IALA

IALA GUIDELINE

G1039
DESIGNING SOLAR POWER SYSTEMS FOR MARINE AIDS TO NAVIGATION (SOLAR SIZING TOOL)

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Association Internationale de Signalisation Maritime

DOCUMENT REVISION

Revisions to this document are to be noted in the table prior to the issue of a revised document.

Date	Details	Approval
December 2004	1st issue	Council 35
December 2017	Whole document: Revision according to the update of the Excel spreadsheet (tool) at IALA Workshop 2017 in Koblenz Section 1: General information on solar technology and batteries added	Council 65
July 2022	Edition 2.1 Editorial corrections.	

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1. INTRODUCTION

This Guideline provides information on the design of photovoltaic (PV) solar power systems and describes how to use a Microsoft Excel spreadsheet calculation tool to assist with designing a PV solar power system. The Excel program provides an iterative method of designing a solar power system for fixed or floating Marine Aids to Navigation (AtoN) installations. To keep the Excel workbook as simple as possible, it has certain limitations and factors that it does not take into account. These include:

- Specific technical data for the products
- Temperature for any location
- Temperatures for batteries or panels
- Land and sea reflection coefficients
- Rate of battery self-discharge
- Seasonal or occasional loads

To obtain the MS Excel workbook, including the password, please contact the IALA Secretariat via e-mail (contact@iala-aism.org). Alternatively, the MS Excel workbook is available for download at the IALA website. In addition, there is a step-by-step manual provided, which includes information on how to obtain meteorological data.

Sections 1.1 and 1.2 deal with some technical information on both solar panels and batteries to assist with the use of the solar sizing tool.

Sections 2, 3 and 4 provide specific information related to the use of the solar sizing tool.

A sample page from the Solar Sizing program is at ANNEX A.

1.1. GENERAL INFORMATION ON SOLAR TECHNOLOGY

1.1.1. TYPES OF SOLAR CELLS

There are three primary types of solar cells for photovoltaic (PV) systems, depending on the manufacturing process:

- Monocrystalline
- Polycrystalline
- Thin Film or amorphous silicon

The materials used for the manufacture of solar cells are mainly:

- Various types of silicon
- Gallium arsenide
- Indium copper diselenide
- Cadmium telluride

The selection of material depends on the panel’s intended application.

1.1.1.1. The monocrystalline cell

It is made from the mineral silicon, which is found in abundance in sand. A single "grown" crystal is gradually formed into a block. The cells are then cut into thin slices from 250 to 350 µm. The efficiency limit of the crystalline cell is around 35%. Currently this type of cell achieves efficiencies of 21%.

1.1.1.2. The polycrystalline cell

It is made from molten silicon glass that is formed in a mould. It is cheaper than the monocrystalline cell, but its limit efficiency is 32%. Currently, this type of cell achieves efficiencies of 19%. It is recognized because its colour is irregular and clearer than the monocrystalline and has a rectangular shape without cuts at the edges.

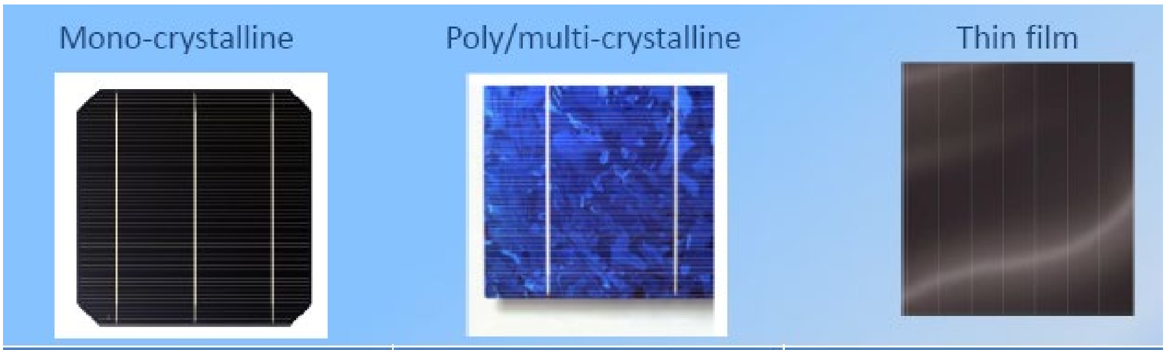
Polycrystalline cells are somewhat less efficient than monocrystalline cells but are more efficient when the sun reaches low incidence angles on the solar cell.

