The OTSunWebApp

-Tutorial 4-

-First edition-

Simulation of a Linear Fresnel Reflector

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Table of Contents

On the OTSun project

The OTSun project is a research project whose main objective is to develop an open-source software to simulate the optical behavior of solar collectors. In this Monte Carlo ray tracing program, the trajectory of light rays is determined by the optical Fresnel equations in its more general form without further simplifications. The geometrical objects used in this package are created using the parametric 3D modeler FreeCAD, which is also a free and open source program and allows for the construction of arbitrary geometries. OTSun determines the optical efficiency of solar-thermal collectors and photovoltaic solar cells. Its library is hosted on GitHub in the following link:

https://github.com/bielcardona/OTSun

In order to make it more user-friendly, a webtool has been developed which is located at the following link:

http://otsun.uib.es/otsunwebapp.

For more details, visit the OTSunWebApp folder documentation:

https://github.com/bielcardona/OTSun/tree/master/OTSunWebApp

1. Objective and first steps

In this tutorial, an example of a simulation with the OTSun web app is outlined step by step. The main goal of this tutorial is to demonstrate how to obtain the optical efficiency of a Linear Fresnel Reflector (LFR).

The LFR is illustrated in Fig. 1, consists of a frame of eleven curved primary mirrors, a truncated Compound Parabolic Concentrator (CPC), a transparent cover surface at the bottom of the CPC, and the receiver: a flat absorber at the top of the CPC. Figure 2 illustrates the cross-sectional view of the mirrors and receptor, together with a description of each element.

Before conducting the simulation, it is recommended that the user visualizes the geometry. To do so, it is necessary to install FreeCAD 0.18. The *FCStd file (FreeCAD format) where the LFR geometry is defined can be downloaded from the following link: test_LFR.FCStd.

When the geometry is visualized in FreeCAD, the object labels contain words in parentheses (see Fig. 3). These are the objects that will interact with the rays during the optical simulation; the first word in the parentheses is the name of the optical material of the object. Due to primary mirrors track the sun in order to reflect the rays at one point in the receiver (the Target), the object mirrors have three additional elements in the parentheses: Axis, Normal, Target. The description of them is given bellow:

- Axis: rotation axis of the mirror.

- Normal: normal vector of the mirror aperture.

- Target: 3D point to reflect the rays.

Note that each name (Axis, Normal, Target) corresponds to the label of a FreeCAD object that matches with the 3D element for such purpose, i.e. Axis and Normal are a line and Target is a point. Here it is advisable to browse through the different objects of the FreeCAD project in order to get a better understanding of the LFR geometry.

Once the user is acquainted with the geometry, he or she can proceed with the configuration of the simulation using the OTSunWebApp, which is located at the following link: http://otsun.uib.es/otsunwebapp/node/start (Fig. 4).

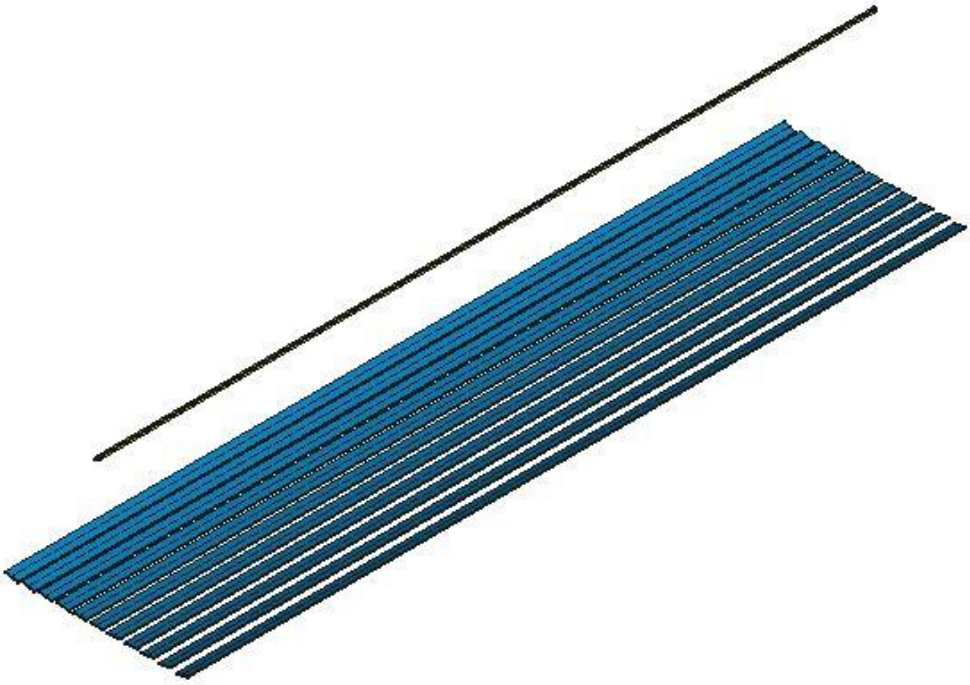


Fig. 1. Geometry of the LFR that is to be simulated.

