Using Real-Time Data to Relate Solar Energy Production to the Sun's Location

Teacher Activity

BACKGROUND

The Ohio State University's Stone Laboratory sits on the 6.5-acre Gibraltar Island in the harbor at Put-in-Bay, Ohio in Lake Erie. Established in 1895, it is the oldest freshwater biological field station in the country. As facilities were renovated in 2013, photovoltaic (PV) solar panels and solar thermal installations were placed on the island to reduce energy consumption. The installations were designed to maximize usage for education, research, and outreach opportunities (Figure 1).

On the left side (west) of Figure 1, the solar pavilion is visible with 44 240-watt panels. Half of the panels (22) are monocrystalline silicon (15% efficiency, a little more expensive, and normally a little more efficient on cloudy days) and half are polycrystalline silicon (14% efficiency and a little less expensive). The panels on top of the solar pavilion are tilted at a 10° angle from the ground. Two 3-panel monocrystalline ground mounts are in front of the pavilion. The panels on the western ground mount are fixed at approximately a 36° angle to Earth's surface so they are perpendicular to the sun's rays in late spring and early summer. The eastern ground mount is set at approximately 26° so that it is perpendicular to the sun's rays at the summer solstice (21 June). This arrangement allows Stone Laboratory to research how the angular placement of panels affects energy produced. Typically, panels should be placed at latitude tilt to maximize energy output over the course of an entire year; for Stone Laboratory, this would be 42° given its location (41.6° N, 82.8° W).

Figure 1: Solar Panel Installations at Stone Laboratory. Circles highlight the Ground West mount and Solar Pavilion panels used in this lesson.

This solar technology curriculum was funded by an OSU CARES grant in partnership with the following Ohio State University departments: Ohio Sea Grant and Stone Laboratory; Extension and Energize Ohio Signature Program; Facilities, Operations, and Development; and the Office of Energy and Environment.

OBJECTIVES

In this activity, students will measure and use the angles at which the sun's rays strike Earth's surface to design a PV solar arrangement that maximizes electrical energy production. Using the results of the investigation and a thorough analysis of real-time data from various PV solar panels at Stone Laboratory, students will present plans for arrangement and use of PV solar technology systems to maximize energy production in various location throughout a year.

After completing this investigation, students will be able to:

- Describe how the angle of the sun's rays influences energy production in a PV solar cell.
- Demonstrate how to use a protractor and calculate the internal angle of a triangle.
- Create and interpret graphical representations of PV solar panel data.
- Design an optimal PV solar arrangement given a set location and season.

GRADE LEVELS – 7-12 Earth and/or Environmental Science

TIME REQUIRED – 2 class periods (one part each day)

MATERIALS PER STUDENT OR GROUP

Part 1: Each student should have access to the internet and a student handout (if not using Nearpod).

Part 2: Each group of students should have:

- pizza box
- sharpened pencil
- large paperclip
- protractor
- ruler
- markers
- tape
- alligator clips
- solar mini panels
- digital voltmeter or multimeter
- student handout

Part 3: Each student should have access to the internet and an online graphing program (e.g., Microsoft Excel), as well as the student handout. A handout for creating a data table and graph are provided if students have limited computer access.

Teacher's Note:
Instructions for using a multimeter are located in the reference documents of this curriculum.

ALIGNMENT

Next Generation Science Standards

DCI: Human Impacts on Earth Systems (ESS3.C)
DCI: Conservation of Energy and Energy Transfer (PS3.B)
DCI: Developing Possible Solutions (ETS1.B)
SEP: Developing and Using Models
SEP: Planning and Carrying Out Investigations
SEP: Analyzing and Interpreting Data
SEP: Constructing Explanation and Designing Solutions
CC: Energy and Matter
CC: Interdependence of Science, Engineering, and Technology
CC: Influence of Engineering, Technology, and Science on the Society and the Natural World

Energy Literacy Principles

#1.4, 1.5, 1.7, 1.8 Energy is a physical quantity that follows precise natural laws.
#2.2 Physical processes on Earth are the result of energy flow through the Earth system.
#4.4 Various sources of energy can be used to power human activities, and often this energy must be transferred from source to destination.

