Preface

HelioFocus's (HF) performance and optimization model is a dedicated computation script, which uses physics and mathematics for calculating a desired HF product query.

This document explains the calculations involved their sequence in the model, and the considerations / assumptions that guide the model architecture.

Base assumptions

Real world flexibility in respects to geometrical considerations and quantity were narrowed down to minimize input parameters (user friendly), eliminating calculative contradictions, and shortening calculation time in general. Assumptions are explained here, in every sub module of the model respectively.

Site location

Global parameters of the site location affect annual weather and sun conditions. In order to evaluate performance location-wise, the parameters that are inputted are:

- Latitude [decimal]
- Longitude [decimal]
- Altitude (positive above sea level) [meters]

The locations available currently (model V3.5 '2014 release') are set by available, reliable TMY (Typical Meteorological Year) files. Locations currently are:

- Sdom (Israel)
- Sde-Boker (Israel)
- Kuqa (China)
- Wuhai (China)
- Kramer Junction (California, USA)

In every location, nearby optical obstacles and mountain ridges are discarded, giving the model the ideally clear horizontal visibility, around the site (Azimuth wise).

A presence of optical obstacles can be influential if its effect is measured in the TMY data files. A slightly different location of the HF site vs the data recording station, which produced the TMY data, is here by neglected, and assumed to be a 'good fit' to site real location.

TMY data

From the many measurements that are logged in a standard TMY, only relevant TMY data compose the file. Each logging is 1 hour apart from its predecessor, making a file that its logged time is one year, giving 8760 (hours) logs for the relevant measurements. These compose of (needed format):

1. Time ('dd/mm/yyyy HH:MM:SS' or 'dd/mm/yyyy HH:MM')
2. DNI [W/m2]
3. Wind speed [m/sec]
4. Wind direction (angle from north) [deg]
5. Ambient temperature [°C]
6. Humidity ratio [%]

Each log starts with the end of the first hour of the year, i.e. – 01/01/yyyy 01:00:00.

Columns are set from left side, by the above order, when the first column is not read by the model. All TMY files are a MS Excel type: *.xls.

Fig.1 – a proper TMY file shown in MS Excel – 'Sde-Boker_TMY.xls'

	A	B	C	D	E	F	G
1	No	time	DNI [W/m2]	Wind S [m/s]	Wind Direction [deg]	T [c]	H (% g[H2O]/Kg[AIR])
2	0.00	01/01/2001 01:00	0	3	330	12	72
3	0.04	01/01/2001 02:00	0	3	330	11	73
4	0.08	01/01/2001 03:00	0	4	340	11	75
5	0.13	01/01/2001 04:00	0	2	290	11	71
6	0.17	01/01/2001 05:00	0	1	290	11	70
7	0.21	01/01/2001 06:00	0	1	230	11	70
8	0.25	01/01/2001 07:00	0	1	60	11	70
9	0.29	01/01/2001 08:00	0.278	2	70	12	70
10	0.33	01/01/2001 09:00	18.904	0	170	12	72
11	0.38	01/01/2001 10:00	69.222	1	100	13	70
12	0.42	01/01/2001 11:00	591.862	2	110	14	70
13	0.46	01/01/2001 12:00	580.464	2	120	15	71
14	0.50	01/01/2001 13:00	306.356	2	120	16	70
15	0.54	01/01/2001 14:00	20.572	2	170	16	68
16	0.58	01/01/2001 15:00	0	2	30	16	69

NOTE: a TMY data file, not in this proper order (columns and cell format) will error a model run, usually prompting an error box.

It is possible to vary the log time step, to issue a different span of interest. Two TMY files are artificial for a design work-points testing and a time dependent work-points analysis of performance. In these cases files are much shorter than the sites TMYs since they are not location oriented.

Each log entry starts a full calculation of HF field performance, and its results are logged in the output file, at the same order as the TMY data, alongside it. Therefore, the TMY file dictates the output file logging order.

Field geometry

HF field is a solar trackers array. It is definitively defined by geometrical parameters. The parameters which define the field geometry are:

1. Dishes per cluster [# ϵ N].
2. Clusters (cluster of dishes connected to the common HTS) in field [# ϵ N].
3. N-S columnar dishes spacing [m].
4. E-W row dishes spacing [m].
5. Alpha (α) angle (from global E-W line +CW) [deg].
6. HEX distance from field center [m].
7. Field azimuth (positive CW from north – i.e. 0° when directed to north) [deg].
8. Field elevation (positive from horizon to zenith – i.e. 0° when directed to horizon) [deg].

Guidelines of the geometry are:

1. Number of dishes per cluster is unlimited and is at least equals to 1 dish.
2. Clusters number is always even, except the case of a single cluster field. This is based on the symmetrical field cluster distribution around the two N-S by E-W axes junction (as shown in 'cluster distribution' chapter below).

In the chapters below, a visual explanation is given to clarify geometry parameters influence.

Angles

Fig.2 – field azimuth angle = 0°

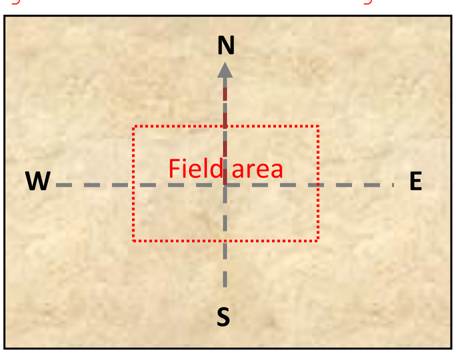


Fig.3 – field azimuth angle > 0°

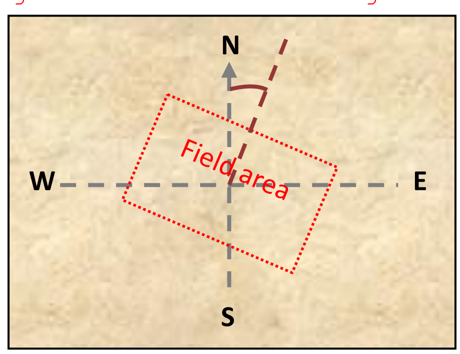


Fig.4 – field alpha angle = 0°

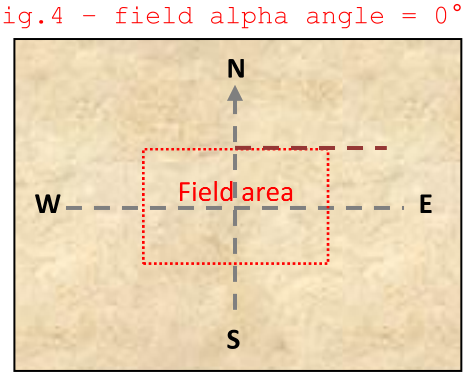


Fig.5 – field alpha angle > 0°

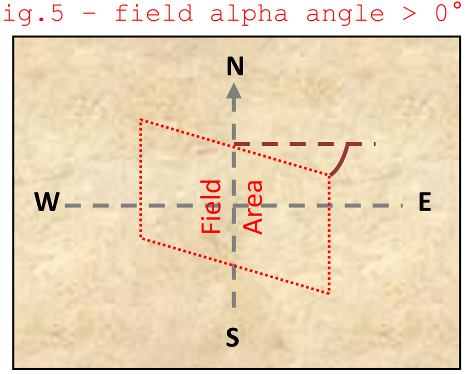


Fig.6 – field alpha angle > 0°

& field azimuth angle > 0°

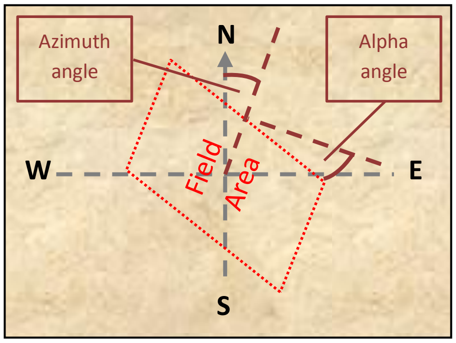


Fig.7 – field elevation angle = 0°

field azimuth angle = 0°

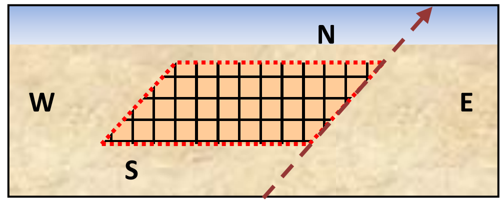


Fig.8 – field elevation angle > 0°

field azimuth angle = 0°

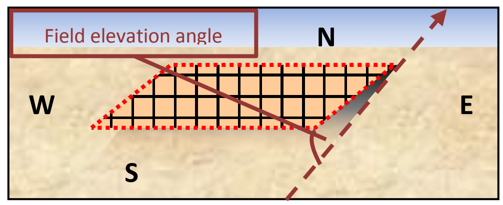
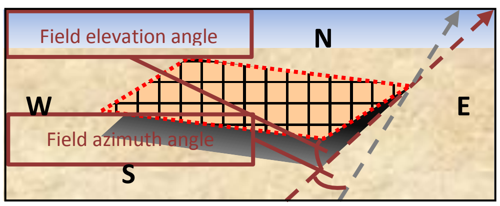


Fig.9 – field elevation angle > 0°

field azimuth angle > 0°



Dish to dish distance

Minimal dish to dish centers distance is 39 [m]. Dishes are set in rows and columns in a parallelogram arrangement (rather than rectangular), to allow better spacing for less dish on dish shading.

Basic arrangement and alpha angle effect is shown below.

X_{N-S} = N-S columnar dishes spacing [m]

X_{E-W} = E-W row dishes spacing [m]

X_{min} = 39 [m], minimal dish to dish distance

Fig.10 – field azimuth angle = 0°

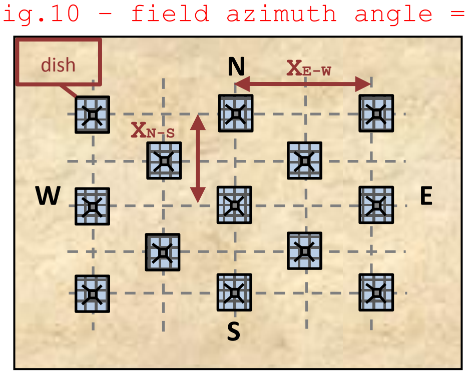
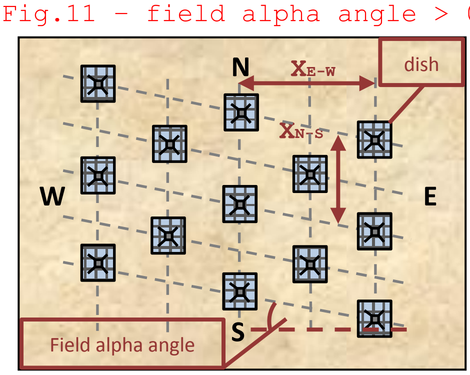


Fig.11 – field alpha angle > 0°



Since dish on dish shading is maximal at sunrise and sunset, X_{E-W} is more critical than X_{N-S} in regards to round year performance. For this reason minimal distance of X_{E-W} is bound by the minimal X_{N-S} distance allowed, while taking under account the alpha angle (α) effect.

Calculating minimal X_{E-W}:

We shall fix X_{N-S} to be the minimal distance allowed: $X_{N-S} = X_{min} = 39$ [m]

$$P_1(S) = 0.5 \cdot S^2 - \left[\frac{X_{N-S}}{2} \cdot \sin(\alpha)\right] \cdot S + \left[\left(\frac{X_{N-S}}{2}\right)^2 - X_{N-S}{}^2\right]$$

$$X_{E-W\,min} = roots(P_1(s)) > 0$$

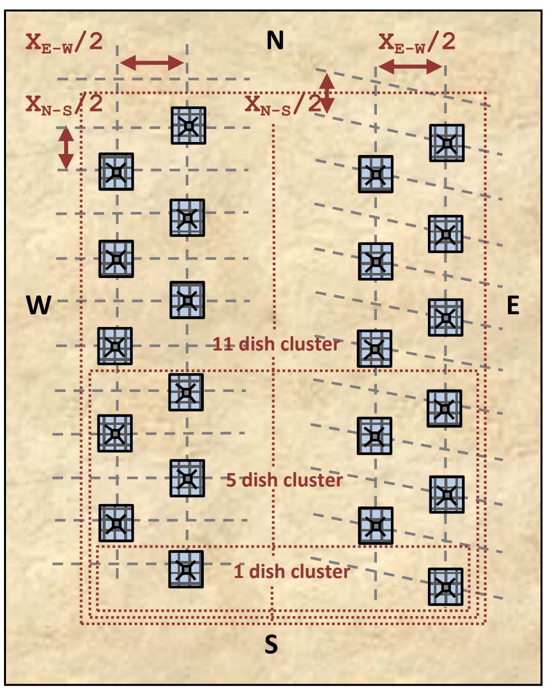
Cluster distribution

Cluster definition:

1. The term 'cluster' refers to the cluster of dishes that are connected to the same HTS common/header (manifold manner).
2. Cluster will contain at least one dish.
3. Cluster will contain one column of sub columnar array (Fig.12).
4. Clusters are parallel to each other along N-S axis of the field, which is angularly tilted from global N-S axis by the 'field azimuth angle' (Fig.13).

