ehp

LESSON:

# Following the Sun to Greener Buildings

**Summary:** Students read the article “Growing Green Communities” and identify green building techniques that have environmental and health benefits. Students continue by reading “Sunny Spanish Energy” and consider another green building technique involving installation of a solar panel as a renewable energy source. Students interpret a sun chart that shows the path of the sun across the sky and use this information to determine how a solar panel should be oriented and tilted to generate the most electricity. This lesson extends discussion of a topic addressed within the articles.

***EHP* Articles:** “Growing Green Communities” and “Sunny Spanish Energy”
*EHP Student Edition*, August 2005, p. A300, A301
http://ehp.niehs.nih.gov/docs/2005/113-5/forum.html

**Objectives:** By the end of this lesson students should be able to:

1. describe green building techniques and their potential health benefits;
2. describe how the Earth’s rotation around the sun and its angle of rotation affects the sun’s location as seen from the Earth;
3. interpret sun charts showing the path of the sun across the sky for different locations, dates, and times; and
4. explain how to determine the direction of orientation and tilt angle of a solar panel to maximize the amount of electricity it would generate.

**Class Time:** 75 minutes

**Grade Level:** 10–12

**Subjects Addressed:** General Science, Physical Science, Environmental Science, Physics and Astronomy

## Prepping the Lesson (15 minutes)

**INSTRUCTIONS:**

1. Obtain a class set of the *EHP Student Edition*, August 2005, or download the articles “Growing Green Communities” and “Sunny Spanish Energy” at http://ehp.niehs.nih.gov/docs/2005/113-5/forum.html and make copies.
2. Review the articles and lesson.
3. Decide if you want students to generate their own sun charts using the Internet. If not, you need to generate sun charts for them that you will distribute. Also decide what locations you want to use to generate the sun charts. (The Student Instructions will walk you through how to generate the charts.)
4. Make copies of the Student Instructions.

**MATERIALS:**

**Per Student**

- 1 copy of *EHP Student Edition*, August 2005, or 1 copy of the articles “Growing Green Communities” and “Sunny Spanish Energy”
- 1 copy of the Student Instructions

**Per Group**

- access to the Internet, if students will generate their own sun charts
- 1 copy of a sun chart, if you are generating the sun charts for your students

**VOCABULARY:**

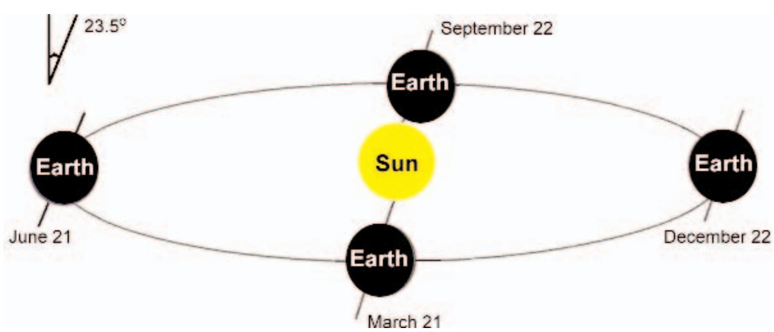
- Daylight Saving Time
- equinox
- green building
- latitude
- longitude
- renewable energy
- solar azimuth
- solar elevation
- solar panels
- solstice
- Standard Time
- sun chart
- sustainable development
- tilt angle
- time zones (U.S. zones)
- Universal Coordinated Time (UTC)

**BACKGROUND INFORMATION:**

Green building design and use of renewable energy is becoming increasingly important in sustainable development. This lesson explores the issue of the environmental and health benefits of green building design, construction, and operation, as well as design issues associated with installation of a solar panel.

In order to install solar panels that operate at maximum energy efficiency, you must place the solar panel in the proper direction and angle that will capture the most sunlight. The Earth travels around the sun in an elliptical path, with the Earth's axis of rotation tilted at an angle of about 23.5 degrees from perpendicular to the ecliptic (Figure 1).

