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COMPARATIVE STUDY ON THE ENERGY EFFICIENCY OF ANGLE-ORIENTED AND GOLDEN SPIRAL SOLAR PANELS

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ABSTRACT

Solar technologies are continuously and rapidly growing these days. Researchers continue to look for ways to optimize the harvesting of solar energy. Application of mathematical concepts is one way of increasing the efficiency of solar panels. This study used the concept of (1) Golden ratio and Fibonacci sequence, and (2) perpendicularity angle to the sun to construct solar panels that would maximize the energy output of the panels. This study aimed to construct a golden spiral solar panel and angle-oriented solar panel respective to location, as well as, measure, record and compare the voltage, current produced, and the power generated by the solar panels. Results showed that the use of mathematical concept in constructing the solar panels significantly affects the energy output of both solar panels. Independent sample t-test revealed that the voltage of both solar panels was significantly different, while the current produced and the power output were comparable. The use of larger photovoltaic cells, data loggers and different orientations for Golden spiral solar panel is highly recommended. Longer period of data gathering under varying weather conditions is also recommended.

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INTRODUCTION

The use of solar technologies has been continually growing and developing in our society. The International Energy Agency reported in 2017 that utilizing solar energy has become the world's fastest growing source of power in the world, being the first-time solar energy's growth being greater than any other fossil fuels. The Golden ratio can be considered as the simplest mathematical pattern found in nature. This concept is used by humans in different architectural designs. The application of the concept of the Golden Ratio, Fibonacci sequence, and angle orientation in designing a solar panel to determine the most efficient design for harvesting solar energy was used by Benguar *et al*. (2018) in their study "Golden Ratio Applied in the Orientation of Solar Cells in a Golden Spiral Solar Panel". Their study concluded that the spiral solar panel applied with the concept of the Golden Ratio and Fibonacci sequence is significantly more effective than the flat-oriented solar panel.

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Though the study produced remarkable results, there is still a need for further research concerning the efficiency of the golden spiral solar panel as compared to the widely used angle-oriented solar panels. With the help of tilting the array at an optimal angle, it is possible to maximize the energy output in solar technologies (Khademia *et al*. 2013). This research sought to fill the gap of the previous research done by Benguar *et al*. (2018) and test whether the golden spiral solar panel design is more efficient than the widely and mostly tested and used angle-oriented solar panel.

This study aspired to compare the efficiency of the golden spiral solar panel and angle-oriented solar panel. Specifically, it aimed to:

- Construct a golden spiral solar panel and angle-oriented solar panel respective to location;
- Measure and record the voltage, current produced and power generated by the golden spiral solar panel and angle-oriented solar panel; and
- Compare the voltage, current produced, and the power generated of the golden spiral solar panel and angle-oriented solar panel.

MATERIALS AND METHODS

In constructing each prototype model, the researchers used the following; (1) 60 pieces photovoltaic solar cell with the same type and dimension; (2) standard tabbing wire for solar panels; (3) glass box to secure the prototypes from external interference; (4) adhesives; (5) glass slides; (6) soldering tools for the construction of circuits; (7) multimeter for measuring the voltage and current; - for each prototype, and (8) iron plane bar for the frame of the golden spiral solar panel prototype and; (9) ply board for the base of the angle-oriented solar panel. The design of the first panel was adapted from the design of Benguar *et al.* (2018) in their study, with modifications on the materials used such as the wire and base for the solar cells for better performance. Conversely, the formula for the angle orientation of the angle-oriented solar panel was adapted from the study of Malicdem (2015), wherein the formula for the month of March and a specific latitude or location, were applied in the research.

General Experimental Procedure

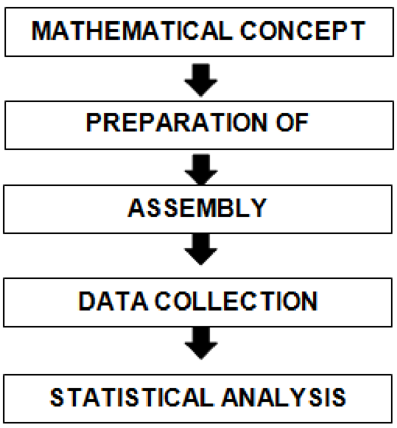

Figure 1. Flow Chart of the General Experimental Procedure of the Study (adopted from Benguar *et al.*, 2018)