Fig.12 – cluster columnar array

0° = field alpha angle > 0° (vs.)



Symmetry

Except for the single cluster case, all fields have even number of clusters, deployed symmetrically along the field's (not global) E-W axis. This arrangement discard any uneven arrangements like: 3, 5, 7 …, in other words: $N_n = n + 2\ ;\ N_0 = 2\ ;\ n = 0,2,4, \ldots\ n \in (Even\ numbers)\ ;\ N - number\ of\ clusters\ in\ a\ field$

Fig.13 – 20 cluster arrangement in the field. field alpha angle = 0°

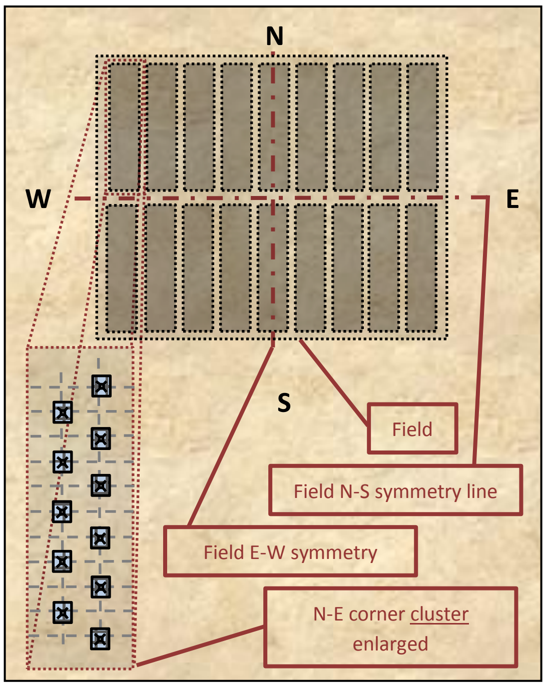


Fig.14 – 20 cluster arrangement in the field. field alpha angle > 0°

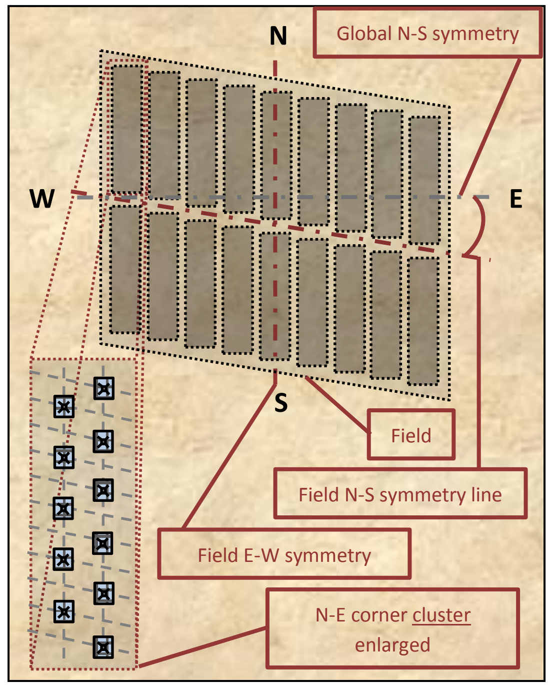
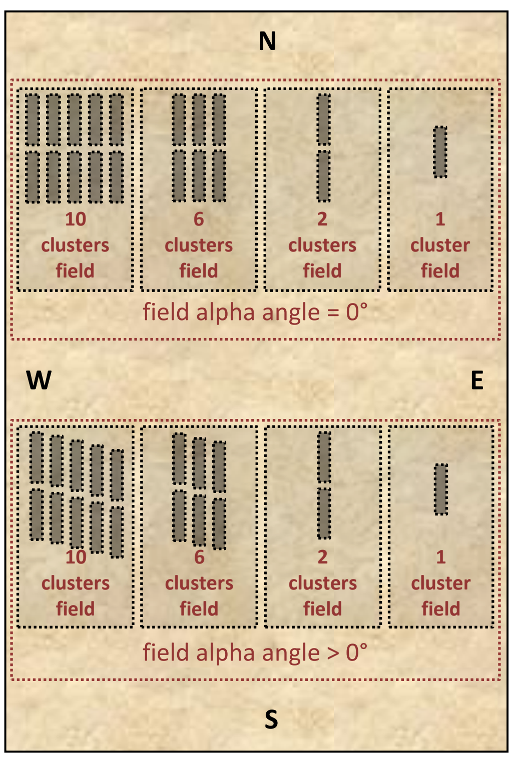


Fig.15 – cluster arrangements



Area

The field area is an ambiguous parallelogram, which inner arrangement of dishes per cluster and clusters number in the field makeup the shape. Distances given along N-S and E-W are from dishes centers, and so, surrounding boundary is extended by 11 [m], for half a dish’s width, and another 4 [m] for surrounding clearance, giving a 15[m] added length from all sides. Field area is calculated as shown here:

$$N_c: number\ of\ clusters\ in\ the\ field$$

$$N_d: number\ of\ dishes\ per\ cluster$$

$$X_{E-W}: E-W\ distance\ between\ dishes\ [m]\ (as\ in\ fig.12)$$

$$X_{N-S}: N-S\ distance\ between\ dishes\ [m]\ (as\ in\ fig.12)$$

$$\alpha: field\ alpha\ angle - parralelogram\ angle$$

$$n = \frac{N_c}{2} \quad ; \quad if\ (n<1) \rightarrow n=1 \quad ; \quad if\ (n \geq 1) \rightarrow n=2$$

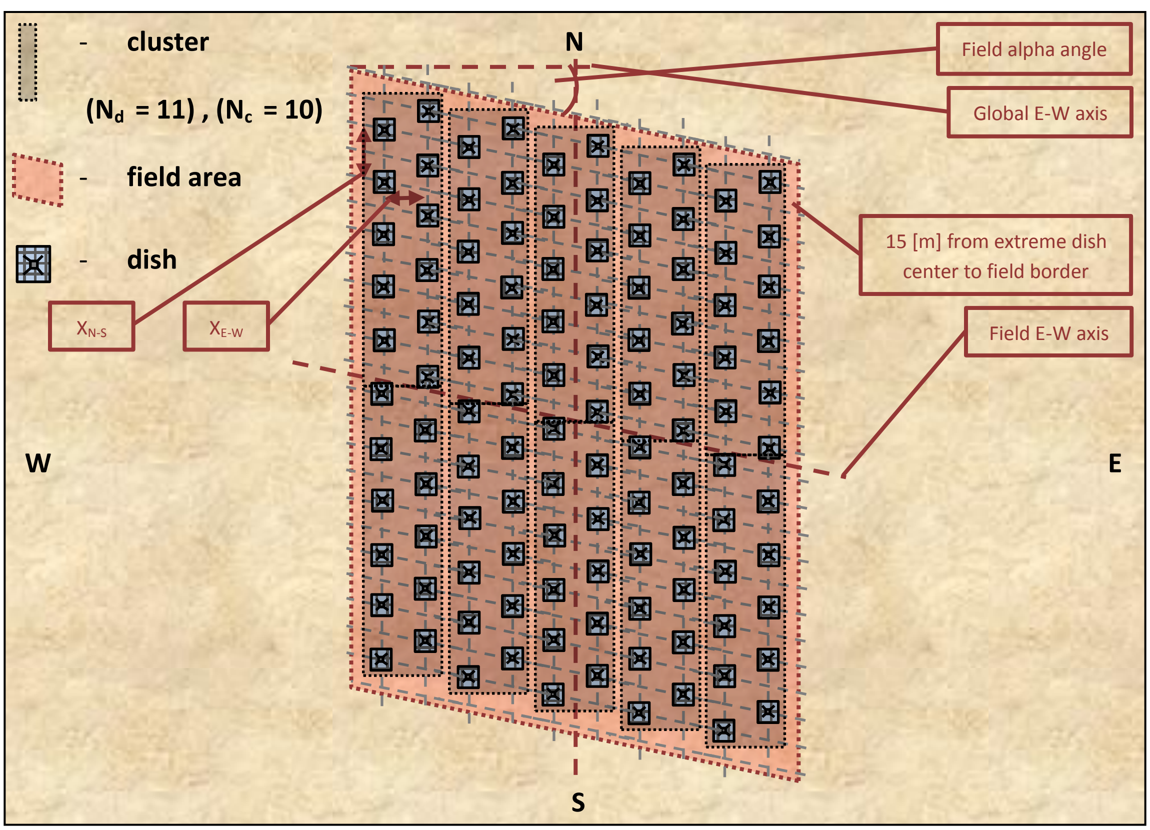
$$X'_{N-S} = n \cdot \frac{N_d}{2} \cdot X_{N-S} + 2 \cdot 15\ [m]$$

$$X'_{E-W} = \frac{N_c}{n} \cdot X_{E-W} + 2 \cdot 15\ [m]$$

$$x_{N-S} = X'_{E-W} \cdot |tan(\alpha)|\ [m]$$

$$S_{field} = X'_{E-W} \cdot [X'_{N-S} - x_{N-S}]\ [m^2]$$

Fig.15 – field area of a 10 clusters with 11 dishes each, field alpha angle > 0°



Restrictions

Quantities and distances are restricted to make modeling viable by the model's calculation methods. List of field shape and makeup restrictions are listed here:

value	units	min	max
Field azimuth angle	[deg]	-90	90
Field elevation angle	[Deg]	-5	5
X_{N-S}	[m]	39	150
X_{E-W}	[m]	69	250
Field alpha angle	[Deg]	0	40
N_d	#	1	30
N_c	# positive and even, besides 1	1	30

HTS

HTS (Heat Transfer System) is delivering heat by system fluid (pressurized air) from the solar receiver to the HEX (Heat Exchanger), to produce steam from liquid water. After heat has dissipated from the system fluid, it returns to the receiver for reheat, and so on – making a circular closed loop rout for the system air.

Producing the flow are blowers, stationed at the end of a cluster's (dishes cluster) common HTS link to the field common of clusters. In this formation, the amount of blowers in the field is by definition, equal to the amount of clusters in it.

There are two basic types of HTSs, which are picked by project:

- Pipes – hot from receiver to HEX) and cold (from HEX to receiver) ducts mutually unaffected, heat transfer wise.
- Annulus – concentric hot (inner duct, from receiver to HEX) and cold (outer duct, from HEX to receiver) ducts, mutually affected heat transfer wise.

The two methods have different parameters for their geometrical definitions and restrictions. The calculation of performance is physically different.

Besides the main rout's HTS, a secular links of the ducts is referred for dynamic pressure loss, and heat losses are bypasses. Theses and other obstacles are being normalized to elbow geometry, for ease of calculation.

