System Advisor Model (SAM) Case Study:

James Forrestal Building

Washington D.C.

Abstract

The James Forrestal Building is the U.S. Department of Energy's (DOE) headquarters in Washington, D.C. The 205 kW rooftop PV array was installed in 2008 with the goal of producing up to 8% of the building's peak energy needs in order to fulfill the Transformational Energy Action Management (TEAM) Initiative. SunPower designed and installed the system, while it is metered and owned by DOE. It is interconnected to the Potomac Electric and Power Company's (PEPCO) grid inside the Forrestal Building. DOE provided climate and system performance data that were measured on the roof for December 2009 to June 2010. The SAM model shows good agreement with the measured data after adjusting for snow cover.

Figure 1: Looking northwest across the rooftop PV array on DOE's Forrestal Building [1]

System Description

The Forrestal Building's 205 kW rooftop array consists of 6 sub-arrays each of a different size and configuration. This can be seen in Figure 2. However, each sub-array is consistent in that they all use 11 modules per string. The system uses SunPower SPR-230-WHT modules and has a total of 891 modules (81 strings with 11 modules per string). All 6 sub-arrays feed through one Xantrex GT250-480 grid-tied inverter. The modules are integrated into the roof using a tongue and groove design with a ballasted system, which allowed for module installation without penetrating the roof. The array is completely flat, and there have been reports from DOE officials that because of the level nature of the array, soiling may be a larger issue here than other systems. There are also four 1 kW "Technology Showcase" arrays located on the northern part of the roof that display different PV technologies including crystalline silicon, amorphous silicon, copper indium gallium diSelenide (CIGS) and cadmium telluride [1].

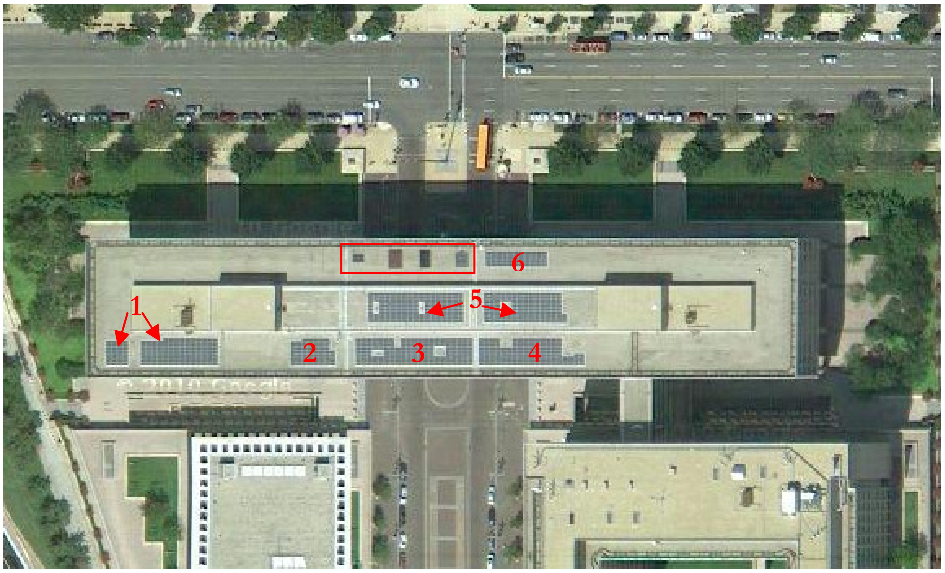

Figure 2: Aerial view of the Forrestal rooftop PV system [2]. The six sub-arrays are labeled in red. The four "technology showcase" arrays can be seen to the left of sub-array 6 (red box).

Data Acquisition

Climate and system performance data that were collected on the Forrestal roof from December 2009 to June 2010 were supplied by DOE. We used the TMY3 creator in SAM to compile the raw weather data into a functional format. Total rainfall data was also included in the weather file provided by DOE, which was used for soiling and capacity factor analysis. Snow depth data was obtained from the online version of the Farmer's Almanac [3]. We were given DC performance data for every minute, so we calculated the DC energy output by taking the average hourly DC power delivered to the inverter. The array layout and specifications were obtained from DOE records. Cost data was extracted from NREL's Open PV Project Database [4].

