Lesson Three

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PASSIVE SOLAR DESIGN

TEP BRIGHT STUDENTS: THE CONSERVATION GENERATION

Important Note: *This activity is very prop and materials intensive. It requires students to build solar houses (or, alternately, you can reuse them once they've been constructed). There are other activities on solar energy that require fewer props and preparation. However, we encourage you to try this activity if you are able to acquire the necessary materials; it's an excellent way for students to get hands on with solar energy concepts.*

Grade level appropriateness: Grades 6-8

Lesson Length:

- 2 full class periods (~ 120 minutes) if having students build the houses
- 1.5 full class periods (~90 minutes) if students are using already constructed houses

Additional documents:

- Template: Making a Box House
- Student Lab Sheet: Passive Solar Research
- Research Project Info Cards
- Average Daily Solar Radiation
- Sun Paths and the Seasons
- Sun Angles and Southern Windows

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LESSON 3

Intro

Introduction/Overview

PASSIVE SOLAR DESIGN

A class discussion after the experiment reinforces key passive solar concepts and relates the experimental variables to seasonal differences in the path of the sun. Each pair of students then teams with another pair of students to conduct an experiment with their two model houses. Teams read an informational card (one of four provided) and make a hypothesis about the variable their team is researching. Outdoors on a sunny day, the class as a whole conducts four different experiments relating to passive solar design features that help control heat transfer by radiation: building orientation, window orientation, shading, and building color. Teams record, graph, and interpret quantitative data. A class discussion after the experiment reinforces key passive solar concepts and relates the experimental variables to seasonal differences in the path of the sun.

Core Concepts

Sunlight, also called solar radiation, is the most inexhaustible, renewable source of energy known to humankind. Average solar radiation levels in southern Arizona are among the highest in the United States. Use of solar energy may be passive or active. Passive solar energy involves using the sun's energy with no or minimal mechanical or electrical devices. Solar thermal energy, or the heat energy of the sun, can be used passively for heating water and heating buildings. Use of solar thermal energy for heating is very efficient compared to many other human uses of energy because the energy is used in the same form rather than converted from one form to another. Passive solar buildings utilize design features and site elements, such as building orientation, window placement, and construction materials to maximize solar heat gain during winter and minimize solar heat gain during summer. Day lighting, or lighting buildings with natural light, can also be considered a form of passive solar energy.

Objectives

Learning Objectives

After completing this lesson, students will be able to do the following:

- State that Arizona and the Southwest receive more sunlight than anyplace else in the United States
- Explain the difference between active and passive solar energy
- Describe heat transfer by radiation and know that it is one of three mechanisms of heat transfer
- Define thermal gain and state that control of thermal gain is important in passive solar design
- Summarize how seasonal differences in the tilt of Earth's axis affect the apparent paths of the winter sun and summer sun and how this relates to passive solar design
- Describe a process of collecting, recording, graphing, and interpreting experimental data
- Explain how their experiments demonstrate use of the scientific method

Preparation

Advance Preparation

MATERIALS NEEDED

- Template: Making a Box House – prepare one 2-page template for each group of 2 students
- Student Lab Sheet: Passive Solar Research – photocopy one per student
- Research Project Info Cards: Energy-Smart Design – photocopy enough sets to provide one card per student or per team (teacher preference); cut into half-sheets; use card stock and laminate if desired.
- Overhead Image: Average Daily Solar Radiation in the U.S.A.
- Overhead Image: Sun Paths and the Seasons
- Overhead Image: Sun Angles and Southern Windows
- White posterboard – one sheet per 6 students (1 sheet makes 3 box houses)
- Black posterboard – one sheet only
- Overhead transparency plastic or equivalent material– one sheet per 12 students (1 sheet makes 6 box house windows)
- Thermometers – one per 2 students (one per box house)
- Glue or double-sided tape
- Blue Masking Tape (ample amounts)
- Clocks, watches, or kitchen timers that are digital and/or show seconds – one per four-student team
- Paperboard or corrugated cardboard – a few sheets for shade in that experiment
- Chalk/white board
- Chalk or white-board markers

Preparation

Advance Preparation *(Continued)*

GENERAL PREP

- The results of these experiments will only be consistent if the box houses are carefully cut and sealed; so this lesson is recommended only if you judge your students to be capable of this.
- Measure and cut each sheet of posterboard into six pieces. Cut it precisely in half lengthwise; then cut each half-sheet into thirds. Each pair of students will need two of these pieces to make one box house. (Posterboard is best: Plain paper lets through almost as much radiant energy as a clear plastic window, and anything heavier than posterboard is difficult to cut and fold. You could use heavy cardstock if need be, but, again, posterboard is best and results with anything besides posterboard could be skewed).
- Cut each sheet of overhead transparency plastic into six "windows" of approximately 5" x 2". Each pair of students will need one window for their box house.
- Be aware that the student lab sheets suggest recording data every one minute for 10 minutes. On a sunny Arizona spring or fall day, temperatures in the boxes usually reach equilibrium in this time frame. In winter or when the air is especially hazy or moist, change may occur more slowly and/or differences due to the experimental variables may be less marked. Adapt the time frame if needed.
- If you wish, the model houses could be made by one class and reused by other classes that day or the next year. To store the boxes with the thermometers removed, provide easy-off (blue) masking tape for students to use in sealing one end of the house so it can be opened without tearing. If it is impossible for your classes to work outside, the experiments could be done inside with high-wattage spotlights and clamp lamps (rated for high-wattage bulbs) mounted on ring stands so that the height and angle of light can be controlled.

