

Appendix

A. Validation

I. In-house Matlab code validation

1. PS-10 heliostat field

The in-house Matlab code for the Monte Carlo ray-tracing (MCRT) method was validated by simulating the PS-10 heliostat field with the parameters listed in the [Table 3 \[15\]](#) (see [line 339 to 348 in the clean manuscript](#)). The coordinates of the PS-10 heliostats were received from Professor John Pye, as shown in [Fig. A.1](#).

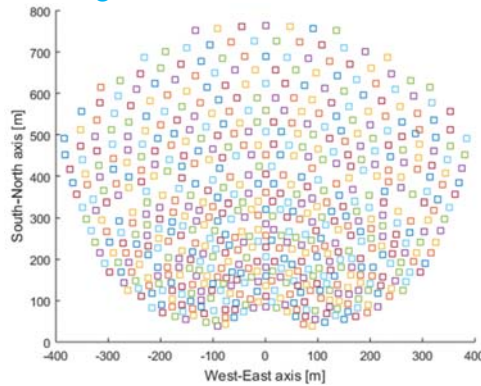


Fig. A.1. Heliostat field PS-10 for the validation code

2. Percentage error

[Fig. 6](#) showed the predicted radiative flux distributions on the receiver surface (see [line 347 to 348 in the clean manuscript](#)). A good agreement was found between our in-house Matlab code and the code developed by [Li et al. \[15\]](#). The percentage error between the two codes is 3.7%.

II. CFD model validation

1. Weizmann heliostats field

The Weizmann heliostats field is shown in the [Fig. A.2 \[49\]](#). Note that the experimental part using a 3D-CPC consists of four heliostats (104, 206, 308 and 408). The four heliostats are shown in this Figure.

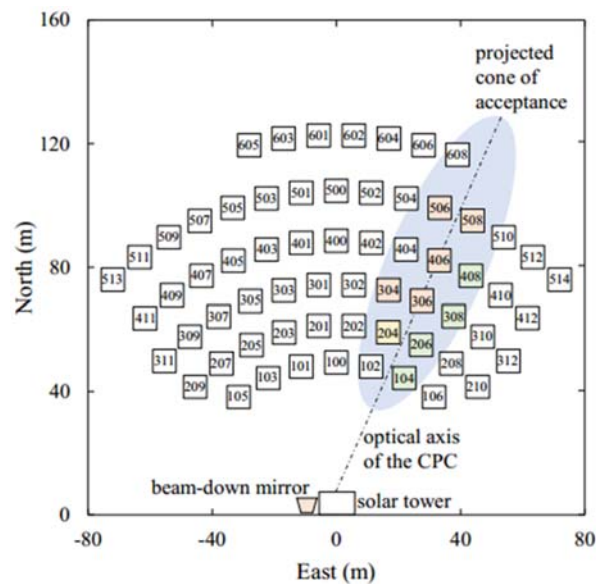


Fig. A.2. Weizmann heliostats layout [49]

2. Solar receiver of the Weizmann heliostats field

The Weizmann solar field uses an indirectly irradiated solar receiver, as we have shown in Fig. A.3. A 3D-CPC is incorporated in the receiver inlet aperture to reduce the size and increase the solar concentration ratio. The dimensions required for its design are given in the Table 4 [41, 49] (see line 360 in the clean manuscript).

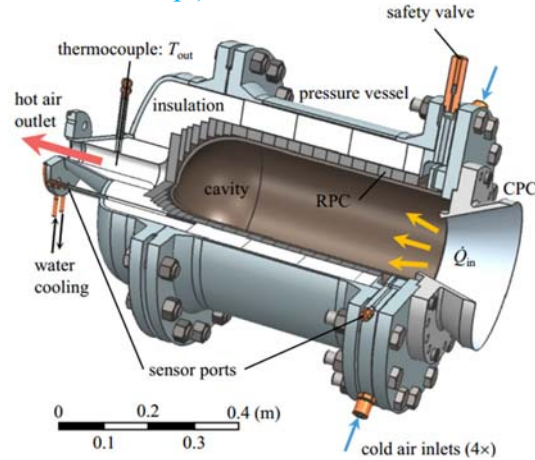


Fig. A.3. Indirectly irradiated solar receiver equipped with a 3D-CPC [49]

