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| IALA Guideline |

1039

Designing Solar Power Systems for Aids to Navigation

(Solar Sizing Program)

Edition 1.0

December 2004

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

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| Date | Page / Section Revised | Requirement for Revision |
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# INTRODUCTION

This program provides an iterative method of designing a solar power system for fixed or floating AtoN installations. The software does not take account of the ambient temperature for any location or specific technical data for the products.

To obtain the MS Excel program, including password, please contact the IALA Secretariat via e-mail: [contact@iala-aism.org](mailto:contact@iala-aism.org). A sample page from the Solar Sizing program is at ANNEX A.

## Basic Information on Solar technology

### Types of solar cells

There are basically three 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 and
* cadmium telluride.

Their use depends on their intended application.

**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%.

**The polycrystalline cell:**

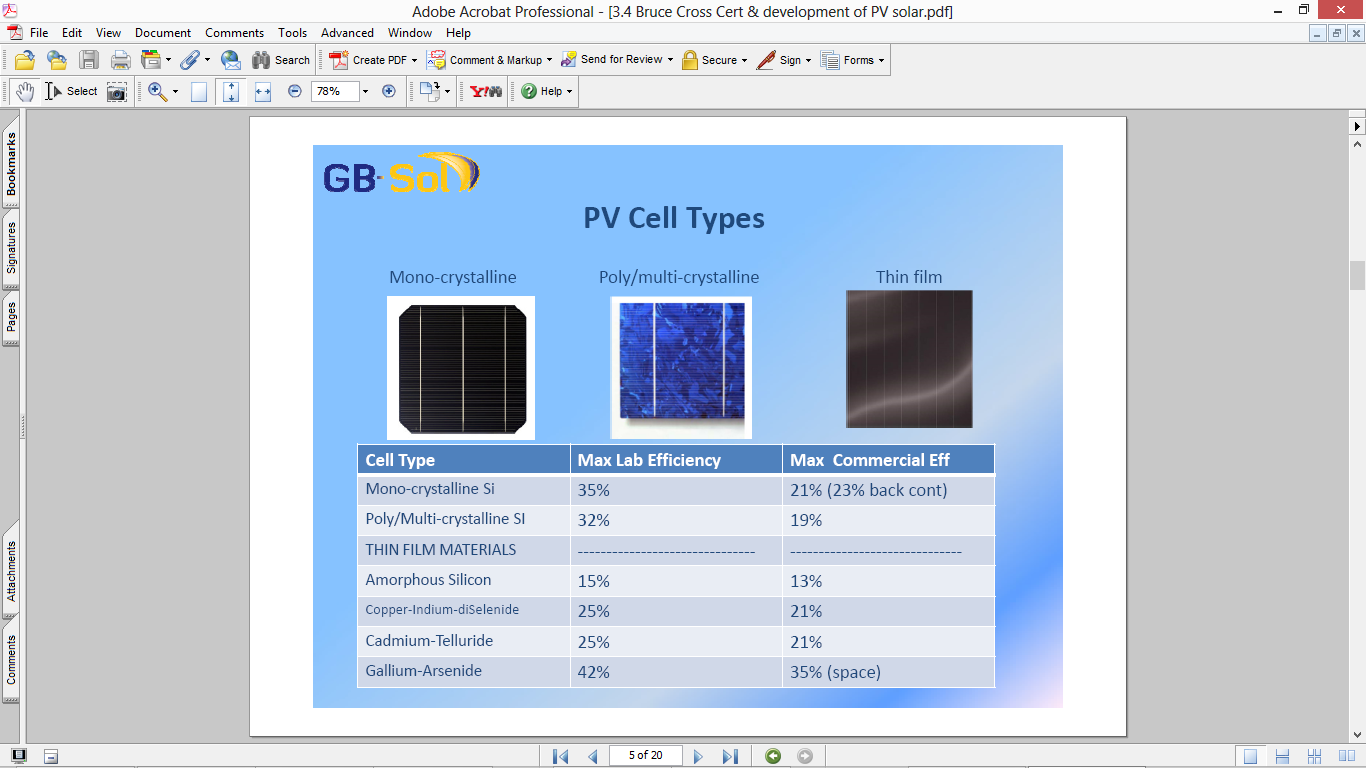
It is made from molten silicon glass that is formed in a mould. It is cheaper than the monocrystalline cell, but its limit efficiency is 32%. Currently this type of cell achieves efficiencies of 19%. It is recognized because its colour is irregular and clearer than the monocrystalline and has a rectangular 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 panel.

**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 panels.

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 the crystalline cells, it allows the formation of flexible panels 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.

