What Does the Sun Give Us?

(Five Activities)

Grades: 5-8, 9-12

Topic: Solar

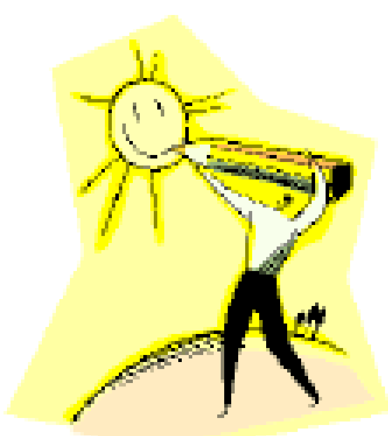
Owner: National Renewable Energy Laboratory

This educational material is brought to you by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy.

What does the Sun give us?

For the Teacher

One of the fun parts of science is discovering things on your own. This is the focus of Content Standard A, Science as Inquiry, from the National Science Education Standards. This standard states, "Students should develop the ability to refine and refocus broad and ill-defined questions." For this reason, we recommend stating the objective and then having the students try to figure out the best options for accomplishing it. We think this is a better approach than giving a step-by-step, cookbook-style approach to making instruments that measure the sun's energy. Because of this, we suggest that you do not show students this book and instead have the students try to design and test their work as much as possible with a little coaching from you. After the students have designed and tried their experiments, get them to suggest improvements and, if there is time, test them. After these experiments are run, then teach the concepts about why they work.



All projects have an element of inquiry (Content Standard A) because they pose questions and then have the students try to discover the answer through data collection, interpretation, and communication. Because these projects involve the sun and its energy, all of them apply to physical science and the transfer of energy (Content Standard B) and earth science and how the sun affects the earth (Content Standard D). In addition to these standards, each of the projects has additional strengths. The second column lists the science content standard, as well as any other strong areas. You know your students the best, but we've also included a suggested range of grades for each project.

Project	Key Standards	Grades
Pizza Box Oven	E-Design	6-8 (3-5 if given Web site first)
Solar Resource Simulator	E-Design, D-Earth, social studies	6-8
Measuring Solar Radiation	E-Design	6-12
Length of Day around the World	A-Communication (ePals), D-Earth, social studies, English	3-8
Capture Solar Energy!	A-Communication (ePals), math	8-12 (3-7 temp only)

Pizza Box Solar Heater: The first project is the pizza box solar heater. We are excited because it has so many possibilities to teach multiple standards and to motivate students. We suggest you do the following:

1. Give each group of students a pizza box.
2. Have various materials such as glue, scissors, clear packing tape, new overhead transparencies, wax paper, aluminum foil, white, black, and other colors of construction paper available in a supply area for all students.
3. Tell the students that their objective is to make the hottest "oven" possible using the sun.

4. You may want to stimulate prior knowledge by asking them why it gets hot in a car.
5. In the first period, have the students design their oven in a notebook.
6. During this period or the next, work with the class to design a rubric on what is meant by the "best" oven. Options could include the hottest oven, the quickest to heat, or the easiest to design.
7. During the second class period, have the students construct their pizza box oven.
8. During the third period, ask the students what factors might affect the temperature in their oven (outside air temperature, wind, clouds). Ask them to measure these factors and the oven temperature over time. Make sure you have thermometers that can register up to 300°F or 150°C.
9. If you have time during a fourth period, have students graph the temperature over time.
10. Allow additional periods to have the students communicate about their ovens and improve their designs.
11. After the students build the "ultimate" ovens, ask the students why they think the best ovens worked the way they did. This could be a discussion or written.
12. Have students grade their ovens based on the rubric the class created.
13. Allow students to improve their grade by making changes to their oven, possibly as homework.
14. Only at this point would we introduce the students to the Web site (http://www.solarnow.org/pizzabx.html) You could have the students construct the oven on the site using their instructions and compare the performance.
15. When students start talking about the sun's angles, the colors of the paper, and the ability of sunlight to bounce and stick in the box, you can introduce the physical science (Content Standard B) concepts. These may include light, heat, and energy definitions including reflection, absorption, photons vs.

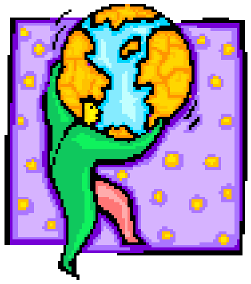
waves, motions of molecules, and so forth. The discussion could also lead to the sun's energy and how the tilt of the earth produces different seasons because the rays of the sun spread out more or less directly. (This applies to Content Standard D, "Earth in the Solar System.")

