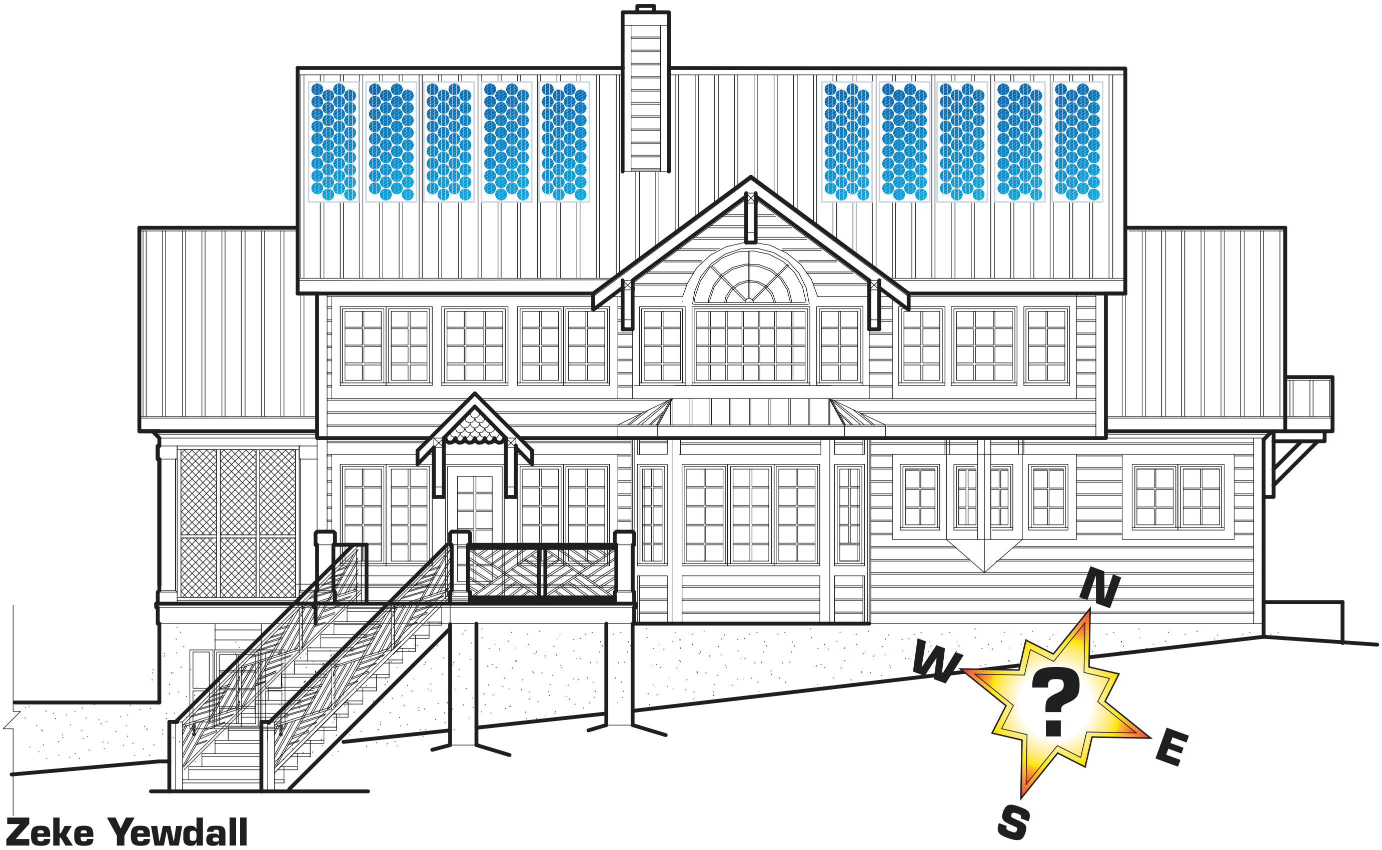
PV Orientation



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If you've read any how-to books on solar energy, you probably know a little about how to orient your PVs. Keep them facing true south. Make sure you've got the correct tilt, or adjustable seasonal tilt, and no shading, not even partial shading. This is all good general advice. But in some cases, true south orientation may not be quite as important as once believed.