### 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 ceases after some time. Thereafter, the performance of the modules is relatively stable. In polycrystalline modules, this kind of degradation is much smaller.

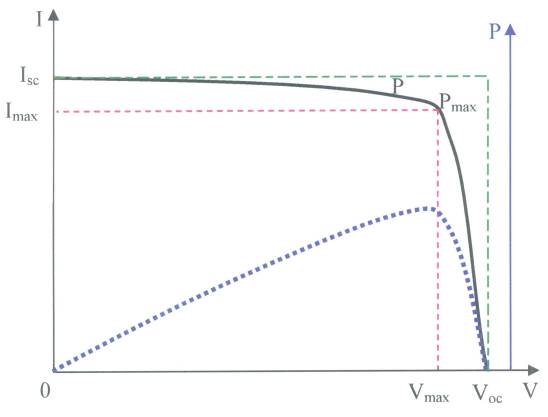
Longer term degradation of around half percent a year can be expected. The overall life span of the PV module is likely to be limited by other factors rather than degradation of the silicon. A lifespan of 20 years or more can typically be expected.

### Current - Voltage Curve

**(Ref.: Annex 1 - Guideline No. 1067 – 0 Selection of Power Systems for Aids to Navigation and Associated Equipment - Edition 1.1 - June 2011)**

The operation of a solar cell can be represented by a current - voltage curve (I-V) as in the figure. When the cell is not connected, an open circuit voltage is obtained Voc, and when the cell is shorted, the current Isc is obtained.

For an increase in voltage from 0 to Voc the current is almost constant up to a maximum voltage Vmax and from there it descends rapidly. As P = V x I, at any point the power P can be calculated, which is shown in the segment curve. What matters is to obtain the maximum power, i.e. when the area of the rectangle V x I is maximum. The Pmax point is also known as the maximum power point (MPP). The power in Watts of the solar panel arises from multiplying Imax by Vmax.

(new diagram)

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

In contrast, the maximum current (Isc) 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 Voc x Isc and the area of the rectangle Umax x Imax and is known as a factor of quadrature (fill factor).

FF = Imax \* Vmax / Isc \* Voc

**Exercise:**

Calculate the maximum power and the quadrature factor of a solar cell of polycrystalline silicon of the following specifications:

Input data:

* Imax = 3,15 Amp
* Vmax = 0,48 Volt
* Isc = 3,35 Amp
* Voc = 0,60 Volt

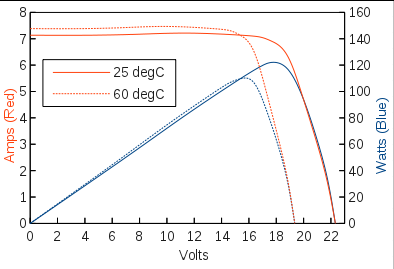
**Solution:**

Pmax = (3,15 [A] x 0,48 [V]) = 1,51 [W]

FF = (1,51 [W] / (3,35 [A] x 0,60 [V]) = 0,75

### 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%.



**Electrical characteristics at nominal operating temperature**

The power of the solar modules is given under standard conditions of measurement, but these conditions do not normally occur when the solar module is in operation. Therefore, the power value at nominal conditions is more relevant (since these conditions are usually more common): 20ºC ambient temperature, 800 W/m2 irradiance, air velocity of 1 m/s and a spectral distribution of 1,5. A typical power value for a 245 W module under operating conditions is 180 W. A good solar module should reflect these data in its data sheet.

### Thermal Characteristics:

They 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 / m2. 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 is better.

* Power temperature coefficient:

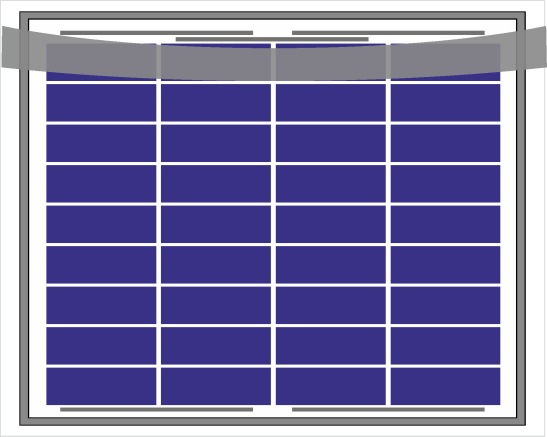
Indicates the percentage loss of solar module output power for each degree above 25°C which increases the temperature of the solar module. The smaller, is better.

