Introduction to the Solar House Module

Descriptions of the Solar House Challenges

Challenge 1: Cool House

Challenge Objective

Construct a roof that will allow the interior of the standard base to maintain the coolest temperature possible during a 3-minute heating trial. Materials are provided by the teacher but only combinations of two materials at a time may be used in any one trial.

Challenge Scenario

You and your team are shipwrecked! You're on an atoll (a tiny, flat, ring-shaped island with little or no plant life) in the North Pacific Ocean, just above the equator. It is very hot, and no trees or plants grow on the atoll to provide shelter from the Sun.

The remains of a very large packing crate perched on its side lie at the far end of the beach. Its previous contents, food and other items, are scattered along the shore. The bottom and three sides of the crate are still intact, but the side facing up is gone. It is too heavy to be moved or turned over. Your goal is to use the materials that have washed up on shore to construct a flat roof that will cover the crate so that the temperature inside will remain cool under the hot Sun.

Challenge 2: Constant Temperature House

Challenge Objective

Build and test a series of roofs made from 3 × 5 inch (7.6 × 12.7 cm) index cards that maintain a cool temperature inside the shelter. The temperature should rise minimally during a 3-minute heating trial. Any type of roof design may be used, but maximum roof height may not exceed 6 inches (15.2 cm) from the top of the table.

Scenario Change

Now that you have created an effective flat roof, you realize that differently shaped roofs may keep the packing crate shelter even cooler. Large sheets of cardboard were among the items stored in the crate. Your goal is to use the cardboard to create a roof shape that will lower the temperature as much as possible inside the crate and maintain it.

Challenge 3: Constantly Cool House

Challenge Objective

Using a variety of pre-approved materials, design any roof shape that will successfully keep the temperature as low as possible and maintain it for three minutes. There are no restrictions on style or material combinations although only two materials may be used at a time. You may use any available materials in any shape and combination that you choose. Maximum roof height may not exceed 6 inches (15.2 cm) from the top of the table.

Scenario Change

Your task in this challenge is to create a new roof for your shelter that will maintain the lowest constant temperature possible. Use your knowledge from the previous designs that you created to build a roof that will keep the house cool while maintaining a constant temperature for three minutes.

Module Goals

This module allows students to explore the nature of heat transfer by manipulating design elements and construction materials in a simple structure.

The goal of each challenge is to design and build a roof to shelter a model structure so that it maintains a constant temperature for three minutes when exposed to a standard heat source. Constraints within each challenge focus on different dimensions of concepts associated with heat transfer.

Content Goals of the Module

1. From the perspective of the *National Science Education Standards*: "As a result of their activities in grades 5–8, all students should develop an understanding of transfer of energy" (pg. 149). The underlying concept objective is that students recognize that:
    - Heat moves in predictable ways, flowing from warmer objects to cooler ones, until both reach the same temperature." (pg. 155)

2. From the perspective of CHALLENGES IN PHYSICAL SCIENCE:

The student's goal is to improve a shelter design to increase its ability to maintain a constant internal temperature when the shelter is exposed to an external heat source. To this end, students encounter the following concepts in order to successfully meet this challenge:

- Some materials conduct heat energy better than others; these are called **conductors.**
- Some materials slow down heat transfer; these are called **insulators.**
- Some materials act as a barrier to heat transfer; some materials can reflect heat. Efficient reflective barriers are called "radiant barriers." An example is aluminum foil.
- When two objects are at different temperatures, heat energy transfers from the warmer object to the cooler one.
- Heat energy is transferred from one material to another if there is a temperature difference between the materials.
- **Delta T (ΔT)** is a term used to describe the difference between two temperatures at two different times or places.
- Energy is not lost. When heat energy seems to disappear from one place, it has moved somewhere else or has been converted into another form of energy.
- Heat transfer occurs when two objects at different temperatures are in contact with each other. This type of heat transfer is called **conduction.**
- Heat transfer can occur when two objects at different temperatures are far apart. The heat energy only travels from the warmer object to the cooler one. This type of heat transfer is called **radiation.**
- Heat transfer can also occur when a substance at one temperature moves to another location. This type of heat transfer is known as **convection.**

Scientific Concepts and Knowledge

Motions and Forces

- Heat is thermal energy that can move from a hotter to a cooler object. Heat is a measure of the total kinetic energy of molecules in a substance.
- Temperature is a measure of average kinetic energy of molecules in a substance and is measured in degrees.
- Delta T (ΔT) is a term used to describe the difference between two temperatures at two different times or places.