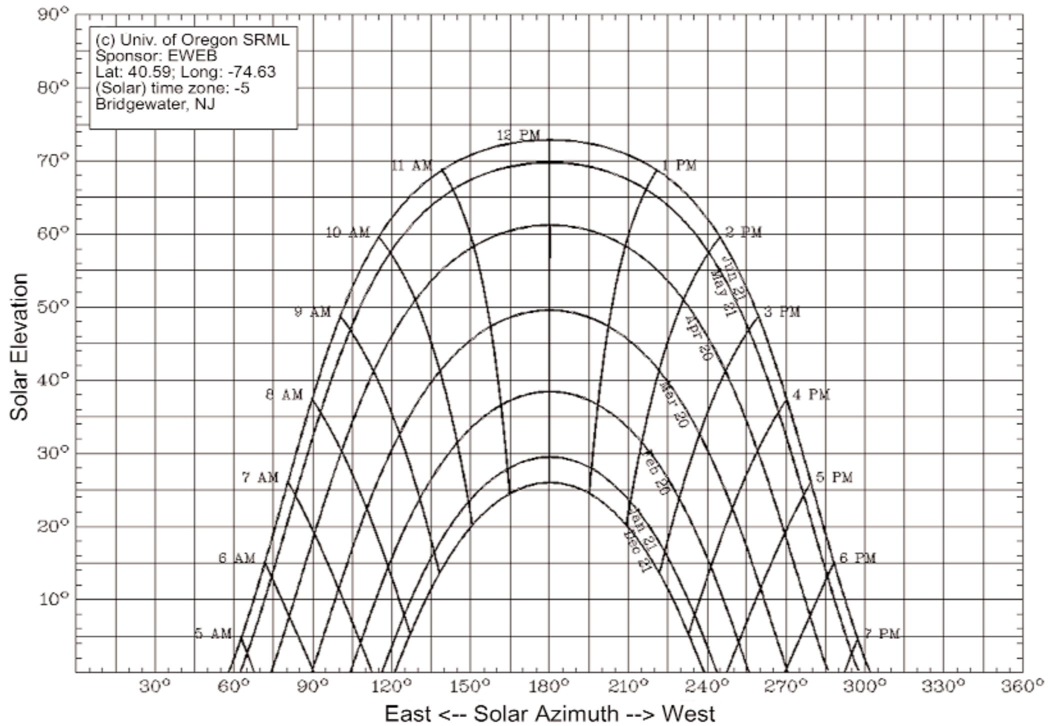
**Figure 1. Earth's Rotation Around the Sun**




This results in the varying seasons as the duration and amount of incident sunlight changes depending on the orientation of the Earth's axis relative to the position of the sun. Twice a year, in the winter and summer, the Earth's axis with respect to the Earth–sun line reaches its maximum of 23.5 degrees. These times are called the winter and summer solstices, corresponding to the shortest and longest days of sunlight for the year.

The sun's path across the sky depends on the geographic location and time of year. The actual path, as viewed from a specific geographical location, can be plotted on what is called a sun chart (Figure 2). The angle of the sun above the horizon is called the solar elevation. The angle of the sun along the horizon is called the solar azimuth, with 180 degrees being true south and zero degrees being true north. A sun chart is a plot of the path of the sun across the sky using the sun's elevation in the sky for one axis and the azimuthal position of the sun for the other axis. This information is useful in the design of buildings to maximize light, increase or decrease solar heating load, and utilize solar panels to heat water or generate electricity.

