Energy Assessment, Analysis, Design and Installation of Optimal Photovoltaic Array on
a Residential Rooftop

Submitted by
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Electrical Engineering

To
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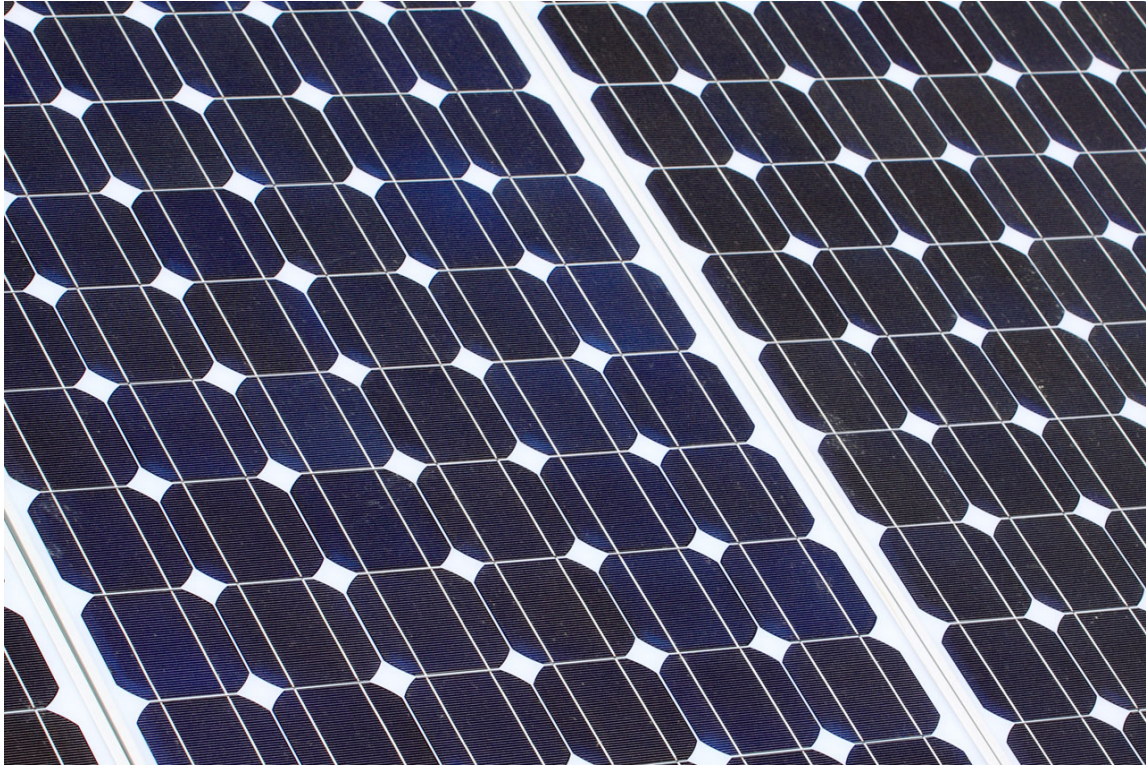Department of Mechanical Engineering
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Foreword By Ryan Gentry

  In choosing my Honors College Thesis topic, I wanted to be able to explore the topic of alternative energy. In exploring different possibilities, I was offered to work on this project. My assignment was to determine the most optimal way to wire a solar array given the constraints of residential roof space, and power output. The result of my calculations and explanation are located in many of the sections of this report I have included this foreword to specifically state my involvement in this project.

  I worked on this project with 3 other mechanical engineering students and 1 engineering chemistry student. With my major being electrical engineering, it provided us with a multidisciplinary team of engineering students. My sections of the paper are as follows: Foreword, Electrical Analysis, Design Analysis, Wiring, Example Resident System vs. other systems, Appendix A, Appendix B, Appendix C, Appendix D and the electrical design analysis sample calculations located in Appendix F. Jesse Ling worked closely with me on the section titled "Solar Panel Operating Temperature Analysis" for use in my section of "Design Analysis". The group as a whole proofread and edited the entire paper, but the calculations and drafting of the report came from our respective disciplines.

  The general description and introduction to the project can be found in the Abstract and Introduction of the report. All other details I will leave for the content in the report to explain.

Abstract

  Adding a photovoltaic (solar) array to a rooftop could be an overwhelming project for the average do-it-yourself (DIY) homeowner. There are many areas of research and engineering that are involved in properly designing a system that will not only function well, but will last a lifetime and fall within the rules and regulations too. The object of this project is to guide the average DIY homeowner through the process of analyzing, designing, and installing a photovoltaic (PV) solar array on a residential rooftop. The pages below will list the steps needed to design a system and provide an example of a residential design along the way. The occupant envelope provided as the example for this project uses a 16.5 kW solar array and, with government incentives, attained a final payback period of 14 years. With the information provided in this guide, one can design a proper sized PV array, apply the best fit energy efficiencies, analyze a rooftop for proper installation, and determine the payback period associated with the combined improvements.

Introduction

  The need for renewable energy is one of the most relevant topics in the world today. There are many reasons to reduce our dependency of Earth's natural resources. One of the greatest motives is the future of our children. Their future depends on the green actions that are taken now to maintain a healthy global environment. The world is extremely dependent on fossil fuels as the main source of energy. In 2009, the United States alone consumed a total combined 94,578 trillion BTU's worth of energy (EIA,

Table 2.1a). Almost 83% of the total consumed energy is that from fossil fuels (EIA, Table 2.1a). This enormous amount of fossil fuel energy consumption in the U.S. and across the global has shaped the era of "going green" and "sustainability." These have become the new cliché's amongst big businesses and energy providers. "Going green" is a general term used to describe actions taken and a mindset created that supports earth friendly operations in industrial and commercial businesses and beyond. It's a change in mentality that begins to heed the surrounding environment and to truly understand the impact of green, or not-so-green, actions taken. The green mentality of energy consumption in the residential sector can and should begin an Earth friendly trend too. In fact, the residential sector uses about 22% of the total fossil fuel energy consumed (EIA, Table 2.1a). Therefore, the residential sector has a great opportunity to engage and utilize renewable energy to help reduce the overall energy consumed.

There are a number of ways to utilize renewable energy and reduce dependency on fossil fuels. Some of these include wind power, hydro power, biomass, geothermal, and solar energy. Of these options, solar energy is one of the best ways to utilize renewable energy in the residential sector. There are many reasons to choose solar energy compared to the other options; for instance, an existing structure on a property may be used, such as a roof top, to mount the PV array. This can be cost effective and save space over other options. There are also many government incentives to aid in the cost of PV array. In terms of legal requirements, there are three main areas that must be approved: building permit, interconnection agreement, and electrical inspection. The aforementioned requirements are somewhat easier to attain for PV arrays than the other renewable energy options. Finally, the overall ease of installation of an array compared to any of the other technologies is a great reason to choose solar energy.

There are six basic sections to review and understand to properly design a PV solar array system. Start with the energy assessment of the residence. Gather the energy usage data and use this to analyze the thermal parameters of the home. From here, calculate the annual energy used and develop the system size. At this point, add in any planned efficiencies and recalculate the final system size. When this is finalized, determine the PV array that best fits the application for power, performance, and price. This should include all of the necessary hardware, such as wiring and inverters. Once this is done, be sure to research the rules and regulations of your specific state. Finally, mechanically analyze the rooftop that the PV array will be installed onto. Perform a stress analysis of the truss sections, taking into account weather variables. Decide which installation system best fits the application and plan the install process. Lastly, install the solar array!

The information and explanations below will cover each of these steps in further detail.

Energy Assessment and Analysis Procedure

There are many aspects that have to be taken into account when sizing a solar array. The energy requirements of the house have to be analyzed, as well as the effects of any energy efficiency improvements made to the home. The array must also be designed keeping local laws and building codes in mind. Finally, the system should be built to qualify for as many tax credits and incentives as possible to decrease the overall costs and

payback period. Per DTE's Net Metering Policy, no residence is allowed to be a net producer of electricity during the course of a year. Essentially, more electricity must be used than produced during the year. If a design proposal fails this requirement, the interconnection agreement is rejected.

In order to analyze, design, and implement alternative energy technologies in any structure, you need to understand the theoretical models which constrain them. Different structures have different parameters ranging from the complete design and construction of the structure, to the environment and surrounding geography which affects the parameters when constraining the system. The thermodynamic system being analyzed is a residential occupant envelope, shown below in Figure 1.
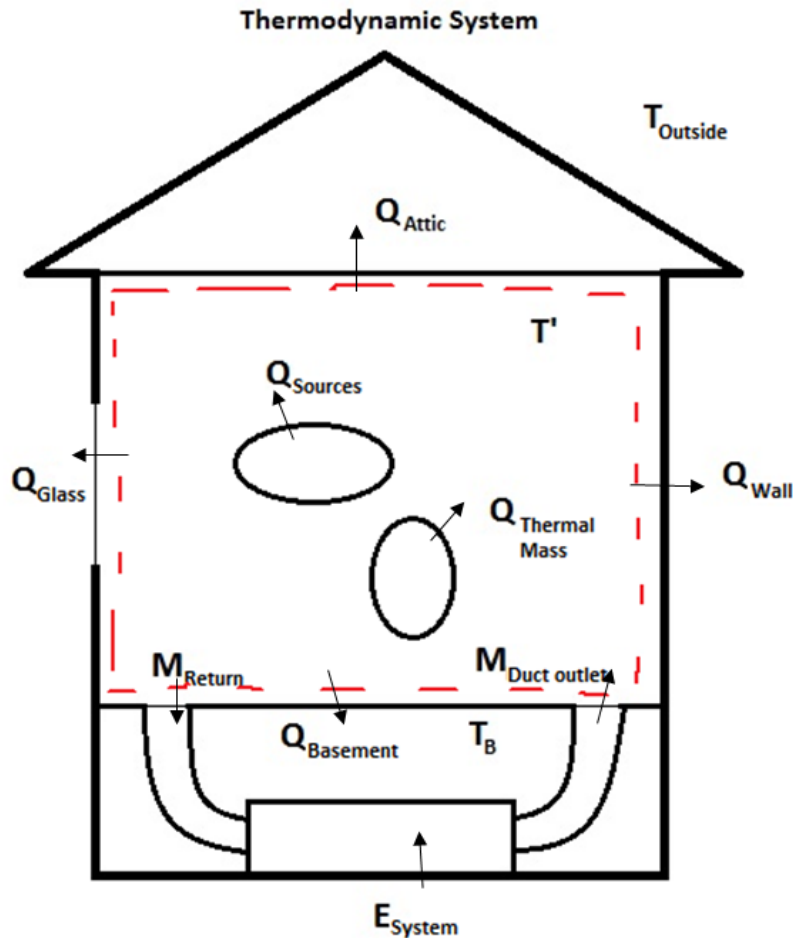
Figure 1

When modeling the occupant envelope, both convection and conduction have to be taken into account on all the sections of the house. Heat can escape through anywhere in the house, and modeling how much heat is lost from each part of the house helps determine where improvements should be made. To determine the overall heat loss of the building, it's necessary to break it down into components and to analyze them individually. The house was broken into four separate sections; the walls, the windows, the basement, and the attic. Any surface that is exposed to air has to be evaluated for

convection, while any surface contacting another surface has to be evaluated for conduction.

All of the preceding sources of heat transfer are assumptions that define our system. Combining these sources of heat loss and breaking down the left side of the equation into individual systems, including both the inside and outside of the residence, we have the governing equation of the system.

$$\frac{dE}{dt} = \dot{Q} + \dot{W} + \dot{E_m}$$

The first term ($\frac{dE}{dt}$) above represents the change in energy over time. Since the energy of the system does not change over time, this can be considered steady state.

Applying the conservation of energy equation all the terms to the right now have to balance. Next, the heat transfer term ($\dot{Q}$) which indicates the total heat transfer of the system and breaks down into the following:

$$\dot{Q} = \dot{Q}_s + \dot{Q}_t - (\dot{Q}_w + \dot{Q}_b + \dot{Q}_a + \dot{Q}_g)$$

The terms to the left are all lumped together because they are all heat transfer losses to the environment.

- $\dot{Q}_s$ is the heat transfer put into the house from occupants,

$$\dot{Q}_t = ha(T - T')$$

- $\dot{Q}_t$ is the heat transfer due to internal convection of thermal masses (chairs, tables, etc.),

$$\dot{Q}_w = U_w A_w(T' - T_o)$$

- $\dot{Q}_w$ is the heat transfer through windows,

$$\dot{Q}_b = U_b A_b(T' - T_b)$$

- $\dot{Q}_b$ is the heat transfer through the basement,

$$\dot{Q}_a = U_a A_a(T' - T_a)$$

- $\dot{Q}_a$ is the heat transfer lost through the attic,

$$\dot{Q}_g = U_g A_g(T' - T_o)$$

- $\dot{Q}_g$ is the heat transfer lost through the glass windows.

It can be said that the heat transfer due to thermal mass $\dot{Q}_t$ on the interior is minimal because the temperature difference between mass and internal air is nearly zero (T=T').