Definitions

Common to all HTS types are the below definitions. These are consistent in all calculations of the model:

1. One blower per cluster.
2. A field has only one HEX.
3. HTS is sectioned and tagged by location. Nx for in-cluster HTS and Hx for field header/common HTS.
4. N1 is tagged and fixed – defined as on-dish.
5. N2 is tagged and fixed – defined as on-dish link to cluster header/common.
6. All N1 and N2 are amounted to the numbers of dishes in the field.
7. N3…Nn are defined as sections belong to the cluster header/common.
8. All N3 to Nn are amounted to the number of clusters in the field.
9. H1…Hn are defined as sections belong to the field header/common.
10. H1 is defined as the extreme section, farthest away from the N-S axis of the field.
11. Nn tag is increased from dish link to dish link (along rout).i.e:

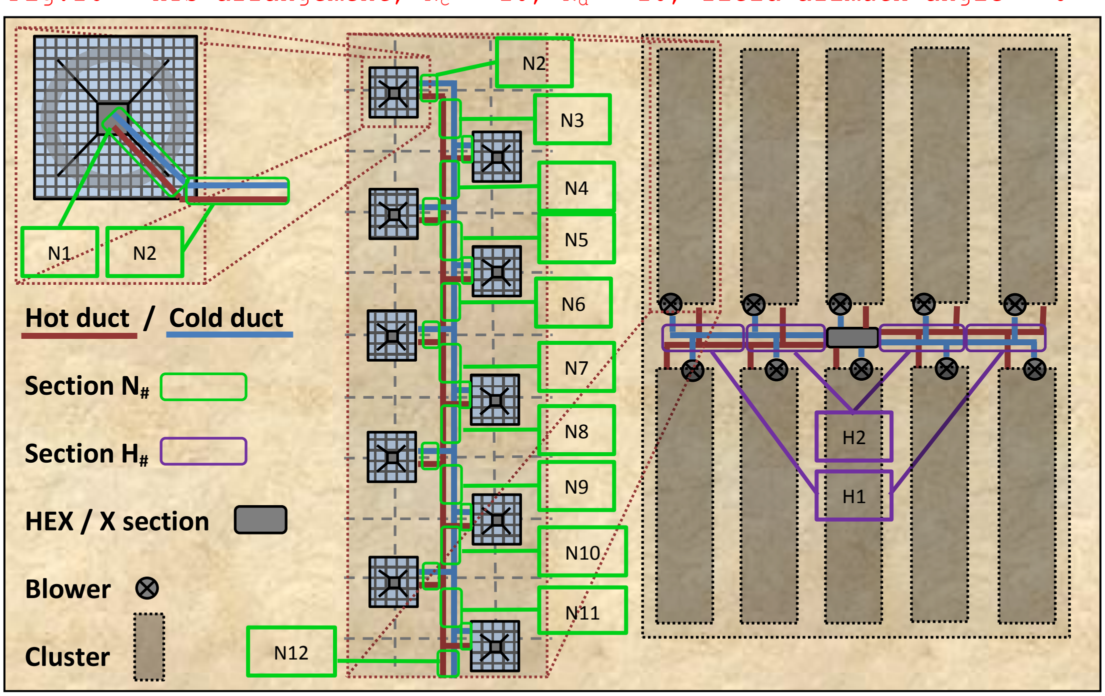
$$N_1 \rightarrow N_2 \rightarrow N_3 \rightarrow (dish\ link) \rightarrow N_4 \rightarrow (dish\ link) \rightarrow \cdots \rightarrow N_n \rightarrow (dish\ link) \rightarrow N_{n+1} \rightarrow \cdots \rightarrow N_{max} \rightarrow H_1$$

12. Final section which conducts all of the flow of the field to and from the HEX, is tagged 'X'. X length is determined by HEXs distance from the center of the field (crossing of N-S and E-W axes of the field.
13. Hn tag is heightened from cluster link to cluster link (along rout).*i.e*:

$$H_1 \rightarrow (cluster\ link) \rightarrow H_2 \rightarrow (cluster\ link) \rightarrow \cdots \rightarrow H_n \rightarrow (cluster\ link) \rightarrow H_{n+1} \rightarrow \cdots \rightarrow H_{max} \rightarrow X \rightarrow HEX$$

14. Blower located on cold duct's link between field header (H_n) and cluster header ($N_{n\ cluster}$).
15. H1 is non-existent in the case of 1 or 2 clusters in a field – clusters will be linked directly to the HEX.

Fig.16 – HTS arrangement, N_c = 10, N_d = 10, field azimuth angle = 0°



16. H# lengths are dependent on N_c and X_{E-W}. there are three cases:
a. In the case ($N_c/2$ is not even & $N_c>1$): H_{max} length is $X_{E-W}/2$, while the rest H# lengths are X_{E-W}.
b. In the case ($N_c/2$ is even & $N_c>1$): all H# lengths are X_{E-W}, and the middle two clusters (which align with the field's N-S axis) are not connected to any H#, but directly to the 'X' section, leading to the HEX (in parallel to $H_{max(\text{from east and west})}$) .

The model is basing the heat dissipation along the HTS, based on field symmetry. Calculation is cascaded by sub assembly repeatability of the field:

1. Dish HTS: N1 & N2 sections.
2. Cluster HTS: N3 to Nmax (set by N_d) when each N2 connects to the cluster's header is similar in temperature and flow rate conditions to the farthest dish in the field (whichever corner).
3. Field header HTS: H1 to Hmax (set by N_c) when each Nmax hookup to the field's header is similar in temperature conditions to the farthest cluster in the field (whichever corner).
4. The field is symmetrical along N-S and E-W axes, so the heat dissipation is also quarterly symmetrical, thus only one cluster and half field header is needed to be computed (besides the case of a single cluster field).
5. HEX link, i.e. HEX/section X (as shown in fig.16) is the final junction of the HTS where all fluid is ducted to (hot) and from (cold) the HEX by a section designated as 'X section', from the symmetry center of the field, or in case of a single cluster field – at the base of Nmax. Essentially, the X section's length is equal to the distance of the HEX from the center of the field (symmetry center of the field).

Fig.17 – HTS heat dissipation calculation cascade, N_c = 10, N_d = 10, field azimuth angle = 0°

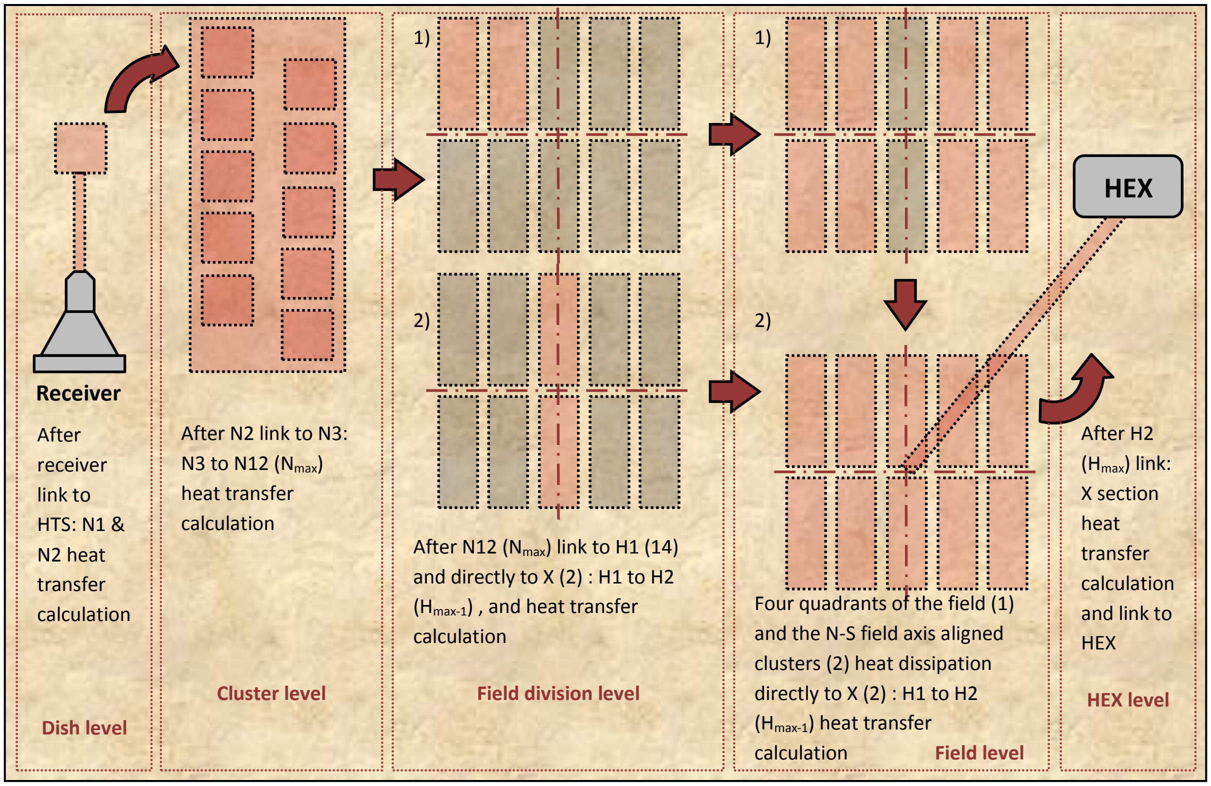
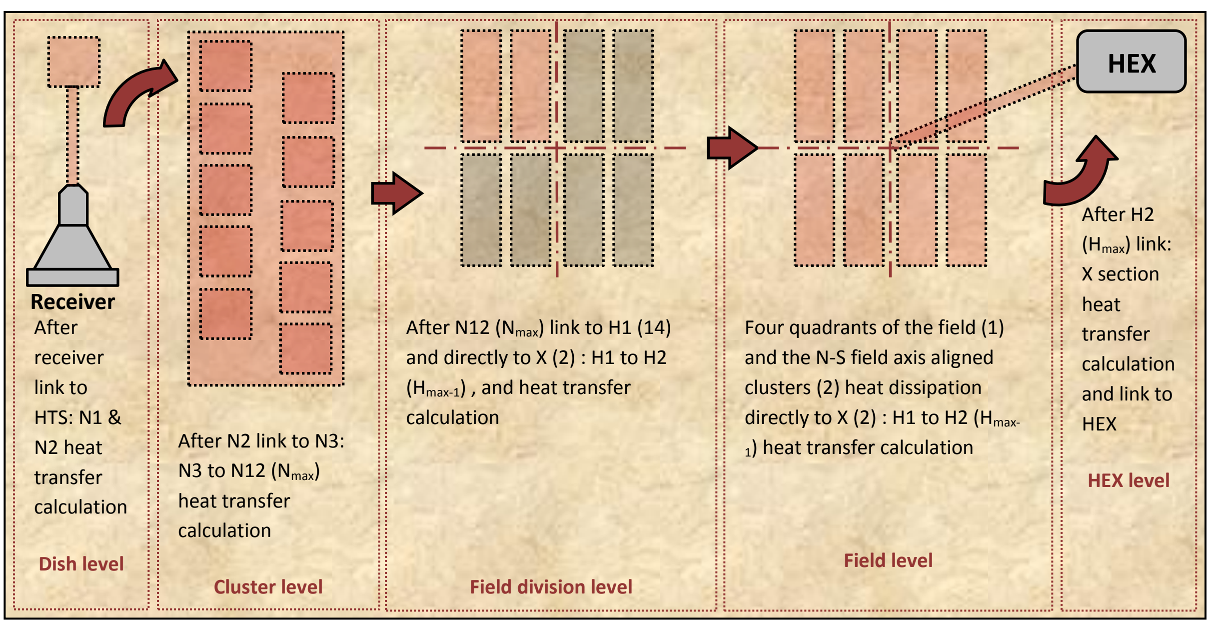


Fig.18 – HTS heat dissipation calculation cascade, N_c = 10, N_d = 8, field azimuth angle = 0°