**Figure 2. Sun Chart for Bridgewater, New Jersey**

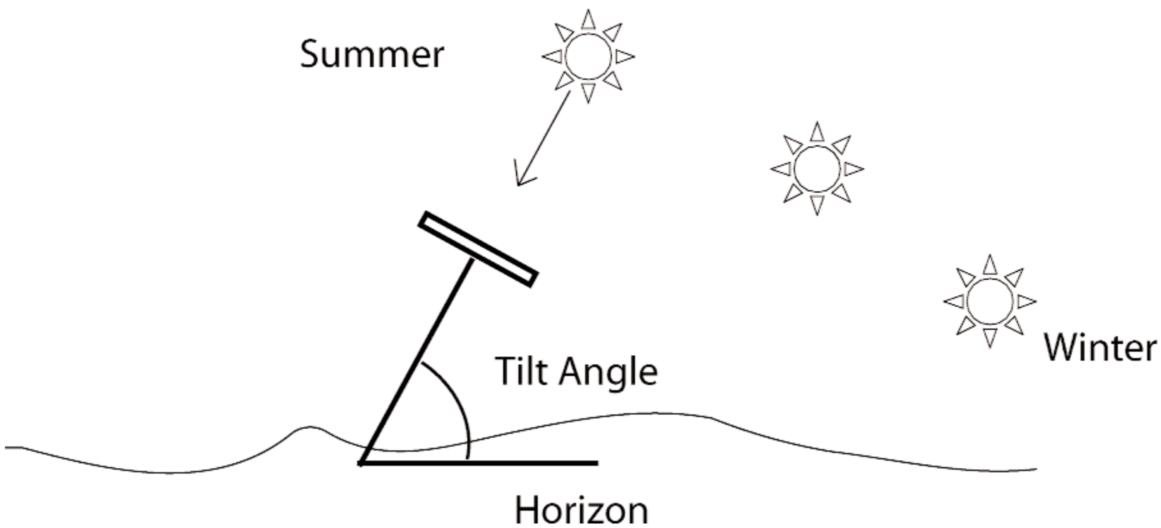



The maximum amount of light is intercepted if the collector faces perpendicular to a light source. This may be illustrated by using a flashlight and a white sheet of paper in a dark room. Shining the flashlight directly on the paper at a perpendicular angle maximizes the amount of light energy per area contacting the paper. If you tilt the paper or flashlight slowly so that the beam of light shines on the paper at an angle, you see the area illuminated by the light increases while the amount of light from the flashlight stays the same. Therefore, the amount of light per unit area is greatest when the flashlight is perpendicular to the sheet of paper.

In general, to optimize incident solar energy, increase solar heat gain, or make the best use of solar panels, the east–west axis of the building or the solar panel should run parallel to the equator. This means that the panel or building should face due south in the Northern Hemisphere and due north in the Southern Hemisphere. In order to maximize the amount of energy incident on a solar panel, one should orient the panel so that it is nearly perpendicular to the incident sunlight as often as possible.

Because the solar elevation varies from month to month at any one location, you also want to adjust the angle of exposure or tilt angle of the building or solar panel to maximize the amount of solar radiation received by the location (see Figure 3). A sun chart can be used to determine the direction of orientation and the tilt angle that gives, on average, the greatest amount of perpendicular sunlight adjusted for shading and other obstructions. It should be noted that the amount of direct solar radiation decreases as the sun gets lower in the sky because of increased absorption by the atmosphere. The average tilt angle is typically the angle corresponding to the latitude of the location or approximately the halfway point between the winter and summer solstice (highest and lowest solar elevations on the sun chart). Deviations of several degrees do not significantly affect performance. Other factors, however, are also important. For example, suppose you use the most electricity in the summer to run your air conditioning. In this case, you would want a higher tilt angle to increase the amount of summer radiation you would receive. Physical obstructions, such as trees, hills, or other buildings, may also need to be considered and may require you to adjust the tilt angle and the direction the solar panel or building faces.

**Figure 3. Solar Panel Tilt Angles and the Sun's Position**




**RESOURCES:**

*Environmental Health Perspectives*, Environews by Topic page, http://ehp.niehs.nih.gov/topic. Choose Built Environment, Sustainable Development/Conservation, Urban Issues

Building Green, http://www.buildinggreen.com/

National Aeronautics and Space Administration, Earth's seasons explanation, http://kids.msfc.nasa.gov/earth/seasons/EarthSeasons.asp

National Renewable Energy Laboratory (NREL)

