electrical model, finite element thermal model so that the working temperatures of the photovoltaic cells could be estimated, a 3D model to understand the reflection of the sun radiation on the collector surfaces. With the experimental measurements, it was possible to validate and adjust the developed models so that these could be used to approximate the power collector behaviour at different geographic locations and as well as at different year seasons.

II. Solarus Power Collector

The solution that Solarus developed consists on a hybrid system, which is included in the CPVT denomination. The collector with the dimensions of 1054x2443x241 mm Figure-2, is able to produce not only electrical but also thermal energy. The thermal energy is obtained by an active cooling process that happens at the photovoltaic cells level, with a circulating fluid that captures the heat waste from the panels. This fluid flows in small canals located between the upper and the lower pane

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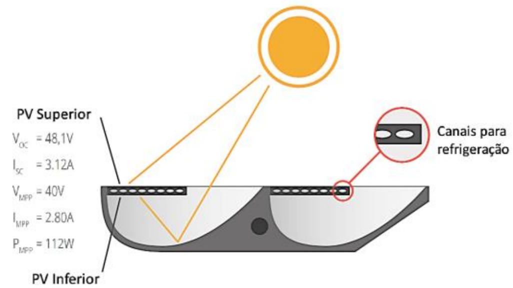

Figure-2. Solarus Power collector side cut and electrical characteristics [1].

Its geometry is based on symmetrical collectors with parabolic concentration surface. However, Solarus's product distinguishes not only in the solar panels location but also on the geometry of the concentrator surface.

A. Elements of the collector

1) *Concentrator*

The used concentrator it is denominated MaReCo (Maximum Reflector Collector) being a geometry composed by two sections, one circular and the other parabolic as it is represented in Fig 3.

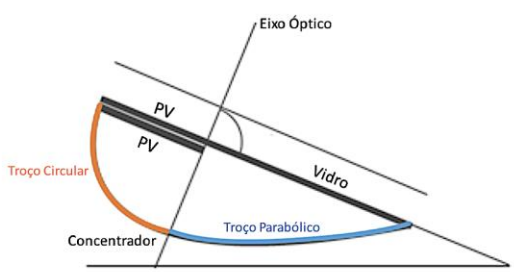

Fig 3. Geometry of the concentrator surface[3].

We can see in the Fig.3 that the optical axis it is perpendicular to the acceptance surface of the collector and, this axis, is essential for the characterization of the acceptance angle for the solar radiation. This tells us that the installation angle with respect to the horizon must be carefully considered so that the concentration effect is not avoided.

2) *Solar Panels*

Each one of the Solarus's power collectors possesses two pairs of solar panels as we could see in the Fig.3.
Each panel has an area of roughly 0.3085 m^2 and, it is constituted by 38 photovoltaic cells. The way these cells are organized has been changed since the first version of the Solarus's CPVT so that a better performance is achieved. At the moment, the 38 cells are distributed in the following way: 8-11-11-8 Fig.4.

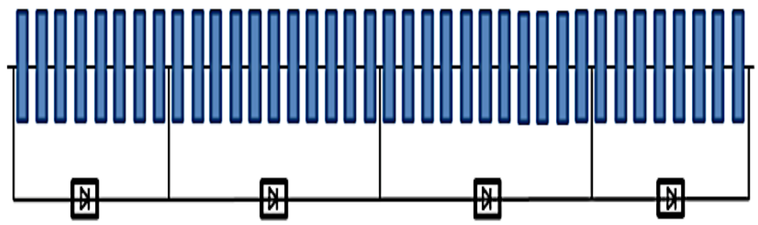

Fig 4. Distribution of the photovoltaic cells in the solar panels installed in the CPVT [2].

Doing a further analysis in the above figure, one can notice the existence of a contour diode by each group of cells. These diodes were installed to prevent negative impacts on the output power, caused by events of cell shadowing. These diodes resistances will be lower when compared with a shadowed cell group and, since they are in parallel, the current will flow through them avoiding this way unnecessary energy loss.

3) *Thermal system*

As mentioned previously, between each pair of solar panels in the CPVT, small canals can be found. This is where the cooling fluid will flow retrieving the wasted heat and, at the same time, contribute to the improvement of the electrical efficiency of the photovoltaic cells. Different geometries were proposed and tested being the results in Fig.5. Since the main objective of these structures is the heat absorption together with temperature homogeneity, we can see that elliptical geometry is the one that fulfils these requisites.

