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The Economic Feasibility of Solar Panels for the University of Nebraska- Lincoln

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The Economic Feasibility of Solar Panels for the University of Nebraska – Lincoln

By

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An Undergraduate Thesis Proposal

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University of Nebraska – Lincoln
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Abstract

The world runs on the electricity provided by gas, oil, and coal. These sources, while cheap, have some major drawbacks associated with them; they are polluting when burned, extraction damages the environment, and the resource reservoirs are limited. With this understanding, the world is turning to renewable energy sources as a means to alleviate its growing energy requirements. But there are problems associated with renewable energy sources preventing them from becoming major sources of electricity generation. These problems are usually monetary in nature.

The cost effectiveness of photovoltaic panels for use by the University of Nebraska-Lincoln as a means of electricity generation was investigated. A simple atmospheric radiation transfer model which estimates solar radiation receipt values for optimally tilted and tracking photovoltaic panels was utilized. An angle of 36° was determined as optimal for the Lincoln area. Model values were applied to solar panel efficiencies and areas to determine actual received radiation per unit area by the panel. Panels averaged 279 kWh per year when fixed; 336 kWh per year when fitted with tracking equipment. Finally, the estimated panel reception was multiplied by the price of electricity per kWh. Photovoltaic systems are not currently cost effective in Lincoln, NE for commercial use due to low conversion efficiencies of the panels, high installation expenses, and cheap public energy.

Introduction

Electricity is the fuel that the world craves; the only question is where will it come from? Currently three main resources satiate most of the world's electricity hunger:

Coal (25%), natural gas (21%), and oil (34%) (IEA, 2006). These three source materials have two things in common; they are all burned to release the energy contained within and combustion releases pollutants. In recent years, there has been a big push towards renewable energy and energy efficient technologies like wind power, solar collectors, and LED lights. This last year the United States set aside $2.7 billion for communities to develop and complete projects designed to increase energy efficiency (U.S. DOE, 2009). Of the funds set aside for energy efficiency Lincoln is slated to receive $2.4 million (City of Lincoln, 2009). Lincoln is presently investigating energy saving applications for these funds.

Literature Review

One of the biggest problems involved with solar energy today is the efficiency coefficient (Aberle, 2009). Even with the newest and best performers the highest lab recordings for panel efficiencies have been ~20% (CIS) and falls to ~13% when attempting commercial applications. Science has tried to combat these low efficiencies by using different materials and production techniques. Graphite sheets with Carbon Nanotubes and Titanium Oxide panels are a couple of examples, but even they are still in the preliminary testing stages (Fuke et al, 2009 & Wijewardane, 2009).

The current cost of photovoltaic (PV) panels is too expensive to implement for most residential uses, but to lower the cost more participation is required. Subsidies may be needed to get consumer buy-in, taxes on current energy production methods to fund these subsidies, and time to allow advocacy groups to become more powerful (Sande'n, 2005). Another approach may combine current fossil fuel power technology with solar energy in an attempt to bridge the difference and drag the price /kWh down to a point where it is profitable. In this piece, the hybrid is a gas/solar station (Schwarzbozl et al., 2006).

Despite low demand, manufacturers and power companies such as IBM, Google, Lockheed and Martin, and PG&E are investing in PV technology (Englander, 2009 & LaMonica, 2009 & Kanellos, 2005). As demand for energy is ever increasing it is possible that by the year 2050 we'll need to increase energy production by 46% or so to meet it. Coal alone cannot meet this increase in demand (Higgens, 2009). The possibility of solar power is as endless as the applications for energy production.

The major problem hampering the expansion of solar power is its cost per kWh. For solar energy to truly flourish, the generating costs of solar electricity must be $0.07-$0.14 per kWh (Schwarzbozl et al, 2006) given the current production cost of solar panels. Today's market value for energy in Nebraska is about $0.07 kWh compared to the national average of roughly $0.10 per kWh (Nebraska Energy Office, 2009). To determine if solar energy is economically feasible in Nebraska, the cost associated with PV collectors (including composition, installation, and maintenance) and average daily receipt of solar radiation has to be considered. For example, current mass produced silicon has a stable average solar to electrical conversion efficiency of 6% or less (Aberle, 2009). Making PV cells with different materials can have a very large impact on the efficiency values of the panel.

