Investigation of how the angle of light hitting a solar panel changes the voltage output of the solar panel

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Abstract:

For a long time, people have been using unsustainable sources of energy for electricity such as fossil fuels and natural gas. Such sources of fuel pollute the environment and would not be able to power our homes and devices forever as they are finite resources. However, scientists found new sustainable energy sources such as hydroelectric, wind, solar, and biomass. For our experiment, we decided to focus on the absorption of solar energy. This experiment specifically focuses on the angle of the light relative to the solar panels on the voltage output of the solar cells. Because the sun moves from the east to the west, we want to find the optimal angle for the most energy to be generated to allow solar panels to be more efficient. We got the relevant materials, and 3D printed a base for the solar panel for the experiment. We will tailor this 3D printed base to suit our requirements, such as having a gap in the middle to allow light from the torchlight to pass through and hit the solar panel in the slot made below, and the semicircle on the two sides to allow us to accurately place a torch along the markings made in the model to allow us to know where to put it. These markings would be the angle it is at. For example, there would be the number 15 at the place where the angle of the torch would be 15 degrees relative to it being directly above the solar panel when placed at that angle. Since it is in the shape of a semicircle, we can be sure that the data we get is accurate since a semicircle would have the same distance from the center to the edge. Although the model will not fully automate the experiment, it will make it much easier to conduct. After experimenting, we figured out that solar panels are most effective when the light source is directly above them, which is a 90-degree angle. We have also created a bar graph with a trend line to show the benefits of having the light hit the solar panels at a 90-degree angle. One practical application of such research is to create systems that can aim the solar panels at the optimum angle for them to produce the most energy. It can also be used to create active solar trackers, which can be used in such systems since they are much more accurate than a passive solar tracker, and they can more accurately find the sun's position to allow the solar panels to generate the most amount of energy. Therefore, we would not have to rely on unsustainable fuel sources since we can maximize the efficiency of the solar panels to make them produce more electricity. Thus, we can work towards the 2 UNSDG goals: Affordable and Clean Energy (UN SDG 7) and Sustainable Cities and Communities (UN SDG 11).

Keywords: unsustainable, fossil fuels, natural gas, pollute, finite resources, optimal angle, solar

1. Introduction

Renewable and sustainable energy sources are replacing non-renewable energy sources, such as fossil fuels, due to the significantly lesser pollution they cause and that they rely on non-depletable energy sources like the light of the sun and hydroelectric power.

Thus, more people and companies have started adopting renewable energy sources to save the environment. A significant example is Tesla, which is making a Gigafactory (Tesla, 2022) that produces batteries. However, since they want it to be a net-zero factory, they used solar energy to power the factory instead, which helps put less carbon dioxide in the atmosphere and saves the environment.

One renewable energy source we can rely on is solar energy since we have developed solar panels. Solar panels come in various rectangular shapes (Donev, 2020) and consist of smaller photovoltaic modules. These modules convert solar energy to electrical energy, which powers homes and devices. Thus, solar energy is cleaner to use than non-renewable sources (Soh, 2020). Solar energy conversion into electricity by photovoltaic modules is also a mature technology that is being actively improved in terms of efficiency in converting sunlight into more electricity (NCBI, 2016).

In recent years, we have seen global warming taking place, which causes Earth's temperature to rise. This can be attributed to our ever-growing electricity consumption. Thus, more fossil fuels have been burned to allow for more electricity production. This, in turn, pollutes the environment with a big amount of carbon dioxide, which also contributes to the enhanced Greenhouse effect. This causes global warming and its harmful effects include rising sea levels, warming of oceans, prolonged droughts (WWF, 2022), dirtier air, a higher rate of species extinction, more acidic oceans (Denchak, 2016). These harmful effects are a repeated cycle and in order to break this loop, we have to transit to renewable energy, which produces less harmful pollutants in the air (US EPA, 2022). Once we make this transition, we would have a higher chance of slowing down the cycle of global warming by minimizing environmental harm. One renewable energy source which we can consider is solar energy since it is now a mature technology and consumers can easily get their hands on solar panels.

