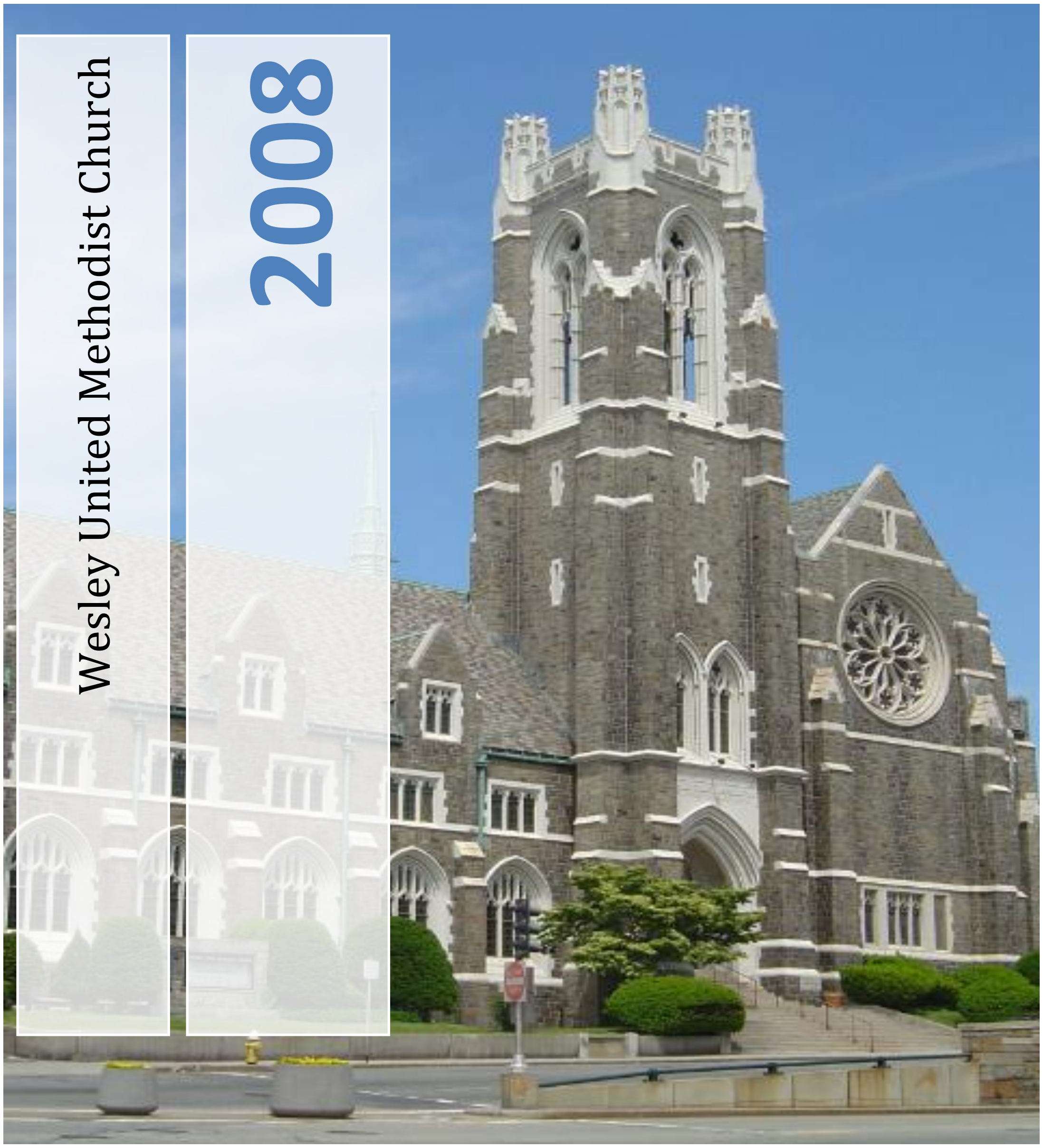
# Solar Panel Feasibility Study

## Wesley United Methodist Church

## 2008



**March 5, 2009**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# Solar Panel Feasibility Study
# At Wesley United Methodist Church, Worcester

*An Interactive Qualifying Project Report*
*submitted to the Faculty of*
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by

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## Abstract

This project evaluated the feasibility of installing a photovoltaic system on the roof of the Wesley United Methodist Church in Worcester, MA. Analysis of the site, weather data, and economic incentives available to church facilitated the creation of a model that could predict the value of a photovoltaic system as an economic investment. This analysis resulted in a long payback period, but projections using this model indicate significant changes as the price of photovoltaic panels continue to fall.

## Executive Summary

The Wesley United Methodist Church, located in Worcester, Massachusetts, was interested in the feasibility of installing a photovoltaic panel system on its roof. The church incurs a costly electric bill, which, coupled with a gas heating bill, imposes a significant financial burden. Concerned that the costs of electricity would only rise in the future, the church's business administrator began looking into alternative energy options. The church has a prominent, south-facing roof space, and its leadership was particularly interested in determining if a solar power system could be installed to utilize this space.

The overall goal of this project was to create an economic model that could predict the feasibility of installing a photovoltaic system on the roof of the Wesley United Methodist Church. Creating a model tailored to the church was important because of the church's status as a non-taxable institution. This meant that traditional models for estimating the feasibility of such a system, which included numerous tax benefits and deductions, would not be applicable.

The secondary goal of this project was to assess the social implications of installing a photovoltaic system on the church. We wanted to determine how much the church's congregation knew about solar panels, as well as how they felt about installing such a system on their church. If installed, the panels may be visible from the ground, which could have a negative aesthetic impact for some congregation members. Besides this, we also wanted to determine how non-economic factors, such as green stewardship and carbon footprint, would affect the overall feasibility of a solar panel installation.

The task of determining the overall feasibility of installing a photovoltaic system was divided into five sections. The first section, site analysis, was concerned with obtaining the physical layout of the roof space suitable for panel placement, as well as determining relevant meteorological data that was needed for energy calculations. The goal of this section was to create an accurate map of where panels could be placed on the roof, as well as how much energy could be gathered given Worcester's

climate. The second section, possible solar panels and placements, dealt with determining the criteria and system that would be used to select the best panel equipment for the church. The third section investigated what effect different orientations and configurations of the panels would have on the amount of energy that could be produced. The goal of this section was to determine the best tilt angle for the solar panels as well as the most effective inter-panel spacing. Economic feasibility of the systems, the fourth section, investigated what economic factors and assumptions should be used in order to create an accurate economic model of the solar panel system as an investment vehicle. In the final section, social implications, our objective was to determine what social factors might come into play that could help or hinder the support for the installation of a photovoltaic system.

From our analysis of Worcester weather data and the roof of the church, we determined that the maximum installation size possible on the roof of the church was approximately 25kW. From the 420 $m^2$ of flat space on the roof, we found that 200 $m^2$ was suitable for installing solar panels. This was because shadows from surrounding portions of the roof would make placing panels in these areas impractical. Determining shadowed areas was done by taking measurements early and late in the day, when shadows were most prevalent.

Our solar panel selection process suggested that the most suitable panel for an installation on the church would be the Kyocera KC200GT. This panel had an efficiency rating of 15% and an overall cost per watt of $4.35, making it the most cost effective panel of those investigated. The power inverter chosen, which was needed to convert the DC electricity from the panels into AC electricity that the church could use, was the Sunny Boy SB7000US. This inverter was chosen because of its 95% efficiency coupled with its ability to be scaled to different system sizes. Using this inverter, we estimated a total DC to AC conversion factor of 79.49%. This factor was a result of the inverter efficiency as well as the efficiency of the AC and DC wiring and connections to the system. Combining the efficiency of the solar panels and the efficiency of the DC to AC conversion, we calculated an overall system efficiency of 11.92%.

Tilting the solar panels at an angle of 42 degrees allowed them to capture the most sunlight. The yearly average of daily irradiation per square meter at this angle was 4.69 kWh/m$^2$/day. With an overall system efficiency of 11.92%, this led to an average monthly electrical generation of 2838 kWh for a 25kW system. Given that the church consumes an average of 9500 kWh, a system of maximum size would cover only 30% of the church's electricity needs.

Through a combination of the equipment chosen, estimates on installation costs gathered from installers, and state averages for similar installations, we found that installing a photovoltaic system on the church would cost approximately $8.00 per watt. Using the maximum size of 25kW would produce a raw system cost of $200,000. However, a number of different system sizes were evaluated, ranging from 10kW to 25kW.

Given an overall price of a photovoltaic system, it was important to determine if this price would translate into an effective investment. The important factors in calculating the investment potential of such a system included: the savings in electricity costs, other income such as renewable energy credits, the rebates and incentives available, how the investment will be financed, and expected trends in inflation and energy costs. The electricity savings produced by a photovoltaic system are directly proportional to the system's size because of the church's contract with the electric utility. Renewable energy credits could generate additional revenues of $0.03 per kWh, but from correspondences with the Mass Energy Consumers Alliance we found that these contracts may not be available in the future.

Because the church is a non-taxable institution, the only significant incentive for installing a solar panel system is the rebate offered by Commonwealth Solar. For installations under 25kW, the rebate offers a price reduction of $3.25 per watt. In order for to receive the rebate, however, the installation must be done by an approved solar panel installation company.

Because the church does not want to incur any debt in order to finance an installation, instead preferring to use money from gifts or a trust fund, we performed our calculations with a 100% down payment.  By analyzing the historical values of the Consumer Price Index we felt that an inflation rate of 3.29% was a good long term estimation, especially considering the estimated 25 year lifespan of a photovoltaic system. The Energy Information Administration predicts that the cost of energy will increase at a rate of 0.6% over inflation.

Evaluating various sized installations using the information above yielded similar economic results across system sizes. Without the additional income provided by renewable energy credits, the investment turns positive after 22 years. With renewable energy credit income, this figure drops to 19 years.

The investment potential of a photovoltaic system was found to be largely tied to the overall cost per watt figure cited by installers. If this figure were to drop, the nature of the investment could change significantly. For example, if the overall price per watt were to drop to $6.50, even without renewable energy credit income, the investment would become economical in 15 years. The cost of electricity and how fast this cost is expected to rise also impacts the investment. For each additional 0.6% of estimated increase in electricity, one year is deducted from the investment breakeven point.

Our recommendation to the church was to delay the purchase of a photovoltaic system. Although the investment would become economical after a period of time shorter than the lifespan of the system, its economic benefit would not be substantial. In addition to this, the costs of photovoltaic panels are expected to drop significantly in the near future, causing an investment taken in a few years to be substantially more beneficial.

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# 1. Introduction

The need for energy from renewable sources has become a pressing issue in recent years. Many individuals and organizations have become concerned about the future energy needs of our society and have begun searching for ways to meet these needs. With the finite and rapidly depleting reserves of oil, coal, and natural gas, it has become a chief issue to discover sources of renewable energy and implement systems that harness them. An energy infrastructure based on renewable sources would be better able to sustain the needs of a society with continually increasing energy demands due to its growth in size and its increased standard of living. The adoption of such systems would also have a positive impact on our environment. Renewable forms of energy, such as solar, wind, or geothermal power produce virtually no pollution. The implementation of renewable energy systems may even be a wise investment; energy produced by such systems would no longer have to be purchased, and over a period of time, these savings in energy costs may exceed the price of the system.

The Wesley United Methodist Church, located in Worcester, Massachusetts, is interested in the feasibility of implementing such a system. The church incurs a costly electric bill, which, coupled with a gas heating bill, imposes a significant financial burden. Concerned that the costs of electricity would only rise in the future, the church's business administrator began looking into alternative energy options. The church has a prominent, south-facing roof space, and its leadership is particularly interested in determining if a solar power system could be installed to utilize this space.

The goal of this project was to determine the economic feasibility of installing a solar power system on the roof of the Wesley United Methodist Church. New incentives and agencies, such as Commonwealth Solar, are making it more affordable to install renewable energy systems. Also, as the demand grows for renewable energy, more cost effective technologies and production processes are being developed to meet the growing demand. It is the infancy and volatility of this market that warrants an up to date investigation of the current options and their costs.

The feasibility of installing a solar array on the Wesley United Methodist Church was determined by gathering pertinent weather data, conducting a site analysis, investigating possible solar panels and mounting solutions, and finally, creating an economic model. These attributes combined to form a final solution through which we determined the investment potential as well as the social and environmental impacts of implementing such a system.  Our results indicated that both a system of small size and a larger size would both have a payback period of roughly 19 years.

## 2. Background

Humans have always been fascinated with the power of the sun. Egyptian pharaohs claimed to be direct descendents of Re, the sun god, and creator of light and all other things. Greek mythology tells the story of Icarus, who flew too close to the sun while using wax wings and plunged to his death. For years, cultures worshipped the sun for the power it gave to life. Many cultures still respect the sun for its central role in sustaining life on earth.

Since the 1800s, scientists have made progress towards harnessing the sun's power in the form of electrical energy. Throughout the last two centuries, significant progress has been made in developing the solar technologies we have today. Many photovoltaic installations are connected to the power grid, and thus each installation is accompanied by many regulations. This chapter provides a broad overview of how photovoltaic panels work, the economics involved in determining the feasibility of a photovoltaic system, and a summary of similar case studies.

### 2.1 History of the Church

The vision of building Wesley United Methodist Church began in two smaller congregations in 1923. After months of planning, the members of Grace Church (formerly on Walnut Street) and Trinity Church (on Main and Chandler Streets) came together with their pastors (Dr. James Wagner and Dr. Berton Jennings) to join their two churches and establish one Methodist Church in the city of Worcester. The present location was chosen as the future site of this joint effort. It was decided that a new name would be chosen for this new church. Wesley United Methodist Church is named after the founder of Methodism, John Wesley. In addition to a new name, both pastors felt a new minister should be appointed to pastor this newly joined congregation.

According to the official histories of Wesley United Methodist Church, the first construction loan of $350,000 was made possible by the trustees who put themselves and their families on the line, signing the bank notes personally. The women of the church had taken on the responsibility of paying for the marble altar in the sanctuary. This was done by donations of gold and silver jewelry as well as other items which were sold to make this gift possible.  A construction firm from Boston was hired and on May 8, 1927 the first Sunday worship was held in the present building. The first Easter services included 2552 people in two services!

The church's foundational statement is etched in stone over the entrance on 114 Main Street. It reads, "To the glory of God and the service of man." Wesley Church continues to exist as a place where all may come to worship God and be nourished by God's love.

## 2.2 Solar Technology

Solar technology has evolved drastically since humans first became interested in the sun.  In the 1800s the photoelectric effect was discovered, and since then, scientific progress has been made towards harnessing the sun's power.   Today, there are many types of solar technology, including crystalline silicon (the traditional method) and newer alternatives such as string ribbon and thin film technologies.

### 2.2.1 The History of Solar Power

The word "photovoltaic" comes from the Greek word "photo" meaning light and after Count Volta, the Italian physicist (1745-1827) whom the electrical unit Volt is named after.  Photovoltaic technology began in 1839 with the French physicist Alexandre Becqueral's discovery of the photo effect. In 1877 the first photovoltaic cell was constructed from Selenium.  The photovoltaic effect was further explained by Albert Einstein and Robert Millikan in the early 1900's.  Finally, in the 1950's, Shockley provided a model for the p-n junction, which enabled the beginning of modern photovoltaic technology development.[1]

In 1954 Bell Labs produced the first modern photovoltaic cell with an efficiency of only four percent.[2] Early solar panels carried high price tags, usually costing a couple of thousand dollars per Watt. Energy generated at this cost was only feasible for space projects. Research in this arena progressively drove the costs lower and the efficiencies higher. In the last half century, photovoltaic technology has continued to improve, as has the economics of photovoltaic power generation.

### 2.2.2 How Solar Power Works

Solar cells, also called photovoltaic cells, are used to convert the electromagnetic radiation from the sun into electricity that can be used to power today's electronic gadgets, as well as residential and commercial dwellings. The simplest photovoltaic cells are comprised primarily of three materials, silicon, and two doping agents.[3] Silicon, which comprises a majority of the photovoltaic cell, has several chemical properties that make it well suited for the use in solar cells. It is the second most abundant element on Earth and has four valence electrons.[4] Valence electrons, in layman's terms, can be thought of as "free" electrons. These "free" electrons are capable of bonding atoms together, as well as doing electro-magnetic work. In pure silicon, atoms bond together via their valence electrons to form a crystalline structure. However, because these valence electrons are tied up bonding atoms together, they cannot be used to produce electricity. This is the primary reason two doping agents are applied to the silicon material. Silicon, on its own, cannot produce electricity. Instead, atoms with greater than or

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[1] Quaschning, Volkerr. *Understanding Renewable Energy Sources.* London : Earthscan, 2005.
[2] Lund, H., Nilson, R., Solamatova, D. & Skare, E. *The History Highlight of Solar Cells.* Retrieved October, 2008, from http://org.ntnu.no/solarcells/pages/history.php
[3] Aldous, S. *How Solar Cells Work.* Retrieved October, 2008, from http://www.howstuffworks.com/solar-cell.htm
[4] Radiochemistry Society. *Periodic Table of Elements: Silicon.* Retrieved October, 2008, from http://www.radiochemistry.org/periodictable/elements/14.html

less than four valence electrons are added to the silicon structure to produce an impurity. Adding this impurity to the silicon structure is what allows the flow of electricity.[5]

If a Phosphorous doping agent, which has five valence electrons, is added to a group of silicon atoms, it produces a crystalline structure with a "free" valence electron. This "free" valence electron can be used to generate electricity. This type of material is given the name "n-type material". The only thing needed is a place for this "free" electron to flow. No electrical work can be done if there is no potential between two points. The solution to this problem lies within our second doping agent.

The second doping agent, unlike the first, has fewer than four valence electrons. As a result, when a structure of Silicon and Boron, an element with only three valence electrons, is formed, "holes" begin to develop within the material structure. These "holes" are the absence of an electron and are capable of being filled by other electrons within the structure. This material is given the name "p-type" material.

Now we have two parts to this puzzle. One puzzle piece is Silicon doped with a material that produces "free" electrons. The second is Silicon doped with an element that produces "holes" within the structure that is capable of being filled by "free" electrons. A solar panel is comprised of both n-type material and p-type material. Both materials are sandwiched together to produce what is referred to as a "p-n junction".

[5] Cooler Planet. (2008). *How Photovoltaic Cells Work*. Retrieved October, 2008, from http://solar.coolerplanet.com/Content/Photovoltaic.aspx

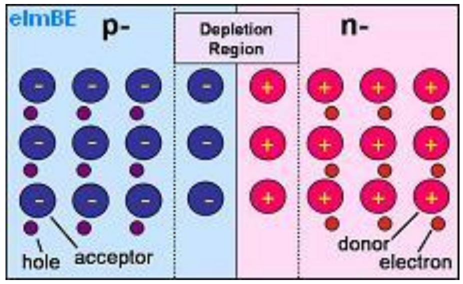


**Figure 1: P-N Junction**[6]

The only remaining piece of the puzzle is the catalyst that starts this transfer of "free" electrons to the "holes" on the other side. This process is called the photovoltaic effect. The photovoltaic effect describes the interaction between a photon, a particle of light, and specific metal materials. When a photon interacts with a metal material it may be reflected or absorbed. If absorbed, the photon transfers its energy to a local atom, which in turn, lends its energy to an orbiting valence electron. This process causes a free electron which is capable of moving to a "hole" creating an electrical current. The more photons that interact with the material, the more valence electrons are freed and allowed to flow to an electron-hole. Once light is absorbed by the two materials, electricity begins to flow through the connected load. The more light that interacts with the solar cell, the more electricity is generated.[7]

[6] REUK. Renewable energy UK. Retrieved October, 2008, from http://www.reuk.co.uk/OtherImages/pnjunction.jpg
[7] Aldous, S. *How solar cells work.* Retrieved October, 2008, from http://www.howstuffworks.com/solar-cell.htm

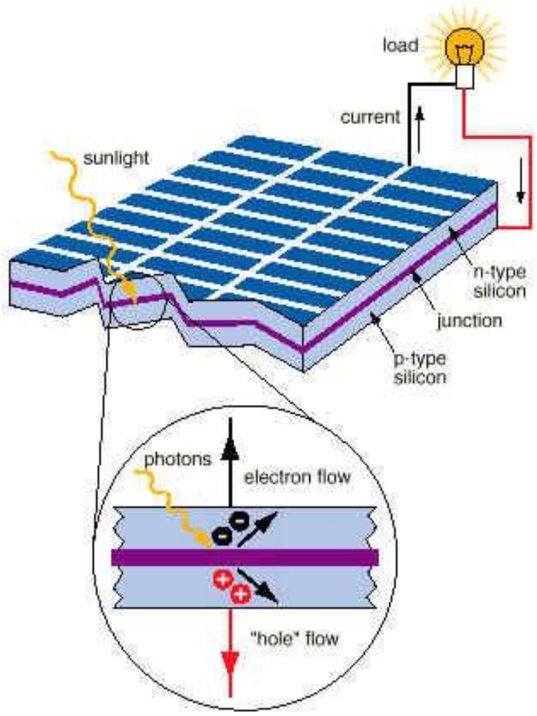


Figure 2: Solar Panel Construction and Implementation[8]

On a bright, sunny day, the sun shines with approximately 1 kilowatt of energy per square meter on the Earth's surface. To gather this energy solar panels are generally coated with a non-reflective surface texture. This texture increases the probability that a photon will be absorbed rather than reflected. A cross section of composition can be seen below.

[8] The Seitch Blog. Retrieved October, 2008, from www.blog.thesietch.org/wp-content/uploads/2007/06/solarcell.jpg

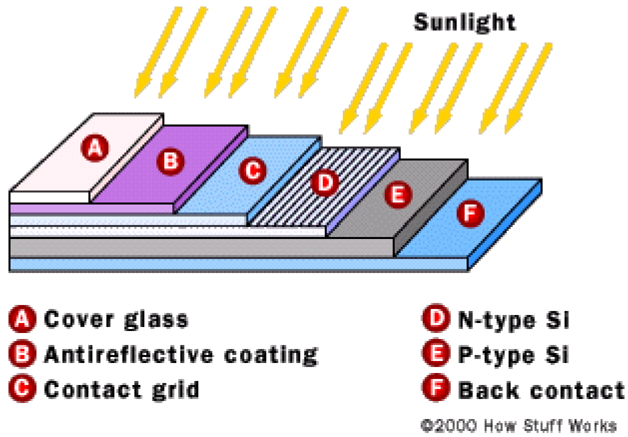


**Figure 3: Solar Cell Composition**

### 2.2.3 Different Types of Photovoltaic Panels

#### *Crystalline Silicon (Traditional Method)*

The largest and most popular solar panel technology on the market today is commonly referred to as crystalline silicon solar cells. Being one of the original solar panel technologies it is not surprising that this type of solar panel currently holds an unprecedented 93% of the market to date. Because of its relatively simple construction and manufacturing process, crystalline solar cells gained large popularity during the infancy of the alternative energy boom.

Today, there are two major types of crystalline silicon used in manufacturing and production: mono-crystalline and poly-crystalline. The first, mono-crystalline, requires absolutely pure semi-conduction material. Melted silicon is first poured in the shape of rods. After a solid has formed, the rods are then sawed into thin small wafers which are up to 150 mm in diameter and 350 microns thick. This type of production results in an approximately 24% lab efficiency, and 15% efficiency in production.[9]

[9] The Solarserver. (2008). *Photovoltaics*. Retrieved October, 2008, from http://www.solarserver.de/wissen/photovoltaik-e.html

Figure 4: Mono-Crystalline Solar Cells

The second type of crystalline silicon chiefly used today is referred to as poly-crystalline. Poly-crystalline production is similar to mono-crystalline in the way that both result in silicon wafers, however, the method by which the final product is created differs. First, liquid silicon is poured into blocks that are then cut into bars, and then finally cut into wafers. Because the silicon hardens in large blocks, many large crystalline structures begin to form, hence “poly-crystalline”. Poly-crystalline cells are more cost effective to produce due to the fact that many cells can be created from a single block, but because every time silicon is cut, the edges become deformed, which results in a lower operating efficiency. The efficiency for a poly-crystalline cell in the laboratory is approximately 18% and in production reaches only 14%.[10]

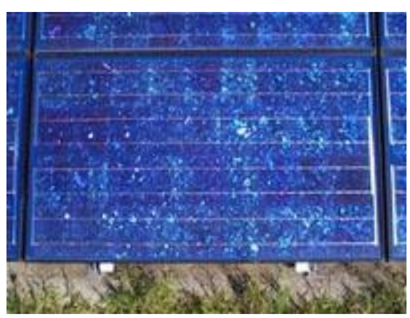

Figure 5: Poly-Crystalline Solar Cells

[10] The Solarserver. (2008). *Photovoltaics*. Retrieved October, 2008, from http://www.solarserver.de/wissen/photovoltaik-e.html

The benefits of a crystalline solar cell come from the fact that the cells that comprise the overall solar panel are very cheap to produce. Because crystalline cells were one of the first technologies on the scene, much of the production and manufacturing techniques have been refined to their maximum potential. Despite effective production processes, one of the largest problems that plague crystalline silicon cells is the limits of their efficiency. When any crystalline structure is split it undergoes deformation. The technique by which mono-crystalline and poly-crystalline cells are created intensely relies on severing of silicon into smaller pieces. This leaves much of the area deformed which decreases operating efficiency for that cell. This is one of the reasons that String Ribbon technology (which is covered in the next section) is so efficient, because it manufactures silicon in a method that produces no deformities.

