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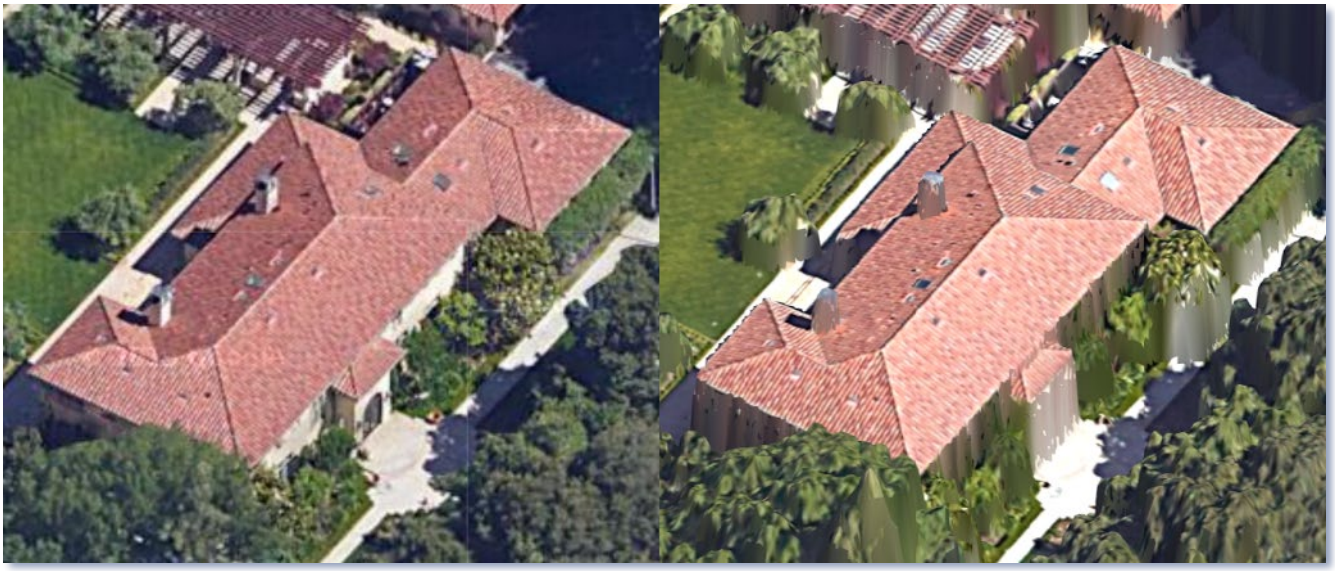
Software Validation

OpenSolar Photovoltaic System Design Tool – Validation of Measurement Accuracy

Report No.: R5594A-2

Date: 29 October 2021



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Project name:	Software Validation
Report title:	OpenSolar Photovoltaic System Design Tool – Bankability Assessment
Customer:	OpenSolar USA, Inc.
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Task and objective:

Complete a bankability assessment and energy production model validation of the OpenSolar web-based design tool.

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Revision	Date	Reason for Issue	Prepared by	Verified by	Approved by
1	10/19/2021	Draft	Owen Westbrook	Max Macpherson	Ryan Desharnais
2	10/29/2021	Revision	Owen Westbrook	Max Macpherson	Ryan Desharnais

Table of Contents

List of abbreviations

Abbreviation	Meaning
3D	Three-dimensional
DSM	Digital surface model; 3D data set capturing the location and elevation of surface features including terrain, structures, and vegetation.
PV	Photovoltaic
PVEL	PVEL LLC

1 Executive Summary

OpenSolar USA, Inc. ("OpenSolar") engaged PVEL LLC ("PVEL") to validate the measurement accuracy of the OpenSolar software application (the "Application"). The Application enables users to design and simulate annual energy production for residential and small commercial-scale solar photovoltaic ("PV") systems. The Application uses digital surface model ("DSM") data, where available, to determine the pitch, scale, and orientation of rooftop mounting surfaces and to build three-dimensional ("3D") shading models for energy production estimation purposes. To validate the Application's measurement accuracy, PVEL has compared on-site measurements of 20 residential rooftops to the Application's remote estimates of roof dimension and slope. Based on its independent analysis of these measurements, PVEL has made the following conclusions:

- Out of 46 remote horizontal distance measurements, all 46 (100%) agreed with the corresponding on-site measurements to with $1^1/_3$ ft (16 in), and 95% of horizontal distance measurements had an absolute error of 0.9 ft or less;
- Out of 67 remote roof slope measurements on roof facets greater than 10 m^2 (108 ft^2) in area, 65 (97.0%) agreed with the corresponding on-site measurements within 4°, and 95% of slope measurements had an absolute error of 2.7° or less; and
- This validation study has demonstrated that the Application is capable of generally meeting OpenSolar's advertised tolerances of $1^1/_3$ ft for horizontal distance measurements and 4° for slope measurements of roof facets greater than 10 m^2 in area, provided the remote measurements are made according to OpenSolar's specified best practices.

2 Remote Measurement Validation

2.1. Methodology

The Application's 3D model leverages DSM data to enable measurements of roof dimensions and orientations. The accuracy of these measurements underpins the feasibility of system designs created in the Application and impacts the associated energy production estimates. To evaluate the accuracy of the Application's distance and slope measurements, PVEL has made physical roof measurements of 20 residences in the San Francisco Bay Area and compared these on-site measurements to remote measurements made using the Application.

2.1.1. Physical Measurements

At each residence, PVEL's site measurement team collected angle measurements of all readily accessible sloped roof surfaces and distance measurements of all accessible horizontal ridgelines and gutters. Distance measurements were made using a 100 ft reel tape measure with markings down to the 1/8 inch, and slope measurements were made using a four-foot digital level electronic level with a manufacturer-stated angle accuracy of 0.1°. For each residence visited, PVEL's site measurement team provided its modeling team with annotated satellite imagery showing the locations of on-site distance and slope measurements. An example annotated image is shown in Figure 2-1.

