



# **SunSim Storage – User manual**

## **Introduction**

The program *SunSim Storage* has been devised and developed to calculate in a simple, quick and reliable way the behaviour of the photovoltaic systems connected to the grid along with their energy storage.

Frequently, the economic calculation for the photovoltaic systems with storage is based on yearly or seasonal average data that do not take into account the actual trend of electric loads. These approximated calculations in most cases lead to totally erroneous results because, especially considering a single user, the highly discontinuous loads trend cannot be reduced to behaviours averaged over time.

Demonstrating how said, one should try to see if the calculation method presently in use can answer positively to the following questions:

- Does it take into account the different seasonal behaviour, also considering the different availability of the solar source and the different trend of the loads (e.g. lighting, heating / cooling devices, etc.)?
- Does it take into account the different load trend in the weekly days (working, Saturdays, Sundays)?
- Does it take into account the presumable periods of summer inactivity (holidays, vacations, closures, etc.)?
- Does it take into account the different type of loads (residential, commercial, industrial, etc.)?

One should note that while for the usual grid connected photovoltaic systems what really matters are the annual values of production and consumption, in case of systems with storage, it is fundamental to foster the storage itself both energetically and economically. Nevertheless, to achieve this result one needs to consider in detail the amount of energy that the storage can turn into self-consumption. Only in this way one can evaluate if its presence is justified and which size can be considered as optimal.

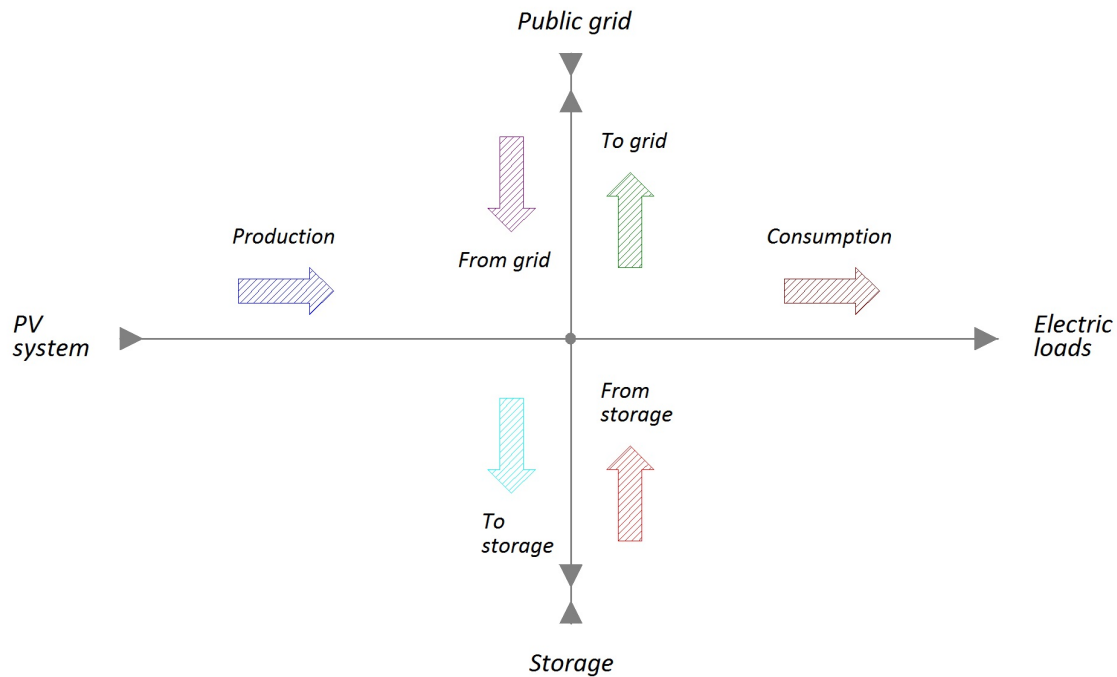
## **Calculation method**

*SunSim Storage* is a simulation program that works in the time domain. As concerns the photovoltaic production, results are 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 those the partial results.

Consumption data are taken instead from a file and continuously compared with the photovoltaic production and with the stored energy. The presence of the electric grid allows to equilibrate the energy balance, as in every considered instant:

- if the photovoltaic production is greater than consumptions the system readdress the surplus toward the storage and, when this is saturated, the exceeding energy is sent to the grid;
- if the photovoltaic production is lower than consumptions the system picks up from the grid the missing energy and, when the storage is empty or has reached its technical minimum, the same energy is taken from the grid.

The corresponding energy fluxes are illustrated in the following figure.



**SunSim Storage** makes the simulation of the energy behaviour for the system composed by photovoltaic plant, storage, electric loads and electric grid for a full calendar year.

The simulation approach, identical to that used by **SunSim 8.0**, allows the exploitation of the initial data in a simple and understandable format (direct and diffuse monthly solar radiation, time series for electric loads). Conversely, results need a huge amount of calculations (the time step adopted by **SunSim Storage** is 5 minutes) and in the Annex B a few details on the used method are shown.

The program is completely written in C/C++ language.

### Minimum system requirements

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

The resources needed by **SunSim Storage** 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 CD or a memory stick.

However, in the same folder of **SunSim Storage** the file **loads.txt** must be present, which contains the input data related to the total consumptions of the electric loads considered.

## Installation

*SunSim Storage* 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 (along with the *loads.txt*) and, by means of the right mouse button, activate the command “Add to Start Menu”.

## Protection

*SunSim Storage* 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 Storage* 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.

## Operation description

The program *SunSim Storage* consists essentially of a main dialogue window through which is possible to control all the main parameters involved in the calculations.

In the following, the specific items of the main window as well as the other windows that is possible to open will be considered.

