LESSON

Solar Site Analysis (Optimum Array Orientation and Placement)

BIG IDEA(S)

How much sun will be at a given location determines how productive it will be. After looking at seasonal differences in energy delivery, it is important to understand how specific techniques and tools work for optimal solar array placement.

OBJECTIVES

Students will:

- Determine azimuth and altitude angles using a sun chart
- Determine magnetic declination for a given site
- List the variables needed to analyze the amount of sunlight available for a particular solar window
- Explain the process of using tilt angle and orientation to provide maximum energy production for a given site
- Demonstrate solar site analysis tools and procedures

BRIGHT SOLAR FUTURES

SOLAR

TOPIC OF STUDY

Solar Fundamentals

3 HOURS

TASK LIST SUBCATEGORY

107 Describe the fundamentals of solar energy

405 Identify the factors related to system sizing and production

411 Use current technology to determine site suitability

415 Demonstrate knowledge of manufacturers specifications

OVERVIEW

The sun changes position constantly and solar technicians need to define the sun through azimuth and altitude angles and how to find its position. This lesson will cover:

- Finding sun position using a sun chart
- Measure Azimuth and Altitude angles to determine sun position
- Determine magnetic declination
- Utilizing an Inclinometer & Compass

STANDARDS

PA

3.4.10.A2. Interpret how **systems** thinking applies logic and creativity with appropriate comprises in complex real-life problems.

3.4.12.B2. Illustrate how, with the aid of technology, various aspects of the environment can be monitored to provide information for decision making.

NGSS

HS-ESS3-4 Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

KEY TERMS

azimuth altitude
peak sun hours
magnetic declination
true south
orientation
tilt angle
shading
solar noon
sun chart
inclinometer
irradiance
solar window
insolation
Solmetric SunEye
sun path

elevation angle: the vertical tilt of your panels

azimuth angle: the horizontal orientation of your panels (in relation to the equator, in this case)

INSTRUCTIONAL

TEXTS/REFERENCES

Solar Photovoltaic Basics, White, 2019. p. 44

Solar Electric Handbook, SEI, 2013. Pp. 96; 102; 104-5

MATERIALS NEEDED

Content:

- Calculating the Sun's Path and Solar Array Orientation - Page 3
- Photovoltaic Tutorial: Calculating the Sun's Path and Solar Array Orientation

MATERIALS

SolMetric

- SunEye
- PV Analyzer
- Other solar test and measurement equipment

Solar Pathfinder

SOLAR

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IMPLEMENTATION (LESSON PLAN)

ENGAGE

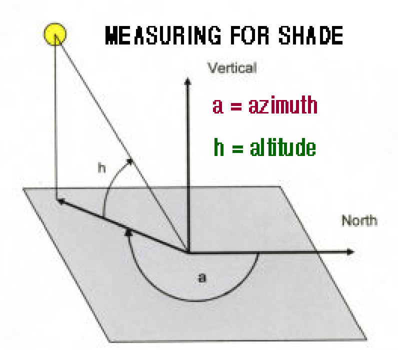
1. Brainstorm: What effects getting the maximum energy in a solar system? (Think-Pair-Share) Have students jot down their thoughts and share with a partner, then report out. Add ideas from all groups.
2. If possible, have students complete the azimuth task in the following lesson plan: Lesson 8: "Watt's" Your Angle?

EXPLORE

- Review tutorial Photovoltaic Tutorial: Calculating the Sun's Path and Solar Array Orientation and Calculating the Sun's Path and Solar Array Orientation - Page 3

EXPLAIN

1. Steps in Determining Array Orientation, Shading, etc.
    - Step 1: Generate a **sun path diagram** online for your latitude.
    - Step 2: Next, go outside to the site of your potential solar array and take a compass bearing to determine the azimuth angle and width of each potential obstruction.
    - Step 3: Record the altitude angle of all the same obstructions.
    - Step 4: On the sun path diagram, plot the coordinates for each potential obstacle.
    - Step 5: Analyze the data to determine how much shading will occur.
2. Azimuth and Altitude: How to Measure a Year's Worth of Shade by Hand
    - A shadow will be cast across an array if an object's elevation or altitude angle is the same or greater than the sun's when they share the same compass bearing—that is, from the perspective of the array. This bearing is called an azimuth angle.



