Solar Design for LEED Gold Proposed Garage, Ferguson Township

Luke Meyers   Eric Podwojski   Nicholas Dobson   Joel Galtieri

I. Executive Summary

TECHNOLOGICAL advances are making solar power an increasingly affordable form of renewable energy. This means society is getting closer to having a clean, pollution free source of electricity at a cheaper cost than most fossil fuels. Tax incentives are also being put into place that are making PV systems even more economically attractive. According to UCSUSA By early 2014, the United States had more than 480,000 solar systems installed, adding up to 13,400 megawatts (MW), enough to power some 2.4 million typical U.S. households. This rapidly growing trend is positively affecting both commercial and residential energy needs. The client, Ferguson Township is seeking to install a solar energy system on top of a LEED Gold certified garage building with the possibility of onsite battery storage. To meet the clients needs, we designed a roof-mounted photovoltaic power system for the garage. This garage is going to act as a maintenance garage as well as office space, which the client would like to be fully powered by solar energy with an electrical storage system utilizing the grid as a back-up when necessary. The client consists of Ferguson Townships local government leaders. Ferguson Township is located in central Pennsylvania, a diverse climate region with four seasons. The site is located at 3147 Research Dr, State College, PA 16801 and the building is specifically at latitude:40.762645 and longitude: -77.873797. Policy concerning renewable energy is constantly changing on both the federal and state level. Pennsylvania has several incentives to progress the use of solar energy. Several incentives used in this project to lower the cost of the energy system are discussed further in the document. Using electricity bills from the existing buildings on the site, it is estimated that the new LEED Gold garage will use 2,200 kWh per month. To properly size the buildings load, we decided on using 102 photovoltaic panels arranged with 17 panels in series and 6 panels in parallel dependent on the inverter we chose. Fortunately, there are not any obstructions to cause shade if the new garage is built higher than the existing garages surrounding it. To make this project finan-

L. Meyers is with the Department Department of Energy and Mineral Engineering, The Pennsylvania State University, University Park, PA 16802. e-mail: ljm5407@psu.edu

E. Podwojski is with the Department of Energy and Mineral Engineering, The Pennsylvania State University, University Park, PA 16802. e-mail: eap5335@psu.edu

N. Dobson is with the Department of Energy and Mineral Engineering, The Pennsylvania State University, University Park, PA 16802. e-mail: ncd50924@psu.edu

J. Galtieri is with the Department of Energy and Mineral Engineering, The Pennsylvania State University, University Park, PA 16802. e-mail: jwg5510psu.edu
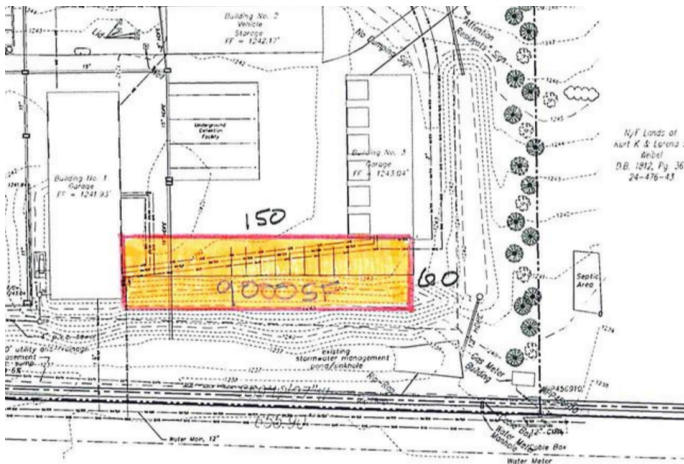
cially plausible, some constraints had to be altered. For instance, the clients request to have onsite battery storage would make the project costly. Financial analysis of the new garage with different constraints is performed later in this document. Due to many constraints and clients needs we were able to make recommendations on whether the client should pursue a solar energy system on their new building. With an estimated payback of 20 years, we recommend Canadian Solar panels with a power output of 36 kW to meet the demands of the winter months. In the summer months, the panels will produce almost double the amount of energy than in the winter, which can be used to power the other pre-existing buildings around the Townships land. A battery is not recommended to use due to cost that amplifies the payback period.

II. Introduction

FERGUSON Township put out a request for an engineering firm to plan and build a new LEED Gold garage on the site in early February 2017. A firm has not been selected as of when this document was written, however a complete solar analysis of the site has been done so when an engineering firm is selected to take on the project, they can use the data in this document to incorporate a solar energy conversion device into their building plans.

A. LEED

Leadership in Energy and Environmental Design (LEED) is a sustainable building design certification that can be obtained through the U.S. Green Building Council (USGBC). The certification is obtained by meeting requirements set forth by the USGBC. Different levels of LEED certification can be obtained by meeting more sustainable building requirements. With respect to this project, the client is seeking to obtain LEED Gold certification. Installing a solar energy conversion device on the proposed garage will help earn the LEED Gold certification.

III. Proposed Site Plan

The proposed garage will be approximately 9,000 square feet located on the Townships property– See Fig 1. The new garage will connect to garages directly next to it that already exist– See Fig The plan is to have the existing garages connected during construction phase. As long as the roofs of the existing buildings do not cast a large shadow on the LEED garage roof, there should not be much of an issue.