- When heat energy seems to disappear from one place, it has not been lost but has moved somewhere else or has been converted to another energy form.

Transfer of Energy

- Energy is never "lost," but can be converted from one form to another.
- Heat transfer takes place through conduction, convection, and radiation.
- When two objects are at different temperatures, energy transfers from the warmer object to the cooler one.
- When two objects are at different temperatures, heat transfer occurs until both objects are the same temperature, or at equilibrium.
- Some materials act as a barrier to heat transfer; some materials can reflect heat. Efficient reflective barriers are called "radiant barriers."

Thermal Properties of Materials

- Some materials conduct heat energy better than others; these are called good conductors.
- Some materials slow down heat transfer; these are good insulators.

Distinguishing between Heat and Temperature

- **Temperature** is a measure of the average kinetic energy of the molecules of a substance. In other words it indicates how quickly the molecules are moving.

  When a substance gains heat energy, the molecules begin to move more quickly. The result is a rise in kinetic energy and thus a rise in temperature.
- **Heat** is the thermal energy that can be transferred from one body to another. As a form of energy, heat is measured in Joules or calories while temperature is measured in degrees. Two glasses of water at the same temperature have different amounts of heat if one glass contains more water than the other.

Science Process Skills

›rocess Goals

- An experiment consists of a hypothesis, a set of standard procedures designed to test the hypothesis, a record of observations and measurements, and an analysis of the data and observations to support or refute the hypothesis.
- Recording and graphing changes in temperature during the testing period helps to show trends which can be used to make predictions.
- By using numerical data such as temperatures and time, predictions of testing results can be made.
- Good recordkeeping during data collection is essential.
- Monitoring testing devices closely promotes attention to detail and accurate results.

[Note: For information on assessment of process skills, see the Rubrics section at the end of this module.]

Science Technology Society

The following STS connections are intended:

- Competition in industry
- Creative design: innovation, ingenuity
- Utilization of alternative energy sources and energy storage devices
- Roles in the working world
- Presentation skills

Assessment

Students will have met the content goals of this module if their discussions, reports, journals, class presentations or storyboards include statements like those above. For process assessment see process rubrics in the Rubrics section at the end of this module.

History of Heating and Cooling Homes

Humans can only survive unprotected within a small range of temperatures. We live throughout the world, however, in many different climates. In desert regions on all of the continents the temperature can reach as high as 136°F (58°C). In Antarctica temperatures can reach as low as –129°F (–54°C). How do people survive in these extreme areas?

Throughout history, people have learned the use of insulating and cooling techniques. Animal skins used as clothing provided protection from colder temperatures by keeping a person's body heat from escaping. Animal skins were also used on shelters such as huts or tents to keep heat inside. In warm areas, shelters were created to allow cooling air to flow through them while providing escape from the hot Sun. Let's look at some of these shelters.

Keeping People Warm

The beehive house was used four thousand years ago by people living in areas of Scotland and Ireland. This kind of house is made of blocks of stone stacked on top of each other to form an oddly shaped dome. This type of structure was small and its thick walls retained heat well.

The yurt may be as old as the beehive house. It was used by people living in Central Asia. These people were nomads; they traveled from place to place in order to find new sources of food for themselves and their livestock. Some people still follow these traditions today. The yurts in which they live are a form of tent that is covered with animal skins or brightly colored woven rugs. These coverings insulate the interior of the yurt from the cold air outside.