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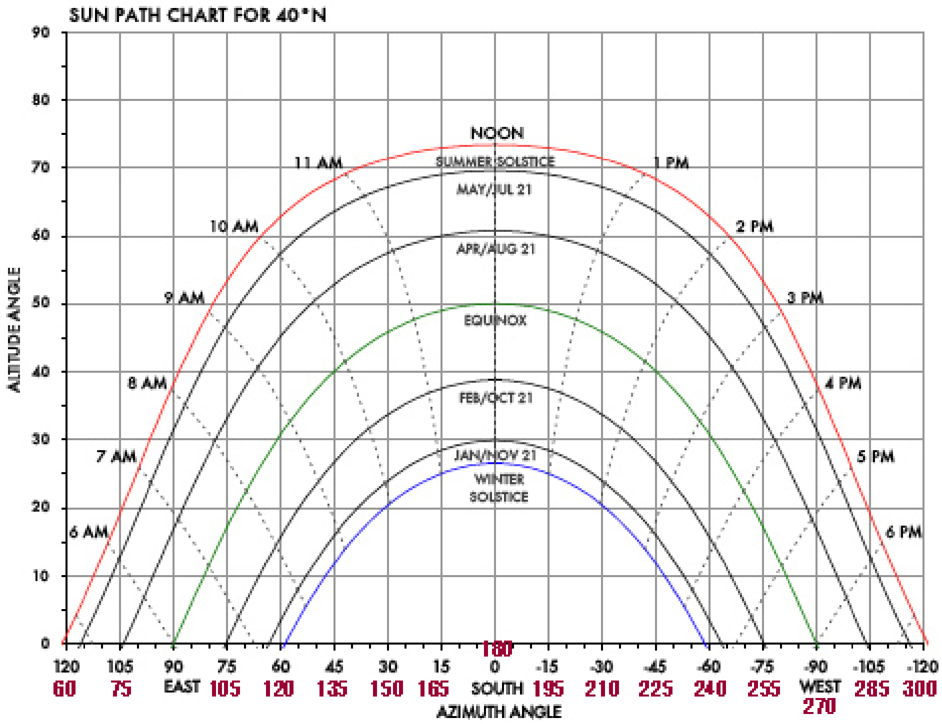
IMPLEMENTATION (LESSON PLAN) - CONTINUED

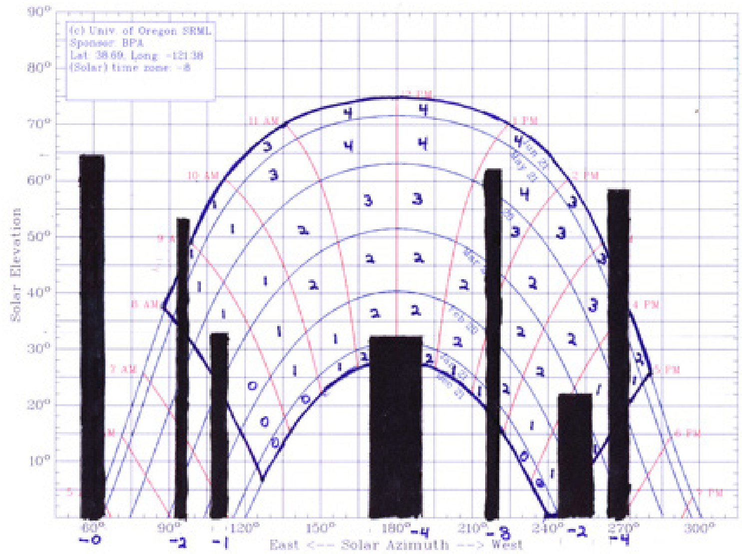


- A sun path diagram provides the track of the sun over a year's time for your local latitude and time zone. Diagram adapted from solardat.uoregon.edu.
- The solid curving lines on the graph represent the sun's path on one day for each two months out of the year (e.g. April and August), except on the solstices, which represent one day. Although there's a white space between each curved line, it's assumed that the sun will gradually track through these spaces over the course of 30 days. The horizontal axis of the graph charts the azimuth angle (compass orientation), while the vertical axis charts the altitude angle.
- The vertical dotted lines plot the time of day in relation to the azimuth and altitude angles. Remember, it's only between the hours of 9 a.m. and 3 p.m. that shading across an array is counted. For this particular chart, any obstruction located outside the compass range of 100 degrees (close to due east) and 265 degrees (close to due west) does not even need to be measured. The top azimuth scale, incidentally, uses the reference-to-due-south system

