Heat Transfer

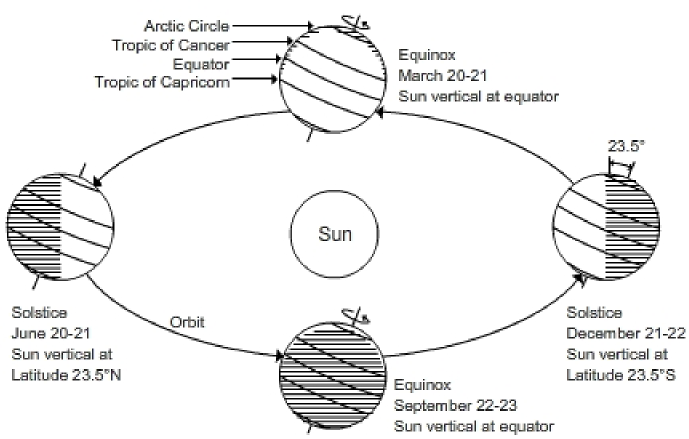
Energy from the Sun

Introduction

The sun rises in the east and sets in the west, but its exact path changes over the course of the year, which causes the seasons. In order to use the sun's energy in a building, we need to know where it is in the sky at different times of the year.

There are two ways to think about the sun's path in the sky. One way is to study the tilted Earth traveling around the sun viewed from outer space and figure out where the sun would appear in the sky at your latitude at different times of the day and year. If you have time, give this a try with your class.

Walk around a light source, real or imagined, with a globe that's tilted at the right angle. Turn the globe at different positions (times of the year). Try to picture the length of the day and the angle of the sun.



The other way is to stand on the Earth and plot the path of the sun from your point of view on the ground. This is easier to apply to a building, although, of course, the two ways give the same results.

We will use the earth-centered approach in this workbook.

For this project students must be able to picture the sun's path to design passive solar features in their houses. The focus of this chapter is not the complex geometry of a tilted earth moving around the sun, but simply the path of the sun from the point of view of someone on the earth. Where does it rise and set at different times of the year? How high in the sky is it at noon? How long are the day and night?

Learning goals

Explain the sun's daily and seasonal path in the sky, in the northern hemisphere at varying latitudes.

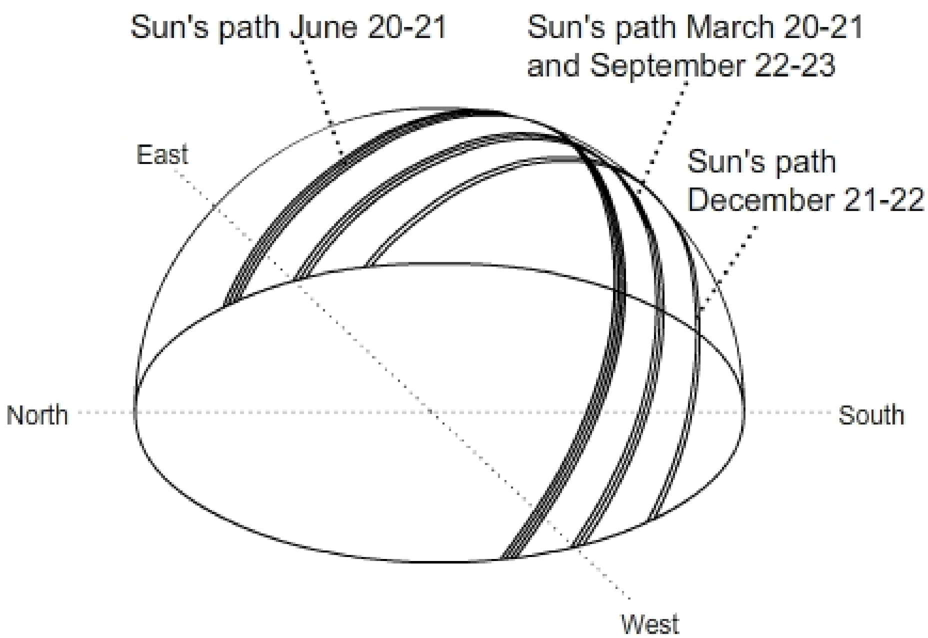
Apply this knowledge to explain how much sunlight energy can be collected using windows, roofs, and other collectors depending on their orientation.