Ohio's Model Science Curriculum

Grade 7 Physical Science: Energy can be transformed through a variety of ways.
High School Environmental Science: Earth's Resources
Global Environmental Problems and Issues

PRIOR TO THE LESSON

1. Review how to use a protractor to calculate the internal angle of a triangle.
2. Ensure students can effectively use a chosen online graphing program.

Lesson

ENGAGE

PART 1: PREPARING FOR THE INVESTIGATION

1. Display the following questions that will promote thinking about the convenience of hot water. Some examples may include:
    1. Have students read the introductory information about solar technology at Stone Laboratory. They should also visit ***ohioseagrant.osu.edu*** and follow the instructions on their paper to learn how the island's technology is converting solar energy into electrical energy.
    2. Elicit information about students' comprehension of the reading and animation by using the paper-based questions.

Teacher's Note:
It is suggested that students complete this part for homework prior to main lesson.

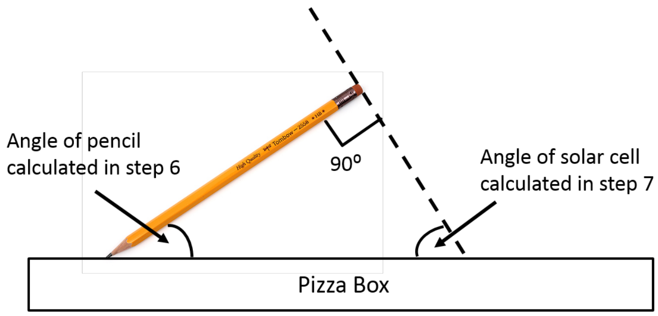
This is a checkpoint for formative assessment; Answers to Questions on Pre-Investigation Checkpoint
1. D 2. E 3. A 4. C 5. B

EXPLORE & EXPLAIN

PART 2: HOW DOES THE ANGLE OF THE SUN'S RAYS INFLUENCE ENERGY PRODUCTION IN A PHOTOVOLTAIC SOLAR CELL?

1. Students will follow instructions on the handout to use a pencil, pizza box, and protractor to determine the angle at which the sun's rays are hitting Earth.

The sum of the inside angles of a triangle is 180°.
180° - 90° - angle of the pencil = angle of the PV solar cell



Teacher's Note:
If students are having difficulty calculating the angle, encourage them to hold a ruler (or piece of paper) perpendicular to the end of the pencil. From there students can calculate the angle by visualizing a triangle. Three angles total 180°; thus, 180° – 90° – angle of the pencil = angle to place PV solar cell.

2. Though basic instructions are provided on the student handout, guide students through the process of designing their own investigation to determine how electrical energy output varies as they change the angle of the pizza box lid (which now holds a PV solar cell).

Placing the pizza box at the angle observed in the first procedure should result in the greatest voltage generated.

Answers to Questions on Student Handout

1. The sun is higher in the sky during the summer months, resulting in a smaller angle of the PV solar cell placement to allow the sun's rays to hit the panel at a 90° angle. During the winter months, students should expect to find the PV solar cell needs to be placed at a larger angle to Earth's surface in order to achieve the most direct sunlight.

2. Answers will vary, but the angle of the sun's rays reaching Earth's surface varies throughout the year. This is because Earth is tilted slightly (23.5°) from its axis. During the summer months in the northern hemisphere, solar radiation reaches Earth at an angle closer to 90° than during the winter months.

PART 3: HOW DOES THE ANGLE OF A PV SOLAR PANEL AFFECT ENERGY PRODUCTION THROUGHOUT THE YEAR?

