Worcester Art Museum: Green Technology Evaluation

Worcester City Project Center

Worcester Polytechnic Institute

12/17/2009

Travis F. Collins ECE
Christopher M. Gowell ME
Aaron S. Hall-Stinson ME

Faculty Advisors:
Professor William Baller
Professor Stephen Bitar

Abstract

The purpose of this project was to conduct a Green Energy Evaluation of the Worcester Art Museum, to determine the efficiency of the facility's energy consumption and provide a green technology solution to supplement current and future usages. Through a systematic audit, current energy usages on a device by device basis were outlined in order to create an energy projection. Photovoltaics, green roofs, and wind power were examined, as well as sources of funding for these technologies. Through research and professional consultations, the focus was narrowed to a photovoltaic design, which prompted a solar evaluation of nearby photovoltaic arrays. Given researched funding sources, two possible photovoltaic array installation options were proposed, comprising an effective energy subsidizing strategy. Additional approaches were outlined for future energy evaluations.

Table of Contents

Table of Figures

1 Executive Summary

Worcester Art Museum in Worcester, Massachusetts, originally opened in 1898 by Stephen Salisbury, houses over 35,000 pieces of art and hosts many education programs and exhibitions. The structure itself has expanded several times over the last one hundred and ten years, leaving the current building with over 15 different elevations. One of the most recent additions is the Higgins Education Wing, which is utilized as primarily office, artistic studio, classroom, and storage space. Due to our national push to reduce our reliance on fossil fuel by minimizing our carbon footprint, the museum is examining modern green solutions, targeted primarily at cost saving for the Higgins Education Wing and future additions associated with this wing.

1. 1 Methodology & Key Findings

The methodology of our project was comprised of five main objectives:

- Quantify electricity use at the museum and evaluate energy billing/usage strategies.
- Evaluate office energy usage.
- Research funding sources for green technologies.
- Analyze the practicality of implementing green energy technologies, such as green roofs and photovoltaics, to reduce energy bills.
- Make recommendations to the museum based on findings.

To complete our first objective, we gathered the museum's energy bills dating back to 1983. Advances in technology have allowed the museum to reduce its energy usage since 1983. However, we analyzed only the bills from the past 3 years to get a clear picture of the museum's energy usage with the technology it utilizes presently. The Higgins Wing uses approximately 33,000 kWh monthly, equivalent to powering 4 two story houses. Next, we looked past the numbers and into the billing process to find out how, if possible, the museum could reorganize its energy use to save money in the billing process. The museum appears to be billed at a typical $0.14 per kWh regardless of the time of day, or peak/off peak usage. As a result, no restructuring of the usage would reduce the museum's energy bill.

Our second objective required us to perform an energy audit of the office space in the Higgins wing to determine what portion of energy was consumed by the offices, and what specific lighting and devices used. Through our interviews with the staff, we found their work habits to be generally energy conscious. In our audit, we considered hours used by lighting and devices, and how long they remained in the on, off, or standby mode, if applicable. We then used this information to determine whether energy efficient replacements for these devices would be economical, and we developed an energy profile of the wing. The profile is based on an extrapolation of usage schemes from a few different office types in order to estimate the usage scheme of the wing as a whole. We used the profile to estimate the future usage of the wing with an additional floor, taking into consideration what types and sizes of offices would be located on the new floor.

The museum will not be able to implement any green technologies with high initial installation costs without significant grant or donor contributions. Since available funding played a factor in the depth of our research into various green technologies, our third objective was to determine what funding is available for the green technologies we considered. Our main focus in this research was the Massachusetts Technology Collaborative (MTC). The MTC offers grants for all types of energy efficiency retrofits, as well as energy producing technologies such as wind turbines and solar panels. We researched past grant amounts from this organization to provide a frame of reference as to what the museum should expect to receive. Worcester State College and the Massachusetts Museum of Contemporary Art were recipients of large grants from the MTC. We are hopeful that the Worcester Art Museum solar project will be as successful as other public projects as a result of MTC support. We also researched alternate payment options such as a "Power Purchase Agreement" and "Third Party Financing." If the museum is unable to qualify for a suitable grant, these payment options may help the museum to move ahead with its renewable energy project.

Our fourth objective was to determine which green technologies would be feasible for the museum to install. We ruled out a wind turbine design due to zoning requirements, and a green roof due to the long payback period. We concluded that electric photovoltaic panels are feasible for select areas of the roof over the Higgins Wing. The panels have a shorter payback period than green roofs, and can provide the museum with considerable energy savings annually.

However, based on both our meeting with museum architect Cutler & Anderson and our own energy evaluation, we must stress that another analysis must be focused around the heating and cooling systems of the museum (Bass, 2009). HVAC alone uses over 60% of the museum entire electrical energy usage.

1. 2 Recommendations

We made an informed set of recommendations to reduce energy and subsidize energy cost of the Higgins Education Wing. These recommendations are as follows:

1. Apply to Massachusetts Technology Collaborative for funding.
2. Install photovoltaic panels on the roof of the Higgins Wing.
3. Review current lighting problems, such as the library, hallways, and conference rooms, and replace all unnecessary incandescent bulbs in the Higgins Wing with compact fluorescents.
4. Reevaluate HVAC System for further energy efficiency gains.

2 Introduction

The increase in the demand for oil and other fossil fuels has resulted in the depletion of our natural resources. Our need for fossil fuels to power our lives has driven up the cost per barrel of crude oil significantly over the past ten years. Alternate sources of energy such as windmills and photovoltaic panels reduce reliance on oil by supplying energy. Other green technologies, like green roofs and more efficient equipment reduce energy usage overall. The main power draws for office buildings are computers, at 46% of the total energy used to power devices in an office. The next major users are monitors, which use 20%. By reducing the amount of time a device is powered on can greatly reduce its impact on the environment and save money on utility bills. Many offices across the country are finding ways to "Go Green" and reduce the amount of wasted energy and become more efficient and environmentally friendly buildings. The Worcester Art Museum is planning on subsidizing their energy usage of a future addition with these kinds of "green" technologies. We conducted an energy audit of the existing offices in the Higgins Educational Wing to determine a baseline energy usage. From this data we suggested the best green technologies to supplement their usage and drive their current energy cost down. We audited five offices and conducted informal qualitative interviews with the employees of these offices to collect and accurately assess how much each piece of equipment operates daily. We compiled the information to get a total usage and make suggestions to reduce energy consumption in the offices. Following the analysis, our group determined the best green technology to help subsidize electricity use. This research and recommendation was presented to the museum and it may be considered during the renovations outlined in the Facilities Master Plan.

3 Literature Review

3. 1 Performing an Energy Audit

The world is extremely reliant on fossil fuels. This reliance was illustrated when gas prices peaked a year and a half ago. It made it clear how imperative it is to research and implement other, “greener”, forms of renewable energy. The idea of green renovation has been considered by numerous organizations worldwide. Green Buildings that are LEED certified are springing up everywhere hoping to attain the highest level of green certification. “Green” is becoming an industry standard and the new direction that construction is heading in and the Worcester Art Museum wants their new renovations to be a part of it.

Our project for the Worcester Art Museum was to research green technologies and methods to reduce energy consumption and costs for a new addition to the Higgins Educational Wing. This addition will relocate existing offices from the first floor of the wing to the newly renovated and more efficient space upstairs. Our first step in executing out project is to conduct an energy audit of existing office spaces on the first floor of the Higgins Educational Wing. Lighting and office equipment require 36% of energy in an average office (See Figure 1).

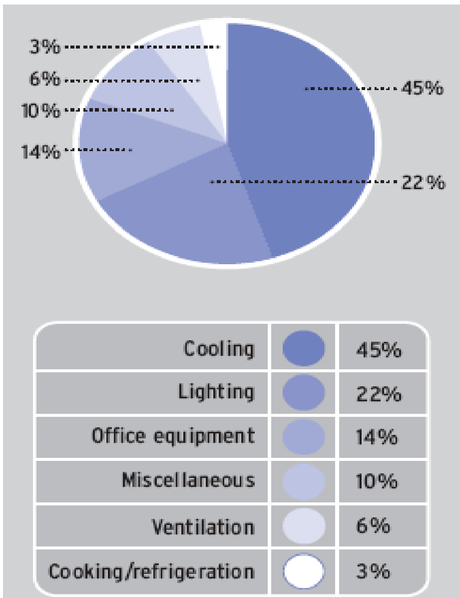


Figure 1 Overall Power Consumption including all Energy Sources (San Diego Gas & Electric)

We then researched ways to supplement the power usage with green technologies. To project the power usage of the proposed addition before it is built we needed to analyze the current offices and find out their power requirements. To do this we needed to perform an energy audit. An energy audit is "an evaluation of energy consumption, as in a home or business, to determine ways in which energy can be conserved," (Answers Corporation, 2009). Audits are used to examine ways to save money on utility bills and thus become more efficient and lessen the amount of pollution that goes into the air from burning fossil fuels. Energy audits are becoming standard practices in order to reduce commercial and residential impacts on the environment (Energy Audits Unlimited, 2008). An audit can be done on most buildings or homes that use energy and have some way of keeping track of it, such as a meter, which most establishments will have because the company they purchase power from needs to know how much to bill them.