16. If desired as a final assessment, have the students explain, in diagrams and words, why the box heats up. This should include their ideas in step 11 but would also include the technical terms that the class discussed in step 15.
17. Another final assessment is to have the students design an even more efficient solar cooker or water heater using any materials they have. You could tell the students that the goal would be to speed up the time for the temperature to reach a certain point or to increase the maximum temperature.
18. As a bonus, have the students cook s'mores, popcorn, cookies, hotdogs or something else fun in their pizza boxes.

Solar Resource Simulator: Project number 2 is also a versatile teaching tool. It can be adapted to teach Earth Systems (seasons) as well as Physical Science (properties of light). Furthermore, the visual nature of the project can help meet the needs of a variety of learners and address the common misconceptions of Earth Systems.

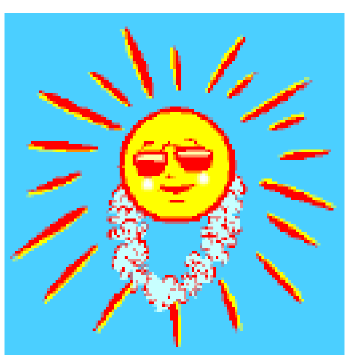
Class Project ideas: The class could investigate the differences in voltage for a given geographic region as the year progresses. For example, the North Pole may read 0.35v in the summer and 0.00v in the winter. Create a spreadsheet and graph the solar irradiance (in volts or amperage) for a given area over a given time frame. The class could also investigate the changes that occur when the Earth is tilted greater than or less than 23.5°.

Measuring Solar Radiation: We liked the pizza box solar cooker because it is so inexpensive to make and most of the materials are easily attainable. The pyranometer is more expensive, but gives more immediate results. This instrument measures the sun's energy by displaying electrical current. It offers a great introduction or illustration of measuring energy and the concepts of electricity. The benefit of this experiment is that the results from the meter are immediate and you can change the environmental conditions and get the result right away. Both these experiments can lead to discussions of pollution and global warming.



The Length of a Day Around World: This experiment is the least expensive if you already have a computer and an Internet connection. The strength of this project is that your students get to communicate with other classes throughout the world and so, in addition to the Physical and Earth Standards you're working on, you can include social science (geography) standards as well. Because of the possibilities of communicating and analyzing results with students across the world via the Internet, this project meets the communication portion of Science as Inquiry (Content Standard A) and Science and Technology (Content Standard E).

You will need to sign up a few weeks before you want to do this project. First, go to www.epals.com and sign up your class. Then find classes that also want to work on this project.



Capture Solar Energy: Project 5 is another lesson that is very inexpensive and a good lesson in understanding energy conversion. As an extension, students could start with ice below 0°C and graph the temperature increase. Students should see the slope of the graph decrease at 0°C due to the latent heat of fusion. (Heat of fusion for water is 0.366 Joules/ gram).

Other ideas: Students can calculate the efficiency of the solar collector and challenge each other to build more efficient solar collectors.

Calculations: The following is an example of calculating the energy captured by a solar collector.

How much solar energy is captured if 100ml of water is raised 10 degrees over 10 minutes using a 10cm x 10cm solar collector?

Answer:
1. 100ml water x 1 g/ml = 100g
2. 100 g x 10°C = 1000 calories
3. 1000 cal x 4.186 Joules=4,186 J
4. 10 minutes x 60 seconds = 600 seconds
5. 4,186 J ÷ 600 s = ~ 6.97 Watts

Answer = ~ 6.97 Watts

To convert to W/M^2:
1. 10cm x 10cm = 100cm^2 = 0.01M^2
2. 6.97 Watts ÷ 0.01M^2 = 697 W/M^2

Answer: 697 W/M^2

*Note: Solar irradiance is ~ 1000 W/M^2 on a clear summer day.

For elementary and middle school students, you could modify this experiment to only have students measure the temperature of this apparatus on various days. Have students record other possible environmental factors that might affect the temperature of the water. To reinforce the inquiry basis of this experiment, ask the students about which variables they think might affect the water temperature.

This is the second experiment that would work well through global collaboration with www.epals.com. Have classes throughout the world send you their data.

