

SunSim 10 – User manual

Introduction

The program *SunSim 10* has been devised and developed to calculate in a simple, quick and reliable way the amount of solar radiation available for the photovoltaic systems, both stationary and sun-tracking. However it can be used also for different types of solar system as those thermal.

Having the aim of obtaining the necessary characteristics of speed and ease of use, it was decided to limit to a minimum the use of the keyboard, instead favouring the introduction of data using the mouse. Simply scrolling the cursor on the sun-path diagram is thus possible to orientate the solar PV array, while buttons or drop-down menus may easily select the different options related to the operation.

Furthermore, *SunSim 10* calculates quickly – but precisely – the production of a PV system on a monthly basis by introducing the PV plant's data by means of simple steps in a proper window.

Calculation method

SunSim 10 is a simulation program that works in the time domain. Results are therefore obtained by tracking the solar paths during the year, thus evaluating the effects on the site in the sampled points and finally by properly adding all partial results.

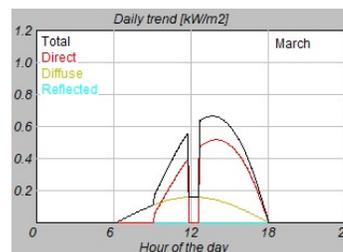
The simulation approach takes into account the various factors that affect the result, firstly the shadings and the atmospheric turbidity. On the other hand, this method requires a huge amount of calculations (one may consider that with a 10 minutes time step, as that adopted by *SunSim 10*, a single result need to calculate the solar radiation in about 600 different conditions). However, modern PCs do not present any difficulty to keep up with these demands calculation and therefore results are obtained almost instantaneously.

Minimum system requirements

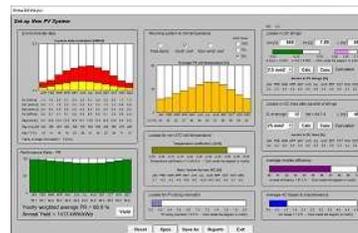
The program *SunSim 10* can work on every PC commercially available with operating system Windows Vista or higher and a minimum screen resolution of 1280×720.

What changes with respect to SunSim 8.0: 2 main news and other improvements

SunSim 10 may now display the daily solar trends for each month



Furthermore, it is now possible to enter the main parameter of a PV system, calculate the Performance Ratio PR e the Yield kWh/kWp



Other interesting improvements concern the optimization of some dialog windows, the shading and the possibility to modify the atmospheric turbidity

SunSim 10 is Ideal for educational use

It gives immediately to the operator the effects of the actions and modification on the used parameters and how these operations affect the results. It is therefore easy and intuitive to learn how a solar plant works in every detail.

The resources needed by *SunSim 10* are anyway very low, because the program does not need the installation of specific drivers, does not use its own DLL libraries and can work without an installation procedure, because it can run from any folder contained in a fixed or movable device such as, for example, a memory stick.

From the website www.sunsim.it however, one can download a test version of the program, named

SunSimTest.exe. You may want to try this preliminary test version on your PC in order to verify that all requirements are met.

Installation

SunSim 10 does not need any installation procedure and can run from any folder contained in a fixed or movable device simply by double-clicking on the program icon.

Firstly, it is advisable to copy the executable file on the Desktop and, by means of the right mouse button, activate the command “Add to Start Menu”.

Protection

SunSim 10 is protected by means of a code of 3 characters that are notified at delivery time and that shall be inserted in the specific editable field named *Insert Code* →.

If the 3 characters are right, the editable field disappear and at its place the text *Code accepted* will appear. Otherwise, an error message will appear and the program terminates its execution.

Every copy of *SunSim 10* distributed under licence is customized, because in the main window the name of the owner is properly marked as it is in the user licence.

SunSim 10 is ideal for the professional

It is based on rigorous and precise methods for the calculation of the results but asking to the operator only the introduction of the strictly necessary data. It does not require the attendance of specific courses, nor the knowledge of complicated 3-dimensional CAD and the obtained results are easily readable and understandable.

It allows the quick execution of a large amount of simulations, in order to assess very large plants or even to make comparisons among different solutions without wasting time compiling long video pages.

Operation description

Main window

The program *SunSim 10* consists essentially of a main dialogue window through which is possible to control all the main parameters involved in the calculations. However, a few of them, for reasons of space, need to be introduced by means of proper dialog windows. These parameters are basically represented by the horizon profile, the albedo and the PV system when required.

Every part of the main window and the sub-windows that is possible to open will be described hereafter.

From the main window, it is possible to find the areas, which contain the main commands for the program:

- *Solar data-base – Meteo station – Shading & Albedo*
- *Atmospheric turbidity TL*
- *MJ/kWh*

- Limit angle
- Tracking area

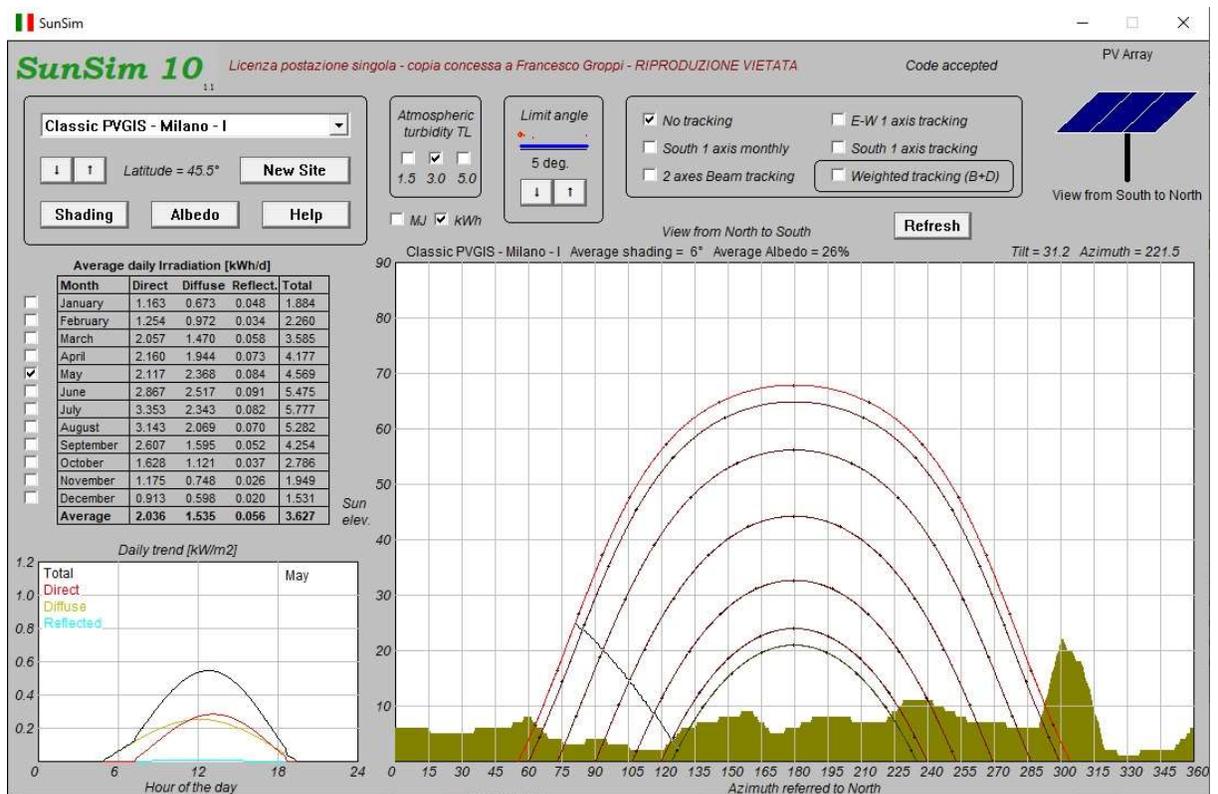
Moreover, there is an operation area with the solar paths:

- View from North to South

Finally, are also present an area that reports the results, an area that help to understand the array orientation by means of a simple animation and an area that draws the daily trends for the selected month:

- PV array – View from South to North
- Average daily radiation
- Daily trend

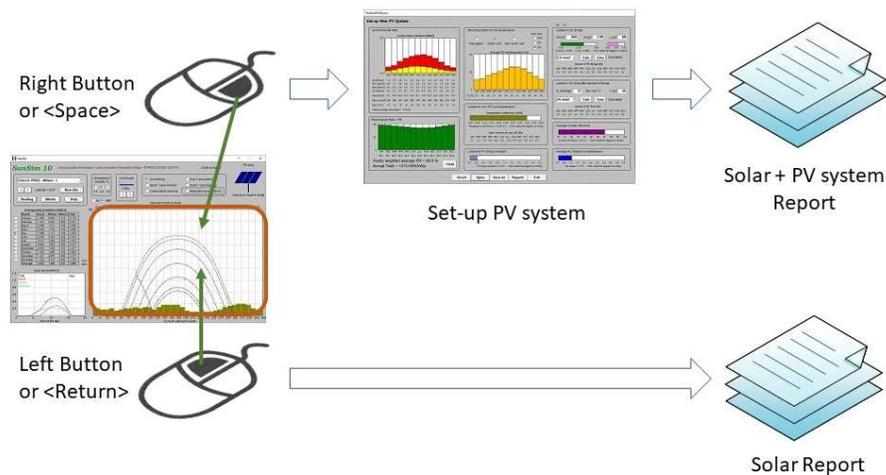
In the next figure an example of main window is shown.



From the main window and pointing the mouse on the diagram of the solar paths it is possible the generation of reports in RTF format, readable by any word processor (e.g. MS Word), and in CSV format, readable by any spreadsheet (e.g. MS Excel).

When reports that include the PV system and the related calculations are needed, the right button of the mouse or the space bar shall be pressed. If instead one is interested to obtain reports containing only solar calculations, the left button of the mouse or the Return key shall be pressed.

The following figure shows both these ways.



Solar data-base – Meteo station

By using the drop-down menu, it is possible to select the data of direct and diffuse radiation on a horizontal plane, the diurnally monthly temperature and the average wind speed for the chosen site. These data refers to those reported in the standard UNI 10349-1:2016 for the Italian sites and to the calculation methods used by Ispra Joint Research Centre (JRC) for the Europe, Middle East and North Africa as well as for a number of representative Italian sites.

Information available on PVGIS are of public domain and can be found on the JRC website.

Data, which refer to the standard UNI 10349-1:2016, concern the following 110 Italian provinces.

Agrigento	Chieti	La Spezia	Padova	Sondrio
Alessandria	Carbonia-Inglesias	Lecco	Parma	Siracusa
Ancona	Caltanissetta	Lodi	Perugia	Sassari
Aosta	Cuneo	Lecce	Pescara	Savona
Ascoli Piceno	Como	Livorno	Piacenza	Taranto
L'Aquila	Cremona	Latina	Pisa	Teramo
Arezzo	Cosenza	Lucca	Pordenone	Trento
Asti	Catania	Monza-Brianza	Prato	Torino
Avellino	Catanzaro	Macerata	Pesaro e Urbino	Trapani
Bari	Enna	Messina	Pistoia	Terni
Bergamo	Ferrara	Milano	Pavia	Trieste
Biella	Foggia	Mantova	Potenza	Treviso
Belluno	Firenze	Modena	Ravenna	Udine
Benevento	Fermo	Massa-Carrara	Reggio di Calabria	Varese
Bologna	Forli	Matera	Reggio nell'Emilia	Verbania
Brindisi	Frosinone	Napoli	Ragusa	Vercelli
Brescia	Genova	Novara	Rieti	Venezia
Barletta-Andria-Tr	Gorizia	Nuoro	Roma	Vicenza
Bolzano	Grosseto	Ogliastra	Rimini	Verona
Cagliari	Imperia	Oriстано	Rovigo	Medio Campidano
Campobasso	Isernia	Olbia-Tempio	Salerno	Viterbo
Caserta	Crotone	Palermo	Siena	Vibo Valentia

Data, which refer to the calculation methods, adopted by the Joint Research Centre, concern the categories Classic PVGIS, PVGIS-Helioclim and Climate-SAF PVGIS.

The 88 sites listed here below have been selected by referring to the Classic PVGIS method.

Belfast (UK)	Bordeaux (F)	Bern (CH)	Genova (I)	Sassari (I)
Birmingham (UK)	Lyon (F)	Innsbruck (A)	Bologna (I)	Cagliari (I)
Edinburgh (UK)	Marseille (F)	Wien (A)	Firenze (I)	Ljubliana (SLO)
London (UK)	Nice (F)	Budapest (H)	Ancona (I)	Zadar (HR)
Manchester (UK)	Paris (F)	Barcelona (E)	Perugia (I)	Beograd (SRB)
Dublin (IRL)	Rennes (F)	Bilbao (E)	Grosseto (I)	Bucaresti (R)
Reykjavik (IS)	Strasbourg (F)	Granada (E)	Pescara (I)	Sofija (BG)
Oslo (N)	Bruxelles (B)	Madrid (E)	Roma (I)	Tirana (AL)
Stockholm (S)	Amsterdam (NL)	Sevilla (E)	Campobasso (I)	Athina (GR)
Helsinki (SF)	Luxembourg (L)	Zaragoza (E)	Napoli (I)	Thessaloniki (GR)
Kobenhavn (DK)	Berlin (D)	Lisboa (P)	Potenza (I)	Istanbul (TR)
Vilnius (LT)	Frankfurt (D)	Porto (P)	Bari (I)	Valletta (M)
Riga (LV)	Freiburg (D)	Aosta (I)	Lecce (I)	Nicosia (CY)
Tallin (EST)	Hamburg (D)	Bolzano (I)	Cosenza (I)	Casablanca (MA)
Moskva (RU)	Munchen (D)	Torino (I)	Reggio Calabria (I)	Algier (DZ)
Minsk (BY)	Warszawa (PL)	Milano (I)	Palermo (I)	Tunis (TN)
Kiev (UA)	Praha (CZ)	Padova (I)	Catania (I)	Tripoli (LAR)
		Udine (I)	Ragusa (I)	Cairo (ET)

For the following 6 sites the reference is represented instead by the calculation method PVGIS-Helioclim.

Doha (Q)	Dubai (UAE)	Riyad (KSA)	Bahrain (Bahrain)	Muscat (OM) Salalah (OM)
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Finally, for the following 26 sites in Italy the calculation method Climate-SAF PVGIS was also used.

Aosta	Napoli	Padova	Cosenza	Firenze
Milano	Lecce	Bologna	Catania	Grosseto
Genova	Palermo	Perugia	Cagliari	Campobasso
Ancona	Sassari	Roma	Torino	Bari
Pescara	Bolzano	Potenza	Udine	Reggio Calabria Ragusa

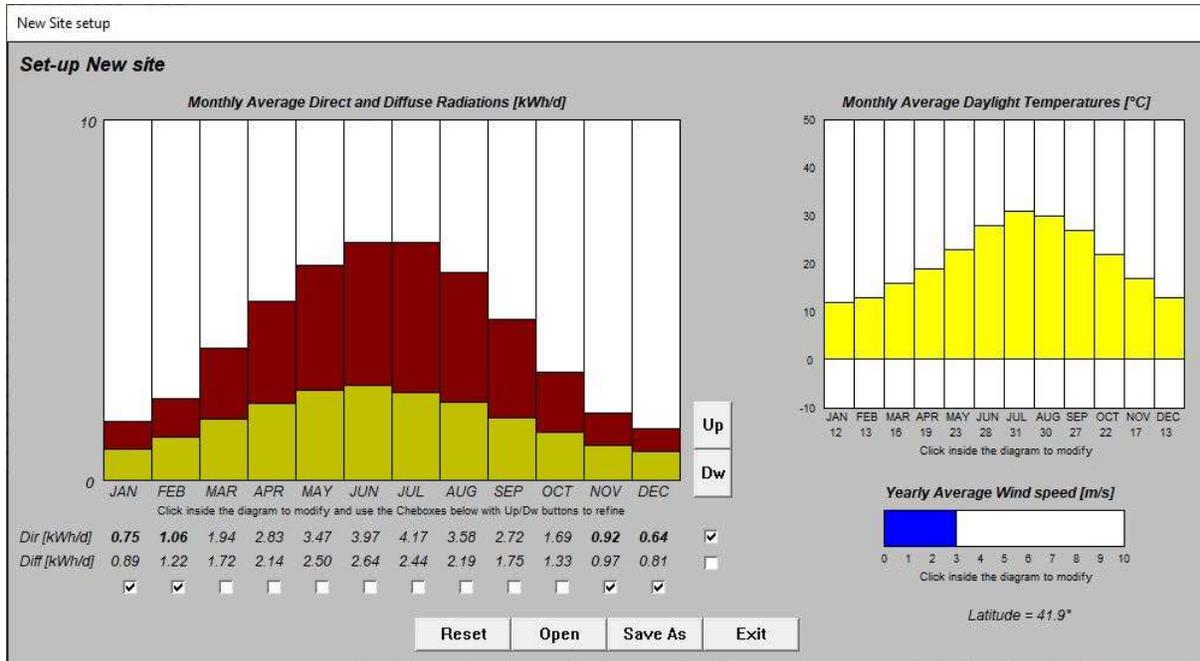
As one can see, a number of Italian sites are recallable both from UNI 10349 and from JRC. In this way it is possible to understand how different solar data can affect results.