3. 1. 1 Types of Energy Audits

There are four main types of energy audits (preliminary, general, investment grade or pollution) that are conducted in buildings depending on the level of energy the auditee wants to save. More in-depth audits typically find more ways to save more money, but also cost more (Answers Corporation, 2009). Thus, the choice of audit depends on the expense and payback period. The payback period, or time it takes for the audit to pay for itself in savings, is very helpful to convince a company to go through with the audit because it will pay for itself in energy savings over a period of time. The pollution audit is not considered by many as a standard type of audit; however, since it may work to reduce the negative effect of energy on the environment, it should be considered. For example, Gard Analytics only uses preliminary, general and investment grade audits (Gard Analytics, 2007). Two other major companies that perform energy audits refer to them with different names but they execute them the same way. Process Quality Associates and Kelcroft Energy refer to a preliminary audit as a "walk-through audit" where a walkthrough of the building is done and energy using devices are noted and results are analyzed (Kelcroft Energy, 2008). Process Quality breaks down the preliminary audit a little further with the use of a historical audit to analyze past energy bills and consumption (Process Quality Associates, 2006). Process Quality also utilizes a technical audit which performs the same tasks as an investment grade by providing detailed energy analysis and energy usage profiles to make the best recommendations. Kelcroft does the same but they call it an investment grade audit. They also do a comprehensive audit which is identical to a general audit, as it is more commonly known.

A *preliminary audit*, or simple audit, involves just a quick walk through and observation of major systems, infrastructure, and potential problems. The auditor does not spend much time doing background research on past utility bills or building construction as is done in a more intense audit. Instead, quick solutions are generated along with rough payback periods and costs of implementation. This type of audit is intended to show only major problem areas and prioritizes the order in which they should be addressed to achieve maximum savings.

Another type of energy audit is the *general audit*, or mini-audit. This is more in depth than the preliminary audit and actually takes what is learned from the preliminary audit and adds to it. Typically the auditor examines past energy bills in more detail and conducts "in-depth interviews with facility operating personnel are conducted to provide a better understanding of major energy consuming systems and to gain insight into short and longer term energy consumption patterns," (Answers Corporation, 2009). We interviewed employees whose offices we are going to be auditing. We needed to know how long they use various electronic devices in their office and when/for how long the devices are off. Then more detailed graphs and charts plotting usage, rates, and schedules are made to produce a better pattern to further understand how energy can be saved and during what season. There is also a more detailed final report that better maps out cost versus payback period, initial investment and cost of implementation, and proposed energy savings to give the auditee a better basis for carrying out the recommendations.

The third type of audit is the *investment grade audit*, also known as the comprehensive audit or technical analysis audit, (Answers Corporation, 2009) which is primarily used on large corporate companies who are looking at more than just energy usage to save money and increase productivity. This type of audit "expands on the general audit described above by providing a dynamic model of energy-use characteristics of both the existing facility and all energy conservation measures identified," (Answers Corporation, 2009). This type of audit focuses not only on how high the energy usage is, but also why it is that high and for how long. It also looks into non-energy related ways to save money, such as making the workplace more comfortable to better employee productivity.

The final type of audit is a *pollution audit*. A pollution audit looks at how much greenhouse and other gases are coming out of a building. This type of audit goes hand in hand with an energy audit, because if you are going to try to help the environment by using less energy, you might as well analyze the gases you are giving off and make them healthier too. This type of audit is conducted similar to an energy audit in the way that the auditor studies fuel and electricity consumption over an extended period of time and then provides "approximations for carbon dioxide, VOCs, nitrous oxides, carbon monoxide, sulfur dioxide, mercury, cadmium, lead, mercury compounds, cadmium compounds and lead compounds," (Answers Corporation, 2009). This data is then typically plugged into an online calculator like the Abraxus Energy Consulting emission calculator (Abraxas Energy, 1999) and total pollution levels are calculated and then recommendations are made.

For the audit of the Worcester Art Museum we utilized a general audit, since we needed to go more in depth than just a preliminary audit. We needed specific energy usage charts and data to figure out rates and schedules of heavy usage so we could plan how to subsidize it. An audit is broken down into several steps. The first step in a general audit is to gather energy bills for the prior two years for the institution under review. Going back beyond two years is not recommended since the energy consumption may reflect old technologies, such as old inefficient computers or printers that are currently not being utilized and skew the data, such as old inefficient computers or printers. Once the past bills are gathered, trends graphs need to be drawn to analyze usage during different periods and seasons. Some useful areas to concentrate on would be Kilowatt/hour consumption, peak demand, billed demand and rates and schedules of usage (New Jersey Sustainable State Institute, 2008). These will be key areas of focus because they are the main drivers in energy billing. If we could reduce the peak usage or kilowatt-hour consumption, the Worcester Art Museum's energy bill would be considerably lower.

3. 1. 2 Demand vs. Usage

When conducting an audit there are many calculations that will take all the measurements made during the walk through stages and yield concrete figures for analysis. For example, the difference between demand and usage needs to be clear. According to the New Jersey

Sustainable State Institute, demand is defined as “the reservation of the capacity the utility has to maintain for the customer 24 hours a day, seven days a week, usually expressed in kilowatts (kW)” (2008), which means that demand is the power company’s ability to set aside some power in case the building needs more than normal for a given period of time (such as if it was unusually hot outside and the HVAC had to work harder to keep the building cool). Whereas usage is “a function of connected load (i.e., power required to run a defined circuit or system, such as a refrigerator, building, or an entire electricity distribution system) multiplied by hours of usage (e.g., 1 kWh = 1,000 watts sustained for a one-hour period)” (New Jersey Sustainable State Institute, 2008), which amounts to usage being the daily load of power the building draws from the power company on a given day.

Another very important aspect that needs to be taking into consideration is an indicator called load factor (LF). The load factor can be calculated by “dividing the monthly electric use by the demand by the number of hours in the billing period,” (New Jersey Sustainable State Institute, 2008) (See **Figure 2** for a sample LF calculation). This gave the ratio “average demand to peak demand,” (New Jersey Sustainable State Institute, 2008). This ratio will provide insight to how much energy is being used during peak hours and how much energy could be moved to off-peak times so the building could lower it demand needs for power and save some money. It is essentially moving around power usage to lower the parameters of your power contract.

Monthly electric use = 648,400 kWh

Demand = 4,184 kW

No. of hours of operation = 600 hrs.

LF = [648,400 kWh / 4,184 kW] / 600 h = 0.26

Figure 2 Load Factor Calculation

By monitoring the LF you can watch for patterns of high and low usage and try to average them out to have better control over the overall usage patterns. Energy management systems can help control and move power usage to off-peak times to reduce costs.

3. 1. 3 Energy Management Systems

An energy management system is a computer controlled system that automatically controls when the heating and air conditioning come on and off in order to maintain a desired temperature with minimal energy usage. The system can also be tied in so it monitors the electrical usage and shuts off power to items that are drawing power but not actively being used. These systems "can cost as little as $100, while complex systems can cost more than $100,000," (Northeast Utilities, 2009). These systems can be programmed to monitor peak and maximum loads, thus by keeping the peak demand as low as possible by spreading out loads; the business can save substantially on their monthly energy bill (Northeast Utilities, 2009). Computers and monitors account for approximately 66% of electricity used by devices in a typical office (Ecos Consulting, 2009), though this will vary according to the nature of the office and the kinds of other equipment. Thus, the Worcester Art Museum needs to carefully examine the type of equipment that will be used in the proposed offices in order to save on energy costs without major renovations.

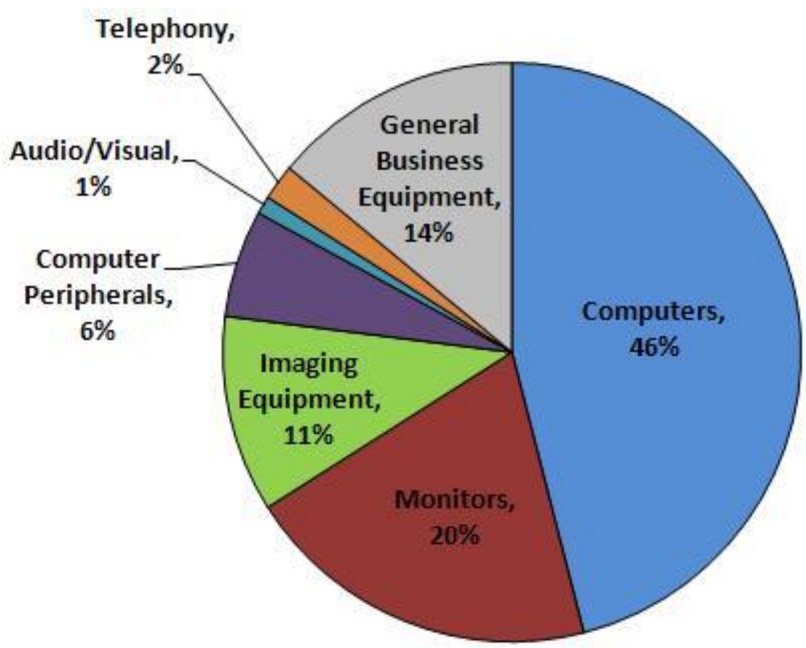


Figure 3 Office Electrical Energy Consumption Breakdown

Two final important measurements to come out of our audit are *baseline* and *seasonal* power usage. The baseline is the average day to day energy needs of the building. This is critical to establish so we know when peak and off-peak demands occur. Seasonal loads come with the changing seasons of New England. By monitoring usage all year round we can extrapolate when the usage is highest and lowest. Typically summer and winter are the extreme power users due to the variation in outside temperatures and hence the draw on the HVAC system. These seasonal spikes were kept in mind with our power production goals of photovoltaics in order to not underestimate the system draw.

3. 2 Green Technology

The Worcester Art Museum Director of Operations, Fran Pedone, wanted to explore green technologies that could be used to reduce energy consumption in the additional office spaces proposed for the Higgins Educational Wing. Green energy technologies either reduce power usage, or make use of a renewable energy source to produce power (Green Technology - What Is It?, 2006). To supplement power and reduce energy bills in the museum we considered several types of green technology. In particular, we researched the possibility of the installation of photovoltaic panels on the roof space of the museum. The ideal goal of these photovoltaic panels was to provide 100% of the electricity needed to power the Higgins Wing, thus lowering the museum's electricity bills and its overall environmental impact. Other energy saving technologies considered include green roofs, alternate lighting, energy monitoring devices, and wind power.

