SolPos

A tool for calculating sun trajectories for any point on the globe and
for estimating the yield of photovoltaic or thermal solar energy harvesting systems.

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Contents

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References

[1] Reda, Ibrahim and Afshin, Andreas; Solar Position Algorithm for Solar Radiation Applications; National Renewable Energy Laboratory Technical Report NREL/TP-560-34302; Revised January 2008. Download from https://www.nrel.gov/docs/fy08osti/34302.pdf.

[2] Klimanormwerte 1981-2010: Relative Sonnenscheindauer; MeteoSchweiz; https://www.meteoschweiz.admin.ch/product/input/climate-data/normwerte-pro-messgroesse/np8110/nvrep_np8110_sremaxmv_d.pdf

[3] Solar Irradiance; Wikipedia; https://en.wikipedia.org/wiki/Solar_irradiance

[4]

Modification History

Version	Date	Author	Description
1.0	March 05, 2020	Felix Meier	created

1 Introduction

SolPos is a software for calculating the sun trajectory at any instant in time at any location on the globe.

Its main use is for optimizing solar panel (both electric and thermic) systems and for estimating the yield of such systems.

Yield estimation takes into account

- system location and elevation
- panel orientation (azimuth and elevation)
- Southern orientation or East/West orientation
- panel layering and layer refraction indexes
- nominal panel efficiency
- possible bypass diodes
- horizon shading
- object shading
- panel row separation in case of multiple rows
- front row shading
- relative sunshine percentage

The outputs are given as curves

- sun trajectories for any day of the year at any location on the globe

- day yield (one hour resolution)
- month yield (one day resolution)
- year yield (one month resolution)

The output can be printed (or saved as a .pdf file if a suitable software for printing to files is available) together with all the relevant parameters for purposes of documentation.

SolPos makes use of the Solar Position Algorithm as published by the US National Renewable Energy Laboratory [1]. For more information, click the "About SolPos" button in the main window.

SolPos does not require any special computer resources. It will run on any PC running under Windows 8 or newer.

2 Technical Terms

Throughout this document, the following terms are used:

2.1 Reference Plane

The reference plane is tangential to the current position on the globe. It is equal to the local earth surface.

2.2 Azimuth

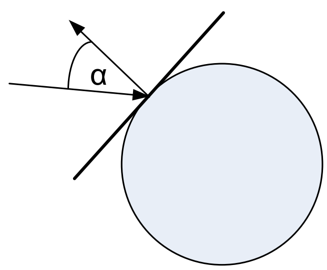
The Azimuth is the angle in degrees between North and the projection onto the reference plane of one of the following:

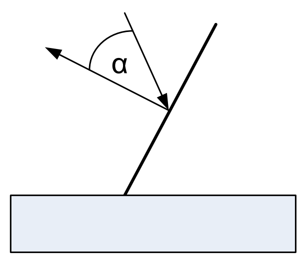
- the incoming rays
- a point on the horizon
- the baseline of the solar panels

Positive from North via East to South and West.

2.3 Incidence

The incidence is the angle between the norm of a (reference plane or panel) surface and the incident rays.

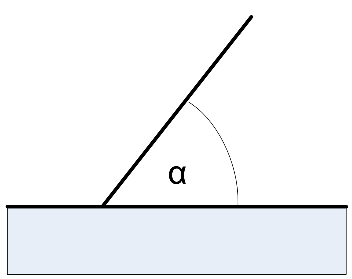




2.4 Elevation

The elevation is the angle between the reference plane and

- the horizon
- the incident rays
- the panel surface



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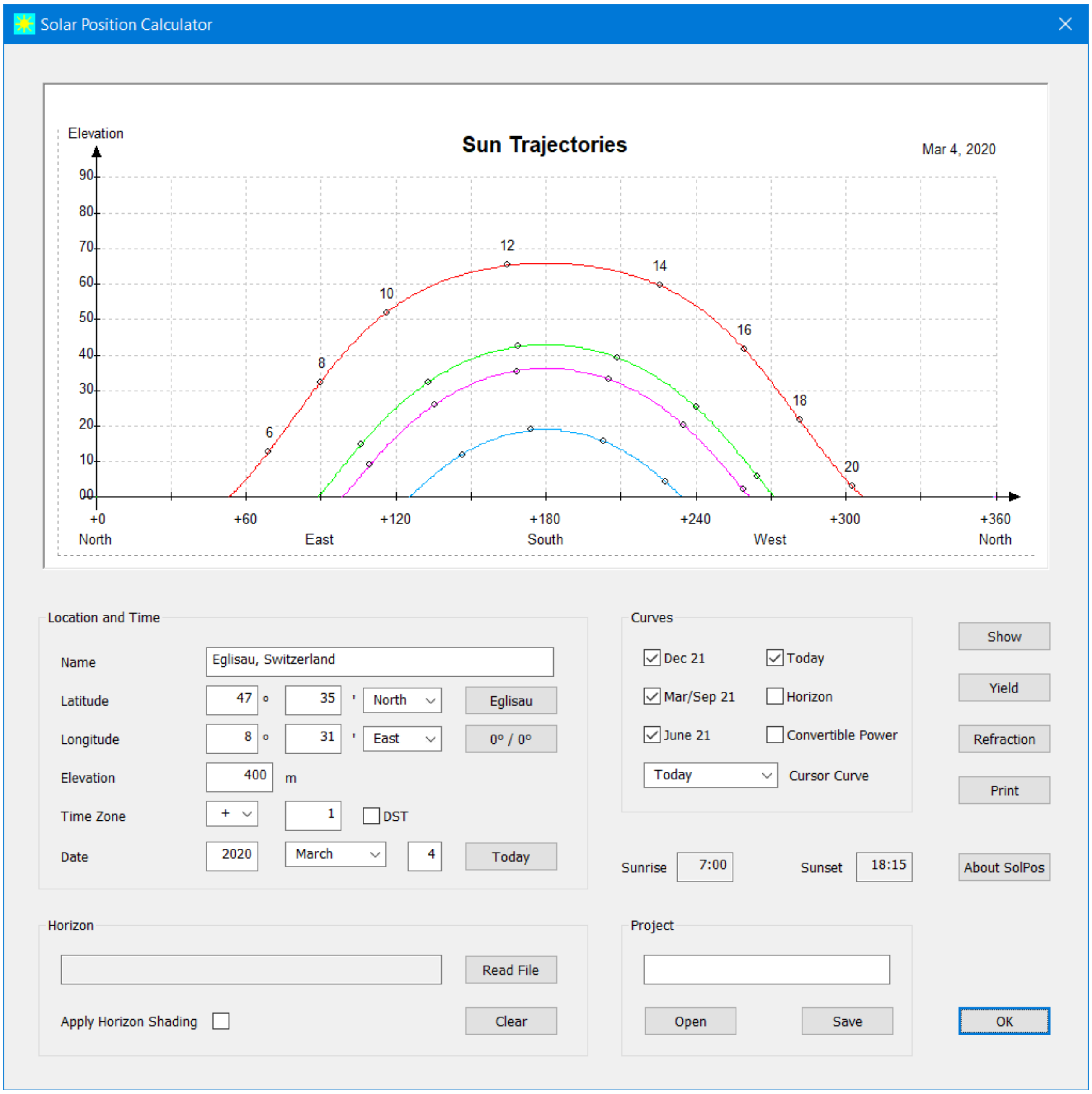
3 The Main Window



The main window shows the sun trajectories on various dates of the year for a given location. The default location at startup is Eglisau, Switzerland, my home town.

