



Capturing Solar Energy at the Sustainability Hub

Sponsored by National Grid

An Interactive **Qualifying Project**

submitted to the Faculty of

Worcester Polytechnic Institute

in partial fulfillment of the requirements for the

Degree of **Bachelor of Science**

Submitted By:

Jacqueline P. Campbell

Zilu Tian

Sakiynah A. Howard

Project Advisors:

John Orr, WPI

Patrick Cody, National Grid

Acknowledgement

The team would like to thank all those who made the culmination of this project possible. Thank you to our advisor John Orr, who guided us through the project and provided valuable comments for our work in different phases. Thank you to our sponsors from National Grid, including Patrick Cody, Justin Woodard, and Colleen Gardner, who helped the team to reach contacts and assisted the approval process. Thank you to Chris O'Neil from Solar Design Associates, who provided the team with initial modeling results and many useful tips along the way. The project would not be a success without the support from all of you.

Abstract

The National Grid Sustainability Hub on Main Street in Worcester is a center for community education on sustainable practices. Adding solar power to the Hub would provide further education on renewable resources and serve as a model to the Worcester public. The Hub has large storefront windows which let in substantial heat and light. This project provided a detailed design of a photovoltaic system which would both capture the light energy and minimize heat gain. Furthermore, this project provides educational resources to the Hub to show to its customers and it also provides a community charging station in order to draw visitors into the Hub. This will hopefully serve as a model for the greater Worcester community.

Table of Contents

Acknowledgement	i
Abstract	ii
Table of Contents	iii
Table of Figures	v
1 : Introduction	1
2: Goals and Deliverables.....	2
2.1: Goals	2
2.2: Deliverables.....	2
3 : Background	3
3.1: The Hub.....	3
3.2: Photovoltaic Systems.....	5
3.2.1: Why photovoltaics?	5
3.2.2: Composition of Solar Cells	6
4: Design Approach.....	8
4.1 : Modeling Outcomes for Different Applications.....	8
4.1.1: Rooftop Solar Panels.....	9
4.1.2 : Photovoltaic Awning	14
4.1.3 : Solar Panels on Bus Stop.....	18
4.2 : Decision Analysis Array	19
5: Implementation	20
5.1 : Solar Awning Design.....	20
5.1.1 : Preliminary Research and Data Collection.....	20
5.1.2 : Calculations	21
5.1.3 : Visualization	22
5.2 : Charging Station.....	23
5.2.1 : Choosing a Charging Station	23
5.2.2 : Integration of Photovoltaic Education.....	26
5.2.3 : Location for the Charging Station	26
5.2.4 : Realization of Charging Station	27
5.3 : Financial Estimation	28
5.4 : Educational Materials	29

5.4.2 : Energy Consumed by Typical Appliances.....	29
5.4.3 : Inverters for Photovoltaic Systems	30
5.5 : Approvals	31
5.5.1 : Funding from National Grid	31
5.5.2 : Building Permissions from Clark University	31
5.6 : Alternatives	32
6 : Results and Conclusions.....	33
References	34
Appendix A : PV System Model by HelioScope.....	36
Rooftop Solar Panel Model Analysis	36
Photovoltaic Solar Awnings Model Analysis	39
Appendix B : Datasheet for Solar Panels.....	41
Datasheet for ReneSola JC310M-24/Ab	41
Datasheet for Suniva Optimus Series OPT-270-60-4-100.....	43
Appendix C: Educational Material	45
Inverters for Photovoltaic Systems.....	45
Power Consumed by Your Appliances	46
Appendix D : Final Presentation to National Grid.....	47

Table of Figures

Figure 1 View of the Sustainability Hub from Main Street	3
Figure 2 Widths of windows and other front-facing features of the Hub	4
Figure 3 Specific feature measurements of the Hub	5
Figure 4 The cost for photovoltaic panels has decreased an average of \$0.50/W (6-7%) per year.....	6
Figure 5 Composition of a solar cell [18]	7
Figure 6 An example of rooftop solar panels [16]	9
Figure 7 Rooftop of the Sustainability Hub from Google Maps.....	9
Figure 8 Estimate for Metal Roof Installation, priced by Homewyse [8].....	10
Figure 9 Estimate for Composite Roof Installation, priced by Homewyse [8].....	10
Figure 10 Monthly Production of the PV System.....	12
Figure 11 An example of a photovoltaic awning	14
Figure 12 Monthly production of PV awnings	16
Figure 13 Examples of bus stop shelters.....	18
Figure 14 Awning from the side.....	22
Figure 15 Awning from the front	22
Figure 16 RAVPower 15W Solar charger withDual USB Port [7].....	23
Figure 17 ChargeTech Floor Stand Unit	24
Figure 18 Closeup of ChargeTech [6]	24
Figure 19 Great Useful Stuff Charging Station and Dock [5].....	25
Figure 20 Artist's rendition of charging station in the Hub.....	26
Figure 21 Charging station in the Hub	27
Figure 22 Example of information from "Power Consumed by Your Appliances"	29
Figure 23 An example of a home photovoltaic system.....	30
Figure 24 An example section from "Inverters for Photovoltaic Systems"	30

1 : Introduction

The Sustainability Hub on Main Street in Worcester is a center for sustainable behavior education. The Hub is operated by National Grid. The main purpose of the Hub is to foster greener communities and promote the new Smart Energy Solutions program being implemented by National Grid. Finding more sustainable ways to power our world is an integral part of creating a greener community. Currently, the Hub is not powered by any renewable power sources, nor is there a current plan to establish such sources. The Sustainability Hub has large windows present at the front of the building, facing the street. These windows allow a lot of sunlight in, which causes the area in front of the window to be very hot. Exploration of how to best capture and use the energy from these solar rays will provide several benefits to Clark University, National Grid, and the Worcester Community. Capture of the light energy and diffusion of some of the heat gained by the windows is one of the primary focuses of this project. This is accomplished through an investigation of both passive and active solar technologies which can be applied to the Hub specifically. Because community education is a large purpose of the Sustainability Hub, another primary focus is creating educational resources to the Hub for distribution and creating a way to further connect the Hub with the Worcester community.

2: Goals and Deliverables

The breadth of this project lends itself to several distinct goals. The overarching purpose of this project is to capture solar energy from the large windows present in the front of the Hub. The photovoltaic energy is to be captured, and the heat energy is to be diverted during the summertime and utilized during the wintertime. The possible means to accomplish this will be further discussed in later sections of this report. The chief goals of this project can be summarized as follows:

- Find the best solution to the heat and light gain through the windows
- Provide educational resources to the Hub for its customers regarding solar energy in the household
- Bring the Worcester community in closer contact with the Hub

These goals are focused around several different themes including the incorporation of education and community, implementation and the maximization of captured solar energy, and reducing the heat gain through the windows. Each of these goals contains sub-goals and provides unique deliverables which will be presented to the Sustainability Hub by the completion of this project.

2.1: Goals

These project goals were chosen so that their accomplishment would provide the most benefit to the Hub and Worcester community.

- Provide a logical and favorable solution through analytic methods
- Develop a comprehensive design of the photovoltaic awnings
- Obtain National Grid approval and funding for the proposed photovoltaics
- Provide alternative measures to reduce heat and light gain
- Create relevant educational materials

2.2: Deliverables

The deliverables will be presented to the Hub at the completion of the project to serve as resources for the Hub and the Worcester community.

- Educational materials (Appendix C)
- Way to further engage Worcester community with the Hub
- Comprehensive photovoltaic design
- Visualization of photovoltaics and other deliverables within the Hub
- Accessible information for the public regarding the proposed photovoltaic system
- Final presentation to the sponsor, (Appendix D)
- Final report

3 : Background

3.1: The Hub

The establishment of National Grid's Sustainability Hub came forth through the help of many community sponsors and advocates. The groundwork for the idea of the Hub however can be attributed to the State of Massachusetts and its people. Massachusetts State is a pioneer in sustainability. In 2008, the state passed what is known as the Green Communities Act which, among other components, set forth several mandates for electric and gas utilities. Of these, one of the most pertinent for the creation of the Sustainability Hub was "the electric distribution companies and municipal aggregators with certified efficiency plans shall jointly prepare an electric efficiency investment plan." It is noted that a plan must include "a description of programs..." within it. The plan goes forth to describe several examples of programs, including educational programs for customers and demand response programs. [1]

National Grid, as an electric distribution company, must comply with these regulations. Unlike many other utilities, National Grid saw this as an opportunity to improve not only their environmental efforts, but also their community outreach. From this, the Green2Growth Summit of 2011 took place. This was a mixture of Worcester Residents, business leaders, politicians, and others who felt that Worcester needed to find a way to become a greener city. Together, they realized the need for a community space for residents to discuss and become educated about Worcester's energy future. Thus, the Sustainability Hub was born [2].



Figure 1 View of the Sustainability Hub from Main Street

The Sustainability Hub is located at 912 Main Street in Worcester and is a bustling source of educational and community resources. A picture can be seen in Figure 1. The main purpose of the Hub is to give Worcester residents a place to meet and discuss their energy usage and to figure out how to become more sustainable in their daily lives. The Hub offers energy saving tips and programs, as well as educational materials for adults and children alike. Furthermore, the Hub aims to teach Worcester Residents about the new Smart Energy Solutions Program which is being tested in Worcester right now. The Smart Energy Solutions Program is, in essence, demand-based electricity pricing. The program encourages use of electricity during “off-peak” hours, or when demand is low, and discourages use during “on-peak” hours, or when electric demand is high. The overall goal of this is to reduce the peak demand of electricity. By decreasing peak demand of electricity, less electricity will need to be produced per day, which would create less pollution and be better for the environment. National Grid is striving to promote greener communities and use of renewable power, which forms the basis for this project.

For this project, as a preliminary resource, the measurements of the Hub were taken. They can be viewed below in Figure 2, which is an altered form of Figure 1, and Figure 3. Individual measurements for each of the large storefront windows was taken, along with the entire storefront area. As can be seen in Figure 1, The Hub has both a large tree and an entranceway almost directly in the middle. The measurements from the tree to the building and across the large entranceway were also taken, as they were considered to be of importance.

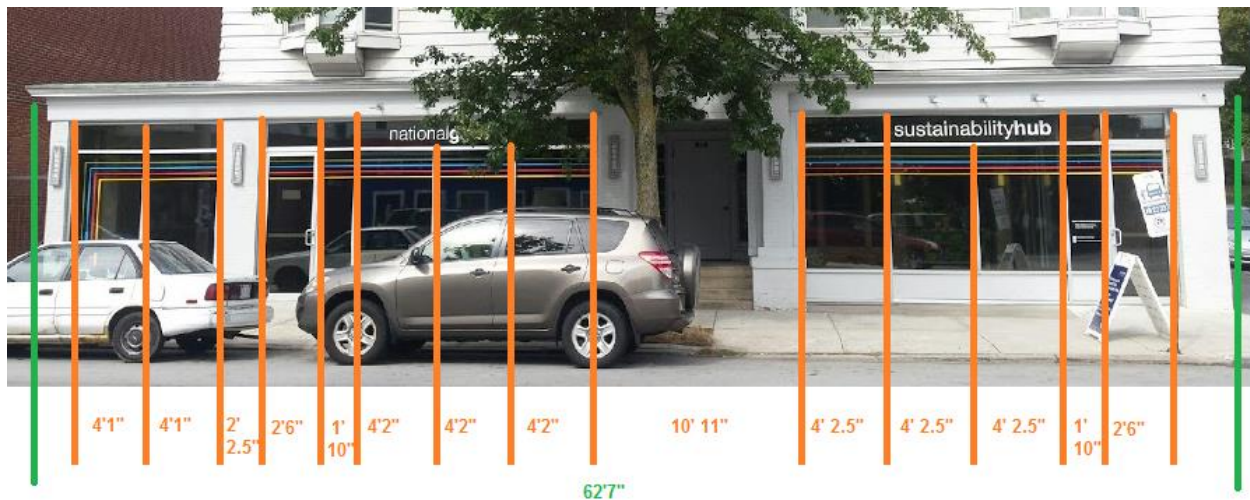


Figure 2 Widths of windows and other front-facing features of the Hub



Figure 3 Specific feature measurements of the Hub

National Grid does not endorse any solar products. National Grid does not generate electricity, but rather is responsible for the transmission and distribution of it. As a result, the company is not able to offer any recommendations on solar panels for home use or other applications. Yet, customers eager to improve their carbon footprint come to the Hub frequently to ask for information on solar solutions for their home. This, combined with the purposes of the Hub, creates a necessity for exploration into solar possibilities there.