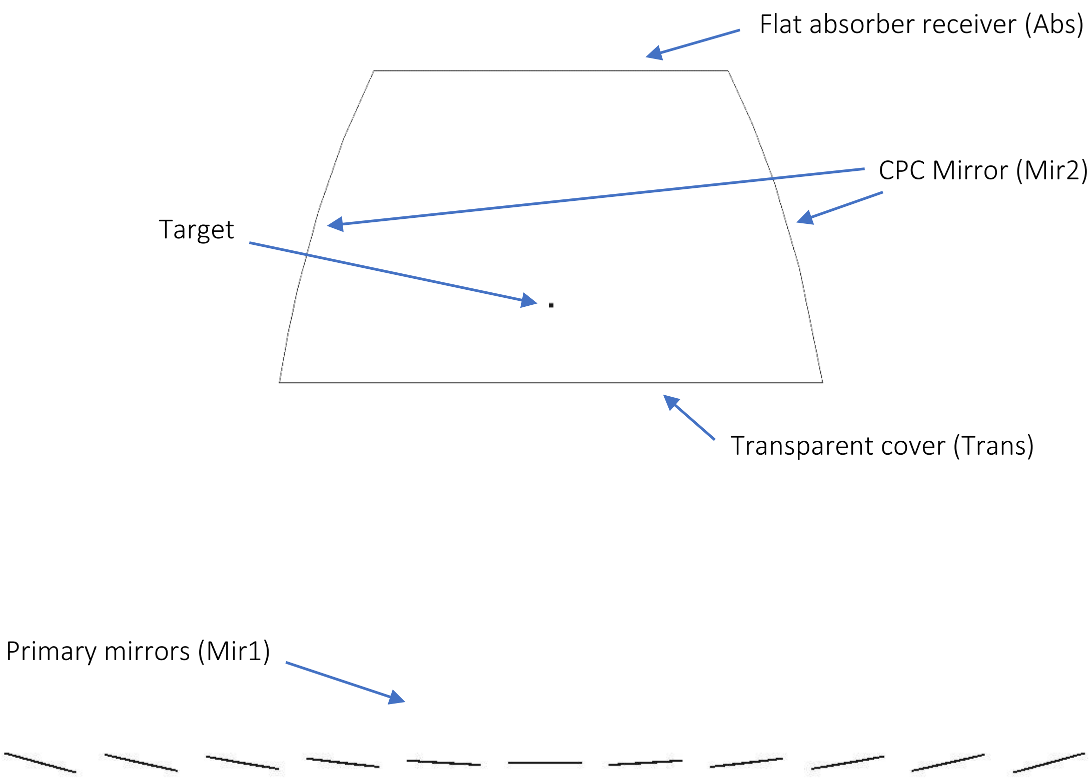


Fig. 2. Cross-sectional of the receiver (CPC, absorber and cover layers), and the eleven primary mirrors. The names of the different objects appear with the corresponding names of the optical material assigned in parentheses. Not to scale.

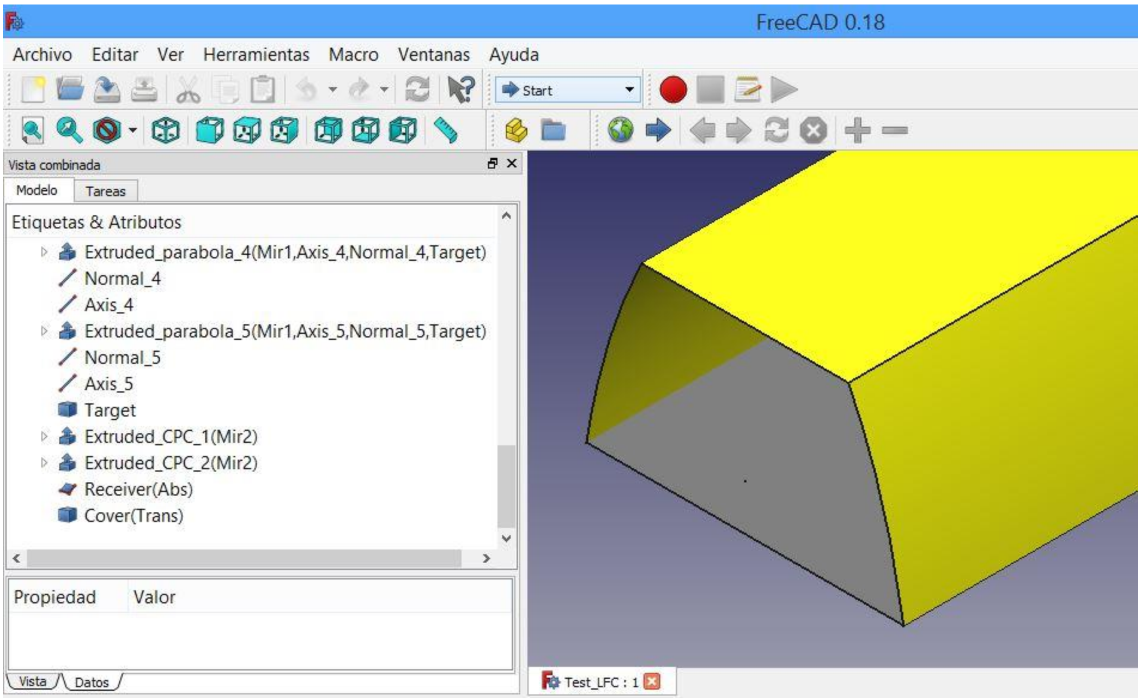


Fig. 3. Visualization of the collector geometry in FreeCAD. The different collector components are listed in the panel on the left. Each object is shown together with its respective label. The names in parentheses indicate the necessary information to assign materials, and/or to perform sun tracking movements.

2. Getting started

Fig. 4. Home page of the OTSun webApp.