Procedure

Suggested Procedure

Part 1: Introduction and Making Models

1. Briefly outline the lesson. Remind the class that solar energy is the most abundant energy resource that we currently know how to harvest. Briefly display the Overhead Image: Average Daily Solar Radiation in the U.S.A and invite students to compare the sunlight received in Arizona with other areas they have lived, visited, or heard of.
2. Clarify the very basic and very important distinction between active solar energy (involving use of mechanical or electrical equipment) and passive solar energy. Mention that passive solar applications include daylighting as well as solar thermal applications like heating water and heating buildings.
3. State that passive solar design involves using building features and site elements to maximize solar gain in winter and minimize it in summer. Doing this requires an understanding of basic science concepts, including the heat transfer mechanisms of conduction, convection, and radiation. Define the latter and mention the example of feeling the sun warm our bodies even when the air is cool.
4. List the four aspects of Energy-Smart Design they will be studying (from the headers of the Research Project Info Cards: Energy-Smart Design) on the board and state that these all relate to heat transfer via radiation or radiant heat transfer.
5. Assign students to a partner and give the partners one copy of the two-page Template: Making a Box House. Discuss the concept of using a model to the extent you wish. Outline the task of making the boxes and provide posterboard, scissors, window plastic, and tape. Emphasize that students need to construct the boxes carefully if their experiments are to work.
6. Allow time as needed. Monitor students' work, giving close attention to their thoroughness in taping all "seams" and applying extra tape on every corner.

Suggested Procedure *(Continued)*

7. Review the scientific method as you wish. Discuss the distinction between a question, prediction, and testable hypothesis, emphasizing the role of the latter in scientific inquiry. Emphasize controlling extraneous variables: For our experiments to be valid, the box houses should be alike in every way except for the experimental variable. (We are studying how specific design features affect indoor temperatures, so if a house is not sealed well, is at an odd angle to the sun, or is otherwise different, it becomes impossible to tell whether any temperature difference is due to this or to the design feature being studied)

Part 2: Passive Solar Design Experiments

8. Assign each pair of students to work with another pair of students as a research team (four students and two houses per team). Distribute copies of the research project info cards on Energy-Smart Design. Also give a copy of Student Lab Sheet: Passive Solar Research to each student.
9. Establish any rules for leaving the classroom and working outside. Be sure to emphasize strongly that students should never look directly at the sun.
10. Walk to a sunny area and provide time for reading the materials, setting up and conducting the experiments, and working on the lab sheets. Circulate and provide support.

Part 3: Recap and Wrap-Up

11. Back inside, after students complete their lab sheets, list the four experimental variables or aspects of Energy-Smart Design (from the Research Project Info Cards: Energy-Smart Design) on the board. Ask volunteers from different teams to describe each of the four experiments. Remind the class that all of the experiments were about heat transfer by radiation.
12. Review the scientific inquiry process and discuss the experimental results, touching on such areas as:
    - Whether the results support the hypotheses
    - Students' conclusions and their confidence in the validity and reliability
    - Their level of success at controlling extraneous variables

Suggested Procedure *(Continued)*

- Other potential sources of investigational error (poorly sealed boxes, incorrect thermometer readings, etc.)
- The value of presenting their data graphically
- How the experiments characterized scientific ways of thinking (Students formed a hypothesis, used an experimental procedure to test it, controlled selected variables, made systematic observations, recorded and organized data, and interpreted their results.)

13. As students share, highlight the following:
    - Passive solar involves no mechanical or electrical equipment
    - Passive solar design aims to minimize solar gain in summer and maximize it in winter
    - Passive solar design requires understanding seasonal differences in sun paths. Describe how the seasons relate to the tilt of Earth's axis in relation to its path around the sun. Display and discuss the two Overhead Images: Sun Paths and the Seasons and Sun Angles and Southern Windows
    - Building color and to some extent shade can be "add-ons" to any building or site whatever the original design
    - Mention public buildings that students are familiar with (such as the school) that may incorporate or lack passive solar features
    - Passive solar design embraces energy conservation measures, including insulation and sealing the building (which limits heat transfer via conduction and convection). Conservation measures are important in any building, whatever the other features!
    - Passive solar design and energy conservation measures are very effective and efficient, make buildings much more comfortable, and cost very little

Assessment Ideas

Ask students to evaluate one or more actual buildings (the school, houses, apartment buildings, or other buildings) and explain why they think the buildings seem well or poorly designed. This could be done on a class walk in the neighborhood around the school or as a homework assignment. Or, for a real hands-on assessment, let student teams plan and build a more elaborate model house that integrates a number of passive solar design principles (and perhaps a model photovoltaic solar array as well).

Extension Ideas

Earth-sun relationships: Use models or balls representing Earth and the sun to demonstrate how the tilt of Earth's axis, as Earth rotates around the sun, determines day length and the angle of incoming solar radiation. Contrast the northern and southern hemispheres, discuss seasonal changes, and compare temperate zones with the equatorial zone.

Additional energy-smart design experiments include the following:

1. Thermal mass helps keep indoor temperatures stable, minimizing fluctuations from day to night and from summer to winter. It is provided by dense materials that absorb and release heat slowly, like thick walls of rammed Earth, solid concrete, or adobe; or floors of concrete or stone; or even barrels of water. Compare box houses with a thick layer of gravel on the floor or containers of water inside to those without.
2. Insulation helps keep heat where you want it, whether that is inside during winter or outside during summer. Line one model house inside with foam mounting board or a couple of layers of polystyrene cut from food trays. Experiments might show that an insulated house better retains radiant heat that enters the window, a desirable trait in winter; the same insulation would better retain cooled air in summer.
3. Caulking and weather-stripping also help keep heat energy where you want it. Experiments might compare a box house sealed with tape to an unsealed house or even one with an "open window." The sealed house offers benefits during both winter and summer, as above.