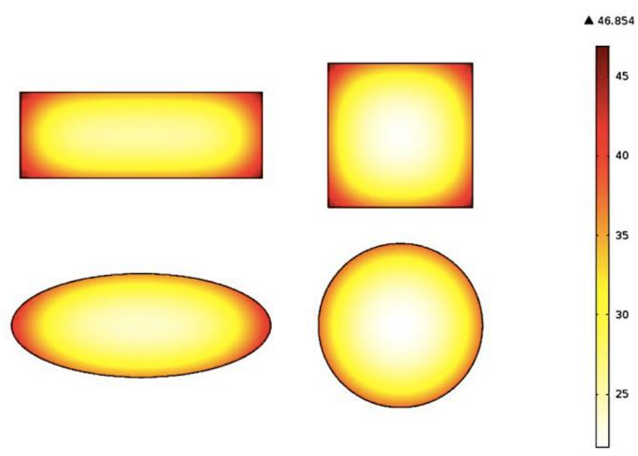

Fig 5. Distribution of the photovoltaic cells in the solar panels installed in the CPVT[2].

B. Models used for simulation

In order to study the electrical behaviour of the CPVT, an equivalent .

1) Electrical model

In order to study the electrical behaviour of the CPVT, an equivalent electrical model was used. The most simple but that describes accurately the functioning of a solar cell is the model with one diode and three parameters presented in Fig.6.

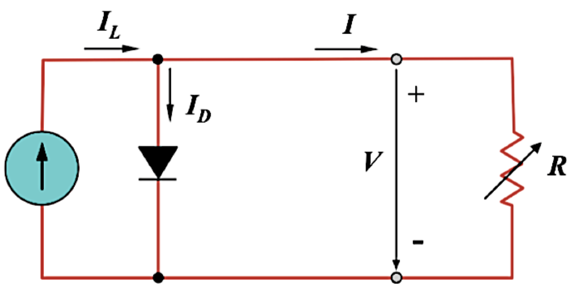

Fig 6. Equivalent electrical model of the solar cell [4].

We can divide it on three parts: R is the load; the current source relates to the current generated by the sun radiation on the cell; the cell p-n junction behaves like a diode with a current I_d given by:

$$I_d = I_o(e^{\frac{V}{mV_T}} - 1) \quad (1)$$

where m is the ideal diode factor and V_T is the thermal potential.
In order to implement this model we then need to use the so-called three parameters as seen in [5]:

$$m = \frac{V_{MP}^r - V_{CA}^r}{V_T^r . \ln\left(1 - \frac{I_{MP}^r}{I_{CC}^r}\right)} \quad (2)$$

$$I_0^r = I_{CC}^r / (e^{\frac{V_{CA}^r}{m.V_T}} - 1) \quad (3)$$

where the third parameter it is the I_{CC}^r it is given in the solar panel datasheet. The values of V_{MP}^r, V_{CA}^r and I_{MP}^r are also given in the datasheet.
Having above values been calculated we can then obtain the following:

$$I_{CC} = \frac{G}{G^r} I_{CC}^r \quad (4)$$

$$I_0 = I_o^r \left(\frac{T}{T^r}\right)^3 e^{\frac{(Ns.h)}{m}\left(\frac{1}{V_T^r} - \frac{1}{V_T}\right)} \quad (5)$$

where *Ns* is the number of cells, *h* is the energy gap of the semiconductor ,*T* is the cell temperature and *G* is the irradiance.
In order to calculate the output power we then have to iterate the following expressions so that we can get the output voltage and current:

$$V_{MP}^{k+1} = mV_T \ln\left(\frac{\frac{I_{CC}}{I_o} + 1}{\frac{V_{MP}^k}{mV_T} + 1}\right) \quad (6)$$

$$I_{MP} = I_{CC} - I_0(e^{\frac{V_{MP}}{mV_T}} - 1) \quad (7)$$

After the iteration is completed, one can calculate the output power of the solar panel.

2) *Finite element thermal model*

To calculate the working temperatures of the cells, a finite element model was used so that a better temperature estimation could be done.
This model takes into account all the materials that constitutes the CPVT as well as all the thermal phenomena that occurs: heat convection, conduction and cooling process. The only input data that was needed were the irradiance distribution and outside temperature. The Fig.7 and Fig.8 shows an example of the output of this model.

