Use of the Energy Trust Shade Effect Evaluation Form

At the request of the Energy Trust and in consultations with those developing the Energy Trust's solar photovoltaic program, the University of Oregon Solar Radiation Monitoring Laboratory has produced sun path charts for four locations in Oregon that contain estimates of a typical PV system performance during various times of year and for specific hours during the day. The sun path chart is a plot of the oath of the sun across the sky using the sun's elevation in the sky for one axis and the azimuthal position of the sun. For each of the locations (Medford, Pendleton, Portland, and Redmond), these enhanced sun path charts were created estimating PV system performance at 0º, 22.5º, 45º, 75º, and 90º tilts with azimuthal orientations ranging from 90º (east), 120º, 180º (south), 240º, and 270º (west) degrees.

At first, sun path charts were created for the first and second half of the year utilizing Typical Meteorological Year 2 (TMY2) data files utilizing a modified PVWatts program that produced hourly estimates of PV system performance at the various tilts and orientations. The quoted absolute accuracy of the TMY2 data is ±9% and the accuracy of the hourly estimates on tilted surfaces is approximately ±15%. Actual system performance will also vary depending on type of solar module, inverter, array size version inverter capacity, and other factors. In addition, the incident solar radiation can vary by 5 to 10% from the typical year and by ±20% from location to location.

To reduce the number of forms necessary and to simplify the calculations, the two forms were averaged together to produce a yearly form and the times were shifted to solar times. Shifting to solar times helps make the forms more useable for locations other than those used to produce the charts. However, some accuracy was lost in the averaging process and some estimates of shading may be different if the forms for each half of the year were used instead of the yearly averaged form.

Choosing the correct form

The effects of shading on photovoltaic (PV) system performance can be estimated by use of the Energy Trust Shade Effect Evaluation Form. The first task is to choose the right form for the location and preferred array tilt and orientation. The Medford forms should be used for southwestern Oregon, the Portland form for northwestern Oregon, the Pendelton form for northeastern Oregon, and the Redmond form for the areas east of the cascades and middle and southeastern Oregon. Fig. 1 is a map of Oregon showing the direct normal beam irradiance and shows areas of similar solar resource.

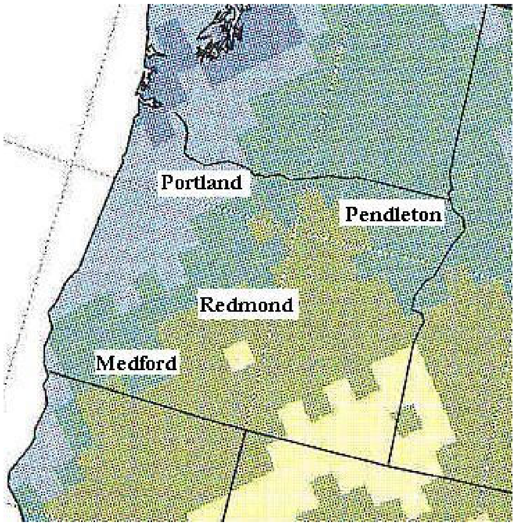

Fig. 1: Locations for which shade forms are available on top of a solar resource map of Oregon. Southeast Oregon has the highest resource while northwest has the least.

Choosing the right form with the appropriate tilt and orientation is also important. Frequently it is not practical to choose the optimal tilt and orientation for the array because of architectural or engineering consideration and constraints brought on by shading. Therefore one might consider several tilt

Table 1: Determining the right chart to use for analysis.