By means of a first pair of buttons marked with the arrows ↓ and ↑ it is possible to modify the latitude of the site from 0° N to 90° N by initiating from that of the chosen site. The use of these buttons for minor corrections does not cause any problem. However, if large variations are needed one should always keep in mind that the radiation data loaded for that site could not be compatible with the new latitude, especially shifting northward. Thus in these cases it is always necessary to verify the correctness of the radiation data and modify them when needed.

The last one of the sites in the list is indicated as <New site>. It is a site for which meteorological values of solar radiation, diurnally monthly temperature and average wind speed can be introduced.

New Site

The button <New Site> allows the customization of the direct and diffuse solar radiation, the diurnally monthly temperature and the average wind speed by means of a specific dialog window as shown in the following figure.



By means of the left button of the mouse, pressed inside the diagrams, it is possible to modify quickly the direct and diffuse solar radiation, the diurnally monthly temperature and the average wind speed. However, it is possible to modify more accurately the solar diagram by means of the buttons Up and Dw that allow the increment or the decrement of the values of the direct and diffuse daily average solar radiation per month. The values to modify are chosen by means of a selection grid made by means of checkboxes placed in correspondence of the months of the year and of the direct and diffuse radiation. By this method it is possible to modify several values at the same time.

As an example, in the figure the direct and diffuse solar radiation for the months of January, February, November and December have been selected. By pressing the buttons Up and Dw it is thus possible to change all the selected values at the same time.

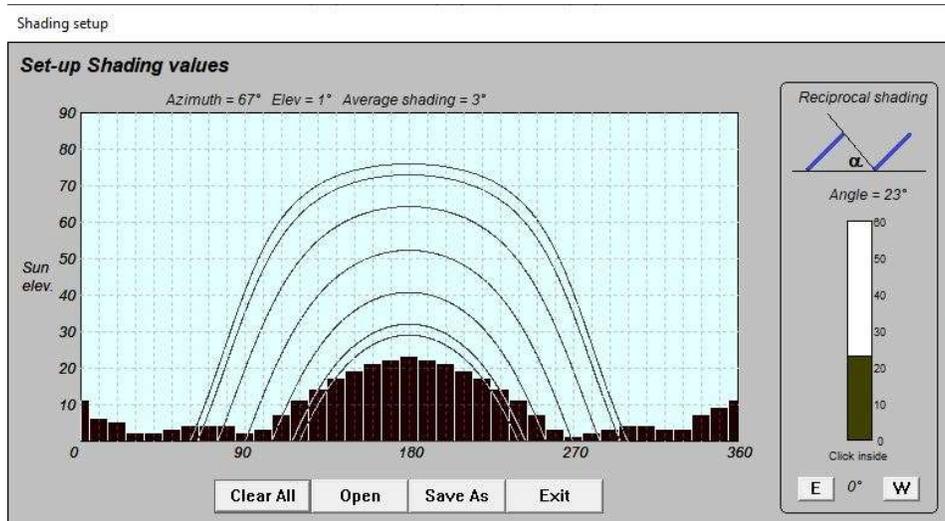
The diurnal average temperatures may be modified as well by means of the left button of the mouse pressed inside their diagram. In this case the variation is more approximate because the temperatures vary with a resolution of 1 °C.

Finally, it is possible to modify the average wind speed with the left button of the mouse inside the corresponding horizontal bar.

It is possible to save the new set-up values in proper files .SIT and to open existing files to retrieve the previously saved data.

Shading

The profile of the shadings on the site is introduced by means of a proper window, where a smaller solar-path diagram is newly proposed, and it is made clicking the left button of the mouse inside the diagram, in correspondence with the position and height of the solar obstructions.



If the PV system is made of a number of inclined and equally spaced supporting structures one may automatically introduce the reciprocal shading by means of the right-hand area. By means of the vertical bar it is possible to choose the obstruction angle between the structures with a 1° resolution. Furthermore, it is possible to rotate the structures eastward or westward with a resolution of 10° by using the two buttons placed below. The shadows thus obtained overlap the existing shading on the diagram.

In this window it is possible to save the new set values in files .HOR and to open the existing ones in order to use the previously saved data.

Albedo

The program *SunSim 10* takes into account the radiation reflected by the ground or by the surrounding objects by means of proper albedo coefficients.

The conditions of albedo here considered are those contained in the previous standard UNI 8477. As these conditions may change seasonally, and furthermore we may have more than one present at the same time, the data input is made by opening a specific window that presents a matrix of possible conditions and allow a large choice of combinations among them. By selecting one or more conditions, the corresponding albedo value is equal to the arithmetic average of the selected values.

In short, a specific albedo coefficient ρ is associated to each month, whose value ranges from 0.00 and 1.00, equal to the arithmetic average of the coefficients selected in the window.

Albedo setup

Set-up Albedo values

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Ref. Values
Snow (fresh with an iced film)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	0.75
Water surfaces	<input type="checkbox"/>	0.70											
Ground (crete, mart)	<input type="checkbox"/>	0.14											
Dirty roads	<input type="checkbox"/>	0.04											
Coniferous forest in winter	<input type="checkbox"/>	0.07											
Forest in Autumn / fields with mature crops and trees	<input type="checkbox"/>	0.26											
Aged asphalt	<input checked="" type="checkbox"/>	0.10											
Aged concrete	<input type="checkbox"/>	0.22											
Dry leaves	<input type="checkbox"/>	0.30											
Dry grass	<input type="checkbox"/>	0.20											
Green grass	<input type="checkbox"/>	0.26											
Roofs or terraces in bitumen	<input checked="" type="checkbox"/>	0.13											
Rubble	<input type="checkbox"/>	0.20											
Dark surfaces of buildings	<input type="checkbox"/>	0.27											
Light surfaces of buildings	<input type="checkbox"/>	0.60											
	0.33	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.33	

Clear All Open Save As Exit

It is possible to save the new set values in the files .ALB and to open the existing files in order to recall the data previously saved.

MJ/kWh

The values of solar radiation calculated and highlighted in the dialog window correspond to the monthly and yearly energies intercepted by the solar system. These values can be made available and calculated as MJ or kWh, by selecting the corresponding button.

Limit angle

The parameter defined as limit angle allow taking into account the lower incidence of the solar radiation on the photovoltaic cells when the angle between the direct solar radiation and the solar PV array plane decreases below a given value.

For low values of this angle, the front glass has a tendency to reflect the solar radiation instead of let it pass through, and this is valid for the surface of the cells as well. This behaviour has induced a few PV modules producers to texture the surface of the cells and front glass, for instance with a pyramidal pattern, such as the solar radiation, however oriented, may strike always on surfaces not excessively inclined.

Thin films tend to be more opaque and are less affected by this phenomenon, especially if cells are externally protected by plastic transparent material or with a suitably treated glass.