### *String Ribbon Panels*

With the ever increasing demand of cheap solar panel production techniques, it has become critical for companies to devise new alternatives for producing silicon. One of the most promising of these techniques is String Ribbon manufacturing. Unlike the generic silicon wafers used in the bulk of solar panel production today, string ribbon provides a healthy alternative which decreases production costs as well as the carbon footprint used to produce a solar cell.  The technique behind String Ribbon silicon is the manipulation of surface tension. Two parallel strings are pulled vertically through a silicon melt. As the strings rise, silicon begins to span the distance between the two strings, much like a bubble spans the ring on which it is blown. As the silicon rises it begins to cool and form a hardened structure between the strings. This process continues uninterrupted until the silicon ribbon is of desired length.[11]

[11] SolarHome.org. (2008). *String-Ribbon*. Retrieved October, 2008, from http://www.solarhome.org/string-ribbon.html

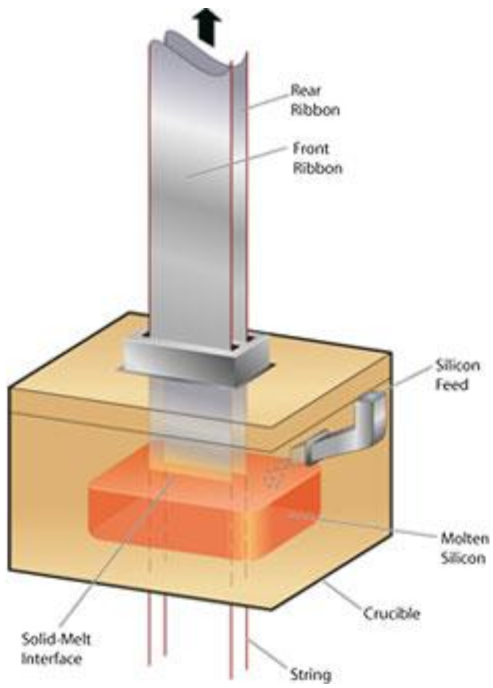


Figure 6: String Ribbon Manufacturing Process[12]

The result of this process is a thin, silicon ribbon, which is twice the yield of the conventional construction per pound of silicon. Due to this fact, String Ribbon panels use significantly less material than crystalline panels. The process of creating String Ribbon panels achieves a much greater reliability and potency than its silicon wafer counterpart and manufacturing it is one of the most environmentally friendly methods in the business.[13]

## *Thin-film Panels*

With advent of micro-manufacturing, many large scale photovoltaic panels are becoming smaller and smaller with each progressive decade. The ability to spread a material over a large scale area that averages 1 to 10 micrometers thick has enabled several manufactures to produce an ultra thin variety of solar panels. This newly emerging technology is aptly named: thin-film technology. Thin-film

[12] Evergreen Solar, Inc. (2008). *String Ribbon*. Retrieved October, 2008, from http://evergreensolar.com/images/techology/stringribbon/diagram_string_ribbon_en.jpg
[13] Evergreen Solar, Inc. (2008). *Our String Ribbon Wafers - Genius in its Simplicity*. Retrieved October, 2008, from http://www.evergreensolar.com/app/en/technology/item/48

technology refers to the act of spreading several consecutive layers of silicon and other material to form a working photovoltaic. Thin-film material is 100 times thinner than traditional solar panels, which range from 100 to 300 micrometers thick, and only contains 1% of the silicon to produce an equivalently sized panel.[14] The greatest advantages of thin-film technology are that it is flexible, light weight, and incredibly thin. Unlike silicon wafers and String Ribbon panels, many thin-film panels are created as an amorphous material. Instead of being manufactured in chunks and assembled into a panel like String Ribbon panels and silicon wafer panels, thin-film panels are created by combining consecutive thin layers of material together. The result is a single film that is capable of being distributed in rolls or sheets. [15]

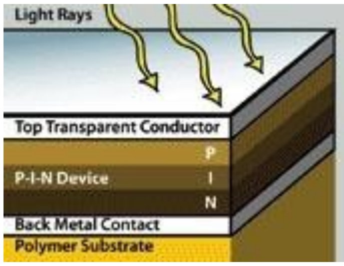


**Figure 7: Thin-film Composition**

Today, many thin-film manufacturers have begun producing what is referred to as monolithic integration. Monolithic integration describes the process of integrating the connection junctions between the silicon substrates, which create paths for the electricity to flow from cell to cell, within the amorphous material. This process is can be referred to as the "All-in-one" technique. Because of the character of thin-film material, manufacturers have been able to integrate these connection junctions with such success that many are capable of tolerating a bullet hole without failing. Some are also capable of performing better than traditional silicon wafer panels under low light or shaded

[14] PowerFilm, Inc. (2008). *Thin Film*. Retrieved October, 2008, from http://www.powerfilmsolar.com/technology/index.html
[15] Quaschning, Volkerr. *Understanding Renewable Energy Sources.* London : Earthscan, 2005.

conditions. Monolithic integration reduces manufacturing costs and increases durability of the overall product.

While thin-film technology receives much praise, it does have several drawbacks. Because of its thin nature, thin-film material generally has a lower efficiency compared to its silicon wafer competitor. In consequence, more area must be dedicated to a thin-film panel to produce the same result as a silicon wafer panel of equal power rating. Another disadvantage of a thin material is that durability begins to suffer over time. Thin film solar panels degrade more quickly than other types of technologies which make them candidates for a more frequent replacement.[16]

## 2.3 Regulations and Installation

There are several rules and regulations in effect that apply to solar array purchasers. Knowing them can not only protect your well being but also save you money. The Massachusetts Technology Collaborative (MTC) provides a wealth of information about the type of funds and rebates available to those interested in installing solar panel arrays on their business or residence. MTC also provides a list of tasks that must be fulfilled before a solar array may be deemed operational and hazard free.

### 2.3.1 How Solar Panels are Installed

The installation of most roof based solar arrays is a relatively simple process. The primary method involves attaching bolts to the roof support beams, through the roof surface and building a simple framework on top of these bolts to allow a gap between the panels and the roof surface. This gap permits the panels to be installed on roof surfaces ranging from rubber membranes, standard asphalt

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[16] U.S. Department of Energy. (2006). *Polycrystalline Thin Film*. Retrieved October, 2008, from http://www1.eere.energy.gov/solar/tf_polycrystalline.html

shingles, tiles, and slate, even if the roof is somewhat uneven. The gap also allows for airflow to keep the panels cool.

The most common way to install panels on a flat roof, like the Wesley Church's, is to purchase separate frames that assemble into some sort of "A" frame. The panels can be mounted vertically or horizontally with approximately four panels per frame. This frame is then either bolted through the roof into the rafters below, or weighted down with sandbags or something similar. These mounting frames can either be situated at a fixed angle or one that can be adjusted to two or three pre-set angles and locked with removable pins. The adjustment process can be done with two people and increases the efficiency of the cells, while only slightly complicating the mounting frames. On the church roof, several lines of these frames could be assembled with enough space in between to prevent shading from the row in front. Based on the sun's effect at various times of the day, different groups would be connected in series and then in parallel to the DC/AC converter. These rows should also be spaced in such a way that the roof is still accessible for regular maintenance.

While it is possible for homeowners to install several systems themselves, such as the Schott Sunroof PV system, it is generally recommended that one work with a professional contractor. Not only are contractors experienced in installation procedures, they are also familiar with the available rebates and other incentives. Most importantly, the contractor will coordinate with a licensed electrician to make the connections to the breaker panel and request an electrical inspection from the town to ensure that all procedures are up to code.

### 2.3.2 Regulations on a Solar Power System

In order to ensure the safety of a solar power system, the system must conform to a number of federal, state, and local regulations. In particular, Commonwealth Solar, an organization that offers rebates to individuals or groups wishing to install a solar panel system, outlines a number of criteria that a solar panel system must meet in order to receive a rebate. These criteria go beyond simple safety measures to include requirements on the life and overall quality of the system.[17]

Many of the safety regulations for solar panel installations regard the electrical safety of the system. A system installed in Massachusetts must be installed by a licensed electrician, and conform to all federal, state, and local electric and building codes. Wiring must be properly insulated and weatherproofed. Devices that can be disconnected from the rest of the electrical system for service and inspection must also be installed. Although it is not required, the MTC recommends that surge protectors are installed to protect the system components from any electrical surges.

## 2.4 Economics

### 2.4.1 Incentives Available to System Buyers

Because of the increasing demand for renewable energies, a number of organizations have been created to foster the growth of systems that utilize renewable sources. Both public and private institutions can benefit from the incentives that such organizations provide. When determining the feasibility of a solar power system, it is important to consider the economic incentives that may apply, because they may account for a considerable portion of the system cost.

Commonwealth Solar is an initiative from the Massachusetts Technology Collaborative (MTC) to provide rebates to residential, commercial, industrial, and public facilities. Commonwealth Solar provides rebates on photovoltaic systems on a non-competitive, first-come, first-serve basis. Starting in 2008, the initiative has $68 million available over the next four years.[18] The amount of reimbursement that an installation may receive depends on the size of the installation (in kW), whether the components

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[17] Commonwealth Solar. (2008). *Solar Photovoltaic Rebates: Program Manual*. Retrieved September, 2008, from http://www.masstech.org/SOLAR/Commonwealth%20Solar%20Program%20Handbook_v2_070108.pdf
[18] Commonwealth Solar. *Overview*. Retrieved September, 2008, from http://www.masstech.org/SOLAR/

of the system were manufactured in Massachusetts, and whether the installation is on a public or private building. The rebates are calculated in dollars per DC watt of energy produced by the system.

The base rebate per Watt, based on system size, is shown below:[19]

| Size of system (kW) | 1 to 25 kW | >25 to 100 kW | >100 to 200 kW | >200 to 500 kW |
|---|---|---|---|---|
| Rebate in dollars per watt | $3.25 | $3.00 | $2.00 | $1.50 |

**Table 1: MTC Rebates**

- An additional $0.25 per watt will be added if the components of the system were manufactured in Massachusetts
- An additional $1.00 per watt will be added if the system is installed on a public building.

In order to receive a grant from Commonwealth Solar, the system that is to be installed must have a projected efficiency of at least 80% compared to a system under optimal conditions. Commonwealth solar derives these optimal efficiencies from the PVWATTS calculations made by the National Renewable Energy Laboratory.

The parameters for optimal installation in Worcester, MA are as follows:

- 77% DC to AC conversion rate
- A 42 degree array tilt
- A due South orientation of the panels

[19] Commonwealth Solar. (2008). *Solar Photovoltaic Rebates: Program Manual*. Retrieved September, 2008, from http://www.masstech.org/SOLAR/Commonwealth%20Solar%20Program%20Handbook_v2_070108.pdf

Applying these parameters to the Worcester area produces a kilowatt per hour price of 11.8 cents with a price of 14.8 cents per kilowatt hour if the system is at 80% for the efficiency of the optimal system. Systems with a projected efficiency less than 80% may still be considered for a rebate, but the amount of the rebate is reduced on a sliding scale with reduced efficiency. Using this scale, systems with efficiencies as low as 65% of optimal may still receive a rebate (70% of the normal rebate with a 65% optimal system). The price per kilowatt hour for a system with 65% of optimal efficiency is 19.7 cents.[20]

In order to be eligible, the installation must be approved by a Massachusetts licensed electrician. The installation must meet all local, state, and federal building and electrical codes. An Interconnection Agreement must also be filed with the utility company to which the system will interface.

The components of the solar system to be installed must have certain minimum warranties in order to qualify, including:

- A five year warranty provided by the installer of the system for defective workmanship.
- A two years product and 20 years performance warranty on the system modules.
- A five year warranty on the system mounting.
- A ten year warranty on the power inverters.

**Other Requirements:**

- The equipment installed must be new.
- The equipment installed must meet the Underwriters Laboratory standard 1703

[20] Commonwealth Solar. (2008). *Solar Photovoltaic Rebates: Program Manual*. Retrieved September, 2008, from http://www.masstech.org/SOLAR/Commonwealth%20Solar%20Program%20Handbook_v2_070108.pdf

- All modules, inverters, and production meters must be on the California Energy Commission's list of eligible renewable energy equipment.
- All photovoltaic projects must have a dedicated production meter
- Systems over 10kw must have a production tracking system (PTS).

A solar-energy system purchased for the principal residence of an individual is fully exempt from Massachusetts sales tax. In addition, solar-energy systems purchased for commercial, industrial, or residential use are exempt from property tax over their first twenty years. A 15% tax credit up to $1000 against personal state income tax is available to any owner or tenant for the purchase and installation of a solar-energy system in their primary residence. The system installed must be new, in compliance with all performance and safety standards, and be expected to last at least five years.

Renewable energy credits (RECs) are based on the environmental attributes associated with the generation of electricity. They do not have to do with the electricity itself, but the means by which the electricity was generated. Renewable Energy credits exist for two primary reasons. For one, the state government sets Renewable Portfolio Standards on utility companies. These require a certain amount of electricity produced by these companies to be from renewable sources. Utilities that do not produce enough electricity from renewable sources may buy RECs from those who produce energy from renewable sources. RECs may also be sold to consumers who want to be sure that the electricity that they are consuming comes from renewable source. RECs may be sold to various state and nationwide organizations. Current prices for these credits range from .5 cents a kilowatt hour to 5.5 cents a kilowatt hour.

Net metering is an electricity agreement between a consumer and their electricity provider which allows the consumer to offset some, or all, of their energy cost by running the electric meter backward via producing a surplus amount of energy. Running the electricity meter backward occurs when a consumer is producing more energy than he or she is currently utilizing.[21] As a result, in any month with a positive net difference, the customer may choose to receive a credit equal to the average monthly market price of generation per kilowatt hour. The utility company cannot impose special fees on net metering customers.[22] The state of Massachusetts currently enforces all investor-owned utilities to offer net metering but does not require municipal utilities to abide by the same standard.

The current standard for net metering was enacted on July 2, 2008, and is applicable to residential, commercial, nonprofit, industrial, school, institutional, agricultural and governmental sectors.[23] Net metering customers are grouped into three classes (I, II and III) which are determined by system size. The most common size class for residential and a small commercial is Class 1. Class 1 describes any system which is less than or equal to 60kW. The second and third class apply to systems which are 1MW and 2MW, respectively. For Class 1 solar installations, credits may be carried forward from month to month indefinitely. These customers may also choose to transfer the credits earned to another customer on the same utility.

### 2.4.2 Factors in Determining Economic Feasibility

The final result of this project will be the determination of whether or not the installation of a solar panel system is economically feasible on Wesley United Methodist Church. Before we proceed with economic analysis of the solar panel system at Wesley United Methodist Church, we must outline what factors determine economic feasibility. The startup costs, operating costs, revenue projections, and financing options will all need to be considered.

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[21] CalFinder. *What is net metering?* Retrieved September, 2008, from http://solar.calfinder.com/blog/solar-information/what-is-net-metering/

[22] DSIRE. *Massachusetts Incentives for Renewable Energy*. Retrieved November, 2008, from http://www.dsireusa.org/documents/Incentives/MA01R.htm

[23] DSIRE. *Massachusetts Incentives for Renewable Energy: Net Metering*. Retrieved November, 2008, from http://www.dsireusa.org/library/includes/incentive2.cfm?Incentive_Code=MA01R&State=MA&CurrentPageID=1

In this solar panel installation, the start up costs will include product cost, installation cost, and the cost of inspection and certification. The product cost will include all of the various hardware components of a solar power system, including the actual solar panels, the frames to mount them on, the inverter to convert the DC power to AC, and the grid tie system which will allow it to connect to the power grid. There will also be the cost of a professional installation, as this is a requirement for the MTC grant. Finally, there is the cost of inspection and certification, which is also required to receive the aforementioned grant. All of these costs will be reduced by the grants and incentives outlined in the previous section to determine the overall startup cost.

After the solar panels are installed and generating electricity, there is an operational cost that goes along with maintaining them. Solar retailers often give information about the maintenance cost of solar panels, which includes any maintenance or repairs or replacement of damaged solar panels. Even smaller costs, such as the cost of shoveling snow off of the solar panels during the winter would fall under this category.

The money generated from the solar panels would ideally offset the costs mentioned above. Money generated from solar panels can be broken into three main categories: energy saved, energy sold-back, and renewable energy credits. The primary category, energy saved, will be the difference in cost between the electric bill with the solar panels installed and what the electric bill would have been without them installed. In the simplest scenario, this would be the number of kWh generated that does not exceed the amount used multiplied by the cost per kWh. The next category, energy sold back to the electric company, would be any amount of electricity generated by the solar system that exceeded energy usage and could be sold back to the electric company. The final way to profit from solar panels is through the sale of renewable energy credits to other corporations. Corporations are regulated by the government to meet a certain quota for the use of renewable energy. Some generate their own renewable energy; however, others buy credits in lieu of generating it themselves. These credits have their own market, and the proceeds from of the sale of credits may be in addition to the money received from the previous two categories.

The final consideration when analyzing the feasibility of such a project is the available financing. Solar panel systems generally require a large capital investment. Much of this cost is typically paid by borrowing from banks or investors. Important considerations when looking for financing are the interest rate, the duration of the loan, the monthly payment, and the required down payment.

## 2.5 Similar Case Studies

There are many factors to consider when analyzing the feasibility of different solar systems for Wesley United Methodist Church. We investigated a number of case studies to evaluate the factors in a feasibility study in the domain of renewable energy.

### 2.5.1 Holy Name Wind Power Feasibility Study

The Holy Name wind power feasibility study investigated the feasibility of installing a wind turbine at Holy Name high school.[24] The main task of the project was broken into various parts. First, site data was gathered, including wind speeds, current energy usage and property characteristics. Using this data, a number of sites were proposed and compared against a set of heuristics to determine the best possible location. Then, based on the size of the installation that would be required to provide an adequate amount of electricity, a list of possible turbines was made. These turbines were then compared against each other to find the best possibility. Also, a mathematical model was created to determine the economic feasibility and break-even points using different financing options. Five, seven, ten, and twenty year loans were simulated and return on investment figures were calculated for each simulation. Grants, net metering, energy certificates, tax incentives, and different loan options were all

[24] Foley, B., Forbes, T., Jensen, H., & Young, A. (2006). *Holy Name High School Wind Turbine Feasibility Study*. WPI Library: http://www.wpi.edu/Pubs/E-project/Available/E-project-121306-104131/

explored. The report concluded that 60 to 70% of the school's electric bill could be saved through the installation of a turbine.

Although this project did not focus on solar panels, there are many aspects of it that are applicable to any renewable energy feasibility study. The process of determining feasibility itself, from site analysis to comparing different technologies to creating an economic model, is similar regardless of which renewable source is considered. Also, many of the incentives for renewable energy are similar for both wind and solar systems.

### 2.5.2 Solar Feasibility Study of a Learning Center at WPI

The Feasibility Study of a Solar Learning Lab at WPI was an incredibly insightful case study due to its similar location to our target and the use of photovoltaic panels.[25] The goal of this Interactive Qualifying Project was to determine the feasibility of acquiring a Solar Learning Lab somewhere on the WPI campus. A Solar Learning Lab would give the students of WPI the ability to study the effects of solar energy without leaving campus. While the objective of this project was not to generate power for the school, the similarities between this project and ours gave us a good idea of the steps we would have to take to determine if the meteorological conditions were acceptable for using photovoltaics.

A Solar Learning Lab is the term used to describe a photovoltaic system integrated with a Heliotronics educational monitoring system. [26] The entire system is used to bring current solar information to a computer display where students are then capable of manipulating the data to generate graphs and plot trend lines. A Solar Learning Lab is designed to provide students with a hands-on understanding of how photovoltaics work without purchasing a large system.

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[25] Wailgum, J., Ledue, J., Chapman, J., & Al-Beik, H. (2003). *Feasibility study of a solar learning lab at WPI.* WPI Library: http://library.wpi.edu/cgi-bin/Pwebrecon.cgi?BBID=251492

[26] Heliotronics. *Heliotronics Data Acquisition Systems*. http://www.heliotronics.com

One of the first tasks that the IQP group undertook was to determine an acceptable location for their solar panels. This meant that each possible location must agree to a set of criteria and is ranked on how well it matched. Several considerations were safety, space and availability, accessibility, security, connectivity, sunlight exposure, and grid tying considerations.

The final location chosen was "Daniels Hall". This building fit each of the criteria and gave the best possible outcome for the project. The decision process of choosing a location was very enlightening and paralleled our own process.

The next step of the group was to establish their projected results. The installation process was reviewed many times to determine what spot on the roof of Daniels Hall provided the easiest installation. Several experts from various contracting companies were brought in to provide their detailed analysis on the location and installation situation. This process established the cost of the Solar Learning Lab as well as the installation and maintenance, which enabled the group to generate a cost analysis of their project.

The last remaining step was to establish an acceptable marketing campaign that would sell WPI on their idea. The group presented their project's financial aspects, academic benefits, and environmental friendly appearance. Each subject was presented in a fair and unbiased manner that depicted the strengths and weaknesses of the project.

### 2.5.3 Janssen Ortho LLC Solar Power Feasibility Study

Janssen Ortho LLC is a subsidiary of Johnson and Johnson based in Puerto Rico and had an IQP team evaluate the feasibility of a solar panel installation[27]. This project discussed the history of Janssen Ortho LLC and the importance of being environmentally friendly to the company (17). Johnson and

[27] Sands, E., Moussa, O., Meagher, G., & Lemaire, J. (2004). *Solar Energy at Janssen Ortho LLC.* WPI Library: http://library.wpi.edu/cgi-bin/Pwebrecon.cgi?BBID=253817

Johnson follow a credo, part of which states that it will be a leader in helping the environment. Janssen Ortho LLC consumes 33 million kWh yearly, certainly too much to be generated entirely from solar power. The project group consulted with Powerlight Corporation, a world leader in solar installations, and eventually recommended a pilot installation. The pilot system would product 101kWp (kilowatts peak), less than 1% of Janssen Ortho's power consumption; however it would demonstrate to the community that they were interested in alternative energy. This group also proposed a possible larger scale solution that would involve the construction of a solar panel mounting structure over the parking lots. Due to the high expense of building on top of the parking lots, the group only recommended pursuing this if they were able to get 70% government aid. The group also created brochures for employees and for the community to spread information regarding the benefits of solar projects.

# 3. Methodology

In order to determine the overall feasibility of installing a photovoltaic system on the roof of the Wesley United Methodist Church, we divided this task into five sections. The first section, site analysis, was concerned with obtaining the physical layout of the roof space suitable for panel placement, as well as determining relevant meteorological data that was needed for energy calculations. The second section, possible solar panels and placements, dealt with determining the criteria and system that would be used to select the best panel style for the church. The third section investigated what the effect of different orientations and configurations of the panels would have on the amount of energy that could be produced. Economic feasibility of the systems, the fourth section, investigated what economic factors and assumptions should be used in order to create an accurate economic model of the solar panel system as an investment vehicle. In the final section, social implications, our objective was to determine what social factors might come into play that could help or hinder the support for the installation of a photovoltaic system.

## 3.1 Site Analysis

Given the relationship between the sunlight available in a region and a solar cell's energy output, site analysis was one of the greatest influences on the feasibility of a photovoltaic project. Given the church's geographical location in Worcester, Massachusetts, several factors were considered. Each factor dealt primarily with the sunlight available or the geographical layout of the designated site. Factors such as location, average sunlight, daily shadows, obtrusive objects, and structural positioning combined to form the project's site analysis. To obtain the data needed to form our site analysis, the project was divided into a number of domains. The first dealt primarily with the meteorological conditions of Worcester. This domain sought to answer the question of how much sunlight is available, as well gather any information that would ease the calculation of how much energy can potentially be produced by an array of solar cells. The second domain dealt with the structural layout of the roof space at the Wesley United Methodist Church. This domain was responsible for determining where solar panels could be placed by taking shadows, obtrusive objects, and structural support into consideration. The third domain consisted of gathering and summarizing the current energy usage of the church. This data could be used to form estimates about how much money could be saved through the energy generated by the installation of a solar panel system. The last domain, concerning the installation of solar panels, dealt with determining what factors would come into play when installing the panels onto the roof, as well as integrating the system into the electrical grid.

### 3.1.1 Meteorological Analysis

Gathering and summarizing meteorological data was a vital aspect for creating the site analysis. Obtaining meteorological data is done with relative ease these days. One of the greatest resources of weather data is provided by GAISMA[28]. It includes information such as monthly atmospheric clearness as well as sunrise and sunset durations. Most importantly, GAISMA offers a monthly insolation calculation. Insolation is a composite measurement that summarizes the amount of solar radiation that an area receives. The insolation value is a numerical value that represents the average kWh/m$^2$/day in a given month. These values are exceptional tools that encapsulate various meteorological events; for example, this calculation encompasses the change in sunlight due to cloudy or partially cloudy days. The result is a value that describes the amount of solar radiation (sunlight) available in a given area per day. This average was used in the calculation of how much energy would be produced by a given solar panel. This allowed for relatively accurate calculations of future energy production which was essential for determining when a return on investment could be realized.

[28] GIASMA [Online] www.giasma.com

### 3.1.2 Layout of Roof Space

To determine the layout of the roof space, we took preliminary measurements of the roof. With these basic dimensions, we were able to calculate a best-case scenario for mounting solar panels. This best-case scenario acted as an upper bound on the size of the system that could be installed. With the preliminary measurements, we were also able to obtain a set of plans for the roof, with detailed dimensions. From this, a simpler and smaller-sized CAD drawing was created using the set of plans and the measurements taken on the roof. However, the primary problem with taking our measurements at only one time of day was that they didn't include all possible shadowed areas. Another problem encountered was that we didn't initially record the locations of any other possible shadows, such as trees or the chimney, which could cast a shadow over several panels at different times of day.

Our research on different panels showed that panels should not be partially shaded. It was therefore decided that we would visit the site at different times of day to take detailed measurements of where shadows fell. This allowed us to create a printed plan of the roof space, including areas representing the shaded portions of the roof, using a software modeling program. With this information, a more accurate calculation of the possible area suitable for a photovoltaic system was made.