3.2: Photovoltaic Systems

3.2.1: Why photovoltaics?

Capturing the energy from the sun is not a new concept. For centuries, different civilizations have found means to use the sun's abundant heat and light energy for different purposes. According to the U.S. Department of Energy, starting in the 7th Century B.C., magnifying glasses were used to concentrate the power of the sun to start fires [9]. From then, the technology has come a long way. Active solar systems can be split into two classifications: Thermal and Photovoltaic.

Thermal systems, which will not be discussed at length in this proposal, essentially capture the heat from the sun and use it to heat up a liquid, typically water. Residential thermal energy systems differ from commercial in that typically the process stops at heating the water. The heated water in a residential system is then used as the hot water source for the house and to heat the house itself. In commercial applications, the system heats water to create steam which is used to spin a turbine [10].

The focus of this project is not on capturing thermal solar power, but rather on creating electricity from light. Photovoltaic systems initially found their most use on satellites and spacecraft in the late 1950's. They still are used on spacecraft today because of their ability to provide power without burning fuels and because of an ever-present sun in space. Sunlight in space is "unimpeded by atmospheric interference" [11], which allows stronger light rays to contact the panels. In more recent history, photovoltaic systems are becoming increasingly more popular for residential applications. This is likely due to the immense decrease in price which solar panels have been seeing in the past few years. According to Figure NUM below, taken from *Tracking the Sun VI : An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2012*, the cost for photovoltaic panels has decreased an average of about \$0.50/W (6-7%) per year for the time shown on Figure 4 [12].

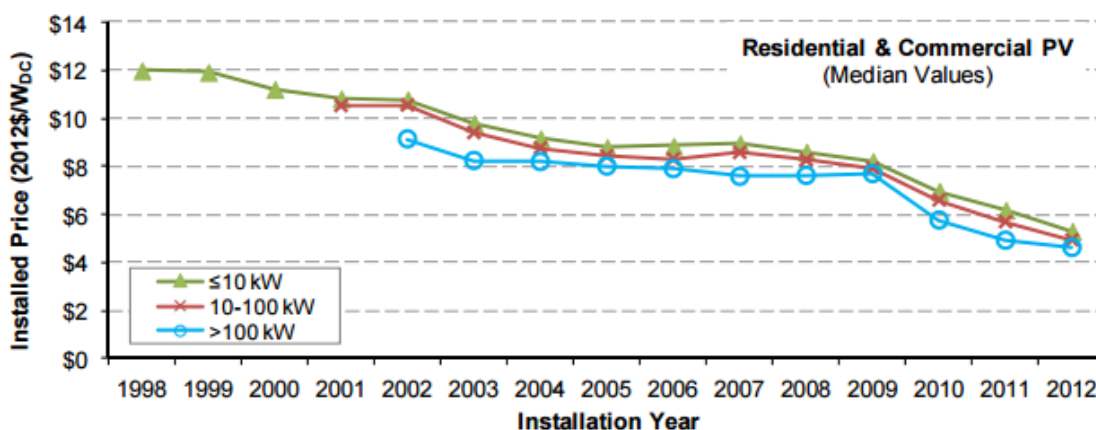


Figure 4 The cost for photovoltaic panels has decreased an average of \$0.50/W (6-7%) per year

Furthermore, photovoltaic efficiency and volume of production has been improving each year. This fact also contributes to their rise in popularity for home use.

3.2.2: Composition of Solar Cells

The composition of solar cells can be dated back to 1839 when a French physicist name Edmund Becquerel found a material that could produce some electric current when that material was exposed to light. This phenomenon, known as the photoelectric effect, was later described in greater detail by Albert Einstein, for which he received a Nobel Prize. On April 25, 1954 the first practical solar cell was built by electrical engineer Daryl Chapin, physicist Gerald Pearson and chemist Calvin Fuller at Bell Laboratories in New Jersey. At the time, the scientist of Bell Laboratories did not intend on using these solar cells and treated them more like a project to stimulate their curiosity because the solar cells were far too expensive to put into widespread use. It was not until the 1960s when these solar cells were used by the space industry. As a result the technology of the solar cells advanced through the space program and in the 1970s, the photovoltaic technology had gotten recognition as a source of power for applications outside of the space program during the energy crisis [17].

A solar cell, also known as a photovoltaic cell, is composed of a semiconductor material, usually silicon, which shares some properties of both electrical conductors, or metals, and electrical insulators. Within the silicon, the semiconductor is sectioned into two parts which are called the n-type and the p-type. When sunlight shines down on a solar cell, packets of energy from the sun's rays called photons transfer their energy to the silicon atoms and loosens their electrons. These free electrons from the silicon atoms are attracted to the p-type of the semiconductor and naturally flow to the n-type as shown in Figure 5 below. This flow of electrons creates an electric field across the cell. If the two semiconductor types of the solar cell are connected to an external load, such as a light bulb, then the electrons will flow from the n-type to the p-type and through the load. This flow of electrons becomes electricity within an electric circuit [15].

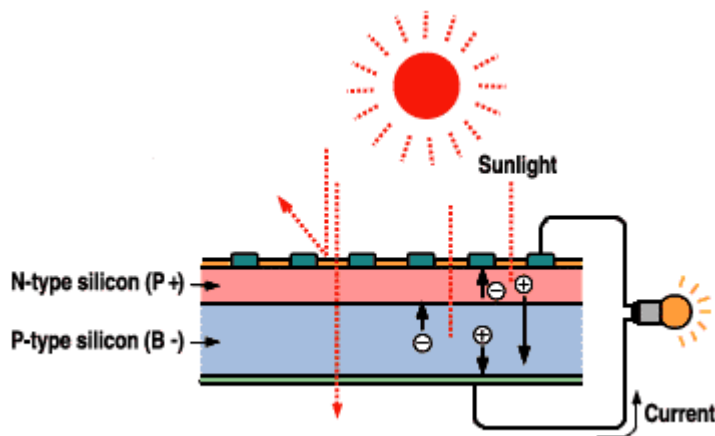


Figure 5 Composition of a solar cell [18]

4: Design Approach

After brainstorming, the team came up with three different ways to accomplish this project: rooftop mounted solar panels (plan A), a photovoltaic awning system (plan B), and the construction of a bus stop equipped with solar panels (plan C). The captured energy would be more than enough to power a commercial phone charging station located inside the hub, with the excess power going into the grid. Each plan targeted at a slightly different aspect: plan A could maximize the energy output of the system; plan B could block the heat through the windows; plan C could be the most beneficial to the public.

This section will provide readers with detailed elaborations on the thinking process while making the judgment call. Before putting down a decision analysis to rank the relevance of each candidate with project goals, the team started with an estimation of the annual energy production for each photovoltaic system.

4.1 : Modeling Outcomes for Different Applications

To have a better understanding of the actual output of the system, the proposed solution was to model each option using HelioScope. HelioScope is an advanced photovoltaic system design tool that combines the system layout with modeling to simplify the engineering process. To help the team get started, Christopher P. O'Neil and Nicolas Lawrence from Solar Design provided the modeling results for rooftop solar panels (plan A) and solar awnings (plan B) [14]. At this point, we could either spend time building a model for a bus stop with solar panels (plan C) or focusing on decision making aspect and using the estimation of the annual production of plan C for comparison. After discussion, we chose to move on with an estimation. If plan C was selected as the final candidate to implement, we would then focusing on modeling to get a better estimation.

4.1.1: Rooftop Solar Panels



Figure 6 An Example of Rooftop Solar Panel System [16]

The rooftop solar panel system was a simple solution to capture solar energy at the Hub. An example of rooftop solar panel system could be seen above in Figure 6. However, it failed to mitigate the heat problem and was invisible from the ground, which reduced its educational value. The roof of the Hub could be viewed as a 52' x 55' rectangle, as shown below in Figure 7.

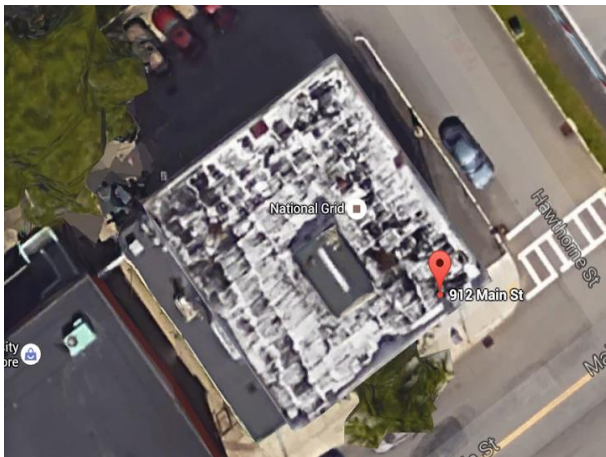


Figure 7 Rooftop of the Sustainability Hub from Google Maps

The roof surface was rugged and unsuitable for direct placement of solar panels. To ensure the proper operation of the photovoltaic system over the lifespan of next two decades, a roof refurbishment would be considered. It would increase current budget significantly. The obstacle in the center of the roof comprised an estimated area of 11' x 13', so the roof replace area was around 2700 square feet. From Homewyse, the overall cost for a 2700 square feet roof varied from \$8,000 to \$27,000, including labor, material, and equipment allowance [8]. Detailed prices for different roof materials are shown in Figure 8 and Figure 9. Metal roofing was in the range of \$20,000, and composite shingle roofing was in the range of \$10,000.

Cost of Metal Roofing

Item	Buy Qty	Low	High
Material	2825 sq ft	\$17,409.49	\$22,022.91
Labor	49.9 hrs	\$3,471.97	\$4,233.66
Supplies, Tools		\$994.37	\$1,150.49
Total		\$21,875.83	\$27,407.06

Roof Surface Area **2700 square feet**

Roofing Grade **Better - value grade**

Labor **Roofing vendor**

Roof Layout* **Low slope, simple shape**

Zip Code **01609** Update

Figure 8 Estimate for Metal Roof Installation, priced by Homewyse [8]

Cost of Composite Shingle Roofing

Item	Buy Qty	Low	High
Material	2825 sq ft	\$2,780.14	\$3,516.84
Labor	76.3 hrs	\$5,313.00	\$7,026.14
Supplies, Tools		\$724.02	\$837.69
Total		\$8,817.16	\$11,380.67

Roof Surface Area **2700 square feet**

Roofing Grade **Better - value grade**

Labor **Roofing vendor**

Roof Layout* **Low slope, simple shape**

Zip Code **01609** Update

Figure 9 Estimate for Composite Roof Installation, priced by Homewyse [8]

Once the planning for roof renewal was complete, the team moved on to analyze the simulation results generated by HelioScope, as explained in the beginning of this section, which included detailed physical layouts. The tool abstracted roof dimensions for the Hub from Google sketch, using Sandia model developed in Sandia National Laboratories tailored for photovoltaic (PV) analysis for temperature. The weather dataset was typical-year data (TMY) released by National Renewable Energy Laboratory. These parameters could be found in the Condition Set shown in Table 1.