The museum is seeking funding to help subsidize these green upgrades. With an extremely limited budget, the museum requires as much grant or other financial support as possible. As a non-profit organization, the museum is at a disadvantage from commercial businesses as it cannot utilize the many solar energy tax incentives offered at the state and federal levels. Accordingly, we have researched ways for the museum to implement these technologies with minimal cost to itself. This research involves determining payback periods, federal grant possibilities, and other alternate payment methods.

3. 2. 1 Photovoltaics

Solar panels can be used in an assortment of applications including solar heating, photovoltaic, and CSP (Concentrated Solar Power). These applications also are open to a variety of physical designs and constructions. For the purpose of our project we will be focusing on photovoltaic and solar heating panels, which will be used to create electricity and addition heating. Photovoltaics operate by directly converting sunlight to electricity, this occurs when photons which comprise light are absorbed by a photovoltaic or PV cell. There is no guarantee that these photons will be absorbed by the PV cell they can be reflected or even pass right through the panel itself. When photons are absorbed by the PV cell the semiconductors that comprise the PV cells convert the energy of the photon to an electron at the collector terminal of the cell (Solar FAQs — Photovoltaics — The Basics, 2008).

Photovoltaic systems consist of four main components: the panel array, inverter, charge regulator, and battery cells. The panels convert the solar energy to direct current electricity and either feed it directly to batteries through the regulator or to the inverter (As seen in **Figure 4** below). The battery array stores additional charge when not in use. Depending on implementation of panels for the museum we may not need a storage solution, which would eliminate both the charge regulator and batteries. Power from the panels also goes to the inverter which converts the direct current voltage to alternating current. Alternating current is the standard power consumption and transportation method throughout the world. When assessing the appropriate solar arrangement we must take into consideration the space requirements of all these elements (Sharma, Colangelo, & Sp, 1995).

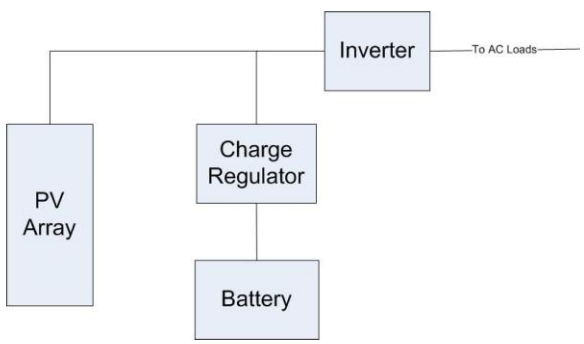


Figure 4 PV System Layout

Solar heating works on a concept similar to the radiator in a typical automobile. A panel called the collector receives energy from the sun and by convention heat water directly or uses intermediate source such as antifreeze to heat water. That water is then pumped through a business or household to heat the building (Solar FAQs — Photovoltaics — The Basics, 2008). We would use this heating source to supplement the present heating system in place. We are exploring the feasibility of using a hybrid design that would include a combination of photovoltaics and solar heating panels, providing both heat and electricity to the future museum addition.

Selection of a solar panel types will become a great consideration in a future projection of power output. We have examined several models of differing materials such as amorphous silicon (a-Si) and poly-crystalline silicon (pc-Si) (Tripanagnostopoulos, Nousia, Souliotis, & Yianoulis, 2002). Other technologies such as Building Integrated Photovoltaic (BIPV) panels and sun tracking models are also an option for us (Henemann, 2008). We considered the cost of static and rotation panels in terms of cost per efficiency gained because if a panel cost ten times more with an added efficiency of 2% the appropriate selection must be made. For example, if we include the cost of external pipes and other components for water circulation cooling we have a total cost increase of about 10%. In other forced air cooled systems, the estimated cost increase is about 5%. The corresponding cost increase of hybrid systems with a-Si PV modules is relatively higher roughly double, compared to that with pc-Si PV modules, with equal solar area. This is explained as the thermal unit is of the same cost, but the a-Si PV modules are of lower cost, about half, compared to pc-Si PV modules. Two aspects of performance we also considered is the addition of possible booster diffuse reflectors and an aggressive cooling system. These can give our panels significant gains at a price. All of these aspects must be considered before installation (Tripanagnostopoulos, Nousia, Souliotis, & Yianoulis, 2002).

Pending the museum's construction plans, we have made some broad estimates and calculations depending on the area of photovoltaic panels that can be installed on the roof. A few good rules of thumb are that a 1kW system takes up about 100 square feet and will produce 1-1.5 kWh annually (Massachusetts Is Running On Solar Energy).

The In My Back Yard (IMBY) calculator from National Renewable Energy Laboratory (NREL) can give us a rough estimate on solar irradiance above the museum. This will allow us to make an accurate projection of energy production possibilities (NREL, 2009). The IMBY calculator estimates that a 5.55kW system can be installed on the wing if the new construction maintains the current flat roof space, at a cost of $47,439. It estimates $14,232 in tax credit and $10,000 in rebates, with a 35 year payback period. Since the museum is a non-profit organization this tax credit is not applicable, but with the anticipated state and federal support the actual payback period should be significantly shorter.

The Massachusetts Technology Collaborative (MTC) website offers a Commonwealth Solar Rebate (CSR) Estimator (Massachusetts Is Running On Solar Energy). The CSR program offers a base rebate of $2.65 per Watt on all photovoltaic systems from 1-25 kW. It offers $2.25/W from 25-100kW, $1.50/W from 100-200kW, and $0.50 from 200kW to its cap at 500kW. The rebate also includes an additional $1.00/W for systems with MA manufactured components, and $0.15/W for a public building. Some MA companies that produce photovoltaic components are Evergreen Solar and Solectria Renewables. Assuming the museum qualifies as a public building and utilizes MA manufactured components, it can receive $3.80/W up to 25kW, and $3.40 up to 100kW. The rebate is designed to defray the necessarily longer payback periods of smaller photovoltaic installations. A 7.5kW system at this rate yields a grant of $28,500, a 15kW system a grant of $57,000, a 25kW system $95,000, and a 50kW system $180,000. The CSR program is granting a total of $68 million (no more than $1.5 million per project) to projects like this between 2008 and 2011 (Commonwealth Solar Rebate Program Manual, 2009). For perspective into the size of these systems, there is no single facility in Massachusetts generating 200kW or more of photovoltaic energy. Considering the initial IMBY estimate of a 5.55kW system and discounts for MA manufactured components in a public space, the MTC offers up to $21,090 in grants. Including the $10,000 rebate from the IMBY estimate, this leaves $16,259 of the $47,439 photovoltaic project to be paid through other means.

In previous years a minor solar audit was done by an engineer from National Grid (Pedone, Director of Operations, 2009). Engineer John Bzura gave a preliminary walk through of the facility and came to the conclusion that the Museum would be a great location for photovoltaics, commenting on the openness of the skyline and other natural features of its location. We hope to contact Mr. Bzura and gain potential cost advantages or expertise from National Grid. We are also focusing energies toward relations with the American Solar Energy Society to gain their perspective.

Once we have a grasp on our power needs and possible solution we will need to consult several solar contractors. Contractors are a wealth of knowledge on what would work best for our needs, based on our available roof space and solar irradiance. Many companies such as Sunlight Electric, Second Generation Energy and SolarFlair Energy offer complete solutions, from installation to a solar audit. Sunlight Electric has been involved in many commercial solar energy installs, including Community First Bank (CFB) in Central Oregon, which was able to achieve a LEED Gold certification. The solar panel array at CFB produces roughly 11,000kW per year which is enough to power an average home in the US for a year. Another Sunlight Electric project was a solar awning install for a mill in Oregon which was completely funded by federal grants. Since we have no capital to start a consultation with, Sunlight may prove to be an invaluable resource (Energy, 2008).

Worcester State College recently underwent an $825,000 project installing a 100kW photovoltaic system on the school library roof. This project was one-hundred percent subsidized by government programs. Worcester State received grants from the MTC in the amount of $570,000. The remaining $255,000 was covered by Clean Renewable Energy Bonds, or CREBs. These bonds were issued by the state of Massachusetts in 2007 as part of a $3.1 million deal with the federal government, involving 11 other photovoltaic installation projects. This deal allowed the state access to extensive federal funding with no interest. Unfortunately, these bonds are offered only to state facilities (Reis, Worcester State Energy Project Is Sunny Side Up; College Gets Funds For Solar Power, 2008).

Potential loans for this project include the U.S. Department of Energy Loan Guarantee Program, which will lend up to $6 billion for renewable energy projects until September 2011. These loans are generally described for projects involving renewable energies, but also for use with projects improving energy efficiency, at a 0% interest rate (U.S. DOE - Loan Guarantee Program, 2009).

Another funding method worth noting is called “Third Party Financing.” This method requires no upfront payment from the building owner. He may enter into a “Power Purchase Agreement” with his power company. The photovoltaic installer installs and maintains the panels at no cost to the owner. The owner buys the power from the installation at a set rate for a set time period, usually ten or more years, with a buyout option available. The installer receives any grants (i.e. CSR) and applicable tax credits throughout the duration of this contract. Mr. Pedone, however, has specified that he would like a payback period of only a few years. However, if sufficient funding for the project cannot be obtained, this option allows the museum to proceed with its efficient energy plan, though possibly delaying the payback for 20 or so years (Legal Pathway Analysis for Third-Party Ownership of Municipal PV Systems, 2008).