My goal is to determine if the installation of silicon dioxide (SiO_2) PV panels on University property is cost effective. Using observational and simulated data, the daily average receipt of solar radiation collected by silicon based PV panels on the University of Nebraska campus will be investigated. Hourly incoming solar radiation data from the High Plains Regional Climate Center (HPRCC) Automated Weather Data Network (AWDN) from the past 20 years will be used; these data represent solar radiation received by horizontally positioned solar collectors. In combination with simulated data, the optimum angle for receipt of solar energy will be determined. A cost analysis comparison between fixed solar panels and units that track the sun will be completed as a means of investigating the cost effectiveness of this power source for Lincoln.

Materials and Methods

Two different panel orientations for solar collection were tested: 1) a static angle and directional panel and 2) a panel with sun tracking capability. Using these two design configurations I compared the cost effectiveness of implementing the Sharp ND224-UC1 and the Sanyo HIT 210N. Two different sets of solar irradiance data were used in the analysis: (1) hourly and daily observational solar irradiance data (W/m^2) collected from the Lincoln 84th and Havelock AWDN (HPRCC, 2009) and (2) station simulated clear sky day solar irradiance. The range of dates collected are 5/5/83 - 12/18/09. Observational data were collected with a Silicon Cell Pyranometer (Model LI-200, Li-Cor Inc., Lincoln, NE) with an accuracy of 2% (HPRCC, 2009); the instrument was installed at a height of 2m.

The observational daily irradiances were sorted by month and then sorted from lowest to highest total daily solar radiation. A statistical analysis assigning a percentage to each day according to its sorted ranking was applied. Clear sky days which fell at or near the 95^{th} percentile category were selected as the clear sky day for that month. The average hourly data for the selected clear sky days were used to calibrate the atmospheric radiative transfer model, SPECTRL 2 (Bird and Riordan, 1986). Simulation was run on an hour by hour basis with the half hour being the time simulated for each. The model represents the direct irradiance ($I_{d\lambda}$) for each wavelength in the solar spectrum (λ) as:

$$I_{d\lambda} = H_{O\lambda} D T_{r\lambda} T_{a\lambda} T_{w\lambda} T_{O\lambda} T_{u\lambda} \mathrm{Cos} Z \qquad \text{Eq. 1}$$

$I_{d\lambda}$ is the direct irradiance at wavelength λ ($Wm^{-2}\mu m^{-1}$)
$H_{o\lambda}$ is the extraterrestrial irradiance at the mean earth-sun distance for wavelength λ
D is the correction factor for the earth-sun distance
$T_{r\lambda}$ is the transmittance due to Rayleigh scattering at wavelength λ
$T_{a\lambda}$ is the transmittance due to aerosol attenuation at wavelength λ
$T_{w\lambda}$ is the transmittance due to water vapor absorption at wavelength λ
$T_{o\lambda}$ is the transmittance due to ozone absorption at wavelength λ
$T_{u\lambda}$ is the transmittance due to uniformly mixed gas absorption at wavelength λ
Cos Z is the solar zenith angle correction (Z is determined from the sun angle on the 15th of each month.)

Transmittance is based on Beer's law. The diffuse radiation is calculated as the scattered portion toward the earth's surface due to Rayleigh and aerosol scattering. Total solar irradiance (I_{tot}) is the sum of the direct and diffuse integrated over all wavelengths.

Input parameters for the model included: (1) aerosal optical depth at 0.5 microns, (2) power of the angstrom turbidity expression, (3) precipitable water, (4) ozone amount, and (5) surface pressure. The angstrom turbidity expression was automatically set by the model. Precipitable water vapor, ozone amount, and surface pressure were provided by archived soundings (University of Wisconsin) and by monitoring devices (ESRL). Other variables were adjusted so that simulated irradiance agreed within 0.5% of observed irradiances.