1.1.1.3. The thin film cell or amorphous silicon

It uses a new technology consisting of a thin film of pure silicon glass on a glass or ceramic substrate. This layer does not exceed 20 µm. The thickness of the entire cell is 300 to 800 µm. The substrate may also be plastic which allows the production of flexible modules.

Currently, the efficiency of these cells is around 13%, although in laboratories, efficiency levels of 15% have been reached. The advantage of this technology is that it is much cheaper than crystalline cells, it allows the formation of flexible modules, and in the manufacturing process, no polluting elements are used. They have a performance less than half that of crystalline type cells.

Typically for 12V Systems, 36 cells are connected in series in one PV module.



Cell Type	Max Lab Efficiency	Max Commercial Eff
Mono-crystalline Si	35%	21% (23% back cont)
Poly/Multi-crystalline SI	32%	19%
THIN FILM MATERIALS	-------------------------------	------------------------------
Amorphous Silicon	15%	13%

Figure 1 Types of solar cells

1.1.2. LIFESPAN

In general, the PV modules are the longest-lasting component of the system, and the lifespan depends on its design, the environment and the operating conditions.

They are designed to withstand all weather conditions, including arctic cold, desert heat, tropical humidity, winds above 125 mph (200 km/h) and 25 mm hail at terminal speed.

Certain PV modules, such as thin film silicon types, suffer a predictable drop in performance during the first few months of operation, which decreases until it eventual cessation. Thereafter, the performance of the modules is relatively stable. In polycrystalline modules, this kind of degradation is much smaller.

Longer term degradation of around half percent a year can be expected. The overall life span of the PV module is likely to be limited by other factors rather than degradation of the silicon. A lifespan of 20 years or more can typically be expected.

1.1.3. CURRENT - VOLTAGE CURVE

The operation of a solar cell can be represented by a current-voltage curve (I-V) as in Figure 2. When the cell is not connected, an open circuit voltage is obtained V_{oc}, and when the cell is shorted, the current I_{sc} is obtained (under standard test conditions of 1000 W/m² solar irradiance, 25°C cell temperature, Air Mass 1.5).

For an increase in voltage from 0 to V_{oc} the current is almost constant up to a voltage $V_{MPP,}$ and from there, it descends rapidly. As P = V x I at any point, the power P can be calculated. What matters is to obtain the maximum power, i.e., when the area of the rectangle V x I is maximum. The P_{max} point is also known as the maximum power point (MPP). The maximum power in Watts of the solar panel arises from multiplying I_{MPP} by V_{MPP}.

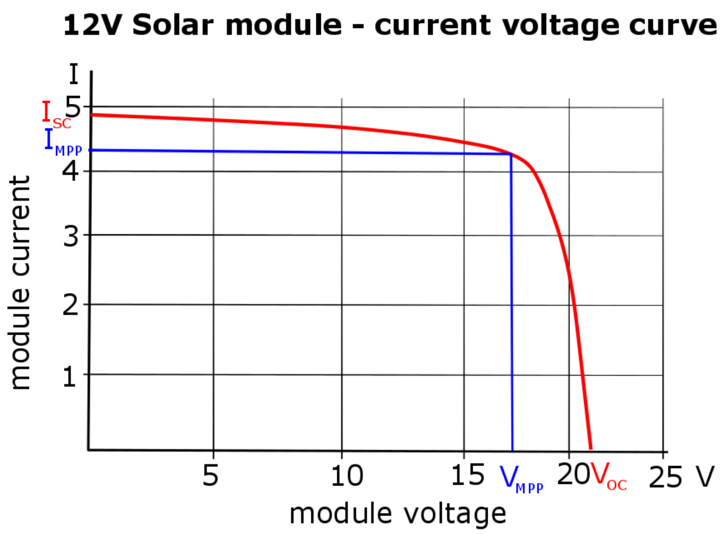


Figure 2 Current voltage curve

It can be observed that the maximum voltage (V_{oc}) corresponds to the measurement without consumption, that is to say, open circuit.

