Solar Structures

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Lesson Focus

This lesson focuses on how the sun's energy can be used to heat and cool buildings. Teams of students construct passive solar houses from everyday materials. They then test their solar houses to determine how well they regulate temperature.

Lesson Synopsis

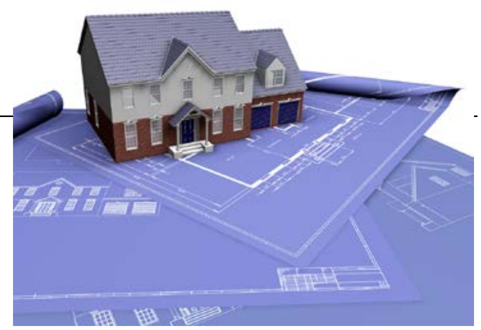
The "Solar Structures" lesson explores how the power of the sun can be harnessed to heat and cool a building. Students work in teams of "engineers" to design and build their own solar houses out of everyday items. They test their solar house, evaluate their results, and present to the class.

Age Levels

8-18.

Objectives

- Design and build a passive solar house
- Test and refine their designs
- Communicate their design process and results



Anticipated Learner Outcomes

As a result of this lesson students will have:

- Designed and built a passive solar house
- Tested and refined their designs
- Communicated their design process and results

Lesson Activities

In this lesson, students work in teams of "engineers" to design and build their own solar house out of everyday items. They test their solar house, evaluate their results, and present to the class.

Resources / Materials

- Teacher Resource Documents (attached)
- Student Worksheets (attached)
- Student Resource Sheets (attached)

Alignment to Curriculum Frameworks

See attached curriculum alignment sheet.

Internet Connections

- TryEngineering (www.tryengineering.org)
- Passive Solar Home (http://planetgreen.discovery.com/videos/worlds-greenest-homes-the-new-zealand-passive-solar-home.html)
- Carbon Footprint Calculator (www.carbonfootprint.com/calculator.aspx)
- ITEA Standards for Technological Literacy: Content for the Study of Technology (www.iteaconnect.org/TAA)
- National Science Education Standards (www.nsta.org/publications/nses.aspx)

Recommended Reading

- Passive Solar House: The Complete Guide to Heating and Cooling Your Home. (ISBN: 978-1933392035)

Optional Writing Activity

- Write a real estate advertisement marketing your passive solar house's selling points.

For Teachers:
Teacher Resources

◆ Lesson Goal
The goal of this lesson is for students to design and build a passive solar house out of everyday materials. The houses will be tested for how well they keep warm or cool depending on the time of year.

◆ Lesson Objectives
- Design and build a passive solar house
- Test and refine their designs
- Communicate their design process and results

◆ Materials
- Cardboard or cereal boxes, construction paper, plastic cups, sand, stones, water, rulers, tape, plastic wrap, felt, light and dark tempera paint, foliage, compass, thermometer or temperature strips, protractor, scissors, pencils

◆ Procedure
1. Before the lesson, ask students to share what they already know about green building. Discuss how engineering homes to make better use of renewable energy sources such as the sun can make homes more energy efficient and environmentally friendly.
2. Show students the various Student Reference Sheets. These may be read in class, or provided as reading material for the prior night's homework.
3. Divide students into groups of 2-3 students, providing a set of materials per group.
4. Explain that students must design a passive solar house out of the materials given. If the activity is being conducted during a cooler time of year the goal is to increase and maintain the temperature of the house by as much as possible. If this activity is being conducted during a warmer time of year the object will be to limit temperature increase as much as possible. Older students can research the sun angle at their location to assist them with their designs at the following website: http://www.susdesign.com/sunangle/
5. The house must have four walls, at least four windows and two working doors, and a roof. It must be at least 15 cm high, and have an area of at least 30 cm. It must also have a place inside for a thermometer, so the temperature can be recorded.
6. Students meet and develop a plan for their solar house. They agree on materials they will need, write or draw their plan, and then present their plan to the class.
7. Student groups next execute their plans. They may need to rethink their plan, request other materials, or trade with other teams.
8. Students groups can then test their solar houses. They should place their solar house in the sun (preferably midday) at the desired orientation using a compass. Students should record the initial inside temperatures of their house, and then again every 2 minutes for 12 minutes. If time permits, they can then bring their house into the shade and record the temperature every 2 minutes for another 12 minutes.
9. Teams then complete an evaluation/reflection worksheet and present their findings to the class.

