PENNSTATE Report Template

Department of Energy and Mineral Engineering

# Solar Feasibility Study for K-12 Schools

April 24th, 2018

Penn State Ground Mounted Solar PV System

Source: psu.edu

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Yes/[✓ No] Intellectual Property Rights Agreement Applies
Yes/[✓ No] Non-Disclosure Agreement Applies

# Executive Summary

As the world moves toward carbon free energy, many school districts across the United States are installing solar photovoltaic (PV) systems, or are studying the financial prospect of such upgrades. Our team conducted a feasibility study to determine whether 18 school districts can implement solar energy systems. The goal was to find out which schools in those districts can best upgrade to solar technologies and to choose one school from each district that was the most viable for solar upgrades. The project was sponsored by PennTAP, and our team looked at many variables, including costs, local policies, and current technologies. To achieve the best results, we used several software packages, including Helioscope, Homer Pro, and System Advisor Model (SAM). Our feasibility analysis took into account local ordinances and utility costs depending on the specific county of the planned solar installation. Our team was able to acquire free student licenses for all of the necessary software, so the only expense was the project poster.

For schools who don't provide monthly load data, the monthly load was approximated using HOMER Pro's feature of scaling a nearby school's electric load by the school's square footage. Systems were sized to meet a payback period of 5-10 years. Capacity factors of 25%, 50%, 75%, and 100% were initially used, and a better analysis was conducted in between based on financial modelling. Financial models for each design included annual energy production, levelized cost of energy, payback period, lifetime expectancy, and cash flow analysis. Inverters and PV modules were manually chosen to also reduce costs and were designed to on mount the solar PVs on rooftops in order to reduce the land area required. Optimization of tilts and azimuths was done by trial and error.

# Table of Contents

# 1.0 Introduction

According to a report by Eaton, which produces an annual blackout tracker, the annual number of blackouts in the United States has risen from 2,169 in 2008 to 3,571 in 2015. The state of Pennsylvania had the 6th highest number of blackouts in the same year, of which 34 blackouts were due to weather/falling of trees on power lines, and 23 blackouts were due to vehicle accidents. Consequently, solar PV systems are gaining attention from power systems planners due to a rising number of benefits like increased resiliency to severe weather, potential reduction in the cost of energy, mitigation of greenhouse gas emissions, and higher energy efficiencies through the avoidance of losses in transmission and distribution.

Pennsylvania Technical Assistance Program (PennTAP) provides organizations that are looking to maximize their efficiency with consultation and technical advice. With the assistance of PennTAP, a team of six Energy Engineering students from Penn State carried out a feasibility study for implementing solar energy conversion systems in 18 school districts in Pennsylvania. The feasibility study included a technical analysis of the solar energy conversion system, along with economic feasibility studies for each school district.

## 1.1 Initial Problem Statement

The study chose 18 schools, each from a different district, that were the best candidates for installation of solar technology. PennTAP and Penn State see the need to reach out to schools in order to bring the energy infrastructure of the Pennsylvanian educational system into a new era. Many children, teachers, and parents hear about solar technology but do not personally experience it. Aside from educating a new generation of students about renewable energies, schools could have the opportunity to sell unused electricity. One aspect of the study was the feasibility of energy storage, such as batteries, so that schools can save money by storing energy on weekends, which they could still sell if needed.

## 1.2 Objectives

The objective was to create feasibility reports for the utilization of solar technologies in schools across 18 different school districts, as well as solar energy designs. Economically, the components that were determined included costs, payback periods, return on investments, and energy production. The team took into consideration normal school operations, how existing solar technologies are used in other school districts, building codes, incentives offered, and sources of funding. The educational value was also be emphasized to provide a more wholesome pitch for implementation. The designs serve as a dynamic model for all schools in each district in terms of economics and educational value that PennTAP will be able to expand from in the future.

# 2.0 Customer Needs Assessment

## 2.1 Gathering Customer Input

The team meetings with the sponsor from PennTAP provided the team with an open-ended project description. The team decided to examine the feasibility of installing a solar PV system in one school from each district provided. Additionally, the possibility of including solar water heating (SWH) was be explored, depending on the information received by the schools. SWH was also considered on a case-by-case basis, in the event that solar PV systems were infeasible. The scope of the project encompassed a financial assessment of the investment, which considered the available funding opportunities for each school. The selling point of the proposal primarily focused on educational benefits from engaging students with renewable energy. The following information was requested in the questionnaire:

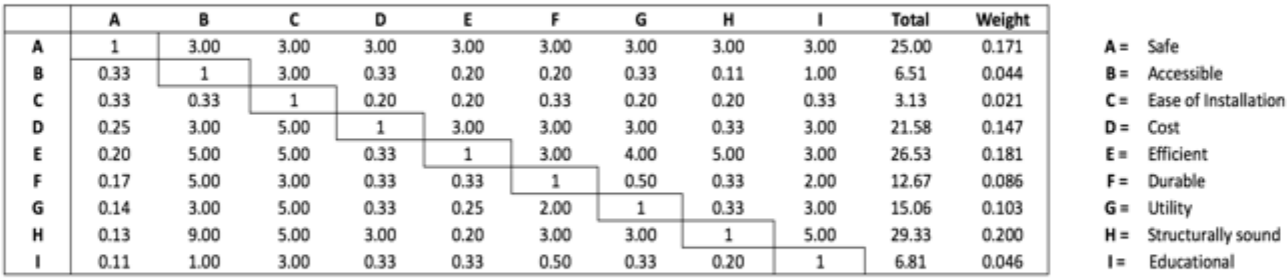
- Existing solar PV systems of SWH systems
- Annual utility bills
- Previous use of any Pennsylvania State Grants
- LEED certification of any schools buildings
- Availability of rooftops

In the case of insufficient information provided by the schools, the team used standard school areas and consumptions for the districts provided. Consumption data was also extrapolated from LEED certified buildings data from Energy Star and online sources.

## 2.2 Weighting of Customer Needs

The following customer needs were considered and ranked using the Analytical Hierarchy Process (AHP) method: safety, accessibility, ease of installation, cost, efficiency, durability, utility, structural soundness and educational benefits. The table below shows the AHP comparison chart for weighing these customer needs.

**Table 2.1. AHP Pairwise Comparison Chart to Determine Weighting for Main Objective Categories**



| | A | B | C | D | E | F | G | H | I | Total | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 1 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 25.00 | 0.171 |
| B | 0.33 | 1 | 3.00 | 0.33 | 0.20 | 0.20 | 0.33 | 0.11 | 1.00 | 6.51 | 0.044 |
| C | 0.33 | 0.33 | 1 | 0.20 | 0.20 | 0.33 | 0.20 | 0.20 | 0.33 | 3.13 | 0.021 |
| D | 0.25 | 3.00 | 5.00 | 1 | 3.00 | 3.00 | 3.00 | 0.33 | 3.00 | 21.58 | 0.147 |
| E | 0.20 | 5.00 | 5.00 | 0.33 | 1 | 3.00 | 4.00 | 5.00 | 3.00 | 26.53 | 0.181 |
| F | 0.17 | 5.00 | 3.00 | 0.33 | 0.33 | 1 | 0.50 | 0.33 | 2.00 | 12.67 | 0.086 |
| G | 0.14 | 3.00 | 5.00 | 0.33 | 0.25 | 2.00 | 1 | 0.33 | 3.00 | 15.06 | 0.103 |
| H | 0.13 | 9.00 | 5.00 | 3.00 | 0.20 | 3.00 | 3.00 | 1 | 5.00 | 29.33 | 0.200 |
| I | 0.11 | 1.00 | 3.00 | 0.33 | 0.33 | 0.50 | 0.33 | 0.20 | 1 | 6.81 | 0.046 |

A = Safe
B = Accessible
C = Ease of Installation
D = Cost
E = Efficient
F = Durable
G = Utility
H = Structurally sound
I = Educational

**Table 2.2. Weighted Hierarchical Customer Needs List**

1. Structurally sound (0.200, 0.200)
    1.1 PVs are south-facing and optimally tilted
2. Efficient (0.181, 0.181)
    2.1 Minimize downtime
    2.2 Low frequency of parts replacement
    *F.1 High energy output to input ratio*
    **C.1 Weather dependent, cloud coverage reduces efficiency**
3. Safe (0.171, 0.171)
    3.1 Safe to install, operate and maintain by laborers
4. Cost (0.147, 0.147)
    4.1 Affordable components
    4.2 Operation costs are economical
5. Utility (0.103, 0.103)
    5.1 Lighting
    5.2 HVAC system during summer months
    5.3 Water heating
    5.4 Battery storage system
    **C.3 System is a fraction of the utility, weather dependent**
6. Durable (0.086, 0.086)
    6.1 Components have a long life
    6.2 Materials are sturdy
7. Educational (0.046, 0.046)
    7.1 Educational poster by each system
    *F.2 Teach students about sustainability and renewables*
8. Accessible (0.044, 0.044)
    8.1 PVs on roofs must be accessible to labor
    *F.3 Visible to students for educational purposes*
    **C.4 PVs must be south-facing**
    **C.5 PVs require large surface area**
9. Ease of Installation (0.021, 0,021)
    9.1 Simple components
    9.2 System is easy to assemble
    **C.6 Components must be available in the United States**

Table 2.2. above shows the ranking of the customer needs. structural soundness, efficiency and safety are the top ranking needs as they relate to the welfare of laborers and usefulness of the solar PV system. The next on the list is cost, which was ranked highly as it was a key factor in whether or not the schools will make the investment. Funding opportunities must be available for schools to consider installing a solar PV system. Utility is next on the list, as applications of solar PV systems are various. Durability of the components are important in the state of Pennsylvania, as components must withstand extreme weather events. However, this is relatively of less importance than previous needs. Educational benefits are the key selling points, though it is not highly ranked as other needs are far more important when installing solar PV system. In order to achieve the educational purposes, accessibility was attempted in the design, though there are constraints to that because solar PV systems need to be places in specific areas. Ease of installation was also considered when selecting components and method of installation.

# 3.0 External Search

## 3.1 Solar Installation Building Codes and Ordinances

Each school district has schools located in one or more townships. Our team parsed through the ordinances and codes that might have restricted solar PV systems or had special design requirements. Districts with ordinances are as follows:

- Upper Dublin
- Downingtown Area
- West Chester Area
- Spring-Ford
- Tredyffrin-Easttown
- Southeast Delco
- Solanco

## 3.2 Existing Products

Each school district has the potential to use any type of solar energy technologies whether it be solar PV systems with or without a battery system, or SWH. For Pennsylvania Specifically, a battery system is not needed due to high costs and an already existing metering system. Normal schools operations were taken into consideration to make sense of which technology would be the most feasible.