The red curve is for June 21, the green curve is for March/Sept. 21, and the blue curve is for Dec. 21. The magenta curve is for the current date.

Also, two more curves can be selected to be shown: The horizon of a specific location (if available), and the relative power that is available for conversion.

The dotted lines to the left and at the bottom are cursor lines. They can be moved by means of the mouse, and the values corresponding to the selected cursor curve will be shown at the right or top end of the cursor line.

3.1 Location and Time

3.1.1 Name

A field to enter the name of the location.

3.1.2 Latitude and Longitude

The geographical coordinates in degrees and minutes. One minute corresponds to about 4 kilometers on the earth surface, so seconds do not make sense. To determine the coordinates of the location of interest, go to e.g. https://www.latlong.net.

The "Eglisau" button enters the coordinates of my home town. The "0º / 0º " button sets the coordinates to the intersection of the equator with the Greenwich meridian.

3.1.3 Elevation

Enter the elevation in meters above sea level.

3.1.4 Time Zone and DST

Fractional hours, e.g. 1.5, are OK for the time zone offset. If "DST" is ticked, one hour is added to the time zone offset.

3.1.5 Date

Enter the year, month and day of interest. For estimating annual yield, the year is taken, and for the month yield, the month of the year is taken.

The "Today" button resets the date to the current date.

3.2 Horizon

A file may be provided with a list of vertices of the horizon line for a specific location. With this data, the shading of solar panels by the horizon can be taken into account.

The file is a simple text file with two integer values per line: Azimuth and elevation in degrees:

```
0    4
17   5
26   5
32   4
…
350  2
350  4
360  4
```

If the shading by the horizon must be taken into account for yield calculations, the check box must be ticked.

For more information on the horizon issue, see section 6.1.

3.3 Curves

The curves to be shown can be selected individually. Also, the curve that is to be used for showing cursor values can be selected.

3.4 Project

All the current settings of the application can be saved to a file and retrieved later. The default file extension is `.solpos`.

3.5 Cursors

The dotted lines to the left and at the bottom are cursor lines. They can be moved by means of the mouse, and the values corresponding to the selected cursor curve will be shown at the right or top end of the cursor line.

3.6 Buttons

3.6.1 Show

Click this button for updating the curves after changing any of the parameters in this window.

3.6.2 Yield

Opens the dialog for yield estimations.

3.6.3 Refraction

Opens the dialog for specifying reflection / refraction parameters of the solar panels to be used.

3.6.4 About SolPos

Provides information about the program version and about the Solar Position Algorithm used by SolPos.

3.6.5 Print

Provides a printout of the curves and of the parameter settings.

3.6.6 OK

Quits the program

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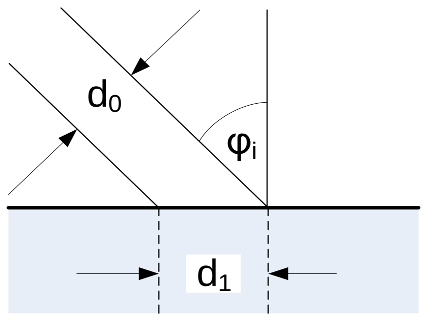
4 AOI (Angle Of Incidence) Effects

4.1 Panel Normal Radiation

Solar radiation in W/m^2 is specified on a surface that is normal to the incident rays, i.e. normal to the angle of incidence:



$$d_1 = d_0 / \cos(\varphi_i)$$

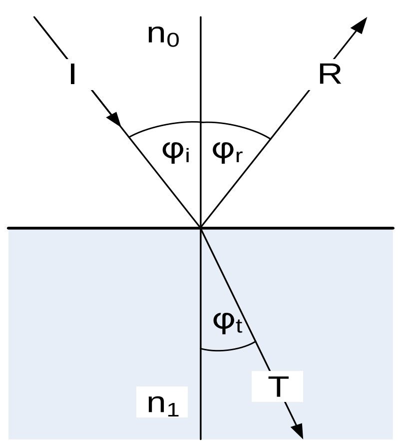
The yield of solar panels is specified assuming that the incident radiation is normal to the surface of the panel. So the incident radiation must be multiplied by cos(φ_i) for obtaining the radiation that is normal to the surface of the panel.

4.2 Reflection and Refraction

Solar radiation traverses several layers with different optical and / or thermal properties before it reaches the PN junction or the heat collection liquid. The final radiation that reaches the energy conversion layer will be reduced by the properties of the intermediate media.

At every boundary between two layers, there will be reflection and refraction due to the difference in refraction index of the materials on either side of the boundary. These effects are governed by Snell's law and by the Fresnel equations:

4.2.1 Snell's Law



Snell's law states:

$$\frac{\sin(\varphi_t)}{\sin\,(\varphi_i)} = \frac{n_0}{n_1}$$

or

$$\varphi_t = \arcsin\left[\frac{n_0}{n_1} * \sin\,(\varphi_i)\right]$$

4.2.2 The Fresnel Equations

For the reflectance and transmission power components that are described by the Fresnel equations, an invisible property of the incident light becomes important: polarization. The polarization of sunlight varies during the day and depends on weather and location, and so it is next to impossible to predict exactly. For reasons of convenience, we assume that the total power is the average from the s and p polarization powers. The reflected powers are

$$R_s = \left|\frac{n_0 cos\varphi_i - n_1 cos\varphi_t}{n_0 cos\varphi_i + n_1 cos\varphi_t}\right|^2$$

$$R_p = \left|\frac{n_0 cos\varphi_t - n_1 cos\varphi_i}{n_0 cos\varphi_t + n_1 cos\varphi_i}\right|^2$$