The four remaining equations can be combined to express only one heat transfer coefficient. This coefficient combines the entire external area of the structure with radiation, heat added due to sources ($\dot{Q}_s$ - occupants and electrical; broken down below), and the climate control system (which is driven by the natural gas furnace):

$$\dot{E}_s = \dot{m}C_p(T_{d,o} - T') = -hA(T - T') - \dot{Q}_s + (U_oA_o)(T' - T_o)$$

The radiation heat transfer term can be neglected since it is small compared to the other forms of transfer and thus $hA(T - T') = 0$, because the temperatures are at equilibrium.

$$\dot{Q}_s = \dot{Q}_{occupants} + \dot{Q}_{electrical}$$

$$\dot{E}_s = (U_oA_o)(T' - T_o) - (\dot{Q}_{occupant} + \dot{Q}_{electrical})$$

In this case the energy requirement for the system is going to be equivalent to what is lost to the environment, minus the occupant load and electrical load. These parameters are going to be different depending on what time of year it is. For example, in the winter the occupant load is going to help and in the summer it will hurt. Knowing usage data for natural gas and electricity, the theoretical model can be solved for the universal heat transfer coefficient. This can be done by utilizing averaged usage data for the climate control system ($\dot{E}_s$). This includes the following components: occupants ($\dot{Q}_{occupant}$), electrical ($\dot{Q}_{electrical}$), thermal exchange area, and temperature data for internal (T') and external (T_o) conditions.

After calculating the overall heat loss of the house through conduction and convection, infiltration can be found using the heating energy usage. After subtracting out the base load (water heater and dryer), the heating load remains. Then the infiltration is just the total heat put into the building minus the heat lost through conduction and convection. With the information on where all of the energy is escaping, improvements can be researched and recommended. Improvements may include plastic over the windows during the winter, foam around any cracks or gaps in exterior walls, weather stripping around doors and windows, and anything else that prevents the exchange of air from inside the house to the outside.

Effects of Improvements

To decrease the amount of energy lost throughout the house, there are numerous improvements that can be made. These improvements may include installing compact fluorescent light bulbs (CFL) throughout the house, installing storm windows, insulating the ceiling of the basement, covering all windows with clear plastic during the winter,

insulating the electrical outlets and switches with insulating foam, replacing the current heating and cooling system with a ductless system, and placing spacers in all of the walls to increase the width of the insulation. All of these improvements can increase the energy efficiency of the house, but not all of them have a reasonable payback period. Typically, an improvement is considered economically reasonable if the payback period is less than 10 years. By conducting an analysis of each of the potential improvements, recommendations for the most economical upgrades can be made.

Compact fluorescent bulbs use much less energy than standard light bulbs, and with subsidized pricing from DTE Energy, the bulbs are more competitively priced. Incandescent bulbs not only use more electricity to operate, but they give off large amounts of heat that increase home cooling costs during the summer months. With each CFL bulb using roughly 75% less energy than conventional bulbs, the energy savings can add up very quickly (Energy Star). A typical 60 watt incandescent light bulb ran for 2 hours a day costs about $4.50 per year, while a similar 13 watt CFL bulb would only cost about $1.00 per year. At a cost of around $5.50 per CFL bulb (The Home Depot), the payback period comes out to just over a year and a half. If the lights are normally used more often, the payback period becomes much quicker. CFL bulbs are a great, inexpensive way to greatly decrease energy usage.

Storm windows can also provide additional insulation by adding an additional layer of insulation to the windows, which reduces the amount of heat lost due to convection and conduction. By adding storm windows, infiltration and convection will be reduced by adding an additional pane of glass to all of the windows. The storm pane can reduce the heat loss by around 6%. Caulking around the frames of the windows also greatly reduces infiltration, adding on another 6% of savings for a heat loss reduction of 12% overall. At an average of $40 per storm window (The Home Depot) and an overall cost of about $1100, the savings comes to $125 per year, with a payback period of almost 9 years.

Insulating the ceiling of the basement helps reduce the heat loss from the occupant envelope to the un-insulated basement. By adding a 3.5" layer of R13 fiberglass insulation, the overall heat loss is reduced by just over 2% for an annual savings of about $21. However, the initial heat loss to the basement was not very large, so the gains in insulation will take longer to return the investment. At a cost of $700 for the insulation, the payback period is 33 years, making this improvement uneconomical (The Home Depot).

Covering the windows with plastic during the winter months helps to stop the infiltration of cold air from outside. The plastic is very inexpensive and can prevent most of all of the air infiltration from the windows. The plastic would cost $70 to cover all of the windows (The Home Depot). Another major source of infiltration is the outlets and switches on the exterior walls of the house. By filling these gaps with expanding foam insulation, the infiltration can be reduced or eliminated. Purchasing a few cans of spray foam costs around $25, and can stop that constant flow of air rushing in through the outlets and switches (The Home Depot). While both of these improvements reduce the overall infiltration of the house, it's difficult to determine a payback period because the exact amount of infiltration at each source cannot be determined.

Switching the current heating and cooling system to a ductless one can have a major impact on the energy efficiency of the house. The current heating and cooling

system has an efficiency of about 60% with heavy losses in the duct system. The Fujitsu ductless system analyzed has a much higher efficiency, creating a savings of about $200 per year on heating alone. At a cost of around $4,000, the payback period comes out to 20 years, making this improvement tough to sell.

By increasing the thickness of the insulation between the exterior walls of the house, the R value can be greatly increased. This would be done by tearing out the current walls and adding spacers to the existing studs, then filling the additional space with insulation and replacing the drywall. Increasing the insulation to 6" deep, the energy loss could be reduced by around 8% for a savings of around $83 annually. While the savings from increasing the R value of the walls would create some energy savings, the project would have a substantial cost for materials and many hours of labor, not to mention the loss of area of the house.

The major basis of the project and the analysis is the viability of installing a solar array to reduce or eliminate the electricity costs of the house. The array includes the panels themselves, the inverters, the wiring, and the rail system that the panels are installed on. Assuming no labor costs due to self installation, the entire system comes out to about $30,000 in materials. This array could provide approximately 100% of the required electricity for the year, effectively eliminating the cost of the utility. This amounts to almost $1,500 in savings every year, and after subtracting the government tax incentive, the payback period becomes 14 years (Energy Star). While this is outside the reasonable payback period, it's still a major upgrade that also adds to the value of the house.

Table 1

Improvement	Cost	Tax Incentive	Annual Savings	Payback Period (years)
CFL Lights Bulbs	$5.50	$0	$3.50	1.6
Storm Windows	$1,100	$0	$125	8.8
Basement Insulation	$700	$70	$21	30.0
Ductless Heating/Cooling	$4,000	$300	$200	18.5
Solar Panels	$30,000	$9,000	$1,500	14.0

Another major aspect of determining which improvements to implement is the associated tax incentives and any subsidies available. Local utilities such as DTE Energy provide subsided prices on items such as CFL light bulbs and other Energy Stay certified products. They even provide coupons for some locations where the subsidies do not exist. The federal government and some state or local governments also have major tax incentives for increasing energy efficiency or other energy related projects (Energy Star). Adding insulation of any kind, such as fiberglass, weather stripping, or spray foam, is covered 10%, up to $500 (Energy Star). CFL light bulbs have $1.50 instant rebates at some stores, while others have special pricing, both courtesy of DTE Energy. Storm windows and plastic window covering are not currently covered by any incentives, but still provide benefits to the home. The ductless heating and cooling system have a maximum tax credit of only $300, barely offsetting any of the systems cost. Finally, the

solar array qualifies for a tax incentive of 30% of the cost of the system with no upper limit (Energy Star). This provides a great option to lower the overall costs and greatly decrease the payback period.

After all of the potential improvements were analyzed, only a few turned out to be economically feasible. CFL lights bulbs provide the largest cost savings over the shortest period of time, and should be implemented as soon as possible. Caulking around windows and doors and filling in gaps around outlets and switches should also be considered, as these upgrades greatly reduce infiltration and have very little cost associated with them. Storm windows are another great energy saving option, but have a much longer payback period than CFL bulbs or caulking. Insulating the basement floor or increasing the depth of the walls becomes too costly and has little economic value to the house in the near future. And while the ductless heating and cooling system is very energy efficient, the payback period is too long to make financial sense.

Analyze Usage Data

Since the energy usage data is provided, the amount of energy lost to infiltration, conduction, and convection can be calculated after the base load has been removed. The base heat load of the house is the amount of energy used to run appliances that are not temperature dependent, such as the dryer and hot water tank. The amount of natural gas used during the summer months is the base load, since there is no heating from the furnace during these months. Once the base load is determined, it is subtracted from the winter months, and the heating load is what remains. The energy lost through the building is known, so the heat put in through the furnace minus the heat lost throughout the building is the amount of heat required to keep the building heated.

For the electrical usage the analysis of the data can reveal the cooling load. This can be done, once again, by taking out the base load that is not temperature dependent. The electrical usage during the winter months can be used as the base load since there is no cooling during these months. Then subtracting the base load from the total load shows the amount of electricity used to cool the house. Using the amount of energy lost throughout the building, improvements can then be analyzed and recommended. For the design of the solar array, it's important to take into consideration the improvements made to the house prior to the installation of the array. The needs of the house will change with improved energy efficiency, and thus the size the array will vary accordingly.

Year Round Overall Heat Loss by Location without Improvements

Roof = 6%

Walls = 34%

Windows = 28%

Infiltration = 28%

Basement = 4%
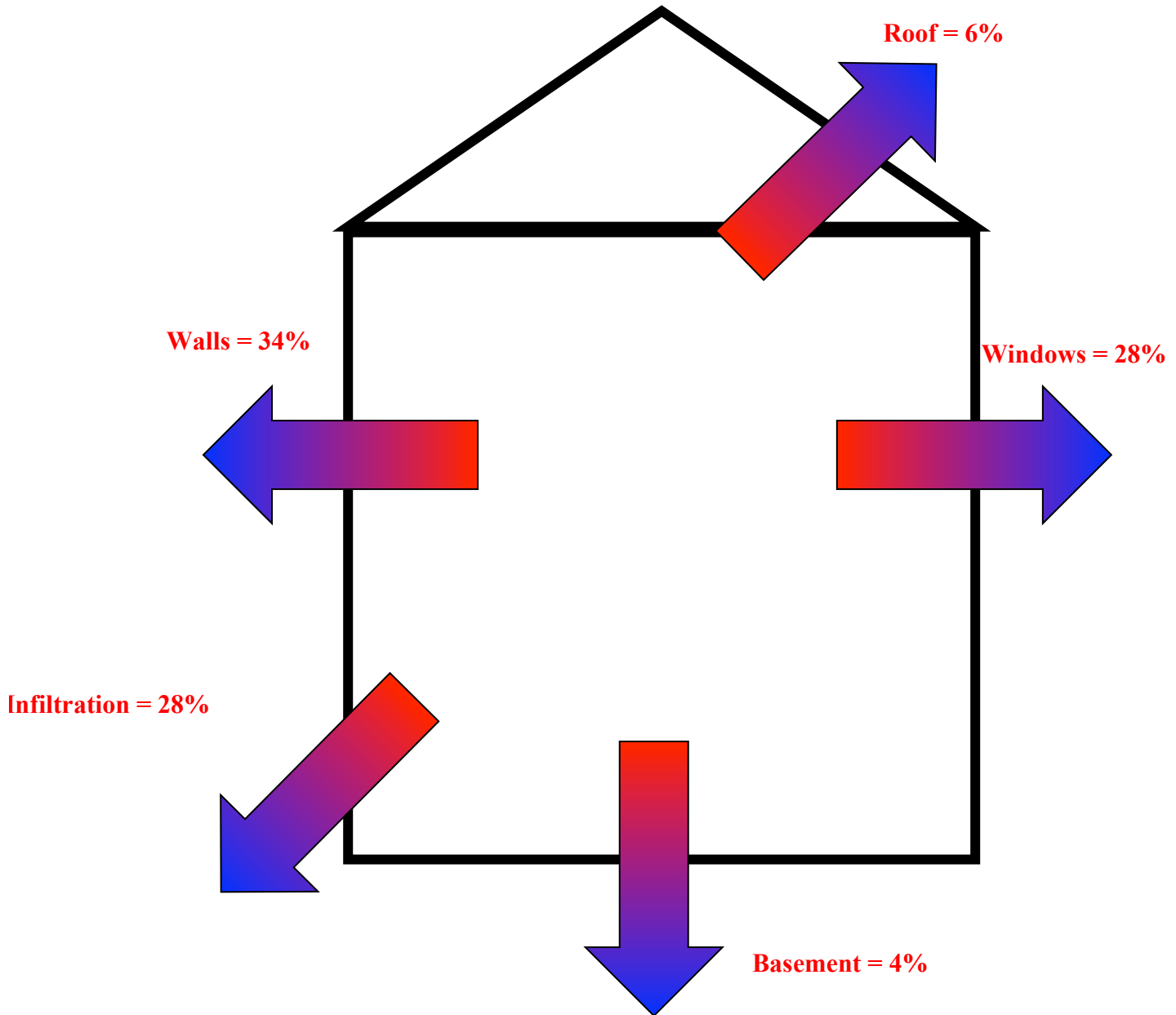
Electrical Analysis

Once the power needs of a system are calculated, the design of the photovoltaic solar array can begin. In designing a solar array for residential use, there are many considerations that need to be taken into account. One consideration is selecting a solar panel for the PV array. There are many options in selecting which solar panel you want to use. The included example is a solar panel with the least cost per watt. There are two major options, staying on the grid or keeping off the grid. The grid is the massive network of electrical lines that make up residential and commercial energy. The major advantage of staying on the grid is the cost reduction from not having to purchase a battery bank to store electricity produced from the solar array.

