Passive Solar Design for Homes

RENEWABLE ENERGY
THE INFINITE POWER
OF TEXAS

For Grades 6, 7 and 8

OVERVIEW

In this unit students will learn about using the right type of materials in a home that conserves energy and the importance of building orientation and window sizing. Students will engage in an activity to measure temperature changes in several thermal storage samples. By the end of the unit, students will appreciate the need to plan construction with proper materials. Students will learn that simple measures, such as landscaping and installing thermal storage, make a big difference in energy consumption.

OBJECTIVES

See Middle School Teacher Resource Guide for TEKS objectives and additional information regarding this and other middle school units.

SUGGESTED TIMEFRAME

Teacher will need to determine how many class periods to devote to each activity, based on the suggested timeframe and length of classes.

Time	Activity	Content Area
10 minutes	**Activity 1** – Teacher Introduction	
15 minutes	**Activity 2** – Assessment of Current Student Knowledge	Science
45 minutes	**Activity 3** – Reading Passage and Vocabulary	Reading Vocabulary
	Homework Assignment – Sentences with Vocabulary	Language Arts
30 minutes	**Activity 4** – Pre-Lab	Science
60 minutes	**Activity 5** – Lab	
30 minutes	**Activity 6** – Post-Lab	Science
30 minutes	**Activity 7** – Assessment	Science

REQUIRED MATERIALS

- copy of the Reading Passage and Student Data Sheets (includes reading comprehension questions, vocabulary and Lab Activity) for each student
- copy of the Assessment Questions for each student
- graph paper
- an equipment kit for each group containing the following items:
  - 200 ml each of optional materials to test, such as water, packed sand, shredded paper, powdered cement, mortar, plaster, rock, etc, (students will measure each into a separate beaker)
  - 3 small thermometers (non-mercury recommended)
  - 1 lab thermometer (non-mercury recommended
  - 3 beakers to hold test materials
  - 1 liter of ice water OR
  - 1 liter of hot water at 85° C approximate, (hot from tap)
  - container to hold beakers (cake pans work well)
  - goggles
  - gloves

SUMMARY OF ACTIVITIES

Activity 1 – Teacher Introduction (10 minutes)

Explain to the class that for the next unit of study, they will be learning about passive solar energy and how these principles can be used in our homes and other buildings. They will be introduced to using appropriate building materials and choosing appropriate design options, such as the position of the building relative to the sun and landscaping. The purpose of the Lab Activity is to test the thermal storage capabilities of several materials that could be used as thermal mass, such as sand, shredded paper and powdered cement, mortar or plaster. Each test material will first be contained in a test beaker and then placed in either a hot water bath or a cold water bath. The effect of the hot or cold water on the test material will be gauged by taking temperature readings of the test material at 1-minute intervals for 10 minutes. Test materials with small changes in temperature will have the better thermal storage capabilities than materials with greater temperature changes.

Activity 2 – Assessment of Current Student Knowledge (15 minutes)

To assess what students already know, prompt a class discussion based on the 4 questions listed below. Based on this discussion, create and display a graphic organizer of the points that were discussed, which can be displayed throughout the unit of study. Refer to the Teacher Resource Guide for a sample bubble graph.

1. What does it mean to use proper building materials to conserve energy in the home? What are examples of these proper building materials?
2. Why would the position of a building relative to the sun be important for the building's heating and cooling needs?
3. Do you think that homes in Texas can be designed to be solar homes?
4. What impact would natural shading and landscaping have on helping to cool or heat a home?

See Teacher Resource Guide for alternative or additional assessment activity.

Activity 3 – Vocabulary and Reading Passage (45 minutes)

Each student will need a copy of the Reading Passage and the Student Data Sheets, which include reading comprehension questions, vocabulary words and the Lab Activity. (As an alternative to making copies, the Student Data Sheets can be displayed so the entire class can view them and copy the information into their science notebook.) Instruct students to study the Reading Passage and complete the questions and vocabulary. This activity will help them learn about passive solar design and prepare them for the Lab Activity in which they will test the thermal storage capabilities of several materials. Key vocabulary words in the Reading Passage will assist them in understanding the Lab Activity instructions. For students who wish to learn more of the detailed principles about passive solar design, direct them to the appropriate resources. Suggested resources are included in the Teacher Resource Guide. At the end of this activity, collect and grade the student's work. Return their graded work the following day.