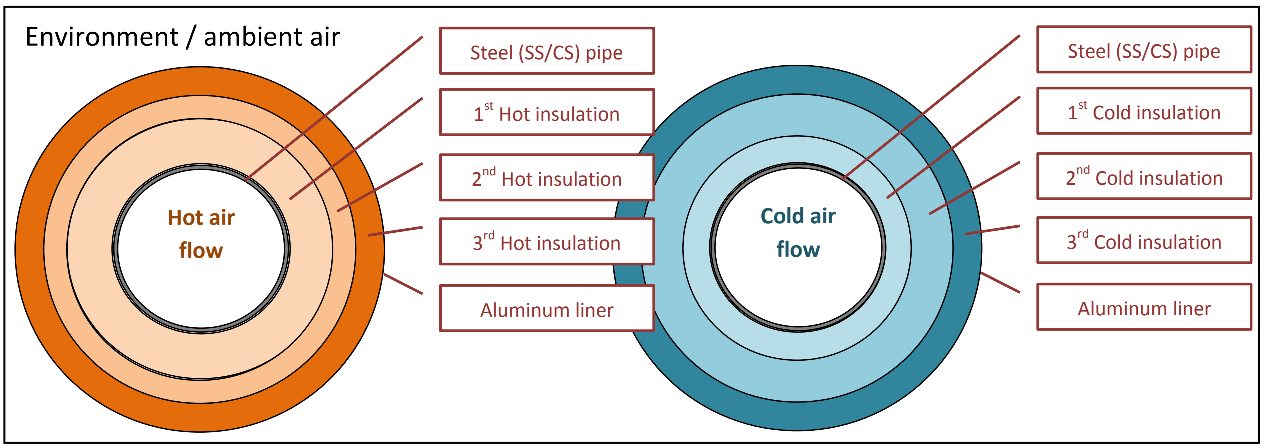


Pipes

Pipes HTS are characterized by the below definitions:

1. Separate ducts, Hot & Cold
2. Adjacent and parallel along rout
3. Circular cross section (cylindrical duct along principle axis)
4. Inner wall roughness of 50 micrometer
5. Each can be layered with up to 3 separate insulating layers; each can be of different material (one per layer) with different installation quality (affects insulation level). Measurement of those is defined by thickness [m]
6. Insulation layers liner / protection / cover is a 0.5 [mm] thick Aluminum sheet (commercial)

Fig.18 - Cut view of pipes layering scheme

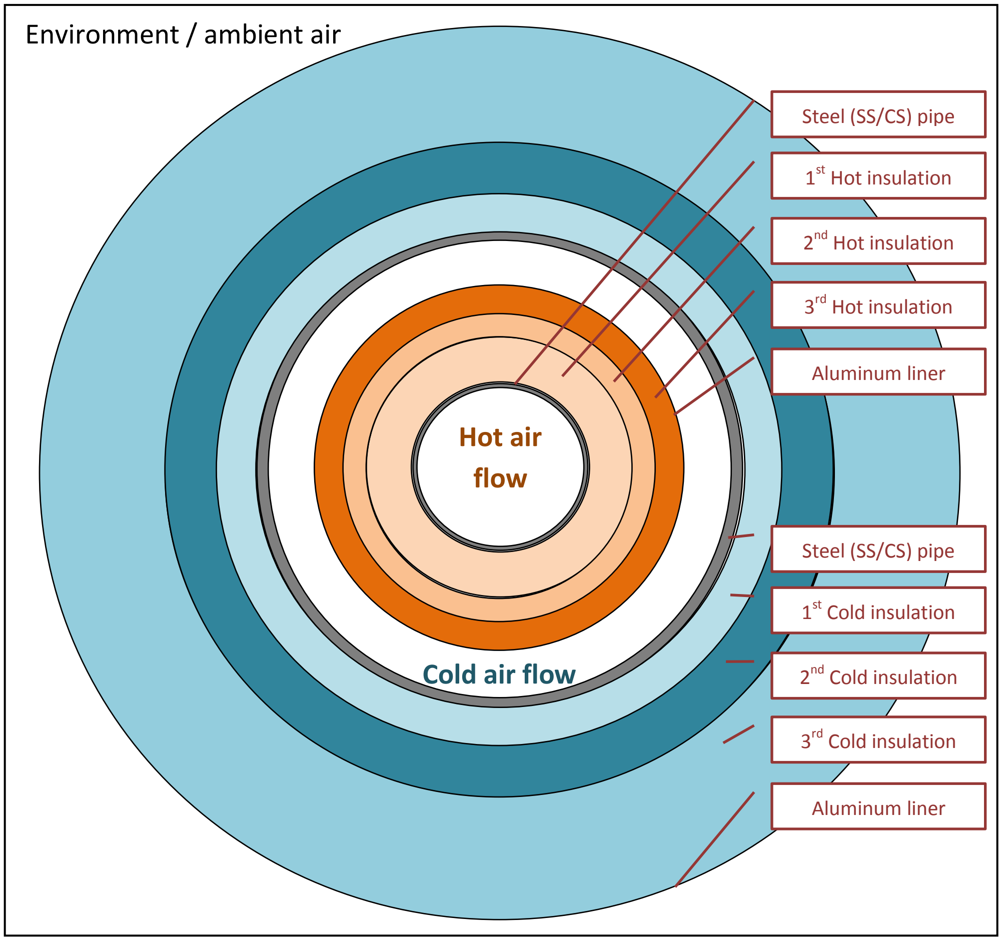


Annulus

Annulus HTS are characterized by the below definitions:

1. Concentric ducts, Hot being the inner and Cold being the outer
2. Concentric along rout
3. Circular cross section (cylindrical duct along principle axis)
4. Inner wall roughness of 50 micrometer
5. Each can be layered with up to 3 separate insulating layers; each can be of different material (one per layer) with different installation quality (affects insulation level). Measurement of those is defined by thickness [m] at the outer insulation, and by occupation [%] of gap between inner and outer pipe, in the inner insulation.
6. Insulation layers liner / protection / cover is a 0.5 [mm] thick Aluminum sheet (commercial)

Fig.19 - Cut view of annulus layering scheme



Bypasses

Bypasses are separate ducts / pipes (not annular) that link the various sections along the route. The length of those is around 1.5 [m] per section at each duct, and they compile of flexible hose / bellow.

Because of the ribbed / wavy wall texture, dynamic pressure loss is heightened in them, and as such, this calculation is separate from the sections dynamic pressure loss calculation.

Obstacles

HTS, pipes or annulus, have in-flow obstacles that increase heat and dynamic pressure losses. These are taken into account in both HTS types, as the below definitions:

1. On-dish (N1): 2 X swivel joints (annular in any HTS)
2. Elbows: 8X(N1) & 2X($N_{n>1}$) – all HTS types, hot & cold ducts
3. T-joints: 2X all sections – all HTS types, hot & cold ducts
4. Pipe bracing – hot & cold for pipes and radially distributed for annulus inner duct.

Heat sinks

Heat sinks along hot & cold ducts are made up of pipe bracing and flanges. Basic assumption is that those are losing heat at a rate similar to the ideal ducts (net duct). This assumption /aspiration was discarded after system testing and a basic empirical heat loss was added to make up for this effect:

$$\frac{\Delta T_{heat\ sink}}{length} = A \cdot \frac{\Delta T_{ideal\ heat\ loss}}{length}\ \left[\frac{°C}{m}\right];\ A - empiric\ scalar\ (A_{hot}\ \&\ A_{cold})$$

$$\frac{\Delta T_{tot}}{length} = \frac{\Delta T_{ideal\ heat\ loss}}{length} \cdot (1 + A)\ \left[\frac{°C}{m}\right]$$

Consumption

System fluid circulation is motioned by the blowers (at the cold entrance of each cluster). The dynamic pressure loss is the load by which the power demanded from the blowers is calculated. The variations in flow during condition transition create fluid inertia, weather positive or negative, to add power demand. This phenomena is neglected in the power consumption calculation since the overall sum / average of it is close or absolute zero, and is significantly smaller (and shorter, variation time wise) in comparison to the dynamic pressure loss load. The blower consumption calculation is sown below:

$$\Delta P - calculated\ dynanic\ pressure\ between\ blower\ inlet\ and\ outlet$$

$\Delta P_{sections}$ *is calculated per section seperately, and with the relevant mass flow going through it* hot and cold duct.

$$\Delta P\ [Bar] = \Delta P_{receiver} + \Delta P_{cluster} + \Delta P_{headers} + \Delta P_{HEX\ link\ section} + \Delta P_{HEX}$$
$$= \Delta P_{receiver} + \Delta P_{HEX} + \sum_{i=1}^{N} \Delta P_{section\ i}$$

$$N = maximum\ sections\ rank\ number\ (N\# + H\# + X)\ ;\ X\ is\ always\ 1$$

$$Q_{blower\ consumption}\ [KW] = \frac{\Delta P\ [Bar] \cdot 100{,}000 \cdot \dot{m}_{cluster}\ \left[\frac{Kg}{sec}\right]}{\rho_{air\ density\ at\ blower}\left[\frac{Kg}{m^3}\right] \cdot \eta_{blower\ efficiency}}$$

$$\eta_{blower\ efficiency} = 0.75 \cdot \left(\frac{1 + \dot{m}_{dish}}{1.85}\right)^2$$

Restrictions

HTS geometry is bound by extreme sizes, which are believed to be close to unrealistic. This variety is set to allow a thorough optimization assessment over HTS measurement span.

Pipes differ from Annular HTS, and shown below:

Pipes HTS

value	Units	min	max
Hot Duct Radius	[m]	0.03	0.1
Cold Duct Radius	[m]	0.03	0.1
Hot - 1st Insulation Thickness	[m]	0.03	1
Hot - 2nd Insulation Thickness	[m]	0	1
Hot - 3rd Insulation Thickness	[m]	0	1
Cold - 1st Insulation Thickness	[m]	0.03	1
Cold - 2nd Insulation Thickness	[m]	0	1
Cold - 3nd Insulation Thickness	[m]	0	1

Annular HTS

value	Units	min	max
Hot Duct Radius	[m]	0.03	0.1
Cold Duct Radius	[m]	0.1	1
Hot - 1st Insulation Occupation	[%]	1	90
Hot - 2nd Insulation Occupation	[%]	0	90
Hot - 3rd Insulation Occupation	[%]	0	90
Cold - 1st Insulation Thickness	[m]	0.03	1
Cold - 2nd Insulation Thickness	[m]	0	1
Cold - 3nd Insulation Thickness	[m]	0	1

Receiver

HeliFocus's receiver heat up circulating air fluid (pressurized air) by convective cooling of porous absorbers. These absorbers are heated by direct, concentrated solar radiation, from the dish (i.e. solar concentrator / reflector). The radiation is introduced to the receiver controlled volume via transparent (hyperboloid cone shaped) window, that separates it from the environment.

Efficiency

The efficiency of receiver's process is influenced by the following parameters:

1. Incoming radiation – measured by its power [KW] and varies every time step by TMY subsequent calculation (hourly, as default).
2. Inlet air temperature – measured by its temperature [°C] and varies every time step by TMY subsequent calculation (hourly, as default). This parameter is indirectly affected by user input of HEX's design parameters.
3. Ambient convective heat dissipation from receiver controlled volume – measured by ambient temperature [°C] and wind speed, which varies every time step by TMY subsequent calculation (hourly, as default).
4. Re-radiation from receiver controlled volume – measured by ambient temperature [°C] and varies every time step by TMY subsequent calculation (hourly, as default).
5. Outlet air temperature from receiver – measured by temperature [°C] and varies every time step by TMY subsequent calculation (hourly, as default). This parameter is indirectly affected by user input of HEX's design parameters.
6. Circulating system fluid mass flow rate – measured in [Kg/sec] and varies every time step by TMY subsequent calculation (hourly, as default).
7. Peak efficiency – a direct user input as limitation of efficiency curve as a function of all above parameters. This definition is set as 91.8 [%] as HelioFocus system default.

Efficiency calculation is explained in 'Physics chapters sub chapter – receiver equilibrium calculation. Internal parameters (scalar) of the various sub calculation are set by empirical statistics – real experiments.

Restrictions

Restrictions in the performance model receiver module were determined solely by physical limitations of the real system, theses being:

1. Maximal outlet temperature of 650 [°C] – limited by materials schedule (yield & lifetime vs. temperature)
2. Minimal mass flow rate of 0.2 [Kg/sec] – limited by heat vacation safety limit, for effective flow profile for receiver cooling (before receiver mechanical failure).