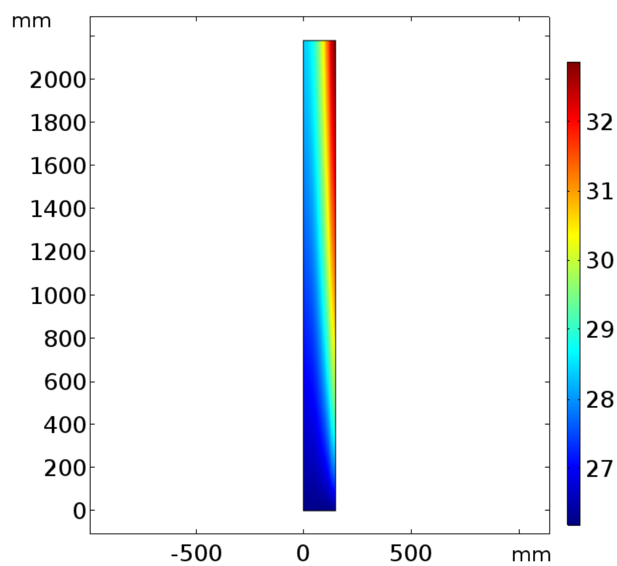

Fig 7. Temperature distribution over the upper panel with active cooling

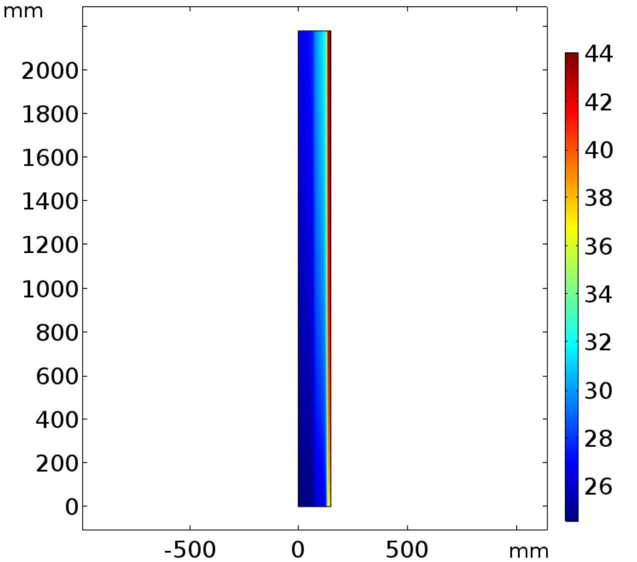

Fig 8. Temperature distribution over the lower panel with active cooling

3) Soltrace Model

The third model that was used, was a 3D model of the CPVT developed in the Soltrace software. It was used to see the way that the sun radiation reflected on the collector surfaces and, how was the radiation distribution in the lower solar panel, for different tilt angles. In the Fig.9 and Fig.10 two simulations are presented for the same hour however with different tilt angles.

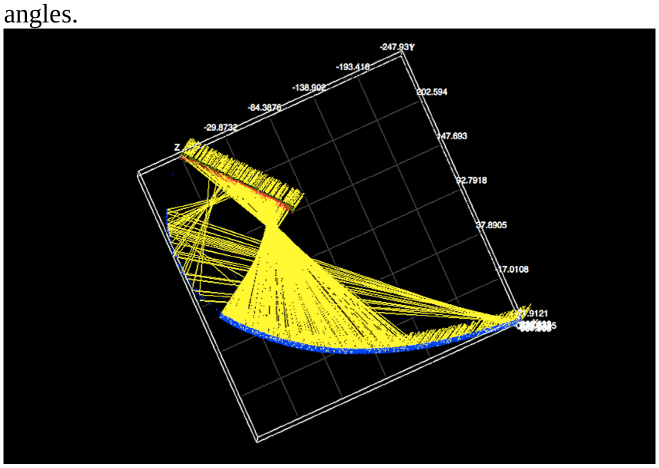

Fig 9. Soltrace simulation for Portugal on January with a tilted angle of 50˚[6].

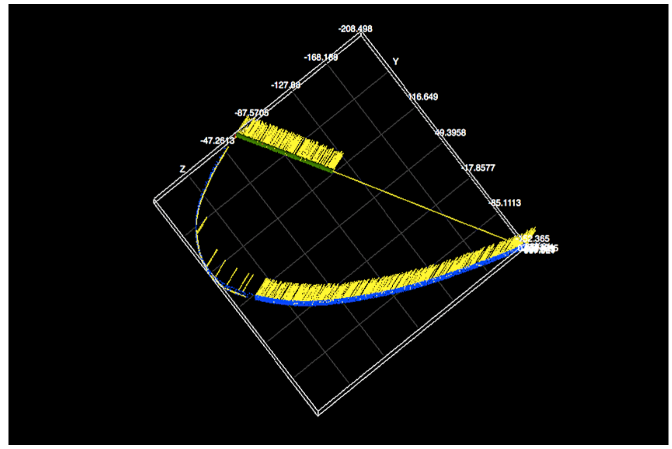

Fig 10. Soltrace simulation for Portugal on January with a tilted angle of 70˚[6].