Homework Assignment – Key Vocabulary List

1. Instruct students to create in their science notebooks meaningful sentences that reflect an understanding of the definition of each vocabulary word. Students should have written the definition of the words in their science notebooks during class. See Teacher Resource Guide for alternative vocabulary homework.
2. Collect and grade this assignment the next day.

Activity 4 – Pre-Lab (30 minutes)

1. Explain to the class that the purpose of the Lab Activity is to test the thermal storage capabilities of several materials that could be used as thermal mass, such as sand, shredded paper and powdered cement, mortar or plaster. For teachers interested in exploring scientific inquiry more fully as it applies to this Lab, see the Teacher Resource Guide for guidelines. Before performing the lab, students can be given the lab instructions to read and summarize the steps involved. The summary can be in the form of a brief chart. Review safety guidelines before students conduct the lab. See Teacher Resource Guide for general safety guidelines. Demonstrate proper use and care of the equipment used in the activity.
2. Divide the class into small groups to test their materials and conduct the activity. To ensure that all students participate, instruct the groups to assign who will be responsible for each step in the activity before beginning.

Activity 5 – Lab Activity (60 minutes)

1. Instruct each group to obtain the materials for one Lab Activity kit. The materials include hot and cold water to use as the water baths. The teacher should decide if each group will test the materials with hot and cold water or if each group will be assigned hot or cold water. The data tables can be modified accordingly.
2. Confirm that the students have recorded their time measurements on their Lab Report Form, as well as answers and calculations to the lab questions.

Suggestions

1. Before conducting the activity, the teacher should gather the test materials for the class (sand, shredded paper, powdered cement, etc.) and store them in buckets, dishpans or other similar containers and label their contents. Before returning tested materials to their original containers so other groups/classes may test them, some materials, like sand should be transferred to a temporary container so it can return to room temperature. They may be cold or warm for a while as a result of the experiment. Dense materials gain and lose heat slowly.
2. Students should not try forcing a thermometer through a dense material, such as sand or cement, because the thermometer may break. Demonstrate how students can pour a portion of the dense material into the beaker, place the thermometer in the beaker, and then continue pouring the material in the beaker around the thermometer.
3. To obtain the correct amount of materials, students can estimate the 200 ml of sand or other materials in a 250 ml beaker.
4. Graphs that can be created from this activity include:
   a) Time vs. Temperature Measurement of Each Material (line graph)
   b) Material vs. Total Temperature Change of Each Material (bar graph)

Sample observations

See Figures 1 and 2 for sample graphs that can be created.

See Tables 1 and 2 for sample data obtained for this activity.

