Solar panels: everything you need to know

Want to add solar panels to your boat, or wonder how to make the most of those you already have? David Berry has some advice

Keeping batteries topped up without resorting to running the engine is an ongoing problem for yachtsmen. Solar panels are an obvious option, not just in the Med but also around the coasts of the UK as the price of panels has fallen over the years.

But choosing them can seem a bit of a black art: after all, how can you possibly predict how much sun you're going to get during the season, or how much power your panel will produce if it's not exactly aligned with the sun? But provided you accept a statistical approach using established databases, then prediction is easier than you think.

Ultimately the only thing we need to know is the conversion efficiency, or, how much sun turns into electrical power. NASA do a trick: they use multi-layer panels where each layer responds to a different wavelength so the usual 20% or so is doubled.

And there is a new material called Perovskite which is also used to provide an overlay on the standard silicone panel and the tandem panel is claimed to convert up to 28% of the sun's energy into electricity. Don't rush though, when I looked on Amazon for one I discovered even the books describing it cost around £100! The panels themselves seem to be still in development.


Catchlight Visual Services/Alamy

While it seems like a good idea to mount a panel on the coachroof the chances of it becoming shaded are increased. Here the mast or rigging can easily throw a shadow over at least part of the panel, seriously reducing its output

How much energy?

The first step is to work out your boat's energy requirements. All you have to do is add up all the energy in watt-hours used by each device on your boat, such as the fridge, lights, computers and so on.

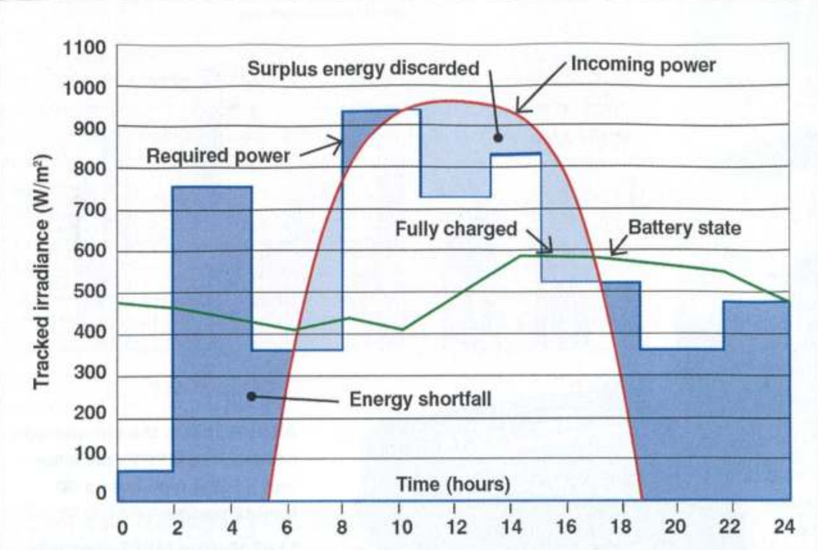
Energy is power accrued over time, so if power is measured in watts, energy is watt-hours. This can be tricky, for example how long is your fridge running for? And how about overnight? How much energy do the instruments take? Or your computer? You can measure the power by measuring the Amps and Volts and multiplying them together to get Watts, but somehow you need to come up with a table similar to the one below left.

Once you have your energy

Device	Current	Duty	Wh/day
Fridge	4	0.5	576
Computer	3	0.1	86.4
Lights	2	0.1	57.6
Fan	0.5	0.5	72
Losses	0.1	0.1	2.88

Energy requirement for *Aderyn Glas* over the course of a day. 'Current' is Amps. 'Duty' is the portion of the day the (12V) appliance is powered up. *eg Fridge 4A x 12V x 12hr = 576Wh*

LEFT David Berry's Moody Eclipse *Aderyn Glas* has solar panels mounted on a stern gantry where shadows are greatly reduced



A hypothetical energy balance. The red line is the clear-sky power that the panel could provide during daylight. The blue line is the power your boat requires. Light blue is surplus energy, where the panel is outputting more than the load, and dark blue is where the load is greater than the panel can deliver.