There have been other experiments that closely resemble our experiment. One such topic is "Investigation of the power output of solar panels under different light intensities", done by the people behind the sciencebuddies.org website. Although the topics are very similar, ours would be testing solar panels at different angles but with the same intensity light, while the one done at the sciencebuddies.org website investigates the effects of different light intensity from the same angle. In that experiment, they came to the conclusion that as the intensity of light increases, the electricity output of the solar panels also increases (ScienceBuddies, 2022). Although these experiments are able to prove that solar panels can be made more efficient, some people remain unconvinced that solar panels can produce the required amount of energy they may need for their work. It can take a few years to see its benefits after incurring a high cost for installing solar panels (Ambort, 2020).

Thus this led us to an objective to find out if the angle of the light affects the electrical output of a solar panel. If we manage to figure out the optimal point at which solar panels can produce the most amount of electricity, people can design systems that allow the solar panels to receive light at that optimal angle, thus allowing for more electricity to be converted from light energy. Thus, this would dispel the people's doubt about the efficiency of solar panels and solar energy. It will also help if we manage to ascertain the optimal angle of installation hence reducing installation time. Thus, if we make solar panels more efficient, more people might be interested in installing solar panels on their roof, which is aligned with two of UN's 17 goals - Affordable and Clean Energy (UNSDG Number 7), and Sustainable Cities and Communities (UNSDG Number 11).

1.4.2 Research Questions

Our research question is as follows:

How does the angle of the light source affect the voltage output of the solar panel?

1.4.3 Research Hypotheses

We decided to test the following hypothesis:

H1: The lower the degree of the light source relative to it being directly above the solar panel, the more voltage output there will be

1.4.3.1 Independent variable

The independent variable is the angle of the light source

1.4.3.2 Dependent variable

The dependent variable is the amount of voltage output from the solar panel.

1.4.3.3 Controlled variables

a) The sampling data should be in a dark room

b) The distance between the light source and the solar panel

c) The duration of each of the readings

d) The intensity of the light from the light source should also be kept the same to allow for correct readings.

e) The light source used should be kept the same

f) The amount of natural light in the room should be kept the same

2. Method

2.1 Equipment list:

- 1x Voltage meter
- 1x Voltage probes (consists of 2 wires, a red and a black one)
- 1x Torchlight
- 1x Solar panel
- 1x Stopwatch
- 1x 3D printed base (Will be printed with 1X 3D printer)
- 1x Retort stand
- 1x Box
- 2x Crocodile clips (attached to one end of each of the voltage probes)