Fig. 1.　Ferguson Township's provided layout and site

Fig. 2.　Ferguson Township's Site Location

IV. Literature Review

A. Choosing Technology

Cost is just one common factor when it comes to choosing technology to be used in a photovoltaic system. The price of different technology is dependant on power output, physical size, material quality, brand, and durability. Durability can be safely assumed based upon the warranty period product feedback. Price will also vary with the number of units being purchased. Usually the cost is cheaper per unit when buying in bulk. To decide on the quantity of the product, you have to find how much power output you will need and also how much area you have to install the panels specifically. One could also look into what products meet criteria for government incentives which can in turn lower costs. There is also a set of other factors to look into. Panel tolerance shows how much the power output could differ from the specifications. A bad tolerance could mean a 200 Watt panel might actually produce 194 Watts. Temperature coefficient explains how heat can negatively affect panel operation. Conversion efficiency is basically how efficient a panel converts

solar power to electricity. Potential-induced degradation caused by stray currents can affect performance. Light-induced degradation is due to stabilization of a panel after installation. Pay back period is how long it will take for the technology to pay for itself. Lastly, the real world performance of products. All of this applies to solar panels however there are some other factors that should be researched before choosing inverters. You have to know the AC/DC ratio, output power, input power, and the type of inverter. Inverter type varies on whether the PV system is connected to the grid or not as well as if a battery for energy storage will be used.

B. Solar Panels: Monocrystalline vs. Polycrystalline

The first step in choosing a solar panel to be used for a photovoltaic system is deciding between Monocrystalline and Polycrystalline. Monocrystalline solar panels are built out of a single continuous crystal structure and is the more developed of the two since it has been in use longer. Mono panels are also more efficient in converting electricity per area by producing a higher amount of power per square foot when used in arrays. They also have a smaller degradation of power output due to falling temperatures when compared to poly. Another benefit is the long life span usually coming with around a 25 year warranty for a panel depending on manufacturer. The disadvantage for mono panels is that they are the most expensive. This is due to manufacturers that still produce mono to target the more premium side of the market. Polycrystalline panels are also made from a silicone crystal structure however they are allowed to cool when being processed, which gives them the graininess and distinctive edges on the cells. The main advantage for poly panels is that they are cheaper due to smaller production costs. They are also more tolerant to heat which means they will fail less in extreme temperatures. The disadvantages to poly however are simply the advantages of mono explained earlier. The next area to look at is price.

C. Batteries: Lithium Ion vs. Lead-Acid

There are some big differences when comparing lithium ion batteries vs lead-acid batteries. First, lithium ion batteries have 2000-5000 life cycles depending on how well you take care of it when compared to 300-500 life cycles for lead-acid batteries. Secondly, lithium ion batteries are a much more clean technology and are more environmentally safer than a lead-acid battery. Also, lithium-ion batteries are nearly 100 percent efficient in both charge and discharge. Lead acid batteries inefficiency leads to a loss of 15 amps while charging and rapid discharging drops voltage quickly and reduces the batteries capacity.The lithium ion battery is a better choice for our project because of how our client wants use to utilize LEED and if lithium ion batteries are safer for the environment and are a cleaner technology than its the best battery for use to employ.

D. Comparing Two Specific Solar Companies

Solar World
- Largest US manufacturer for solar panels
- Produced solar panels for 40 years in both Germany and US
- 25-year linear performance guarantee
- 20-year product workmanship warranty

Canadian Solar
- Based in Canada
- 16-year-old company and only getting bigger
- Have state-of-the-art manufacturing facilities in Canada, China and Vietnam
- Leading Global solar company
- panels have high system energy yield at low irradiance and low NOCT

V. Technological Constraints

A. System Losses

Losses occur in any PV system. Our system in particular, contains a string of panels connected to either several or a single inverter, then further connected to a battery bank (Dependent upon Simulation ran).The system losses can be summarized in Fig. 3.

The task of the inverter is taking the Direct Current (DC),created initially by the panels during photogeneration, and convert it to Alternating Current (AC)– typically appliances and machines run off of AC current. In doing so there is roughly some amount of energy lost. Of the two inverters we simulated there was varying losses (A loss of 1.8 percent for the 36kW inverter and a 2.43 percent loss of energy for the 5200W converter). The decline of efficiency occurs from small circuitry losses and moving mechanical parts.The Panel's soiling losses are caused from the estimated layer of dust and pollen that accumulate on the receiver's surface. During the summer drought months and the pollen heavy fall and spring are the times when this loss is at its highest. The remainder of the losses in Fig. 3 are an accumulation of circuitry and wiring losses in the system. Be aware that the addition of a battery system may be useful to store the daytime captured energy, but with this comes additional losses when AC energy is stored and then later dispatched. As a final, the panels themselves have an efficiency of converting the incoming irradiation into usable solar power. As advised before, the installation of low efficiency panels is not the best choice. The panels selected for review ranged from 16.17 to 18.20 percent efficient. Price is usually a correspondent to efficiency, so, the choice of panel would need to be made upon that parameter. The panel of best fit for this location was the Canadian Solar CS6U-335 mono. It was noticed that no matter what panel was chosen the amount of Dollars/kWh did not change substantially. The advised choice was the Canadian Solar CS6U-335 mono technology with an efficiency of 17.3994 percent and a price of $\frac{70 cents}{kWh}$.This panel gave a close estimate to the demand of electricity for the winter months, as well as a good installation price– more economic concerns are given later in the report.
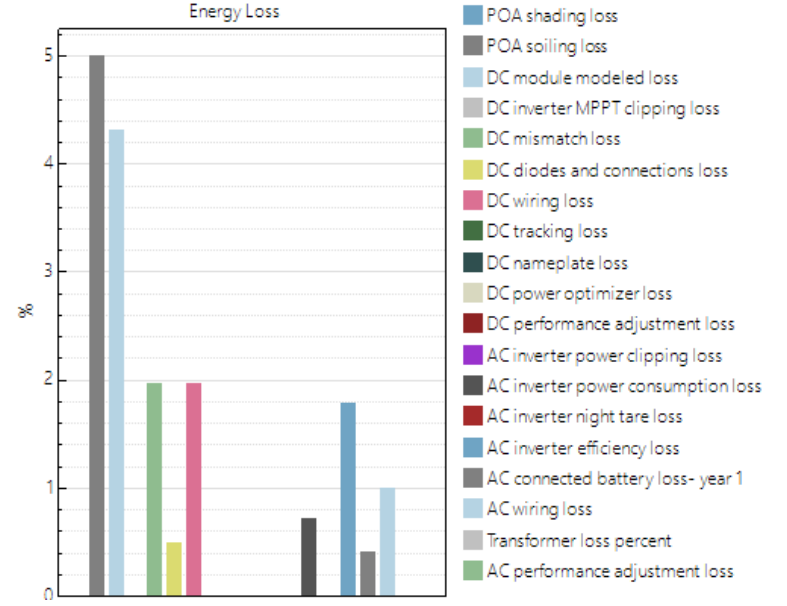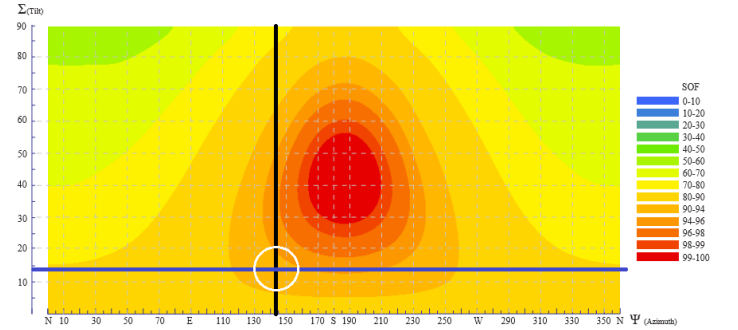