## 3.3 Normal K-12 School Operations

To better understand which type of solar energy technology could provide the most impact, solar savings, and the greatest feasibility, our team investigated the normal operations of the school. This included electricity usage, water usage, and any other processes going on that can be subsidized with solar. From our investigation, we found that Pennsylvania schools typically run at full capacity for 9 months long- with some schools operating in the summer months with air conditioning running. Although a realistic annual electricity consumption number could not be found, with the help of NREl data and HomerPro an approximation of 16 kWh/sqft/yr was determined.

## 3.4 Existing Solar Utility in Commercial Settings

To get an idea of how we can use solar in K-12 schools, we researched how solar power is utilized in other schools and commercial settings. This helped us understand if deviations from a solar PV system to a SWH, or a solar PV system with a battery system were more favorable. We found that most schools do solar PV with building upgrades to reduce electricity consumption.

## 3.5 Incentives for Solar Power in School/Commercial Use

Tax incentives offered by state and federal resources helped decrease the cost of the solar PV system upon installation. Solar Renewable Energy Credits (SRECs) help in reducing the cost of the system as the system generates its energy. Upon further research, possible grants for projects of this kind were also found to be available. All sources of aid were used in accordance with the size and uncertainty of the designs to determine a levelized cost of energy. DCED, DSIRE, and LEED Gold grants were found to be helpful in incentivising solar PV installation in Pennsylvania schools.

# 4.0 Engineering Specifications

## 4.1 Establishing Target Specifications

Since our target customers are public schools, we understood that the schools were not only interested in viewing the solar PV system as an investment, but also as a means to educate their students and faculty. Accordingly, the solar feasibility study focused on documenting the design and engineering process, in addition to the finance side of the project. Documenting the process (in the form of a poster) served as a great opportunity for school students, and even the faculty, to learn about solar energy engineering.

In identifying the viability of the solar PV project as a feasible investment, we focused on determining the payback period of the solar PV system, its Net Present Value (NPV), its rate of Rate of Return (ROR), its Levelized Cost of Energy (LCOE), and thus preparing a detailed cash flow over a 15-year period of analysis.

Even though the primary scope of this project was to determine the solar feasibility for k-12 schools, our primary customers included PennTAP and the potential schools. Consequently, determining the financial feasibility of this project was the ultimate goal. However, we needed to carry out a detailed, engineering feasibility study as a first-step. This included designing (sizing and analyzing) the solar PV systems on the basis of (see Appendix, figures A1-A3):

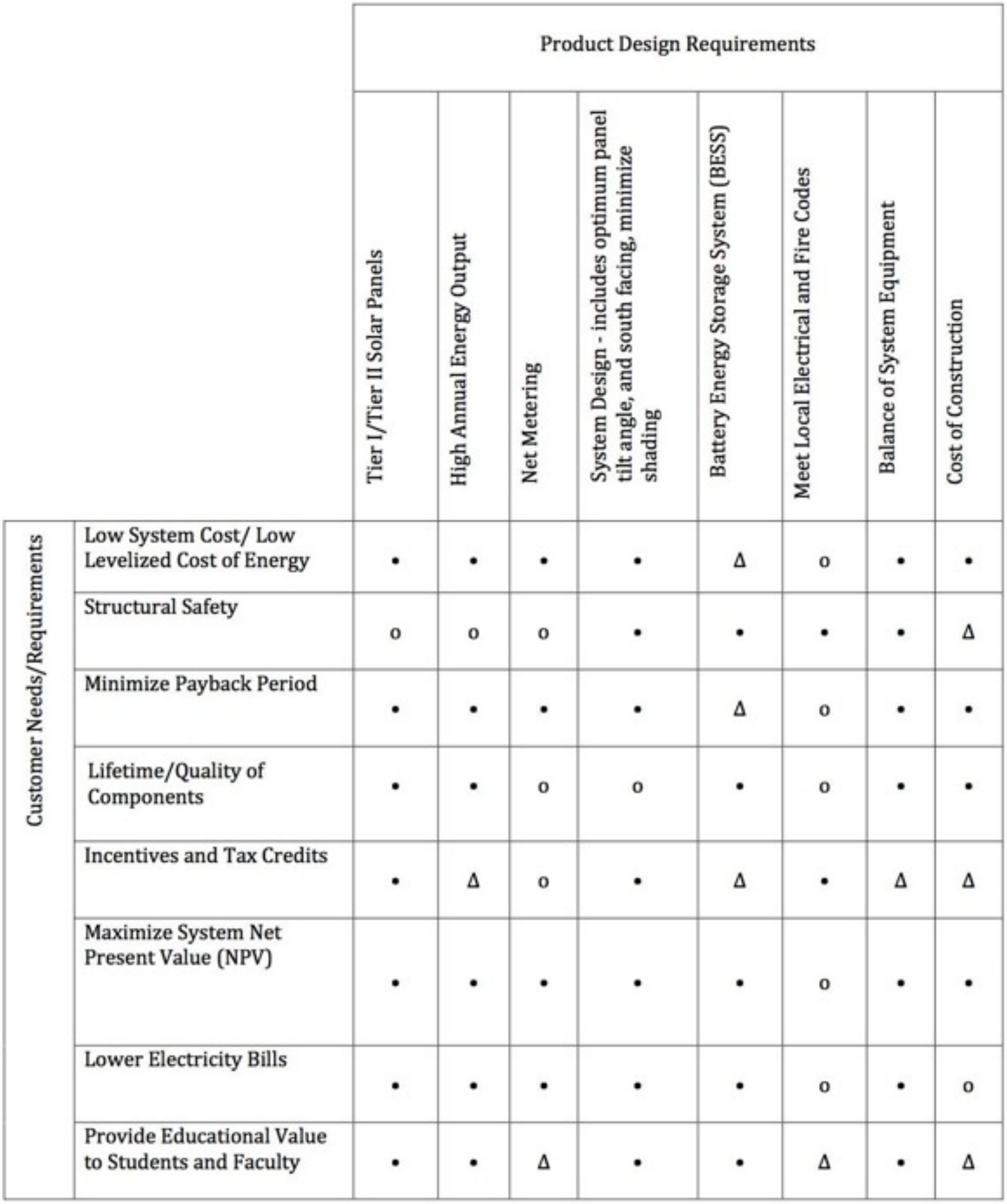
1. Available area for construction.
2. Determining the load bearing potential of rooftops
3. The electrical load requirements of the school – with a focus on maximizing the renewable penetration of the PV system.
4. Minimizing losses from shading, snow, dirt, etc.
5. Maximizing resiliency – with an option of incorporating battery energy storage systems

The main focus of the engineering design of the solar PV system was to maximize its solar utility for the client at the given locale, i.e., maximize annual energy output while minimizing the overall system costs.

## 4.2 Relating Specifications to Customer Needs

Given the open-ended nature of the project, the customer needs and requirements specific to a solar PV system was set by the team. These assumptions were dependant on the criteria of maximizing solar utility for the client in their respective locales. Thus, we began with the main assumption that the client would like to maximize annual energy output and minimizing overall cost of the system. Table 3 outlines the relationship between the customer's need and requirements, and the necessary product design requirements.

**Table 4.1. Customer Needs and Related Product Design Requirements**



| | | Product Design Requirements | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Tier I/Tier II Solar Panels | High Annual Energy Output | Net Metering | System Design - includes optimum panel tilt angle, and south facing, minimize shading | Battery Energy Storage System (BESS) | Meet Local Electrical and Fire Codes | Balance of System Equipment | Cost of Construction |
| Customer Needs/Requirements | Low System Cost/ Low Levelized Cost of Energy | • | • | • | • | Δ | o | • | • |
| | Structural Safety | o | o | o | • | • | • | • | Δ |
| | Minimize Payback Period | • | • | • | • | Δ | o | • | • |
| | Lifetime/Quality of Components | • | • | o | o | • | o | • | • |
| | Incentives and Tax Credits | • | Δ | o | • | Δ | • | Δ | Δ |
| | Maximize System Net Present Value (NPV) | • | • | • | • | • | o | • | • |
| | Lower Electricity Bills | • | • | • | • | • | o | • | o |
| | Provide Educational Value to Students and Faculty | • | • | Δ | • | • | Δ | • | Δ |

• Strong Relationship
Δ Moderate Relationship
o Weak Relationship

# 5.0 Concept Generation

## 5.1 Problem Clarification

The overall goal of this project was to examine schools across 18 different Pennsylvania school districts and create design concepts for the utilization of solar technologies. Our task was to investigate the different school districts and the individual schools that they're comprised of. Several factors impacted the feasibility reports and the likelihood of the school implementing solar technology. For example, solar technology could have been pitched to a school on an economic level, discussing things such as payback period and electricity savings. Conversely, solar technologies could also have contributed to education, giving back to the community, and overall student experience. The level of school (elementary, middle, high) also impacted the need of the school as well as the primary reason for implementing solar technologies. We also examined the budget of the individual school as well as the school district. Some schools were recently upgraded (to LEED status for example) while other schools have gone decades without a significant renovation. Our team recorded different statistics and pieces of information for each school and compared the schools analyzed. This allowed us to generate the most realistic concepts for each application and arrive at a conclusive result.

## 5.2 Concept Generation

Concept generation revolved around research and data collected on each specific school we chose to examine. We examined aspects such as shading, climate, locale, and school structure. This information was collected through a combination of on site and online visits in order to create a detailed and accurate model of each location. Using HelioScope software, we were able to use virtual scale models and images to project the solar application on to any given school. Homer, and System Advisory Model (SAM) software were also used to generate project cash flow and other financial outcomes. These models and the data they provide were essential in analyzing each design and generating our feasibility reports.

