Hot or Not?

Student Objective
The student:
- will be able to explain how the sun's rays through conduction and convection heat things on the Earth
- will be able to explain the various factors that determine how much radiant energy is absorbed by a solar collector on Earth
- will be able to calculate the solar heat gain in a solar thermal collector in BTUs
- will be able to explain the Solar Constant

Key Words:
British Thermal Unit (BTU)
conduction
convection
radiation
reflection
thermal

Time:
(1) class

Materials:
- quart size zipper type plastic bags (3 per group)
- thermometers (3 per group)
- black construction paper
- white paper
- stiff cardboard
- masking or duct tape
- binder clips or clothespins (2 per group)
- box cutters
- rulers
- scale
- timer or stopwatch
- graph paper
- colored pencils
- Science Journal

Background Information

Energy from the sun travels through space and our atmosphere by **radiation**. This radiant energy travels through the clear glazing on the collector (i.e. glass, plexiglass or plastic) which changes its wavelength so it can be absorbed as heat. The water in the collector heats up by **convection**. Heat in the collector is trapped by the glazing and the collector gets hotter and hotter inside.

Procedure

1. Lead the class in a discussion of heat energy from the sun. Points to cover should include:
   - heat from the sun occurs during all seasons and weather
   - heat rays are the infrared waves of the electromagnetic spectrum.
   - energy from the sun travels through the vacuum of space by **radiation**. Even though the sun is 90 million miles from the Earth, it takes less than 10 minutes for the heat to reach us.
   - heat energy travels through materials by **conduction**
   - heat energy travels through a gas or a liquid by circulation of currents in the gas/liquid. This is **convection**.
2. Explain to the class that they will be investigating how much solar energy they can capture in water in several different conditions and calculating the amount of solar heat gain in British Thermal Units, commonly called BTUs.
3. Write the **BTU formula for water** on the board

   BTU = amount of energy needed to raise 1 pound of water 1^{o} F
4. Explain that BTU is a unit of measurement used when describing the amount of heat energy in sunlight and fuels, and also when describing the ability of appliance to heat or cool.
5. Divide the class in groups of 2 - 4 students per group.
6. Explain the procedure to the class
   - each group is to make a stand for their experiment out of cardboard
   - make up three experiment bags–each one will hold one pound of water and a thermometer. Seal the bags tightly with as little air in the bags as possible. *(Note: 1 pound of water also equals 454 mL, 454 grams, or 2 cups minus 4 teaspoons)*
   - place the experiment stand in full sun and follow the directions in their Science Journal
7. Assist the students as necessary during the set-up of the experiment.
8. Students should complete their Science Journals.
9. Have one of the groups report their results to the class. Ask the other groups if their results were identical. Lead a discussion about why there are small discrepancies between groups (differences in position in relation to the sun, different material underneath the stands, more/less time handling the bags before beginning, inaccuracies in measurements, etc).
10. Explain to the students the difference between **replication** of an experiment by different groups, and **repetition** of the experiment by the same group, and how repetition can minimize many of the discrepancies of materials, set-up and handling.
11. Lead a discussion on the factors that influence the amount of solar heat that strikes the earth. Make sure the students include weather factors as well as seasonal effects.
    - Note: If you had passing clouds during the experiment time, discuss how the clouds affected the rate of temperature increase (as shown in the graphs).

Answer Key

1. Air temperature and the surface that the bag is setting on (which has also been heated by the air if it is in the shade). All environmental temperature came from the sun originally.
2. Answers will vary, but this number should = Sun/White BTU - Shade BTU (Check to make sure the students did the BTU calculations in Table B correctly.
3. Answers will vary, but this number should = Sun/Black BTU - Sun/White BTU.
4. Answers will vary. Students should have time on the x-axis and temperature on the y-axis. They should also include an appropriate key for their colors.
5. Answers will vary, but students should explain that the slope for the Sun/Black temperature is steeper.
6. Answers will vary, but students should have made the proper unit change, rounded their answer to two decimal places and labeled their units correctly.
7. Answers will vary. Students should multiply their answer from question 6 by 25 then divide by 1800.
8. Students should recognize that the majority of the losses are from the sunlight going through the atmosphere, but may additionally mention being blocked by clouds and jet contrails, as well as the seasonal variations in the distance between the earth and the sun.