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

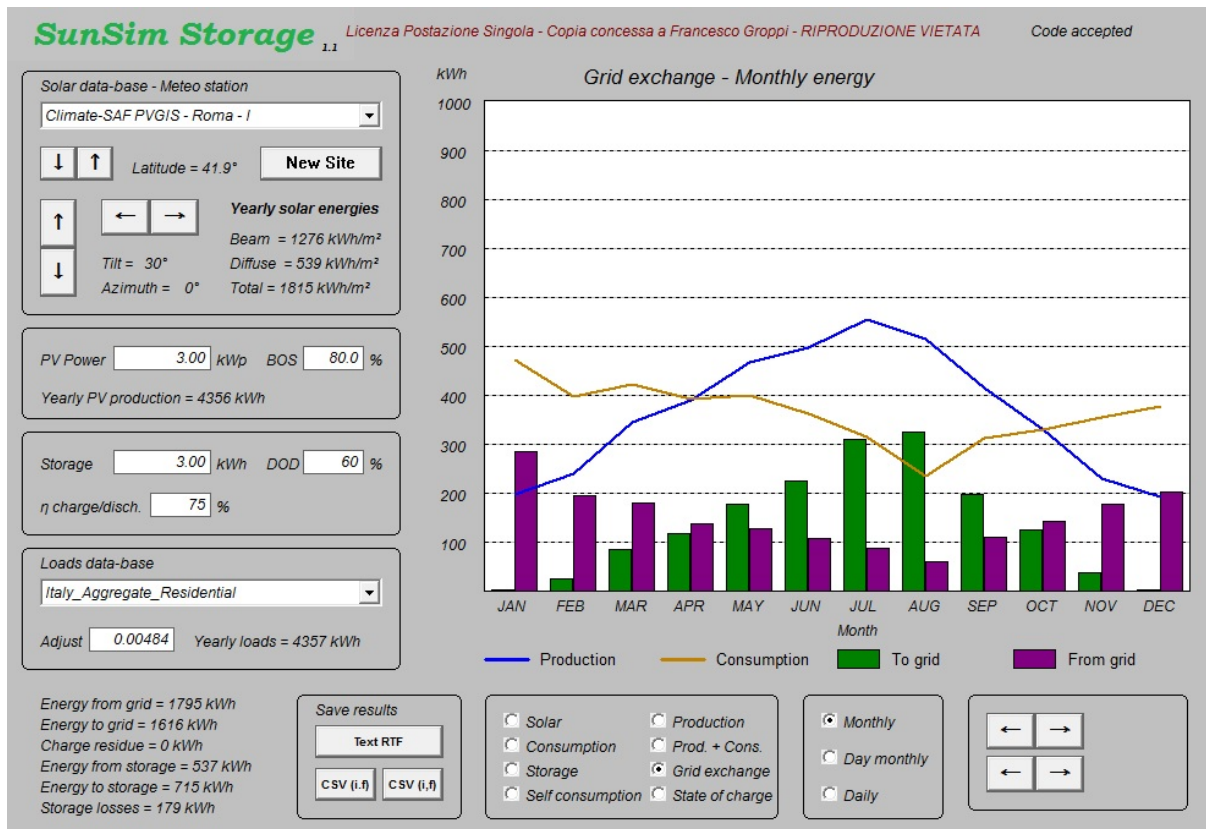
- *Solar data-base – Meteo station*
- *PV Power, BOS*
- *Storage, DOD,  $\eta$  chsrge/disch.*
- *Loads data-base*

Moreover, there are further areas where it is possible to select the graphical presentation of results:

- *Solar, Production, Consumption, Prod. + Cons., Storage, Grid exchange, Self consumption, State of Charge*
- *Monthly, Day monthly, Daily*
- *Buttons for the selection of the current month and the current day*

Finally, there are a report area for the yearly results and an area that allow to save the calculated values on files .RTF e .CSV:

In the next figure an example of main window is shown. As almost all operations made without opening further windows, the main window include a graphical sub-window where all trends of the results can be plotted by selecting those that interest.



## Input data

### Solar data-base – Meteo station

This pane manages the choice of the solar source and the orientation of the photovoltaic array. The following figure shows an example of this section.

Solar data-base - Meteo station

Climate-SAF PVGIS - Roma - I

Latitude = 41.9° **New Site**

Yearly solar energies

Beam = 1276 kWh/m<sup>2</sup>

Diffuse = 539 kWh/m<sup>2</sup>

Total = 1815 kWh/m<sup>2</sup>

Tilt = 30°

Azimuth = 0°

By means of the drop-down menu it is possible to select the data of direct and diffuse radiation on a horizontal plane 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	<b>Prato</b>	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	Forlì	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	Oristano	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)	Hamburg (D)	Roma (I)
Birmingham (UK)	Munchen (D)	Campobasso (I)
Edinburgh (UK)	Warszawa (PL)	Napoli (I)
London (UK)	Praha (CZ)	Potenza (I)
Manchester (UK)	Bern (CH)	Bari (I)
Dublin (IRL)	Innsbruck (A)	Lecce (I)
Reykjavik (IS)	Wien (A)	Cosenza (I)
Oslo (N)	Budapest (H)	Reggio Calabria (I)
Stockholm (S)	Barcelona (E)	Palermo (I)
Helsinki (SF)	Bilbao (E)	Catania (I)
Kopenhagen (DK)	Granada (E)	Ragusa (I)
Vilnius (LT)	Madrid (E)	Sassari (I)
Riga (LV)	Sevilla (E)	Cagliari (I)
Tallin (EST)	Zaragoza (E)	Ljubliana (SLO)
Moskva (RU)	Lisboa (P)	Zadar (HR)
Minsk (BY)	Porto (P)	Beograd (SRB)
Kiev (UA)	Aosta (I)	Bucaresti (R)
Bordeaux (F)	Bolzano (I)	Sofija (BG)
Lyon (F)	Torino (I)	Tirana (AL)
Marseille (F)	Milano (I)	Athina (GR)
Nice (F)	Padova (I)	Thessaloniki (GR)
Paris (F)	Udine (I)	Istanbul (TR)
Rennes (F)	Genova (I)	Valletta (M)

Strasbourg (F)  
 Bruxelles (B)  
 Amsterdam (NL)  
 Luxembourg (L)  
 Berlin (D)  
 Frankfurt (D)  
 Freiburg (D)

Bologna (I)  
 Firenze (I)  
 Ancona (I)  
 Perugia (I)  
 Grosseto (I)  
 Pescara (I)

Nicosia (CY)  
 Casablanca (MA)  
 Algier (DZ)  
 Tunis (TN)  
 Tripoli (LAR)  
 Cairo (ET)

For the following 3 sites the reference is represented instead by the calculation method PVGIS-Helioclim.

Doha (Q)

Dubai (UAE)

Riyad (KSA)

Finally, for the following 26 sites in Italy the calculation method Climate-SAF PVGIS was also used.

Aosta  
 Milano  
 Genova  
 Ancona  
 Pescara  
 Napoli  
 Lecce  
 Palermo  
 Sassari

Bolzano  
 Padova  
 Bologna  
 Perugia  
 Roma  
 Potenza  
 Cosenza  
 Catania  
 Cagliari

Torino  
 Udine  
 Firenze  
 Grosseto  
 Campobasso  
 Bari  
 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.