National Science Education Standards by the National Academy of Sciences

Science Content Standards: 5-8

Science As Inquiry
– Content Standard A:
"Abilities Necessary To Do Scientific Inquiry"
"Understandings About Scientific Inquiry"

Physical Science
- Content Standard B:
"Transfer of Energy"

Earth Science
- Content Standard D:
"Earth in the Solar System"

Science and Technology
- Content Standard E:
"Abilities of technological design"
"Understandings about science and technology"

Science Content Standards: 9-12

Science As Inquiry
– Content Standard A:
"Abilities Necessary To Do Scientific Inquiry"
"Understanding About Scientific Inquiry"

Physical Science
- Content Standard B:
"Conservation of energy and increase in disorder"
"Interactions of energy and matter"

Earth Science
- Content Standard D:
"Energy in the Earth System"

Science and Technology
- Content Standard E:
"Abilities of technological design"
"Understandings about science and technology"

Technology Description

Ah, the sun. Picture yourself outside right now. Or even better, go outside if the sun is shining. What do you think the sun is good for? How does it affect you? There is no right answer. Just think a minute before you continue reading.

You may have thought about how the sun provides us with heat. It feels so good to feel the warm sun on our skin when we are cold. Of course, if we get too much sun, we get sunburned. Can you imagine if the Earth were closer to the sun? Yeah, we would get toasted. If we got too much sun, it would be too hot for us and other living things to live. The sun gives off an amazing amount of heat, and we get a very small amount since we are so far away, but that amount is just right for us.

You also might have thought about the light. Without the sun, we couldn't see. You might ask, "Well, what about the moon?" Aha, the moon doesn't have any light of its own! All of the light we see is really just sunlight that is reflected, or bounced off of, our moon.

You might argue, "Well I would just turn on a light or use a flashlight. Then I would be able to see." But where did that energy come from? In fact, where does the energy to build, light, and heat our houses and schools come from? The sun has created almost all of the energy we use today. Oil and gas are made up of compressed plants, dinosaurs and other living things from many millions years of ago. Living things depend on plants to make energy from sunlight. We can use that stored energy now, at least until we run out or it gets too expensive.

If we want to find more energy, we can look back to the sun itself. All the light and heat we feel is energy that we might be able to use. How much energy could the sun give us? How much would this energy cost us? How can we capture the energy and use it for our needs? You will be doing some experiments that will begin to answer these questions.

The first experiment you can do is build a solar oven from a pizza box. The energy from the sun will increase the temperature inside the box. The more efficient you make your solar oven and the more energy you can get from the sun, the higher the temperature will go inside the box. You can measure the energy you have by using an oven thermometer.

For Advanced Students: The term for the amount of energy produced by the sun over a specific area is **solar irradiation** and it is usually expressed in terms of watts per square meter (Watts/m^2). One of the ways you can measure this energy is through special instruments called **pyranometers** or **pyrheliometers**. A pyranometer measures the sun's radiation and any extra radiation that has been scattered by particles in the sky. A pyrheliometer measures the direct sun's radiation. In project 3 you will make a pyranometer and pyrheliometer by using a solar cell (also called a **photovoltaic or PV cell**). You will connect the cell to something that measures current such as a millameter or voltmeter.

The first step in understanding solar irradiation is understanding the sun itself. The sun is a sphere of intensely hot gasses that is about 150 million kilometers from Earth. The temperature on the sun ranges from about 5,700 degrees Celsius at the surface to an estimated 14 million degrees Celsius in the center. The amount of energy that reaches earth is an extremely small fraction, only about one-billionth of the energy on the sun.

The energy that reaches the outside of the Earth's atmosphere only changes about +/- 3% over the course of the year. This energy is known as the **solar constant**. The number for this is generally accepted as 1367 Watts/m^2. However, the dust, air molecules, and moisture in the atmosphere, combined with the exact location of the observer in relation to the sun, dictate the amount of energy that reaches Earth's surface. In project 2 you will measure the difference in energy between different parts on a model of the Earth and in project 4 you will measure the amount of light people see in different parts of the world.

Resources:

C. Freudenrich, "How the Sun Works," [Online document], Available: http://science.howstuffworks.com.

National Aeronautics and Space Administration (NASA), "The Sun. NASA Fact Sheet," [Online document], Available: www.nasa.gov.

National Aeronautics and Space Administration (NASA), "Watching the Sun: Measuring Variation in Solar Energy Output to Gauge its Effect on Long-term Climate Change" [Online document], Available: http://earthobservatory.nasa.gov/ and http://terra.nasa.gov/. These sights also contain images and data about global conditions.

