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What Will it Take to Make Solar Panels Cool?

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What Will it Take to Make Solar Panels Cool?

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1. Executive Summary

With the predicted results of climate change looming, humanity must do all it can to limit greenhouse gas emissions. Maintaining a habitable environment along with the high quality of living associated with developed nations requires investment in renewable energy. Because national governments often fail to make responsible decisions for their country's future, this burden falls to institutions like UMass Amherst. Although costly investments like solar panels substantially improve the sustainability of campus, some innovative improvements of existing solar energy infrastructure can go a long way. For example, when solar panels heat up they lose photovoltaic efficiency. We propose that UMass institute cooling systems on current and future solar panel structures. This may sound extravagant, but in this paper we outline a plan for a simple and affordable cooling system that can be constructed from supplies bought at a local hardware store.

The University spent approximately $1.5 million dollars on the new solar canopy atop the Robsham's Visitor Center. This structure generates an estimated $40,000 worth of electricity each year, with a 38 year return on investment. We expect a cooling system for each canopy to cost around $500 and to improve power output by more than 10 percent. This means that by the most conservative estimate, a $500 investment will generate an additional $4,000 worth of electricity, reducing the return on investment time by 4 years. Compared with the initial solar canopy investment, this magnitude of electricity generation would have cost $150,000. By comparison, $500 is peanuts. Read on to see how a little ingenuity can go a long way to save money and the environment.

2. Introduction

Solar energy makes up the smallest fraction of renewable energy generated by the US, only 0.6% of total energy consumed [1]. In stark contrast, the solar energy striking the Earth's surface in one hour could power human activities for one year [2]. Humanity can capitalize on this staggering potential by implementing and improving solar technology to capture more of this clean and renewable energy, thereby preventing further environmental crises caused by burning

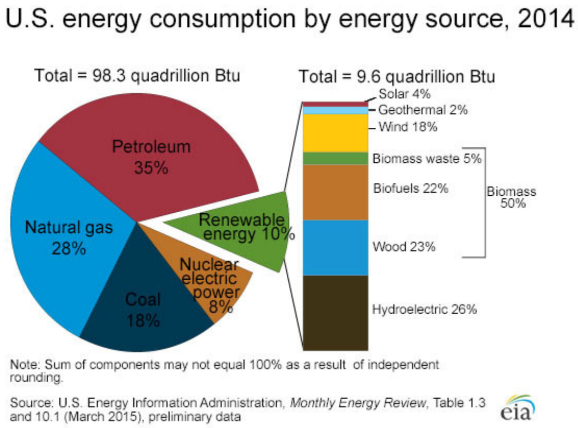

Figure 1. In 2014 solar energy made up 0.4% of energy consumed in the U.S. This has increased to 0.6% in 2015 [1].

fossil fuels. The amount of electricity generated by photovoltaics (PV) is controlled by their conversion efficiency and the amount of panels employed. Gains in either of these quantities yield necessary improvements to the sustainability of our energy infrastructure.

For most institutions, such as UMass Amherst, improving energy sustainability through increased solar PV implies investing in more panels. But what if solar panel owners could do something simple and affordable to increase power output from their existing solar installations? Due to internal electrical resistance in PV devices and solar infrared radiation, solar panels heat up during use. The PV devices have been shown to lose 0.5 percent of maximum power output per 1°C increase in temperature [3]. Such loss of efficiency has a substantial negative impact on the return-on-investment and economic viability of solar PV implementations everywhere.

Hybrid photovoltaic thermal cells (PVT) solve this problem by cooling the panels with water and using that warmed water for other applications. Complex and expensive, solar PVT has yet to see significant implementation. We propose a simpler cooling solution that we expect to quantifiably improve the power output of on-campus solar structures. Only if we move forward with this project can we learn how best to improve solar panel cooling so that solar structures on campus and everywhere, current and future, can reap these benefits.

3. Best Commercially Available Technology - How Does it Work?

Commercially available PVT devices cells tackle much of the same problems that we address and more. PVT collects electrical energy just like any other typical solar cell. In addition to this, solar PVT devices also collect thermal energy, something not done by traditional solar cells. This technology combines different forms of solar energy collection in a unique way that has provided it with success in the solar energy market.