In contrast, the maximum current (I_{sc}) is obtained by short-circuiting the positive and negative terminals of the solar panel.

The quality of a solar cell is determined by the relation between the area of the rectangle V_{oc} x I_{sc} and the area of the rectangle V_{MPP} x I_{MPP} and is known as a factor of quadrature (fill factor FF).

$$FF = \frac{P_{max}}{V_{OC} \times I_{SC}}$$

Equation 1 Solar cell factor of quadrature (fill factor FF)

1.1.4. TEMPERATURE INFLUENCE

Solar cells lose efficiency of voltage generated when their temperature increases. It is not surprising that a solar panel reaches temperatures in excess of 50ºC in summer, causing a reduction of the generated voltage of 15%.

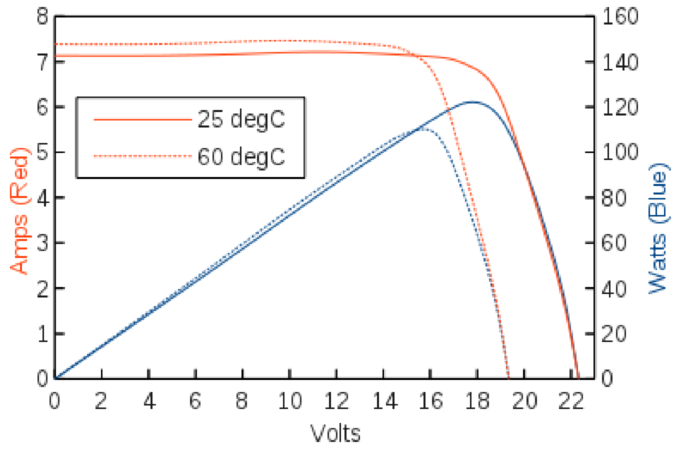


Figure 3 Influence of temperature to efficiency of solar cells

The power of the solar modules is given under standard conditions of measurement, which is 1000 W/m² solar irradiance, 25°C cell temperature and Air Mass of 1.5. The typical power output of a module is usually less than the output under standard conditions.

1.1.5. THERMAL CHARACTERISTICS

Thermal characteristics are the most significant technical parameters to predict the future behaviour of the voltage in a solar module. The output current has low influence due to thermal changes. There are two important parameters:

- Nominal operating temperature of the cell (NOCT)

  It is the temperature reached by the cells of the module under normal operating conditions, mainly at 20ºC of ambient temperature and irradiance of 800 Watt/m^2. The NOCT has a direct relationship with the temperature reached by the cells at a given ambient temperature, and the lower the module temperature, the better it will work and the more power it will deliver. Therefore, the smaller the NOCT, the better.

- Power temperature coefficient

  Indicates the percentage loss of solar module output power for each degree above 25°C which increases the temperature of the solar module. The smaller, the better.

1.1.6. SOLAR PANEL ORIENTATION

Solar panels should be usually oriented toward the equator to maximize power output. The tilt angle should be chosen with regard to insolation, geographic location, self-cleaning capabilities, available space, etc.

In the case of floating AtoN it is not possible to guarantee the orientation of the modules, so a reduction factor must be applied.

It should also be taken into account that solar modules are sensitive to the presence of small shadows, even a narrow shadow can significantly decrease the output power. For example, shadows generated by vegetation, buildings, daymarks and handrails can cause problems and should be avoided.

In some locations, fouling of the surface may be an issue. In these locations, it is recommended to avoid horizontal placement, and that solar panels are installed with an inclination that promotes self-cleaning.