Table 1 Condition Set of the Rooftop PV System

Condition Set												
Description	Condition Set 1											
Weather Dataset	TMY, 10km grid (42.25,-71.85), NREL (prospector)											
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					
	JC310M-24/Ab (Renesola)						Default Characterization, PAN					

To cover the entire roof, the tool placed thirty-three JC310M-24/Ab solar panels and two SE6000 (240V) inverters. The size of the solar panel is 77" x 39.1" x 2" each and the power rating is 282.9 W under PVUSA Test Condition (PTC). Its datasheet can be found at Appendix B which included power ratings, conversion efficiency, maximum system voltage, and other technical details.

The resulting PV system has an annual production of 12.4 MWh, as indicated in Table 2 System Metrics of the Rooftop PV System. Note that the modeling result assumed no shading, which would result in a higher annual production comparing to the actual photovoltaic system with shading.

Table 2 System Metric of the Rooftop PV System

System Metrics	
Design	Design 1
Module DC Nameplate	10.2 kW
Inverter AC Nameplate	12.0 kW Load Ratio: 0.85
Annual Production	12.37 MWh
Performance Ratio	79.3%
kWh/kWp	1,209.6
Weather Dataset	TMY, 10km grid (42.25,-71.85), NREL (prospector)
Simulator Version	153 (443094f0ad-ea93f843ef-fce6caf820-00aa14f623)

The monthly production of the modeled PV system varies dramatically throughout the year. In summer the monthly production reaches its peak at over 1400 kWh but in winter it drops to an average of 500 kWh. The charging station itself requires energy input of 220W (110V, 2A), and the maximum monthly power consumption is $220\text{W} \times 8\text{hr} \times 30 = 52.8\text{ kWh}$, which is much less than the monthly power production. The power unused by the charging station will power the rest of the Hub and sell back to the Hub's energy provider, National Grid.

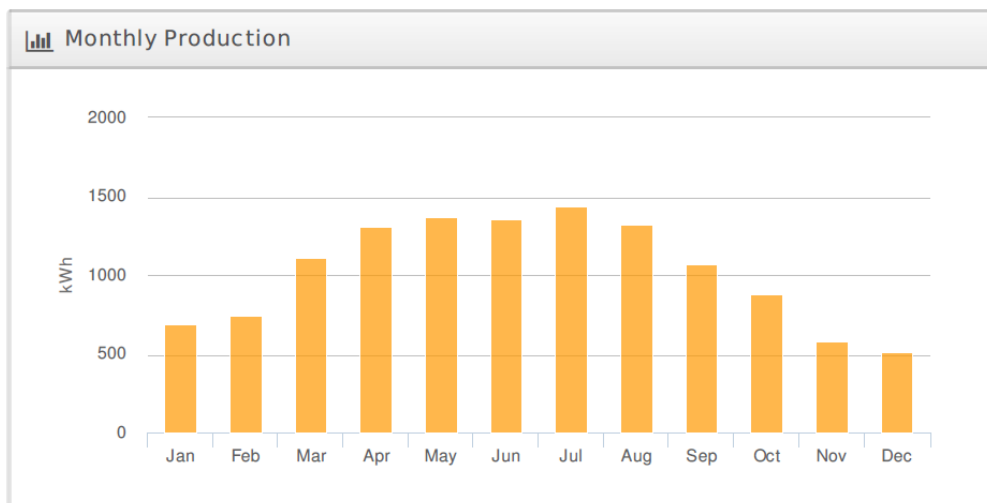


Figure 10 Monthly Production of the PV System

As for the budget, the estimation was \$45150, including hardware and other costs, which is listed in Table 3 Financial Estimate for Rooftop Solar Panels. The hardware costs include prices for solar

panels, string inverters, and roof renewal. Other costs include tree removal, labor, permit, and the charging station.

Table 3 Financial Estimate for Rooftop Solar Panels

Hardware Cost		Note
Solar Panels	\$10000 (Include taxes and other fees)	Based on Renesola JC310M-24; \$260 each, 33 in total
String Inverters	\$2500 (Include taxes and other fees)	Based on SolarEdge SE3000A, \$1188, 2 in total
Roof Renewal	\$10000 (Include taxes and other fees)	
Others		
Tree removal	\$800	Average cost in Worcester
Labor cost	\$21000	Estimate \$1 per Watt for solar panels, 270x33=\$8910; 6 workers 20 hours at \$100/h: 20h x \$100/h x 6pl = \$12000;
Permit	\$300	Electrical permit, solar wiring, \$300 <i>minimum</i>
Charging Station	\$550	Based on ChargeTech S9, \$550
Total	\$45150	

Overall, rooftop solar panel system was a simple proposal with low education value and indirect community impact.

4.1.2 : Photovoltaic Awning



Figure 11 An Example of A Photovoltaic Awning

A solar awning system was a practical and presentable form of solar solution for the Sustainability Hub. Solar awnings would both capture the solar energy and help with the problem of heat in the space near the windows, which could be seen from Figure 1. In addition, the educational value would be much higher compared to the rooftop mounted solar panels due to its visibility from the ground and the community impact would be greater since it served as a shelter from the rain and snow days.

The modeling for photovoltaic awnings [14] adopted the same weather and temperature data as used in the previous rooftop simulation. The details of the condition set could be found on the next page in Table 4.

Table 4 Condition Set of PV awnings

Condition Set												
Description	Condition Set 1											
Weather Dataset	TMY, 10km grid (42.25,-71.85), NREL (prospector)											
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								
	OPT270-60-4-100 (Suniva)			OPT270_60_4_100_9_14_2012.PAN, PAN								
Component Characterizations												
Device								Characterization				
SE4000 (240V) (SolarEdge Technologies)								CEC 2014-08-16				

The solar panels used for modeling are the Suniva Optimus Series OPT-270-60-4-100. The dimensions are 65.04" x 38.66" x 1.57" and the power rating is 270 W under PVUSA Test Condition, which are similar to the ReneSola. The main difference between the two panels is weight: a Suniva series solar panel weighs only 39.5 lb while the other is 64 lb. The datasheet of the panel can be found at Appendix B for other technical details.

Table 5 summarized the system metrics. The system is consisted of 12 solar panels and 1 inverter. The resulting PV system could generate 3.6 MWh per year.

Table 5 System metrics for PV Awnings

System Metrics	
Design	Solar Canopy
Module DC Nameplate	3.24 kW
Inverter AC Nameplate	3.97 kW Load Ratio: 0.82
Annual Production	3.657 MWh
Performance Ratio	72.1%
kWh/kWp	1,128.6
Weather Dataset	TMY, 10km grid (42.25,-71.85), NREL (prospector)
Simulator Version	153 (443094f0ad-ea93f843ef-fce6caf820-00aa14f623)

As can be seen from Figure 12 below, the monthly production is relatively stable across the year, with an average of 300 kWh, in contrast to the annual variation presented by rooftop solar panels. Spring and summer are the most productive months, with a monthly average of over 350 kWh. The least productive month is December, little below 200 kWh.

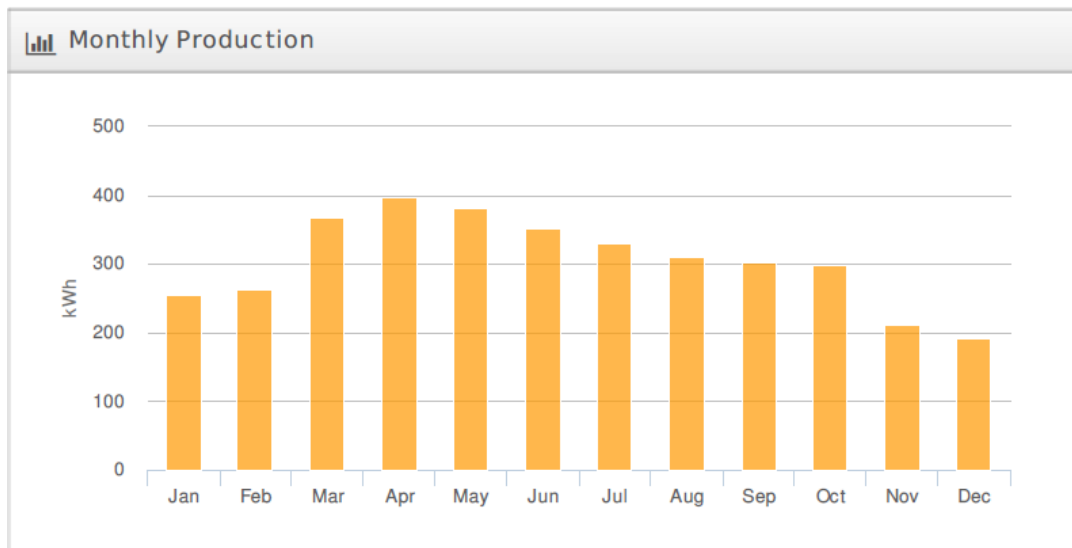


Figure 12 Monthly production of PV awnings

The budget estimation was \$13950, which is listed below in Table 6. The hardware costs include prices for solar panels, string inverters, and awning structure itself. Other costs include tree removal, labor, permits, and the charging station.

Table 6 Financial Estimation for solar awning system

Hardware Cost		Note
Solar Panels	\$3800 (Include taxes and other fees)	Based on Suniva OPT 270-60-4-100; \$310 each, 12 in total
String Inverter	\$1300 (Include taxes and other fees)	Based on SolarEdge SE3000A, \$1188
Awning Structure	\$1000 (Include taxes and other fees)	Based on EasyShade, \$799
Others		
Tree removal	\$800	Average cost in Worcester
Labor cost	\$6000	Estimate \$1 per Watt for solar panels, 270x12=\$1890; 2 workers 20 hours at \$100/h: 20h x \$100/h x 2pl = \$4000;
Permit	\$500	Building permit, \$135 Electrical permit, solar wiring, \$300 <i>minimum</i>
Charging Station	\$550	Based on ChargeTech S9, \$550
Total	\$13950	

In summary, a photovoltaic awning system was easy to implement and did not require modification to the existing building structures. It possessed a high educational value and direct community impact. The monthly power output was relatively stable at 300 kWh and the variation was within 50 kWh.

4.1.3 : Solar Panels on Bus Stop

The implementation of solar panels on an enclosed bus stop would serve as a great benefit to the Worcester community as well as a great display to show off and promote solar energy. Passengers waiting for the bus would be provided shelter from rain and snow in the enclosed bus stop. A bench could also be placed inside for those who would like to take a seat. It would have high educational value and great impact on the community.



Figure 13 Examples of Bus Stop Shelters

The construction of the bus stop would involve various aspects. Permissions from the City of Worcester Department of Public Works would be needed and these may take quite a long time to obtain. The cost would also be significant.