Once installed an important consideration is the maintenance of the panels and equipment themselves. Even though these are sealed panels, corrosion leading to loss of groundings can occur. Glass failures can occur from the external environment, moisture ingress, and delimitation. The panels themselves can have cracked cells or even the housing that supports them can fail, in addition to the moving parts in the sun tracking options. The panels can be very delicate and will be prone to damage. This must be taken into account, as well as performance maintenance which can be as simple as cleaning the snow off the panels (NREL, 2009). While Mr. Pedone is most interested in a large scale photovoltaic project, this may not be the best financial decision for the museum. Other energy saving options should not be overlooked.

3. 2. 2 Green Roof

Green roofs have been present throughout history dating back to the ancient Hanging Gardens of Babylon in the 7th century. From ancient times up to the 1970s, green roofs were generally considered a luxury. In 1970, German Professor Hans Luz developed the idea of using green roofs as building improvements to add to the health of urban environments (Rodriguez, 2006). With green roofing technology we hoped to increase savings interims of thermal insulation, attracting publicity to the museum and providing the employees with more natural space.

The current roof structure is in dire need of repair, and since work is already needed on the roof it is an obvious choice to review this simple adaption. One option available was a palletized green roof system from GreenGrid (Weston Solutions, 2009). This was initially a very attractive installation because of the unique roof space we would need to occupy, especially since it competed for space with photovoltaics. The GreenGrid system is modular in nature, and it can be easily adjusted and rearranged even after installation to meet a change in preferences or building modifications (Weston Solutions, 2009).

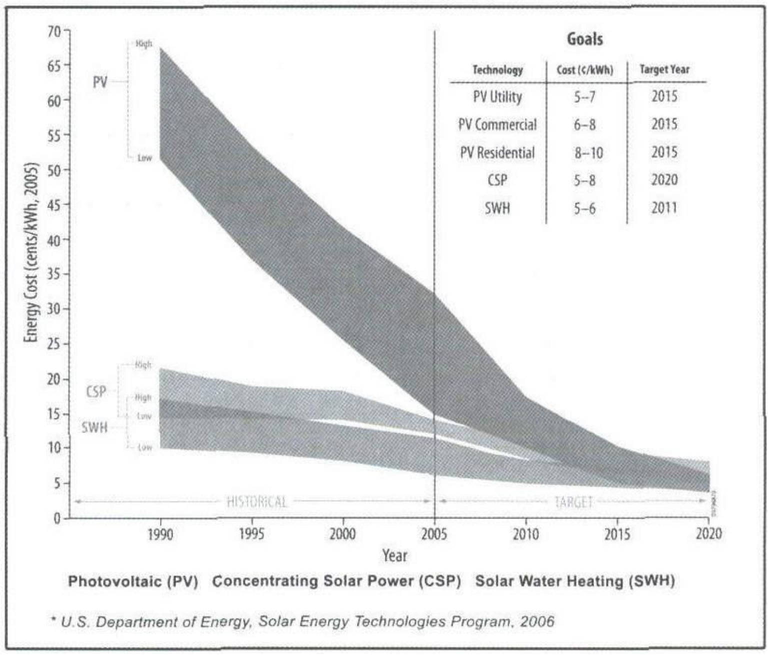


Figure 5 US Renewable Energy Cost Comparison (Fischer, 2006)

Because they are modular we could install green roofs first and easily install photovoltaics in the near future. This would provide us with two advantages: firstly, the heat savings by thermal insulations, and secondly, potentially lower installation cost of more efficient photovoltaic panels in the future as the technology matures. As seen in **Figure 5** above, the cost of solar panels is decreasing, and as seen from modern research and public interest in solar panels, the technology will only improve. Based upon similar projects with less roof space, the museum may have a payback period no longer than 1 to 3 years, less the cost of updating the current roof which needs to be replaced before this technology is implemented (Snow, Holmes, Galligan, & Downey, 2009).

3. 2. 3 Lighting

Fluorescent bulbs are a promising lighting alternative to traditional incandescent light bulbs. These bulbs offer an increased life span while using less power. **Figure 6** shows the possible yearly cost of two light bulbs producing a competitive amount of light, one incandescent and one fluorescent (TCP Incorporated).

$$\text{Cost of 150 W Incandescent} = \frac{150\text{ W X }\$0.10/\text{kWh X }4{,}000\text{ h}}{1000} = \$60.00\text{ Per Year}$$

$$\text{Cost of 42 W Compact Fluorescent} = \frac{42\text{ W X }\$0.10/\text{kWh X }4{,}000\text{ h}}{1000} = \$16.80\text{ Per Year}$$

Figure 6 Incandescent Cost vs. Fluorescent Cost

While the up-front cost of these efficient bulbs may be significantly greater, for example, $5.00 per fluorescent versus $0.75 per incandescent, the fluorescent bulbs quickly save enough on energy costs to pay their up-front cost. In other words they offer a short payback period given the sample usage and cost of electricity. The ROI (Return on Investment) formula in **Figure 7** indicates the percent amount of money saved over a one year period, in terms of the up-front cost, and shows the calculation of the payback period of the lights.

$$\text{ROI} = \frac{\$60-16.80}{\$5-0.75} = 1016\%$$

$$\text{Payback} = \frac{\$5-0.75}{\$60-16.80} = 0.10\text{ Years}$$

Figure 7 Return on Investment Sample Calculation

3. 2. 4 Devices

Electricity efficiency at the museum could be improved by the use of Smart Power Strips™. These strips work by cutting off power to devices not in use, as opposed to allowing them to run indefinitely on standby power. The total amount of power that can potentially be saved by this device will be determined during the energy audit portion of this project. The energy savings is defined by the type of devices plugged into the strip, the amount of power used by these devices in regular and in standby mode, and the amount of time these devices spend in these certain modes (i.e. left on in standby mode at night, left in on mode but used rarely, turned off when not in use). These strips cost approximately $30 for a 7 outlet unit, $45 for a 10 outlet unit, and may yield payback periods of a few years or less (Dunn, 2005).

3. 2. 5 Wind Power

We are anxious to observe any green energy source available to the art museum which naturally raised the question of wind power. As seen from projects such as Holy Name High School and the town of Hull, Massachusetts, wind is a vast resource available to us. Holy Name's wind turbine in Worcester is rated for 1.1 million kilowatt hours annually, which is enough to power 150 homes for a year (Reis, A Whirl of Difference at school, 2009). Unfortunately the zoning of the museum does not permit wind power installations of any economical magnitude (Voorhees, 2006).

4 Methodology

The goal of this project is to assess options for the reduction of energy costs for the Higgins Educational Wing of the Worcester Art Museum. To accomplish this goal, we must complete the following objectives:

- Quantify electricity use at the museum and evaluate energy billing/usage strategies.
- Evaluate office energy usage.
- Research funding sources for green technologies.
- Analyze the practicality of implementing green energy technologies, such as green roofs and photovoltaics, to reduce energy bills.
- Make recommendations to the museum based on findings.

4. 1 Objective 1: Quantification of Electricity Usage

Our first task was to collect and analyze the museum's electricity bills for the past three years. These bills illustrated the trends in the energy usage at the museum on weekly, seasonal, and yearly basis. We met with Mr. Pedone to gain insight into how the museum is billed for its power usage and researched ways that the museum could restructure its power usage to save money (e.g. use less electricity during hours of peak demand). He was able to supply us with all the energy bills since 1983. This allowed us to take a deeper look at the energy usage trends over time at the museum. As seen in Figure 3.1 below, the overall usage over the 16 year period has actually gone down; however, the cost has gone up.

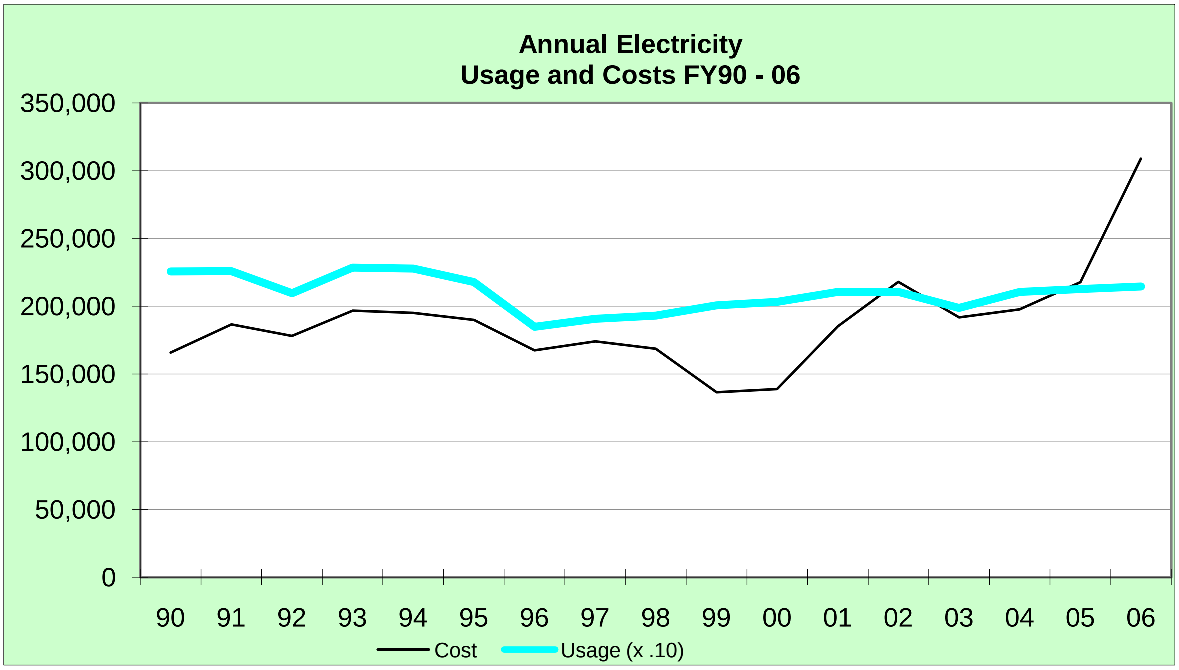


Figure 8 Electricity Usage and Cost for the Higgins Wing

The Art Museum is fortunate enough to pay the same cost for peak and off-peak hours according to their bills, from both Direct Energy and National Grid. They are billed by total kilowatt use which allows them to use power in any arrangement they feel appropriate, they are currently billed at $0.10371 kWh. The only difference in their bills month to month is their usage, and multiplicative factor. There usage changes as expected with the season, for example more power is needed in the summer and winter because of the heat and air conditioning needed. The multiplicative factor is a unit used primarily by national grid is change their cost depending on season, meaning that the factor is higher in the summer and winter, and lower in the spring and fall. This is a common occurrence which correlates to the demand during those times of the year. From our perception, this is the best possible arrangement for the museum, allowing for the lowest possible electric bill.