The input variable settings used to reach acceptable simulation results were used to simulate clear sky irradiance for the 15th of each month from which the optimum angle for the static angle directional panel was determined. Simulations for panels inclined from 25 to 45° were run for each month. In addition, the daily radiation for each month using a tracking panel was simulated. Monthly solar radiation receipt (I_{month}) was calculated as the sum of the product of hourly values multiplied by 3600 s hr-1 multiplied by the number of days (n) in the month (in MJ/m^2):

$$I_{month}\ \{MJ\ m^{-2}\} = [\sum Itot\ \{J\ m^{-2}s^{-1}\}\cdot 3600\ (s\ h^{-1})]\ \cdot n \qquad \text{Eq. 2}$$

A ratio of the mean daily radiation receipt for each month from observation data to the radiation received during the simulated representative clear sky day of the same month was applied to each month to represent the monthly mean radiation receipts for the solar panels (static and tracking).

Simulated monthly total radiation receipts were from a radiant flux (MJ/m^2 per month) to kilowatt hours per month (E_{month}) by multiplying by panel efficiencies (η) and areas (A) and using the relation of 1kWh per 3.6 MJ to determine the amount of electricity (kWh) that would be produced by the panels.

$$E_{month}\{kWh/m^2\ \text{per month}\} = I_{month}\{MJ/m^2\ \text{per month}\}\cdot\eta\cdot A\cdot 1\{kWh\}/3.6\{MJ\} \text{Eq. 3}$$

These results were summed over all months to produce an annual electricity production per panel and then multiplied by 18, the number of panels in a typical solar panel collection unit. This amount was multiplied by the cost of electricity per kWh to yield the equivalent electrical cost generated by the panel assembly (Eval):

$$Eval = [\sum Emonth\{kWh\ \text{per month}\}]\cdot 18\cdot cost\ \{\$/kWh\} \qquad \text{Eq. 4}$$

The length of time it would take to repay the cost of solar panel installation was calculated by dividing the cost of the 18 panel installation by the annual energy savings.

Results

Results from sorting the daily total radiation values by month and then by highest to lowest value yielded a list from which the 95th percentile was chosen as the representative clear sky day for each month (Figure 1). June 21st of 2002 received the most solar radiation of all the days; December 1st 1995 had the least (Figure 2). These days served as the template by which the SPECTRL 2 model was calibrated. Model out puts for each selected day were accepted (i.e., model calibrated) when the total difference between observed and simulated daily irradiance was within 0.0035% or when the difference was less than or equal to 856 J/m^2 (Figure 3).Simulations for panels inclined from 25 to 45° were run for each month. The calibrated model was used to determine the optimum angle for a fixed angle direction panel. The 25° and 45° panels showed the least radiation; the 36° angle was found to be optimum for fixed angle direction panels while the tracking panel was found to have the highest estimated solar radiation receipt (Table 1).

To relate simulated clear sky values to all sky conditions, a ratio was constructed by dividing the observed mean monthly radiation by the observed clear sky day radiation (Table 2). When applied to each month's simulated radiation totals the ratio lowered the simulated annual radiation receipt significantly. The monthly totals were then converted from radiant flux to kWh/m^2 (Eq. 3); the totals became less than the observed when the ratio was applied (Figure 4). Using these data, the radiation for the optimum angle and tracking panels were compared over the course of the year; the tracking panel is much better at collecting solar energy, especially during May, June, and July where the two lines are the furthest apart (Figure 5).

The Sanyo HIT 210N and the Sharp ND224UC1 solar panels were selected based on the recommendation of (personal communication, Jon Dixon). The Sanyo has the greater efficiency but also the greater cost while the Sharp has the greater surface area and lower cost; adding tracking hardware adds $8,500 to both models (Table 3). Applying the panel areas and efficiencies to the simulated monthly radiation totals (Eq. 3) I found that the Sharp ND224UC1 converted the most energy regardless of panel set up, this despite the Sanyo's 3.2% advantage in efficiency (Figure 6). Applying the UNL energy prices to the annual radiation receipt for each panel (Eq. 4) yielded annual energy savings. The Sharp model produced about $10 per year more than the Sanyo panel each time. All panels had replacement rates of 141 years or more when the panel costs were divided by the annual energy savings (Table 4).

Discussion

The goal of my thesis has been to determine if the installation of solar panels would be cost effective for the university. When it comes to solar energy, several natural factors need to be considered. Location is one of these factors so the question then becomes does Lincoln receive enough solar radiant energy during the year to justify the installation of solar panels. However, not every day will receive the same amount of energy; some days will produce more and some less. Another factor is angle of solar receipt. To gather as much energy as possible changing the angle of the plane of solar receipt can increase or decrease the amount collected. The best angle for solar radiation collection in Lincoln, Nebraska was found to be 36° (Table 1). Further, a tracking panel which maintains the best angle for solar receipt will gather more energy than any fixed panel (Fig. 5).