When night falls, the boat's energy needs have to be met by the battery. In daylight, the battery becomes a load for the panels as it is charged. The green line is a notional illustration of the state of the battery; it winds downwards when there's a shortfall and upwards when there's a surplus available for charging.

In winter, the load profile will be different and the captured power will be lower.

requirements worked out, I suggest you add a goodly margin for expansion and errors – at least 10%. Next, you need to decide how much of this requirement should be met by the solar panels. We sail our Moody 33 *Aderyn Glas* throughout the summer season from our base in Preveza, Greece, so our requirements are essentially those of liveaboard sailors. We want the panels to be able to supply most of our power needs and allow us not to have to ruin the peace of a quiet anchorage by running the engine simply for charging.

Weekend sailors might be content with a small panel to recharge – over the course of a week – the energy used during a weekend's sailing. Getting the balance right is important, especially if you want to install enough solar panels to more or less cover your power requirements.

But will you get the quoted wattage from your panel? If the panel is a 100W panel, will you get 100W? Panels are rated as the electrical power produced under certain strict test conditions, and these are solar irradiation (called insolation) of 1,000W/m^2 at 25°C and an atmosphere of a particular clarity. Do we ever get these conditions in practice? Well, yes, we do, but life is never that simple – and later I'll explain about how to assess the real insolation over the course of a day in your chosen location.

Types of solar panel

Leaving aside the exotic new Perovskite panels, there are three types that you might consider – a choice that hasn't changed in years. There are amorphous panels (good in shady conditions but large for any given wattage), printed panels (manufactured with an inkjet printer but really low conversion efficiency) and crystalline panels either poly- or mono-crystalline.

What type should I fit?

This question is a bit of a red herring – in reality, the question should be 'How much space do I have?'

The academic drive is to make panels that are more environmentally friendly, both to make and dispose of, and to reduce the cost per watt. But ironically this has resulted in a much poorer conversion efficiency generation by generation, which is not helpful to sailors with a small area available to mount the panels. So, back to the first generation: crystalline panels come in mono- or polycrystalline species, but they only differ slightly in cost per watt and efficiency.

Added to the mix is the flexibility aspect: flexible panels require a bit of clever manufacture, and this is passed on in higher prices. Many sailors think flexible panels are a solution because they can be mounted on the deck or coachroof or even the bimini but I've not considered them because all those places seem to suffer from shading, more of which later. So does this mean the default starting point for any installation is a rigid, crystalline panel? In short: yes!

Where should I install my solar panels?

If you're just fitting a small panel to top-up batteries on a mooring, buy a cheap rigid panel and find places on your boat where you can tilt it to catch the sun's rays for the majority of the day.

We do this during the winter in Greece, where we strap on 20W or so of car battery top-up panels, and it works well for us. Choose a spot that isn't shaded for the majority of the day and this technique should serve you well.

Do the sums. I have heard of people whose batteries have been damaged by a constant high power being applied to an already charged battery, even through a regulator. My rule of thumb for trickle-charging is a panel wattage about 10% of the battery's stated amp-hours, but that's a guess.

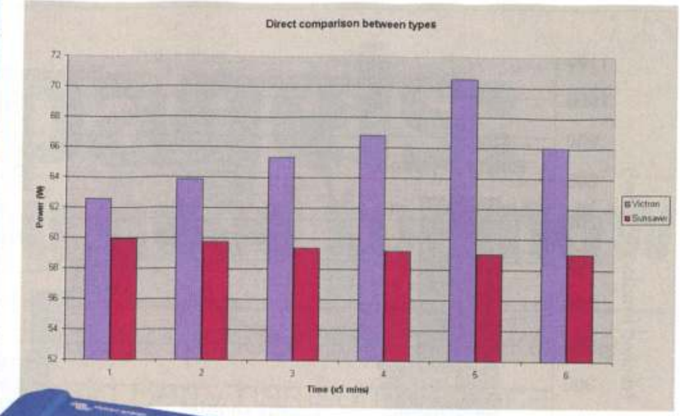
If you spend more time on board and need to get the best from your panels, mono- or polycrystalline panels will give more power from the same space. We replaced our 75W bank of amorphous panels with 200W of monocrystalline panels in the same area.