I'm not advocating anything drastic, like pointing them north (or south, if you're in the Southern Hemisphere). Under certain conditions, the orientation can be flexible without drastically reducing the energy produced. But this depends a lot on exactly what kind of system you have. Wait a minute, you say. We always want the maximum amount of energy collection from our expensive solar-electric panels, right? Well, not always.

Depending on your specific load, climate, and other factors, computer simulations of PV systems with various orientations and configurations show that the ideal orientation for your PVs is not necessarily the standard formula. There is little documentation of actual "non-ideal" arrays in the real world, so more data is necessary to verify this. But several respected computer programs indicate that perfect orientation is not as important as once thought. If any *HP* readers have real-world data to back this up, I would be interested in working it into further research.

For the purposes of this article, orientation is defined as a combination of two independent variables.

- Tilt is the angle of the PV array from horizontal.
- Azimuth is the angle between the PV array and true south.

Typically, tilt is the only variable adjusted, and azimuth is kept at zero (pointing directly south). However, as more roof-integrated, grid-tied arrays are installed, installers and users are increasingly choosing or accepting a non-south azimuth.

Off-Grid Systems

Off-grid systems will usually produce much less usable energy per installed watt than grid-tied systems. Aside from battery losses and older, non-MPPT controllers, this is because they are usually sized for less than ideal sun conditions in the winter months. During the summer, the batteries may be completely charged by noon, so the solar-electric array is turned off by the series charge controller. The potential energy of those PVs is wasted by not being captured all afternoon.

Off-grid, we try to tilt the array at the optimal tilt, and directly south. Often, tilt angles are changed throughout the year. Take a look at the monthly and annual KWH results for different tilt angles in the two graphs. These graphs are from a computer simulation of the potential production from a 100 watt PV array in Spokane, Washington, latitude 47.8 N. The combined line graph shows monthly energy production for four tilt adjustment regimes. The bar graph shows the annual energy production for each of these four tilt adjustment regimes.

According to the simulation represented in the graphs, if you are going for a fixed array, the 40 degree tilt angle gives the best production of the two fixed regimes. Note that this is a little flatter than the standard rule—tilt equals latitude—perhaps because Spokane is very sunny in the summer, and very cloudy in the winter.

This simulation also indicates that if you are willing to adjust your array twice a year, you'll get the maximum energy with angles of about 20 degrees for summer and 60 degrees for winter. Annual energy will be 3.3 percent higher than with a fixed array. If you are willing to adjust once a month, annual energy will increase by 4.7 percent over a fixed array. This may be enough to justify the added expense of an adjustable rack.

If you have a stand-alone system, you want the energy when you need it, not just sometime during the year. Depending on the appliance usage patterns of its occupants, the electrical load of off-grid homes may be higher in the winter, the summer, or fairly constant from season to season. Since there's significantly more fuel (sunshine) during the summer months, optimizing the tilt angle of a fixed array for winter makes sense in some cases. But some off-grid systems have larger summer loads such as irrigation or air conditioning, so optimizing the array to catch winter sun is not always the best choice. Maximum annual energy production is not the holy grail of off-grid systems. What you want is maximum energy production when you need it.

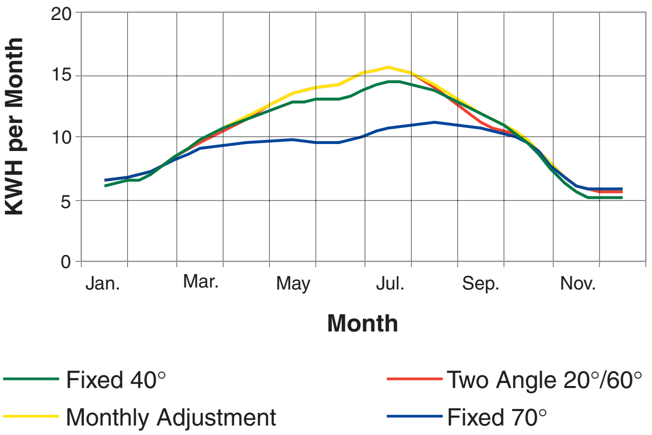
Grid-Tied Systems

Nowadays, more and more systems are grid-tied. Investing in solar electricity on the grid is cost effective for more and more places in the U.S.