Tilt \ Orientation	75º - 105º	105º - 140º	140º - 220º	220º - 255º	255º - 285º
0º - 10º	0º, 90º	0º, 120º	0º, 180º	0º, 240º	0º, 270º
10º - 35º	22.5º, 90º	22.5º, 120º	22.5º, 180º	22.5º, 240º	22.5º, 270º
35º - 60º	45º, 90º	45º, 120º	45º, 180º	45º, 240º	45º, 270º
60º - 85º	75º, 90º	75º, 120º	75º, 180º	75º, 240º	75º, 270º
85º - 90º	90º, 90º	90º, 120º	90º, 180º	90º, 240º	90º, 270º

Select the tilt range in the first column that is most appropriate for the array and go across to the orientation range appropriate for the array. The values in the box identify the shading effect form to use for the analysis. For example, if the array is tilted 55º and is facing an orientation of 200 degrees, the correct form for the analysis would be the one with a 45º tilt and 180º orientation.

and orientations before a final configuration is determined.

This is one circumstance where the enhance sun path charts, available on the Energy Trust web site, might help with placement and orientation of the array. These forms have information on annual PV system performance at different tilts and orientation as well as the hourly fraction for monthly periods. One can also go to the PVWatts web page (http://rredc.nrel.gov/solar/codes_algs/PVWATTS/) and calculate the monthly and annual PV system performance for specific tilts and orientations. Note that the input system peak performance is specified as AC peak and not DC peak.

Table 1 shows the appropriate form for a given range of tilts and orientations. If the tilt or orientation of the array is near either extreme of the angular range, it might be worthwhile to look at the adjacent form to view the differences.

Filling out the shade evaluation form:

Before one attempts to evaluate the form, one must make a site evaluation using a standard instrument to obtain the shape of the horizon as seen from the array or use a compass and an inclinometer to map out the horizon.

When one is doing a site analysis, one must know the direction of due south. This can be done with a compass and correcting the reading for deviation of the magnetic pole from the true north pole. In this area, the difference is roughly 17 degrees east. More explicitly if a compass needle is pointed due north (0 degrees), it is actually pointing at 17 degrees east. This deviation from true north differs from location to location. A more precise value can be obtained from the Internet at http://www.ngdc.noaa.gov/cgi-bin/seg/gmag/fldsnth1.pl. On the web page one can enter either the latitude and longitude or the zip code of the location of interest. Be sure to click on the button next to the zip code box to automatically fill in the latitude and longitude for the magnetic pole declination. The value of the magnetic pole declination changes over time, but the estimator on the web page assumes that one is asking for the information on the current date.

Sun path charts for a given location can be found on the UO SRML web site at http://solardata.uoregon.edu/SunChartProgram.html. All that is required is the knowledge of the zip code of the location or the latitude and longitude. This sun chart can be used can be used for sketching the horizon prior to entering it onto the chart on the shade evaluation form. This sun path chart can have the local standard time to help verify the information being put down in the field. On a clear day, one can use the sun path chart to confirm that the compass corrections are approximately correct by making sure that the sun's position on the sun path chart corresponds with the angles determine with the compass plus the declination correction.

When sketching the horizon, it is important that the perspective is approximately in the middle of the array. For larger arrays, evaluations at two or more locations may be necessary to provide a more accurate estimate of the shading reductions. Often the shadow of a tall narrow object will sweep across an array as the sun moves across the sky. If these shadows only affect part of the system and segments of the array are connected to different inverters a diagram for each section of the array should have its own shading diagram. Multiple shading diagrams are only necessary if there are objects higher than 10º above the horizon.

Once the horizon is drawn on the Sun path chart on the shade evaluation form, it is necessary to fill in the table. The horizon line outlines the obstructions along the horizon. Make sure that the azimthal angles are adjusted for true south by correcting the compass' deviation from due north. Lightly shade the area under the horizon line. An example of drawing the horizon and shading is given in Fig. 2 for an east facing vertical surface.

The next step is to fill in the information in the table. An example is given in Table 2 for Fig. 2. While there is some shading between 4:00 and 5:00, the percentage of system power output for the year is zero. Between 5:00 and 6:00, shading occurs during times when there would be measurable system power. Between May and June 2.4% of the annual power produced occurs between 5:00 and 6:00. However only about ¼ of that area shows the effect of shading. Therefore the loss of power between 5:00 and 6:00 is 2.4%*1/4 or 0.6%. This is shown in Table 2. Between April and May 1.0% of the total annual power output is between 5:00 and 6:00. Only about 70% of this period is affected by shading so the loss do to shading is equal to 1.0%*.7 = 0.7. Therefore, approximately 70% of the power between April and May is lost due to shading and this value is entered into the table as shown in Figure 2.