To adequately model the solar receipt for Lincoln a day from each month at the 95th percentile was selected to represent a clear sky day from that month (Fig. 1 & Fig. 2). These were used to calibrate the SPECTRL 2 model (Eq. 1). Calibration yielded simulated clear sky days from the SPECTRL2 model within a 9.25 to 856 J/m^2 margin of observed values (Fig. 3). To equate the simulated values received by the panels to all sky conditions, the ratio of the mean daily radiation receipt for each month from observation date to the radiation received during the simulated representative clear sky day of the same month was applied (Table 2), ranging from 0.60 to 0.77. This ratio has a substantial impact on estimated solar receipt on a panel. Considering that this ratio was heavily influenced by the choice of clear sky day, a choice of day at a lower percentage, while lowering the simulated 36° and tracking panel out put, should bring the simulated and observed monthly values much closer (Fig. 3 & Table 2).

Beyond the natural factors, there are also manufacturing aspects which may inhibit or facilitate the collection of solar energy. For instance, just like the Earth, the greater the surface area the greater the energy receipt. The Sharp panel had the greatest surface area of the two panels that I tested. Solar panels vary widely in their light energy to electricity conversion. The Sanyo had the advantage in conversion efficiency. In the end the Sharp panels had the greater surface area but a lower efficiency rating yet ultimately collected the most energy (Table 3 and Fig. 6). The best panels will be a combination of large surface area, high electrical conversion efficiency, and cost effective materials. Panel selection will be dependent on the use and situation. The two panels used in this research were selected because they were the closest in electrical output for commercial purposes.

Cost analysis indicates that solar panels are not cost effective, regardless of brand and panel inclination of the two compared panels (Table 4). The university requires that commercial grade panels be installed. Also, there are more building regulations associated with university property than with residential property. The university also requires a state engineer to sign off on these projects. Thus, the cost associated with installing panels on university property is roughly 30% more than the base cost of installing at similar residential projects. The price of energy has a large impact on the replacement rate for solar panels. The residential energy price is \$0.07 per kWh while the universities cost is \$0.049. Both prices are inhibitive to implementing solar power for users who want to recover costs through energy production (personal communication, Clark DeVries). For the selected PV panels to become cost effective, the price of energy per kWh would need to be at a maximum \$0.43 and at minimum \$0.30 (Table 5).

As a result, installing solar panels is not economically feasible for the University of Nebraska –Lincoln campus. Solar panels typically have a lifetime of 25 years; the University would only consider solar panels if the cost was recouped at a maximum of 20 years (personal communication, Clark DeVries).

Summary & Conclusions

My goal was to investigate the cost effectiveness of installing solar panels on the University of Nebraska – Lincoln campus. The tilt angle of a panel has a large impact on collected solar energy; for the university the best tilt was found to be 36°. However, the addition of tracking hardware gives energy collection amounts a great boost by constantly pointing the panel in the optimum direction at all times, but there are additional costs for such hardware. The other method is an increase in electrical conversion efficiency. The best panel will have high efficiency; the Sharp and Sanyo panels had efficiencies of 13.5% and 16.7% respectively. A higher efficiency rating would significantly shorten the cost recovery time.

Not all panels are made the same. They can be made of different materials, have differing efficiencies, and feature different surface areas. Of the two panels that I compared the Sharp ND224UC1 had the shortest cost recovery rate and the highest amount of solar energy collected despite the Sanyo HIT 210N having the greater efficiency. It is apparent that the best panels will have a combination of high electrical conversion efficiency, large surface area, and cost efficient materials.

In conclusion photovoltaic panels are not cost effective for the University of Nebraska – Lincoln campus. Current electrical rates are too inexpensive, due mostly to a cheap source of coal, oil, and natural gas. Also, solar panels themselves are too expensive, attributed to the lack of demand, high costs of production and stricter commercial building codes. Finally, photovoltaics have yet to reach an electrical conversion efficiency allowing them to gather energy well enough to offset the cost of purchase and installation. Any commercial entity who wishes to install these panels will more than likely be doing this for reasons other than energy savings, such as environmental concerns.

