CASPER - CSP Performance Comparison Tool (BETA)

Abstract

CASPER has been developed by Solarflux as a way to compare the Solarflux FOCUS parabolic dish with a comparable CSP technology, parabolic trough. Every effort has been made to provide an impartial comparison between the technologies. Please bear in mind that this is a beta version of the tool and some shortcomings exist in the methodology (see Limitations section). The tool is under ongoing development and further refinements and features can be expected.

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1. Overview

The goal of the CASPER is to provide a clear comparison between the Solarflux FOCUS and generic parabolic trough technology and to illustrate the significant difference in efficiency between the 2-axis[2] FOCUS and single-axis trough. The tool is divided into three sections:

1. The Upper Bar where location is input and some info is available.
2. The Chart Area which illustrates a yearly profile of the two technologies.
3. The Lower Bar where trough efficiency is input and location details are displayed.

Fig. 1

The **Upper Bar** (Fig. 1) contains two sections. On the left is the location section which prompts the user to enter a location. When the calculate button is clicked, the address will be converted into coordinates to be used in the calculations. The address lookup process is called Geocoding and is provided by OpenStreetMap's Nominatim service.

On the right side of the Upper Bar is the *FOCUS vs Trough Efficiency %* output. This shows the estimated difference in collected energy between the two technologies per month. A positive number indicates the FOCUS collected more than the trough. Negative indicates the trough fared better. The figure is the percentage difference between the two. Finally on the far right is a CSV download button which when clicked will download a more detailed breakdown of the calculations.

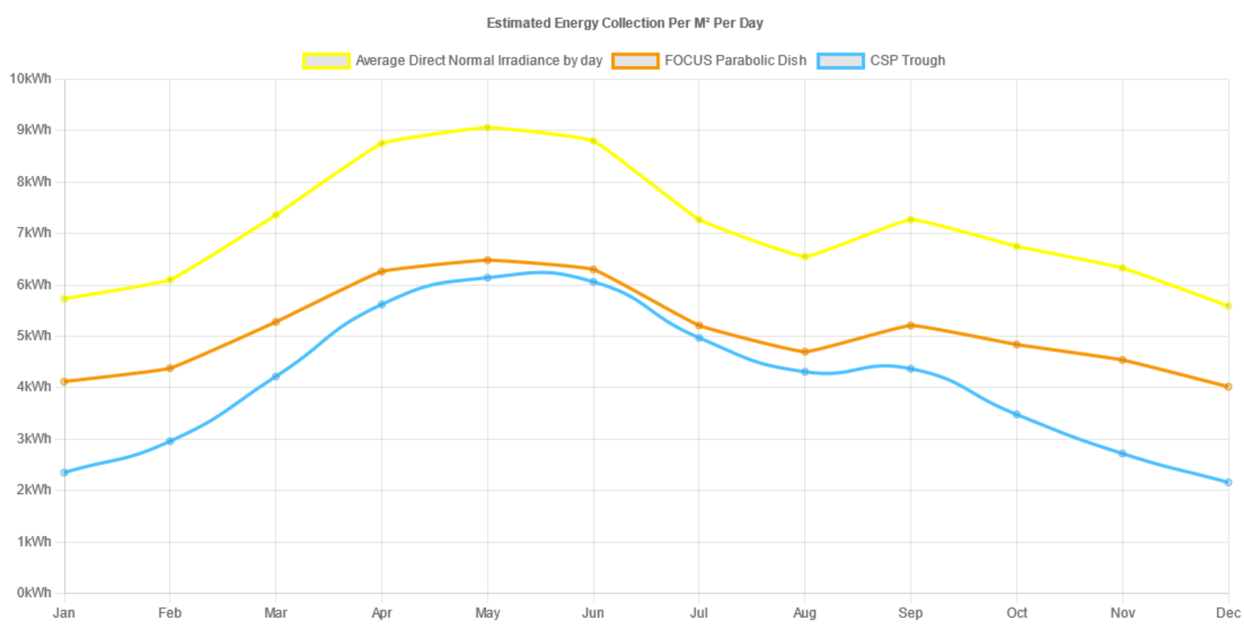

Fig. 2

The **Chart Area** (Fig. 2) displays a line graph with three lines. The yellow line is the average DNI[3] per day for each month in kWh. The orange line is the estimated energy collection per day for the Focus. The blue line is the estimated energy collection per day for the selected trough model. Each point on the graph represents the estimated average per day for each month of the year.

Trough Solar-to-thermal Efficiency
70%

Location	latitude	longitude	Average DNI (kWh/m²/day)
Phoenix, AZ, USA	33.4	-112.1	7.13

Fig. 3

The **Lower Bar** (Fig. 3) also contains two areas. The first invites the user to enter a peak solar-to-thermal efficiency for the trough. This value defaults to 70% which is around the upper range of parabolic trough conversion efficiency.
The other section displays the other parameters of the calculation, namely, the location, the location coordinates and the average daily DNI for that area. It can be useful to the user to double check the coordinates provided are correct because a confusing address might return the wrong location. For example, if a user enters “Reading” the geocoding service might return coordinates for Reading, PA, USA or Reading, Berkshire, England.

Finally, the **CSV Download** offers a more detailed breakdown of the information contained in the chart.

- The first two columns, **Month** and **DNI(kWh/m²/Day)** are self explanatory.
- **Incident Energy** is the daily average amount of solar energy falling on the device calculated simply as DNI * Reflective Aperture. CASPER assumes a reflective aperture of 1 square meter so this value is the same as DNI but in the future the tool may allow user defined aperture areas.
- **Peak Solar-to-Thermal Efficiency** is the expected conversion rate when the sun’s rays are perfectly perpendicular to the device.
- The **Cosine Effect** is the effective reduction in reflective aperture caused by the sun’s rays striking the device at an angle.
- **Average Solar-to-Thermal Efficiency** is the expected conversion rate of the device after the *Cosine Effect* has been applied.
- **Energy Collected** is the portion of Incident Energy the device is capable of collecting for a given Average *Solar-to-Thermal Efficiency*.
- **FOCUS Dish vs Trough** shows the estimated difference in collected energy between the two technologies per month. A positive number indicates the Focus collected more than the trough. Negative indicates the trough fared better. The figure is the percentage difference between the two.