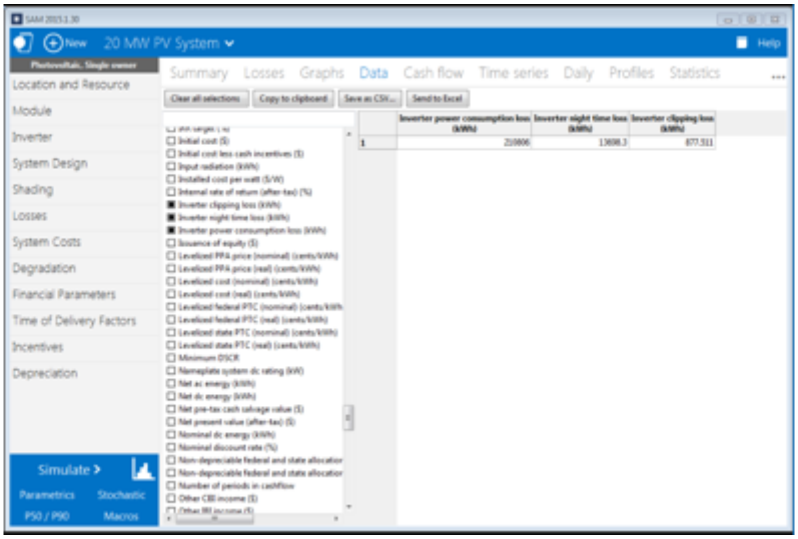


**Figure 5.1. Example System Advisory Model (SAM) detailing financial analysis for a solar PV system**

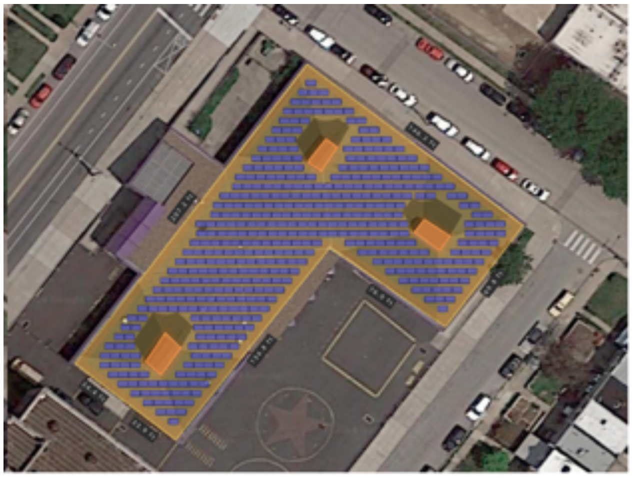
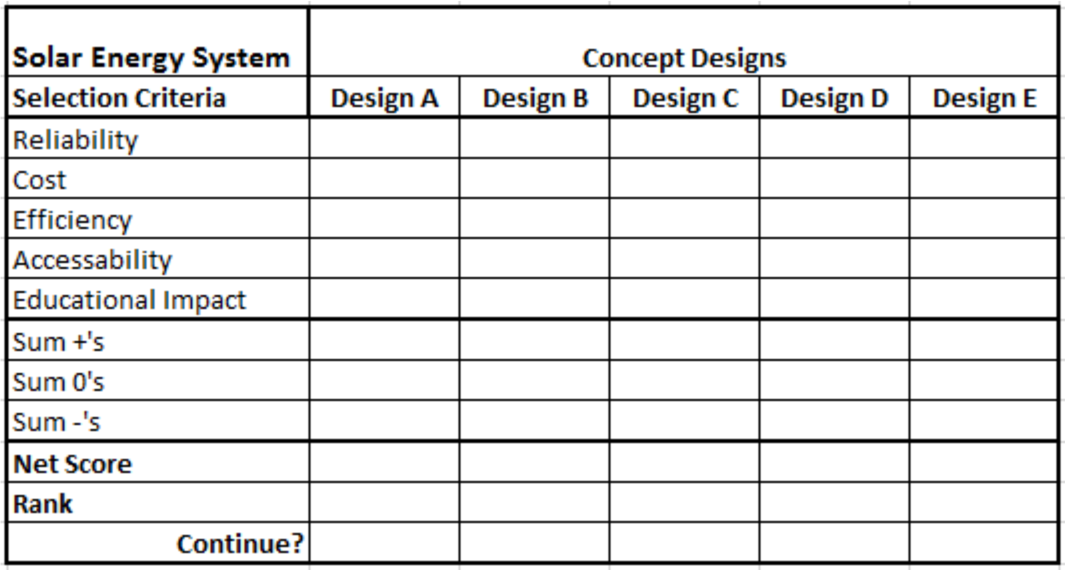


**Figure 5.2. Example** of Helioscope software projecting a solar PV system design on a building rooftop

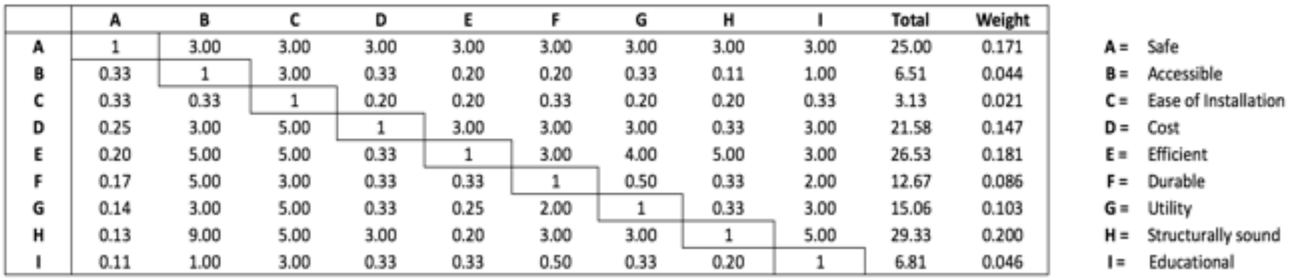
## 5.3 Concept Selection

**Table 5.1. Concept Selection Matrix**



| **Solar Energy System** | **Concept Designs** | | | | |
|---|---|---|---|---|---|
| **Selection Criteria** | **Design A** | **Design B** | **Design C** | **Design D** | **Design E** |
| Reliability | | | | | |
| Cost | | | | | |
| Efficiency | | | | | |
| Accessability | | | | | |
| Educational Impact | | | | | |
| Sum +'s | | | | | |
| Sum 0's | | | | | |
| Sum -'s | | | | | |
| **Net Score** | | | | | |
| **Rank** | | | | | |
| **Continue?** | | | | | |

### Table 5.2 AHP Pairwise Comparison Chart to Determine Weighting for Main Objective Categories



| | A | B | C | D | E | F | G | H | I | Total | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 1 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 25.00 | 0.171 |
| B | 0.33 | 1 | 3.00 | 0.33 | 0.20 | 0.20 | 0.33 | 0.11 | 1.00 | 6.51 | 0.044 |
| C | 0.33 | 0.33 | 1 | 0.20 | 0.20 | 0.33 | 0.20 | 0.20 | 0.33 | 3.13 | 0.021 |
| D | 0.25 | 3.00 | 5.00 | 1 | 3.00 | 3.00 | 3.00 | 0.33 | 3.00 | 21.58 | 0.147 |
| E | 0.20 | 5.00 | 5.00 | 0.33 | 1 | 3.00 | 4.00 | 5.00 | 3.00 | 26.53 | 0.181 |
| F | 0.17 | 5.00 | 3.00 | 0.33 | 0.33 | 1 | 0.50 | 0.33 | 2.00 | 12.67 | 0.086 |
| G | 0.14 | 3.00 | 5.00 | 0.33 | 0.25 | 2.00 | 1 | 0.33 | 3.00 | 15.06 | 0.103 |
| H | 0.13 | 9.00 | 5.00 | 3.00 | 0.20 | 3.00 | 3.00 | 1 | 5.00 | 29.33 | 0.200 |
| I | 0.11 | 1.00 | 3.00 | 0.33 | 0.33 | 0.50 | 0.33 | 0.20 | 1 | 6.81 | 0.046 |

A = Safe
B = Accessible
C = Ease of Installation
D = Cost
E = Efficient
F = Durable
G = Utility
H = Structurally sound
I = Educational

### Table 5.3 Design Concept Pros and Cons

| **Solar Energy System** | **Concept Designs** | | | | |
|---|---|---|---|---|---|
| **Selection Criteria** | **Design A** | **Design B** | **Design C** | **Design D** | **Design E** |
| Pros | | | | | |
| Cons | | | | | |

After the location had been researched and analyzed and concept generation was completed, our team began the concept selection process. To help aid in the selection process by comparing designs, we utilized a concept selection matrix as well as the AHP chart as previously discussed. The concept selection matrix allowed us to analyze different aspects of the concept design and rate their effectiveness when compared to other designs. We were then be able to determine and decide which concept to continue with. By keeping the customer needs in mind, we were able to analyze the important factors in the solar energy system and select the best design concept for the job. Additionally, we generated a pros and cons table to further outline in greater detail the benefits and drawbacks of each concept.

# 6.0 System Level Design

In this report, we analyzed the installation of a solar PV system at various schools and districts across the Pennsylvania commonwealth. The solar PV systems installed provided electricity to these school districts, and also served as a clean renewable energy alternative. We began by visiting the site to understand our project better, determine a good site for our system, and learn more about the client's demands.

Our system implemented solar design technology from Folsom Labs' Helioscope software. By combining streamlined layout tools with bankable energy simulations, HelioScope simplified the process of designing, engineering, and selling solar arrays.

Although, we prioritized solar PV systems implementation, we also considered adding in SWH. There were two types of SWH to choose from. The first type was the active SWH system. This system included circulating pumps and controls. There were also two types of active SWH systems. There was the direct circulation system, which pumps household water through the collectors then into the home. The direct circulation systems worked well in warmer climates where it rarely freezed, while the other active SWH technology, the indirect circulation system, worked better in climates where freezing temperatures regularly occur. This was because the pump circulates a non-freezing, heat-transfer fluid through the collectors and heat exchanger. If there were specific ordinance problems when generating solar PV system concepts for a given school, our team was able to focus on exploring the SWH systems for that given location.

The second type of SWH system was the passive system. Both the active and passive systems included a storage tank and solar collectors, but the passive system differed from the active system in that it did not have pumps and controls to circulate the water. Our team found that passive systems were usually less expensive than active systems, but not as efficient. What they lacked in efficiency is made up their increased reliability and longer lifetime. There were two basic types of passive solar water heating systems we looked at. The first one was the integral collector-storage passive system. This system combined the collector and tank into a single unit, which avoided the need for circulation pumps. This system was also known as a "batch" system, which was elaborated on in the collector section. This system worked best in areas that rarely experience freezing temperatures.

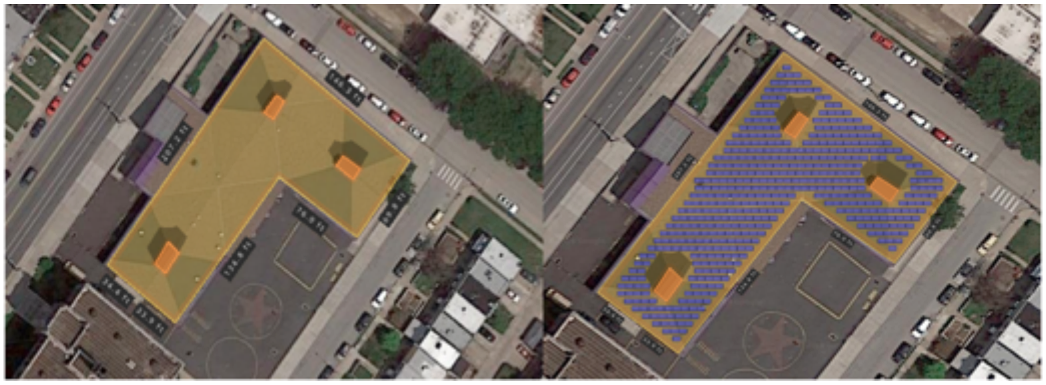


**Figure 6.1. Sample Helioscope diagrams detailing solar PV system design on a building rooftop**

# 7.0 Special Topics

## 7.1 Budget and Vendor Purchase Information

The below paragraph states our initial budget and purchase information that we anticipated earlier in the project timeline. The updated final version of the purchase information can be found in section 8.7, with an updated budget chart.