Fig. 3. System Losses

Fig. 4. Winter Months Optimum Tilt and Azimuth

B. Resource Losses and Optimizations

By utilizing Skelion (Program Extension for Solar Design), the exact location and directional orientation of the proposed building's site plan can be evaluated. This is known as the Azimuth of the collector. This parameter is needed for estimating the amount of solar resource able to be captured– compared to that of the ideal condition. Similarly the tilt of a collector is used to determine the amount of usable irradiation absorbed by the collector. Depending on the orientation of the roof and the building there is a certain percentage of collection available– seen in figure 4 and 5. The Optimum location is within the red sector. As marked by the blue line, being the proposed realistic tilt of the roof, (14.04^o) and the black line being the building's proposed location azimuth (144.71^o, North = 0° and South = 180°, East reducing toward North), this shows the location of our collectors being placed directly in the plane of the roof. Electric demand for the garages is highest in the winter months, so an additional tilt could be given to the panels upon installation The Panels could be given an ad-
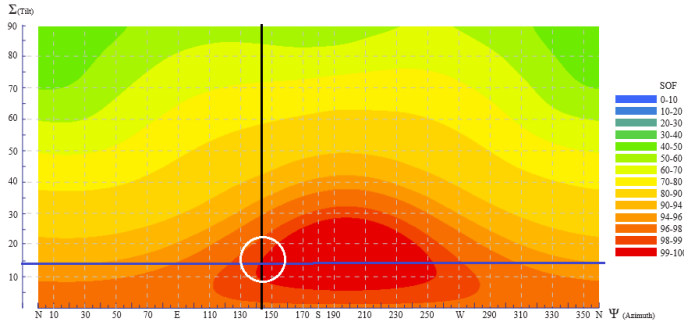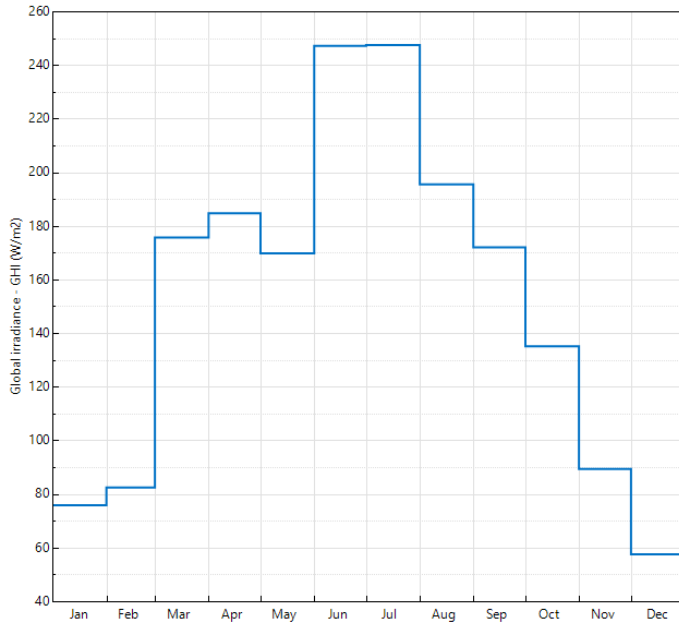
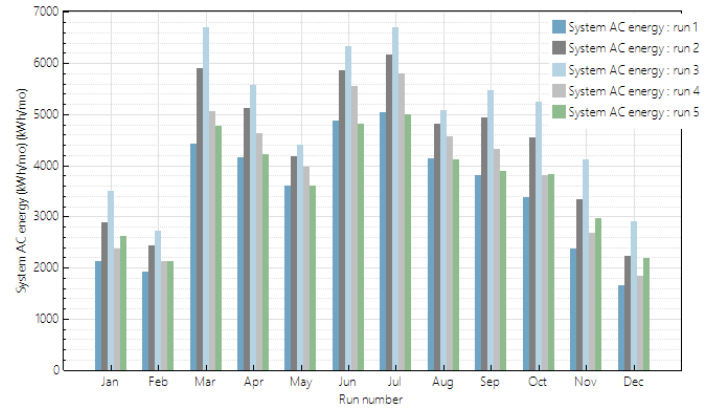Fig. 5.   Summer Months Optimum Tilt and Azimuth

Fig. 7.   Tracking System Variances

California, there is a larger amount of irradiance– especially in the winter months. This is where the investment of a tracking system or mounting manipulations make for a favorable difference (both economically and solar harvesting wise). The main goal for us designers is to minimize these losses and maximize the amount of solar in this locale, simultaneously we look to minimize the cost of unnecessary installations. The exact value of a tracking system of those mentioned is not absolute because it would vary on the amount of panels you would need as well as the desired orientation. What we do know is that operation and maintenance cost are going to increase significantly compared to just laying panels out flat on the desired tilt of the roof.