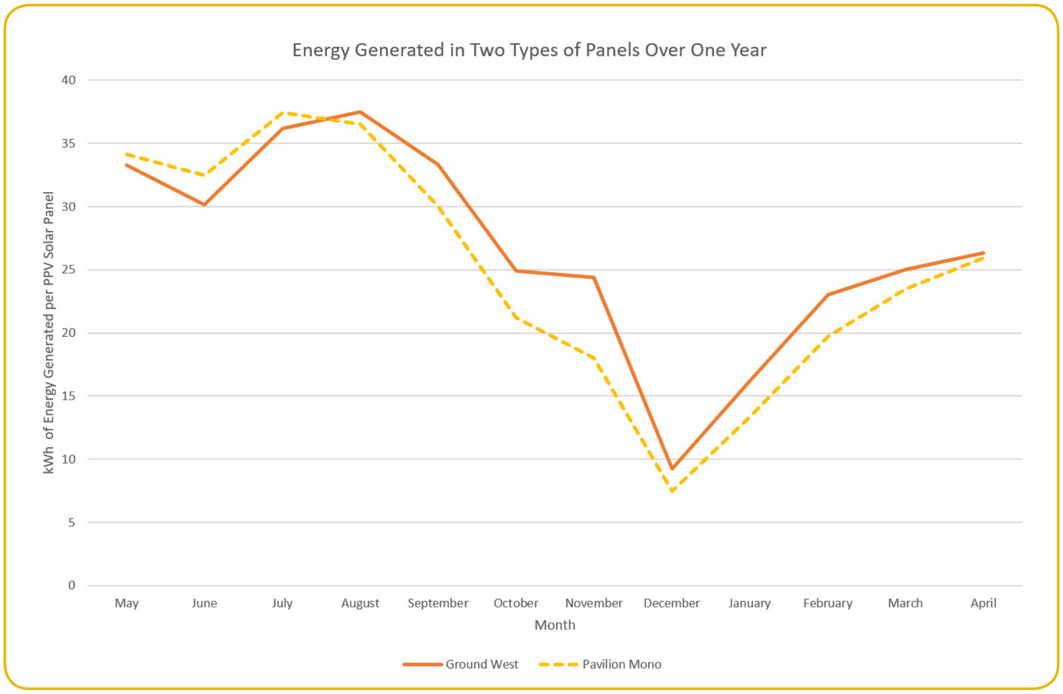
1. Have students access real-time PV solar panel data at ***ohioseagrant.osu.edu*** and use an online graphing program to analyze the energy output by season in two different panel arrangements at Stone Laboratory. Students should scroll halfway down the page to find the Solar Panel Data on the right hand side of the page. Click the *Solar Dashboard* button to access more detailed information.
   a. Clicking on *Live Data* will display the nine types of solar technology across the top of the screen; clicking on the tabs displays the total kilowatt hours (kWh) of energy produced by that type of panel.
   b. The tabs to change the time interval of the graphs (days, weeks, months, years, lifetime) are on the right side of the screen.
   c. Clicking on a bar graph will display the exact amount of energy produced.

Teacher's Note:
Remind students that the table and graph will not be by calendar year; the last bar will be the current month and may not show a full month of generation.

2. Students will work with data from the last 12 months for the three panels on the western ground mount (Ground West) and the 22 monocrystalline silicon panels on the solar pavilion (Pavilion Mono). Using an online graphing program, they will create a spreadsheet listing the PER PANEL output in kWh by month for the current YEAR of data for the Ground West and Pavilion Mono solar panels . A sample data table is shown here.
   a. Months are shown with the current month as the last bar on the graph (not necessarily January).
   b. Data in the columns "Ground West Total" and "Pavilion Mono Total" are directly from the website.
   c. Energy production per panel is calculated by dividing the total by 3 (for the Ground West panels) or 22 (for the Pavilion Mono panels).

	Energy Output (kWh)			
Month	Ground West Total (3 panels)	Ground West Per Panel	Pavilion Mono Total (22 panels)	Pavilion Mono Per Panel
May	99.75	33.25	750.41	34.11
June	90.48	30.16	714.72	32.49
July	198.56	36.19	823.51	37.43
August	112.48	37.49	804.12	36.55
September	100.04	33.35	660.88	30.04
October	74.75	24.92	467.09	21.23
November	73.20	24.40	396.45	18.02
December	27.79	9.26	164.88	7.49
January	48.59	16.20	292.24	13.37
February	69.12	23.04	434.14	19.73
March	75.00	25.00	516.34	23.47
April	78.94	26.31	536.01	25.95

3. Students should then create a line graph showing the per panel output in kWh by month for the past year of data for the Ground West and Pavilion Mono solar panels. The graph should have two lines, one for the Ground West and one for the Pavilion Mono panels. The shown below is an example that uses the above data.



