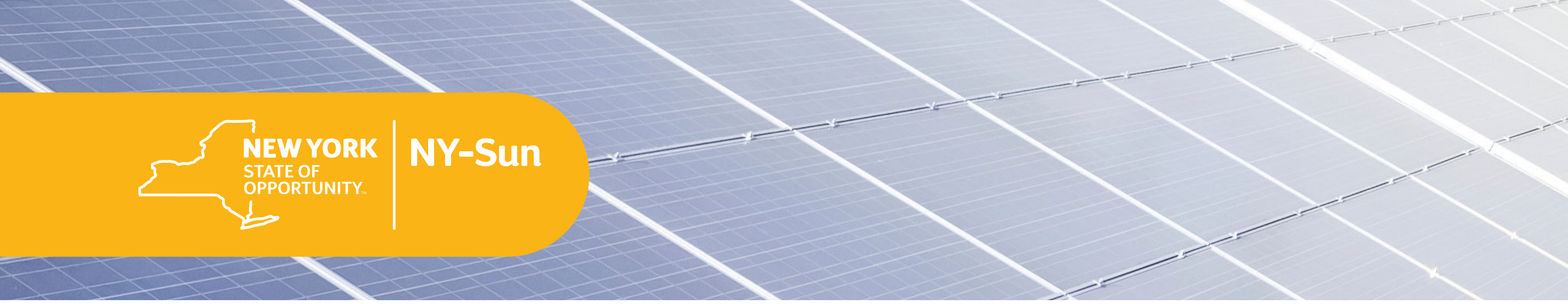

Positioning Solar Panels II: Explorations with Stationary Panels

Suggested Level: Grades 6 through 9

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 in New York State typically mount PV modules 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/m2) 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.

This is the second of two related 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.

MATERIALS

Per work group

- Bubble level
- Compass
- One 1 V, 400 mA mini–solar panel with conversion curve (See the 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

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.

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.

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.

Table 1: Degree of tilt from horizontal

Board No.	1	2	3	4	5	6
For Five Teams	0°	20°	40°	60°	80°	
	5°	25°	45°	65°	85°	
	10°	30°	50°	70°	90°	
	15°	35°	55°	75°		
For Six Teams	0°	20°	35°	50°	65°	80°
	5°	25°	40°	55°	70°	85°
	10°	30°	45°	60°	75°	90°
	15°					

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 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 lesson Positioning Solar Panels I: Explorations with Tracking.)