With this information, it was possible to map the best tilt angles for each region for every month of the year so that solar concentration could be guaranteed. In order to see the sun distribution on the lower panels, a flux graphs were used. As an example, the flux graph for the lower panel simulated in the Fig.9 is presented in Fig.11.

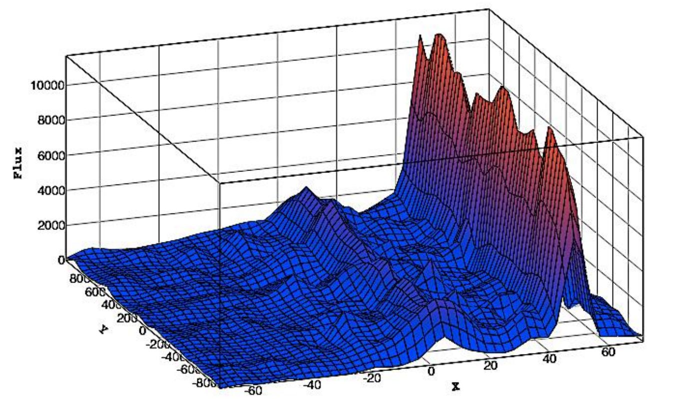

Fig 11. Radiation flux for the lower panel simulated in Fig.9.

III. Results

A. Experimental Results

The experimental installation was done in the Instituto Superior Técnico Tagus Park campus with the CPVT facing south with a tilt angle of 15˚. The Fig.12 shows the structure final position.

Fig 12. Installation of the Solarus's CPVT.

The measurements took place on the 6th of July (see weather conditions on the Fig.13 and Fig.14) and two working modes were tested: working without cooling, working with cooling. For each one the output powers were measured and then compared with the developed electrical model.

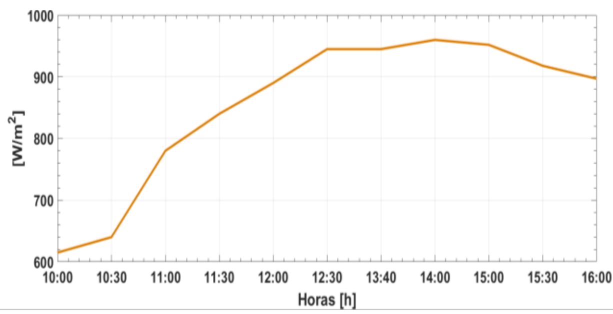

Fig 13. Irradiance for 6th of July.

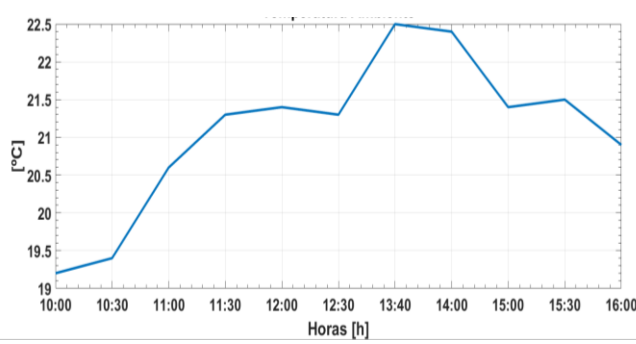

Fig 14. Outside temperature for 6th of July.

1) *CPVT Working without cooling*

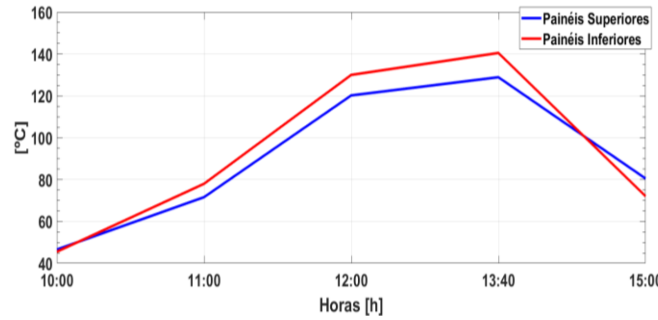

Fig 15. Cells working temperatures calculated by the thermal model (in blue the upper panel, in red the lower panel).