SAM Inputs

The SAM technology for this system is Component-based Photovoltaics while the market and associated financing is Commercial. Because the six sub-arrays feed through one inverter and they all have the same source circuit (11 modules in series) we were able to model the entire system as one array. We started with the default set of inputs using the Sandia performance model for the SunPower SPR-230-WHT module and the Sandia grid-connected inverter model for the Xantrex GT250-480 inverter. Table 1 shows the few changes made from the defaults in order to fit the system specifications.

Table 1: SAM performance inputs that differ from the default values for the Forrestal roof system

Page	Variable	Default	Forrestal Building
Climate	Location	Phoenix, AZ (TMY2)	Custom TMY3 (Washington, D.C.)
Array	Modules per String	21	11
	Strings in Parallel	95	81
	Number of Inverters	50	1

The defaults were already set with 0° tilt and 0° azimuth so very few values needed to be changed on the performance side of the model. However, there were significant changes to the financial model to reflect the financing of a federal building. These changes are shown below in Table 2.

Table 2: SAM financial inputs for the Forrestal PV array that differ from the default values

Page	Variable	Default	Forrestal Building
Financing	Real Discount Rate	12.0%	5.0%
	Federal Tax	35.0%	0.0%
	State Tax	8.0%	0.0%
	Sales Tax	5.0%	0.0%
	Insurance	0.5%	0.0%
	Property Tax	2.0%	0.0%
	Loan Rate	8.0%/year	0.0%/year
Tax Credit Incentives	Federal ITC Percentage	30.0%	0.0%
PV System Costs	Module Cost	$2.05/Wdc	$5.59/Wdc

The financial inputs in Table 2 are rough estimates and should not be taken as exact values; they are just our best guess at approximating the financing and cost of the system. Because the Forrestal PV system is on a federal building, all of the taxes as well as the investment tax credit were set to zero. The loan rate was also set to zero because the federal government paid for the system up front. Finding the module cost was slightly more involved. We found the total installed cost of similar sized (180-250 kW) systems throughout the U.S. that were installed around the same time (May-November 2008) that the Forrestal system was installed, using NREL's Open PV Project Database [4]. After calculating the cost per watt, we took the average for these systems, which gave us a total installed cost per capacity of $8.00/W. In SAM, we varied the Module cost to achieve a total installed cost per capacity of $8.00/W; the value that did that was $5.59/W.

Results and Discussion

The SAM metrics table is shown in Table 3. As mentioned above, these values should be interpreted with caution. For example, the net annual energy estimate is based on a weather file that uses seven months of recorded climate data from the Forrestal roof, while the other five months are from the Baltimore TMY3 file that was used as base file while creating the custom weather file.

Table 3: SAM metrics table

Metric	SAM value
Net Annual Energy	232,257 kWh
LCOE Nominal	49.98 ¢/kWh
LCOE Real	38.23 ¢/kWh
First Year Revenue without System	$ 0.00
First Year Revenue with System	$ 55,741.72
First Year Net Revenue	$ 55,741.72
After-tax NPV	$ -501,074.13
Payback Period	24.9846 years
DC-to-AC Capacity Factor	12.9 %
First year kWhac/kWdc	1,132
System Performance Factor	0.75
Total Land Area	0.68 acres

We can visualize the real and nominal LCOE values in Figure 3. Because the Forrestal PV array is part of a federal building, the tax credit incentives were set to zero so the LCOE values with and without incentives are the same.