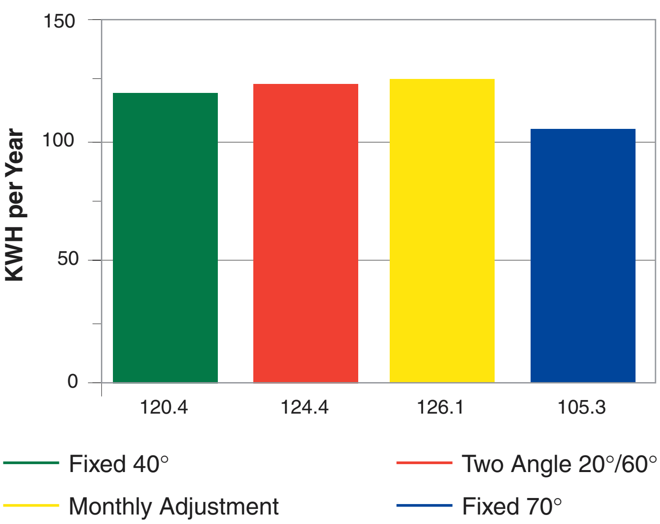
Grid-tied systems with annualized net billing have the benefit of essentially unlimited energy "storage." Any surplus put into the grid in the summer is immediately used by another utility customer, and provides energy credits to the system owner. If more energy is needed in the winter (or at nighttime), it can be purchased back from Mr. Utility. With this unlimited "battery," return on investment is maximized by putting the panels where they generate the most annual energy.

The contour plot (see next page) gives the percentage of the optimal annual energy production for different orientations for Spokane, Washington. As expected, moving far away from the optimal orientation reduces performance. What is interesting is how large the greater-than-90-percent area is. Depending on your exact location, your array could be up to 75 degrees off from solar south, or 10 or 15 degrees too steep or too shallow of a tilt, and still get 90 percent of the benefit. We've all heard of goofs when someone didn't know the difference between true and magnetic south. In most

