Good Day Sunshine!

Key Words:
hypothesis
irradiance
irradiation
pyronometer

Time:
1 class period

Student Objective

The student:
- will explain the relationship between the available sunlight and the power produced by a photovoltaic device
- will be able to predict the performance of a photovoltaic system when given a graph of solar irradiance
- given a graph of a photovoltaic system's power output will be able to deduce what the weather was for the given days
- will be able to infer from a table of irradiation data the relative amount of sunlight in different locations at different times of the year.

Materials:
- computer with internet access

Background Information

The performance of the school's solar photovoltaic system at any given time depends primarily on the amount of sunlight available to it. On bright, sunny days, the system gradually produces more and more energy throughout the day until the sun is directly overhead. A graph showing the energy production of the PV system over time on a sunny day will resemble a smooth, tall, bell shaped curve.

On consistently overcast days, the curve will have the same width but will be much lower, and on partly cloudy days with patched of clouds intermingled with bright sun, the curve will tend to be spiky, showing that the system produces more energy during sunny periods and less energy during cloudy periods.

Procedure

1. If necessary, divide the students into groups according to how many computers are available to them.
2. **Engage:** Lead a review discussion on their findings during the *Solar Powered System*

activity as it related to sun and shade.

3. **Explore:** Students will research, explore, and analyze data as they complete their Laboratory Manual and related exercises.
4. Evaluations in the Integration section of the Laboratory Manual and the Problem set are provided to evaluate previous and current lessons learned.

Related Research

1. Look up irradiation data from:
   - different latitudes worldwide
   - different climatic regions
   - different altitudes

   Compare the data and determine how each parameter would affect the output of a phtovoltaic array.
2. Look up the yearly insolation data from near the same latitudes at selected cities in the northern and southern hemisphere that have similar weather patterns. Graph both sets of data. Analyze the graphs by comparing and contrasting the curves. What astronomical and sunlight conclusions can be made from the information?

Math Extension - Calculus

1. Have students use graphs of irradiance data for Orlando and Spokane to understand and apply continuity theorems, derivatives, and integrals. (Note: the integral of irradiance is insolation).

Internet Sites

http://rredc.nrel.gov/solar/old_data/nsrdb/

National Solar Radiation Database contains 30 years (1961-1990) of solar radiation and supplementary meteorological data from 237 NWS sites, plus a user manual to help in reading the tabular information.

http://sol.crest.org/solrad/data/index.html

Center for Renewable Energy and Sustainable Technology (CREST), solar radiation and climate data for the United States for flat plate, tracking and concentrating collectors.

http://wrdc-mgo.nrel.gov/

World Radiation Data Centre. Worldwide solar radiation site.