But with the higher efficiency comes higher sensitivity to poor mounting conditions, so if you want the best from your panels you need to do your utmost to ensure they're not shaded, and also that they are tilted as close to a right-angle to the sun as possible. This is why liveaboards often mount theirs on adjustable gantries at the stern or on the pushpit.

ABOVE LEFT The smaller amorphous panel is 15W and the larger crystalline panel is 100W. So the larger panel is approximately twice the area, but seven times the power

ABOVE RIGHT These panels are printed on a continuous inkjet printer with the idea that they can effectively be an endless strip. The problem with that, though, is the current can build up and eventually burn out the connecting cables. Furthermore, they are no good for yachts because the conversion efficiency is so low so you'd need a battleship in order to have enough space!

ABOVE ***Aderyn Glas*** **is fitted with two monocrystalline panels which are rated at 100W apiece – they take the same space previously occupied by amorphous panels which could only muster 75W between them**



ABOVE This is the comparison between an MPPT controller and a PWM type over a 30 minute period

LEFT Victron MPPT controller

Intrinsic losses

Let me just revisit this: the relationship between the nominal power of a solar panel and what you really get. When the manufacturer quotes, for example, 100W for a panel, that is the expected output under test conditions. The test conditions are an insolation of 1,000W/m^2 at 25°C. So a typical panel of half a square metre will receive 500W of insolation, then we multiply by the efficiency of 22% or 0.22 and you get roughly 100W. So if you get a sunny day that insolates your 100W panel at 1kW/m^2 then you have the potential to get 100W output for a short time around solar noon.

But the energy over 24 hours will be below this owing to the declination of the sun over the course of the day. This can be partly remedied with a tracking panel, but as the sun declines the light has to pass at a more oblique angle through the atmosphere, hence losing power.

The insolation will also be affected by your latitude, and by any form of shading or scattering from atmospheric dust, haze or cloud. Another important intrinsic loss is that heat reduces a panel's output by about 5% for every 10°C rise in temperature greater than 25°C. For this reason, it's quite possible to get a higher output from a solar panel in cooler northern latitudes than on the Equator!

So you see what I mean when I say the question is all about how much space you have: the default option should be a crystalline panel because it has the best watt per unit area coupled with price per watt, and we only need to deviate from this simple first-generation solution if other factors are important.

Cost and efficiency

Since we're only talking about crystalline panels the efficiency is always going to be around 20% and the cost less than £1/Watt. There are a large number of suppliers out there now but I should stick to the well known names such as Kodak, Polaroid, LG, Panasonic and Victron. For suppliers I would look at Amazon (of course) or, in the UK, Midsummer Energy which stocks not just panels but all the cables and bits you will need to fit them.

Other system losses

Cables

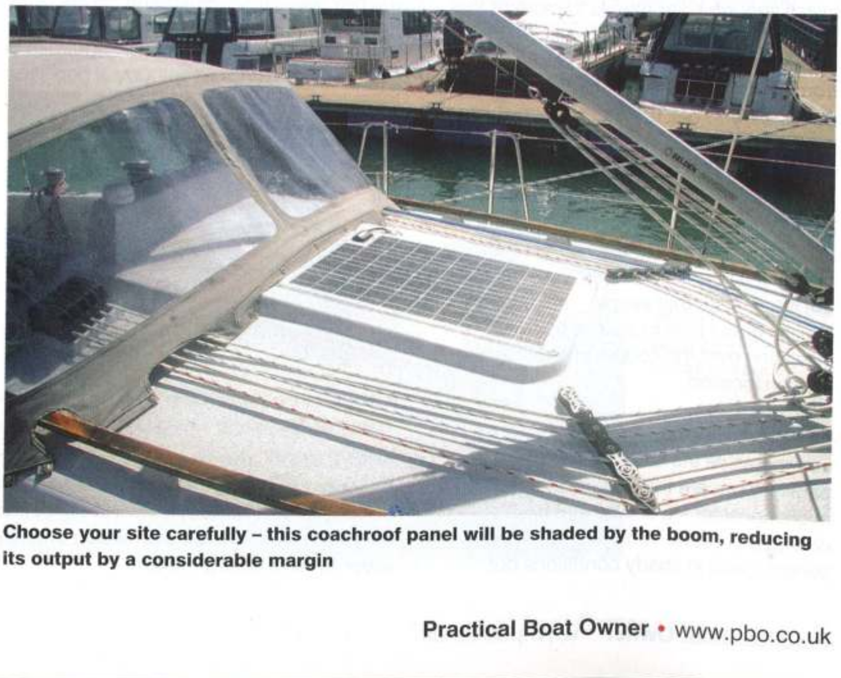
Losses in cables are proportional to the square of the current. The equation is $P=(i \times 2) \times R$ where 'i' is the current in amps, R is the resistance in ohms and P is the power lost in watts. The voltage gradient from the high voltage at the panels to the lower one at the regulator is fixed by the cable resistance and current (Ohm's law), which is in turn set by how sunny it is and the power required. But the resistance is a matter of design. To minimise cable losses and prevent potential cable overheating, large-core cables are needed. Resistance is also proportional to the length of the cable, so long cables need to be even fatter than short ones. I tend to use car speaker cable which is fat and can insulate the 12V we need.