Mathematical Concept: The concept that was used for the golden spiral solar panel in this study is the Golden Ratio. A variation of this concept, called the Golden Spiral, was used for making the outline of the different prototype. The base of the prototype constructed following the concept of the Golden Rectangle. The concept of Fibonacci sequence was used for the height of the prototypes. For the angle-oriented solar panel, the concept that was used is the solar rate correction to the perpendicular angle of the sun's ray to the ground as studied by Malicdem (2015) in his study, "Optimal Tilt of Solar Panels in the Philippines". A country average value and formula obtained for the month of March is:

$$0.952525*(\text{latitude} + 7.8) = \text{angle from horizontal} \quad ....(3.1)$$

Using this formula and the latitude from the equator of the locale can be computed and applied as the orientation angle for the second solar panel.

Preparation of Materials: Materials and equipment that were used in the study were gathered. Each prototype was composed of thirty pieces of photovoltaic solar cells and tabbing wires. Iron rod and glass slides were used as the base for the golden spiral, while ply board was used as the base for the angle-oriented. Glass, multimeter, soldering rods and wire are materials that were used throughout the study.

Assemblage: The design for the golden spiral solar panel was adapted from Benguar *et al.* (2018) with simple modifications on the materials. The golden spiral solar panel was incorporated with Fibonacci sequence as the consistent augmentation for the elevation composed of five pillars. Glass slides were attached in the spiral to form a surface that would accommodate the photovoltaic solar cells. The base was constructed following the concept of the Golden Rectangle, serving as the foundation of the prototypes. The flat-oriented was applied with an angle orientation of 15 degrees, South which is the elevation perpendicular to the location of the altitude of the research site. Solar cells were carefully soldered and linked together with the help of tabbing wires, per adaptation of the methods in the study of Fiegna and Nicolai (2015). Each prototype was enclosed in a glass box for protection from external factors.

Simulation/Data Collection: The voltage, current, and power of the different prototypes were monitored nine hours every day for seven days. All the prototypes were exposed to similar weather conditions; thus, weather was considered in comparing the energy output between the prototypes.

Statistical Analysis: The data was gathered and analyzed to evaluate and determine the most efficient angle orientation. Voltage, current, and power were the dependent variables, and the two solar panel prototypes were the independent variables.Statistical analysis was carried out using descriptive statistics and independent sample t-test with the software Statistical Package for the Social Science Software (SPSS).

RESULTS AND DISCUSSION

This chapter presents the results and analysis of the data collected guided by the objectives of the study.

Solar Panel Design: Two different models of solar panel design were made to achieve the objectives that was set for the study. One being the design conforming to the design of the golden spiral and the other is the angle-oriented solar panel design.

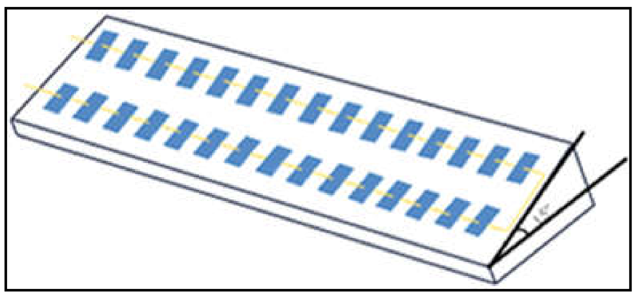

Figure 2. Angle-Oriented Solar Panel Design

Figure 2 shows the design for the angle-oriented solar panel applied with the solar rate correction to the perpendicular angle of the sun's ray to the ground. The solar panel was angled to approximately 15º in horizontal facing South to the equator adopted from the discovery of Diaz *et al.* (2014) saying that the optimal direction of panels located in the northern hemisphere should face true south or the equator and should be perpendicular to the sun. The optimum angle-orientation for solar panel design was achieved through applying the formula acquired by Malicdem (2015). The perpendicularity of the solar panel's surface to the rays of the sun multiplied to the solar insulation rate would obtain the country's average value formulas for any month. Using the achieved formula for the month of March and the latitude from the equator of the locale which is 7.8706ºN. The angle from the horizontal computed was 14.9º or approximately 15º and was used as the orientation angle for the second solar panel.