3. Magnetic Declination: The difference between true and magnetic north varies by location. This is important for panel orientation and calculations. Declination for a given location can be found on the NOAA website in the National Geophysical Data Center: www.ngdc.noaa.gov/geomag

IMPLEMENTATION (LESSON PLAN) - CONTINUED

4. Shading



   a. The chart will tell you if an obstruction will eclipse the sun as it shines on the array. It will also tell you how long the shade will occur. As you can see, a sun path diagram is a simple line graph with X and Y axes.
   b. Plot each set of coordinates in pencil (i.e. the two azimuth measurements and one altitude angle), one by one. Mark the points near the axes lines on the chart. Now draw and fill in a vertical bar shooting up from the Azimuth axis. Once that's done, you can erase the horizontal line emanating from the Altitude axis.
   c. Repeat the process for all the other objects you measured. And if you took readings from more than one location, repeat the tasks -- one sun path chart per location.

5. Array Tilt Angle and Orientation: A surface perpendicular to the sun receives the most irradiance. However, for fixed-mount-grid-direct systems, a 30-degree array tilt angle maximizes annual production. (Review SEI pages 141-145). Demonstrate the Inclinometer https://www.youtube.com/watch?v=7thWAa0xXsU

6. Solar Window: the time the solar array is free of shade
   a. Data that pertains to the solar window: demonstrate how a solar window is determined. Draw a border along the following lines: the 9 a.m and 3 p.m. dotted lines between the uppermost and lowermost curved sun path line; and the curved sun path upper and lower lines, stopping at the 9 a.m. and 3 p.m. borders.
   b. Demonstrate how this is provided by a Solar Pathfinder Solar Pathfinder - Solar site analysis

Solar Obstruction Data

Month	Actual Solar Rad w/o Shading Azimuth=180.0 Tilt=0.0 KWH/m ^{2} /day	Actual Solar Rad w/ Shading Azimuth=180.0 Tilt=0.0 KWH/m ^{2} /day
January	5.85	4.95
February	6.61	5.98
March	7.26	6.86
April	8.82	8.48
May	8.33	8.15
June	7.64	7.64
July	7.33	7.27
August	7.28	7.09
September	6.65	6.46
October	6.76	6.36
November	6.13	5.52
December	5.53	4.08
Totals	**84.19**	**78.84**
	Effect: 100.00%	**Effect: 93.64%**
	Sun Hrs: 7.02	**Sun Hrs: 6.57**

The chart is excerpted from a report by the Solar Pathfinder software and provides the month by month impact of shading on a proposed solar array. The photo on the right

IMPLEMENTATION (LESSON PLAN) - CONTINUED

shows another module placement scheme designed to avoid a year round obstruction - the chimney.

7. Shading remedies:If your assessment produces more than 10% shading, you can take a variety of steps to improve that number. Moreover, any amount of shade -- even one percent! -- can cause a loss of voltage that affects all modules wired in the same series string. In addition to changing the placement or orientation of an array, you can and should try to mitigate its impact within the electric circuit.
   a. Here are the most common adjustments solar designers employ to address shading over an array site:
      i. Move the site farther down the roof (or off the roof).
      ii. Use a non-rectangular configuration.
      iii. Leave an empty space within the array to avoid an obstruction.
      iv. If possible, arrange for a tree removal or seasonal pruning.
      v. Raise the array's height so that the object altitude angle is lower than the sun's altitude/elevation.
      vi. Use a module model with extra shade mitigation features.
      vii. Use several microverters instead of one central inverter, or some form of DC optimization, so that shaded modules won't affect the production of non-shaded modules.
      viii. Run separate cables to the central inverter for each module string so that a lower voltage in one string won't affect the voltage of the others.
      ix. Use a tracking system instead of a fixed arraymount.
8. Peak Sun Hours: the daily amount of sun available on average is given in peak sun hours. The irradiance element of a peak sun hour (1,000 W/m2) is the solar radiation component of Standard Test Conditions.

EXTEND

- Site Analysis Tools
   a. Inclinometer
   b. www.solarpathfinder.com
   c. www.solmetric.com

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