THE EFFECTS OF MIRRORS ON SOLAR PANELS

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ABSTRACT

The purpose of the study was to see if the application of mirrors to a solar panel would increase the power output of the solar cells. From this study a method of enhancing solar panel output by the application of mirror at an efficient productivity angle was hoped to be accomplished. In this study the experimental design included a collection of power readings of the solar panels, with and without mirrors, and analysis of the data through the process of comparing mirror angle readings to the ones without through the evaluation of a T-test. Also an average of all the data was taken to compare power output shown through graphs. The angles used in this experiment to place the mirror were 90 degrees, 100 degrees, 110degrees, and 120 degrees. The power output at 120 degrees was greater on average then the power output without a mirror but when t-tests were performed it was found that their was not a significant difference.

INTRODUCTION

Fossil fuels are energy-rich substances that have formed over millions of years from buried plants and organisms. Coal, petroleum, and natural gas are fossil fuels. Twenty-seven billion barrels of petroleum, four billion metric tons of coal, and 2.4 trillion cubic meters of natural gas were used by the world in 1999 (“Fossil,” 1997-2002).

Coal has four levels of concentration: lignite, sub bituminous, bituminous, and anthracite (“Coal,” 1997-2002). In 1804, construction of a practical locomotive began the demand for coal.

However, by World War One (1914-1919), world usage of petroleum began to replace the usage of coal ("Coal," 1997-2002).

Only 33 percent of petroleum is removed from each oil well. The cost to remove the oil becomes greater than the profit after 33 percent. Petroleum can be used to produce fertilizers, medicines, plastics, building materials, paints, cloth, and to generate electricity ("Petroleum," 1997-2002). In the United States, petroleum usage steadily grew until the 1970's when, for several years, the usage fell until leveling off in the 1980's ("Energy," 2002).

Natural gas is used as a fuel and as a raw material to produce petrochemicals, the base product of fertilizers and detergents. It contains methane, ethane, propane, butane, pentane, and other alkanes ("Natural," 1997-2002). Natural gas has an advantage because it produces no smoke or ash while burning, although it is usually much more expensive than coal.

The use of these fossil fuels has had some serious adverse impacts on the earth. The greenhouse effect is a natural process where certain gases trap energy from the sun. Unfortunately, excess carbon dioxide, which unavoidably occurs when fossil fuels burn, contributes to a global increase in temperature which leads to an increase in sea-level. A shift of food-producing areas and patterns of disease and extinction are caused by the increase in temperature and sea-level. These changes, and the migration of people they could cause, may affect all areas of life (Fusion, 2002).

Since fossil fuels are so widely used, future problems are inevitable. Fossil fuels cause many problems with the environment; the burning of these produces ash and contributes to acid rain and the greenhouse effect. Carbon monoxide poisoning is one possible danger. This occurs when the fuel does not completely combust during a combustion reaction (burning). Carbon monoxide is a colorless, odorless, tasteless, non-irritating, toxic gas (Marland, 2001). Acidic pollution of the air is increasing from the emission of sulfur and nitrogen oxides. It is highly involved in the rising incidence of asthma and other respiratory diseases, the acidification of lakes, and damage to trees and buildings (Fusion, 2002).

Renewable fuels are energy sources that can be used more than once. If fossil fuels continue to be used, eventually there would be no energy sources to power the world. Fuel cells, biomass, solar, wind, hydroelectric, and geothermal are all renewable fuels. The fuel cell is a device in which the energy of a chemical reaction is converted directly into electricity. A fuel cell is powered by hydrogen and its only emissions are water and heat (“Fuel,” 2002). Biomass is organic matter that is used like coal to generate power through combustion (“Union,” 1993). A windmill is rotated by the wind and turns a turbine producing wind energy. Hydroelectric is the power produced when water falls onto and turns waterwheels or hydraulic turbines (“Water,” 1997-2002). Finally, geothermal is energy production by the natural heating of water underground. Research is constantly being performed to raise the power output of renewable energy sources so that they can slowly take the place of the non renewable energy sources.

The photovoltaic effect was discovered in 1839, when Edmund Becquerel, a French scientist observed that a current could be produced by shining light onto certain chemical solutions; this formed the basis for solar power. In the 1880’s, selenium photovoltaic cells were built converting light in the visible spectrum into electricity (Scanlon, 2001). In the early 1950’s, the Czochralski meter was developed to produce pure crystalline silicon. In 1954, the Bell Telephone Laboratories produced a silicon solar cell with four percent efficiency. In 1958, the Vanguard satellite used a small array to power its radio. From the 1970’s to the 1990’s, North American interest in solar power diminished (Scanlon, 2001). Majority ownership of many U. S. photovoltaic manufacturers transferred to German and Japanese interests (Scanlon, 2001).