We also determined the necessary spacing of an array using different panels, to figure out how many panels could effectively fit onto the roof's surface. Inter-panel spacing was important because tilting the panels for the optimum angle of the sun could potentially cause them to cast shadows onto each other. Using trigonometric calculations, we found the spacing necessary between panels to avoid these types of shadows, as well as determined the maximum number of panels as a result of this spacing. This maximum number of panels allowed us to determine how much power could be harnessed in each of our panel configurations.

### 3.1.3 Energy Usage

We found it necessary to gather previous energy data from the church in order to gain a better understanding of how a solar panel system would affect the overall amount of energy that the church could save. Previous electric bills contained the number of kilowatt hours consumed by the church, as well as the price paid for these hours. Using this data, we were able to summarize the trends in energy usage over the course of the year, and more importantly, compare this energy data to the estimated energy that could be produced by a solar panel installation. The electrical purchasing history of the church also gave us an initial cost of electricity, which was very useful in our economic analysis.

### 3.1.4 The Installation Process

Researching the installation process was another important aspect of the site analysis. This involved contacting local installers and analyzing the Worcester Code Enforcement to better understand the electric codes relevant to the installation of a photovoltaic system. In addition to this, we contacted National Grid, the power supplier for the church, to find any other regulations pertaining to connecting the church's solar panel system to the electrical grid. It was also important to determine the nature of the materials that the roof was composed of, and what methods of mounting the panels would work best on these surfaces. Research was done to create a contact list of local installers who would be able to install a system if it were found to be feasible.

## 3.2 Analysis of Solar Panels and Systems

In our pursuit of the most economical solar panel solution for Wesley United Methodist Church, we came across many possible options for panels, inverters, and other equipment, each with their own costs and benefits. In order to determine which solution was optimal, we enumerated a list of criteria that was used to evaluate each solution.

We decided that the best metric for evaluating a solar system was the cost per Watt produced by the panel. Naturally, the lower this number, the greater energy production that can be purchased for the same dollar amount. This criterion will lead to a better return on investment and fewer years until the church recovers their initial capital.

We determined that the second most important criterion for determining the feasibility of a solar panel system was its durability. Less durable systems would incur higher maintenance costs and exhibit a shorter lifetime of operation. The longer the solar system lasts the more energy the church will be able to obtain from it.

We decided that the efficiency rating of the photovoltaic panel was important because it is directly related to the maximum power a system using the panel could produce. The church had a set amount of space available for a solar installation. The higher the efficiency of the solar system, the higher the amount of power we could get from a system covering the same amount of space.

The availability of a certain solar technology also factored into our analysis of feasibility. There are long waiting lists for some of the newer solar panel technologies, such as thin film solar panels. For this criterion, there was a trade-off between only looking at what is readily available and waiting for a better technology to become available.

The weight of the solar panel system was important. The roof at Wesley United Methodist Church is able to support 35lb per square foot, so any system heavier than that was disregarded.

Finally, we considered the carbon footprint of the manufacturing process as we analyzed solar panel feasibility. Some manufacturing processes place a larger burden on the environment than others. Because one of the greatest benefits to using renewable technologies is the positive effects they have on the environment, this was something to consider. It was not, however, as important as some of the previous criteria because the most important part of this study was to find a solar solution that would be economically feasible. We would not recommend proceeding with a solar panel solution that caused a negative cash flow, so it was more important that we found a solution that is economically feasible than that we found the most environmentally friendly solution. Certainly, any renewable energy source that gets implemented is significantly better for the environment than continuing to use nonrenewable resources for energy production.

In order to determine which solar panels were best suited for this project, we first discarded any that were too heavy for the roof to support. Next, we performed a competitive analysis on the remaining panels. Competitive analysis is a process that can aid in making decisions when there are many factors to consider. First, we created a list of criteria and weights, which can be seen in the table below. Weights were assigned to each of the criteria, based on the decided importance of each. The different solar solutions were then rated in each of these categories. Finally, each weight was multiplied by its respective rating and then all of these results were tallied for each solution. At the end of this process, each solution was given a number representing its overall score.

| Criteria | Weight |
|---|---|
| $/Watt | 10 |
| Durability | 8 |
| Efficiency | 7 |
| Availability | 4 |
| Manufacturing Carbon Footprint | 2 |

**Table 2: Solar Panel Criteria**

We found cost per Watt to be the most important criterion because it is most directly related to the economic feasibility of the system. For this reason, we assigned cost per Watt a weight of ten. A system's durability is also very important to its overall performance, as a greater system lifespan will increase the amount of energy that it can produce. However, we decided that durability was less important than cost per Watt, giving it a weight of eight. Efficiency was not as important as the previous two criteria. In spite of this, it was still important that we meet a certain level of efficiency in order to generate enough power given the limited roof space. Therefore, we gave efficiency a weight of seven. The availability of a system was not very important due to the numerous solar panel options available, so it was given a weight of four. Finally, the carbon footprint was important from an environmental point of view, but weighting this category too heavily could lead us to selecting a solar power system that wasn't economically feasible, and therefore would not be implemented at all. For this reason, we gave the manufacturing carbon footprint a weight of only two. After performing this analysis on many different solar panels, we were left with a single number for each, representing how well each panel style met our criteria. We selected the top five as finalists for our recommended solar panel implementation.

## 3.3 Solar Panel Placement

Determining where to physically place the panels on the roof, as well as how to orient them, was important. This is because a panel's orientation can have a large effect on the amount of solar energy it can gather and power it can generate. In order to decide how to optimally place the solar panels that were chosen, we created a number of placement scenarios. For each of our proposed scenarios, we determined a corresponding solar panel placement. Each placement has been carefully laid out attempting to meet the following criteria: maximum amount of power generation while still leaving room on the roof to walk. If at any point throughout the analysis, we felt that the given layout would not allow enough room to walk, we would remove the offending panels.

In order to generate the maximum amount of power, we wanted to place as many panels as possible at the optimal angle, without any of them being shaded between 9:00am and 3:00pm, the time period of maximum sunlight.[29]. Aside from placing the panels outside of the shadowed area produced by the building, we also needed to ensure that the panels were not shaded by the row of solar panels in front of them. The minimum separation between the panels must be calculated using the worst case scenario sun position: when the sun is 30° above the horizon.

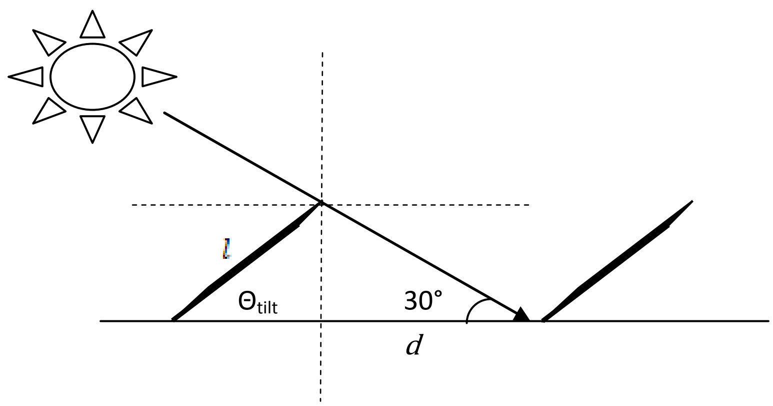



Figure 8: Depiction of the Sun Rays vs the Tilt of the Solar Panels

Solving for *d* in the above illustration yields the minimum separation distance between rows of solar panels without shading any of the panels at any point during the year. A solution for *d* can be found by using the equation below.

$$d = l \cdot \sin(\theta_{tilt}) \cdot \sqrt{3}$$

Calculating the minimum distance a row takes up is done using the following equation:

$$r = l \cdot \cos(\theta_{tilt}) + l \cdot \sin(\theta_{tilt}) \cdot \sqrt{3}$$

With this knowledge, we proceeded to break the roof up into a series of rectangles and determined the solar panel placement for each rectangle. We divided the width of each rectangle by the width of the solar panel and rounded down to get the number of solar panels for a given row. We then took the length of the rectangle and divided it by the minimum allowable distance for a row. This gave us the number of rows that we could have inside this rectangle. We did this for each rectangle, and then combined the results, making sure that there was enough walking space between the last row

[29] **Lenardic, Denis.** Solar radiation estimation and site analysis. http://www.pvresources.com/en/location.php.

of one rectangle and the first row of an adjacent rectangle. This process generated our optimal panel placement.

To determine how we would wire the solar panels together, we followed the concept that we would wire solar panels in series that could potentially be shaded at the same time, and putting those rows in parallel with other rows.

We calculated the maximum number of solar panels that could be placed in parallel by dividing the maximum current rating for the inverter by the peak current generated by the solar panels under ideal conditions. Rounding this number down gave us the maximum number of parallel rows.

$$MAX_{parallel} = \left\lfloor \frac{I_{inverter}}{I_{panel}} \right\rfloor$$

Dividing the maximum voltage rating for the inverter by the peak voltage of the panels under ideal conditions and rounding down gave us the maximum number of solar panels that could be wired in series.

$$MAX_{series} = \left\lfloor \frac{V_{inverter}}{V_{panel}} \right\rfloor$$

Based on the maximum number of panels that could be wired in series, we created rows of maximum length, going from north to south. This guaranteed that if there was shade, all of the panels in series would be shaded at the same time. We then placed as many adjacent rows in parallel as was allowed by the $MAX_{parallel}$ calculation, and wired them all to one inverter. We repeated this process until all solar panels were wired to an inverter.

It is important to note that if shading occurs on a given solar panel, then current is unable to flow through it or any panels that are in series with this panel. This is important to consider when wiring up the panels, so that they are done in a way such that a small patch of shade won't prevent multiple rows of panels from producing electricity.

## 3.4 Economic Feasibility of the Systems

The crux of this project was the determination of economic feasibility. In order to determine economic feasibility, one must do a thorough job of both understanding the mathematical analysis behind it and estimating the various parameters that are taken into account. This section will describe the mathematical analysis that we employed during our project as well as explain our methodology for the analysis. Later, during the economics section, we will present our choice of various parameters that go into the economic calculations along with our reasoning for their selection.

Initially, we gathered information about similar projects that have been done to determine economic feasibility. The Massachusetts Technology Collaborative (MTC) offers a Microsoft Excel spreadsheet that helps users determine the feasibility of solar panel installations.[30] This spreadsheet was helpful because it accurately calculated the total rebates available in Massachusetts. It had a detailed depiction of cash flow analysis, and overall, cleanly presented the data. While being an excellent tool, we believed that there were many drawbacks to directly applying this economic analysis to Wesley United Methodist Church. The largest concern was that MTC's analysis was specific to either a taxable commercial entity or a personal residence, while the Wesley United Methodist Church is neither, being a non-profit organization exempt from taxes. Rather than trying to modify what MTC had done, we decided to assume the relevant portions from their spreadsheet and use them as a basis for our own calculations. This allowed us to make a spreadsheet tailored specifically to the Wesley United Methodist Church.

The spreadsheet that we made contained the following sections:

Section 1: System Size and Cost

Section 2: Installation and Fees

Section 3: System Life Expectancy

[30] Non-Residential Rebate Calculator. *Commonwealth Solar.* http://www.masstech.org/SOLAR/Attachment%20A2-Non%20Residential%20Solar%20Rebate%20Calculator%20Only-070208.xls.

Section 4: Incentives and Rebates

Section 5: Financing

Section 6: Energy Generation and Usage

Section 7: Worldwide Economic Factors

Section 8: Results and Analysis

The first section dealt with the scale of the system, the cost of the solar panels per Watt, and the cost of the inverter and other components. We chose to have the data entered in this way because by using cost per Watt as a primary variable, the economic analysis is more readily scalable to systems of various sizes. Until a company makes a final estimate, we feel it is best to analyze the data on a per Watt basis because other parameters can be changed to see how they affect the cost of the overall system. The end of Section 1 displays the total cost of the photovoltaic system components.

The next section dealt with the cost of the installation and other associated fees. The largest contributor to this category was the installation cost per Watt. The most accurate way to determine an installation cost would be to get multiple estimates from different contractors. In the meantime, we have chosen to look at the installation cost on a per Watt basis because we can estimate it with a reasonable amount of certainty and because it is scalable to different system sizes. After taking into account electrical inspection costs and other fees, section two calculates the total cost of installation and fees.

Section three dealt with the system's lifespan and maintenance costs. The system life expectancy is an important factor because it determines the amount of time the solar panel will be producing energy. A longer life expectancy generates a better net present value (the sum of future cash flows discounted to the present value) and a better return on investment. This section also deals with system degradation, as each year solar systems put out slightly less energy than they did before. This is due to the system slowly breaking down. Maintenance costs, as well as a maintenance cost adjustor were also included in this section. The maintenance cost adjustor allowed us to predict how much maintenance costs will increase over the lifetime of the system.

The next section, incentives and rebates, came primarily from MTC's spreadsheets for determining economic feasibility. Its parameters are the system size, whether or not the building is a public building, and whether or not the components are manufactured in Massachusetts. It uses these factors to determine the total system rebate. This section also takes the Renewable Energy Credit (REC) price per Watt and an accompanying adjustor for this price and estimates the revenue that will be generated each year from renewable energy credits. At the end of this section, we were able to calculate the total cost of the solar panel system, by taking into account the cost of the components, the cost of installation and fees, and the total rebate received.

The section on financing allows the user to input the down payment percentage, which is useful to help the church determine how the size of the down payment affects the system's overall economic feasibility. The interest rate and loan period are also inputs in this section. With this data, we were able to calculate the size of the down payment and the monthly payment.

The next section, energy generation and usage, allows us to calculate how much energy will be produced from the solar panels. There are fields to input the average daily insolation per $m^2$ for each month. Using this data, along with the system efficiency, we can determine the total amount of energy expected to be generated in the system's first year. Using the degradation factor from Section 3, we can then determine the expected energy generation for each year of the system's life expectancy.

The last section, analysis, takes information from the previous sections to compute typical economic values such as net present value, the breakeven point, and cash flow. The yearly cash flow (a value which changes from year to year) is calculated by taking the amount of money saved in the year, from both RECs and saved energy costs, and subtracting the cost of the loan. Net present value is determined by taking these future cash earnings and discounting them by the present value interest factor and then subtracting the initial down payment, as outlined in "ISD Module: Quantitative Methods in Economics."[31] We can determine the break-even point by figuring out when the discounted value of future earnings is equal to the initial investment, in this case the down payment.

In many cases throughout this analysis, we used adjustor percentages for different factors. This was so that we could have a more accurate economic model for the dynamic future. Taking these factors into account and having them accurate is important for the overall accuracy of our model as we look forward.

The economic values determined in Section 8, Analysis, will essentially determine the economic feasibility of the project. We would not be able to recommend beginning a project that had a negative net present value, a negative cash flow, or an internal rate of return lower than that of a typical savings account.

A printout of the economic spreadsheet described in this section can be found in Appendix X.

## 3.5 Social Implications

Uncovering the possible social impacts of installing a photovoltaic system on the Wesley United Methodist Church was important, not only for determining the feasibility of the project, but for determining how this project might affect the growth in the number and scope of such systems in the surrounding community. Current viewpoints on the acceptance of solar panel systems, especially the viewpoints of the Wesley Church congregation, were important to consider. The congregation's support of such a system may even lead to donations specifically for its construction, a key factor for a non-profit organization.

The first step in this process was discovering what possible social and cultural effects would be witnessed from the installation of a photovoltaic system, as well as the extent of each effect. We

[31] **Woods, Douglas W.** *ISD Module: Quantitative Method in Economics.*

determined that the notion of environmental stewardship would be a key factor.  Besides this, we investigated the educational opportunities such a system would provide, as well as the broader effects that photovoltaic panels can have on society.

A brochure was created in order to inform the congregation about the benefits of solar panels as well as address some of the questions that may arise in regards to an installation on the roof of their church.  It was important for this brochure to be informative as well as succinct.  Outlining key financial, environmental and social benefits was the most important feature of the brochure.

It was also important to judge the congregation's receptiveness to a photovoltaic system.  In order to measure their views, we created a survey that was oriented towards the leadership group of the Wesley United Methodist Church that attended our final presentation (Appendix N).  The survey focused on how members of the congregation felt about having solar panels installed on their church.  It was important to measure how the congregation felt about the installation of solar panels in general. This was used to determine if it was the receptiveness of solar panels in general that caused the congregation to react in a particular way, or rather the installation of solar panels on their church in particular.  We also wanted to access from this survey if members of the congregation felt that the social benefits of installing such a system could outweigh the economic benefits.   That is, we wanted to know if the church would still install a solar panel system if there were limited or no economic incentive to do so.

The survey was designed to maximize the the opportunities for qualitative responses to open-ended questions.  The goal was to make the survey so that it could be completed in a few minutes.

In addition to determining the overall feasibility of installing solar panels on the Wesley United Methodist church, a secondary goal of this project was to promote the awareness of solar panel systems the greater Worcester community.  To achieve this, it was important to create a set of information that could be presented and distributed to the community.  This final presentation included information about solar panels in general, the steps required to determine their economic impact and get them installed, and reasons why solar panel systems are beneficial both economically and to the environment.

# 4. Site Analysis

This chapter is concerned with the physical conditions of the church and area around it that would affect the installation of a solar panel system. The nature of a solar array requires that the site analysis take into account the physical structure and layout of the roof space, as well as the weather. The weather plays an important role with such a system, determining the amount of sunlight that can be gathered by the panels and converted into energy. After a brief introduction to the location of the church, this chapter begins by discussing the meteorological findings for the area in which the church is located. The next section describes the physical layout of the roof space. This is followed by an analysis of the Church's energy usage, and a look into the installation process.

## 4.1 Location of the Church

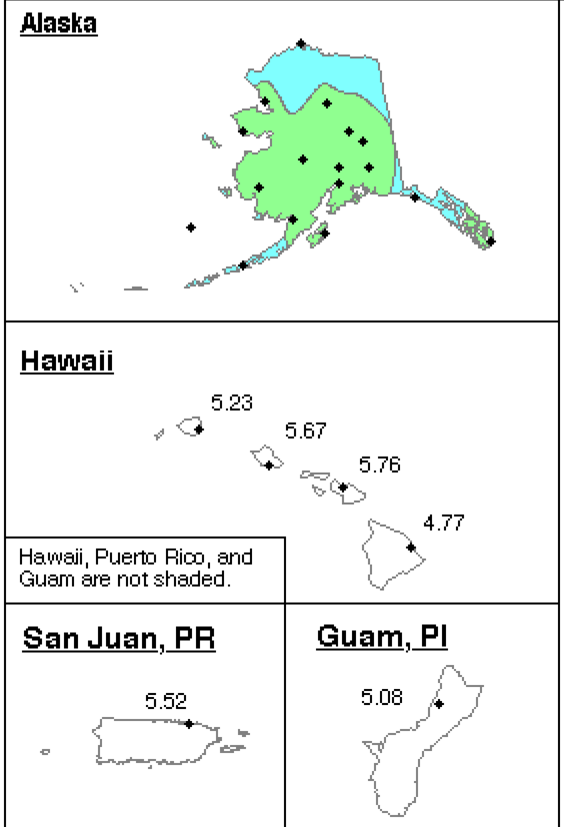
The Wesley United Methodist Church is located near the heart of Worcester Massachusetts. When traveling down Main Street the United Methodist Church becomes apparent as you approach the Johnson Tunnel, between State Street and Gertrude Ave. The church is located on 114 Main Street and resides at approximately 42.3 degrees latitude and -71.8 longitude. The building is four stories tall and formed primarily out of grey brickwork.

## 4.2 Meteorological Analysis

One of the greatest challenges in determining the feasibility of a solar project is determining the amount of energy that is provided by the sun. For solar panels, the primary factor of whether or not a project is feasible is the amount of sunlight a chosen area receives. To calculate this, many factors must be considered: average sunny days, clearness of the weather, precipitation, average sun duration, and latitude. To find how each of these factors effects the overall conclusion, tedious calculations must be done. Weather data from previous years need to be consolidated and then averages can be calculated from this data.  Fortunately, much of this information is readily available. The United States Renewable Resource Energy Data Center (RREDC) contains all the information needed to address these factors.[32]

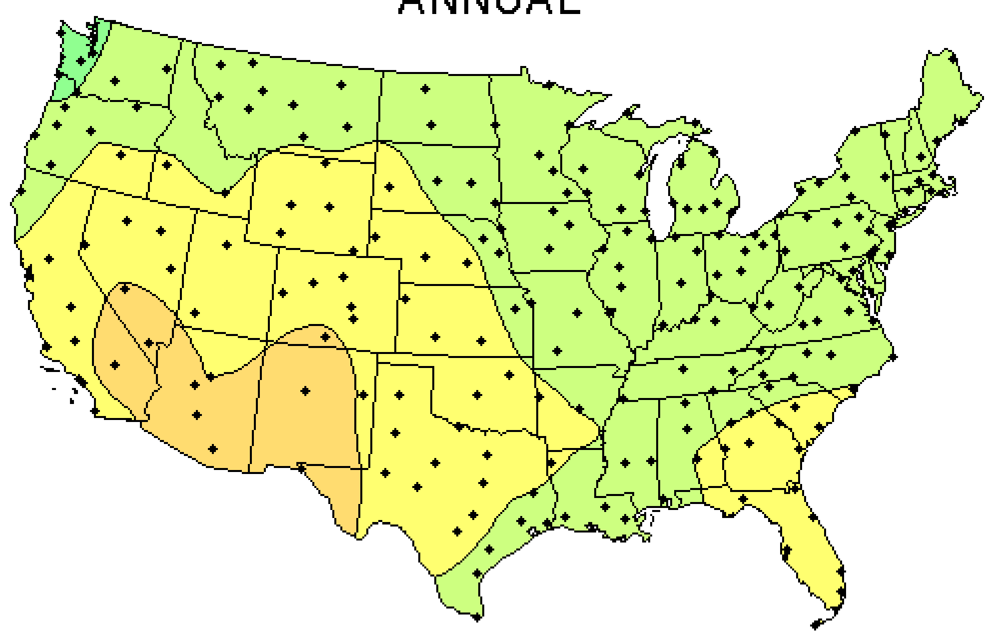
One of the most useful ratings provided by the U.S Renewable Resource Data Center is the insolation graph. This graph displays the average solar energy per square meter per day in any given month. This value is calculated from thirty years of data gathering and is extremely useful when calculating the energy that can potentially be generated if solar panels are installed. From RREDC's website many different insolation graphs can be calculated. The website provides the user with three options. The first is what type of data to be displayed. This value can either be: average, minimum, or maximum. The second option is which month's data to view. The user is given an option of choosing a specific month out of the twelve, or the annual reading, which provides an average. Finally, the third option specifies how the solar panels are to be orientated. Because Worcester is located at approximately 42 degrees latitude, the choice of orientation could drastically change the insolation values. For this project, the solar panels can be oriented southward at latitude. On the following page is a graph of the United States generated from RREDC's website which encompasses the average annual solar radiation for south facing panels. Each region on the map relates to a specific insolation value, where higher is better. In the case of Worcester, this area falls within the average of 3 to 5 $kWh/m^2/day$.

[32] RReDC. U.S. Solar Radiation Resource Maps. *Renewable Resource Data Center.* [Online] National Renewable Energy Laboratory. http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/




# Average Daily Solar Radiation Per Month

## ANNUAL



**Flat Plate Tilted South at Latitude**

### Collector Orientation

Flat-plate collector facing south at fixed tilt equal to the latitude of the site: Capturing the maximum amount of solar radiation throughout the year can be achieved using a tilt angle approximately equal to the site's latitude.

This map shows the general trends in the amount of solar radiation received in the United States and its territories. It is a spatial interpolation of solar radiation values derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). The dots on the map represent the 239 sites of the NSRDB.

Maps of average values are produced by averaging all 30 years of data for each site. Maps of maximum and minimum values are composites of specific months and years for which each site achieved its maximum or minimum amounts of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

**National Renewable Energy Laboratory**
**Resource Assessment Program**

**$kWh/m^2/day$**

- 10 to 14
- 8 to 10
- 7 to 8
- 6 to 7
- 5 to 6
- 4 to 5
- 3 to 4
- 2 to 3
- 0 to 2
- none

FLATA13-208

Expanding on the information above, the GAISMA organization also provides in-depth analysis of monthly insolation values.[33] By selecting the Worcester area, GAISMA provides a plethora of solar information from sunrise and sunset times, sun path diagrams, and solar energy and surface meteorology. While much of the information is enlightening, the most valuable statistic is the "insolation, kWh/m$^2$/day" value found in the solar energy section. The GAISMA organization provides a very simple breakdown of insolation values for each month during the year. The difference between GAISMA's data and RREDC's is the fact that GAISMA provides a precise numerical value where RREDC only provides a range between two integers.

