Types of experiments to run in OTSunWebApp

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Abstract

This tutorial describes how to make simulations with OTSunWebApp.

1 Available simulations

Once the FreeCAD project and the optical materials have been uploaded to the wepApp, the user must choose the type of computation to run. Although the modular design of the webapp allows for the inclusion of new experiments, there are currently implemented three different ones, which we call: "Single experiment with plot of rays", "Total analysis (AM1.5 ASTM G-173-03 direct)" and "Spectral analysis (single solar direction)".

The details of the respective simulations are given below, but we first remark that for the sun position (which is a parameter common to all the computations) we use spherical coordinates (as defined in ISO-80000-2), where the parameters of interest are the solar zenith angle θ (the angle between the sun rays and the vertical direction, or Z axis), and the azimuth angle ϕ (the angle between the X axis and the orthogonal projection of the position vector on the XY plane). See Fig. 1 for a depiction.

1.1 Single experiment with plot of rays

With this simulation, the user can visualize the solar rays traced through the scene as they interact with the optical system. Although this experiment gives no analytical results on the performance of an optical system, it is useful to detect macroscopic problems in its design. Tutorial number 3 in (1) gives a step by step demonstration of how to run a simulation that plots rays in a Parabolic Trough Collector (PTC).

Table 1 shows the parameters that the user has to enter in this computation, and notice that in this case all the rays are emitted with the same wavelength, which is given by the user. Once the computation is finished, the user gets as output a single file `drawing.FCStd` showing the mecanical model together with the rays that have been simulated. Figure 2 shows a simulation of the Solar Power Tower (SPT) plant.

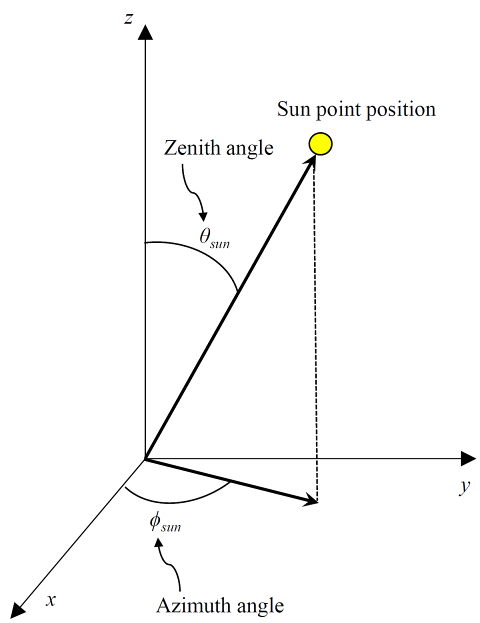

Figure 1: Solar zenith angle and solar azimuth angle used to define the sun point position in the coordinate system of OTSunWebApp.

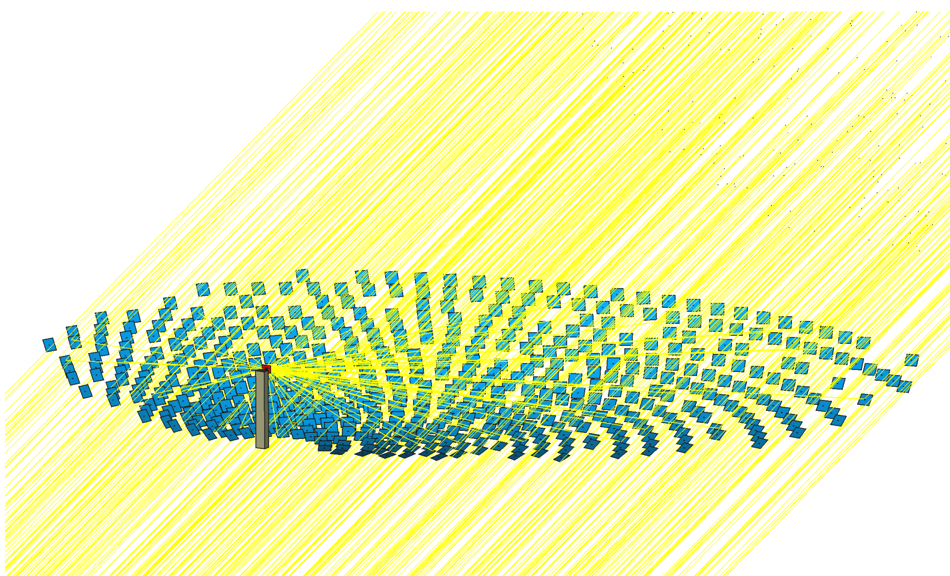

Figure 2: Solar tower power plant based on the PS10 power plant simulated using the computation "Single experiment with plot of rays". Note: the output file is generated without colors associated to objects; we have modified them to improve its visibility.

