



**THE DIFFERENCE IN ENERGY COLLECTION OF
SEASONAL VS YEAR-ROUND ANGLES IN A FIXED SOLAR ARRAY**

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ABSTRACT

Photovoltaic solar panels are used to generate electricity in a clean, environmentally friendly way. In order to optimize energy collection, solar panels are adjusted to collect the rays. The panels were adjusted according to the latitude of Frostburg, which is 39° . Subtracting 15° from the latitude angle determined the seasonal angle for the study. The hypothesis of this study states that solar panels positioned at the seasonal angle would collect more energy than the solar panels positioned to the year-round angle. The purpose of this study was to determine whether it is beneficial to change the angle of a fixed solar array each season or to leave it at one angle all year-round. Data was collected beginning at 8:45 A.M. until 2:30 P.M. for five days. The azimuth and altitude of the sun, cloud coverage, voltage of the battery, and the temperature were collected every 15 minutes. A two-sample T-test determined that the findings proved to reject our null hypothesis. Statistically, there was no significant difference of energy collection between the panel set at 39° and the panel set at 24° . Some experimental flaws were the lack of replication, human error, and a short amount of time, there left room for misinterpretation of the data. If additional solar panels were added, or if the study was extended to include the winter season, there could prove to be a statistical difference between the energy collections of the two panels.

INTRODUCTION

Coal-fired power plants generate a large amount of pollution, which is increasing due to the demand for higher energy to power new technology. Although there are ideas of cleaner ways to burn coal, there is no way to prevent the excess pollution that the process still emits. A chemical reaction occurs when coal is burned; this process creates

pollutants such as carbon dioxide, sulfur dioxide, and nitrogen oxide. These pollutants, when emitted into the air, cause a high acidity level of precipitation known as acid rain (Moore 2000).

Coal is deemed the most abundant and low priced nonrenewable resource; therefore, coal consumption is increasing in undeveloped countries. The world's energy consumption is projected to increase by two-thirds over 21-year period (Energy Information Administration 2001). Rapid development is expected to occur in Asia and Central/South America raising the annual growth rates to 3.5 percent between 1999 and 2020 (EIA 2001). With the increase of energy, the Energy Information Administration predicts an increase of pollutants (2001). Many die, globally, each year from some type of condition related to air pollution (Moore 2000). All across the world, a small minority of people have integrated renewable energy into their daily lives, and according to projections from EIA, renewable energy use will increase by 53 percent between 1999 and 2020. However, the current nine percent share of total energy usage that is renewable would decline to eight percent (EIA 2001).

To solve numerous environmental harms, new ideas of renewable energy have been coming into light. Renewable energy can contribute greatly to the world. For example, the United States could become more energy independent by eliminating the need to import fossil fuels and other nonrenewable resources; therefore, the budget could be directed toward renewable technologies (Careless 1993). Various renewable alternatives can provide safe, reliable, and clean energy; hence, renewable energy is applicable to rural communities that are not connected to the grid and have isolated populations (Careless 1993). One renewable resource that can benefit everyone globally

would be solar energy. The sun is the single largest energy resource, and it is accessible from all around the world (Careless 1993). The sun's energy can be harnessed and used in many ways such as: solar cooking, satellites and the space shuttles, automobiles, energy to run households, heating water, and much more.

Different solar panels optimize energy more efficiently. The three main types of solar panels in order of descending efficiency are single crystalline, polycrystalline, and amorphous. Single crystalline panels are the most efficient and also the most expensive. On the other hand, polycrystalline panels are not as costly or efficient. Lastly, amorphous or thin film panels are the cheapest and least efficient photovoltaic cell (Byrne 2001).

During the course of the day, the apparent motion of the sun advances from east to west due to the axis rotation of the earth. Due to the earth's tilt during the summer months, the Northern hemisphere is angled toward the sun, making the sun higher in the sky. In the winter, the sun is lower because the Northern hemisphere is tilted away from the sun (See Figure 1).