Along with the construction of the bus shelter, the solar panels placed on top could collect enough energy to power a charging station. Though placing the charging station inside the shelter would provide easy access to the public, there would be a risk of theft and misuse. As a result, the team decided to place the charging station inside the Hub instead. People could also look around in the Hub learning about energy conservation while charging their phones.

As for the budget, the construction of a bus stop costs between \$2000 and \$15000, with an annual maintenance fee ranging from \$500 to \$3000 [4]. The roof structure can hold three to four solar panels, which would add another \$7000 including hardware (solar panels \$800-\$1000, inverter \$1300, charging station \$550, permit \$300, tree removal \$800, labor cost \$3000.) This would result in an estimate of \$17000, assuming a construction fee of \$10000.

4.2 : Decision Analysis Array

When choosing which photovoltaic system should be implemented, the three options were put into an analytical array where the different benefits for each option were rated on a scale from 1 to 3, where a rating of 3 meant that the option would be the most beneficial for a specific aspect and a rating of 1 meant that the option would be the least beneficial. Rating in factor Cost was slightly different from others, 1 being the most expensive and 3 being the cheapest.

Constructability was evaluated on the complexity and feasibility of the plan. The photovoltaic awning system didn't require any changes to existing building structures, as opposed to rooftop solar panels or bus stop.

The educational value was mostly judged based on the visibility of the project. The photovoltaic awning system was ranked the same as solar panels on a bus stop, while the rooftop solar panels had the least educational value.

The costs were detailed in the previous sections. As stated before, estimated prices for rooftop solar panels, photovoltaic awnings, and solar panels on a bus stop were \$45150, \$13950, and \$17000 separately.

Community impact was another important factor. All the plans would contribute to the Worcester community by powering a free phone charging station, but awnings and bus stop would also provide shelter for people. As a result, awnings and bus stop were given a 2 and rooftop solar panels system was given a 1.

Table 7 Decision Analysis Array

	Constructability	Educational Value	Cost	Community Impact	Total Score
Rooftop Solar Panels	2	1	1	1	5
Photovoltaic Awnings System	3	2	3	2	10
Solar Panels on Bus Stop	1	2	2	2	7

As could be seen from Table 7 Decision Analysis Array above, the photovoltaic awnings system was ranked the highest among all three options. Logically, the team decided to build solar awnings for the project.

5: Implementation

As stated above in Section 4, solar awnings are the chosen project design because their constructability, price point, community impact and educational value outrank the competitors. The process of researching, designing, and constructing solar awnings for the front of the Hub is certainly an involved task, and is therefore outlined below in order to ensure an organized approach. Furthermore, in addition to the physical awnings themselves, other components must be implemented in order to ensure a successful project. These auxiliary elements are necessary to complete the goals of the project, and include the educational materials for the Hub and the cell phone charging station.

5.1 : Solar Awning Design

5.1.1 : Preliminary Research and Data Collection

Preliminary data is collected in order to ascertain the efficiency of the design. Physical dimensions of the Hub can be seen in Section 3.1, Figure 2. These dimensions are used to calculate and create a drawing of the Hub design.

Adequate research on the functionality and maximization of photovoltaics is detailed above in Section 3.2. Specific research into solar angles for Worcester has been prepared in order to determine the best angle to maximize solar shade in the summer. The angle of the awnings to the Hub can be chosen such that more heat is let in during the winter and less during the summer. This is called passive solar design.

According to the National Oceanic and Atmospheric Administration (NOAA) 's Solar Position Calculator, the awnings can be designed to optimize the allowance of heat for the season. The coordinates of the Hub are 42.2514 degrees north and 71.8203 degrees west. These numbers are accurate to the 6th significant figure. Using the coordinates for the Hub, (42.2514°,-71.8203°) the solar elevation can be determined. The solar elevation is defined to be the angle measured from the horizon up to the sun. This number is primarily responsible for determining the optimal angle for sun shade and energy gain. Using the NOAA Solar Position Calculator, Table 8 below results.

Table 8 Solar elevation for the hub at different times

Date	Time [EST]	Elevation (Degrees from Horizon)
Dec. 10 th , 2014	12 PM	24.20
June 10 th , 2014	12 PM	70.39

The solar elevation is clearly much higher in the summertime. Due to this, the angle of the awning to the building can be chosen to gain an appreciable amount of electricity in the summertime, while blocking heat. By the same token, more heat will be let in during the winter months, which is certainly desirable for New England. An unfortunate aspect of this is that during the wintertime, the awnings are designed to not block as much sun, and therefore they will gather less solar energy.

5.1.2 : Calculations

Rough calculations of the angle of the awnings to the building and the amount of energy produced by the system were obtained. These calculations were not done by a professional and were simply done to serve as a guide and to give an idea of the benefits of the solar awnings.

The angle of the awnings to the building is a very important number. This number helps determine the amount of shading caused by the awning as well as the amount of the electricity generated by the panels. This angle is primarily based on the latitude of the building and the solar elevation. Other factors do affect the desired angle, however for simplicity only the latitude will be addressed. Given that the latitude of the building is approximately 42.25 degrees, and given Table 6 from the section above, simple trigonometry is used to decide a basic angle.

Using the PVWatts calculator and the rough area estimate of the solar array based on the dimensions of the Hub itself, a DC system size and annual production is approximated. Employing the knowledge of the physical size of the Suniva OPT 270-60-4-100, the specification sheet for which can be viewed in the appendix, the size of the array is a total of 13 m², which is 7 panels. This amount is different from the 13 panels as in the analysis because the 13 panels used a rough estimation of the amount of area available for photovoltaics, whereas 7 panels reflects a more accurate area. Based on this information, the DC output of the system would be 1.8 kW. Entering this information into the PVWatts calculator yields an annual output of 2400 kWh.

5.1.3 : Visualization

The culmination of the information obtained above produces the following rendition of the awnings:

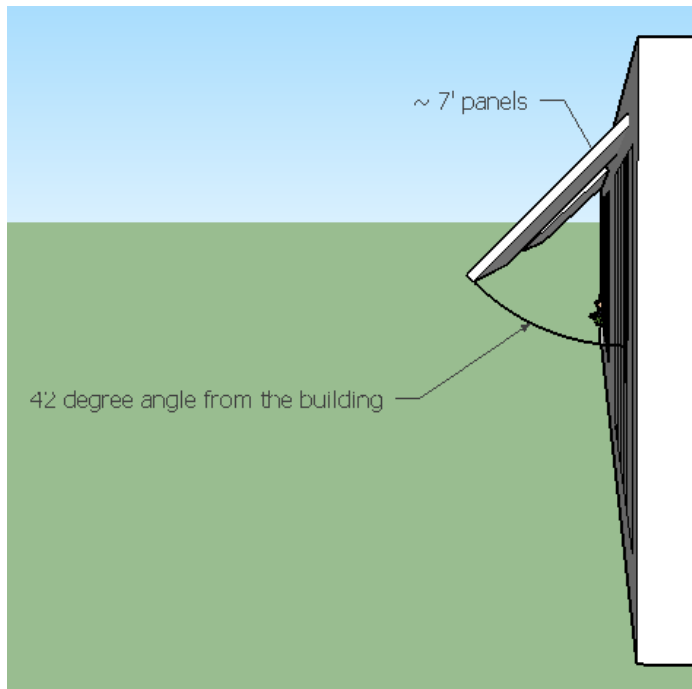


Figure 14 Awning from the Side

This image shows the awning from the side, how it will appear on the Hub.

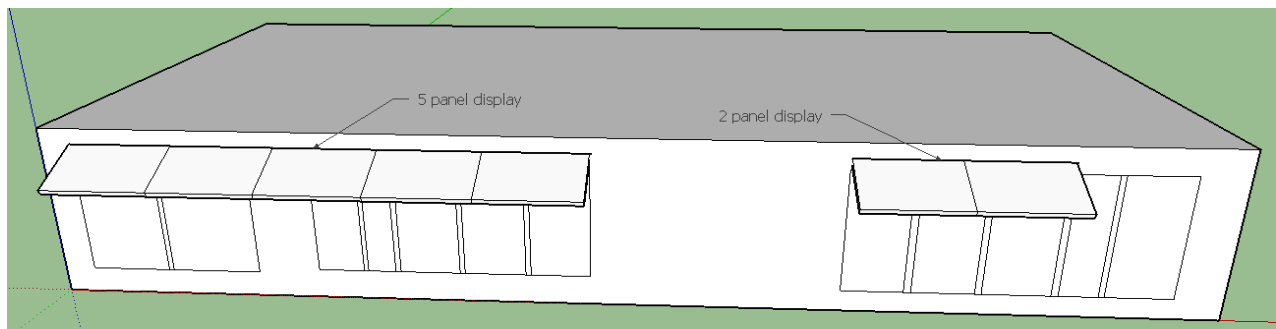


Figure 15 Awning from the Front

Figure 15 shows the design of the awnings from the front of the Hub. These images ideally shows how the canopy will look from the street.

5.2 : Charging Station

Bringing the Hub together with the Worcester community is one of the major goals of this project. A way to both help the Worcester community and draw it into the Hub was discussed. The decided solution for this was to install a cell phone charging station into the Hub. This cell phone charging station is educationally integrated with the photovoltaic awnings to provide a learning experience in addition to the utility of the station.

5.2.1 : Choosing a Charging Station

Three very different charging stations were initially selected for comparison. Several technical factors went into choosing an appropriate charging station. Criteria included price, community impact, utility, appearance, as well as other characteristics.

The three charging stations initially looked into were the RAVPower 15W Solar Charger with Dual USB Port, the ChargeTech Power Floor Stand Unit, and the Great Useful Stuff Charging Station and Dock. Very contrasting stations were chosen in order to provide a great spectrum of choices.

The RAVPower Solar charger, pictured below in Figure X, was identified as an option because of its solar charging capability. This proposed the ability to use the solar charger for demonstrations, and it increased its educational capability. Unfortunately, the practicality of an indoor solar charger was questioned, as it is unsure if enough light would be provided through the windows to make the solar charger functional.

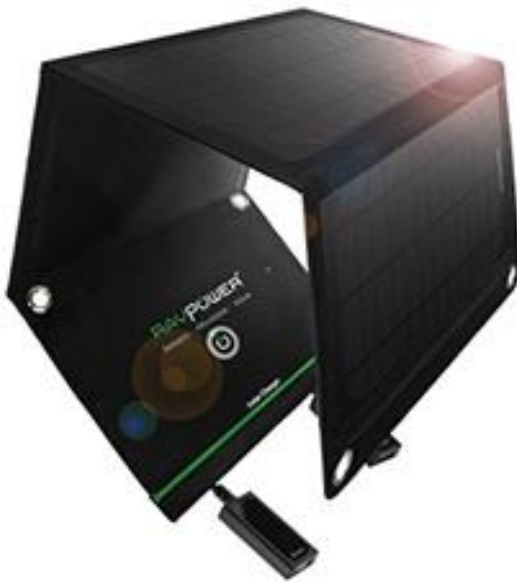


Figure 16 RAVPower 15W Solar charger with Dual USB Port [7]

The ChargeTech Power Floor Stand unit, hereby abbreviated to simply ‘the ChargeTech’, provides great visibility through the windows of the Hub. By simply being easily visible, it will certainly draw the most attention from the community, thereby potentially drawing in more customers. The ChargeTech does provide educational opportunities due to its design; the back display part of the ChargeTech has the ability to hold brochures and display facts, as can be seen labelled as “Custom Branding” in Figure 18. The full ChargeTech can also be seen below in Figure 17.