Shading

Of all the possible ways to lose power from a panel, this is the most significant. On a crystalline panel, even the stripe of a rope's shadow can wipe out a huge amount of the potential output power. Why is this? The individual cells in a crystalline panel are wired in such a way that a cell which is in shadow and not producing will act as a sink for the power produced by the other cells it's wired to, with the result that virtually no power escapes from the panels as a whole.

Regulator

You must have a regulator. The job of the regulator is to throw power away. It does this to ensure the power passing on to the batteries or services is not too great for them to handle. Normally it does this by controlling the amount of power passing through it and hold the output voltage at some predetermined value such as the



Choose your site carefully – this coachroof panel will be shaded by the boom, reducing its output by a considerable margin

float charge voltage of 13.4V. The value of the power it passes depends on the current required by the load: the sum of batteries, lights, fridge and so on that are sucking the current from the panels. If the fridge is on, for example, more power will flow through the regulator and it will throw less power away as heat. Most common, older regulators use a pulse width modulation (PWM) system which is more efficient than simply controlling the output voltage. Maximum power point tracking (MPPT) devices provide more usable power by seeking the panel's optimum power voltage although they are expensive. Chief among the suppliers is Victron (avoid the so-called MPPT types from ebay, they are almost certainly not MPPT controllers). And if you have the room it might be better to spend the money on a larger solar panel than on an MPPT controller. This is what we've done on our canal boat, settling for a PWM type.

To the solar panel, the regulator is part of the load – a consumer of power – which is why the entry to the regulator is an appropriate place to measure the voltage and current if you want to see exactly how much is being generated by the panels.

What power do I really get?

If you do the sums, the unavoidable losses on a new panel operating at 65°C (measured in full summer sunlight in Greece) are going to be in excess of 20% from the temperature increase alone. Our example 100W panel is therefore only putting out 80W, and that's only for a few hours. If you really need every scrap of power then you need to find a way to keep the panel cool, and you need to invest in an MPPT regulator. As the panel gets older its performance will drop off even more. All a bit depressing, isn't it? I have to say, though, that in our particular installation on *Aderyn Glas* we regularly get more than 10A from our 200W panels, and our highest recorded value was 170W, which suggests that these loss figures are conservative. In reality, with a well set-up installation you can expect to get a maximum of 75% of the power you would expect from a continuously insolated panel operating at its rated power.

Insolation: or how much power is reaching me?

The sun is 93 million miles away, give or take. Packets of energy called photons leave it and travel at 186,000 miles per second just to fall on us and keep us supplied with energy. If you held up a solar panel outside our atmosphere, it would be irradiated by broad-spectrum sunlight at 1,370W/m^2: this is called insolation.

Because the Earth is tilted on its axis, we see more of the sun in the summer than the winter: in the winter it just about creeps above the horizon, and the stream of photons has to travel through a far longer atmospheric path than when it is overhead in the summer.

At sunrise and sunset, the atmospheric path length is about 11 times the noon path length. The longer the path length, the more of the sun's energy is lost by atmospheric absorption and through scattering.