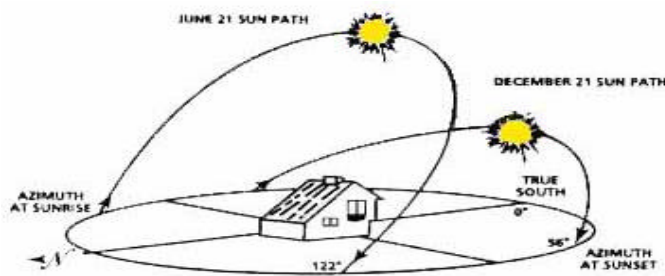


Fig. 1- This figure shows the location of the sun due to the yearly changes of the Earth's axis and revolution.

Therefore, the purpose of this study is to determine the benefits of adjusting the angle of the fixed array (mounting to a surface) according to the seasonal angle (summer= latitude- 15°; winter= latitude + 15 °) or leaving them at the same angle all year round (latitude). Adjustments of 15° are made because it is the average deviation

from the sun moving through the winter and summer skies. The year-round angle is determined by the location of the panel on the earth. The latitudinal number of the location is the same as the number of degrees the panel is tilted. For example, Frostburg is located at approximately 39° latitude; therefore, the seasonal angle of this location is 39° . The latitude is used for the year-round angle because it is the average angle for the year that the sun is perpendicular to that point on the earth. Solar noon occurs when the sun is highest in the sky due true south.

A fixed array is a group of solar panels that does not move by themselves, while tracking arrays continuously follow the azimuth and altitude of the sun. The azimuth is the horizontal angle of the sun from true south, while the altitude is the height of the sun in the sky measured from the horizon (See Figure 2).

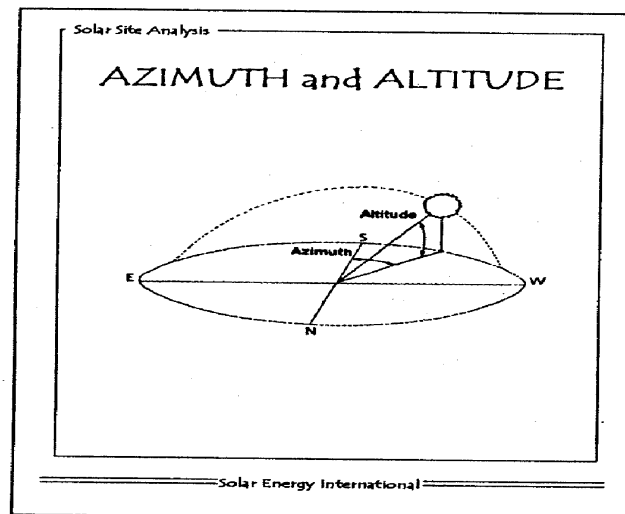


Fig. 2- Azimuth and Altitude of the Sun (Courtesy of Solar Energy International Staff).

The most effective performance of the solar panel is obtained when the sun's rays are perpendicular to the array. When the sun's rays are perpendicular, striking the surface at a 90-degree angle, the panel would collect more energy. If the rays strike the surface in a

smaller angle, the rays would cover a larger area (See Figure 3); therefore, the panels would receive less energy (Norton 1977).

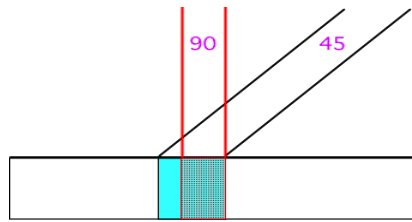


Fig. 3. – This figure taken from the website <http://www.geog.ovc.bc.ca/physgeog/contents/6i.html> shows the relationship of the 90° angle striking the surface perpendicularly.

In that respect, many people use different ways to mount a fixed array of solar panels such as roof mount, pole mount, and ground mount.

It is hypothesized that adjusting the angle of solar panels seasonally should increase energy output, relative to panels set at a year round angle. Compensating for the seasonal change of the sun's position will increase output since the solar panel will be perpendicular to the sun for a longer period of time annually.

METHODS

The term solar potential is used to describe a surface where solar panels or other solar units could be placed because it is possible to convert the sun's energy easily into useable energy (Diab & Achard 1999). The site used was the Frostburg State University practice baseball field for two reasons. First, it was close to the students conducting the experiment and, second, it has very high solar potential with no shading to interfere with the testing. The latitude of Frostburg, Maryland is 39°; therefore, one of the adjustable solar panels is set at 39° for the year-round angle. The other adjustable panel is set at an angle that accommodates the seasonal movement of the sun (24°). The panels were set facing due south. Each panel had an individual battery pack to store the energy collected at the two angles.