1. Type in the email address where the user wants to receive the results of the simulation.
2. Click on “submit”.

3. Upload the geometry

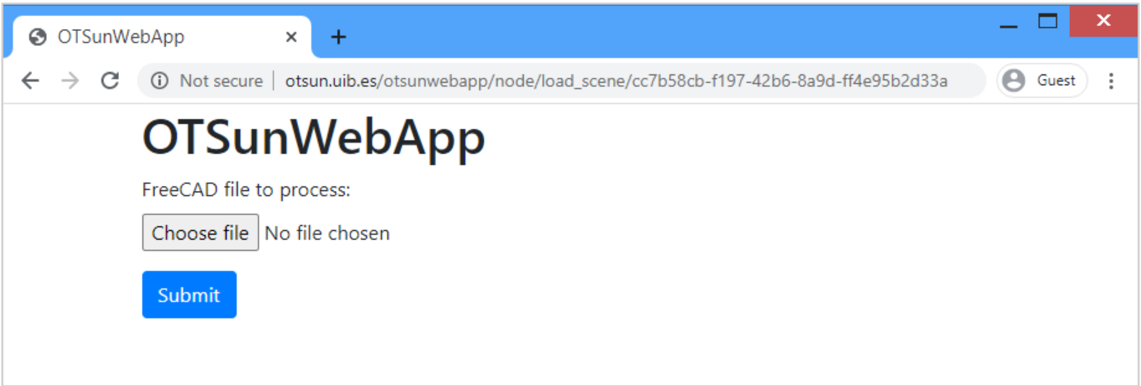


Fig. 5. Website to which the FreeCAD file (where the solar collector geometry is defined) should be uploaded.

1. Select the file test_FR.FCStd, which contains the geometry of the Linear Fresnel Reflector.
2. Click on “submit”.

4. Objects and materials

On the next webpage, the optical objects of the uploaded solar collector appear (see Fig. 6). These objects are:

- Surface material: Trans, Mir1, Abs, Mir2

At this point, the optical materials of the objects that interact with rays must be defined. For each material, a *.otmaterial file is needed. How to create such files is explained below.

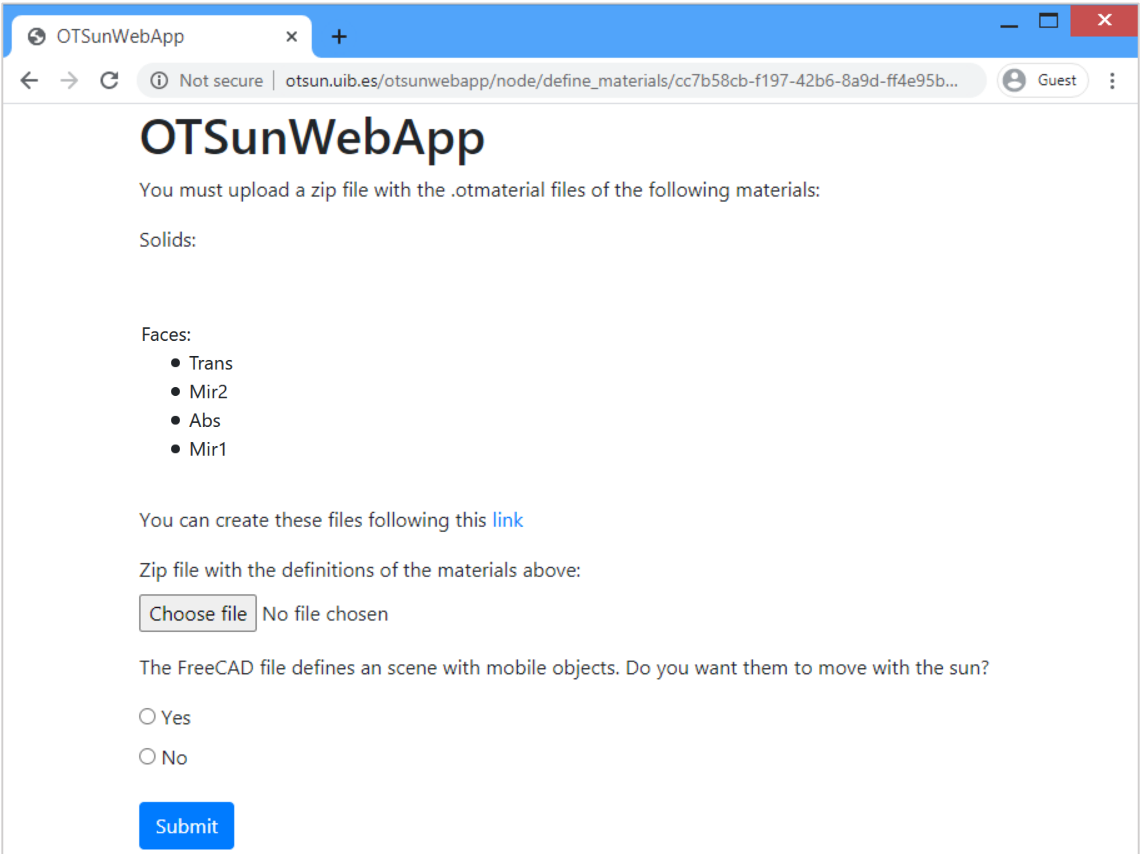


Fig. 6. Webpage for uploading material files present in the solar collector design.

It is important to note that the names of the material files must be identical to the first word in parentheses of the label of each respective FreeCAD object. Fig. 3 shows the label of each material in this particular case.