Calculation

$if\ DNI\ \left[\frac{W}{m^2}\right] > 300\ \rightarrow$

$\sigma\left[\frac{\mathrm{W}}{m^2\cdot K^{\circ 4}}\right] = 5.67037321\cdot 10^{-8}$ (Stefan–Boltzmann $constant$)

$h\left[\frac{W}{m^2\cdot K^{\circ}}\right] = natural\ convection\ coefficient\ (ambient);\ as\ explained\ in\ 'Physics'\ chapter$

$\varepsilon = 0.5\ (emissivity)$

$\eta_{receiver\ peak\ efficiency} = 0.918$

$A_{receiver}\ [m^2] = 3.18\ (receiver\ shell\ outer\ surface)$

$R_{receiver\ apperture}\ [m] = 0.275\ (receiver\ window\ apperture)$

$A_{receiver\ apperture}[m^2] = \pi\cdot R_{apperture}{}^2\ (receiver\ aperture\ area\ for\ re-radiation\ calculation)$

$A_{dish\ apperture}\ [m^2] = 450\ (effective\ dish\ area)$

$\Delta T_{window}\ [K^{\circ}] = 200\ (receiver\ window\ delta\ temperature\ vs.outgoing\ hot\ air)$

$\Delta T_{ambient}\ [K^{\circ}] = 0\ (radiational\ temperature\ variation\ vs\ ambient\ temperature)$

$\Delta T_{receiver\ face}\ [K^{\circ}] = 0\ (receiver\ face\ temperature\ variation\ vs\ incoming\ cold\ air)$

$C_{reradiation} = 0.1\ (reradiation\ scalar - empiric)\ ;\ derived\ from\ experiments$

$Cp_{air}\left[\frac{W}{Kg\cdot K^{\circ}}\right] \sim 1080\ (air\ specific\ heat\ at\ average\ temperature\ in\ the\ receiver)$

$Q_{collected}\ [W] = DNI\cdot A_{dish\ apperture}\cdot \eta_{dish}$

$$Q_{reradiation}[W] = C_{reradiation}\cdot A_{receiver\ apperture}\cdot \varepsilon\cdot\sigma \cdot\left[(T_{receiver\ air\ outlet} + \Delta T_{window})^4 - (T_{ambient} + \Delta T_{ambient})^4\right]$$

$$Q_{convection}\ [W] = h\cdot A_{receiver}\cdot\left(T_{receiver\ air\ inlet} + \Delta T_{receiver\ face} - T_{ambient}\right)$$

$$\dot{m}\left[\frac{Kg}{sec}\right] = \eta_{receiver\ peak\ efficiency}\cdot\frac{Q_{collected} - Q_{reradiation} - Q_{convection}}{(T_{receiver\ air\ outlet} - T_{receiver\ air\ inlet})\cdot Cp_{air}}$$

$$\Delta P_{receiver}\ [Bar] = 2000\cdot\frac{\left(\frac{\dot{m}}{\dot{m}_{design}}\right)^2}{100{,}000}\ ;\ \dot{m}_{design} = 0.6\left[\frac{Kg}{sec}\right]$$

$$\eta_{receiver} = \frac{\dot{m}\cdot Cp_{air}\cdot(T_{receiver\ air\ outlet} - T_{receiver\ air\ inlet})}{Q_{collected}}$$

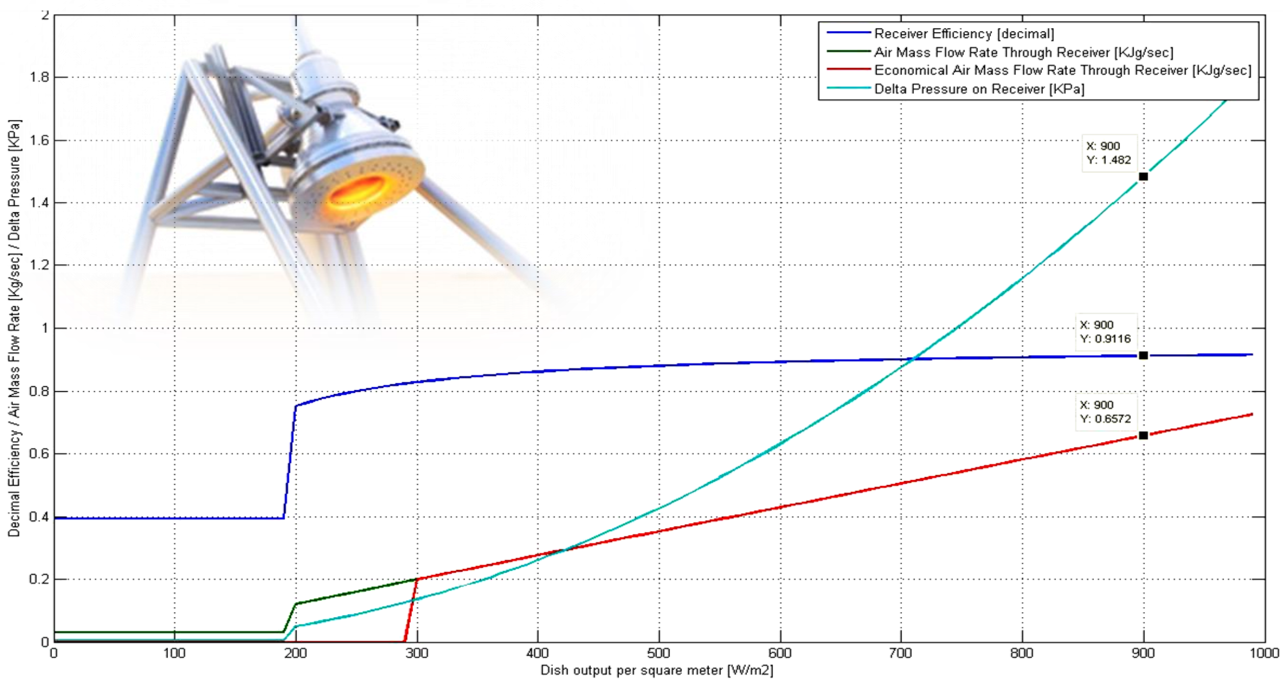
$if\ \dot{m} < 0.2\left[\frac{Kg}{sec}\right]\ \rightarrow$

$$\dot{m} = 0\left[\frac{Kg}{sec}\right]$$

$$\Delta P_{receiver}\ [Bar] = 0$$

$$\eta_{receiver} = 0$$

Fig.? - HeloFocus receiver characteristics



Dish

HelioFocus's solar reflector/concentrator is a squared Dish-like structure. It compiles of a 219 1.5 by 1.5 [m] square mirrors. Each one of those is arched along two of its planar axes to focus the reflecting sunlight to the relevant focal target. A 2 axes Fresnel layout of these mirrors (facets), focuses the sunlight caught on the dish aperture onto the focal plain at the target's position – i.e. receiver aperture intercept.

Fig.? – HeloFocus Prototype Dish – 2D Fresnel array of mirror facets

The overall power transferred to the receiver is calculated as:

$$Output\ Dish\ Power\ [KW] = DNI\left[\frac{KW}{m^2}\right] \cdot Effective\ Dish\ Area\ [m^2] \cdot \eta_{Dish\ total\ efficiency}$$

Where

$$\eta_{Dish\ total\ efficiency} = C_{correction} \cdot \eta_{Slope\ Error} \cdot \eta_{non\ shaded} \cdot \eta_{Structural\ load} \cdot \eta_{Reflectivity\ (non\ dirted)}$$

And $C_{correction}$ = 0.98, for the actual intercept fit.

These parameters are explained below.

Effective Dish area

Dish aperture is roughly 219 x 1.5^2 [m^2] = 492.75 [m^2]. Actual effective area for solar collection takes into account the below conditions:

1. Facets are not flat and are tilted, so that cross flux area is lower than 1.5^2 [m^2] for each of them, and varies with facet location on the dish.

2. Incoming sun rays are blocked by receiver, its support construction, and the HTS piping along the support. This small shadow area amounts to about 7 [m2] of gross dish aperture.
3. Deflected sun rays, going from the mirrors towards the receiver are blocked by receiver support construction and the HTS piping along it. This 'receiver shadowed' rout after concentration amounts to about 36 [m2] of gross dish aperture equivalent.

The overall effective dish aperture area is estimated at 450[m2].

Optics

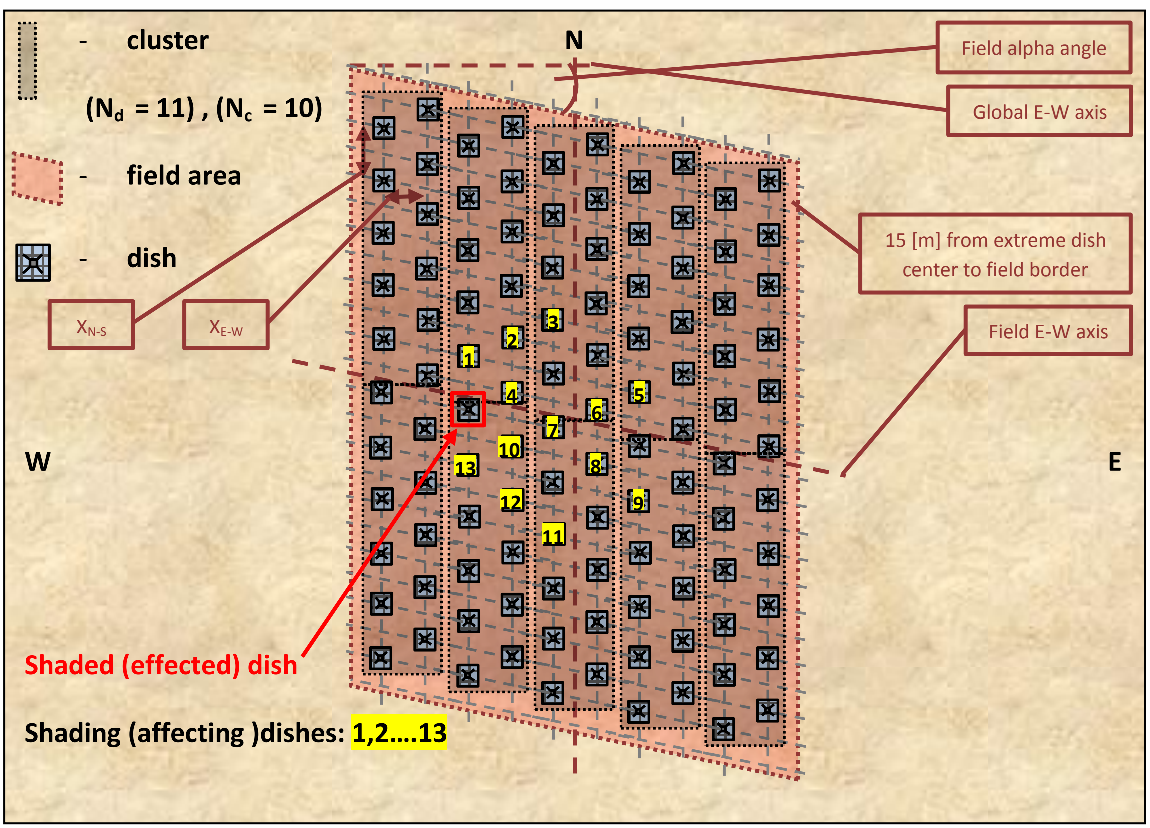
The dish follows the sun, in a direct line of sight manner, along the day – solar / earth (stellar) relative angular position, i.e. solar Azimuth (from north 0° [deg]) and Elevation (from horizon 0° [deg]). The dish is driven by an automated hydraulic cylinders system.

Mutual dish on dish shadowing in a dish array / matrix / field is calculated according to a HelioFocus's proprietary algorithm. The uniqueness of it is the 4th circle accuracy around the representing pseudo-dish, and the effect of the squared dishes shade-shape along the field array.