The most productive time for solar collecting is between 9:00 and 15:00 because this is when the sun is highest in the sky and more of the sun's rays reach the surface of the earth directly (Byrne 2001). Testing took place from 8:45 in the morning until 14:30 in the afternoon on June 28, July 2, and July 3. On July 9, testing took place from 8:45 to 17:30. This extra time was taken to study the movement of the sun. On July 10, testing took place from 8:45 to 16:15 due to weather complications. Data was collected and recorded every fifteen minutes.

Two groups gathered the data at different time intervals on the testing days. One group would go in the morning and then switch in the afternoon with the second group. Each student took turns recording the cloud cover (%), the sun's azimuth and altitude angle ($^{\circ}$), the temperature ($^{\circ}\text{C}$), and the number of volts in each of the two 12 volt deep cycle lead acid batteries. Equipment included two adjustable twenty-one watt photovoltaic amorphous solar panels, two twelve volt deep cycle lead acid batteries with built-in inverters, a thermometer, a Sunsite, and a voltmeter. Amorphous solar panels were used because they can be moved easily and they are affordable. Lead-acid batteries are both affordable and efficient compared to most batteries used with solar panels. The batteries are deep cycle batteries, which are designed for the purpose of charging and discharging repeatedly without harming the battery. The thermometer was used to determine the temperature, and a Sunsite was used to find the sun's altitude angle and azimuth. The voltmeter was used to determine the voltage of the batteries. The cloud cover percentage was an estimate; no tools were used to determine the exact percent.

When the testing was completed each day, the batteries were fully charged using an electrical adapter. They were then discharged by plugging a lamp into the

inverter of the battery pack. This process keeps the rate of charge consistent and extends the life of the battery.

Each day, the data from both panels was entered into a Microsoft Excel spreadsheet where it was analyzed and graphs were made to interpret the data. The daily voltages collected in the battery for each panel from 8:45 until 14:30 were compared using a two sample T-test. A correlation was performed to find out if a relationship existed between the cloud cover percentage and the amount of voltage collected for each angle.

RESULTS

In this experiment, the differences in voltage collections of each panel during the five-day period from 8:45 until 14:30 were calculated (see Figure 4). The mean voltage collection with a 95% confidence level was found to be 1.058 ± 0.2377 volts for the 39° panel and 1.144 ± 0.2894 volts for the 24° panel. Thus, the calculation of the F-test resulted in the use of a parametric test, the two-sample T-test. The calculated t value was found to be 0.637 ($p > 0.05$).

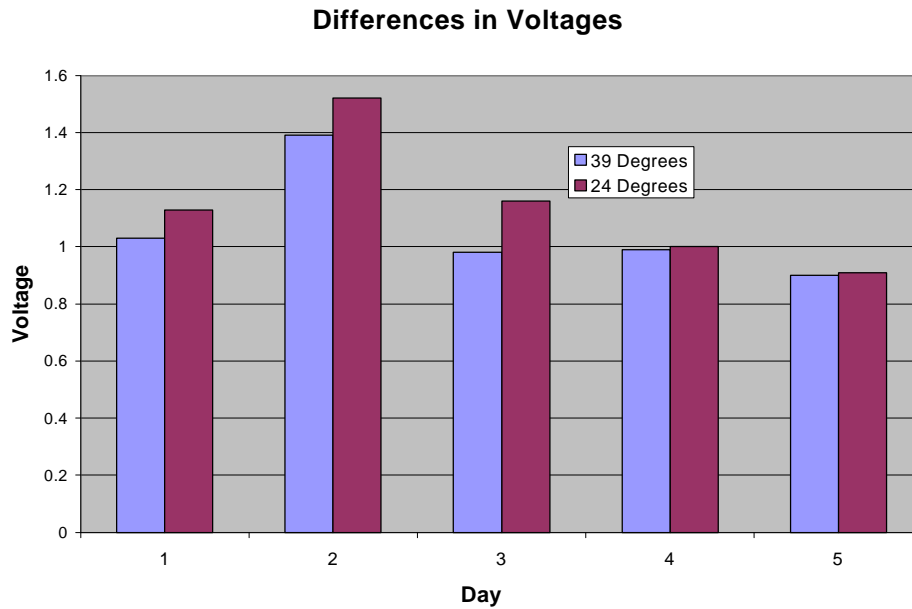


Figure 4-This graph shows the difference in voltage collection during the five days of the study.