If the user has already created a *.zip file containing all the optical property material files:

1. Select the *.zip file that contains all the material files.
2. Click on "submit".

Otherwise, the user must create the files for each material manually:

1. Click on the hyperlink shown in Fig.6, which will redirect the user to the "*Creator of Materials*" site (http://otsun.uib.es/otsunwebapp/material). This link leads to the tab shown in Fig. 7.
2. Identify each of the materials with the names that appear in Fig. 6 (Trans, Mir2, Abs and Mir1). The following instructions describe how to create the material file called Mir1, which is the label for the primary mirrors of the collector.
3. Select "Surface" from the "Kind of material" drop-down list, since it is a surface material (Fig. 7).
4. Select "Reflector Specular Layer" from the "Kind of surface" drop-down list (Fig. 8), since it is a surface material with a constant reflective index.
5. The parameters are the following: Probability of reflection = 0.95, the rest empty.

6. Click on “submit”. At this moment, the application has generated a file for this material called “Mir1.otmaterial”.
7. For the rest of the materials, the same steps must be followed, choosing the characteristics described in Table 1 for each one of them.
8. Once all the four material files have been created, they should be stored in the same local folder and compressed into a single *.zip file, as illustrated in Fig. 9.
9. Go back to the previous tab and upload the *.zip file (see Fig. 10).

Before submitting, click on “Yes” in the item “the FreeCAD file defines a scene with mobile objects. Do you want them to move with the sun?” to perform the sun tracking movements in primary mirrors.

Click on “submit”.

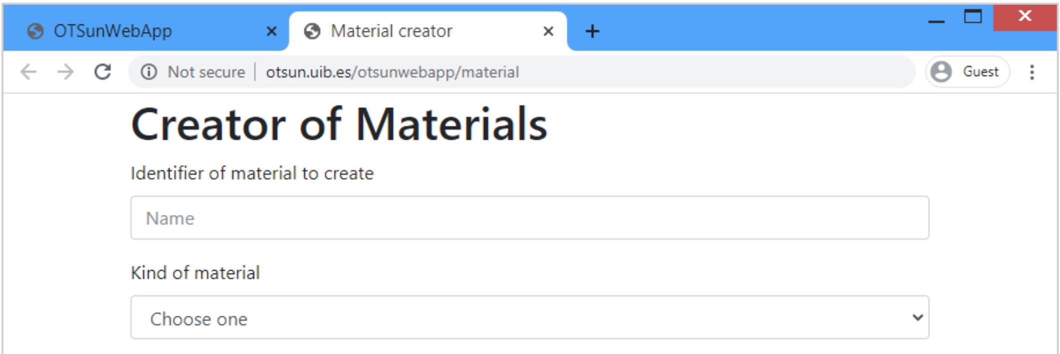


Fig. 7. Webpage for the creation of OTSun material files.

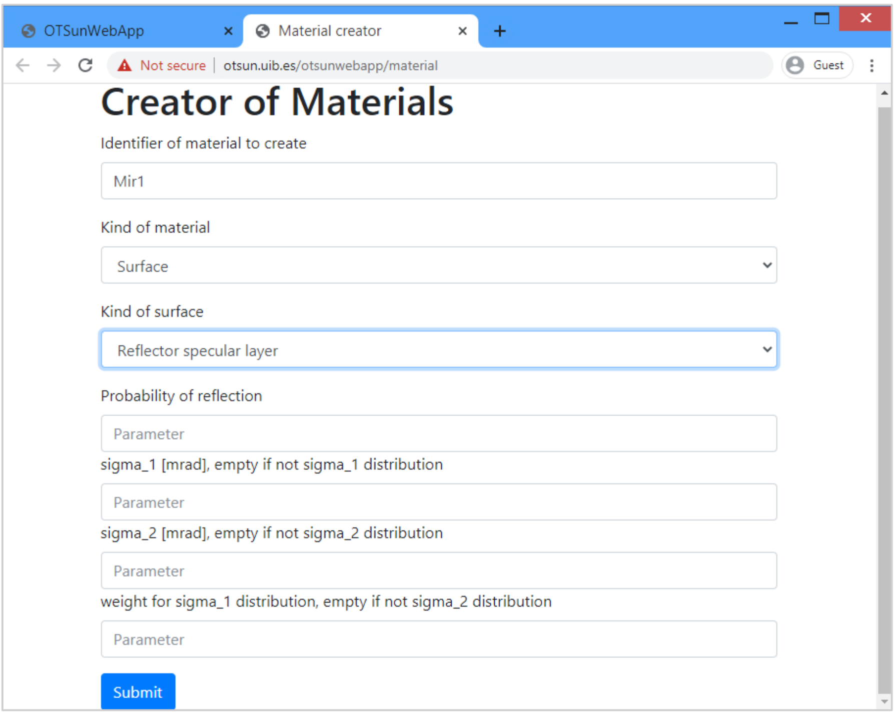


Fig. 8. Webpage for the creation of OTSun material files.

Table 1. Characteristics of the materials.