As regards the choice of the limit angle, *SunSim 10* suggests a value of 5°, giving the possibility to change such a value in the range between 0° and 25°.

Help

This button open a window that contains information on the use of commands by keyword and by mouse buttons.

It is specified that by using the arrows one can move in the working area of the solar diagram, obtaining therefore the same effect of the mouse but with the possibility of making more precise displacements.

The left button of the mouse or the key *Return* of the keyboard allow the generation of the file of results for the solar data only and copy the solar diagram in the clipboard.

If instead you want to take into account the losses associated with a PV system and calculate its yield it is necessary to use the right button of the mouse or the key *Space* of the keyboard. In this way the window for the input of the PV system's data is opened and it is possible to make the subsequent calculations starting from the solar data previously calculated. Afterward it is possible the generation of the file of results for the solar data and the PV system. Also in this case the solar diagram is copied in the clipboard.

Tracking area

In the Tracking area, it is possible to move from the calculation of the solar radiation collected on a surface with a steady tilt and orientation to the simulation of a few types of solar tracking systems. It must be stated that the simulations of the tracking systems do not take into account in detail of their mutual shading, because these calculations would require the knowledge of the actual shape of the supporting structures in use. The results obtained from the simulations of tracking systems give therefore indicative results and might require further refinements at design stage.

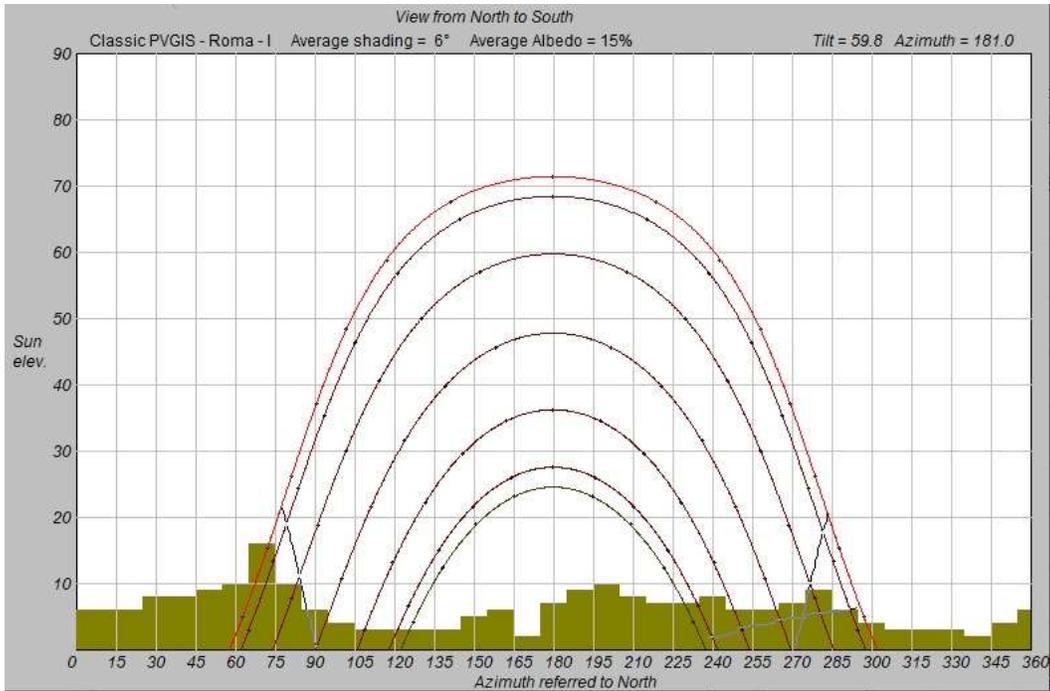
The possibilities of solar tracking that one can select by using *SunSim 10* are the followings:

<i>No tracking</i>	Normal operation without tracking (default choice)
<i>E-W 1 axis tracking</i>	Sun-tracking with a single-axis structure that can be oriented East-West, therefore rotating the solar PV array on the North-South axis
<i>South 1 axis monthly</i>	Single-axis tracking with a Southward orientation of the solar PV array and a tilt that changes monthly and corresponds to the solar height at noon
<i>South 1 axis tracking</i>	Single-axis tracking with a Southward orientation of the solar PV array and a tilt that change according to the solar height. In those periods when the sun would be on the back of the solar PV array, the latter assumes a horizontal deployment
<i>2 axes beam tracking</i>	Two-axes tracking that keeps perpendicular the direct solar radiation on the solar PV array

The button *Weighted tracking* can be used along with every tracking possibility and allow to take into account the diffuse radiation by reducing the inclination of the PV module plane as a function of the average monthly ratio between the diffuse radiation and the direct radiation.

View from North to South

The solar diagram represents the fundamental part of the program *SunSim 10*. It is composed by a working area with a white background, that reports a x-scale from 0° to 360°, which correspond to the solar azimuth with respect to North with an increase clockwise, and a y-scale from 0 to 90°, which corresponds to the solar elevation. The following figure gives an example of this diagram.



Solar paths and shading diagram

In the working area, the solar paths related to the latitude of the selected site (or to a different latitude if it was decided to change it) are plotted.

Throughout the solar diagrams are 7. In most cases the lower one refers to 21 December and the higher one (having a different colour) refers to 21 June. However, in case of low values of latitude (tropical sites) this order may vary.

The 5 intermediate paths are related to the pairs of months November-January, October-February, September-March, August-April and July-May.

The values of the solar elevation θ_h and of the azimuth angle θ_a are obtained from the latitude Φ e the declination δ (different curves have different declinations). Each curve is therefore obtained by varying the hour angle ω in the following formulas.

$$\cos \theta_h = \sin \delta \cdot \sin \Phi + \cos \delta \cdot \cos \Phi \cdot \cos \omega$$

$$\cos \theta_a = \frac{\sin \theta_h \cdot \sin \Phi - \sin \delta}{\cos \theta_h \cdot \cos \Phi}$$

Where:

$$\delta = 23,45 \cdot \sin \left(360 \cdot \frac{284 + n}{365} \right) \quad (n \text{ is the day of the year calculated from the 1}^{\text{st}} \text{ of January})$$

$$\omega = 15 \cdot t + \Delta\omega - 180 \quad (t \text{ is the time in hours and } \Delta\omega \text{ depends from the longitude)}$$

In the working area the shading diagram is also represented, when is needed, in order to point out the periods of the year and the hours of the day when the solar paths are shaded.

Orientation of the solar PV array

The innovation introduced by the program *SunSim 10* (also present in the previous releases) consists in using the same working area containing the solar paths and shadings for the orientation of the solar PV array.

In this case, the cursor, represented as a cross-hair, point out the orientation of the perpendicular line (or the normal) to the solar PV array. In other words, the solar PV array is exactly oriented in the direction indicated by the cursor.

This process is quite intuitive but one should consider that the PV module tilt is not that read on the solar elevation scale, it is instead its complement to 90° . Conversely, as regards the azimuth angle there are not variations.

However, to avoid misunderstandings, just above the working area the tilt and azimuth values of the PV module plane are reported.

In the heading of the working area, the sentence *View from North to South* recall that when pointing the solar PV array one should figure to be behind the plane itself and look at the sun paths. The figure placed on the top right corner moves accordingly and represent the solar PV array seen by an observer placed in front of it, and therefore the note below reports the sentence *View from South to North*.

When the mouse cursor is placed inside the working area or when it is moved inside of it, *SunSim 10* calculates the values of direct, diffuse and reflected solar radiation for the solar PV plane oriented according the cursor position.

The possible values for the tilt β vary from 0° to 90° , and those for the azimuth α vary from 0° e 360° (that is from -180° and $+180^\circ$ with respect to South). This possibility to operate on all the diagram allow to simulate also solar PV arrays tilted northward.

In the working area, a pair of curves, overlapped to the solar paths, represent the limits of the solar diagram over that the direct solar radiation cannot be seen by the front of the solar PV array because of its tilt and azimuth. One can easily verify that if the solar PV array is horizontal these curves disappear and instead, if it is vertical these curves have the appearance of vertical segments that exclude all the space region on the rear of the module plane. For intermediate conditions, these curves have a shape more or less accentuate according to the tilt, while their symmetry depends from the difference to South of the azimuth angle. However, one can observe that there are combinations of tilt and azimuth that do not allow to fully plot these limits for the direct radiation.

