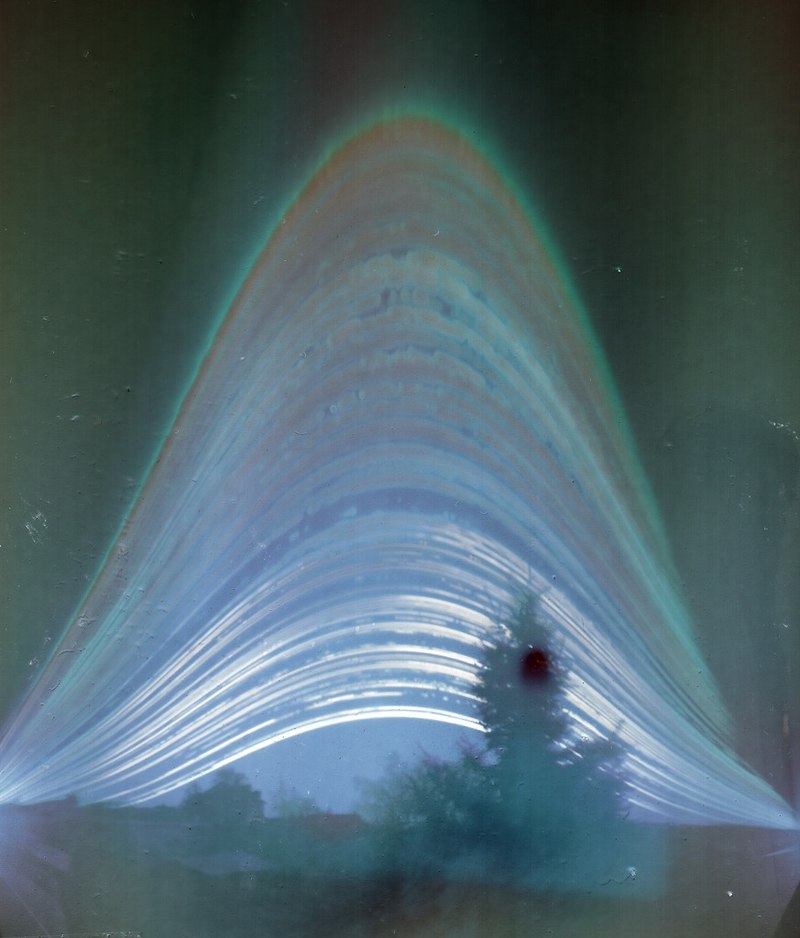
**Solarize Your World: Teacher’s Guide**

**Chapter 1: Science Concepts**

As a renewable source, solar energy is important to the sustainability of our society. The solar energy that hits the Earth's surface in just one hour is enough to power the whole world for an entire year. Yet, only less than 2% of the total electricity generated in the United States in 2018 came from the Sun. To protect our environment, we must increase the use of solar energy. The Solarize Your World project leverages this important context to create rich, authentic project-based learning opportunities to engage students in learning and practicing science and engineering as envisioned in the Next Generation Science Standards for K-12 schools.

In the Solarize Your World project, your students will take on the role of a solar energy engineer to devise creative renewable energy solutions for their own world. But before students can accomplish their mission, you need to make sure that they understand fundamental science concepts related to solar energy. Without a solid understanding of those concepts, student work may not be guided by scientific laws, resulting in designs that do not make scientific sense. The integration of science and engineering in the Solarize Your World project aims to deepen science learning through engineering practices and, in the meantime, rationalizes engineering design with deeper conceptual understanding in science.

This chapter provides a series of interactive activities based on Energy3D for students to learn basic science concepts essential to designing effective solar energy solutions. Students will explore how the Sun moves in the sky as the Earth orbits the Sun and rotates around its own axis, how its path changes from season to season, and how the length of the day varies. Students will also investigate how the Sun’s position relative to a surface affects the intensity of sunlight that shines on it, why the intensity depends on the time of the day and the weather, and how solar energy reaches an object on the ground through different pathways. At the end of this chapter, students will apply the knowledge that they have learned to solve a simple practical problem.



*Figure 1. Solargraphy captures the Sun path across the sky throughout the year of 2014 in Budapest. Credit: Elekes Andor*

1. **The Sun Path**

The Sun path refers to the daily and seasonal arc-like path in which the Sun appears to move from the perspective of an observer on the ground of the Earth (Figure 1). The Sun path affects the length of daytime and amount of sunlight received at a certain latitude in a given season.