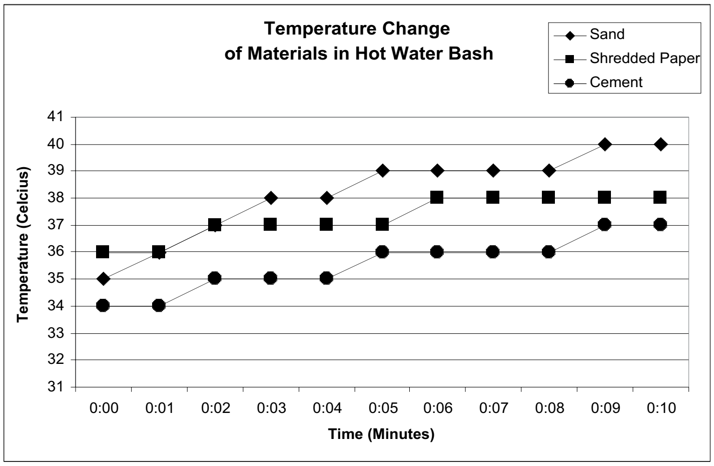

Figure 1. *Sample graph: Time vs. Temperature Measurement of Each Material*

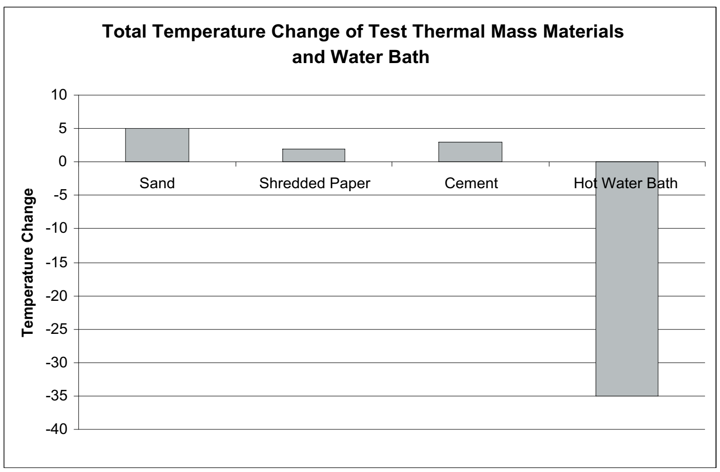

Figure 2. *Sample graph: Material vs. Total Temperature Change of Each Material*

Activity 6 – Post Lab (30 minutes)

After students have completed their Lab Report Forms and have created graphs, discuss their results and their answers to the lab report questions.

Activity 7 – Assessment (30 minutes)

Distribute a copy of the Assessment Questions to each student. Instruct each student to work alone and answer the short answer and multiple-choice questions. Collect the handouts, grade and return them to the students.

ADDITIONAL ACTIVITIES

1. **Using Opposite Temperature Water Bath**
   Have the groups repeat the Lab Activity, using the opposite temperature of water for the bath. If they used hot water during the Lab, have them repeat the activity using ice water and vice versa.
2. **Internet or Library Research**
   Students can research information available on the Internet about passive solar design for buildings. Suggested resources are included in the Teacher Resource Guide. You may divide the class into 4 groups and assign each group to a particular topic. Each group can create a display of the information that they found and provide a short summary of their findings. Suggested group topics include:
   Group 1 – earliest uses of passive solar design in homes
   Group 2 – current areas of the U.S. that are using solar home and green building construction techniques
   Group 3 – commonly used home building materials and alternative building materials that could replace them to create thermal mass
   Group 4 – Trombe wall construction in homes
3. **Collage**
   Collect newspapers and magazines with advertisements from home improvement centers. Ask students to create a collage of the building materials that are advertised for creating floors, walls, fireplaces and other applications where thermal mass could be utilized. The collage should also contain a description of each material and its thermal storage abilities. The color of a particular building material can also be a factor, along with the material itself.

Teacher's Sample Data Table

Table 1. *Temperature Readings (°C) in Hot Water Bath, 2 Minute Intervals*

Minutes	200 ml Cement	200 ml Sand	200 ml Paper	Water Temp.
0	35	35	35	85 (Starting Temp.)
2	39	35	35	75
4	43	36	36	63
6	44	36	36	58
8	45	37	37	52
10	45	37	37	50

Table 2. *Temperature Readings (°C) in Cold Water Bath, 2 Minute Intervals*

Minutes	200 ml Cement	200 ml Sand	200 ml Paper	Water Temp.
0	38	38	38	8 (Starting Temp.)
2	32	38	37	8
4	30	38	37	9
6	28	37	37	9
8	25	35	34	9
10	23	34	33	10

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HIGHLIGHTS

- **Direct or indirect gain, solar heating can save money**
- **House orientation and window sizing are keys to proper design**
- **Thermal storage helps control overheating of spaces**
- **Porches and trees are important elements in solar control**

SUMMARY

Sometimes when architects and builders decide where to locate a home or building on a piece of land, they try to position it so that it can make the most use of the sun's heat in the winter. At the same time, they make sure the building will not be too hot in the summer. Locating and placing a home based on the sun is called "solar orientation." Solar orientation for heating and cooling buildings is not a new idea. Builders in China and Greece were designing buildings that used the sun's heat over 2,000 years ago. Buildings in any climate can take advantage of the sun. All that is required is an interest in using passive solar design in the building. Once this design is chosen, the building basically becomes a large solar collector.

THE SUN AND YOUR HOME

The sun is much lower in the sky during the winter than it is in the summer at most places on Earth. The only exception to this fact is when the location is near the equator. Then the sun remains directly overhead. Solar homes are designed to use the changing position of the sun to benefit the home throughout the year. This is done by allowing the sun to shine into the house in the winter, which heats the home, and by blocking out the sun during the summer, which helps keep the home cooler. To do this, architects and builders must know the exact position of the sun in the sky at various times of the year. Then they can predict the angle that the sun's rays will shine into a home. Using that information, they will know where to place windows and roof overhangs.