- Solar Research, http://www.nrel.gov/solar/
- PVWatt Program (Version 1) for calculating the performance of solar electric systems at various angles and orientations, http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version1/

University of Oregon, Solar Radiation Monitoring Laboratory

- Solar energy lesson plans (three additional lessons on photovoltaic [PV] systems), http://solardat.uoregon.edu/LessonPlans.html
- Solar radiation basics, http://solardat.uoregon.edu/SolarRadiationBasics.html
- Sun chart program, http://solardat.uoregon.edu/SunChartProgram.html

U.S. Department of Energy, Smart Communities Network, http://www.sustainable.doe.gov/

U.S. Department of Energy, Solar Energy Technologies Program, http://www.eere.energy.gov/solar

U.S. Department of Environmental Protection

- Green Buildings, http://www.epa.gov/greenbuilding/
- Green Power Partnerships, http://www.epa.gov/greenpower/index.htm

U.S. Green Building Council, http://www.usgbc.org/

U.S. Naval Observatory, Astronomical Applications Department, What Is Universal Time?, http://aa.usno.navy.mil/faq/docs/UT.html

Webexhibits, Daylight Saving Time, http://webexhibits.org/daylightsaving/b.html

World Time Zone, http://www.worldtimezone.com/

## Implementing the Lesson

**INSTRUCTIONS:**

1. Have students read the articles "Growing Green Communities" and "Sunny Spanish Energy."
2. As needed, lead a discussion with the students about green buildings and health, renewable energy, and how seasons and day length are affected by the path of the Earth around the sun and the angle of rotation of the Earth.
3. Make sure students are familiar with the U.S. time zones, Standard and Daylight Saving Time changes, and Universal Coordinated Time (UTC).

4. Pass out the Student Instructions and sun charts, if necessary, for the activity. If your students are working in groups, you may want to have the groups identify different green building techniques listed in "Growing Green Communities" and read sun charts for different parts of the country to see if and how the sun's solar elevation and tilt angle of the solar panel changes.
5. Once all the groups have completed the activity, have each group present its findings and conclusions to the class.
6. After all the groups have presented, discuss and summarize the groups' results.

**NOTES & HELPFUL HINTS:**

1. You may have students research the actual health benefits of green building after they have speculated about the benefits. They could check their own work and explain why they were correct or incorrect in their speculation.
2. You may consider extending this activity by trying to design a solar panel for your school and determining how much energy would be saved. There is sufficient information on the Internet to help you work through the design process. You (or the students) should also contact your local utility company or city, county, or state environment offices to find out if they have any programs to help fund school solar projects.
3. Another extension of this activity would be to have students draw the sun's path across the sky (over the course of a day and through one solstice season) using the correct angles from the sun chart. Although this activity will generate something that looks quite similar to the sun chart, it will help students better conceptualize the sun chart and visualize what is really happening in the sky.

## Aligning with Standards

**SKILLS USED OR DEVELOPED:**

- communication (note taking, oral, written—including summarization)
- comprehension (listening and reading)
- critical thinking and response
- graph reading
- technological design

**SPECIFIC CONTENT ADDRESSED:**

- solar radiation intensity
- seasons
- rotation of the Earth on its axis
- rotation of the Earth around the sun
- design of solar panels
- impact of solar radiation on building design
- impact of solar energy on health
- time zones
- green building
- renewable energy

**NATIONAL SCIENCE EDUCATION STANDARDS MET:**

**Science Content Standards**

Unifying Concepts and Processes Standard

- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement
- Evolution and equilibrium

Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Physical Science Standards

- Interactions of energy and matter

Earth and Space

- Energy in the Earth system


National Institute of Environmental Health Sciences
Community Outreach & Education Program

Science and Technology
- Abilities of technological design

Science in Personal and Social Perspectives Standards
- Natural resources
- Environmental quality
- Science and technology in local, national, and global challenges

## Assessing the Lesson

**Step 2:** List three of the features of the Seattle, Washington, apartment building described in the "Growing Green Communities" article that make the building "green." Next to each feature, also list a possible health/environment benefit.