Latitude is the other great influencing factor. If you were sitting at the North or South Pole, the atmospheric path length would be almost constantly 11 times as long as the path length above someone sitting on the equator.

Atmospheric path length vs hours after dawn

Light has to travel much further through the atmosphere when the sun is on the horizon. This is a purely geometrical effect; the actual energy lost will depend on the clarity of the atmosphere, but there is always some loss. (This graph assumes a 100km deep atmosphere and two-dimensional geometry.)

Stern mount keeps solar panels well away from stray shadows

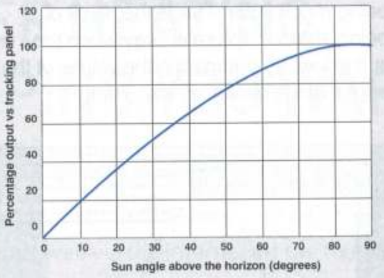
Can an angled panel catch substantially more power?

At solar noon, the horizontally-mounted panel performance will get as close to the panel on a tracking mount as it will ever get. However, as the sun declines the power drops off rapidly. The graph (below) shows how the irradiance of a horizontal panel varies as a percentage of the irradiance of a tracking panel. I mounted the panels on *Aderyn Glas* on a tilting mount so that I could track the sun in elevation but not in azimuth. This is a compromise: if you cruise a particular latitude and can tilt your panels to the optimum angle for your latitude and track the sun in azimuth from east to west. You will get much more from your panels. Suitable two-axis mounts are available, but it may be better to spend your money buying bigger panels and settling for a more modest mounting arrangement. We just try to swing *Aderyn Glas* to track in azimuth – but of course we can't always do so.

An alternative is to mount your panels at a fixed angle so that they are permanently tilted and do not track the sun at all. Again, this is better than a horizontal panel and is the technique used by solar panel 'farms'.

It's most useful if you tend to sail in a constant latitude (but only if you can point the panel at the sun in azimuth), since the optimum tilt angle is latitude-dependent. If you choose to do this, consider whether to fix the tilt at a summer or winter position: you may decide there's little need for winter energy input so you'll set the angle for summer cruising.

Horizontal panel output vs tracking panel



When the sun is directly overhead, a tracking panel and a horizontal panel will both provide the same energy. At all other points the tracking panel will have an advantage. When the sun is at 10° above the horizon, for example, the horizontal panel will only convert about 20% of the energy available.

The tilting mount on *Aderyn Glas* allows us to track the sun's elevation

The panels are flattened for motoring through the Corinth canal

How much sunlight can you expect?

The final crucial piece of information you need to be able to scientifically specify your system is how much sunlight you can expect to receive. This might sound impossible, but in fact it's easier than you think, thanks to some handy scientific data published online by the European Joint Research Centre.

How can I find the maximum I'm likely to get out of my panels?

Most people want to know this either to check their installation or to plan the size and number of panels to install. The EU calculator is here: **re.jrc.ec.europa.eu/pvg_tools/en/tools.html**

I was interested in finding out how much my nominal 200W installation of crystalline panels should deliver in my chosen cruising area of Corfu in the summer months and then seeing if I could work back to estimate the efficiency of the installation taking into account the panels, regulator, wiring and general losses – in other words, 'from sunshine to battery'.

> **'You gain 33% more energy if you can follow the sun'**

The calculator is fairly straightforward to use. First use the map and zoom controls to navigate to the position you are interested in then click 'off-grid' and enter the data in the boxes. Enter also your daily energy requirement in Watt-hours (Wh) then click 'visualise results' and have a look at the year's predictions for your setup. The calculator allows you to download the results as a csv file which you can turn into a graph using Excel or something similar.

The following graphs are the output for *Aderyn Glas* in the Corfu channel with 200W solar panels and 220Wh of battery. Out of interest I changed the location to Cardiff and found there was only a shortfall in January and December.