Teacher's Note:
If students do not have access to a spreadsheet and graphing program, please use the blank table and graph provided with this lesson.

4. Questions on the handout then guide students through analyzing and interpreting the data, applying their knowledge to additional scenarios, and presenting a plan for arrangement and use of PV solar technology systems to maximize energy production at various locations throughout a year.

Answers to Questions on Student Handout

1. The Ground West array produced the most energy from August through April. Conversely, the Pavilion Mono array produced more energy in May through July.
2. The table should be completed as follows:

Season	Spring	Summer	Fall	Winter
Array Producing the Most Energy Per Panel (kWh)	Ground West	Pavilion Mono	Ground West	Ground West

3. a. One would expect the Pavilion Mono to produce more energy in the summer because it has a smaller angle of incline (10°), which allows the sun's rays to hit more directly (closer to a 90° angle) when the sun is higher in the sky during the summer. One would expect the Ground West array to produce more energy in the winter because of its larger angle of incline (36°) when the sun is lower in the sky.

   b. Answers will vary. If Stone Laboratory's data do not support the hypotheses above, this could be a result of equipment malfunction on one set of panels. It could also be due to the fact that the angle difference between the two panels is not drastic. Therefore, even small issues with equipment, tree shading, weather, etc. can affect the data output.

4. This will vary depending on the location and calendar year of the school. Many Ohio schools are in session August through May, and have a greater energy demand in those months than in the summer. Assuming the array cannot be moved, an angle close to latitude tilt (~42°) is preferred since school is not in session in the summer when a smaller angle is more beneficial. Schools at higher latitudes would place their PV solar arrays at an even greater angle, whereas schools at lower latitudes would place their PV solar arrays at a smaller angle.

5. Miami, Florida sits at approximately 26° north latitude; the city receives more direct sunlight in the summer months than winter months. The PV solar panels should be installed at an angle lower than 26° (potentially near 10°) as there will be a greater energy demand in the summer than winter months.
6. Duluth, Minnesota sits at approximately 46.7°.
   a. The PV solar panels should be installed at the same angle as the city's latitude to maximize energy production throughout the course of the year.
   b. Duluth receives more direct sunlight in the summer than winter months. Thus, the PV solar panels should initially be installed at an angle less than 46.7° (potentially almost near 30°). As fall approaches the angle should be increased and ultimately be slightly greater than 46.7° in the winter months. The angle needs to be greater as Duluth is tilted further from the sun in winter months. As spring arrives, the angle should be reduced back towards 46.7° and even less as Duluth receives more direct sunlight during summer months.

ELABORATE
Integrate engineering skills into the activity. Provide students with a small PV solar panel and a variety of recycled building materials (cardboard, foam, wood scraps, dowel rods, tape, glue, etc.). Assign each group of students a city and provide them with this prompt:

You work for a solar technology installation firm. You have clients that are unhappy with their PV solar panels not generating maximum energy due to the angle of the sun and its movement throughout the year. Using only recycled or reused materials found at home or school, design a model of a system that would maximize the energy generated from the PV solar panels year-round that you could offer your clients. Additionally, develop a short presentation that explains and justifies the rationale of your design.

A number of websites are available for students to research installation angles, PV solar panel movement, and structural designs. A few examples include:

pvsolar.com
energy.gov/science-innovation/energy-sources/renewable-energy/solar
nrel.gov

EVALUATE
The following questions can be used on formative assessments to evaluate students' understanding and application of concepts in this activity.

You are designing a PV solar panel array for a new home in Phoenix, Arizona; the owners plan to live there year-round.

a. Scenario A: The owners are asking for stationary panels where the angle cannot be changed. To maximize energy production, at what angle should they set the PV solar panels? Justify your reasoning.
b. Scenario B: The owners are willing to pay the extra costs associated with installing the PV solar panels on a mobile frame that allows for the angle of the panels to change. The panels will be installed in November. To maximize energy production, at what angle should they initially place the PV solar panels? Develop a monthly plan for how the owners should shift the PV solar panels each month.

