Let the Sun Shine In

Summary: Students calculate how much solar energy contributes to their home or school heating.

Objectives

Students will be able to

- list the factors that affect the solar heat gain of their home or school; and
- determine the amount of solar heat gained through windows.

Rationale

As future homeowners, students need to understand heating and cooling principles including the impacts of sun angle on solar heat gain.

Materials

- Copies of ***Solar Windows, Data Table 1***, and ***Data Table 2***
- Compass–magnetic
- Tape measure
- Calculator

Getting Ready

You'll need to know the cost of natural gas, fuel oil, and electricity for your area.

Background

Every building collects solar energy. Sunlight falls on the house or building, passes through windows, and is absorbed by the roof and walls. This is called passive solar heating. It can help heat a home in the winter months, but it can overheat in the summer months. Often, homes are built with little consideration to their orientation to the sun or the placement of windows; but, with careful design and construction of a home, one can optimize the heat gain in the winter, while preventing heat gain in the summer.

The amount of solar heat gain depends upon seven basic factors: latitude, season of the year and weather, aperture, absorber, thermal mass, air distribution, and temperature control. Cloud cover, the type of window glazing, and shading of windows, also influence solar heat gain.

Latitude: The sun shines at different angles depending on the location of the structure. In Wisconsin, we live at about 44° north latitude.

Seasons: Earth's axis is tilted at an angle of 23.5 degrees and points in the same direction as it revolves around the sun. This inclination of Earth's axis affects the amount of sunlight different parts of Earth receive throughout the year. Wisconsin is in the northern hemisphere which tilts toward the sun during and around the month of June resulting in the summer season. In winter the sun's rays are less direct. Therefore, there is more potential for solar gain for Wisconsinites in the summer.

Aperture: Otherwise known as the collector, the aperture is the area where the sunlight enters the building. Large, south-facing windows collect the most sunlight throughout the year.

Absorber: When sunlight hits a surface, it absorbs heat. Think about a sunny spot on the floor of your home on a cold day. That "sun spot" is nice and warm, right? It is warm because it holds the sun's heat; we call such things absorbers. Darker surfaces absorb more heat than light colored surfaces.

Thermal Mass: Material that retains or stores the sun's heat when it strikes an absorber is called the thermal mass. It is usually below or behind the surface or absorber.

Air Distribution: The way air is circulated around a room, house, or building is by heat transfers. Three natural heat transfer modes include conduction, convection, and radiation. Fans, ducts, and blowers are examples of air distributors. They help the circulation of air.

Temperature Control: Operable vents and dampers, automatic thermostats, window quilts, and landscaping techniques are all examples of how temperature can be regulated within a structure.

A properly designed passive solar home is not only warmer in the winter, but also cooler in the summer. Taking the above factors into consideration will allow less heat to be transmitted into the building during the summer months when the sun is

Grade Level: 9–12

Subject Areas: English Language Arts, Mathematics, Science, Technology Education

Setting: Classroom

Time:
Preparation: 45 minutes
Activity: Two 50-minute periods

Vocabulary: Absorber, Air distribution, Aperture, British thermal unit (Btu), Clerestory, Conductivity, Convection, Energy efficiency, Heat equivalent, Kilowatt-hour, Latitude, Passive solar heat gain, Radiation, Temperature control, Thermal mass

Major Concept Areas:

Theme II

- Development of energy resources
- Development of renewable energy resources
  - Solar energy

Theme IV

- Management of energy resource use

Standards Addressed:

Wisconsin Model Academic:
MA: A.12.5, A.12.6, B.12.3, D.12.2, D.12.3, E.12.5
SC: A.12.5, B.12.1, B.12.3, B.12.5, C.12.3, C.12.6, D.12.11, E.12.1, G.12.3, G.12.4, H.12.5, H.12.6, H.12.7
TE: A.12.2, A.12.5, A.12.7, B.12.3, B.12.8, C.12.2

Common Core ELA: RST.9-12.3, RST.9-10.7, SL.9-10.1, W.9-12.7

Common Core Math: MP1, MP5, MP6, 5.MD.1, 7.G.6, 7.NS.3, N-Q.1, G-MG.3

NGSS: HSETS1-2, HS-ESS3-2
SEP: Constructing Explanations and Designing Solutions, Engaging in Argument from Evidence
DCI: ESS3.A: Natural Resources, ETS1.C: Optimizing the Design Solution
CCC: Influence of Science, Engineering, and Technology on Society and the Natural World

high in the southern sky and more during winter months when the sun is low in the southern sky. There are several things homeowners can do to create a more energy efficient home just by studying the movement of the sun. For additional information see ***Renewable Energy Fact Sheets*** on the KEEP website.

Procedure

Orientation

Ask students if they have ever seen a cat lying by a sunny window and why they think cats do this. Do students think this sunlight can affect room temperature?

Steps

Caution: This activity will require students to measure the area of windows. Tell the students that all measurements should be taken with caution and from the indoors only.

1. Introduce the term passive solar heating. Why do students think the term "passive" is used and what does it mean? Challenge students to provide examples of active solar energy.

2. Provide students with information on factors that determine passive solar heat gain as described in the **Background**.

3. Explain that they will be measuring the amount of heat a house or school receives from solar gain. Provide students with copies of ***Solar Windows*** and have them complete the activity sheet in groups during class or as homework on their own homes. Make sure students are comfortable using a compass and determining directions with this tool.

4. After students have completed their activity sheets, discuss one or more of the following questions:

- Which window orientation receives the greatest solar heat gain during winter months? Why?
- What fuel is used to heat your home or school? How much more might it cost to heat your home or school from November through March if there were not solar energy entering through the windows?
- What percentage of your total space heating needs is supplied by solar gain? How much money is saved due to solar gain? Is this savings significant? Hint: Divide the figure calculated in question ten of the activity sheet by the total heating cost (solar equivalent divided by your annual fuel cost.)

