COMPARING HORIZONTAL AND TILTED PHOTOVOLTAIC ARRAYS

Ronald B Swenson
ElectroRoof®
P O Box 7080, Santa Cruz, CA 95061
rbs@electroRoof.com

ABSTRACT

Cosine losses significantly reduce output of horizontal photovoltaic (PV) panels during winter months in temperate and high latitudes. Three types of PV panels were installed on the roof of a commercial building and a real-time online monitoring system(1) was employed to measure performance with special attention to cosine losses. Year-around losses were greater than predicted by generally available solar modeling tools.

1. INTRODUCTION

Placing solar panels horizontally on rooftops is a practice that was pioneered some years ago with frameless crystalline photovoltaic (PV) modules. This technique has now been broadly adopted, for crystalline and thin-film building-integrated PV installations.

Depending upon the latitude of an installation, horizontal coverage doubles or triples the amount of PV that can be placed on a roof relative to (stationary) tilted panels, but cosine losses reduce output of horizontal panels during winter months. Are those losses substantial or significant? More to the point, at what latitude do losses become significant enough to discourage the practice? Under what conditions does the additional revenue gained by optimal tilting relative to horizontal placement justify the incrementally higher costs of racks and roof space?

The fact of cosine losses is well known and generally acknowledged, with the argument being made that horizontal placement is sufficiently less expensive to make up for the difference. If that argument is challenged, the additional notion is advanced that the value of produced electricity is sufficiently greater during summer peak rate periods to justify the difference. But do these arguments stand up to the test?

Fig. 1. Three types of solar array: Comparing horizontal amorphous panels, tilted amorphous panels and poly-crystalline panels

2. PUT TO THE TEST

Horizontally positioned and tilted thin-film arrays and tilted crystalline solar arrays were installed in November of 2003 at 37° North Latitude. (Fig. 1) A series of tests is in progress with these arrays. Preliminary results from six months of testing were reported at the 2004 ASES conference; data for a full year are now available. Results depicting monthly losses are shown in Fig. 5, where the differences in monthly production between tilted and horizontal arrays are compared. One may observe the values through the seasons, starting with losses exceeding 40% near winter solstice and then gradually improving until June 2004, when losses were 2% to 5%, whereupon overall performance began declining again on the trajectory towards winter solstice.

On August 8, the tilted Poly-Crystalline (Kyocera) array under test was lowered to a minimum slope approximately 2 degrees from horizontal. Subsequently the performance of that array has conformed fairly closely to the horizontal thin film laminates.

Cumulative results since the time of installation are shown in Fig. 6. At 12 months, the cumulative value reaches 20%. After that, system performance is expected to decline for the balance of the winter months and then improve to less than 20% again. Viewed as cumulative data, each year the variation will be less.

It is not clear that the observed differences are fully attributable to cosine losses. Local weather and temperature play a role and may contribute noticeably to the differences, especially with crystalline panels, but based on published temperature sensitivity of amorphous thin-film arrays, temperature is deemed a secondary effect. While solar radiation as well as panel and ambient temperatures are being logged, analysis specifically to isolate temperature variation has not been made. Inverter losses may also come into play because the panel arrays were sized slightly over the inverter limits. It is deemed that this effect is also minimal because all of the array types were subjected to the same limitations.

Similarly, models of cosine losses are available for comparison (4), but results of such models differ significantly from the results derived from direct experience based on this test. Have these readily available simulation models been tested against systems in real-world conditions?

3. <u>DATA LOGGER</u>

In order to have open inspection and make data available to anyone who might want to examine the performance of these systems, each array is separately measured using the rMeter online "energy awareness engine." (1) The data is transmitted from field sensors through an on-site data logger via the internet to a web server where the data is channeled into a database for subsequent retrieval by interested parties at any time. In addition to a summary page with a variety of graphs to aid in interpretation (5), the rMeter website provides 15-minute interval (power) data (Fig. 3) and cumulative energy (kWh, $, BOE, or CO2) data – with daily, monthly and yearly (Fig. 6) intervals. (6) The complete data measurement and presentation process is illustrated here. (Fig. 2)