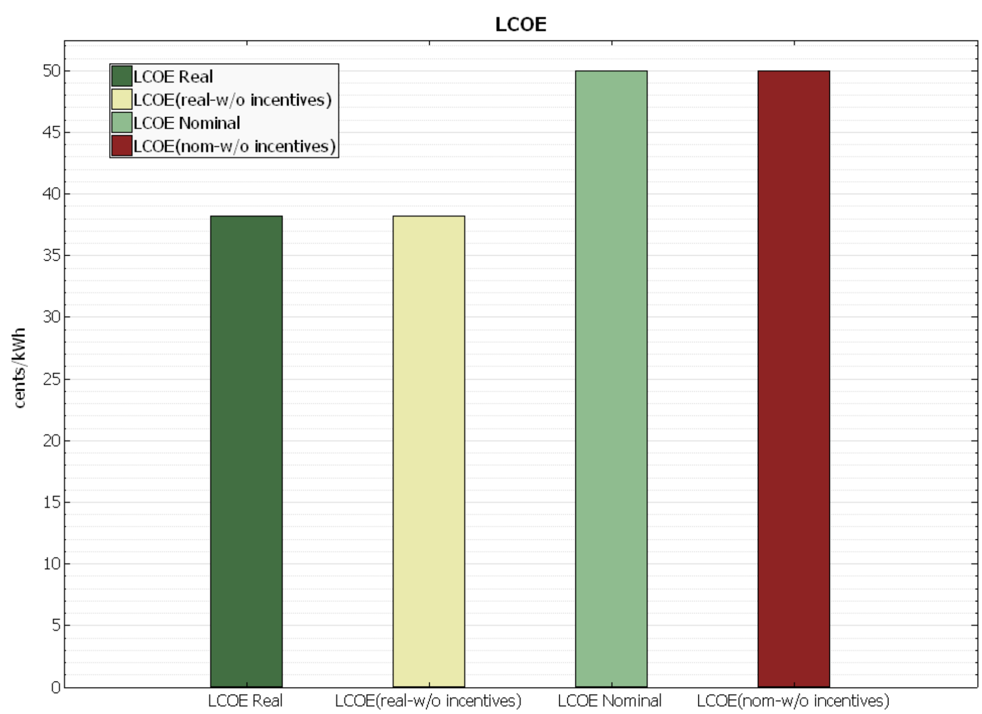

Figure 3: Simulated LCOE values, showing no difference with incentives because it is a federal system

Though the financial side of the model is rather rough due to the lack of cost and financing data, the performance side is much more precise. In order to analyze how accurately this SAM case represents the actual Forrestal system, we compared the SAM output data to the available measured performance data. Figure 4 shows the monthly DC energy output comparison between the SAM estimates and the measured data for December 2009 - May 2010.

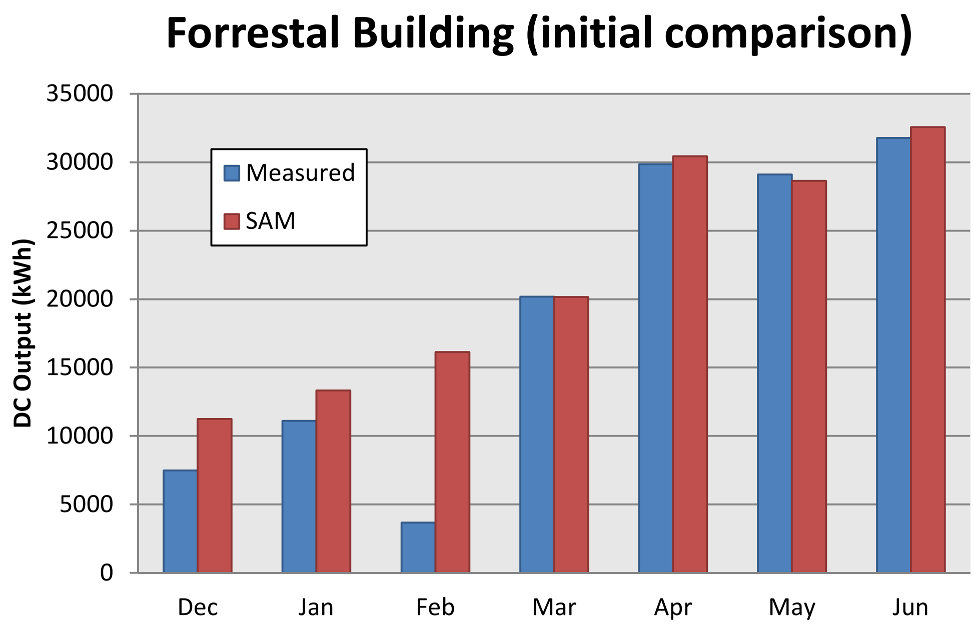

Figure 4: Initial comparison of measured DC output (blue) to SAM estimates (red)