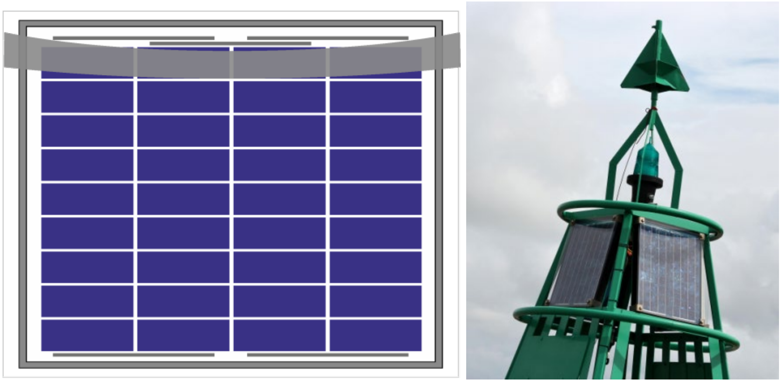


Figure 4 Power reduction of approximately 90% due to shadow

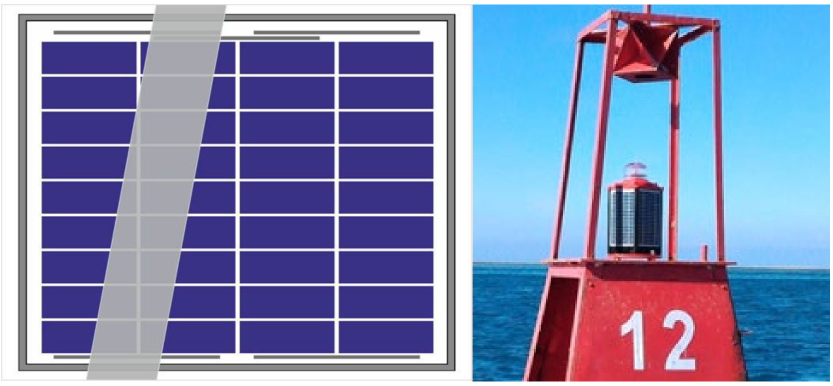


Figure 5 Power reduction of approximately 75% due to shadow

1.2. GENERAL INFORMATION ON BATTERIES

1.2.1. MINIMUM AND MAXIMUM CAPACITY

The minimum battery capacity will depend on the choice made or imposed for the following design constraints:

- Maximum daily depth of discharge
- Lowest acceptable level of charge during the winter months
- Allowance for "no sun" days (from meteorological or insolation data). According to the inquiry, 20 days minimum is a rule of thumb for medium latitude (less in lower latitudes and more in higher ones)
- Ease of access to the AtoN
- Ability of the battery to accept the peak output of the generator without overcharging, mainly for sealed batteries (a situation that may arise with a self-regulating system)

It should be noted that:

- The maximum battery capacity will usually be determined by consideration of cost, available space, weight, and handling capacity. As a general rule, the number of batteries in parallel should be kept to a minimum. (Five is a typical figure for good quality batteries coming from the same production batch, installed at the same time and working under the same regime of charge and discharge. It could vary according to the quality of the battery). Some manufacturers offer individual cells or blocks of 2 or 3 cells, with high capacity, and it is usually better to use these in series rather than to parallel smaller batteries.

- Use of lead-acid batteries may require an increase in battery capacity to prevent deep discharge during winter months, but in this situation, the effect of low temperature on the battery should be taken into account. For these reasons nickel-cadmium, nickel metal hydride and lithium ion batteries should be considered for the worst cases (very high latitude in the northern and southern hemispheres and very low temperature).
- Batteries with low self–discharge become important when the design requires a long autonomous period for the system.

1.2.2. AUTONOMY TIME

The battery is designed to supply energy under specified conditions for periods of time without or with minimum solar insolation. When calculating the required battery capacity, the following items should be considered:

- Required daily/seasonal cycle (there may be restrictions on the maximum depth of discharge)
- Time required to access the site
- Ageing
- Temperature impact
- Future expansion of the load
- Local weather conditions

2. INPUT DATA

In the process of designing a solar power system it is also important to be aware of some general safety factors. The following examples highlight issues to consider as you enter data into the solar sizing program.

To use the program, it is necessary to input information on local solar irradiation, technical details of the AtoN loads, and details of the particular types of solar modules and batteries that are planned to be used. These are described below.