In eastern regions of North America some groups of people lived in longhouses. These structures were made of wood and were between 40 (12 m) and 330 (100 m) feet long, but never wider than 25 feet (8 m).[1] The long structure was only one story tall and was divided into many small stalls along the sides. Each family lived in a stall and shared fires that were built in a row down the center of the longhouse. The high walls of the stalls broke up any breezes that might have traveled through the long, narrow building and retained the heat inside. The people living in these structures were known as the Iroquois.

In the northern regions of North America and Greenland, people known as the Inuit constructed shelters made from snow and ice. These shelters are known as igloos and are still used today. Mainly temporary, they are designed to keep people warm while they are on fishing and hunting expeditions in the Arctic. Igloos are made by stacking blocks of very firmly packed snow in a spiral pattern to form a dome. The thickness of the blocks insulates the interior of the igloo, retaining any heat inside. The Inuit also learned how to create insulating windows without losing a great deal of heat by placing a clear piece of ice in a hole between the blocks of snow. The Inuit keep icy drafts from blowing into the igloo by hanging a piece of sealskin over the passageway to the door.

In the southwestern United States, some people, referred to today as Pueblo, lived in cliff dwellings. These multistory houses were built into caves and under rock overhangs on cliffsides. The Pueblo people lived in these dwellings between 700 and 1,000 years ago. These dwellings were made primarily of stone and often faced south or southwest so that they could absorb the most heat from the Sun.

Keeping People Cool

In the ancient Middle East and in ancient Greece, a structure known as a megaron was designed. This structure consisted of an open porch, a small entrance hall, and a main hall where a fire could be built. The

[1] *Encyclopedia Britannica.*

open porch allowed breezes to flow through it, while also providing shade from the hot Sun. The main hall served as the living space and allowed air to circulate, cooling its inhabitants.

Many Mediterranean cultures learned a simple way to reflect the Sun's rays: whitewashing. Whitewash is a mixture of lime (which comes from limestone) and water. The mixture is painted on the sides of the buildings to form a white surface that is highly reflective. The whitewash keeps most of the Sun's heat from reaching the inside the buildings. The dwellings stay cool within while the hot Sun glares outside.

Cultures in southeast Asia also learned how to keep their shelters cool. The walls of their dwellings do not reach the roof. The gap between the wall and the roof, known as a clerestory, allows rising hot air to escape. The rising and escaping motion creates a convection current in the air that constantly cools the interior.

Houses of Today

In modern times, air conditioners, fans, and elaborate heating and cooling systems, often called climate control systems, govern the temperatures of our buildings. Climate control systems use electricity or fuel to heat or cool the air, then to circulate the air around the building. Many buildings today do not even have windows that open!

People are now thinking about ways to combine the heating and cooling methods of the past with modern methods to find less expensive solutions to the problem of keeping shelters at a comfortable temperature. Houses designed and built today often use many old methods of keeping warm or cool air inside. Insulation is often used for both purposes. Air flow patterns are created that circulate either warm or cold air to the areas where people live. Houses are even placed at the proper angles so that they collect the most sunlight or avoid it. The structures that use the old methods of heating and cooling are referred to by architects as "sustainable designs."

In the future, as we explore areas beyond our own planet, we need to think about how heating and cooling processes work in areas with very little or no atmosphere. Astronauts are comfortable inside their spacecraft, but outside temperatures can soar to hundreds of degrees or plummet well below freezing. Insulation, reflection, and air flow are very important considerations when designing structures for use in space, or perhaps someday, on other planets.

Class Preparation and Set-Up

Module Materials

Materials for Solar House

- Aluminum foil, 3 × 5 inch (7.6 × 12.7 cm) pieces
- Balsa wood, 3 × 5 inch (7.6 × 12.7 cm) pieces, 1/8 inch (3 mm) thick
- Styrofoam™, 3 × 5 inch (7.6 × 12.7 cm) pieces, 1/8 inch (3 mm) thick
- Paper, various qualities and colors, 3 × 5 inch (7.6 × 12.7 cm) pieces
- Cardboard, corrugated and plain, 3 × 5 inch (7.6 × 12.7 cm) pieces
- White Index cards, 3 × 5 inch (7.6 × 12.7 cm) size
- Cellophane tape, 3/4 inch (2 cm) (one roll per team)
- Overhead transparencies or clear acetate sheets cut into 3 × 5 inch (7.6 × 12.7 cm) pieces (at least one per team)
- Preliminary Data Sheet
- Design Sheet
- Data Sheet
- Summary Sheet
- Rulers
- Scissors

NOTE: Amounts of each material for each challenge are found in the challenges themselves.