With a starting budget of one thousand dollars, the estimation is that most of the funds will be retained by the end of the project. We predict that the expenses will be the software, traveling, and a poster. We plan on using two programs for two months, Helioscope ($95/month)and Homer ($42/month). Traveling will cover the gas costs, tolls, or bus fees. The costs will vary depending on the route traveled. The team is also showing interest in creating a poster to present the results to the Spring 2018 College of Engineering Capstone Design Project Showcase. The team is going to set aside $100 for the poster, which is the estimated maximum that we will spend to create a poster. Due to the nature of the project, we do not plan on using any materials or supplies from the Learning Factory workshop. We estimate our final expenses to be $184, with an estimated surplus of $816. We will hold on to any receipts for documentation.

**Table 7.1. Estimated Spendings**

| Title | Amount | Units | Comments |
|---|---|---|---|
| Total budget | 1000 | $ | |
| | | | |
| Gas | 0 | $ | 54.5 cents/mile, 0 miles traveled |
| Bus | 0 | $ | |
| Travel expenses | 0 | $ | |
| | | | |
| Helioscope | 0 | $ | Student license |
| Homer | 84 | $ | $42/month, 2 months |
| Software Total | 84 | $ | |
| | | | |
| Poster | 100 | $ | Estimation |
| | | | |
| Total Expenses= | 184 | $ | |
| Surplus Total= | 816 | $ | |

## 7.2 Project Management

The team used a Gantt chart to stay on track throughout the duration of the project. We completed all of the tasks in a timely manner based on the timeline we set for ourselves. The 18 school districts were divided into groups of 3 so that each of our 6 team members were responsible for the design and simulation of a few schools. Each member was responsible for collecting information about their assigned school districts, such as electricity rates in the area, square foot area of the buildings, and solar PV quotes from local solar energy system installers. The analyses performed included designing the solar PV array on HelioScope and creating the financial model for it on HomerPro.

**Table 7.2. Gantt Chart**

| | **February** | | | | **March** | | | | **April** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Week | | | | | | | | | | | | |
| Put together presentation | | | | | | | | | 🟨 | 🟨 | 🟨 | 🟨 |
| Put together SOW | 🟥 | 🟥 | 🟥 | | | | | | | | | |
| Create Budget Sheet | | 🟧 | 🟧 | | | | | | | | | |
| Research | | | | | | | | | | | | |
| -Building Codes | | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | | | | |
| -Existing Solar Tech. | | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | | | | |
| -Normal School Ops. | | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | | | | |
| -Existing Solar Utility in Schools | | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | | | | |
| -Incentives Offered for Solar Power | | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | 🟦 | | | | |
| Create Risk Plan | | 🟪 | 🟪 | 🟪 | | | | | | | | |
| Determine Environmental Impact | | 🟫 | 🟫 | 🟫 | 🟫 | 🟫 | 🟫 | 🟫 | 🟫 | | | |
| Create Concept Map | | | | | | | | | 🟧 | 🟧 | | |
| Perform analysis on school in | | | | | | | | | | | | |
| -Upper Merion | | | | | 🟦 | 🟦 | Riham | | | | | |
| -Cheltenham | | | | | 🟦 | 🟦 | | | | | | |
| -Norristown Area | | | | | 🟦 | 🟦 | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| -Upper Dublin | | | | | 🟦 | 🟦 | Joe |
| -Downingtown Area | | | | | 🟦 | 🟦 | |
| -West Chester | | | | | 🟦 | 🟦 | |
| -Spring-Ford | | | | | 🟦 | 🟦 | Parangat |
| -Tredyffrin-Easttown | | | | | 🟦 | 🟦 | |
| -Southeast Delco | | | | | 🟦 | 🟦 | |
| -Garnet Valley | | | | | 🟦 | 🟦 | Mark |
| -Solanco | | | | | 🟦 | 🟦 | |
| -Hazleton | | | | | 🟦 | 🟦 | |
| -Norwin | | | | | 🟦 | 🟦 | Nyriis |
| -Mount Pleasant | | | | | 🟦 | 🟦 | |
| -Bangor | | | | | 🟦 | 🟦 | |
| -Spring Grove | | | | | 🟦 | 🟦 | Roberto |
| -Penncrest | | | | | 🟦 | 🟦 | |
| -Lakeview | | | | | 🟦 | 🟦 | |

## 7.3 Risk Plan

The team faced certain risks during this project. The lowest level risk was a delay in team meetings. A few times we had to reschedule team functions, which did not impact the production of the team nor the timeline of the project. Table 3 below expands on some of the initial risks we evaluated before delving deeper into the project. The chart includes prevention strategies, as well as backup strategies.

**Table 7.3. Risk Plan**

| Risk | Level | Actions to Minimize | Fall Back Strategy |
|---|---|---|---|
| Schools (or districts) not wanting to engage in the study. | High | -Make client (schools) feel comfortable to open communication and participation<br>-The best way to do this is to explain the goal of the study and its benefits to the community | -Find public information that is available on the locale of interest (info like energy consumption, environmental rating, etc)<br>-Move on to the next client (school or district) |
| Meeting delays and scheduling issues. | Low | -Figure out the best meeting times for the team members and the sponsor<br>-Figure out the best time and the best method that school representatives can communicate | -Communicate virtually. Some methods are email, Zoom, Google Drive, or GroupMe |

## 7.4 Ethics Statement

During our time spent on this project, every member of our team strive to make ethical decisions as they pertain to engineering, business, and professionalism. Our team was dealing with a multitude of contacts and other sources of information as we reached out to different districts and schools. We stuck by ethical business and engineering code as we made decisions and judgements throughout the solar design process.

## 7.5 Environmental Statement

For this project, the team paid very close attention to environmental standards and expectations. The basis of the project revolved around being environmentally conscious and gaining exposure to renewable energy in new applications. We took a very close look at LEED certification and what that status entails when applied to different schools. During our assessment of each application, we also took a look at feasibility of the solar project and how this impacted the environmental position associated with each specific school. We took great care during our analysis to make environmentally ethical decisions a priority while at the same time keeping the needs of the school in mind.

## 7.6 Communication and Coordination with Sponsor

The sponsor for this project was Alanna Colvin, a representative for PennTAP. The team remained in constant contact with Alanna throughout the project. We communicated an effective schedule where we met with Alanna via Zoom Video Conference every Wednesday afternoon. On days when Wednesday was not ideal for Alanna, we rescheduled for a Friday afternoon meeting either by phone call or video chat. We met with Alanna in person the week of February 19 on Penn State's campus to discuss the project in further detail. As the project began to move into the analysis phase, we only contacted Alanna in situations where we required her advice or input.

# 8.0 Detailed Design

## 8.1 Feasibility Evaluation Plan

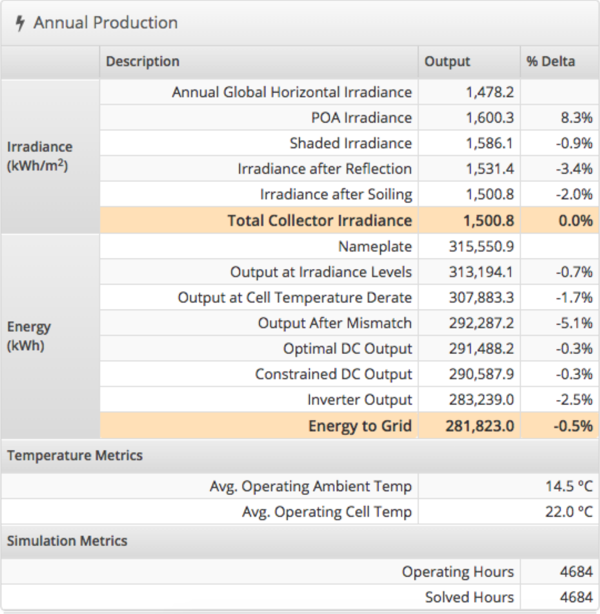
The feasibility of solar PV for each school was determined by the optimal choice of panels and inverters for our given locale. The system was sized to meet a payback period of 5-10 years. In order to achieve a payback period within this range, two main scenarios were created: school has 100% ownership of the solar panels, or a Purchase Power Agreement (PPA) was used. In the first scenario, the school is responsible for funding the system. Grants and solar energy incentives such as Solar Renewable Energy Certificates (SRECs) were incorporated in our financial analysis. However, if the payback period still exceeds 10 years, our recommendation to the schools would be to consider the PPA route. The cash flow analysis also included a sensitivity analysis for inflation and discount rates. The financial analysis conducted for the system was evaluated within the context of the specific school and county.

On Helioscope, the optimal tilt angle used for flat roofs was 35 degrees, while the azimuth angle depended on the availability of space on the south-facing sections of the roofs. For schools who don't provide monthly load data, the monthly load was approximated by using HomerPro's feature of scaling a nearby school's electric load by the school's square footage. This was taken into account to build a financial model for each design. These models included annual energy production, levelized cost of energy, payback period, lifetime expectancy, and cash flow analysis.

## 8.2 Analysis

Performing hand calculations to verify our solar PV system design and magnitude of results proved be a tedious, and laborious task. This is because modelling solar energy conversion systems involves a number of independent and dependent variables, including: calculating the sun path as a function of time, choosing an appropriate sky model, determining shading as a function of sun path and time, the global horizontal irradiance as a function of time, etc. Therefore, a different approach was adapted to verify our design and the magnitude of our results. The team designed the same rooftop solar PV system on West Chester Henderson High School on three different softwares: Helioscope, HOMER, and System Advisor Model (SAM). They are mutually exclusive softwares that serve a similar purpose of designing, and simulating distributed energy generation systems.

Designing and simulating the same rooftop PV system on West Chester Henderson High School in HOMER, SAM, and Heliscope yielded similar results within a close range. The close proximity of the outcomes therefore verified our design and magnitude of results. Figures 4a-4d are sample screenshots of the design and simulation results obtained for West Chester Henderson High School.