Assuming unpolarized light, we take the average of the s and p reflected power as an effective reflected power:

$$R_{eff} = \frac{1}{2}\left(R_s + R_p\right)$$

Since the energy is conserved, the transmitted power then becomes

$$T_{eff} = 1 - R_{eff}$$

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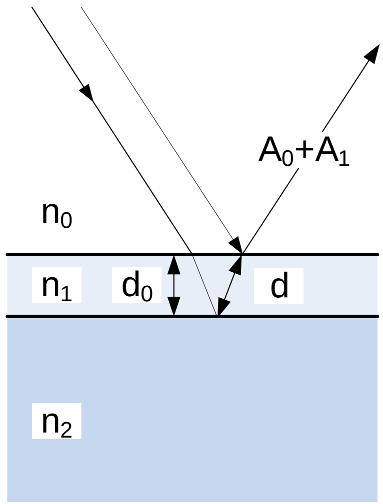
4.2.3 Anti-Reflection Coating

In order to improve the efficiency of the solar cell by minimizing the reflected power, ARC (Anti Reflection Coating) is introduced at some layer boundaries:



The thickness of the ARC layer is chosen so that the group delay of A_1, the refracted and reflected radiation amplitude at the exit to the top medium, is equal to half the period of the incident light. So the reflected components A_0 and A_1 (almost) cancel each other, and a larger portion of the incident power is propagated into the layer underneath the ARC. The optimum index of refraction for the ARC material is

$$n_1 = \sqrt{n_0 * n_2}$$

Obviously, this will never be perfect, since solar radiation comes at a wide range of wavelengths, and the calculation is only perfect at an incidence angle of $\varphi_i = 0°$.

When the angle of incidence is $\varphi_i = 0°$ and the waves travel through the ARC, the phase shift of A_1 is equal to π. However, if the angle of incidence is different from 0°, then the reflected waves will not cancel each other exactly. If $\varphi_i \neq 0°$, then the distance that the waves travel inside the ARC is longer, and the phase shift at the exit point of the reflected waves will be

$$\Delta\varphi_1 = \pi * \frac{d}{d_0} = \frac{\pi}{cos(\varphi_t)}$$

The relative sum of the reflected wave amplitudes then becomes

$$A_0 + A_1 = \cos(0) + \cos\left(\frac{\pi}{cos\ (\varphi_t)}\right)$$

or

$$A_0 + A_1 = \ 1.0 + \cos\left[\frac{\pi}{\cos(\varphi_t)}\right]$$

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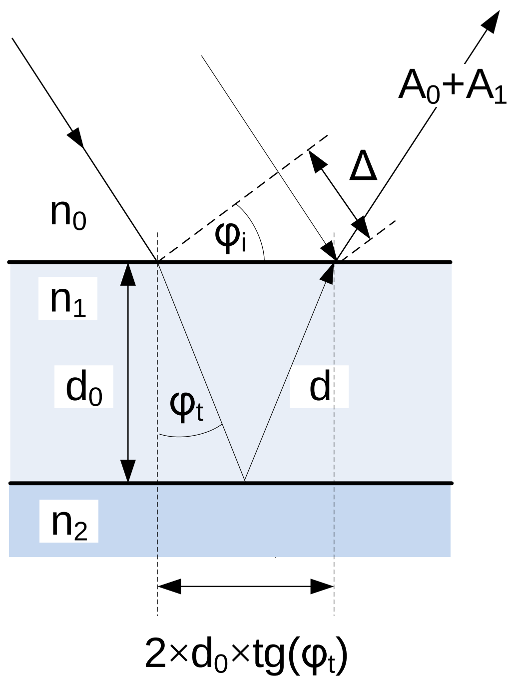
And the reflected power is equal to the square of (A_0 + A_1) times the incident power:

$$P_r = P_i * \left\{1.0 + \cos\left[\frac{\pi}{\cos(\varphi_t)}\right]\right\}^2$$

The power transmitted into the bottom medium is

$$P_t = 1.0 - P_r$$

Note that this is just a rough approximation, since the reflected waves leave the ARC at a point that is different from the entry point, and so the incoming waves at the exit point are also phase shifted relative to the incoming waves at the entry point. If this delay is to be taken into account, a more detailed analysis is required:



At the exit point, the incident wave has traveled another distance of

$$\Delta = 2 * d_0 * tg(\varphi_t) * sin(\varphi_i)$$

Since

- the phase shift over distance d_0 in the medium with refractive index n_1 is $\pi/2$,
- and the wavelength in the medium with refractive index n_0 is longer by n_0/n_1,

the phase shift of the incident wave a the exit point relative to the incident wave an the entry point is

$$\Delta\varphi_0 = 2 * \frac{\pi}{2} * \frac{n_0}{n_1} * tg(\varphi_t) * sin(\varphi_i)$$

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The phase delay inside the ARC layer is

$$\Delta\varphi_1 = \frac{\pi}{cos(\varphi_t)}$$

The phase difference at the exit point of the reflected rays will then be

$$\Delta\varphi_{exit} = \Delta\varphi_1 - \Delta\varphi_0 = \frac{\pi}{2} * \frac{2}{cos(\varphi_t)} - 2 * \frac{\pi}{2} * \frac{n_0}{n_1} * tg(\varphi_t) * sin(\varphi_i)$$

$$\Delta\varphi_{exit} = \pi * \left[\frac{1}{cos(\varphi_t)} - \frac{n_0}{n_1} * tg(\varphi_t) * sin(\varphi_i)\right]$$

Unfortunately, in most cases the requirement that n_1 be equal to the square root of n_0 x n_2 cannot be satisfied, so the effects of the ARC will not be optimal.

Assuming that $A_1 \approx A_0$, the relative reflection amplitude at the exit point then becomes

$$A_{rel} = 1.0 + cos(\Delta\varphi_{exit})$$

or

$$A_{rel} = 1.0 + cos\left\{\pi * \left[\frac{1}{cos(\varphi_t)} - \frac{n_0}{n_1} * tg(\varphi_t) * sin(\varphi_i)\right]\right\}$$

The reflected power then is

$$P_r = P_i * \left[1.0 + cos\left\{\pi * \left[\frac{1}{cos(\varphi_t)} - \frac{n_0}{n_1} * tg(\varphi_t) * sin(\varphi_i)\right]\right\}\right]^2$$

Or

$$P_r = P_i * A_{rel}^2$$

And again, the power transmitted into the bottom medium is

$$P_t = P_i - P_r$$

If A_{rel} is 0, then there is total extinction of the rays reflected at the first and second interfaces. With an increasing angle of incidence, A_{rel} will grow and approach 0.5 for an angle of 90°.