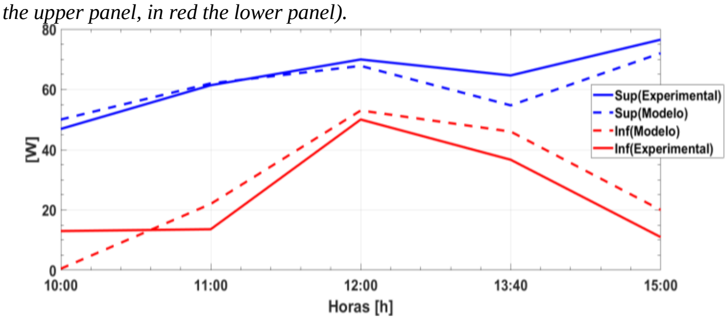

Fig 16. Output powers of the upper panels (in blue) and lower panels (in red). The spaced coloured lines represent the electrical model prediction.

Regarding the electrical efficiency, two ways were used to calculate this value. In the Fig.17 the spaced light green line represents the solar panels efficiency, calculated by electrical model with the following expression:

$$\mu = \frac{Power}{(Area.G_{lower}) + (Area.G_{upper})} \tag{8}$$

The dark green lines represent the global electrical efficiency from the point of view of the CPVT. For this, the following expression was used:

$$\mu = \frac{Power}{Area.G} \tag{9}$$

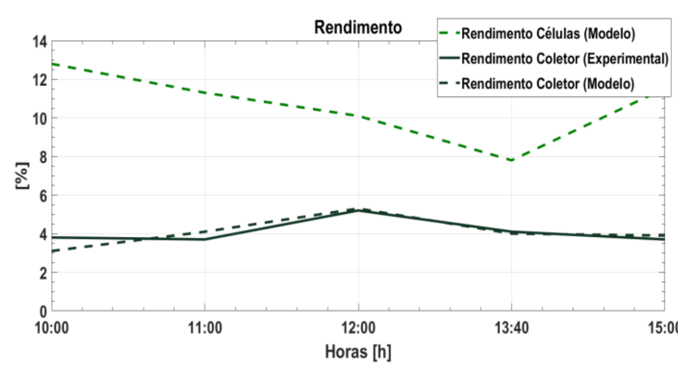

Fig 17. Electrical efficiencies from the point of view of the solar panels (light green line, calculated by the electrical model) and from the CPVT point of view (dark green lines)

2) CPVT Working with cooling

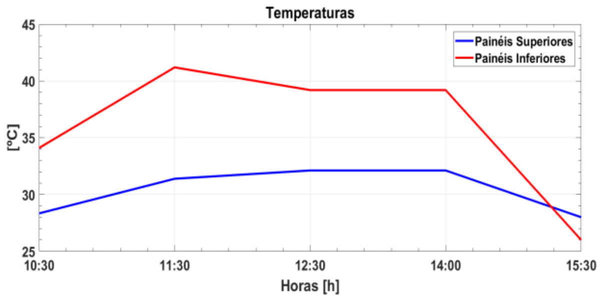

Fig 18. Cells working temperatures calculated by the thermal model (in blue the upper panel, in red the lower panel).

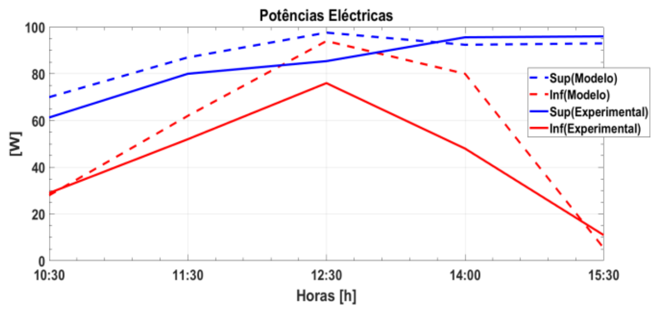

Fig 19. Output powers of the upper panels (in blue) and lower panels (in red). The spaced coloured lines represent the electrical model prediction.

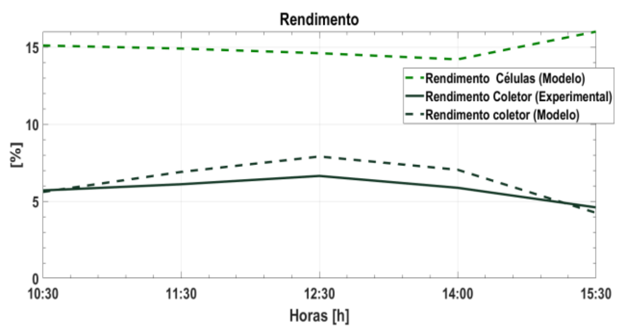

Fig 20. Electrical efficiencies from the point of view of the solar panels (light green line, calculated by the electrical model) and from the CPVT point of view (dark green lines)

B. Portugal vs Sweden comparison

As proposed in the objectives of this work, the comparison of the CPVT working at these two regions was done. For each country we simulated the CPVT working in January and August, being the optimal tilt angles the following:

- Portugal January: 50˚
- Portugal August: 20˚
- Sweden January: 70˚
- Sweden August: 30˚

The simulations preformed were similar to the ones done at the ones done for the 6th of July. The next set of figures show the obtained results.