Including a battery backup for a grid-tied solar array would also require further work done in preparation for the system to include batteries. A charge controller would be required to charge the batteries. The batteries would also have to be wired up in series and parallel to work with the charge controller similar to how the solar panels and inverter work together in this analysis. For this analysis, battery backup will not be included.

DTE is the major electric utility in Michigan. In order to stay on the grid when producing electricity with solar cells, an interconnection agreement must be put in place. After the interconnection agreement is accepted, a net meter will be installed in place of the normal meter. A net meter keeps track of how much electricity is pushed out to the grid verse the amount of electricity used in the home pulled from the grid. A normal meter only allows electricity to flow into a home from the grid.

Connecting your solar array to the grid is done through an interconnection agreement with the local power utility. There are many regulations and requirements that are needed to ensure a safe hookup to the rest of the grid (DTE). More details of the rules and regulations can be found in later sections.

In designing a solar array for grid hook up, there are two major components that need to be analyzed: the type of solar panel and the type of inverter. Once these components have been selected they must be wired up in a manner that provides maximum power output for the inverter, as well as run within the means of the wire and inverter capabilities. When selecting a solar panel, the main concerns should be: power (P), short circuit current (I_{sc}), open circuit voltage (V_{oc}), maximum power voltage (V_{mp}), maximum power current (I_{mp}), weight and cost. When selecting an inverter, the main concerns should be: CEC efficiency, continuous watt rating, DC input voltage low, DC input voltage high, DC maximum input current, and cost. All of these variables will affect the performance of the solar array.

When matching the solar array for the example system's needs in the installation on a residential home, cost and power output are the top priorities. The other variables will determine how the solar array is wired together.

In the past, buying solar panels for the residential sector has not been very economically sound. In 2007, solar costs were nearly $3.65 per watt and were projected to come down (Bullis). That is clearly seen as solar costs are in the range of $1.50-1.75 per watt as of Spring 2011, which is a huge decrease.

There are many reasons to not connect the solar array to the grid. Allen Barnett wrote that connecting the solar array to the grid was too difficult to acquire, integrate, and

measure the energy produced, as well as being too expensive (1,6-7). Barnett also speaks strongly of the use of solar cells in off-grid technologies (1). An example of an off-grid modern technology is the satellites that orbit the earth. This has largely been solved in recent years, as there is a process through the DTE electric utility to integrate solar panels to the grid through an interconnection agreement (DTE).

As of now, it is rare to drive by and see a solar array on top of a residential home. Studies have been done in monitoring the economic value of a solar array on a residential home. A large reason that most residential communities don't already have this form of alternative energy is the high installation cost (Redfield, 1).

Design Analysis

Once the energy need of the system is determined by previous analysis, the solar panel wiring design can begin. There are many things to keep in mind when wiring a solar array together. Some basic concepts to remember are how voltage and current behave when solar panels are wired together.

Solar panels are wired in series when the negative terminal of one solar panel is connected to the positive terminal of the next panel. Solar panels are wired in parallel when they share common terminals (i.e. multiple positive terminals connected by a wire).

Solar panels connected in series have the same current, but their voltages become summed together at the end of the series. Solar panels connected in parallel have the same voltage across them all, but their currents become summed together at the end of the parallel circuit.

Keeping these key concepts in mind, the remainder of the wiring process is inputting numbers into equations. The amount of panels wired in series must keep the voltage in the range that is capable of being handled by the inverter. The amount of panels wired in parallel must keep the current below the max current that can be handled by the inverter as well.

Table 2 shows calculation results for the example residential system.

Table 2

Photovoltaic Solar Array Calculations			
Amount in Series	V_{mp} Total (V)	V_{oc} Total (V)	
19	412.528	495.79645	
Amount in Parallel	I_{mp} Total (A)	I_{sc} Total (A)	
2	23.69563	24.0465	
Total Panels			Solar Panel Used
38			ES-A-215-fa3
Total Power			
9775.110853	Watts		

Variables
V_{mp} = Voltage max power
I_{mp} = Current max power
V_{oc} = Open circuit Voltage

I$_{sc}$ = Short circuit current

   The specifications for the solar panel and inverter used in the example system (Table 2) can be found in Appendix A and Appendix B.

   Another variable to keep in mind is the temperature of the area surrounding the solar panel. Solar array voltage is sensitive to ambient temperature (Photovoltaics, 55). Voltage output will decrease as the temperature increases around the panel. Current output will slightly increase, as temperature increases, but it can be considered negligible for this system. Voltage is very important to monitor because, the inverter can be damaged if high amounts of voltage go through it. The inverter will also not run if it does not have enough voltage going through it. Both will affect cost, so it is important to keep the voltage within a certain range. Below are the equations to determine how voltage output of the photovoltaic solar cell will be affected by temperature.

Variables
V$_{mp}$ = Max Voltage
βV$_{mp}$= Temperature Coefficient for V$_{mp}$
I$_{mp}$ = Max Current
αI$_{mp}$ = Temperature Coefficient for I$_{mp}$
V$_{oc}$ = Open circuit Voltage
βV$_{oc}$ = Temperature Coefficient for V$_{oc}$
I$_{sc}$ = Short circuit current
αI$_{sc}$ = Temperature Coefficient for I$_{sc}$
P$_{mp}$ = Power
STC = Standard Test Conditions (at operating temperature of 25 °C)
T = Temperature (°C)

$$Total\ V_{mp}(T) = V_{mp}(STC) - \left(\frac{\beta V_{mp}}{100}\right) * V_{mp}(STC) * (25 - T)$$

$$Total\ V_{oc}(T) = V_{oc}(STC) - \left(\frac{\beta V_{oc}}{100}\right) V_{oc}(STC)(25 - T)$$

$$Total\ I_{mp}(T) = I_{mp}(STC)\left(1 - \frac{\alpha I_{sc}}{100}\right)(25 - T)$$

$$Total\ I_{sc}(T) = I_{sc}(STC)\left(1 - \frac{\alpha I_{sc}}{100}\right)(25 - T)$$

$$P_{mp} = V_{mp}I_{mp}$$

(King, 1186)

   Table 3 is the raw calculation data used in the following figures for determining how P$_{mp}$, V$_{oc}$, I$_{sc}$, V$_{mp}$ and I$_{mp}$ within the solar panels are affected by ambient temperature.

Table 3

Amount in Series	Total Panels	Inverter Specs			
19	38	Type	SB7000US	Max current	30 A
Amount in Parallel		Max Voltage	600 V	Max V_{mp}	480 V
2		Min Voltage	300 V	Min V_{mp}	250 V
Temperature (°C)	P_{mp} (W)	V_{oc} (V)	I_{sc} (A)	V_{mp} (V)	I_{mp} (A)
-20	9775.110853	495.79645	24.0465	412.528	23.69563
-15	9595.20886	489.0524	24.108	405.536	23.66056
-10	9415.797287	482.30835	24.1695	398.544	23.62549
-5	9236.876132	475.5643	24.231	391.552	23.59042
0	9058.445396	468.82025	24.2925	384.56	23.55535
5	8880.505079	462.0762	24.354	377.568	23.52028
10	8703.055181	455.33215	24.4155	370.576	23.48521
15	8526.095702	448.5881	24.477	363.584	23.45014
20	8349.626641	441.84405	24.5385	356.592	23.41507
25	8173.648	435.1	24.6	349.6	23.38
30	7998.159777	428.35595	24.6615	342.608	23.34493
35	7823.161974	421.6119	24.723	335.616	23.30986
40	7648.654589	414.86785	24.7845	328.624	23.27479
45	7474.637623	408.1238	24.846	321.632	23.23972
50	7301.111076	401.37975	24.9075	314.64	23.20465
55	7128.074948	394.6357	24.969	307.648	23.16958
60	6955.529239	387.89165	25.0305	300.656	23.13451
65	6783.473948	381.1476	25.092	293.664	23.09944
70	6611.909077	374.40355	25.1535	286.672	23.06437
75	6440.834624	367.6595	25.215	279.68	23.0293
80	6270.25059	360.91545	25.2765	272.688	22.99423
85	6100.156975	354.1714	25.338	265.696	22.95916
90	5930.553779	347.42735	25.3995	258.704	22.92409
95	5761.441002	340.6833	25.461	251.712	22.88902
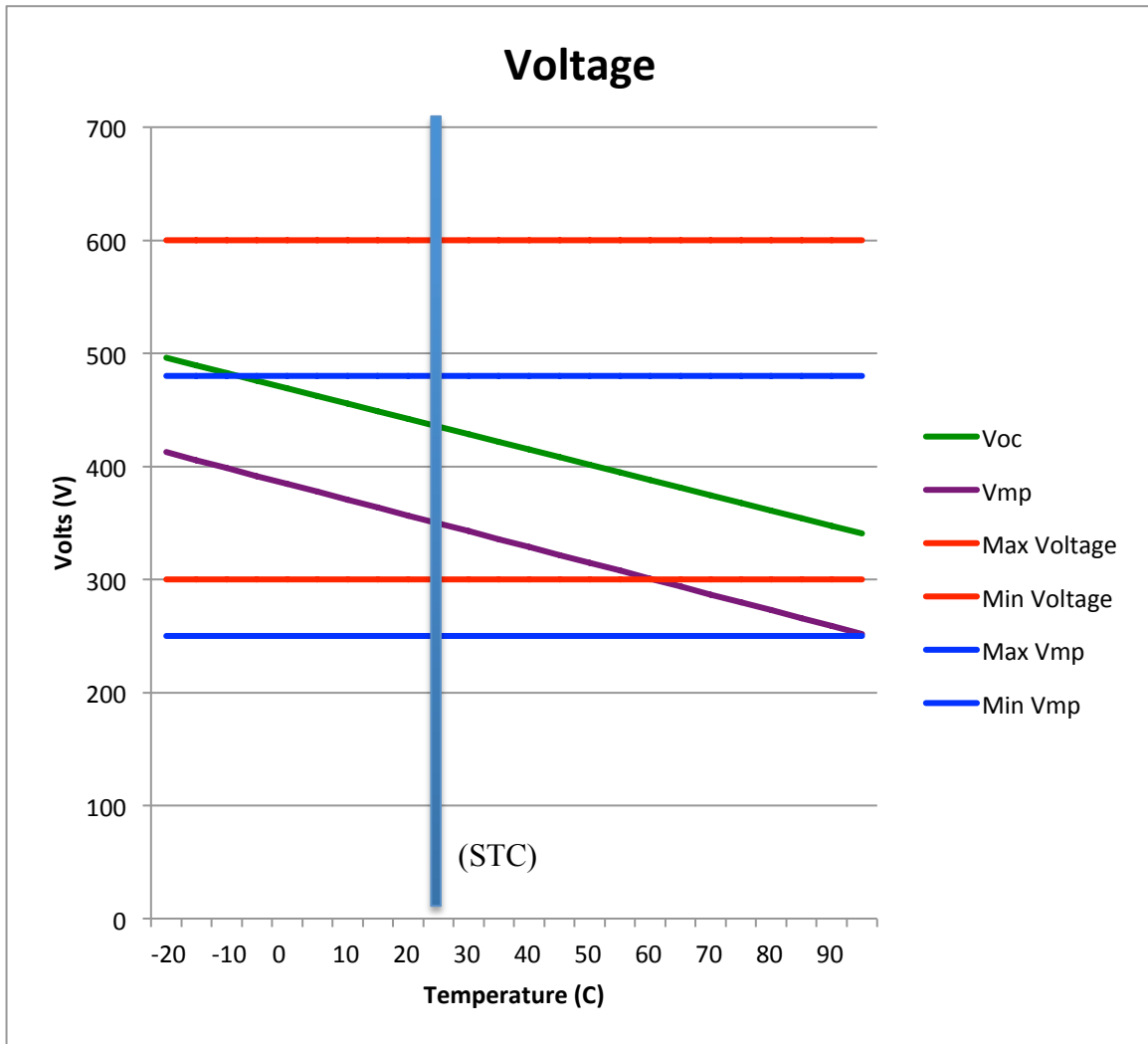
Figure 2