SOURCE
Solar Energy Curriculum Consortium
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Name ______________________________

Using Real-Time Data to Relate Solar Energy Production to the Sun's Location

PRE-INVESTIGATION CHECKPOINT

Match each term with the phrase that best describes it:

1. ______ otherwise known as photovoltaic cells
2. ______ generated by movement of a loop of wire or a disk of copper between the poles of a magnet
3. ______ converts direct current to alternating current
4. ______ measures the amount of electricity supplied or produced
5. ______ an energy source that has the potential to provide for all of Earth's energy needs

A. inverter B. sun C. meter D. solar panels E. electricity

Using the five terms above, write a short description of the process of how solar energy can be transformed to electricity.

____

____

____

____

Name ______________________________

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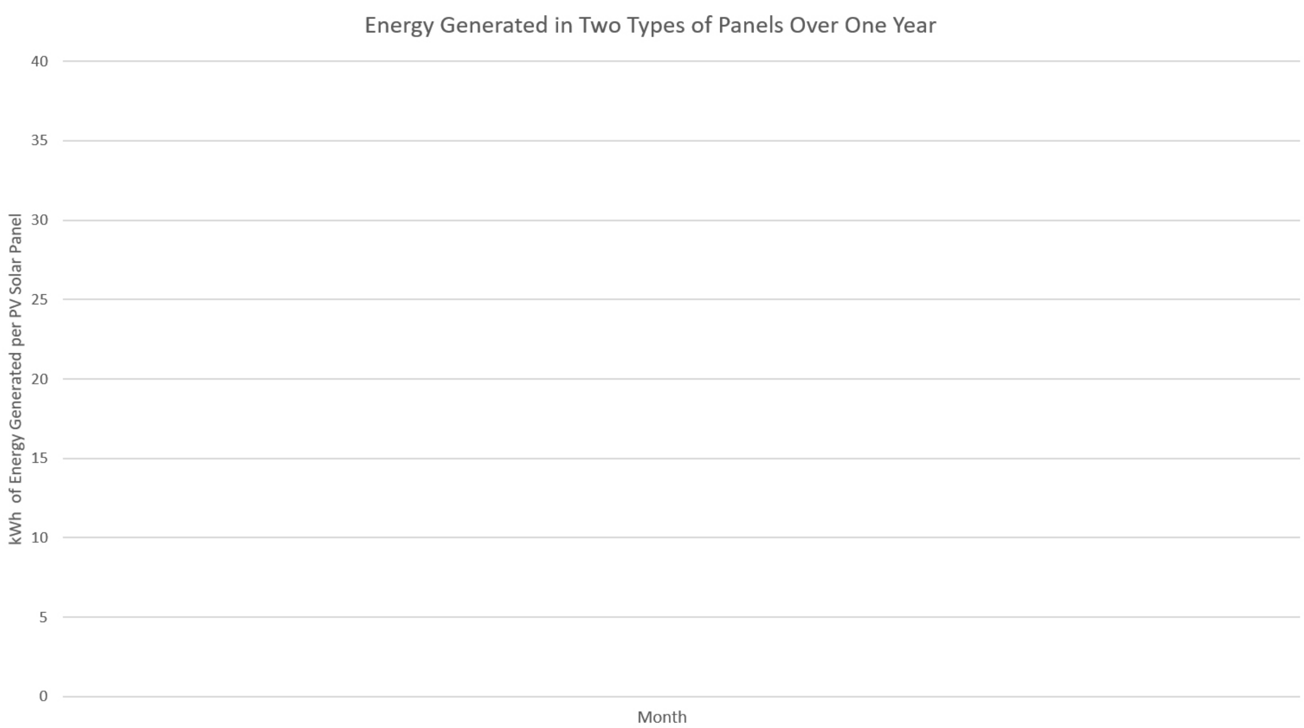
HOW DOES THE ANGLE OF A SOLAR PANEL AFFECT ENERGY PRODUCTION THROUGH TIME?