The algorithm:

HelioFocus.ltd dish (square) array mutual shading calculation / algorithm

By Natanel Davidovits – 04 / 03 / 2013



$\underline{\textbf{\textit{Base assumption}}: \textit{dishes in the field always follow the sun across the sky.}}$

$\psi \ = \ sun\ elevation\ (off\ horizon)\ [deg] :\ 0° \ < \ \psi \ < \ 90°$

$$\color{blue}{If} \ \psi \ \leq \ 0 \ \color{blue}{\rightarrow} \ No\ shading\ and\ no\ calculation \ \color{blue}{\rightarrow} \ \color{red}{\boldsymbol{shading} = \mathbf{0}\%}$$

$$\color{blue}{If} \ \psi > \ 0 \ \color{blue}{\rightarrow}$$

$\varphi \ = \ sun\ azimuth\ (off\ north)\ [deg]: 0° \ < \ \varphi \ < \ 360°$

$\alpha \ = \ field\ alpha\ angle\ (parallelogram\ angle\ from\ E - W\ line\ (clock\ wise)\ [deg]: 0° \ < \ \alpha \ < \ 45°\ allowed$

$Faz \ = \ field\ azimuth\ orientation\ angle\ (clock\ wise\ from\ north)\ [deg]: 0° \ < \ \alpha \ < \ 90°\ allowed$

$Fel \ = \ field\ elevation\ orientation\ angle\ (@\ Faz\ line)\ [deg]: 0° \ < \ \alpha \ < \ 10°\ allowed$

$az \ = \ \varphi \ + \ Faz \ = \ actual\ azimuth\ of\ sun\ relating\ dishes\ array\ [deg]$

$\color{blue}{If} \ az \ > \ 180° \ \color{blue}{\rightarrow} \ az \ = \ az \ - \ 180°$

$el \ = \ \psi \ + \ Fel \ = \ actual\ elevation\ of\ sun\ relating\ dishes\ array\ [deg]$

$a \ = \ dish\ width\ [m]$

$S \ = \ a^2 = \ dish\ area\ (sail)\ [m^2]$

$D \ = \dfrac{a}{sin(el)} \ = \ one\ dish\ shadow\ length\ on\ the\ ground\ /\ at\ elevation\ axis\ plane\ [m]$

$atg \ = \ tan(\alpha)$

$X_{N-S} \ = \ north\ to\ south\ distance\ of\ dish\ rows, \quad parallel\ to\ field\ (not\ global)\ N - S\ axis\ [m]$

$X_{E-W} = \ east\ to\ west\ distance\ of\ dish\ columns, at\ the\ same\ row,\ parallel\ to\ field\ (not\ global)\ E - W\ axis\ [m]$

$N_{N-S} \ = \ number\ of\ dishes\ rows\ along\ north\ - \ south\ axis,\ parallel\ to\ field\ (not\ global)\ N - S\ axis$

$N_{E-W} = \ number\ of\ dishes\ columns\ along\ east - west\ axis,\ parallel\ to\ field\ (not\ global)\ E - W\ axis$

$\underline{\boldsymbol{surrounding\ dishes\ location\ coordinates\ for\ 4th\ rank\ distance}}$:

$\boldsymbol{designating\ field\ E - W\ coordinates\ (X\ axis)}$: by dish order as clockwise from nort > dish 1 to 13

$$B\ [m] \ = \ X_{E-W} \cdot [0 , 0.5 , 1 , 0.5 , 2 , 1.5 , 1 , 1.5 , 2 , 0.5 , 1 , 0.5 , 0]$$

$\boldsymbol{designating\ field\ N - S\ coordinates\ (Y\ axis)}$: by dish order as clockwise from nort > dish 1 to 13

$$C1 \ [m] \ = \ X_{N-S} \cdot [1 , 1.5 , 2 , 0.5 , 1 , 0.5 , 0 , -0.5 , -1 , -0.5 , -2 , -1.5 , -1]$$

$\boldsymbol{Designated\ field\ N - S\ alteration\ due\ to\ alpha\ angle}$: by dish order as clockwise from nort $>$ dish 1 to 13

$$C2 \ = \ atg \cdot [-1\,, -1\,, -1\,, -1\,, -1\,, -1\,, -1\,, 1\,, 1\,, 1\,, 1\,, 1]$$

$\boldsymbol{designating\ field\ N - S\ actual\ coordinates\ (Y\ axis)}$:

$$A\ [m] \ = \ C1 \ + \ C2$$

$\boldsymbol{designating\ affecting\ dishes\ distance\ from\ effected\ (representing) dish\ at\ field\ center}$:

$$Dto_i\ [m] \ = \ \sqrt{A_i^2 + B_i^2}$$

$\boldsymbol{designating\ hand\ (radius) angle\ from\ field\ north\ to\ affecting\ dishes\ radial\ location}$:

$$Azto_i\ [deg] \ = \ \tan^{-1}\left(\frac{B}{A}\right)$$

$$If\ Azto_i < \ 0 \ \rightarrow \ Azto_i \ = \ Azto_i + 180°$$

$$Azto_N \ = \ 180°$$

$\boldsymbol{shade\ on\ representing\ dish\ by\ elevation}$:

$$El.shade_i\ [m] \ = \ (D - Dto_i) \cdot \sin(el)$$

$$if\ El.shade_i < 0 \ \ \rightarrow \ El.shade_i = 0$$

$\boldsymbol{shade\ on\ representing\ dish\ by\ azimuth}$:

$$Az.shade_i\ [m] \ = \ a - Dto_i \cdot |\sin(Azto_i - az)|$$

$$if\ |Azto_i - az| \geq 90° \ \ \rightarrow \ Az.shade_i = 0$$

$$if\ Az.shade_i < 0 \ \ \rightarrow \ Az.shade_i = 0$$

$\boldsymbol{each\ shading\ dish\ azimuthial\ /\ width\ span\ on\ target\ dish}$:

$if\ \ Az.shade_i > 0 \ \rightarrow$

$$if\ \{sign[sin(Azto_i - azimuth)] > 0°\}\ AND\ \{|Azto_i - azimuth| \geq 90°\} \rightarrow$$
$$Az.shade.span_{1,i} \ = \ \frac{a}{2}$$

$$Az.shade.span_{2,i} = \frac{a}{2} - Az.shade_i$$

else, *if* $\{sign[sin(Azto_i - azimuth)] < 0°\}$ *AND* $\{|Azto_i - azimuth| \geq 90°\} \rightarrow$

$$Az.shade.span_{1,i} = Az.shade_i - \frac{a}{2}$$

$$Az.shade.span_{2,i} = -\frac{a}{2}$$

else, *if* $\{sign[sin(Azto_i - azimuth)] = 0°\}$ *AND* $\{|Azto_i - azimuth| \geq 90°\} \rightarrow$

$$Az.shade.span_{1,i} = \frac{a}{2}$$

$$Az.shade.span_{2,i} = -\frac{a}{2}$$

else $\rightarrow$

$$Az.shade.span_{1,i} = 0$$

$$Az.shade.span_{2,i} = 0$$

else $\rightarrow$

$$Az.shade.span_{1,i} = 0$$

$$Az.shade.span_{2,i} = 0$$

1^{st} ***order shade overlap***:

if $\{Az.shade_1 > 0\}$ *AND* $\{Az.shade_2 > 0\} \rightarrow$

$p1 = Az.shade.span_{1,1}$

$p2 = Az.shade.span_{2,1}$

$s1 = Az.shade.span_{1,2}$

$s2 = Az.shade.span_{2,2}$

if $s1 < p2 \rightarrow$

$s1 = p2$

$L = s1 - s2$

else, *if* $s2 < p2 \rightarrow$

$s2 = p1$

$L = s1 - s2$

else $\rightarrow$

$L = Az.shade_2$

$Az.shade_2 = L$

if $\{Az.shade_2 > 0\}$ *AND* $\{Az.shade_3 > 0\} \rightarrow$

$p1 = Az.shade.span_{1,2}$

$p2 = Az.shade.span_{2,2}$

$s1 = Az.shade.span_{1,3}$

$s2 = Az.shade.span_{2,3}$

if $s1 > p2 \rightarrow$

$s1 = p2$

$L = s1 - s2$

else, *if* $s2 > p2 \rightarrow$

$s2 = p1$

$L = s1 - s2$

else $\rightarrow$

$L = Az.shade_3$

$Az.shade_3 = L$

$if\ \{Az.shade_4\ >\ 0\}\ AND\ \{Az.shade_3\ >\ 0\}\ \rightarrow$
$p1\ =\ Az.shade.span_{1,4}$
$p2\ =\ Az.shade.span_{2,4}$
$s1\ =\ Az.shade.span_{1,3}$
$s2\ =\ Az.shade.span_{2,3}$
$if\ s1 > p2\ \rightarrow$
$s1\ =\ p2$
$L\ =\ s1 - s2$
$else,\quad if\ s2 > p2\ \rightarrow$
$s2\ =\ p1$
$L\ =\ s1 - s2$
$else\ \rightarrow$
$L\ =\ Az.shade_4$
$Az.shade_4\ =\ L$

$if\ \{Az.shade_4\ >\ 0\}\ AND\ \{Az.shade_5\ >\ 0\}\ \rightarrow$
$p1\ =\ Az.shade.span_{1,4}$
$p2\ =\ Az.shade.span_{2,4}$
$s1\ =\ Az.shade.span_{1,5}$
$s2\ =\ Az.shade.span_{2,5}$
$if\ s1 > p2\ \rightarrow$
$s1\ =\ p2$
$L\ =\ s1 - s2$
$else,\quad if\ s2 > p2\ \rightarrow$
$s2\ =\ p1$
$L\ =\ s1 - s2$
$else\ \rightarrow$
$L\ =\ Az.shade_5$
$Az.shade_5\ =\ L$

$if\ \{Az.shade_6\ >\ 0\}\ AND\ \{Az.shade_5\ >\ 0\}\ \rightarrow$
$p1\ =\ Az.shade.span_{1,6}$
$p2\ =\ Az.shade.span_{2,6}$
$s1\ =\ Az.shade.span_{1,5}$
$s2\ =\ Az.shade.span_{2,5}$
$if\ s1 > p2\ \rightarrow$
$s1\ =\ p2$
$L\ =\ s1 - s2$
$else,\quad if\ s2 > p2\ \rightarrow$
$s2\ =\ p1$
$L\ =\ s1 - s2$
$else\ \rightarrow$
$L\ =\ Az.shade_6$
$Az.shade_6\ =\ L$

$if\ \{Az.shade_7\ >\ 0\}\ AND\ \{Az.shade_6\ >\ 0\}\ \rightarrow$
$p1\ =\ Az.shade.span_{1,7}$
$p2\ =\ Az.shade.span_{2,7}$
$s1\ =\ Az.shade.span_{1,6}$
$s2\ =\ Az.shade.span_{2,6}$
$if\ s1 > p2\ \rightarrow$
$s1\ =\ p2$
$L\ =\ s1 - s2$

$else, \quad if\ s2 > p2 \ \rightarrow$
$s2 = p1$
$L = s1 - s2$
$else \ \rightarrow$
$L = Az.shade_7$
$Az.shade_7 = L$

$if\ \{Az.shade_7 > 0\}\ AND\ \{Az.shade_8 > 0\} \ \rightarrow$
$p1 = Az.shade.span_{1,7}$
$p2 = Az.shade.span_{2,7}$
$s1 = Az.shade.span_{1,8}$
$s2 = Az.shade.span_{2,8}$
$if\ s1 > p2 \ \rightarrow$
$s1 = p2$
$L = s1 - s2$
$else, \quad if\ s2 > p2 \ \rightarrow$
$s2 = p1$
$L = s1 - s2$
$else \ \rightarrow$
$L = Az.shade_8$
$Az.shade_8 = L$

$if\ \{Az.shade_8 > 0\}\ AND\ \{Az.shade_9 > 0\} \ \rightarrow$
$p1 = Az.shade.span_{1,8}$
$p2 = Az.shade.span_{2,8}$
$s1 = Az.shade.span_{1,9}$
$s2 = Az.shade.span_{2,9}$
$if\ s1 > p2 \ \rightarrow$
$s1 = p2$
$L = s1 - s2$
$else, \quad if\ s2 > p2 \ \rightarrow$
$s2 = p1$
$L = s1 - s2$
$else \ \rightarrow$
$L = Az.shade_9$
$Az.shade_9 = L$

$if\ \{Az.shade_{10} > 0\}\ AND\ \{Az.shade_9 > 0\} \ \rightarrow$
$p1 = Az.shade.span_{1,10}$
$p2 = Az.shade.span_{2,10}$
$s1 = Az.shade.span_{1,9}$
$s2 = Az.shade.span_{2,9}$
$if\ s1 > p2 \ \rightarrow$
$s1 = p2$
$L = s1 - s2$
$else, \quad if\ s2 > p2 \ \rightarrow$
$s2 = p1$
$L = s1 - s2$
$else \ \rightarrow$
$L = Az.shade_{10}$
$Az.shade_{10} = L$

$if\ \{Az.shade_{10} > 0\}\ AND\ \{Az.shade_{11} > 0\} \ \rightarrow$
$p1 = Az.shade.span_{1,10}$