Figure 2 shows the voltage relationship to temperature. As temperature increases within the solar panel, the voltage decreases. STC shows the 25 °C operating temperature of the solar panel. Min and Max voltage are specifications of the inverter capabilities (Appendix B). V_{oc} and V_{mp} are determined by the specifications of the solar panel and by how many are wired together in series (Table 2). Keeping the operating temperature voltage between Max and Min voltage is absolutely required. However, the inverter will be able to function below the Min voltage as long as it has started running above 300V and does not fall below 250V. Keeping the operating temperature between Max V_{mp} and Min V_{mp} is necessary to keep power output maximum. Although the inverter will still function outside of the range of V_{mp}, it is highly desirable to keep it within that "sweet spot" in order to gain maximum power output.
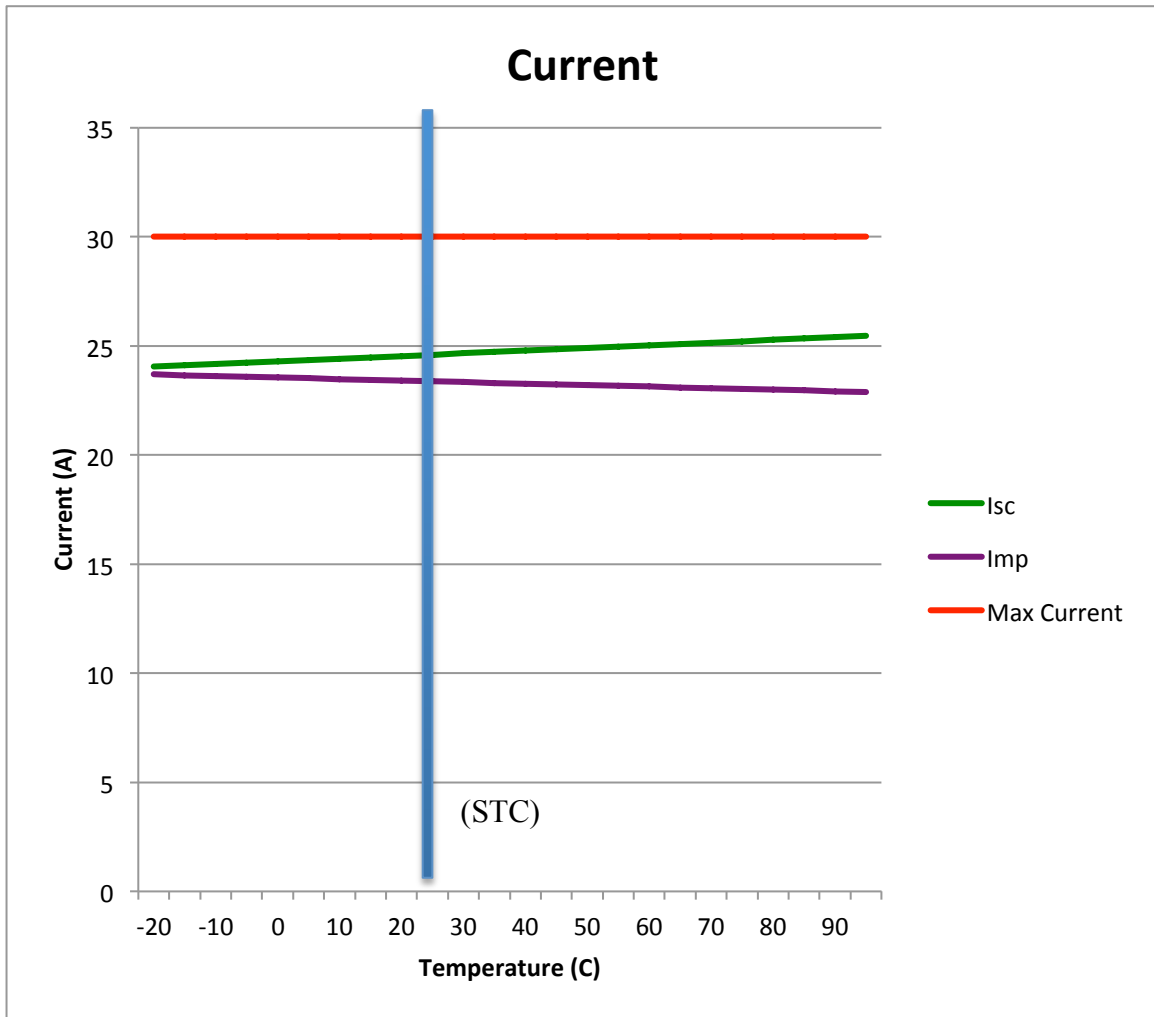
Figure 3

Figure 3 shows how current is affected by temperature. It is obvious that the temperature variance does not greatly affect current output from the solar panel. I_{sc} and I_{mp} are determined by the specifications of the solar panel and by how many are wired together in parallel (Table 2). STC is a reference for the 25 °C operating temperature of the solar panels. Max current is the maximum amount of current that can be handled by the inverter (Appendix B).
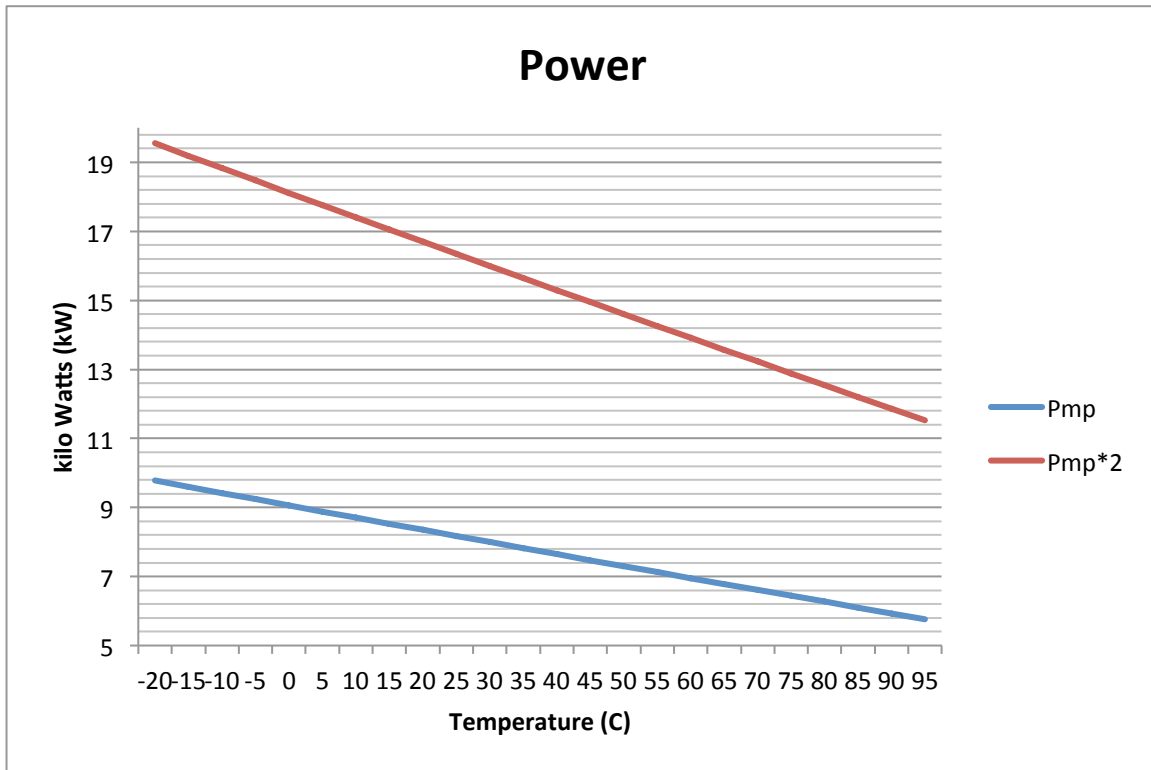
Figure 4

Figure 4 shows how power is affected by the change in temperature. As Figure 1 showed, voltage is greatly affected by temperature. Given this trend, power is going to also be affected. Power can be represented by the equation: P=IV. This shows that power is directly proportional to the amount of voltage loss that is incurred as the temperature of the solar cell increases.

Solar Panel Operating Temperature Analysis

To calculate the range of temperatures that a solar panel would be operating within, a conservation of energy equation is needed. Since energy can neither be created nor destroyed, the panels can only do two things with the light that hits them. They can reflect the light or absorb the light. The panels absorb the light rays and convert some rays into electrical energy and the rest is transformed into heat.

Tests on the solar panel from the specification sheet of the panel listed the nominal tests at 800 W/m^2 for irradiation (Appendix 1). Under the conservation of energy equation, the energy in to a system is equal to the energy out of a system under steady-state conditions.

$$dE/dt = E_{in} - E_{out}$$

The energy added to the system is equivalent to the light the solar panel is irradiated by in concert with the ambient temperature. Since the ambient temperature is initially the same as the panel and a panel that is hotter than the surrounding area is

releasing energy rather than absorbing it, this energy is negligible or not being added at all.

Energy leaving the system leaves in three forms: light, heat, electricity. The light reflected off the panel will be assumed to be a common ratio to the entire panel and not based on orientation, placement, or light ray wavelength. These details would be needed for more in depth analysis, but this is analysis only used for an operational temperature range from month to month. Therefore, the most accurate model is not necessary.

Energy leaving as light is assumed to be a constant fraction of the light striking the panel. So as a ratio this energy will be ignored, since a ratio of light to heat needs to be calculated. The energy leaving as electricity and heat then need to be balanced. From the nominal tests, the panel output is 157.4 W. The panel is 65 inches by 37.5 inches or 1.573 m^2. Meaning for the surface area of the panel, at 800 W/m^2, 1258 W is the incoming energy. Given the output at 157.4 W, the panel efficiency is 12.5% for light to electrical energy. The specification sheet also notes the "typical relative reduction of panel efficiency" down to 200 W/m^2. So, using these values the nominal light to electrical efficiency was assumed across the range of lighting conditions and for a general range of temperatures the panels would be operating within.

The amount of irradiation changes over the course of a year. This is analogous to the average and peak temperatures. Because the ambient temperature sets a baseline of the lowest temperature available, the energy added by heat will only add upon the ambient temperature. Local meteorological data needs to be gathered for temperatures, irradiation and wind speeds throughout the year. This data will aid in the irradiation estimations.

The ambient temperatures give the baseline for the lowest amount of heat the panels contain with no irradiation. The irradiation gives the amount of additional energy that's added to the panel at 87.5%. Using a spreadsheet, each piece of the information was put in to tables (Table 3). The calculations for the amount of energy transferred to heat for each month was calculated.

The heat added to the panel by irradiation is not the sole variable for determining the temperature of the panel. The panel gains energy from irradiation and loses energy by convection to the surrounding air. The loss of energy to the air is dependent upon the temperature of the panel. The following equation depicts this:

$$dE/dt = \rho P/A \text{ [irradiation]} - \sigma A(T^4 - T_c^4) \text{ [radiation]} - hA(T - T_c) \text{ [convection]}$$

Where:
ρ is reflectivity of the panel surface
P/A is the irradiation rate from light source (W/m^2)
σ is the Stefan-Boltzman constant (5.6703×10^{-8} W/m^2K^4)
A is area of the panel (m^2)
T is the temperature of the panel (K)
T_c is the temperature of the surroundings (K)
h is convective heat transfer coefficient (W/m^2K)

Since the radiation that leaves the panels is negligible by comparison, the balance happens between the irradiation and the convection which is primarily determined by the medium (air) and the speed the medium is moving. For this reason, wind speeds were also needed for the region. The wind speed is used to calculate the Reynold's number, Nusselt number, and Convective heat transfer coefficient for air in the given circumstances. Were there no air flow whatsoever, natural convection occurs. Since the panels will be outdoors, it is to be assumed there will be some air flow and that the convection will be forced for ease of temperature range calculations as well as still air is fairly rare outdoors.

$$Re = \rho VL/\mu$$

Where:
Re is the Reynold's number
ρ is density
V is velocity
L is the characteristic length (in this case the length of the panel)
μ is the viscocity

$$Nu = 0.0296 \, Re^{0.8}Pr^{\frac{1}{3}}$$

Where:
Nu is the Nusselt number
Re is the Reynold's number
Pr is the Prandtl number

$$h = kNu/L$$

Where:
h is the convective heat transfer coefficient
k is the conductive heat transfer coefficient
Nu is the Nusselt number
L is the characteristic length (in this case the length of the panel)

The resulting equation used to calculate the convective heat transfer coefficient with air data:

$$h = 0.0296 \, (\rho V/\mu)^{0.8}Pr^{\frac{1}{3}}k/L^{0.2}$$

Where:
ρ is the density of air
V is the velocity of air
μ is the viscosity of air
Pr is the Prandtl number
k is the conductive heat transfer coefficient
L is the characteristic length (in this case the length of the panel)

By calculating the convective heat transfer coefficient, it is then possible to balance out the irradiation compared to the convection heat transfer at steady-state.

$$dE/dt = 0 = \rho P/A \text{ [irradiation]} - hA(T-T_c) \text{ [convection]}$$

$$\rho P/A \text{ [irradiation]} = hA(T-T_c) \text{ [convection]}$$

The efficiency of irradiation to heat is known from nominal tests by ratio at 87.5%, thus ρ = 0.875.

Each of the month's data for wind speed, temperature, and irradiation rates were tabulated for southeast Michigan giving data to calculate the temperature of the panel based on the month. Individual conditions per day, time, and irradiation rate will vary the temperature, but a range of average as well as peak temperatures is given in Table 4.

With all the operating temperatures calculated, it was then determined which range of operating temperatures could be used for the electrical design analysis. The maximum temperature that a panel could be operating at is 60 °C and the lowest temperature that a panel could be operating at is -25 °C. These are under the most extreme of circumstances, so it is not likely that the solar panels would experience such extreme climate conditions. The average high for a solar panel to be operating at during the hottest times of the year is 41 °C. The average low for a solar panel to be operating at during the coldest times of the year is -3 °C. All of the maximum and minimum operating temperatures and their respective months can be found in Table 4.