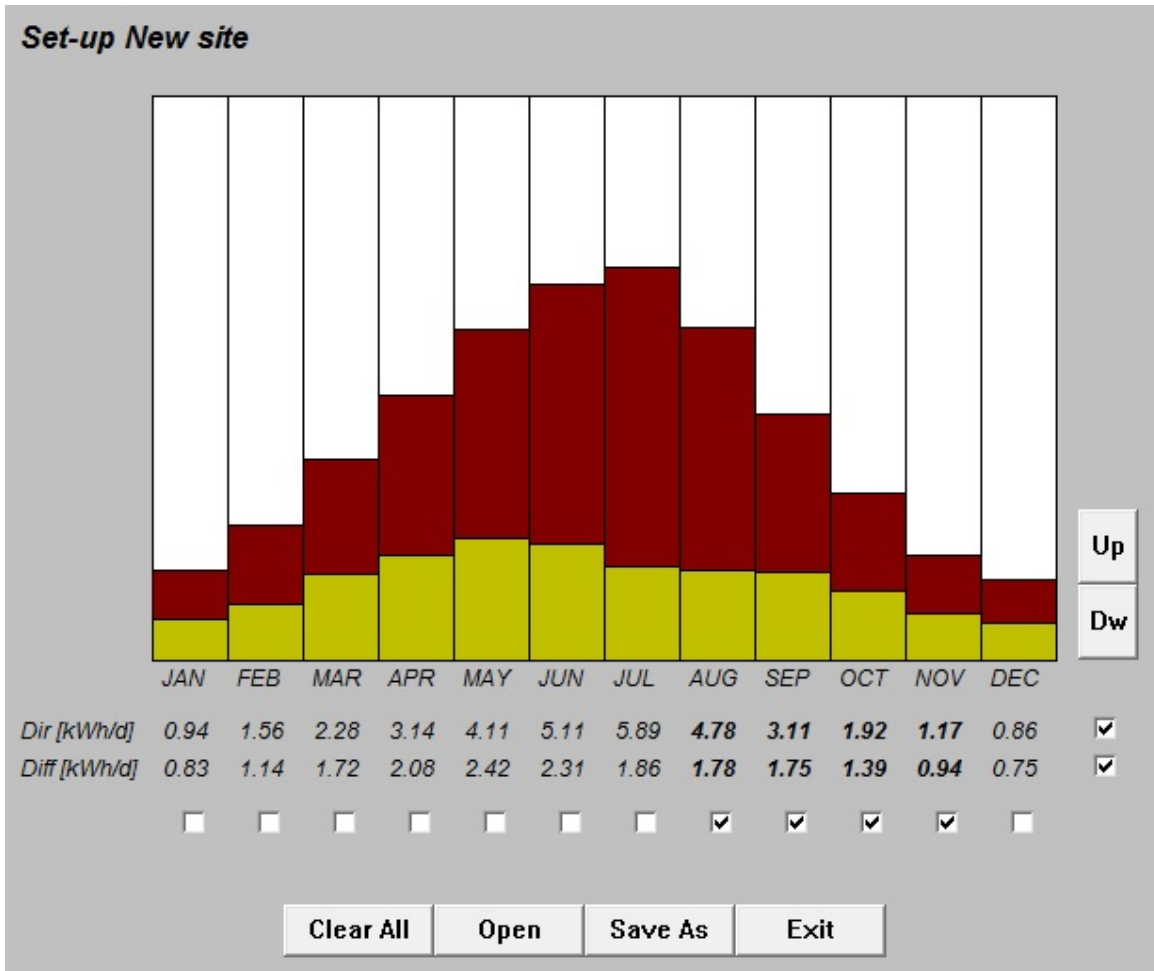
By means of a first pair of buttons marked with the arrows ↓ and ↑ it is possible to modify the latitude of the site from 0° N to 90° N by initiating from that of the chosen site. The use of these buttons for minor corrections does not cause any problem. However, if large variations are needed one should 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.

There is also a second pair of buttons marked with the arrows ↓ and ↑, by means of which it is possible to modify the tilt of the PV array plane from 0° N to 90° N. Similarly, with the arrows ← and → it is possible to modify the azimuth between -180° and +180° compared to the South.

The last one of the sites in the list is indicated as <New site>. It is a site for which it is possible to introduce solar radiation data from an existing site.

In this section, the solar radiation values for the selected site and the specific orientation of the solar array are also displayed. These values refer to the direct, diffuse and total radiation.

The button **New Site** allows the personalization of the direct and diffuse solar radiation by means of a specific dialog window as shown in the following figure.



By means of the buttons **Up** and **Dw** it is possible to increase or decrease the values of 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 August, September, October and November 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 window allow to save the new set values in a proper file .SIT and to open the existing files to load the data previously saved.

## Yearly production

As seen, the section *Solar data base – Meteo station* refers to the solar radiation values intercepted by the PV modules array, regardless of the solar conversion technology employed and the characteristics of the photovoltaic system.

Conversely, in this section dedicated to the yearly production, it is possible to specify the rated power of the photovoltaic system (defined as the sum of the rated powers of the PV modules that compose it) and the overall efficiency (BOS) of all the chain up to the output connections.

The following figure shows an example of this section.

PV Power  kWp BOS  %

Yearly PV production = 5083 kWh

Based on the solar radiation values previously calculated and the characteristics of the PV system introduced in this section, the yearly production value of the PV system is also calculated and displayed.

### Storage characteristics

The characteristics of the storage are identified by the parameters contained in the following figure, reported as an example.

Storage  kWh DOD  %

$\eta$  charge/disch.  %

The parameter associated to **Storage** refers to the rated value of the storage capacity, expressed in kWh.

DOD (Depth Of Discharge) refers to the maximum percentage of the dischargeable energy from a chemical storage before a degradation might occur. This parameter, typically, is applied to lead-acid elements that cannot be completely discharged. A value equal to 60%, as in the example, means that actually only a 60% of the rated capacity of the storage can be employed. Conversely, if the storage has not such problems it is possible to indicate a value equal to 100%.

The parameter  $\eta$  charge/disch. takes into account the fact that not all the energy entered in the storage can be retrieved afterwards. In the given example, the 75% of the stored energy is actually recovered.

### Loads data-base

It must be stated that the temporal values of the electric loads are contained in a single file named *loads.txt*. In this file one can insert up to 10 different types of electric loads also differently organized.

Loads data-base

Adjust  Yearly loads = 4357 kWh

By choosing a specific electric load from the dropdown menu, the total yearly consumption in kWh is automatically displayed. Normally it is however necessary to conform such a value to specific needs, while maintaining the trend over time and for this reason by means of the parameter **Adjust** it is possible to introduce a proper multiplying factor. In the above example, the yearly energy consumed by loads was made almost coincide with the yearly energy produced by the photovoltaic system (although these two values could differ anyway).



The file *loads.txt* provided with *SunSim Storage* contains a few examples, but it is possible to add others in a pretty simple way as reported in the annex C.

## Graphical views

SunSim Storage can plot the results in different ways by means of very simple selection tools.

The time range that one can display is one of the followings:

- Monthly – display of 12 monthly averages in the year
- Day monthly – display of the average daily trend in a given month
- Daily – display of a trend for a specific day in the year

Referring to the variables to be plotted it is possible to have the following graphs:

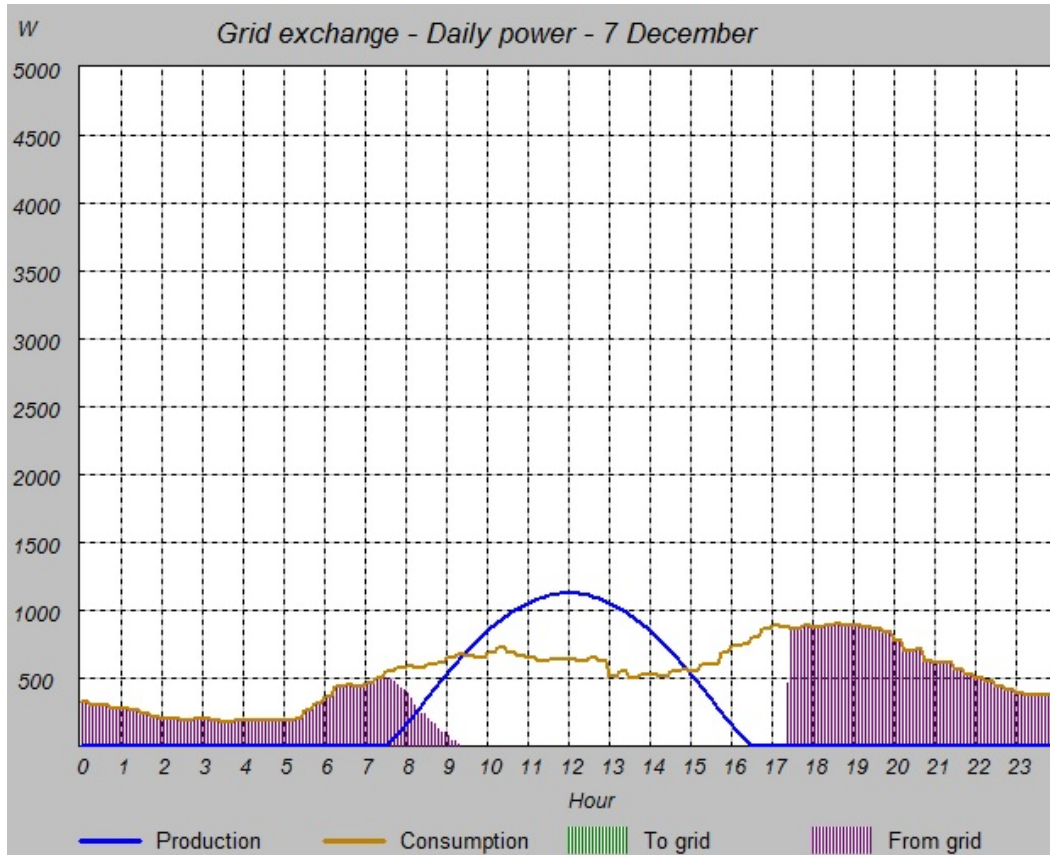
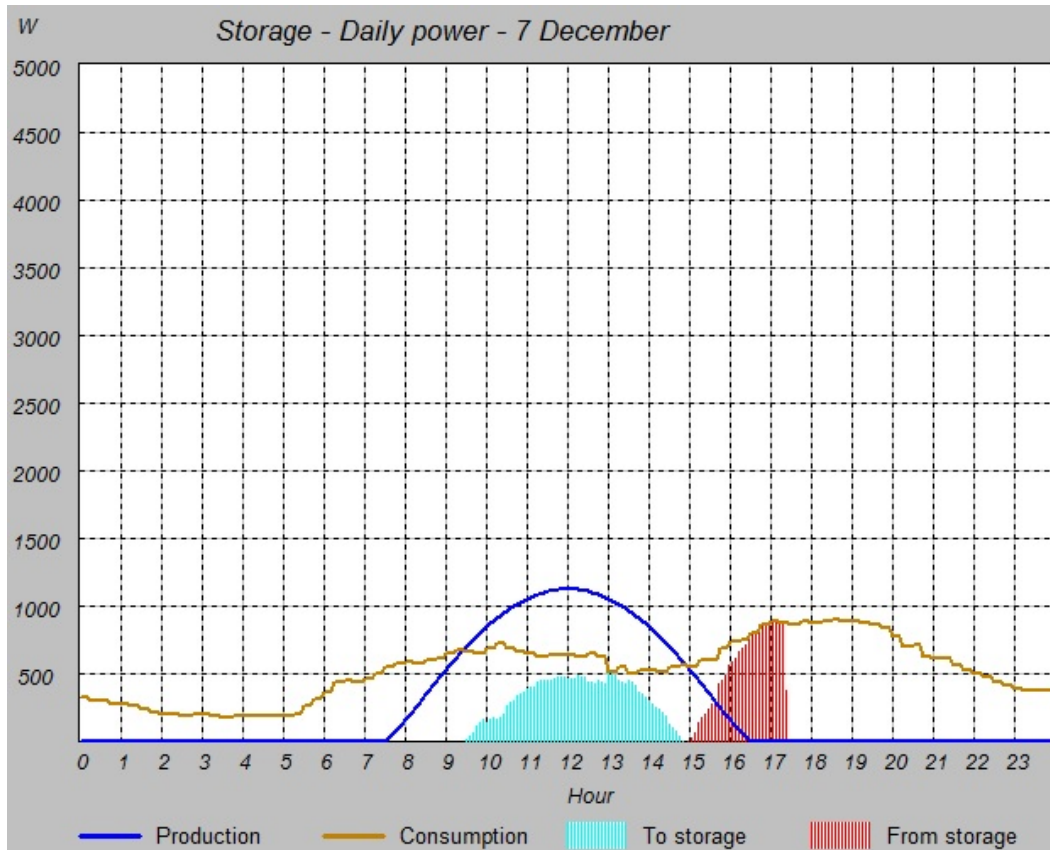
- Solar – values of the direct and diffuse solar radiation
- Production – photovoltaic production
- Consumption – consumption of the electric loads
- Prod. + Cons. – photovoltaic production and consumption of the electric loads in the same graph
- Storage – energies in transit from and to the storage, compared with production and consumptions
- Grid exchange – energies in transit from and to the grid, compared with production and consumptions
- Self consumption – percentage of consumptions that have been covered by the produced energy
- State of charge – state of charge of the storage