Figure 17 ChargeTech Floor Stand Unit



Figure 18 Close up of ChargeTech [6]

The Great Useful Stuff Charging Station and Dock is the third of the options. This station fits in with the aesthetic of the Hub and is easily set up. This station does require a table however, and is not very visible from the window, nor does it provide any great educational value. This station can be seen below in Figure X.



Figure 19 Great Useful Stuff Charging Station and Dock [5]

A chart was created to compare the specifications of each charging station. This table is visible on the next page in Table 9.

Table 9 Comparison of Charging Stations

	Great Useful Stuff Charging Station and Dock	ChargeTech Floor Stand Unit	RAVPower 15W Solar Charger with Dual USB Port
Total Price	\$34.99(dock) + \$15 (USB power strip) + \$20 (4 x charging cords) = \$70	\$550	\$55 (device) + \$10 (2 x charging cords) = \$65
Capabilities	4 devices	8 devices	2 devices
Max power needed	~36 W	~240 W	15W
Output	2.1 A to each device	5 V, 1.5 A each	3 A each
Notes	Need to buy accompanying USB power strip and charging cables	51" tall x 19" wide x 7" deep	May not necessarily work with just light from window Need to buy charging cables

From this table, it is easy to see that the Great Useful Stuff Charging Station and Dock is comparable in both price and wattage to the solar charger. The ChargeTech costs more money and uses more power to operate than its competitors. However, the ChargeTech has the ability to charge many more devices, and is ready for installation upon purchase. Moreover, the ChargeTech is the most attention grabbing of the three. Because the primary purpose of the charging station is to draw community attention, the desired charging station was chosen to be the ChargeTech.

5.2.2 : Integration of Photovoltaic Education

The charging station must thematically tie into the photovoltaic aspects of the project. It was decided to use the back portion of the charging station in order to display brief facts about the functionality of the charging station. These facts relate to the amount of sunlight necessary to charge one phone, the time necessary, and how much pollution is saved through the solar energy. Additionally, a brochure detailing the design plan of the awnings and its benefits will be placed on the charging station.

The purpose of these materials is to ensure that the public relates the community charging station to the photovoltaic awnings. While waiting for construction of the awnings, the charging station will serve as notice to the public of its impending arrival.

5.2.3 : Location for the Charging Station

The charging station was originally going to be located on the artificial grass right in the entrance of the Hub. The purpose of this is so that it would be visible right from the street, attracting the Worcester community. An artist's rendition of the location choice is shown below in Figure 20.

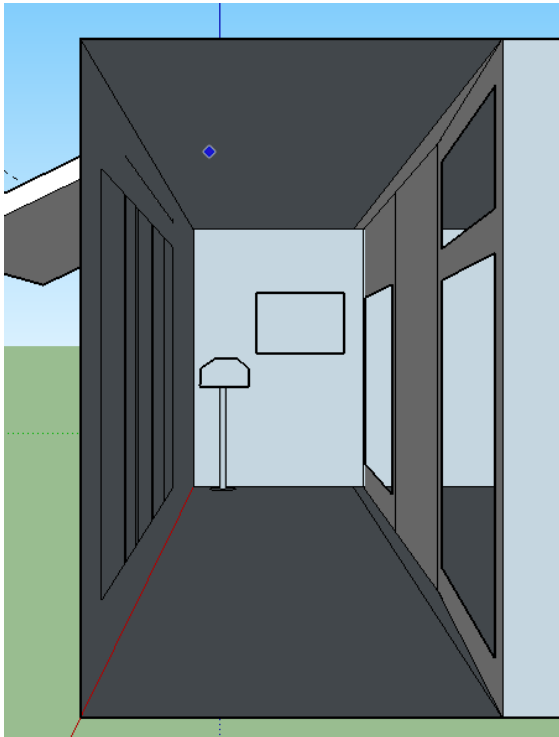


Figure 20 Artist's Rendition of Charging Station in the Hub

This placement of the station in the Hub allowed for an electrical connection right behind the television. Visitors would be introduced to this charging station right at the beginning of the tour, allowing the visitors ample time to have their phones charged. Passersby on the street would also be allowed to use the station.

5.2.4 : Realization of Charging Station

The charging station arrived to the Hub on February 23rd, 2016. It was built and installed that same day. There were unforeseen electrical constraints with placing the charging station in the previously mentioned location. The television located in that area blocked easy electrical connection for the charging station. Therefore, the station was installed in the corner of the main room of the Hub, still visible from the entranceway. Figure 21 below shows a photo of the station in the Hub:



Figure 21 Charging Station in the Hub

5.3 : Financial Estimation

Below in Table 10 is a detailed financial estimation for our chosen photovoltaic awning system. The hardware cost is based on models specified in column Note. Apart from applying funding from National Grid, the team was also seeking for donation options for the hardware: solar panels, string inverter, and awning structure. Other costs include tree removal, labor cost, permit applications, and charging station. The final funding request is \$12350 including hardware cost, or \$7850 without hardware cost.

Table 10 Financial Estimation for Solar Awning System

Hardware	Cost	Notes
Solar Panels	\$2300 (Includes taxes and other fees)	Based on Suniva OPT 270-60-4-100; \$310 each, 7 in total; possible donation options.
String Inverter	\$1300 (Includes taxes and other fees)	Based on SolarEdge SE3000A, \$1188; possible donation options;
Awning Structure	\$1000 (Includes taxes and other fees)	Based on EasyShade, \$799; possible donation options
Others		
Tree removal	\$800	Average cost in Worcester
Labor cost	\$5900	Estimate \$1 per Watt for solar panels, $270 \times 7 = \$1890$; 2 workers 20 hours at \$100/h: $20h \times \$100/h \times 2pl = \4000 ;
Permit	\$500	Building permit, \$135 Electrical permit, solar wiring, \$300 <i>minimum</i>
Charging Station	\$550	Based on ChargeTech S9, \$550
Total	\$12350 / \$7850	\$7850 if hardware is donated

5.4 : Educational Materials

In addition to cultivating a green economy in the city of Worcester and providing smart energy solutions to benefit its customers, the Worcester Sustainability Hub strives to educate its customers on renewable energy sources, power usage and how to become more sustainable. To contribute to their goals, educational materials were created. These educational materials include knowledge on solar energy, inverters and energy consumption of typical household appliances. By delivering this information, the visitors of the Sustainability Hub will be able to grasp a general idea of how solar power works, what inverters are, how they work and why they are needed as well as being aware of the energy that they use in their own homes.

5.4.2 : Energy Consumed by Typical Appliances

Through anecdotal evidence, it was discovered that the majority of customers who come into the Hub are unaware of how their electricity is consumed. To promote conservation, it is first necessary to understand what in a home uses the most energy. As a result, a provided educational material concerning the amount of energy used by typical household appliances was created. An example of the information on this handout is shown in Figure 22. The entire handout is visible in the appendix.



Coffee maker

Energy: 120 kWh

Cost per year: \$24

Figure 22 Example of Information from "Power Consumed by Your Appliances"

As can be seen in Figure 22 above, the material includes a clipart picture of an appliance, the approximate energy usage of that appliance per year, and the approximate cost per year. A variety of appliances are featured, including a clothes dryer, a window air conditioning unit, as well as other high-energy usage items. The cost is based on a price of \$0.20/ kWh, which is a standard price for the Worcester area. In order to calculate the energy usage per year, the typical usage time of each appliance was taken into account, as well as the rated wattage of a typical appliance. As an example, the coffee pot above was based on an average usage of 20 minutes a day at 1000 W. Seasonal items, such as a window air conditioner and space heater, were approximated with their hours of usage and approximate days of usage. This is because these seasonal items are not used 365 days of the year, but rather about 100.

This material was created by first thinking what appliances actually do use the most power in a house. Appliances with heating elements such as irons and clothes dryers tend to consume a lot of power. The list of appliances was narrowed down into what is common in Worcester. Initially, the handout included information for a pool pump, but the majority of customers in the city of Worcester do not own a pool. This ensures that the educational material is as relevant to the Worcester community as possible. Then, various resources were referenced to determine the energy usage of typical appliances [3]. This information was all culminated into a visually appealing format with lots of pictures.

5.4.3 : Inverters for Photovoltaic Systems

The educational material on inverters for photovoltaic systems was designed for the public to have a general idea of the functionality of inverters and the structure of a home photovoltaic system, as illustrated below in Figure 23. The handout was organized into three sections: definition of an inverter, different types of inverters, and the connections of inverters to solar panels. Each section contains graphical illustration, as can be seen below in Figure 24. The full handout can be seen in Appendix C.

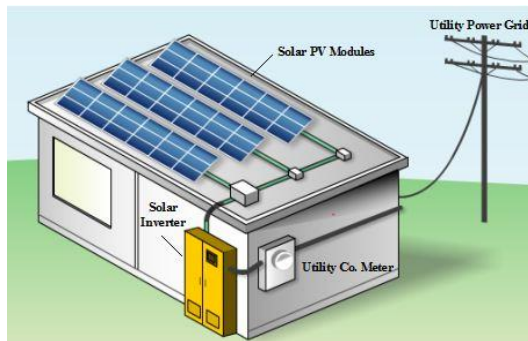
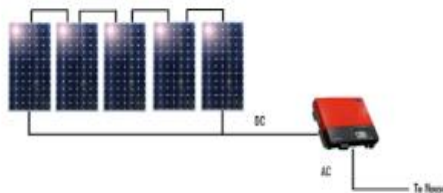


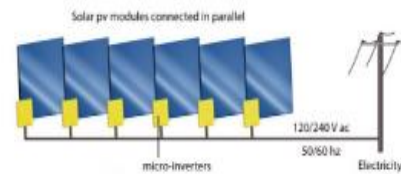
Figure 23 An example of a home photovoltaic system

- How are they connected with solar panels?

A centralized inverter is adopted for a centralized architecture (lower left). Only one inverter is used for the PV system. A micro inverter is adopted for a distributed architecture (lower right). Multiple inverters are used for the PV system.



Connection of a centralized inverter (red)



Connection of micro inverters (yellow)

Figure 24 An Example Section from "Inverters for Photovoltaic Systems"

5.5 : Approvals

5.5.1 : Funding from National Grid

In order for the photovoltaic awnings to be implemented, a proper financial estimate of the construction of the project had to be put together. Within the photovoltaic awning project many financial aspects had to be accounted for and each needed to be priced as accurately as possible. These aspects include the cost of the solar panels, the awning structure, the inverter, labor costs for the construction, permit fees, removing the tree from the front of the hub and the charging station that was purchased and placed inside the hub. Each of these prices were developed by a great deal of research in order to assure that they were as accurate as possible. All the prices as well as the information about where the numbers came from were organized and put into the final financial estimate chart, which is shown above in section 5.3 (Financial Estimate). Once the financial estimate was created we proceeded to request the funds that were needed to support the solar awning construction.

A slide presentation, visible in Appendix D, was created for National Grid where the funds were being requested from. In the presentation each of the team members introduced themselves and gave a brief overview of what the purpose of the presentation is and the desired outcome that would come from after the presentation. The presentation provided background information about the purpose of the project, why photovoltaic awnings were chosen as the basis of the project, the benefits that the awnings would provide, the educational value that the project would deliver and of course a detailed financial statement. After the presentation was given we were able to successfully get the approval the funding that was needed from National Grid to put the implementation of the project into action.