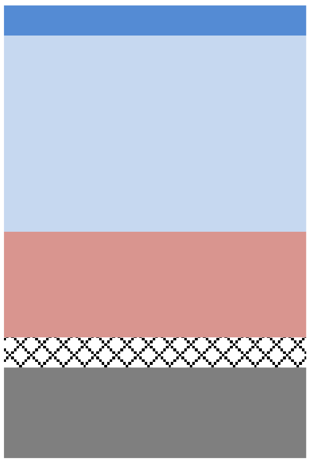
All the above derivations do not take into account multiple reflections and reflections from more layers below layer 2. But they do provide a pretty good first approximation to reality.

Note that, in order to further reduce reflections, the bulk silicon surface is often textured, e.g. by means of randomly placed small pyramids.

4.2.4 The Layer Model

4.2.4.1 Photovoltaic Panels

SolPos uses the following layer model for photovoltaic panels:

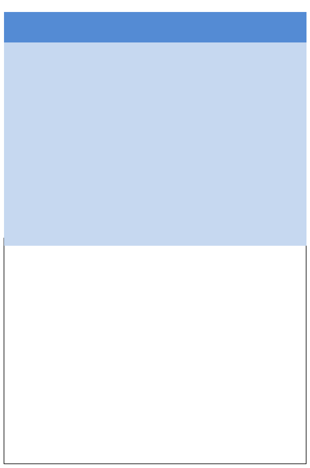


Layer	Material	n @ 600 nm
Glass ARC	MgF_2	1.380
Cover Glass	Lime Glass	1.520
Encapsulant	EVA (Ethyl Vinyl Acetate)	1.491
Cell ARC	SiN_x	2.094
Photocell	Bulk Silicon	3.493

Note that different materials may be used for some layers, e.g. porous silicon for the glass ARC.

4.2.4.2 Thermal Panels

For thermal panels, a simpler model with an ARC coated cover glass is used. There are no EVA, cell ARC and silicon layers:



Layer	Material	n @ 600 nm
Glass ARC	MgF_2	1.380
Cover Glass	Lime Glass	1.520
Air	Air	1.000

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4.3 AOI into the Energy Conversion Medium

4.3.1 Bulk Silicon Photocell

The AOI on the bulk silicon surface will be different from the AOI on the ARC coating of the cover glass. Since the refraction indexes are increasing with every layer, the rays will be bent towards the norm of the surface at every layer boundary. For a photovoltaic panel, for example:

	n_i	Angle of Incidence	
Cover ARC	1.380	30.0°	60.0°
Cover Glass	1.520	21.2°	38.9°
EVA	1.491	19.2°	34.7°
Silicon ARC	2.094	19.6°	35.5°
Silicon	3.493	13.4°	24.4°
		Angle Inside Layer	
Silicon		8.0°	14.4°

4.3.2 Thermal Converter

The AOI on the thermal conversion media (heat absorber) will be equal to the AOI on the panel surface, since the bending of the incident rays at the top of the cover will be undone by the reverse bending at the exit of the panel cover.

4.4 Power Into the Energy Conversion Medium

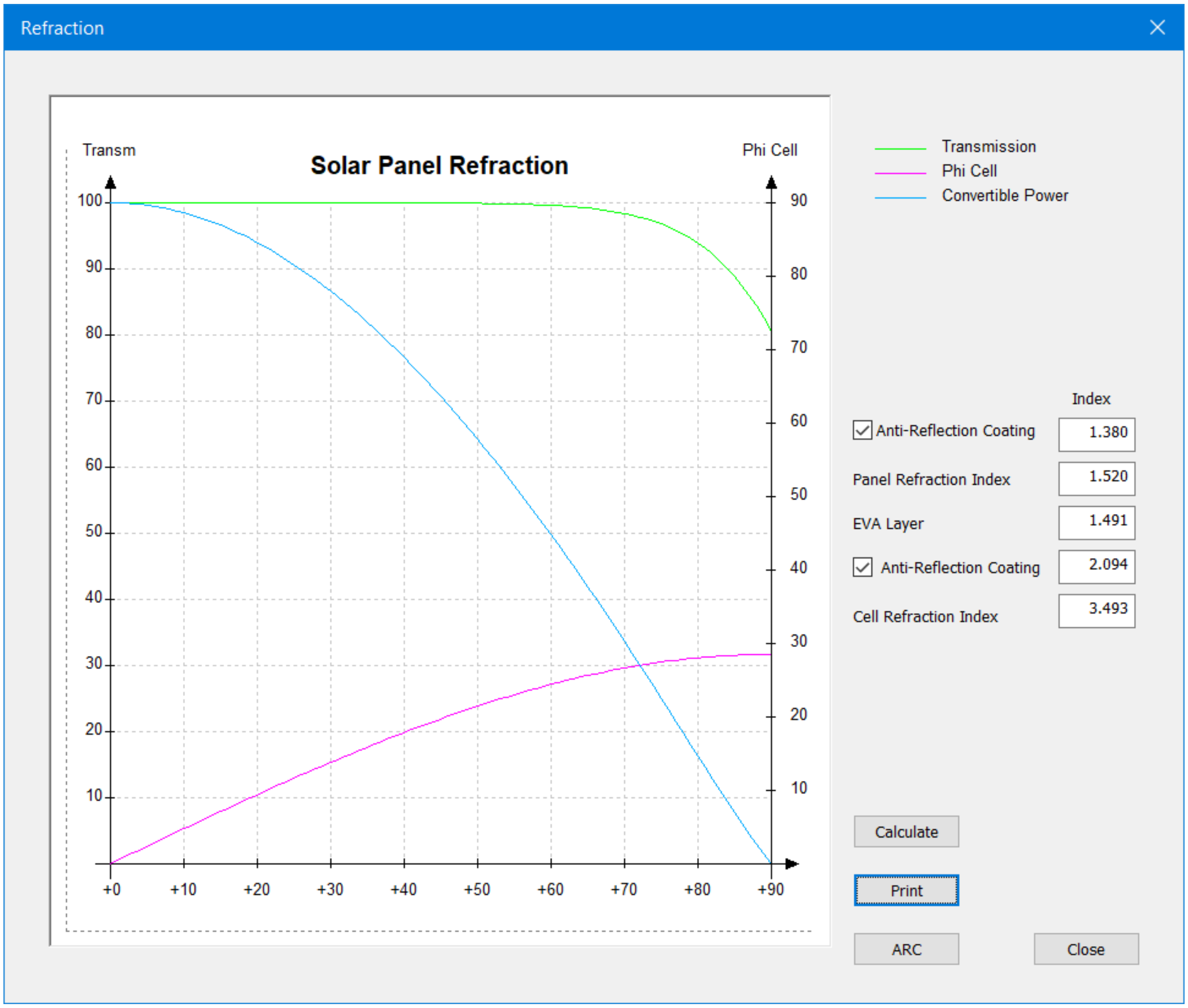
Due to the angle of incidence and to reflection, the effective power per unit of surface that reaches the energy conversion layer will be less than the power of the incident radiation per unit of surface:

	photovoltaic			thermal		
angle of incidence	0°	30°	60°	0°	30°	60°
cos(φi)	1.000	0.866	0.500	1.000	0.866	0.500
transmission	1.000	1.000	0.995	0.959	0.956	0.904
convertible power	1.000	0.866	0.498	0.959	0.828	0.452

Without any ARC, there is less power available for conversion:

	photovoltaic			thermal		
angle of incidence	0°	30°	60°	0°	30°	60°
cos(φi)	1.000	0.866	0.500	1.000	0.866	0.500
transmission	0.803	0.801	0.758	0.916	0.914	0.824
convertible power	0.803	0.694	0.379	0.916	0.792	0.412

5 The Refraction Dialog



This dialog serves to specify and evaluate the effects of the various layers of a solar panel above the actual energy conversion medium, i.e. the bulk silicon or the heat absorber.