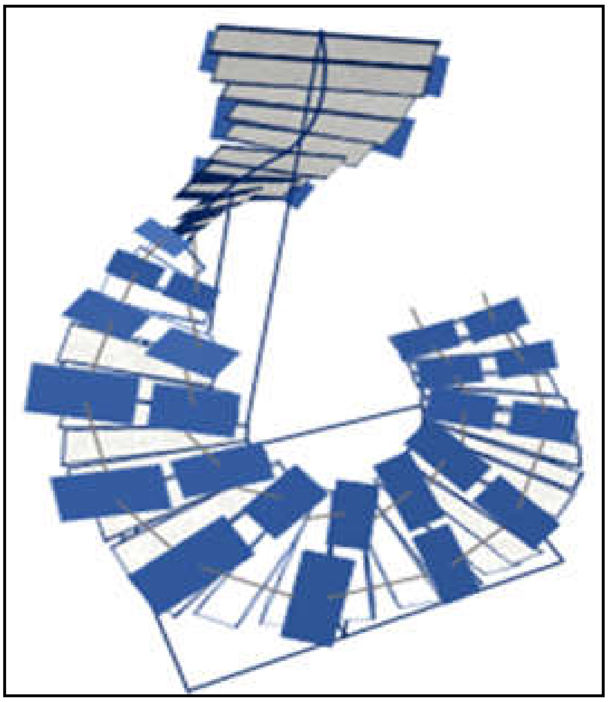

Figure 5. Golden Spiral Solar Panel Design

The Popsicle sticks that were used by Benguar *et al.* (2018) in their design was replaced with glass slides in this study to maximize the solar energy output of the golden spiral design. These glass slides were glued to the spiral which produced a dynamic angle due to the curvature of the spiral caused by the different elevations of each pillar, as shown in Figure 6. Glass slides were utilized for glass as the base of a solar panel prototype serves as a layer of protection and as an inciting factor to increase the concentration of sunlight ("Solar glass and Mirrors", 2016). The 15 solar cells were connected in series and placed parallel to each other on the glass slides spiraling the prototype.

Measurement of Voltage, Current Produced, and Power Generated of Both Designs

Table 1. Voltage Mean Data per hour of Golden Spiral and Angle-Oriented Solar Panels

Voltage mean per hour		
Time	Golden Spiral design	Angle-Oriented design
8:00 AM	16.53857	16.71714
9:00 AM	16.71571	16.47
10:00 AM	16.80571	16.36143
11:00 AM	16.70857	16.20714
12:00 PM	16.77143	16.01857
1:00 PM	16.54714	16.15429
2:00 PM	16.37571	16.01571
3:00 PM	16.39571	15.97143
4:00 PM	15.73571	15.87429

The voltage produced by the golden spiral ranged from 15.02V – 17.2V while it ranged from 15.17V – 17V for the angle-oriented design. Overall, the golden spiral design has a mean of 16.5105V and 16.1989V for the angle-oriented design. In the study of Benguar *et al.* (2018), the voltage produced ranged from 7.49V – 8.57V for the golden spiral design and 6.71V – 7.81V for the flat oriented. Voltage was measured by attaching one end of the multimeter to be connected to the system and out in the opposite end. This is supported by McGranaghan *et al* (1981) in their study about simultaneously measuring voltage and current on a system.

Table 2. Current Mean Data per Hour of Golden Spiral and Angle-Oriented Solar Panel

Current mean per hour		
Time	Golden Spiral design	Angle-Oriented design
8:00 AM	1.602857	1.614286
9:00 AM	1.605714	1.591429
10:00 AM	1.602857	1.582857
11:00 AM	1.444286	1.411429
12:00 PM	1.438571	1.395714
1:00 PM	1.585714	1.541429
2:00 PM	1.552857	1.535714
3:00 PM	1.545714	1.545714
4:00 PM	1.492857	1.522857

For the current, which was measured in milliAmps (mA), the golden spiral ranged from 0.53mA – 1.6mA. For the angle-oriented, it ranges from 0.53mA – 1.66mA. The golden spiral design yielded the higher mean of 1.5413 compared to the overall mean of 1.5268 for the angle-oriented. Current did not vary much among the two designs. Previous data from the study of Benguar *et al.* (2018) showed a range of 5.2mA – 6.0mA for the current of the golden spiral design while the flat-oriented design ranged from 4.4mA – 5.3mA. This is supported by the study of Khelifa *et al.* (2015), stating that photovoltaic systems use only the photons from light to generate current. Different designs do not have a great difference in terms of current because they were exposed to almost the same amount of sunlight.