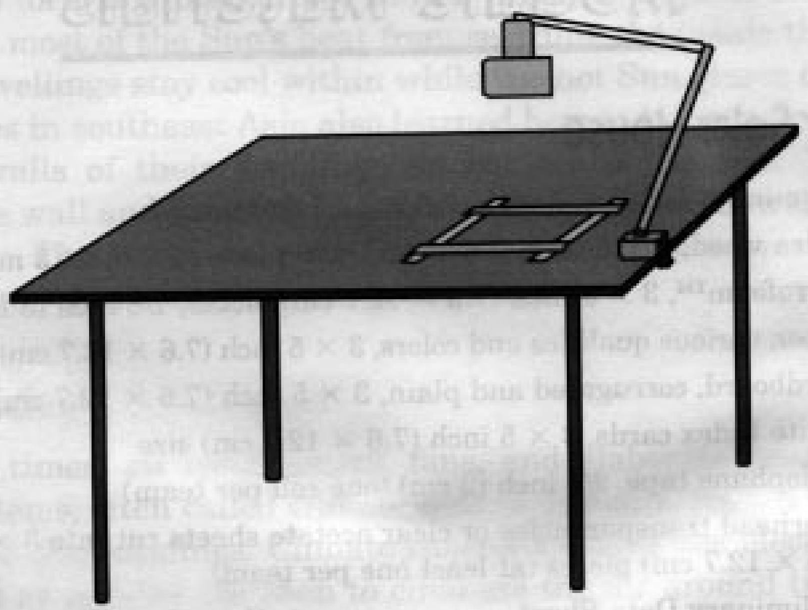
Materials for Testing Station

- Extension cord
- Duct tape, use to tape extension cord to the floor
- Light bulb, 100-watt frosted, incandescent
- Adjustable light fixture OR adjustable ring stand and clamp lamp with reflector[1]
- 2 or 3 alcohol thermometers (0°–50°C), shorter than 5 inches (12.7 cm) long (maximum size to fit into shelter)
- Index card, 3 × 5 inch (7.6 × 12.7 cm) (as a support for the thermometer)
- Jumbo paper clips, 2 per thermometer (use to attach thermometer to index card stand)
- Cup with room temperature water (use to cool down thermometers)
- Stopwatch or timer
- Masking tape, 1 inch (2.5 cm) wide (2 rolls)

[1] See **WARNINGS and Trobleshooting Tips** on page 16.

Construction

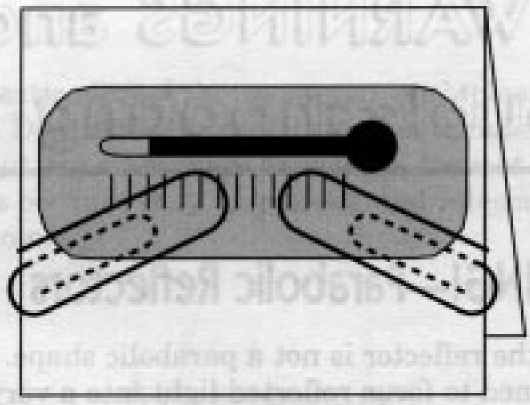
Creating the Test Station



1. Define an area on the table surface where the testing is to be done. Using masking tape, mark a 3 × 5 inch (7.6 × 12.7 cm) rectangle on the table.
2. Position the lamp to shine directly down on the 3 × 5 inch (7.6 × 12.7 cm) rectangle. Adjust the lamp height with each new test so that the bulb (heat source) is 9 inches (22.9 cm) from the top of the solar house roof.
3. Be sure to conduct a test trial of all materials provided to the students prior to student testing to make sure that materials do not scorch or burn.
4. The same test station is used for all three challenges. Depending on class size and availability of equipment, you may want to set up two or more identical test stations.