5.1 The Curves Window

The curves window provides three curves. For all curves, the horizontal axis is scaled by the angle of incidence onto the top of the panel.

5.1.1 Transmission

The transmission curve shows the percentage of energy that reaches the conversion medium due to attenuation by reflection at the various layer interface. It is given in relative to the normal incident power on the panel surface. Note that the effects of reflection are dependent on the angle of incidence. Also, there is a heavy dependence on ARC coatings.

5.1.2 Phi Cell

Phi cell is the incident angle of radiation onto the surface of the energy conversion layer.

5.1.3 Convertible Power

The convertible power percentage indicates the power relative to the incident sun radiation power that reaches the energy conversion medium.

The dotted lines to the right and at the bottom are cursors for measuring an angle or a curve value. Place the tip of the mouse pointer over the line, press the right mouse button and keep it pressed to move the cursor to the location of interest.

5.2 Layer Properties

The refraction indexes of the individual layers can be specified for the actual type of solar panel. If a layer is not existing, just insert the refraction index of the layer above it. Then there will be no reflection and no ray bending at the interface between the missing layer and the layer above it.

For thermal panels, the refraction indexes for the three lowest layers are set to 1.000. It is assumed that all the heat energy that reaches the air space below the cover glass ultimately reaches the heat absorber.

5.3 Buttons

5.3.1 Calculate

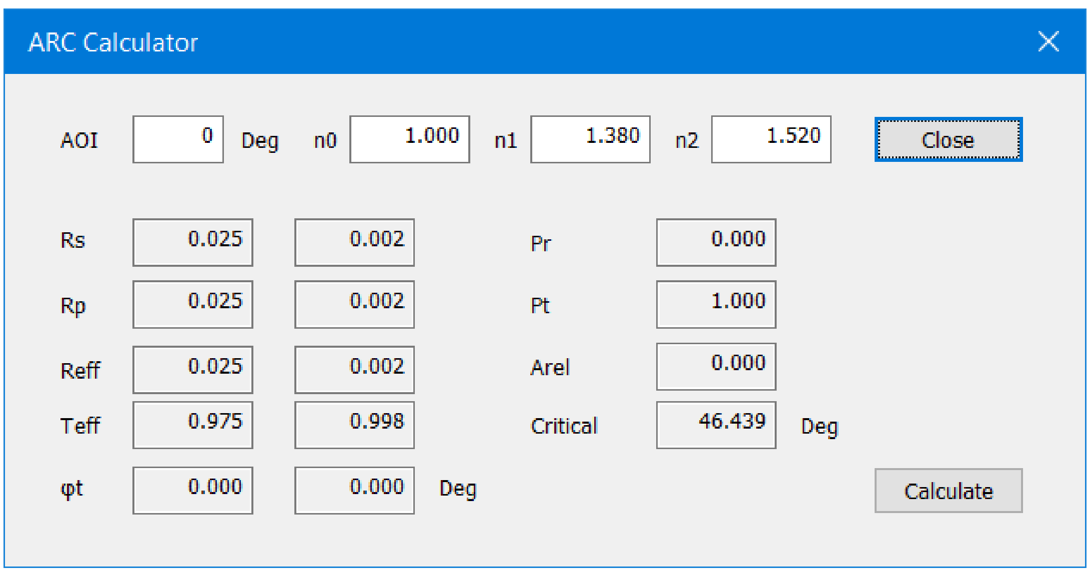
Click this button to update the curves after a change in parameters.

5.3.2 Print

Prints the curves together with the actual parameters.

5.3.3 ARC

This button opens a calculator dialog for evaluating the effects of an anti-reflection layer:



The top line is for entering the parameters. n0, n1, n2 are the refraction indexes of the three layers involved.

The outputs are:

R_s	The reflected power of the s-polarized part of the incident power at the first and at the second layer interface
R_p	The reflected power of the p-polarized part of the incident power at the first and at the second layer interface
R_{eff}	The average of R_s and R_p power at the first and at the second layer interface
T_{eff}	1 – R_{eff}, the average power exiting the first and at the second layer interface
φ_t	The angle of the rays exiting the first and the second layer interface
P_r	The total reflected power
P_t	The total power into the third layer
A_{rel}	The relative reflection amplitude at the first layer interface
Critical	The critical angle for rays not exiting from the second layer to the first layer.

6 Shading

Obviously, systems that harvest solar energy are sensitive to shading. SolPos can handle two types of shading.

6.1 Horizon Shading

The horizon at the system location may cause significant shading of the panels. The panels are most sensitive to nearby shading objects such as trees or chimneys or other buildings.

The horizon line can be characterized by its significant vertexes:

A file may be provided with a list of vertices of the horizon line for a specific location. With this data, the shading of solar panels by the horizon can be taken into account.

The horizon specification file is a simple text file with a `.hor` extension. The file must hold one line per vertex, with two integer values separated by a space or tab character: Azimuth and elevation in degrees:

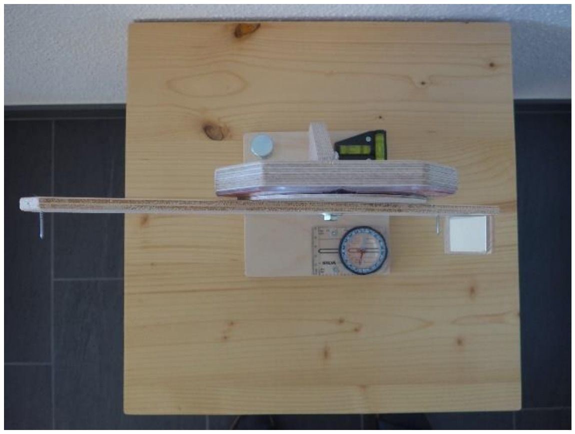
```
0    4
17   5
26   5
32   4
…
350  2
350  4
```

```
360 4
```