Annual Production

| | Description | Output | % Delta |
|---|---|---|---|
| Irradiance (kWh/m$^2$) | Annual Global Horizontal Irradiance | 1,478.2 | |
| | POA Irradiance | 1,600.3 | 8.3% |
| | Shaded Irradiance | 1,586.1 | -0.9% |
| | Irradiance after Reflection | 1,531.4 | -3.4% |
| | Irradiance after Soiling | 1,500.8 | -2.0% |
| | **Total Collector Irradiance** | **1,500.8** | **0.0%** |
| Energy (kWh) | Nameplate | 315,550.9 | |
| | Output at Irradiance Levels | 313,194.1 | -0.7% |
| | Output at Cell Temperature Derate | 307,883.3 | -1.7% |
| | Output After Mismatch | 292,287.2 | -5.1% |
| | Optimal DC Output | 291,488.2 | -0.3% |
| | Constrained DC Output | 290,587.9 | -0.3% |
| | Inverter Output | 283,239.0 | -2.5% |
| | **Energy to Grid** | **281,823.0** | **-0.5%** |
| Temperature Metrics | | | |
| | Avg. Operating Ambient Temp | | 14.5 °C |
| | Avg. Operating Cell Temp | | 22.0 °C |
| Simulation Metrics | | | |
| | | Operating Hours | 4684 |
| | | Solved Hours | 4684 |

**Figure 8.1.** Simulation Results Showing Summary Table for West Chester Henderson High School

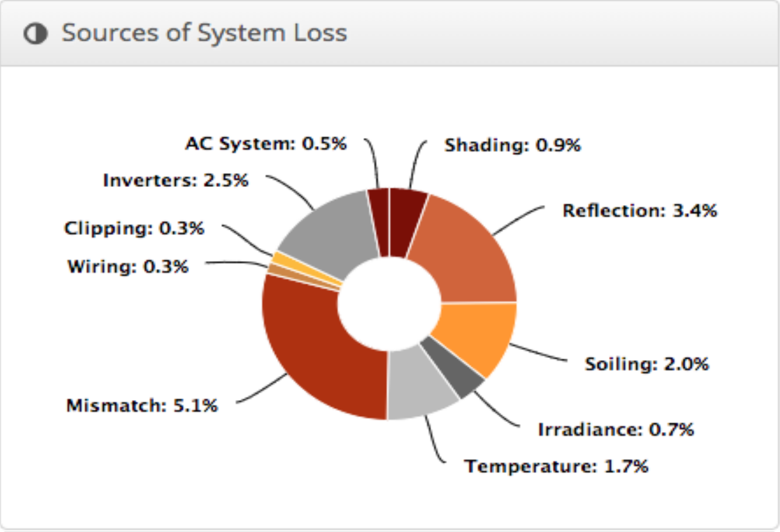


**Figure 8.2.** Simulation Results of System Losses for PV System Designed for West Chester Henderson High School

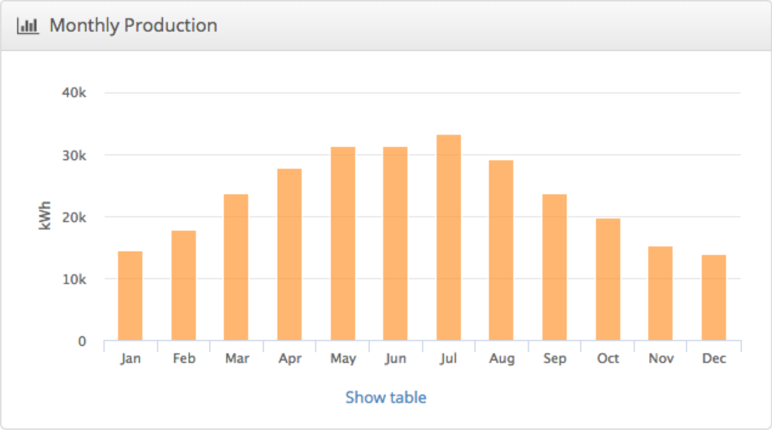
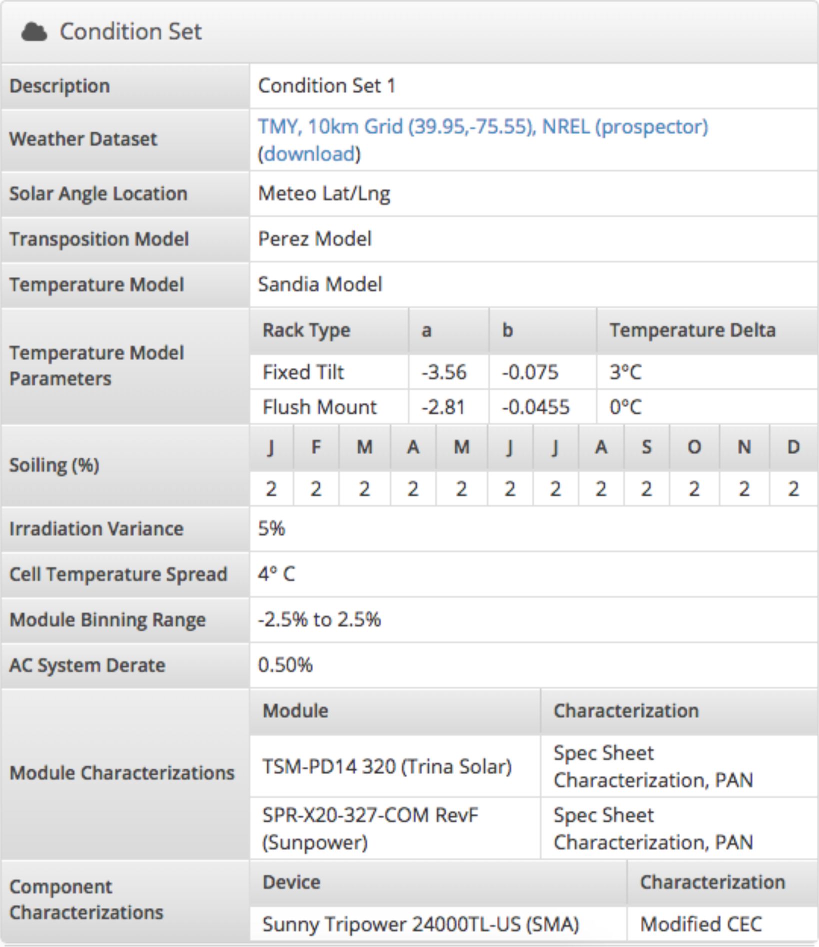


**Figure 8.3.** Simulation Results for Monthly Electricity Generated from Rooftop PV System on West Chester Henderson High School



Condition Set

| | |
|---|---|
| **Description** | Condition Set 1 |
| **Weather Dataset** | TMY, 10km Grid (39.95,-75.55), NREL (prospector) (download) |
| **Solar Angle Location** | Meteo Lat/Lng |
| **Transposition Model** | Perez Model |
| **Temperature Model** | Sandia Model |

**Temperature Model Parameters**

| Rack Type | a | b | Temperature Delta |
|---|---|---|---|
| Fixed Tilt | -3.56 | -0.075 | 3°C |
| Flush Mount | -2.81 | -0.0455 | 0°C |

**Soiling (%)**

| J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |

| | |
|---|---|
| **Irradiation Variance** | 5% |
| **Cell Temperature Spread** | 4° C |
| **Module Binning Range** | -2.5% to 2.5% |
| **AC System Derate** | 0.50% |

**Module Characterizations**

| Module | Characterization |
|---|---|
| TSM-PD14 320 (Trina Solar) | Spec Sheet Characterization, PAN |
| SPR-X20-327-COM RevF (Sunpower) | Spec Sheet Characterization, PAN |

**Component Characterizations**

| Device | Characterization |
|---|---|
| Sunny Tripower 24000TL-US (SMA) | Modified CEC |

**Figure 8.4.** Design Parameters for Solar PV System on West Chester Henderson High School

## 8.3 Material and Material Selection Process

The nature of this project required the team to design photovoltaic energy systems. To achieve this, we designed the system with premade components, as shown in Section 8.4. However, with regard to system wiring, the material of copper was chosen, because of its effective conductivity and the fact that copper is cheaper than other wiring materials.

## 8.4 Component and Component Selection Process

The components chosen for the project were an inverter, wire, and a solar PV module. The specific components were initially chosen by Helioscope, but could be changed in the event that further financial analysis was required. Generally, the system design was more relevant than the components in a solar PV system, with the exception of batteries (which we may not cover in this project). We assumed that the solar PV system (all the components combined) are estimated to degrade over 0.5% annually.

**Table 8.1. Solar Energy System Components**

| **Component** | **Model** | **Supplier** |
|---|---|---|
| Inverter | Sunny Tripower 24000TL-US | SMA Solar Technology |
| Wire | 10 AWG (Copper) | TBD |
| Solar PV Module | TSM-PD14 320 (320 Watts) | Trina Solar |

## 8.5 CAD Drawings

The Helioscope models for each school are shown in this section. The solar PVs were generally placed on south-facing sections of the roofs that are flat and easy to access. The team chose to mount the solar PVs on rooftops in order to reduce the land area required for the panels. Solar PV's were placed away from obstacles such as HVAC systems. Any external obstacles near the solar PVs were accounted for with cutouts in the Helioscope software and can be identified in orange in the models below.