Behaviour when one of the solar tracking mode is selected

The above consideration on the use of the working area are obviously valid for the steady PV systems (function *No tracking* selected). Conversely, in case of one of the possible tracking mode is selected, it is not possible to choose the solar PV array orientation and therefore the working area, however visible, does not allow any operation.

However, the values of solar radiation on the solar PV array are calculated only when the cursor s placed on the working area.

By selecting one of the solar tracking modes, the figure on the top-right part of the window start to move autonomously and show the different orientation of the solar PV array during the day and in each different month of the year.

Calculation of the direct solar radiation

The calculation of the direct solar radiation is made by examining separately the solar paths referred to different months. Each solar path is thus considered as composed by a number of points, whose radiation with respect to the solar PV array is calculated for each of them on the basis of the following factors:

- Solar radiation data
- θ angle between the path of the direct radiation and the normal to the plane of the module array

- Turbidity of the atmosphere

The solar radiation data are those previously loaded on the site, while the θ angle is calculated according to the following expression:

$$\begin{aligned}\cos \theta = & \sin \delta \cdot \sin \Phi - \sin \delta \cdot \cos \Phi \cdot \sin \beta \cdot \cos \alpha \\ & + \cos \delta \cdot \cos \Phi \cdot \cos \beta \cdot \cos \omega + \cos \delta \cdot \sin \Phi \cdot \sin \beta \cdot \cos \alpha \cdot \cos \omega \\ & + \cos \delta \cdot \sin \beta \cdot \sin \alpha \cdot \sin \omega\end{aligned}$$

The turbidity of the atmosphere is calculated by means of the Linke formula:

$$I_B = I_0 \cdot e^{-\delta_{CDA} \cdot T_L \cdot am}$$

The Linke formula therefore allows the calculation of the value of the direct solar radiation on ground I_B from the extra-atmospheric one I_0 . The formula uses the value of the Air mass am , set to $1/\sin \theta_h$, and the Linke turbidity coefficient, which may vary according to the site and the season of the year and that is possible to select between 1.5 and 5. Initially it has been set constant and equal to 3, considering this last as an average value commonly used.

As concerns the parameter δ_{CDA} a number of expressions may be used. Among these, that proposed by Kasten was chosen, which is valid in a wide interval of am :

$$\delta_{CDA} = \frac{1}{9,4 + 0,9 \cdot am}$$

From a geometric point of view, as already pointed out, the points of the paths that compose the monthly values of the direct solar radiation are considered in calculations only if they do not intersect the shading diagram, otherwise their contribution is set to zero.

Calculation of the diffuse solar radiation

The calculation of the diffuse solar radiation on the solar PV array I_D takes into account the inclination β of the solar PV array with respect to the horizontal plane and uses the expression:

$$I_D = I_{D0} \cdot \frac{1 + \cos \beta}{2}$$

However, it is necessary to take into account the effect of the objects, which surround the site, namely the shadings, because these decrease the portion of sky that the PV module array can see. For this purpose, the space surrounding the site has been divided in 2 portion, each of them having an azimuthal amplitude of 180° .

In the first of these, namely the portion in front of the solar PV array, the presence of obstacles reduces always the diffuse radiation, because the energy collecting surface is in any case oriented in such direction.

As regards the second portion, namely that relative to the backward space of the PV module array, the presence of the obstacles is felt only if their angular height β_h is greater than the tilt β , and in this case the effect is due solely to the portion of sky above the space delimited by the tilt β .

This way, for instance, one can take into account the solar PV arrays placed on vertical surfaces, typically represented by sunblind, which, in most cases, have a $\beta_h = 90^\circ$ for an azimuthal angle of 180° , correspondent to all the space placed on the rear of the solar PV array.

Calculation of the reflected radiation

The calculation of the reflected solar radiation on the solar PV array I_R takes into account the inclination β of the solar PV array with respect to the horizontal plane and uses the expression:

$$I_R = \rho \cdot (I_B + I_D) \cdot \frac{1 - \cos \beta}{2}$$

The values of the albedo coefficients ρ , of the direct solar radiation I_B and of the diffuse solar radiation I_D change monthly, while the tilt β of the solar PV array is kept constant during calculations.

Refresh

This button cleans the working area in case of shading lines that could be still present, after the opening of a window from the main window of *SunSim 10*.

Average daily radiation

The table Average daily radiation appears when the mouse come into the working area and reports the daily averages on a monthly basis of the solar radiation divided into its three components: direct, diffuse and reflected.

In the following figure one can see an example of this table with the column of the totals and the row of the yearly averages. In the example the energy measurement unit *kWh* has been selected.

Month	Direct	Diffuse	Reflect.	Total
<input type="checkbox"/> January	0.696	0.730	0.071	1.498
<input type="checkbox"/> February	0.943	1.004	0.035	1.981
<input type="checkbox"/> March	1.662	1.414	0.056	3.132
<input type="checkbox"/> April	2.284	1.756	0.076	4.116
<input checked="" type="checkbox"/> May	2.684	2.053	0.092	4.828
<input type="checkbox"/> June	2.999	2.167	0.101	5.267
<input type="checkbox"/> July	3.214	2.007	0.101	5.323
<input type="checkbox"/> August	2.885	1.802	0.089	4.775
<input type="checkbox"/> September	2.331	1.437	0.069	3.836
<input type="checkbox"/> October	1.519	1.095	0.046	2.660
<input type="checkbox"/> November	0.854	0.798	0.029	1.681
<input type="checkbox"/> December	0.601	0.661	0.063	1.325
Average	1.889	1.410	0.069	3.369

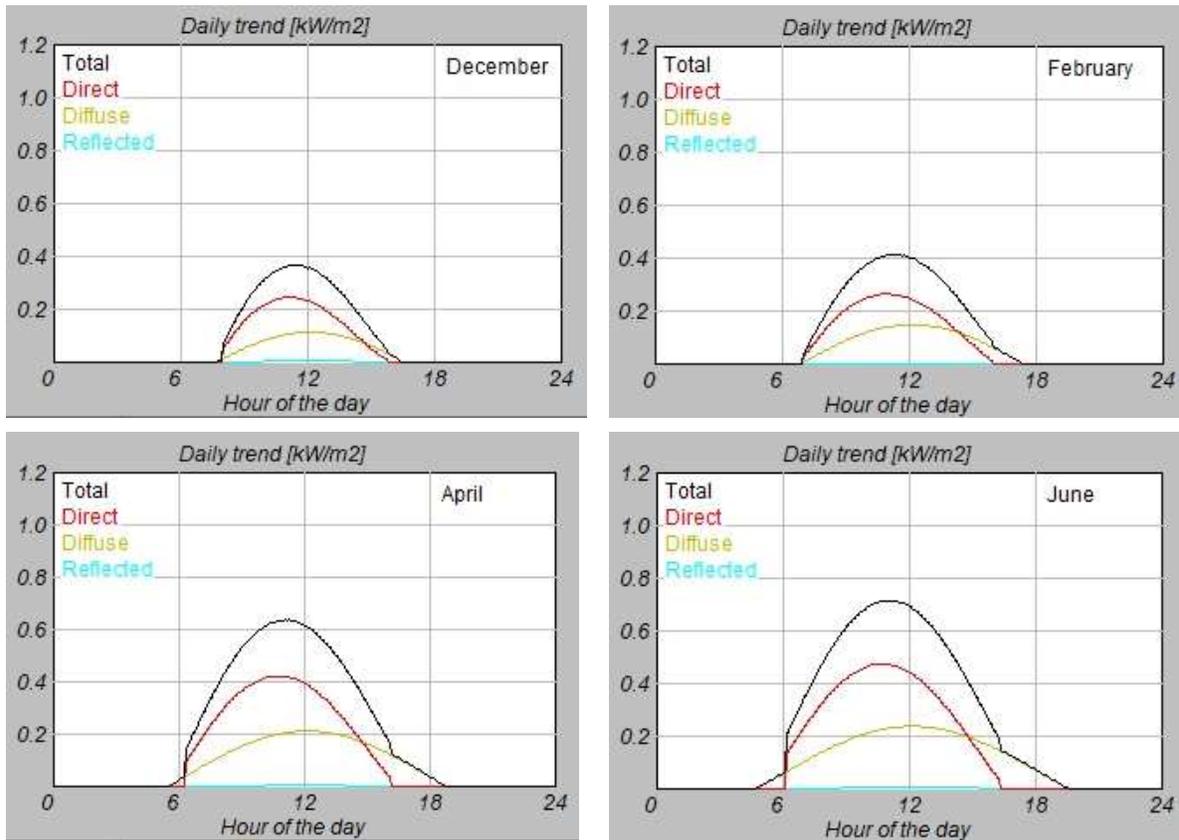
The 12 check-boxes on the left are used to select the month whose daily irradiance trend is displayed as shown below.