Key Words & Definitions

- **British Thermal Units (BTU) -** the amount of energy needed to raise the temperature of one pound of water 1° F. One BTU is roughly equal to 1055 joules and .253 Kcal.
- **conduction -** the transmission of heat across matter
- **convection -** heat transfer in a gas or liquid by the circulation of currents from one region to another
- **radiation** - the way we receive heat from the sun each day. The energy is emitted in the form of waves/particles, and can move from one object to another without heating the area in-between.
- **reflection -** the throwing back of rays of light, heat, or sound by a surface without absorbing them.
- **thermal** - relating to heat and cold

Related Research

1. What would happen if you had a larger bag with 2 gallons of water in it? Would the BTUs remain the same? Try it and find out.
2. What would happen if you placed your bag on a reflective surface? On a different colored surface than black or white? Would colored water heat faster than plain water? Design an experiment and test it out.
3. How could you use mirrors or other reflectors to concentrate the Sun's energy? What about sheet magnifiers? Have a competition between lab groups to see who can capture the most solar energy as heat.

Related Reading

- ***Solar Energy Projects for the Evil Genius*** by Gavin Harper (McGraw-Hill, 2007)
  This book includes more than 50 solar energy projects with plans, diagrams and schematics.

Internet Sites

https://www.youtube.com/watch?v=uOWzNBXk3ss

Short video, *From Solar Energy to Heat*, explains how photons from the sun turn into heat

http://www.neok12.com/video/Solar-Energy/zX4501794c04647766705041.htm

Video on Solar Thermal usage in Europe

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			.1	.2	.3	.4	.5	.6	.7	.8	.9	.10	.11	.12
Grade 6														
Practice of Science	**# 1**	**SC.6.N.1**	**X**			**X**								
Earth Systems & Patterns	**# 7**	**SC.6.E.7**	**X**											
Grade 7														
Practice of Science	**# 1**	**SC.7.N.1**	**X**	**X**		**X**								
Forms of Energy	**# 10**	**SC.7.P.10**	**X**	**X**										
Energy Transfer & Transformations	**# 11**	**SC.7.P.11**	**X**	**X**										
Grade 8														
Practice of Science	**# 1**	**SC.8.N.1**	**X**											
Earth in Space & Time	**# 5**	**SC.8.E.5**											**X**	

Sixth Grade Benchmarks
Science–Big Idea 1: The Practice of Science

- SC.6.N.1.1 - Define a problem from the sixth grade curriculum, use appropriate reference materials to support scientific understanding, plan and carry out scientific investigation of various types, such as systematic observations or experiments, identify variables, collect and organize data, interpret data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions.
- SC.6.N.1.4 - Discuss, compare, and negotiate methods used, results obtained, and explanations among groups of students conducting the same investigation.

Science–Big Idea 7: Earth Systems and Patterns

- SC.6.E.7.1 - Differentiate among radiation, conduction, and convection, the three mechanisms by which heat is transferred through Earth's system.

Seventh Grade Benchmarks
Science–Big Idea 1: The Practice of Science

- SC.7.N.1.1 - Define a problem from the seventh grade curriculum, use appropriate reference materials to support scientific understanding, plan and carry out scientific investigation of various types, such as systematic observations or experiments, identify variables, collect and organize data, interpret data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions.

- SC.7.N.1.2 - Differentiate replication (by others) from repetition (multiple trials).
- SC.7.N.1.4 - Identify test variables and outcome variables in an experiment.

Science–Big Idea 10: Forms of Energy

- SC.7.P.10.1 - Illustrate that the sun's energy arrives as radiation with a wide range of wavelengths, including infrared, visible, and ultraviolet, and that white light is made up of a spectrum of many different colors.
- SC.7.10.2 - Observe and explain that light can be reflected, refracted, and/or absorbed.