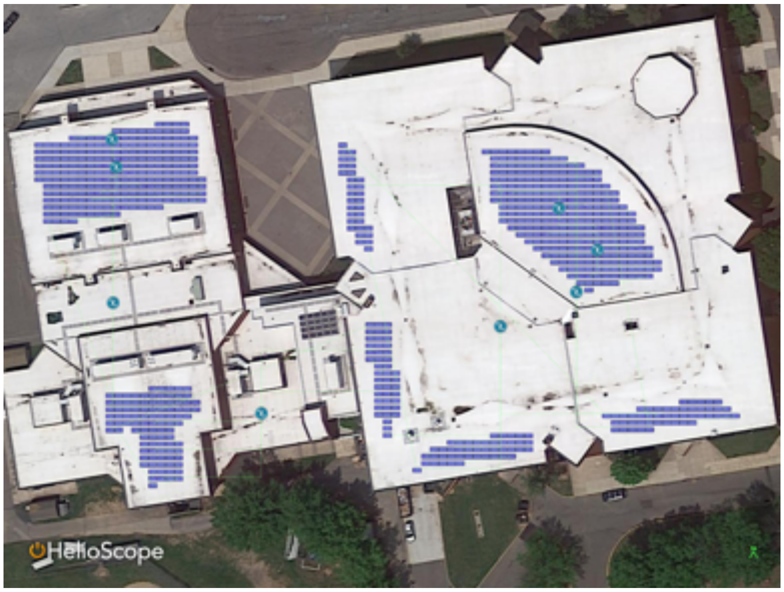


**Figure 8.5.** Norristown Area High School, 1900 Eagle Dr, Norristown, PA 19401

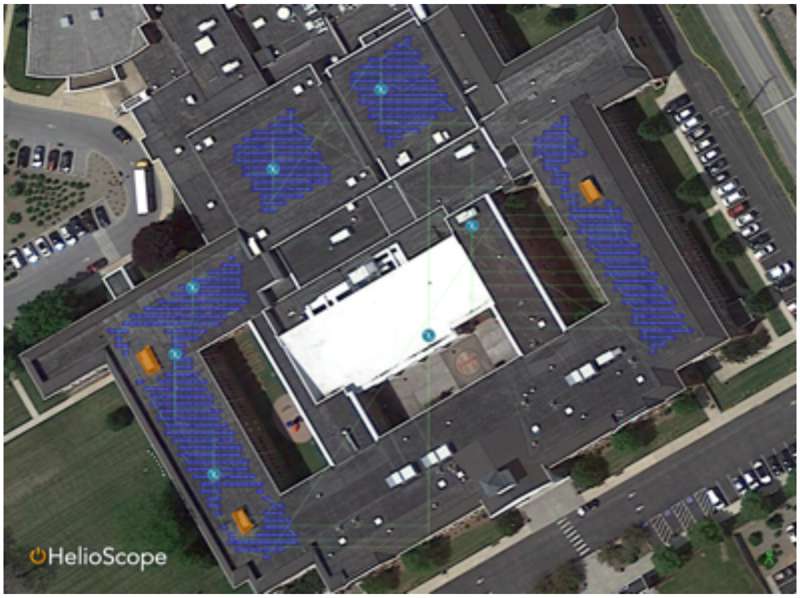


**Figure 8.6.** West Chester Henderson High School, 400 Montgomery Ave West Chester, PA 19380

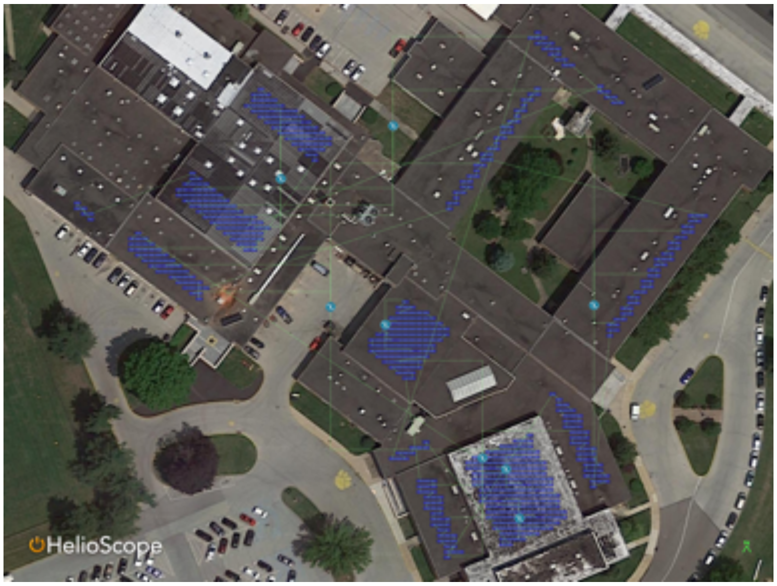


**Figure 8.7.** Cheltenham High School, 500 Rices Mill Rd, Wyncote, PA 19095

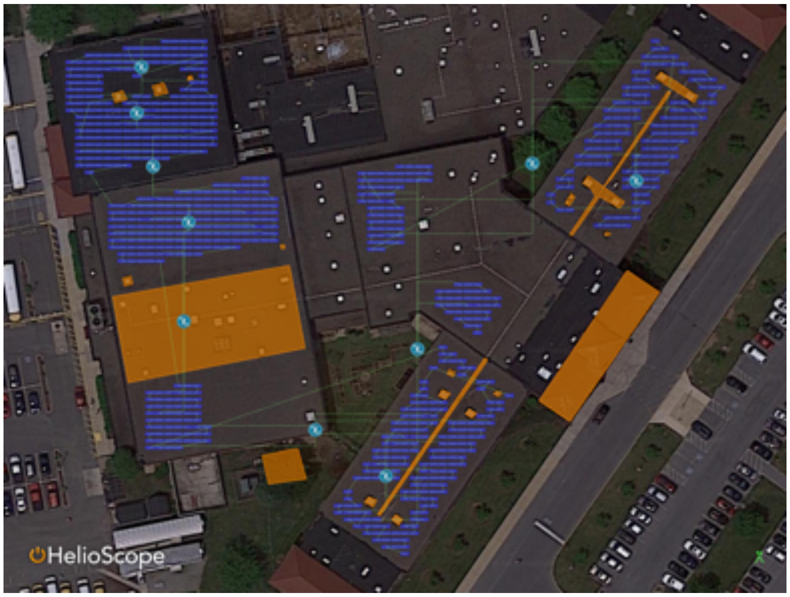


**Figure 8.8.** Garnet Valley Middle School, 601 Smithbridge Rd, Glen Mills, PA 19342

**Figure 8.9.** Hazleton Area High School, 1601 W 23rd St, Hazle Township, PA 18202

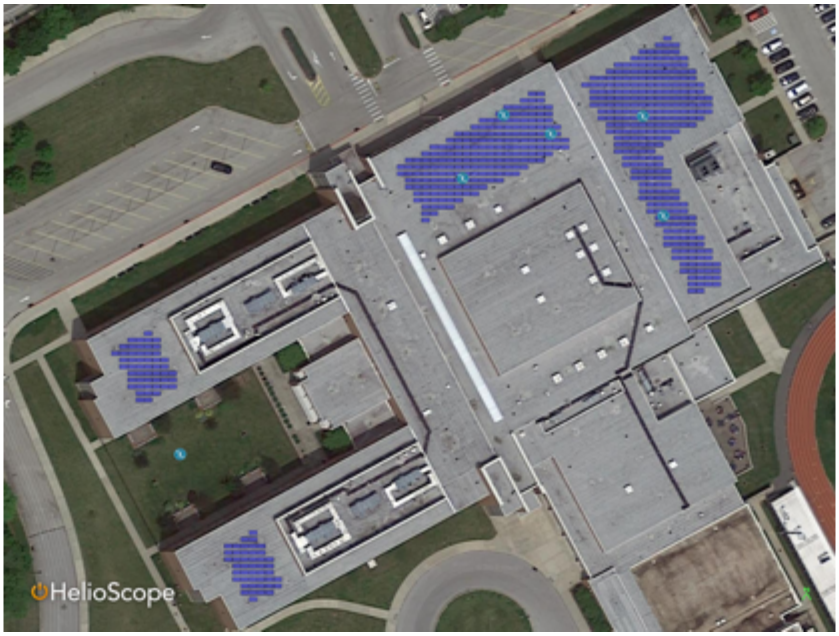


**Figure 8.10.** Upper Merion Area High School, 440 Crossfield Rd, King of Prussia, PA 19406

## 8.6 Test Procedure

It was not possible to test our solution/design physically, since the project was a feasibility study of potential rooftop solar PV systems on schools throughout the state of Pennsylvania. However, as mentioned in §8.2, our design was tested on three different softwares (HOMER, SAM, and Helioscope) to ensure the validity of results.

We created different scenarios for designs by size to see how it affected the financial outcome. Capacity factors of 25%, 50%, 75%, and 100% were preliminary and then a better analysis was done in between based on financial modeling.

Figure 8.11 summarizes the generic steps the team has adapted for meeting our customer needs. The local fire codes of each district were closely referenced during the design of the rooftop solar PV systems to ensure maximum safety. Moreover, the local ordinances of each district were referenced as well, to ensure legality of our design.

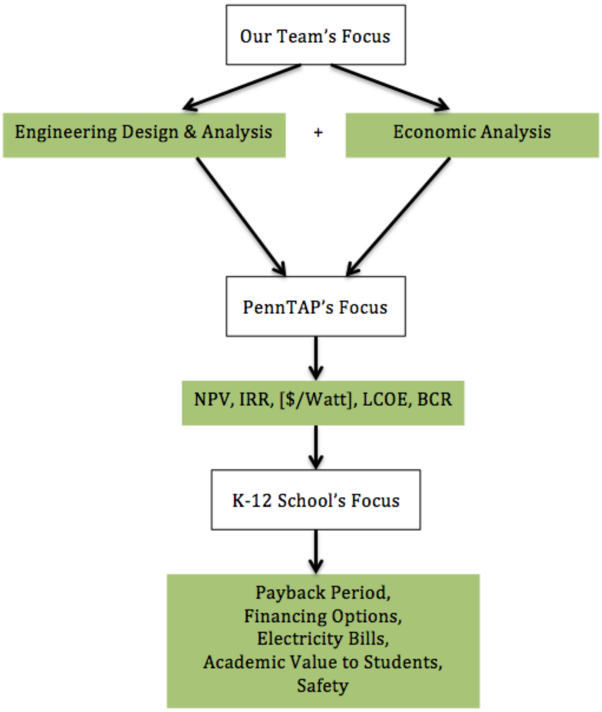


**Figure 8.11.** Test Procedure to Meet Client Needs

## 8.7 Economic Analyses - Budget and Vendor Purchase Information

With a starting budget of one thousand dollars, the estimation was that most of the funds would be retained by the end of the project. We predicted that the expenses would include the software, traveling, and a poster. We used the Helioscope software for a period of approximately 2 months. The software used normally had a payment associated with it, Helioscope ($95/month) and Homer ($42/month). However our team was able to acquire a free trial period and a later student license deal that allowed us to use the software for the entire semester free of charge. Out of town travel was not performed, so no costs were associated with travel. The team was very interested in creating a poster to present the results to the Spring 2018 College of Engineering Capstone Design Project Showcase. The team allocated approximately $70 for the printing of the project poster. Due to the nature of the project, we did not use any materials or supplies from the Learning Factory workshop.

**Table 8.2. Final Team Spending Analysis**

| Title | Amount | Units | Comments |
|---|---|---|---|
| Total budget | 1000 | $ | |
| | | | |
| Gas | 0 | $ | 54.5 cents/mile, 0 miles traveled |
| Bus | 0 | $ | |
| Travel expenses | 0 | $ | |
| | | | |
| Helioscope | 0 | $ | Student license |
| Homer | 0 | $ | Student license |
| Software Total | 0 | $ | |
| | | | |
| Poster | 64 | $ | |
| | | | |
| Total Expenses= | 64 | $ | |
| Surplus Total= | 936 | $ | |

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# 9.0 Final Discussion

## Section 9.0.1 Modifications to Statement of Work and DSR Sections

Revisions to the Proposal and DSR Sections 1 through 8 are listed as 9.0.1.X:

9.0.1.1. Introduction - No change

9.0.1.2. Customer Needs – No change

9.0.1.3. External Search – the following changes were made: addition of solar building installation codes and ordinances; addition of a stipulation on whether or not a battery system was necessary for solar panel installations; discovery of normal k-12 operations of Pennsylvania schools.

9.0.1.4. Engineering Specifications – No change

9.0.1.5. Concept Generation and Selection – No change

9.0.1.6. System Level Design – No change

9.0.1.7. Special Topics – Updated explanation of group responsibilities and how school districts were assigned, added notes describing meetings with Alanna and the collaboration process, updated Gantt Chart to reflect recent team accomplishments

9.0.1.8 Detailed Design – Updated feasibility evaluation plan to reflect PPA and 100% ownership scenarios, added Solar Renewable Energy Credits (SREC) to financial analysis, added scaling of electric load to schools square footage in energy consumption calculation, added chart for component selection detailing model and supplier selected

# 9.1 Construction/Completion Process

Once the design results and parameters were established, an excel file was created to obtain financial outputs from Helioscope. These included the electric power per module capacities (kWh/kW) generated by the solar arrays. The file is designed to be customized and adjusted for different schools being analyzed. Parameters are able to be easily changed to determine how they affect the outputs of the entire simulated system.