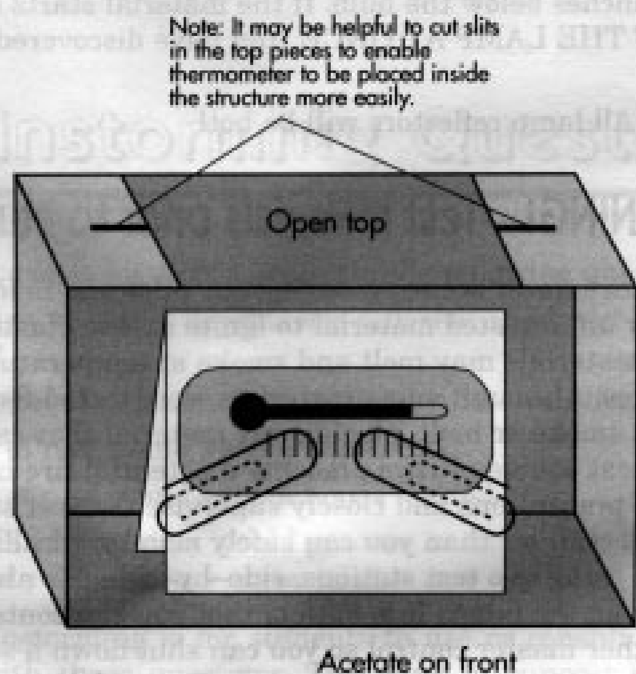
Thermometer Stand

1. Create a thermometer stand. Fold a 3 × 5 inch (7.6 × 12.7 cm) card in half and secure a thermometer horizontally to it using two jumbo paper clips so that the thermometer is elevated above the table surface.
2. Use more than one thermometer to expedite the testing process. Alternate thermometers so that each one can return to room temperature between tests.



Standard Base for the Solar House

All shelters must utilize the standard base as shown in the diagram:



1. Tape two 3 × 5 inch (7.6 × 12.7 cm) index cards together along the 5 inch (12.7 cm) side to create the floor and back wall. Tape one 3 × 5 inch (7.6 × 12.7 cm) piece of clear acetate to the floor to create a front wall (the viewing window).
2. To form the side pieces, measure one inch in from the ends of two more 3 × 5 inch (7.6 × 12.7 cm) cards. Draw a line across the ends of the cards at the one inch marks and fold the edges up along the lines.
3. Tape the side pieces to the floor and walls assembly. The one inch flaps will fit over the top and bottom of the assembly while the remaining 3 × 3 inch (7.6 × 7.6 cm) sections form the side walls.
4. Place the thermometer stand in the house structure to make sure that it will fit properly and that you can read it without disturbing the structure.

WARNINGS and Troubleshooting Tips

FIRE HAZARD WARNING!—Parabolic Reflectors

- Be sure that the reflector is not a parabolic shape. Parabolic reflectors are designed to focus reflected light into a very small area and thus can generate very high temperatures quickly. Only certain kinds of reflectors with a curved "bowl" shape are parabolic types. If your reflectors are flat-sided, like standard lamp shades, they are not parabolic. Test any curved reflector by placing a bulb in it, turning the light on, and placing a piece of paper or other flammable material 8 inches below the bulb. If the material starts to smoke, TURN OFF THE LAMP AT ONCE. You have discovered a parabolic reflector!
- CAUTION: All lamp reflectors will be hot!

FIRE HAZARD WARNING!—Test materials prior to student use

- Although a fire never occurred during our pilot and field trials, the potential for an untested material to ignite exists. Plastic insulation or packing materials may melt and smoke at temperatures within the test range. Although many materials were tested for this module that did not smoke or melt, placing any material that can burn beneath a heat source always presents a potential fire hazard. Take appropriate precautions and closely supervise the test stations. Use no more test stations than you can safely monitor at all times. We recommend using two test stations, side–by–side. We also recommend plugging the lamps into outlets that you can control by a wall switch or other master control so you can shut down a station quickly. Make sure that the test stations are not between you and the classroom fire extinguisher.

