The Impact Snow Has on Solar Energy Production:

A case study of the Morley photovoltaic array and the necessity for the removal or prevention of accumulated snow in the future

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Introduction

Solar energy has long seemed one of the most viable forms of renewable energy. But it was not always the most *efficient* way to produce energy. Until the introduction of photovoltaic (PV) cells and their implementation in silicon solar panels[1], solar cells were barely capable of converting energy at 1% efficiency (NREL). Needless to say, the silicon-photovoltaic system quickly rendered the less efficient selenium solar cells obsolete. Ever since this important advancement in solar energy technology, photovoltaic solar panel arrays have become the most feasible way to harness the sun's "free energy." The solar energy industry has expanded greatly since the fifties, and now solar energy makes a 1% contribution to the United States' energy production (brighthub). There are numerous advantages to solar energy, which caused it to become widely accepted and utilized by the public. Some of these advantages include: reduction in energy costs, increase in property value, and reduction in carbon footprint[2]. These advantages, along with others, spurred businesses, homeowners, and institutions to invest in PV arrays. Academic institutions, namely colleges and universities, became interested in starting solar energy projects when governmental incentives were developed and expanded. Currently, incentives for installing PV arrays in the U.S. range from up-front state rebates that reduce costs by around 20% to federal grants in the form of the IRS's Clean Renewable Energy Bonds (IRS). Williams College jumped on the solar energy

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[1] Gerald Pearson, Calvin Fuller and Daryl Chapin introduced the photovoltaic cell in 1954. Their silicon solar cell could convert the sun's energy into electricity at 6% efficiency.

[2] A carbon footprint is essentially a measure of how much carbon-based gases (CO_2) would have been emitted had the energy been produced by burning coal, oil, etc.

bandwagon back in 2004 with the installation of the 24-panel PV array on top of Morley Science Center.

Figure 1. *The photovoltaic array on top of Morley Science Center at Williams College*

So we have looked at what institutions have to gain from installing PV systems but the real question for this paper is: How do we assess the effectiveness of a PV system (specifically the one on top of Morley) once it is installed? Furthermore, what variables come into play when we talk about the effectiveness of a solar energy system? And, what can we do to prevent these variables from significantly affecting the PV array atop Morley? While it is important to understand what is gained from investing in a PV array, it is more important to look at the impact of the system post-installation.

Setting

Solar energy (in the U.S.) is mostly produced in the Southwest. This is for two reasons: First, the southwest provides very large, open areas to install arrays. Second, the Southwest provides the most constant and direct sunlight possible. This allows for optimum efficiency because the PV arrays are in ideal conditions. Oddly enough, Massachusetts has a respectable contribution to the U.S.'s solar energy production. This may seem strange considering the fact that geographically Massachusetts is the near

opposite of the Southwest. But it is not the geographical placement of Massachusetts as much as it is the governmental programs that promote the growth of the solar industry within the state. Programs like the Commonwealth Solar Program which approves about $22 million per year in rebates, have residents of Massachusetts genuinely interested in installing PV arrays. The importance of the setting to this research was not, surprisingly, about the geographical issues involving PV array performance. The "setting" of this project has more to do with the *climate* issues. The climate of the Northeast, as most know, is rather harsh. Heavy precipitation in fall, spring and winter in tandem with high winds can create problems for PV arrays. Climatically, the most significant setback is snow. As I discovered, snow greatly affects the PV array on top of Morley. Because the winters in Williamstown are notoriously relentless, the array could spend weeks buried under a foot of snow. Since the snow covers the PV cells from any light, the array loses months of energy production. As I will show with a plethora of data and calculations, something must be done to avoid the effects of snow on the array because doing so would reduce Williams College's energy costs, increase the projected payback period[3] of the array, and increase the overall efficiency of the array (as it's efficiency is effectively 0 when snow-covered).