A negative correlation between the cloud cover percentage and voltage collected was found to be -0.69 for the 24° angle and -0.72 for the 39° angle (see Figures 5 and 6). Figure 7 expresses the altitude angle of the sun on July 9, 2001, and Figure 8 shows the azimuth of the sun for July 9, 2001.

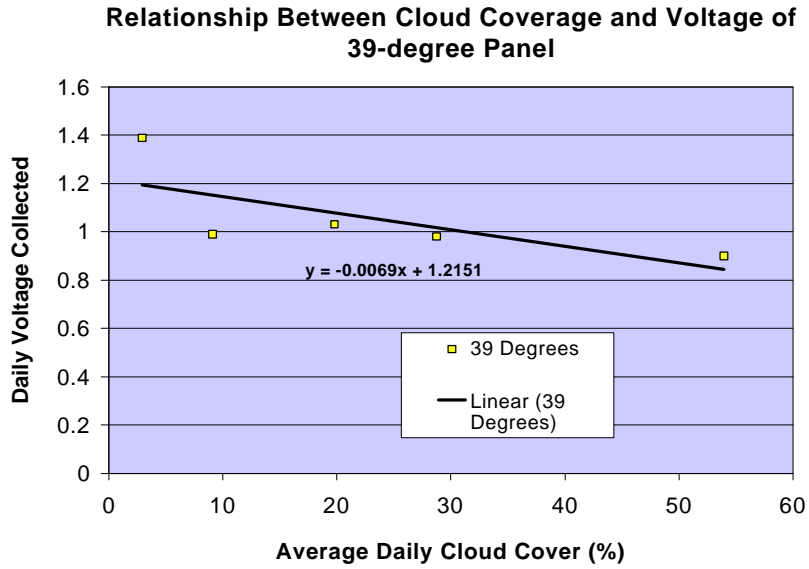


Figure 5-This graph shows the relationship between cloud cover and voltage collected for the panel set at 39 degrees.

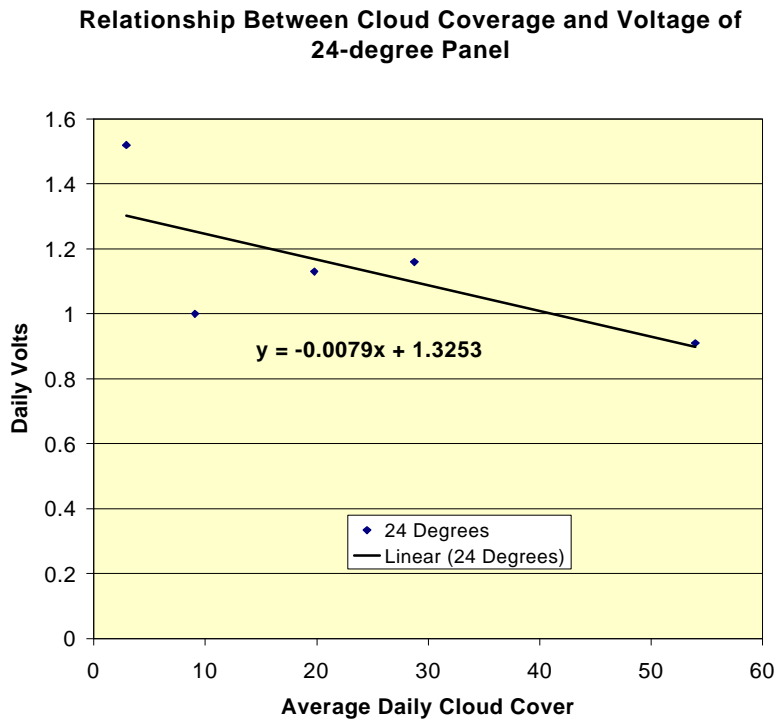


Figure 6-This graph shows the relationship between cloud cover and voltage collected for the panel set at 24 degrees.