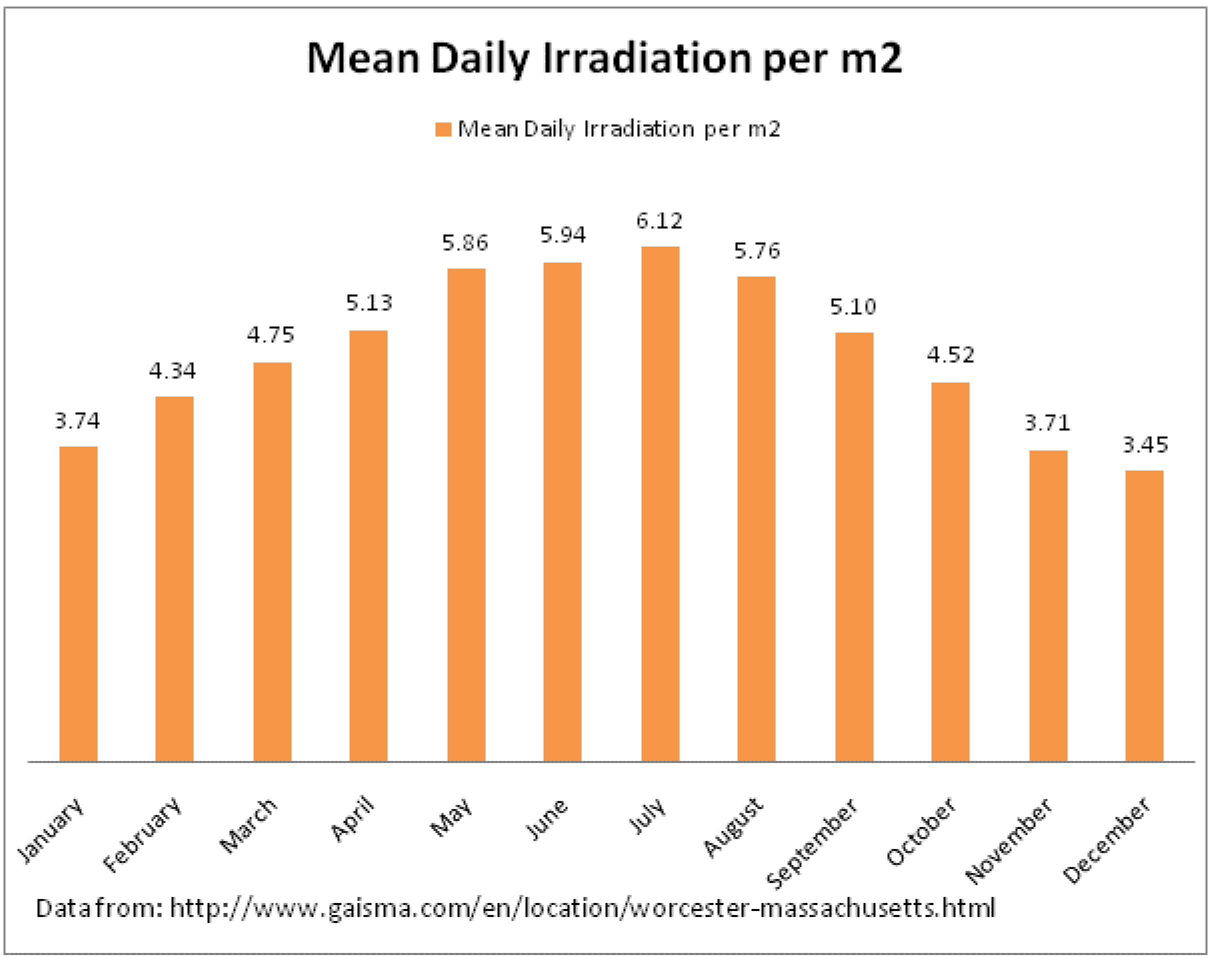


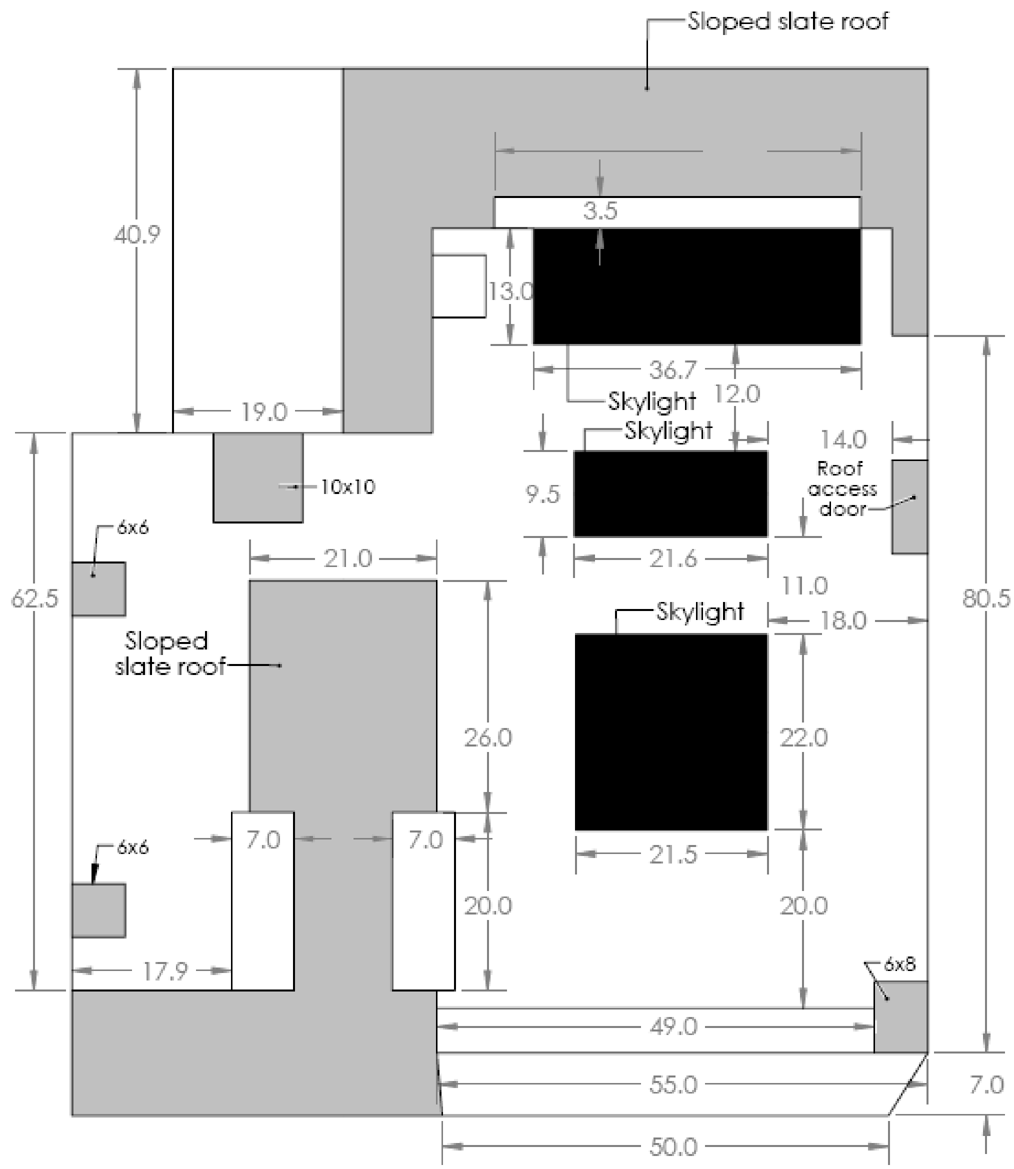

**Figure 9: Mean Daily Irradiation for Worcester**

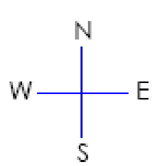
[33] *GAISMA.* [Online] www.gaisma.com

Using the data we have collected concerning insolation values, we are now capable of determining an approximate output of the panels. For example, when the project was in its infant stages, we estimated we had 270 square meters to work with. We then wanted to determine what the average energy was available to that given area. To calculate this we multiplied an insolation value of a specific month by the area available. The result is in kWh per day. Currently, the average efficiency of a solar panel is approximately 10%, so we multiplied our result by 10%. The result is an average amount of energy we could hope to acquire in a day if we covered the entire area with solar panels of an appropriate power rating. To determine what the average energy would be in a month we multiply this value by the number of days in the month. The result is a value that we can use to directly compare with electricity bill's consumption value sent monthly by the local energy provider. The benefit of determining this is that we can determine if the energy produced by that area is enough to meet, or exceed the church's current consumption.

## 4.3 Layout of Roof Space

The primary roof space that would potentially be used for the solar panel array is a mostly flat area that is about 55 feet wide and 80 feet long. The area has an open southern exposure that makes it ideal for solar power collection. The flat part of the roof is situated in such a way that it is sunny with few shadows throughout the day, and anything mounted to the roof would not affect the aesthetics of the building from most angles, particularly Main Street in front of the building.




NOTES:
- All dimensions in feet
- All shaded areas are unusable for mounting solar panels
- All White areas are flat rubber roof surfaces

Thomas Parenteau

TITLE:
Wesley United Methodist Church Flat Roof Area

| | | |
|---|---|---|
| SIZE A | DWG. NO. 1 of 5 | Roof area with dimensions |
| SCALE: 1:200 | 11-20-2008 | |

The flat roof area is covered with a white rubberized roofing material. In the center of the main open area are two large skylights (shaded black in the drawing), which take up space and cannot be removed or covered with panels. There is a third skylight mounted to the side of the north sloped roof. To the west side of the large open area is another section of sloped roof that rises above the flat roof about 20 feet. This creates a separate flat section that is primarily shaded by the sloped roof and the large chimney. On the east side is the sloped roof that runs parallel to Main street in front of the church and will completely block anything on the flat roof from view. The southern exposure is open to the side street next to the church building, but the height of the building blocks anything not on the edge of the roof from view.

In the northwest corner is an elevated flat portion about 40 feet taller than the rest. This 20 foot by 40 foot section is almost entirely in the sun throughout the day and is covered in the same white rubberized material. It's accessible by a ladder mounted to the wall, and is somewhat isolated from the rest of the roof area. This makes it somewhat less convenient to use. There is internal access to the main portion of the roof, making inspections, repairs and snow removal easier. This would also facilitate in monitoring the solar panels.

## 4.4 Energy Usage

Due to the church's size and daily activities it is no surprise that the Wesley United Methodist church uses a significant amount of electricity. Currently the church uses an average amount of 9500 kWh of energy a month; which totals to $1300 dollars a month in electricity costs. It is apparent why the church has sought cheaper, renewable energy to offset electricity cost.

To correctly assess the impact of renewable energy sources, such as solar panels, we determined the church's past and present electricity usage. The easiest method for determining the consumption trends from month to month is using past electricity bills. After consolidating electricity usage bills for one year in 2007 we created the graph below to help visualize the months of greatest demand. This graph displays the amount of energy consumed, in kWh, from month to month. From the graph, it can be seen that although there are not huge fluctuations in the amount of energy needed by the church, certain months, such as August and December, have higher energy demands. This may be due to factors such as air conditioning in the summer, and the increased need for lighting along with holiday activities in December.

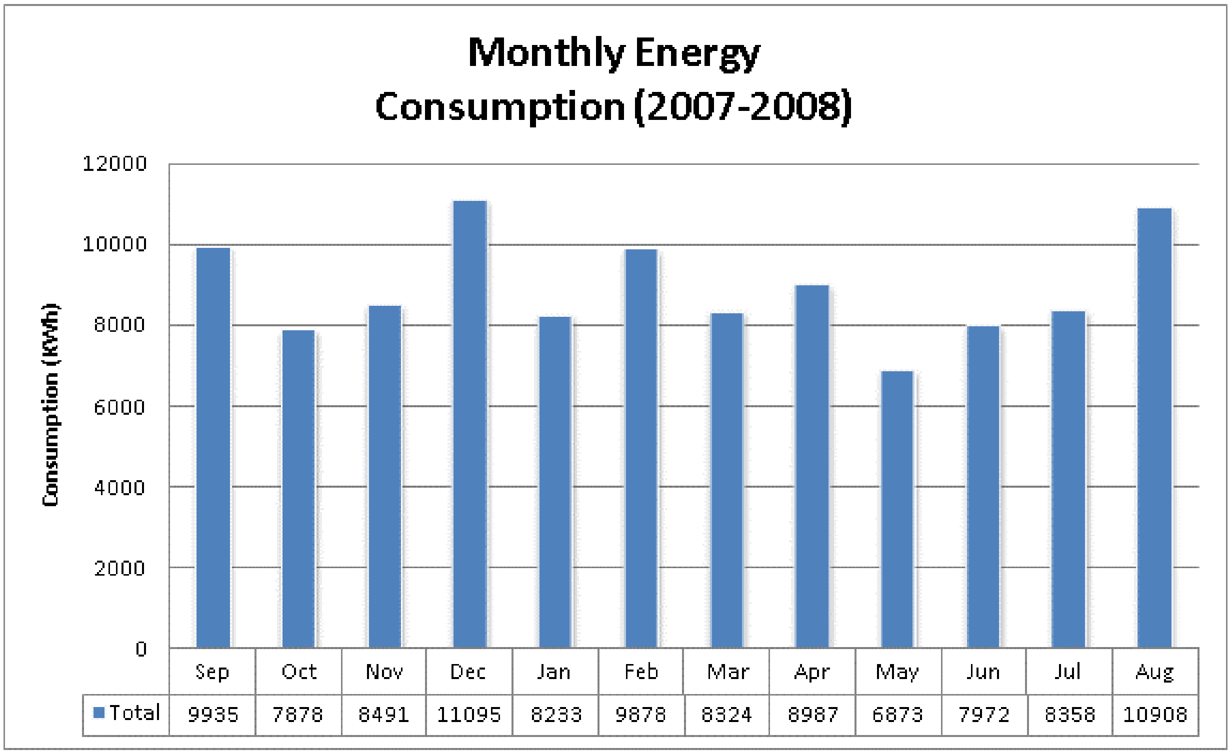



Figure 10: Wesley United Methodist Church's Electricity Consumption

Using the meteorological data from section 4.2, we compared the energy consumption data of the church to the amount of energy that could be produced by a solar panel system. Although in chapter 7 we discuss a number of scenarios corresponding to various system sizes, the graph below demonstrates a system size of twenty kW. The blue bars in the graph represent the monthly energy demands of the church, as in the previous graph. The red bars represent the amount of energy that can be produced by a 20kW system. The difference between these two, which corresponds to the net energy demand after installing such a system, is displayed in green.

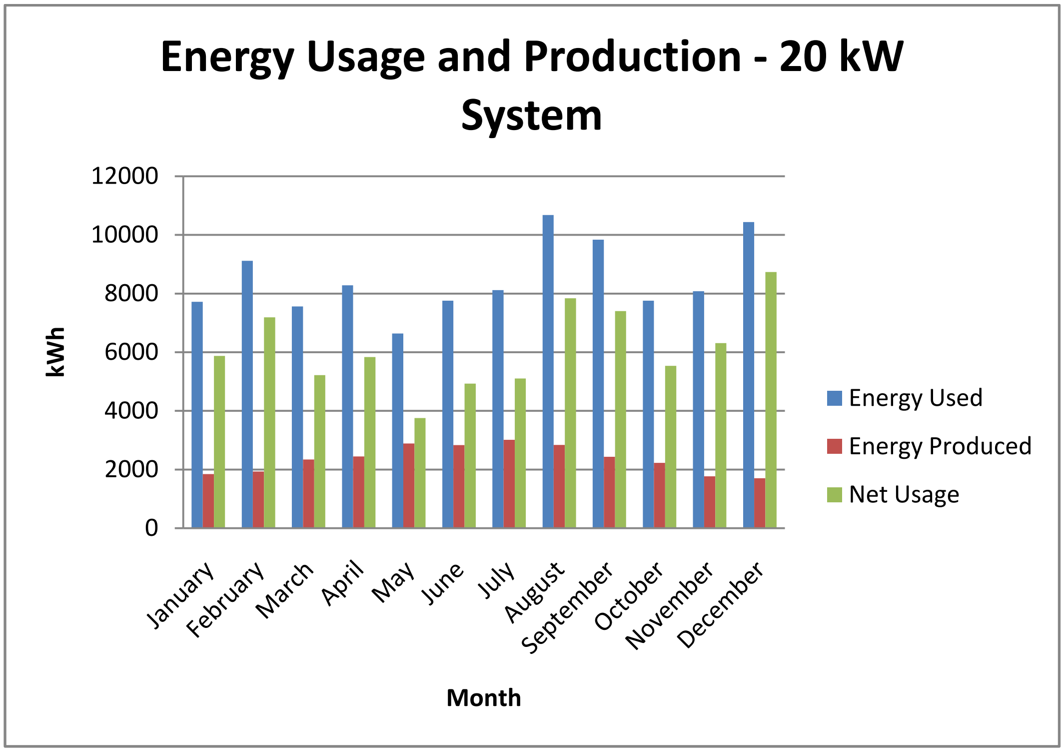



Figure 11: Power Consumption vs. Energy Production of a 20 kW System

From this graph, it can be seen that the system displayed does not produce enough electricity to fully offset the demands of the church. Because of the very large energy demand required by the church, coupled with the amount of irradiation in the Worcester area, it would take system that is larger than could be supported by the available roof space. So although it is unlikely that the church will be able to sell any excess energy back to the utility company, the amount produced could defer a considerable fraction of their overall energy demands.

## 4.5 The Installation Process

Because the church has a newly installed membrane roof on its flat areas, installation on this portion of the roof should be relatively simple. The mounting structure for the panels can be directly connected to the roof and sealed to maintain insulation. These portions of the roof are rated for 35 lbs per square foot, which should not be exceeded.

The slanted portions of the roof, however, are covered in slate. If any solar panels were to be put on this area of the roof, we would recommend removing the slate tiles on these portions. This is because the fragility of slate requires that it be given higher level of maintenance. For example, cracked tile may need to be replaced. If solar panels were mounted on a slate portion of the roof that needed to be repaired, significant work would need to be done in order to fix the underlying slate. Also, the installation procedure for mounting panels on a slate roof is more complex, and the tilt angle of the panels is restricted to the slope of the roof.

It is important that during the installation process all necessary electrical and building codes are adhered to. Certain requirements are also stated by Commonwealth Solar in their minimum technical requirements.[34] These include the use of a Massachusetts licensed electrician to do all of the electrical work, making sure all wiring modifications are properly insulated, and that the system can be disconnected for maintenance.

Another aspect of the installation process is tying the solar panel system into the electric grid. This allows the excess electricity produced by the system to flow into the local electrical grid to be used by other members of the grid. This process begins by completing an interconnection agreement with the local utility company. The utility company reviews the project to make sure that it will have no negative impacts on the grid. The utility company, town and local inspectors, and the contractor installing the system are all involved in this process. It is best to begin the interconnection process during the final design stages of the system, but before construction, due to the level of technical detail needed by the utility company in order to assess the installation's possible effects.

In order to give the church the information necessary to pursue an installation if they found it to be feasible, we created a list of installers who would be able to install such a system. This list can be seen in Appendix <Solar Panel Installer Appendix>. The list was compiled using information in a

[34] Massachusetts Technology Collaborative. *Commonwealth Solar Rebate Program*. Retrieved 1/15, 2009, from http://www.masstech.org/SOLAR/CS_AttachmentDMinimumTechnicalRequirements_v3_010109.pdf

spreadsheet of Massachusetts solar panel installers provided by Commonwealth Solar.[35] Installers were then selected based on the costs of their installations, the size and scope of previous installations, and reviews and recommendations gathered from our various correspondences.

[35] Massachusetts Technology Collaborative. *Information on Installers and Costs*. Retrieved 1/15, 2009, from http://www.masstech.org/SOLAR/CS%20Installer-Cost-Location%20Data%20for%20Website%20as%20of%2001-31-09.xls

# 5. Possible Solar Panels and Inverters

One of the most important factors in devising a photovoltaic array is determining which solar panels to purchase and what type of inverter to utilize for the situation at hand. To correctly assess which panels and which inverters would make greatest impact on our feasibility solution for the Wesley United Methodist Church a component matrix was conceived. The component matrix contains pertinent information about potential photovoltaic/inverter candidates that have a high chance of success in our solution. The matrix incorporates many of the highest quality products made by various manufactures in the field of solar technology. By consolidating these potential products we are capable of determining which panels or which inverters have benefits over their competitors and how those benefits will affect our goal of feasibility.

This chapter is separated in two distinct sections: solar panel choices, and inverter choices. Each section will discuss the criteria used to filter out unwanted components as well as which devices hold the greatest chance of success.

## 5.1 Solar panels

At first glance, the amount of solar panels available is overwhelming. To overcome this, a set of benchmarks was established and each panel was ranked against the set of criteria. If a given panel ranked poorly it was discarded. Any panel that was moderate or exceptional was added to the matrix of possible panels to be later scrutinized when all variables had been considered. The criteria were comprised of these important attributes: power output, efficiency, size, and weight.

Many selection criteria were initially established out of back of the envelope calculations and later altered when additional variables were realized. Judging by the electrical consumption of the Wesley United Methodist Church as well as the limited amount of space available for solar cells, we concluded that our solar panels must have a power output of at least 175 Watts. Panels that are equal to or greater than 175 Watts are ideal for a project of this magnitude. Last year alone the church consumed 102,000 kWh of electricity. To even begin to offset a fraction of the electricity used a solar system must be powerful enough to produce enough electricity to be viable. In conjunction with this, a minimum allowed solar cell efficiency was established at 10%. A higher efficiency also allows the solar cells to produce its maximum power output more than a lower efficiency counter-part in the same amount of sunlight.

The size limitations arise from the desire to keep the panels as small as possible. Because space is a limited commodity the panels that occupy the space must be kept small to allow for more panels in the limited space. Smaller panels also provide a bonus when discussing shadow effects. Shadows that are cast on a given solar panel render that entire panel obsolete. A small shadow may render a large array useless. Having a larger number of smaller panels decreases the chance that a small shadow will create such detrimental effects as compared to the larger panel. In addition to size, weight was considered to ensure that the panel could be structurally supported by the rooftop without any unforeseen consequences. The weight limit was determined by questioning the building inspector on all possible points on the rooftop.

| Model | Power | Price | $/Watt | L (in) | W (in) | H (in) | W/in^2 | Weight | Efficiency |
|---|---|---|---|---|---|---|---|---|---|
| **Kyocera's** KD200GT | 200W | $870 | $4.35 | 56.2 | 39 | 1.4 | 0.09 | 40.7 | 15.00% |
| **Sun power Corp.'s** SPR-315 | 315W | $1510 | $4.80 | 61.39 | 41.18 | 1.81 | 0.12 | 53 | 19.30% |
| **Sharp's** ND-V230A1 | 230 | $1,150 | $5.00 | 64.6 | 39.1 | 1.8 | 0.09 | 44.1 | 14.00% |

Table 3: Potential Solar Panels

The table above displays three of the most promising photovolatics for utilization in no particular order.

## 5.2 Inverter Choice

Unlike the photovoltaic selection choice, inverters had a much smaller pool to choose from. Many inverters were found to either in the midrange, 3000W-7000W output, or in a commercial range, 100000W or above. Because the list of possible choices was so small, all types of inverters were added to the component matrix. This gave us the opportunity to contrast having one large inverter compared to several smaller inverters.

Knowing that the maximum energy that could be utilized by filling the Church's roof entirely with panels was approximately 25000W it became apparent that the much larger inverters were overkill. Inverters such as Satcon's AE30, was capable of connecting up to 37500W to the grid. This meant that even if we were capable of covering the roof with panels we would only be utilizing 66% of the inverters capacity.

On the other hand, smaller inverters such as Sunny Boy's SB7000US would require three inverters to handle the electrical output of the solar array. While this may seem unfavorable, it actually carries many advantages. First, smaller inverters can be used to precisely match the power output of the photovoltaic array. This means that there is approximately 100% utilization of the inverters compared to only 66% when using Satcon's AE30. In addition, one AE30 would cost $33,780.00 to handle 25000W of electricity, while three SB7000US would cost only $12,057.00, more than half the price. Another benefit to having smaller inverters is the ability to region the array. This means the array, in its entirety, can be broken into several smaller, independent parts. This method avoids a total shutdown of the array system if a single inverter fails. Finally, a smaller inverter increases maintainability when compared to a large commercial inverter. If a large inverter requires replacement it may take days or even weeks to swap out, not to mention the assistance of a professional. A smaller inverter is generally much simpler to operate and maintain. The SB7000US is actually capable of being carried to the site and is simple enough to be installed by someone with elementary electrical knowledge. The table below shows a list of possible inverters.

| Model | Efficiency | Power (W) | Current (A) | Cost | $/Watt |
|---|---|---|---|---|---|
| **Sunny Boy's** SB7000US | 95.00% | 7000 | 34 | $4,019.00 | $0.57 |
| **Sunny Boy's** SB6000US | 95.00% | 6000 | 29 | $3,725.00 | $0.62 |
| **Fronius** IG 4500-LV | 94.40% | 4500 | 21.6 | $2,899.99 | $0.64 |

**Table 4: Potential Inverters**

Once it became apparent that smaller inverters were more beneficial in this situation than their larger, commercial counter-parts, it was only a matter of reducing cost to arrive at the chosen inverter. Above is a table which represents the top three chosen inverters for Wesley United Methodist Church.