2.2 Diagrams

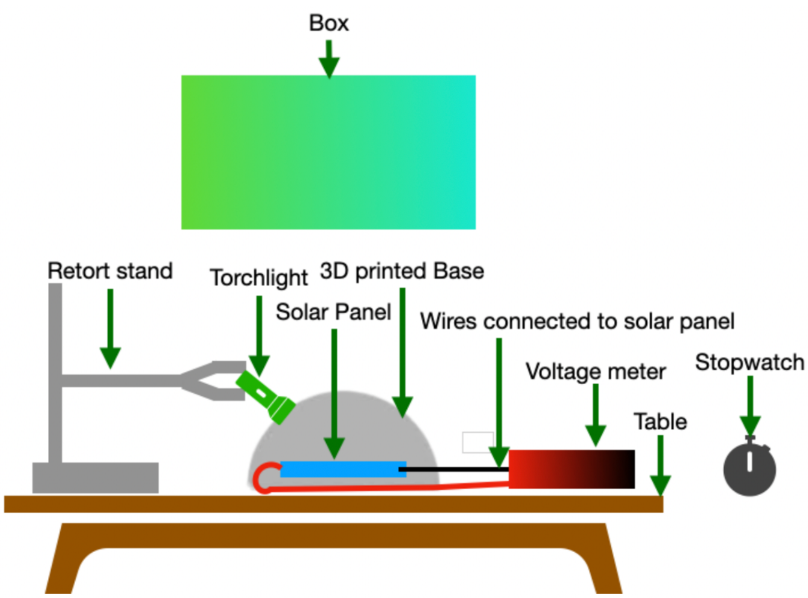

Figure 1 (Left): Digital model of our experimental setup

Figure 2 (Right): Picture of our real life set-up

2.3 Procedures: Detail all procedures and experimental design to be used for data collection

1. 3D print the base for the solar panel. The 3D model has special features specifically for this experiment, the 3D model will have a slot in it which will allow the solar panel to fit. From there, it will be a perfect semicircle, because the distance (radius) from the edge of the semicircle to the center point is the same throughout. The model will also have a gap in the middle to allow the light from the torchlight to pass through and hit the solar panel. On the outer ring, it will allow a torchlight to slide along the model and there will also be markings on the model to indicate where to put the torchlight at each angle. These 6 markings were precisely measured out in the 3D model app for each of our 6 angles (15^o , 30^o, 45^o, 60^o, 75^o, 90^o) before being printed out, which allows us to easily align the torchlight and ensure that the angle that the torchlight is at is correct.

2. If the voltage probe does not already come with a crocodile clip head pre-attached, attach one crocodile clip to 1 end of each of the different coloured voltage probes.

3. Next, insert the solar panel into the 3D printed base and connect one end of the voltage probe to the solar panel using the attached crocodile clips and the other end to the voltage meter, the end that you need to connect to your voltage meter depends on the brand of the voltage meter.

4. Put the torchlight at the starting angle as shown on the 3D print. The starting angle is 15^o relative to the light source being directly above the solar panel. Then, use a retort stand to hold the torchlight in place.

5. Turn on the torchlight in a dark room or in an opaque box and leave the light on for 10 seconds. After 10 seconds, take down the final voltage of the solar panel and record that as the first reading for the first angle.

6. Repeat steps (5 & 6) for all of the angles (15^o , 30^o, 45^o, 60^o, 75^o, 90^o), each angle will be done 3 times, and then take the mean of the 3 angles for the average result.

7. Record all readings into the table below, and then plot the graph found below the table afterward once you're done. With that, you've completed the experiment!

2.4 Data Analysis: Describe the procedures you will use to analyze the data/results.

7. Tabulate the data and calculate the average voltage reading of the solar panel below:

Table 1: Table of values for the voltage output of the solar panel at different angles.

Angle of light source / °	Voltage / V			
	Reading 1	**Reading 2**	**Reading 3**	**Average Reading**
15				
30				
45				
60				
75				
90				

8. Plot a graph of the average voltage output of the solar panel against the 6 different angles in which the light source was placed below:

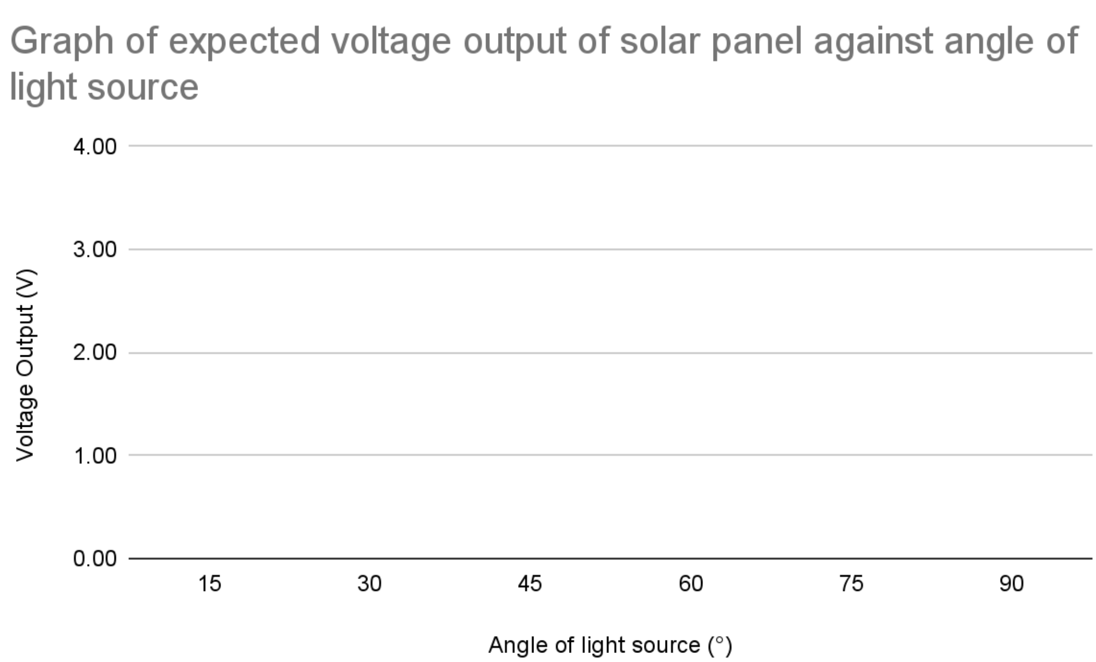

Figure 3: Graph of the expected average reading of voltage output from solar panel against the angle in which the light source was placed

9. From the graph, we can determine the relationship between the angle of the light source and the efficiency of the solar panel, by plotting the voltage of the solar panel against the angle of the light source. We think that when the angle of light hitting the solar panel is the lowest, the voltage output of the solar panel will be the greatest. Hence, if the graph shows that as the angle of light decreases, the voltage output from the solar panel increases, or in other words it shows a decreasing trend, we can be sure that our hypothesis is correct. The blue line represents the average voltage from each angle, shown as a decreasing trend, in accordance with our hypothesis.

2.5 Risk, Assessment, and Management: Identify any potential risks and safety precautions to be taken.

Table 2: Risk Assessment and Management table

Risk	Assessment	Management
Fire hazard when 3D printing holder for the solar panel	Medium	Make sure they have hourly watches on the 3d printer and watch out for thermal runaway sensors which will sound an alarm
Solar panel could be too warm from the heat from the light source and we could burn ourselves	Medium	Make sure to not touch the solar panel during the experiments
Exposed wired could cause an electric fire	High	Make sure to check that the wires are not frayed before attempting the experiment

3. Results

The results of our experiment are as shown below:

Table 3: Table of voltage output readings from the solar panel against the angle of the light source.

Angle of light source / °	Voltage / V			
	Reading 1	**Reading 2**	**Reading 3**	**Average**
15	1.64	1.56	1.59	1.60
30	2.79	2.85	2.81	2.82
45	2.89	2.81	2.90	2.87
60	2.99	2.97	3.02	3.00
75	3.15	3.11	3.21	3.16
90	3.22	3.24	3.34	3.27