Altitude Angle of Sun

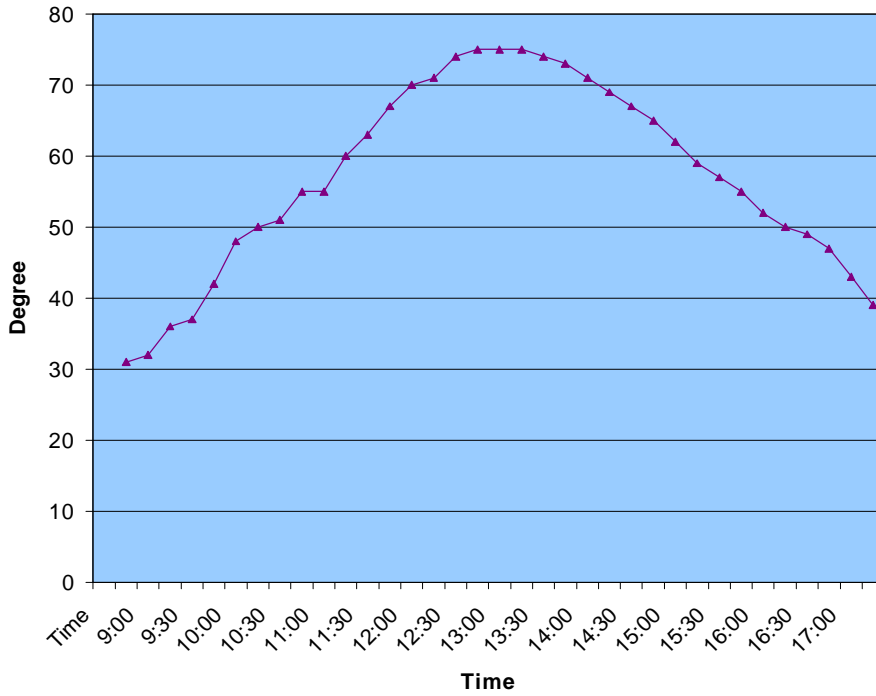


Figure 7-This figure shows the altitude angle of the sun on July 9, 2001.

Azimuth for July 9, 2001

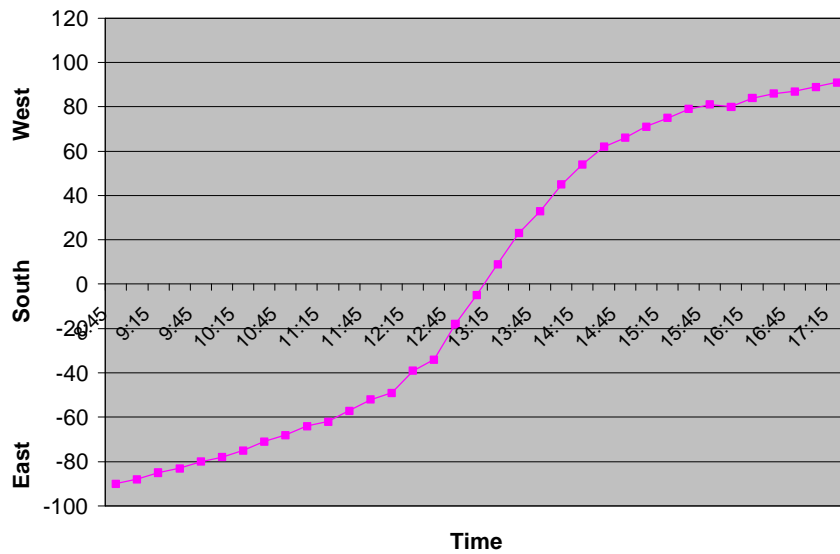


Figure 8-This figure shows the azimuth angle of the sun on July 9, 2001.

DISCUSSION

The null hypothesis stated that no significant difference would be present between the voltages obtained from the seasonal-angled versus the year-round-angled panels. Researchers believed that the fixed seasonal angle of the solar panel would obtain more energy than the fixed year-round-angled solar panel due to the seasonal position of the sun. Statistically, no significant difference was found between the volts collected by the year-round and seasonal-angled solar panels; therefore, the group failed to reject the null hypothesis.