Fig. 6.   Global Horizontal Irradiance Averaged for Each Month

C. Modeling Limitations

One parameter that was unavailable to model was the affect of snow losses for the PV system. This may not have been much of a concern in the recent years with mild winters. This is not the case for a 25 years evaluation period. There is bound to be some winters with large storms. Since our main concern is the winter supply of energy for the garage This would be an issue to evaluate more in depth before installing a large array on the roof. Certain parameters that were found we believe disrupted the accuracy of our simulations. Specifically, the simulation of distributing our electricity to other parts of the location and reducing the overall bill of our location. The cost of our modules and inverters were found through a retail market supplier. This would mean for larger prices than those you through an installation company like Solar City. This could have affected the payback period of our project significantly. Also, the inflation rate of fuel prices and electricity prices was unknown. Arbitrarily the default inflation value of money was used, but this does not model the realistic decline of the fossil fuel reserves. The use of batteries in a simulation was complicated. I am not sure if the simulation was ran properly for modeling them. there are specific that are needed for a proper simulation, such as dispatch rates and exact charge rates. Shading was another limitation, described however in it's own section.

ditional tilt when installed but as seen in the Optimization diagrams the losses do not improve by much, at most the winter months you may gain an additional 2-4 percent. As seen in fig. 6 there is a large difference between the potentials of each month. The materials going in to making the pitch of the roof or adding mounts to the system would most likely cost more than the additional 4-6 percent of irradiance that is gained from changing directional parameters.
Similarly to optimizing direction, the idea of using a tracking systems over a fixed one is used to harvest a greater amount of the sun's rays. A tracking azimuth (follows the azimuth of the sun across the sky),Seasonal tilt (tilts according to the declination of the sun), tracking axis 1 and 2(tracks north and south or North,South, East,and West) systems were all tested in parametric simulations and the results are shown in figure 7 with runs 1,2,3,4,5 being Fixed, 1 axis, 2 axis, azimuth, and seasonal respectively.

When you are in a location such as Arizona or Southern

D. Shading

This site has an optimal no shading feature. Fig 1 shows the pitch of the other garage roofs are sloping towards the centralized pavement area. The optimal direction and tilt of the LEED garage is the opposite of the other preexisting garages. This would put the garage just about due south with a tilt appropriate for the panels. The location of this garage will have no shading problems from existing structures or trees, as long as the pitch of the roof points south East. as for features on the roof, we were at a disadvantage with not knowing of any vents or high profile objects on the roof. If there are any after construction they would have to be evaluated for possible shading on the panels. Shading only hurts the performance of solar panels. The roof has a substantial amount of surface area available for manipulation of solar panel orientation, so minor shadings should not be an issue.

As a way to simulate the installation of possible bathroom vents (bathrooms are in the design plan). We installed a 1.5 meter venter on the roof of the garage. Through Skelion, using the Geo-location, we were able to map out the path of the sun and show the shading on panels that surround the Vent. Through the Minimum Shading analysis, the shadow of the vent was given a perimeter of shading area through the course of the year. This perimeter as well as the surrounding shading losses are shown in pictures at the end of the document. The path of the sun moves east to west over the course of the day as well as an aphelion pattern through the course of the year– due to the elliptical orbit of earth around the sun coupled with the 23.5 degree tilt of the earth. These shading losses were not considered in our simulations simply because the usable area of the roof is much greater than the small area of shading caused by a 1.5 meter object. This was done to give awareness to the affect of a small item in a PV system.

VI. Socioeconomic Analysis

A. Carbon Prevention

The client is in need of a LEED Gold building with considerations of solar energy energy incorporated into the building with a possibility of onsite battery storage. The building is still in the design phase, so the analysis in this report includes several simulations of solar design. Ferguson Township is seeking to reduce their carbon footprint. This is why the township is calling for a sustainable building with renewable energy generation and storage. The client asked for a shadow price of carbon calculation to evaluate how much the township will be reducing their carbon footprint. For the large simulation performed, the solar array will produce about 40,000 kWh over a year. At a conversion of 0.55 kg of CO2 emitted per kWh, the client will prevent 22,000 kg or 24.3 tons of carbon from going into the atmosphere every year [7]. Being a LEED building, the carbon prevention will be even higher as the building is built to be more energy efficient.
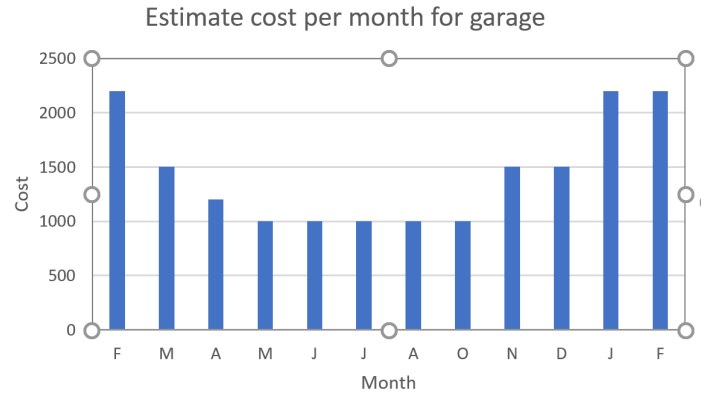