1.1.1 Total analysis (AM1.5 ASTM G-173-03 direct)

This option is used to calculate the optical efficiency under the solar standard spectrum AM1.5 direct ASTM G-173-03, with solar radiation equal to 900.14W/m^2.Note that the simulation generates rays following the standard solar spectrum for the distribution of wave-

Single experiment with plots of rays (single wavelength)	
Input name as it appears in OTSunWebApp	*Remarks*
ϕ_{sun} (solar azimuth angle)	Value in degrees
θ_{sun} (solar zenith angle)	Value in degrees
Wavelength (in nm).	Value in nanometers
Number of rays to draw	We recommend ≤ 1000
Aperture collector for PV (in mm^2)	Area over which the solar radiation enters the PV material
Aperture collector for thermal (in mm^2)	Area over which the solar radiation enters the thermal absorber material
Ray distribution from the source: None or Buie model (CSR value)	Type the CSR value according to the Buie model for the size of the sun (2), or let empty for a punctual model of the sun

Table 1: Summary of data needed to define the computation in OTSunWebbApp that allows to visualize how rays interact with the scene.

lengths. Consequently, we can calculate the overall amount of power collected by the device for each of the selected sun positions. Tutorial number 1 from (1) shows, step by step, how to compute the optical efficiency of a PTC.

In this computation, the user must define the range of sun positions to simulate (which could be reduced to a single position). To do so, for both ϕ_{sun} and θ_{sun}, he has to give the initial and final values for these angles (in degrees), together with the step between consecutive samples. The rest of parameters needed to launch this computation are listed in Table 2.

The output that the user gets is a text file whose first lines give the parameters that have been used in the computation. The rest of file shows the results of the computation, where each row gives the data $(\phi_{sun}, \theta_{sun}, \eta_{Th}, \eta_{PV})$. Here, η_{Th} and η_{PV} are the optical efficiency for thermal absorber and PV material (respectively) for the position of the sun determined by ϕ_{sun} and θ_{sun} define the sun position. The following example shows the output file of a simulation that calculates the optical efficiency of a PTC, namely the one used in tutorial number 1 from (1).

```
19.090215 # Collector Th aperture in m2
0.0 # Collector PV aperture in m2
900.139329284215 # Source power emitted by m2
10000 # Rays emitted
0.05 # CSR value
PTC.FCStd # FreeCAD file
materials.zip # Materials file
#phi theta efficiency_from_source_Th efficiency_from_source_PV
90.000 0.000 0.800253 0.000000
90.000 10.000 0.772047 0.000000
90.000 20.000 0.734084 0.000000
90.000 30.000 0.663456 0.000000
```

Total analysis (AM1.5 ASTM G-173-03 direct)	
Input name as it appears in OTSunWebApp	*Remarks*
ϕ_{sun} initial	Value in degrees
ϕ_{sun} final	Value in degrees
ϕ_{sun} step	Value in degrees
θ_{sun} initial	Value in degrees
θ_{sun} final	Value in degrees
θ_{sun} step	Value in degrees
Number of rays	Rays for each sun position
Aperture collector for PV	Area (in mm^2) over which the solar radiation enters the PV material
Aperture collector for thermal	Area (in mm^2) over which the solar radiation enters the thermal absorber material
Ray distribution from the source: None or Buie model (CSR value)	CSR value according to the Buie model for the size of the sun (2), or empty for a punctual model of the sun

Table 2: Summary of data needed to define the computation in OTSunWebbApp that allows to compute the total efficiency of systems.

```
90.000 40.000 0.569514 0.000000
90.000 50.000 0.455517 0.000000
90.000 60.000 0.318276 0.000000
90.000 70.000 0.170794 0.000000
90.000 80.000 0.037053 0.000000
90.000 90.000 0.000056 0.000000
```

The optical efficiencies are calculated by OTSunWebApp using the equations:

$$\eta_{Th} = \frac{E_{Th}/A_{Th}}{N/A_{source}}, \tag{1}$$

$$\eta_{PV} = \frac{E_{PV}/A_{PV}}{N/A_{source}}, \tag{2}$$

where E_{Th} is the sum of the energies of all the rays collected by the thermal absorber material (see Tutorial Optical materials), A_{Th} is the so called "Aperture collector for thermal" (see Table 2), N is the number of emitted rays (see Table 2), A_{source} is the area of the ray source (generated internally); E_{PV} is the sum of the energies of all the rays collected by the "PV material" (see Tutorial Optical materials), and A_{PV} is the so called "Aperture collector for PV" (see Table 2). The power collected by the system is the result of multiplying the optical efficiency by the aperture area and by the power emitted by the source, which is $900.14\mathrm{W/m}^2$. Finally, note that the optical efficiencies calculated by OTSunWebApp do not include the cosine factor between source and aperture areas.