The school is initially selected in the excel file, which automatically loads the region specific information such as electricity rates. The school can either be analyzed for feasibility of the system or for Power Purchase Agreements (PPA). To start the analysis, we utilized a ratio of energy to power (time variable) that was generated by Helioscope. The biggest obstacle that the team encountered was the lack of data on any of the schools' energy consumption. Homer was useful, with regards to giving the team a reference point. To elaborate, Homer provided a database with sample data on a local school. This database contains values for energy consumption per feet squared. This prompted the team to conduct extra research on the square footage areas of each school.

Due to the lack of concrete numbers, our team used Google Earth and its ruler measure tool. This enabled each team member to estimate the overhead area of their respective school. Buildings with multiple floors were multiplied by the number of floors to yield the total approximate area of the school. These values represent an estimate of the real floor area of the school. Although not exact, they were adequate in making a calculation with the values in the Homer database. The determined square footage of the school was multiplied by the approximate annual kWh/sq ft value generated by the Helioscope simulation, yielding the annual power consumption for the school. All determined values were different and were relative to the specific school being analyzed. This annual consumption was further used to calculate how much a 100 kW solar PV system would realistically contribute to a school's overall energy consumption.

The excel file is able to run multiple scenarios of this model in a very short period of time. The scenarios look at different combinations of system size and grant amount, determining the feasibility of each scenario. Cash flow analysis, payback period, return on investment, and net present value are all calculated as outputs. If the payback period is determined to be greater than 10 years, the PPA route is automatically suggested for the system. Additionally, if the PPA mode is initially chosen, a coded Visual Basic Application (VBA)  is able to determine the optimal LCOE for the school as well as the PPA owner. The loan model for the system is based on a 4.5% interest rate for twenty years. Last, the VBA in excel took into account the physical degradation of the system, as part of the model.

## 9.2 Test Results and Discussion

### Full Ownership of Solar Energy Conversion System

The graph shows the relationship between the percentage of capital cost covered by grants, and the payback period of the investments. Intuitively, the larger the share covered by grants, the lower the payback period to the school. Our results show that ten schools are able to completely fund the investment and have an acceptable payback period, ranging between 5 to 10 years. These schools are located in the districts: Upper Dublin, Cheltenham, Norristown, Spring-Ford, Upper Merion, Westchester and Downingtown. These schools are illustrated as a bump on the graph. The other schools are feasible but to a certain extent. The project is feasible if 30 to 40 percent of the capital costs are covered by grants. Grants can potentially provide up to $2 million in funding, which would put a cap on the size or the solar PV system for these schools.

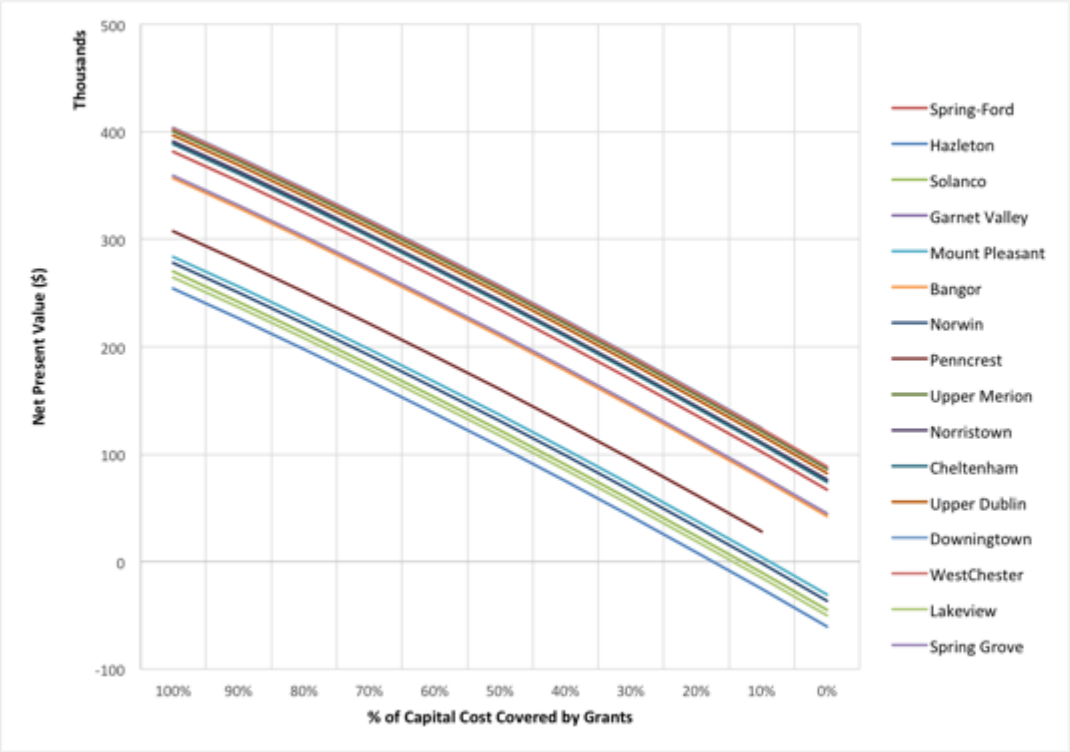


**Figure 9.1** NPV vs % Capital (Grants)

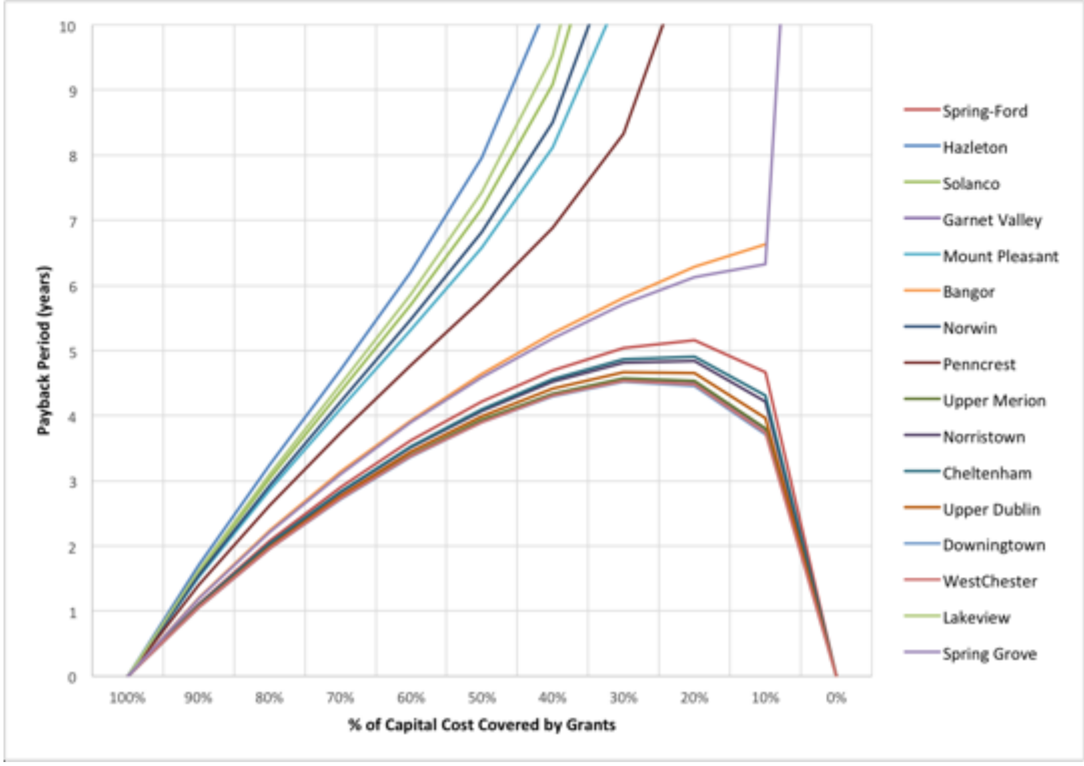


**Figure 9.2** Payback vs % Capital (Grants)

## Contribution of Solar to Overall Consumption

Another important aspect of our feasibility is to show that the solar panels are contributing significantly to the overall energy consumption of the schools. The graph below showing the share of solar power to the overall energy consumed for each school. Solanco is the only school with a significant solar share of 12 percent. This is due to the smaller size of this school relative to all the others. All the other schools range between 2 to 4 percent. This suggests that the panels are not significantly contributing to the overall power consumption, which may deem the investment infeasible to our clients. Our future recommendations would be to consider taking the PPA route and build a larger solar energy conversion system, and to conduct a full energy audit and take measures to reduce the overall electric consumption of the schools.

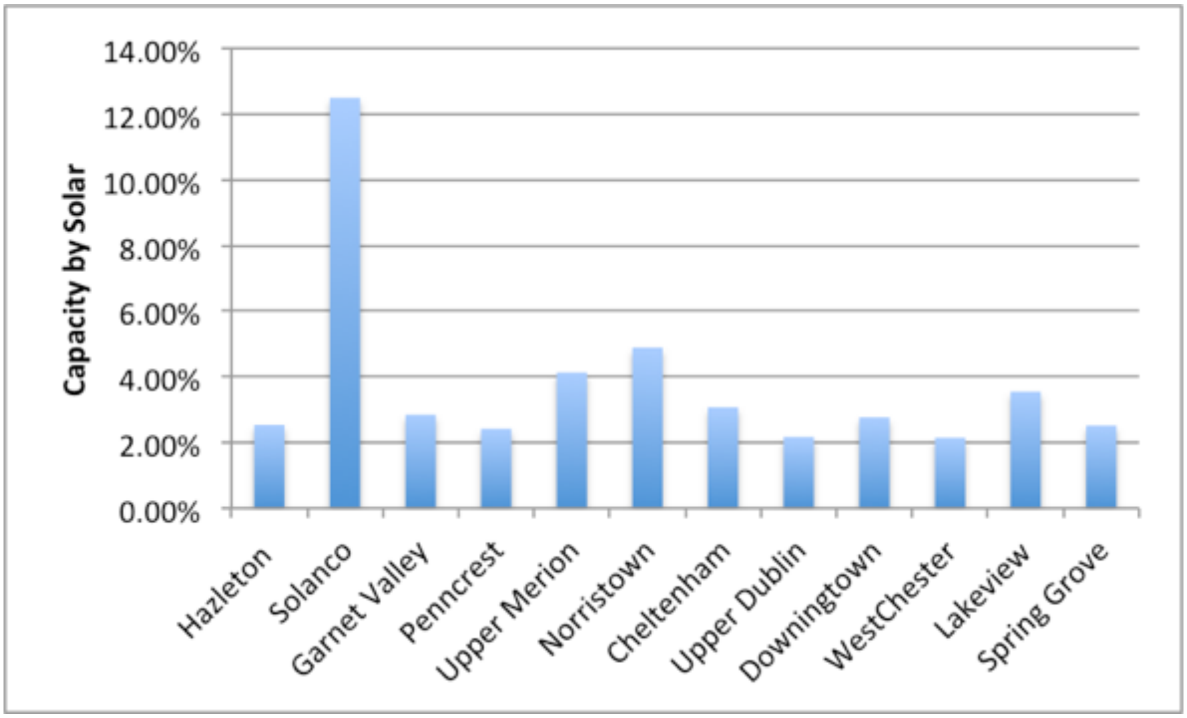


**Figure 9.3** Share of solar in overall electric consumption

## 10.0 Conclusions and Recommendations

In an evolving energy economy, data on the vitality and utility of different renewable and non-renewable energy sources is necessary to establish energy fuel source price and production levels. Our team conducted a feasibility study to determine whether eighteen school districts can successfully implement solar energy systems. The NPV increases are the model favors grants. Some of the schools, according to the shown results, are not feasible without grants covering at least 10-20% of the capital cost. Most schools are feasible over the course of twenty five year and those schools will generate a profit in that time interval. The schools near Philadelphia have a smaller smaller payback period as loans cover most of the capital cost, compared to the schools in rural counties.