Material	Name	Type - subtype of material	Optical properties
Primary Mirror	Mir1	*Surface - Reflector Specular layer*	R = 0.95
CPC Mirror	Mir2	*Surface - Reflector Specular layer*	R = 0.91
Transparent material	Trans	*Surface - Transparent Simple layer*	T = 0.965
Absorber material	Abs	*Surface - Absorber simple layer*	α = 0.95

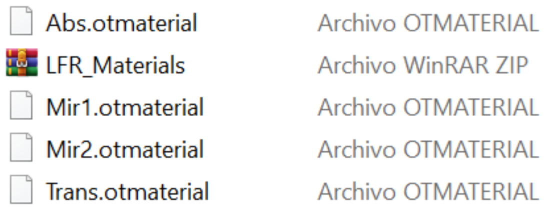


*Fig. 9. Directory containing the OTSun material files of each component, and the collective *.zip folder.*

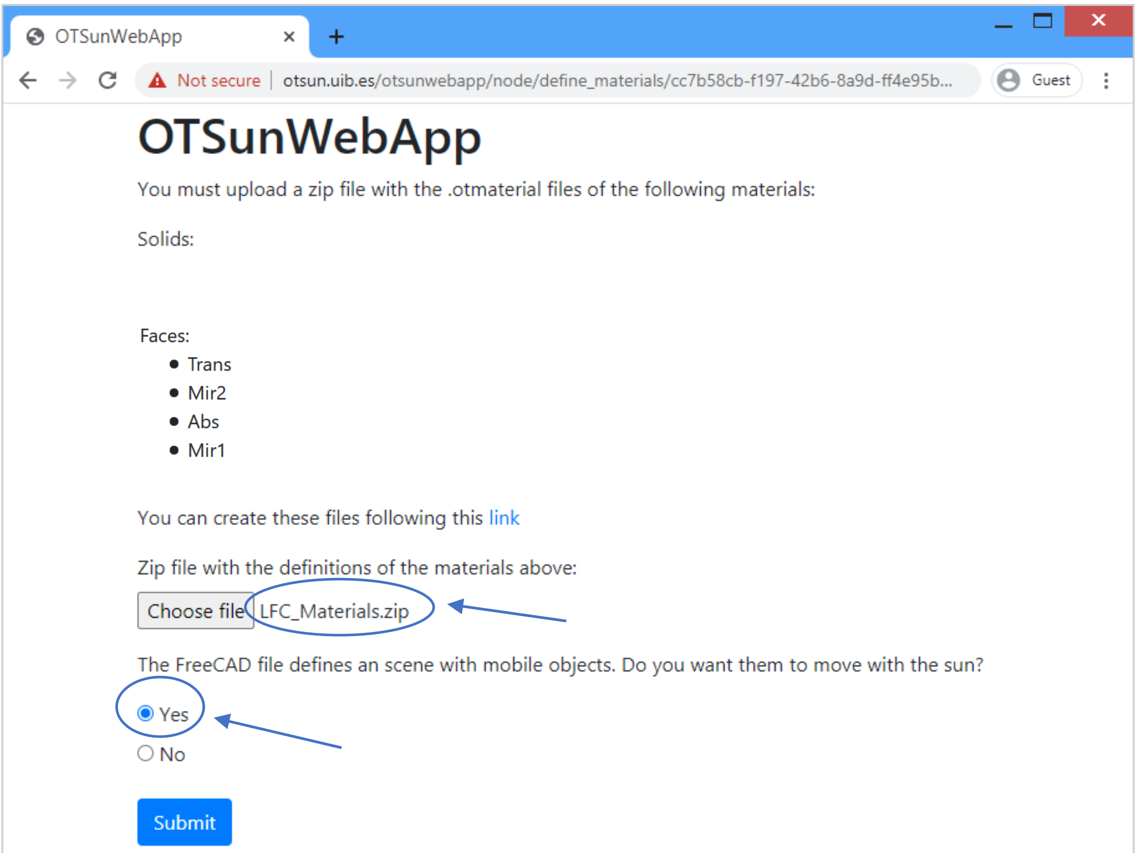


*Fig.10. Webpage for uploading the material files. The *.zip folder containing all material properties has been selected.*

5. Inputs for the simulation (experiment)

In the drop-down list shown in Fig. 11, there are three types of analysis to perform in the simulation. In this case, the user will select "*Total analysis*", the purpose of which is to obtain the optical efficiency for different positions of the sun, based on the Reference Air Mass 1.5 Spectra for direct solar radiation: ASTMG173. The results are presented in *.txt files.

In this example, the simulation is at normal incidence. The number of rays is 1000. This number has been chosen so that the calculation is quick. To obtain a more reliable result, the use of at least 100000 rays is recommended for this LFR. The aperture area of the LFR is 176000000 mm^2. Note that the LFR is a solar thermal collector, hence this is the aperture area for optical thermal efficiency, while the aperture area for photovoltaic is null since there is no photovoltaic material. Finally, a Circum Solar Ratio (CSR) value of 0.05 is chosen for the Buie model of the Sun [1].

The parameters are summarized below:

1. Select "Total analysis" and click on "submit". The simulation parameters will then be defined (see Fig. 12).
2. Sun position: $\phi_i = \phi_f = 0^{\text{o}}$, and $\theta_i = \theta_f = 0^{\text{o}}$.
3. Number of rays: 1000.
4. Collector aperture area for thermal: 176000000 mm^2. This is the aperture area of the LFR.
5. CSR value: 0.05.
6. Click on "submit".