4. 2 Objective 2: Office Energy Evaluations

First we met with museum staff in the Higgins Wing to characterize the energy usage habits of the employees. We categorized rooms by type (e.g. storage, office, conference room, etc.) and compiled data describing the average amount of time office equipment/lights in these spaces are left on, off, or, if applicable, in standby. See Appendix A for our office equipment power usage checklist. Once we had our checklist complied we completed audits for five offices. Since the museum is planning on moving roughly fifty offices once the addition is complete, we decided to take a general approach to our audit. We determined from a preliminary walkthrough that a large majority of the offices contain the exact same electrical equipment. With this knowledge, we can extrapolate our measured data to estimate the total power usage.

Our measurements consisted of a number of attributes which formed a detailed summary of a number of different operating modes and situations. The data collection categories consisted of the rated power of the device, the measured power in operation, and the measured power in standby mode if applicable. We also supplied an estimated usage period for each measured power mode. To conduct the actual measurement we utilized a Fluke 322 Clamp Meter which was supplied by the facilities department of the WPI campus. From this we could measure current (AC), voltage (AC), and resistance. This information allowed us to determine what devices use the most energy, which waste the most energy, and hence the best ways to help the museum reduce its overall energy use.

From our walkthroughs and measurements were determined that the two major power consumers are lighting and computers. Printers used some of the most power measured but based on how infrequently they are in use compared to lighting and computers, their consumption is insignificant. Ceiling lighting could not be practically measured; therefore we used the Philips lighting catalogue to provide accurate power consumption figures of the fluorescent lighting arrays used in the museum.

From our calculations and measurements we were able to make several determinations based on energy usage and savings. First of all, most office lighting consisted of primarily fluorescents with one or two desk lamps depending on office. These lamps are on for roughly thirty-two hours a week, and from the fluorescent perspective turning those lights on and off many times can severely limit the life of a bulb. Also, fluorescent lights use the most power when turning on. Therefore we would recommend installing desktop occupancy sensors that control desktop lighting and possibly the monitors of the computers to improve energy efficiency. Based on a rough estimate these sensors could pay for themselves in eight months.

Figure 9 Leviton Occupancy Sensor

(Occupancy Sensors Deliver Hands-Free Switching and Energy Savings, 2009)

From our staff interviews we determined that most staff members shut off their computers at the end of the day, but we would highly recommend creating a standardized policy for the entire staff to enforce this practice. For every hour the computer is on and not in use it is wasting energy. The next step in improving energy efficiency was determined by a preliminary meeting with Michael Bass and Jack Moran, representatives of Cutler Anderson Architects. Cutler recommended a re-evaluation of the HVAC system as a primary concern for energy consumption and waste; however, due to financial limitations, the museum is unlikely to update these systems in the near future.

Based on many different factors, we believe that a photovoltaic array would be the most beneficial green technology for the Worcester Art Museum to pursue. We met with Mike Balch from the Garland Company who inspected the museum roofs for PV potential and consulted with us on the viability of this option (Balch, 2009). The Garland Company installs both PV arrays and green roofs and he informed us that, in the case of the art museum, green roofs would be more for looks than savings. Green roofs are most useful in big cities where runoff is a problem because soil traps the water and allows it to drain more gently and over time, without back-up and street flooding. Other than that, they are mainly used for displays on rooftops where patios are built and become an area to relax, primarily for aesthetic reasons.

From the standpoint of energy savings a green roof does bring other efficiency and cost savings factors that deserve mentioning. First of all they provide a significant environmental barrier for the structural roof underneath, allowing it to last an estimated seventy years. This would almost double the expected life for the roof, but it does require the buyer excepting a payoff period of over 30 years and the initial cost of building a stronger roof that can support a green roof. Also of note is the potential of combining a green roof with photovoltaics. The green roof keeps the roof at a relatively cooler temperature during the hot summer months which allows the panels to operate at a more efficient temperature. Unfortunately compared with the large cost of installing both a green roof and a photovoltaic array, the efficiency gain of roughly 5% is not as attractive or an economical decision.

After viewing our rooftop Mr. Balch pointed out that the best energy solution for the museum was to utilize all the space on the roof with a PV array. The roof top that he specifically has in mind is about 15 years old, but the unobstructed sunlight that it receives all day long is perfect for PVs. However, as the current roof is not strong enough to support the additional weight of all the panels, this is an ideal time to meet with the Cutler Architects and Garland to design the new roof for the proposed addition to best accommodate the weight of the panels. Mr. Balch also suggested numerous other places we could mount panels to get the most power out of solar energy. The most appealing suggestion was to build a slanted overhang over the museum parking lot on the other side of Lancaster Street. This lot receives plenty of sunlight and is a wide open space with huge potential for solar power production, aside from a few tall trees bordering the lot.

4. 2. 1 Energy Profile

We completed an electrical energy profile for the offices that will be moving to the proposed new addition. To do this we first had to perform an energy audit of five common offices proposed by Mr. Pedone. He said that all the offices contained pretty much all the same electronic devices so if we audited five, took the average usage and multiplied by fifty, because there are fifty offices that are slated to be moved, we would an accurate number for the total amount of energy that they use. We went from office to office and used our checklist and the Fluke 322 Clamp Meter and audited each device. We simply unplugged the device and plugged it into extension cord that had the outer insulation removed. With the outer insulation remover we were able to clamp the meter solely around the "hot" wire and not get the ground and common wires. If were clamped all the wires the resulting current would be zero. Once we did every device, in every office and made note of the type of lighting and how many, we calculated the total use. Based on our checklist we were able to get a total usage by device and by office. This made it very clear that even though the printers use the most instantaneous power, over the course of the month, the lighting and computers consumed the most energy. With this conclusion, we were able to focus our efforts to reduce power consumption in these two specific areas. Hopefully our research for the museum will allow them to make future energy decisions based upon our recommendations.

4. 3 Objective 3: Project Funding

The art museum recently received an estimate from Cutler that the new wing will cost in the area of $2.5 million to construct, as planned. This decrease in the estimated price suggests that the museum will be able to move forward with its construction plans in the nearer future, possibly within a few years, however this estimate may not account for roofing strong enough to accommodate as large a photovoltaic array as is possible on top of the proposed addition. For this reason, it is critical that funding for the photovoltaic aspect of this project be located in the near future to ensure that Cutler's and Garland's collaboration can proceed as the museum continues planning the construction.

We have conducted research in this area in hopes of helping the museum reach its goal of an externally subsidized PV project. There is significant data to suggest that this project could be almost completely funded by the state of Massachusetts' Renewable Energy Trust (MRET) Program. In 2005, for example, the MRET granted $709,500 to the Massachusetts Museum of Contemporary Art to fund "a 50 kW solar project and [perform] energy efficiency retrofits, and [build] related educational displays and activities," (Massachusetts Museum of Contemporary Art Solar PV Array and Efficiency Retrofits, 2005). Since then, the MRET has continued to grant millions of dollars to businesses and other private institutions to help finance solar installations. Entering some simple information about the PV project into the Commonwealth Solar Rebate Calculator yields potential rebate values. The rebate program does not offer additional funding for PV systems over 200kW, but for building 200kW system the museum can expect a grant of $457,500 from the MRET, at approximately $2.29 per Watt. This is assuming the public building bonus and that Massachusetts manufactured components are used in the project. Without MA manufactured components, the museum loses $0.15 per Watt, up to $30,000 (Commonwealth Solar Photovoltaic Rebate Program, 2009).

Initially we had been hoping to save the museum some money by restructuring its energy usage to cut energy billing costs. However, after looking over the museum's energy bills, they appear to be billed at a flat rate per Watt, so there is little that can be done to reduce bills besides reducing actual energy usage.

4. 4 Objective 4: Viability of Green Energy Implementation

In order to subsidize energy costs for primarily the Higgins Education Wing and the proposed addition to be built, our next step was to examine possible green technologies to supplement their energy usage. Our primary focus was around photovoltaic arrays and vegetative or green roof designs. In our preliminary research, both provided a reasonable cost saving benefits for differing applications.

To improve our understanding of real world application of these green technologies our team explored two green sites: East Hall's green roof at WPI, and the Worcester State Photovoltaic array atop their library. We also conducted an onsite overview of the Worcester Art Museum facility to gain a professional perspective on the feasibility of a photovoltaic array, which was chosen from conclusions made from the East Hall and Worcester State experiences. Coupled with our preliminary research, our goal was to make the appropriate decision for the correct green technology installation at the museum.