Solar power is energy produced when a photon, the amount of electromagnetic energy regarded as a discrete particle with zero mass, no charge, and an indefinitely long life time, comes in contact with a photovoltaic (ACRE, 2002). Other names for photovoltaic cells are solar cells, solar panels, solar arrays, and photovoltaic panels. A solar array is a group of solar panels, and a solar panel is a group of solar cells. A photovoltaic solar panel consists of two layers, called wafers, made up of silicon. In most solar panels, the n-layer is doped with phosphorous and the p-layer is doped with boron. Doping is the process of adding impurities intentionally (Aldous, 2002). When the layers are placed together, electrons from the n-layer are transferred to the p-layer, creating a positive characteristic in the n-layer and a negative characteristic in the p-layer. The union of the p-layer and n-layer forms an electron bond called the p-n junction. When the sun's photons hit the panel, they energize the electrons in the p-layer and knock some loose from their atoms. Energized electrons are attracted by the positive characteristic of the n-layer and pass through the p-n junction. These electrons that pass through the p-n junction are attracted to the p-layer. This attraction carries the electrons through a wire back to the p-layer. Electrons don't flow from the n-layer directly to the p-layer because the p-n junction acts like a diode, allowing electrons to flow in one direction but restricting electron flow to another. They then travel through a load and into the p-layer followed by the electrons traveling through the p-n junction into the n-layer as the process repeats itself (Aldous, 2002).

There are three types of solar cells: single crystal, polycrystalline, and amorphous. Single crystal cells are wafers sliced from a larger silicon crystal, they are the most expensive to purchase and are about 25 percent efficient (ACRE, 2002). Polycrystalline cells are melted and poured into molds; the molding process causes this type of solar cell to be less efficient, about twenty percent (ACRE, 2002). Amorphous cells are similar to a film; they are deposited on a glass or plastic substrate from a gas in a vacuum. Amorphous cell efficiency is only about ten percent (ACRE, 2002).

The earth's position in the solar system in relation to the sun is important to the efficiency of a solar array. The earth revolves around the sun in a counter-clockwise fashion while it is rotating on its axis, which is tilted at approximately 23.5 degrees ("What," 2002). The sun's rays are most direct in the northwestern hemisphere during the summer solstice, when the earth is leaning toward the sun. Inclination is the extent or degree of incline from a horizontal or vertical position. Solar panels have to be set to a different inclination depending upon whether the earth is near its summer solstice or winter solstice. The sun's rays are least direct during the winter solstice, when the northern hemisphere is tilted away from the sun. More solar energy could be collected during summer in the northern hemisphere because the sun's rays would be more direct and the days would be longer. The study was done during the summer, increasing the energy available to the solar panels.

Solar arrays can be used for a variety of purposes such as electric fences, remote lighting systems, telecommunications and remote monitoring systems, water pumping, rural electrification, water treatment systems, consumer products, emergency power systems, portable power supplies, for the powering of a spacecraft, and cathodic protection systems. A cathodic protection system is a method of protecting metal structures from corrosion ("Australian," 2002). More than one type of solar cell can be used for these purposes.

Solar power only generates about .04 percent of the world's power (Fairley, 2002). One of the main reasons solar power is not widely used is because of its cost. According to the owner of Sine Electric in Santa Rosa, California, Stephen Lyons, installation of a solar power system can cost from $8, 500 to $10, 500 dollars per kilowatt hour (Whiteley, 2001). In 1999, the national average retail price for electricity created by fossil fuels was 6.66 cents per kilowatt hour. The average retail price for Maryland was 7.04 cents per kilowatt hour ("Energy," 2002).

This particular experiment was conducted to discover if the addition of a mirror to a solar panel would increase a solar panel's power output. This would make the usage of solar panels more cost-effective, which in turn would increase their consumption rate. The initial hypothesis was that a mirror would enhance solar panel power output. If a mirror could be used to increase the power output of a solar panel or array, solar power usage could surpass the usage of fossil fuels, diminishing some of the current environmental problems. The environmental problems would diminish because fewer harmful gases from the use of fossil fuels would be present in the atmosphere. Fewer harmful gases would decrease the amount of pollution present and decrease the greenhouse effect.