### Solar Panel Orientation

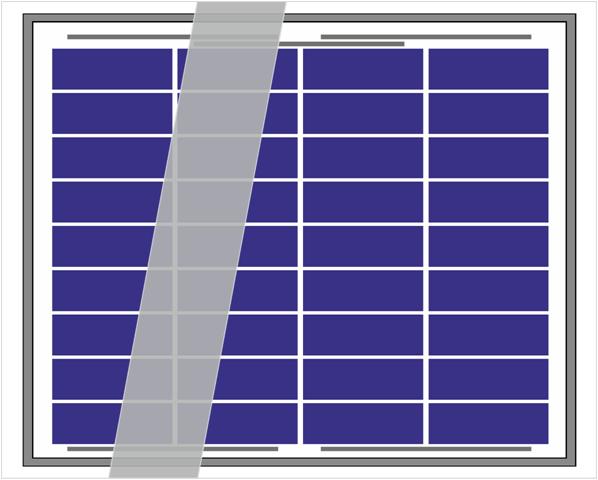
Solar panels should be usually oriented toward the equator to maximise power output. The tilt angle should be chosen with regard to insolation, geographic location, self cleaning, available space, etc.

In the case of floating aids 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 shrubs, buildings, daymarks and handrails can cause problems and should be avoided.



Power reduction 90 % approximately



Power reduction 75 % approximately

If modules are mounted horizontally, fouling of the surface might be a problem. Therefor it is recommended to install the solar modules with an inclination that allows their self-cleaning.

# 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 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 program spreadsheet with a yellow background require input data. References in brackets (‘[ ]’) are to the cells in the program spreadsheet in which the data must be entered.

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

## Solar Irradiation

Solar irradiation information can be obtained from a solar atlas, from the local meteorological office or from various Internet sites. This is entered in the lower part of the table ‘simulation’ as average DAILY RADIATION [B21..B32] in kWh/m² for each month of the year for the chosen mounting angle. Information for angles of 0°, 30°, 60° and 90° are usually presented in a solar atlas. The date of the start of the annual solar irradiation cycle must be the month of maximum irradiation.

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

## Latitude

The LATITUDE [B4] of the station is entered as degrees North or South.

## Orientation

A value must be entered 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.

## Voltage

The VOLTAGE [B6] must be entered. 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.

## Electrical Loads

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

* Lantern Load;

LANTERN LOAD [B10] is the load in Watts presented by the lantern (or other AtoN operating with a character) when it is switched on. 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.).

## 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).

## Solar Panels

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

* Voltage

These are voltage at maximum power point, entered at UMPP [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 panel during its working life (e.g., if the panel 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 panels 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.

## 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 German Administration considers that batteries are completely discharged only once per year (during wintertime), and hence ten or twelve times in total battery life. Thus, they calculate with 100% of maximum useable capacity.

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] sometimes called ‘Round Trip Efficiency’ 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.

# 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.

The table ‘simulation 2-year’ calculates the system for a second year. In case the batteries are not fully charged at the end of first year, there will occur an error in the simulation of the second year.

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# ACRONYMS

Ah Ampere hours

AIS Automatic Identification System

AtoN Aid(s) to Navigation

C100 Capacity at 100 hour discharge rate, Annex A

EULA End-user Licence Agreement

IALA International Association of Marine Aids to Navigation and Lighthouse Authorities - AISM

kWh/m2 kilowatt hours per square metre

m metre(s)

min minute

NiCd Nickel Cadmium (battery)