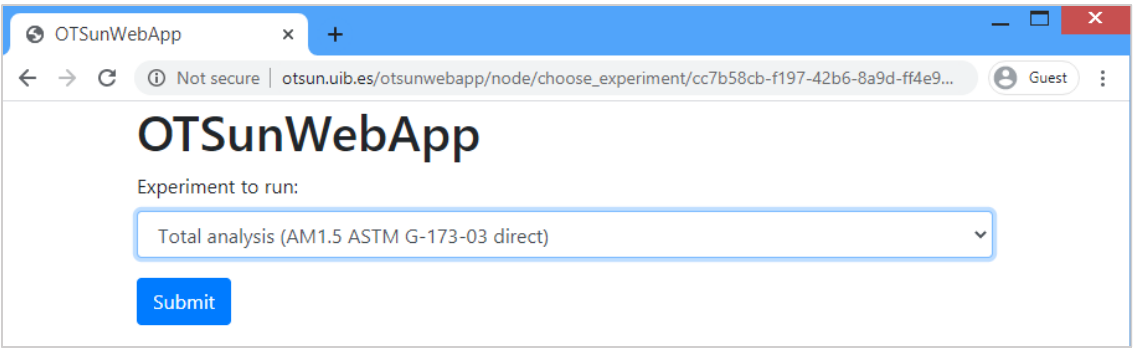


Fig. 11. On this webpage, the simulation type can be selected. In this case, a "Total analysis" will be conducted.

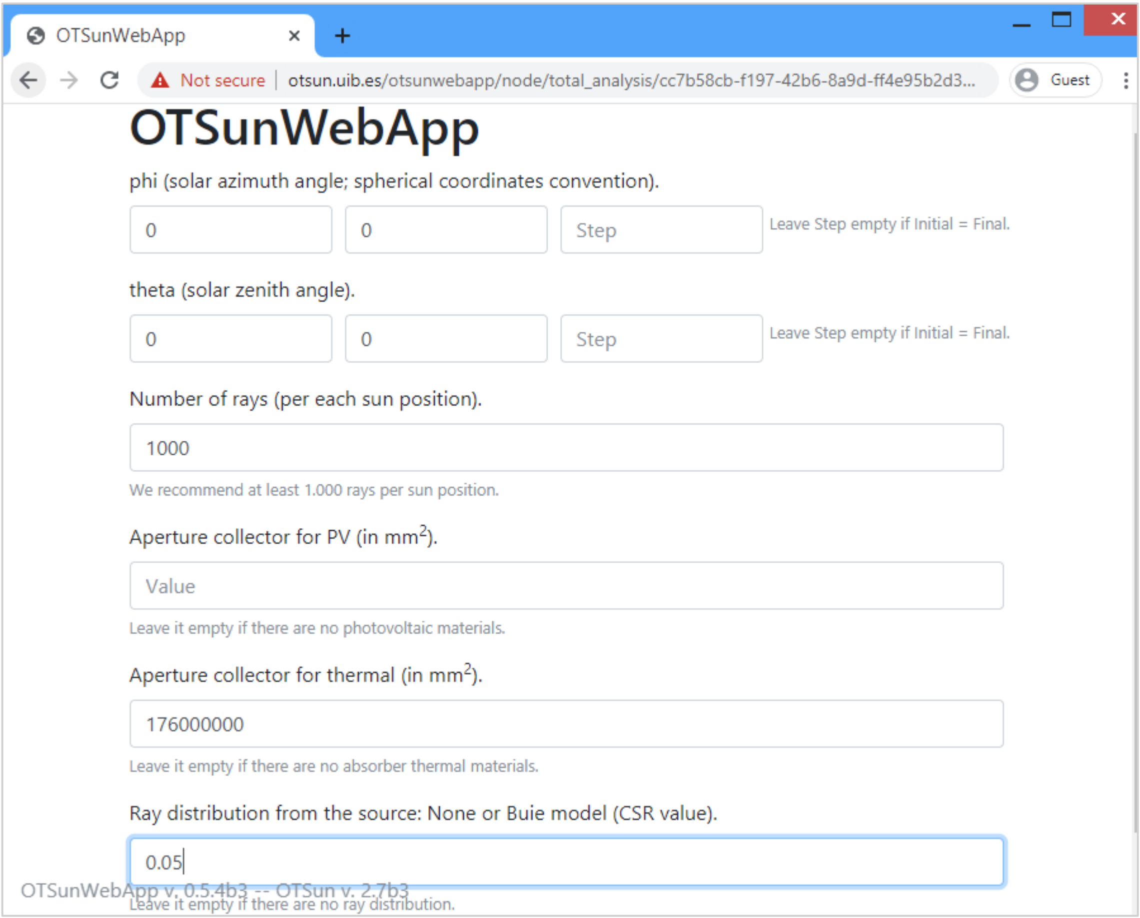


Fig. 12. Webpage with the ray tracing configurations.

6. Run simulation

At this point, the application displays the webpage illustrated in Fig. 13. The instructions presented on this webpage must be followed to start the simulation process. By clicking on “OK”, the user will reach the webpage illustrated in Fig. 14, which will show whether there is an error. An error indicates that the simulation could not be executed. If there are no errors, a link appears from which the simulation status can be accessed (see Fig. 15). On this webpage, if the user refreshes the webpage, the simulation progress is displayed.

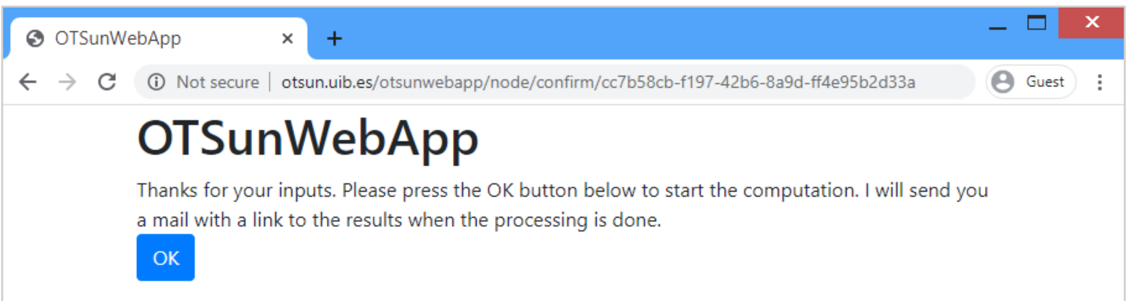


Fig.13. Confirmation message after all ray tracing settings have been uploaded successfully.