Method

In order to determine the effects of snow on the Morley PV array we have to know how much energy (expressed in kilowatt-hours) the array would produce without snow. Once this is known, it becomes necessary to compare the values to the actual energy produced by the array. Well, luckily for the Williams community, a computer

[3] The projected payback period is amount of time the system will take to save enough money in energy costs to outweigh the installation costs.

records the data for actual produced energy from the array. However, it took more legwork to find values for the energy that we would *expect* from the array. It may seem logical to do many averages of monthly energy production and find some general baseline values for energy production. But, this would be counter-productive as these averages would already be skewed by the snow that has covered the array for three-month periods in the four years since its installation[4]. In other words, averages of monthly energy production values would include the low winter production and thus lower the average values to the extent that the results would truly be below the expected values for energy production. So to avoid the skewing of expected energy production – to keep expected production a constant – we have to find another way to model expected production. Soltrex, a solar technologies group, makes it possible to track the energy production of countless PV array around the U.S. including the one on the roof of Morley. As a close investigation of the website reveals, Soltrex uses a model for predicted energy output of the array. The National Renewable Energy Laboratory (NREL) developed this "PVWatt" model for expected production; it takes into account the size of the array, its location, its angular tilt and azimuth. As for climate, the model uses the Typical Meteorological Year (TMY) to determine general temperature, wind speed, and other conditions. Since this model seemingly does not account for snow coverage, it serves the purpose of keeping expected production constant even in light of variables like snow. With these constant expected values, we can compare the actual values for energy production. This will all become more apparent visually in the next section on data and its explication.

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[4] After looking at snowfall records and array production, I deemed the winter months to be a roughly 3 month per year period from early December to late February.

Data and Comparisons

The first data to look at in conquering this problem of snow is that which expresses the actual energy production (by month).

Table 1. *Actual monthly energy production (in kWh). 2005-2009*

	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
2005	55	365	573	914	902	1037	976	842	777	382	300	142
2006	170	362	738	858	810	756	988	913	621	473	277	193
2007	249	153	383	586	1138	1001	1016	932	808	497	300	51
2008	189	209	525	882	960	873	978	900	754	533	250	151
2009	45	203	721	777	*	*	*	*	*	*	*	*

From this data, we know exactly how much the Morley PV array is producing on a monthly basis. This is necessary because now we can look at this data in relation to the Hopkins Forest snowfall record and try to find when the snow would most likely be affecting the production of the PV array [Appendix A]. For the sake of brevity, I will relate the three lowest monthly energy production values (denoted in red) to average snowfall for that month; more data such as yearly and monthly comparisons can be found in Appendix B. Starting with January 2005, we see that the snowfall record shows a total snow on the ground of 60 inches[5]. If we divide this total by the amount of days that measurable snow on the ground was recorded (11 days), we can determine that when snow fell, the average snow on the ground was 5.45 inches. I did this same process for December 2007 and January 2009. I found that the average snowfall was 6.37 inches and

[*] These values are unknown as of yet

[5] Here, I am using measured snow on the ground because we are only interested in snow that actually stayed on the ground and thus significantly covered the Morley PV array.

3.03 inches respectively. From this data comparison we can start to see trends between low production and snow coverage. However, we cannot definitively say snowfall *is* causing the low energy production. This is where I used NREL's "PVWatt Calculator" values for modeled (expected) energy production at the Morley array.

Table 2. *Modeled/Calculated expected monthly energy production (in kWh).*

Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
326	436	628	775	893	866	902	815	661	488	288	250