1) August results

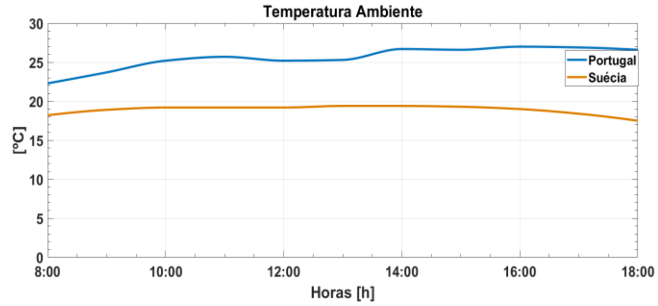

Fig 21. Average outside temperatures for Portugal (blue line) and Sweden (orange line).

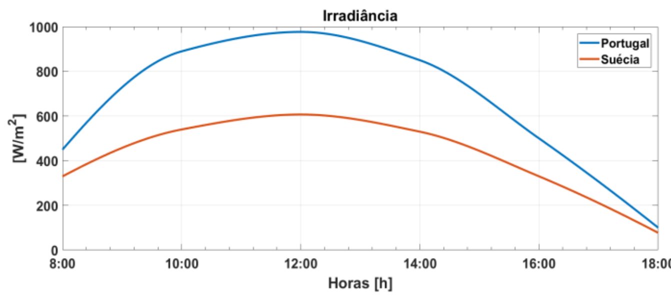

Fig 22. Average irradiance for Portugal (blue line) and Sweden (orange line).

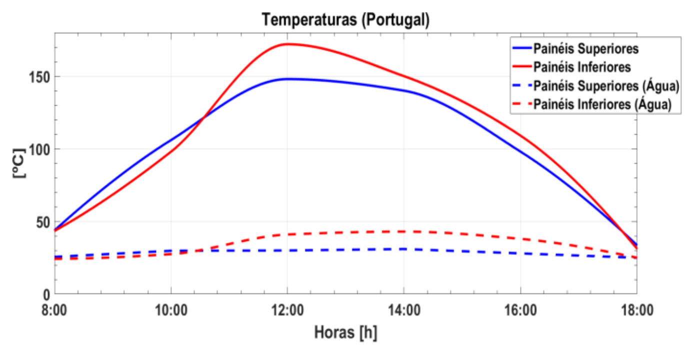

Fig 23. Cells working temperatures in Portugal calculated by the thermal model (in blue the upper panels, in red the lower panels). The spaced lines represent the cooling functioning.

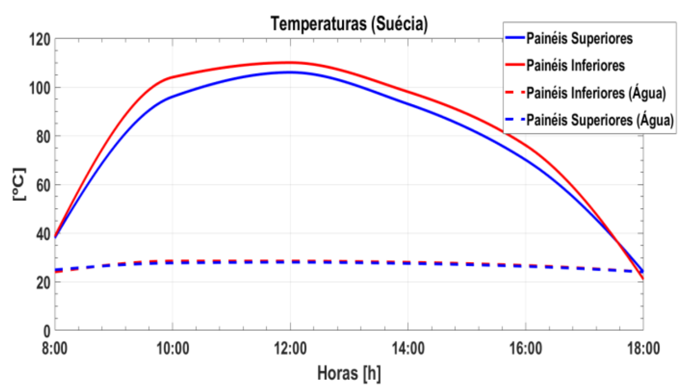

Fig 24. Cells working temperatures in Sweden calculated by the thermal model (in blue the upper panels, in red the lower panels). The spaced lines represent the cooling functioning.