	Energy Output (kWh)			
Month	Ground West Total (3 panels)	Ground West Per Panel	Pavilion Mono Total (22 panels)	Pavilion Mono Per Panel



Using Real-Time Data to Relate Solar Energy Production to the Sun's Location

Student Activity

Name ______________________________

BACKGROUND

The Ohio State University's Stone Laboratory sits on the 6.5-acre Gibraltar Island in the harbor at Put-in-Bay, Ohio in Lake Erie. Established in 1895, it is the oldest freshwater biological field station in the country. As facilities were renovated in 2013, **photovoltaic (PV) solar panels** and solar thermal installations were placed on the island to reduce energy consumption. The installations were designed to maximize usage for education, research, and outreach opportunities (Figure 1).

On the left side (west) of Figure 1, the solar pavilion is visible with 44 240-watt panels. Half of the panels (22) are monocrystalline silicon (15% efficiency, a little more expensive, and normally a little more efficient on cloudy days) and half are polycrystalline silicon (14% efficiency and a little less expensive). Two 3-panel monocrystalline ground mounts are in front of the pavilion.

In this activity you will measure and use the angles at which the sun's rays strike Earth's surface to design a PV solar arrangement that maximizes electrical energy production. Then using the results of the investigation and a thorough analysis of real-time data from various PV solar panels at Stone Laboratory, you will present plans for arrangement and use of PV solar technology systems to maximize energy production in various locations throughout a year.

Figure 1: Solar Panel Installations at Stone Laboratory. Circles highlight the Ground West mount and Solar Pavilion panels used in this lesson.

PROCEDURE

PART 1: PREPARING FOR THE INVESTIGATION

1. Visit ***ohioseagrant.osu.edu*** and scroll to the middle of the page to access the Solar Panel Data (right side).
2. Click on *Solar Dashboard* and then *How It Works*. Click through the five tabs under How It Works to learn how solar energy is converted into electrical energy. Be prepared for your teacher to check your understanding of the basic process of how solar technology works.

PART 2: HOW DOES THE ANGLE OF THE SUN'S RAYS INFLUENCE ENERGY PRODUCTION IN A PHOTOVOLTAIC SOLAR CELL?

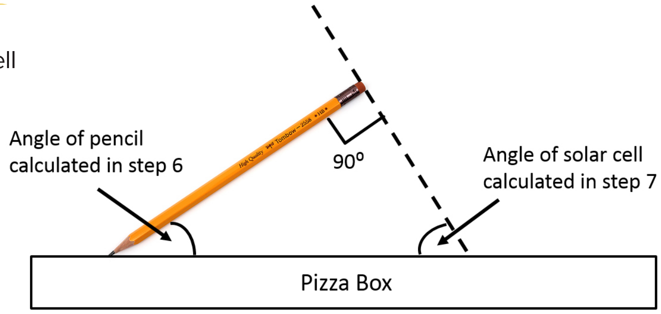
Photons may be reflected away from, pass through, or be absorbed by PV solar cells. Only the absorbed photons provide energy to generate electricity. Identifying the angle at which the sun's photons strike Earth's surface and understanding how sunlight interacts with the PV solar panel allows for the optimal performance of a solar energy system.

Follow the directions below to determine the angle at which the sun's rays are currently striking Earth's surface.

1. Note the time of day and location of your investigation.
2. Place a pizza box on a flat sunny surface.
3. Carefully straighten the paperclip and insert it into the pencil eraser creating a handle.
4. Place the sharpened end of the pencil on the center of the box surface and hold the paperclip handle.
5. Use the pencil shadow to identify the angle the sun's rays are striking Earth's surface. (Hint: Face the pencil eraser toward the sun and adjust it until there is no shadow.)
6. Use a protractor to measure the angle between the pizza box and pencil; this is the angle the sun's rays are hitting Earth. Record the angle of the pencil.
7. Calculate the proper angle for the placement of a solar panel so the sun's rays hit the solar panel at a 90^0 angle.

The sum of the inside angles of a triangle is 180°.
180° - 90° - angle of the pencil = angle of the PV solar cell

Your teacher may provide you with a ruler to hold perpendicular to the eraser end of the pencil so that you can confirm the calculated angle.