Note: This is one section of the "Science of Heat Transfer" chapter of the Engineering Energy Efficiency Project. See: http://concord.org/engineering

Here is a diagram of the sun's path in the sky at different times of the year. It is roughly correct for a northern latitude of 40°. Note the three lines showing the sun's path. One is the summer solstice, one is the spring and fall equinoxes, and one is the winter solstice.

One is the summer solstice (June 21), one is the spring and fall equinoxes (March 20 and September 23), and one is the winter solstice (December 21). The exact dates change a little bit from year to year.

Point out that the winter arc above the horizon is both **lower in the sky** and **shorter in length (hence time)** than the summer arc. These two key facts explain the seasons.



Where is the sun?

Learn the basic facts about the sun's path at your latitude. Use the above diagram, your background knowledge, and class discussion to fill out the following table. Here are some hints.

a) At the equinox at noon, the angle of the sun above the horizon is (90° minus the latitude). For example, at the equator this is 90°; at the pole this is 0°.

b) At the two solstices, the angular height of the sun at noon either increases or decreases by 23.5°– the tilt of the earth's axis – compared to the equinox.

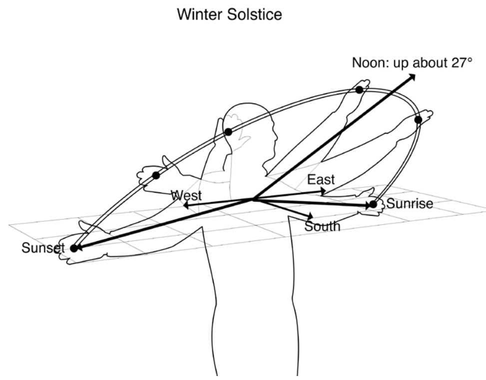
c) For the length of the day, do some Internet research. Many sites give the times of sunrise and sunset. (For 40°N, daylight is about 3 extra hours in summer and 3 fewer hours in winter.)

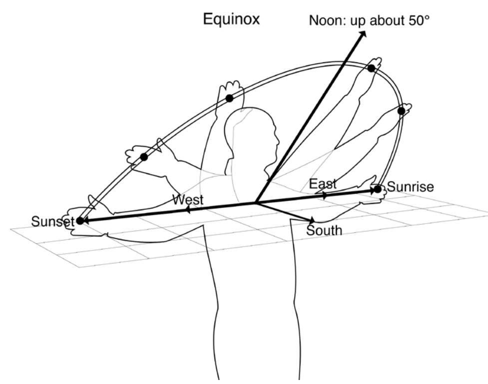
Chapter 2: Sun's path throughout the year					
Your latitude: 40°N (Boston, Massachusetts)					
Event	Date	Length of day	Height of sun at noon	Sun rises in what direction?	Sun sets in what direction?
Winter solstice	December 21-22	9 hours	26 ½° (50° - 23 ½°)	23 1/2 ° **south** of East	23 1/2 ° **south** of West
Spring equinox	March 20-21	12 hours	50° (90° - latitude)	East	West
Summer solstice	June 20-21	15 hours	73 ½° (50° + 23 ½°)	23 1/2 ° **north** of East	23 1/2 ° **north** of West
Fall equinox	September 22-23	12 hours	50° (90° - latitude)	East	West

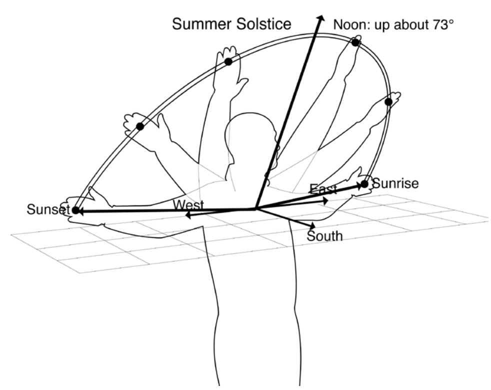
Fill out this chart together in class or assign it as homework, and then discuss the meaning of the numbers. Do the Sun's Path Calisthenics with the class (next page). This is the easiest way to show everyone exactly what the sun does all year.