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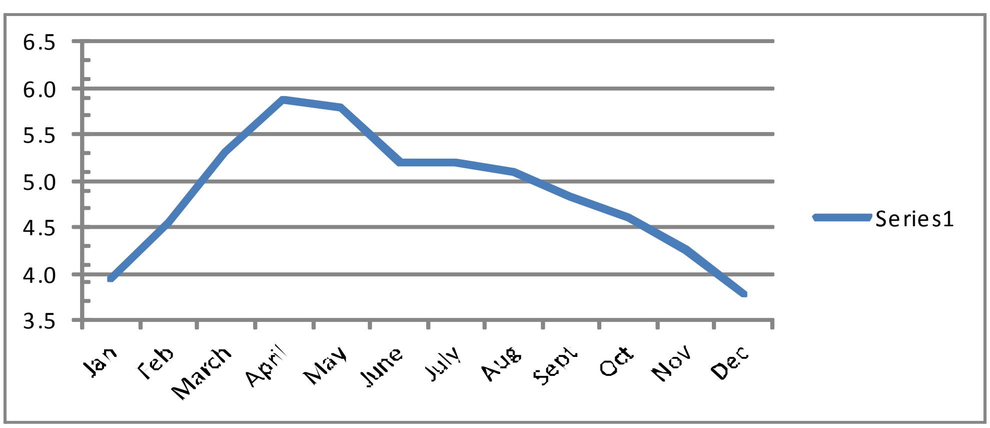
1. Answers will vary, but students should show an understanding that high irradiance values directly correlate to available sunlight. Lower values indicate cloud cover. Advantages of solar energy should include the fact that it is non-polluting and renewable. Disadvantages should include the fact that weather can hamper the amount of solar irradiance reaching the earth.
2. The curves should look very similar. The irradiance levels should be higher than the current due to the resistance in the electrical system. Other losses include reflection back into the environment and energy that is transformed into heat.
3. This is a linear relationship.
   Y=mx + b where
   b = the irradiance due to the location on Earth
   m = the number of panels in the system
   x = the current
   y = irradiance
4. March has a higher insolation value. Students should take the average of the tilt angles to find that March has an average of 5.3, and August has an average of 5.05 peak hours.
5. Not necessarily true for Orlando, Florida when summer is our cloudy, rainy season and April and March are drier and less cloudy.
6. April. Students should be able to explain what they did to obtain this answer. Acceptable methods include taking the average, choosing the month that has the highest output for their school's tilt angle.
7. December.
   During the winter solstice the Earth is closer, but is also tilted away from the Sun in the Northern Hemisphere.
   No. In the Southern Hemisphere, the sun is farther away but Earth is tilted toward the Sun (their summer), therefore more light energy is being received in December.
8.



9. Spokane
10. Answers will vary, but most will feel that Florida should have had more sunlight (the Sunshine State!)
11. Answers will vary, but should include the facts that during the summer months the Earth's tilt is facing the Sun more directly giving Spokane more daylight hours (earlier sunrises and later sunsets) than during the same dates in Orlando which is a lower latitude. Students may also know that July is Spokane's dry season while it is during Orlando's rainy season.
12. Orlando. Students should be able to explain their method of comparing the tables. Acceptable methods include comparing the 0^{o} data for each location, averaging the monthly data for the tilt angle closest to the site's latitude, or averaging the annual per month averages.
13. Spokane is at 47^{o} N latitude and Orlando is at 28^{o} N latitude, which makes the Sun higher in the sky for Orlando, so the tilt angles for Orlando are less to make the panel surface close to perpendicular to the Sun's rays.
14. The Spokane plant would contribute the most solar energy to the grid during June - August.
15. The Orlando plant would contribute the most solar energy to the grid during January - March.
16. 35^{o}, because the highest annual insolation value is achieved at that angle.

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		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Nature of Science																					
Standard 4	**SC.912.N.4**		X																		
Earth and Space																					
Standard 5	**SC.912.E.5.**				X																
Standard 6	**SC.912.E.6.**						X														
Life Science																					
Standard 17	**SC.912.L.17.**											X									
Mathematics Standards		**MA.912.A.1.1, MA.912.A.1.4, MA.912.A.1.5, MA.912.A.2.2, MA.912.A.2.7, MA.912.A.2.12, MA.912.A.2.13, MA.912.A.5.5, MA.912.A.5.7**																			

Science Standards
Standard 4: Science and Society

- SC.912.N.4.2 - Weigh the merits of alternative strategies for solving a specific societal problem by comparing a number of different costs and benefits, such as human, economic, and environmental.

Standard 5: Earth in Space and Time

- SC.912.E.5.4 - Explain the physical properties of the Sun and its dynamic nature and connect them to conditions and events on Earth

Standard 6: Earth Structures

- SC.912.E 6.6 - Analyze past, present, and potential future consequences to the environment resulting from various energy production technologies.

Standard 17: Interdependence

- SC.912.L.17.11 - Evaluate the costs and benefits of renewable and nonrenewable resources, such as water, energy, fossil fuels, wildlife, and forests.

Mathematics Standards
Algebra - Standard 1: Real and Complex Numbers

- MA.912.A.1.1 - Know equivalent forms of real numbers (including integer exponents and radicals, percent, scientific notation, absolute value, rational numbers, irrational numbers).