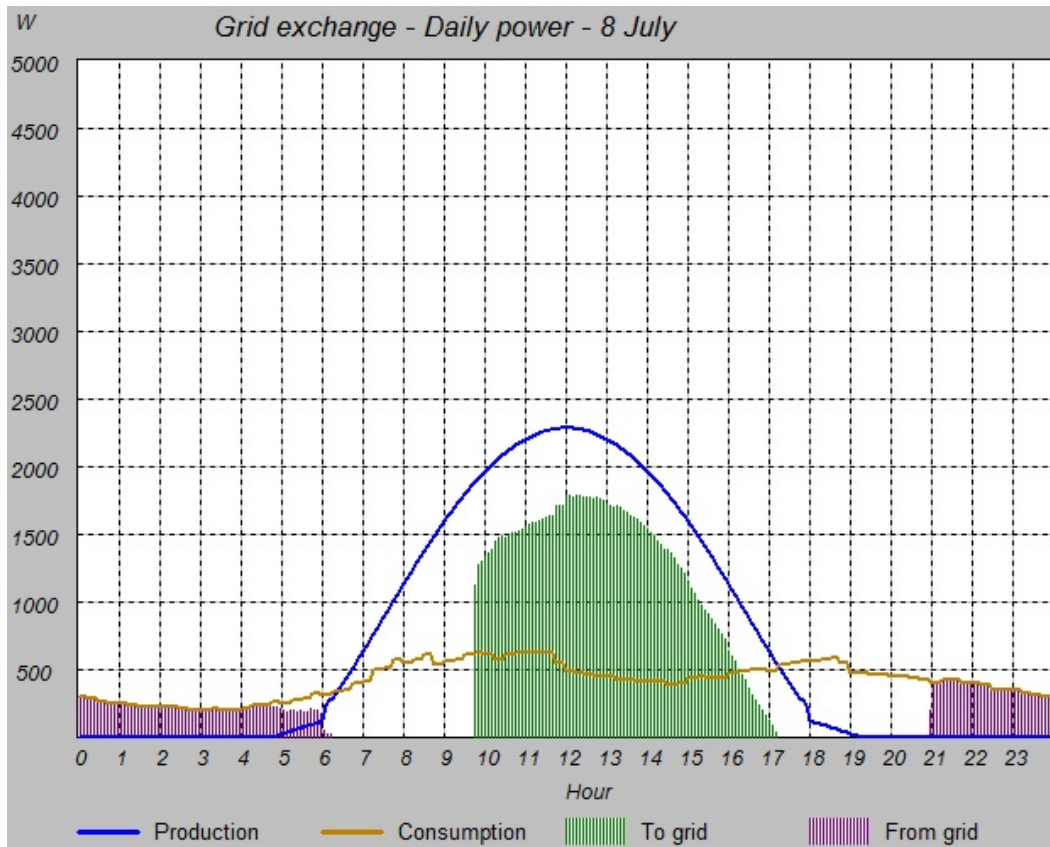
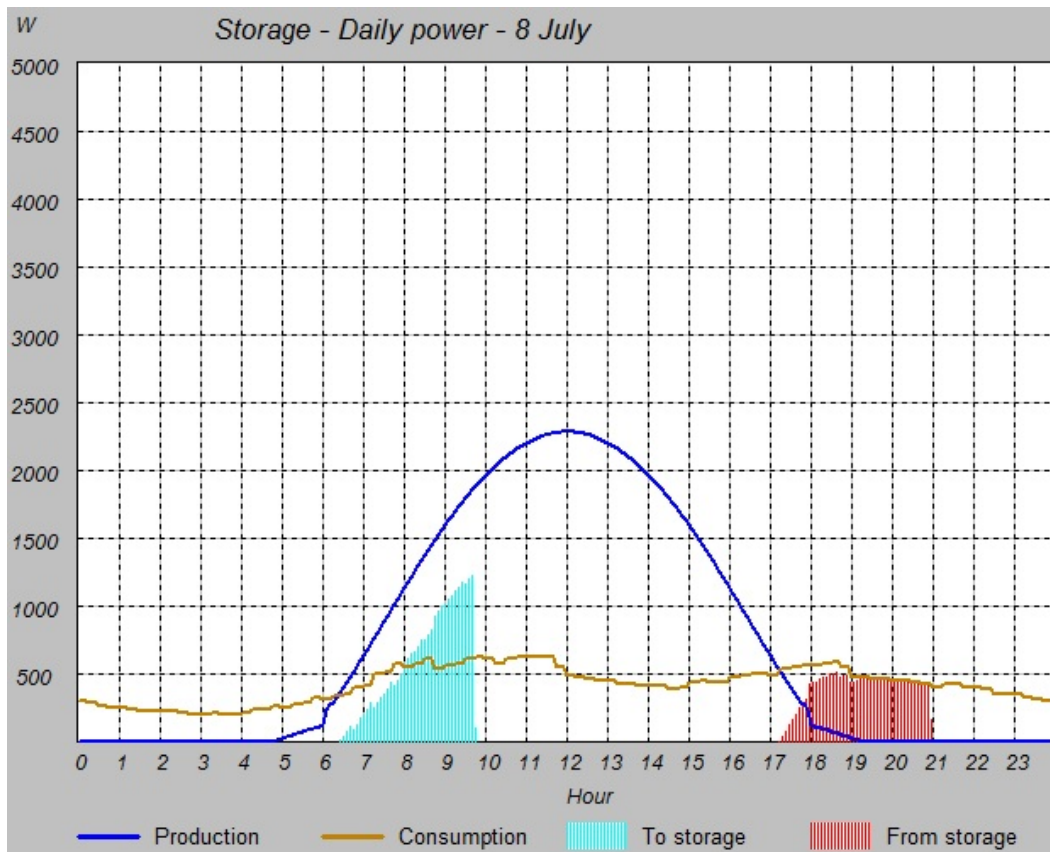
The following figure shows the area where it is possible to take these options.



From a simple simulation as that reported in the example (3 kWp PV + 3 kWh storage) and with the residential-type consumptions as indicated, one can observe that in some winter-autumn periods there are days where the produced energy is totally self-consumed and the storage can therefore transfer all the daily production to the evening hours. Conversely, in the months of higher production, the storage cannot store all the exceeding energy and, once it is saturated, it must be perforce disconnected up to the end of the day, when it will be required to give back the stored energy.

The following figures show these behaviours in two specific day chosen in the months of December and July.





The program displays also a summary table that reports the energies exchanged during the year. The following figure shows an example.

```
Energy from grid = 1795 kWh
Energy to grid = 1616 kWh
Charge residue = 0 kWh
Energy from storage = 537 kWh
Energy to storage = 715 kWh
Storage losses = 179 kWh
```

## Reports

*SunSim Storage* allows to obtain 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).

In the section **Save results** it is possible to generate the reports of interest, that is:

- |           |   |
|-----------|---|
| Text RTF  | File readable by every word processor   |
| CSV (i.f) | File readable by every spreadsheet with a dot between the decimal and the integer part of the values and those separated from one another by a comma (English standard) |
| CSV (i,f) | File readable by every spreadsheet with a comma between the decimal and the integer part of the values and those separated from one another by a dot (Italian standard) |

### Text file .RTF

The content of the **.RTF** files is different depending on the temporal interval selected.

If **Monthly** is selected, the file reports the monthly averages and the daily trends.

It is the report most frequently used and that can give a general view of the trends of the system variables, as in the example reported in the following figure that displays a portion of the file.

## MONTHLY AVERAGES

Month	Solar Yield [kWh/m²d]			PV production [kWh]	Load consump. [kWh]	From grid [kWh]	To grid [kWh]	From storage [kWh]	To storage [kWh]	State of charge [kWh]	Self prod. [%]	
	Direct	Diffuse	Total									
1	1.86	0.78	2.63	196	470	283	0	25	33	1	40	
2	2.50	1.06	3.56	239	396	193	23	43	57	2	51	
3	3.01	1.61	4.62	344	421	178	84	48	64	2	58	
4	3.45	1.94	5.39	388	391	136	117	47	62	2	65	
5	4.00	2.25	6.25	465	399	126	176	48	64	2	68	
6	4.74	2.15	6.89	496	362	106	224	47	62	2	71	
7	5.70	1.74	7.44	553	314	86	309	48	64	2	73	
8	5.24	1.66	6.90	513	233	58	323	48	64	2	75	
9	4.10	1.63	5.73	413	310	110	196	47	62	2	65	
10	3.11	1.30	4.41	328	329	142	125	48	64	2	57	
11	2.31	0.88	3.19	230	354	176	36	47	62	2	50	
12	1.86	0.70	2.56	190	376	202	2	40	54	1	46	
Avg	3.49	1.48	4.96								2	60
Sum				4356	4357	1795	1616	537	715			