Below is a list of some possible answers. The article may not explicitly list a corresponding health benefit; however, students should be encouraged to think and speculate about corresponding health benefits to the "green" features they list. Please note that panelized wood is listed as "green," but the article does not explicitly define what panelized wood is. In most cases it means th0e......... panels were preconstructed off-site. This can save money and time, but unless the wood they use is plywood, plyboo (made with bamboo), recycled wood, wood from sustainable forests, or wheat board with low volatile organic chemicals (VOC) glue, health benefits are unknown. If oriented strandboard is used, toxic offgassing from glues will be greater.

| Feature that Makes the Building Green | Possible Health/Environment Benefit |
|---|---|
| Building oriented along an east–west axis (south facing) | Facing south increases solar gain in the winter and decreases solar gain in the summer, so less energy is used to heat and cool the building. If less electricity is used to cool, then less mercury, carbon dioxide ($CO_2$), and other air pollutants are released into the air from coal-fired power plants. Using less gas to heat will reduce the $CO_2$ emission, which will contribute less to global warming (which can cause increase in disease, overheating, food loss, etc.). Carbon monoxide (CO) is a dangerous potential by-product of improperly burning (incomplete combustion of) gas. |
| Maximizing natural lighting | Reduction of electricity use, reduction of air pollution from coal power plants. |
| Centralized hydronic gas heat and high-efficiency water heater | Decreased use of heat/gas, decreased $CO_2$ emission, and potential CO emission. |
| Energy-efficient lighting on photo- and occupancy-sensors | Reduction of electricity use, reduction of air pollution from coal power plants. |
| Carpets made from recycled plastics | Reduces plastics in land fills, which reduces the area of land fills, and minimizes the risk of water contamination from land fills. |
| Rainwater captured and recycled | Uses less drinkable water. |
| Low-VOC, low-toxic finishes | Reduces exposure to harmful gasses. |
| Durable 50-year exterior materials | Eliminates the use of harmful asphalt-based materials. This has immediate health benefits (avoid offgassing into the building) and long-term benefits because it eliminates throwing away asphalt materials that can leach chemicals into groundwater from landfills. |
| Ventilation fans | Reduces risk from mold and mildew (better indoor air quality). |
| Close to public transportation | Reduces air pollution from vehicles. |
| Communal garden | Can have organic produce (avoid pesticides) that does not use fossil fuels to transport to a market (less air pollution). A communal garden also encourages people to eat healthy food. |

**Step 3:** Develop a definition of what is meant by a "green building."

A "green building" is a building that is designed, built, and operated to be water-conserving, energy-efficient, environmentally friendly, and protective of indoor air quality.

**Step 4:** What benefit is gained by having the building oriented along an east–west axis (meaning the longest length of the building is facing south)? Explain (be sure to discuss latitude and the Earth's tilt).

Since the building in the article is located in the Northern Hemisphere at a latitude of 47.6 degrees, the building facing south receives the most sunlight with this orientation. This reduces the cost of electricity for artificial lighting and may also aid in heating in the winter by allowing the building to capture some of the sun's heat. Since the Earth rotates on its axis at an angle of 23.5 degrees as it travels around the sun during the year, the sun in the Northern Hemisphere never reaches a point directly overhead but always shines at an angle from the southern direction.

**Step 5:** Would it make a difference if the apartment building was being constructed at the equator? Explain.

Yes, since at the equator the sun does not shine at much of an angle, but rises in the east and sets in the west, exposing the southern side of the building to little direct sunlight. At the equator, a building built on a north–south axis would get the most natural sunlight. However, buildings at the equator are not typically oriented to face north and south because they get too hot in the morning and afternoon. Since the sun is directly overhead much of the time and cooling is needed in the afternoon, many houses are designed with courtyards. Then one can move to the area of the house which has the greatest/least amount of solar energy, and there is plenty of day lighting from the exterior and interior windows. Solar collectors should be laid nearly flat on the roof. They should be at a slight tilt, say 10 degrees, to reduce the buildup of dirt.