Fig. 8. Estimated Load for the months of the year, this was done using the calculation in the Loading Estimate Section

B. Client Demands

The client also stressed that the townships seeks to be more independent and sustainable. Ferguson Township insisted on not selling energy back to the grid to power more on sight equipment and buildings. This decision lowers the ability for the photovoltaic system to pay itself off sooner, however if the client has the appropriate funds, then it will be a worthy decision to become more independent. The client also suggested the need for onsite battery storage to charge their equipment and use for backup power in case of grid failure. Some of the equipment includes truck batteries, power tools, and small electric vehicles. Appropriately sized batteries for the system are needed to ensure all the clients charging needs can be met. Unfortunately, incorporating batteries into the design makes the cost of the project dramatically higher.

C. Loading Estimates

As mentioned, the new building will be much more energy efficient than the pre existing garages already onsite. From previous electric bills obtained from the client, the new buildings electricity consumption was estimated. The analysis in this report includes a solar energy system sized for a normal building like the rest already onsite as well as a more energy efficient building estimated to use 25 percent less energy. The system was sized to meet the energy needs of the winter months when the garages use the most amount of energy, according to the previous electricity bills. The loading estimates for a given winter month is 2,200 kWh. Sizing the system to produce 2,200 kWh in the winter increases cost dramatically. During the warmer summer months, the buildings load is cut in half, but the solar array produces twice the amount of energy. If a battery is incorporated into the system, the township can export the unused energy into the battery for use during the night. An energy efficient LEED building will cut costs of the 2,200 kWh sized solar energy system as the building load will be reduced.

Load estimate Calculation for The Billing Period of Jan 20th to Feb 20th:

$$kWh_{consumed} = 6,388kWh$$

$$ft^2_{total} = 26,180.327ft^2$$

$$\frac{6,388kWh}{26,180.327ft^2} = .244\frac{kWh}{ft^2}$$

$$.244\frac{kWh}{ft^2} * 9,000ft^2 = 2,196.0kWh$$

Note: This value calculated was rounded up to make for an over estimated energy output. Also, since this building is LEED is is most likely going to be designed to consume less energy than a normal maintenance garage.

D. Incentives

To help lower costs of the solar energy system, different federal and state incentives were taken into account. One of the biggest federal incentives driving renewable energy projects across the country is the Investment Tax Credit (ITC). The ITC is a 30 percent tax credit for solar systems on residential or commercial properties [8]. As long as the photovoltaic panels are designed and installed between 2017 and 2019 then the project will be able to utilize the full 30 percent tax credit. The utility company providing power to Ferguson Township, West Penn Power participates in many state wide incentives for renewable projects as well. One of the utility companies incentives is a 25,000 dollar grant program for non profit entities (https://energy.gov/savings/west-penn-power-sef-grant-program). West Penn Power also offers net metering for electricity sales back to the grid, however the grant program and the net metering incentive cannot be used together. The client also prefers to not use net metering to stay independent from the grid. Through simulations, the 25,000 dollar grant was deemed to be more financially worth it to utilize.

E. Electricity Rate Structure

Ferguson Township municipal buildings include offices and garages. Using previous electric bills, it is calculated that the township pays about 8.3 cents per kWh on all the buildings and garages. This estimation includes the electricity rate of 6.07 cents per kWh plus extra costs including the inflation rate of fuel of 2.5 percent. The inflation rate of fuel will make the average price the township pays for electricity to increase, however the new onsite electricity generation from the solar system will save the township from increased electricity prices over the years.

VII. Design Criteria

The Size, cost, and production of kWh are all results that were dependent upon many factors. The panel, the inverter, and the desired wattage can all be changed by a small amount and the entire system is changed. Three Solar World panels were tested each of a different material and watt rating as well as two Solectria inverters. These technologies were simulated according to the lowest cost. The appropriate combination of the two were used to reduce Capital cost for the system. The final outputs were summarized by S.A.M.(Systems Advisory Model) and as

the final design proposition we decided to model the Canadian Solar Panel CS6U-335 mono with a single Solentria Inverter PVI-36kW TL 480 V$_{AC}$ as well as the Solar World SW 350 XL mono with the same inverter. These two were chosen because we are not constrained with space and wish to have a panel that works best in low irradiance conditions.

A. Design Goal

The goal when designing for rooftop solar for the LEED Gold garage was to maximize the amount of power extracted during the winter months. The roof top has more than enough room for panels and minimal shading. The idea of maximizing for the winter and having excess during the summer for storage or other on site locations was issued.

B. Panel: Canadian Solar CS6U-335W mono

To achieve the 36 kW of power needed, 102 panels are being implemented. To meet the 36 kW of power and 480 volts of DC current, the modules are placed with 17 panels in series and 6 rows of parallel series of panels.

Note: Voltage increases when panels are placed in series and current increases when panels are placed in parallel. Voltage stays the same in parallel and current stays the same in series. The limiting factor to the orientation of the solar circuitry is the inverter. It has a maximum DC voltage so the panels have to be placed accordingly to the limit the inverter can handle.

The cost of the Canadian solar panel system is 23,919 dollars at year of installation plus the cost of installation itself would end in a net price of about 95,000 dollars. With certain incentives and grants the price I simulated was 74,527 dollars. The surface area of the roof allows for freedom in placement of panels. As long as the circuits configuration match that of the inverter's limits.