METHODS

Data was collected in two locations on the campus of Frostburg State University. One site was in a parking lot along College Avenue. The other site was located on an athletic field. Both sites were chosen because they were level and not shaded, with low traffic and similar elevations. Data was collected at 9:45 a.m., 11:10 a.m., 12:35 p.m., and 1:50 p.m. at each site on alternating days. The sites were visited on the eleventh and twelfth of July and from the fifteenth to the eighteenth of July. This totaled to six days of testing where experiments were performed four times daily.

Materials needed to conduct this procedure included a solar intake enhancer, two voltmeter, polycrystalline solar panels, leveling agents, and two variable resistor (Figure 1). The solar intake enhancer was used because it was practical for the study and was cost-effective. The solar intake enhancer was made of panels of wood with the bottom piece of wood level to the ground and a second panel of wood tilted at a 24-degree angle on top of it. This panel was tilted at a 24-degree angle because it is the best angle for solar intake during the summer in the northern hemisphere. This is calculated by subtracting fifteen degrees from the latitude of the experiment location, which is 39 degrees north. Fifteen is the difference between 39 degrees latitude (our location) and 24 degrees latitude (the latitude where the sun's rays are being received most directly). This calculation allows the solar panel to receive the most direct rays of the sun. A third panel of wood with a mirror on its down-facing side was hinged on the top left-hand side of the angled panel of wood. The bottom panel of wood had a level placed on it to ensure that the device remained level during testing. The second panel had a protractor attached to its side, which would indicate what angle the mirror was set to. Since the ground is not always level, the solar intake enhancer needed to be propped up with leveling agents.