The layout of PVT cells are not complex, they are essentially made by putting thermal energy collectors on the underside of tradition photovoltaic solar cells [4]. Typically, thermal energy component of PVT cells use water to collect energy but some models use air or a combination of both. Water runs through conductive metal pipes on the back of the solar panel. While the water in the conductive pipes absorbs heat off of the panels, the panels are subsequently cooled down. Due to increased electrical resistance, traditional solar panels decrease in efficiency at higher temperatures. Significant effects on energy output from traditional solar panels are seen as these panels can reach temperatures upwards of 50 degrees Celsius [5]. PVT panels not only operate at a much lower temperature which increases their efficiency, but also harness heat energy that would ordinarily be wasted. The heated water is used in buildings either to heat the air or as a hot water source. Some companies boast that they can collect as much as 71 percent of the thermal energy plaguing traditional photovoltaic panels [4]. This thermal energy is used in homes and buildings for heat and hot water instead of going to waste.

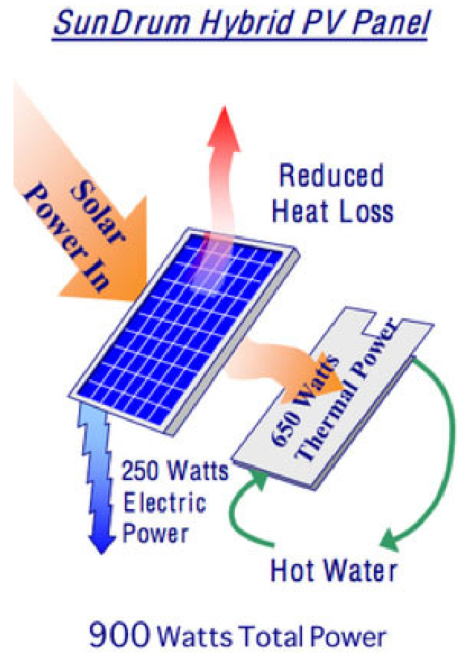

Figure 2. By combining photovoltaic and thermal collectors in a hybrid setup, energy harnessed per square foot can be maximized [4].

Hybrid PVT panels are essentially a symbiotic combination of traditional photovoltaic solar cells and thermal collector panels in the same amount of surface area that any traditional solar cell would take up. This combination increases power output per square foot. Combining these two methods has been shown to have a greater total possible energy output of panels versus either photovoltaic or thermal standalone [4]. The electrical component performs better compared to standalone photovoltaic cells due to a reduction in their operating temperature. However, the thermal aspect underperforms compared to standalone thermal collector panels, also called solar thermal energy (STE). This results from the design--thermal collectors lie underneath the PV panels and receiving heat through conduction as opposed to receiving solar heat energy directly.

Despite the fact that research and development of PVT cells began in the 1970’s they have not yet gone mainstream due to some important disadvantages they face. The biggest disadvantage of PVT is the cost. These panels cost 10% more than traditional solar cells [5] and depending on where they are installed geographically, they may not have a reasonable return on investment. One company in Boston found that the return on investment would take 72 years, 50 years after accounting for tax breaks [6]. Another disadvantage is the installation of these panels. Unlike traditional solar cells that just need to be hooked up to the electrical system, these cells also need to be hooked up to some kind of heat or hot water system which would require permits from plumbing facilities. Traditional solar cells don’t have these pressing issues which make them more viable for the general public than PVT.

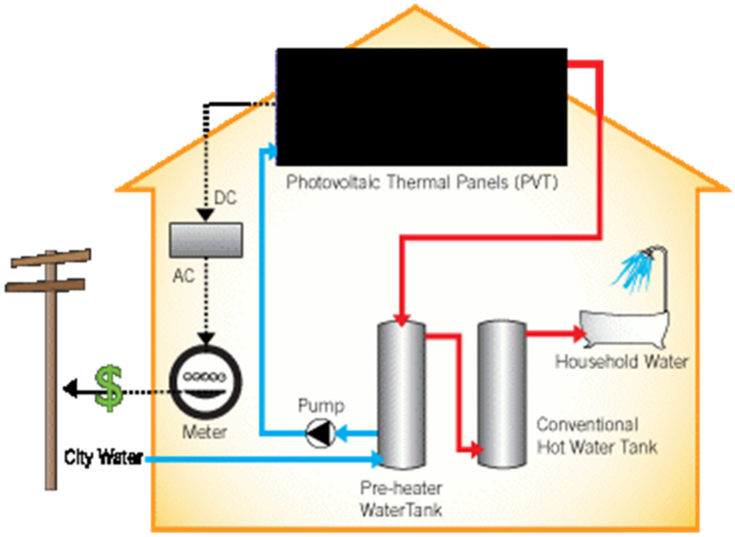

Figure 3. PVT harnesses two forms of solar energy [5].