TOXIC FUMES WARNING!—Test materials prior to student use

- Many materials will emit hazardous gases when heated. Do not heat materials for longer than the three-minute test trial. Do not lower the lamp to less than 9 inches (22.9 cm) from the test surface. Avoid materials that are not in the Module Materials list presented earlier in this section. If you are unsure about the toxicity of a material when it is heated, do not use it.

Thermometer

- Inexpensive, plastic alcohol thermometers with plastic bases seem to work very well. Digital thermometers with a temperature probe are also effective, but are often more expensive. **Do not use mercury thermometers** because they may break and release toxic mercury into the classroom.

Pretest

Before constructing the standard design, administer the Pretest to determine students' thoughts about heat transfer.

Brainstorming Questions

Lead a class discussion by asking students the following questions:

- Do you think that roof designs are different in Mexico than they are in Alaska?
- What types of roof designs are common where you live?
- What sort of roof would keep a house cool?
- What sort of roof would keep a house warm?
- What kinds of materials would you use to make a roof for a house? Why would you use these materials?

The goal of brainstorming is for students to use or consult their experiences when dealing with these questions. This kind of support helps develop the expectation that understanding begins with challenging one's own experiences. If students suspect that the goal is to guess what the teachers want, then students are missing a necessary experience to advance their understanding.

Challenge 1

Cool House

Challenge Objective

Construct a roof that will allow the interior of the standard base to maintain the coolest temperature possible during a 3-minute heating trial. Materials are provided by the teacher but only combinations of two materials at a time may be used in any one trial.

Challenge Scenario

You and your team are shipwrecked! You're on an atoll (a tiny, flat, ring-shaped island with little or no plant life) in the North Pacific Ocean, just above the equator. It is very hot, and no trees or plants grow on the atoll to provide shelter from the Sun.

The remains of a very large packing crate perched on its side lie at the far end of the beach. Its previous contents, food and other items, are scattered along the shore. The bottom and three sides of the crate are still intact, but the side facing up is gone. It is too heavy to be moved or turned over. Your goal is to use the materials that have washed up on shore to construct a flat roof that will cover the crate so that the temperature inside will remain cool under the hot Sun.

Materials

- Aluminum foil, 3 × 5 inch (7.6 × 12.7 cm) pieces
- Balsa wood, 3 × 5 inch (7.6 × 12.7 cm) pieces, 1/8 inch (3 mm) thick
- Styrofoam™, 3 × 5 inch (7.6 × 12.7 cm) pieces, 1/8 inch (3 mm) thick
- Paper, various qualities and colors, 3 × 5 inch (7.6 × 12.7 cm) pieces
- Cardboard, corrugated and plain, 3 × 5 inch (7.6 × 12.7 cm) pieces
- White Index cards, 3 × 5 inch (7.6 × 12.7 cm) size
- Cellophane tape, 3/4 inch (2 cm) (one roll per team)
- Overhead transparencies or clear acetate sheets cut into 3 × 5 inch (7.6 × 12.7 cm) pieces (at least one per team)
- Preliminary Data Sheet (one per team)
- Design Sheet (one per team for each design)
- Data Sheet (one per team for each design)
- Summary Sheet (one per team)

Troubleshooting Tips

Mark fold lines on the index cards that are to become the sides of the standard base prior to giving them to students. This will help students to fold them more quickly and accurately.

Caution

Inspect all available materials prior to their use by students and test them for flammability.

Procedures

Set-Up

Construct and display an example of a flat roof on the standard base so that students can observe its design and performance.

Demonstration

Show students the example flat roof design and demonstrate how the solar house test operates by measuring the internal temperature.

Class Discussion

Ask students to explain how they think the flat roof design functions. Ask them to speculate on how to alter its performance through design changes.

Cooperative Learning Groups

Challenge student teams to design a flat roof that will remain the coolest under a heat source.