Daily trend

SunSim 10 displays the daily trend of the solar irradiance, expressed in W/m^2 , by means of a diagram that changes continuously according to the inclination and the azimuth of the solar collection system. It is possible to select the reference month by means of the 12 check-boxes placed on the left of the table Average Daily Radiation.

Each graph shows the curves of direct, diffuse, reflected and total irradiance and thus their variation in the daytime.

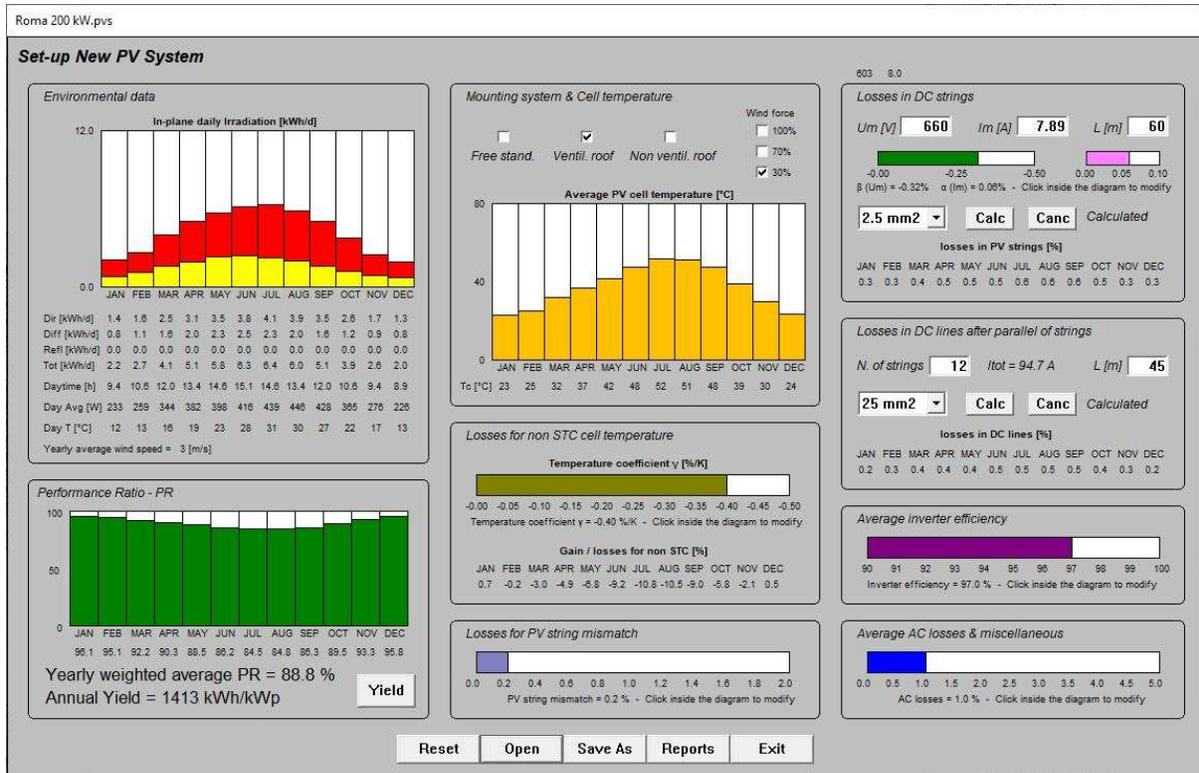
For instance, the figures here below report the daily graph for the months of December, February, April and June with a 40° tilt, 140° azimuth to North (-40° if we look Southward) and the shading condition previously seen in the solar diagram. We may see in this example that the orientation South-East affects the direct irradiance, that has its maximum value before noon, and that the presence of an Eastward obstruction causes the solar irradiance to drop to zero early in the day in the months of April and mostly June since the respective solar paths intersect this obstruction.



Photovoltaic System

The window Set-up New PV System refers to everything downstream from the calculation of the solar energy incident on the surface of the PV modules

The window shows a set of values that can be easily modified. From this window it is possible to proceed to the generation of the reports that include the PV system or return to the main window.



The window is composed by a number of areas described here below.

Environmental data

This area is only informative and shows the values of daily average solar radiation for every month, divided into direct, diffuse and reflected components. Furthermore it adds the average daily daylight duration from dawn to sunset, the average irradiance in daylight time and the associated average air temperature. The wind speed instead refers to a yearly average period.

Mounting system & Cell temperature

This area makes reference to the calculation of the monthly average temperature of the PV cells in daylight time. These values are used in subsequent calculations, the temperature losses and the wiring losses on DC side in particular.

It is possible to select 3 different mounting systems:

- **Free standing** – which is representative of the PV systems that use inclined structures on ground or terraces, where the air is free to flow on the front and rear of the PV modules.
- **Ventilated Roof** – which is applicable to the installations where the PV modules are placed on a tilted surface with a gap between where the air may circulate.
- **Non ventilated roof** – in all cases where the PV modules are placed on a surface without an air gap or there is not air circulation on the rear surface anyway.

SunSim 10 takes into account the average wind speed in the site but it is possible that a given installation is lickered only in a mitigate way by the air movement. Therefore, in some cases it could be unrealistic to consider the rated wind speed for the site, that normally is measured at a height of 10 m in an area free of obstacles. By using the check-boxes below the caption **Wind force** it is thus

possible to use in calculations the 70% or the 30% of the rated value, but one can use the 100% when circumstances allow.

The cell temperature T_c is calculated with the formula:

$$T_c = T_a + k \cdot \frac{3.8}{9.81 + 2 \cdot W_v} \cdot G_i$$

Where W_v is the wind speed in m/s, k is the coefficient that takes into account the type of installation and G_i is the total irradiance on PV modules. The formula used by SunSim 10 is slightly different from that normally reported in literature, in order to make it consistent with the definition of NMOT in the IEC 61215-1, which considers a wind speed of 1 m/s (further than $G_i = 800 \text{ W/m}^2$ and $T_a = 20 \text{ }^\circ\text{C}$) e $k = 1$ (Free standing condition). However, the Ventilated roof and Non ventilated roof conditions are simulated by using increasing values of k , respectively 1,35 and 1,80.

The cell temperature T_c is calculated on a monthly basis and is graphically reported inside the area.

Losses for non STC cell temperature

The average PV cell temperature calculated month by month is used in this area to calculate the average monthly losses due to the difference between the cell temperature and the SCT conditions. However, when the cell temperature is lower, possible event in the winter months, one gets a gain rather than a loss.

The calculation requires the knowledge of the temperature coefficient γ , expressed as a percentage on grade centigrade (reported in the data-sheet of the PV module), which is adjustable by means of a dedicated scroll-bar. The power obtained Pm' is therefore modified with respect to the power that does not take into account the effect of the temperature Pm as follows.

$$Pm' = Pm \cdot [1 + \gamma_{\%} \cdot (T_c - 25)/100]$$

Losses for PV string mismatch

In this area it is possible to input the yearly average losses for string-mismatch by means of a dedicated scroll-bar.