4. 4. 1 East Hall Green Roof Tour

WPI's green roof over East Hall is a source of pride for many on the WPI facilities staff. Assistant VP for Facilities Alfredo DiMauro, Mechanical Operations Super Norman Hutchins, and WPI Chief Engineer Bill Grudzinski, as well as Brent Arthaud of Cardinal Construction, provided our group a presentation on the energy efficient features and green roof of East Hall, and showed the team around the dormitory to point out these features. Our primary interest in this presentation was the function and performance of the green roof. According to Mr. DiMauro, the roof was never envisioned as an active contributor to energy savings, aside from negligible insulation savings. Since the green roof was part of the original construction of the dormitory, there was no way to measure any additional energy savings the roof may yield through heat insulation. The roof's primary purpose is to provide additional drainage on the roof's surface, extend the life of the existing traditional roof, and to collect and drain storm water for student and faculty research. (DiMauro, Hutchins, Grudzinski, & Arthaud, 2009)

Figure 10 Green Roof over East Hall (East Hall Sustainable Features, 2009)

This presentation solidified our limited study of green roofs as a mostly aesthetic entity. The museum should not pursue this type of project as green roofs do not offer significant savings aside from extending roof life. These savings are long term (30+ years) and well outside the payback period Mr. Pedone specified. (DiMauro, Hutchins, Grudzinski, & Arthaud, 2009) The green roof does provide many benefits to a building but in our case does not meet the specific needs of the museum; therefore we must discourage the museum from investing in such a green roof design.

4. 4. 2 Worcester State Photovoltaic Array Tour

To expand our knowledge base about photovoltaics and see a real world installation, we conducted a site visit at Worcester State College. On November 24 we met with the Worcester State Facilities Department to discuss the photovoltaic array operating since August 2009. The meeting included the Director of Facilities, Sandra Olson, and Associate Director of Facilities, Robert Daniels. They provided our team with installation information from panel selection to construction phase logistics. Most importantly we received a personal walkthrough of the installation itself which sits atop the college's library.

The install itself took just over three months, but the overall project took roughly three years to complete. A large encumbrance to the project was the state's involvement, in terms of logistics. Special approvals were needed in many sections of the project which, in turn, delayed overall progress and completion time. The project's scale was great publicity for the college but also did provide its own delays. Fortunately for the museum, as a privately operated entity as opposed to a state facility, the Worcester Art Museum would be in entire control of the project, creating a much smaller time scale. The museum is also likely to install far fewer panels on the main building (Daniels & Olson, 2009).

The entire project was designed and installed by groSolar, a solar contractor based out of White River Junction Vermont. GroSolar used 540 Evergreen Solar Panels with a SolarDock docking system for panel conduction and structural support. The panels themselves have a guaranteed power tolerance of 195W (-0% Tolerance) and maintain a five year warranty through groSolar (Daniels & Olson, 2009). The estimated full power output of the entire array is 105kW instantaneously. As seen from the photographs below, the panels operate at a 25° tilt from the roof of the building and utilize a ballast system rather than having to create additional penetrations in the roof (Case Studies, 2009). Robert Daniels specifically commented on the additional maintenance due to roof leakages that would be needed had the library chosen to create more penetrations (Daniels & Olson, 2009). Ballast systems are recommended by Michael Balch of Garland Co., over systems requiring additional roof penetrations (Balch, 2009).

Based on information from the manufacturer (Evergreen Solar) the panels are guaranteed to operate within 90% of the rated 195W for the first ten years, and within 80% the following ten years. The docking stations from SolarDock, which the panels rest on, are guaranteed to last twenty-five years. The combination and installation of these two separate technologies, dock and panels, were completely transparent to the client Worcester State College because of groSolar's relationship in the solar community, which is comparable with our consulted contractor Garland Company (Daniels & Olson, 2009).

Figure 11 WSC Solar Array Front View (Collins, 2009)

Figure 112 WSC Solar Array SolarDock System (Collins, 2009)

There were several problems that were mentioned in the WSC meeting that occurred during the construction phase of the project. First of all, since the worksite took up a portion of a campus road, the congestion around the site created by the student body was a hazard and made it very difficult to measure off a secure work environment around the library. Secondly, upon installation there was an issue with the grounding system between the Solar Dock and the panels themselves. This was a minor hiccup taken care of efficiently and at no cost to Worcester State, by groSolar. Only three months into operation, the array has shown no problems or failures (Daniels & Olson, 2009).

An issue that needs consideration when dealing with ballasted docking systems is the added weight of the panels and supporting equipment that will be added to the roof. The solar docking system alone adds 5 pounds per square foot to the roof's surface. Fortunately for Worcester State, the library was originally designed to support the weight of an additional floor. Coupled with the cement structure of the building they were able to come in well under the maximum roof weight possible for the library. The museum does share the cement structure of the library but the roof needs a reevaluation for its structural capacity (Daniels & Olson, 2009).

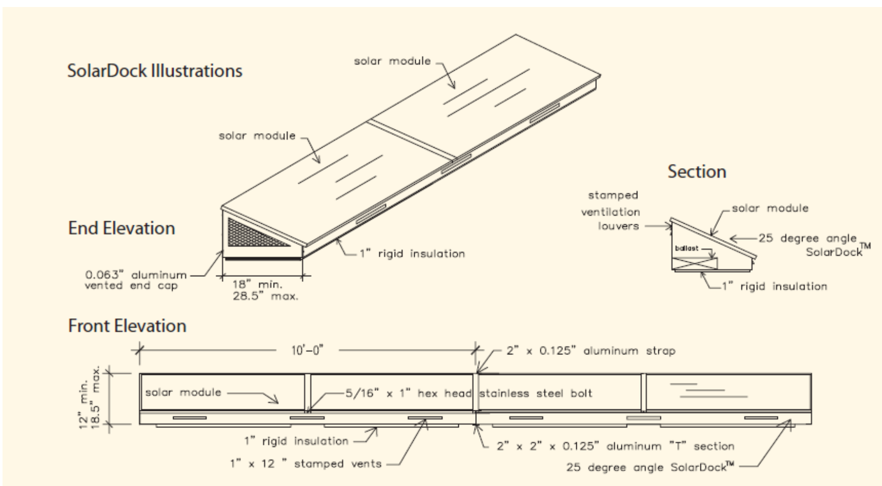


Figure 13 SolarDock Illustrations (Technical specifications, 2009)

The overall cost of the project was $825,000 including labor and materials. Robert Daniels provided a more specific outline of the cost as seen in the chart below. As mentioned in our meeting, Worcester State purchased this solar power system as a single package from groSolar, which in turn had groSolar deal with its own local distributors and manufacturers necessary for the installation. The system was fully funded by both IRS Clean Renewable Energy Bonds (only available for state facilities) in the amount of $255,000, and a sizeable grant of $570,000 from the Massachusetts Technology Collaborative. Worcester State had no upfront costs and will be paying back the IRS bonds at a zero percent interest rate (Daniels & Olson, 2009).

Product	Cost
Satcon Inverter	$60,000
SolarDock Racking	$135,000
Evergreen ES-195 Panels	$350,000
Labor	$280,000
Total	**$825,000**

Figure 14 WSC Cost Breakdown

The complete system as it stands today takes up roughly 33,000 square feet of roof space and produces 140,000kWh annually. That is enough power to supply twenty homes with an average size of 2,800 square feet (Case Studies, 2009).

4. 4. 3 Garland Roofing Consultation

To further our relationships with the solar installer Garland Roofing we arrange a meeting between the head of facilities of the Worcester Art Museum Fran Pedone and Michael Balch, a consultant from Garland Roofing. Garland Roofing is a subsidiary of the Garland Company headquartered out of Cleveland, Ohio. They are a solar contractor that works with local installers and producers of solar panels to complete commercial, industrial and public installations (Commonwealth Solar Photovoltaic Rebate Program, 2009). Since construction of the museum's addition is in such an early stage, it will provide the museum and Garland with a perfect starting ground for the introduction of a solar array.

During our meeting, Mr. Pedone outlined two options for construction plans of the array and museum expansion. The first option would provide an original array to be constructed on the present roof. The panels would be installed as a ballasted system, anchoring them to the roof with concrete blocks. No additional roof penetrations would reduce the risk of leaks. Unfortunately this design can only allow provide panel installations on the east side of the Higgins Wing, due to shading problems from the South side studio roof protrusions. This area is approximately 6,100 square feet (Pedone, Director Of Operations, 2009), and the system would only be temporary and the ballasted mounting system would allow for movement of the panels to the new roof when the addition is complete.

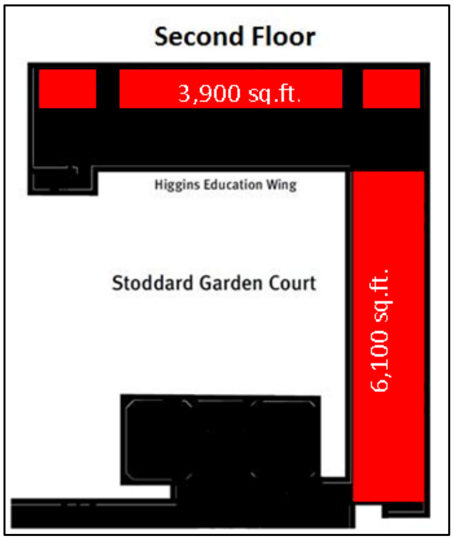


Figure 15 WAM Ballast Solar Option 1

The second option is holding off on purchasing panels until the addition is complete, and then covering the entire wing with permanently mounted panels. The entire wing has a usable area of 11,200 square feet (Pedone, Director Of Operations, 2009). This excludes an additional 3,900 square feet area above the studio roof protrusions. These south facing protrusions have small roof tops and more significantly slanted roofs that extend down. Facing the south, this slanted section would have exposure to sun almost all day. This area can also be considered with the first option, with the understanding that the panels installed in that section will be permanently mounted, not ballasted.