3. Optical model

From all the above design parameters, as show in Table 4, the optical model of the Weizmann heliostats field is designed and shown in Fig. A.4. As thus, the same procedure used the flow chart show in Fig.5 (see line 297 in the clean manuscript), is adopted. The Monte Carlo ray tracing (MCRT) method is use to simulate optical model and the volumetric heat source is obtained from the solar flux absorbed in the receiver. This volumetric heat source is used as boundary conditions in the CFD code to determine the air outlet temperature as a function of mass flow rate like Pozivil et al. [14]. It should be noted that the incident solar flux on the receiver inlet aperture was 47 kWth on average with a variation of 8.7% [49]. We found an average solar flux at the receiver inlet aperture of 45.21 kWth. The result obtained is shown in Fig. 7 in line 363 in the clean manuscript.

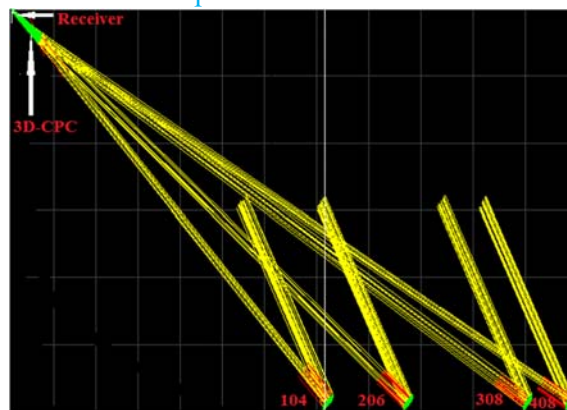


Fig. A.4. Optical model of the model CFD validation

4. Coefficient of determination

The result obtained is shown in Fig. 7 (see line 363 in the clean manuscript). To know if the results found are in agreement with those of Pozivil et al. [14], the coefficient of determination (R^2) is calculated. The Fig.A.5 gives the result obtained, which shows that $R^2=0.98$. This result shows that our CFD model is in perfect agreement with that of Pozivil et al. [14].

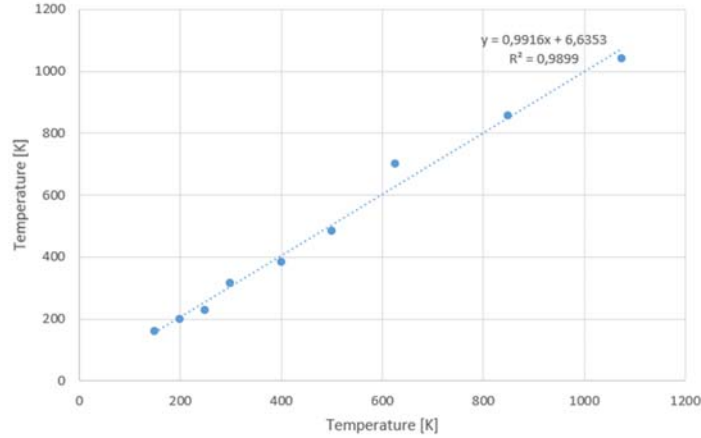


Fig. A. 5. Coefficient of determination of the results found in this work and Pozivil et al. [14]

