

Solar Kit Lesson #8 Positioning Solar Panels II: Explorations with Stationary Panels

TEACHER INFORMATION

LEARNING OUTCOME

After collecting and analyzing data on the amount of sunlight that strikes solar panels in various stationary positions, students are able to identify an optimum mounting position for a given day of the year and explain why engineers typically mount PV modules in New York State facing due south and tilted at about 43 degrees from horizontal.

LESSON OVERVIEW

Students use a graphical integration technique to determine the amount of solar energy (W- hr/m^2) received by solar panels over a day in different stationary positions. From this data, they deduce which position a panel should be placed in to receive the most solar energy over a day at this time of year. Using what they have learned, they propose reasons why the 2 kW solar panels mounted on the 50 School Power ... Naturally $^{(sm)}$ schools are positioned as they are.

This is the second of two related Solar Kit lessons. In the first lesson, *Positioning Solar Panels I: Explorations with Tracking*, students propose stationary positions for solar panels to receive the most energy at a given time of year. In this activity they experimentally check the accuracy of their proposals.

GRADE-LEVEL APPROPRIATENESS

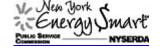
This Level II lesson is intended for use in physical science and technology education classrooms in grades 6–9.

MATERIALS

Per work group

- Bubble level
- Compass
- One 1 V, 400 mA mini–solar panel* with conversion curve (see the Solar Kit lesson *Calibration Curve for a Radiation Meter*)
- Digital multimeter or ammeter
- Student handouts
- Experiment station consisting of three to four solar panel props mounted on a flat board of approximately 20 x 5 inches

*Available in the provided Solar Education Kit; other materials are to be supplied by the teacher



SAFETY

Tell students not to look directly at the Sun. Permanent eye damage might result. Instead, tell them to use a maximum current reading to indicate when a solar panel faces the Sun directly.

TEACHING THE LESSON

Allow for continuous data collection by performing the activity with all of your classes on the same day. If successive classes are working in small groups, numerically assign groups to particular setups. During lunch, preparatory, and supervisory periods, consider making arrangements for a few students to collect data. You might want to collect early morning and late afternoon data yourself. Data needs to be collected until the Sun is as low in the sky in the afternoon as it was when data collection started in the morning. (Daily data on solar altitude vs. time of day for specified geographic locations is available at: http://aa.usno.navy.mil/data/docs/AltAz.html)

Preparation for day one: Prepare five or six portable experiment stations, enough for one class working in small teams. Teams in different classes will use the same stations to collect data.

	Table	1: Deg	gree of	tilt fro	m horiz	zontal
Board No.	1	2	3	4	5	6
For	$0_{\rm o}$	20°	40°	60°	$80^{\rm o}$	
Five	5°	25°	45°	65°	85°	
Teams	10°	30°	50°	70°	90°	
	15°	35°	55°	75°		
For Six Teams	$0_{\rm o}$	20°	35°	50°	65°	80°
	5°	25°	40°	55°	70°	85°
	10°	30°	45°	60°	75°	90°
	15°					

Build each experiment station on a portable flat board. Use the template in figure 1 to create cardboard props for students to mount their solar panels at the required tilt from horizontal. For each angle of tilt from horizontal:

- 1) Copy or glue the template to a piece of cardboard and cut it out along the outline.
- 2) Fold the two outside tabs back along the dashed lines. Fold each back 90 degrees.
- 3) Trim each of these tabs along the proper angled line for the desired angle of tilt.
- 4) Fold the bottom tab backward along the dashed line until it meets the bottom (trimmed) edges of the two side tabs.
- 5) Glue the bottom tab flat and the bottom edges of the two side tabs to the board. Mount three to four props on each board so that they all face one long side of the board and tilt up from the horizontal at the angles described in table 1.

Prepare Data Logs for each experiment station by filling in the horizontal tilt angles on the blank Data Log supplied as a student handout. Supply each station with one Data Log for every direction east of north to be tested. To determine these directions, use student suggestions for

question 8 from the handout *Tracking Solar Panel: Data Analysis* (see the Solar Kit lesson *Positioning Solar Panels I: Explorations with Tracking*).