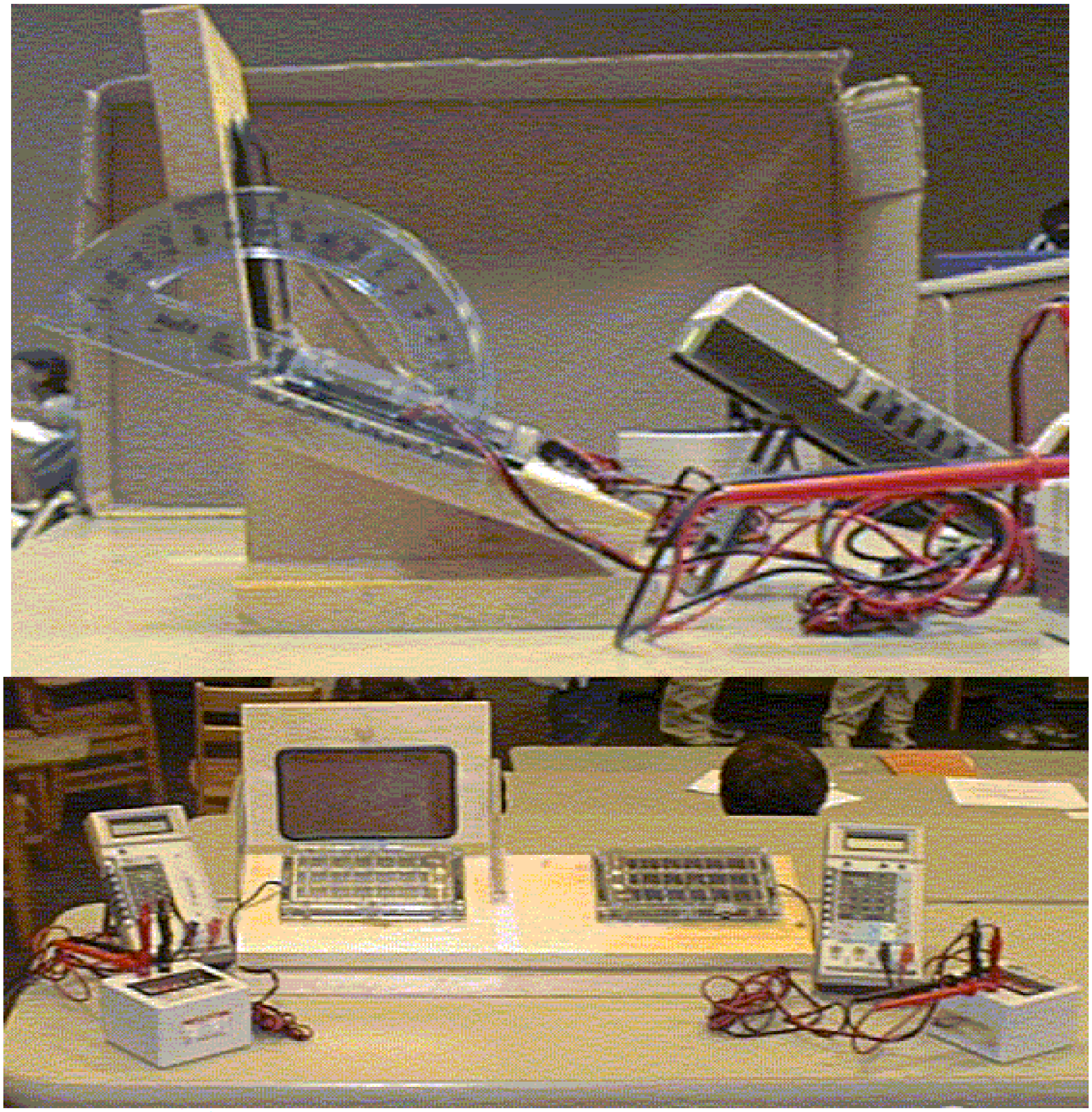

Fig. 1. – Experimental Apparatus

A digital voltmeter was an instrument used to measure the voltage obtained from the solar panel. The variable resistor was connected to the panel and meter to reach a maximum power output. The maximum power output is reached when the internal resistance of the solar panel is equal to the resistance of the resistor.

The first step in the experiment was to set up the solar panels on the solar intake enhancer to face south, set the levels, and adjust the mirror to the first angle needed. Each solar panel was attached to its own voltmeter and variable resistor. The next step was to give each group an angle with which to begin their readings. The voltage was then recorded using a voltmeter. Each group then progressed, increasing the angles, which ranged from 90 to 120 degrees. For example, if group three started with 110 degrees, group three then read 120 degrees, then 90 degrees, and then 100 degrees. Once the maximum angle being tested was reached, the groups restarted with the minimum angle being tested and continued in an ascending order until the original angle was reached.

The power equation of $P=\frac{V^2}{R}$ was used to find the power output of the solar panels at each reading. For the solar panel without the mirror, all the groups' averages from one day were averaged to produce a figure. For the solar panel with the mirror, each group averaged each angle for each day. These group averages were then averaged together to produce a total average for the class by location. A statistical test, or T-test, was also used to analyze whether or not there was a statistical difference between the data collected. A T-test was performed to compare the angles and time intervals of data collection. A bar graph was made to show the average power output for different time intervals. This graph showed each angle in each time interval. Another bar graph was made to show the average power output for the three weather conditions, which were sunny, partly cloudy, and cloudy. This showed the power output for the solar panel without the mirror and the combined readings of the solar panels with the mirrors

RESULTS

As stated earlier the experiment was performed on six dates: July tenth, eleventh, fifteenth, sixteenth, seventeenth, and eighteenth of the year 2002.

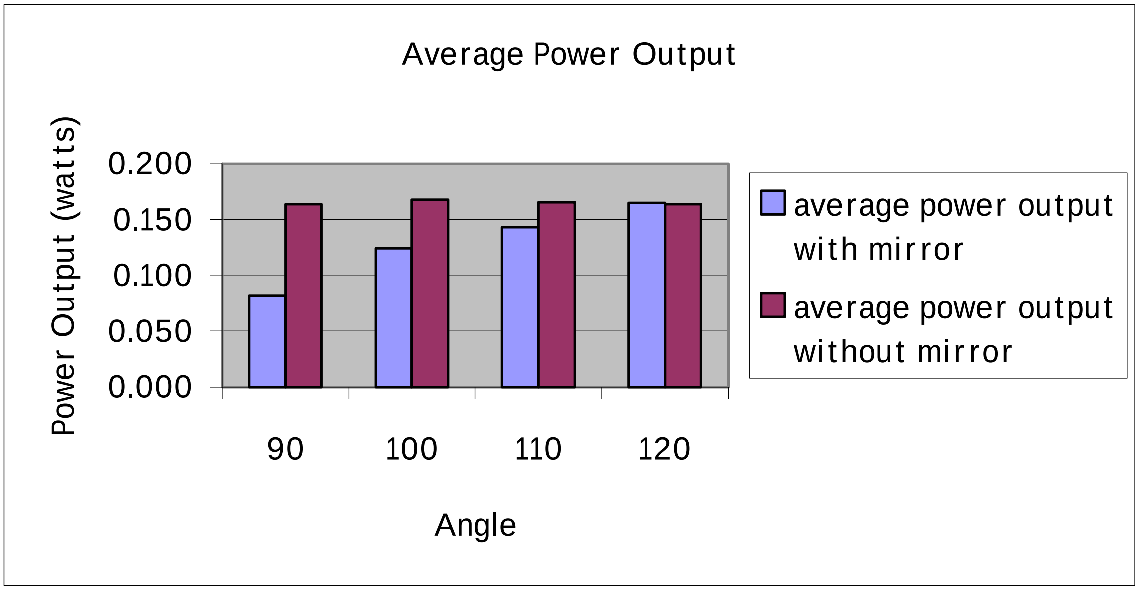

Fig. 2 – The average Power Outputs at specified angles, with and without mirrors.