## DAILY TRENDS - MONTHLY AVERAGES

### January

Hour	Solar Yield [W/m <sup>2</sup> ]			PV production [kWh]	Load consump. [kWh]	From grid [kWh]	To grid [kWh]	From storage [kWh]	To storage [kWh]	State of charge [kWh]	Self prod. [%]
	Direct	Diffuse	Total								
0	0	0	0	0.00	0.38	0.38	0.00	0.00	0.00	1.20	0
1	0	0	0	0.00	0.31	0.31	0.00	0.00	0.00	1.20	0
2	0	0	0	0.00	0.27	0.27	0.00	0.00	0.00	1.20	0
3	0	0	0	0.00	0.24	0.24	0.00	0.00	0.00	1.20	0
4	0	0	0	0.00	0.24	0.24	0.00	0.00	0.00	1.20	0
5	0	0	0	0.00	0.30	0.30	0.00	0.00	0.00	1.20	0
6	0	0	0	0.00	0.42	0.42	0.00	0.00	0.00	1.20	0
7	18	11	29	0.07	0.54	0.48	0.00	0.00	0.00	1.20	12
8	105	51	156	0.37	0.67	0.30	0.00	0.00	0.00	1.20	55
9	201	86	287	0.69	0.80	0.15	0.00	0.00	0.03	1.21	82
10	275	111	386	0.93	0.83	0.03	0.00	0.00	0.12	1.28	97
11	315	125	439	1.05	0.81	0.00	0.00	0.00	0.24	1.44	100
12	317	125	442	1.06	0.79	0.00	0.00	0.00	0.27	1.67	100
13	280	113	393	0.94	0.64	0.00	0.00	0.00	0.30	1.92	100
14	209	89	297	0.71	0.62	0.00	0.01	0.02	0.10	2.10	100
15	113	54	168	0.40	0.69	0.02	0.00	0.26	0.00	1.98	97
16	23	13	36	0.09	0.86	0.42	0.00	0.36	0.00	1.56	52
17	0	0	0	0.00	1.03	0.89	0.00	0.14	0.00	1.28	14
18	0	0	0	0.00	1.08	1.05	0.00	0.03	0.00	1.21	3
19	0	0	0	0.00	1.06	1.06	0.00	0.00	0.00	1.20	0
20	0	0	0	0.00	0.81	0.81	0.00	0.00	0.00	1.20	0
21	0	0	0	0.00	0.70	0.70	0.00	0.00	0.00	1.20	0
22	0	0	0	0.00	0.58	0.58	0.00	0.00	0.00	1.20	0
23	0	0	0	0.00	0.48	0.48	0.00	0.00	0.00	1.20	0
Avg	77	32	110							1.35	42
Sum				6.32	15.17	9.13	0.01	0.80	1.07		

### February

Hour	Solar Yield [W/m <sup>2</sup> ]			PV production [kWh]	Load consump. [kWh]	From grid [kWh]	To grid [kWh]	From storage [kWh]	To storage [kWh]	State of charge [kWh]	Self prod. [%]
	Direct	Diffuse	Total								
0	0	0	0	0.00	0.36	0.36	0.00	0.00	0.00	1.20	0
1	0	0	0	0.00	0.30	0.30	0.00	0.00	0.00	1.20	0

In the case instead that Day monthly is selected, the file reports every single value with a 5-minute interval of the average daily trend for the selected month, as in the example reported in the following figure that displays a portion of the file.

## DETAILED DAILY TREND - MONTHLY AVERAGES

### January

Hour	Solar Yield [W/m <sup>2</sup> ]			PV production [kW]	Load consump. [kW]	From grid [kW]	To grid [kW]	From storage [kW]	To storage [kW]	State of charge [kWh]	Self prod. [%]
	Direct	Diffuse	Total								
00:00	0	0	0	0.00	32.98	32.98	0.00	0.00	0.00	0.40	0
00:05	0	0	0	0.00	32.98	32.98	0.00	0.00	0.00	0.40	0
00:10	0	0	0	0.00	32.98	32.98	0.00	0.00	0.00	0.40	0
00:15	0	0	0	0.00	32.98	32.98	0.00	0.00	0.00	0.40	0
00:20	0	0	0	0.00	32.98	32.98	0.00	0.00	0.00	0.40	0
00:25	0	0	0	0.00	32.98	32.98	0.00	0.00	0.00	0.40	0
00:30	0	0	0	0.00	32.98	32.98	0.00	0.00	0.00	0.40	0
00:35	0	0	0	0.00	32.98	32.98	0.00	0.00	0.00	0.40	0
00:40	0	0	0	0.00	32.98	32.98	0.00	0.00	0.00	0.40	0
00:45	0	0	0	0.00	32.98	32.98	0.00	0.00	0.00	0.40	1
00:50	0	0	0	0.00	32.98	32.98	0.00	0.00	0.00	0.40	1
00:55	0	0	0	0.00	32.98	32.98	0.00	0.00	0.00	0.40	1
01:00	0	0	0	0.00	31.17	31.16	0.00	0.00	0.00	0.40	1
01:05	0	0	0	0.00	31.17	31.16	0.00	0.00	0.00	0.40	1
01:10	0	0	0	0.00	31.17	31.16	0.00	0.00	0.00	0.40	1
01:15	0	0	0	0.00	31.17	31.16	0.00	0.00	0.00	0.40	0
01:20	0	0	0	0.00	31.17	31.16	0.00	0.00	0.00	0.40	0
01:25	0	0	0	0.00	31.17	31.16	0.00	0.00	0.00	0.40	0
01:30	0	0	0	0.00	31.17	31.16	0.00	0.00	0.00	0.40	0
01:35	0	0	0	0.00	31.17	31.16	0.00	0.00	0.00	0.40	0
01:40	0	0	0	0.00	31.17	31.16	0.00	0.00	0.00	0.40	0
01:45	0	0	0	0.00	31.17	31.16	0.00	0.00	0.00	0.40	0
01:50	0	0	0	0.00	31.17	31.16	0.00	0.00	0.00	0.40	0
01:55	0	0	0	0.00	31.17	31.16	0.00	0.00	0.00	0.40	0
02:00	0	0	0	0.00	30.18	30.18	0.00	0.00	0.00	0.40	0
02:05	0	0	0	0.00	30.18	30.18	0.00	0.00	0.00	0.40	0
02:10	0	0	0	0.00	30.18	30.18	0.00	0.00	0.00	0.40	0
02:15	0	0	0	0.00	30.18	30.18	0.00	0.00	0.00	0.40	0
02:20	0	0	0	0.00	30.18	30.18	0.00	0.00	0.00	0.40	0
02:25	0	0	0	0.00	30.18	30.18	0.00	0.00	0.00	0.40	0
02:30	0	0	0	0.00	30.18	30.18	0.00	0.00	0.00	0.40	0
02:35	0	0	0	0.00	30.18	30.18	0.00	0.00	0.00	0.40	0
02:40	0	0	0	0.00	30.18	30.18	0.00	0.00	0.00	0.40	1
02:45	0	0	0	0.00	30.18	30.18	0.00	0.00	0.00	0.40	1
02:50	0	0	0	0.00	30.18	30.18	0.00	0.00	0.00	0.40	1
02:55	0	0	0	0.00	30.18	30.18	0.00	0.00	0.00	0.40	1
03:00	0	0	0	0.00	29.62	29.62	0.00	0.00	0.00	0.40	1
03:05	0	0	0	0.00	29.62	29.62	0.00	0.00	0.00	0.40	1
03:10	0	0	0	0.00	29.62	29.62	0.00	0.00	0.00	0.40	1
03:15	0	0	0	0.00	29.62	29.62	0.00	0.00	0.00	0.40	1

Finally, if **Daily** is chosen, the file reports every single value with a 5-minute interval of the specific selected day, as in the example reported in the following figure that displays a portion of the file.