- MA.912.A.1.4 - Perform operations on real numbers (including integer exponents, radicals, percent, scientific notation, absolute value, rational numbers, irrational numbers) using multi-step and real-world problems.
- MA.912.A.1.5 - Use dimensional (unit) analysis to perform conversions between units of measure, including rates.

Algebra - Standard 2: Relations and Functions

- MA.912.A.2.2 - Interpret a graph representing a real-world situation.
- MA.912.A.2.7 - Perform operations (addition, subtraction, division, and multiplication) of functions algebraically, numerically, and graphically.
- MA.912.A.2.12 - Solve problems using direct, inverse, and joint variations.
- MA.912.A.2.13 - Solve real-world problems involving relations and functions.

Algebra - Standard 5: Rational Expressions and Equations

- MA.912.A.5.5 - Solve rational equations
- MA.912.A.5.7 - Solve real-world problems involving rational equations (mixture, distance, work, interest and ratio)

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hypothesis – an explanation for an observation, phenomenon, or scientific problem that can be tested by further investigation.

irradiance - the measure of the power density of sunlight. Expressed in watts per square meter.

irradiation - the measure of the energy density of sunlight reaching an area summed over time. Usually expressed in kilowatts per square meter per day.

pyronometer – a device to measure the amount of solar irradiance

Good Day Sunshine!

Irradiance is the scientific term for the amount of sunshine that strikes an object. To investigate how the amount of irradiation affect the amount of electricity that your school's photovoltaic system produces, print a copy of your school's data graphs from the Energy Whiz website.

1. From the *Plane of Array Irradiance* graph, what can you say about the available sunlight on each of the three days? Describe each day below and include the advantages and disadvantages of using solar energy to provide electric energy.

2. Study the *Plane of Array Irradiance* and the *PV System DC Current* graphs. Are they similar or different? Describe below how they are similar and how they are different.

3. Use your comparison above to mathematically describe the relationship between the *Plane of Array Irradiance* and *PV System DC Current*.

Scientists have been collecting irradiance data from places all over the world since 1960. This data has been used to calculate the average amount of sunlight at these places for different times of the year. In order to make the data comparable from place to place and even out the effects of daily weather, the data is converted into an equivalent number of peak sun hours. "Peak sun hours" is defined as the number of hours that the given sun would equal when converted to 1000 watts per square meter. A very sunny day would have a value of 4 - 6 sun hours while a cloudy day may only have the equivalence of 1 sun hour.

The irradiance data for Orlando, Florida is shown below.

Insolation (irradiance) – kWh/m^2-day – for Orlando, FL (28.55º North Latitude)

Tilt	**Jan**	**Feb**	**Mar**	**Apr**	**Ma**	**Jun**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Annual**
0º	3.14	3.92	4.99	5.99	6.27	5.78	5.68	5.28	4.72	4.11	3.46	2.92	4.69
15º	3.75	4.43	5.30	6.05	6.10	5.54	5.49	5.24	4.89	4.53	4.06	3.56	4.91
20º	3.92	4.56	5.36	6.01	5.99	5.41	5.37	5.18	4.90	4.63	4.23	3.74	4.94
25º	4.07	4.67	5.39	5.95	5.85	5.26	5.23	5.10	4.89	4.70	4.37	3.90	4.95
30º	4.19	4.75	5.39	5.85	5.67	5.07	5.06	4.99	4.86	4.75	4.49	4.04	4.93
35º	4.29	4.80	5.36	5.72	5.47	4.87	4.87	4.85	4.79	4.77	4.58	4.15	4.88
40º	4.37	4.82	5.31	5.56	5.24	4.63	4.66	4.69	4.71	4.76	4.64	4.24	4.80

Use the tilt angle in the table above, that best matches the tilt angle of your school's PV system to answer questions 4 - 8.

4. According to the chart above, which of these two months, March or August, has the greatest amount of available or irradiated sunlight when considering all the listed tilt angles?

   How did you obtain this answer?

5. We usually think of the summer months as being the sunniest and therefore the best for photovoltaic systems. Is this a correct assumption?

   Why or why not?