RTE Radar Target Enhancer

UMPP Voltage at Maximum Power Point, Annex A

W Watts

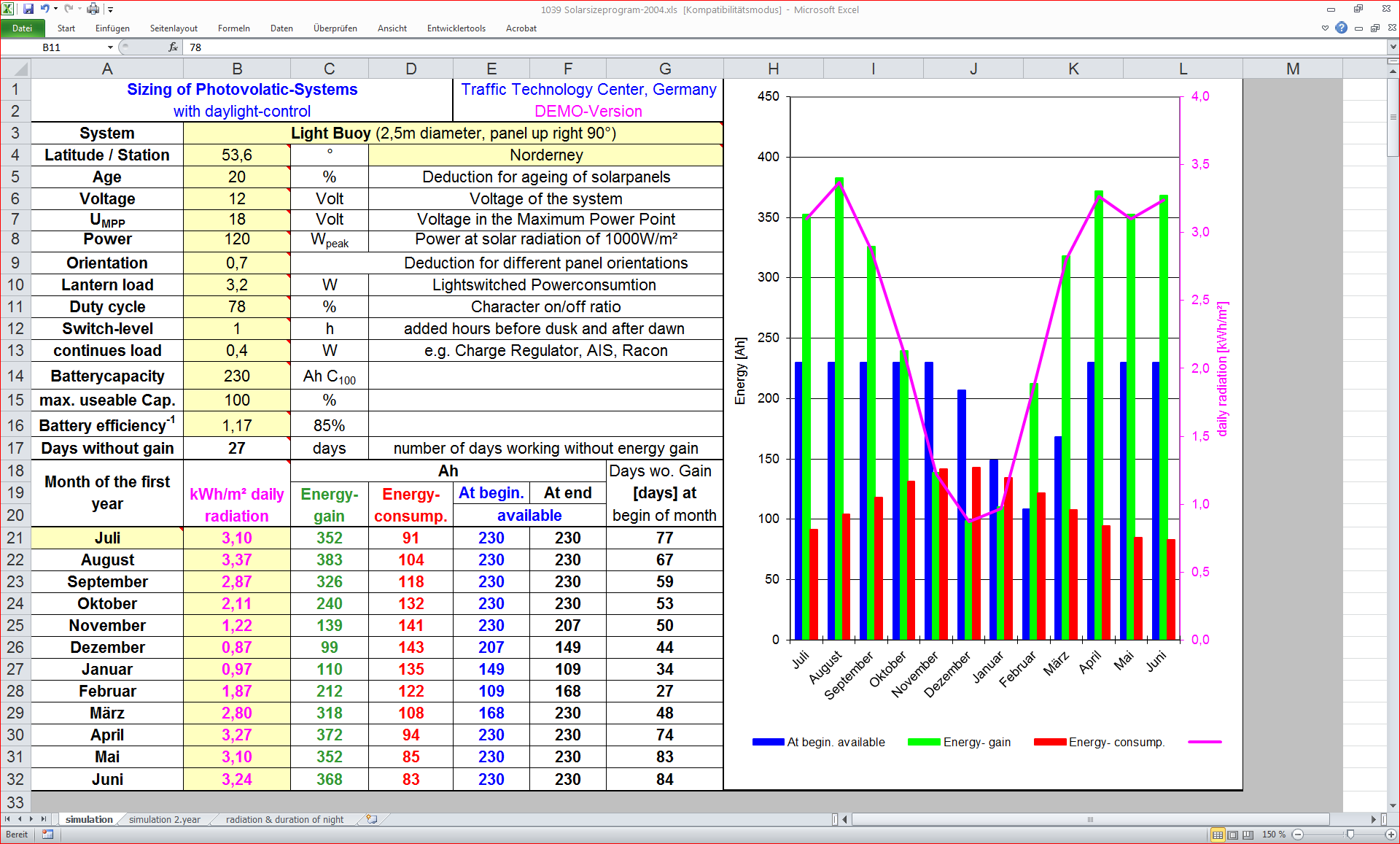
W/m2 Watts per square metre

Wpeak Watts peak







1. SAMPLE PAGE FROM THE SOLAR SIZING PROGRAM

Short manual for meteorology and Solar Energy

Follow the descriptions in the table below to extract relevant data.

|  |  |
| --- | --- |
| **Description** | **Action** |
| <http://eosweb.larc.nasa.gov/sse/> | Click on the link on the left side to access the NASA's website. |
|  | **Step 1:**  Click on the link shown on the left side. |
|  | **Step 2:**  Click on the link shown on the left side. |
|  | **Step 3:**  Enter the geographical position where your AtoN are located  Then press the button “Submit”  In this example, it is used a location in Svalbard |
| **Description** | **Action** |
|  | **Step 4:**  Select the headlines. Depending on where you are and what you choose of solution  click on the link "Parameters" for more information and definition |
|  | **Step 5:**  Add more choices to suit your location  Select al parameters and press Submit button at the bottom |
|  | **Step 6:**  Use parameters in "Monthly Average…”  and subtract the percentage difference according to "Minimum" column below. This must be done manually. The result is passed into the IALA excel sheet |
| **Description** | **Action** |
|  | **Step 7:**  Values calculated in step 6 is entered in the IALA excel sheet as shown here. |
|  | **Step 8:**  Use the value of NASA table for the monthly average hours of daylight into the IALA excel sheet. Example for the month of June are shown here. |
|  | **Step 9:**  Paste in the values that you collected from Section 8 here. |
| **Description** | **Action** |
| <http://www.latlong.net/> | Click on the link on the left side to access free program to find location available online |
|  | Click the map and the position with respect. Latitude and longitude of the location you have selected is displayed. |