# 6. Economic Context

We developed an economic feasibility spreadsheet in Microsoft Excel as described in the Methodology section to aid us in feasibility calculations for various scenarios. In the Methodology section we explained how the spreadsheet worked. An accurate economic model depends not only on accurate formulas, but on various parameters that can be estimated with a high degree of certainty, backed by historical figures or measurements. This section explains our justification for the parameters that we entered into the spreadsheet. A screenshot of the spreadsheet can be seen below.

| | A | B | C | D |
|---|---|---|---|---|
| 1 | Solar Feasibility Analysis for the Wesley United Methodist Church | | | |
| 2 | | | | |
| 3 | Section 1: System size and cost | | | |
| 4 | Desired System Size: | 25000 | W | |
| 5 | Actual Size (given area and efficiency): | 25000 | W | |
| 6 | Cost per Watt: | $ 4.35 | dollars | |
| 7 | Inverter and other Equipment: | $ 12,057.00 | dollars | |
| 8 | Solar Component Cost: | $ 120,807.00 | dollars | |
| 9 | | | | |
| 10 | Section 2: Installation and Fees: | | | |
| 11 | Installation cost per watt: | $ 0.50 | dollars | |
| 12 | Electrical Inspection: | $ 500.00 | dollars | |
| 13 | Other Fees: | $ 1,000.00 | dollars | |
| 14 | Total Installation and Fees: | $ 14,000.00 | dollars | |
| 15 | | | | |
| 16 | Section 3: System Life and Maintainence | | | |
| 17 | System Life Expectency: | 25 | years | |
| 18 | Yearly Degradation: | 0.50% | percent | |
| 19 | Yearly Maintainence Cost: | - | dollars | |
| 20 | Maintainence Cost Adjustor: | 3.00% | percent | |
| 21 | | | | |
| 22 | Section 4: Incentives and Rebates: | | | |
| 23 | MA-Manufactured Components: | NO | Yes / No | |
| 24 | MTC Rebate Per Watt: | $ 3.25 | dollars | |
| 25 | Total MTC Rebate: | $ 81,250.00 | | |
| 26 | REC Revenue per Watt: | $ 0.03 | dollars | |
| 27 | REC Revenue Annual Adjustor: | 4.00% | percent | |
| 28 | REC Term Length: | 5 | years | |
| 29 | | | | |
| 30 | Total Initial System Cost: | $ 53,557.00 | | |

| | | | |
|---|---|---|---|
| 32 | Section 5: Financing | | |
| 33 | Down Payment Percentage: | 25.00% | percent |
| 34 | Down Payment: | $ 13,389.25 | dollars |
| 35 | Loan Interest Rate: | 6.00% | percent |
| 36 | Loan Period: | 20 | years |
| 37 | Monthly Payment: | $ (287.77) | |
| 38 | | | |
| 39 | Section 6: Energy Usage | | |
| 40 | Yearly Energy Consumption: | 102000 | kWh |
| 41 | Cost of Electricity: | $ 0.16 | $ per kWh |
| 42 | Electricity Cost Annual Inc per Year: | $0.0018 | |
| 43 | | | |
| 44 | Section 7: Economic Factors | | |
| 45 | Current Interest Rates: | 3.00% | |
| 46 | | | |
| 47 | Section 7: Analysis | | |
| 48 | Net Present Value: | $ 112,865.19 | dollars |
| 49 | Monthly Cash Flow (Year 1): | $ 275.31 | |

**Figure 12: A screenshot of the economics spreadsheet.**

In the first section of the spreadsheet, "System Size and Cost" we are required to determine the cost per Watt of the solar panels and the cost of the inverter and other equipment. This data comes directly from our list of solar panels and our inverters and is explained in depth in the section titled "Possible Solar Panels and Placements".

The second section, "Installation and Fees", describes an estimated cost for installation on a per Watt basis, an estimation of electrical inspection costs, and several other fees. The installation cost per Watt is the largest factor in determining system cost, so it must be estimated with high precision. We used the average cost for a solar system, installation and component costs combined, of $8.03 provided by the MTC[36] and subtracted out the component cost to leave us with our installation cost alone.

[36] Massachusetts Technology Collaborative. *Information on installers and costs.* Retrieved 1/15, 2009, from http://www.masstech.org/SOLAR/CS%20Installer-Cost-Location%20Data%20for%20Website%20as%20of%2001-31-09.xls

Unfortunately, without getting an actual bid from contractors, this is the most accurate estimate we cost estimate we can get. We also came in correspondence with some installers, who confirmed the rate of $8.00 per watt and gave us a further cost breakdown. A summary of these correspondences can be found in “Appendix X: Correspondence”.

Section three titled “System Life and Maintenance” provides an estimation of the system life expectancy, the yearly degradation factor, and the yearly maintenance cost. To use a safe estimate of system life expectancy, we chose twenty-five years, as that is the typical warranty on solar panels. It could be the case that the system continued to work after twenty-five years; however we would rather use a conservative estimate and analyze the feasibility over the next twenty-five years.

The yearly degradation factor is the percentage that the electricity production is decreased each year, due to several factors such as: packaging material disintegration, adhesional degradation, interconnect loss of integrity, moisture intrusion, and semiconductor device degradation.

Unfortunately, an effort to collect data regarding photovoltaic degradation has not been well coordinated. There are, however, two studies that look at degradation on single and multicrystalline photovoltaics. The Sandia study, which was on multicrystalline photovoltaics, reported 0.5% degradation per year. The National Renewable Energy Laboratory reported 0.7% degradation per year on a study they did looking at single and multicrystalline photovoltaic. The graph below shows what the overall efficiency of a solar panel would be over the course of twenty five years, assuming it started at 13% efficiency[37].

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[37] “Commonly Observed Degradation in Field-Aged Photovoltaic Modules.” Quitana, M.A.; King, D.L..; McMahon, T.J. and Osterwald, C.R.

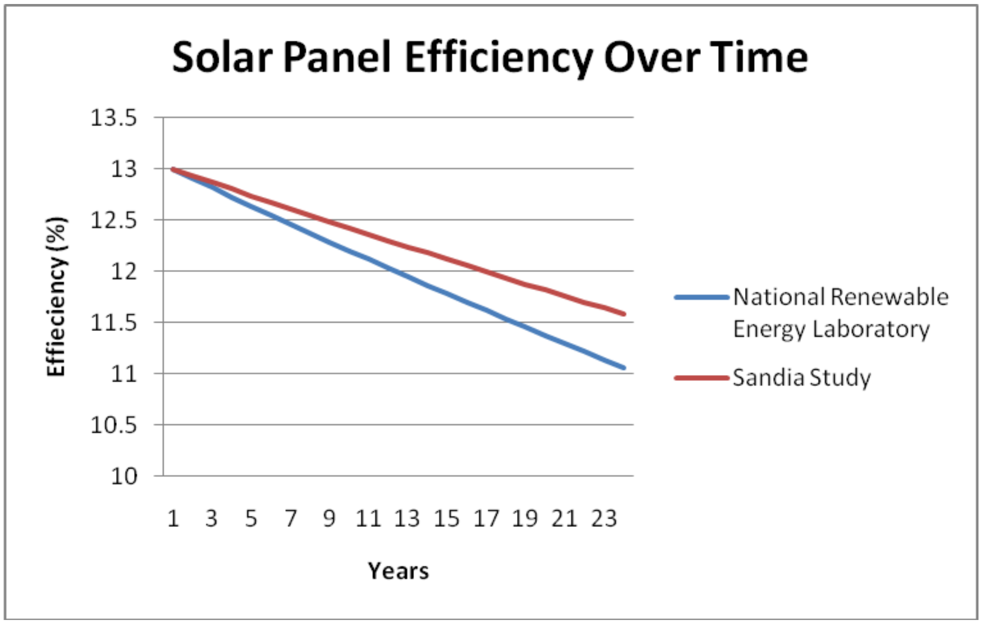


Figure 13: Solar panel efficiency over time

Based on these two studies, we have decided to use the average of their results, and estimate 0.6% annual degradation.

Because solar panels contain no moving parts maintenance costs are found to be extremely minimal. Due to the fact that the lifetime warranties of solar panels are generally found to be twenty years or more, it is unlikely that any maintenance costs will be realized within this time span. The cost of maintaining an array will generally reside in labor, not replacement parts. Thus, maintenance costs for solar systems are estimated at costing 4% of the initial system cost.[38]

The "Incentives and Rebates" section is straightforward and its content is taken directly from MTC's economic spreadsheet. It describes the total MTC rebate based on the system size, whether or not the building is public (churches are not considered public in this case), and whether or not the components are manufactured in Massachusetts. This rebate will most likely be $3.25 per Watt for Wesley United Methodist Church. Unfortunately, the MTC rebate is the only incentive applicable to the church, because all other aid is in the form of tax incentives.

[38] A Rural Electric Co-op's Experience with Photovoltaic Systems for Livestock Water Pumping, Skinner, Rolland http://www.usda.gov/rus/electric/engineering/sem2002/skinner.htm

Section five, “Financing” allows the option for testing how the feasibility of a system changes by using a loan. This section requires the percentage of the entire loan that the down payment makes up, the interest rate, and the loan term. It assumes that a fixed rate mortgage will be used, and calculates the monthly payment. If you wish to not use any financing, simply put down that the down payment makes up 100% of the loan.

Section six deals with energy cost. The current cost of electricity was based on recent electricity bills from Wesley United Methodist Church. Current electric rates are $0.16 per kWh. The energy cost adjustor, or the amount that electricity costs will increase each year was determined based on historical data from the Energy Information Administration[39]. Data for the national average cost per kWh from 1973 to 2007 was taken and plotted to show the trend over time.

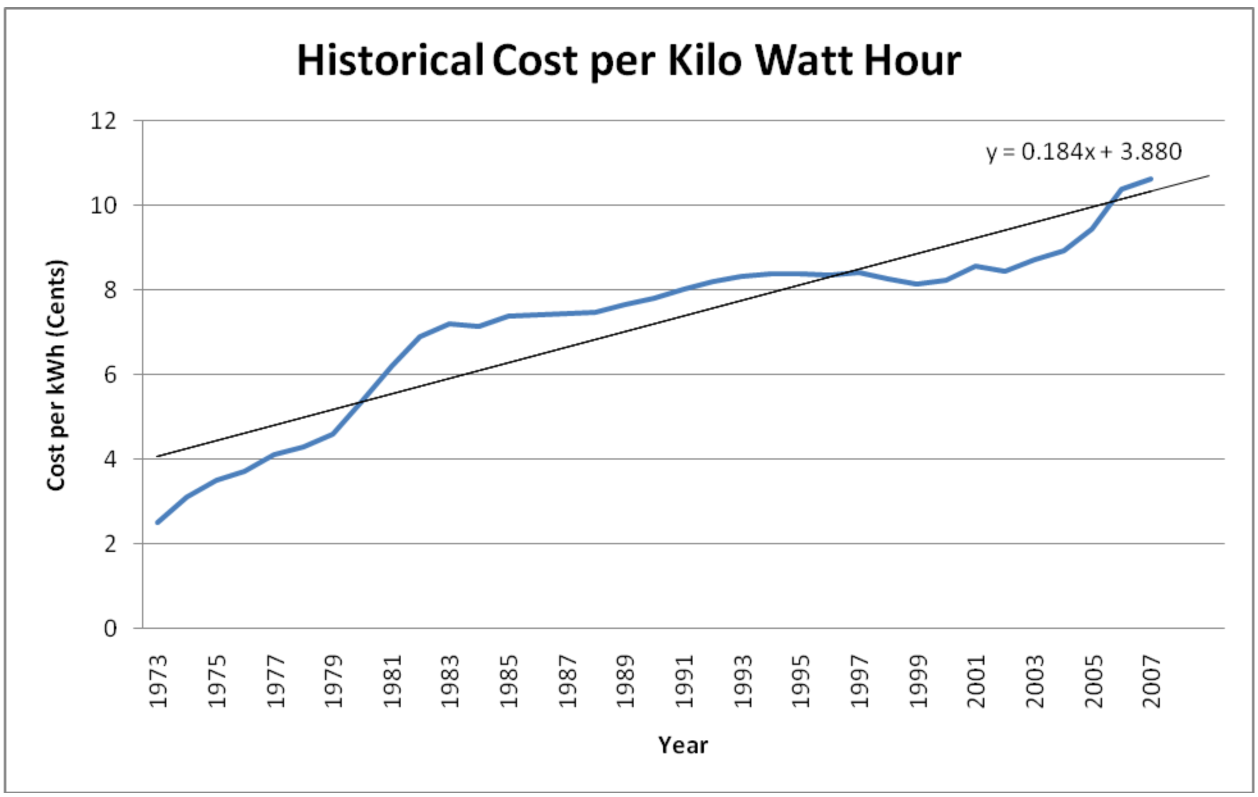


**Figure 14: Historical prices of the national average cost per kWh.**

39 Average Retail Prices of Electricity, Energy Information Administration http://www.eia.doe.gov/emeu/mer/prices.html

We initially expected an exponential increase in energy cost, or a certain percentage per year, however, the data clearly shows a linear increase of about $0.0018 per year. It is possible, and in fact likely, that energy costs will increase more rapidly in the future, though, as we begin to run out of fossil fuels. However, we will use the historical data as a way to predict future increases.

The data above is taken at a national level and the costs of electricity can vary at a local level, based on the competition between companies, demand, and distribution fees, however, energy price trends happen at a national level. We have addressed this by taking the starting value for our predicted energy costs to be the present cost of electricity from one of Wesley United Methodist Church's recent bills. We then estimated that this current cost of $0.16 per kWh would increase at a rate of $0.0018 kWh per year as the national data predicts.

The last section in the economic spreadsheet requiring input is the "Economic Factors" section, which calls for an estimation of the average inflation. This was determined by looking at historical data for the Consumer Price Index (CPI)[40]. The CPI was at 10 in 1914, and ended up at 217 in 2008. The percent change in the CPI from year to year was dramatically different, as shown below.

[40] U.S. Department Of Labor, Bureau of Labor Statistics.

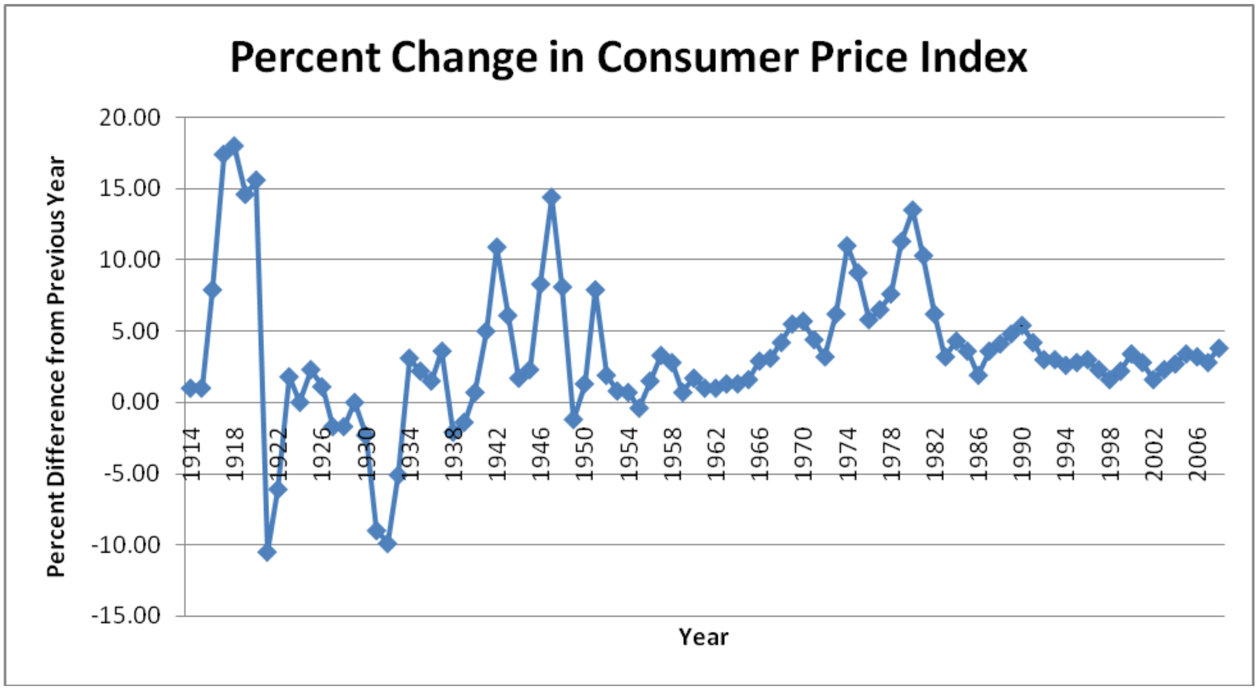


**Figure 15: The year to year percent change in the Consumer Price Index.**

Solving the traditional compound interest formula for the interest rate, we found that typical inflation is 3.29% per year. A graph comparing the value of $10 by 1914 standards can be seen below, comparing the actual inflation with this estimate of 3.29% per year.

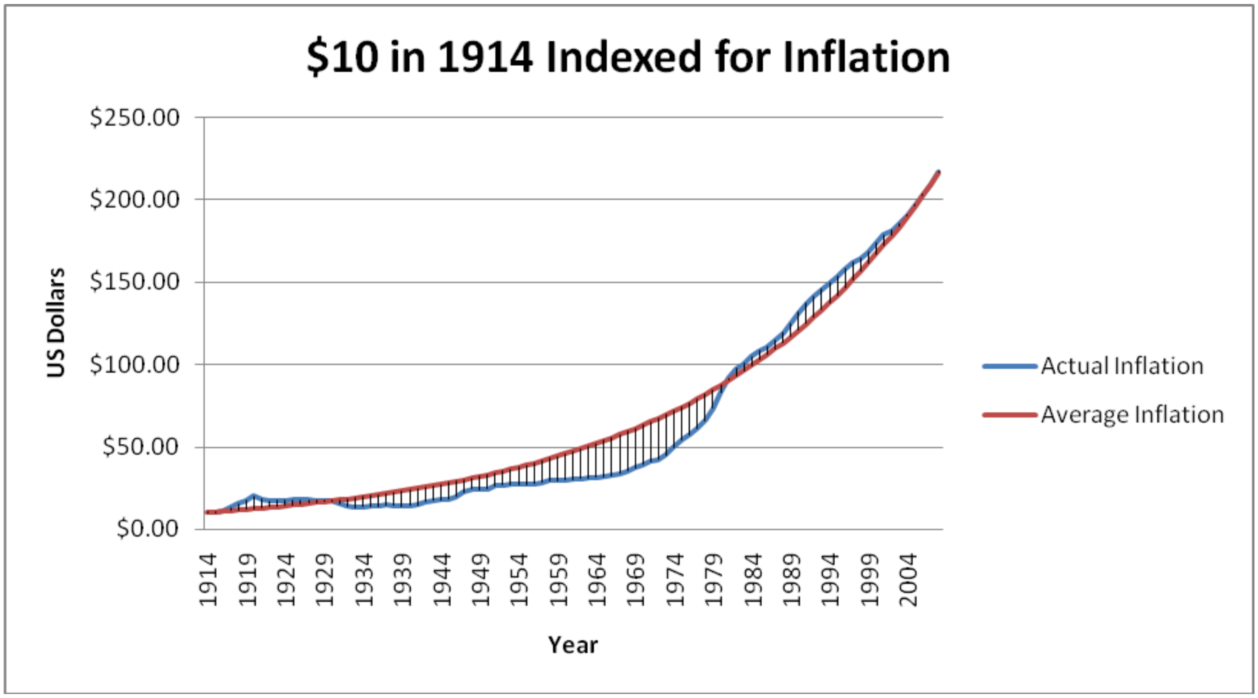


Figure 16: The amount of money required to have the same value as $10 in 1914.

By comparing the two graphs, we see that although it is very difficult to predict what the CPI will be in a given year, over long periods of time, such as the length of this solar panel investment, the average rate of 3.29% is a good estimation.

By obtaining these parameters from historical data, measurements, or by professionals in the business, we have given ourselves the tools necessary to analyze the feasibility of different solar panel systems. The next section in this report, “Scenarios”, will use what we have outlined here to expand upon the feasibility details of certain photovoltaic systems.

# 7. Scenarios

To correctly assess the feasibility and impact this project would have on the church a number of practical scenarios were generated. These scenarios are analyzed using the economic spreadsheet in the economic context presented in chapter six. In each scenario, the system size is varied. In order to accommodate a larger system size, different installation procedures are necessary.

## 7.1 Assumptions and Selection of Solar Panels

The first objective in creating a list of practical scenarios was to determine the base assumptions. The summation of these assumptions is then factored into each scenario to build a base by which all scenarios can be assembled on. By taking this approach we limit the number of changing variables to more correctly display the affect that each scenario has on the outcome of the entire project. The assumptions listed below are values that extend those found in the Economic Context section.

**100% Down Payment:**

After discussing with the financial representative at Wesley United Methodist Church we discovered the church holds no debt. Thus, there is no reason to take out a loan to pay for the system. The church representative assured us that if a system was purchased, it could be paid either through gifts or through a trust fund.

**Using Kyocera's KC200GT Solar Panel:**

One of the most critical choices in constructing a solar panel array is the choice of which solar panel to use. To choose the most practical panel available a list of potential solar panels was constructed and from that list the panel with the best credentials was taken. This list compounded several important factors, the most important of which were: energy production, cost-per-watt, and panel size. Based on these factors, the recommended panel was Kyocera's KC200GT. This panel embodied high energy production, 200 Watts, low cost-per-watt at $4.35, and relatively small footprint.

**42 degree solar panel array tilt:**

Another critical factor in determining how much energy is realized by the solar panel array is the tilt of the panel relative to the sun. Throughout the year the sun's position changes every month. For solar panels, the optimum tilt is the one that is perpendicular to the incident angle of the sunlight. However, for this system, the panels would not be mechanically tracking the sun, instead they are manually set. The conclusion to this problem was to tilt the panels at 42 degrees, the exact latitude of the Worcester area. This provides the best energy production for non moving arrays.

**Sunny Boy Inverters:**

For system sizes 25kW and less, the Sunny Boy line provides a very inexpensive inverter to match the output of a chosen array size. As discussed in Chapter 5, the Sunny Boy products are effective in price, efficiency, and reliability and fits quite nicely in the following scenario sizes. Using these inverters, we estimated a total DC to AC conversion factor of 79.49%.  This factor was a result of the inverter efficiency as well as the efficiency of the AC and DC wiring and connections to the system. Combining the efficiency of the solar panels and the efficiency of the DC to AC conversion, we calculated an overall system efficiency of 11.92%.

## 7.2 Scenario 1: Small System Size:

First we investigated the smallest system available. This system, while humble in size, must still be capable of providing a moderate percentage (10%-15%) of power to the church. However, due to the church's large energy usage, a small system might actually be considered large in other applications. For the "Small System" scenario we chose to implement a 10kW system.

## Characteristics:

One of the most notable advantages to constructing a small solar panel system is the fact that it comes with a small capital cost. The initial system cost was calculated to be $49,000.00 after the appropriate rebates are applied. This system consisted of forty seven solar panels ($40,898.00) and two SB4000US DC-to-AC inverters ($5,370.00) with the installation accounting for the remaining cost. The entire system spanned 126.42 square meters and required very few, if any, elevated platforms.

The greatest disadvantage of small solar array is the fact it provides such a small percentage of the total power consumed by the church. This solar array will produce less than one-sixth of the energy that the church is currently consuming and will take nineteen years to payback its initial cost. A system with such a long payback period is also susceptible to being quickly outdated by new and improved technology.

## Impact:

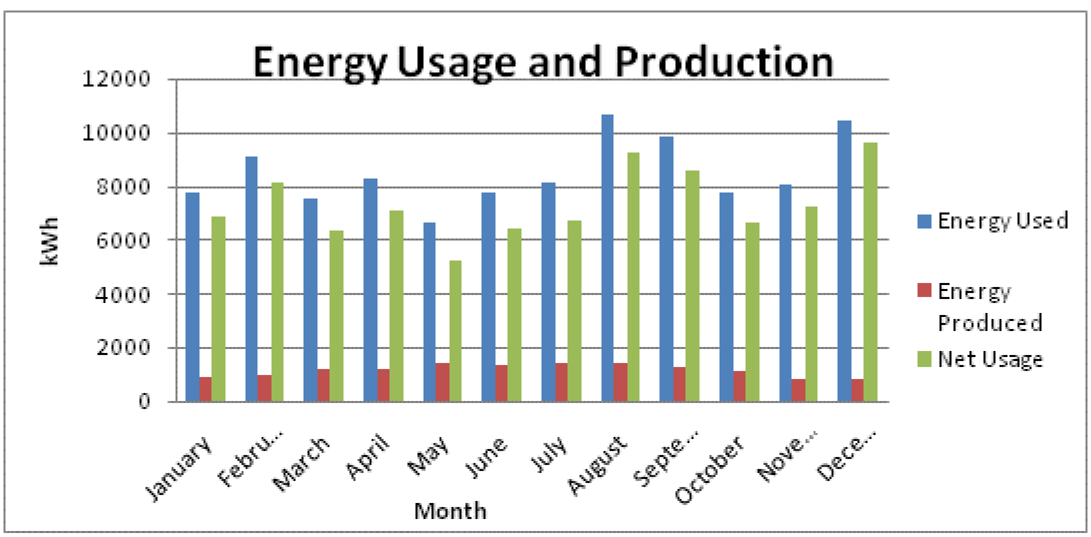


Figure 17: 10kW System Energy Production

The chart above depicts the energy consumed by The Wesley United Methodist Church, seen in blue, and the electricity produced by the 10kW solar array, seen in red. The total "net" usage is seen in green which is the difference between the energy consumed and the energy produced.

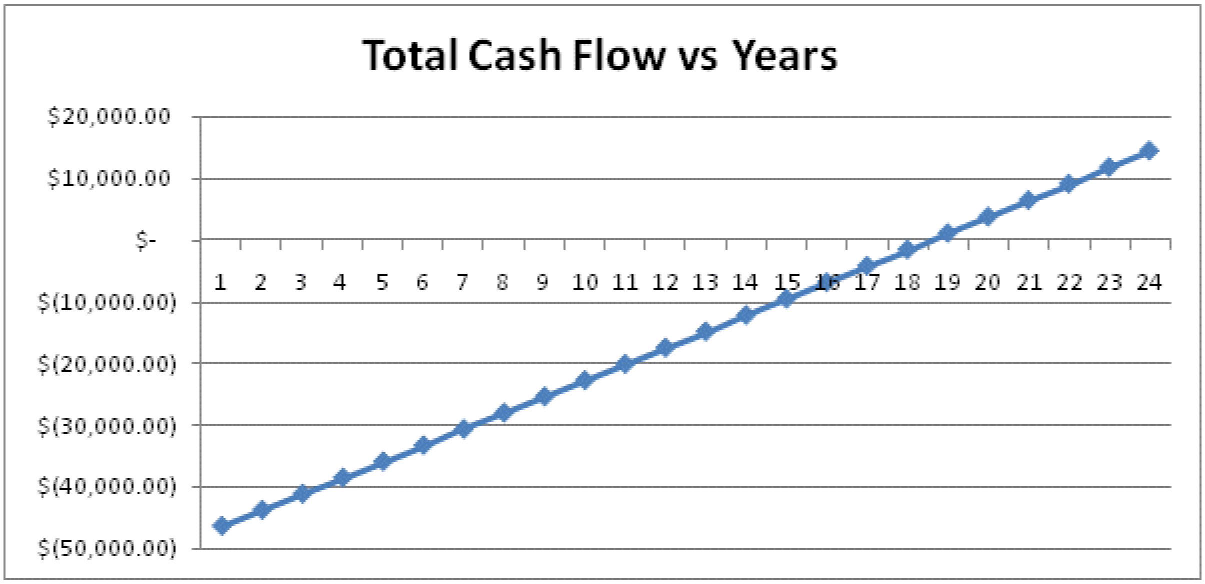


Figure 18: 10kW System Cash Flow

Figure 2 depicts the total cash flow of the 10kW array. The figure describes the trend of savings from the initial purchase in year one to the life expectancy of a solar array, year 25.