There is clearly substantial disagreement between the SAM DC output estimates and the measured DC output, most noticeably in February but also in December and January. The gross overestimates in the winter are a trend we found in many of the case studies, and we attributed it snow cover. After researching the weather history during the months in this study, it was obvious that snow cover again played a major role in limiting system output. During February 2010, there were two large blizzards that hit the Northeastern states that completely shut down activity throughout the Mid-Atlantic region. Between February 5th and 6th, 20-36 inches of snow fell in the Washington, D.C. area with another 15-20 more inches of snow falling on February 9-10. The snowstorms were the worst the region had witnessed since 1922 and were coined in media reports as "Snowpocalypse" and "Snowmageddon". Earlier in same the winter, there was a record snowfall for a single snowstorm in December (Dec. 16-20, 2009), as well as other smaller snowstorms in January 2010. In order to take snow cover into account in the analysis, we looked up snow depth data using the Farmers' Almanac online [3]. We entered the Washington, D.C. zip code (20006) in the "search history" box and then recorded the snow depth for every day during December 2009 as well as January and February 2010. The DC energy output is plotted with the snow depth for every day in February 2010 in Figure 5 (below).

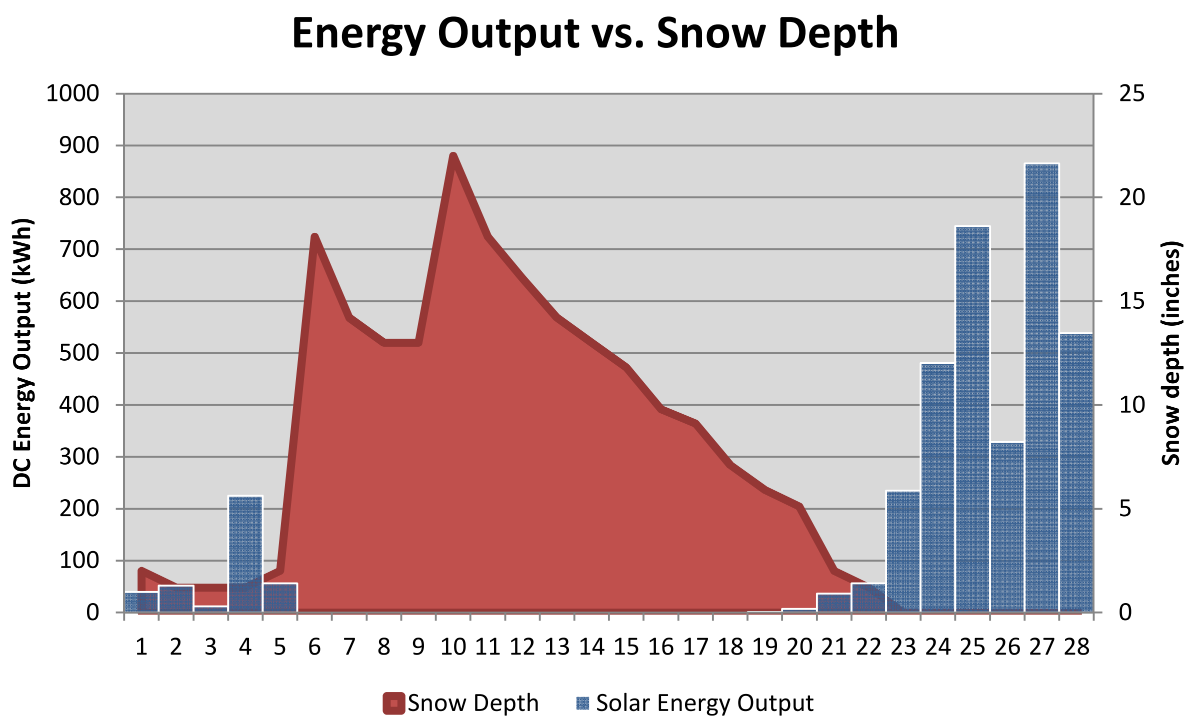

Figure 5: Snow depth (red) and DC energy output (blue) for each day in February 2010, clearly showing the two Mid-Atlantic blizzards (6th and 10th) and the limiting effect that snow cover has on solar energy generation.