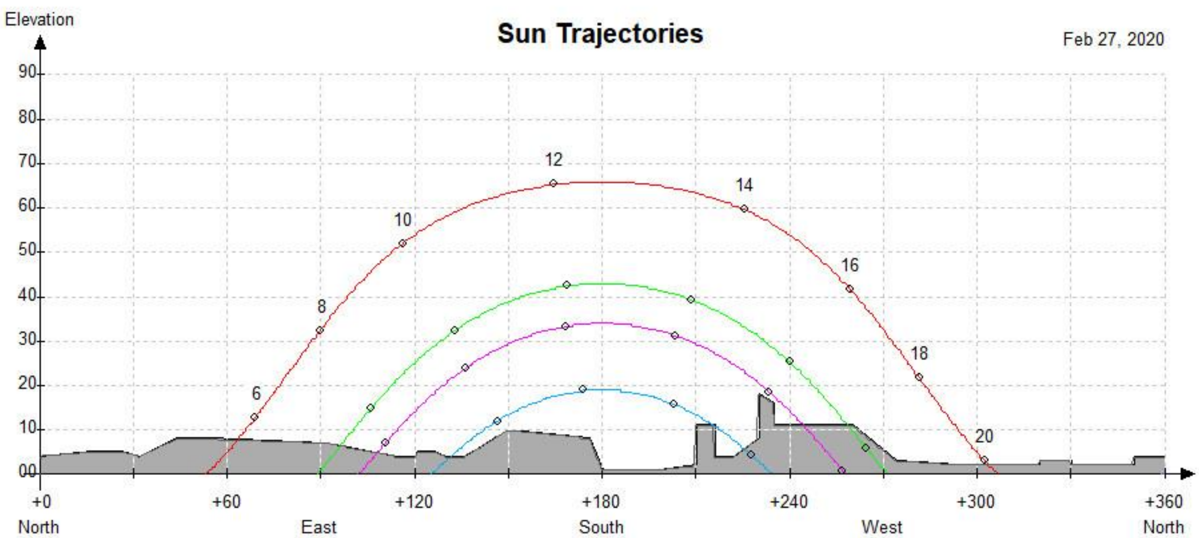
Make sure to cover the entire azimuth range from 0° to 360°. SolPos will then define a horizon line by interpolating between the vertexes. If the sun is below that horizon line, the panels will be considered to be totally shaded.

SolPos will interpolate the horizon line between the points given by means of a straight line.

Horizon points can be acquired by means of a simple goniometer or a theodolite or another surveying instrument. This is an example of a simple homemade goniometer:



This is the horizon as seen on the flat roof of my home building:



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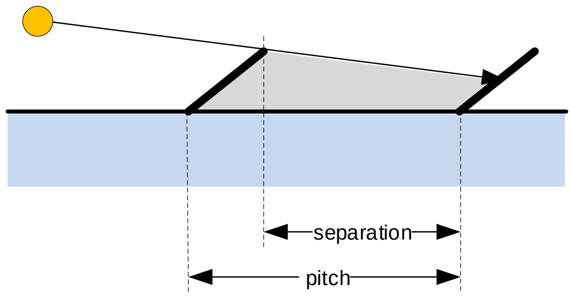
6.2 Row Shading

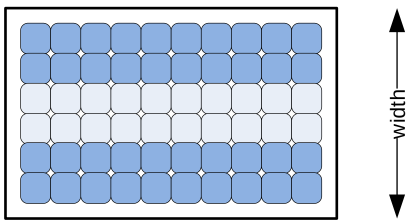
On a horizontal (flat) roof, all rows behind the first one will be shaded by the previous row when the sun is low:



SolPos always considers the first (front) row not to suffer from any shading.

6.2.1 Photovoltaic Panels

Photovoltaic panels typically are made of about 60 cells, arranged in 6 rows of 10 cells each. The individual cells are connected in series:



If no measures are taken, a single shadowed cell will drastically reduce the output from the entire panel. To mitigate the problem, sections of n cells, typically 20 in the above example, will be equipped with a bypass diode. If any of these sections are shaded, the bypass diodes enable the cells in the other sections to still deliver their full power. If, for example, any cell in the two bottom rows of the example is shaded, the panel will still deliver about two thirds of its full power rating.

Since panel configurations are variable, SolPos provides a parameter for the number of bypass diodes of the panels in use. The panel width is then divided into n segments, and the shading is calculated for each of the segments to accommodate the effects of partial panel shading.

6.2.2 Thermal Panels

Thermal panels also suffer from shading, but the effect is less serious on them, since the effects are proportional to the portion of the panel surface that is shaded. For row shading calculations, thermal panels are treated as a photovoltaic panel with 32 bypass diodes.