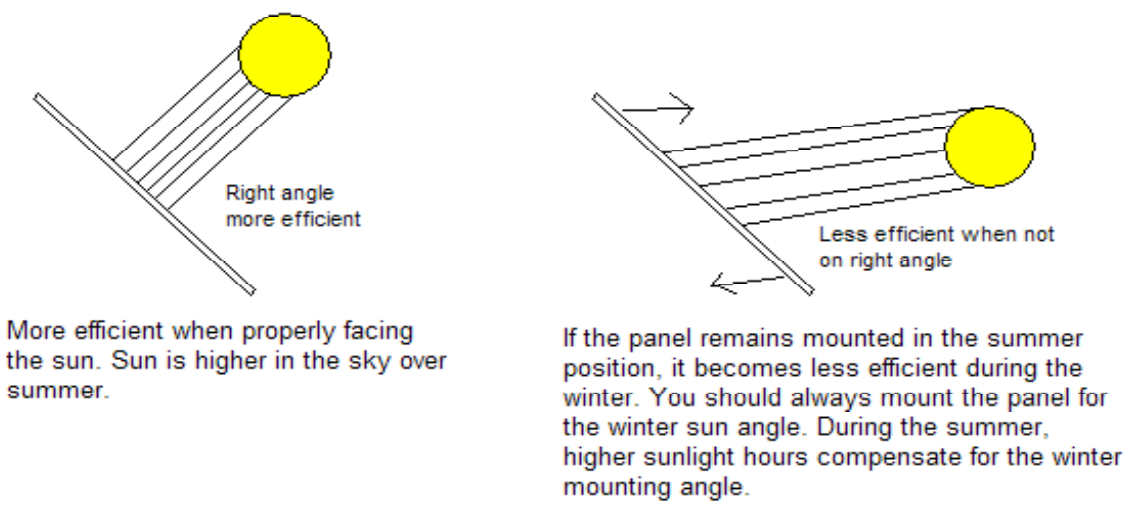
One major and obvious difference between Table 2 and Table 1 is that there are no years notated in Table 2. The "PVWatt" calculator for expected energy production predicts the amount of energy the Morley array would be producing under standard conditions regardless of year. These values are constant. Therefore, we can compare these expected values for energy production to the actual values and make a judgment as to whether or not snow [Appendix A] has a significant negative effect on energy production. One can see that, since its installation, the Morley PV array has never produced its expected amount of energy in December, January, and February. This lends to my earlier point that the winter-time months with snow are roughly early December through late February. But more importantly, this comparison between actual and expected values given the data in the snowfall record proves that snowfall has a *decisive* effect on energy production. If there were certain winter months (in the last four years) in which the PV array had produced the expected amount of energy, there would be scientific doubt about whether or not we could say snow had an actual effect. However, given the four years of data I am working with, I have no choice but to say with conclusive evidence that snow has a significant impact on the Morley array's production. After reaching this

conclusion, my next step is to come up with some solutions for snow coverage. A discussion on solutions, how they would affect energy production, and their viability is to follow.

Solutions and the Basics of Viability

One issue needs to be addressed before looking at solutions for the problem of snow coverage. The Morley PV array is oriented at 160 degrees South-Southwest with an angular tilt of 6 degrees. Let it be noted that because of the position of the Sun in relation to the Earth at the summer and winter solstices, the photons delivered by the Sun do not always make 90-degree contact with the PV array. PV arrays are the most efficient when they are exposed to light that approaches them at a 90 degree angle. Because of the low angular tilt of the array atop Morley, the PV cells are most efficient during the summer because of direct, perpendicular sunlight [Figure 2].

Figure 2. *Differences in sunlight ray angles of approach in summer and winter*



Courtesy of Ubiquiti Networks, Inc.

As the captions in the figure describe, when the panels are at a low angular tilt, they receive more perpendicular light in the summer. The Morley PV array is mounted for a 6-degree tilt so it becomes less efficient in winter.

I. This leads me to my first possible solution of panel tracking. Panel tracking is not more complicated than it sounds. It is simply mounting panels in a way that they follow the sun. There are two types of panel tracking. First is continuous panel tracking, which literally moves the panels to follow the Sun throughout the day. Depending on the position of the Sun during the day, the panels constantly create a 90-degree angle with incoming rays. The second form of panel tracking is seasonal panel tracking. This type of panel tracking either automatically adjusts the panels to be tilted *by season*, or includes a manually adjustable mounting that allows for the array to be tilted at the autumnal and vernal equinoxes[6]. Now that the goal of panel tracking is known, we have to assess the solution's effectiveness in eliminating the problem of snow covering the Morley PV array. Continuous panel tracking could help in keeping snow off of the array because the panels rest at a vertical before sunrise and after sunset. This would at least keep overnight snow – a significant portion of snow – off the array. Also, the constant movement of the panels would hopefully prevent the stability needed for snow accumulation. The problem with panel tracking is that it generally requires pole mounting, which essentially raises the panels to a significant height above the ground (or roof in the case of Morley) so that the array gets the full mobility needed to follow the Sun. Raising and mounting the array alone surely presents structural problems. Yet