Write on the chalkboard the stationary mounting positions that students suggested for question 8 from the handout *Tracking Solar Panel: Data Analysis* (see the Solar Kit lesson *Positioning Solar Panels I: Explorations with Tracking*).

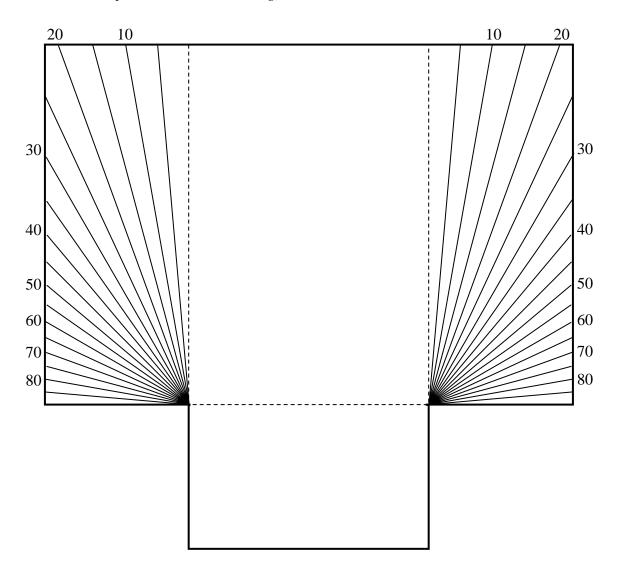


Figure 1: Template for building mounting props for solar panels

Suggested Approach – day one: Introduce the activity by posing the following situation. Describe a group of farmers who use solar panels to pump water to irrigate their crops. These farmers can't afford to buy or maintain tracking systems for their solar arrays but can adjust the arrays once each morning so as to get the most power during that day to pump water. Ask students to think about what angle east of north and what angle of tilt up from horizontal they

would recommend for positioning a solar panel to receive the most solar energy over the course of a day at this time of year.

Solar Panels II: Stationary Panels

Review with the class the selection of student responses to question 8 from the handout *Tracking Solar Panel: Data Analysis* (see the Solar Kit lesson *Positioning Solar Panels I: Explorations with Tracking*). Tell students that they will work in teams to test an array of positions and then extrapolate from the data how each of their suggested positions would perform.

Divide the class into small groups and hand out materials. Go over with students how to use the compass and the bubble level to position a board horizontally and to face the direction to be tested (e.g., one direction to test is due south, 180 degrees east of north). Assign as many student-suggested panel directions as time allows.

Demonstrate how to hold the mini–solar panels against the props for each experimental setup. Demonstrate how to use an ammeter and a panel's conversion curve to obtain milliamps and then convert to watts per square meter (W/m²). (See the Solar Kit lesson *Calibration Curve for a Radiation Meter.*) Distribute the handout *Stationary Solar Panel: Data Collection*.

Direct students to collect data at a location where they will receive sunlight for as many daylight hours as possible, unobscured by the shadows of trees, buildings, or other objects. Have teams set their board to face one specified direction east of north, take one set of readings, and then adjust the direction of the experiment platform for the next set. Have them record data for each set of readings in a separate Data Log.

Preparation for day two: On day two, students will work in teams of two. Depending on the size of the class, each team will analyze data from two or more horizontal angles of tilt. Data for one horizontal angle of tilt is considered one data set. Copy the completed Data Logs as needed to distribute two or more data sets to each team.

Use the data collected to determine the vertical scale for students to use for graph 1. For the horizontal scale, let the distance between each solid vertical line represent one hour. Fill in the appropriate scales on the master copy. It is important that each student work with the same scale in order to visually compare data sets. Assign a pencil color for each direction that data was collected. Make 20 copies of graph 1, one for each horizontal angle of tilt and one for data on tracking.

Suggested Approach – day two: Distribute two or more data sets to each team along with a copy of graph 1 for each data set. Distribute the handout *Stationary Solar Panel: Data Analysis*. Help students with graphs and questions as appropriate.