6. Which month out of the year has the greatest amount of sun hours? To justify your answer, briefly explain the procedure you followed to obtain this answer.

7. Which month of the year has the least amount of sun hours?

What contributing astronomical event can be used to justify your answer?

Would someone in the southern hemisphere share this same answer? Why or why not?

8. Draw a line graph on a separate sheet of paper to show the average amount of sun hours (y-axis) for each month of the year (x-axis).

The irradiance data for Orlando and Spokane, Washington are below.

Insolation (irradiance) – kWh/m^2-day – for Orlando, FL (28.55º North Latitude)

Tilt	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
0º	3.14	3.92	4.99	5.99	6.27	5.78	5.68	5.28	4.72	4.11	3.46	2.92	4.69
15º	3.75	4.43	5.30	6.05	6.10	5.54	5.49	5.24	4.89	4.53	4.06	3.56	4.91
20º	3.92	4.56	5.36	6.01	5.99	5.41	5.37	5.18	4.90	4.63	4.23	3.74	4.94
25º	4.07	4.67	5.39	5.95	5.85	5.26	5.23	5.10	4.89	4.70	4.37	3.90	4.95
30º	4.19	4.75	5.39	5.85	5.67	5.07	5.06	4.99	4.86	4.75	4.49	4.04	4.93
35º	4.29	4.80	5.36	5.72	5.47	4.87	4.87	4.85	4.79	4.77	4.58	4.15	4.88
40º	4.37	4.82	5.31	5.56	5.24	4.63	4.66	4.69	4.71	4.76	4.64	4.24	4.80

Insolation – kWh/m^2-day – for Spokane, WA (47.63º North Latitude)

Tilt	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
0º	0.99	1.91	3.28	4.72	6.05	6.57	7.44	6.13	4.53	2.65	1.25	0.81	3.86
35º	1.84	2.93	4.13	5.10	5.91	6.14	7.12	6.41	5.45	3.84	2.18	1.63	4.40
40º	1.92	3.01	4.16	5.04	5.76	5.95	6.92	6.31	5.46	3.93	2.27	1.71	4.38
45º	1.99	3.08	4.17	4.97	5.59	5.73	6.69	6.18	5.44	3.99	2.34	1.78	4.34
50º	2.05	3.13	4.16	4.86	5.39	5.49	6.42	6.01	5.39	4.03	2.40	1.84	4.27
55º	2.09	3.15	4.12	4.73	5.17	5.22	6.13	5.81	5.31	4.05	2.44	1.89	4.18
60º	2.12	3.16	4.06	4.58	4.92	4.93	5.80	5.59	5.20	4.04	2.46	1.92	4.07

9. Based on the data above, which city has the greatest amount of sun hours in July?

10. Is this what you would have expected? Why or why not?

11. What factors do you think contribute to this effect?

12. Which location has the greatest yearly average irradiance? How did you obtain this answer?

13. Why are the tilt angles different for the two cities listed in the data tables?

14. Looking at the big picture, supplying electricity to the U.S. using photovoltaic power plants, during what months would the Spokane plant contribute the most solar energy to the grid?

15. During what months would the Orlando plant contribute the most solar energy to the grid?

16. What tilt angle would you recommend for the Spokane solar array? Why?

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1. Using the output power from your school's array at 1000 w/m^2, and the insolation data from the NREL chart closest to your location, calculate how many lbs of CO_2 were not released into the atmosphere by using the electricity your SunSmart photovoltaic array produced versus the average coal fired power plant.
(Note: to calculate CO_2 emissions, use 2.3 lb CO_2 per kWh of electricity)

2. Your school decides to design a rack system for your SunSmart array that can be set at two different tilt angles to maximize the output of the system for both winter and summer conditions. For the largest increase in power, what two angles should the array be set at, and what months should the array tilt be changed?

3. What would be the average daily increase in sun hours over the course of a year for the array with the new racking system?

4. If the new racking system cost $1000. to fabricate, how long would it take for the additional savings in electricity cost to pay for the new rack? (Assume electricity at 12 cents per kWh)