2. Solar Energy Data

The dataset used to predict average DNI values is taken from the NASA Atmospheric Science Data Center. This particular dataset consists of monthly averages taken from earth observation satellites over a 22 year period. The resolution of the dataset is 1 degree so coordinates of higher resolutions are rounded to the nearest degree. Values for each coordinate are regional averages not point data so the rounding effect should be minimal.

3. Cosine Effect Calculations

Cosine effect is defined as the reduction of the receiving area caused by the cosine angle formed between the solar radiation and the normal line. The normal line is the optimal angle of incidence, 90 degrees. For a 2-axis tracking system like the Focus there is no cosine effect because it is always normal to the sun's rays. For a single axis system like a parabolic trough the incidence angle is the same as the solar declination. This is because the sun's apparent movement in the sky is factored out by the trough's east-west tracking leaving only the solar declination.

To calculate the incidence angle, the solar position at noon is calculated using the Sun_Calc javascript library. 'Noon' at the given coordinates is calculated as an offset from GMT/UTC noon based on the longitude and not time zones which are too granular and in some cases don't adhere to the lines of longitude. The cosine of this angle is the cosine effect. Because the comparison tool averages its output over months and the solar declination changes constantly it is necessary to calculate the *average incidence angle by month.* This is done by iterating over each day of the month and calculating that day's angle. The angles for each day can then be averaged together.

4. Focus Calculations

The Focus parabolic dish model is based on a methodology consistent with the ASTM E905 − 87 standard and its predictions are consistent with measurements made by Solarflux during extensive field testing. Because of the 2-axis design cosine effects can be ignored so the output can be estimated as a function of the incident energy and any optical or thermal losses in the system. The losses are as follows:

- **Solar Weighted Reflectance** - Percentage of solar energy that is reflected off of the devices reflective surface. Estimated at 88%
- **Cleanliness** - Estimated at 98%
- **Geometric Distortions** - Warping or other imperfections in the reflector - Estimated at 5%
- **Thermal Distortions** - Warping caused by metal expansion in the reflector - Estimated at 1-(0.0012 * dailyAvgIncidentEnergy)
- **Receiver Strut Shadow** - The shadow cast by the receiver's supporting structure - 3%

- **Reflector Integrity** - Any Damage or thermal degradation of the receiver coating. -Assumed 100%
- **Receiver Conversion Efficiency** -Percentage of energy collected by the receiver and transferred into the HTF[4] - 91%

These parameters are used to estimate the *Average Solar-to-Thermal Efficiency* and from there the predicted *Energy Collected* can be calculated using the *Incident Energy*.

5. Trough Calculations

The Trough calculations use a very basic model which assumes that the user only knows the peak *Solar-to-Thermal Efficiency* of the trough they're comparing. This parameter is then multiplied by the calculated cosine effect to get the *Average Solar-to-Thermal Efficiency*.

6. Limitations

CASPER is provided as a tool to get a general overview of how the FOCUS Parabolic dish compares to Parabolic Trough technology but it is limited in a number of areas. What follows is a brief outline of these shortcomings and how they might affect the tool's accuracy.

1. Operating Temperatures

The efficiency of all CPS receivers is dependent on the temperature at which they are operating. Ultimately, if the fluid in the system is too hot or cold the efficiency will suffer. For this tool it is impossible to predict operating temperature as it is dependent on the energy available, starting temperature, flow rate and the specific heat of the fluid being used, any of which might change day to day.

2. Tracking

The calculations used in the tool assume perfect tracking of the sun. In reality this is rarely the case though the degree to which misalignment might affect the performance of the device is dependent on the geometry of the collector, the positioning of the receiver etc. which cannot be modelled by this tool.

3. Shading

In a CSP array, the collectors are likely to cast shadows on their neighbors when the sun is very high or low in the sky. This shading is dependent on the topology of the site, the time of year, time of day, latitude, positioning of the collectors and their size and shape. These variables and how they relate to shading are not modelled in CASPER.

4. Field Losses

In any installed CSP system some energy will be lost from things like the plumbing between collectors, storage tanks etc. These losses are not factored into this tool as they are highly dependent on numerous variables which cannot be modelled here.

5. Elevation and Topology

The Performance Comparison Tool does not currently take into account the effects of elevation and topology on a systems performance. High elevations may see more sunlight than low ones and sites in the shadow of mountains may receive less daylight. These effects are not factored into the tools models.

6. Climate Change

The models used in this tool make use of 22 year average DNI data. With the world's climate changing rapidly, areas that previously received more rainfall may receive less or vice versa. This might mean that DNI estimates for some parts of the world might be slightly inaccurate.

7. References

- Sun Calc Library - https://github.com/mourner/suncalc
- Nasa Climate Data - https://asdc.larc.nasa.gov/
- ASTM Standard - https://www.astm.org/Standards/E905.htm
- Geocoding Service - https://wiki.openstreetmap.org/wiki/Nominatim

8. Glossary

1. **CSP** - Concentrated Solar Power
2. **2-Axis Tracking** - Solar technology which tracks the sun east-to-west (Azimuth) and up and down (Zenith/Elevation) as it rises and sets.
3. **DNI** - Direct Normal Irradiance measured in Watts per square meter.
4. **HTF** - High Temperature Fluid