When all teams have reached question 4, have them compare which direction (east of north) provided the solar panels with the greatest amount of solar energy throughout the day. Some students may have to count squares formed by the graph's grid to determine the curve with the largest area. Taken together, the data should point to one direction and it should be due south.

For question 5, have students use data for the panel direction east of north decided upon for question 4. Have each student estimate the area under the curve for his or her data set by

estimating a count of the number of square grids and multiplying that number by the watt-hours per meter squared each grid represents.

Each grid represents a specific quantity in watt-hours per meter squared (W-h/m²), depending on the scale used for the graphs. Students can calculate this value by multiplying the incremental difference between gridlines used for the y-axis by 0.5 hours, the incremental difference between gridlines for the x-axis. For instance, if the gridlines on the y-axis are marked for every 50 W/m^2 , then each square grid represents 25 W-h/m^2 .

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION Data Collection

The data collected will vary but specific patterns should emerge: panels facing true south should receive the most solar radiation as should panels tilted to face within a few degrees of the Sun's highest altitude.

Data Analysis

- 1) Students record the proper data on their Data Logs.
- 2) Accurate representation of the data collected.
- 3) Accurate assessment of plotted data.
- 4) Constructive and timely contribution to class discussion.
- 5) Accurate assessment of plotted data.
- 6) Constructive and timely contribution to class discussion.
- 7) Although results will vary, students should notice electrical output increase by up to 30 percent when compared to a non-tracking solar panel.
- 8) A solar panel tilted 43 degrees from the horizontal faces the mean apex altitude of the Sun over the course of a year. A panel directed at the Sun's highest altitude at the summer solstice would tilt $90^{\circ} 70^{\circ} = 20^{\circ}$. A panel directed at the Sun's highest altitude at the winter solstice would tilt $90^{\circ} 24^{\circ} = 66^{\circ}$. The mean between these two angles is 43° .

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY

The basic idea for this activity is adapted from *Thames & Kosmos Fuel Cell Car & Experiment Kit Lab Manual*, Thames & Kosmos, LLC, Newport, RI, 2001. The organization of classroom activities was adapted from *Renewable Energy Activities for Junior High / Middle School Science*, prepared for the U.S. Department of Energy by the Solar Energy Project in

cooperation with the New York State Education Department and the University at Albany Atmospheric Sciences Research Center (out of print).

BACKGROUND INFORMATION

Determining whether a tracking or stationary photovoltaic system is a wise investment depends on many factors including the intended application. Adding a tracking mechanism to a solar electric system introduces new electronic and mechanical components that will need to be purchased and maintained at a cost. Tracking systems are relatively expensive and this cost must be weighed against the alternate option of purchasing additional solar panels to increase power output.

Tracking systems give you the biggest boost of power output in situations where the Sun travels a wide arc in its daily traverse across the sky, such as during summer months in higher latitudes or year-round near the equator. In some situations, such as at a remote water pumping station, this increased output matches demand and the tracking system may be cost-effective. In other applications, such as an off-the-grid system designed to charge a homeowner's bank of batteries, the increased power is needed most in the winter and the extra power provided in the summer may be wasted. For a grid-tied system, the cost of adding a tracking system must be weighed against the cost of purchasing from the utility the amount of electricity the tracker would provide.

REFERENCES FOR BACKGROUND INFORMATION

The Solar Electric Independent Home Book, Fowler Solar Electric, Inc., 1993.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

Standard 1—Analysis, Inquiry, and Design: Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

Mathematical Analysis Key Idea 1: Abstraction and symbolic representation are used to communicate mathematically. (intermediate level)

Key Idea 2: Deductive and inductive reasoning are used to reach mathematical conclusions. (intermediate and commencement levels)

Key Idea 3: Critical thinking skills are used in the solution of mathematical problems. (intermediate and commencement levels)

Scientific Inquiry Key Idea 1: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process. (intermediate and commencement levels)

Key Idea 2: Beyond the use of reasoning and consensus, scientific inquiry involves the testing of proposed explanations involving the use of conventional techniques and procedures and usually requiring considerable ingenuity. (intermediate level)