**Step 7:** What environmental and health benefits are gained from using renewable energy?

Using renewable energy results in less impact on the environment by not depleting natural resources and preventing harmful air, land, and water pollution that results from using fossil fuels such as natural gas, oil, and coal. Examples of air pollution that would be reduced include greenhouse gasses such as carbon dioxide, sulfur oxides, nitrogen oxides, carbon monoxide, and large and fine particles. Health benefits include reduced respiratory problems such as asthma, chronic bronchitis, and upper respiratory irritation. Heart problems and increased mortality linked to air pollution would also be reduced.

**Step 8:** If you were going to make your school more "green" by installing a solar panel to generate electricity, what direction would you want the solar panel to face? Explain.

You would want the school to face true south, if the school is in the Northern Hemisphere. Most of the direct sunlight comes from a southern direction because of the Earth's angle of rotation as it travels around the sun. The only exception to having the solar panel face south is when there is an obstruction or shading that blocks the sun's radiation.

**Step 9:** In addition to the optimum direction for a solar panel to face, there is also an optimum angle you would want the solar panel to lean or tilt. This will maximize the amount of sunlight your solar panel will receive throughout the different months of the year. Explain why the optimum angle for a solar panel to tilt is based on latitude.

The further north you go, the higher the latitude. The higher the latitude, the lower the maximum solar elevation the sun reaches during the year. The lower the solar elevation, the lower the tilt of the solar panel needs to be to maximize the amount of incident solar radiation.

**Step 11:** Answer the following questions based on your sun chart:

a) Which month of the year has the least amount of possible sunlight?

In the Northern Hemisphere, it is in December.

b) Which month of the year has the greatest amount of possible sunlight?

In the Northern Hemisphere, it is in June.

c) What is the maximum solar elevation angle for your location, and on what date does it occur?

The maximum solar angle varies with the location. It is 90 degrees minus the latitude plus 23.5 degrees. The date is June 21, the summer solstice or longest day of the year.

d) What is the maximum solar elevation angle on December 21 for your location?

The maximum solar angle varies with the location. It is 90 degrees minus the latitude minus 23.5 degrees. The date of December 21 is the winter solstice or shortest day of the year.

e) At 12:00 noon (solar time), what angle (in degrees) should the panel tilt in order to receive the maximum amount of sunlight being generated in December? What about in June? Explain why there is a difference between the solar panel tilt angle in the summer versus the winter (you may draw a picture to illustrate this concept).

Using the Bridgewater, NJ, example, the tilt in the winter at 12:00 noon (solar time) would be approximately 26 degrees. In the summer, it would be approximately 73 degrees. There is a difference between the tilt angle in the summer compared to the winter because in the winter the sun is lower in the sky, closer to the horizon. Therefore, the tilt angle needs to be decreased in the winter. The images students draw may be similar to Figure 3 in the Background Information section of this lesson.

**Step 12:** Look at the picture of the Denny Park Apartments in the "Growing Green Communities" article. What is the problem with the roof design of the apartments that would make it difficult to install solar panels on the roof?

The roof is configured in directions and angles that would make it very difficult to install a solar panel on the roof that would face south at the appropriate tilt angle to capture the most sunlight.

## Authors and Reviewers

**Authors:** Barry Schlegel, UMDNJ–School of Public Health and Laura Hemminger, UMDNJ–School of Public Health

**Reviewers:** Susan Booker, Dean Hines, Stefani Hines, Liam O'Fallon, Kimberly Thigpen Tart, Frank Vignola

ehp

Student Instructions:

# Following the Sun to Greener Buildings

**Step 1:** Read the article "Growing Green Communities."

**Step 2:** List three of the features of the Seattle, Washington, apartment building described in the "Growing Green Communities" article that make the building green. Next to each feature also list a possible health/environment benefit.

| Feature That Makes the Building Green | Possible Health/Environment Benefit |
|---|---|
| | |
| | |
| | |

**Step 3:** Develop a definition of what is meant by a "green building."

**Step 4:** What benefit is gained by having the building oriented along an east–west axis (meaning the longest length of the building is facing south)? Explain (be sure to discuss latitude and the Earth's tilt).