◆ Time Needed
- 2-3 forty-five minute class periods

Student Resource: Solar Building Design

◆ Solar Energy
Solar energy is energy from sunlight. We can feel this energy as warmth when outside on a sunny day. Solar energy is a renewable source of energy, which means that it can be replenished by nature in a short period of time. Buildings can be designed to harness the power of the sun for heating and cooling purposes. This can be accomplished using active solar design, passive solar design, or a combination of both. Solar building designs are much more energy efficient resulting in structures with smaller carbon footprints that are much friendlier towards the environment.

◆ Active Solar Design
Active solar design relies on the use of mechanical or electrical devices to convert sunlight into electricity, which can then be used to supply heat or power to a building. "Photovoltaics" refers to the field of science that is concerned with the application of solar cells to generate electricity for use by people. A solar cell is a small device that converts the sun's energy into electricity. Solar cells create direct current, which can be used to power electrical devices. Solar cells can also be assembled into solar panels, which are being used more frequently in building design.

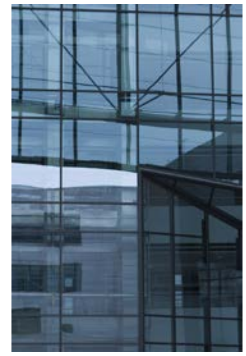
◆ Passive Solar Design
Passive solar design on the other hand, involves selecting and placing design elements and materials to help keep a building warm during the winter months and cool during the summer months. Although a combination of both active and passive means may be utilized in solar building design, true passive solar design does not incorporate mechanical or electrical devices of any kind. Passive solar design is very cost effective for this reason.

Native American Cliff Dwellings, Mesa Verde National Park

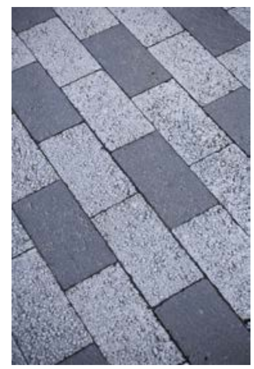
Passive solar design has been used for thousands of years. Ancient Greeks and Chinese built dwellings designed to take advantage of the sun's warmth. Native Americans also used passive solar design elements when they built cliff dwellings. Solar design relies on the sun's relative position in the sky to regulate the temperature inside a building. The angle of the sun's rays at different times of the year must be analyzed when designing buildings according to the principles of passive solar design. Optimal building design will allow more sunlight to enter the building in the winter, retaining warmth, and less in the summer, keeping things cooler.

◆ Passive Solar Design Elements
Passive solar design relies on several design elements. The orientation of the building itself, is of particular importance. It is recommended that buildings be oriented along the east west axis to take maximum advantage of the sun's orientation. Rooms that will be used the most are typically placed along the south side of the building. Rooms that are not used as frequently are placed along the north side of the building.

Windows are another vital component of passive solar design as they allow sunlight to enter into a building. The optimal orientation for major windows in passive solar design is southern-facing. Windows on the north and west sides of the building should be minimized. Windows can also be treated with glazing materials to prevent heat loss.



When the sun shines through the windows of a building it needs a way to be stored. Materials known as thermal mass absorb and store the sun's energy as heat for an extended period of time. In direct solar gain systems, thermal mass materials are part of the living space itself. Dark colored materials such as tile in walls or floors are quite effective at storing the sun's heat. Therefore these materials help prevent large fluctuations in temperature which may be occurring outdoors. Thermal mass should be placed to get the most sunlight in winter but should be shaded during the summer.



Thermal mass tiling

Indirect solar gain systems involve the use of thermal mass in between the sun and the living space. These can include walls with insulating materials behind them, known as trombe walls, or rooftop water storage tanks. The heat from the sun is stored in these materials and transferred to the living area through convection and radiation respectively. Another technique known as isolated solar heating uses an area adjacent to the main living area called a sunspace (sunroom, solar greenhouse etc.), which collects the heat from the sun and then transfers it throughout the rest of the building.