The areas on the spreadsheet with a yellow background require input data. References in brackets (“[ ]”) are to the cells in the spreadsheet in which the data must be entered.

When the cursor is placed on any of the red-edged boxes, information windows are displayed.

2.1. SOLAR IRRADIATION AND DURATION OF NIGHT

Information on solar irradiation and duration of night can be obtained from a solar atlas, from the local meteorological office or from various Internet sites. IALA provides further information on how to acquire that data from public sources in the internet at http://www.iala-aism.org/products-projects/technical-area/calculation-working-tools/solar-sizing-tool.

The data is entered in table “radiation & duration of night”. In that table many locations can be stored. Stored data can be easily used in the “simulation” table with the scroll down button [H4] which will transfer:

- Name
- Latitude
- Longitude
- Radiation data
- Night hours (if available)

to the "simulation" table. DAILY RADIATION [D#..O#] is entered in kWh/m² for each month of the year for the chosen mounting angle. In choosing minimum radiation data this is taking the worst-case-scenario. Information for angles of 0°, 30°, 60° and 90° are usually presented in a solar atlas.

In locations where solar irradiation is low, solar power systems may not be sufficient and other additional power sources may be required.

2.2. LATITUDE AND LONGITUDE

The LATITUDE [B#] of the station in table "radiation & duration of night" is entered as degrees North or South. If no duration of the night is given in [P#..AA#] the duration of the night will be calculated by the given latitude. Please be aware that this calculation is only an approximation which works in lower latitudes but get less accurate in higher latitudes.

The LONGITUDE [C#] is used for description but could also be useful for deriving data from the internet.

2.3. ORIENTATION

A value must be entered in the "simulation" table to account for ORIENTATION [B9] of the solar panels.

- If the panels are South facing in the Northern hemisphere (North facing in the Southern) this will be 1
- If the panels are randomly orientated as would be the case on a floating AtoN, this will be 0.7

2.4. VOLTAGE

The VOLTAGE [B6] must be entered in the "simulation" table. This is the nominal design voltage for the power system and will usually be 12 volts, but in some cases may be 6 or 24 volts.

2.5. ELECTRICAL LOADS

The electrical loads that the system will support must be entered as lantern load for day- and nighttime and continuous load.

- Lantern Load

  LANTERN LOAD DAY [B10] and LANTERN LOAD NIGHT [F10] are the loads in Watts presented by the lantern (or other AtoN operating with a character) when it is switched on. The day load is only applicable if the lantern is in 24h use, e.g., a port entry light that is switched to a higher intensity during day time.

  The proportion of the time that this load is switched on is described as the DUTY CYCLE [B11], which is entered as a percentage (e.g., 2sec on, 8sec off, would be a 20% duty cycle). Note: Switch closure time must be used rather than incandescent time.

- Continuous Load

  CONTINUOUS LOAD [B13] is the fixed or continuous load in Watts, presented by the flasher, charge regulator and any other fixed AtoN (racon, RTE, communications etc.).

2.6. SWITCH LEVEL

SWITCH LEVEL [B12] is entered as the time (in decimal hours) that the light switches on before dusk and switches off after dawn (e.g., 30 min. would be entered as 0.5 hour). Be aware that a light for 24h use could be switched to date time load with a negative number of switch level.

2.7. SOLAR PANELS

The parameters of the solar panels that you intend to use must be entered.

- Voltage

  This is the voltage at maximum power point, entered at U_{MPP} [B7] in volts. This value can be obtained from manufacturers data.

- Age

  AGE [B5] is a measure of the reduction in the efficiency of the module during its working life (e.g., if the module degrades 1% each year of its working life and it will be used for 15 years then a figure of 15x1=15% will be entered). The manufacturer can provide some guidance on this.

- Power

  The peak power of the total number of solar panels that you will use (the array) will be entered as POWER [B8] in watts. This will be a multiple of the peak power of the individual modules that you have chosen. Again, this information will be available from the manufacturer.

In practice, the size and number of the panels will depend on available space at the AtoN site and possibly by transport constraints. An initial estimate (guess) will have to be made of the number and hence peak power of the solar panels. This will then be refined by iterative use of the program.