Before you continue, the teacher will lead a discussion on the Sun's Path Calisthenics so that this diagram makes more sense.

Have everyone stand up and do this exercise.



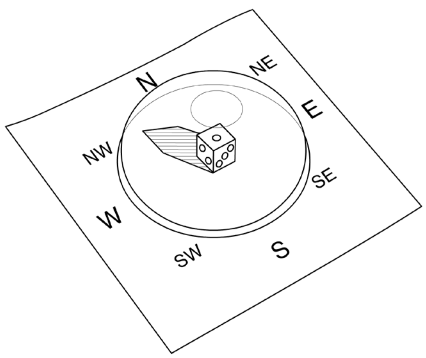




Represent the sun's path through the sky

Procedure & data collection

1. Place the plastic dome lid on a piece of paper.
2. Place a small cube under the center of the dome, as if it were your house.
3. Tape the dome to hold it in place.
4. Draw the directions N, S, E, W around the dome. Then add NE, SE, SW, and NW.



5. Draw the path of the sun in the sky on the dome at the spring equinox, using the marker. Do this by drawing points for the sun's position at sunrise, noon, and sunset at the equinox, using what you recorded on the table above. Estimate the angles, knowing that a right angle is 90°. Then connect the points with a smooth arc.
6. Draw the path of the sun in the sky at the summer solstice, the winter solstice, and the fall equinox, using the same procedure.

Tools & materials

- Clear dome lid from soft drink or ice cream cup
- Clear tape
- Marker
- Die or small cube
- Piece of white paper

The dome lid may seem a bit childish, but it is the easiest way for students to draw an actual sun's path diagram. Each team should do at least one. If they feel adventurous, they can draw others for different latitudes.

Analysis

The sun always travels at the same speed across the sky (15° per hour). If that's true, why does the length of the day change from summer to winter?

The length of the arc when the sun is above the horizon changes with the seasons.

How would the path on the dome lid appear if you were on the equator?

At the Equator, it would be a half-circle directly overhead at the equinox, moving slightly north and south at the solstices.

How would the path on the dome lid appear if you were at the North Pole?

At the North Pole, it would be a circle just above or below the horizon. It would be right at the horizon at the equinox.

Based on your sun's path diagram, explain why it's warmer in summer than in winter when you are not near the equator.

There are two primary reasons: 1) the sun is higher in the sky in summer, so the intensity of sunlight per unit area of the earth's surface is greater; 2) the length of the day is greater, so more heat is received.

Solar radiation through windows

Now that you know the path of the sun in the sky at different times of year, how can you use this information to use solar energy for heating your house?

The simplest form of solar space heating is windows that face the sun. Sunlight passes through the windows and is absorbed by surfaces within the house. There are no moving parts and no mechanical systems. **This is called passive solar heating.**

In this experiment you will investigate the best orientation for windows for passive solar heating by measuring how much the radiation meter is heated up by the gooseneck light at different orientations.