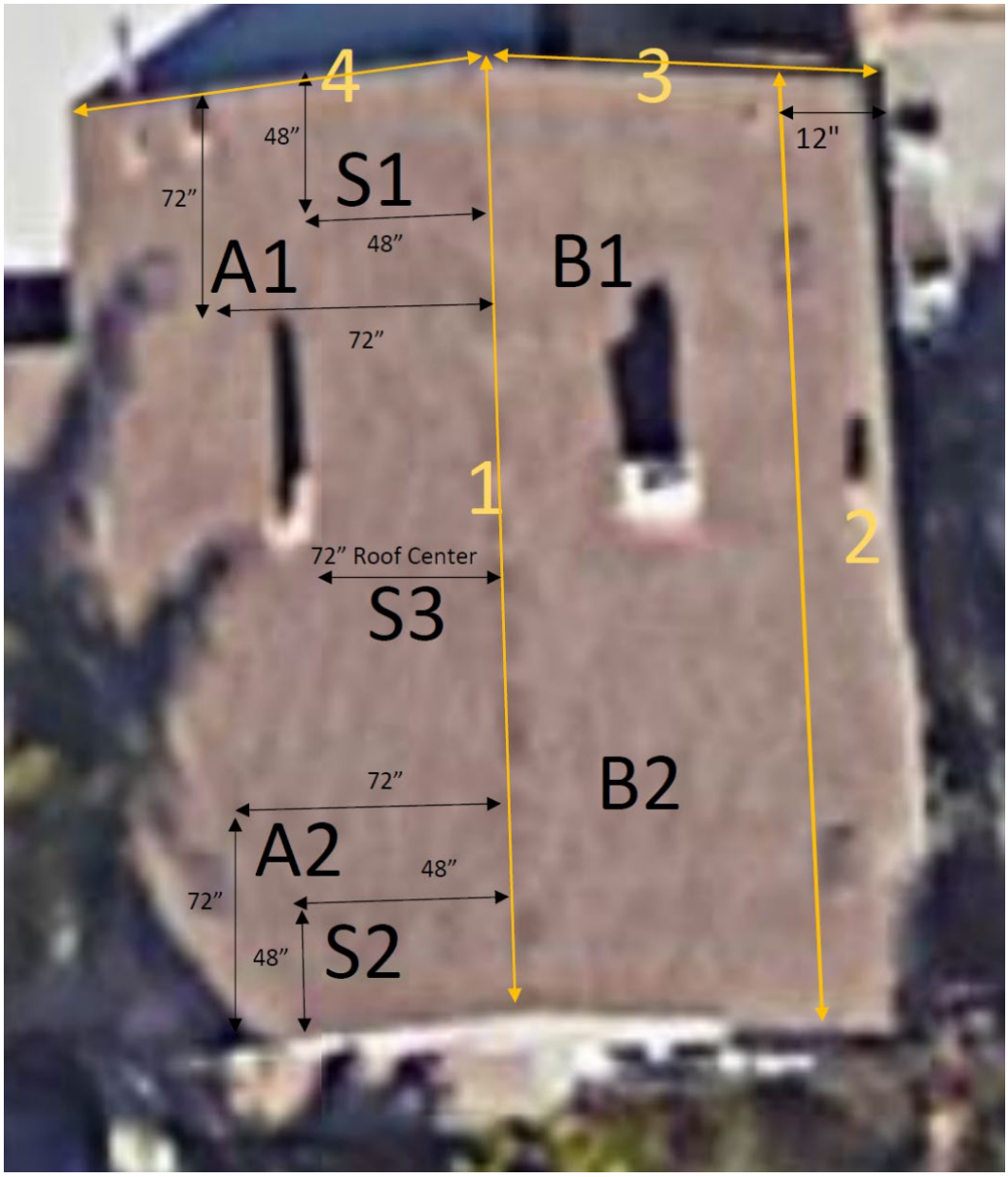

Figure 2-1: PVEL annotated satellite image of a sample roof in the study. Numbered yellow lines indicate distance measurements; A1, A2, B1, and B2 denote slope measurements. Imagery source: Google Earth.

2.1.2. Remote Measurements

PVEL's modeling team then used the Application to replicate the physical on-site measurements. Within the Application's 3D modeling mode, PVEL used the node placement drawing tool to measure distances and placed PV modules on roof facets to measure roof slopes. Per OpenSolar's recommended best practices, PVEL placed the center of each node marker on the desired point and viewed the node position from multiple orientations to

ensure accurate placement. Similarly, when positioning PV modules in the Application for slope measurements, PVEL avoided encroaching on roof facet boundaries and obstructions such as chimneys and vents. For roofs with an existing solar array, PVEL placed the simulated PV modules only directly atop the existing array area, except when modules could be placed so as to avoid the existing PV system entirely. OpenSolar then checked PVEL's remote measurements to ensure that PVEL had not made any obvious errors. Neither OpenSolar nor the PVEL personnel making the remote measurements viewed the physical measurement results until after the remote measurements were finalized.

After PVEL and OpenSolar agreed upon final remote measurements, PVEL compared the remote measurements to the on-site measurements. The final comparison data set included 67 slope measurements and 46 horizontal distance measurements. All slope measurements were made on roof facets greater than 10 m^2 (108 ft^2) in area.

2.2. Results and Discussion

Tables 2-1 and 2-2 summarize the results of the measurement validation study. For both slope and horizontal distance, the average absolute error and median absolute error fell well within OpenSolar's specified tolerances. All 46 distance measurements agreed within $1^1/_3$ ft. Of the 67 slope measurements, 65 measurements (97.0%) agreed within 4°. In percentile terms, 95% of the distance measurements had errors of no more than 0.9 ft, and 95% of the slope measurements had errors of no more than 2.7°. Based on these comparisons, PVEL has concluded that the Application generally meets OpenSolar's advertised tolerances.

Table 2-1: Absolute measurement error between the OpenSolar Application's remote measurements and PVEL's on-site measurements. 95% of measurements have absolute errors less than or equal to the 95th percentile error.

Measurement	Average Absolute Error	Maximum Absolute Error	Median Absolute Error	95th Percentile Error
Slope (°)	1.0	10.4	0.5	2.7
Distance (ft)	0.4	1.3	0.4	0.9

Table 2-2: Compliance of the OpenSolar Application's measurements with OpenSolar's stated measurement tolerance.

Measurement	Tolerance	# Values	Compliant Values	% Compliant
Slope (°)	4°	67	65	97.0%
Distance (ft)	1 1/3 ft	46	46	100.0%

The two outlying slope measurements had absolute errors of 6.3° and 10.4°. For the latter roof facet, the underlying DSM model had obvious issues beyond the control of OpenSolar. OpenSolar has stated that they are investigating means for detecting such DSM issues and alerting users when measurements may have higher than normal uncertainty.

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