## 7. 3 Scenario 2: Moderate System Size:

The second system we chose to investigate was a moderately-sized solar array. The goal of this system was to provide more electricity than the smaller apparatus while not drastically increasing cost. This system must be capable of providing approximately 20% of the churches electricity consumption. For the "Moderate System" scenario we chose to implement a 15kW system.

### Characteristics:

The advantages to a 15kW system are that it produces much more electricity than its smaller system counter-part. In addition, the cost of constructing such a system is relatively inexpensive when compared to the larger systems. To carry out such a system would require a total initial payment of $72,750.00 after rebates, consist of 70 solar panels ($60,900.00), two SB6000US inverters ($7,450.00) and installation costs. The system would be capable of producing slightly less than one quarter of the energy consumption of the church.

With an increase in the number of solar panels on the roof of Wesley United Methodist Church, it becomes apparent that space is limited. A majority of the seventy solar panels, occupying 188.28 square meters, will need to be raised on an elevated platform to avoid shadowing affects. In addition to being space-limited, the "Moderate system" scenario will take nineteen years to pay off.

## Impact:

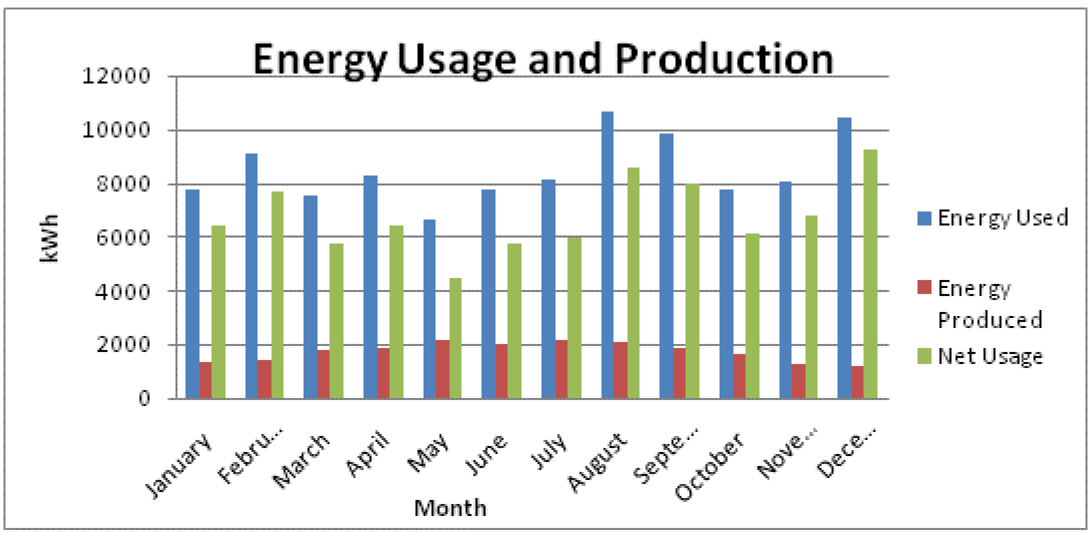


**Figure 19: 15kW System Energy Production**

The chart above depicts the energy consumed by The Wesley United Methodist Church, seen in blue, and the electricity produced by the 15kW solar array, seen in red. The total "net" usage is seen in green which is the difference between the energy consumed and the energy produced.

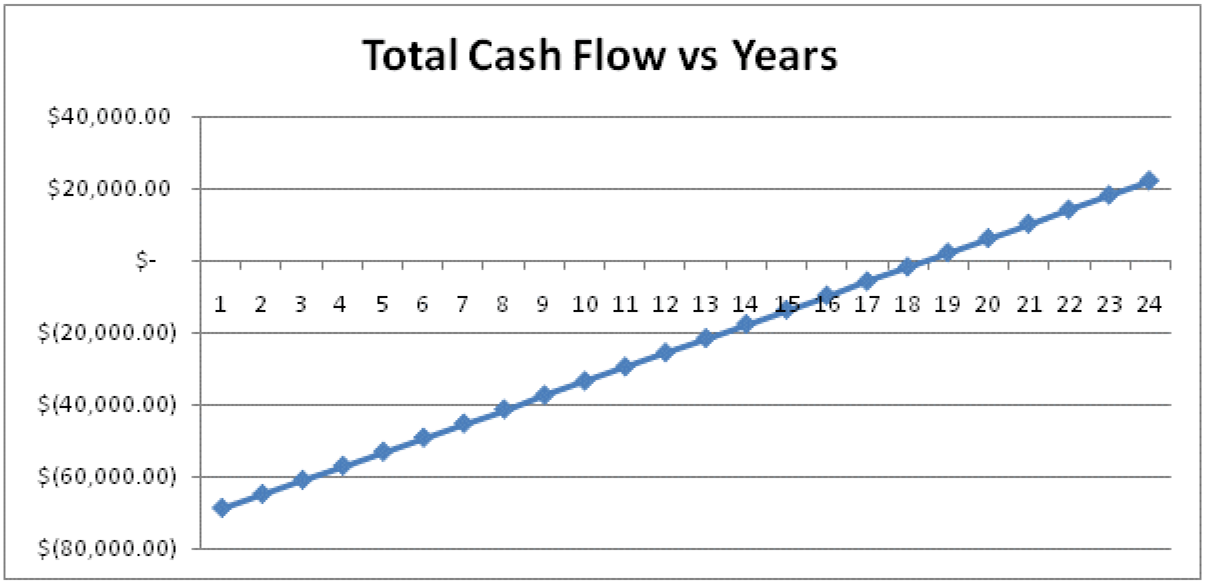


Figure 20: 15kW System Cash Flow

Figure 4 depicts the total cash flow of the 15kW array. The figure describes the trend of savings from the initial purchase in year one to the life expectency of a solar array, year 25.

## 7.4 Scenario 3: Maximum System Size:

The third scenario maximized the number of solar panels that could be placed on roof. The energy produced by smaller systems is almost trivial compared to the total power consumption by the church. Thus, the goal of this system is to provide the most electricity possible using the maximum roof space available. For the "Maximum System" scenario we chose to implement a 25kW system.

### Characteristics:

The greatest advantage of a large system is the large power output. A 25kW system is capable of producing more than one-fourth the church's electricity, and, at various times, almost one third the total power consumption.  Based on current costs, the maximum system size also has a payback period of nineteen years, the same as the modernly sized system found in the previous section: nineteen years. Although the system payback period is equivalent to the last three scenarios, this example produces a much higher cash flow: averaging around $6,800 per year compared to $4,000 for the moderate system and $2,800 for the smallest system.

The greatest disadvantage to this system is the cost to implement. Constructing a system of this size takes an initial $120,250.00 of capital investment, consisting of 117 solar panels ($101,790.00), three SB7000US inverters ($12,057.00) and installation costs. To fit 117 panels on the roof of the church requires elevating almost all of the panels and placing several of them on the slated section of the roof.

## Impact:

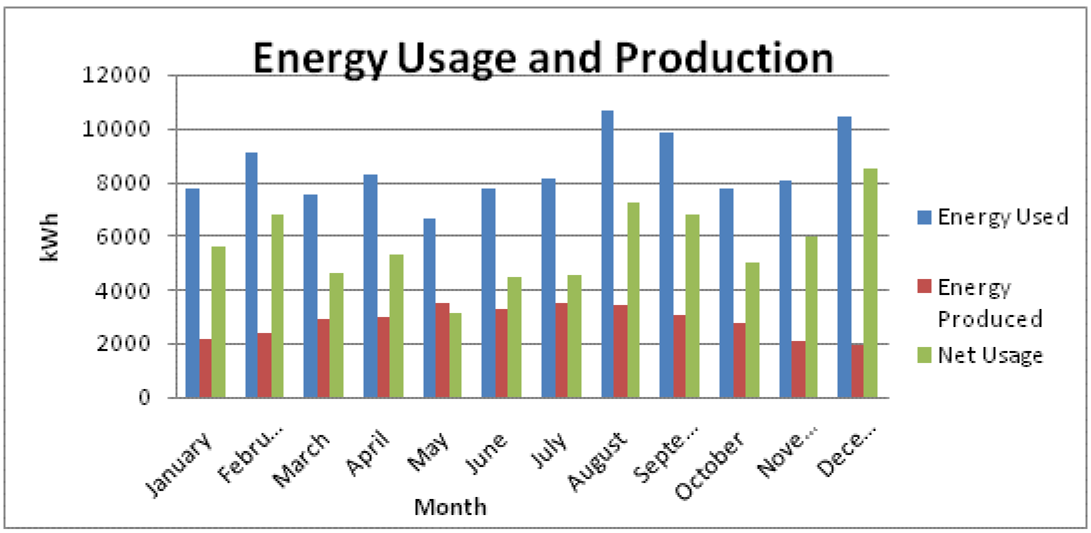


Figure 21: 25kW System Energy Production

The chart above depicts the energy consumed by The Wesley United Methodist Church, seen in blue, and the electricity produced by the 25kW solar array, seen in red. The total "net" usage is seen in green which is the difference between the energy consumed and the energy produced.

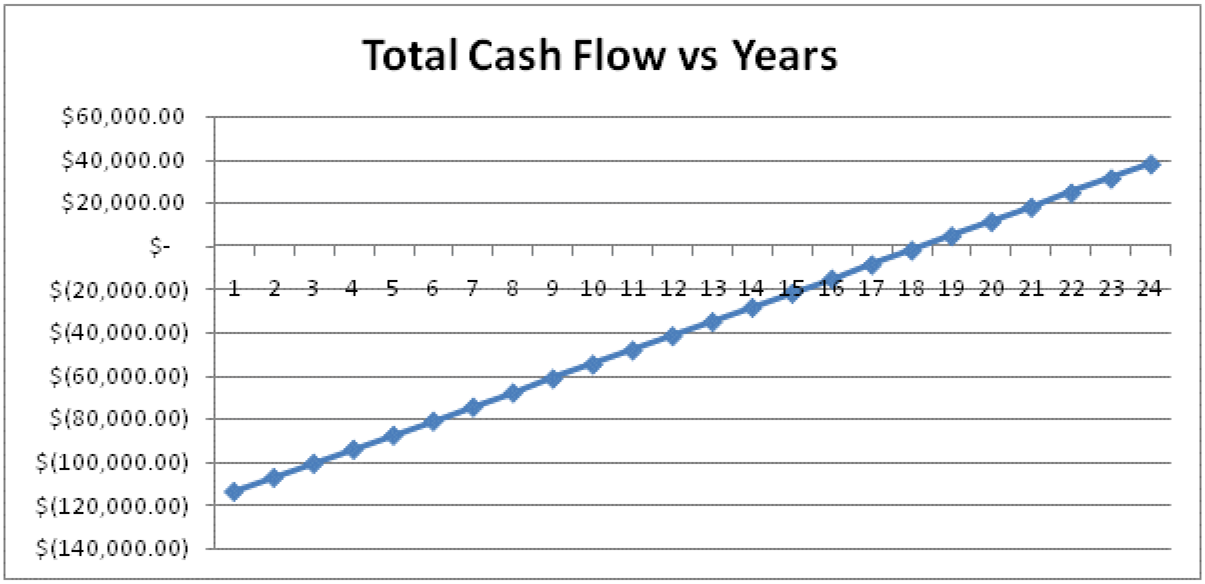


Figure 22: 25kW System Cash Flow

Figure 6 depicts the total cash flow of the 25kW array. The figure describes the trend of savings from the initial purchase in year one to the life expectancy of a solar array, year 25.

## 7.5 Scenario 4: Maximum System Size with Volunteer installation:

The final scenario produced assumed that the installation cost could be reduced by using volunteers to provide most of the necessary labor. Labor is the most significant cost involved in installing a solar panel array besides the cost of the system itself. The only requirement is that a licensed electrician supervises the electrical work.

### Characteristics:

As stated in the section above, a solar system of this magnitude is capable of producing more than one fourth the energy consumption of the church. With volunteer work the system initial cost drops drastically from $120,250.00 to $41,057.00. The return on investment drops from nineteen years to only six! The disadvantage to implementing such a large system is the need for elevated platforms for each panel. One hundred and seventeen solar panels require all the flat space on the roof including the slated area.

## Impact:

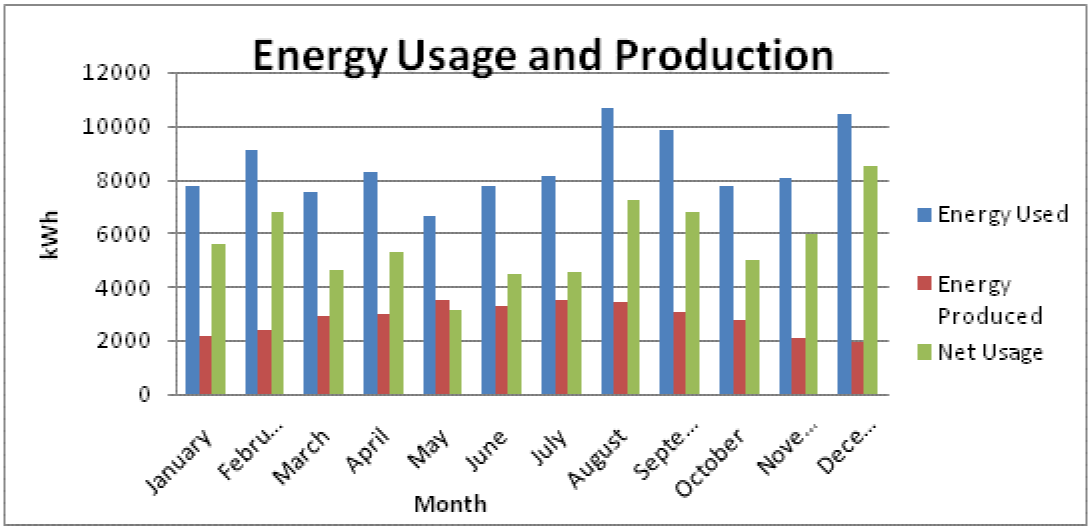


Figure 23: 25kW System Energy Production

The chart above depicts the energy consumed by The Wesley United Methodist Church, seen in blue, and the electricity produced by the 25kW solar array, seen in red. The total "net" usage is seen in green which is the difference between the energy consumed and the energy produced.

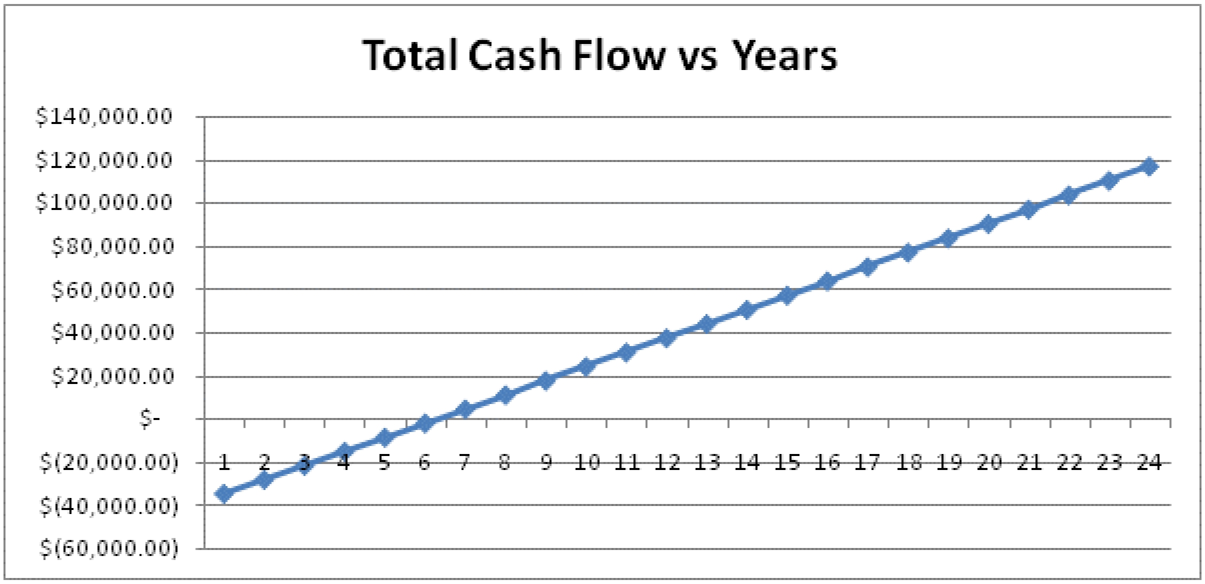


Figure 24: 25kW System Cash Flow with Volunteer Installation

Figure 8 depicts the total cash flow of the 25kW array with volunteer installation. The figure describes the trend of savings from the initial purchase in year one to the life expectancy of a solar array, year 25.

## 7.6 Assessment:

Revisiting the scenarios above, cost of installation is the single most important factor in whether a system will be feasible. Currently, the cost-per-watt of solar panels is generally fixed at $4-$5. This allows minor room to reduce the cost. However, because installation is not necessarily a fixed cost and most of the work can be done by knowledgeable volunteers it is possible to keep this cost much lower.

Another noticeable result of analyzing these scenarios is that the systems of varying sizes all have a break-even point of approximately nineteen years. The main reason for this phenomenon is the fact that larger arrays, despite their greater initial investment, recover savings much quicker because of their greater electricity production. The 25kW array may generate $164,997.40 in the course of 25 years compared to a smaller, 10kW array which may only produce $65,998.96 of revenue. This observation displays the fact that a larger solar array is much more beneficial in the long term; however a small one is financially easier in the short term.

## 7.7 Sensitivity Analysis

Although we have determined that a largest array is the optimal scenario for the production of electricity the nine-teen year break-even point is near the system life expectancy of 20-25 years. However the cost of solar cells is constantly decreasing. Based on discussions with solar manufacturers and installers, it is expected that costs for solar panels will fall quickly in the next three to five years and the payback period will thus decrease rapidly. To illustrate the effect influence lower costs on the solar market we decided to create a sensitivity analysis. This analysis below offers a fifth scenario that projects possible costs and efficiencies of solar panels in five years.

The following is a scenario assumes that in the future, technology will reduce the cost-per-watt of a solar panel from $4.30 to $2.00 and increase the solar cell efficiency from 15% to 20%. The result is a dramatic drop in the amount of time it takes to break-even. The period of time necessary to break-even drops from nineteen years to only nine and the number of panels required to generate the same amount of electricity is reduced from 117 panels to 88. The reduction in the number of panels also reduces the need to install solar panels in sub-optimal locations.

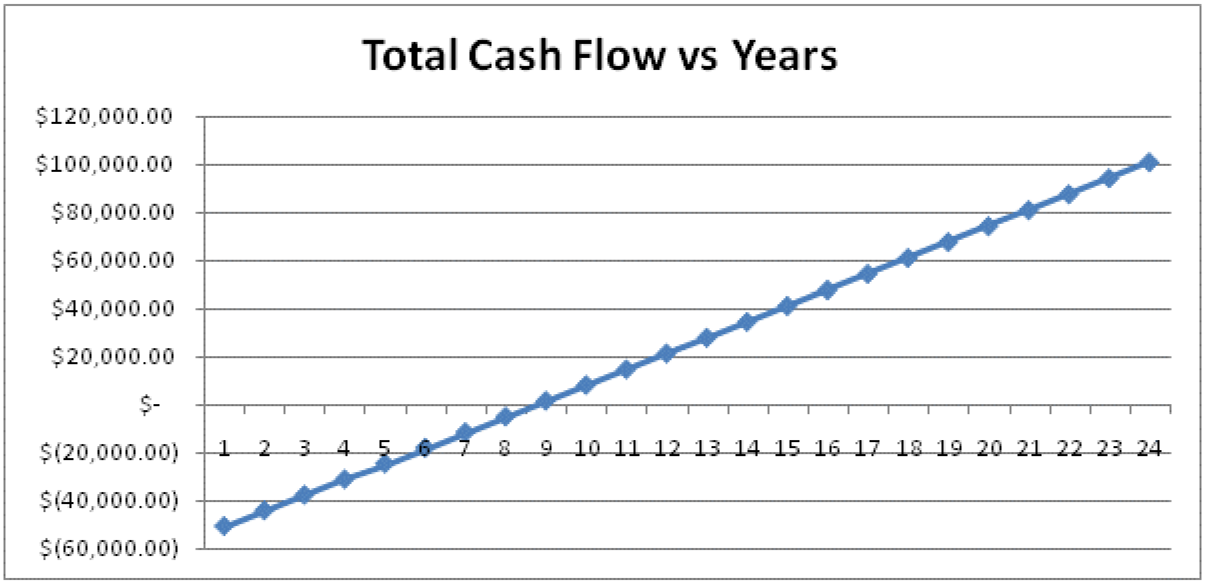


Figure 25: Futuristic 25kW System Cash Flow

Figure 9 depicts the total cash flow of a 25kW array purchased in five years. The figure describes the trend of savings from the initial purchase in year one to the life expectency of a solar array, year 25.

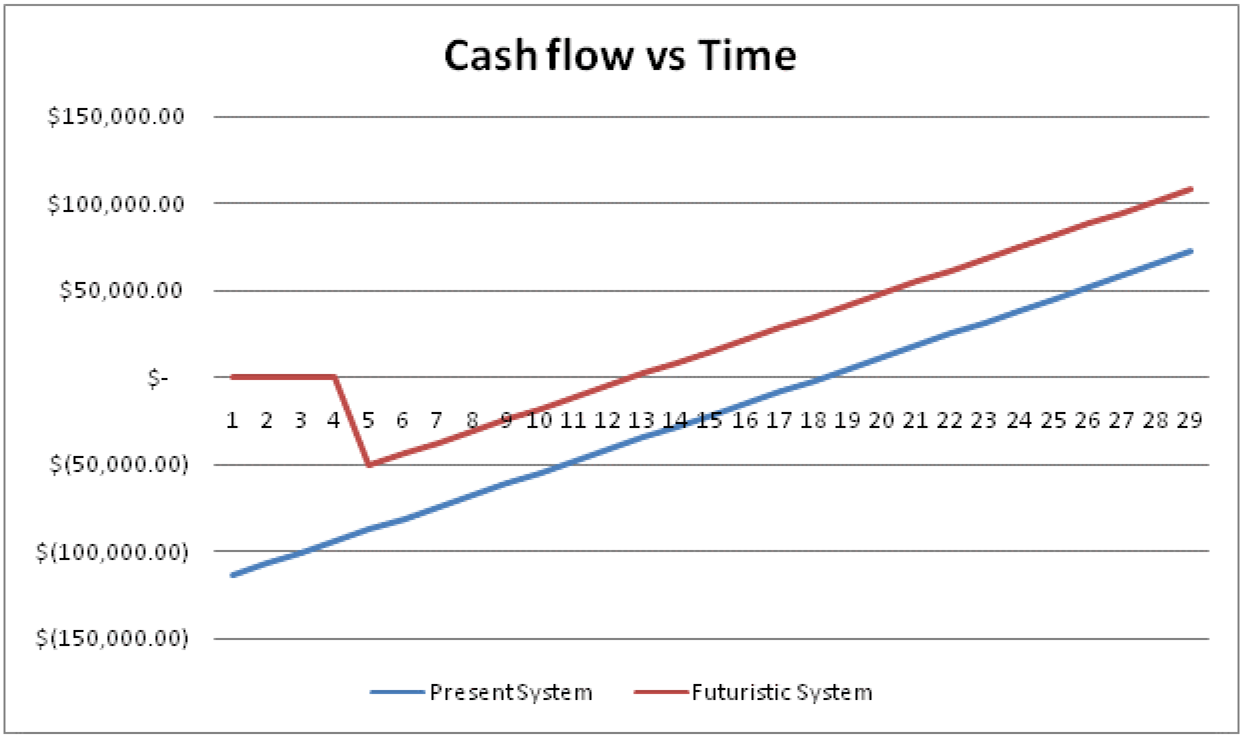


Figure 26: The Effect of Waiting 5 Years

The chart above depicts the outcome if a 25kW system, scenario three, was purchased in the present time period and if a 25kW system was purchased in five years using the data described above. As the results in figure 10 clearly demonstrate, it would be much more beneficial, economically, to implement a 25kW system after five years rather than at the current time period.

# 8. Social and Environmental Impact

The significance of solar panel systems go far beyond financial factors. Alternative forms of energy are important to the sustainability of our planet. This section identifies the social and environmental impacts that a solar panel installation would have on the church and what we have done to disseminate information about solar panel installations.