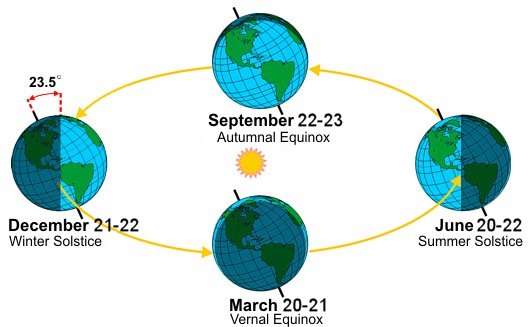
The relative position of the Sun is a major factor in the heat gain of buildings and in the performance of solar energy systems. Accurate location-specific knowledge of the Sun path and the climatic conditions is a prerequisite to solar energy engineering.

**1.1 Daily Change of Solar Angles**

The Sun moves across the sky from sunrise to sunset (Figure 1). The direction of the Sun relative to a horizontal surface on the Earth at a given time dictates how much solar energy it receives at that moment (which partly drives the temperature variations throughout a day). The direction can be represented by three angles: zenith angle, elevation angle, and azimuth angle. The zenith angle is the angle between sunlight and the vertical direction. The elevation angle is the angle between sunlight and the horizontal direction (complementary to the zenith angle). And the azimuth angle is the angle between sunlight and the north direction. These angles change all the time as the Sun moves along its path during a day.

**Energ3D activity**: To observe the changes of the angles, open *Tutorials > Solar Science Basics > Sun Path* in Energy3D and follow the instruction in *Sheet 1*. To acquire some quantitative sense about the Sun’s angles at different times of the day, students are required to collect data and answer questions in a worksheet, which is provided separately.

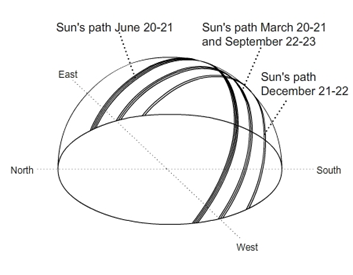
**1.2 Seasonal Change of Solar Angles**



*Figure 2. Solstices and equinoxes. Credit: National Weather Service*

The seasonal change on the Earth occurs due to the tilt of its axis of rotation relative to the ecliptic—the plane of its orbit around the Sun.[[1]](#footnote-1) There are four special points on the Earth’s orbit around the Sun, which correspond to four special days of the year—the equinoxes and solstices, as shown in Figure 2.

**Energy3D activity**: To observe the seasonal changes of the Sun path, open *Tutorials > Solar Science Basics > Sun Path* in Energy3D and follow the instruction in *Sheet 2*. Students are required to collect data and answer questions in a worksheet, which is provided separately. To simplify the data collection, only the zenith angle at noon needs to be recorded.



*Figure 3. The daytime varies from season to season as the Sun path changes (viewed in the northern hemisphere).*

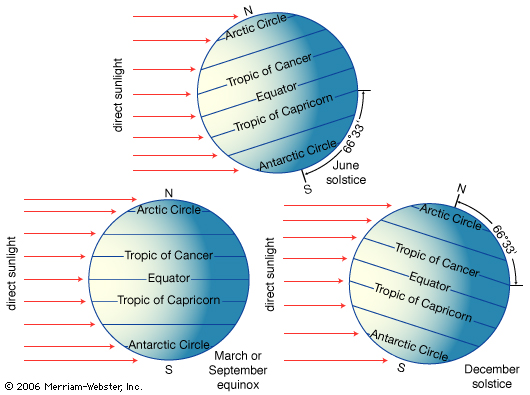
**1.3 Seasonal Changes of Daytime**

Apparently, the total solar energy that strikes a surface on the Earth in a given day depends on the length of the day—the lapse of time from sunrise to sunset known as daytime. As the Sun’s path changes from season to season, the daytime varies throughout the year (Figure 3).

**Energy3D activity**: To observe the seasonal changes of daytime, open *Tutorials > Solar Science Basics > Sun Path* in Energy3D and follow the instruction in *Sheet 3*. Students are required to collect data and answer questions in a worksheet, which is provided separately. Students will record the sunrise and sunset time and calculate the daytime by subtracting the sunrise time from the sunset time for four seasons.

**1.4 The Sun Path in Different Parts of the World**

As the Earth spins, different parts of the world may receive different amounts of solar energy on the same day. During the March and September equinoxes, the Sun is directly overhead at the Equator and the daytime is the same everywhere on the Earth (the lengths of day and night are also the same—12 hours each). But during the June solstice, the Sun is above the Tropic of Cancer (23.5° north to the Equator). It never sets at the North Pole and never rises at the South Pole. On the other hand, during the December solstice, the Sun is above the Tropic of Capricorn (23.5° south to the Equator). It never rises at the North Pole and never sets at the South Pole. Figure 4 illustrates the Sun’s direction relative to different parts of the world in different seasons.