DIRECT-GAIN SYSTEM

The simplest way to use passive solar heating is to just let the sun shine into

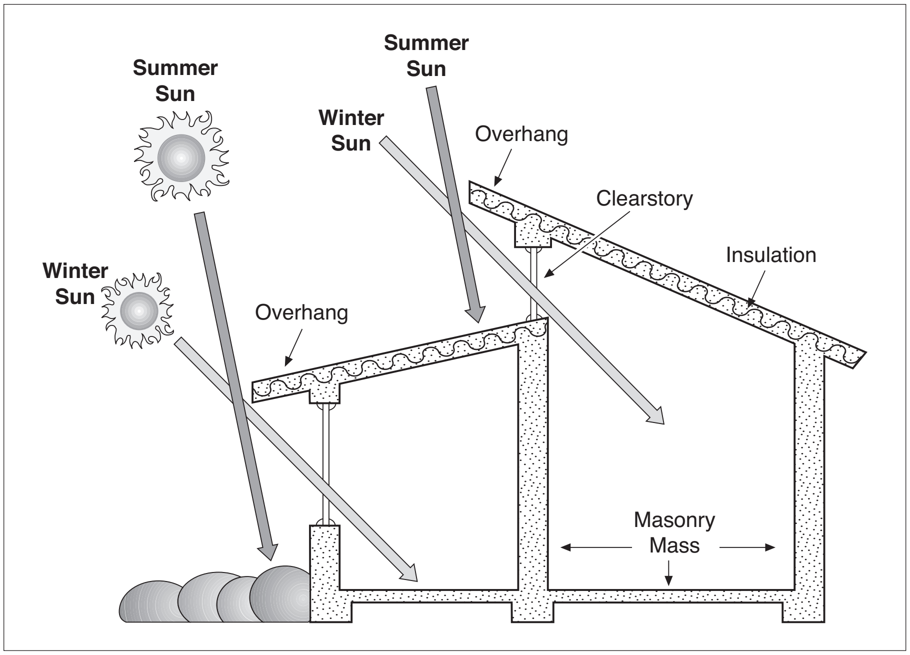


FIG. 1 SUN ANGLES *This diagram shows the direct gain system.*

the home. This is known as a direct gain system. During the winter, a direct gain system uses south-facing windows that allow heat from the sun to enter the home (See Fig. 1). That heat is then stored using thermal mass. Thermal mass is a dense material that gains or looses heat slowly. Examples of thermal mass include concrete, adobe, stone, brick and water. Heat that is stored in the thermal mass is eventually released into the home later when the sun is no longer high in the sky. During the summer, when the sun is higher in the sky, window overhangs block the sun. For Texans, the most important thing to consider is that the home has the right number of south-facing windows. The right number of south-facing windows depends on how big the home is, also known as the square footage of the house. Too many windows will make the home too hot, which could be worse than no windows at all.

When designed correctly, a direct-gain solar home in a Texas city like Amarillo could get 75 percent of the heat it needs from the sun.

INDIRECT-GAIN SYSTEMS

The most common type of indirect system is a greenhouse or sun porch (See Fig. 2). These rooms trap heat from the sun that can be used in other parts of the house. These structures are usually built to provide more living space in the home or as a place to grow plants. They also contain a large amount of thermal mass to help store heat from the sun. This heat can then be used in other parts of the house by natural air movement or by a fan.

During the hot Texas summer, when we want to keep our homes as cool as possible, these structures can be covered with a curtain, shades or blinds. Or we can let the warm air out by opening windows, door or vents.

THERMAL STORAGE

Solar homes work best when they are made with dense material that absorbs and loses heat slowly. These dense materials are known as thermal mass. Examples of thermal mass include water, adobe, insulated concrete slabs, masonry or even a brick fireplace. The