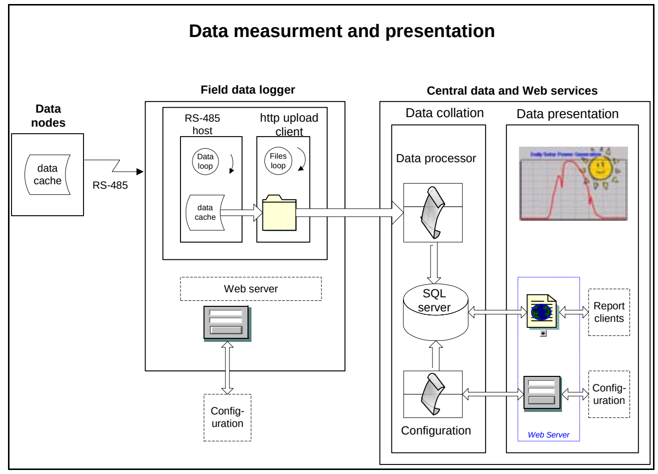

Fig. 2. Data Measurement and Presentation

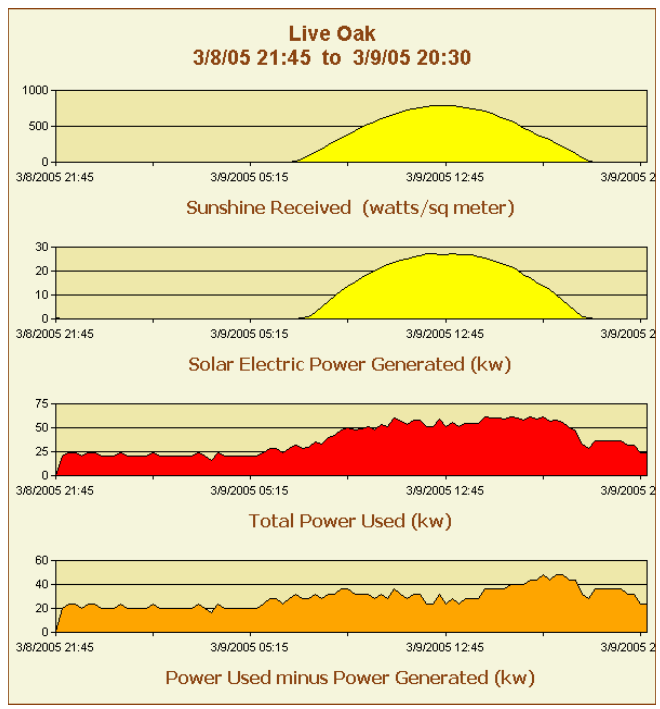

Fig. 3. Overall system performance, power for 24 hours, observed March 9th 2005

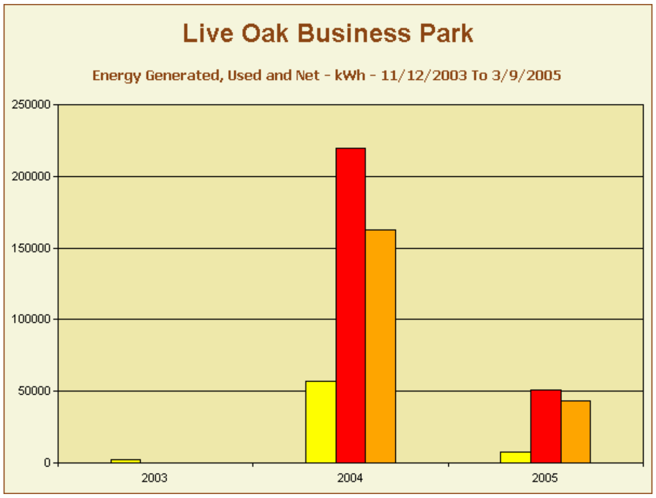

Fig. 4: Overall system cumulative energy performance. As of February 2005, the solar system is meeting about 25% of the building's electrical load.

6. CONCLUSIONS AND RECOMMENDATIONS

With the arrival of Winter Solstice and the completion of a full year's cycle, overall annual cosine losses at this latitude and location have been determined. Cosine losses for the horizontal array are approximately 20%, in comparison with an optimally tilted array, approximately twice the amount predicted by readily available solar energy simulation models.

REFERENCES

1. rMeter real-time online Energy Awareness Engine, www.rMeter.com
2. Ron Swenson: "Flat Roof Thin-Film PV Compared to Tilted Thin Film and Crystalline PV," Proc. ASES Solar Conference, July 10-14, 2004, Portland, Oregon.
3. Allan Gregg, Terence Parker, Ron Swenson: "A 'Real World' Examination of PV System Design and Performance," 31st IEEE Photovoltaic Specialists Conference, Jan 3-7, 2005, Lake Buena Vista, Florida.
4. Volker Quaschning, · Winfried Ortmanns, · Rainer Kistner, · Michael Geyer: "Greenius - A New Simulation Environment for Technical and Economical Analysis of Renewable Independent Power Projects" Proceedings of Solar Forum 2001, Solar Energy: The Power to Choose, April 21-25, 2001, Washington, DC.
5. http://www.rmeter.com/station.asp?stn=13
6. See www.rMeter.com/emon/lb.aspx for 15-minute interval (power) data and www.rMeter.com/emon/gb.aspx for cumulative energy (kWh, $, BOE, or CO2) data – daily, monthly and yearly data.