In absence of partial shading these losses are normally very low and normally do not exceed 0,4÷0,5%. In case of AC modules or PV modules with power optimizer these losses are equal to zero. Instead, if we are in presence of strings and these are affected by significant partial shadings, the mismatch losses take substantial values, typically exceeding 1%.

Losses in DC strings

These losses refer to the single PV strings up to the arrival to the DC combiner box or to the inverter. In order to obtain reliable values is thus necessary to insert the nominal voltage of the string at the maximum power point U_m , the current at the maximum power point I_m and the length of the route L in meters, considered as the distance between the string and the point of arrival (not as the total length of the cable).

The voltage U_m and the length L are to be inserted without decimal point, instead the current I_m may have the fractional part. This because the value of I_m is normally a few amps and so it is not possible to approximate it to an integer. The values of U_m and I_m are taken directly from the data-sheet of the PV module used. Of course, before its insertion U_m shall be multiplied by the number of PV modules in series that form the string.

Furthermore it is necessary to select the cross-section of the cable, considered as a copper cable, among a series of normalized values between 1.5 and 240 mm². Finally, one press **Calc** to calculate the losses.

It is important to note that in calculations *SunSim 10* takes into account that the average string current is a fraction of the I_m , equal to the average incident power during the daylight time divided by the reference irradiance at STC (1000 W/m²). Therefore, *SunSim 10* does not calculate the losses at the nominal current but at a weighted average current that represents the production period for the day.

SunSim 10 takes into account the voltage and current variations due to the PV cell temperature different from the STC value. When the temperature increases the string voltage decreases significantly, and the string current increases (although the latter to a much lesser extent than the voltage). In general therefore, the string voltage and current to use for the calculation of the losses are not the nominal ones but those modified by the temperature. This effect is taken into account by means of the coefficients β for the voltage and α for the current that one may modify by means of two dedicated scroll-bars.

In conclusion therefore, the average string voltage and current are modified as follows (one may note that *SunSim 10* repeat this calculation for each month of the year).

$$Um' = Um \cdot [1 + \beta_{\%} \cdot (Tc - 25)/100]$$

$$Im' = Im \cdot [1 + \alpha_{\%} \cdot (Tc - 25)/100]$$

Furthermore, *SunSim 10* take partially into account the increase of the cables resistance with the temperature. A precise account would require additional information on cable routing, because the overtemperature due to the current passing also depends on the characteristics of the cable and its placement (conduits, trunks, trays, bundles, etc.). Since is not realistic to assume such a level of detail and observing that normally the string cables are oversized in terms of current flow, we see that in most cases the overtemperature due to the passage of current is quite low. Therefore, with a certain degree of approximation the temperature of the cables has been set equal to that of the air in daylight time. However, a limit of 20 °C has been set and below this limit the temperature of 20 °C is used in this calculation anyway. Therefore, the resistivity values at 20 °C are those given by the cable manufacturers and an increase of +0,393 %/°C is used for higher temperatures. Also in this case the calculation is made monthly.

NOTE: The calculations made by *SunSim 10* are aimed to the calculation of the energy yield and thus they make use of the weighted average values for the day of the various parameters. Therefore, the obtained results are not directly applicable to the sizing of the PV system and its components. This operation instead requires knowledge and calculation of the limit operating conditions for materials, components and equipment.

Losses in DC lines after parallel of strings

This area is used when the strings are collected in a combiner box from which a DC line departs toward the inverter.

It is thus possible to specify how many strings are connected in parallel (**N. of strings**), the length of the line toward the inverter (**L [m]**) and its cross-section. The string voltage and current, modified according to the PV cell temperature, are those already inserted for the calculation of the losses in DC strings.

Average inverter efficiency

In this area it is possible to insert the average efficiency of the inverter by means of a dedicated scrollbar. Generally, manufacturers provide the European efficiency or the Californian efficiency whose values are very similar anyway. Having to choose, between the two it is better to use the one that best interprets the features of the given site.

Average AC losses & miscellaneous

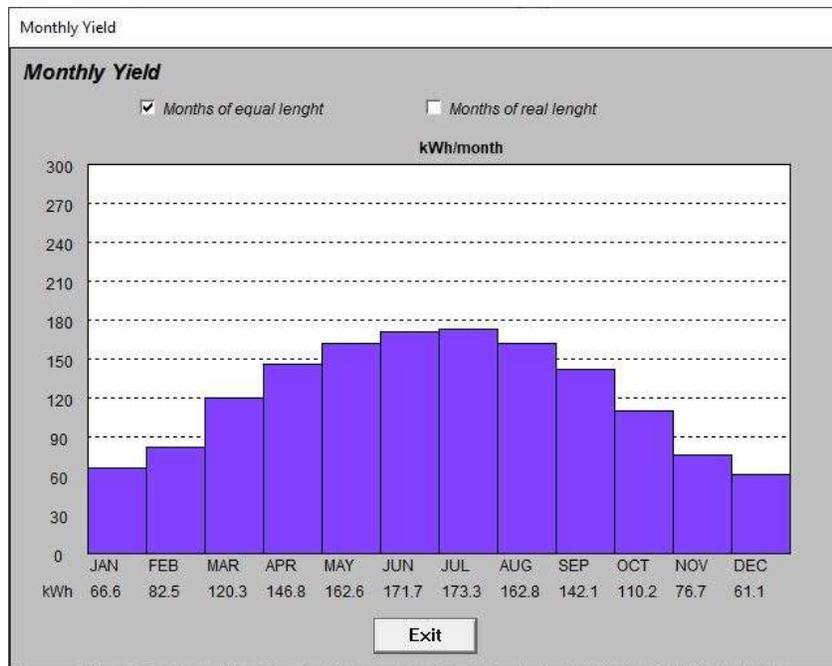
In this area it is possible to insert the losses due to the lines and components on the AC side, as for instance the transformers and the switchgears both LV and HV.

Furthermore it is possible to use this area to take into account the sources of loss different from those previously listed.

Performance Ratio – PR

This area reports numerically and graphically the Performance Ratio on a monthly basis for the PV system, calculated on the basis of all sources of loss present in the window. Furthermore, it is reported the yearly weighted average value of the PR and the total yield per kWp installed.

By means of the button **Yield** the window below appears. It reports the monthly yield of the PV system

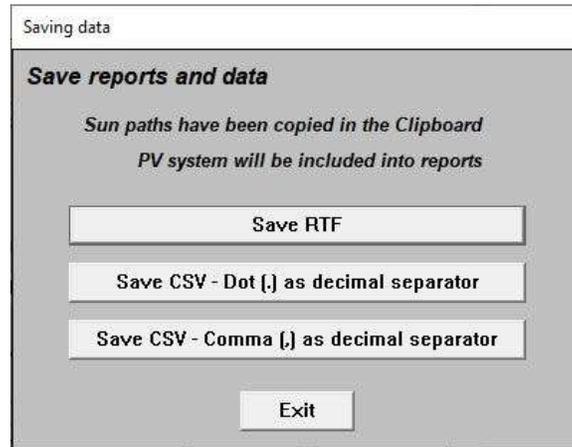


In this window it is possible to choose to consider all months having the same length, which is useful to make comparison and energy assessments, or alternatively to take into account the real length of each month. This last is more useful for economic and administrative accounting.

Reports

SunSim 10 produces a number of reports that can be used by word processors and spreadsheets, because it can produce files .RTF (Rich Text Format) and .CSV (Comma-Separated Values).