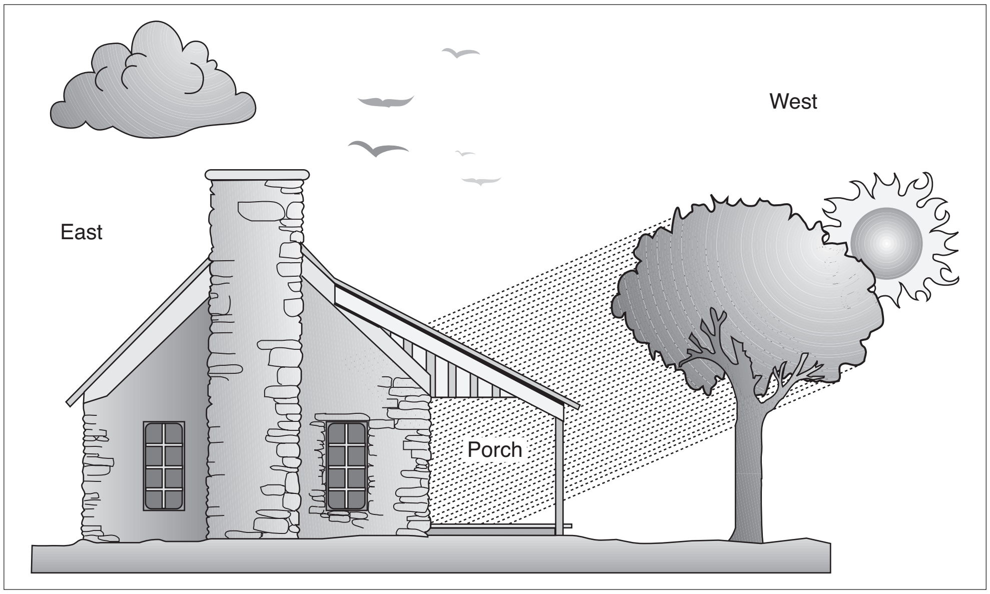


FIG. 2. LANDSCAPING CAN LOWER ENERGY COST *Using natural shading from trees and placing spaces, such as porches and garages, on the west side of the house can lower heating and cooling costs.*

thermal mass absorbs heat during the day when the sun is shining and releases it at night and when it is cloudy outside. Thermal mass also helps prevents homes from getting too hot during the day by absorbing excess heat.

Builders can use thermal mass walls on the south side of homes and cover it with glass. These types of walls have been in use for centuries. These walls are sometimes called Trombe walls named after the French architect Felix Trombe. If the walls are constructed of masonry, small vents can be added in the top and bottom so that warm air from the air space in the wall will move into the home. If the home becomes too warm, the vents can be closed.

In Texas, where cooling is usually more of a problem than heating, vents can be added to thermal walls that will move hot air to the outside during the summer. In addition, if a roof overhang is the right size, it will prevent sunlight from hitting the wall during the hot summer months.

NATURAL SHADING AND LANDSCAPING

Deciduous trees may be considered low-tech, but they are one of the best ways to keep a home cool in the summer and warm in the winter. During the summer, the trees provide shade that blocks the sun and keeps it from making the house warm. In the winter, when the leaves have fallen, sun can shine through the branches and into the home to provide some heat. Studies have shown that when the right type of shade trees, bushes and grass are planted in the right places, energy that is used to cool and heat a home can be reduced by up to 30 percent.

Understanding the Reading Passage

1. What is solar orientation? ______________________________

____

2. What is thermal mass? ______________________________
List 3 examples:
1 ______________________________
2 ______________________________
3 ______________________________

3. How can greenhouses and sun porches help heat and cool our home? ______________________________

____

4. What is a Trombe wall and how can it help heat and cool our home? ______________________________

____

____

5. How can landscaping help heat and cool our home? ______________________________

____

____

6. In your own words, explain how Figure 1 and Figure 2 are similar.

____

____

Vocabulary

Based on the Reading Passage, write down your understanding of these words or word pairs and verify your definitions in a dictionary, on the Internet if available or with your teacher:

architect ______________________________
climate ______________________________
deciduous ______________________________
dense ______________________________
direct gain ______________________________
indirect gain ______________________________
passive solar ______________________________
solar collector ______________________________
thermal mass ______________________________
Trombe wall ______________________________

Lab Activity – Testing Thermal Storage Materials

Introduction

The purpose of this activity is to test the thermal storage capabilities of several materials that could be used as thermal mass.

Before You Start

Review the vocabulary words from the Reading Passage. Ask your teacher if you are unsure of any of the meanings. Divide up all the steps in the Lab Activity first, so that everyone has a clear job to do.