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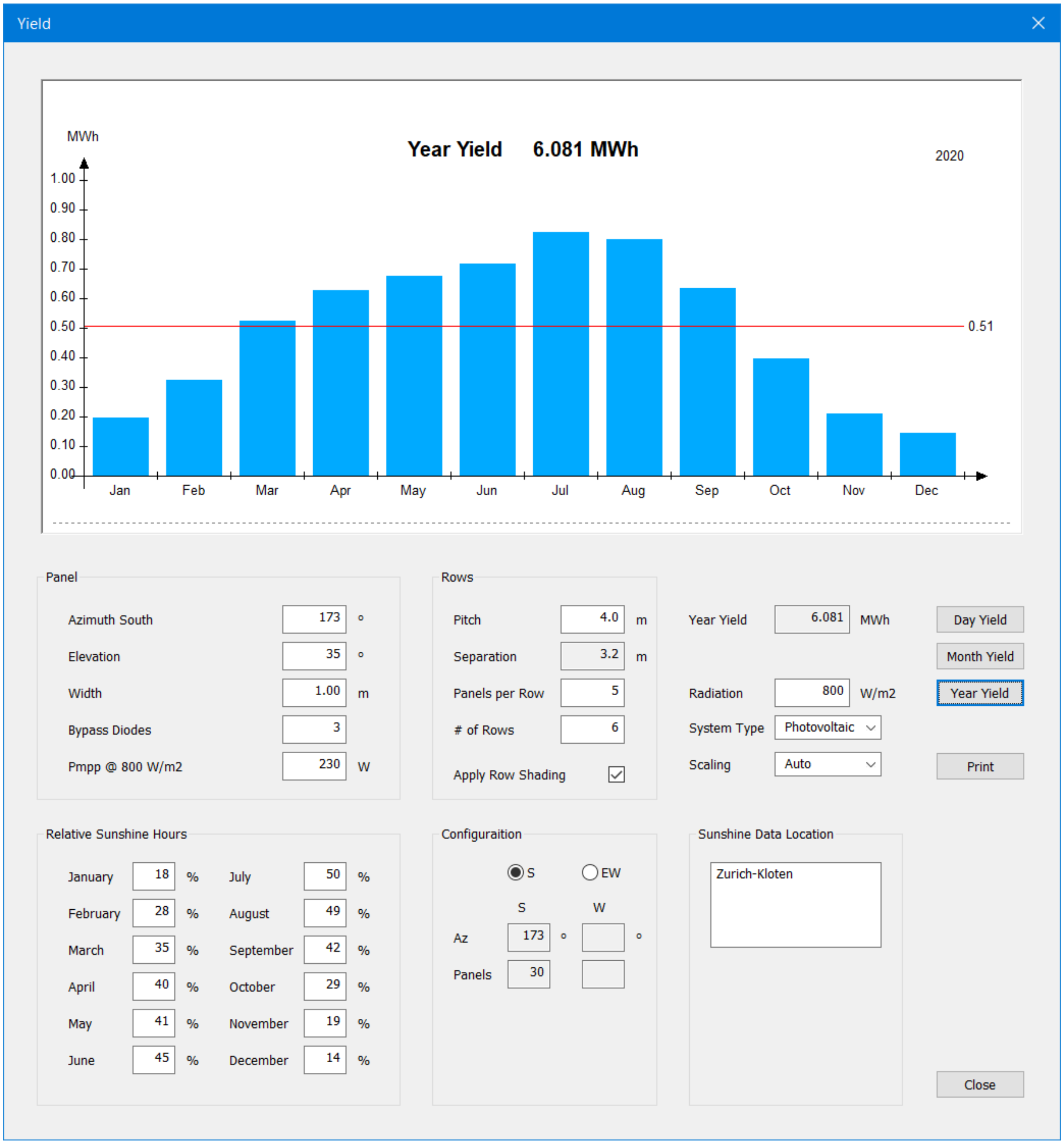
7 The Yield Dialog

This is the yield dialog for photovoltaic systems:



7.1 Parameters

7.1.1 Panel

The panel section defines the parameters of the individual panels.

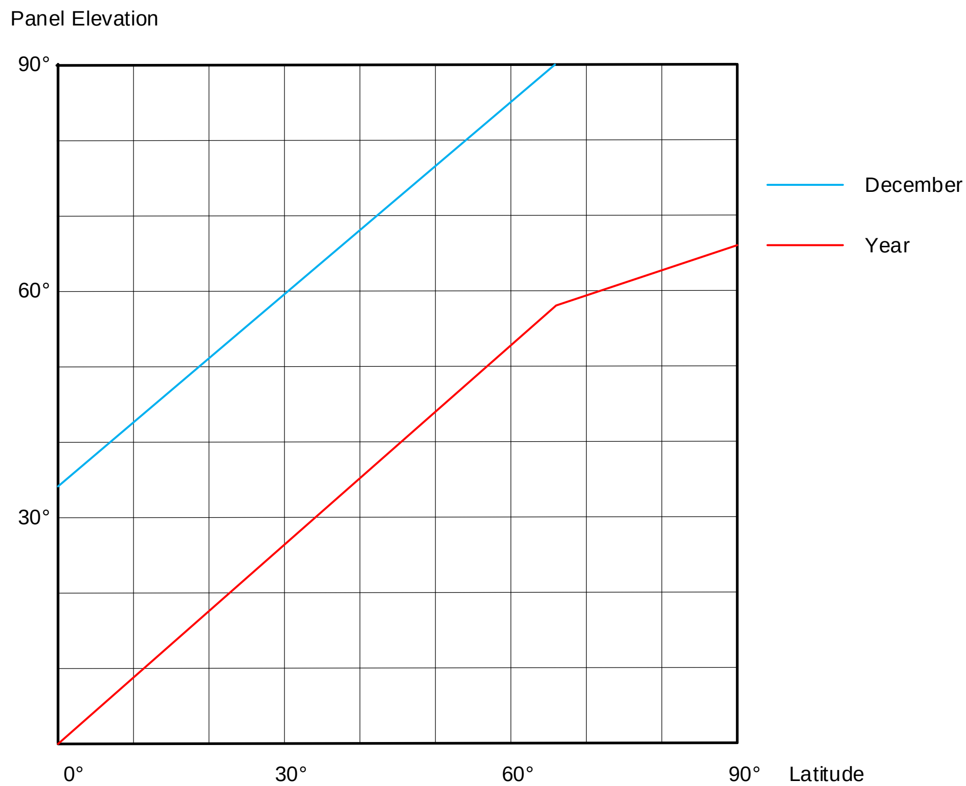
7.1.1.1 Azimuth South (East)

The azimuth defined the orientation of the panels relative to North in degrees, positive from North to East to South to West.

7.1.1.2 Elevation

The panel elevation is relative to the earth surface at the location of the system, not to the roof surface. At first sight, the panel elevation should be equal to the geographic latitude of the system location. To maximize the yield over a full year, the elevation should be a little lower in order to maximize the yield in the summer months. To maximize the yield in the winter months, when most of the energy is needed, the elevation should be higher than the latitude by about 34°. Above the arctic circle on the northern hemisphere (below on the southern hemisphere), things are a little different because there is no sunshine in all in the winter months.

For panels with an azimuth of 180° on the northern hemisphere, and with a relative sunshine duration of 100%, the panel elevations as shown will result in the best yield for the month of December or for the full year:



7.1.1.3 Width

The panel width is needed for row shading calculations.

7.1.1.4 Bypass Diodes

The number of bypass diodes is needed for row shading calculations. For more details, see section 6.2. For thermal systems, this item is replaced by the gross panel surface. It can be found in the thermal panel data sheet.

7.1.1.5 Pmpp @ 800 W/m²

This value must be taken from the photovoltaic panel data sheet. For thermal systems, this item is replaced by the gross panel efficiency, to be taken from the thermal panel data sheet.

The P_{mpp} specifies the output power of the panel when operating a the maximum power point and under irradiation normal to the panel surface.

7.1.2 Rows

This is part of the system configuration specification.

7.1.2.1 Pitch

The distance at which rows of panels repeat. For the definition, see section 6.2.

7.1.2.2 Separation

The row separation, i.e. the spacing in between the rows, is calculated from

- the row pitch,
- the panel width,
- the panel elevation.

It is shown for information only.

7.1.2.3 Panels per Row

This is self-explaining.

7.1.2.4 Number of Rows

This is self-explaining.

7.1.2.5 Apply Row Shading

On steep roofs, where panels are parallel to the roof surface, do not tick the 'Apply Row Shading' check box.