## 8.1 Effects on Carbon Footprint

A Carbon footprint is a measurement of the impact a person or a building has on the environment. It is usually represented as the number of tons of carbon dioxide released into the atmosphere by things such as power plants, cars, or burning heating oil. Based on information available from the Global Footprint Network, current levels of emissions exceed the capacity that the earth is able to absorb. This rate has been sharply increasing since the 1960s.[41] Finding solutions to the problem of increased emissions is critical to environmental sustainability. However, offsetting the world's carbon emissions by planting trees isn't an efficient solution to the problem of increased emissions. A better solution is reducing the emissions themselves.

Reduction of emissions requires cutting back the use of fossil fuels. This means driving less, using cars that are more efficient, and meeting high standards for emissions testing. It also means using less electricity, and when possible looking for 'green' alternatives. Sources of environmentally friendly electricity include solar PV, wind energy, and hydroelectric; although hydroelectric plants significantly disrupt the river upon which they are built.

The church's carbon footprint is primarily made up of the electricity it consumes, and the natural gas used for heating. Based on the formulas used by the Global Footprint Network the annual

[41] Global Footprint Network. *Globalfootprintnetwork.com.* [Online] [Cited: December 2, 2008.] http://www.footprintnetwork.org/en/index.php/GFN/page/carbon_footprint/.

electricity consumption creates 59 tons of carbon dioxide.[42] The total amount of carbon dioxide created by or on behalf of the church is at least 67 tons of $CO_2$ emissions per year.[2] If the church were to install a 25kW solar array, they would significantly reduce the their annual emissions to 39 tons of $CO_2$, a thirty three percent reduction.

## 8.2 Environmental Stewardship

Wesley United Methodist Church commissioned this study of green technology as an expression of its commitment towards “environmental stewardship.” Many of the individuals who participate in the church feel that it is their responsibility to the community to contribute to the adoption of clean energy. For that reason, the implementation of a solar array would not only reduce green house emissions, but also spread awareness to the wider community and inspire other community members to follow suit. As stewards of the Earth, a church could send a powerful message to the community by acting on these values in their place of worship.

Green stewardship is rapidly becoming a popular topic in the Christian community. There is a new bible that has been printed called the “Green Bible”. It highlights eco-friendly passages in green and has an index in the back where one can look up “green” passages. It is said that the “Green Bible sets out an urgent agenda for the Christian community.”[43] One particularly relevant passage from Leviticus is as follows, “You shall not strip your vineyard bare, or gather the fallen grapes of your vineyard; you shall leave them for the poor and the alien: I am the Lord your God”. Another moving passage in support of green stewardship is from Psalm 24, “The earth is the Lord’s and everything in it, the world, and all who live in it.”

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[42] Global Footprint Network. *Globalfootprintnetwork.com.* [Online] http://www.carbonfootprint.com/carbonfootprint.html

[43] Harper Collins Publishers. (2009). *The Green Bible.* Retrieved 3/1, 2009 from http://greenletterbible.com/

Green stewardship is a movement within the church that is rapidly gaining momentum as more and more Christians become aware of the threat humans pose to the planet. As the earth's destruction continues, many are starting to feel it is part of their calling as followers of God to help.

The city of Worcester has many churches of many faiths each concerned about the cost of rising electricity as well as the benefits of helping the environment. If the Wesley United Methodist Church were to decide to implement a solar system, it would be recognized as one of the first churches in the area to do so and demonstrate its leadership as an environmental steward in the community. If the implementation of green energy proves to be beneficial the Wesley United Methodist Church will become an example to those in Worcester and New England.

## 8.3 Informational Brochure

An informational brochure has been created to spread information to the church about the benefits of solar panel installations. Our correspondence with a Methodist Church from Maine showed us that the spread of information about a solar panel project can greatly reduce opposition and build support for this costly expenditure. The brochure captures the essence of our results. It has financial information, including a graph about the amount of energy produced with a large scale system and a graph showing how the payback period is directly related to the system cost per watt. The brochure also includes a couple of passages from the bible that support the concept of green stewardship and accompanying pictures of God's magnificent creation. The brochure can be found in Appendix M: Informational Brochure.

## 8.4 Survey

After our final presentation, given on March 1, 2009, we handed out a brief survey to those who were in attendance (Appendix N). The audience consisted primarily but not exclusively of members of the Board of Trustees and Finance Committee at Wesley. There were only fourteen people in attendance, so the survey is of little statistical value; however it has helped us to realize some of the general perceptions held by the congregation.

All fourteen people responded they felt that investment in alternative energy is important, however their reasons for this answer varied. Some cited green stewardship as their primary reason, while others pointed to the fact that there is a finite supply of fossil fuels. Still others felt that alternative energy was important so that the country could become independent of foreign oil. Most mentioned that it was important to be environmentally conscious and many responses included a combination of these reasons.

In response to the second question, which asked about what the public's perception of a solar panel installation on Wesley United Methodist Church would be, the answers were again unanimous. All responses stated that the public's view of such an installation would be positive. One responder felt that it would have limited affect, and only be slightly positive, while many responded that this would be "very positive", "forward thinking", and "green."

The last two questions had a wider range of responses than the first two. When asked whether or not a solar panel installation should be pursued even if there was no economic gain, most said that it should be pursued for environmental reasons, however, there were a few responses that said that the only factor that was important to them was the financial savings.

Finally, on the last question, which asked whether or not Wesley United Methodist Church should pursue a solar installation now, in the future, or not at all, there was the widest disparity of answers. A number of people felt that the church should wait for five years and then reevaluate the situation, while others felt that church should do more research about it now. Some people felt that the church should absolutely pursue it now, while there was one response that said it should not be pursued at all.

While everyone in attendance of our final presentation felt that alternative energy was important, it can be seen by looking at the remainder of the questions that this belief was weighted differently by each person.  Looking into the future, the congregation will have a lot to debate as they try to decide what to do with the results of this project.

## 9. Conclusions and Recommendations

The benefits of solar panel installations are numerous, ranging from green stewardship to reducing the church's carbon footprint, and from building a strong public image for the church to reducing the church's monthly electricity bills.

The feasibility of such a system is not determined by a financial analysis alone. Based on current prices, a solar panel system installed at Wesley United Methodist church would have a nine-teen year payback period.

We recommend that the church strongly weigh the positive impacts of solar panels alongside the economic feasibility of installation. With the present conditions, it is unlikely that a solar panel installation will lose money over the lifetime of the system; however, it requires a large capital investment and has a slow payback. The church should monitor future the economic conditions using the "Simplified Economics Spreadsheet for Wesley United Methodist Church" that we have provided to get an estimate of economic feasibility of a solar power system.

When it is determined that the benefits from a solar panel installation outweigh its drawbacks, such as when the cost per watt drops below a threshold price, the church should follow the procedure outlined below:

1. Form a committee of people who are interested in seeing this project carried forward.
2. Have the committee hold meetings/focus groups with interested members of the congregation to educate the congregation about solar panels and answer any concerns. The committee can use our presentation, brochure, and any of the other materials in this report.
3. Have the committee members contact three to five installers and go through the bidding process as we have outlined.

4. Use the graph “Simplified Economics Spreadsheet for Wesley United Methodist Church” with current data to determine the financial feasibility of this system.

After estimates have been received, the selection process can begin. After choosing an installer, the rest of the process, such as acquiring the Commonwealth Solar rebate and fulfilling permit obligations will be handed by the chosen installer. Hopefully, as solar panel technology continues to drop in price, the church will be able to reap the benefits of clean, renewable energy.

## Appendix A: Solar Panel Tilt Analysis

Analysis of the installation orientation of solar panels is crucial to getting the highest power output from the solar panels. Solar panels receive the most energy from the sun when the surface of the solar panel is perpendicular to the sun's rays.

Some solar panels track the position of the sun. The surface of these panels is always perpendicular to the sun, giving tracking panels the highest output of any mounting system. However, the increase in efficiency does not come without a cost. Tracking mounting systems are significantly more expensive than other mounting options and are also a lot more likely to break.

In some cases, solar panels are mounted directly on the roof. However, this is also a sub-optimal solution because the sun will never be perpendicular to the solar panel. In Worcester, MA, the sun is at an angle of 80° above the horizon at noon during the summer and only 30° above the horizon at noon during the winter. [44] It is typically recommended to mount solar panels with a tilt angle that is equal to the latitude for the site location.[45] Another approach is to use a solar panel mounting structure that can be changed twice a year, realigning the panel during the winter and the summer.

It is essential to predict how much energy will be generated from different panel orientations in order to compare these different solutions and predict the overall energy output from the system. To do this, one must be able to accurately predict the power from the solar panel at any time.

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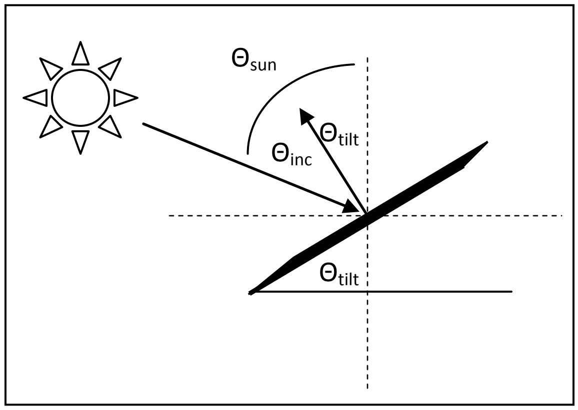
[44] *GAISMA.* [Online] www.gaisma.com.

[45] Lenardic, Denis. Solar radiation estimation and site analysis. *Atomstromfreie Website.* [Online] Greenpeace Energy, September 13, 2008. http://www.pvresources.com/en/location.php.




The tilt angle is represented above by $\Theta_{tilt,}$ which is the angle between the solar panel and the ground. This angle is also the angle between the vertical y-axis and a vector normal to the surface of the solar panel. It is shown in both places in the diagram above. The angle between the y-axis and a vector representing the sun's rays coming onto the surface of the solar panel is represented by $\Theta_{sun.}$ Subtracting these two values yields the value for $\Theta_{inc}$.

Looking at this as a two dimensional problem the amount of energy from the sun that hits the solar panel at any given moment is related to the size of the solar panel times the cosine of the incident angle between the solar panel and the sun's rays. The incidental power, or actual power, can be determined based on the amount of power that would land on the surface of the solar panel using the equation below.

$$P_{inc} = \cos(\Theta_{inc}) \cdot P_{perp}$$

Since the sun moves not only vertically in the sky but also across the sky from east to west, this concept must be extended to three dimensions in order to get the instantaneous power throughout the day.

To determine what the optimal tilt angle for solar panel installation is, a group from Taiwan created a simulation that used a Genetic Algorithm (23). They simulated the amount of power generated by the solar panel at five minute intervals using historic weather data for five years. They could then estimate the amount of energy that would have been generated by the solar panels over that time period at a given tilt angle.

To find the optimal tilt angle, they created a pool of genes (binary strings) that represented the tilt angle. With each iteration of the program, a selection process is applied, selecting only the best performing solution. The genes then reproduce. Some are direct copies of the previous generation, other experience a mutation, where one bit changes between 0 and 1. Still others experience crossing over, where a substring from one gene is switched with a substring of another. With each generation, the program gets closer to finding an optimal solution.

A similar experiment could be done for Worcester, MA, however the difference in power output between this new solution and the usual recommendation of using the Latitude as your angle is likely to be insignificant, as was the case in this experiment.

## Appendix B: Recommended Bidding Process

The first step in the bidding process is defining the system the church wants. This needs to include all the specific details including the amount of power the church hopes to generate, the preferred brands of panels, and the DC/AC inverter. This is also the time to determine the areas on the roof which are suitable for mounting panels. Much of the decision should be made by this point as to what the church is willing to install and pay for in order to make providing information to potential contractors simpler.

The second step is to gather a list of local contractors that are known to install similar systems in the area. This is as simple as contacting the MTC for a list of installers in the Worcester area or using a phonebook's yellow pages. It is important to get a list of installers and to determine which of them are interested in putting in a bid for an installation of this size. After a simple phone conversation with each of them, the church should have a list of contractors that are interested in bidding on their project.

These first two steps are mostly covered by this report. The report has a recommended system and location on the roof already selected to meet the needs of the church. The report also includes a list of potential installers in the Worcester area. To complete these two steps, the church only needs to agree to the recommended system and call the installers to make a list of those that are interested.

The third step in the process is to draft formal letters requesting bids. These letters need to include very detailed information to simplify the process. First of all, there need to be timetables involved. They should include a deadline for the church to receive the quotes from installers, as well as preferred beginning and ending dates for the installation. It's also important to give all the details determined in step one of the process. It is best to give as much information as possible so that the church does not need to field calls from contractors seeking more information.

Along with this letter, the church should request a cost breakdown. This should detail what portion of the cost is for labor, panels, mounting equipment, etc. Having costs broken down in this way will help determine which installer is the best choice and it helps clarify their overall cost.

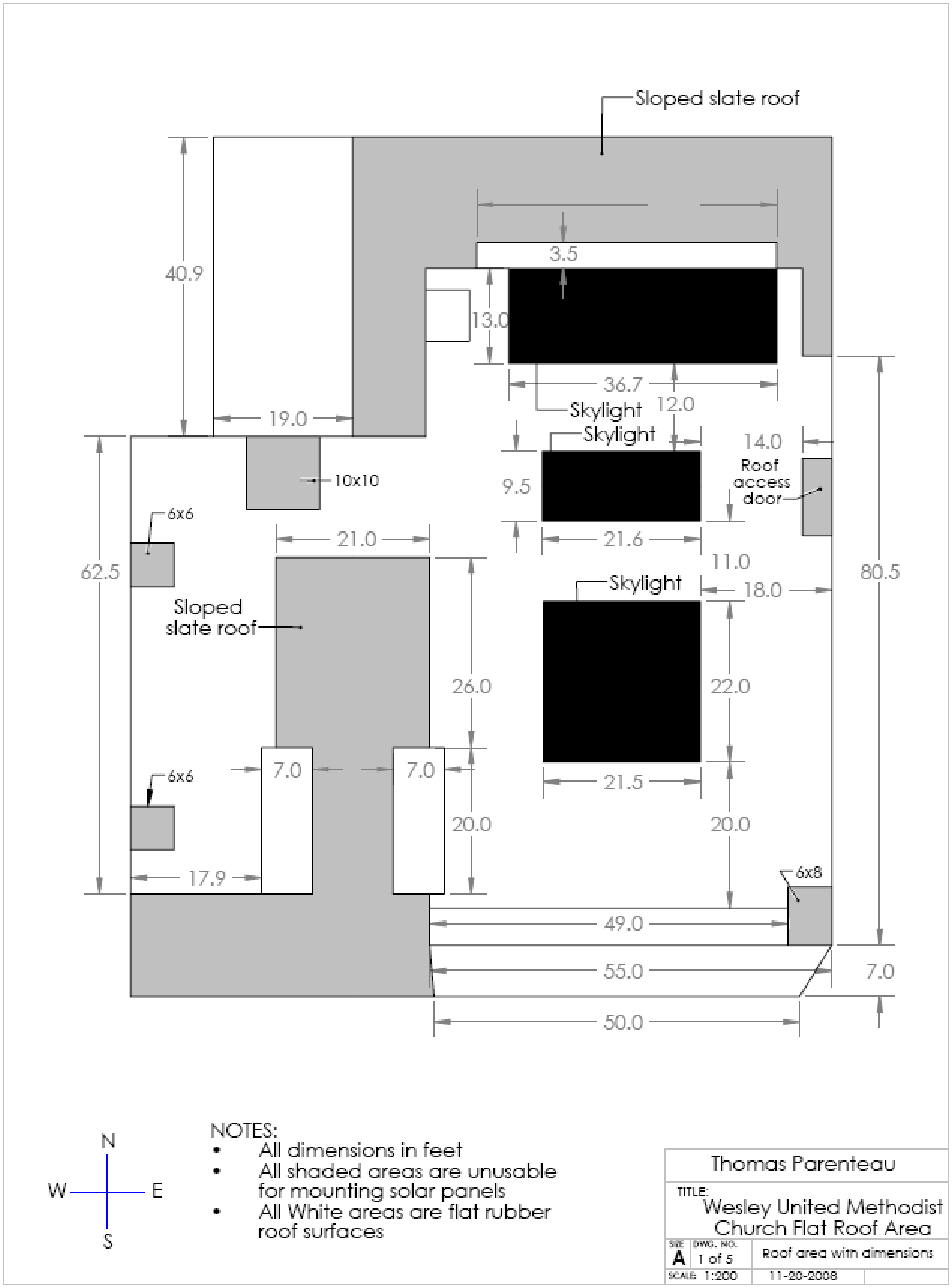
Step four is to receive the quotes from the contractors. Generally speaking, any quotes received after the given deadline should be disregarded. If the contractor doesn't meet the requested deadline for the quote, then they probably can't be counted on to be reliable when it comes to the installation. Simply put, a company that can't meet the deadline for a quote is probably not professional enough for a system of this size.

The fifth step is to begin the down selecting process. In this part, the church needs to generate several factors that are the most important to them. Generally, cost is one of these. Other important factors to consider are the type and quality of the panels and mounting hardware, expected completion date, or use of local labor. Once the church establishes their important criteria, they can begin to rank the different installers. It is important to keep in mind the two factors of cost and quality of materials and find the best compromise between the two.

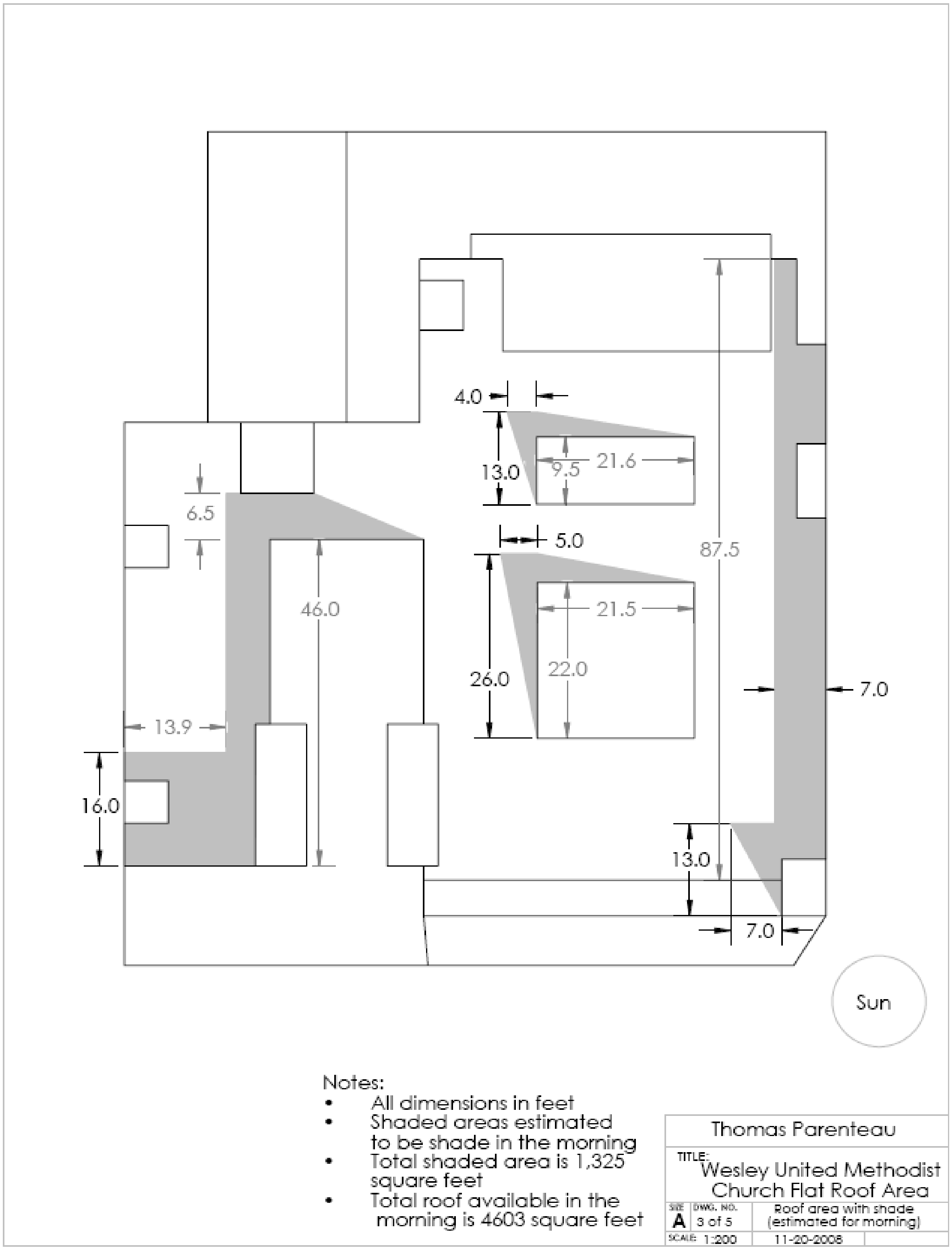
The sixth and final step is to send letters to all the contractors who submitted quotes. Inform the one the church chose and clarify a payment schedule. It's also important to inform the contractors that didn't win and inform them as to why they were not selected.

These are the steps involved in requesting a bit from a contractor and are designed to streamline the process for both the contractor and the customer. Following these steps should put the church in the best position to select the installer that they determine to have the greatest value.

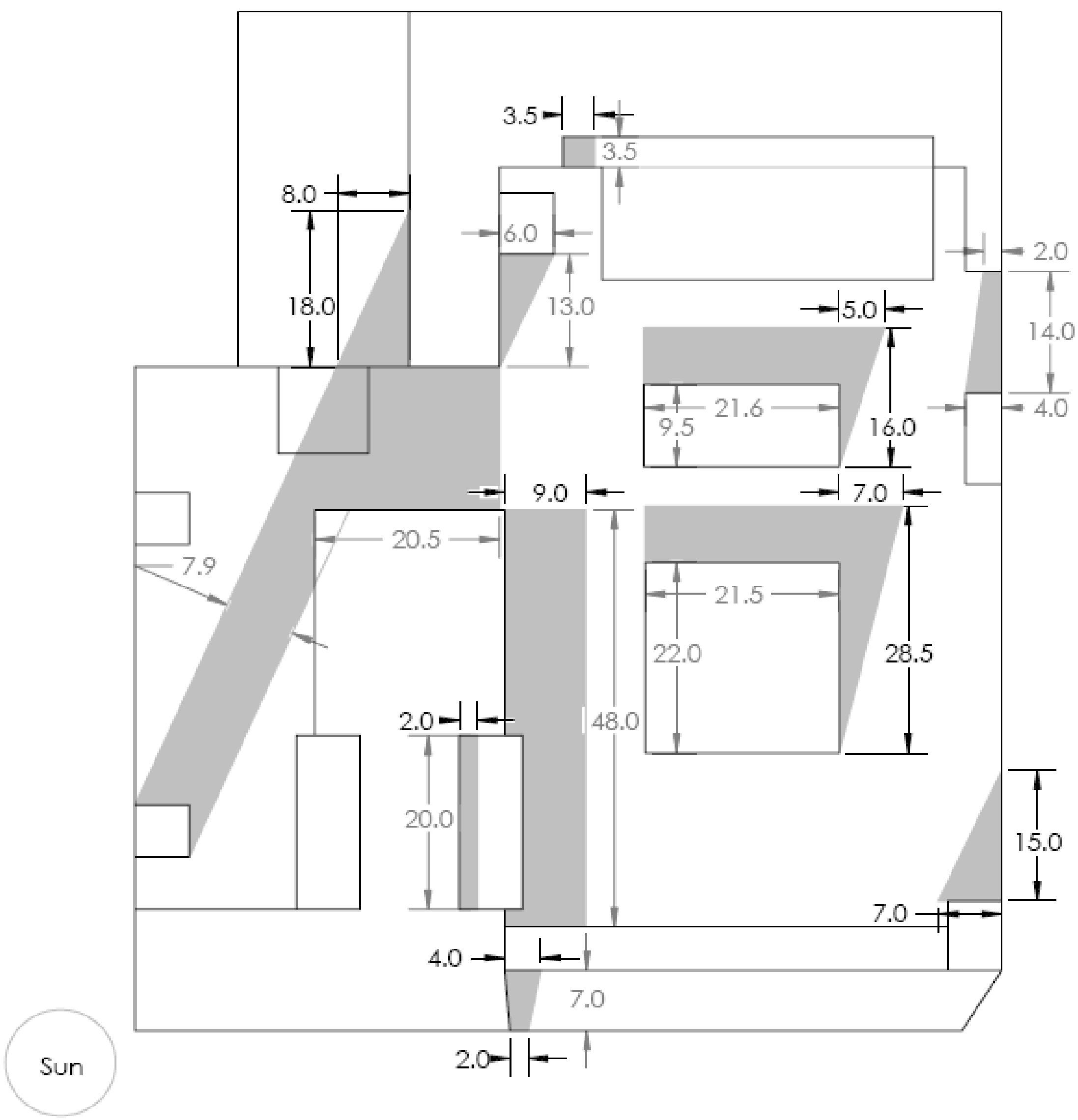
Appendix C: Site Dimensions



# Appendix D: Morning Shade



# Appendix E: Afternoon Shade

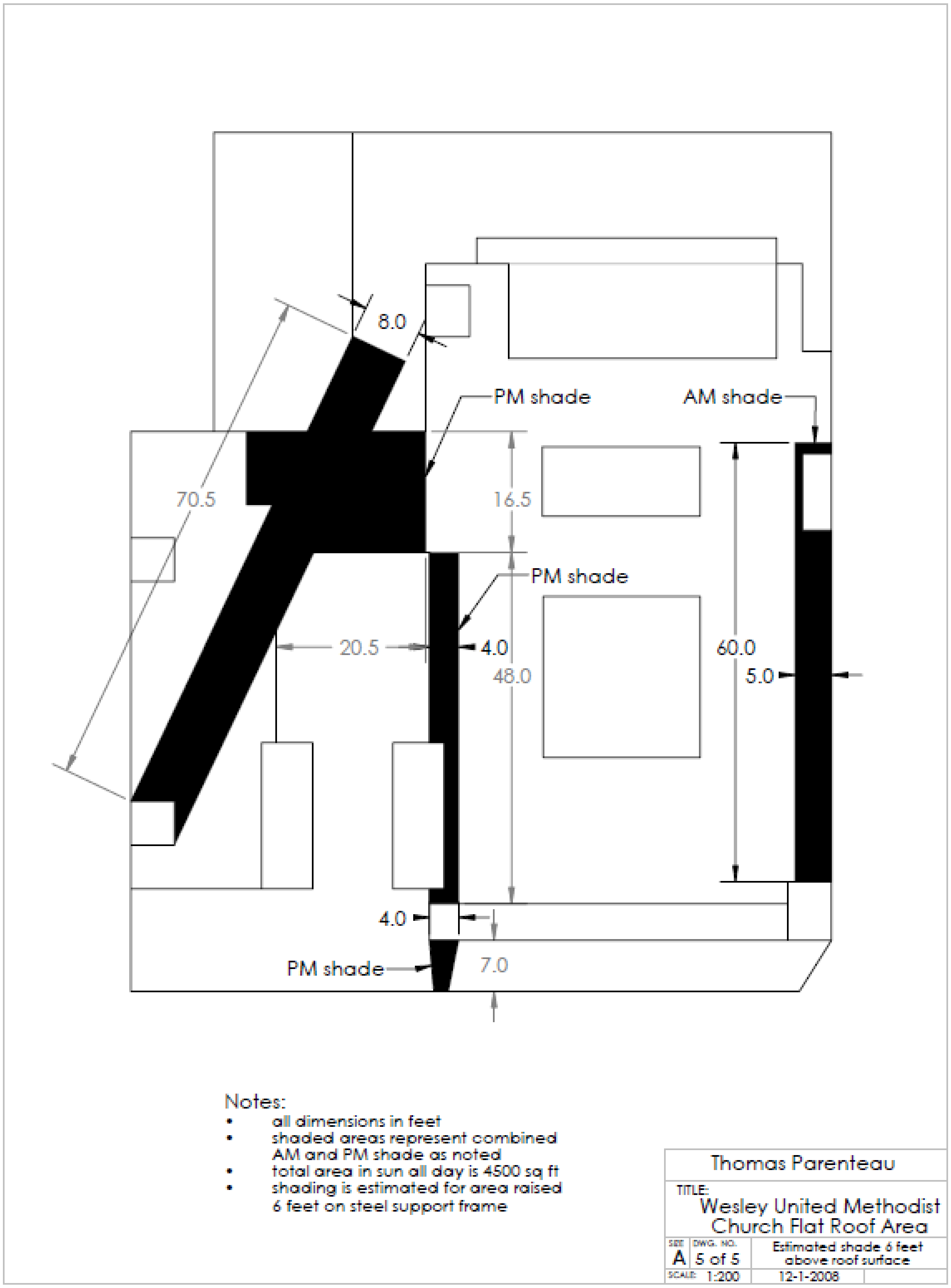



Notes:

- All dimensions in feet
- All shaded areas covered with shade at 1:30 pm
- Total shaded area is 1,525 square feet
- Total available roof area is 4,405 square feet

| | | |
|---|---|---|
| Thomas Parenteau | | |
| TITLE: Wesley United Methodist Church Flat Roof Area | | |
| SIZE A | DWG. NO. 2 of 5 | Roof area with shade(1:30pm, 11-12-08) |
| SCALE: 1:200 | 11-20-2008 | |

## Appendix F: Shading with Raised Panels



# Appendix G: Meetings and Correspondence

## Meeting with Tom Sikina on December 5, 2008:

After introducing ourselves and our project, the first topic of discussion was regarding irradiation data. Mr. Sikina made the point that different sites and organizations that offer irradiation data may not take the same factors into account. For example, some sources do not consider cloud cover. The inclusion or exclusion of such factors in a model could have substantial impacts on a final result.

Next, we discussed third party financing. Mr. Sikina told us to think of having a third party finance a solar panel system analogous buying a bond. The third party would own the system for a given period of time (25 years, for example) and the buyer would get electricity at a discounted rate. After the contract is over, the buyer usually has the option to buy the solar panel system from the third party for a small price.

Another issue that was brought up was the level of confidence in our model. This level of confidence refers to how sure we are that our model would be an accurate predictor of feasibility. Mr. Sikina urged us to compare our model to similar projects that have been found to be feasible, and run them through our model.

After showing Mr. Sikina our economic model, he had a number of comments. One was that we pay particular consideration to the percentage increase in electricity costs per year. Overall, he said that our current estimates were fairly conservative.

The next topic of discussion concerned the accuracy of the ratings that solar panel companies give their panels. On Mr. Sikina's installation, the solar panels only operate at 85% of the rating on their data sheet. However, Mr. Sinkina knows of another installation using a different brand of panels that operate at 5% over their specifications. It was suggested that the accuracy of solar panel production data should verified before making a final choice. Furthermore, Mr. Sikina suggested that WPI may be able to act as a third party that rates solar panels against their factory specifications.

On the topic of installing solar panels, we discussed the feasibility of changing the angle of solar panels throughout the year to produce more energy. One of the simplest and most effective methods would be a two-pin system, where the panels can be locked into one of two different tilts. At different time during the year, the tilts could be manually adjusted. Mr. Sikina encouraged that we calculate the net energy change from employing such a system.

Expanding on the topic of installation and optimum panel placement, we discussed the idea of creating a small scale model to test different panel placements and orientations. A model may give insight to how spacing the panels affect net energy production as well as how shadows are cast in a more complex system.

The final topic of the discussion was about the bid process for finding an installer. Mr. Sikina outlined the following steps:

1. Find the system you want to buy
2. Select the bidders
3. Write a bid proposal (RFQ letter) and send to bidders
4. Receive quotes
5. Prepare a justification of the bid (known as a down select) based on your lists of criteria
6. Award the winning bidder

Mr. Sikina suggested that since we may not be involved in the church's actual installation process that we give the church a recommended bidding process to follow if they decide to go forward with installing a solar panel system.

## Meeting with York-Ogunquit United Methodist Church

Research for similar case studies discovered that the York-Ogunquit United Methodist Church in York, Maine, installed a system of solar panels approximately 6 months before our project began. A meeting was set up with this church to find specific information, since both churches are in a similar region, less than 2 hours apart. The meeting began with explaining the project and the specific situation of the Wesley United Methodist Church to Rev. Shook. After detailing the project goals and the needs of the church, Rev. Shook began to share all the information he had available on the solar installation for the his church. On this particular day, it was snowing so taking pictures of the system was difficult.

The system the church decided on is rated for 7,700 W, however the maximum output that has been achieved to date has peaked at 6000 W. The system consists of 42 panels that are mounted directly to the raised seams of the steel roof. The installation was completed by Solar Market of Arundel, Maine, in two days for a total system cost of $58,000. Of this overall cost, $11,220 was the cost of 2 days of installation. In this case, the installation cost is about 20% of the total, which led us to reevaluate our previous information stating that installation accounted for nearly half of the total cost.

This system produces enough extra electricity in the summer months to provide the church with renewable energy credits with Central Maine Power. These credits cover about half of the winter electricity use. This means that the church only needs to pay for using electricity for about 4 months a year. The other bills are only to cover various other charges, and are usually around 25 dollars. In this way, the church is not only reducing its environmental impact, but it is saving a considerable amount of money in its monthly operating expenses.

The money for the system came from a trust fund set up by the church after selling one of their two buildings several years ago. In addition, the proponents of the system held information sessions for about a year to help the congregation understand the options and benefits of the investment. By holding these sessions, most of the questions people had were answered; leaving very little opposition by the time a decision was made.  Rev. Shook said that the members of the church are glad to be better environmental stewards that set the example for their community just as much as they enjoy the economic benefits.

### Correspondence with the Massachusetts Technology Collaborative:

In order to understand the nature and stipulations of the rebate offered through Commonwealth Solar, we contacted a member of the Massachusetts Technology Collaborative (MTC), the parent organization of Commonwealth solar.  Through email conversations, we learned two important factors in regards to the rebate:

1. The church was not considered a public building for the sake of the rebate.  This meant it did not qualify for the extra $1.00 per watt entitled to public buildings.

2. Installation had to be done though an installer certified through Commonwealth Solar.  This meant that a volunteer installation could not be done without a special agreement through the installer chosen to do the installation.

### Correspondence with solar panel installers:

In order to get an estimate of cost breakdowns for the overall price per watt figure given by solar panel installers, we sent an email to seven major installers in the area asking them for estimates. Of the seven companies asked, three responded, and the results can be seen below:

Company 1:
Solar Panel Components: 75%
Mounting Materials 10%
Installation Labor Costs 15%

Company 2:
Solar panels: 55%
Inverter, electrical wiring, disconnects: 15%
Mounting hardware: 15%

Installation: 13%
Permits: 2%

Company 3:
Solar Modules: 60%
Racking and Inverters: 20%
Labor: 20%

## Appendix H: Solar panel installers

Below is a list of recommended solar panel installers. These installers have been chosen on their overall system cost per watt, the size of the systems they have previously installed, and recommendations from our sources.

**New England Breeze, LLC**
President: Mark Durrenberger
Phone: 978-212-2665
Email: Info@NewEnglandBreeze.com
Web: www.newenglandbreeze.com

**Solar Works, Inc.**
Regional Project Director: Terry Dupuis, P.E.
Phone: 508-360-4907
Email: tdupuid@solarworksinc.com
Web: www.solarwaorksinc.com

**Berkshire Photovoltaic Services**
Phone: 413-743-0152
Email: info@bpvs.com
Web: http://www.bpvs.com/

**Borrego Solar Systems, Inc.**
Phone: 978-513-2600
Web: www.borregosolar.com/

**Nexamp, Inc.**
Phone: 978-688-2700
Email: info@nexamp.com
Web: www.nexamp.com

**SolarFlair, Inc.**
Phone: 508-293-4293
Email: info@solarflair.com
Web: www.solarflair.com

**SolarWrights, Inc.**
Phone: 401-396-9901
Email: info@solarwrights.com
Web: www.solarwrights.com/

## Appendix I: Future Solar Panel Costs

It is the widely held expectation that solar panel costs will continue to fall over the coming years, naturally increasing the likelihood that solar panel projects will become feasible. Many cite economics of scale and the experience of other industries: as the demand rises and the supply increases to meet it, larger, more efficient factories are set up. It is difficult to predict with much accuracy what the cost of solar panels will be in the future, but many companies and researchers in field of solar panel pricing expect that the price of solar panels will come down.

Nanosolar, a startup company that has opened a manufacturing facility in Silicon Valley, is claiming that they have found a way to reduce the cost of solar panel production by 80% by "printing" thin film solar panels onto Aluminum and saving significant amounts of silicon. Martin Roscheisen, CEO of Nanosolar, says that they will be the first company to profitably sell solar panels for under $1.00 per watt, and that "with a $1-per-watt panel, it is possible to build $2-per-watt systems."[46] These are certainly bold, and if they prove to be true, would make solar panel systems instantly feasible. The company has orders for their first 18 months of production.

Another small company, 1366 Technologies from Massachusetts, says they have found a breakthrough technology that makes there solar panels 27% more efficient. This will allow them to start selling solar panels soon for $1.30 per watt, and they expect that by 2012 they will also be selling solar panels for $1.00 per watt.[47]

In a study done by Travis Bradford, president of the Prometheus Institute for Sustainable Development in Cambridge, MA, even with the traditional production methods, solar panel costs could fall by as much as 1/3rd over the next couple years. His research shows that solar panel demand is

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46 http://www.nytimes.com/2007/12/18/technology/18solar.html?ex=1355634000&en=091b06819623f9d0&ei=5088&partner=rssnyt&emc=rss

47 http://dvice.com/archives/2008/03/solar_cell_effi.php

increasing by 50% per annum, but that the supply will outpace it at 80% growth per year. "This should be putting some downward pressure on prices," he says.[48]

There are many companies working hard to bring down the cost of solar energy, and continue a trend that has gone on for a long time. Some of the first solar panels cost nearly $1800 per watt, while today people are striving to break the barrier of $1.00 per watt. Below is a graph showing the cost of solar panel installations in Japan since 1993.

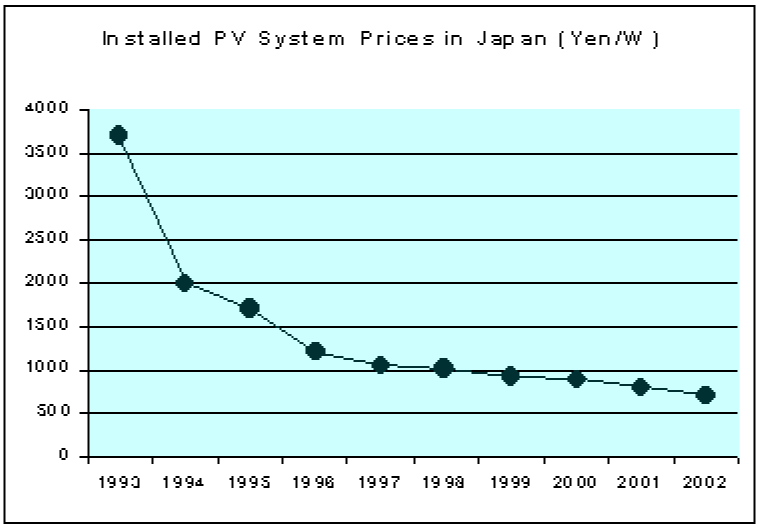


**Figure 27: Graph showing the falling cost of PV installations in Japan.** [49]

Though the graph is in Yen per Watt, the trend is a worldwide trend. The cost of solar panel systems is falling. Though it is difficult to predict exactly when solar panels will reach these predicted levels, one would expect that it will not be a long wait.

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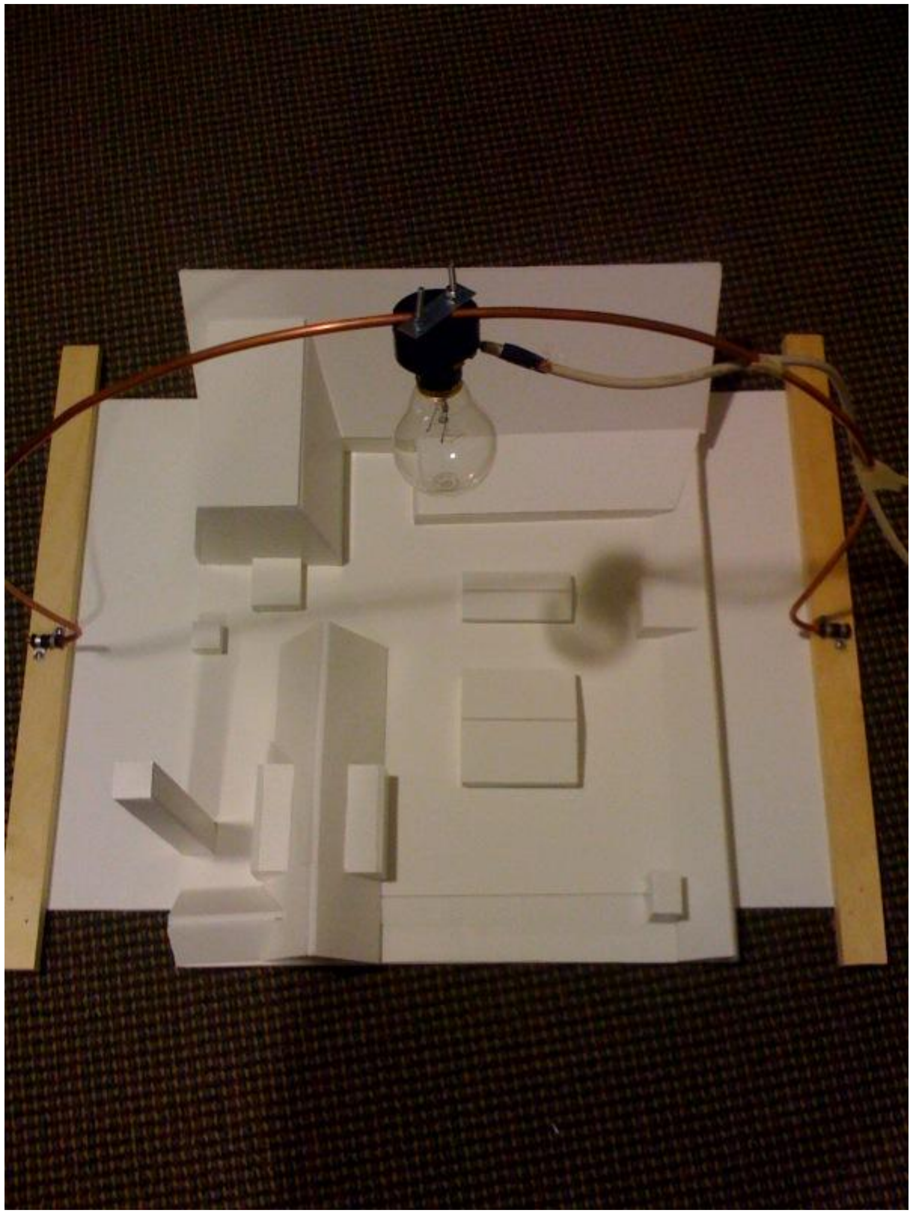
[48] http://features.csmonitor.com/innovation/2008/06/05/brighter-future-for-solar-panels-silicon-shortage-eases/
[49] http://www.solarbuzz.com/statsCosts.htm

## Appendix J: Scale Model

In order to create a better visual representation of the roof space and the shading throughout the day, a model was constructed. Along with this model was an arced piece of thin copper tubing with a light socket mounted to it. The base of the copper was hinged so that a combination of moving the arc up and down along with sliding the light from side to side approximated the sun at different times of day and the different times of the year.

In a dark room, the 67-watt bulb provided enough light to get a good imitation of the shade. To further the experiment, a small solar cell was connected to a small LED and could be moved around to demonstrate how well light was absorbed at different locations on the roof.

An added benefit of the model was its use in presentation to the church. By using the model as a presentation aid, potential panel locations the members of the church had a better idea of what would happen if they were to have the panels installed. See pictures of the model on the next page.



## Appendix K: Site Pictures

## Appendix L: Simplified Economic Spreadsheet

In order for the church to re-evaluate investing in a photovoltaic system in the future, we created a simplified version of our economic spreadsheet using assumptions from our project. The three primary variables in this spreadsheet have been reduced to the overall cost per watt of the system, the proposed system size, and whether or not the solar panel components are manufactured in Massachusetts. The overall cost per watt would be given as a quote from an installer. If the solar panels are manufactured in Massachusetts, the rebate offered by Commonwealth Solar increases.

The assumptions portion of the spreadsheet lists the various systems, economic, and rebate assumptions that were made in order to calculate the overall feasibility of the system. These assumptions can also be changed to see what different assumptions have on the overall feasibility. One factor of particular interest is the income generated by renewable energy credits. Because at the time of the report the future of such credits was uncertain, this number may change.

The calculations section of the spreadsheet lists the raw system cost, the amount realized from the Commonwealth Solar rebate, the system cost after rebates are applied, the amount of energy the system would produce in a given year, how much savings this energy generation would translate to, and the number of years before this investment breaks even.

The other pages of the spreadsheet are used as tools to help calculate the energy that the system would generate, and the value of the system as an investment. Below is a sample of the spreadsheet with $8.00 per watt and a system size of 20kW.

# Solar Feasibility Analysis for the Wesley United Methodist Church

## Entry Section:

| | | |
|---|---|---|
| Overall System Cost Per Watt: | $8.00 | dollars / Watt |
| System Size: | 20000 | Watts |
| Solar Panels Manufactured in Massachusetts: | NO | YES / NO |

## Assumptions:

**System Assumptions:**

| | | |
|---|---|---|
| System Life Expectancy: | 25 | years |
| Yearly Performance Degradation: | 0.50% | % |
| Efficiency of Solar Panels: | 15.00% | % |
| DC to AC derating factor: | 79.49% | % |

**Economic Assumptions:**

| | | |
|---|---|---|
| REC Revenue per Watt: | $0.00 | dollars |
| REC Annual Cost Adjuster: | 4.00% | % |
| Yearly Energy Consumption: | 102000 | kWh |
| Cost of Electricity: | $0.16 | dollars |
| Electricity Cost Inflation: | 0.60% | % |
| Overall Inflation: | 3.29% | % |

**MTC Assumptions:**

| | | |
|---|---|---|
| System Size: | 0 to 25 kW | 25 to 100 kW |
| Base Incentive: | $3.25 | $3.00 |
| MA Component Adder: | $0.25 | $0.25 |
| Incremental Capacity: | 20000 | 0 |

## Calculations:

| | | |
|---|---|---|
| Raw System Cost: | $160,000.00 | dollars |
| Rebate Amount: | $65,000.00 | dollars |
| System Cost: | $95,000.00 | dollars |
| Yearly Energy Generation: | 27248 | kWh |
| First Year Energy Production Value: | $4,359.68 | dollars |
| Break Even Year: | 22 | years |

## Appendix M: Informational Brochure

To create a simple way to showcase the work we have done and our results, we created a brochure, which can be seen below:

## What is the environmental impact?

- A 20kW solar panel system is the equivalent of planting 1800 trees.
- It is also the equivalent of driving 420,000 less miles.

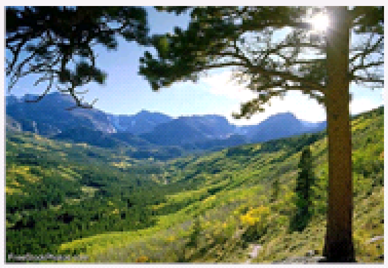
### Our Group

Stephen Mueller
Brian Bates
Dillon Buchanan
Thomas Patenteau

# Solar Panels

## at Wesley United Methodist Church

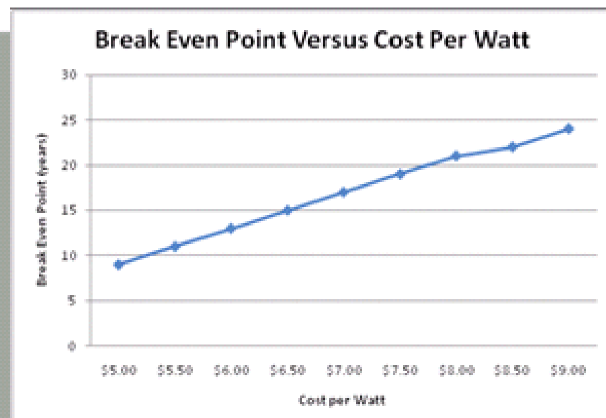
*"The earth is the LORD's, and everything in it, the world, and all who live in it."*
*Psalm 24:1*



*"Is it not enough for you to feed on the good pasture, but you must tread down with your feet the rest of your pasture? When you drink of clear water, must you foul the rest with your feet?"*
*Ezekiel 34:18*

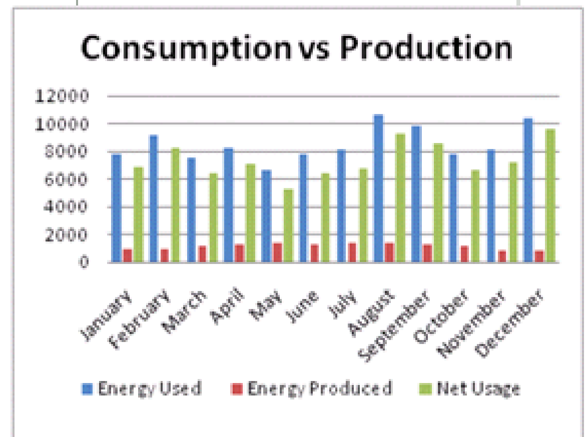
## Investment Details

- The **break even point** for a system is the number of years it takes for the energy savings to pay for the cost of the solar system. It takes into account the fact that money in the present is worth more than money in the future, and discounts future energy savings based on the estimated inflation rate.
- The **cost per Watt** for a system is a convenient way to compare prices for systems of various size.
- The average system cost in Massachusetts was $8.03 per Watt in the year 2007

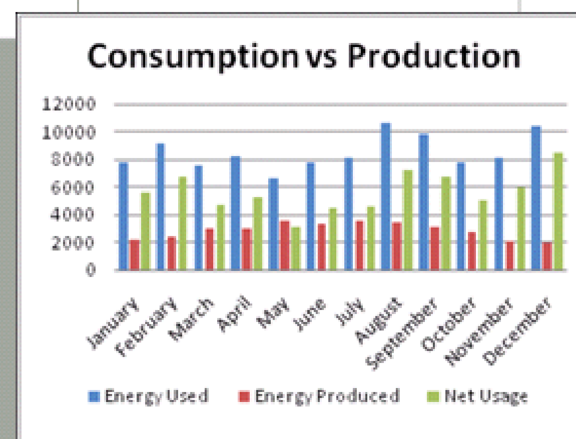



## Example Systems

### Small Scale (10kW)




### Large Scale (22kW)



## Appendix N: Survey

Below is a listing of the questions that made up the survey given to our presentation audience:

Do you believe that investing in renewable energy is important?  If so, Why?

What kind of image do you think a solar panel installation would give Wesley United Methodist Church?

Would you install a solar panel system if there was no economic incentive to do so?  In other words, if installing a solar panel system would have only have environmental benefits, would you still consider installing one?

Do you know of any specific solar panel installations in the area, either residential or commercial?

Do you think that a solar panel installation on the Wesley United Methodist Church is something that should be perused now, sometime in the future, or not at all?

What do you feel was the overall quality of this presentation?

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