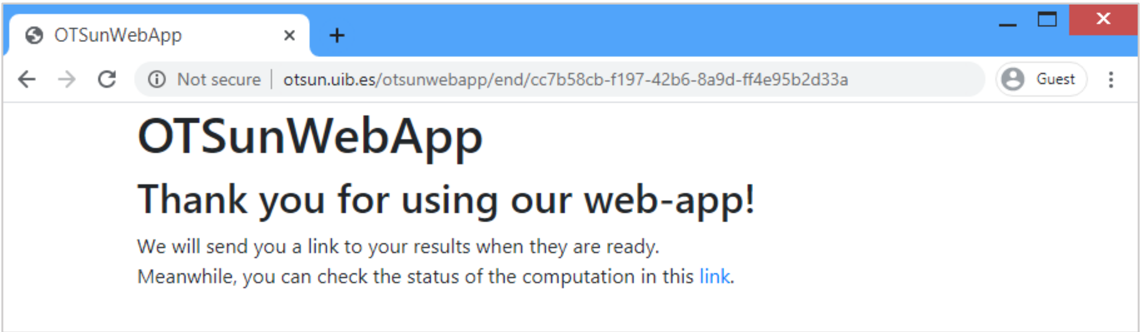


Fig.14. "Thank you" message. The link that appears leads the user to the webpage with the computation status.

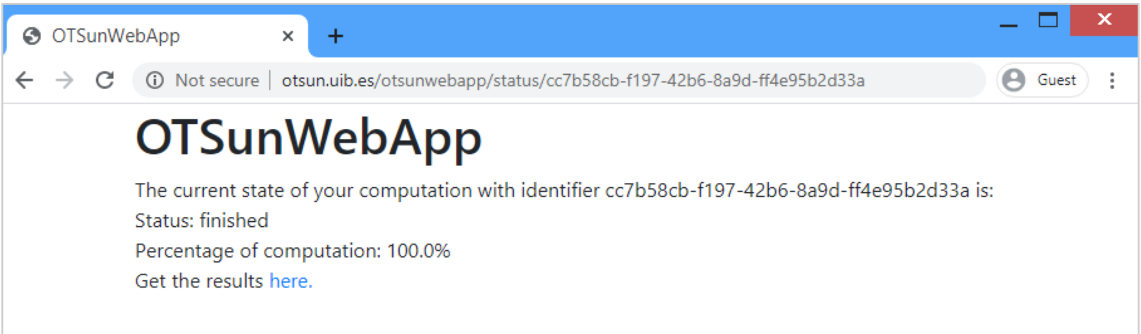
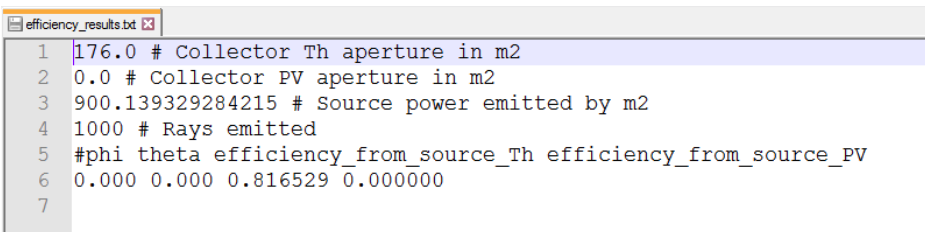


Fig. 15. Webpage with the computation status.

7. Results

Shortly after the simulation has finished, the user will receive an email at the address that he or she previously specified. The email contains a hyperlink ("Get your results at: *link*"), which will trigger an automatic download of an "output.zip" file that contains the results. This compressed file contains the "efficiency_results.txt" file.

In addition to a short summary of the main configuration parameters, the file also contains the simulated optical efficiency at normal incidence (see Fig. 16). In this example, the optical efficiency at normal incidence is 81,65%. This value is only indicative; the result can oscillate around this value because a greater number of rays is needed for the convergence of the optical efficiency.


efficiency_results.txt

```
176.0 # Collector Th aperture in m2
0.0 # Collector PV aperture in m2
900.139329284215 # Source power emitted by m2
1000 # Rays emitted
#phi theta efficiency_from_source_Th efficiency_from_source_PV
0.000 0.000 0.816529 0.000000
```

Fig.16. Text file with the results of the simulation.

8. Practical examples

In the following examples, the parameters to be introduced are shown in order to obtain the optical efficiency in the longitudinal plane and in the transversal plane of the LFR.

8.1. Longitudinal plane

The purpose of this example is to obtain the optical efficiency in the longitudinal plane. The simulation of the LFR is carried out in the same way as in the previous sections, but now introduces the following values for the parameters described in Section 5:

1. Sun position: $\phi_i = \phi_f = 90^\mathrm{o}$, and $\theta_i = 0^o, \theta_f = 90^\mathrm{o}$ and $\Delta\theta = 5^\mathrm{o}$.
2. Number of rays: 100000.
3. Aperture collector for thermal: 176000000 mm^2.
4. CSR value: 0.05.

Please note that due to the high number of rays emitted and the number of sun positions now considered, the calculation will take longer, depending on the availability of the server. The results are illustrated in Fig. 17 and in Table 2.