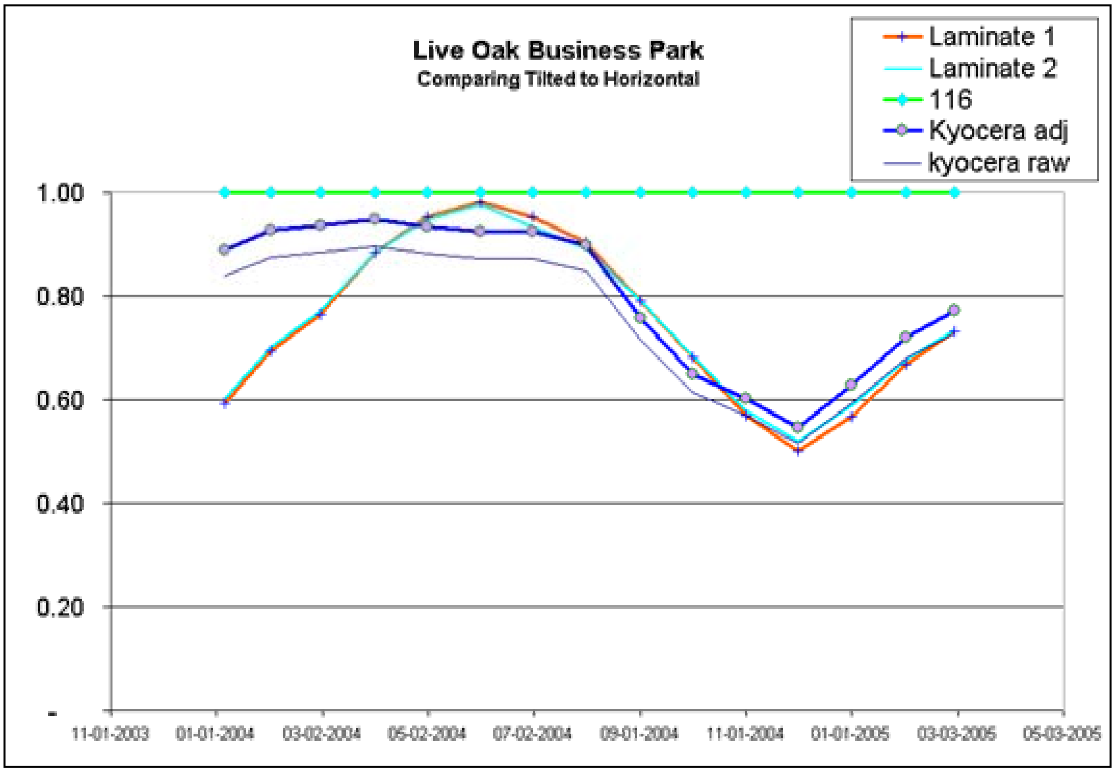

Fig. 5: Monthly averages for each panel type

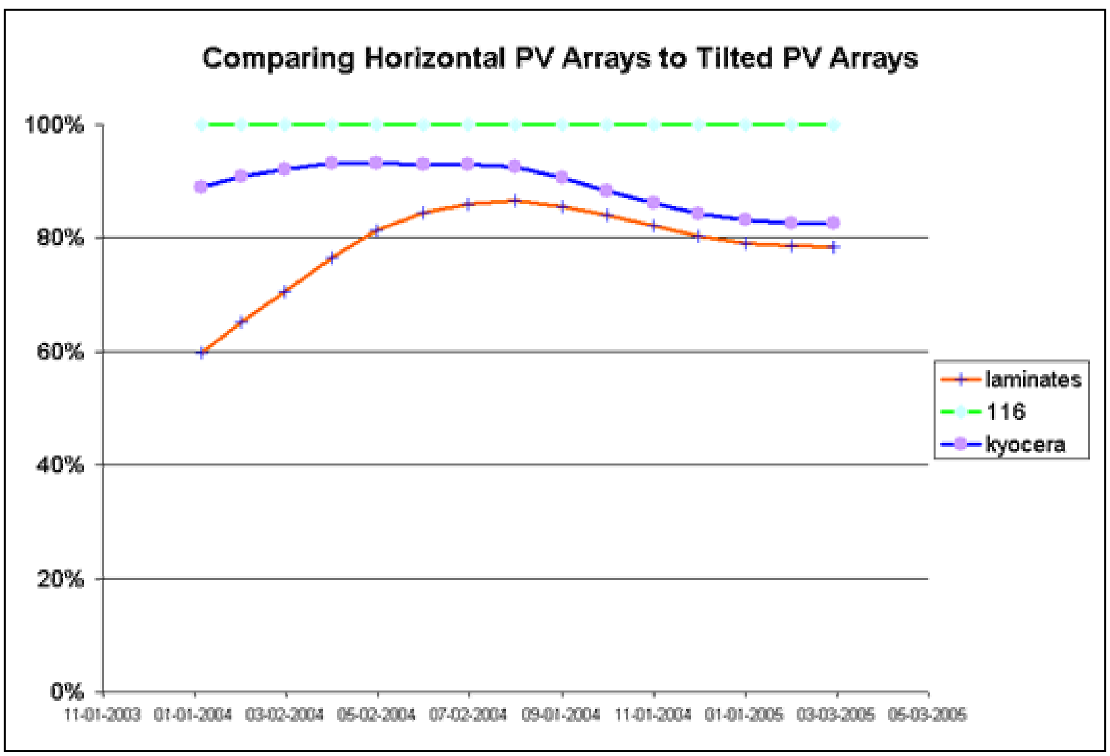

Fig. 6: Cumulative horizontal laminate and crystalline performance in comparison to tilted #116 modules