Location	Time of Day	Angle of the Sun's Rays	Angle of the Solar Cell

Now determine the angle at which the solar panel produces the most electricity.

8. Use tape to fasten the mini solar cell to the top of the pizza box.
9. Connect the voltmeter or multimeter to the alligator clips.
10. Experiment by positioning the pizza box top at different angles (measured by the protractor) and note the voltage output on the voltmeter or multimeter. Record the results of at least five angles different from the one previously calculated.

Angle of Solar Panel								
Electricity Produced (volts)								

QUESTIONS

1. At what angle did the solar panel produce the most volts? What does this indicate about the current location of the sun?

2. Pick a season different from the current one. Would you hypothesize that your angle of greatest productivity would increase or decrease during that season and why?

PART 3: HOW DOES THE ANGLE OF A SOLAR PANEL AFFECT ENERGY PRODUCTION THROUGH TIME?

Follow the directions below and use an online graphing program to analyze the energy output by season in two different panel arrangements at Stone Laboratory.

1. Go to ***ohioseagrant.osu.edu*** and scroll halfway down the page to find the *Solar Panel Data* on the right hand side of the page. Click on *Solar Dashboard* to access more detailed information.
    a. Clicking on *Live Data* will display the nine types of solar technology across the top of the screen; clicking on the tabs displays the total kilowatt hours (kWh) of energy produced by that type of panel.
    b. The tabs to change the time interval of the graphs (days, weeks, months, years, lifetime) are on the right side of the screen.
    c. Clicking on a bar graph will display the exact amount of energy produced.
2. You will work with data from the last 12 months for the three panels on the western ground mount (Ground West) and the 22 monocrystalline silicon panels on the solar pavilion (Pavilion Mono). Months are shown with the current month as the last bar on the graph (not necessarily January).
    a. Create a spreadsheet with five columns: Month, Ground West Total, Ground West Per Panel, Pavilion Mono Total, Pavilion Mono Per Panel
        i. Data in the columns “Ground West Total” and “Pavilion Mono Total” come directly from the website.
        ii. Calculate energy production per panel by dividing the total value by 3 (for the Ground West panels) or 22 (for the Pavilion Mono panels).
    b. Create a line graph showing the per panel output in kWh by month for the past year of data for the Ground West and Pavilion Mono solar panels. The graph should have two lines, one for the Ground West and one for the Pavilion Mono panels. Be sure to include a title, key, and axis labels on your graph.

QUESTIONS

1. Which solar array (Ground West or Pavilion Mono) produced the most kWh of energy per panel for each month of the year?

2. Complete the chart. Which solar array (Ground West or Pavilion Mono) produced the most kWh of energy per panel for each season?

Season	Spring	Summer	Fall	Winter
Array Producing the Most Energy Per Panel (kWh)				

3. Consider the different angles of the panels (Ground West = 36° and Pavilion Mono = 10°) in each type of array.
    a. Explain which array you would expect to produce more energy per panel in the summer. Explain which array type you would expect to produce more energy per panel in the winter.

    b. Do the real-time data collected by Stone Laboratory support the above hypotheses? If not, provide reasons why this may be.

4. You are designing a stationary PV solar panel array for your school. Based on the geographic location and calendar of your school, at what angle should the PV solar panels be installed? Justify your reasoning.

5. You are designing a stationary PV solar panel array for a new home in Miami, Florida; the owners plan to live there only from May through August. To maximize energy production, at what angle should the PV solar panels be installed? Justify your reasoning.

6. You are designing a PV solar panel array for a new home in Duluth, Minnesota; the owners plan to live there year-round.
   a. Scenario A: The owners are asking for stationary panels where the angle cannot be changed. To maximize energy production, at what angle should the PV solar panels be installed? Justify your reasoning.

   b. Scenario B: The owners are willing to pay the extra costs associated with installing the PV solar panels on a mobile frame that allows for the angle of the panels to change. The panels will be installed in June. To maximize energy production, at what angle should they initially place the PV solar panels? Develop a seasonal plan for how the owners should shift the PV solar panels throughout the year.
   Justify your reasoning.