Right away we can see the massive effect these snowstorms had on solar energy generation; the Forrestal rooftop array was at least partially covered for more than 3 of the 4 weeks in February. The snow cover also explains why SAM greatly overestimated. The weather file that was used in SAM had irradiance values for many of the days in the middle of the month where the energy production values were zero. When the simulation was run in SAM, the energy production calculations were made assuming the array was clear. Therefore, SAM calculated energy output values for days where energy generation could not be possible due to the snow cover, which explains why SAM overestimated in February, as well as the other snowy months, December and January. There is an issue regarding the reason the devices that measured the irradiance (which were on the Forrestal roof as well) were still able to collect data while the entire PV array was completely covered in snow. The most likely explanation is that the irradiance measuring equipment is fairly small and raised up in such a way that snow did not accumulate on it, and therefore was able to collect data well before any of the massive snow drifts had melted off the PV array. Another contributing factor to the SAM overestimation is that when snow data is available, the model increases the ground reflectance (albedo) because it assumes that the snow melts or slides of quickly from most arrays. Thus, system output is actually enhanced when it should be reduced most of the time; this issue is currently being worked on and should be improved in future model releases.

Snow cover also affected the solar energy production in January and February, though on a smaller scale. To make a more accurate comparison, we decided to zero the irradiances in the weather file for days when snow was reported on the ground during the winter months. The comparison between the measured data and the SAM estimates after adjusting for snow cover is shown below (Figure 6).

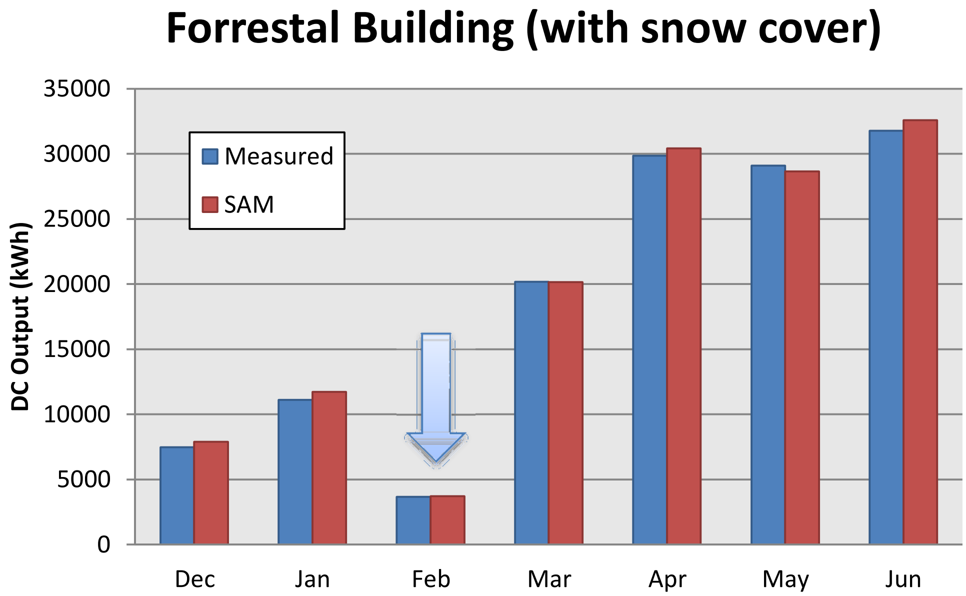

Figure 6: Comparison of measured DC output (blue) to SAM estimates (red) after adjusting for snow cover

After zeroing the irradiances on days with snow cover, the SAM estimates show a much better agreement in the winter months. The SAM estimates for February-June were all within 2.5% of the measured DC output values. SAM overestimated by about 5.6% in December and January, which can be attributed to the rough method of dealing with days that may have partial snow cover.