National Renewable Energy Laboratory (NREL), "Glossary of Solar Radiation Resource Terms," [Online document], Available: www.nrel.gov.

National Renewable Energy Laboratory (NREL), Science Projects in Renewable Energy and Energy Efficiency, 1991, American Solar Energy Society.

Project Ideas

1 Pizza Box Solar Oven

Learning Objective: To design an effective pizza box solar oven.

Questions: How can you trap the energy from the sun and turn it into something useful, like heat? What factors will affect how high the temperature will go?

Control and Variables: Day of year (season and tilt of earth will determine how direct the rays of the sun are), sky conditions (pollution, clouds), temperature of the air, design and dimensions of oven.

Materials and Equipment: Pizza box (eat out or ask for one at a pizza restaurant), black construction paper, aluminum foil, clear transparencies (office supply store), scissors, clear packing tape or glue, drinking straw or dowel to hold the box open, oven thermometer.

Safety and Environmental Requirements: Never look directly at the sun. If the temperature in your oven gets too warm, you may need oven mitts or open the box and wait until the box cools down to touch anything inside the box.

Suggestions: Cover bottom of box with aluminum foil and a layer of black paper. Cut a hole in the top of the box one inch from the edge, leaving one edge on the same side as the box's hinge. Glue aluminum foil on inside part of the box lid. Tape clear plastic over this hole. When you glue the clear plastic to the pizza box, make sure you have a tight seal. Point the opening of the box directly at the sun and prop the lid open. Record the temperature inside the box on different days. Also, record any data you think might affect the temperature in the box (cloud cover, date and time, and temperature outside the box). After you check the temperature, line your box with plastic wrap and try cooking popcorn, cookies, or heating water to make tea or hot chocolate.

For your science project, display the data you recorded above. Explain how the oven works. Make suggestions on how to create a better solar oven. For example, you might check out http://www.solarnow.org/pizzabx.htm and see how they did their box.

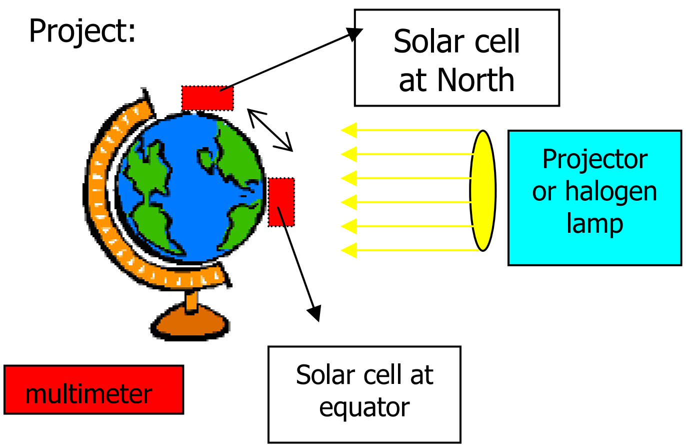
2 Solar Resource Simulator

Learning Objective: To design an earth-sun simulator in order to learn how solar energy is distributed around the Earth.

Control and Variables: Day of the year, time of day.

Costs: Solar cell ($5), multimeter ($20), globe (varies), 100 Watt halogen lamp ($10). (You can substitute the lamp with a projector, if available.)

Project:



Materials and Equipment: World globe or Styrofoam sphere, solar cell and/or pyranometer, multimeter, Velcro tape, protractor/angle finder, projector and/or halogen lamp.

Solar cells, voltmeter, halogen lamp and projectors can be found at all major electronic stores. You can purchase the Styrofoam sphere at a hobby shop.

Safety and Environmental Requirements: CAUTION: Don't look directly at the sun or the projector. You can damage your eyesight permanently.

Suggestions: Cut the Velcro strip long enough to reach both North and South poles of the globe or Styrofoam sphere. Tape the "other side" of the Velcro to the solar cell. Stick the solar cell where you want on the globe. Place the projector or light source about 20-30 inches from the globe and shine the light on the equator. Make sure the solar cell is parallel to the globe's surface. Measure the voltage/amperage for North Pole, 40° N latitude, the Tropic of Cancer, the equator, the Tropic of Capricorn, 40° S latitude, and the South Pole.