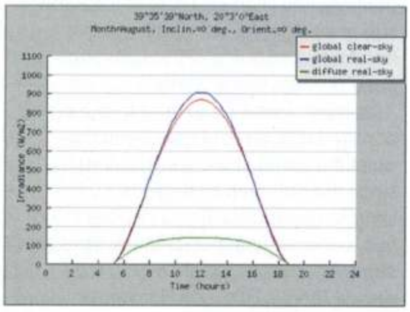
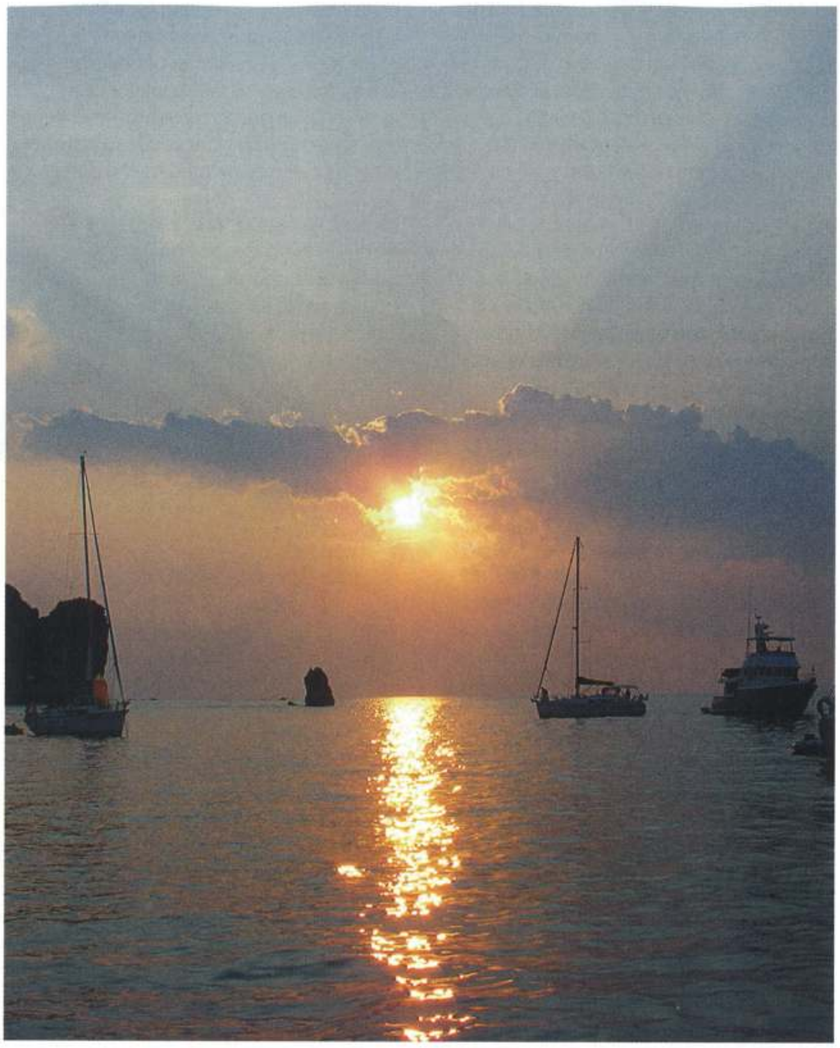


Fig 1: Insolation on a horizontal panel in Corfu in August (European Commission JRC)



The first obvious difference between horizontal and tracking installations is that the peak power output is less if you can't tilt the panel. This is because the sun is never exactly overhead in Corfu so they can't be equal.

Secondly, the shapes of the curves are different, with the tracking installation being much fatter. This is the result of being able to capture energy when the sun is low: try comparing the values at the edges of the curves at, say, 7am.

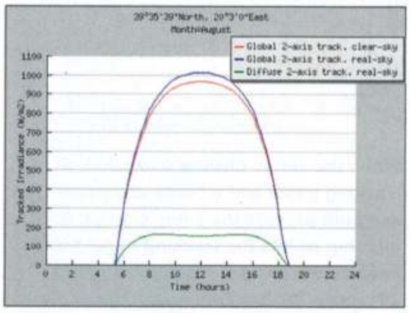


Fig 2: Insolation on a two-axis tracking panel in Corfu in August (European Commission JRC)

ABOVE This was a sunset in Vulcano near Sicily and shows the change of colour of the light which results from certain frequencies being absorbed by the atmosphere reducing the insolation

Theory and reality

To compare theory with reality I wanted to extract something measurable from this result. One obvious thing would be electrical power. If I could measure voltage and current delivered to the battery at the same point and time then multiply the two I would get power. So this would be something I could use my multimeter to check.