One final issue to address is the soiling on the array. To examine how prevalent soiling was in inhibiting system output, we calculated the DC capacity factor for each day in the time period studied and then looked at the rainfall data that was measured on the Forrestal roof. If soiling was a major factor, we would expect the capacity factor to increase considerably on days following a rainfall because the dirt would be washed off and the modules would perform better. The correlation between total rainfall and capacity factor for the month of March is depicted in Figures 7 and 8 (below). It is clear in Figure 7 that there is indeed a strong relationship between rainfall and an increase in capacity factor. One thing to note is that most of the time the rainfall occurs in the morning or during the daylight hours so the there will be a higher capacity factor for that day. On the other hand, sometimes the rain is during the night so we don't see the effect on the capacity factor until the following day; this is the case on the 2nd, 25th and 28th.

From Figure 8, we can see that on days where it rains, as well as on the day following a rain, the capacity factor nearly doubles. In compiling the data for Figure 8, we chose the capacity factor for either the same day that the rain fell or the following day (depending on the time of day that the rainfall was recorded) and then took the average. The results are a strong indication that soiling is a major factor on the performance of the Forrestal PV array. This can be at least partially attributed to the flat nature of the array so dirt tends to accumulate on the modules. One way to get around this and increase system output would be to wash the array regularly, especially in the drier seasons.

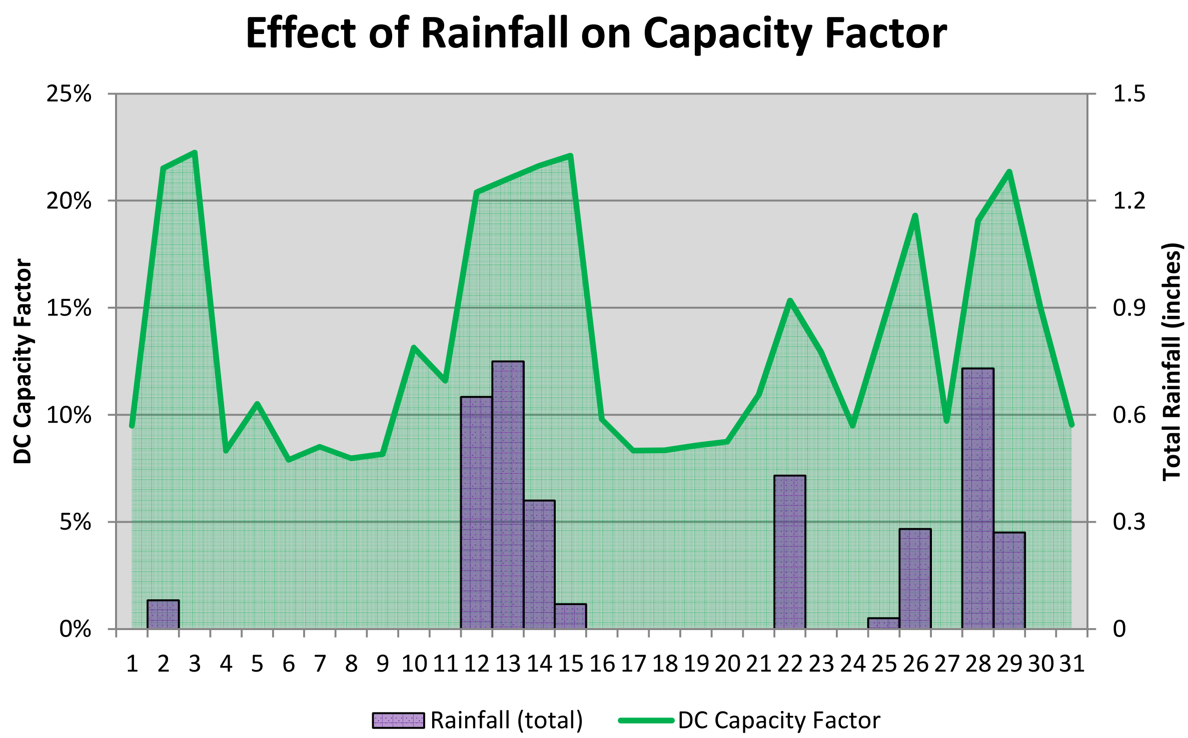

Figure 7: Shows a strong correlation between DC capacity factor (green) and total rainfall (purple) during March 2010, highlighting the fact that the Forrestal array has significant soiling issues