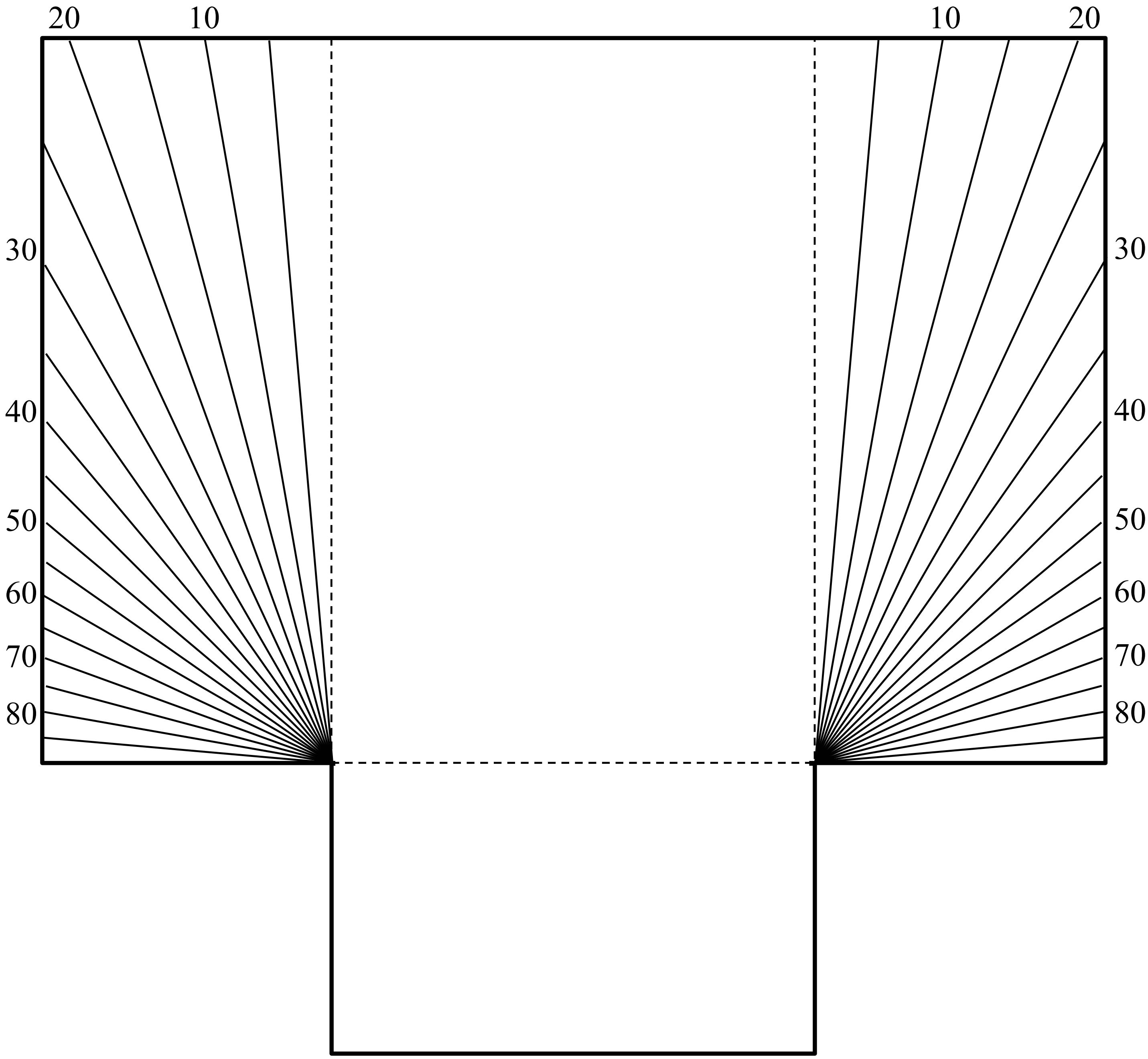

Figure 1: Template for building mounting props for solar panels

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 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.

Review with the class the selection of student responses to Question 8 from the handout, Tracking Solar Panel: Data Analysis. (See the 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 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/m^2), 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 STUDENT RESPONSES

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° – 70° = 20°. A panel directed at the sun's highest altitude at the winter solstice would tilt 90° – 24° = 66°. The mean between these two angles is 43°.

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.

(STUDENT HANDOUT FOLLOWS)

Name ______________________ Date ______________

Data Log

Date ____________________ Station Number ________________

Direction East of North (degrees):					
Weather Conditions:					
Time (hh:mm)	Horz. Tilt: ________ (W/m^2)	Horz. Tilt: ________ (W/m^2)	Horz. Tilt: ________ (W/m^2)	Horz. Tilt: ________ (W/m^2)	Tracking (W/m^2)

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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/m^2), 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/m^2) 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 in which direction (east of north) the farmers should position their solar panels 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.

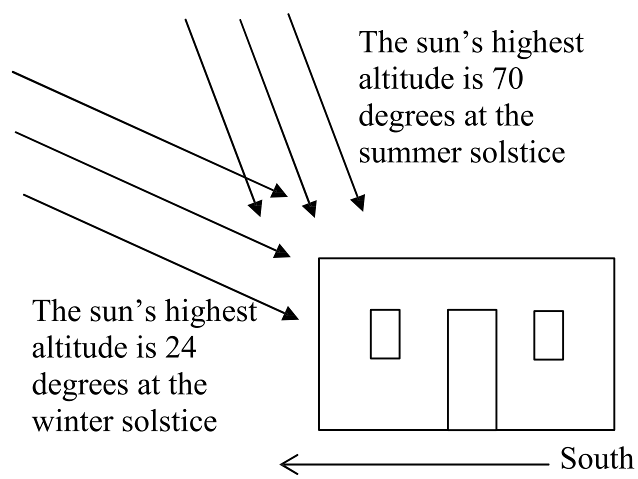
   A solar panel facing ________ degrees east of north, and tilted at an angle of ___________ degrees from the horizontal, would have received _____________watt-hours per square meter (W-h/m^2) of power on the day of your data collection.

6) With your teacher's direction, compare your estimate with the results derived from data plotted by other students. As a class, decide in which horizontal angle of tilt the farmers should position their solar panels 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) Suppose a school recently installed a solar electric system. 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.



Name ______________________________ Date ______________

Graph 1: Solar Intensity versus Time of Day

Date: ______________ Weather conditions: ______________________________

Horizontal Angle of Tilt (degrees) ______________________________

Solar Intensity (W/m^2)

Time of Day

Name

Date

Direction East of North (degrees)	**Pencil Color**