5.5.2 : Building Permissions from Clark University

A major part of the construction process is obtaining the necessary permits that are needed to build on the sustainability hub. The city of Worcester requires both a building and an electrical permit for the construction of the project. Along with these permit, the permission from the building manager at Clark University is necessary to go through with the implementation. Clark University runs a sustainability office that strives to create a greener campus and making its staff, faculty and students more aware of how to be sustainable. In an effort to make a great contribution to this mission the university allowed National Grid to make use of their building for the Worcester Sustainability Hub. As the owner of the actual building of the hub, it is also required to obtain the approval Clark University's building manager to have the photovoltaic awnings be built on the hub. Not only did the representative from Clark University graciously gave the approval to have the awnings built, but they were very fond of the idea. Once everyone was on board and the appropriate permits and permissions were acquired the photovoltaic awnings were finally ready to be set up for construction.

5.6 : Alternatives

With the interactive qualifying project only lasting 21 weeks, by the time the project was created and all the necessary preparations were made to implement the project, there was not enough time for the photovoltaic awnings to be built before the 21 week time period ended. As a result the construction of the awnings could not take place until after the project would be completed. Instead an alternative deliverable was created to be given in order to provide a visual and physical contribution to serve as the ending result of the project. This alternative idea was to have a single solar panel that would also power the charging station and would be displayed for visitors of the hub to see. The solar panel display would serve as a tangible representation of the solar information that the project aims to provide. Although the display may not contribute to the main goal of the project, it would help contribute to the mission of the sustainability hub. Along with the information about solar energy, power consumption of home appliances, inverters and the cell phone charging station, the solar panel display would certainly satisfy the educational value of the project.

6 : Results and Conclusions

The team is hopeful that this project will prove useful to National Grid, WPI, and the Worcester community. The established goals of this project were chosen such that their completion would benefit the aforementioned. To reiterate, the major goals of the project were to

- Find the best solution to the heat and light gain through the windows
- Provide educational resources to the Hub for its customers regarding solar energy in the household
- Bring the Worcester community in closer contact with the Hub

Our major goal of discovering a method to reduce the heat gain and capture the solar energy was completed. Determining and designing a photovoltaic awning and delivering this solution to the Hub fulfills that goal. Following through with the National Grid processes to ensure installation gave more stability to this solution. Furthermore, the implementation of photovoltaic awnings along with the purchased charging station will complete the goal of bringing the Worcester community closer to the Hub. The awning and charging station will certainly draw attention to the Hub and raise questions about photovoltaics on homes here in Worcester. Additionally, the realization of a community charging station and educational materials will educate the Worcester community on the purpose of the Hub and sustainable practices, fulfilling the team's last goal.

Working on this project has proven that the integration of humanity with technology is so necessary. Making sure the community understands the importance of renewable energies requires communication to ensure that engineering can flourish. The deliverables given to the Hub, shown below:

- "Power Consumed by Appliances" Educational material
- "Inverters in a Photovoltaic System" Educational material
- ChargeTech Floor Stand Unit charging station
- Educational backsplash for charging station
- Pamphlet regarding awning design and photovoltaics for charging station
- Completed awning design
- Financial estimation for the awnings

These will ideally impress upon National Grid's customers the necessity of renewable power and the importance of conservation for years to come. These deliverables exhibit various aspects of the project and the need for sustainable energy. They are easily accessible to the Worcester community and will hopefully influence their ideas of conservation and sustainability for the future.

References

- [1] Massachusetts State Legislature. (2008, July 2). *An Act Relative to Green Communities*[Online]. Available: <https://malegislature.gov/Laws/SessionLaws/Acts/2008/Chapter169>
- [2] Green2Growth Committee. (2015, September 13). [Online]. Available: green2growth.com
- [3] Estimating Appliance and Home Electronic Energy Use. [Online]. Available: <http://energy.gov/energysaver/estimating-appliance-and-home-electronic-energy-use>
- [4] Memorandum. [Online]
<http://www.slconfbase.com/CouncilArchives/agendas/2006reports/September2006/092106A6.pdf>
- [5] Great Useful Stuff Charging Station and Dock. [Online]. Available: <http://www.greatusefulstuff.com/tech-storage-and-organization/multi-device-charging-station-and-dock/>
- [6] ChargeTech FloorStand Power Unit. [Online]. Available: <https://chargetech.com/product/phone-charging-power-kiosk-stand-s9/>
- [7] RAVPower 15 W Solar Charger with Dual USB Port. [Online]. Available: http://www.amazon.com/dp/B00OQ0CAW6/?tag=googhydr-20&hvadid=77836497891&hvpos=1t1&hvexid=&hvnetw=g&hvrand=7691604835297259746&hvpone=&hvpstwo=&hvqmt=e&hvdev=c&ref=pd_sl_43uyvvygj_e
- [8] Homewyse (2015, Oct 3). *Cost to Install a Shingle Roof* [online]. Available: http://www.homewyse.com/services/cost_to_install_shingle_roof.html
- [9] U.S. Department of Energy. (2015, September 28). *The History of Solar* [Online]. Available: https://www1.eere.energy.gov/solar/pdfs/solar_timeline.pdf
- [10] Maria Trimarchi. (2009, June 24). *How Solar Thermal Power Works* [Online]. Available: <http://science.howstuffworks.com/environmental/green-tech/energy-production/solar-thermal-power.htm>
- [11] Steven J. Strong and William G. Scheller, "The History and Development of Photovoltaics" in *The Solar Electric House*. Still River: Sustainability Press, 1993, pp 4-12.
- [12] Galen Barbose et al. (2013 July). *Tracking the Sun VI: An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2012* [Online]. Available: <https://emp.lbl.gov/sites/all/files/lbnl-6350e.pdf>
- [13] PVAWNING. (2015, September 29). [Online]. Available: <http://www.pvawning.com/>
- [14] Christopher P. O'Neil, personal communication, September 30, 2015
- [15] Solarenergy.net (2015, Oct 4). *How Photovoltaic Cells Work* [online]. Available: <http://solarenergy.net/solar-power-resources/how-photovoltaic-cells-work/>

[16] TR Solar (2015, Oct 2). [Online]. Available:

http://www.trsolarchina.com/index.php?main_page=news&c_id=1688&chapter_id=61

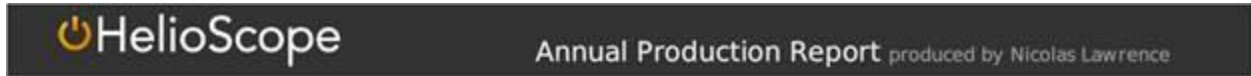
[17] Gil Knier (2015, Oct 4). *How Do Photovoltaic Work?* [Online]. Available:

<http://science.nasa.gov/science-news/science-at-nasa/2002/solarcells/>

[18] *The Photovoltaic Effect* [Online]. Available : http://www.bls.gov/green/solar_power/diagram_1.png

Appendix A : PV System Model by HelioScope

Rooftop Solar Panel Model Analysis

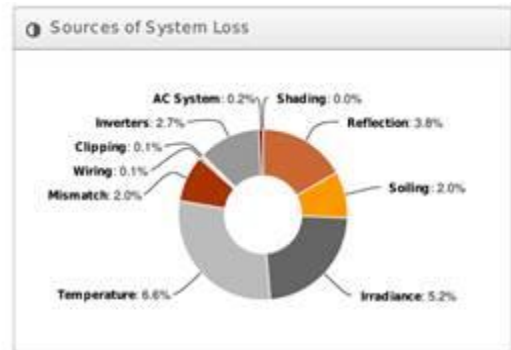
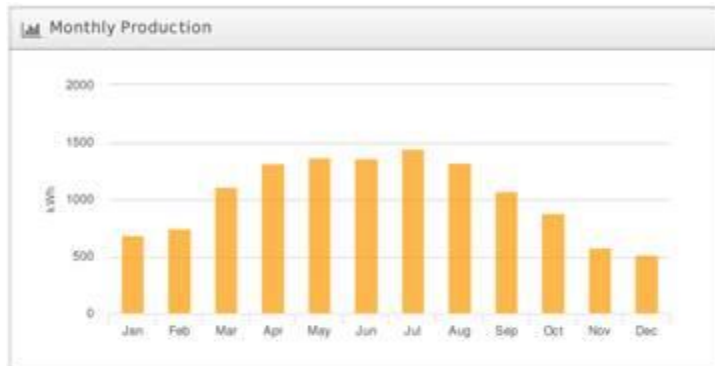


Design 1 NGrid Sustainability Hub, 912 Main Street, Worcester, MA

Report	
Project Name	NGrid Sustainability Hub
Project Address	912 Main Street, Worcester, MA
Prepared By	Nicolas Lawrence nlawrence@solar-design.com



System Metrics	
Design	Design 1
Module DC Nameplate	10.2 kW
Inverter AC Nameplate	12.0 kW Load Ratio: 0.85
Annual Production	12.37 MWh
Performance Ratio	79.3%
kWh/kWp	1,209.6
Weather Dataset	THY, 10km grid (42.25, -71.85), NREL (prospector)
Simulator Version	153 [443094f2ad-ea93843af-fc6c6aff20-00aa]48623]



⚡ Annual Production			
	Description	Output	% Delta
Irradiance (kWhm ⁻²)	Annual Global Horizontal Irradiance	1,422.2	
	POA Irradiance	1,525.1	7.2%
	Shaded Irradiance	1,525.0	0.0%
	Irradiance after Reflection	1,467.0	-3.8%
	Irradiance after Soiling	1,437.7	-2.0%
	Total Collector Irradiance	1,437.7	0.0%
Energy (kWh)	Nameplate	14,710.3	
	Output at Irradiance Levels	13,942.4	-5.2%
	Output at Cell Temperature Derate	13,026.6	-6.6%
	Output After Mismatch	12,764.1	-2.0%
	Optimal DC Output	12,750.2	-0.1%
	Constrained DC Output	12,739.5	-0.1%
	Inverter Output	12,397.1	-2.7%
Energy to Grid	12,374.6	-0.2%	
Temperature Metrics			
	Avg. Operating Ambient Temp		11.6 °C
	Avg. Operating Cell Temp		26.4 °C
Simulation Metrics			
	Operating Hours	4697	
	Solved Hours	4697	

🏠 Condition Set						
Description	Condition Set 1					
Weather Dataset	TMY, 10km grid (42.25,-71.85), NREL (prospector)					
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
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				
	JC310M-24Ab (Renesola)	Default Characterization, PAN				
Component Characterizations						
Device	Characterization					
SE6000 (240V) (SolarEdge)	Default Characterization					

Components

Component	Name	Count
Inverter	SE6000 (240V) (SolarEdge)	2 (12.0 kW)
Combiner	1 pole Combiner	3
Combiner	2 pole Combiner	1
AC Home Run	10 AWG (Copper)	2 (82.4 ft)
Strings	10 AWG (Copper)	3 (72.5 ft)
Module	JC310H-240b (Renesola)	33

Wiring Zones

Description	Combiner Poles	String Size	Stringing Strategy
Wiring Zone	12	11	Along Racking

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules
Field Segment 1	Flush Mount	Vertical (Portrait)	10°	145°	1.3 ft	1x1	33	33