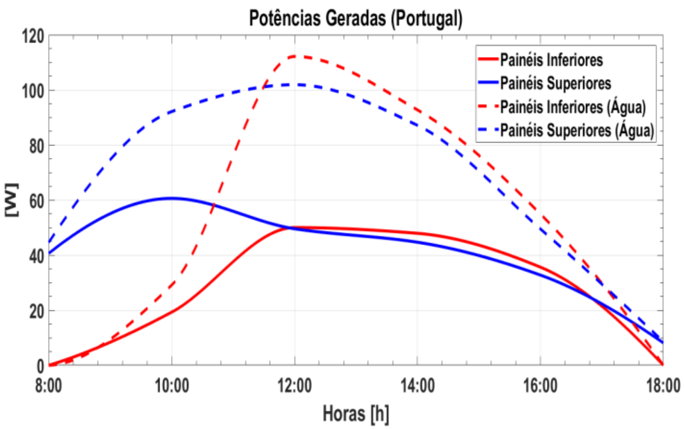

Fig 25. *Output powers in Portugal calculated by the electrical model (in blue the upper panels, in red the lower panels). The spaced lines represent the cooling functioning.*

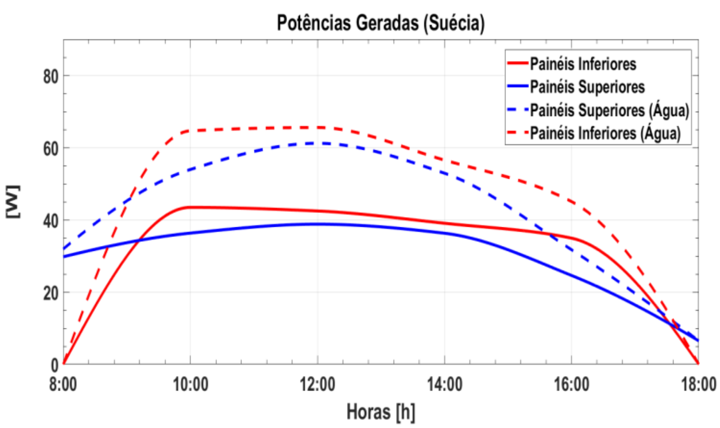

Fig 26. *Output powers in Sweden calculated by the electrical model (in blue the upper panels, in red the lower panels). The spaced lines represent the cooling functioning.*

2) January results

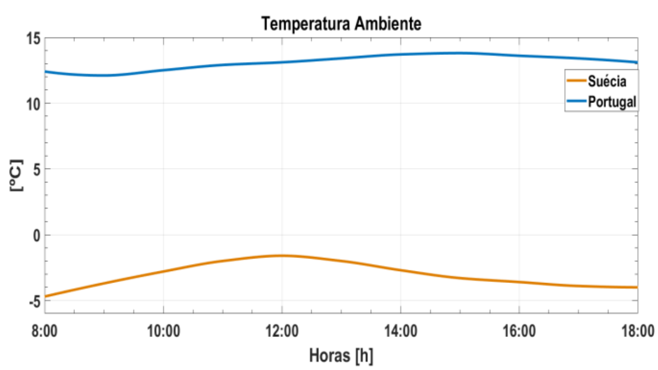

Fig 27. *Average outside temperatures for Portugal (blue line) and Sweden (orange line)*

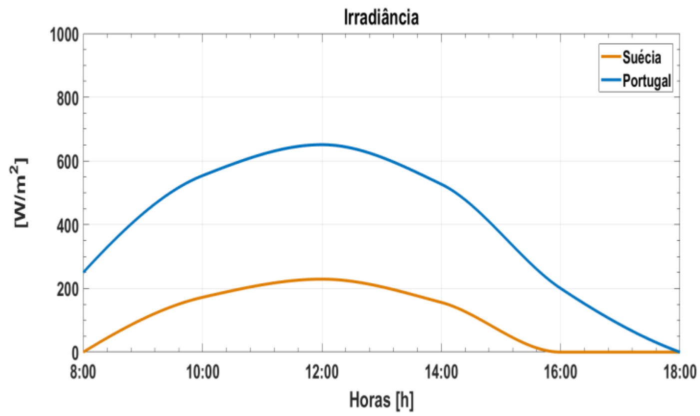

Fig 28. *Average irradiance for Portugal (blue line) and Sweden (orange line)*

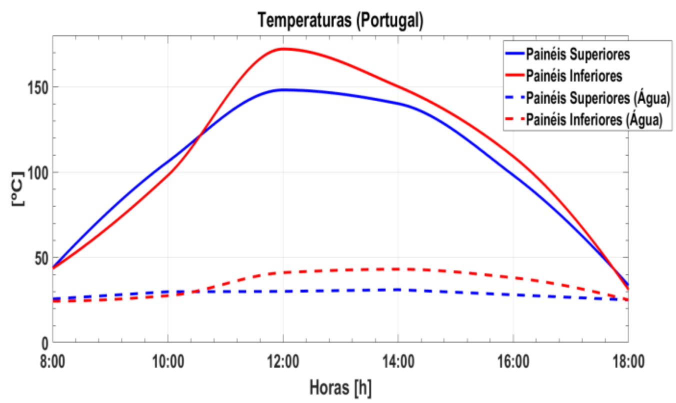

Fig 29. *Cells working temperatures in Portugal calculated by the thermal model (in blue the upper panels, in red the lower panels). The spaced lines represent the cooling functioning.*