C. Panel: SW 350 XL mono

A similar kW output was desired and because of this the same amount, 102 panels placed in same 17 series and 6 parallel, was needed. This is due to the similar range of max power voltages, Canadian solar has one of 37.8V and Solar world has a V_{mp} of 38.4 V. Similar to the Canadian Solar simulation the 36 kW inverter was used. The price for the SW panels are a little higher giving a net cost at year of installation of 31,773 dollars with a total installation cost of 86,301 dollars. The Solar World panels had a better review than Canadian Solar according to the literature review section, but a simple analysis was done to show which panel to model with batteries.

This break down gave that the amount of power produced from both simulations compared to the reduced price from grants and incentives; resulting in the Canadian Solar being the best choice to do a modeling scenario.

CS6U-355 Mono	
Panels	102
Dollars/W$_{DC}$	.70/W
System Price per Unit Power	1.795/kWh

TABLE I

CANADIAN SOLAR PANEL BREAKDOWN

SW 350 XL- mono	
Panels	102
Dollars/W$_{DC}$	.89/W
System Price per Unit Power	1.952/kWh

TABLE II

SOLAR WORLD PANEL BREAKDOWN

D. Inverters

This algorithm will leave the decision of inverter choice up to the designer. As long as the information on the inverter and panel of choice is known then this calculation will give the appropriate circuit orientation of the panels. The Superscript P is for the module and I is for the Inverter.

$$V_{mid}^I = \frac{V_{mppmin}^I + V_{mppmax}^I}{2}$$

$$N_{series}^P = \frac{V_{mid}^I}{V_{mp}^P}$$

if:

$$N_{series}^P * V_{oc}^P \geq V_{dcmax}^I, N_{series}^P = N_{Series}^P - 1$$

if not then:

$$N_{inverter} = \frac{N_{series}^P * N_{Parallel}^P * P_{module}}{F_{dc-ac} * P_{inverter}}$$

$$N_{Parallel}^P = \frac{P_{array}^P}{N_{Series}^P * P_{module}}$$

Example Inverter Checks:

Calculations:

Case 1:5200 W Inverter

$$V_{mid} = \frac{200V+500V}{2} = 350V$$

Solectria PVI-5200TL 208V	
V_{mmpmin}(min. Power Point)	200 V
V_{mmpmax}(max. Power Point)	500 V
V_{dcmax}(max DC voltage)	5,338.07 W$_{dc}$
$P_{Inverter}$ (max AC power)	5,200 W$_{ac}$
F_{dc-ac} (Ac/Dc ratio)	1.20
$N_{inverters}$	5

TABLE III

KNOWN OF DESIRED INVERTER

Solectria PVI-36kW TL 480V	
V_{mmpmin}(min. Power Point)	520 V
V_{mmpmax}(max. Power Point)	800 V
V_{dcmax}(max DC voltage)	36,715.2 W$_{dc}$
$P_{Inverter}$ (max AC power)	36,000 W$_{ac}$
F_{dc-ac} (Ac/Dc ratio)	1.20
$N_{inverters}$	1

TABLE IV

KNOWN OF DESIRED INVERTER

$N_{series} = \frac{350V}{37.8V} = 9$

$9*46.1V \leq 5,338.07W$ so, $N_{parallel} = \frac{33,193W}{9*335W} = 11.01 = 11$

$N_{inverter} = \frac{9*11*335W}{1.20*5,200W_{AC}} = 5.3 = 5 inverters$

Note: the ideal ratio is 1.2 for DC to AC current, but for this case it is 1.28.

Case 2: Solectria PVI- 36kW TL 480 V

$V_{mid} = \frac{520V+800V}{2} = 660V$

$N_{series} = \frac{660V}{37.8V} = 17.46 = 17$

$17*46.1V \leq 36,715.2W$ so, $N_{parallel} = \frac{34,199W}{17*335W} = 6.005 = 6$

$N_{inverter} = \frac{6*17*335W}{1.20*36,000W_{AC}} = .791 = 1 inverters$

Arbitrarily we chose to look at two Solectria Inverters. One with a low Voltage at 5200 Watts$_{DC}$ and one with a higher voltage of 36 kW$_{DC}$. The two were modeled with each of the panels tested. The unit price for a Solentria PVI 36 kW TL 480 V inverter is 4,411.76 dollars/unit and the price for a Solentria PVI-5200 TL 208 V inverter was 1,640 dollars/unit. When the load required is in need of multiple inverters vs. having one with a greater voltage and current capacity then after a certain point, it is more economically feasible to purchase one inverter at a higher unit cost; rather than purchase multiple smaller inverters. In this specific case the 36 kW of 102 panels required one 36 kW inverter or four 5200 W inverters. The better choice economically was to choose the single inverter.