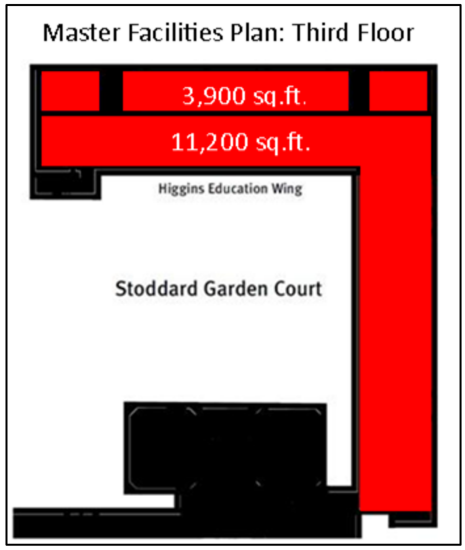


Figure 16 WAM Solar Option 2 with Addition

Mr. Pedone's concern about the first option is that the labor costs associated with moving the panels and docking system for the construction may outweigh the benefit of purchasing them earlier. These costs will depend greatly on the panel selections made by Garland, and how productive the panels will actually be.

4. 5 Objective 5: Recommendations

In the conclusion of our project we provided the Worcester Art Museum with the results of our findings which will include: a detailed energy profile of the migrating offices, possible low-cost energy management solutions for the current office space, and a recommendation for an aggressive green technology installation. Our recommendations will be based on extensive data collection within the museum itself and from professionals in the field of green technologies. From these professionals we will gain the knowledge to make appropriate forecasts that take into account the unique characteristics of the museum, and will be based on scientific and economical determinations.

Our conclusions provided the museum with a thorough outline of possible avenues of green installations and possible funding options for these plans. The recommendations will take into account the limited resources of the museum's budget, the most effective green technology economically available to the museum, and feasibility of our solutions. The recommendations will include estimated energy savings and projected future energy consumption. The decisions will be based on supporting evidence of market trends and upcoming technologies to make the best possible decision upon installation.

4. 6 Conclusions

Based on extensive research and consultations with not only green technology installers but with also costumers, we were able to conclude on the most appropriate green technology approach for the museum. Our solution needed to take into account not only the structural diversity of the museum, but also the exact needs most important to the museum.

There are two main benefits of a green roof design. First of all, it will extend the life of the existing roof by acting as a physical barrier to the elements and greatly reducing the effects of erosion from rainwater and other particles to the tradition underroof. Secondly, it provides vast improvements in draining efficiencies by actually absorbing rainwater instead of letting it run rampant. A green roof at first did target some of the museums weaknesses, being its roof leakage problems and roof replacement needs. Unfortunately the installation would result in major downsides of its own. If the green roof was to be installed on the existing roof, a new roof would need to be added first to provide the structural support to hold the necessary vegetation. This creates a costly install of roughly 30 dollars per square foot, and may produce a new roof which will be built on top of in the upcoming years (Balch, 2009). This would result in the new roof being an expensive waste of funds. Finally drainage, which green roofs are mainly installed for, is only a minor problem with the current roof system. This would provide an excessive and expensive solution to a considerably minor problem. Therefore we concluded that the solutions that a green roof provide do not coincide with the concern of the Worcester Art Museum, allowing us to rule out a green roof design and choose a photovoltaic installation instead.

Based upon our consultations with Garland Roofing, our team was able to produce two feasible photovoltaic options as presented earlier. A photovoltaic array provides the museum with four basic advantages. Photovoltaics produce a measurable active amount of power, rather than the passive approach of the green roof design. This power production provides the best comparable payback period, which can even be shortened by the large amount of funding solutions that exist for such solar arrays (Balch, 2009). Therefore we determined that due to these benefits, photovoltaics provide the best applicable advantage to the museum of any green technology currently on the market.

5 Recommendations

Many energy efficient actions can be employed to reduce energy waste and consumption. We researched and studied several different green technologies to determine their viability for the unique needs of the Worcester Art Museum. We have determined that a photovoltaic array will be the most beneficial green technology for the museum, based on their facilities and energy needs. All estimates in this section are based on professional estimates.

5. 1 Photovoltaics

As the building exists now, the museum can install up to 57 kW array over the west most side of the Higgins Wing. Due to existing system components already located on other areas of museum roofs, the Higgins Wing is the only space on which solar panels can be installed. With an array this size, the museum can expect to produce 71,000 kWh for a savings of $11,000 annually. The array will cost around $427,000 total. We recommend that this array be installed as a ballasted system for two reasons: firstly, to reduce the number of roof penetrations and preserve the integrity of the roof membrane, and secondly, to allow the array to be moved with greater ease. The Facilities Master Plan for the museum allows for a third floor to be installed over the existing Higgins Wing, in which case any solar panels on the roof of the existing structure would have to be moved before construction begins. In the case that this construction is completed, the museum would be granting itself an additional 5,100 sq. ft. on which to install solar panels. With this space, the Higgins roof could house a total array of 87 kW, which would produce approximately 109,000 kWh and $16,000 of energy savings annually. The additional cost to include the new 30 kW array with the existing 57 kW array would be about $223,000, for a total array cost of $650,000. An additional option worth considering is utilizing the museum parking lot space by building roof-like photovoltaic structure over the lot. The 12,400 sq. ft. lot could house a 71 kW array, producing up to 89 kWh annually. However, the steep cost of a steel framework to support these panels makes this subproject infeasible in lieu of substantial external funding.

Without any financial support from the MTC or other sources, the payback period for the arrays recommended may be as long as forty years. Minimum grants from the MTC can cut 10-12 years off this estimate, and it should be noted that large scale public projects, such as Worcester State College and Mass MoCA solar arrays, often receive more than the minimum grant. Accordingly, we recommend that the museum actively pursue MTC funding as well as solicit donations from potential contributors within the community. A $10,000 donation will reduce the payback period by approximately 1 year.

5. 2 HVAC & Other

Aside from the photovoltaic project, we recommend that the museum audit its HVAC system and explore options to reduce energy usage in those areas. The museum's HVAC system accounts for over 60% of its energy usage, so small upgrades in efficiency in this area will have a larger effect than large improvements in efficiency in the area of lighting/office usage.

Museum lighting should be examined as well. Due to the unique lighting requirements of an art museum, lighting must be examined on a case by case basis. Some concerns in particular are the library and hallway lighting.

Bibliography

Abraxas Energy. (1999). *Abraxas Emission Calculator*. Retrieved September 25, 2009, from Abraxas Energy Consulting: http://www.abraxasenergy.com/emissions/

Answers Corporation. (2009). *energy audit*. Retrieved September 15, 2009, from Answers.com: http://www.answers.com/topic/energy-audit-1

Balch, M. (2009, November 23). Garland Solar Installation. (T. Collins, C. Gowell, & A. Hall-Stinson, Interviewers)

Bass, M. (2009, October 25). Printer's Building Meeting. (T. Collins, C. Gowell, & A. Hall-Stinson, Interviewers)

Case Studies. (2009). Retrieved November 28, 2009, from groSolar: http://grosolar.com/case-studies/

Collins, T. (Director). (2009). *Solar Panels Arrays* [Motion Picture].

Commerical Roofing Systems from The Garland Company. (2009). Retrieved November 22, 2009, from The Garland Company: http://www.garlandco.com/

(2009). *Commonwealth Solar Photovoltaic Rebate Program.* Massachusetts Technology Collaborative.

Daniels, R., & Olson, S. (2009, November 24). Worcester State College Solar Array. (T. Collins, C. Gowell, & A. Hall-Stinson, Interviewers)

DiMauro, A., Hutchins, N., Grudzinski, W., & Arthaud, B. (2009, November 23). WPI East Hall Green Construction. (T. Collins, A. Hall-Stinson, & C. Gowell, Interviewers)

Dunn, C. (2005, December 15). *"Smart" Power Strips: Helping to Stop Idle Current Now!* Retrieved September 25, 2009, from Tree Hugger: http://www.treehugger.com/files/2005/12/smart_power_str.php

East Hall Sustainable Features. (2009). Retrieved December 2, 2009, from WPI Sustainability: http://www.wpi.edu/about/Sustainability/eastha764.html

Ecos Consulting. (2009). *Efficient Products*. Retrieved 10 8, 2009, from http://www.efficientproducts.org/productImages/Commercial-Plug-Load-Pie-Graph.JPG

Energy Audits Unlimited. (2008). *Benefits of an Energy Audit*. Retrieved September 19, 2009, from Energy Audits Unlimited: http://www.energy-audits-unltd.com/benefits.html

Energy, S. S. (2008, June). *POWER YOUR BUILDING. EMPOWER YOURSELF.* Retrieved September 15, 2009, from Sunlight Solar Energy: http://www.sunlightsolar.com/images/stories/documents/SSE_CFB%20Executive%20Summary.pdf

Fischer, J. (2006). Solar Energy Technology: What's New Under the Sun? *Resource: Engineering and Technology for a Sustainable World* , 3.

Gard Analytics. (2007). *Types of Energy Audits*. Retrieved 9 25, 2009, from Gard Analytics: http://www.gard.com/auditType.htm

Green Technology - What Is It? (2006). Retrieved October 10, 2009, from Green Technology: http://www.green-technology.org/what.htm

Habin, B., Dupuis, M., & Cancel, D. (2009). *Energy Audit of Higgins Laboratory.* Worcester, MA: WPI.

Henemann, A. (2008). BIPV: Built-in solar energy. *Renewable Energy Focus* , 14-17.