Key Idea 3: The observations made while testing proposed explanations, when analyzed using conventional and invented methods, provide new insights into phenomena. (intermediate level)

- **Standard 3—Mathematics:** Students will understand mathematics and become mathematically confident by communicating and reasoning mathematically, by applying mathematics in real-world settings, and by solving problems through the integrated study of number systems, geometry, algebra, data analysis, probability, and trigonometry.
- Key Idea 1: Students use mathematical reasoning to analyze mathematical situations, make conjectures, gather evidence, and construct an argument. (intermediate level)
- Key Idea 4: Students use mathematical modeling/multiple representation to provide a means of presenting, interpreting, communicating, and connecting mathematical information and relationships. (intermediate and commencement levels)
- Key Idea 5: Students use measurement in both metric and English measure to provide a major link between the abstractions of mathematics and the real world in order to describe and compare objects and data. (intermediate and commencement levels)
- Key Idea 6: Students use ideas of uncertainty to illustrate that mathematics involves more than exactness when dealing with everyday situations. (intermediate level)
- Key Idea 7: Students use patterns and functions to develop mathematical power, appreciate the true beauty of mathematics, and construct generalizations that describe patterns simply and efficiently. (intermediate level)
- **Standard 4—Physical Setting:** Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.
- Key Idea 1: The Earth and celestial phenomena can be described by principles of relative motion and perspective. (intermediate and commencement levels)
- Key Idea 4: Energy exists in many forms, and when these forms change energy is conserved. (intermediate level)
- **Standard 5—Technological Education:** Students will apply technological knowledge and skills to design, construct, use, and evaluate products and systems to satisfy human and environmental needs.
- Key Idea 1: Engineering design is an iterative process involving modeling and optimization used to develop technological solutions to problems within given constraints. (intermediate level)
- Key Idea 4: Technological systems are designed to achieve specific results and produce outputs, such as products, structures, services, energy, or other systems. (intermediate and commencement levels)
- **Standard 6—Interconnectedness: Common Themes:** Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.
- Key Idea 2: Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design. (intermediate and commencement levels)
- Key Idea 5: Identifying patterns of change is necessary for making predictions about future behavior and conditions. (intermediate level)
- Key Idea 6: In order to arrive at the best solution that meets criteria within constraints, it is often necessary to make trade-offs. (intermediate and commencement levels)

Standard 7—Interdisciplinary Problem Solving: Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

Key Idea 1: The knowledge and skills of mathematics, science, and technology are used to make informed decisions and solve problems, especially those relating to issues of science/technology/society, consumer decision making, design, and inquiry into phenomena. (intermediate and commencement levels)

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www.nyserda.org

Should you have questions about this activity or suggestions for improvement, please contact Chris Mason at cmason@nesea.org.

(STUDENT HANDOUT SECTION FOLLOWS)

Data Log

r			$\frac{\text{Tracking}}{(\text{W/m}^2)}$								
Station Number			Horz. Tilt: $\overline{(W/m^2)}$								
			Horz. Tilt: $\overline{(W/m^2)}$								
):		Horz. Tilt: $\overline{(W/m^2)}$								
	Direction East of North (degrees):	Weather Conditions:	Horz. Tilt: $\overline{(W/m^2)}$								
Date	Direction	Weather C	Time (hh:mm)								

Name_			
Date			

Stationary Solar Panel: Data Collection

- 1) Record in the Data Log the weather conditions that best match what you see outside.
- 2) Position the experiment station so it lies level and faces the first direction to be tested. Record the time in the Data Log.
- 3) Connect the ammeter to the solar panel. For each position, hold the solar panel against the prop, read the ammeter, convert the reading to light intensity (W/m²), and record this in the proper Data Log. Use the Data Log designated for this test direction.
- 4) Reposition the experiment station so it lies level and faces the next direction to be tested. Repeat step 3 for this new direction. Continue this for each direction to be tested.
- 5) Point the solar panel toward the Sun and position it to obtain the maximum current reading from the ammeter. Convert this reading to light intensity (W/m²) and record this in the last Data Log you used under "Tracking."
- 6) Repeat the above measurements as often as your teacher instructs you to do so.