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1.1.2 Spectral analysis (single solar direction)

This numerical experiment computes, among other results, the optical efficiency of the system, depending on the wavelength. Tutorial number 2 available at (1) shows, step by step, how to run a *Spectral analysis* of a Silicon solar cell.

The inputs parameters are listed in Table 3. In this case, a single sun position and a range of values for the wavelength have to be given. In addition, the user must give the Internal Quantum Efficiency (IQE) of the PV material, defined as the ratio between the number of electron-hole pairs generated and the number of photons absorbed within the active layer of the device. In case that IQE is constant for all wavelengths, the user must input this value; otherwise he has to upload a text file with rows of the form $(\lambda, \mathrm{IQE}(\lambda))$.

Upon completion, the user gets a zip file containing the following eight files:

- `source_wavelenth.txt`: contains the surface aperture of the source emitting rays [m^2] and settings defined by the user to run the simulation.
- `Th_spectral_efficency.txt`: contains the thermal optical efficiency for each wavelength, in rows formatted as (λ, η_{Th}).
- `Th_integral_spectrum.txt`: contains the power energy absorbed by the thermal absorber material [W], the overall power emitted by the source [$\mathrm{W/m}^2$] and the thermal optical efficiency, all of them considering the AM1.5 ASTM G-173-03 direct spectrum in the range of wavelentghs given by the user.
- `Th_points_absorber.txt`: contains information on the rays at their points of intersection with the absorber material. The information is stored in four columns: energy of the incident ray on the absorber material, 3D-coordinates of the point of intersection with the absorber material, 3D-coordinates of the previous point of intersection with the absorber material, normal vector of the absorber surface, and wavelength of the ray.
- `PV_spectral_efficency.txt`: contains the PV optical efficiency for each wavelength, with rows formatted as (λ, η_{PV}).
- `PV_integral_spectrum.txt`: contains the power energy absorbed by the PV material [W], the overall power emitted by the source [$\mathrm{W/m}^2$], the PV optical efficiency and the photo current generated by surface [A/m^2] in open circuit conditions and having into account the IQE, all of them considering the AM1.5 ASTM G-173-03 direct spectrum in the range of wavelentghs given by the user.
- `PV_paths_values.txt`: contains information about the paths of rays as they interacted with the PV material. The information is stored in the following order: 3D-coordinates of the point at which the ray first enters the PV material, 3D-coordinates of the point at which the ray leaves the PV material, energy of the ray when entering the PV material, energy of the ray when leaving the PV material, wavelength of the ray, absorption coefficient of the PV material at the given wavelength [mm^{-1}], incidence angle of the ray to the PV material (in degrees), and the label of the PV material.

Spectral analysis (single solar direction)	
Input name as it appears in OTSunWebApp	*Remarks*
ϕ_{sun} (solar azimuth angle)	Value in degrees
θ_{sun} (solar zenith angle)	Value in degrees
Wavelength initial	Value in nanometers
Wavelength final	Value in nanometers
Wavelength step	Value in nanometers
Number of rays	Rays for each wavelength
Aperture collector for PV	Area (in mm^2) over which the solar radiation enters the PV material
Internal Quantum Efficiency: Either a float or a file with values	Value or file with rows of the form $(\lambda, \mathrm{IQE}(\lambda))$
Aperture collector for thermal	Area (in mm^2) over which the solar radiation enters the thermal absorber material
Ray distribution from the source: None or Buie model (CSR value)	Value of CSR (Buie model for the size of the sun (2)), or empty for a punctual model of the sun

Table 3: Summary of data needed to define the computation in OTSunWebbApp that allows to compute the spectral efficiency of systems.

References

[1] G. Cardona, R. Pujol-Nadal, Otsunwebapp tutorials (2021).
URL `https://github.com/bielcardona/OTSun/tree/master/OTSunWebApp`

[2] D. Buie, C. J. Dey, S. Bosi, The effective size of the solar cone for solar concentrating systems., Solar Energy 74 (5) (2003) 417–427. `doi:http://dx.doi.org/10.1016/S0038-092X(03)00156-7`.
URL `http://www.sciencedirect.com/science/article/pii/S0038092X03001567`