Table 3. Power Mean Data per Hour of Golden Spiral and Angle-Oriented Solar Panels

Power mean per hour		
Time	Golden Spiral design	Angle-Oriented design
8:00 AM	26.51091	23.39784
9:00 AM	26.8423	26.2182
10:00 AM	26.94059	25.90677
11:00 AM	24.16271	22.81614
12:00 PM	24.09873	22.28539
1:00 PM	26.2523	24.90617
2:00 PM	25.43226	24.5946
3:00 PM	25.35577	24.6963
4:00 PM	23.50461	24.18143

Power was solved using the formula $P=IV$; where P is the power, I is the current and V is the voltage. For this study, power was measured in milliwatt ($x10^{-3}$). The angle-oriented flat design produced power ranging from 8.7662mW – 28.036mW while the golden spiral design produced power ranging from 8.8033mW – 28.0872mW. The study of Benguar *et al.* (2018) produced data for power which ranges from 38.96mW – 50.50mW for the golden spiral and 29.52mW – 40.45mW for the flat-oriented design. Based on the data collected, power is highest in noontime where the sun is directly above the set-up around 12pm – 1pm and lowest in late afternoon around 3pm – 4pm where the sun is about to set. This was supported by Handoyo *et al.* (2012), citing that the optimal tilt angle is the angle where the solar radiation will arrive perpendicularly upon the surface.

Table 4. Independent Sample t-test for Voltage, Current, and Power

		t	df	Mean	p-value
Voltage	Golden Spiral Angle-Oriented	.31159	1.488	4.150	.000
Current	Golden Spiral Angle-Oriented	.72294	.066	1.252	.213
Power	Golden Spiral Angle-Oriented	.01444	.051	.430	.668

The parameters that will be needed include latitude, time, day, and the surface orientation.

Comparison the voltage, current produced, and the power generated of the golden spiral solar panel and angle-oriented solar panel: Table 4 shows the result of Independent Sample t-test for voltage, power, and current. There is a significant difference between the voltage produced by the two panels, with t = 4.150 and $p<0.05$; power produced by the two panels as with t = 1.252 and $p<0.05$; and the current generated by the two panels as shown in table 1, with t = 4.30 and $p<0.05$.The voltage generated by the golden spiral is greater than the angle-oriented by 1.90% with mean values of 16.51V and 16.20V respectively. The power produced by the golden spiral is also greater than the angle-oriented by 2.91% with means of 25.46mW and 24.74mW respectively. The current produced by the golden spiral is greater than the angle-oriented by 0.95% with means of 1.54mA and 1.53mA respectively. The results display that only the voltage demonstrated a significant difference in favor of the golden spiral solar panel while the power and current of the golden spiral solar panel and angle-oriented showed similar outputs. Even though the power and current has no significant difference, the results still show that there is a distinction when it comes to percentage difference in favor of the golden spiral solar panel. In the study of Benguar *et al*. (2018), the comparison of golden ratio solar panel and flat-oriented solar panel resulted to the three outputs to coincide with the golden spiral solar panel as being more efficient than the flat-oriented one, which means that angle-orientation had a great effect in optimizing the outputs of the solar photovoltaic cells. This is supported by Tlijani *et al*. (2017) stating that application and optimization of tilt angles and orientations can be used to generate maximum electrical power and output voltage. The tilt angles and orientation vary in every place in the world depending on its geographical location (Malicdem, 2015).