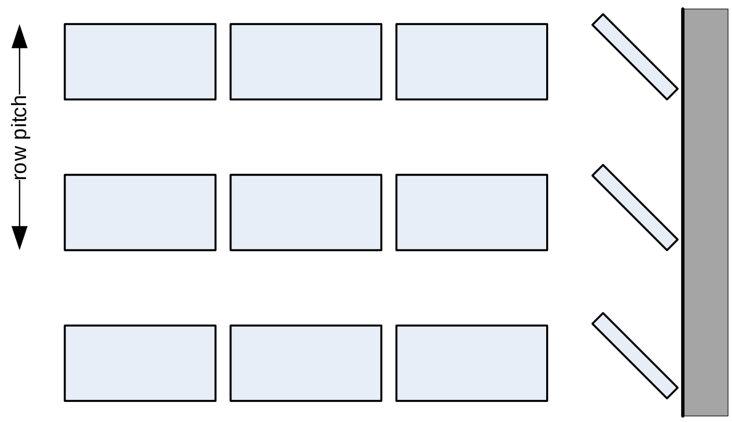
7.1.3 Relative Sunshine Hours

Part of the time when the sun is above the horizon, it is shaded by clouds or fog. For some locations, statistic information about the average percentage of sunshine hours is available. For Switzerland, this information is provided by MeteoSchweiz [2].

7.1.4 Configuration

Panels are typically arranged in one of these two configurations:

7.1.4.1 S(outh)

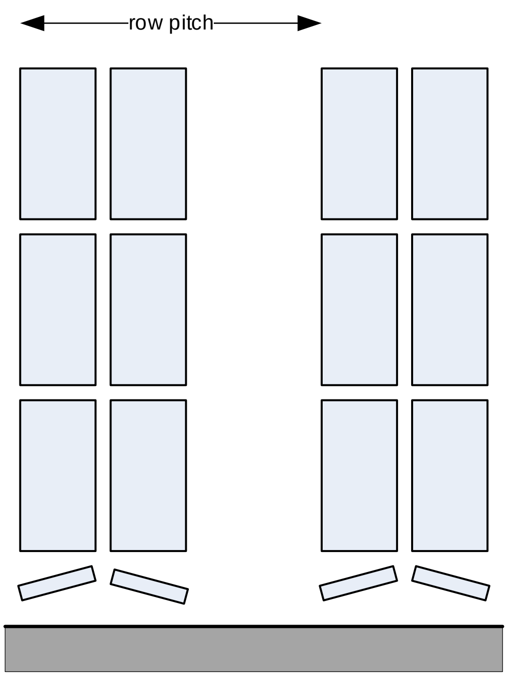


South

In this configuration, the panels are preferably facing South. However, the orientation may be quite different from South because of the roof (mounting surface) orientation.

Ticking the S radio button selects this configuration.

7.1.4.2 E(ast)W(est)



East/West

In this configuration, half of the panel rows are facing East, and the other half of the rows are facing West. Again, the orientation may be quite different depending on the roof orientation.

Ticking the EW radio button selects this configuration. The orientation of the East facing panels is taken from the panel section, and the orientation of the West facing panels is calculated by adding 180° to the orientation of the East facing panels.

Typical EW configurations use lower panel elevations in order to minimize row shading and to optimize the radiation inclination angle. This allows for more panels on a given surface. But the yield per panel will be less than with a South facing system.

7.1.4.3 Sunshine Data Location

For reference on the print output, the location where the relative sunshine hours have been taken can be specified here.

7.1.5 System

7.1.5.1 Radiation

Solar radiation onto the earth surface at sea level is considered to be about 1'000 W / m^2 [3]. The effective value at a specific location, however, depends on may additional factors: average water content of the air, air pollution, altitude above sea leval etc.

For cautious yield estimates, keep this value at 800 W / m^2. For very good locations, you may increase this value.

7.1.5.2 Type

The important properties of photovoltaic and thermal panels are specified in different ways, therefore, two specification items in the panel section are different:

Photovoltaic	Thermal
Number of bypass diodes	Gross panel surface
P_{mpp} @ 800 W/m^2	Gross panel efficiency

The yield calculations are then adapted to the panel specifications: The P_{mpp} of a thermal panel is calculated from the radiation, the gross panel surface and the gross panel efficiency.

7.1.6 Output

7.1.6.1 Yield

This item gives the result of the last day/month/year calculation.

7.1.6.2 Scaling

The vertical axis of the bar diagrams showing the yield is scaled automatically per default. When comparing different system versions, this may cause a different scaling of the graphics. By selecting a fixed scaling for the vertical axis that accommodates the most efficient version, the bar graphs for the individual versions will become easier to compare.

7.2 Buttons

7.2.1 Day Yield

Clicking this button triggers the calculation of the yield estimate for the day as given in the main window.

When the day yield is calculated, the main window will also show a curve indicating the convertible power per panel relative to P_{mpp}.

7.2.2 Month Yield

Clicking this button triggers the calculation of the yield estimate for the month as given in the main window.

7.2.3 Year Yield

Clicking this button triggers the calculation of the yield estimate for the year as given in the main window.

7.2.4 Print

Clicking this button prints the current bar graph and the parameters.

7.3 The Bar Graph Window

This window shows the result of the last estimation.

The dotted line at the bottom is a cursor for measuring the height of the individual bars. Place the tip of the mouse pointer over the line, press the right mouse button and keep it pressed to move the cursor to the desired location.

8 Calculating Yield

Before any yield is calculated, a reference day yield is obtained based on the following assumptions:

- The panels are irradiated during the entire time that the sun is above the ideal horizon (sunshine inclination < 90°) on March 21.
- The orientation of the panels is tracking the incoming rays, i.e. the inclination of the rays onto the panel is always 0°.
- The sampling interval is 2 minutes.
- Every sample value is 1.0.

The samples are accumulated. Their sum corresponds to a yield of x.y hours times the P_{mpp} of the panel times the number of panels in the system and serves as a reference for scaling the yield calculations.

8.1 Day Yield

The day yield is obtained by calculating the angle of incidence onto the panels every 2 minutes of the time that the inclination of the incoming rays is smaller than 90°, i.e. the sun is above the ideal horizon. This provides the component of the incident radiation power that is normal to the plane of the panels. The samples are then adjusted for the effects of reflection and, if activated, for the effects of horizon and row shading. Again, the samples are accumulated. Relating the sum of the samples to the reference day yield provides the scaling of the effective day yield.

8.2 Month Yield

The month yield is obtained by calculating the day yield for every day of the month.

8.3 Year Yield

The year yield is obtained by calculating the month yield for every month of the year.

8.4 East/West Configuration

The yield is calculated separately for the East and for the West sections of the system. Then, the results are combined into a single number.

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