Tools & materials

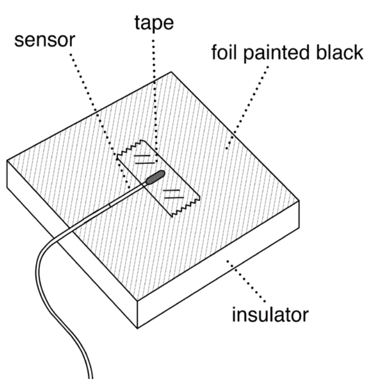
- One fast-response temperature sensor (for example, the Vernier surface temperature sensor STS-BTA)
- Computer or other graphing interface for temperature sensor
- "Radiation meter": foil-faced rigid insulation, about 5 cm square, painted black
- One 150-300 W light bulb in a gooseneck fixture (note: this will exceed the fixture's wattage rating, but it's on for a short time.)
- Sun angle template

This experiment drives home the importance of angle with respect to the sun for heating. It also shows the difference between summer and winter sun. A common design error is to put in lots of skylights, which aren't good collectors in winter and overheat in summer. This experiment illustrates that with a horizontal orientation.
If you skip the experiment, have students theorize about the results and fill out page 9.

Procedure & data collection

Part I: Winter

1. Tape your temperature sensor to a "radiation meter." The clear tape should cover the sensor so that it is held tight against the black surface.



2. Place the radiation meter on a table facing straight up.
3. Use the sun angle template (page 11) to position the sun light bulb 20 cm away from the radiation meter at the winter sun angle. Picture the direction of the light as being south at noon in the winter.
4. Connect the temperature sensor to your computer.
5. Turn on the light and start collecting data.

6. Every 30 seconds, change the angle of the radiation meter, in the following sequence:

7. In 30 seconds, the temperature will approach a new value but not quite stop changing. After you have finished the sequence, stop collecting data and write down the temperature for each orientation at the end of its 30 seconds.

8. Save your data.

Winter sun angle		
Time	Orientation of radiation meter	Ending temperature
0-30 s	Horizontal	
30-60 s	Vertical facing NORTH	
60-120 s	Vertical facing EAST	
120-180 s	Vertical facing SOUTH	
180-240 s	Perpendicular to light rays	

Part II: Summer

9. Connect the temperature sensor to your computer.

10. Reposition the sun light bulb to the summer test angle, using the sun angle template. Repeat the sequence and fill out the following table.

Summer sun angle		
Time	Orientation of radiation meter	Ending temperature
0-30 s	Horizontal	
30-60 s	Vertical facing NORTH	
60-120 s	Vertical facing EAST	
120-180 s	Vertical facing SOUTH	
180-240 s	Perpendicular to light rays	

Results

Compare winter and summer by filling out the following table. Rank the various orientations from most to least solar heating.

Summer vs. winter solar heating		
Solar heating	Orientation (winter)	Orientation (summer)
5 (most)		
4		
3		
2		
1 (least)		

What is the best orientation for windows so that a building will gain heat in the winter but not in the summer?

South vertical or slightly sloped.
Also east and west, but less so.

Explain a strategy for using shades or overhangs to control winter heat loss and summer heat gain.

Overhangs can cut down solar gain when the sun is high (summer) but allow it when the sun is low (winter), for south-facing windows.

What are the advantages and the drawbacks of passive solar heating?

The main advantage is free energy. The main drawback is that sunlight is available only during the day, is interrupted by clouds, and is less available during the winter heating season. (That's why it's colder!) Also, passive solar heating requires large windows, which lose more heat than walls. So passive solar heating can cause large temperature swings in a building unless thermal storage is provided.

Summary

Think about a house you'd like to design. What directions and slopes (vertical, sloped, horizontal) would you choose for large windows? What directions and slopes would you choose for smaller windows? Why?

Vertical south-facing glass has good heat gain in winter and low heat gain in summer.
Sloped south-facing glass has slightly better heat gain in winter but much greater heat gain in summer.
Horizontal glass has modest heat gain in winter and very high heat gain in summer – generally not desirable!
East and west-facing glass has modest heat gain in winter and fairly high heat gain in summer that is hard to shade because the sun spends a lot of time at low angles in those directions in the summer.
Smaller windows to the east, west, and north are generally good to let in some natural light but not cause overheating or excessive heat loss.

CUT OUT THE QUARTER-CIRCLE
& GLUE IT TO CARDSTOCK