The results of the comparison between the power output of the solar panel with the mirror and the corresponding solar panel without mirror power readings show that none of the mirror angles created more power than the solar panel without a mirror except for the 120 degree. The graph shows that the average power output for the 120 degree angle was not that much higher than the average power output of the solar panel without the mirror. The T-tests showed that they were not statistically different.

Comparing the results of each time throughout the day for each angle, the 120-degree angle had the highest voltage readings.

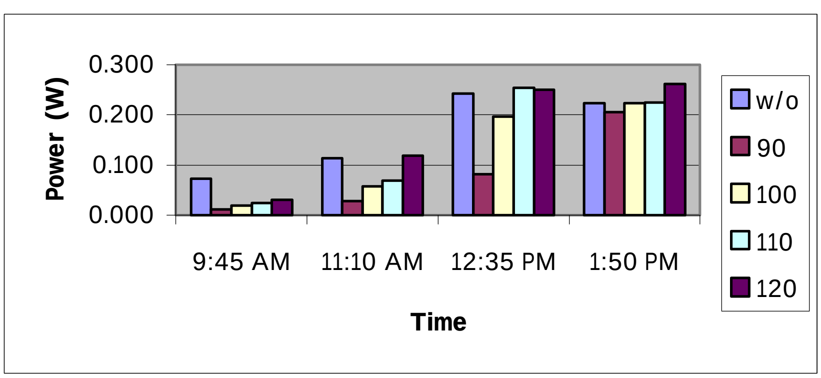

Fig. 3 – Average Power Outputs at each angle for each test time.

As shown in Figure 3, the average power outputs of the 120-degree angles have the highest power output at 9:45 A.M., 11:10 A.M. and 1:50 P.M. compared to the other mirrored angles. The 90-degree angles produced the least amount of power, the without mirror readings showed a significantly higher power output than the others. At 9:45 A.M. the 120-degree angle was statistically different than the 90-degree angle but not the 100, 110-degree angles or the without angles with less than a 90-percent confidence level. At 11:10 A.M. the 120-degree angles were statistically different from all of the readings. At 12:35 P.M. was not statistically different from any of the angles except for the 90-degree angle. At 1:50 P.M. the 120-degree angle power output readings were not statistically different from any of the other readings.

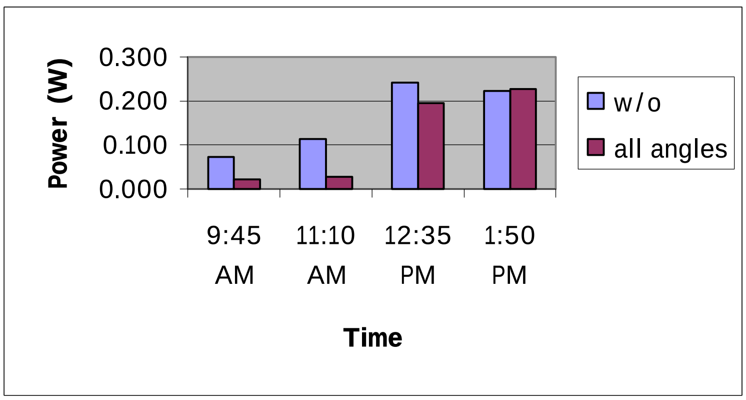

Fig.4 – Comparison of panel power output at different times with and without mirrors.

Looking at this graph, at every time except for 1:50 P.M. has shown that the panel without a mirror had overruled the output of the panel with the mirrors. According to the statistical paired T-Test, the confidence level of the T-values of all of the angles compared with their corresponding without mirror aided panels varied from less than 90 percent to 99 percent. Although the graph shows a noticeable difference between the power outputs with and without mirrors of all the angles other than the 120-degree angle, the T-tests show that they are statistically different. At the 90-percentile confidence level, the without mirror panel is different than the panel with a mirror.