A truly passive design uses only convection, radiation and conduction to distribute the heat. Devices such as fans, blowers and ducts can be integrated into the design to help distribute the heat, although they are considered to be active devices. To regulate the temperature of the building, electronic devices such as thermostats or blinds may also be used. When these types of devices are used it is sometimes known as "hybrid" heating.

Sunroom

Passive solar design also incorporates design elements that will keep a building cool especially during the summer. It is very important that there be a way for cool air to enter the building and hot air to exit the building. Vegetation, ponds and light colored surfaces around a building can help cool air as it enters. Features such as skylights and thermal chimneys can let hot air out of a building. When windows are southern facing, there is a potential for overheating during the summer months. Overhangs above the windows can help ensure that too much sunlight does not enter during the summer and that full sunlight can enter in the winter. Trees can also be helpful for providing shading during the summer months. Reflective materials beneath the roof can prevent too much heat from being absorbed from the sun. These design features will ensure that a passive solar building does not become too hot.

Student Worksheet:
Design a Passive Solar House

You are a team of engineers who have been given the challenge to design a solar house. If the activity is being conducted during the cooler months, the goal is to increase and maintain the internal temperature of the house by as much as possible. If this activity is being conducted during the warmer months the object will be to limit temperature increase as much as possible. The house must have 4 walls, at least four windows and 2 working doors, and a roof. It must be at least 15 cm high, and have an area of at least 30 cm. Your design must also have a place inside for a thermometer so you can record the temperature.

◆ Planning Stage
Meet as a team and discuss the problem you need to solve. Then develop and agree on a design for your solar house. You'll need to determine what materials you want to use.

Draw your design in the box below, and be sure to indicate the description and number of parts you plan to use. Present your design to the class.

You may choose to revise your teams' plan after you receive feedback from class.

Design:

Student Worksheet (continued): Design a Passive Solar House

◆ Construction Phase

Build your solar house. During construction you may decide you need additional materials or that your design needs to change. This is ok – just make a new sketch and revise your materials list.

◆ Testing Phase

Each team will test their solar house. Place your solar house in the sun at the orientation decided on by the team (use your compass). Use the thermometer to record the initial temperature of the inside of your house. Then record the temperature of your house every 2 minutes for 12 minutes. If time permits, you can then bring your house into the shade then record the temperature every 2 minutes for another 12 minutes. Be sure to watch the tests of the other teams and observe how their different designs worked.

◆ Evaluation Phase

Evaluate your teams' results, complete the evaluation worksheet, and present your findings to the class.

Use this worksheet to evaluate your team's results in the "Solar Structures" Lesson:

1. Did you succeed in creating a solar house that could increase and maintain its temperature or keep cool (depending on the time of year)? If not, why did it fail?

2. Did you decide to revise your original design or request additional materials while in the construction phase? Why?

3. Did you negotiate any material trades with other teams? How did that process work for you?

Student Worksheet (continued): Design a Passive Solar House

4. If you could have had access to materials that were different than those provided, what would your team have requested? Why?

5. Do you think that engineers have to adapt their original plans during the construction of systems or products? Why might they?

6. If you had to do it all over again, how would your planned design change? Why?

7. What designs or methods did you see other teams try that you thought worked well?

8. Do you think you would have been able to complete this project easier if you were working alone? Explain…

9. What advantages does passive solar building design have?

10. What drawbacks does passive solar building design have?

For Teachers:
Alignment to Curriculum Frameworks

Note: Lesson plans in this series are aligned to one or more of the following sets of standards:
- U.S. Science Education Standards (http://www.nap.edu/catalog.php?record_id=4962)
- U.S. Next Generation Science Standards (http://www.nextgenscience.org/)
- International Technology Education Association's Standards for Technological Literacy (http://www.iteea.org/TAA/PDFs/xstnd.pdf)
- U.S. National Council of Teachers of Mathematics' Principles and Standards for School Mathematics (http://www.nctm.org/standards/content.aspx?id=16909)
- U.S. Common Core State Standards for Mathematics (http://www.corestandards.org/Math)
- Computer Science Teachers Association K-12 Computer Science Standards (http://csta.acm.org/Curriculum/sub/K12Standards.html)