E. Battery

Referring to the Canadian Solar Panel and the 36 kW inverter with 102 panels.During the summer months there is an excess of energy produced compared to the amount demanded. Roughly 1,650 kWh to 1,850 kWh of extra power is available during the months of July and June respectively (estimates made from the Demand and production figures). A month has 30 days, so 60 to 33 kWh for each of those months of extra power per day. This is the value to which we are going to size the battery bank. Using 60 kWh, the Lithium ion: Nickel Cobalt Aluminum Oxide battery was chosen. Compared to other batteries this material required only three in a string. The Lithium Ion was chosen due to the detailed literature review section. The life time of the battery is much longer than the other Lead based batteries, and considering the LEED project the Lithium Ion is less likely to pollute and is more sustainable.
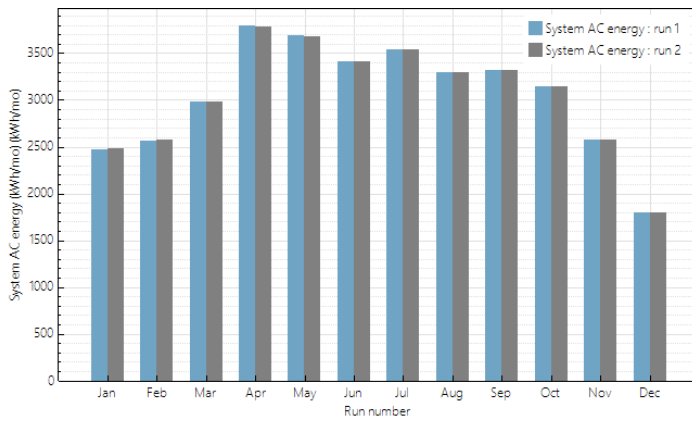
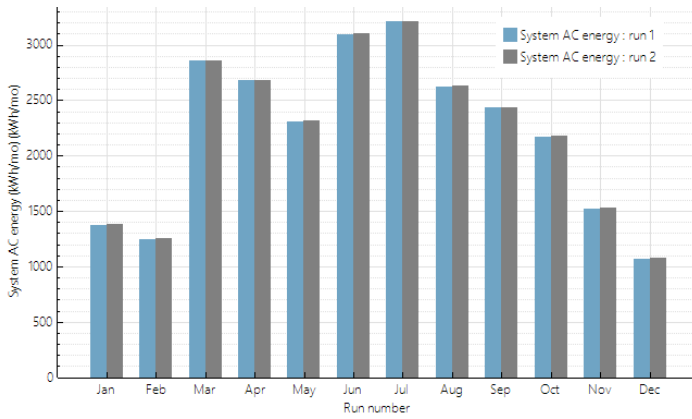Fig. 9.   Mono vs. Poly power production: Arizona

Fig. 10.   Mono vs. Poly power production: State College, Pa.

F. Poly. vs Mono. - 255W Panels

As seen in figure 8 and 9, run 1 and 2 being Mono and Poly-silicon crystals respectively, there is no visible difference in the amount of irradiation collected. Different locations with a noticeable difference in irradiance were simulated simultaneously. There is however a difference in the price per Watt. The Poly-silicon panels range around 90 cents/W and mono-silicon ranges at 1.10 dollars/W. Depending on the brands of panels and the desired wattage we would suggest picking a poly-silicon based, however there is better economic parameters and higher energy output with higher watt rated PV panels. This type of panel is what we decided to model as our final simulation output.

VIII. Model Description

A. Economic Evaluation

After running parametric simulations with different PV modules, inverters, tracking systems, and batteries. We decided to simulate the Canadian Solar CS6U-335 W Panel, with the Solectria 36 kW 480 V Inverter, the fixed mounting system, and the installation of Lithium Ion battery banks. The payback period as well as the alternative economic simulations were examined to suggest the best system to install for this particular site. First a brief overview of the parameters being ran.

- Modules: CS6U-335 W- 102 panels, Area- 196.6 m^2, cost- 23,939.42
- Array: Series-17 panels, Parallel- 6 Sets
- Inverter: PVI-36kW 408V- 1 inverter, Cost- 4,411.76
- Lifetime Evaluation: 25 Years
- Orientation: Azimuth- 144.71^o East of south, Tilt- 14.04
- Tracking System: None, Fixed to Plane of Roof
- Battery: Lithium ion: Nickel Cobalt Aluminum Oxide, 400 V, 60 kWh Storage, 3 on site, Cost- 11,088.00/battery
- Financial: Mortgage, 25 years
- Incentives: West Penn power Sustainable programs- 25,000 Grant, West Penn loan Program, Investment Tax Credit- 30 percent Electric Buy rate: .0838/kWh (Averaged with all bill charges) Load: (See Socioeconomics Section) LEED garage only w/ battery storage.

The next biggest challenge was getting the project to pay off. Since the electricity is not being sold back to the grid then we had to find other ways to bring the payback period down. Coupling the battery bank with the large PV installment we are looking at a total of 108,656 dollars after the West Penn Power Grant. Over the 25 years this project will not pay off. The battery bank alone cost more than the panels and the inverters combined. The economics ran were as follows:

- Buying Price: .0838 dollars/kWh
- Savings Price: .0838 dollars/kWh
- Grant: 25,000 dollars year zero
- ITC: 30 percent off installation cost
- Buying Price Inflation: 2.5 percent

Limitation: In the simulation we accumulated the kWh produced each month over the course of the year. At the end of the year the amount left over is credited as 'selling' back, even though realistically the electricity would just be used elsewhere on site. So, we modeled this by selling the left over kWh at the end of each year as .0838 dollars/kWh, Figure 10 shows the amount of kWh left over at the end of the year that is able to be used elsewhere in our site location. The problem with this is every year the price of electricity will change(most likely going up with fossil fuel constraints). This aspect we could not model.The payback period would most likely be quicker considering by year 25 the savings price of electricity could be well above the 8.83 cents that was modeled.

Since the price for a battery bank was so high We ran a simulation with no battery bank. The results were as follows:

- Payback Period: 20.1 years
- Net Present Value: 185 dollars
- Net Capital Cost: 74,527 dollars