Instructions to Students

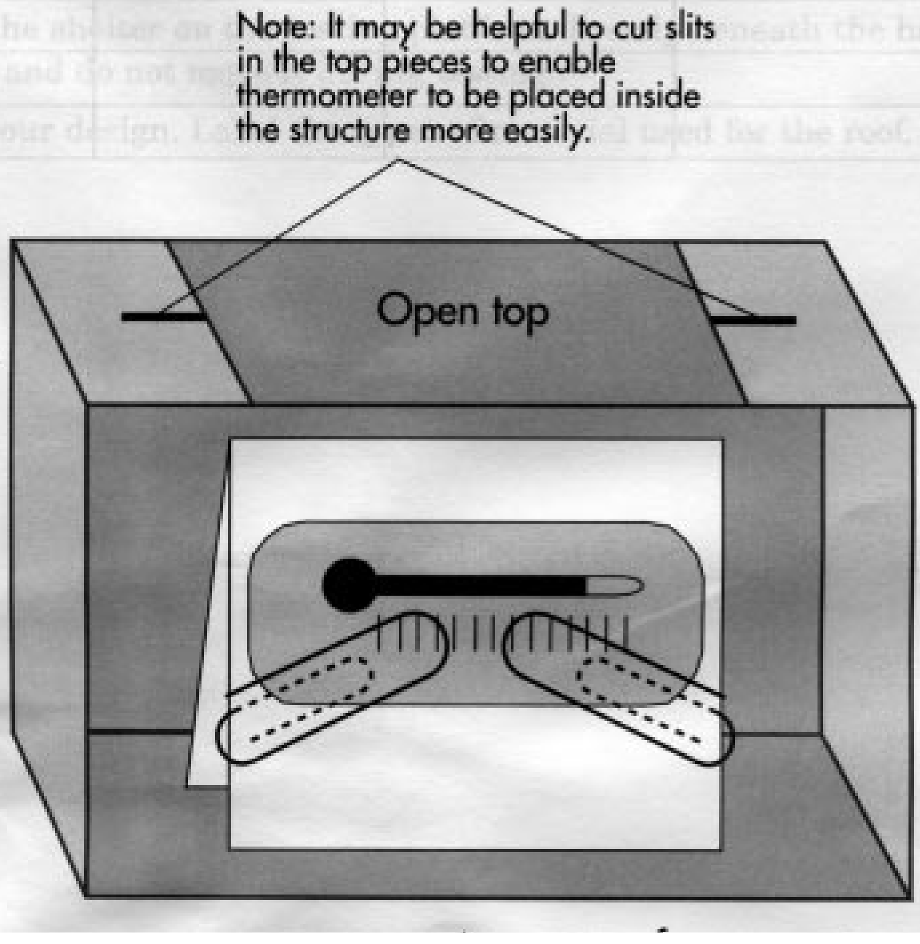
1. Construct the standard base to be used in all of the challenges.
2. Construct a flat roof for the base. The roof must measure 3 × 5 inches (7.6 × 12.7 cm).
3. Test each material for the roof individually and record the initial temperature and the temperature after three minutes on the Preliminary Data Sheet.
4. Construct the best roof for keeping the standard base cool by layering different materials. You may only combine two types of materials at a time. Complete a Design Sheet before testing the design.
5. Test the shelter at the test station and fill in the table on the Data Sheet. Be sure to record the temperature in the shelter before turning on the light. Record the temperature every 30 seconds for 3 minutes once the light in the test station is on.
6. After at least three iterations, review all of your results and summarize them on the Summary Sheet.

Cool House

TEAM NAME: **DATE:**

You must build and test at least three different roof designs.

1. Build a shelter base by carefully following the directions in the diagram. You will recycle this base for all of the designs in this challenge.
   - The shelter must cover the standard base as shown in the diagram. You may not trim the 3 × 5 inch (7.6 × 12.7 cm) plastic piece to a smaller size.
   - The thermometer must fit inside the shelter so that you can read it from the outside without disturbing the base.



2. Individually test all of the roof materials provided by your teacher. You must note the starting temperature, then the temperature after three minutes. Record the results of your test in the table below, and calculate the difference in temperature between the start and the end of the test. This difference is known as ΔT (delta T).