B. Three-dimensional Compound Parabolic Concentrator (CPC-3D)

1. 3D_CPC design procedure

From the sizes found, the geometrical shape of the 3D-CPC is at first designed in SolidWorks v18, as shown in Fig. 9(a). Then, the 3D-CPC is meshed in Ansys Meshing, as shown in Fig. 9(b). The mesh is used to determine the information needed to design the 3D-CPC in SolTrace. For this purpose, we used the mechanical APDL tool in Ansys Workbench to edit two mesh files. One file contains the mesh elements and their nodes (N_1, N_2, N_3) and the other file contains the nodes and their coordinates (x, y, z). It should be noted that the positions of the element values, nodes and coordinates are disordered in the initial files. Thus, they must be grouped together in the same file and in order. For this purpose, in-house code C is developed under RStudio software to couple and order the elements and constituent nodes with their respective coordinates. After that, we calculated the centroids (x_G, y_G, z_G) and aim point (x_{Ap}, y_{Ap}, z_{Ap}) coordinates of each mesh element. These coordinates are used to design the 3D-CPC in SolTrace, as shown in Fig. 9(c) (see line 388 to 389 in clean manuscript).

2. 3D-CPC truncated

Fig. A.6 shows the 3D-CPC untruncated (25°) and truncated at 35° ; 40° and 55° . We can see that the truncation decreases the 3D-CPC length and increases the inlet aperture of the 3D-CPC

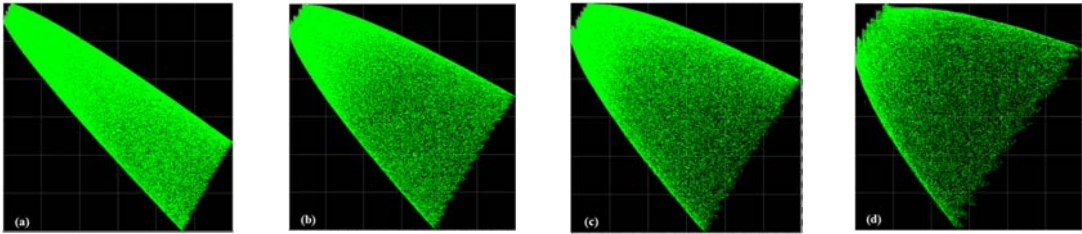


Fig. A.6. 3D-CPC truncated at: (a) 25° (untruncated), (b) 35° , (c) 40° and (d) 55°

Fig.A.7 shows the daily average solar flux collected at the receiver equipped with a 3D-CPC and without a 3D-CPC. The average solar flux absorbed in the receiver equipped with a 3D-CPC is 574.4 kW/m^2 . The average solar flux absorbed in the receiver without 3D-CPC is 111.7 kW/m^2 . This shows an efficiency of 80.66%. The average solar flux collected in the 3D-CPC inlet aperture is 117.0 kW/m^2 . The result shows that the 3D-CPC increases the concentration ratio by a factor of 4.91.

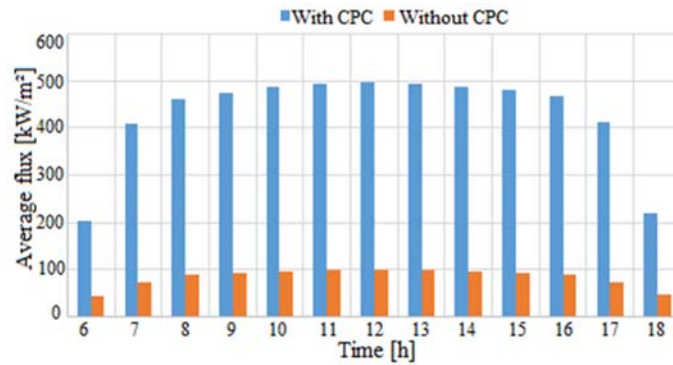


Fig. A.7. Average solar flux absorbed in the receiver equipped a with and without 3D-CPC