Limitations: Similar to as described before, the 'saving' price is not inflated with time. Payback period is most likely a lot lower.
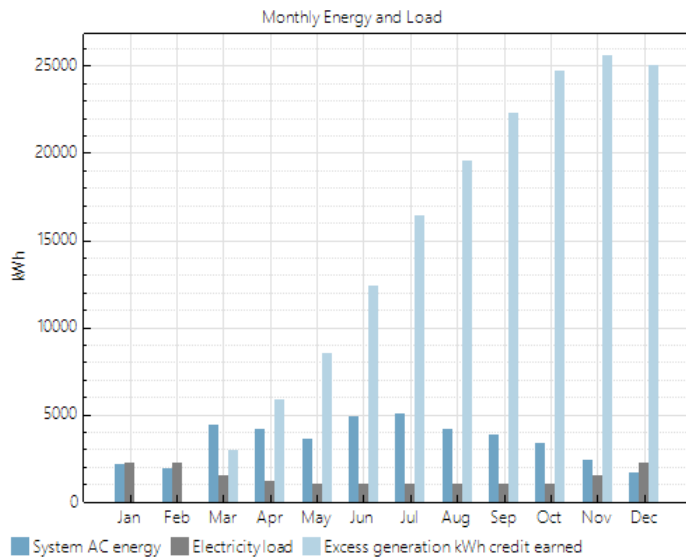
Fig. 11. Monthly Load and Energy Production with Yearly kWh excess viable for diverting to other on site locations
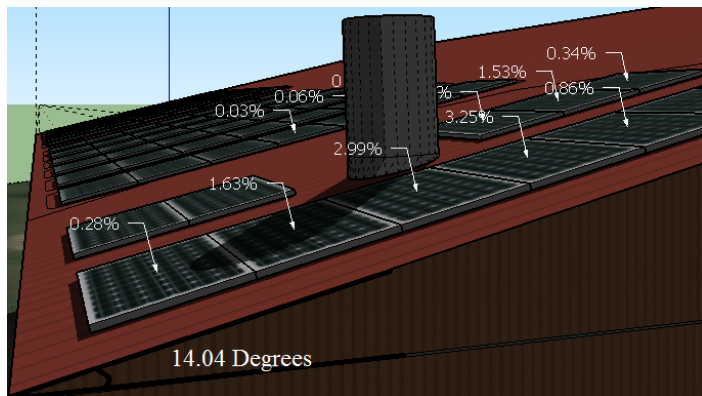

Fig. 12. Evening Hours shading during the month of June, casts a shadow on the lower panels over the solar azimuth sun path

B. Visual Models

Now that the design of ours is deemed economically feasible we used the skelion program to model the look of the 102 panels on the total surface area of our roof. Simultaneously, we ran a simulation of features on the roof that caused shading. We were limited to exact locations, heights, and other features of high profile objects on our roof (vents, HVAC units, etc). However, panels that are within a distance of 5.3 meters from a 1.5 meter object are subjected to partial shading at some time of the day. These percentages of shading over the course of the year are not relevant in the course of the entire year. Some objects cast larger shadows for longer periods of the day and at that point the panels would be better to be moved elsewhere. Even if some minor causes of shading were to occur in some sections of the roof, there is such a vast surface area available for installation that we could work around this in some way. When 102 panels is mentioned, it seems like the area of the roof would be constrained.However, totaling an area of 196.6 m^2 compared to the 862.845 m^2 of
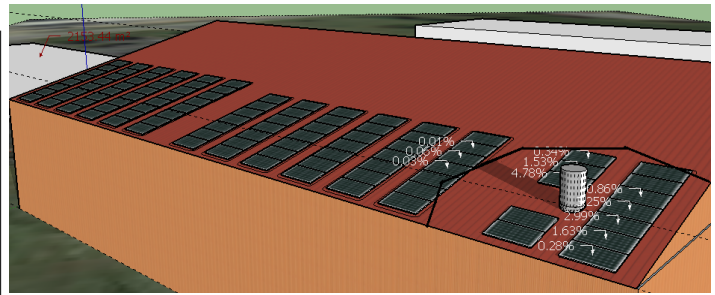

Fig. 13. Area Comparison of the Panels to Surface area Available, Shading location and Shading area is outlined to show locations of losses

available space. There is more than enough room to orient the panels so they are not obstructed by shading and also are in a location that makes for easy battery or power line hook up. Figure 12 shows the l02 panels on the proposed building with an area of shading that was evaluated.

IX. Conclusions and Recommendations

In comparing the simulations that we ran, here are the recommendations that we suggest. First, the tilt of the roof is not proposed yet. If the client wishes to maximize the winter irradiance collected then you should assign a tilt to the roof over the realistic 14.04 degrees. Anything over this would improve the efficiency by about 2-6 percent. Eventually the tilt of the roof would make for difficult maintenance and installation. The proposed roof of 14.04 degrees still gives a decent amount of winter irradiance and during the summer the 14.04 degrees would give for 99 percent of the available solar resource, thus maximizing the amount to be diverted to either the battery bank or the highly suggested of the other on-site locations. Second, if you would decide to proceed with this project and wish to change from our suggested Canadian Solar panel, the choice between a poly and mono silicon based crystal material would be the options.From our results we found that the irradiance captured from the poly and mono panels were negligibly different.The difference in price would lead us to suggest the ply based panels. Third, even though no shading was needed to be done, the installment of bathrooms in the garage could potentially mean putting vents or fans on the roof top. Due to the skelion shading analysis an arbitrary height of an object of 1.5 meters was modeled to cast a 5 meter diameter around the object. In this area any panels would experience some type of shading losses. As a suggestion, if any objects are on the roof, since there is an abundance of space available, refrain from putting them around such objects to avoid unnecessary losses. Fourth, for our client we recommend that they do not include a battery in their system. The price increase from a battery system alone would cause the payback period to well over 25 years rather than our current 20.1 year payback period and would not be worth it for the client unless required for charging stations or something that requires a large amount of energy. (Reference model description for exact battery costs.) Instead, the excess energy can be utilized

in other buildings on the property such as in the offices for air conditioning during the summer. The only reason a battery bank would be suggested, is if the bank is coupled to an electric charging station. Having a charging station installed would not only decrease fuel costs further but also increase the LEED rating significantly. In a final conclusion this site was assessed and the output of the evaluated parameters were not as favorable as we hoped. Considering the wishes of the client to become more sustainable and reduce their carbon footprint then I would suggest the installation of PV on the roof top of the proposed LEED Gold maintenance garage.

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