Kelcroft Energy. (2008). *Kelcroft energy*. Retrieved 9 29, 2009, from Energy Audit Standards: http://energy.kelcroft.com.hk/energy_audit_types.htm

Massachusetts Is Running On Solar Energy. (n.d.). Retrieved September 20, 2009, from Massachusetts Technology Collaborative: http://www.masstech.org/solar/threebiz2009.html

Massachusetts Museum of Contemporary Art Solar PV Array and Efficiency Retrofits. (2005, July 12). Retrieved November 16, 2009, from Massachusetts Technology Collaborative Site: http://www.masstech.org/project_detail.cfm?ProjSeq=135

New Jersey Sustainable State Institute. (2008, 1 25). *Green Future Roadmap Energy Audit Tool*. Retrieved 9 15, 2009, from New Jersey Sustainable State Institute: http://www.njssi.org/uploaded_documents/EnergyAudit1-25-08.pdf

Northeast Utilities. (2009). *Energy Management Systems*. Retrieved 9 23, 2009, from Customer Service of New Hampshire: http://www.psnh.com/Business/Commercial/EnergyMgmt.asp

NREL. (2009, June 2). *Reliability Concerns Associated with PV Technologies.* Retrieved September 15, 2009, from National Renewable Energy Laboratory: http://www.nrel.gov/pv/performance_reliability/pdfs/failure_references.pdf

Occupancy Sensors Deliver Hands-Free Switching and Energy Savings. (2009, November 8). Retrieved November 14, 2009, from SmartHome: http://www.smarthome.com/2522W/Leviton-Wall-Mounted-Occupancy-Sensor-White-PR150-1LW/p.aspx

Pedone, F. (2009, October 27). Director of Operations. (C. Gowell, T. Collins, & A. Hall-Stinson, Interviewers)

Pedone, F. (2009, November 23). Director Of Operations. (C. Gowell, T. Collins, & A. Hall Stinson, Interviewers)

Process Quality Associates. (2006). *Energy Audits*. Retrieved 9 29, 2009, from Process Quality Assoicates: http://www.pqa.net/ProdServices/Energy/energy_audit.htm

Reis, J. (2009, November 1). A Whirl of Difference at school. *Worcester Telegram and Gazette* , p. A6.

Reis, J. (2008, May 7). Worcester State Energy Project Is Sunny Side Up; College Gets Funds For Solar Power. *Worcester Telegram & Gazette* , p. 7.

Rodriguez, R. (2006, September 26). *The History of Green Roof Technology*. Retrieved October 6, 2009, from IfEnergy: http://www.ifenergy.com/50226711/the_history_of_green_roof_technology.php

SAN DIEGO GAS & ELECTRIC. (2007). *Energy-Saving Solutions*. Retrieved 10 8, 2009, from SAN DIEGO GAS & ELECTRIC: http://www.sdge.com/documents/forms/OfficeFactSheet.pdf

Sharma, V. K., Colangelo, A., & Sp, G. (1995). Photovoltaic technology: Basic concepts, sizing of a stand alone photovoltaic system for domestic applications and preliminary economic analysis. *Energy Conversion and Management* , 161-174.

Snow, D., Holmes, P., Galligan, P., & Downey, M. (2009). *Long-Term Green Renovations for the Printer's Building of Worcester, Massachusetts.* Worcester: Worcester Polytechnic Institute.

Solar FAQs — Photovoltaics — The Basics. (2008, August 13). Retrieved September 15, 2009, from U.S. Department of Energy: http://apps1.eere.energy.gov/solar/cfm/faqs/third_level.cfm/name=Photovoltaics/cat=The%20Basics

TCP Incorporated. (n.d.). *Cost of Lighting*. Retrieved September 20, 2009, from TCPI Web Site: http://www.tcpi.com/commercial/cost_of_lighting.aspx

Technical specifications. (2009, June 19). Retrieved November 30, 2009, from SolarDock: http://www.solardock.com/images/SolarDock%20Spec%20Sheet.pdf

Tripanagnostopoulos, Y., Nousia, T., Souliotis, M., & Yianoulis, P. (2002). Hybrid photovoltaic/thermal solar systems. *Solar Energy* , 217-234.

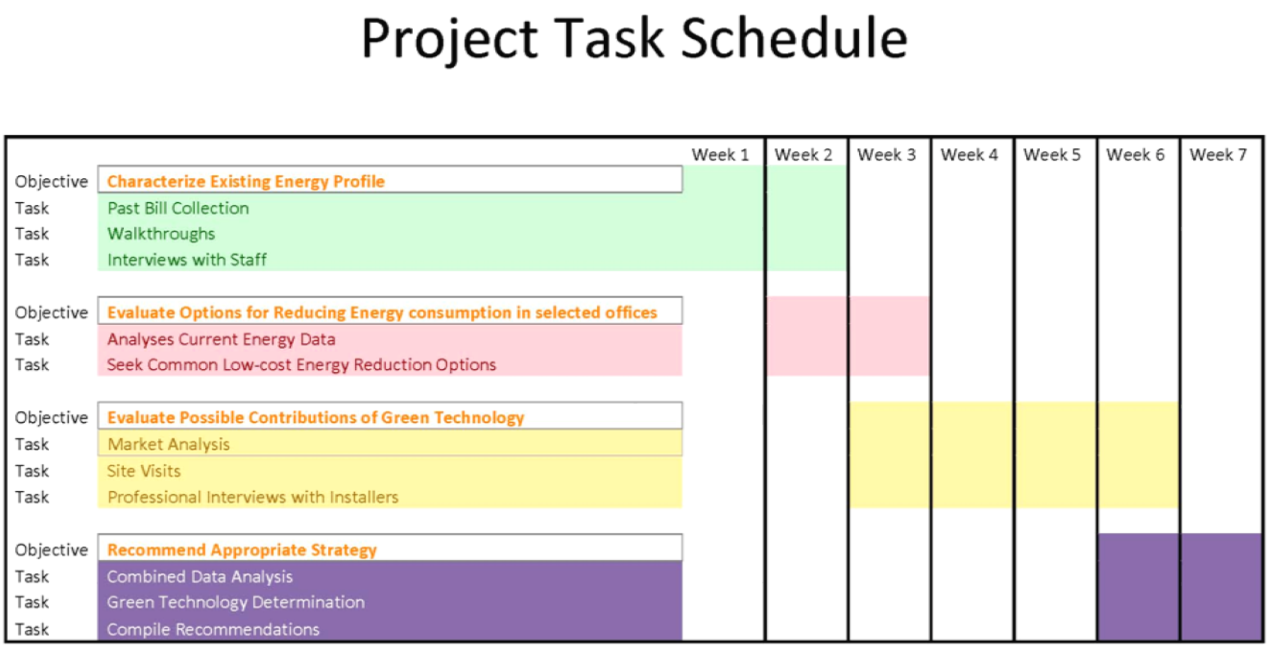
(2009). *U.S. DOE - Loan Guarantee Program.* Washington D.C.: U.S. DOE.

University Of Colorado at Boulder. (2008). *Facilities Manangement*. Retrieved 10 1, 2009, from University Of Colorado at Boulder: http://www.colorado.edu/facilitiesmanagement/about/conservation/auditchecklist.html

Voorhees, D. (2006, December 26). *Model Amendment to a Zoning Ordinance or By-law: Allowing Wind Facilities by Special Permit.* Retrieved September 25, 2009, from Mass.gov: http://www.mass.gov/Eoca/docs/doer/renew/model-allow-wind-by-permit.pdf

Weston Solutions, I. (2009). *GreenGrid® Frequently Asked Questions (FAQ)*. Retrieved September 25, 2009, from GreenGrid: http://www.greengridroofs.com/system/faq.htm

Appendix A


Project Task Schedule
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Week 7
Objective
Characterize Existing Energy Profile
Task
Past Bill Collection
Task
Walkthroughs
Task
Interviews with Staff
Objective
Evaluate Options for Reducing Energy consumption in selected offices
Task
Analyses Current Energy Data
Task
Seek Common Low-cost Energy Reduction Options
Objective
Evaluate Possible Contributions of Green Technology
Task
Market Analysis
Task
Site Visits
Task
Professional Interviews with Installers
Objective
Recommend Appropriate Strategy
Task
Combined Data Analysis
Task
Green Technology Determination
Task
Compile Recommendations

Appendix B

Office Equipment (University Of Colorado at Boulder, 2008)

Item	Check Point Description	Yes	No	N/A	Corrective Action Request / Comments / Add'l Info
1	Are PC monitors shut off, or on sleep, mode at the end of the work day?				
2	Are copying machines shut off, or on sleep mode, at the end of the work day?				Location
3	Are fax machines shut off, or on sleep mode, at the end of the work day?				
4	What are the labs' functions?				
5	What lab equipment, if any, is used?				
6	General comments				

Appendix C

Lighting (University Of Colorado at Boulder, 2008)

Item	Check Point Description	Yes	No	N/A	Corrective Action Request / Comments / Add'l Info
7	Areas to change incandescent lights to fluorescent lights				Location Type Qty
8	Exit signs, upgrade to LED type(signs made up group of small lights like PC or phone lights)				Location Qty
9	Would you like to install local switches for more control for very large area & lights?				Location
10	Delamp/deactivate extra lights & fixtures				Location Qty
11	Is lighting only used when needed?				
12	Is lighting on after hours & weekend used only when needed?				
13	What percentage of lights is being shut off during after hours/weekends?				
14	Outside lights (outside building & entry) acceptable? Change to compact fluorescent?				Location Type Qty
15	Special Lighting needs/concerns where?				

16	What do you hear most often regarding lights in this building?				
17	Do you need additional light switch stickers to remind people to turn off lights when not in use?				Location Qty

Appendix D

Power Usage Checklist

Checklist						
	Room	Room	Floor	Personnel		
	Lighting	Bulb Type	Brand	Hours Used	Daily Power Usage	Quantity
	Devices	1	2	3	4	5
	Type					
	Brand					
	Model					
	Age					
	Measured Usage On					
	Measured Usage Standby					
	Rated Power Usage					
	Daily Hours On					
	Daily Hours Standby					
	Daily Power Usage On					

	Daily Power Usage Standby					
	Alternative Replacements					
	Brand					
	Model					
	Rated Power Usage					
	Expected Daily Energy Savings					
	Expected Payback Period					