I was aware from the start there'd be a number of assumptions and guesses in this calculation, some made by JRC (they explain these in their help sections) and some by me. Nevertheless, I should be able to get into the right ballpark.

If I calculated the theoretical power then took my highest-ever measured current and voltage readings for August, dividing measured by theory would give me the efficiency value I wanted. I have a tilting mount so I could use the tracking results. ➲

Sarah Norbury

LEFT These semi-flexible solar panels have been cleverly incorporated into a sprayhood roof

BELOW Two-axis tracking mounts allow solar panels to make the most of the available sun

My panels are a 200W. The peak value of the tracking curve was 1,010 W/m^2 (from the tabulated results) so the peak output was: 200W x 1,010W/m^2 ÷ 1,000W/m^2 = 202W. The result for a horizontal panel returns 181W.

Unfortunately for my master plan, catching the greatest current going into the batteries is like trying to photograph a dolphin; by the time you've seen it, it's gone. The current depends on the load more than the source, so maximum currents are likely to occur when the battery charge is low, and that means in the morning – but the sun is not at its peak then. The best I've seen to date is 13.1A at 13.4V, giving me 170W and an overall system performance of 170 ÷ 200 x 100% = 85%, which represents a system loss of 15%. In other words, 85% of the theoretical electrical output from the panel reaches my battery, which is pretty good.

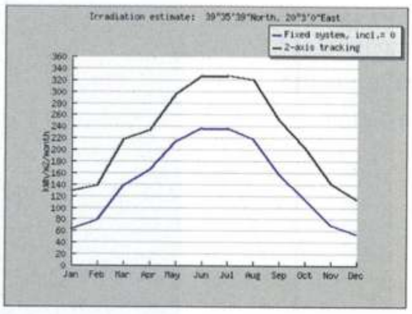
Energy

The total area under the curve represents the energy collected in a typical day, and I wanted to quantify the difference between a fixed horizontal panel and a tilting one. This was fairly simple. I went to the PV estimation tab and filled in the blanks leaving the JRC estimate of system losses at 14% and entering my 0.2 kW solar panels. I entered zero for the angle to generate a horizontal panel output and also selected two-axis tracking since this was the comparison I wanted to make.

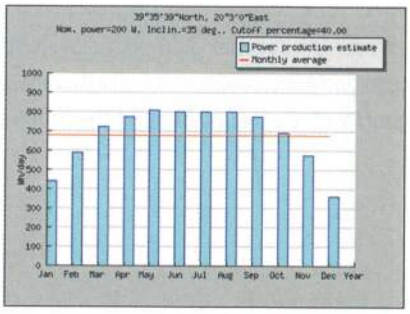
The result is pretty graphic: you gain a minimum of 33% more energy if you can follow the sun; much more in winter.

I calculated my power requirement at 800Wh/day in the summer and plotted how this could be met. The blue bars show the energy produced, and these reach the target value of 800Wh/day throughout the cruising months of the summer.

But the panels will need a bit of help from September onwards and before May.



Irradiation estimates by month for a horizontal panel and a two-axis tracking panel (European Commission JRC)



Power produced from my 200W tracking array compared to my 800Wh/day requirement (European Commission JRC)

Verdict

If you're choosing solar panels, start by working out what space you have available and what your energy requirements are. Then try to find an unshaded location where you can mount rigid crystalline panels, preferably on a tilting mount. Many boat owners will want to mount them on deck, in which case semi-flexible crystalline panels may seem a sensible choice but can be up to 10 times as expensive as rigid panels. For tracking mounts or gantries, rigid panels will be necessary, so crystalline units will again be the best option.

ABOUT THE AUTHOR

David Berry learned to sail in dinghies and now owns a Moody Eclipse, *Aderyn Glas*, which he keeps in Preveza, Greece. Since his retirement from design engineering he has written an account of his voyage with his wife, Ann, from France to Greece, entitled *Time to go South*.