Our team recommends that PennTap and school districts that are considering implementation of solar PV systems use the VBA created, inputting the appropriate grant, loan, and PPA data to produce outputs. Such outputs include a cash flow analysis with payback period, net present value and optimal LCOE for the school district in question. This analysis will assess whether or not the payback period for such investment will be less than 10 years and, subsequently, decide if solar PV system installation is feasible or not.

# 11.0 Self-Assessment (Design Criteria Satisfaction)

## 11.1 Customer Needs Assessment

In our self assessment, our team rated our ability to meet customer needs a 9 out of 10. We were able to generate a usable spreadsheet to determine the payback period and financial estimations for simulated solar PV arrays for a variety of schools. This spreadsheet can be adjusted based on different factors such as cost of electricity and size of the system. We worked very closely with our sponsor in designing the outputs of this spreadsheet so that all customer needs were met and simulated values could be estimated. Due to availability of information, values of the loads and other information such as cost per kilowatt were assumed based on local values. Additionally, our team made approximations for installation price based on average school values for each of the 18 simulated school districts. The assumptions made for these different data points contributed to the uncertainty of the output results. Access to more accurate information would have resulted in output values tailored to each specific school, and a 10 out of 10 customer needs assessment.

## 11.2 Global and Societal Needs Assessment

For the global and societal needs assessment, our group rated our ability 10 on a 1-10 scale. Unlike other projects, our tasks focused on a simulation and analysis of the feasibility of different solar systems. Because of the virtual nature of the project, very little work physical was done that would violate any environmental or ethical issues. However, we encountered different environmental aspects when scouting out school locations and making decisions. During our planning of the project, we took great care to abide by environmental regulations in regards to the solar systems. We also examined local zoning and ordinance codes for the specific Pennsylvania counties where solar systems were planned. We were able to analyse these codes and make decisions on the solar systems that did not compromise the safety of anybody in close proximity to the system. We were able to meet the needs of the local community and society by providing a solar system that fit within the budget of the area and was a legitimate possibility for the school.

# References

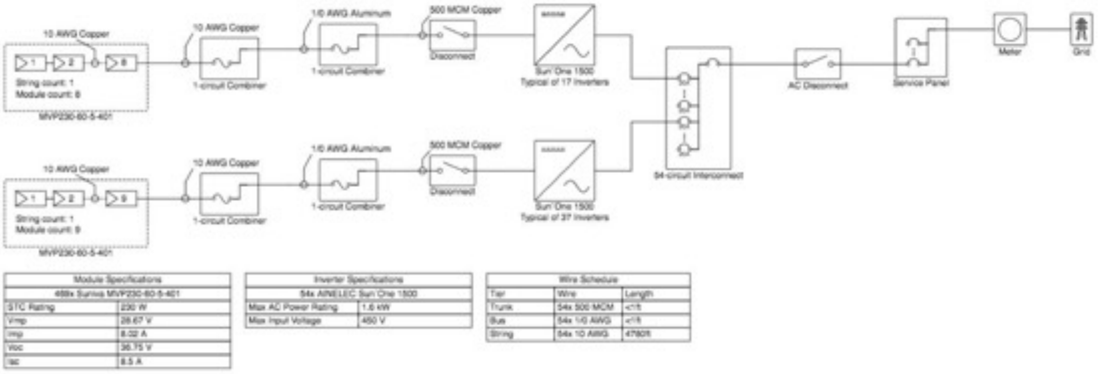
NREL. (n.d.). System Advisor Model (SAM). Retrieved February 15, 2018, from https://sam.nrel.gov/

Folsom Labs. (2017). HelioScope: Advanced Solar Design Software. Retrieved February 15, 2018, from https://www.helioscope.com/

HOMER Energy LLC. (n.d.). Microgrid Decisions Made with Confidence. Retrieved February 15, 2018, from https://www.homerenergy.com/index.html

Johnstonbaugh, E. (2013). Solar - extension.psu.edu. Retrieved February 13, 2018, from extension.psu.edu/solar-pv-electric-systems

# Appendix



| Module Specifications | |
|---|---|
| 469x Suniva MVP230-60-5-401 | |
| STC Rating | 230 W |
| Vmp | 28.67 V |
| Imp | 8.02 A |
| Voc | 36.75 V |
| Isc | 8.5 A |

| Inverter Specifications | |
|---|---|
| 54x AINELEC Sun One 1500 | |
| Max AC Power Rating | 1.6 kW |
| Max Input Voltage | 450 V |

| Wire Schedule | | |
|---|---|---|
| Tier | Wire | Length |
| Trunk | 54x 500 MCM | <1ft |
| Bus | 54x 1/0 AWG | <1ft |
| String | 54x 10 AWG | 4780ft |

**Figure A1.** Sample Single Line Diagram Designed as Part of the Engineering Design of Solar PV System

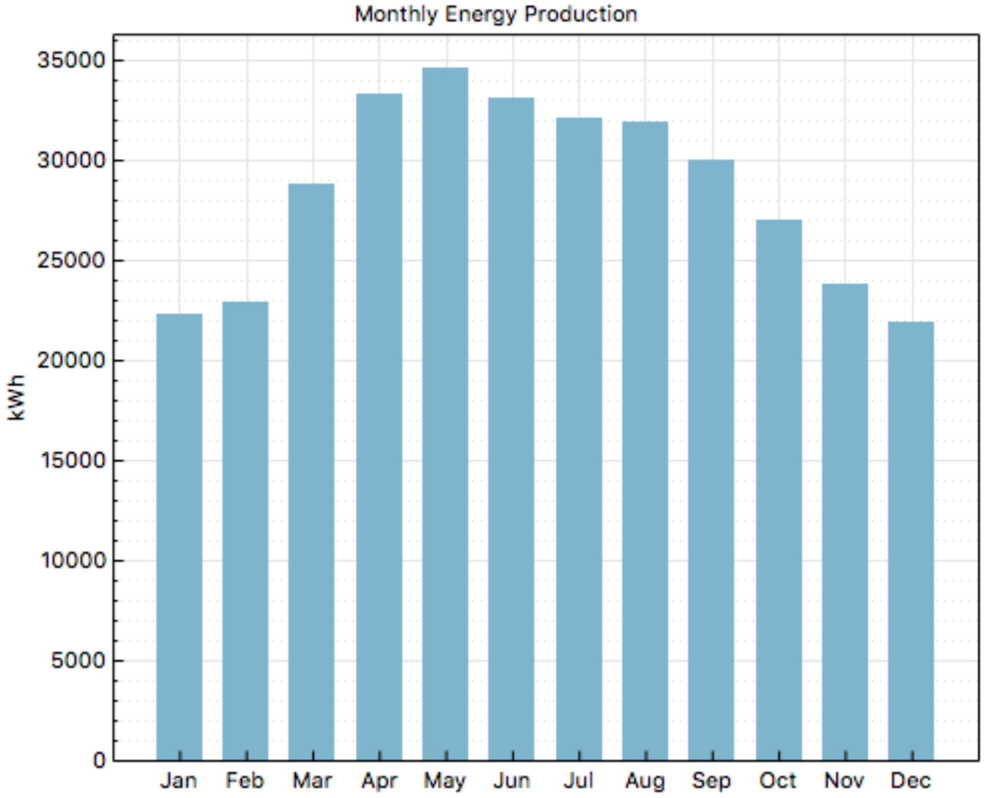
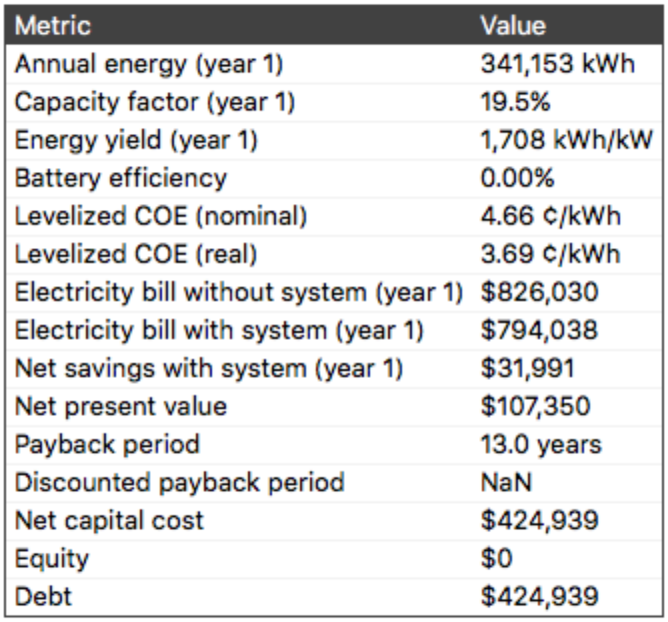


**Figure A2.** Sample Monthly Energy Production by Solar PV System



| Metric | Value |
|---|---|
| Annual energy (year 1) | 341,153 kWh |
| Capacity factor (year 1) | 19.5% |
| Energy yield (year 1) | 1,708 kWh/kW |
| Battery efficiency | 0.00% |
| Levelized COE (nominal) | 4.66 ¢/kWh |
| Levelized COE (real) | 3.69 ¢/kWh |
| Electricity bill without system (year 1) | $826,030 |
| Electricity bill with system (year 1) | $794,038 |
| Net savings with system (year 1) | $31,991 |
| Net present value | $107,350 |
| Payback period | 13.0 years |
| Discounted payback period | NaN |
| Net capital cost | $424,939 |
| Equity | $0 |
| Debt | $424,939 |

**Figure A3.** Sample Summary Table of Engineering and Economic Results