Further Inquiry:

1. Compare the length of time of illumination and the angle of the light rays with the energy collected from the solar cell. For example, record the energy for direct rays for 5, 10, and 15 minutes. Then record the energy for indirect rays.
2. Investigate the effects of the distance from the light source to the solar cell. Compare this to the distance sunlight travels through the atmosphere from sunrise to noon and/or the equator to the Arctic Circle.
3. What conclusions can you make? What can you say about how hot the sun must be to receive the amount of energy at the Earth's surface?

3 Measuring Solar Radiation

Learning Objective: To measure the energy of the sun.

Questions: How much solar radiation is available each day? Week? Month?

Control and Variables: Day of year (hours of daylight), orientation of equipment toward sun: Horizontal, tilt angle, azimuth, sky conditions.

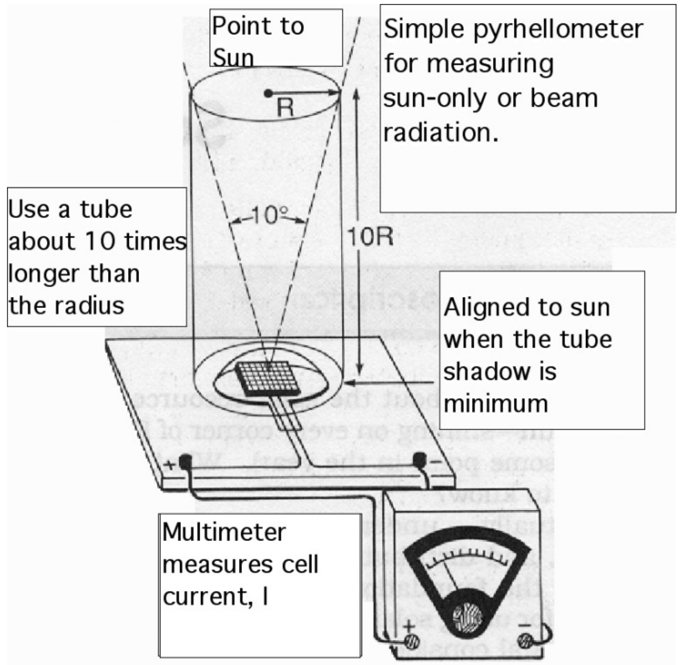
Materials and Equipment: Solar cell. Paper towel tube or another tube that is 10 times longer than radius. Millammeter (0-50) or resistors and a voltmeter (0-10 volts).

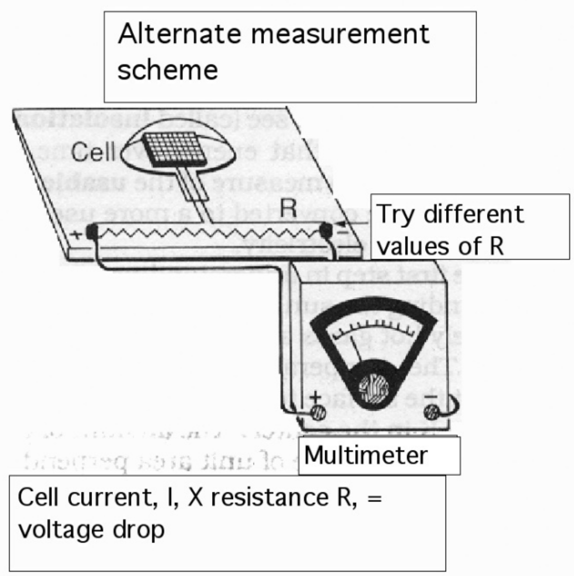
Safety and Environmental Requirements: CAUTION: Do not look directly at the sun. It can damage your eyesight permanently.

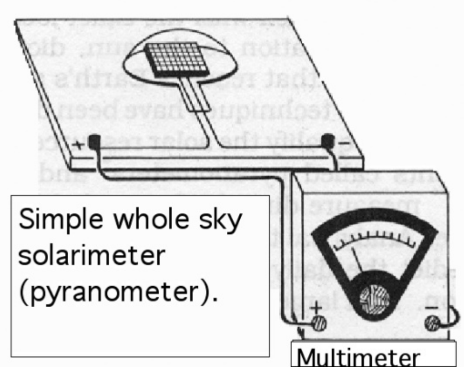
Suggestions: Install a low-cost pyranometer (without tube) and pyrhellometer (with tube) system as shown in the figures. Compare the data you get with summaries of the 30-year means.