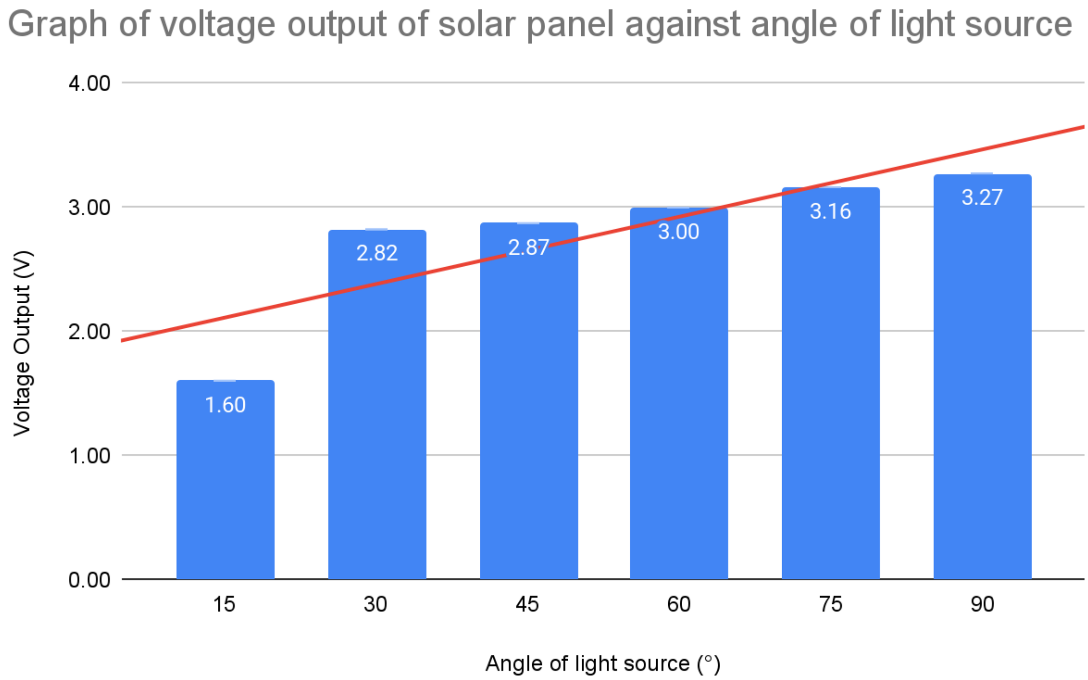

Figure 4: Line and bar graph of the average voltage output of the solar panel at different angles

4. Discussion

4.1 Key Findings, Comparison, and explanations

From the data collected, it was clearly found that the most efficient way to angle your solar panel if your light source is fixed is directly above the solar panel, as this gives out the most amount of voltage output, as observed in figure 3. From figure 3, we can conclude that the higher the angle relative to the top of the solar panel, the more the voltage output from the solar panel will be. Another observation we made is that the voltage output increases dramatically from 15° to 30°, and it just slowly increases from there. This means that the bare minimum angle your light source should be angled at is at least 30°, as the voltage output difference between 30° and 90° is just 0.45 volts while the difference between 15° and 30° is a whopping 1.22 volts. In our experimental findings, it differed from what we had originally expected. Our original hypothesis stated that the voltage output would go down as the angle of the light source relative to the top went up, but the exact opposite happened in our case and the voltage output increased when the angle of the light source relative to the top increased.

From our research of past experiments that are similar to what we have done, we found that in other instances of people doing similar experiments, the results were the same as the ones we obtained, that the voltage output from the solar panel was the greatest around midday/noon (12 pm) which is about 90° relative to the light source being above the solar panel. The rest of their graphing is also in line with the results we had, with the amount of electricity generated by the solar panel increasing as the day (or angle in our case) goes on/increases. Our data can also be used to extrapolate to see the decrease in the voltage output after its peak point during noon. This can be done because 75^{o} relative to it being directly above the solar panel is the same on both sides, meaning that if we were to plot a full graph from morning to night (15^{o} to 90^{o} and back down to 15^{o} on the other side), it will form the shape of a mountain. This "mountain" graph result is also what we see in their experiment, with the amount of electricity generated by the solar panel dropping after 1 pm and decreasing downwards from there. (Sahab & Mosli, 2011)

The reason why the output is higher when the light source is directly above it compared to at the side is because when the light source is angled, the same amount of light will be spread out over a larger plane of area as the light rays will have to travel further before hitting the solar panel, meaning some light rays may not have even hit the solar panel, which results in a drop in the amount of voltage outputted by the solar panel. This is in stark contrast to when the light source is directly above the solar panel, this is when most of the light rays are concentrated into a certain spot on the solar panel, with the extra rays that angles off the light source hitting the far ends of the solar panel, which increases the total voltage output of the solar panel. (Wald, 2018)

4.2 Limitations and Recommendations

Throughout the planning of the proposal for our experiment, we did our best to make it as simplified and as easy to do and understand as possible. But all good things come with at least some hardships/limitations. The first limitation we faced was that we were not able to get a dark room to do our experiment, since everyone was doing their own experiments in the lab. As such, we had to improvise and come up with a better solution on the spot, to which we chose to use a box that we got from the ADMT Studio to simulate a dark room, which turned out to work relatively well. Secondly, another limitation we faced was that the 3D printed model's dimensions shrunk due to the heat from the 3D printer. As such, we were forced to use scissors to slowly but surely saw off bits of the model to ensure that the solar panel will be able to snuggly fit in there, along with the voltage probes to ensure that it is connected to the voltage meter. Our last limitation was that the torchlight was too big to fit in the box when held up by the retort stand. We resolved this limitation by getting a smaller but still effective torchlight so that it will be able to fit in the box.