Name	 	 	
Date _	 	 	

Stationary Solar Panel: Data Analysis

Your teacher will assign you data for two or more horizontal angles of tilt. Data for one horizontal angle of tilt is considered one data set. Complete the following for each data set. Use a separate graph for each data set.

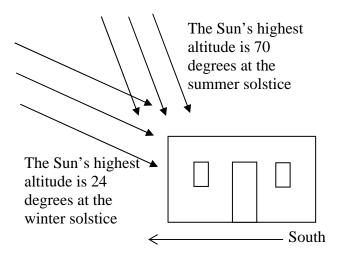
- 1) On the graph supplied by your teacher, record the date and general weather conditions for the day in the title of the graph
- 2) For the assigned horizontal angle of tilt, plot one set of data for each direction east of north that data was collected. Use the pencil colors specified in the key to draw a smooth line through the data points for each set of data.
- 3) You can compare the total amount of energy that would be received over a day by a solar panel facing in each direction by comparing the area under the curves plotted for each direction. For which direction (east of north) that you plotted is the area under the curve the largest? (You can estimate the area under a curve by counting the number of square grids under the curve.)
- 4) With your teacher's direction, compare this with the results derived from data plotted by other students. As a class, decide which direction (east of north) the farmers should position their solar panels in to obtain the greatest amount of power.
- 5) For a panel facing in this direction and at your specified horizontal angle of tilt, estimate the total number of watt-hours of radiation a panel one square meter in size would have received on the day of your data collection. This is easier than it sounds. Your teacher will explain how to proceed.

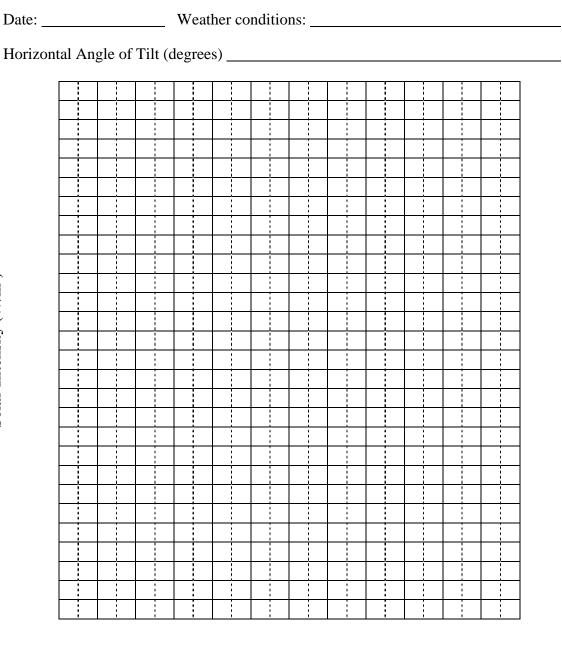
A solar panel facing	degrees east of north, a	nd tilted at an angle of	
degrees from the horizontal, v	vould have received	watt-hours per square	
meter (W-h/m ²) of power on t	he day of your data coll	ection.	

- 6) With your teacher's direction, compare your estimate with the results derived from data plotted by other students. As a class, decide which horizontal angle of tilt the farmers should position their solar panels in to obtain the greatest amount of energy from the Sun at this time of year.
- 7) What percentage difference is there in solar radiation received between the best performing stationary panel and the tracking panel?

8) Fifty New York State schools have recently installed solar electric systems, in part to help supply energy to New York State's electrical power system. These panels were mounted facing due south with a tilt of 43 degrees from horizontal. In central New York State, the Sun's highest daily altitude changes from 24 degrees at the winter solstice (December 21) to 70 degrees at the summer solstice (June 21). Why do you think the engineers made the design choice of tilting the panels 43 degrees from horizontal?

Hint (see question 2 from the handout *Tracking Solar Panel: Data Analysis*): Use the relationship between the Sun's altitude and the optimum tilt of a solar panel to calculate the optimum tilt of a solar panel at the summer and winter solstices.





Time of Day

Direction East of North (degrees)	Pencil Color