With all the operating temperatures calculated, it was then determined which range of operating temperatures could be used for the electrical design analysis. The maximum temperature that a panel could be operating at is 59.94 °C and the lowest temperature that a panel could be operating at is -24.64 °C. These are under the most extreme of circumstances, so it is not likely that the solar panels would experience such extreme climate conditions. The average high for a solar panel to be operating at during the hottest times of the year is 41.09 °C. The average low for a solar panel to be operating at during the coldest times of the year is -2.96 °C. All of the maximum and minimum operating temperatures and their respective months can be found in Table 4.

Table 4

	January	February	March	April	May	June	July	August	September	October	November	December	Yearly
Wind Speed (m/s)	5.32	5.10	5.23	5.05	4.52	4.11	3.80	3.62	3.89	4.34	5.01	5.05	4.60
Reynold's Number	290938	278714	286048	276269	246930	224927	207813	198033	212702	237151	273824	276269	250801
Nusselt Number	621	600	613	596	545	506	475	457	484	528	592	596	551
Heat transfer coefficient (W/m^{2}K)	17.7	17.1	17.5	17.0	15.6	14.4	13.6	13.0	13.8	15.1	16.9	17.0	15.7
Irradiation Average (W/m^2)	100	138	171	208	238	254	254	233	200	154	100	79	179
Irradiation Minimum (W/m^2)	75	113	146	154	192	225	233	200	163	108	63	58	167
Irradiation Maximum (W/m^2)	121	192	213	242	279	300	283	275	233	196	138	104	188
Heat Loss Average (H)	274	377	468	571	651	697	697	640	548	423	274	217	491
Heat Loss Minimum (H)	206	308	400	423	525	617	640	548	445	297	171	160	457
Heat Loss Maximum (H)	331	525	583	663	765	822	777	754	640	537	377	286	514
Temperature Difference Average (K)	4.9	6.8	8.4	10.3	11.7	12.5	12.5	11.5	9.9	7.6	4.9	3.9	8.8
Temperature Difference Minimum (K)	4.8	7.1	9.3	9.8	12.2	14.3	14.8	12.7	10.3	6.9	4.0	3.7	10.6
Temperature Difference Maximum (K)	7.7	12.2	13.5	15.3	17.7	19.0	18.0	17.5	14.8	12.4	8.7	6.6	11.9
Record high (°C)	19.4	21.1	27.8	31.7	35	40	40.6	40	37.8	33.3	27.2	20.6	40.6
Average high (°C)	-0.5	1.33	7.33	14.33	21.22	26.11	28.56	27.44	23.17	16.22	8.78	2.17	14.67
Average low (°C)	-7.89	-6.67	-1.94	3.56	9.67	14.94	17.56	16.78	12.28	5.83	0.83	-4.78	5
Record low (°C)	-29.4	-28.9	-20	-13.3	-3.3	2.2	5.6	3.3	-1.7	-8.3	-17.8	-23.9	-29.4
Panel Highest Peak Temperature (°C)	27.1	33.3	41.3	47.0	52.7	59.0	58.6	57.5	52.6	45.7	35.9	27.2	59.0
Panel Average High Peak Temperature (°C)	4.4	8.1	15.7	24.6	32.9	38.6	41.1	38.9	33.0	23.8	13.7	6.1	41.1
Panel Average Low Peak Temperature (°C)	-3.0	0.1	6.5	13.8	21.4	27.5	30.1	28.3	22.1	13.4	5.8	-0.9	-3.0
Panel Lowest Peak Temperature (°C)	-24.6	-21.8	-10.7	-3.5	8.9	16.5	20.4	16.0	8.6	-1.4	-13.8	-20.2	-24.6

Wiring

Follow the NEC guidelines to determine what wire gauge to use. Each system will require a different gauge wire since the distance from the solar panels to each of their respective inverter will depend on the system.

http://www.electriciancalculators.com/calculators/wireocpd_ver_1.html

The above website is a calculator that follows the NEC guidelines. NEC Table 310.16 is referenced to calculate each of the wire gauges on this website (Appendix C)

For the case of our example system, the wiring between the panels given each has max current of ~13A will require #8 gauge wire. This is only if these panels are no more than 10 ft apart from one another. The wire from the roof where the solar panels are located to the inverter next to the net meter will require #3 gauge wire. That distance is approximately 100 ft.

The calculator will be able to take other variables into account that will not be used for this system. Each system is unique and wiring must be done in order to not only meet the standard for NEC, but also to reduce voltage drop as much as possible.

Example Resident System vs. Other Systems

For the example system, similar calculations could be followed as performed in this analysis to obtain various amounts of solar power. If cost is a limiting factor, solar panels can be added or subtracted by taking out different series of solar panels. It is important to note, that voltage must be kept within the ranges that the inverter is capable of operating within. This is the main reason that entire series of solar panels need to be removed, rather than removing exact amounts of solar panels. If the inverter is swapped out for a smaller inverter, or multiple smaller inverters are purchased in place of a larger inverter, different amounts of solar panels can be wired in series. The larger solar panels typically need to stay with larger inverters and smaller solar panels with smaller inverters. This makes sense for power generation, so it is important to keep in mind when sizing any other system.

The complete calculation for the example system to meet the energy needs for 16.5kW can be found in Appendix D. Note that there is extra kW to compensate for the

loss incurred due to the location that the solar panels are mounted on the roof according to PV watts.

Mechanical Installation Analysis

The photovoltaic (PV) array is intended to match the draw of the occupant envelope thus the amount of energy calculated to be consumed was 16.5 kW. The occupant envelope had four roof surfaces that could be used for a PV array, one facing in each direction of the compass. Because of the location of the occupant envelope being in Southeast Michigan, the ideal direction would be south. However, the roof is offset by 26 degrees clockwise.

The ideal roof is still the roof facing primarily south, however it is 34.8 feet by 20.5 feet for surface area. This limited size makes a secondary roof surface necessary for a PV array in this example. The east and west facing roofs are both much larger, 56 feet by 27.5 feet. While the east roof would be of preference since the 26 degree offset, it also overlooks a large drop. For installation safety, the west side roof was chosen to minimize risk.

Given that the primary roof will be the south roof and the additional roof will be the west roof, the size of the array can now be determined. While 16.5 kW is the intended system size, a 16.5 kW PV array will not generate 16.5 kW, because of the roof pitch and angle. A PV array generates electrical power from light and as such needs to be as directionally normal to the light source as possible. While it is not feasible to try to change the source of the light considering it is the sun, the angle at which the array is placed is the only other choice. To avoid using additional structures, the PV array is laid parallel to the roof surface.

The angle of inclination needs to be taken into account with trying to place an array. Having a panel that lies directly up does not help if the cross section for light is minimized. The azimuth angle, the vertical angle in a spherical reference, would be the angle to take into consideration when judging which way to place panels. It is because of this reason that south would be the most ideal facing direction when in the northern hemisphere, such as southeastern Michigan.

Additionally, the most ideal azimuth angle should be taken so as to maximize the cross sectional area of the panels thereby converting the most amount of energy. The south roof is a 4x12 pitch. This means for every twelve feet of length the roof rises up four feet. This gives and angle of 32 degrees. Both the east and west roofs are 6x12 pitches, giving them a 46 degree rise.

Using a solar calculator, PV Watts, to determine the efficiency of the angles for each roof, the south roof would have an efficiency of 114.2% from rating and the west roof would have an efficiency of 84.5% from rating. Obviously the first choice would be the south roof until the desired array size was met or the surface was full before going the west roof. Because there is a 30% difference, panel spacing on the south roof is most important to ensure the minimal number of panels used.

For sizing, a spreadsheet was created that had all the approved panels entered for specifications. The spreadsheet was used to calculate the maximum number of panels that could be laid out widthwise or lengthwise with the incline using the "rounddown" excel

function. This space analysis combined with the lowest cost per kW panels was used to determine which panel to use.

Once a panel was selected, dimensions could be taken into account for if it would work best lengthwise or widthwise. This was done by giving an input for the desired offset from the edges for maintenance and dividing the length and width by panel length and width and using the "rounddown" function in excel again. Then the "maximum" number of panels was selected and shown to the spreadsheet user in an "H" for height wise or "W" for widthwise for each of the two roofs.

The design of the support structure for the PV array consists of lengths of 2x4 pressure treated wood with clips to pin the PV cells to the frame. The frame runs perpendicular to the incline along the short or long side of the panel depending on the maximum fit for panels. Then the frame is screwed down to the roof through another small section of wood as a leg so as to raise the frame off the roof shingles. This allows for rainfall to pass harmlessly under the PV array without build up along the edges of the frame. This was done to minimize stress on the shingles so as to avoid creating a water leak in the roof. However, because of this design, the weight is centered on each of the legs rather than being distributed uniformly across the roof. This design allows for the placement of legs only above the trusses to minimize stress on unsupported areas of the roof.

The legs land directly over the trusses that are spaced every 24 inches along the south and west roof moving perpendicular to the incline. Parallel to the incline are truss reinforcements; wooden 2x4's vertically reinforcing the trusses at the roof. The truss reinforcements are located 108, 212, 314, and 418 inches up from the bottom of the south roof and 124, 212, 330 inches up from the bottom on the west roof. Because pinewood is around fifteen times stronger in compression parallel to the grain, it is highly unlikely that the truss structure would fail in the support beam rather than the two beams taking the force perpendicular to the grain.

To ensure that the roof will not collapse, a shear force and bending diagram is necessary. Also the wood needs to be analyzed under working and not failure conditions. There are quite a few different types of pine that are plausible lumber. Because of this the lowest strength measurements were taken to ensure the roof would hold up under the stress.

A shear force diagram gives the forces acting on a truss to see if the truss can hold up in working conditions and how much deflection the truss would go through.
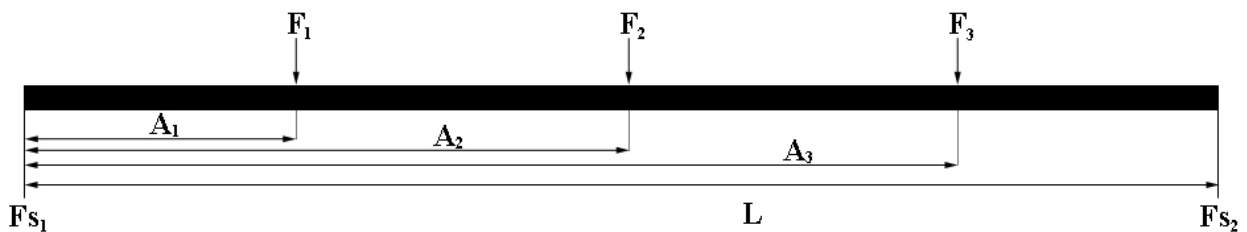
The trusses are immobile so all the forces need to sum to zero. The largest amount of force is going down due to the weight of the panels and possible snow. Because the panels are going on a roof, there is a lateral force on the truss, which is negligible by comparison to the vertical weight since the strain is against the truss fasteners that are much stronger than the wooden trusses.

The sum of the weight must be equal to the two forces supporting each truss. However, another formula is needed to balance out all the forces. Because the truss is known not to move, a rotational perspective is taken where one end point is set as the reference and the other points are summed for torque. No movement gives a net zero torque. So each force is multiplied by the distance from the reference end to give its torque. Finally the other end being supported by other trusses is multiplied by the length of the truss to give net zero torque. This way all the leg forces and truss structure forces can be solved.

In the case of the frame that is uniform, each leg supports one quarter of four panels, thus one panel in size and weight. This gives a known to each force of the legs, needing only be solved for the truss structure forces keeping the frame up.

The problem exists that between each truss support as few as one leg may land and as many as four legs could land. This means that solving for the forces acting on each truss member could be using up to four different formulas. This only causes problems if trying to automate the calculations through a spreadsheet program. Calculations by hand are still quite simple considering there are only two unknowns and two formulas, however, since there are multiple trusses and in this case, more than one roof, the tedious process of solving by hand can be very time consuming. To ease the speed of calculations a spreadsheet was used for calculations.

Once all the forces are known, a bending diagram is needed. This is a diagram to find the amount of deflection each truss goes through from the forces being applied. The deflection is calculated by:

$$\text{Modulus} = \text{Force/strain}$$

While each of the calculations are fairly simple to do by hand, over the given south roof being 20.5 feet across gives at least eleven trusses across and four trusses deep. To make the calculations faster and simpler, a spreadsheet was designed with all the formulas to calculate the shear forces and deflection based on chosen input such as which panels to use.

All the panel data was entered into the spreadsheet and roof dimensions. Calculations followed as listed above. However, because more than one leg could rest on each truss, an "if-then" function noted how many legs were on each truss based on the panel length or width, panel orientation, distance of trusses and offset from the bottom of the roof to choose which formula to apply appropriately. The spreadsheet then gives all the calculations and output a force on each truss as well as the deflection that truss would experience. The spreadsheet was limited to calculate only up to four legs per truss, since panel size and truss length only allowed for a maximum of four legs per truss. If additional panels of smaller size were considered the conditional statements would need to be altered to take this into account.