Materials

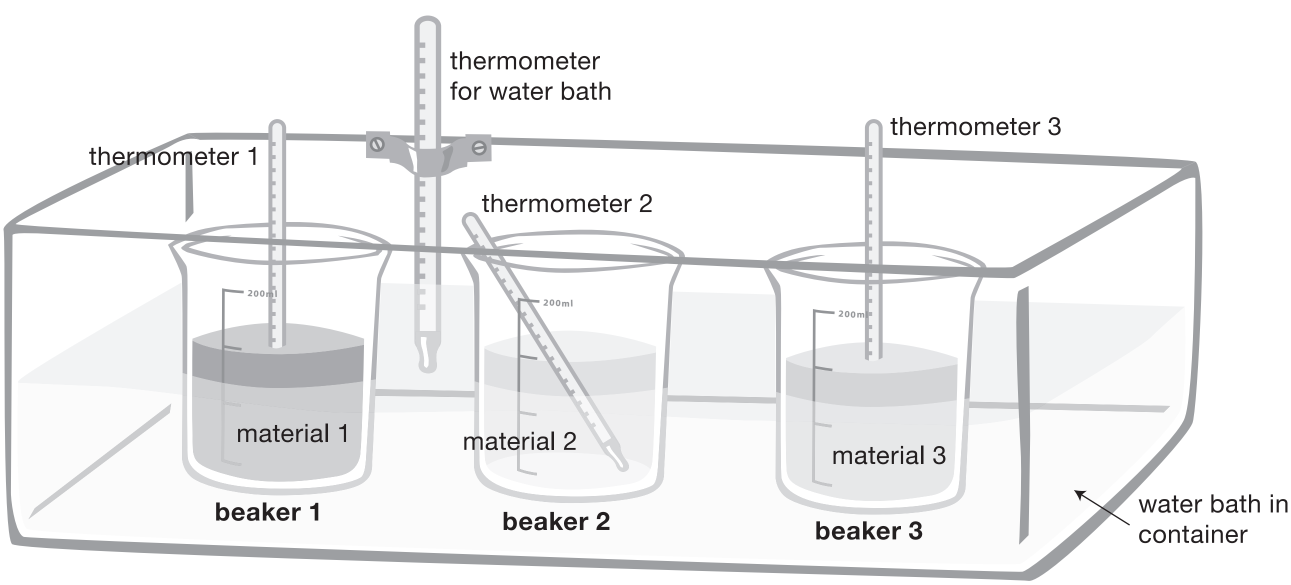
Obtain an equipment kit from your teacher. Check that it contains the following materials:

- 200 ml of any 3 test materials your teacher has prepared
- 3 small thermometers
- 1 lab thermometer
- 3 beakers to hold test materials
- 1 liter of ice water OR
- 1 liter of hot water at 85° C approximate
- container to hold beakers
- goggles
- gloves

Performing the Experiment

(wear goggles, use gloves)

1. As directed by your teacher, obtain 200 ml of each material you will be testing: sand, paper or other material.
2. Place 200 ml of one test material in beaker #1, 200 ml of the second test material in beaker #2, and 200 ml of the third test material in beaker #3. If you are using a more dense material as the teacher instructs, fill the beaker halfway then place the thermometer into the material and finish filling the beaker. You should avoid forcing a thermometer into dense materials because the thermometer may break.
3. Place a small thermometer in each beaker you will test. Be sure the test material covers the bottom of the thermometer.
4. Record the starting temperatures of the test materials on your Data Table.
5. Place your 3 beakers to be tested into the container.
6. Take 1 liter of either hot or cold water as directed by your teacher and pour the water into the container with the 3 standing beakers.
7. Place a separate thermometer in the water bath.
8. Read and record on your Data Table the temperature of the test materials and the water bath every minute for 10 minutes.
9. Dispose of the contents of your beakers as directed by your teacher.



Lab Report Form – Testing Thermal Storage Materials

Date ______________________________

Purpose of this lab is to ______________________________

____

Instructions:

Follow the instructions listed in the Lab Activity and record your measurements in the Data Table below. Once you have completed all the measurements and calculations, answer the questions at the end of this form and create a graph according to your teacher's instructions.