With further research and development, hybrid PVT cells have the potential to replace traditional PV cells as the go-to solar cell. For the purposes of the Sustainability Innovation and Engagement Fund, however, they cost too much and do not offer the innovation and engagement that a student-designed rain cooling and cleaning system does. Future solar collection technologies even beyond the PVT will continue to expand the possibilities of harvesting the sun’s energy with maximum efficiency, but in the present, we can find simpler and more cost effective solutions to maximizing the energy output on campus.

4. Best Commercially Available Technology - Advantages and Disadvantages

Despite the many practical reasons to implement PVT solar cells, this technology holds more promise for the future than the present. These devices output more energy per square foot, though due to conflicting studies, just how much cannot be said with certainty [7]. Concerns over efficiency and cost-to-benefit ratio, however, call into doubt the feasibility of this technology. The questionable return on investment and higher startup cost trump the potential benefits of improved power output per square foot. A handful of overwhelming flaws prevent the hybrid

PVT technology from substantially impacting campus sustainability without further development and improvements.

Marginal gains in renewable energy do not justify large investments, so energy sustainability technologies must provide or save substantial energy. PVT panels output more power than their PV counterparts. This results from cooling the panels and storing that heat for later use. Both PVT and PV cells lose power output due to heating. PVT panels use thermal collectors to cool themselves. However, STE operates more efficiently when working separately from the PV panels. Since STE panels receive sunlight directly, they operate more efficiently than PVT thermal collection, which relies on conduction from the PV device. Essentially, this issue comes down to optimal conditions: PV panels have the best power output at low temperatures, while STE cells heat water best at high temperatures. Combining these systems forces a compromise, which diminishes the efficiency of each. Many studies which all reach different conclusions make it impossible to say with certainty whether hybrid PVT operates more efficiently than PV and STE separately [4, 6]. The most efficient and effective system must make maximal use of the available area to generate the most useable electricity.

Figure 4. PVT panels come with a more complex installation process due to the need for both electrical and hot water attachments [9].

Because this project seeks to improve campus sustainability, analyzing its benefits requires a holistic view of how its implementation affects the environment. This analysis splits into two main areas of concern: the manufacturing of panels and their implementation. This question also relates to social equity. Implementation of new technologies must not subject any groups to unfair conditions or benefit well-off groups while leaving the rest behind. In terms of manufacturing, questionable safety practices affect the environment, as well as workers. The cleaning and purification of panels during their manufacturing requires several chemicals hazardous to people and the environment [8]. Manufacturers generally recycle these chemicals due to their price and limited nature. Additionally, PV manufacturing necessitates water cooling.

Though water use varies based on plant location and design as well as the type of cooling system, to produce one panel, a PV plant can circulate well over 3000gal of water, some or all of which may be reused. Though water-free "dry-cooling" technology exists in these plants, it lacks efficiency at temperatures exceeding 38°C (100°F) [8]. Despite these environmental hazards, PVT's efficiency makes it a beneficial technology. PVT hybrid technology outputs more energy per square foot than PV and STE alone [7]. This leads to improved efficiency, or less "wasted" solar energy. Though production of PVT poses several environmental problems, PV panels undergo the same process.

Lastly, any technology that substantially improves sustainability in an eco-friendly manner and does not preferentially help nor harm any social groups still falls to the mercy of the budget. With too high an initial investment or too low a return rate, a proposal will not receive funding. Return on investment is not easy to calculate for PVT panels. Sundrum solar, a leading PVT manufacturer, boasts an average return on investment of 5-10 years [9]. On the other hand some studies have done calculations on PVT panels in Boston and estimate a return on investment upwards of 70 years [6]. These discrepancies make it hard to draw a definitive conclusion on the economics of PVT panels without first testing their performance in the location and conditions of their implementation.

Without further improvements and testing PVT has too many potential drawbacks for reasonable application at UMass. Although the device outputs more power per square foot than other types of solar panels, the cost of PVT panels per square foot makes them a less feasible solution for harnessing solar energy. Uncertainty in return on investment do not allow for any immediate definitive conclusion into the effectiveness of PVT at UMass. Perhaps further PVT studies or development will lead to more proven benefits that will make their installation on campus more reasonable.

5. Promising Future Technology - How Does it Work?

Solar panels are a rising technology that have recently been implemented here at UMass. However, due to some uncontrollable factors such as heating, the energy output of solar panels has room for improvement. Using water to cool solar panels down has been found to be an effective method [10]. We designed an original system that would collect rainwater from the solar panels at UMass and use that water to cool them on hot summer days. Additionally, solar panels can lose up to 25 percent power output from dust, pollen and other debris collecting on them according to the National Renewable Energy laboratory [11]. Implementing a system that runs water over the top of the panels addresses both of these potential sources of power loss. We intend to collect rainwater that is already guttered off of the panels for reuse on hot sunny days for this purpose of cooling and cleaning (Figure 5). Inexpensive products from any hardware store can be used to give purpose to otherwise unutilized rainwater in a way that improves the power output of a sustainable energy source on campus.