Tables & Figures

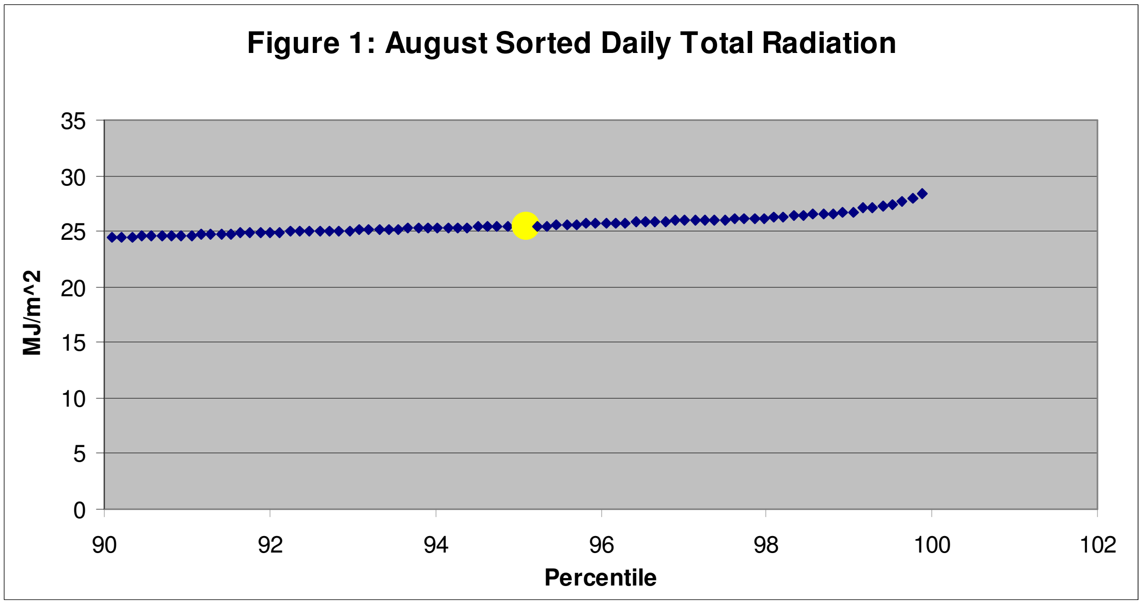

Figure 1: August Sorted Daily Total Radiation

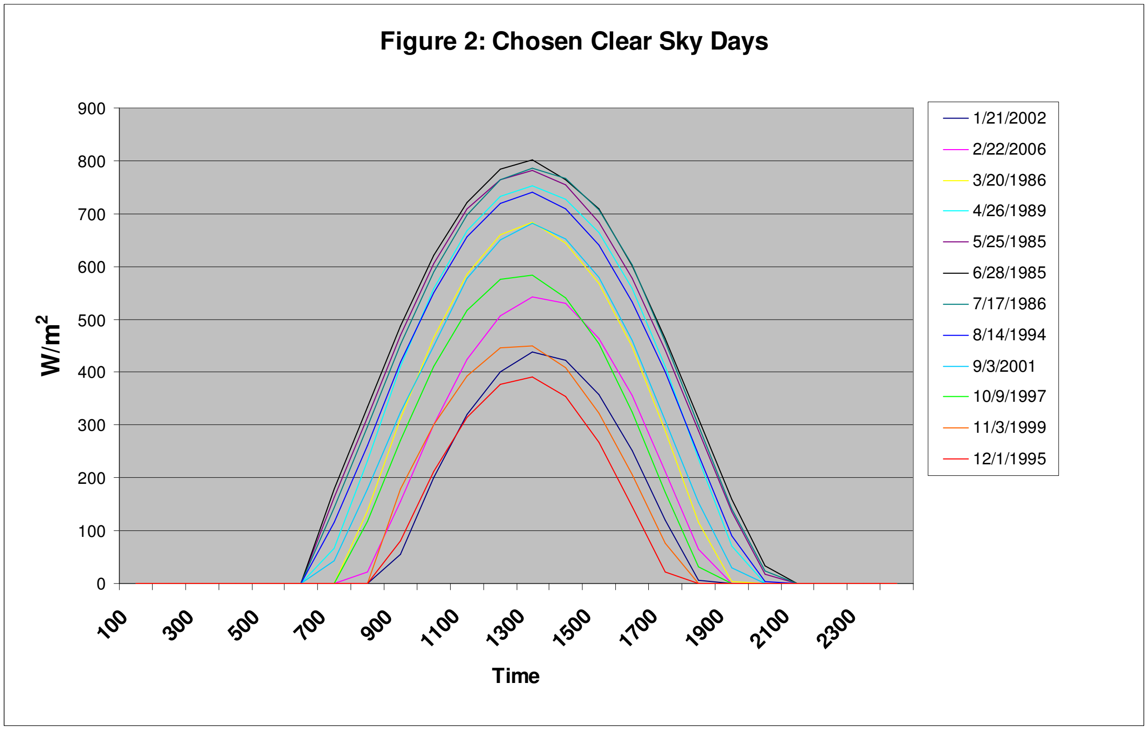

Figure 2: Chosen Clear Sky Days

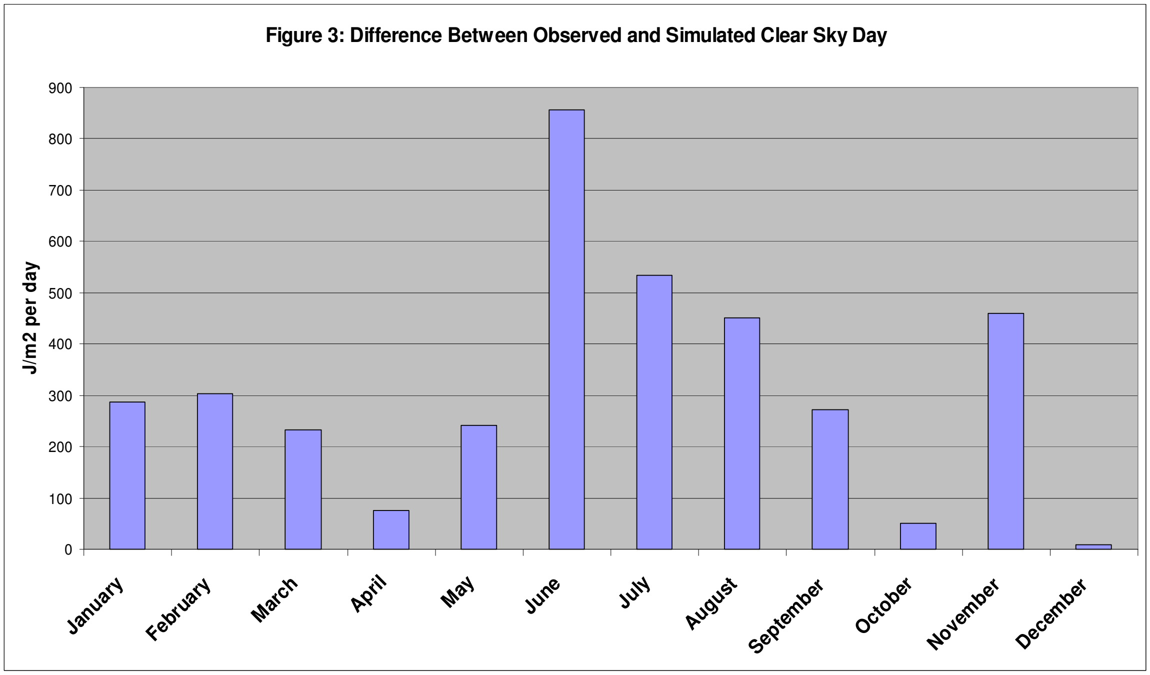
Figure 3: Difference Between Observed and Simulated Clear Sky Day

Table 1: Panel Tilt Angles and Resulting Average Monthly Radiation Receipts

Panel Tilt	Received Radiation
25 Degrees	5.25
30 Degrees	5.30
35 Degrees	5.3215
36 Degrees	5.3217
37 Degrees	5.315
40 Degrees	5.310
45 Degrees	5.27
Tracking Panel	6.402334

Table 2: Monthly Clear Sky vs Non-Clear Sky Ratio

Months	Ratio
January	0.644388
February	0.644017
March	0.624804
April	0.640477
May	0.683036
June	0.747184
July	0.775335
August	0.738106
September	0.723634
October	0.637449
November	0.598439
December	0.645757