Through these improvements, we were able to express that we could think on our feet when given a tough situation, allowing us to easily adapt and change into different atmospheres and environments. This also enabled us to quickly continue on with our experiment and not waste any precious lab experimental time on other things.

Table 4: Table of the limitations and recommendations we faced during the experimental phase

Limitations	Type of limitation	Recommendation
Not able to find a dark room	Equipment	We chose to use a box that we got from the ADMT Studio to simulate a dark room
3D printed model's dimensions shrunk due to the heat from the 3D printer	Equipment	We used a pair of scissors to saw off bits of the model to ensure that the solar panel fits
The torchlight was too big to fit in the box when held up by the retort stand	Equipment	We got a smaller but still effective torchlight so that it will be able to fit in the box

4.3 Evaluation of Hypothesis

From the results obtained above, we can generally conclude that the hypothesis H1 that "The lower the degree of the light source relative to it being directly above the solar panel, the more voltage output there will be" has been proven wrong. Specifically, the experimental results that were obtained after we concluded the experiment showed the complete opposite of what our hypothesis predicted. The correlation of the experimental results showed that as the higher the degree of the light source relative to it being directly above the solar panel increases, the more the voltage output will be. This new hypothesis is also in line with the real-world observations of how the sun's rays are the strongest and how the most UV rays are shone down on Earth around noon, which is when the sun is directly above us. We expected the trend to be in a decreasing direction where the higher the angle relative to it being at the top the lower the voltage output. However, the trend turned out to be in an increasing direction where the higher the angle the higher relative to it being at the top the voltage output.

To summarise, our expected trend was a decreasing trend, where as the angle relative to it being at the top increases, the voltage output decreases. Instead, after our experiment, our obtained results showed an increasing trend, where as the angle relative to it being at the top increases, the voltage output increases as well.

5. Conclusions

5.1 Summary of findings

Through this experiment, we managed to conclude that if the position of light is directly above the solar panel, the amount of energy generated is the most. This means that during noon time (12 pm) when the position of the sun is above the solar panels on a building, the solar panels will generate the highest voltage output. This is an advantage as the solar panels can then produce the highest energy voltage. From our research findings, we found out that sustainable energy is one of the most important factors. Other types of energy generation are bad for the environment and can cause global warming. Thus we need to make the most of sustainable energy and generate the most energy out of these types of ways. On a regional scale, solar panels are used to improve the heating and cooling systems by almost 30%. To be able to make this experiment more efficient and more accurate, people calculate how much energy the solar panel generates without light, and minus it out of the total energy generated. Our data shows an upwards trend, with the voltage output increasing as the angle of the light source relative to it being at the top increases, which means 15^o gives off the least voltage output, while 90^o gives off the most voltage output. This is an advantage as it allows us to be able to generate the most energy during the daytime, by having the solar panel collect more energy during noon when the sun is directly above. We hypothesized that the exact opposite of the results would happen and that it would show a downward trend, with the voltage output decreasing as the angle of the light source relative to it being at the top increases, which means we predicted that 15^o would give off the most voltage output, while 90^o will give off the least voltage output.

Through our data collected from the experiment, we can conclude that our initial hypothesis was wrong, hence we can disprove our initial hypothesis, and that our initial hypothesis is not verified.

Thus, through this experiment, we managed to find the optimal angle at which the most amount of energy is produced. With our experiment findings, we can then harness modern-day technology, to increase the efficiency of solar energy generation. This could be done by solar trackers which use motors to angle the solar panel so that the sun is directly above the front face of the solar panel which contains the necessary c=solar cells to generate energy. The angling of the solar panel using solar trackers helps the solar panel to find its optimum angle to generate the greatest amount of energy.