Figure 5. Our design will collect rainwater on rainy days and use it to cool and clean panels on hot sunny days.

This system is intended to be implemented on the already existing solar panel canopies in the UMass Amherst visitors center parking lot. The three canopies produce a combined 60 kilowatt system and are estimated to save the university $40,000 per year [12]. We estimate that our rainwater cooling system will be able to improve the energy output of these panels by approximately 10 to 20 percent for warmer two thirds or 8 months of the year. This would translate to about an additional 20 to 40 kilowatts on average and a monetary savings of $2,600 to $5,300 per year. Using inexpensive materials this design is estimated to cost less than $2,000 to implement on all three canopies and would therefore translate to a return on investment in less than a year. The main reason this project is so feasible is because of the relatively low cost of installation in addition to the extraordinarily quick return on investment.

Figure 6. UMass Solar Canopies [20].

In order for this system to be effective there are two main components that are needed. The first is a source of water that is at a lower temperature than that of the solar panels. The solar canopies in the Visitor's Center parking lot are shaped in a way that all of the rainwater that collects on them is already guttered to one specific point. By placing a plastic barrel at this point all of the rainwater can easily be collected for reuse. The other necessary component is a driving force to get the water onto the solar panels. Various vendors sell electric magnetic drive pumps for around only $300 [13]. These pumps are typically for used in large household aquariums or ponds. These are low maintenance and can run constantly. All pumps typically have at least a 3 year warranty and are expected to last far past that [13]. The pumps will not be running constantly however, as they are not needed to. They will be on a timer with a time interval to be determined through experimentation to determine the optimal interval to allow the rainwater to cool down some while still constantly keeping the panels cool. It is important to keep in mind that although some energy gained is lost to the energy needed for pumping it is the only usage of electricity in our entire system. For routing the water, the pump fittings depend on the model, but any hardware store sells adaptors, which can be used to connect to any type of plumbing, such as PVC or garden hose. Cheap and low-maintenance components make this system as efficient as possible.

To ensure a low cost of maintenance for this system, installing filters prior to collection in the storage barrels will keep most debris from damaging the panels or the system as a whole. Once pumped over the panels, water will be recollected in the same gutter system that collects the rainwater from the panels and will be sent back into the storage barrels to cool down and be reused. A release valve will allow excess water to exit the system when necessary. The major foreseeable management cost is in the winter when the system will need to be turned off and drained to ensure that nothing freezes up and breaks in the extremely cold days. We estimate that this will put the system out of commission from the beginning of December through mid-March or about 3 and a half months. Other unexpected costs of ownership will come into play but this is the most certain foreseeable cost. Self-sustaining nature, low maintenance and management costs, and inexpensive material allows for this system to have an extremely rapid return on investment.

6. Promising Future Technology - Advantages and Disadvantages

Our plan of making a system that can collect and reuse rainwater has many merits but also has the possibility of many problems if not designed carefully. The water requires appropriate filtration to prevent damage to the system. We must look at every aspect of our design: the water, pump, and hoses, and assure that they all work synchronously. If any part of our design were to fail this would cause the whole system to fail, but its success would increase the sustainability of campus. Rainwater as of now is an unused resource that could be used to help increase the efficiency of solar panels, but not without addressing a few concerns.

Figure 7. Rainwater collection barrel similar to what will be used for our project.

The rainwater acts as the coolant and cleaner in our system. If the water is used well, we estimate conservatively that we can increase the three solar canopies by around 15 percent, or 30 kilowatts. While the water cleans and cools the solar canopies it will become hot and dirty itself. This must be addressed, as pumping hot dirty water back onto the panels would defeat the purpose of the system. To combat the heat we plan to store the rainwater in a container outside and in the shade. Although the system was experience marginal decreases in efficiency throughout the day as the water warms up, it will reset each night and start fresh the next day. The operating temperature of typical PV cells is around 20 to 30 degrees Celsius higher than the air temperature [14,15]. The model of panel used in the visitor's center parking lot has a nominal operating cell temperature of 45 +/- 2 degrees Celsius [16]. With a 50 - 100 gallon storage barrel and the pump being on timed interval the water will cool some before it is used again. For the sediment we plan on installing a filter for the barrel so while the clean water enters the barrel the sediment will not be able to. The filter will have to be manually cleaned which will incur maintenance costs. How often the filter will have to be cleaned is wholly dependent on how dirty the solar panels are throughout the year. With the design in place the water should be clean and cool enough at all times to in turn help clean and cool the solar canopies.