2.8. BATTERIES

Information regarding the batteries must be entered. A battery type must be chosen that will be suitable for the AtoN environment (e.g., spill-proof batteries for buoys, NiCd batteries may be considered for very low temperatures, battery dimensions will be limited on buoys, weight may be limited by local lifting facilities, transport systems, etc.).

- Maximum Useable Capacity

  From manufacturer's information and design guidelines, a value must be chosen for the MAXIMUM USEABLE CAPACITY [B15]. This is the percentage of the battery capacity that can safely be discharged without reducing the working life of the battery (e.g., 80%).

  The maximum useable capacity may be adjusted dependent on the location of the system and the importance of the AtoN. The higher the significance of the AtoN, the higher safety level (and lower maximum usable capacity) may be required.

  The type of the battery and the manufacturer specifications have to be considered to realize the expected lifetime. Storage and loading conditions are essential for the durability of the battery.

- Efficiency

  BATTERY EFFICIENCY [B16] is the recharge efficiency of the battery expressed as a ratio of the charge energy (input) to the energy delivered to the load (output). This is calculated as input over output. This figure can be obtained from the manufacturers.

  The variation of temperature and the surrounding humidity will affect the lifespan of the battery. To sustain the safety and efficiency of the battery, good ventilation of the battery enclosure is required.

- Capacity

  BATTERY CAPACITY [B14] is entered as Ah (Ampere hours) when the total battery bank is discharged over a 100-hour period. This will be a multiple of the capacity of the individual batteries. If an estimate (guess) is entered for the total battery capacity, then the program will calculate the number of days that the system will be able to work, without any solar gain, at the time of year when there is the minimum sunlight. It will also provide a graphical presentation of the solar system energy balance throughout the year.

Please note At “simulation” table columns [S..U] are hidden. They include some auxiliary calculations only.

3. OUTPUT DATA AND ITERATION

The DAYS WITHOUT GAIN [B17] provides a measure of the reserve capacity of the system. This may be referred to as the “No Sun Reserve”. Numbers of days may be chosen, depending on the local weather conditions for recharging the system during the winter period, or the distance to travel to the site for repairs if failure should occur. An adapted preventive maintenance is necessary.

The system design can then be refined by varying the numbers of solar panels (POWER [B8]) or batteries (BATTERY CAPACITY [B14]) to achieve a practical solution to provide the required number of DAYS WITHOUT GAIN [B17].

If the initial system design is incorrect and the proposed battery becomes fully discharged then an “error” sign will appear in the DAYS WITHOUT GAIN [B17] and Ah [E21..F32] columns.

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5. DEFINITIONS

The definitions of terms used in this Guideline can be found in the *International Dictionary of Marine Aids to Navigation* (IALA Dictionary) at http://www.iala-aism.org/wiki/dictionary and were checked as correct at the time of going to print. Where conflict arises, the IALA Dictionary should be considered as the authoritative source of definitions used in IALA documents.

6. ABBREVIATIONS

Ah	Ampere hours
AtoN	Marine aid(s) to navigation
C100	Capacity at 100 hour discharge rate, Annex A
EULA	End-user licence agreement
ISC	Current at short circuit
IMPP	Current at Maximum Power Point
kWh/m2	kilowatt hours per square metre

NiCd	Nickel Cadmium (battery)
Pmax	Maximum power
RTE	Radar Target Enhancer
VOC	Voltage at open circuit
VMPP, UMPP	Voltage at Maximum Power Point, Annex A
W	Watt
W/m2	Watts per square metre
Wpeak	Watts peak