**Step 5:** Would it make a difference if the apartment building was being constructed at the equator? Explain.

**Step 6:** Although not mentioned in the article, use of renewable energy is often considered in "green building" design and operation. Renewable energy is any energy resource that is naturally regenerating in a short period of time and is never depleted. Examples of renewable energy include wind, solar, geothermal (heat from underneath the Earth's surface), and hydropower. Fossil fuels used for generating electricity, such as natural gas, oil, and coal, are not renewable. Read the article "Sunny Spanish Energy."

**Step 7:** What environmental and health benefits are gained from using renewable energy?

**Step 8:** If you were going to make your school more green by installing a solar panel to generate electricity, what direction would you want the solar panel to face? Explain.

**Step 9:** In addition to the optimum direction for a solar panel to face, there is also an optimum angle you would want the solar panel to lean or tilt. This will maximize the amount of sunlight your solar panel will receive throughout the different months of the year. Explain why the optimum angle for a solar panel to tilt is based on latitude.

**Step 10:** You will now generate a sun chart for your geographic area to determine the optimum angle that you would use to generate electricity from a solar panel. A sun chart is a graphical picture of how the sun travels across the sky from your perspective standing at a particular location and looking directly south (180 degrees) at different times and dates. The solar elevation is the angle above the horizon where the sun is located. The solar azimuth is the angle you face away from the south to see the sun at a particular time and date.

To generate your sun chart, you need to know either your latitude and longitude or your zip code. You also need to know your time zone. Your teacher may ask you to use different locations to see how location affects the sun chart or may provide copies of prepared sun charts for you to analyze.

If generating your own sun chart, go to the following website run by the University of Oregon Solar Radiation Monitoring Laboratory: http://solardat.uoregon.edu/SunChartProgram.html.

If the link does not work, then go to google.com and enter the phrase "solar data sun chart program."

a) Enter either your latitude and longitude or your zip code. Make sure to check the box for which type of data you enter.

b) Specify your time zone (select from the table below). UTC is the Universal Coordinated Time at zero degrees longitude.

| | **Pacific Time** | **Mountain Time** | **Central Time** | **Eastern Time** |
|---|---|---|---|---|
| April–October (Daylight Saving Time) | UTC-7 | UTC-6 | UTC-5 | UTC-4 |
| November–March (Standard Time) | UTC-8 | UTC-7 | UTC-6 | UTC-5 |

c) Choose the data to be plotted: "Plot dates 30 or 31 days apart, between solstices, December through June." The summer solstice occurs approximately on June 21 and is the longest day of the year. The winter solstice occurs on approximately December 21 and is the shortest day of the year.

d) Next, type in "Plot hours in local solar time." Solar time is based on the idea that when the sun reaches its highest point in the sky, it is noon (solar noon). The actual local time is different from solar time and varies according to your longitude, whether or not you are on Daylight Saving Time, and the time of year.

- Leave chart format parameters as listed in the default position (step 4 on the webpage).
- Specify labeling options with the name of the location in Line 1.
- Choose PDF file format for the chart.
- Click on "Create chart."
- Download and print PDF file with your sun chart.

**Step 11**: Answer the following questions based on your sun chart:

a) Which month of the year has the least amount of possible sunlight?

b) Which month of the year has the greatest amount of possible sunlight?

c) What is the maximum solar elevation angle for your location, and on what date does it occur?

d) What is the maximum solar elevation angle on December 21 for your location?

e) At 12:00 noon (solar time), what angle (in degrees) should the panel tilt in order to receive the maximum amount of sunlight being generated in December? What about in June? Explain why there is a difference between the solar panel tilt angle in the summer versus the winter (you may draw a picture to illustrate this concept).

**Step 12:** Look at the picture of the Denny Park Apartments in the "Growing Green Communities" article. What is the problem with the roof design of the apartments that would make it difficult to install solar panels on the roof?