The purpose of the study was to determine if adjusting a fixed array solar panel to a seasonal angle rather than leaving it at the year-round angle, which would yield higher voltage collection. From this study, it cannot be concluded that adjusting panels is entirely beneficial, but there is an indication that a sufficient sample size could result in a greater energy collection by seasonal angled panels for the year. Future research may conclude that it may be valuable for the consumers to adjust their fixed panels to the seasonal angle depending on the time of year.

The mean voltage collected each day from 8:45 to 14:30 for each panel was found. Then the variance and standard deviation was calculated. Next, an F-Test was performed to see if a parametric or non-parametric test should be used to analyze the data. The calculated F value was less than the tabulated F value, meaning a parametric test would be used to test if the two samples are significantly different. The samples in the experiment were independent, meaning a two sample T-Test would be used to decide whether to accept or reject the null hypothesis. The results of the T-Test showed that statistically there was no significant difference between the seasonal angle and the year-

round angle. Although a higher voltage was consistently collected with the seasonal angle, the sample size was not large enough to yield a significant difference. Figure 4 shows the daily differences in voltages collected for the 24° panel compared to the 39° panel. A slight difference is noticed in the daily collection.

A negative correlation existed between the cloud coverage and the difference in the voltage. The 24° panel had a correlation coefficient (R) of -0.679 and the 39° panel had an R-value of -0.717 (Figures 5 and 6). The closer the value is to a negative one, the more powerful the relationship is between the variables. There is an inverse relationship between the variables, therefore, it can be stated that as the cloud coverage increased, the voltage decreased and vice versa.

The altitude and azimuth angles are important because at certain angles the panels absorb more direct sunlight. In Figure 7, the graph shows the highest and lowest points of the sun on a full day as the sun moved across the sky. On July 9, 2001 data was collected from 8:45 to 17:15. The maximum altitude was 75° at about 13:15 and then it began to decrease. Solar noon is when the sun is highest in the sky. For example, in Camden, New Jersey, the central point of the Eastern Time Zone, solar noon occurs at 13:00 due to daylight-savings time. In Frostburg, solar noon would occur at approximately 13:15 since four minutes are added to solar noon for every longitude line to the west of Camden, New Jersey. Four minutes are subtracted for every longitude line to the east of the central point of the time zone. The apparent movement of the sun in the Earth's sky is east to west; to show the azimuth of the sun the Sunsite was read from south (0°). The location of the sun is important because to get the most direct sunlight the rays of the sun must strike the panels at a perpendicular angle.

With only having five testing days out of 365 days, a small sample size was found to be a disadvantage for data analysis. A larger sample size would allow for the statistical test to detect a smaller difference between the variables. Furthermore, the energy was only measured during one season, which does not account for data that could be measured during the winter months if the panels were adjusted seasonally. Another limitation of this study was the lack of replication. Due to affordability, only one panel was adjusted at 39°, and only one panel was adjusted at 24°. To improve this study, multiple panels set at the same angles could be used to increase sample size and the study could continue over a longer period of time. This experiment should be conducted for at least one year because of the daily and yearly movement of the sun. It would be difficult to determine an optimum solar panel angle based upon five days. Thus, if the study were longer, the experiment's results might reveal a significant difference and allow researchers to conclude that adjusting panels would optimize solar energy collection.

Because of human error, the instruments could not be completely reliable. The Sunsite used to determine the azimuth and altitude angles had to be level with the ground. However, with many different people manipulating the Sunsite, it can't be concluded that the Sunsite was always level. Also, the cloud coverage was only an estimate. A person's deduction of the cloud cover percentage could have differed from the previous person's estimation; therefore, the correlation between the cloud coverage and voltage collected could have been altered.

Some questions arose while the study was being conducted. First, does humidity and temperature effect the collection of solar energy? Also, are there any other methods for collecting solar energy? Lastly, another question might be about shading; not

everybody lives in an open field, so what's the solution for constantly shaded areas? The unanswered reservations may perhaps be addressed with further research.

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