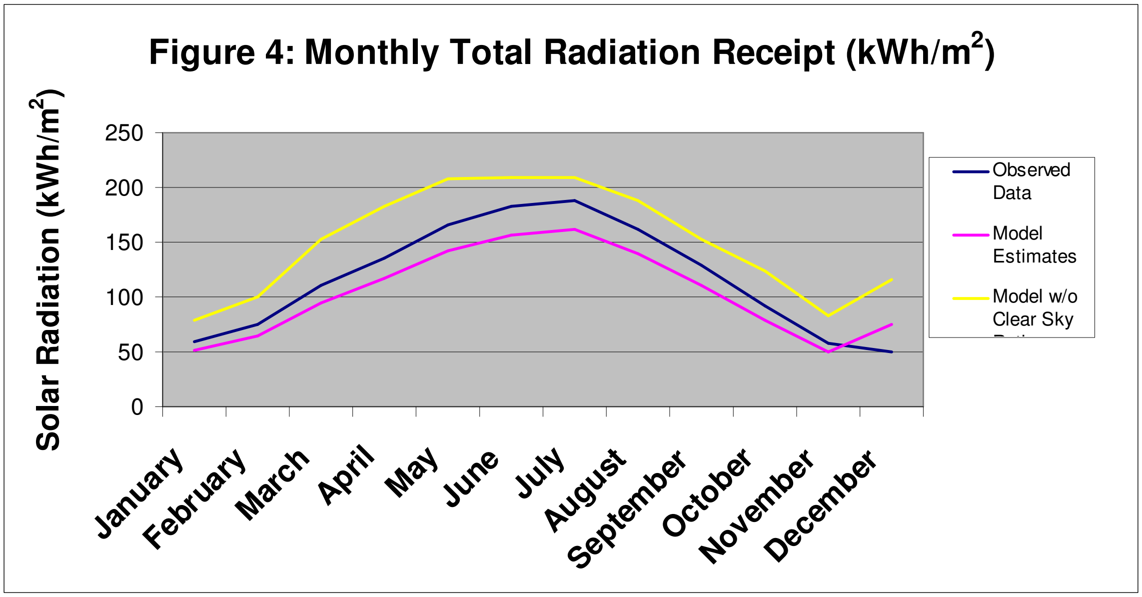

Figure 4: Monthly Total Radiation Receipt (kWh/m^2)