## DETAILED DAILY TREND - 08 July

08 July

Hour	Solar Yield [W/m <sup>2</sup> ]			PV production [kW]	Load consump. [kW]	From grid [kW]	To grid [kW]	From storage [kW]	To storage [kW]	State of charge [kWh]	Self prod. [%]
	Direct	Diffuse	Total								
00:00	0	0	0	0.00	62.71	0.30	0.00	0.00	0.00	1.20	0
00:05	0	0	0	0.00	62.71	0.30	0.00	0.00	0.00	1.20	0
00:10	0	0	0	0.00	62.71	0.30	0.00	0.00	0.00	1.20	0
00:15	0	0	0	0.00	60.34	0.29	0.00	0.00	0.00	1.20	0
00:20	0	0	0	0.00	60.34	0.29	0.00	0.00	0.00	1.20	1
00:25	0	0	0	0.00	60.34	0.29	0.00	0.00	0.00	1.20	25
00:30	0	0	0	0.00	55.40	0.27	0.00	0.00	0.00	1.21	91
00:35	0	0	0	0.00	55.40	0.27	0.00	0.00	0.00	1.40	100
00:40	0	0	0	0.00	55.40	0.27	0.00	0.00	0.00	1.90	100
00:45	0	0	0	0.00	52.74	0.26	0.00	0.00	0.00	2.74	100
00:50	0	0	0	0.00	52.74	0.26	0.00	0.00	0.00	3.00	100
00:55	0	0	0	0.00	52.74	0.26	0.00	0.00	0.00	3.00	100
01:00	0	0	0	0.00	53.33	0.26	0.00	0.00	0.00	3.00	100
01:05	0	0	0	0.00	53.33	0.26	0.00	0.00	0.00	3.00	100
01:10	0	0	0	0.00	53.33	0.26	0.00	0.00	0.00	3.00	100
01:15	0	0	0	0.00	50.37	0.24	0.00	0.00	0.00	3.00	100
01:20	0	0	0	0.00	50.37	0.24	0.00	0.00	0.00	3.00	100
01:25	0	0	0	0.00	50.37	0.24	0.00	0.00	0.00	2.95	100
01:30	0	0	0	0.00	49.04	0.24	0.00	0.00	0.00	2.54	100
01:35	0	0	0	0.00	49.04	0.24	0.00	0.00	0.00	1.98	100
01:40	0	0	0	0.00	49.04	0.24	0.00	0.00	0.00	1.45	100
01:45	0	0	0	0.00	47.79	0.23	0.00	0.00	0.00	1.20	4
01:50	0	0	0	0.00	47.79	0.23	0.00	0.00	0.00	1.20	0
01:55	0	0	0	0.00	47.79	0.23	0.00	0.00	0.00	1.20	0
02:00	0	0	0	0.00	48.30	0.23	0.00	0.00	0.00	1.20	0
02:05	0	0	0	0.00	48.30	0.23	0.00	0.00	0.00	1.20	0
02:10	0	0	0	0.00	48.30	0.23	0.00	0.00	0.00	1.20	0
02:15	0	0	0	0.00	48.30	0.23	0.00	0.00	0.00	1.20	0
02:20	0	0	0	0.00	48.30	0.23	0.00	0.00	0.00	1.20	2
02:25	0	0	0	0.00	48.30	0.23	0.00	0.00	0.00	1.20	30
02:30	0	0	0	0.00	44.39	0.21	0.00	0.00	0.00	1.23	94
02:35	0	0	0	0.00	44.39	0.21	0.00	0.00	0.00	1.53	100
02:40	0	0	0	0.00	44.39	0.21	0.00	0.00	0.00	2.22	100
02:45	0	0	0	0.00	43.65	0.21	0.00	0.00	0.00	2.96	100
02:50	0	0	0	0.00	43.65	0.21	0.00	0.00	0.00	3.00	100
02:55	0	0	0	0.00	43.65	0.21	0.00	0.00	0.00	3.00	100
03:00	0	0	0	0.00	43.50	0.21	0.00	0.00	0.00	3.00	100
03:05	0	0	0	0.00	43.50	0.21	0.00	0.00	0.00	3.00	100
03:10	0	0	0	0.00	43.50	0.21	0.00	0.00	0.00	3.00	100
03:15	0	0	0	0.00	46.31	0.22	0.00	0.00	0.00	3.00	100
03:20	0	0	0	0.00	46.31	0.22	0.00	0.00	0.00	3.00	100
03:25	0	0	0	0.00	46.31	0.22	0.00	0.00	0.00	3.00	100
03:30	0	0	0	0.00	43.36	0.21	0.00	0.00	0.00	2.83	100
03:35	0	0	0	0.00	43.36	0.21	0.00	0.00	0.00	2.46	100
03:40	0	0	0	0.00	43.36	0.21	0.00	0.00	0.00	1.99	100

### File for the spreadsheet .CSV

The .CSV files type generated by *SunSim Storage*, contain the same informations of the report files .RTF but these can be read by every spreadsheet.

## Annex A

### Files managed by SunSim Storage

LOADS.TXT	File containing the data of the load types that SunSim Storage can use
<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>.RTF	Report file readable by a word processor
<filename>.CSV	Report file readable by a spreadsheet

### Files included in the software package

SunSim Storage.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_Storage_Manual.PDF	User manual of <i>SunSim Storage</i>

### Possible problems of use in a few PC

Although SunSim Storage was made with the aim of having the widest possible diffusion on different PCs and versions of the Microsoft Windows operating system, in a few cases some compatibility problems have been detected as listed hereafter.

#### Windows 8.0 e Windows 8.1

In some installations of these versions of Windows the library msvcrt100.dll is not present, although C-written programs, as SunSim Storage, often use it. In these cases, one can fix this problem by adding the proper file in the system folder or by installing Microsoft Visual C++ 2010 (free).

#### Windows XP

On this version of Windows, no working problems have been reported, but the icon of the program is not always properly read and in these case Windows shows the default symbol for unknown icons.

## Annex B

### Method used for the calculation of the solar radiation

#### Solar paths and shadows diagram

The values of the solar elevation  $\theta_h$  and of the azimuth angle  $\theta_a$  are obtained from the latitude  $\Phi$  e the declination  $\delta$  (different curves have different declinations). Each curve is therefore obtained by varying the hour angle  $\omega$  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:

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

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

#### Orientation of the PV module array

The possible values for the tilt of the array  $\beta$  range from  $0^\circ$  and  $90^\circ$ , while those of the azimuth  $\alpha$  must range between  $-180^\circ$  and  $+180^\circ$  referred to South. This possibility to operate on the entire diagram allow the simulation of northward tilts for the PV module array.

#### 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 PV module array is calculated for each of them on the basis of the following factors:

- Solar radiation data
- $\theta$  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  $\theta$  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 may allow 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, but for sake of simplicity has been set constant and equal to 3, considering this last as an average value commonly used.

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

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

#### Calculation of the diffuse solar radiation

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

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

## Annex C

### **Structure of the file *loads.txt***

The file *loads.txt* allows a rather flexible management of the electric consumption data, because it is able to host both simple tables and very detailed tables, containing data collected with a high frequency.

The main characteristics of the tables contained in *loads.txt* are reported here below.