C. Interpolation of the volumetric heat source

1. Procedure of interpolation

The interpolation procedures are described by the following steps

- 1) Under Define/User-Defined, activate one scalar UDS-0 for all cell zones (fluid and solid) and one user-defined memory location (UDM-0).
- 2) Initialise case and data, or if the data exist, patch zero values to UDS-0 and UDM-0 for all cell zones.
- 3) In the File/Interpolate, interpolate each individual source file (*. ip file) to the UDS in each corresponding cell zone.
- 4) Define and interpret a UDF: **DEFINE_ON_DEMAND** ([copy_UDS_to_UDM](#)) to copy the interpolated scalar data from UDS-0 to UDM-0.
- 5) Define and interpret a UDF: **DEFINE_SOURCE** that links a source name to the UDM.
- 6) Assign the source term of the appropriate name-selected solid cell zone to the UDF name in 6).
- 7) For saving memory during the ensuing simulation, the scalar “UDS-0” can be de-activated.

2. UDF Code

The UDF code used in the interpolation is:

```
Solar-heat.c
/*=====*/
/* UDF to use interpolated solar heat source data as an energy source */
/* NOTICE: to use, set one UDS and UDM in interface, patch 0 to each, then interpolate appropriate source to
each cell zone. */
/*=====*/
#include "udf.h"
/*=====*/
DEFINE_ON_DEMAND (copy\_UDS\_to\_UDM)
{
Domain* d = Get_Domain (1);
Thread *t;
cell_t c;
thread_loop_c (t, d)
{
begin_c_loop (c, t)
{
```

```

C_UDMI(c, t, 0) = C_UDSI(c, t, 0);
}
end_c_loop(c, t)
}
return;
}
/*=====*/
DEFINE_SOURCE(solar_heat, c, t, dS, eqn)
{real source;
dS[eqn] = 0.0;
source = C_UDMI(c, t, 0);
return source;}
/*=====*/

```

3. *. Ip file format

The format of the interpolation file is as follows:

- 1) The first line is the interpolation file version. It is 1.0 for ANSYS FLUENT 5 and 2.0 for ANSYS FLUENT 6.
- 2) The second line is the dimension (2D or 3D).
- 3) The third line is the total number of points.
- 4) The fourth line is the total number of fields (temperature, pressure, etc.) included.
- 5) The fifth line contains a list of field names. To see a complete list of field names used by ANSYS FLUENT, enter the command display/contour text and view the available choices by pressing Enter at the contours of prompt. The list depends on the activated models.
- 6) After the field names is a list of x, y and (in 3D) z coordinates for all data points.
- 7) At the end is a list of field values for all points in the same order as their names. The number of coordinate points and fields must correspond to the number indicated in line 3.

4. Volumetric heat source (W/m^3)

Fig.A.8 shows how to calculate the volumetric heat source interpolates in Ansys Fluent. First, the hit (in the red box) is multiplied by the power per ray (in the red box) to obtain the power (W). Then the power (W) is divided by the element surface (m^2) to obtain the power (W/m^2). Finally, this power is divided again by the thickness of the heated solid to get the power (W/m^3).

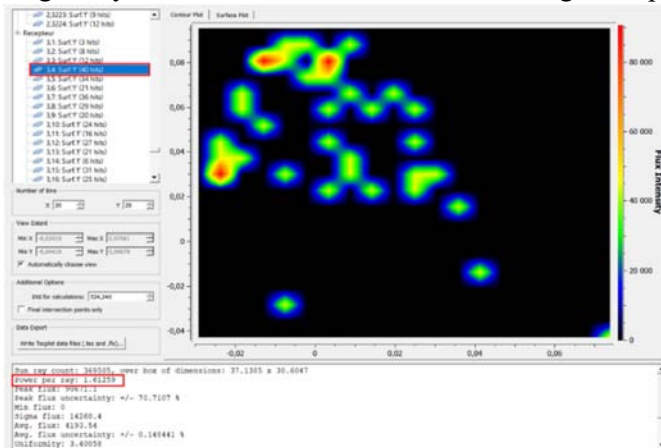


Fig. A.7. The SolTrace interface showing how to determine the volumetric heat source

D. Outline of paper

To better understand the structure of the manuscript, we have given the outline

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