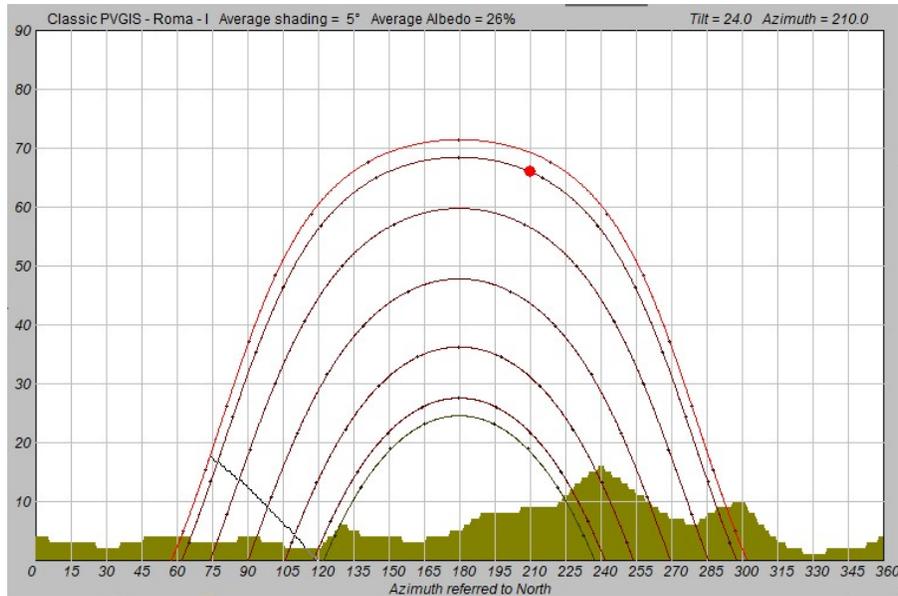
When from the window **Set-up new PV system** the button **Report** is pressed, the window **Save reports and Data** appears, through which a report that includes the PV system can be obtained.



Instead, when in the working area the left mouse button or the **<Return>** key are pressed the same window is shown but the reports generated do not include the PV system. By means of the window **Save Reports and Data** it is possible to generate the reports of interest, that is:

Save RTF	File readable by every word processor (e.g. MS Word)
Save CSV - Dot (.) as decimal separator	File readable by every spreadsheet (e.g. MS Excel) with a dot between the decimal and the integer part of the values and those separated from one another by a comma (English standard)
Save CSV - Comma (,) as decimal separator	File readable by every spreadsheet (e.g. MS Excel) with a comma between the decimal and the integer part of the values and those separated from one another by a dot (Italian standard)

At the same time, the working area is saved in the clipboard, as shown in the following figure.



The file .RTF contains the data used by *SunSim 10* and the table of the resulting monthly average values of the solar radiation as in the following example that includes also the PV system.

SUNSIM 10 - Simulation report

Input data of the site

Sun data: Classic PVGIS - Roma - I
 Latitude: 41.9° N
 Average shading: 5°
 Average albedo: 26 %

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Dir [kWh/d]	0.750	1.056	1.944	2.833	3.472	3.972	4.167	3.583	2.722	1.694	0.917	0.639
Diff [kWh/d]	0.889	1.222	1.722	2.139	2.500	2.639	2.444	2.194	1.750	1.333	0.972	0.806

Azimuth [°]	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170
Shading [°]	4	3	3	2	3	4	4	3	3	4	3	2	2	6	4	4	3	4

Azimuth [°]	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350
Shading [°]	5	8	8	9	9	13	16	13	10	7	6	9	10	5	2	1	2	2

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Albedo	0.50	0.26	0.26	0.26	0.26	0.23	0.20	0.20	0.20	0.23	0.26	0.26

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Day T [°C]	12	13	16	19	23	28	31	30	27	22	17	13

Yearly average wind speed = 3 m/s

Input data of the PV system

Tilt: 24.0° N
 Azimuth: 210.0°
 Limit angle: 5.0°
 mounting type: Ventil. roof
 Wind effectiveness: 70 %
 Temperature coefficient (power): -0.40 %/K
 Temperature coefficient (voltage): -0.35 %/K
 Temperature coefficient (current): 0.1 %/K
 PV string mismatch: 0.21 %
 PV strings: Um = 660 V Im = 7.89 A Lenght = 60 m
 Cable cross_section = 2.5 mm² r = 16.4200 mOhm/A m
 DC lines after parallel: Number of strings in parallel = 12 Lenght = 45 m
 Cable cross_section = 25 mm² r = 1.5900 mOhm/A m
 Avg inverter efficiency: 97.0 %
 AC losses & others 1.0 %

Calculated average radiation per day [kWh/d]

Month	Beam [kWh/d]	Diffuse [kWh/d]	Reflected [kWh/d]	Total [kWh/d]	Daytime [h]	Avg power [W]
January	1.192	0.828	0.034	2.054	9.4	218
February	1.429	1.139	0.024	2.592	10.6	244
March	2.372	1.605	0.039	4.016	12.0	336
April	3.062	1.993	0.053	5.107	13.4	381
May	3.438	2.329	0.063	5.830	14.6	400
June	3.811	2.459	0.062	6.332	15.1	421
July	4.116	2.277	0.054	6.447	14.6	441
August	3.865	2.045	0.047	5.957	13.4	443
September	3.320	1.630	0.037	4.987	12.0	416
October	2.318	1.242	0.028	3.588	10.6	340
November	1.468	0.906	0.020	2.393	9.4	255
December	1.094	0.751	0.015	1.860	8.9	208
Average	2.624	1.600	0.040	4.264	12.0	342

Average daily PV cell temperature [°C]

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T cell [°C]	21	23	29	34	39	44	48	47	43	35	27	21

Calculated average losses of the PV system [%]

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Temperature	1.8	1.0	-1.7	-3.6	-5.5	-7.8	-9.3	-8.9	-7.3	-4.1	-0.8	1.5
Mismatch	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
PV strings	-0.3	-0.3	-0.4	-0.5	-0.5	-0.6	-0.6	-0.6	-0.5	-0.4	-0.3	-0.2
DC lines	-0.2	-0.2	-0.4	-0.4	-0.4	-0.5	-0.5	-0.5	-0.5	-0.4	-0.3	-0.2
Inverter	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0
AC & others	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0

Performance ratios [%]

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
PR [%%]	97.1	96.3	93.5	91.6	89.7	87.5	85.9	86.3	87.9	91.2	94.5	96.9

Monthly Yield [kWh/kWp]

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Equal lenght	60.7	75.9	114.3	142.4	159.2	168.5	168.6	156.4	133.5	99.6	68.9	54.8
True lenght	61.8	70.5	116.4	140.4	162.2	166.1	171.8	159.3	131.5	101.4	67.9	55.9

Yearly weighted average PR: **90.1 %**
 Annual Yield: **1403.0 kWh/kWp**

The file .CSV contains the data used by *SunSim 10*, and the results of the simulation, similarly to the content of the file .RTF.

Moreover, the file .CSV contains also the table of the monthly average values of solar radiation and the average hourly values of the solar radiation in its components direct, diffused and reflected.

Annexes

Files managed by SunSim 10

<filename>.SIT	File containing the latitude and the values of solar radiation data as monthly averages for a given site not included in the list proposed by the program
<filename>.HOR	File containing the values of the angles of the obstacles to the solar paths related to a given point of observation
<filename>.ALB	File containing the albedo coefficients to use for the calculation of the reflected radiation on a monthly basis
<filename>.PVS	File containing the data of the PV system, except the inclination and orientation of the PV modules, that are chosen directly by the user on the solar diagram
<filename>.RTF	Report file readable by a word processor
<filename>.CSV	Report file readable by a spreadsheet

Files included in the software package

SunSim.exe	Executable program
Protection.txt	File containing the 3 characters to digit in order to enable the operation of the program
Licence.PDF	User licence of the program
SunSim_Manual.PDF	User manual of <i>SunSim 10</i>

References

- IEC 61215-1 – Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1: Test requirements
- IEC 61215-2 – Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 2: Test procedures
- IEC 60891 – Photovoltaic devices - Procedures for temperature and irradiance corrections to measured I-V characteristics
- IEC 61724-1 – Photovoltaic system performance – Part 1: Monitoring
- UNI 10349-1:2016 – Riscaldamento e raffrescamento degli edifici. Dati climatici
- M. D’Orazio, C. Di Perna, E. Di Giuseppe (2013) – Performance assessment of different roof integrated photovoltaic modules under Mediterranean Climate – ELSEVIER
- G. A. Migan (2013) – Study of the operating temperature of a PV module
- A.Virtuani, D. Pavanello, G. Friesen (2010) – Overview of Temperature Coefficients of Different Thin Film Photovoltaic Technologies
- F. Groppi, C. Zuccaro – Impianti solari fotovoltaici a norme CEI – Editoriale Delfino
<https://re.jrc.ec.europa.eu>