[](https://www.britannica.com/story/whats-the-difference-between-a-solstice-and-an-equinox)

*Figure 4. The Sun’s direction relative to the Equator, the Tropic of Cancer, and the Tropic of Capricorn in different seasons. Credit: Merriam-Webster, Inc.*

**Energy3D activity**: To observe the Sun path in different parts of the world, open *Tutorials > Solar Science Basics > Sun Path* in Energy3D and follow the instruction in *Sheet 4*. Students are required to collect data and answer questions in a worksheet, which is provided separately. A few different locations, including one close to the South Pole, are selected in this activity for students to investigate the degree to which the Sun path varies in vastly different parts of the world both in the summer and in the winter.



*Figure 5. The projection effect on a horizontal surface. The sizes of the dashed areas represent the amounts of solar radiation that the surface receives at the two angles.*

1. **The Projection Effect**

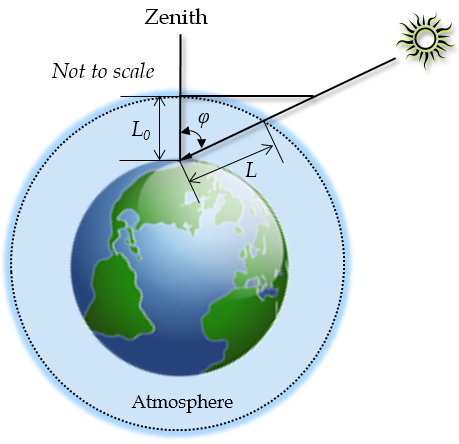
It is easy to understand that the longer the daytime is, the more solar energy a surface receives. But the angle of the Sun relative to the surface also affects the amount of solar energy it gets. This is known as the projection effect.

Solar radiation on a surface is the strongest when it faces the Sun directly. As the angle between the sunlight beam and the surface normal (the direction perpendicular to the surface) increases, the intensity of solar radiation on the surface decreases. Mathematically, this is governed by the following formula:

where *E*max is the maximum solar energy that hits the surface when it faces the Sun directly and *θ* is the angle between the sunlight beam and the surface normal. Figure 5 illustrates this effect.[[2]](#footnote-2)

Insolation (short for incident solar radiation) is a measure of solar radiation energy shining on a horizontal surface area and recorded during a given time. The projection effect is the main reason that insolation is the strongest at noon and in the summer, resulting in higher temperatures under those conditions than other time of the day and other seasons of the year.

**Energy3D activity**: To investigate the projection effect on insolation, open *Tutorials > Solar Science Basics > Projection Effect* in Energy3D and follow the instruction in *Sheet 1*. In *Sheet 2*, students can change to a different location and compare the results. They are required to collect data and answer questions in a worksheet, which is provided separately. Students will compare the projection effect in a northern location and in a southern location.



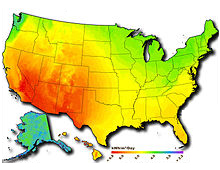
*Figure 6. The attenuation of solar radiation in the atmosphere depends on the travel length.*

1. **The Effect of Air Mass**

When the Sun shines from a lower angle, sunlight must travel a longer distance in the atmosphere before reaching the ground (Figure 6). While the light travels through the atmosphere, it can be absorbed or scattered by air molecules, causing its intensity to diminish on the way. This is why the Sun appears to be weaker at dawn and dusk. In solar energy engineering, the loss of solar radiation to atmospheric absorption or scattering is known as air mass.[[3]](#footnote-3)

**Energy3D activity**: To study the effect of air mass on insolation, open *Tutorials > Solar Science Basics > Air Mass* in Energy3D and follow the instruction in *Sheet 1*. This activity allows students to turn on and off the atmospheric attenuation to evaluate the effect of air mass on solar energy gains. Two virtual sensors are placed on the eastern and top sides of a box to measure the solar radiation intensity in the morning and at noon, respectively. Without the atmospheric attenuation, the peak intensities measured by the two sensors would be similar. This “what-if-there-is-no-air” experiment is something that cannot be done in the real world but can be carried out in a computer simulation for an educational purpose. Students are required to collect data and answer questions in a worksheet, which is provided separately.

1. **The Effect of Weather**

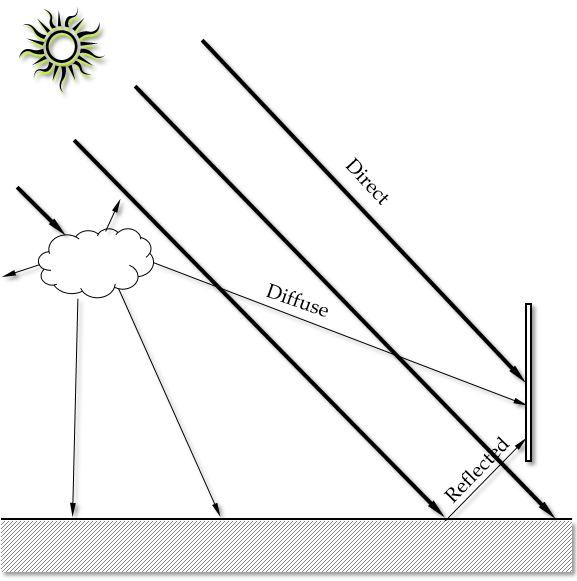


*Figure 7. A distribution of yearly insolation in the United States (Credit: Wikipedia).*