To make things simpler for the output the greatest amounts of force and deflections were chosen for the trusses and output to be compared to the shear force under working conditions. This gives a simple feedback to the user to see if there would be too much force on each truss and if the trusses were within working conditions.

The largest amount of weight a PV array will take is from accumulated snowfall if the region has snowfall. The largest snow accumulations were tabulated for Michigan along with the density of snow to know the amount of force the snow will be applying. This was integrated into the spreadsheet to allow the user to choose the amount of accumulated snow to see the effects on the truss' stress and deflection.

In architecture, a safety factor is used to ensure that the structure will not only hold the load in working conditions, but also if working conditions change to be larger than expected. The safety factor is calculated by:

$$Safety\ factor = F_w/F_m\text{-}1$$

Where:
F_w is the force on the structure under working conditions
F_m is the maximum force the structure can take before failure

As a rule of thumb, structures generally aim to have a safety factor of at least two. This way, even if the force doubles on the structure, it can still sustain its load. The safety factor was added to the spreadsheet to give better feedback to the stress load the array would be taking under different conditions such as snow and panel orientation.

Installation Outline and Regulations

Attaining the correct requirements and approvals for a grid-tied photovoltaic system is extremely important. A lot of research must be done before designing a system, becoming familiar with proper requirements (varied depending on location), and choosing a system within a specified budget. When the proper PV system size is determined for the home, start working on the Interconnect application. The interconnect application outlines the PV system location, components, and overall site plan (Appendix G). Once the review of the application is complete, the electric provider will send the Interconnect contract, and all terms must be agreed to. Now it is time to install the PV system according to all applicable codes and standards outlined in the agreement. Return the Parallel Operating Agreement with copies of each of the following:

- Proof of installation paid in full (final Invoice)
- The approved municipal inspections (as required by the interconnection program)
- Photographs of the completed installation (panels, inverters, disconnects, and metering)

Panel photo should include all of the installed panels and inverters. Also, the panel and inverter photos should be close enough to verify the products information. All this documentation will be sent the resident electric provider. As soon as the electric provider approves the system a representative will install necessary metering, perform

safety testing, and authorize the system to be energized. Once the PV system is energized it will be up to the homeowner to keep detailed documentation of all maintenance, array malfunctions, and system inspections. All documentation needs to be updated on a yearly basis with your local energy provider.

Conclusion

Installing a photovoltaic array onto a rooftop provides many benefits. These include reducing energy consumption, decreasing living expenses, and helping to create a green environment. A PV solar array system can last for 25 years with the proper analysis, design, and installation. Given the benefits stated above the PV solar array system will continue to "pay for itself" over the years. In addition to the array, the effects of green home improvements will further diminish the overall energy consumption of a residence. Whenever a PV solar array is under consideration for installation, be sure to contact the local state authorities to best understand the legal compliance required. It is best practice to fully understand and research each component for compatibility prior to installation. Utilizing the design and analysis process presented in this report to create a PV solar array and paring it with green home improvements will provide amazing reduction in energy consumption. Reduction in energy consumption directly reduces energy costs and drives towards a greener environment.

ELECTRICAL characteristics

Standard Test Conditions (STC)[1]

	ES-A-200 -fa3*	ES-A-205 -fa3*	ES-A-210 -fa3*	ES-A-215 -fa3*	
P_{mp} [2]	200	205	210	215	W
$P_{tolerance}$	-0/+4.99 (-0/+2.5)	-0/+4.99 (-0/+2.5)	-0/+4.99 (-0/+2.5)	-0/+4.99 (-0/+2.5)	W (%)
$P_{mp, max}$	204.99	209.99	214.99	219.99	W
$P_{mp, min}$	200.00	205.00	210.00	215.00	W
P_{ptc} [3]	180.7	185.4	190.0	194.6	W
η_{min}	12.7	13.1	13.4	13.7	%
V_{mp}	18.1	18.2	18.3	18.4	V
I_{mp}	11.05	11.27	11.48	11.69	A
V_{oc}	22.6	22.7	22.8	22.9	V
I_{sc}	11.80	11.93	12.11	12.30	A

Nominal Operating Cell Temperature Conditions (NOCT)[4]

|					
T_{NOCT}	45.4	45.4	45.4	45.4	°C
P_{max}	146.4	150.1	153.8	157.4	W
V_{mp}	16.5	16.6	16.7	16.8	V
I_{mp}	8.87	9.04	9.21	9.37	A
V_{oc}	20.8	21.0	21.1	21.2	V
I_{sc}	9.44	9.57	9.76	9.95	A

Low Irradiance

The typical relative reduction of panel efficiency at an irradiance of 200 W/m² both at 25°C cell temperature and spectrum AM 1.6 is 0%.

Temperature Coefficients

$\gamma\, P_{mp}$	-0.43	%/°C
$\beta\, V_{mp}$	-0.40	%/°C
$\alpha\, I_{mp}$	-0.03	%/°C
$\beta\, V_{oc}$	-0.31	%/°C
$\alpha\, I_{sc}$	+0.05	%/°C

System Design

Series Fuse Rating	20 A
Maximum DC System Voltage (UL)	600 V

1 1000 W/m², 25°C cell temperature, AM 1.5 spectrum; 2 Maximum power point or rated power; 3 At PV-USA Test Conditions: 1000 W/m², 20°C ambient temperature, 1 m/s wind speed; 4 800 W/m², 20°C ambient temperature, 1 m/s wind speed, AM 1.6 spectrum; 5 Cell color may vary due to our unique manufacturing process but does not affect the performance of the panel; 6 Per UL 1703. When using Mounting Methods A3 (long side end mounting) or B (three rails) as described in the Mounting Guide for this product; 7 Per IEC 61215; * A-framed, a-low voltage, 3-inset blue (textured) cells and black anodized frame.

⚠ ELECTRICAL EQUIPMENT
CHECK WITH YOUR INSTALLER

MECHANICAL specifications
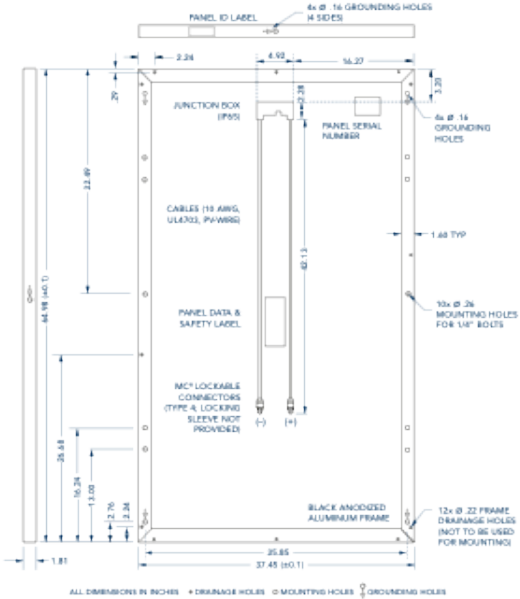
External Dimensions	65.0" x 37.5" x 1.8" / 1650.5 x 951.3 x 46 mm
Weight	41 lbs
Solar Cells[5]	114 Multi-Crystalline Silicon String Ribbon® Cells
Frame	Black Anodized Aluminum—Doubled Walled
Front Cover	Anti-Reflective Tempered Solar Glass 1/8" Thickness
Encapsulant / Back Cover	EVA / TPE
Maximum Certified Wind & Snow Load[6]	80 lbs/ft²
Hailstone Impact Test[7]	ø 1" ice ball at 23 m/s (52 miles/h)

Product packaged 28 per pallet and tested to International Safe Transit Association (ISTA) Standard 2B. All specifications in this product information sheet conform to EN 50380. See the Evergreen Solar Safety, Installation and Operation Manual, Mounting Guide and Inverter Selection Guide for further information on approved installation and use of this product.

Due to continuous innovation, research and product improvement, the specifications in this product information sheet are subject to change without notice. No rights can be derived from this product information sheet and Evergreen Solar assumes no liability whatsoever connected to or resulting from the use of any information contained herein. MC® is a registered trademark of Multi-Contact AG.

PARTNER

ES-A_200_205_210_215_fa3_US; effective January 1st 2011   SM-0089 RevC

Appendix B – Inverter Specifications

Technical Data

	SB 5000US	SB 6000US	SB 7000US	SB 8000US
Recommended Maximum PV Power (Module STC)	6250 W	7500 W	8750 W	10000 W
DC Maximum Voltage	600 V	600 V	600 V	600 V
Peak Power Tracking Voltage	250–480 V	250–480 V	250–480 V	300–480 V
DC Maximum Input Current	21 A	25 A	30 A	30 A
Number of Fused String Inputs	3 (inverter), 4 x 20 A (DC disconnect)	3 (inverter), 4 x 20 A (DC disconnect)	3 (inverter), 4 x 20 A (DC disconnect)	3 (inverter), 4 x 20 A (DC disconnect)
PV Start Voltage	300 V	300 V	300 V	365 V
AC Nominal Power	5000 W	6000 W	7000 W	8000 W
AC Maximum Output Power	5000 W	6000 W	7000 W	NA @ 208 V 7700 W @ 240 V 8000 W @ 277 V
AC Maximum Output Current (@ 208, 240, 277 V)	24 A, 21 A, 18 A	29 A, 25 A, 22 A	34 A, 29 A, 25 A	N/A, 32 A, 29 A
AC Nominal Voltage Range	183 – 229 V @ 208 V 211 – 264 V @ 240 V 244 – 305 V @ 277 V	183 – 229 V @ 208 V 211 – 264 V @ 240 V 244 – 305 V @ 277 V	183 – 229 V @ 208 V 211 – 264 V @ 240 V 244 – 305 V @ 277 V	N/A @ 208 V 211 – 264 V @ 240 V 244 – 305 V @ 277 V
AC Frequency: nominal / range	60 Hz / 59.3 – 60.5 Hz	60 Hz / 59.3 – 60.5 Hz	60 Hz / 59.3 – 60.5 Hz	60 Hz / 59.3 – 60.5 Hz
Power Factor (Nominal)	0.99	0.99	0.99	0.99
Peak Inverter Efficiency	96.8%	97.0%	97.1%	96.5%
CEC Weighted Efficiency	95.5% @ 208 V 95.5% @ 240 V 95.5% @ 277 V	95.5% @ 208 V 95.5% @ 240 V 96.0% @ 277 V	95.5% @ 208 V 96.0% @ 240 V 96.0% @ 277 V	N/A @ 208 V 96.0% @ 240 V 96.0% @ 277 V
Dimensions: W x H x D in inches	18.4 x 24.1 x 9.5	18.4 x 24.1 x 9.5	18.4 x 24.1 x 9.5	18.4 x 24.1 x 9.5
Weight / Shipping Weight	141 lbs / 148 lbs	141 lbs / 148 lbs	141 lbs / 148 lbs	148 lbs / 152 lbs
Ambient Temperature Range	−13 to 113 °F	−13 to 113 °F	−13 to 113 °F	−13 to 113 °F
Power consumption at night	0.1 W	0.1 W	0.1 W	0.1 W
Topology	Low frequency transformer, true sinewave	Low frequency transformer, true sinewave	Low frequency transformer, true sinewave	Low frequency transformer, true sinewave
Cooling Concept	OptiCool™, forced active cooling	OptiCool™, forced active cooling	OptiCool™, forced active cooling	OptiCool™, forced active cooling
Mounting Location: indoor / outdoor (NEMA 3R)	●/●	●/●	●/●	●/●
LCD Display	●	●	●	●
Communication: RS485 / wireless	○/○	○/○	○/○	○/○
Warranty: 10 years / 15 years / 20 years	●/○/○	●/○/○	●/○/○	●/○/○
Compliance: IEEE-929, IEEE-1547, UL 1741, UL 1998, FCC Part 15 A & B	●	●	●	●
Specifications for nominal conditions		● Included ○ Optional		

NOTE: US inverters ship with gray lids.