Science–Big Idea 11: Energy Transfer and Transformations

- SC.7.P.11.1 - Recognize that adding heat to or removing heat from a system may result in a temperature change and possibly a change of state.
- SC.7.P.11.2 - Investigate and describe the transformation of energy from one form to another.

Eighth Grade Benchmarks

Science–Big Idea 1: The Practice of Science

- SC.8.N.1.1 - Define a problem from the eighth grade curriculum, use appropriate reference materials to support scientific understanding, plan and carry out scientific investigation of various types, such as systematic observations or experiments, identify variables, collect and organize data, interpret data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions.

Science–Big Idea 5: Earth in Space and Time

- SC.8.E.5.11 - Identify and compare characteristics of the electromagnetic spectrum such as wavelength, frequency, use, and hazards and recognize its application to an understanding of planetary images and satellite photographs.

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The **BTU** (British Thermal Unit) is a unit of measurement used when describing the amount of **heat energy** in sunlight and fuels, and also when describing the ability of appliances, solar water heaters, and air conditioning systems to heat or cool.

By definition:

1 BTU = amount of energy needed to raise 1 pound of water 1° F

(Or in Celsius: 1.8 BTU = amount of energy needed to raise 1 pound of water 1° C)

In this experiment you will measure how much heat energy (BTUs) you can capture from sunlight in water, and experiment with different materials to see what methods work better to capture more heat energy.

- Make up three sandwich bags of plain water for your experiment. Put 1 lb. of water and a thermometer in each bag. Squeeze out as much air as possible, and seal tightly.
- Make a stand out of cardboard (see diagram below). Each side of the triangular stand should be at least the width of two plastic baggies side by side and the height of one baggie. (For our example, each side of the triangular stand was 17" wide and 9" tall.) Make your stand 3-sided (with a bottom) for stability and also to give a similar surface for your 'control' (shade) bag to rest on.
- Put white paper on the left side of the face of the stand and black paper on the right side. Cut a slit on the top seam of the triangle on both sides for the clips that hold the baggies.

- Record the starting temperature of the water (in Celsius) in the chart for all three bags.
- Place the stand in the sun on a piece of cardboard or insulation (not directly on the hot concrete!).

- Clip one bag on the white paper side and one bag on the black paper side.
- Place one bag in the shade inside of the stand.
- For each bag, record the temperature every 5 minutes and fill in the table below.

Table A

	Start Temp	**5 min**	**10 min**	**15 min**	**20 min**	**25 min**	**30 min**
Shade							
Sun/White							
Sun/Black							

Calculate the change in temperature during the 30 minutes for each bag, record below and then calculate the BTUs for each bag.

Table B

	Change in temperature (△T)	**BTUs in 30 min. (1.8 x degrees C)**
Shade	**º C**	**BTUs**
Sun/White	**º C**	**BTUs**
Sun/Black	**º C**	**BTUs**

1. The bag in the shade gained heat from the environment instead of directly from the sun's rays, what was the source of this heat?

2. The bag in the sun on the white paper gained heat energy from the environment and from direct sunlight. How much heat energy did this bag get from direct sunlight? Give your answer in BTUs.

3. How much more heat energy did the black background absorb than the white?

4. Graph the data from Chart A (rate of temperature increase) below, using a different color for each bag. Label both axis, and include a key.

5. Which bag gained heat at the fastest rate? Explain.

6. In your science classes, we have typically used joules (J) as the standard unit of measure of energy. The conversion from BTU to joules is

1 BTU = 1055.05585 joules

How many **kJ** of energy did the Sun/Black water absorb? (round to two decimal places)

Challenge Questions

7. One kilojoule per second is approximately the amount of solar radiation received by one square meter of the Earth's atmosphere in full daylight. This is called the **Solar Constant**.

What part of a Solar Constant did the water in your experiment absorb? In other words, how many kJ per second / per square meter did the water absorb?

To figure this out:

- calculate how many kJ per *meter* your system would absorb (assume that your baggie measures 200cm x 200cm – 1/25th of a square meter)
- calculate how much of your 30 minute energy total would be collected in one second.

8. What factors account for the decrease in solar radiation that was collected in the water during your experiment compared to the Solar Constant?