The purpose of this project is to find out what is the optimum light angle hitting the solar panel for it to generate the greatest amount of energy. To conduct the experiment for this project, we decided to go for a research question which is: “How does the angle of the light source affect the voltage output of the solar panel?”. We also went for a hypothesis which is: “How does the angle of the light source affect the voltage output of the solar panel?”. We analysed the data that we got after conducting the experiment, and it showed that the voltage output increases as the angle of the light source relative to it being at the top increases, which means that 15 degrees gives off the least voltage output, while 90 degrees gives off the most voltage output.

Through the data collected from the experiment, we can conclude that our initial hypothesis was wrong, hence we can disprove our initial hypothesis, and that our hypothesis is not verified

5.2 Contributions of research

Through this research, our group has contributed by conducting research on the best way to angle your solar panel for the most efficient way to generate the most amount of electricity from your solar panels. This is important because the world is currently shifting towards cleaner sources of energy, mainly because of the unnecessary amount of harmful carbon emissions being emitted into the atmosphere, and also since resources such as coal and natural gases are limited resources, meaning that one day we will eventually run out of it and we will still need to switch to more sustainable sources of producing electricity. This knowledge also contributes to the United Nations Sustainable Development Goal (UN SDG). Specifically, UNSDG 7 and 11, which are “Affordable and Clean Energy”, and “Sustainable Cities and Communities” respectively. Given the world’s unique situation with climate change and depleting natural resources, there is an urgent need to switch to a renewable source of energy quickly. The knowledge gained from this research can also be shared with professionals and amateurs alike in developing a more environmentally sustainable and environmentally aware populace.

5.3 Practical Applications

The practical application of this experiment is as follows. Due to the fact that the most energy is generated when the position of light is directly above the solar panel, we can devise a system where the solar panel follows the light source, the way a plant might lean towards the sun to absorb the most light. This technology is not particularly new. However, passive solar trackers can only work well in hot climates and are not very accurate when it comes to tracking the position of the sun.

Passive solar trackers use the concept of heat from the sun, which then boils a liquid that has a low boiling point, which then activates an actuator that moves the solar panel based on how warm the liquid is. This means that during certain climate conditions, like the winter or during a cold day, these solar trackers will not be accurate at all. (Rooij, 2020)

Active solar trackers on the other hand are much more accurate than a passive solar tracker and also works well in cold climates. This is because active solar trackers use a combination of instruments, sensors, and algorithms to determine the sun’s location, which allows them to absorb the most amount of sunlight, giving off the most amount of energy output. (Yoshitake, 2016)

Thus, our team wanted to develop a system that solely tracks the light. Unlike passive trackers, our tracker is active. Through this process, we can make an efficient solution for the use of solar energy possible, which is a step forward to sustainable energy. With this idea, we can slowly but surely reduce global warming and processes harmful to the environment.

5.4 Areas for further study

We can do further investigation on solar panels by performing an experiment on how heat affects the power output of solar panels, and if we find out that heat negatively affects the solar panels’ energy generation. The independent variable of the experiment is the temperature of the solar panel, which will be handled with care. The controlled variables of the experiment would be the angle of the light source, the distance of the light source from the solar panel, the amount of light in the room which must be none, the solar panel used, and the light source itself. Lastly, the dependent variable would be the voltage output of the solar panel. Using the data from the experiment, we can then find out means and ways to create a cooling solution for them. Another way we can use the information of heat affecting solar panels is to use our current experiment, which plots the angle of the light source along with how heat affects solar panels, which will enable us to plot a chart throughout the year, representing when is the optimal time throughout the year for solar panels, this is especially important for regions that also experience cold seasons like the United States for example. It is also proven that generally if the solar panels are subjected to a higher temperature, they would be less efficient. There have been solar panels designed out there that can resist such temperatures causing an efficiency drop but can still cause them to lose 10% of their rated efficiency. (Villazon, 2022)

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8. Acknowledgments

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