- The file may contain up to 10 types of loads (tables), also with different formats. The integer number in the first line (**Number of loads**) specify the number of loads.
- Each type of loads has its own name, to be typed without spaces, (**Load name**) with a maximum of 45 characters.
- Data may be monthly, where for each month there is a record of data referred to the average day, or alternatively may be daily, where it is necessary to introduce 365 records of data, one for each day of the year. A proper value in the header of each table specify if data are to be considered:
  - Monthly, in this case type 0 (=0 → Monthly data)
  - Daily, in this case type 1 (=1 → Daily data)
- In case of daily data, each month is considered as composed by the corresponding number of days in a year of 365 days (28 days for February).
- As previously indicated, the difference between monthly and daily data is in the fact that monthly data consider that the trends of load consumptions are the same in all days of the same month, while the daily data are different for each day of the year. In other words, in case of monthly data we have 12 records of hourly or intra-hourly data, while in case of daily data we have 365 records for the same data.
- In all cases, at the beginning of the data of each month, a number indicates the reference month (**Month**), between 1 (January) and 12 (December).
- The minimum frequency of the daily data is hourly (24 values for each day), but the program is able to accept frequencies also further, provide they correspond to a multiple of 5 minutes in each hour. The maximum number correspond to the time interval used in calculation, equal to 5 minutes, that is 12 data each hour. A suitable integer value in tables, between 1 and 12 (**Number of data per hour**), provided is a submultiple of 12 (i.e. 60/5), specify the number of data per hour. For sake of clarity, here below a list is reported with the number of consumption data for each day that *SunSim Storage* needs to read according to the value previously set.
  - 1 → 24 daily values (1 data every hour)
  - 2 → 48 daily values (1 data every half hour)

- 3 → 72 daily values (1 data every 20 minutes)
- 4 → 96 daily values (1 data every 15 minutes)
- 6 → 144 daily values (1 data every 10 minutes)
- 12 → 288 daily values (1 data every 5 minutes)
- Consumption data contained in the tables are expressed in kW (that is the average power value in the period) with a free number of decimals.

The next figure visually shows a portion of the file `loads.txt`, highlighting the structure. It is important that the organization and the number of data actually inserted be consistent with the values indicated in the fields above specified. If not, the program reports the error and cannot perform calculations correctly.

Number of loads      Load name (no space allowed)

4      0      1      =0 --> Monthly data      Number of data per hour

1      2      Month (1=Jan, 2=Feb, etc.)

31.981 31.165 30.177 29.621 29.813 31.591 37.210 44.580 49.469 50.846 50.665 50.4

34.403 32.062 30.994 30.700 30.912 32.319 37.582 43.669 49.235 52.129 52.933 53.0

31.182 29.459 28.730 28.335 28.521 30.204 33.598 39.242 43.401 44.787 45.432 45.7

30.697 28.927 28.012 27.474 27.727 29.265 32.827 38.253 42.924 44.717 45.538 45.7

30.807 28.863 28.114 27.788 28.027 28.811 31.582 37.202 41.812 43.915 44.576 44.7

36.051 33.936 32.850 32.208 31.945 31.856 34.665 40.176 46.135 49.343 50.418 51.4

36.452 34.394 33.320 32.600 32.529 33.040 35.481 40.534 46.066 49.209 50.500 51.1

28.642 27.115 26.044 25.358 24.978 24.874 24.071 24.910 26.795 28.367 29.327 29.9

32.277 30.339 29.286 28.943 29.208 30.523 34.732 39.485 43.791 45.387 45.651 45.9

29.919 28.221 27.452 27.237 27.417 28.701 33.637 39.142 42.773 43.962 44.586 44.9

30.615 28.861 27.963 27.650 27.984 29.631 34.720 39.966 44.189 45.529 45.637 45.7

31.169 29.235 28.363 27.974 28.208 29.802 35.343 42.281 46.329 47.775 47.608 47.8

Italy\_Aggregate\_Residential      1      4      =1 --> Daily data      Data in kW

88.26      87.52      86.86      81.10      74.67      75.56      77.41      72.16      70.68      69.65      70.68

86.34      85.01      80.06      77.55      70.76      64.63      58.13      58.42      56.43      54.88      52.07

88.11      85.01      78.51      74.97      69.06      63.30      57.61      56.80      55.69      52.07      51.85

92.55      83.09      72.31      72.01      72.01      70.68      68.10      61.67      51.85      52.74      57.76

91.29      85.46      82.28      80.29      74.82      62.85      58.87      58.57      57.98      57.76      55.69

96.09      93.36      88.19      80.06      72.53      67.80      66.25      65.22      62.56      55.69      63.89

93.06      87.01      85.38      85.97      78.96      78.44      77.85      68.17      67.80      63.89      62.04

91.96      86.71      84.27      87.15      84.27      83.46      79.10      72.09      69.65      62.04      51.48

90.40      81.39      76.15      71.35      64.41      62.78      61.16      57.54      55.32      51.48      54.07

80.21      79.62      76.45      72.68      66.77      63.67      57.09      53.47      55.84      54.07      60.12

93.06      85.75      78.00      74.75      71.94      67.66      65.51      65.81      62.41      60.12      55.54

79.03      79.33      67.80      68.54      64.70      61.60      62.34      57.24      56.95      55.54      51.85

78.66      74.23      71.64      72.01      67.06      64.78      55.62      53.25      51.26      51.85      59.83

94.76      89.08      81.84      78.00      71.87      69.95      72.68      65.66      60.05      59.83      62.63

94.17      81.47      83.68      78.07      72.97      70.76      66.70      68.54      68.25      62.63      51.41

79.99      73.49      69.28      68.62      61.01      59.09      56.13      54.36      53.70      51.41      51.85

87.52      76.59      68.91      63.96      59.46      61.16      58.05      52.51      55.69      51.85      56.43

75.48      68.32      64.48      68.62      62.93      61.16      56.36      53.55      52.44      56.43      54.88

87.97      79.99      81.98      73.27      65.59      64.18      65.88      57.24      53.25      54.88      53.55

85.01      78.59      73.12      68.32      68.25      60.57      57.68      56.06      56.50      53.55      57.83

96.02      89.52      83.46      82.50      77.70      71.35      65.96      62.34      57.54      57.83      61.97

85.31      81.47      75.63      75.78      71.50      70.46      69.35      62.34      60.93      61.97      50.82

83.68      77.48      72.68      69.06      64.04      61.89      59.97      57.91      55.25      50.82      48.30

74.01      71.64      67.14      65.00      59.83      54.14      51.55      52.15      50.22      48.30      52.44

83.39      79.47      73.79      67.51      63.67      63.74      58.79      54.80      54.29      52.44      48.67

88.56      79.69      73.49      68.84      63.00      59.90      58.42      55.47      49.86      48.67      51.78

75.34      71.13      68.32      60.64      61.16      56.06      55.40      56.36      55.62      51.78      55.17

81.25      75.48      71.64      70.61      68.10      65.51      65.14      64.41      62.78      55.17      60.71

89.59      85.38      85.75      79.77      71.27      64.04      64.04      62.34      58.42      60.71      57.46

82.87      84.20      73.79      73.49      70.17      67.29      63.08      60.57      58.13      57.46      56.43

82.58      74.82      66.18      68.76      66.55      69.95      66.40      60.05      56.43      53.62      57.46

79.10      73.27      70.61      69.28      65.51      64.18      59.38      58.94      58.72      57.46      57.32

85.60      80.36      77.41      73.71      64.63      62.49      62.49      58.28      60.79      57.3