[6] This form of seasonal panel tracking would have the array tilted at the equinoxes in preparation for the solstices (e.g. 5 degrees in preparation for summer and 30 degrees in preparation for winter).

factors like storm-force winds in Williamstown present more of a problem with pole mounting. With pole-mounted panels, the wind would potentially rip the panels from the roof because of the large, elevated surface area. The costs associated with panel tracking are also a problem and will be discussed in the next section.

II. Another solution to snow coverage on the Morley PV array would be to implement some sort of solar hot water system that could keep the array at temperature warm enough to repel incoming snow. If there were some way to capture the heat energy lost by the PV array and heat water that circulated throughout the array, it could solve the problem of snow. SunDrum Solar, a Massachusetts-based solar energy company, has released a new hybrid type of solar panel. These panels are hybrids because they capture the heat energy lost in producing energy and use that heat for water. Essentially, this makes the panels more efficient – by SunDrum's calculations ten percent more efficient – than normal silicon solar panels. The "SDM100" hybrid panel is also supposed to capture heat loss with an efficiency of more than fifty percent.

Figure 3. *A small array of SunDrum Solar's Model SDM100 hybrid panels*

These hybrids are also made to cool the system in order to promote ideal energy production conditions. Unfortunately, it does not seem that these panels would warm the panels given cold conditions though the "20 mil air gap between PV panel and SDM collector" might help to regulate the internal temperature of the panels. If there were some way to circulate water that could slightly heat the panels in winter and cool them in the summer, this solar hot water idea might work. However, there are still problems such as the fact that the snow may just melt initially and accumulate once the water freezes and becomes a layer of ice. Also, based on the information from the SunDrum website, the max output of one panel is one half of a kilowatt. This means that if each panel in the Morley array were replaced with an SDM100, the array would have a max output of twelve kilowatts. This is about four more kWh than the standard PV panels atop Morley now. For the price of the hybrid panels, it may not be worth it to install them if only to reap a maximum of four more kilowatts. In the next section, I will take a look at paybacks and how that factors in into the viability of these two aforementioned solutions.

Economics Behind the Viability of Solutions

Twenty-four RWE Schott ASE-300 DGF/50 solar panels were installed on the roof of Morley back in 2004. These panels cost roughly $1200 dollars each, meaning the total for the array would have been $28 000. But with the costs of the inverters and installation we could project the total to be around $70 000. Luckily substantial governmental rebates and incentives would have reduced the cost by about 20 -30%, making the final total between $40 000 and $50 000. At the current rate of energy production at the Morley array (maximum 7300 kWh per year [Appendix B]) and given the current cost of purchasing energy (12.9 cents per kWh), we can figure that the saves

the college about $950 dollars ($941.70) per year. We can then calculate the payback period of the array to be between 42 and 53 years (see footnote 3). The payback period is of interest because we can weigh the viability of certain solutions based on how they affect the projected payback of the array. The NREL PVWatt modeled yearly value for energy production from the Morley array would show that if the expected amount of energy were produced, 200 kWh more energy would be gained [Appendix B]. At the 12.9-cent price of a kWh purchased by the college, 200 kWh would about another $30 per year. But a more specific month-by-month investigation would reveal that the array could actually gain about 500 kWh of energy per year[*], which translates to a savings of $65 per year. This additional $65 would decrease the payback period by about 5 years. Essentially, the earlier proposed solutions would have to either have to cost less than $65 per year or would have to significantly decrease the payback period in the long run, in order to be worth the cost.