ANNEX A SAMPLE PAGE FROM THE SOLAR SIZING PROGRAM

	A	B	C	D	E	F	G	H / I
1	Sizing of Photovolatic-Systems							
2	with daylight-control				version 31.03.2017			
3	**System**	**Light Buoy** (2,5m diameter, panel up right 90°)						
4	**Lat. / Long. / Station**	51.6	°	3.97	°	LH Mumbles		
5	**PV Age factor**	20	%	Deduction for ageing of solarpanels				
6	**Syatem Voltage**	24	Volt	Voltage of the system				
7	**PV voltage U_{MPP}**	35.2	Volt	Voltage in the Maximum Power Point				
8	**PV Power**	812	W_{peak}	Power at solar radiation of 1000W/m²				
9	**Orientation**	1		Deduction for different panel orientations				
10	**Lantern load night**	17.77	W	**Lantern load day**		0	W	
11	**Duty cycle**	100	%					
12	**Switch-level**	1	h	added hours before dusk and after dawn				
13	**Continuous load**	10.02	W	1W monitoring, 2W RACON				
14	**Battery capacity**	1363	Ah C_{100}					
15	**max. useable Cap.**	90	%					
16	**Battery efficiency**	80	%					
17	**Days without gain**	**32**	days	number of days working without energy gain				
18		kWh/m²	**Average**	**Ah**				Days wo. Gain
19	**Month of the first year**	daily	**night**	Energy-	Energy-	At begin.	At end	begin of
20		radiation	**hours**	gain	consump	available		month
21	**July**	4.10	8.85	2301	549	1227	1227	68
22	**August**	3.81	10.71	2138	591	1227	1227	63
23	**September**	3.27	12.76	1835	638	1227	1227	59
24	**October**	3.23	14.71	1812	682	1227	1227	55
25	**November**	1.30	16.13	730	713	1227	1097	52
26	**December**	1.03	16.31	580	718	1097	844	47
27	**January**	1.16	15.15	652	692	844	674	37
28	**February**	1.93	13.29	1084	649	674	892	32
29	**March**	3.00	11.24	1685	603	892	1227	45
30	**April**	3.93	9.29	2209	559	1227	1227	67

Info | simulation | radiation & duration of night

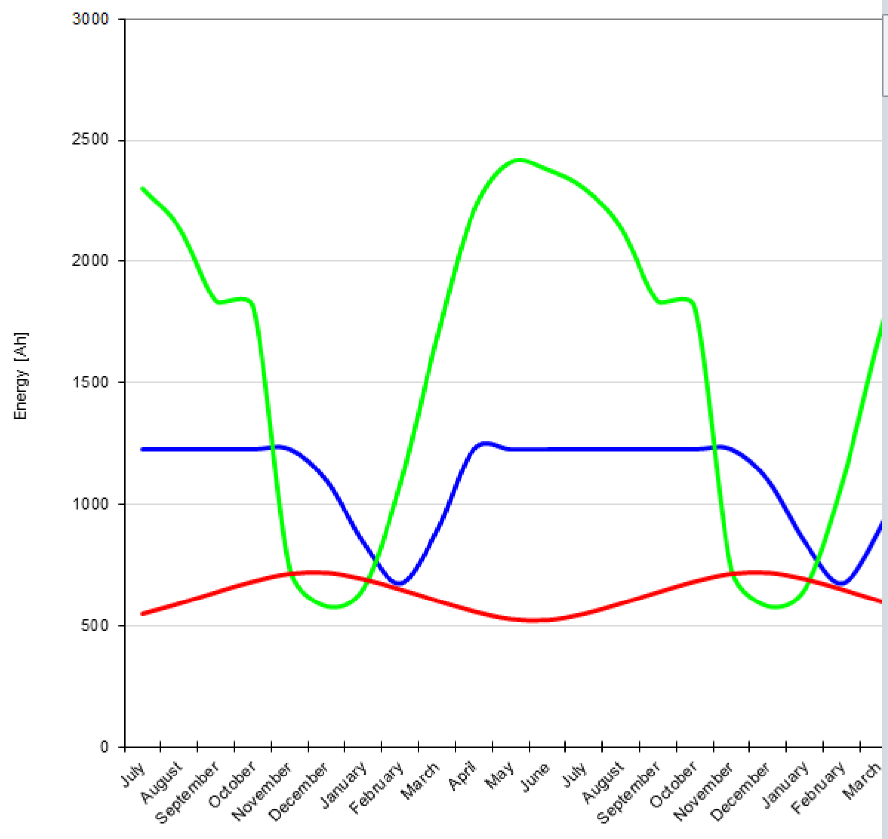

Figure 6 Screenshot of the Excel workbook