Efficiency Curves
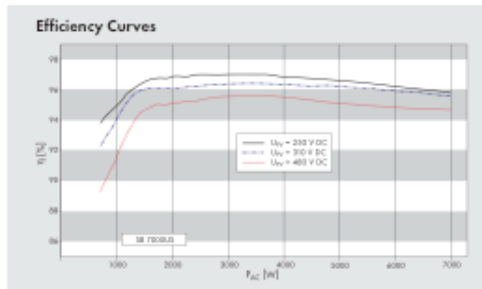
Tel. +1 916 625 0870
Toll Free +1 888 4 SMA USA
www.SMA-America.com

SMA America, LLC

Appendix C – National Electric Code - Table 310.16

Table 310.16 Allowable Ampacities of Insulated Conductors Rated 0 Through 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)

	Temperature Rating of Conductor (See Table 310.13.)						
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Size AWG or kcmil
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			
18	—	—	14	—	—	—	—
16	—	—	18	—	—	—	—
14*	20	20	25	—	—	—	—
12*	25	25	30	20	20	25	12*
10*	30	35	40	25	30	35	10*
8	40	50	55	30	40	45	8
6	55	65	75	40	50	60	6
4	70	85	95	55	65	75	4
3	85	100	110	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	150	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	190	230	255	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500
600	355	420	475	285	340	385	600
700	385	460	520	310	375	420	700
750	400	475	535	320	385	435	750
800	410	490	555	330	395	450	800
900	435	520	585	355	425	480	900
1000	455	545	615	375	445	500	1000
1250	495	590	665	405	485	545	1250
1500	520	625	705	435	520	585	1500
1750	545	650	735	455	545	615	1750
2000	560	665	750	470	560	630	2000

CORRECTION FACTORS

Ambient Temp. (°C)	For ambient temperatures other than 30°C (86°F), multiply the allowable ampacities shown above by the appropriate factor shown below.						Ambient Temp. (°F)
21–25	1.08	1.05	1.04	1.08	1.05	1.04	70–77
26–30	1.00	1.00	1.00	1.00	1.00	1.00	78–86
31–35	0.91	0.94	0.96	0.91	0.94	0.96	87–95
36–40	0.82	0.88	0.91	0.82	0.88	0.91	96–104
41–45	0.71	0.82	0.87	0.71	0.82	0.87	105–113
46–50	0.58	0.75	0.82	0.58	0.75	0.82	114–122
51–55	0.41	0.67	0.76	0.41	0.67	0.76	123–131
56–60	—	0.58	0.71	—	0.58	0.71	132–140
61–70	—	0.33	0.58	—	0.33	0.58	141–158
71–80	—	—	0.41	—	—	0.41	159–176

* See 240.4(D).

Appendix D – Calculations for sizing of 16.5kW array

4/12 Roof PV Array Sizing Calculations

Amount in Series	V_{mp} Total (V)	V_{oc} Total (V)	Inverter
15	325.68	391.41825	**7000US**
Amount in Parallel	I_{mp} Total (A)	I_{sc} Total (A)	
2	23.69563	24.0465	

Total Panels
30

Total Power
7717.192778 Watts

6/12 Roof PV Array Sizing Calculations

Amount in Series	V_{mp} Total (V)	V_{oc} Total (V)	Inverter
20	434.24	521.891	**8000US**
Amount in Parallel	I_{mp} Total (A)	I_{sc} Total (A)	
2	23.69563	24.0465	

Total Panels
40

Total Power
10289.59037 Watts

Total Wattage	**Total Panels**
18006.78315	**110**

Appendix E – Raw Energy Usage Data

Natural Gas Usage in CCF								
	2011	2010	2009	2008	2007	2006	2005	2004
JAN	371	263	388	344	137	335	393	
FEB	397	329	388	236	367	260	350	
MAR		275	283	330	331	298	338	
APR		136	215	266	119	201	190	
MAY		78	71	96	128	76	97	
JUN		64	74	79	34	68	40	
JUL		45	26	21	24	30	22	
AUG		37	38	27	28	26	24	
SEP		21	46	34	5	20	20	
OCT		40	35	35	26	35	44	
NOV		102	94	71	33	123	79	
DEC		197	150	244	178	185	265	269
TOTAL	768	1,587	1,807	1,783	1,410	1,657	1,862	269
30-Day Average	384	132	151	149	118	138	155	269

Amount Billed								
	2011	2010	2009	2008	2007	2006	2005	2004
JAN	$371	$263	$388	$344	$145	$378	$328	
FEB	$401	$329	$388	$236	$371	$274	$276	
MAR		$275	$283	$330	$338	$317	$269	
APR		$136	$215	$266	$133	$230	$178	
MAY		$78	$71	$96	$143	$92	$95	
JUN		$64	$74	$79	$45	$84	$45	
JUL		$45	$26	$21	$34	$40	$29	
AUG		$37	$38	$27	$37	$35	$31	
SEP		$21	$46	$34	$14	$30	$27	
OCT		$40	$35	$35	$36	$45	$54	
NOV		$102	$94	$71	$43	$130	$93	
DEC		$197	$150	$244	$191	$191	$299	$237
TOTAL	$771	$1,587	$1,807	$1,783	$1,531	$1,845	$1,723	$237
30-Day Average	$386	$132	$151	$149	$128	$154	$144	$237

Electricity Usage in kWh								
	2011	2010	2009	2008	2007	2006	2005	2004
JAN	1,322	848	1,342	1,236	1,047	1,300	1,229	633
FEB	1,306	1,090	1,185	1,335	1,380	1,085	1,363	1,119
MAR	1,008	900	1,073	1,028	1,343	1,048	1,039	817
APR	800	823	749	926	842	1,026	904	799
MAY	652	801	997	807	808	769	732	720
JUN	1,026	1,043	734	971	911	1,014	671	873
JUL		2,025	1,244	546	1,397	1,794	1,705	972
AUG		2,310	864	1,394	666	648	2,610	809
SEP		1,238	1,391	907	535	778	1,583	1,275
OCT		791	855	698	1,141	855	1,258	995
NOV		879	952	774	737	1,002	752	863
DEC		1,136	1,152	1,224	1,026	1,096	1,083	1,134
TOTAL	6,114	13,884	12,538	11,846	11,833	12,415	14,929	11,009
30-Day Average	1,019	1,157	1,045	987	986	1,035	1,244	917

Amount Billed								
	2011	2010	2009	2008	2007	2006	2005	2004
JAN	$167	$114	$169	$146	$121	$132	$122	$61
FEB	$155	$135	$149	$159	$163	$119	$135	$109
MAR	$140	$120	$136	$122	$158	$115	$102	$78
APR	$112	$111	$95	$109	$97	$119	$87	$77
MAY		$108	$126	$88	$93	$87	$70	$68
JUN		$141	$93	$114	$104	$117	$63	$84
JUL		$273	$158	$62	$163	$215	$171	$94
AUG		$298	$109	$171	$74	$73	$267	$78
SEP		$160	$186	$109	$59	$88	$159	$125
OCT		$104	$116	$82	$131	$96	$124	$98
NOV		$121	$128	$92	$83	$114	$72	$83
DEC		$156	$154	$149	$120	$125	$107	$112
TOTAL	$573	$1,840	$1,619	$1,404	$1,367	$1,400	$1,477	$1,067
30-Day Average	$143	$153	$135	$117	$114	$117	$123	$89

Appendix F – Sample Calculations

Electrical Design Analysis
Adding voltage sources in Series
$$V_{Total} = V_1 + V_2 + ... + V_n$$
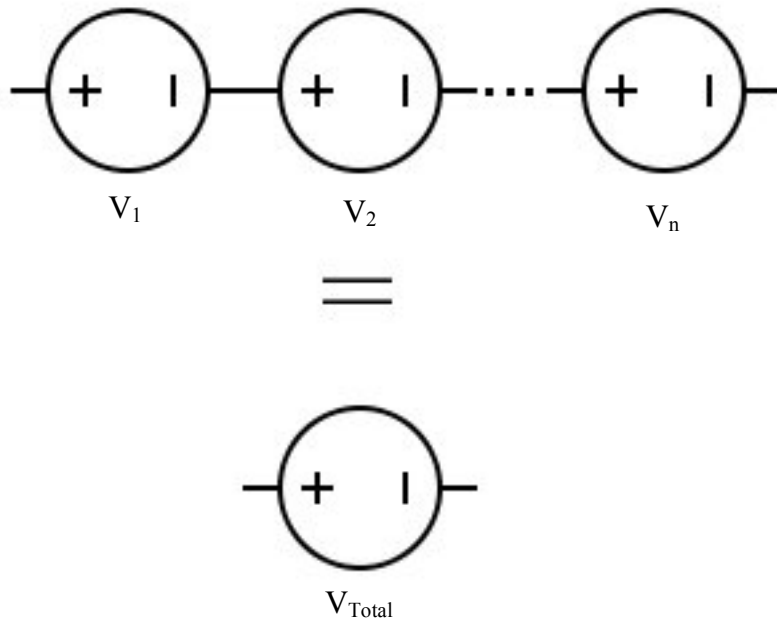
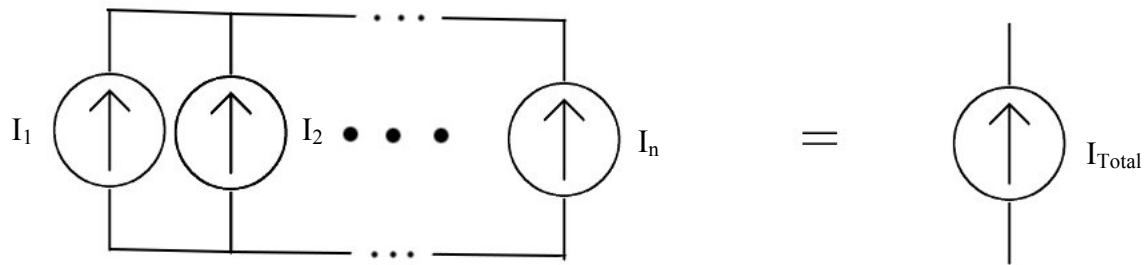
Given a system with 3 voltage sources
$V_1 = 10V$
$V_2 = 4V$
$V_3 = 20V$

V_{total} would be:
$$V_{total} = 10V + 4V + 20V = \boxed{34V}$$

Adding current sources in Parallel
$$I_{Total} = I_1 + I_2 + ... + I_n$$

Given a system with 3 current sources
$I_1 = 4A$
$I_2 = 15A$
$I_3 = 2A$

I_{Total} would be:
$$I_{Total} = 4A + 15A + 2A = \boxed{21A}$$

With these two basic concepts the preceding can be used to find V_{mp}, V_{oc}, I_{mp}, I_{sc} totals.

Given an example solar panel with the following specifications:
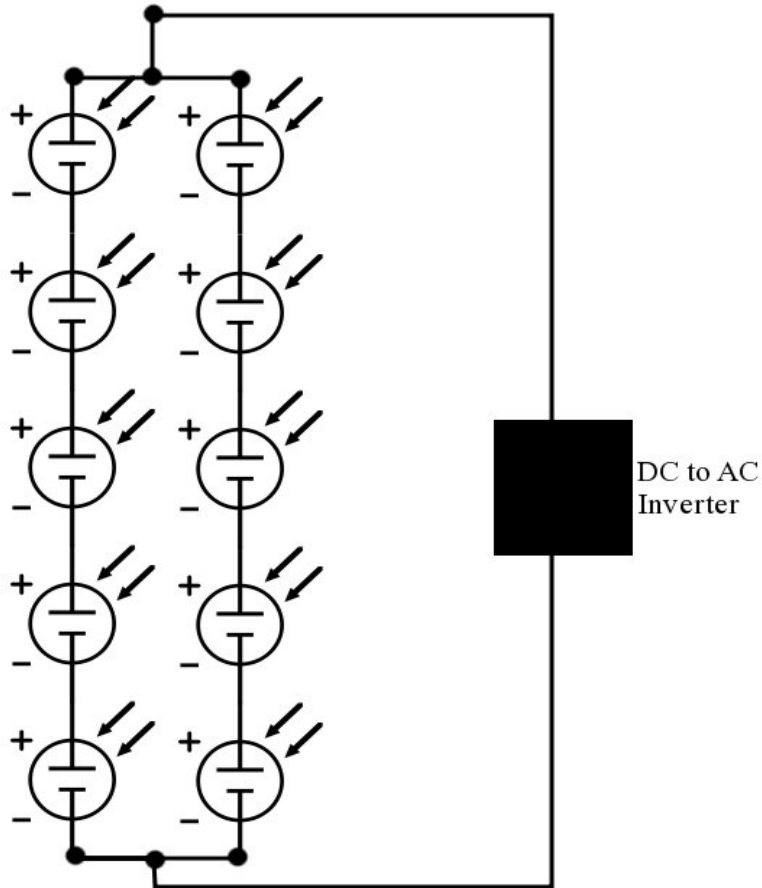V_{mp} = 17.40 V
V_{oc} = 21.50 V
I_{mp} = 10.92 A
I_{sc} = 11.95 A
N = amount of panels in series
M = amount of parallel branches

Wiring them up as the following, totals would be equated as follows:

The result:

$$Total\_V_{mp} = N * V_{mp} = 5 * 17.40 = \boxed{87V}$$

$$Total\_V_{oc} = N * V_{oc} = 5 * 21.50 = \boxed{107.5V}$$

$$Total\_I_{mp} = M * I_{mp} = 2 * 10.92 = \boxed{21.84A}$$

$$Total\_I_{sc} = M * I_{sc} = 2 * 11.95 = \boxed{23.9A}$$

Max power P_{mp} could be calculated from the specifications of a solar panel as follows:

$$P_{mp} = Total\_I_{mp} * Total\_V_{mp} = 21.84 * 87 = \boxed{1900.08W}$$

Heat Transfer Calculations

$$Convection = \dot{Q} = h * A * \Delta T$$

Where: $\dot{Q}$ = Rate of Heat Transfer (Btu/hr)

h = Convective heat transfer coefficient (Btu/hr-ft^2-°F)

A = Surface area for heat transfer (ft^2)

ΔT = Temperature difference (°F)

.35(Btu/hr-ft^2-°F) * 739.8(ft^2)* 10(°F) = 2,589.3(Btu/hr)

$$Conduction = \dot{Q} = k * A * \frac{\Delta T}{\Delta x}$$

Where: $\dot{Q}$ = Rate of Heat Transfer (Btu/hr)

k = Thermal conductivity of slab (Btu/ft-hr-°F)

A = Surface area for heat transfer (ft^2)

ΔT = Temperature difference (°F)

Δx = Thickness of slab (ft)

.55(Btu/ft-hr-°F) * 739.8(ft^2)* 10°F * .125/12(ft)= 42.38 (Btu/hr)

Resistivity Value (R-Value) = 1/Thermal Conductivity

Payback Period Calculations

Payback Period (Years) = Cost of Improvement/Annual Savings

CFL bulbs: $5.50/$3.50 per year = 1.57 Years

Truss & Temperature Calculations

Given 20 inches of snowfall at an average density of 18.7 lb$_f$/ft^3 and panel 65 in by 37.5 in, then including the weight of the panels being 41 lbs, the total weight of one panel would be:

(65in/12)*(37.5in/12)*18.7lb$_f$/ft^3*(5/3)ft + 41lb$_f$ = 569 lb$_f$/panel (65inx37.5in)

If the panel is oriented height-wise, then the frame would land every 65 inches up the roof. So each leg would have a total of 65 inches by 24 inches across due to the spacing of the trusses. That would cut the amount down on each leg to be:

569 lb$_f$/panel (65inx37.5in) * 65in*20in (leg spacing) = 364 lb$_f$/leg

For the shortest section of truss, 88 in, there would be at least one leg and for the longer sections two legs.