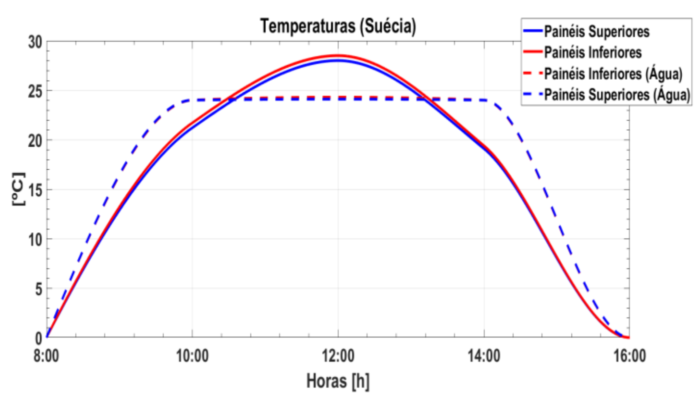

Fig 30. *Cells working temperatures in Sweden calculated by the thermal model (in blue the upper panels, in red the lower panels). The spaced lines represent the cooling functioning.*

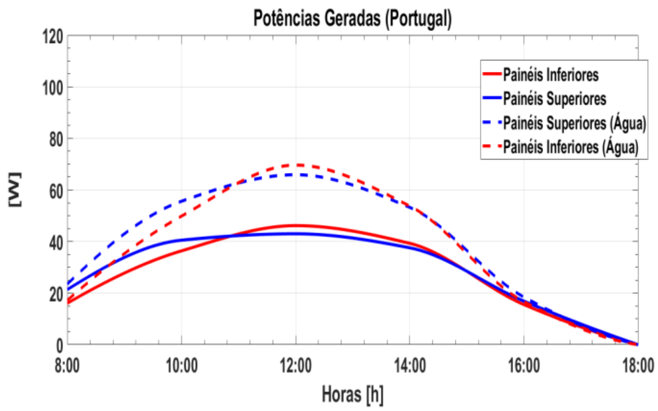

Fig *31. Output powers in Portugal calculated by the electrical model (in blue the upper panels, in red the lower panels). The spaced lines represent the cooling functioning*

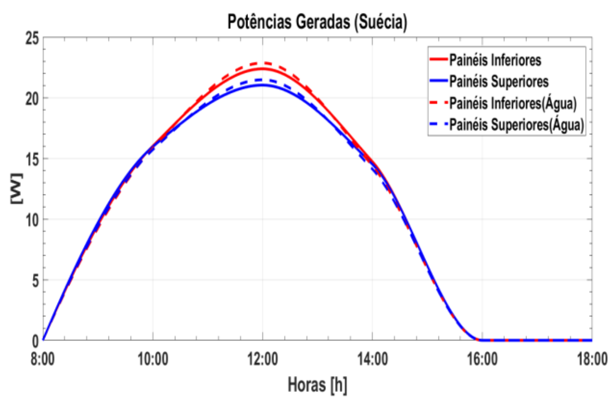

Fig *32. Output powers in Sweden calculated by the electrical model (in blue the upper panels, in red the lower panels). The spaced lines represent the cooling functioning.*

IV. Conclusions

By the end of this work it was possible to understand the main factors to take into account when modelling a system like this. Details like the tilt angle have an extreme influence on how a CPVT like this is going to behave.
Bearing in mind the models developed and when comparing its results with the experimental ones, it is possible to see that the electrical model output behaviour it is satisfactory.

Focusing now on the comparison between Portugal and Sweden, the following can be remarked:

- At both regions we got high levels of solar concentration, taking in to account that the simulations were performed for the optimal tilt angles.
- Speaking of electrical performance (considering here the cooling functioning) it was clear that there is an advantage for the Portuguese installation. The solar profile here is a key factor as we could see, in January there was a short duration of solar exposure for the Swedish installation.
- For the same reason above, the thermic potential is higher in Portugal on the winter season when compared with Sweden.
- We could see also that the CPVT has a poor global efficiency. For the same area of exposure would be better to install full photovoltaic panels.
- However, it was possible to understand that the built in cooling system works as expected even though, the full thermal system could not be implemented as desired.

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