Roof material	Start Temperature	End Temperature	ΔT
Aluminum foil			
Corrugated cardboard			
Black construction paper			
Yellow construction paper			
Styrofoam™			
Balsa wood			
Cardboard			
Clear acetate			

Challenge 1: Design Sheet

Cool House

TEAM NAME: **DATE:**

DESIGN ITERATION #:

1. Construct a roof out of the approved materials. The roof and shelter should meet all of the following criteria when assembled:
   - The flat roof can measure no larger than 3 × 5 inch (7.6 × 12.7 cm).
   - You may combine two types of materials in any single roof design.
   - Each test roof must use the same standard base.
   - There must always be a 9 inch (22.9 cm) clearance between the bulb and the top of the roof. If necessary, adjust the lamp height to maintain this clearance.
   - Place the shelter on the testing platform directly beneath the heat source and do not move it during testing.
2. Sketch your design. Label the types of material used for the roof.

3. Describe your design.

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____

4. How is it different from your previous design?

____

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5. What do you think the total temperature change between the start and the end of the test will be?

____

____

Challenge 1: Data Sheet

Cool House

TEAM NAME: **DATE:**

DESIGN ITERATION #:

1. Test your design. Use the data table below to record the test results at 30-second intervals:

Material A: ______________

Material B: ______________

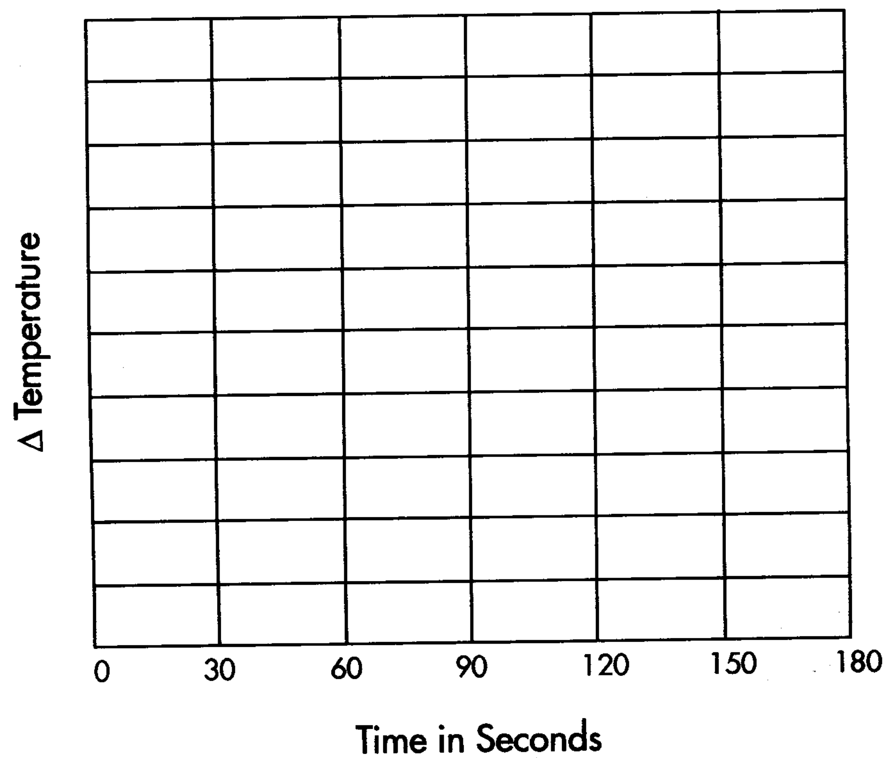
TEST RESULTS	Temperature	ΔT (Change from initial temperature)
Start		
30 seconds		
60 seconds		
90 seconds		
120 seconds		
150 seconds		
180 seconds		

What was the final value of ΔT from the time you started the test to the time that it was completed?

____

Write this number on the roof of the model.

Make a line graph of your temperature data. Remember to label the vertical axis.



- Describe how or why the design succeeded or failed.

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- Was this design an improvement over the last design? Explain how it was or was not an improvement.