◆National Science Education Standards Grades K-4 (ages 4 - 9)

CONTENT STANDARD A: Science as Inquiry
As a result of the activities, all students should develop
- ✦ Abilities necessary to do scientific inquiry

CONTENT STANDARD B: Physical Science
As a result of the activities, all students should develop an understanding of
- ✦ Properties of objects and materials

CONTENT STANDARD D: Earth and Space Science
As a result of the activities, all students should develop an understanding of
- ✦ Objects in the sky
- ✦ Changes in the earth and sky

CONTENT STANDARD E: Science and Technology
As a result of the activities, all students should develop
- ✦ Abilities of technological design
- ✦ Understanding about science and technology

CONTENT STANDARD F: Science in Personal and Social Perspectives
As a result of the activities, all students should develop an understanding of
- ✦ Types of resources
- ✦ Changes in environments

◆National Science Education Standards Grades 5-8 (ages 10 - 14)

CONTENT STANDARD A: Science as Inquiry
As a result of activities, all students should develop
- ✦ Abilities necessary to do scientific inquiry

CONTENT STANDARD B: Physical Science
As a result of their activities, all students should develop an understanding of
- ✦ Transfer of energy

CONTENT STANDARD D: Earth and Space Science
As a result of the activities, all students should develop an understanding of
- ✦ Structure of the earth system

CONTENT STANDARD E: Science and Technology
As a result of the activities, all students should develop
- ✦ Abilities of technological design
- ✦ Understanding about science and technology

CONTENT STANDARD F: Science in Personal and Social Perspectives
As a should develop an understanding of
- ✦ Populations, resources and environments

For Teachers: Alignment to Curriculum Frameworks (continued)

◆**National Science Education Standards Grades 9-12 (ages 14-18)**

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- Abilities necessary to do scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop understanding of

- Interactions of energy and matter

CONTENT STANDARD D: Earth and Space Science

As a result of the activities, all students should develop an understanding of

- Energy in the earth system

CONTENT STANDARD E: Science and Technology

As a result of the activities, all students should develop

- Abilities of technological design
- Understanding about science and technology

CONTENT STANDARD F: Science in Personal and Social Perspectives

As a should develop an understanding of

- Natural resources

◆**Next Generation Science Standards Grades 3-5 (Ages 8-11)**

Energy

Students who demonstrate understanding can:

- MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.

Engineering Design

Students who demonstrate understanding can:

- 3-5-ETS1-1.Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- 3-5-ETS1-2.Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- 3-5-ETS1-3.Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

◆**Next Generation Science Standards Grades 6-8 (Ages 11-14)**

Engineering Design

Students who demonstrate understanding can:

- MS-ETS1-1 Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

For Teachers:
Alignment to Curriculum Frameworks (continued)

◆**Principles and Standards for School Mathematics**

Measurement Standard

- Instructional programs from prekindergarten through grade 12 should enable all students to:
  - ✦ Apply appropriate techniques, tools, and formulas to determine measurements.

◆ **Common Core State Standards for School Mathematics Grades 3-8 (ages 8-14)**

Measurement and data

- Measure and estimate lengths in standard units.
  - ✦ CCSS.Math.Content.2.MD.A.1 Measure the length of an object by selecting and using appropriate tools such as rulers, yardsticks, meter sticks, and measuring tapes.
  - ✦ CCSS.Math.Content.2.MD.A.3 Estimate lengths using units of inches, feet, centimeters, and meters.

The Number System

- Apply and extend previous understandings of numbers to the system of rational numbers.
  - ✦ CCSS.Math.Content.6.NS.C.5 Understand that positive and negative numbers are used together to describe quantities having opposite directions or values (e.g., temperature above/below zero, elevation above/below sea level, credits/debits, positive/negative electric charge); use positive and negative numbers to represent quantities in real-world contexts, explaining the meaning of 0 in each situation.

◆**Standards for Technological Literacy - All Ages**

Technology and Society

- ✦ Standard 5: Students will develop an understanding of the effects of technology on the environment.

Design

- ✦ Standard 8: Students will develop an understanding of the attributes of design.
- ✦ Standard 9: Students will develop an understanding of engineering design.
- ✦ Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

The Designed World

- ✦ Standard 20: Students will be able to select and use construction technologies.