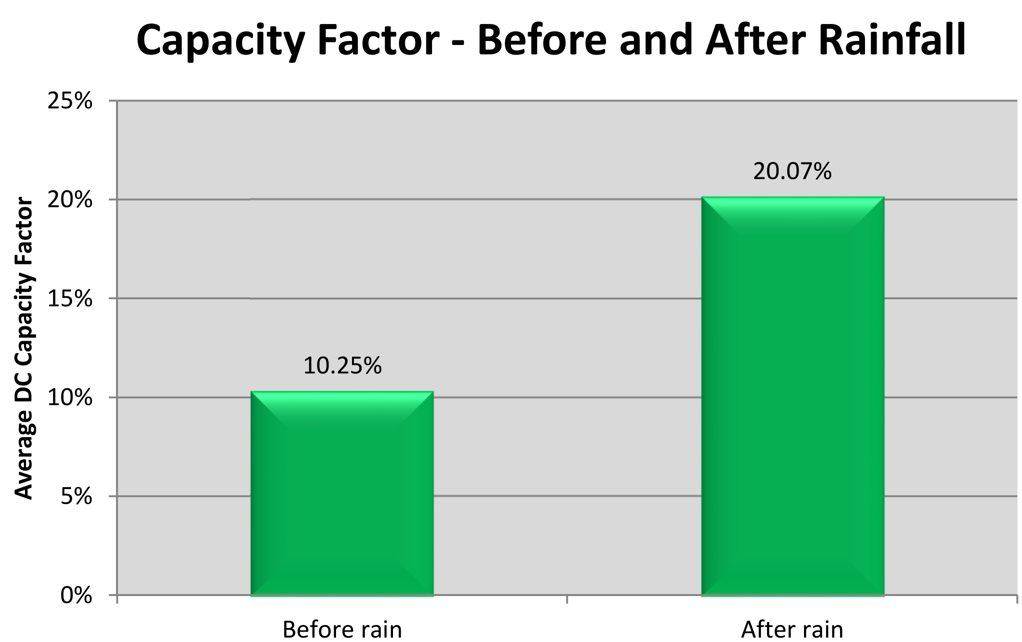

Figure 8: The average DC capacity factor nearly doubles on days after a rain because soiling on the array is washed off (only includes days in March 2010)

Conclusions

Using SAM, we modeled the PV array on the James Forrestal Building, the headquarters for the U.S. Department of Energy. Based on the system specifications provided by DOE, we were able to model the system with very minimal changes to the default inputs. After adjusting for snow cover in the winter months, the SAM model showed good agreement with the measured data at the monthly level. Five of the seven months studied were within 2.5% of the measured data while the other two (December 2009 and January 2010) were within 5.6% of the measured DC output values. This case study was another example of the effect that snow cover has on system output and the importance of including a way to model snow cover in future versions of SAM. The system capacity factor was also studied in relation to rainfall, showing a strong correlation. Adding the effect of rainfall on system performance is also currently being looked into for future model releases. Overall, the Forrestal system is a good example of a commercial rooftop PV system. The SAM file associated with this case study is located in the SAM samples folder.

References

[1] "205 kW Photovoltaic (PV) System Installed on the U.S. Department of Energy's Forrestal Building." *U.S. Department of Energy*. Fact Sheet, September 2008. <http://www1.eere.energy.gov/solar/pdfs/forrestal_pv_system.pdf>

[2] Satellite photograph found on Google maps: http://maps.google.com/

[3] Historical weather data from the Farmer's almanac: http://www.farmersalmanac.com/weather-history/

[4] PV system cost data available at: http://openpv.nrel.gov/