Insolation is largely determined by the latitude, but it is also affected significantly by the weather pattern, especially the sky clearness (which is approximately represented in Energy3D as the sunshine hours). Figure 7 shows an insolation map of the United States, on which red color represents high insolation and blue color represents low insolation.

**Energy3D activity**: To examine the weather effect on insolation in different locations, open *Tutorials > Solar Science Basics > Weather Effect* in Energy3D and follow the instruction in *Sheet 1*. Four different locations in the United States that are approximately along the same latitude but in different climates are selected for students to compare. Students are required to collect data and answer questions in a worksheet, which is provided separately.

1. **Solar Radiation Pathways**

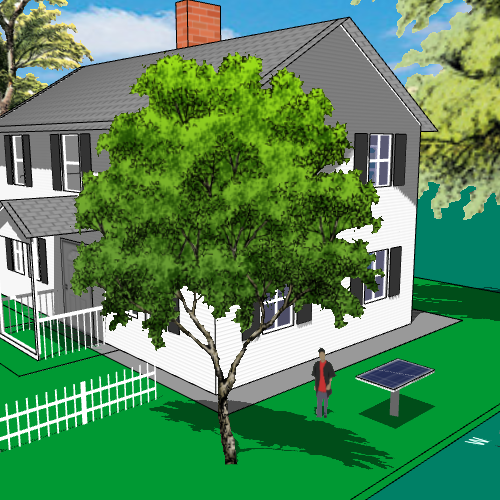


*Figure 8. Direct, diffuse, and reflected radiation onto a vertical surface.*

A surface on the Earth receives solar radiation through three different pathways: direct, diffuse, and reflected. The direct radiation is the solar radiation that travels to the surface from the Sun without being absorbed or scattered. The diffuse radiation is the portion of solar radiation scattered or re-emitted by the atmosphere in all directions, which can be as little as 15% when the Sun is high in the sky or as much as 40% when the Sun is low. The reflected radiation is the radiation bounced off non-atmospheric objects such as the ground or the objects on it. The ratio of the reflected radiation from a surface to the incident solar radiation is known as albedo. The albedo of land is in the range between 0.1 and 0.4. The albedo of green grass is about 0.25 whereas that of fresh snow can be as high as 0.9. Figure 8 illustrates these three different pathways with a vertical surface as an example.

**Energy3D activity**: To investigate these pathways, open *Tutorials > Solar Science Basics > Solar Radiation Pathways* in Energy3D and follow the instruction in *Sheet 1* and *Sheet 2*. As with the air mass activity, students can turn on and off diffuse radiation and change the reflectance of the ground in a computer simulation to evaluate their effects. Students are required to collect data and answer questions in a worksheet, which is provided separately.

**Test Your Knowledge**



*Figure 9. Find a position and orientation for a solar panel around a house that generates most electricity throughout a year.*

Students will have an opportunity to apply what they have learned to solve a real-world problem described as follows.

Judd just bought a solar panel. Now he has to figure out where to install and orient it around his house (Figure 9) so that it can generate the most electricity for the whole year. To help him make decision, open *Tutorials > Solar Science Basics > Optimize It* in Energy3D to work on a 3D model of his house and the solar panel. Follow the instruction in *Sheet 1* to search for a “sweet spot” for the solar panel. Students are required to document the position, orientation, and output of the solar panel and answer questions in a worksheet, which is provided separately.

This Energy3D activity can be used as an assessment to measure student learning through Chapter 1. To stimulate student interest in exploring the problem more thoughtfully and add dynamic interactions in the classroom, you can engage students in a competition and even incentivize the winners who can find solutions that result in outputs higher than a set goal.

1. The seasons are not caused by the Earth’s proximity to the Sun. In fact, the Earth is slightly closer to the Sun in the winter than it is in the summer for the northern hemisphere. [↑](#footnote-ref-1)
2. Although Figure 5 uses a horizontal surface as an example for clarity, the project effect applies to surfaces in any direction. When we design a solar energy system, we have to consider not only the Sun path but also the orientation of the system. [↑](#footnote-ref-2)
3. Not to be confused with air mass in meteorology, which refers to a volume of air defined by its temperature and water vapor content that can cover many hundreds or even thousands of miles. [↑](#footnote-ref-3)