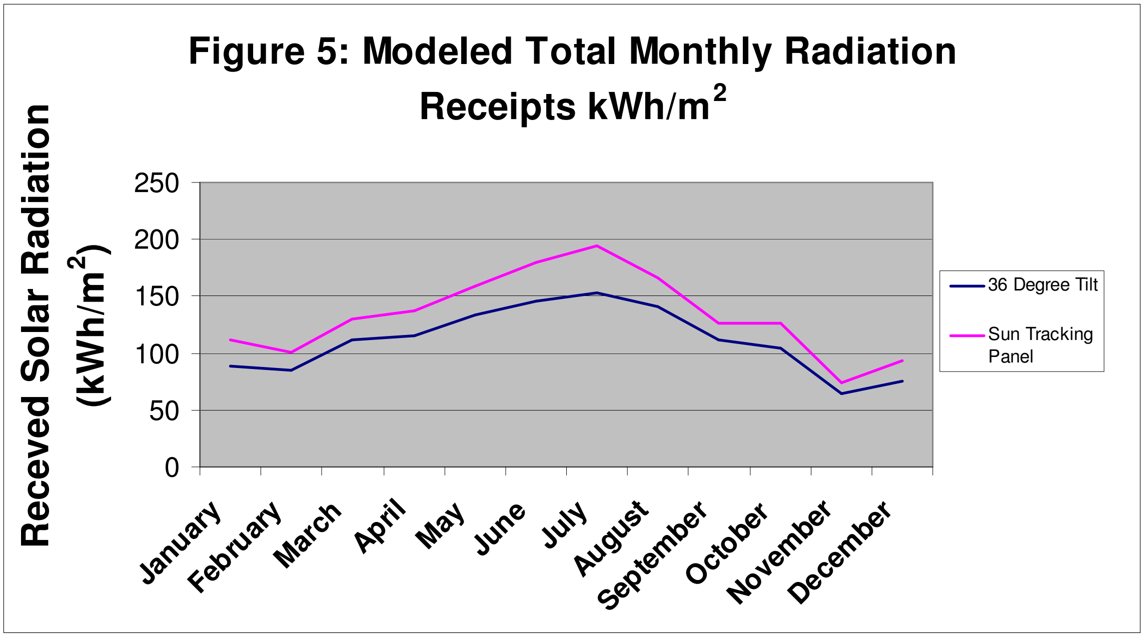

Figure 5: Modeled Total Monthly Radiation Receipts kWh/m^2

Table 3: Panel Properties, Costs, and Radiation Receipts

Sanyo HIT 210N	Sharp ND-224UC1
Efficiency: 16.7% Panel Dimensions: 31”x62” University Cost: Fixed $36,010 Tracking $44,510 Annual Solar Radiation Receipt: Fixed 274 kWh Tracking 330 kWh	Efficiency: 13.5% Panel Dimensions: 39”x64” University Cost per Panel: Fixed $35,490 Tracking $43,990 Annual Solar Radiation Receipt: Fixed 284 kWh Tracking 342 kWh

Figure 6: Monthly Total Radiation Receipts with Solar Panel Efficiencies and Areas

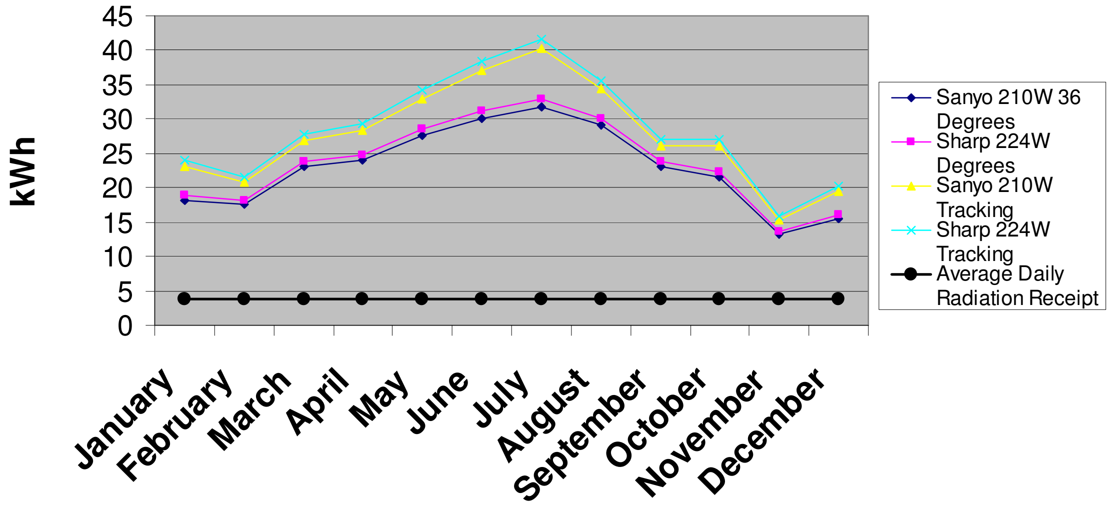

Table 4: Cost Analysis of Sanyo HIT 210N and Sharp ND224UC1

Panel Orientation	Panel Brand	University Cost	Annual Energy Savings	Panel Replacement Rate (years)
36° Degree Panel	Sanyo HIT 210N	$36,010	$242.25	148.65
	Sharp ND224UC1	$35,490	$250.74	141.53
Tracking Panel	Sanyo HIT 210N	$44,510	$291.76	152.55
	Sharp ND224UC1	$43,990	$301.99	145.66

Table 5: Price of Electricity for Solar Panels to Reach a 20 Year Replacement Rate If No Change in Efficiency

Panel Orientation	Panel Brand	Required Annual Energy Savings	Cost of Electricity for 20 year replacement rate (per kWh)
36° Degree Panel	Sanyo HIT 210N	$1,800.50	$0.36
	Sharp ND224UC1	$1,774.50	$0.30
Tracking Panel	Sanyo HIT 210N	$2,225.50	$0.43
	Sharp ND224UC1	$2,199.50	$0.36

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