Summary, Conclusion and Recommendation

Two solar panels were made using mathematical concepts: one followed the commonly available angle-oriented solar panel design and the other one adapted the Golden Spiral solar panel design by Benguar *et al*. (2018). The tilt angle orientation of the angle-oriented solar panel was approximately 15 degrees perpendicular to the sun and was facing south. The Golden Spiral solar panel follows the pattern of the Golden ratio. The materials that were used in the latter design were modified. Instead of using popsicle sticks, the researcher used glass slides in order to optimize the harvesting of solar energy. The computed means of the three outputs are 16.51V, 25.46mW and 1.54mA for the golden spiral solar panel while for the angle-oriented one are 16.20V, 24.74mW and 1.53mA. The golden spiral solar panel yields 1.90% more voltage, 2.91% more power and 0.95% more current than the angle-oriented solar panel. The Independent Sample T-test depicts that there is a significant difference in voltage in favor for the golden spiral solar panel. Both the power and current did not show significant difference, but it does not mean that there is nothing positive to come up with their outputs. The power and current have differences in their mean values even though that the researchers only created a small prototype, so there is still a possibility that the results will have a significant difference if the said study will be conducted in a larger proportion. The following are recommended for further research and examination. For the prototypes, the researchers recommend to use larger photovoltaic cells and materials. Larger prototypes could help produce a larger variation of data and results. The same sort of materials to be used in constructing the prototypes, like using glass as the uniform base to all the prototypes, is also encouraged to attain a more comparable set of models. Using data loggers is highly suggested for a systematic and convenient collection of data. It is highly suggested that further research will have a data gathering period of one year be and in full days. Results gathered from this period will have the highest reliability as the sun path differs throughout a year.

REFERENCES

Aldobhani, S. and Mohamed, A. 2014. Effect of Altitude and Tilt Angle on Solar Radiation in Tropical Regions. *Journal of Science and Technology.* Vol 19 No 1. Retrieved from: http://ust.edu

Benguar, A. N., Casiano, P. G., Valdehueza, T. L., & Tan, D. 2018. Golden Ratio Applied In The Orientation Of Solar Cells in A Golden Spiral Solar Panel . *International Journal of Development Research*, 20416-20420. , 8(05), 20416-20420. Retrieved from: https://www.journalijdr.com /golden-ratio-applied-orientation-solar-cells-golden-spiral-solar-panel

Fiegna, C., Nicolai, M., 2015. Simulation Study of Multi-wire front Contact Grids for Silicon Solar Cell.*Energy Procedia*, 77 (2015), 129 – 138. doi: 10.1016/j.egypro.2015.07.020.x

Handoyo, E., Ichsani, D. and Prabowo 2012. The optimal tilt angle of a solar collector. *International Conference on Sustainable Energy Engineering and Application*. Energy Procedia 32 (2013) 166 – 175. Retrieved from: https://www.researchgate.com

Khademia, M., Jafarkazemi, F., Ali Saadabadi, S., & Ghazi, E. 2013. Optimizing the Tilt Angle of Solar Panels by SQP Algorithm. Applied Mechanics and Materials, Vols. 253-255, pp. 766-771, 2013. Retreived from: www.scientific.net

Khelifa A., Touafek K., Ben Moussa H., Tabet I., Ben cheikh El hocine H. and Haloui H.2015. Analysis of a Hybrid Solar Collector Photovoltaic Thermal (PVT). *International Conference on Technologies and Materials for Renewable Energy, Environment and Sustainability, TMREES15*. Energy Procedia 74 (2015) 835 – 843. Retrieved from: https://www.researchgate.com

Mafimidiwo, O. and Saha, A. 2016. Incorporating a three dimensional photovoltaic structure for optimum solar power generation - the effect of height. *J. energy South Africa*. vol.27 n.2. Retrieved from: http://www. scielo.org.za

Malicdem, E. 2015. Optimum Tilt of Solar Panels in the Philippines. *Research Gate Publications,* 1-9. doi: 10.13140

Mazumder, N. and Verma, S. 2014. An Investigation of Solar Trees for Effective Sunlight Capture Using Monte Carlo

Simulations of Solar Radiation Transport. *The Amrican Society Of Mechanical Engineers.* Volume 8A. Retrieved from: proceedings.asmedigitalcollection.asme.org

McGranaghan M., Shaw J. and Owen R. 1981. Measuring Voltage and Current Harmonics on Distribution Systems. *IEEE Transactions on Power Apparatus and Systems*. Volume: PAS-100 , Issue: 7. Retrieved from: https://www.researchgate.com

Narejo, G. and Panjwani, M. 2014. Effect of Humidity on the Efficiency of Solar Cell (photovoltaic). *International Journal of Engineering Research and General Science.* Volume 2, Issue 4. Retrieved from: http://ijergs.org. managewebsiteportal.com

Tlijani, H., Aissaoui, A. and Younes, R. B. 2017. Optimization of tilt angle for solar panel: Case study Tunisia. *Indonesian Journal of Electrical Engineering and Computer Science*, 8(3), 762-769. doi: 10.11591/ijeecs. v8. i3. pp762-769

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