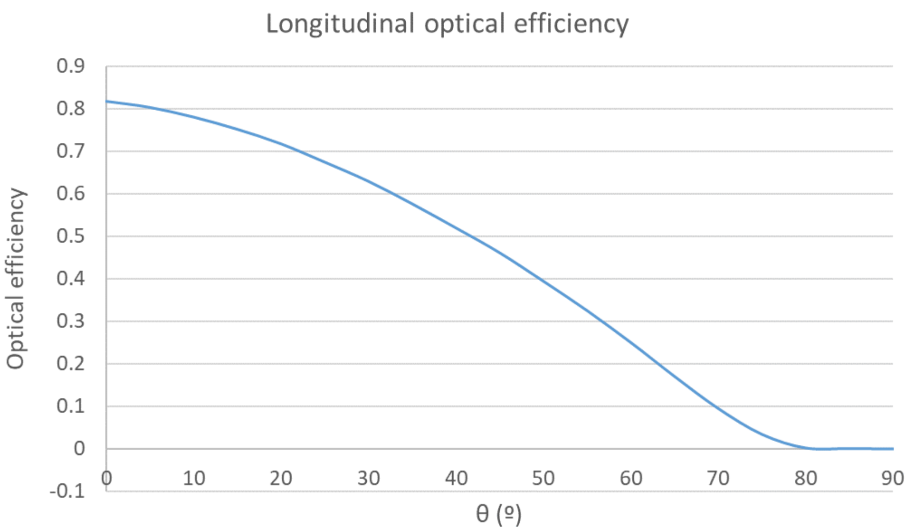


Fig. 17. Optical efficiency depending on the incidence angle in the longitudinal plane.

Table 2. Simulation results for the longitudinal plane of the LFR.

Φ (°)	θ (°)	Efficiency from Source Th
90	0	0.818545
90	5	0.80429
90	10	0.781446
90	15	0.752685
90	20	0.718439
90	25	0.675358
90	30	0.630182
90	35	0.577036
90	40	0.520422
90	45	0.461848
90	50	0.394732
90	55	0.325536
90	60	0.250385
90	65	0.170442
90	70	0.094932
90	75	0.034128
90	80	0.002237
90	85	0.001055
90	90	0.000028

8.2. Transversal plane

The purpose of this next example is to obtain the optical efficiency in the transversal plane. The simulation of the LFR is carried out in the same way as in the previous sections, but now introduces the following values for the parameters described in Section 5:

1. Sun position: $\phi_i = \phi_f = 0^o$ and $\theta_i = 0^o, \theta_f = 90^o$ and $\Delta\theta = 5^o$.
2. Number of rays: 100000.
3. Aperture collector for thermal: 176000000 mm^2.
4. CSR value: 0.05.

Please note that due to the high number of rays emitted and the number of sun positions now considered, the calculation will take longer, depending on the availability of the server. The results are illustrated in Fig. 18 and in Table 3.

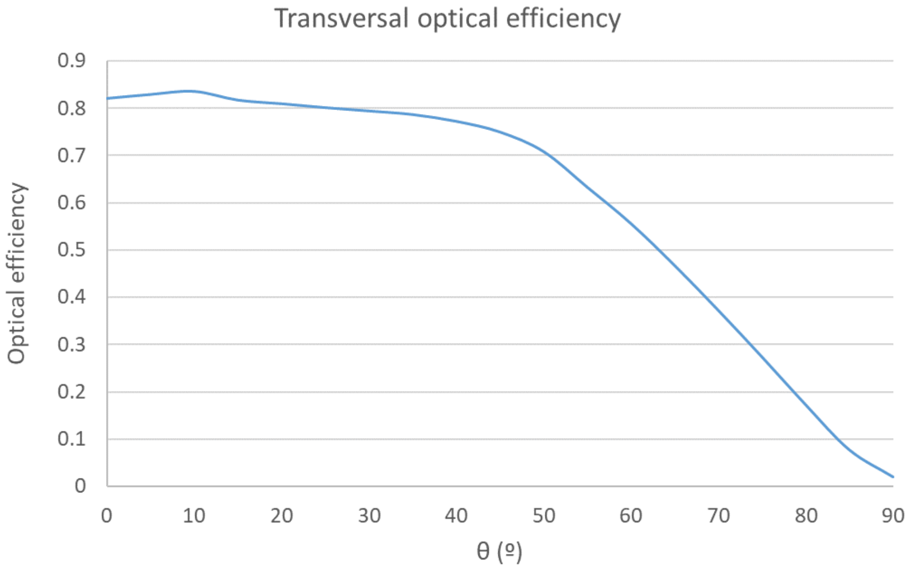


Fig. 18. Optical efficiency depending on the incidence angle in the transversal plane.

Table 3. Simulation results for the transversal plane of the LFR.

Φ (°)	θ (°)	Efficiency from Source Th
0	0	0.820296
0	5	0.828681
0	10	0.835087
0	15	0.816732
0	20	0.808979
0	25	0.800801
0	30	0.793747
0	35	0.786141
0	40	0.771758
0	45	0.749149
0	50	0.707766
0	55	0.632492
0	60	0.555557
0	65	0.467019
0	70	0.371959
0	75	0.273568
0	80	0.172322
0	85	0.07697
0	90	0.019705

References

[1] Buie D, Dey CJ, Bosi S. The effective size of the solar cone for solar concentrating systems. Sol Energy 2003;74:417–27. doi:http://dx.doi.org/10.1016/S0038-092X(03)00156-7.