As an exercise, check the other values added into Table 2. When filling out the table on the shade effect evaluation form, only the final numbers need to be included.

After the table has been filled out, the next step is to sum the values in each time period. In table 2, the shading from 5:00 to 6:00 reduced the potential system production by 1.3%. From 6:00 to 7:00 the annual production is reduced by 2.5% from shading. Totally the sum of hourly shading losses in the bottom row results in an annual loss do to shading of 6.7%. This value is then entered next to the Pct Annual Shading on the bottom left side of the form.

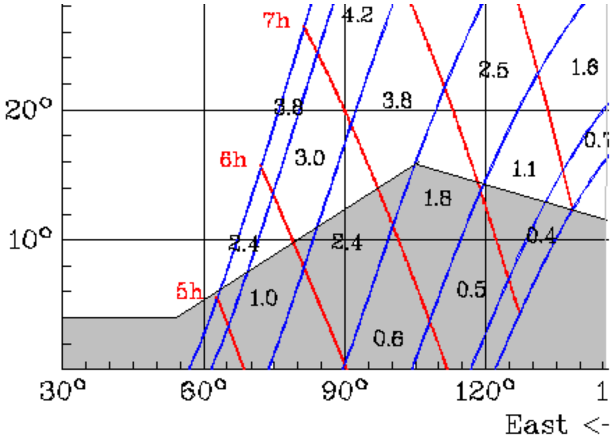

Fig. 2: Example of shading for an east facing vertical surface.

The next task is to estimate the effects of orienting the system in comparison with an optimally oriented system. An estimate is given for the annual kW hours produced for a 1 kW_{peak} DC system with a near optimal orientation for the location specified on the form. This estimate assumes that the AC peak performance is 85% of the DC peak

Table 2: Sample calculation of shading. Annual shading is 6.7%

Period\Hr	5-6	6-7	7-8	8-9	9-10	10-11
May-Jun	2.4*(1/4)=.6	0	0	0	0	0
Apr-May	1.0*(.7)=.7	3.0*(.1)= .3	0	0	0	0
Mar-Apr	0	2.4*(2/3)=1.6	3.8*(.1)=.4	0	0	0
Feb-Mar		.6*(1)=.6	1.8*(.7)=1.3	0	0	0
Jan-Feb		0	.5*(1)=.5	1.1*(1/3)=.4	0	0
Dec-Jan			0	.4*(.8)=.3	0	0
Sum of Hourly Shading	1.3	2.5	2.2	.7	0	0

performance.

The next step is to determine the annual production of the system for the system with the orientation and tilt with which it will be installed. There are two ways to do this. The simple way is to use the ratio between the performance of the optimally oriented system and the installed system given on the form as long as it is the correct form for the tilt and orientation as shown in Table 1. This ratio is shown on the left hand side under the paragraph giving the optimally oriented system.

A more accurate method to estimating the decrease in performance due to less that an optimally oriented system is to use PVWatt to calculate the annual performance. When using PVWatt, be sure the system size is given at 0.85 kW_{peak} AC and the proper tilt and orientation for the collector is given. To get the ratio of the installed system performance to the optimally oriented system, divide the result of the estimate system output by the annual output of the optimally oriented system. The ratio should always be less than or equal to 1.0. One can check the ratio obtained by this calculation with the value on the shade evaluation.

To obtain an estimate of the decrease in annual system performance due to shading and orientation as compared to the annual performance of an optimally oriented system with no shading, multiply (1- percent annual shading) time the ratio of performance to an optimally oriented system. This value should be greater that .75 or 75% for the system to qualify for the Energy Trust program.