We plan to buy magnetic drive pumps to pump the water throughout this system. The two problems we could face include: the pump uses more energy than is generated through cooling and cleaning, or the pump is not strong enough. These pumps operate at around 200 to 400 watts [13], a little more than 1 percent each of the expected power output increase from cooling and cleaning. Additionally, the pumps will only run intermittently and they account for the only usage of electricity in our design. The pump might also lack the power to pump the entirety of the water needed to clean and cool the solar panels. This must be addressed in the first part of our project where we test design of the project. This time will allow us to find a pump that is sufficiently strong enough to pump the water through our plumbing system. The hoses will have to be able to deliver the pumped water evenly across the surface of the solar panels. This is going to be wholly based on the design we come up with during the first part of our project.

If implemented properly, rainwater that normally just falls onto the solar panels, will be able to be reused repeatedly to keep the solar panels cool and clean. In the event that the weather causes a shortage of rainwater the barrels can easily be filled with already filtered ground water. Some aspects of our design have potential disadvantages, but because we are designing it ourselves, we can address them. Unlike a product bought off the shelf, we can revise any part of our design to address problems we may encounter, improving the viability of this solution to the problem of solar panel performance here at UMass.

7. Conclusions

The benefits of cooling solar panels demonstrate just one way that innovation can trump hefty investments. In the age of ‘smart’ technology, why not take a smart approach about our renewable energy, inarguably the most pressing issue of today? Although current studies do not give us the information necessary to make definitive claims, this project offers potential huge gains for a tiny fraction of what most renewable energy infrastructures cost.

In order to harness the awesome power of the sun, we must increase implementation and efficiency of photovoltaic technologies. We must harness this power in order to reduce greenhouse gas emissions, which threaten wildlife and us according to the EPA [17]. Of UMass' greenhouse gas emissions, 85 percent come from building related energy use. More than half of this comes from natural gas combustion and can be replaced by carbon-free solar power. The University emitted 150,000 tons of CO_2 equivalent (eCO2$_2$) in 2015 [18], or about 5 tons per student. For reference, the average US citizen has a carbon footprint of 20 tons of eCO_2 per year [19]. This means that the University contributes about 25 percent of each students' carbon emissions. As global warming threatens our habitat, the University must do all it can to reduce carbon emissions on behalf of its students. The University generates too much avoidable greenhouse gas pollution. By implementing our proposed solar panel cooling system, the university can substantially improve sustainability on campus at very low cost.

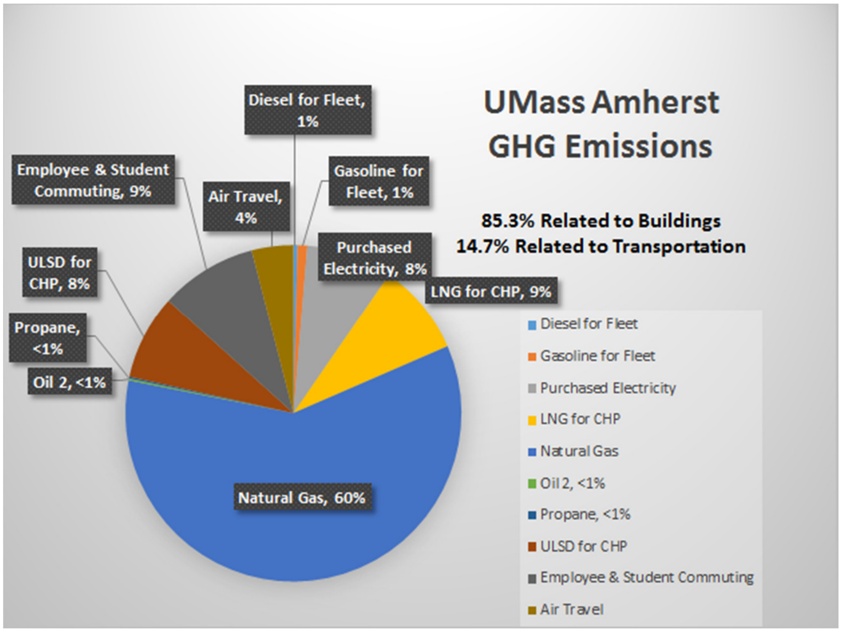

Figure 8. UMass Amherst GHG Emissions
Data published in 2016 [18].

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