Further Inquiry:

1. Compare direct sun (with tube) with full sky radiation (without tube).
2. How do cloud cover and humidity affect measurements?
3. How do different colored filters affect measurements? Try colored transparencies or other transparent material.
4. How does air pollution affect your results? What could you use to simulate air pollution?







4 Length of Day around the World

Learning Objective: To measure how the length of day changes depending on where you are in the world.

Control and Variables: Day of year and geographic location.

Materials and Equipment: Internet access, local newspaper.

Suggestions: Epals.com is a Web site for students and teachers. This site allows you to communicate with over 4 million students around the world. The teacher needs to sign up the class first. You will need to record how long the day is and send this information to other students throughout the world and record and graph their answers.

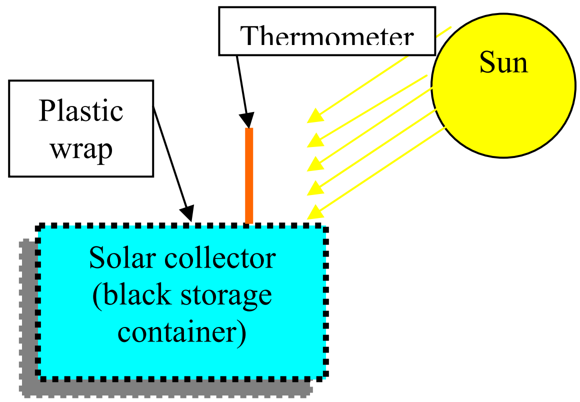
5 Capture Solar Energy!

Objective: To measure solar energy with a homemade solar collector.

Variables: Time of day, time of year, location, atmospheric conditions.

Special Equipment: Square plastic food storage container, black paint, heavy-duty clear plastic wrap, thermometer, graduated cylinder, clock / watch, and ruler.

Set up:



Hints: What was the volume of water before you started? What is the area of your solar collector? What was the temperature of the water vs. outside air before you began your investigation? What was the final temperature of the water? Did you use the metric system? How often did you record the temperature? What did the graph look like?

Useful Conversions:
1 calorie = 1 gram water raised 1°C
1 Watt = 1 Joule per second (1 J/s)
1 calorie = 4.186 Joules
Area = Length x Width
1 ml water = 1 gram water
Standard irradiance value (Sun's Power) = Watts per Meter squared (Watts/ M^2)

Further Inquiry:
1. Does the rate of temperature increase differ if you start with ice instead of water?
2. Can you use something other than water to collect the sun's energy?
3. What factors can affect solar irradiance?
4. How does outside air temperature affect your measurements?

More Project Ideas

What is the connection between weather variables—such as temperature, relative humidity, and cloudiness—and changes in available solar energy?

How does the available solar energy change with altitude or elevation? (Hint: How does the density of the atmosphere change with altitude?)

How does the brightness of various indoor lamps compare to that of sunlight?

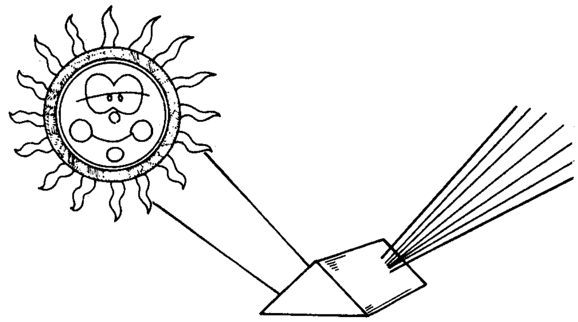
How would you determine the approximate solar radiation resource for your home if you had values for several cities nearby?

How does the pattern of solar radiation through the day (or year) match the need for air conditioning, heating, cooking, and hot water in your home?

Where are the warmest and coldest parts of your home in the summer? In the winter? Compare the locations with the position of the sun in the sky.

How much solar energy comes from scattered light, rather than directly from the sun? What factors affect this?

What is the color of sunlight?



How rapidly does the focused light from a magnifying glass move at different times of a day?

How does a light source spread out with distance?

How can you determine solar noon and solar north at various longitudes and days of the year?

Why are sunrises and sunsets predominantly red?

Why does the sky turn blue?

Why are the oceans blue?

Investigate the terrestrial solar irradiance spectrum. Why is the UV spectrum relatively low? Why are there "dips" periodically in the spectrum? (For irradiance data, see www.nrel.gov/srrl/)