Detailed Layout



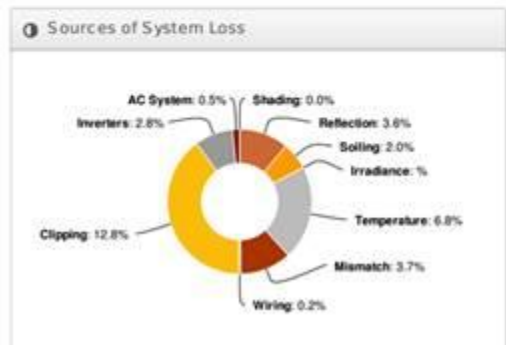
Photovoltaic Solar Awnings Model Analysis

Solar Canopy NGrid Sustainability Hub, 912 Main Street, Worcester, MA

Report	
Project Name	NGrid Sustainability Hub
Project Address	912 Main Street, Worcester, MA
Prepared By	Nicolas Lawrence nlawrence@solar design.com



System Metrics	
Design	Solar Canopy
Module DC Nameplate	3.24 kW
Inverter AC Nameplate	3.97 kW Load Ratio: 0.82
Annual Production	3,657 MWh
Performance Ratio	72.1%
kWh/kWp	1,128.6
Weather Dataset	TMY, 10km grid (42.25,-71.85), NREL (prospector)
Simulator Version	153 (4430940ad-ea93843ef-fc6ca820-00aa148623)



Annual Production			
	Description	Output	% Delta
Irradiance (kWh/m ²)	Annual Global Horizontal Irradiance	1,422.2	
	POA Irradiance	1,564.8	10.0%
	Shaded Irradiance	1,564.7	0.0%
	Irradiance after Reflection	1,508.8	-3.6%
	Irradiance after Soiling	1,478.6	-2.0%
	Total Collector Irradiance	1,478.6	0.0%
Energy (kWh)	Nameplate	4,805.1	
	Output at Irradiance Levels	4,842.4	0.8%
	Output at Cell Temperature Derate	4,512.2	-6.8%
	Output After Mismatch	4,344.7	-3.7%
	Optimal DC Output	4,337.1	-0.2%
	Constrained DC Output	3,781.0	-12.8%
	Inverter Output	3,675.0	-2.8%
	Energy to Grid	3,656.6	-0.5%
Temperature Metrics			
	Avg. Operating Ambient Temp		11.6 °C
	Avg. Operating Cell Temp		26.9 °C
Simulation Metrics			
	Operating Hours	4697	
	Solved Hours	4697	

Condition Set			
Description	Condition Set 1		
Weather Dataset	TMY, 10km grid (42.25,-71.85), NREL (prospector)		
Solar Angle Location	Meteo Lat/Lng		
Transposition Model	Perez Model		
Temperature Model	Sandia Model		
Temperature Model Parameters	Rack Type	a	b
	Fixed Tilt	-3.56	-0.075
Soiling (%)	Flush Mount	-2.81	-0.0455
		J	F
Irradiation Variance		M	A
		M	J
Cell Temperature Spread		J	J
		A	S
Module Binning Range		O	N
		D	
AC System Derate			
Module Characterizations	Module	Characterization	
	OPT270-60-4-100 (Suniva)	OPT270_60_4_100_9_14_2012: PAN, PAN	
Component Characterizations			
Device			Characterization
SE4000 (240V) (SolarEdge Technologies)			CEC 2014-08-16

 Components

Component	Name	Count
Inverter	SE4000 (240V) (SolarEdge Technologies)	1 (3.97 kW)
Combiner	1 pole Combiner	2
Strings	10 AWG (Copper)	1 (0.0 ft)
Module	OPT270-60-4-100 (Suniva)	12

 Wiring Zones

Description	Combiner Poles	String Size	Stringing Strategy
Wiring Zone	12	12	Along Racking

 Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Inrow Spacing	Frame Size	Frames	Modules
Field Segment 1	Flush Mount	Horizontal (Landscape)	15°	145°	0.0 ft	1x1	12	12

 Detailed Layout

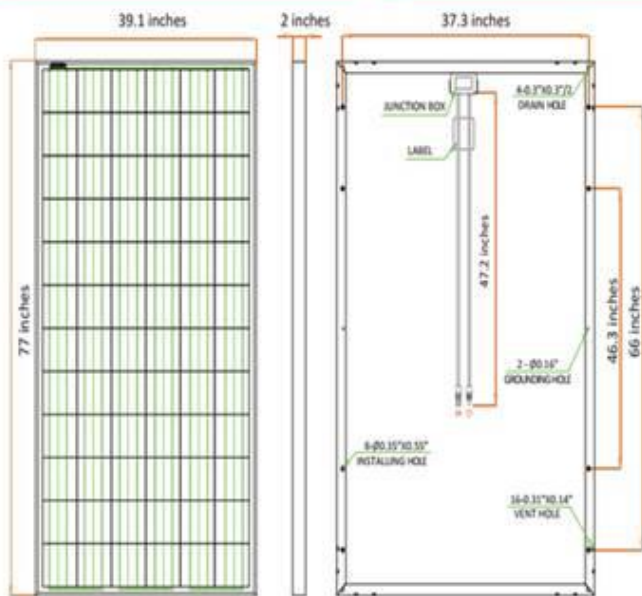

Appendix B : Datasheet for Solar Panels

Datasheet for ReneSola JC310M-24/Ab



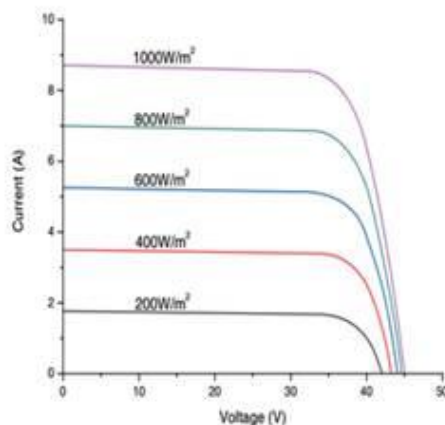
290W, 295W, 300W, 305W

Dimensions



Drawing Only for Reference

I-V Curves



Efficiency at Varied Irradiation

Irradiance	200W/m ²	400W/m ²	600W/m ²	800W/m ²	1000W/m ²
Efficiency	15.8%	16.2%	16.2%	16.1%	16.0%

Electrical Characteristics STC	JC290M-24/Abh	JC295M-24/Abh	JC300M-24/Abh	JC305M-24/Abh	JC310M-24/Abh
Maximum Power (Pmax)	290 W	295 W	300 W	305 W	310 W
Power Tolerance	0 ~ +5W	0 ~ +5W	0 ~ +5W	0 ~ +5W	0 ~ +5W
Module Efficiency	14.9%	15.2%	15.5%	15.7%	16.0%
Maximum Power Current (Imp)	8.08 A	8.13 A	8.20 A	8.33 A	8.38 A
Maximum Power Voltage (Vmp)	35.9 V	36.3 V	36.6 V	36.6 V	37.0 V
Short Circuit Current (Isc)	8.56 A	8.62 A	8.69 A	8.73 A	8.80 A
Open Circuit Voltage (Voc)	44.6 V	44.7 V	44.8 V	44.9 V	45.0 V

Values at Standard Test Conditions STC (Air Mass AM1.5, Irradiance 1000W/m², Cell Temperature 25°C)

Electrical Characteristics NOCT	JC290M-24/Abh	JC295M-24/Abh	JC300M-24/Abh	JC305M-24/Abh	JC310M-24/Abh
Maximum Power (Pmax)	215 W	219 W	222 W	226 W	230 W
Maximum Power Current (Imp)	6.52 A	6.57 A	6.67 A	6.72 A	6.80 A
Maximum Power Voltage (Vmp)	33.0 V	33.3 V	33.4 V	33.6 V	33.8 V
Short Circuit Current (Isc)	6.91 A	6.96 A	7.02 A	7.04 A	7.10 A
Open Circuit Voltage (Voc)	41.7 V	41.8 V	41.9 V	42.0 V	42.1 V

Values at Normal Operating Cell Temperature, irradiance of 800 W/m², spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s

Mechanical Characteristics		Characteristics	
Cell Type	6 inches Virtus® II (Polycrystalline), 72 (6x12) pcs in series	Temperature Coefficient of Voc	-0.29%/°C
Glass	High Transmission, Low Iron, Tempered Glass	Temperature Coefficient of Isc	0.04%/°C
Frame	Anodized Aluminum Alloy	Temperature Coefficient of Pmax	-0.39%/°C
Junction Box	IP65/IP67 rated, with bypass diodes	Nominal Operating Cell Temperature (NOCT)	45°C±2°C
Dimension	*77 x 39.1 x 2 inches		
Output Cable	12 AWG, 47.2 inches		
Weight	63.9 lbs		
Installation Hole Location	See Drawing Above		

Packing Information				Maximum Ratings	
Container	20' GP	40' GP	40' HQ	Operating Temperature	-40°F ~ +185°F
Pallets per Container	10	24	24	Maximum System Voltage	1000VDC (EU) / 1000VDC (US)
Pieces per Container	200	480	528	Maximum Series Fuse Rating	20A (EU) / 20A (US)

Rev. No. JC/T15/2013.00 *Contact Renesas for tolerance specification.
CAUTION: All rights reserved. Design and specification are subject to change without prior notice.

Datasheet for Suniva Optimus Series OPT-270-60-4-100



OPTXXX-60-4-100 (60 CELL MODULE)

The Optimus® modules consist of Suniva's latest technology, ARTisun® Select. These superior monocrystalline cells are designed and manufactured in the U.S.A. using our proprietary low-cost processing techniques. Engineered with our pioneering ion implantation technology, high power-density Optimus modules provide excellent value, performance and reliability.


Certifications:




UL 1709
IEC 61215
IEC 61739-1:2016



PSEC



AS5003
Compliant



PVLPID CERT

CEC AUSTRALIA

Engineering Excellence

- Built exclusively with Suniva's highest-efficiency ARTisun Select cells, providing one of the highest power outputs per square meter at an affordable manufacturing cost
- Suniva's state-of-the-art manufacturing facility features the most advanced equipment and technology
- Suniva is a U.S. -based company spun out from the Georgia Tech University Center of Excellence in Photovoltaics (one of only two such research centers in the U.S.)

Features

- Contains the latest ARTisun Select cell technology - over 19%
- Positive only tolerance ensures predictable output
- Marine grade aluminum frame with hard anodized coating
- Industry leading linear warranty (10 year warranty on workmanship and materials; 25 year linear performance warranty delivering 80% power at STC)
- Buy America compliant upon request
- Qualifies for U.S. EXIM financing
- System and design services available

Quality & Reliability

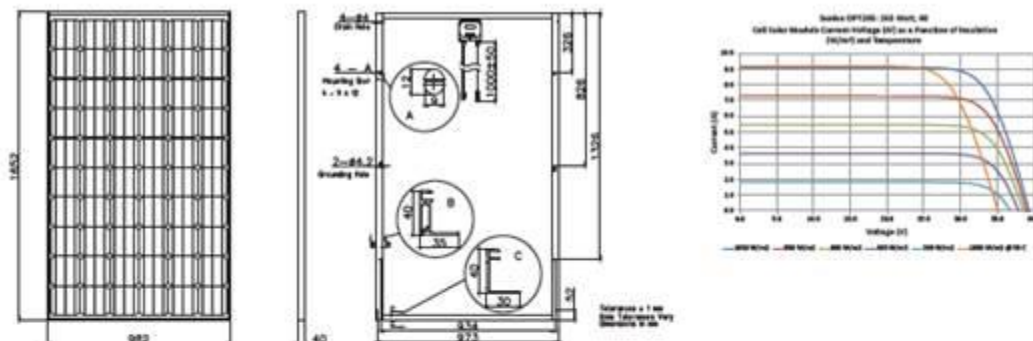
Suniva Optimus modules are manufactured and warranted to our specifications assuring consistent high performance and quality worldwide.