728 lb_f/truss acting downward

While acting on the truss, a 2x4 piece of wood the cross section being 1.5 in x 3.5 in. Since the force is perpendicular to the truss, then the angle of incline need be considered, and the pressure would be:

$\cos(18.43)*728$ lbf/(1.5in*3.5in) = 132 psi on each 2x4 truss (douglas fir perpendicular working shear is 2021 psi)

This is worst case scenario assuming that the legs would both hit in the same place in the center of the truss, which is infeasible since the legs are spaced 65 inches apart. Also the 4x12 pitch angle is used since the lesser the angle the greater amount of force would be perpendicular to the truss. For safety sake, this assumption is made to ensure that the integrity of the roof is upheld.

The shear modulus of Douglas Fir pine is 1145800 psi. For the force acting upon the truss at 132 psi:

1145800psi = 132psi*length from reference/displacement
For maximum deflection, the length from reference will need to be greatest. 124 inches is the longest truss, which will be used.

Displacement = (132psi/1145800psi)*124in = 0.0143 inches of deflection

Solving forces acting upon a beam, using two legs at 22 inches up and 87 inches up on a 108 inch truss. Continuing the 20 inch snowfall assumption:

$F_1 + F_2 = F_{s1} + F_{s2}$
$F_1 = F_2 = 364$ lb_f/leg
$F_1L_1 + F_2L_2 = F_{s2}L$

$\cos(18.43)*364lb_f*22in + \cos(18.43)*364lb_f*87in = F_{s2}108in$
$F_{s2} = 349$ lb_f

$\cos(18.43)*364lb_f*2 = 349lb_f + F_{s1}$
$F_{s1} = 342$ lb_f

Solving for the temperature of a solar panel while being irradiated:
where:
$h = 0.0296 \, (\rho V/\mu)^{0.8} Pr^{\frac{1}{3}} k/L^{0.2}$

Values for air:
$\rho = 1.203$ kg/m^3 at 20° C

μ = 0.00001983 kg/m s at 27° C
k = 0.0257 W/mK
Pr = 0.713

In this case, data from July is being used to calculate the average peak temperature of a panel.
July average wind speed = 3.80 m/s
July average irradiation = 254 W/m^2

h = 0.0296 $(1.203[kg/m^3]*3.80[m/s]/0.00001983[kg/m$ s])$^{0.8}$0.713^{⅓}0.0257[W/mK]/0.8[m]$^{0.2}$
h = 13.9 W/mK

ρP/A [irradiation] = hA(T-T$_c$) [convection]
0.875*254 [W/m^2]* 3.125[m^2] = 13.9 [W/mK]* 3.125[m^2]* ΔT

ΔT = 16° C
Average high temperature in July is 28.6° C so the solar panel would be 44.6° C at the peak of the day.

Appendix G – Site Plan

LOT 26

North

N60°24'00"W 154.25'

5' PVT. ESMT. FOR OAKLAND KNOLLS (CO.) DRAIN

PR. SWALE @ MIN. 1% SL.

NEW PR. 975.50

6' PVT. ESMT. FOR SURF. DRN.

NEW PR. FIN.GR. 976.50

NEW PR. FIN.GR. 976.50

NEW PR. FIN.GR. 979.50

PR. SLOPE 4%
PR.DR. 978.95

PR. HOUSE PLAN: 4 PR.FIN.G AS SHO
PR.FIN.FL. 981.48

3 C GAR PR.GA 979.8

PR. SLOPE 4%

NEW PR. FIN.GR. 979.50

NEW PR. FIN.GR. 979.50

PR.DR. 978.95
PR.DR. 979.27

PR. 3' CONC.

PR. 16' CONC. DRIVE

PR. SLOPE 3.9%

PORCH 28'0"

PR. 1" TYPE "K" COPPER WATER SER.

PR. 6" SCH. 40 P.V.C. SAN. LEAD @ MIN. 1% SLOPE

C.O.

10' PVT. ESMT. FOR PUBLIC UTL. & WATER SUPPLY SYS.

10' PVT. ESMT. UTL. & WATER S

TRANS PAD

UTL. FED

UTL. MRK

NEW PR 978.00
PR. 976.50

NEW PR. 977.20

C-1

G.V.W.

N25°57'10"E 151.87'
PR. SWALE @ MIN. 1% SL.

N45°59'56"E 169.89'
PR. SWALE @ MIN. 1% SL.

6' PVT. ESMT. FOR SURF. DRN.

Appendix H – Fujitsu Specifications

Multi Zone Specification

FUJITSU

ASU9RMLQ
Multizone Wall Mount

THE POSSIBILITIES ARE INFINITE

Job Name:_____ Approval:_____
Location: _____ Date:_____
Engineer:_____ Construction: _____
Submitted to: _____ Unit #:_____
Submitted by:_____ Drawing #:_____
Reference:_____

Power	V/Hz/P	230/60/1
Fan type		Cross Flow
No. Motors	(W)	42-1
CFM	(Hi,Me,Lo,Qu)	312/271/224/194
Sound Pressure Level	db (Hi,Me,Lo,Qu)	37/33/27/24
F.L. A.	(A)	.2
Refrigerant		410A
O.D. Discharge	in (mm)	1/4"(6.35)
O.D. Suction	in (mm)	3/8"(9.52)
Dimensions		H x W x D
Uncrated	(in)	11-5/32 x 31-3/32 x 9-1/16
	(mm)	(283x790x230)
Crated	(in)	12-7/16 x 32-7/8 x 14-3/16
	(mm)	(316x835x360)
Weight		
Net	lbs. (kg)	20(9.5)
Gross Shipping	lbs. (kg)	26 (12)

Cooling Capacity	(BTU/h)		9,500 (5,100-11,300)
Moisture Removal	pt/h (l/h)		1.7 (.8)
Heating Capacity	(BTU/h)		11,000 (5,100-13,000)
Temperature Setting Range			
Cooling	°F(°C)		64~90 (18~32)
Heating	°F(°C)		60~80 (16~31)
Drain Pipe Size	OD in (mm)		Ø5/8 (16)
	ID in (mm)		Ø9/16 (14)
Remote Controll Type			Wireless (Wired Optional)
Electriacl Connection*	AWG		14/3 with ground

*Power and communication are fed from the outdoor unit.

Unit : in. (mm)

31-3/32 (790)

9-1/16 (230)

11-5/32 (283)

Front view

Side view
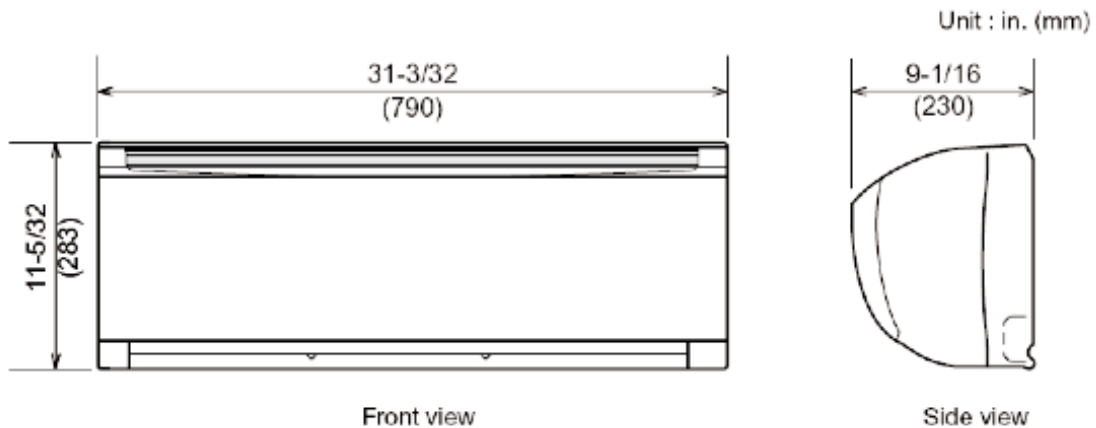
Fujitsu General America, Inc.
Fairfield, NJ 07004
Toll Free: 1-888-888-3424
Fax: (973) 836-0447
www.fujitsugeneral.com

Note:
Specifications are based on the following conditions.
Power source of specifications : 230V
Cooling: Indoor temperature of 80°F(26.67°C)DB / 67°F(19.44°C)WB, and outdoor temperature of 95°F(35°C)DB/75°F(23.89°C)WB.
Heating: Indoor temperature of 70°F(21.11°C)DB / 60°F(15.56°C)WB, and outdoor temperature of 47°F(8.33°C)DB/43°F(6.11°C)WB.
Pipe length : 24ft. 7in.(7.5m),Height difference : 0 ft.(0m) [Outdoor unit - Indoor unit]
Fujitsu products are subject to continuous improvements. Fujitsu reserves the right to modify product design, specifications and information in this data sheet without notice and without incuring any obligations.

Appendix I – ABET Objectives/Requirements

a. An ability to apply knowledge of mathematics, science, and engineering.
   - Conservation of Energy analysis and load calculations on an occupant envelope (Energy Assessment and Analysis Procedure)
   - Calculation of thermal characteristics based on electric and gas usage data (Analyze Usage Data/Energy Assessment and Analysis Procedure)
   - Based on energy needs, economic analysis (capital cost, payback schedule, cashflow calculations) for conservation technology and energy generation needs (solar panels) (Effects of Improvements/Energy Assessment and Analysis Procedure)
   - Optimal wiring calculations for current/voltage from solar panel array to dc/ac inverters (Wiring Calculations)

b. An ability to design and conduct experiments, as well as to analyze and interpret data.
   - Calculation of thermal characteristics based on electric and gas usage data (Analyze Usage Data/Energy Assessment and Analysis Procedure)
   - Calculating infiltration rate, and heat loss through windows, walls, attic and basement from just monthly energy usage data (Analyze Usage Data/Energy Assessment and Analysis Procedure)
   - System will be designed to meet specific requirements laid out by DTE Energy along with local, state and federal codes and laws (Installation Outline and Regulations)

c. An ability to design a system, component, or process to meet desired needs within a realistic constraints such as economic, environmental, social, political, ethical, health, safety, manufactured ability, sustainability.
   - The goal is to design a system including a photovoltaic array, wiring, inverters and interconnects to match the energy needs of an occupant envelope after conservation improvements are made based on an economic and thermal analysis (Electrical Analysis, Design Analysis)
   - Solar arrays are one of the major sources of alternative energy, and with many people "going green" this technology and its implementation has many important environmental and political applications. (introduction and throughout)

d. An ability to function on multi-disciplinary teams.
   - Teammates are from ME, ECE and Engineering Chemistry, and the project will have economic as well as engineering aspects. (Title page and throughout)

e. An ability to identify, formulate, and solve engineering problems.
    - Same as a).

f. An understanding of professional and ethical responsibilities.
    - Designing and installing the system as per code and application requirements. (reference to NEC and bibliography referencing different things) (Installation Outline and Regulations)

g. An ability to communicate effectively.
    - A detailed written technical report on the entire project will be presented as well as an oral presentation. (Written report was furnished. Ryan is presenting December 1st for honors college requirements)

h. The broad education necessary to understand the impact of engineering solutions in a global economical, environmental, and societal context.
    - Globally, alternative energy is a growing field and solar power could help resolve some of the energy issues in different parts of the world due to its simplicity (no moving parts) and distributed nature adding to national energy security, as well as lowering dependence on fossil fuels. (Introduction and throughout)

i. A recognition of the need for, and an ability to engage in life-long learning.
    - A broad perspective of the usefulness of solar power in the larger global context. (Introduction and throughout)

j. A knowledge of contemporary issues.
    - Same as h).

k. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
    - The project will require a great number of skills and tools, such as analyzing usage data and backing thermal characteristics from it, developing a strategy for optimal energy usage for that particular occupant envelope, and designing the system for best cost savings within building code constraints. (Appendices)

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