I. Continuous panel tracking is simply out of question because each mount for one panel would cost about $1500 and thus well over the price of the current array. With added installation costs, we can see that this option is not viable. Seasonal panel tracking, however, could be more compatible since there is an option of manual tilting twice a year. The mounting would be significantly cheaper because it is not motorized and automatic. Even still, it is doubtful that mounting for seasonal panel tracking would be less expensive than just purchasing more solar panels (which would decrease the payback period in the long run). Panel tracking as a whole seems slightly out of price range for

[*] This investigation involved taking monthly winter-time averages of actual energy production values and calculating the differences between the modeled production. Adding these differences represents the total energy gain given the array's expected production.

the Morley array given the potential energy gain the college would gain. If the panels were tilted seasonally, the array would likely experience no more energy gain than it would have without the snow[7]. This would make it pointless to purchase panel tracking mounts because the Morley array would still not produce the expected amount of energy.

II. The solar hot water idea would potentially work, and surprisingly an active solar hot water collector system would only cost around $4000 plus installation costs. A standard installation would heat about 100 gallons of water per day (NAHB). Based on data from the Williams College Sustainability website, the college uses about 150 000 to 200 000 gallons of water per day. This means that a standard solar hot water system would deliver only .05% to .07% of the daily water usage. The Sundrum SDM100 panel would produce electricity as well, but only at about 15 % efficiency and at a maximum of 0.5 kW. If the standard size for the SDM100 solar hot water array is 6 panels, the array would have a maximum output of 3 kW. Thus at 4 times the size – the size of the Morley array – it would have a maximum of 12 kW and would potentially contribute 400 gallons of hot water per day. This system is beginning to look more efficient than the current array despite its relatively low efficiency in electricity conversion. A 24-panel array of SDM100 models would produce as much as 4000 to 5000 kWh more than the current Morley array. This was calculated by simply finding an array in the Soltrex database that had a similar max output to the SDM model. Because I could not find data specifically for those models, we can use NREL's epxected energy production values for a 12 kW system (with the same tilt and azimuth) to roughly predict yearly values for kWh

[7] This was determined in light of Williamstown Elementary School, which has arrays tilted at 32 degrees. The energy production was still less than the NREL modeled energy production in December, January, and February (Soltrex).

produced by the array. These calculations show that the college could save from $500 to $650 in energy costs per year with a 24-panel array of SDM models rather than the current RWE Schott models. While I cannot decisively say that it would be worth investing in an array of Sundrum's hybrid panels at this time, it may be worth the cost in the future as it would have a shorter payback period and at least slightly reduce the hot water costs for the college.

Conclusions and Suggestions

By analyzing data on snowfall, actual energy production, and expected energy production, we determined that snow accumulation is having a significant impact on the Morley array's production of energy. A few options arose to combat the problem of snow and yet few of the options seem viable. Panel tracking is simply too expensive and cumbersome to deal with in light of the New England climate. Mounting panels for tracking is not viable because of structural difficulties that would surely arise and the high winds throughout the year would present the problem of damaging the array if it were pole mounted. Furthermore, tilt is not as important of problem as snow. Changes in tilt only slightly increase the energy production. A solar hot water system seems more viable because it could payback the college in the form of energy *and* hot water. In the case of the SunDrum SDM100, it would produce energy at a higher rate than our current array on Morley. However, this system would come at a higher price and it would not be worth it to install a SunDrum system as we already have an array. I can only wish, along with the college, that SunDrum technology had existed back in 2004 because of better economic returns. I think the next step the college needs to take is perhaps hiring someone or adding the responsibility of clearing the array to a current custodial job. This

is the only true way to find out the effects of snow on the array without significantly extending the payback period. We just need to get some values for energy production without snow coverage in the winter so we can use those values as benchmarks for winter production. If we have values for winter-time energy production without snow, this will also help to establish the effects of other variables like tilt. Based on these conclusions, seasonal panel tracking may become more viable. In short, I recommend that the college do a series of short studies that would seek to find out how much energy we are *actually* losing to snow coverage. I have made the prediction that about 500 kWh per year are lost. The Williams community is lucky to have such facilities that values for energy production can be taken in fifteen-minute intervals and uploaded to computers. This allows for us to do a short study of snow effects. Even a ten to fifteen day period of manually clearing snow away from the array would give researchers (like me) a lot to go on and could either confirm or deny the significance of snow on energy production with finality.

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