- Rigorous quality management
- Performance longevity with advanced polymer backsheet
- Produced in an ISO 9001: 2008 certified facility
- Passed the most stringent salt spray test (Severity 6) based on IEC 61701
- Passed enhanced stress tests based on IEC 61215 conducted at Fraunhofer ISE
- Certified PID free
- Ask about our validated PAN files

OUR PRODUCTS:

<p>Monocrystalline Modules OPTIMUS SERIES 60 cell OPTIMUS SERIES 72 cell</p>	<p>Monocrystalline Cells 19%+ efficiency</p>
<p>Multicrystalline Modules MV SERIES 60 cell MV SERIES 72 cell</p>	<p>Balance of Systems Solutions (BOSS) Racking, Inverters, Batteries, Energy Storage Appliances and EV Chargers</p>

OPTIMUS SERIES: OPT 60 CELL MODULES



ELECTRICAL DATA (NOMINAL)

The rated power may only vary by ± 0.4 00Wp and all other electrical parameters by $\pm 5\%$.

Power Classification	Pmax (W)	255	260	265	270
Module efficiency	%	15.71	16.02	16.33	16.60
Model Number	OPT	255-60-4-100	260-60-4-100	265-60-4-100	270-60-4-100
Voltage at Max. Power Point	Vmp (V)	30.00	30.20	30.70	31.20
Current at Max. Power Point	Imp (A)	8.50	8.60	8.64	8.68
Open Circuit Voltage	Voc (V)	37.90	38.10	38.30	38.50
Short Circuit Current	Isc (A)	9.05	9.08	9.12	9.15

The electrical data apply to standard test conditions (STC): irradiance of 1000 W/m² with AM 1.5 spectra at 25°C.

DIMENSIONS AND WEIGHT

Cells / Module	60 (6x10)
Module Dimensions	1652 x 982 mm (65.04 x 38.66 in.)
Module Thickness (Depth)	40 mm (1.57 in.)
Approximate Weight	17.9 +/- 0.5kg. (39.5 +/- 1.1 lb.)

CHARACTERISTIC DATA

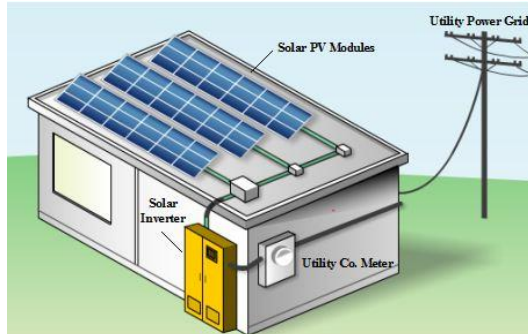
Type of Solar Cell	High-efficiency ARTisun® Select monocrystalline cells of 156 x 156 mm (6 in.)
Frame	Silver anodized aluminum alloy; black frame available by custom order
Glass	Tempered (low-iron), anti-reflective coating
Junction Box	NEMA IP65 rated; 3 internal bypass diodes
Cable & Connectors	12 AWG (4.0 mm ²) cable with Tyco or MC4 compatible connectors ² ; cable length approximately 1000 mm
Hardware (Available Upon Request)	Grounding screws: (2) #10-32 12.7 mm (#10-32 x 0.5 in.) Stainless steel flat washers: (4) 5 x 10 x 1 mm (0.2 in. ID x 0.394 in. OD x 0.030 in.)

TEMPERATURE COEFFICIENTS

Voltage	β , Voc (%/°C)	-0.335
Current	α , Isc (%/°C)	+0.047
Power	γ , Pmax (%/°C)	-0.420
NOCT Avg	(+/- 2 °C)	46.0

Appendix C: Educational Material

Inverters for Photovoltaic Systems



- **What is an inverter? Why do we need it?**

An inverter is an electronic device that converts direct current (DC) generated from solar panels to alternating current (AC) for home use or connecting to the grid.

- **Are there different types of inverters in photovoltaic systems?**

Yes! The most common ones used are centralized inverters (as shown on the left) and micro inverters (as shown on the right).



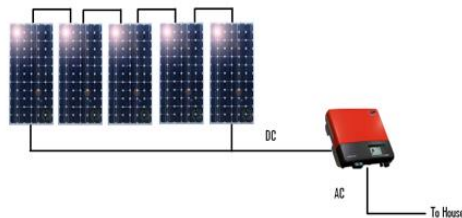
A centralized inverter



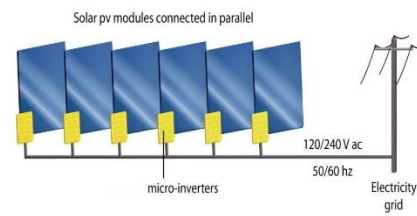
Micro inverters

- **How are they connected with solar panels?**

A centralized inverter is adopted for a centralized architecture (lower left). Only one inverter is used for the PV system. A micro inverter is adopted for a distributed architecture (lower right). Multiple inverters are used for the PV system.



Connection of a centralized inverter (red)



Connection of micro inverters (yellow)

Power Consumed by Your Appliances

Power Consumed by Your Appliances

According to the Energy Information Administration (EIA), the average American household uses 10,932 kWh per year! Check out where some of that power is going per year and the cost!



Dishwasher

Energy: 240 kWh
Cost per year: \$48

Iron

Energy: 240 kWh
Cost per year: \$48



Blow-dryer

Energy: 90 kWh
Cost per year: \$18



Clothes Dryer

Energy: 1000 kWh
Cost per year: \$200



Coffee maker

Energy: 120 kWh
Cost per year: \$24



Desktop Computer
Energy: 700 kWh
Cost per year: \$140

Window Air Conditioner

Energy: 400 kWh^{**}
Cost per year: \$80



Space Heater

Energy: 2100 kWh[†]
Cost per year: \$420

* Based on 200 days of use a year
† Based on 4 hours a day, 100 days
Information taken from energy.gov

Appendix D : Final Presentation to National Grid

Capturing Solar Energy at the Sustainability Hub

nationalgrid
HERE WITH YOU. HERE FOR YOU.



Jacqueline Campbell
Sakiynah Howard
Zilu Tian

Advised by:
Professor John Orr
Patrick Cody



The Interactive Qualifying Project

nationalgrid
HERE WITH YOU. HERE FOR YOU.



WPI
Main Entrance
Worcester Polytechnic Institute

Project Goals

nationalgrid
HERE WITH YOU. HERE FOR YOU.



- Find the best solution to the heat gain
- Harvest the solar energy
- Provide educational resources to the Hub and its customers concerning electrical usage and solar power
- Bringing the Worcester community in closer contact with the Hub



2

Proposed Solution

nationalgrid
HERE WITH YOU. HERE FOR YOU.

Solar Awnings



Charging Station



3

What's been accomplished

nationalgrid
HERE WITH YOU. HERE FOR YOU.

- Photovoltaic options and decision
- Creation and approval of solar design
- Educational materials
- Charging station and information



4

Decision Process

nationalgrid
HERE WITH YOU. HERE FOR YOU.

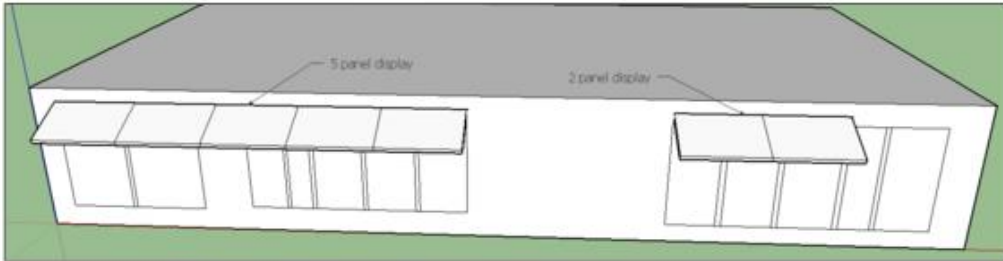
- 3 different solar panel solutions were examined using a decision analysis array: roof mount (left), bus stop (middle), and awnings (right).



5

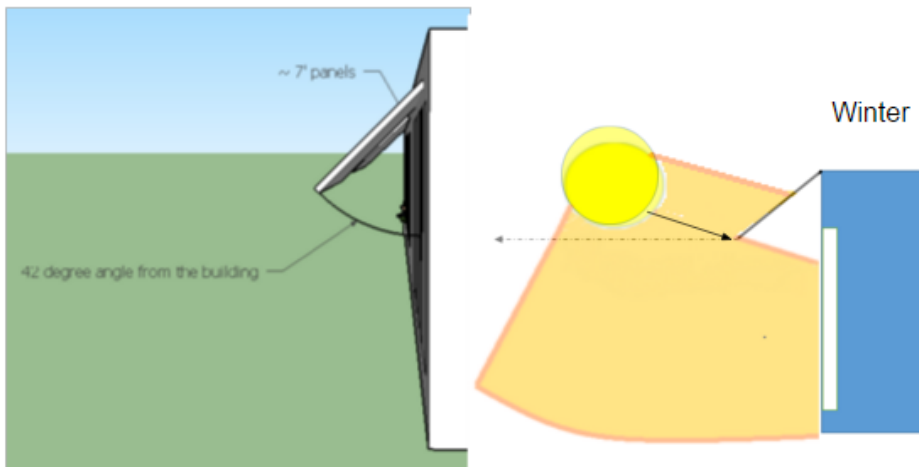
Awning Visual Design

nationalgrid
HERE WITH YOU. HERE FOR YOU.



Awning Visual Design

nationalgrid
HERE WITH YOU. HERE FOR YOU.



Preparation for approval

nationalgrid
HERE WITH YOU. HERE FOR YOU.

- Email exchange as well as remote meeting with senior solar engineers about design process and technical details
- Reached out to different solar companies for estimations of lead construction time
- Created financial estimate for the awning system
- Presented and received approval from Fouad
- Demonstrated the design to procurement team



Hardware Cost	Rate
Solar Panels	\$2000
String Inverter	\$1000
Awning Structure	\$1000
Wires	\$500
Grid-tied Inverter	\$500
Labour cost	\$5000
Permit	\$500
Charging Station	\$500
Total	\$12000 - \$17000

9

Charging Station

nationalgrid
HERE WITH YOU. HERE FOR YOU.

- A charging station will provide great convenience to the public.
- Setting up a charging station by the window will bring people in.
- Cross compared different options based on prices and tech specs; folded pamphlet

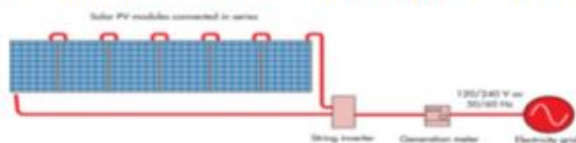


10

Educational Material

nationalgrid
HERE WITH YOU. HERE FOR YOU.

- Role of an inverter in a photovoltaic system



- Energy consumption of typical household appliances



11

Conclusion

nationalgrid
HERE WITH YOU. HERE FOR YOU.



Special thanks to Patrick Cody, Colleen Gardner, and Justin Woodard from National Grid, Christopher O'Neil from Solar Design Associates, and Professor John Orr from WPI

12