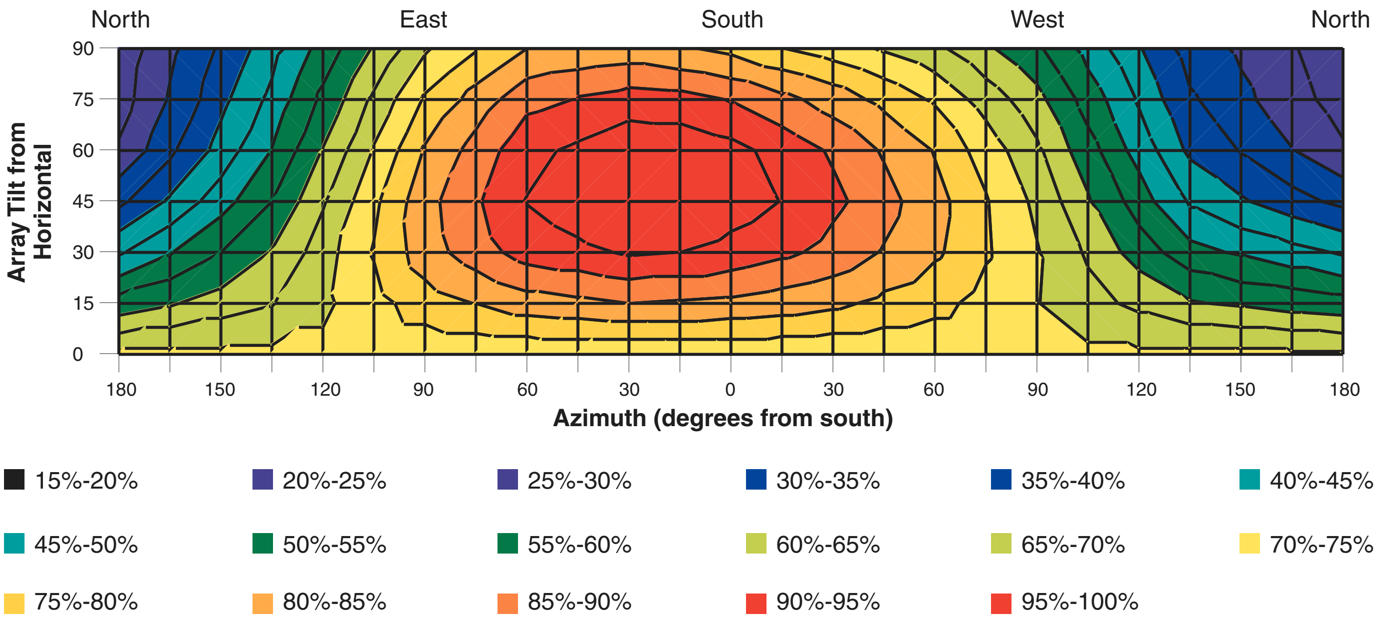
Tilt Angle vs. Monthly Array Output



Annual Array Output per Tilt Angles



Percent of Maximum Possible Solar Energy Collection vs. PV Array Orientation for Spokane, Washington



locations in the U.S., this is less than 20 degrees, so in reality, it doesn't have a significant impact on PV performance.

Interesting Orientation Details

Plots generated for various locations can show the effect of particular weather patterns. Since these are simulated with hourly weather data, the difference between using a more eastern and western azimuth can be determined. The effects of afternoon thunderstorms, such as in Spokane for example, will cause the ideal orientation to shift towards the east of true south. The effect of hotter modules in the afternoon decreasing production also contributes to this shift. Plots can also be done for each month of the year, with the ideal orientation shifting for weather conditions, such as afternoon thunderstorms and morning fog.

In general, the sunnier the climate, the more forgiving it will be of off-ideal orientation. The higher the latitude, the less sensitive it will be to off-azimuth error (since the long summer days outweigh winter days, and the long path of the summer sun cannot be effectively captured by any fixed array).

Special Considerations

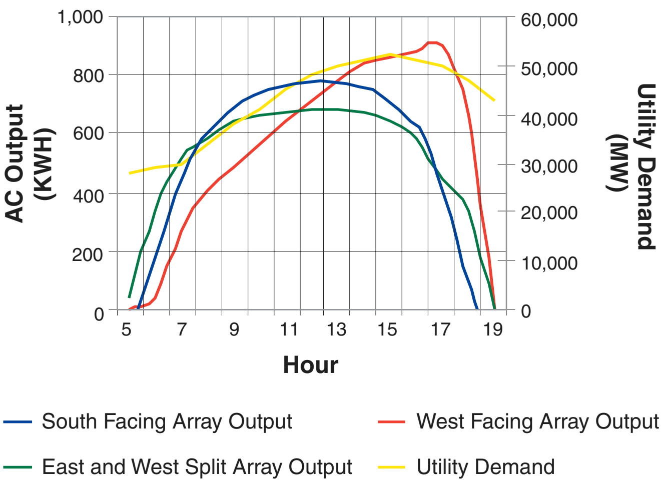
Now you are thinking, "Well, I have a grid-connected array, so all I care about is how close I can get to that optimum annual energy production, without being an aesthetic liability." Not necessarily.

Maybe you are lucky enough to have time of use metering for your grid-tied system. It may pay more to aim the array significantly to the west for your peak power to coincide with the middle of the peak rates. You may even be doing the utility a greater favor by generating during peak utility demand. Not only can you offset your own load on the grid, but that of several other houses as well. By offsetting the emissions of an inefficient peaking plant, instead of a more efficient baseload plant, you may offset more carbon emissions, despite generating less total energy with your array.

A graph of the hourly production of three simulated solar-electric arrays in San Francisco, along with the statewide California peak demand of a sunny August

This installation maximizes the array's exposure to the sun, but is it worth the extra hassle and poor aesthetics?

Hourly Output of Different Facing Arrays



day is shown here. Note that the west-facing array produces 92 percent as much as the south-facing array annually, and actually produces more during the utility peak. All arrays are at 22 degrees tilt (5:12 roof pitch).