DISCUSSIONS AND CONCLUSION

The findings from this investigation are important if there are to be any significant positive advances in the field of solar technology. It has been proved that by using the steps taken in this experiment, one cannot enhance the power output of a solar panel using the means of an angled mirror set at 90, 100, or 110 degrees. However, even though a solar panel can be enhanced with the usage of a mirror set at 120 degrees (Figure 2) t-tests show, with a .883 p-value, that there is no statistical difference between a panel without a mirror and with a mirror set at 120 degrees. The hypothesis that a mirror will enhance solar panel output was rejected. If it had been found that a mirror could enhance a solar panel's power output, then even though the price of a solar powered electrical generation system would have stayed the same, more consumers may have been inclined to purchase solar power.

Figure 2 showed that the solar panel without a mirror produced from .08 watts to .02 watts more than a solar panel enhanced by a mirror set at 90, 100, 110 degrees. This is because at 90 and 100 degrees for certain times the solar panel was in the shade caused by the mirror, causing the power output to be less at those times. Figure 2 helps explain why a mirror set at 110 degrees produces less power output than the solar panel without a mirror.

With one exception, Figure 3 shows that power output without a mirror increases until the 12:35 P.M. test and after the 12:35 P.M. test the power output declines. A mirror used to enhance solar panel power output at 120 degrees increases rapidly until 12:35 P.M., but even though power output continues to increase, this increase slows down after 12:35 P.M. Both 90 and 100 degrees also increase at each test time, but the increase in power output is slower in the earlier test times. This slower increase in power output from each testing time was caused by shadowing of the solar panel by the mirror. The data from 1:50 P.M. shows that 90, 100, 110 degree angles are all closely related. The close relationship of the three angles there was little if any enhancement by the mirror to increase power output. However, you can see that the output from 120 degrees is higher than the others, inferring that at that testing time 120 degrees did help to enhance solar panel output. The paired t-tests show, however, that there is no statistical difference between any angles compared at that testing time.

Figure 4 was used as an exhibit to explain why the hypothesis is rejected. At 9:45 A.M., 11:10 A.M., and 12:35 P.M. you see that power output with a mirror is much lower than power output without a mirror. At 1:50 P.M., however, power output with a mirror is slightly higher than without a mirror. Using common sense a person can tell that if the power output is greater without a mirror three out of four times and the fourth time power output with and without a mirror are similar, then the power output without a mirror must be greater than the power output with a mirror.

Several limitations became relevant during this experiment. Some of them, such as weather conditions, could not have been controlled. At times, it was cloudy during the experiment, which did not allow for a maximum voltage reading. The internal resistance levels of each solar panel varied, no one group recorded the same voltage readings at the same time. Also it was later found that the maximum power output of each solar panel was not correctly found. Finally, the mirror actually shaded the panel from sunlight at certain angles. This may had an affect on the voltage readings also.

This experiment produced many questions because of the limitations as well as the process of science. Does the type of solar panel affect which angle is optimum to raise the power output?

If a mirror were to increase solar panel output, would a higher amount of consumer's consider or purchase solar power? Would increasing the power output of a solar panel help reduce the cost of using power modules by photovoltaics? Would increased testing of the internal resistance of a solar panel produce results that could coincide with the hypothesis? The solar panels may not have produced a maximum power output, and one panel could have been closer to its maximum power output then another. Another question was, does elevation affect the power output of a solar panel? Since both the College Avenue Lot and the athletic field were at similar elevations, the elevation was not a testable factor in this experiment. If the experiment had taken place at locations with two different elevations, a different outcome may have been found.

Suggestions to improve this experiment if it were to be conducted again include, the use of arrays, increased testing of internal resistance in a solar panel, use of solar panels with the same internal resistance, a longer experimental time frame, and the use of different size mirrors and panels. Using an array would produce a higher power output because more solar panels will be connected together. Had an array been used then the results could have been related to power generation on a home or larger basis. Had the internal resistance of each solar panel been tested then the maximum power output for each panel would have been found. Dividing the voltage found on the panel in half and then changing the resistance on the variable resistor until the new voltage was found, only gave the general area in which the maximum power output would be. A longer experimental time frame would have allowed for less of an error rate in the investigation. If different size mirrors were to be used then more photons could be reflected onto and absorbed by the solar panel and a higher power output could be produced. This research may be used in the future to find out if the power output of a solar panel with a mirror, set at 120 degrees, when compared to the power output of a non-enhanced solar panel, both being over a certain period of time, would be statistically different.

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