$p2 = Az.shade.span_{2,10}$
$s1 = Az.shade.span_{1,11}$
$s2 = Az.shade.span_{2,11}$
$if\ s1 > p2 \rightarrow$
$s1 = p2$
$L = s1 - s2$
$else, \quad if\ s2 > p2 \rightarrow$
$s2 = p1$
$L = s1 - s2$
$else \rightarrow$
$L = Az.shade_{11}$
$Az.shade_{11} = L$

$if\ \{Az.shade_{12} > 0\}\ AND\ \{Az.shade_{11} > 0\} \rightarrow$
$p1 = Az.shade.span_{1,12}$
$p2 = Az.shade.span_{2,12}$
$s1 = Az.shade.span_{1,11}$
$s2 = Az.shade.span_{2,11}$
$if\ s1 > p2 \rightarrow$
$s1 = p2$
$L = s1 - s2$
$else, \quad if\ s2 > p2 \rightarrow$
$s2 = p1$
$L = s1 - s2$
$else \rightarrow$
$L = Az.shade_{12}$
$Az.shade_{12} = L$

$if\ \{Az.shade_{13} > 0\}\ AND\ \{Az.shade_{11} > 0\} \rightarrow$
$p1 = Az.shade.span_{1,12}$
$p2 = Az.shade.span_{2,12}$
$s1 = Az.shade.span_{1,13}$
$s2 = Az.shade.span_{2,13}$
$if\ s1 > p2 \rightarrow$
$s1 = p2$
$L = s1 - s2$
$else, \quad if\ s2 > p2 \rightarrow$
$s2 = p1$
$L = s1 - s2$
$else \rightarrow$
$L = Az.shade_{13}$
$Az.shade_{13} = L$

$\boldsymbol{2^{nd}\ order\ shade\ overlap}$:

$if\ \{Az.shade_{1} > 0\}\ AND\ \{Az.shade_{3} > 0\} \rightarrow$
$p1 = Az.shade.span_{1,1}$
$p2 = Az.shade.span_{2,1}$
$s1 = Az.shade.span_{1,3}$
$s2 = Az.shade.span_{2,3}$
$if\ s1 > p2 \rightarrow$
$s1 = p2$
$L = s1 - s2$

$else, \quad if\ s2 > p2 \ \rightarrow$
$s2 = p1$
$L = s1 - s2$
$else \ \rightarrow$
$L = Az.shade_3$
$Az.shade_3 = L$

$if\ \{Az.shade_4 > 0\}\ AND\ \{Az.shade_2 > 0\} \ \rightarrow$
$p1 = Az.shade.span_{1,4}$
$p2 = Az.shade.span_{2,4}$
$s1 = Az.shade.span_{1,2}$
$s2 = Az.shade.span_{2,2}$
$if\ s1 > p2 \ \rightarrow$
$s1 = p2$
$L = s1 - s2$
$else, \quad if\ s2 > p2 \ \rightarrow$
$s2 = p1$
$L = s1 - s2$
$else \ \rightarrow$
$L = Az.shade_2$
$Az.shade_2 = L$

$if\ \{Az.shade_4 > 0\}\ AND\ \{Az.shade_6 > 0\} \ \rightarrow$
$p1 = Az.shade.span_{1,4}$
$p2 = Az.shade.span_{2,4}$
$s1 = Az.shade.span_{1,6}$
$s2 = Az.shade.span_{2,6}$
$if\ s1 > p2 \ \rightarrow$
$s1 = p2$
$L = s1 - s2$
$else, \quad if\ s2 > p2 \ \rightarrow$
$s2 = p1$
$L = s1 - s2$
$else \ \rightarrow$
$L = Az.shade_6$
$Az.shade_6 = L$

$if\ \{Az.shade_7 > 0\}\ AND\ \{Az.shade_5 > 0\} \ \rightarrow$
$p1 = Az.shade.span_{1,7}$
$p2 = Az.shade.span_{2,7}$
$s1 = Az.shade.span_{1,5}$
$s2 = Az.shade.span_{2,5}$
$if\ s1 > p2 \ \rightarrow$
$s1 = p2$
$L = s1 - s2$
$else, \quad if\ s2 > p2 \ \rightarrow$
$s2 = p1$
$L = s1 - s2$
$else \ \rightarrow$
$L = Az.shade_5$
$Az.shade_5 = L$

$if\ \{Az.shade_7 > 0\}\ AND\ \{Az.shade_9 > 0\} \rightarrow$

$p1 = Az.shade.span_{1,7}$

$p2 = Az.shade.span_{2,7}$

$s1 = Az.shade.span_{1,9}$

$s2 = Az.shade.span_{2,9}$

$if\ s1 > p2 \rightarrow$

$s1 = p2$

$L = s1 - s2$

$else, \quad if\ s2 > p2 \rightarrow$

$s2 = p1$

$L = s1 - s2$

$else \rightarrow$

$L = Az.shade_9$

$Az.shade_9 = L$

$if\ \{Az.shade_{10} > 0\}\ AND\ \{Az.shade_8 > 0\} \rightarrow$

$p1 = Az.shade.span_{1,10}$

$p2 = Az.shade.span_{2,10}$

$s1 = Az.shade.span_{1,8}$

$s2 = Az.shade.span_{2,8}$

$if\ s1 > p2 \rightarrow$

$s1 = p2$

$L = s1 - s2$

$else, \quad if\ s2 > p2 \rightarrow$

$s2 = p1$

$L = s1 - s2$

$else \rightarrow$

$L = Az.shade_8$

$Az.shade_8 = L$

$if\ \{Az.shade_{10} > 0\}\ AND\ \{Az.shade_{12} > 0\} \rightarrow$

$p1 = Az.shade.span_{1,10}$

$p2 = Az.shade.span_{2,10}$

$s1 = Az.shade.span_{1,12}$

$s2 = Az.shade.span_{2,12}$

$if\ s1 > p2 \rightarrow$

$s1 = p2$

$L = s1 - s2$

$else, \quad if\ s2 > p2 \rightarrow$

$s2 = p1$

$L = s1 - s2$

$else \rightarrow$

$L = Az.shade_{12}$

$Az.shade_{12} = L$

$if\ \{Az.shade_{13} > 0\}\ AND\ \{Az.shade_{11} > 0\} \rightarrow$

$p1 = Az.shade.span_{1,13}$

$p2 = Az.shade.span_{2,13}$

$s1 = Az.shade.span_{1,11}$

$$s2 = Az.shade.span_{2,11}$$
$$if\ s1 > p2 \ \rightarrow$$
$$s1 = p2$$
$$L = s1 - s2$$
$$else, \quad if\ s2 > p2 \ \rightarrow$$
$$s2 = p1$$
$$L = s1 - s2$$
$$else \ \rightarrow$$
$$L = Az.shade_{11}$$
$$Az.shade_{11} = L$$

$$if\ Az.shade_i < 0 \ \rightarrow \quad Az.shade_i = 0$$

average shading with respect to exterior rows:

$$if\ \{0° \leq\ az <\ 90°\}\ OR\ \{180°\ \leq az < 270°\} \quad \rightarrow$$
$$A.outer.rim = (N_{N-S} - 1) \cdot (Az.shade_1 \cdot El.shade_1) + (N_{E-W} - 1) \cdot (Az.shade_7 \cdot El.shade_7)$$
$$A.secondary.rim = [(N_{N-S} - 2) + (N_{E-W} - 2)] \cdot (Az.shade_4 \cdot El.shade_4)$$
$$else \ \rightarrow$$
$$A.outer.rim = (N_{N-S} - 1) \cdot (Az.shade_{13} \cdot El.shade_{13}) + (N_{E-W} - 1) \cdot (Az.shade_7 \cdot El.shade_7)$$
$$A.secondary.rim = [(N_{N-S} - 2) + (N_{E-W} - 2)] \cdot (Az.shade_{10} \cdot El.shade_{10})$$

$$S.shade = \sum_{i=1}^{13} Az.shade_i \cdot El.shade_i$$

$$A.inner.field.shade = S.shade \cdot (N_{N-S} - 2) \cdot (N_{E-W} - 2)$$
$$A.shade = |A.outer.rim + A.secondary.rim + A.inner.field.shade|$$
$$\boldsymbol{shading = 1 - \frac{A.shade}{S \cdot N_{N-S} \cdot N_{E-W}}} \ [.\%]$$

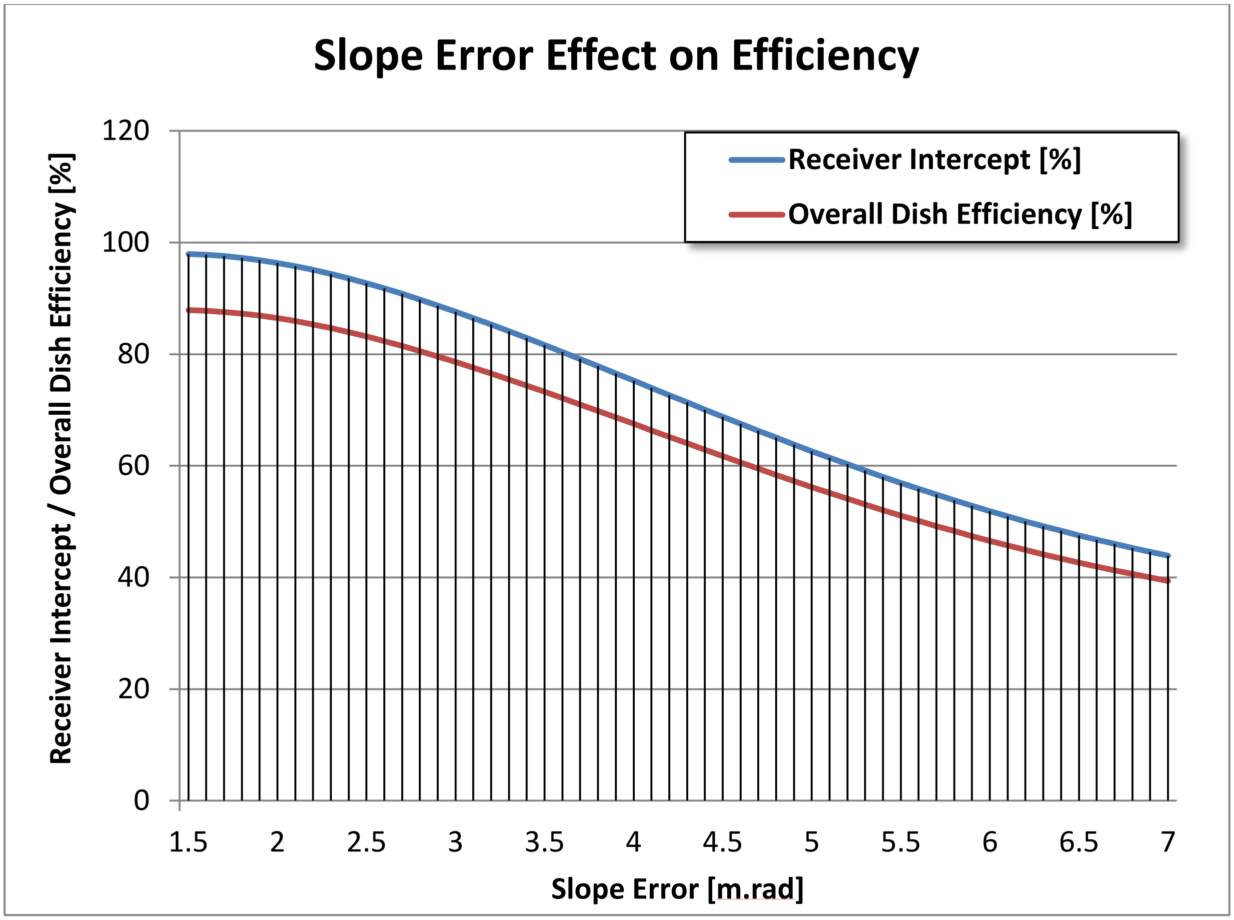
Slope error

Each 1.5 by 1.5 [m] mirror / facet is designed to fit a spherical surface. Since production is imperfect, a slope error is an inherent side effect. This slope deviation reflects incoming light to an off target direction, pending deviation severity. The slope deviation is measured in [m.rad] as RMS of X & Y principal axes of mirror facets. The base intercept is the highest limit for dish efficiency, from which degraded on to other factors (reflectivity / dirt, structural). This value is then implemented in the below polynomial to evaluate the receiver’s intercept base value:

$SE\,[m.rad] = Slope\ Error\,[m.rad] + 0.2$ (0.2 [m.rad] is correction for 1.5 RMS [m.rad] fit to 98 [%] receiver's intercept)

$$Intercept\,[\%] \; = 0.98 \cdot (-0.0525 \cdot SE^4 \; + 1.3333 \cdot SE^3 \; - 11.372 \cdot SE^2 \; + 27.422 * SE + 78.08)$$

Fig.? – receiver's intercept [%] vs. RMS Slope Error [m.rad]



Calibration

In the model, the dish always follows the sun azimuthally, and during the day time elevationally as well.