And if you have the ridge of your roof running north-south, you could just put half the array facing east and half facing west. The split array still produces 86 percent of the annual energy of an ideal south-facing array, and spreads it out during the day a little more. Note that series strings should not be broken across different orientations, since the current of all modules will be reduced to that of whichever module in the string has the least sun. Shading presents issues in this case, as well.

Suppose you have a large PV array, but unluckily for you, the utility zeros the meter every month instead of at the end of the year. If you can't carry the surplus from the summer over to the winter, it makes more sense to adopt a similar stance to a stand-alone system.

**This roof's pitch and orientation is almost perfect.
A standard roof installation made sense and looks nice.**

The SunSlate PVs are hard to spot because they're also roofing material. They were installed here with a westerly orientation—which makes sense for some utility-interactive systems.

If your PV array is off-grid, or your utility zeros out your meter each month, and your system must meet the load during every time of the year, a little more care in orientation is warranted. Tilt equals latitude is not always the best approach. Using the orientation that would theoretically give the maximum annual energy production isn't either. A careful analysis of your load is necessary to determine the best orientation, and whether tracked, fixed, or adjustable is your best choice.

Maximum Energy vs. Aesthetics

Roughly two-thirds of the new residential PV systems being installed in the U.S. are grid-tied arrays. Grid-connected PV arrays are more likely to be in towns and cities where more people will see them. And they are more likely to be on the roof than a remote mountain home's array. A beautifully done, rooftop PV array will go a long way towards convincing your neighbors that solar electricity is the energy source of the future. An unattractive array may convince them to complain to the town council.

Riding my bike around Boulder, Colorado, I found three houses with new rooftop PV arrays. One homeowner made sure that the modules wrung the maximum amount of energy from the sun. The second homeowner made the installation look nice. And the third homeowner really paid up and bought SunSlate solar shingles.

Based on simulations, the second example above will produce around 2,500 KWH per year for each rated KW. This owner was lucky enough to have an almost ideal roof orientation. The first owner didn't have the ideal roof, so stilts were used to tilt the PV rack to the ideal angle. This array will also generate 2,500 KWH per year for each rated KW. But this is only 10 percent better than if the array had been installed flat on the 22.5 degree, southwest-facing roof.

The third rooftop system will only generate 2,100 KWH per year, per rated KW since it is on a west-facing roof. But it is an example of how solar roofing is the future. No one is going to call the city council about this roof. In fact, I didn't even recognize it the first few times I saw the house. Which system does more to advance PV as a viable technology for residential electricity generation?

Research Method

The monthly tilt analysis simulations were done with PV F-Chart. This software was developed by the University of Wisconsin Solar Lab, and uses a monthly correlation method to predict performance. In sunny climates, it is within a few percent of PVFORM (described below), but it can overestimate up to 15 percent in some cloudy climates. It costs US$400, and a demonstration version is available. The user interface is good, but geared a little more towards theory than practical application. (You enter PV area and efficiency rather than the rated wattage, for example.)

The contour plots discussed were generated with simulations from the computer program PVFORM. Developed by Sandia National Lab in the 1980s, it is still one of the most respected programs for hourly PV system simulation. The simulated system was four AstroPower, 120 watt modules connected to a 1 KW grid-tie inverter. Results will vary depending on which grid-tied system is used, and depending on how sensitive the modules are to heat.

PVFORM is a public domain, DOS-based program, and takes a little while to get used to. Generating the correct 8,760 hour weather file for each location is tedious.

PVFORM was compared extensively with real world data when it was being developed by Sandia in the early 1980s, and is probably the most respected program in research circles because of this. It starts with a physics-based model of a PV cell and the sun's path through the sky, and uses "typical" hourly weather data, which is generated from 30 years of data for more than 200 sites around the U.S.

PV F-Chart is based on a correlation approach instead of a physics-based approach. Many of the correlation constants were determined using physics-based programs such as PVFORM. PV F-Chart is accurate to within 2 to 15 percent (compared to PVFORM) for monthly values, although it tends to be closer to real world results in sunny climates than cloudy climates.

Access

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www.fchart.com • PV F-Chart software

See "PV Module Angles," by Richard Perez & Sam Coleman, in *HP36,* page 14, available on *Home Power's* Solar1 and Solar2 CDs.