DATA TABLE. Temperature Measurements of Thermal Mass In Water Baths

Time	Material: ________ Temperature of Material	Material: ________ Temperature of Material	Material: ________ Temperature of Material	Temperature of Water
Start				
00:01				
00:02				
00:03				
00:04				
00:05				
00:06				
00:07				
00:08				
00:09				
00:10				
Total Temperature Change				

1. Which material retained its initial temperature the longest? ______________________________
2. Which material changed its initial temperature the quickest? ______________________________
3. How did this lab help you determine how thermal storage works? ______________________________

   ____
4. According to your teacher's instructions, create a graph with the data you have collected.

Assessment Questions

1. What local materials do you think would provide good thermal mass?

____

____

2. Which material used in the activity kept its starting temperature the longest? ____________

   Why? _______________________________________

3. How is landscaping used in an energy efficient home design?

____

____

Multiple Choice Questions

1. Passive solar design:
   a) is useful in all climates
   b) depends on proper house orientation
   c) can save you money
   d) all answers a, b, and c

2. The sun is:
   a) higher in the sky in winter
   b) the same height in winter and summer
   c) lower in the sky in winter
   d) lower in the sky in summer

3. The direct-gain system is dependent on:
   a) south-facing design
   b) correct sun angles
   c) any sun angle
   d) answers a and b

4. An example of thermal mass is:
   a) adobe
   b) styrofoam
   c) shade
   d) glass

5. Landscaping can:
   a) change the sun's position
   b) be thermal storage system
   c) be a direct gain glazing
   d) reduce energy costs

6. The Trombe wall is:
   a) a fire wall
   b) a glass covered thermal mass wall
   c) vented on top and bottom
   d) b and c

7. Deciduous means:
   a) evergreen
   b) indecisive
   c) losing leaves in autumn
   d) a flowering bush

8. Solar contribution is greatest in
   a) Lufkin and Corpus Christi
   b) El Paso and Lubbock
   c) Brownsville
   d) Houston

9. Generally in Texas:
   a) Cooling is more of a problem than heating.
   b) Having east-facing windows is important.
   c) Porches are unnecessary for shade.
   d) a and b

10. In order to keep a home cooler:
    a) shade trees are used
    b) blinds for windows are shut during the day
    c) hot air spaces are allowed to be vented
    d) all answers a, b, and c

Understanding the Reading Passage

1. Solar orientation is locating and positioning a home on a piece of land so that it takes advantage of the sun for its heating and cooling needs.
2. Thermal mass is a material that gains and loses heat slowly. Examples include concrete, brick, tile, etc.
3. They contain a large amount of thermal mass that can help store heat from the sun and can be enhanced by adding a fan to distribute air to different parts of the house.
4. A thermal mass wall on the south side of a home that is covered in glass allows heat to be collected and stored. The heat can be circulated to the home by natural air movement or by vents.
5. Deciduous trees and bushes can prevent the sun from entering and heating a home thereby keeping the home cool. In the winter their bare branches allow sunlight in the home to keep it warm.
6. Accept students' answers. Both Figures show how a house design can impact the amount of solar heat on a home.

Assessment Questions

1. The local materials will vary among concrete, brick, adobe, etc.
2. Answers will vary depending on lab results. In general, more dense materials will retain their starting temperature the longest.
3. Well planned landscaping with deciduous trees can provide shade, especially on the west side of the house in the summer, and can allow sunlight to filter into the home in the winter. Plants and grass around the home are cooler than rocks and concrete, which create thermal mass in the yard, making the house hotter.

Multiple Choice Questions

1 d; 2 c; 3 d; 4 a; 5 d; 6 d; 7 c; 8 b; 9 a; 10 d

Vocabulary Definitions

architect – a person who designs buildings

climate – the weather pattern in a region over a long period of time

deciduous – a tree whose leaves shed each year at the end of the period of growth, often in autumn

dense – thick, packed closely together

direct-gain – solar radiation directly entering and heating living spaces, such as south-facing windows that admit heat from the winter sun and warm the room's air

indirect-gain – storing or trapping heat so that it can be used in other parts of a building, such as a room with a substantial amount of thermal mass (concrete, adobe, brick, water, etc.), with many windows through which the thermal mass captures the heat from the sun and releases the stored heat at night

passive solar – using or capturing solar energy without any external power

solar collector – device that collects solar radiation and converts it into heat energy

thermal mass – a dense material that gains or loses heat slowly; examples are concrete, adobe, stone, brick and water

Trombe wall – a glass covered thermal mass wall on the south side of a home that uses small vents in the top and bottom to allow warm air to flow into the house

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RENEWABLE ENERGY
THE INFINITE POWER
OF TEXAS

State Energy Conservation Office
111 East 17th Street, Room 1114
Austin, Texas 78774
Ph. 800.531.5441 ext 31796
www.InfinitePower.org

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