The sun's position is calculated by the algorithm explained in:

Revised January 2008 – NREL / TP-560-34302

Solar Position Algorithm for solar Radiation Applications

Ibrahim Reda and Afshin Andreas

Structural load effect

The dish is a rigid structure made out of steel bars – truss formation. It keeps its geometrical properties well but as all physical structures, it deflects slightly under a force load. This deflection decreases the optical accuracy of the dish, lowering the receiver’s / focal target’s intercept. The intercepted amount is measured in percent (as in table below).

Two forces are affecting the dish:

- Gravity (the structure self-weight load) – defined by elevation angle alone (azimuth irrelevant)
- Wind load (sail effect) – defined by dish-elevation, dish-azimuth, wind direction (azimuthal - for principal angle of attack) and its intensity.

The combined loads were similitude pre-calculated by the dish design contractor, *schlaich bergermann and partner*, and include the designed slope error intercept. The data is shown tabled below:

wind 0 [m/s]	**Azimuth**	**El. 0° - II**	**El. 10°**	**El. 45°**	**El. 90°**
	0	96.99%	97.22%	97.54%	98.05%
Wind 7 [m/s]	**Azimuth**	**El. 0° - II**	**El. 10°**	**El. 45°**	**El. 90°**
	0	96.88%	96.91%	97.01%	97.99%
	15	96.86%	96.94%	97.05%	98.00%
	30	96.85%	96.91%	97.09%	98.00%
	45	96.83%	96.99%	97.16%	98.02%
	60	96.83%	97.03%	97.24%	98.03%
	75	96.81%	97.10%	97.38%	98.08%
	90	96.79%	97.15%	97.49%	98.01%
	105	96.81%	97.19%	97.57%	97.92%
	120	96.92%	97.19%	97.57%	97.88%
	135	96.88%	97.21%	97.57%	97.79%
	150	96.87%	97.33%	97.59%	97.83%
	165	96.87%	97.34%	97.53%	97.74%
	180	96.87%	97.33%	97.59%	97.80%
Wind 14 [m/s]	**Azimuth**	**El. 0° - II**	**El. 10°**	**El. 45°**	**El. 90°**
	0	96.17%	95.47%	93.10%	95.84%

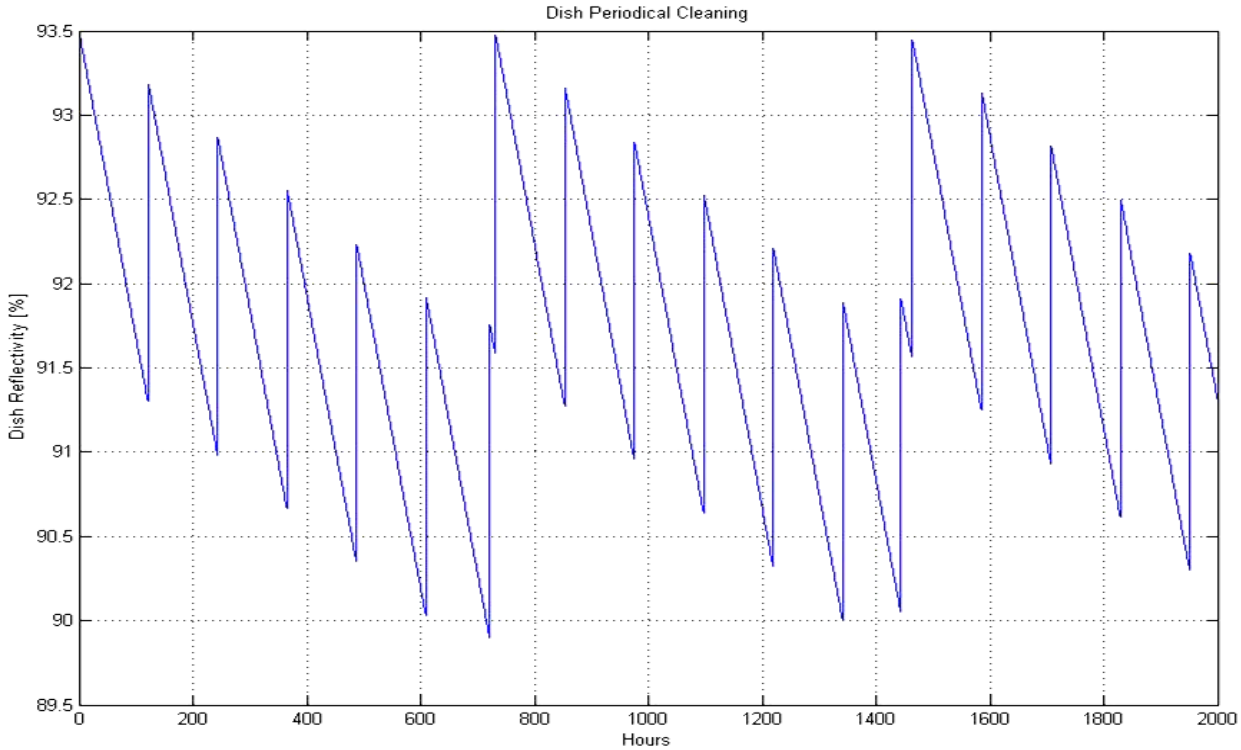
15	96.13%	95.52%	93.47%	95.93%
30	96.07%	95.34%	93.85%	96.10%
45	96.01%	95.73%	94.51%	96.33%
60	96.12%	95.78%	95.34%	96.94%
75	96.09%	96.21%	96.29%	97.49%
90	95.99%	96.53%	96.92%	97.37%
105	96.33%	96.76%	97.19%	97.02%
120	96.35%	96.76%	97.03%	96.65%
135	96.26%	97.03%	96.99%	96.21%
150	96.21%	97.20%	97.06%	95.75%
165	96.18%	97.18%	97.02%	95.56%
180	96.20%	97.14%	97.06%	95.39%

This lookup table is interpolated (by least squared method) into a sleeked volumetric [dish-elevation, (dish-azimuth - wind-direction), wind intensity] function to define the receiver's intercept accurately.

Dirt

The reflectivity of the dish decreases with time due to dust / dirt coverage. This dirt gets lite cleaned periodically, and totally cleaned after a few periods. These two timings are set as default 100 [hours] for slight increases and 750 [hours] dramatic increases of reflectivity, measured by percent. Base reflectivity / mirror design reflectivity is set as default: 92.5 [%]. The recursive double cleaning of the dirt can be seen below:

Fig.? – Recursive double cleaning, reflectivity [%] vs. time [hours]



Consumption

Dish's consumption is based on sun tracking average power consumption of the hydraulic pump. Each time step of TMY file (default is 1 hour) the delta elevation [deg] and azimuth angle [deg] is calculated from the previous step and then implemented in the below summation:

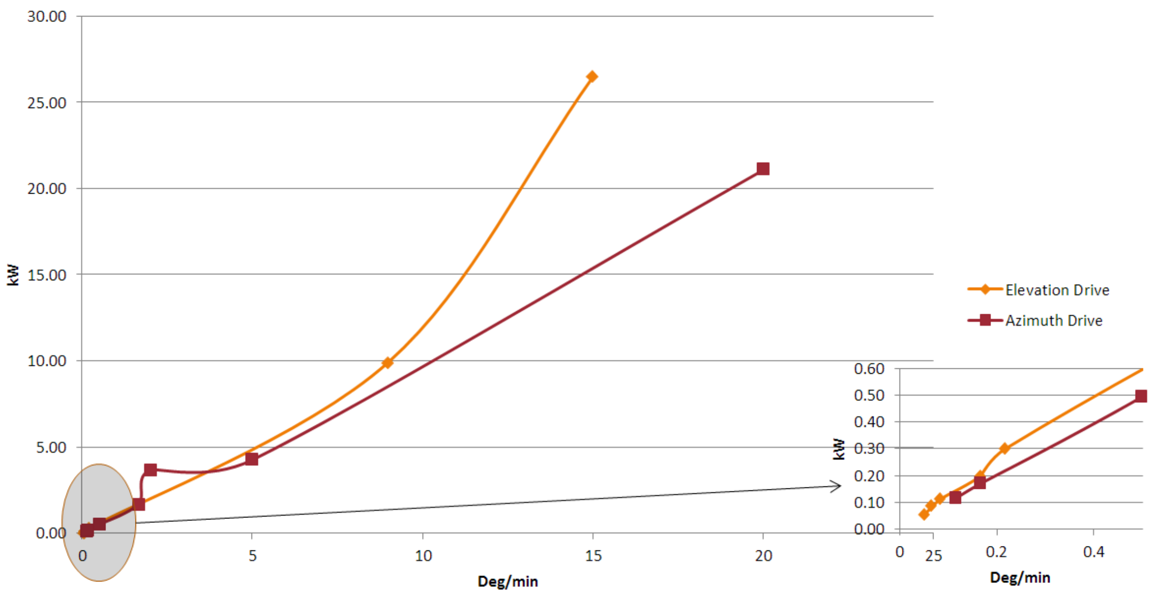
If the elevation angle is lower than 0°, the ΔElevation = 0°.

$$one\ dish\ consumption\ [KW] = 1 \cdot \frac{\Delta Elevation^{\circ}}{\Delta Time\ Step} + 0.833 \cdot \frac{\Delta Azimuth^{\circ}}{\Delta Time\ Step}$$

$$Total\ field\ consumption\ [KW] = one\ dish\ consumption \cdot dishes\ in\ field$$

This calculation was taken from the dish design contractor, *schlaich bergermann and partner*, and is described in the below figure.

Fig.? – single dish hydraulic drive consumption [KW] vs. [Deg/min]



HEX

Efficiency

Steam tables source

Consumption

Restrictions

Power block

Efficiency

Restrictions

1. Physics

Materials

Air

Heat capacity

Reynolds number

Prandtl number

Rayleigh number

Nusselt number

Heat onduction coefficient

Heat convection coefficients

- At circle pipe wall
- At inner wall annuli
- At outer wall annuli
- At cylinder outer wall

Carbon steel

- Heat capacity
- Heat conductive coefficient
- Density

Stainless steel

- Heat capacity
- Heat conductive coefficient
- Density

Aluminum

- Heat capacity
- Heat conductive coefficient
- Density

Micro porous insulation

- Heat capacity
- Heat conductive coefficient

Density

Rock-wool insulation

Heat capacity

Heat conductive coefficient

Density

HTS dynamic pressure loss

Annular walls mutual radiation

Assumptions

Calculation

1D cylindrical steady state heat transfer

Assumptions

Calculation

1D cylindrical transient state (time dependent) heat transfer

Assumptions

Calculation

Meshing

Fourier number

Biot number

Time step

Receiver equilibrium

HEX steam production

Math

- Power block methods – standalone / fixed / combined cycle
- Blower's consumption
- Steam pumps consumption
- Dirt collected & cleaning effect
- Dish Structural deformation – load and wind
- Slope error intercept
- Dish hydraulics consumption
- HelioFocus field dish array mutual shading
- HTS section heat dissipation
  - Pipe
  - Annular

Operation logics

- Annular section dynamic pressure loss
- Transient state (time dependent) heat transfer time sub-stepping by TMY step
- 1st order HTS performance convergence
- 2nd order HTS performance convergence – receiver inlet control
- 3rd order HTS performance convergence – HEX inlet control

Optimization

- TMY data statistical evaluation
- Optimization target function
- Optimization variables and bounds
- Available case studies