Closure

Ask students what changes could be made to their home or school to improve its solar heat gain. Remind them of the factors that affect solar heat gain.

Assessment

Formative

- Were the students able to complete the tables accurately?
- Can they list factors that influence solar heat gain?

Summative

Have students design an "ideal" window for solar heat gain during the winter. What qualities would it have? Check to see how students would orient the windows, as well as their design and size.

Extensions

Heat losses through windows are about 12 Btu per square foot per day per degree Fahrenheit for double glazed windows, and 24 Btu for single glazed. Have students find the total window area of a building (e.g., their home) and the number of heating degree days for the months of November, December, January, February, and March. Then have them estimate the windows' heat losses and compare this value with the solar heat gain.

Find the average percentage of sunshine in your area for the winter months. Sources for this information might include *Wisconsin Energy Statistics*, the National Weather Service, or your local weather station. Multiply this percentage by the total solar heat gain from ***Data Table 2***. This will give you a more accurate estimate of the heat gain through your home's windows.

A variation of this investigation is to consider how window orientation contributes to unwanted and expensive heat during the summer. Do south-facing windows gain more or less heat in the summer? How can window shades and awnings prevent unwanted heat gain? Would it be better to have deciduous trees or evergreen trees outside windows? Have students do the ***Connect-the-Dots Portico*** to explore home construction practiced today and in ancient Greece. Clerestory: The term clerestory refers to a part of a building whose windows rise higher than the roofs of adjoining parts of the structure. Pierced by windows, it is chiefly a device for obtaining extra light. It had an early use in certain Egyptian temples, as at Karnak, and was used later in the great halls of Roman basilicas. It became a characteristic element of medieval churches, receiving its fullest development in churches of the Gothic period. Now many buildings incorporate "day lighting" based on clerestory windows. Have students find a building in their community that incorporates day lighting. What benefits are there to this time honored practice?

Final Connection

Use this activity to provide a basis for thinking about solar heating techniques. Then, challenge students to incorporate what they have learned in the cumulative project, "Green Home Design."

Credits

Activity adapted from Solar Energy Project "The Sun's Contribution to Home Heating" pp. 4—1 to 2–12 in Renewable Energy Activities for Earth Science. Albany, N.Y.: Solar Energy Project, State University of New York at Albany for the U.S. Department of Energy under contract number AC01-77CS 34039, n.d.

Solar Windows

1. Using a compass, estimate direction for each room in the test, and record the number of windows facing each direction (N, S, E, W, and NE, NW, SE, SW) in Column A of ***Data Table 1***. Some spaces may be blank, as your home or school may not have windows facing every direction. NOTE: If you are doing this activity at school and the school is large, you may want to limit your measurements to one room or floor. The number of windows is irrelevant.

2. Measure the area of each window in square feet. To do this, multiply the length of each window by its width (area = length × width).

3. Add the areas of the windows facing each direction and record the sums in the spaces provided in Column B. You should now have a record of the total window area facing each direction.

4. Next, multiply each daily solar heat gain listed in Column C by the total window area listed in Column B. You will obtain five monthly values for each of the window orientations. Record these values in Column D.

Additional information:

- Keep in mind that these daily solar heat gains are based on heat coming from consistently sunny days. If you measured the actual heat gained, it would vary from these figures.
- A British thermal unit (Btu) is a unit used to measure heat. One Btu is the amount of heat energy required to raise the temperature of one pound of water one degree Fahrenheit. The heat given off by a lit wooden match is approximately one Btu.
- In this activity, 44° latitude applies to all areas of Wisconsin.

5. In Column D you have listed the total daily solar heat gain for each orientation during each month in Btu. To convert to monthly solar heat gains, multiply each of the values in Column D by the number of days for the month specified. Record these findings in Column E.

6. To determine the solar heat gain for the windows facing each direction throughout the winter months, add the monthly values listed in Column E for each orientation and place the totals in Column F.

7. To obtain the total solar heat gain from all the windows of your home or school throughout the winter months, add the recorded values of Column F and place this figure at the bottom of Column F.

8. Transfer the total heat gain from the bottom of Column F to Column 1 of ***Data Table 2***.

9. Calculate how much natural gas, fuel oil, and electricity would be necessary to supply an amount of heat equal to solar gain through your windows during the winter. (This is called heat equivalent.) To do this, divide the total Btu of solar heat gain by the heat content (number of Btu in each fuel unit). The heat contents of natural gas, fuel oil, and electricity are provided below. Enter the heat equivalent in Column 2 of ***Data Table 2***.

Heat Equivalent Numbers

Fuel		***Heat Content***
1 cubic foot natural gas	=	750 Btu
1 gallon fuel oil	=	89,700 Btu
1 kilowatt-hour electricity	=	3,413 Btu

Calculations:

$$\frac{\text{Btu of solar heat gain}}{\text{Heat content (Btu/unit of fuel)}} = \text{heat equivalent (units of fuel)}$$

Example:

If the solar heat gain is 15 million Btu, divide this by 3,413 to get the heat equivalent for kilowatt-hours of electricity.

$$\frac{\text{15 million Btu of solar heat gain}}{\text{3,413 Btu/kWh of electricity}} = \text{4,395 kWh}$$

10. Using the current fuel costs per unit in your area for natural gas, fuel oil, and electricity, compute the costs of quantities of the fuels determined in step 9. (Ask your teacher for these values.) Record these costs in Column 3 of ***Data Table 2***.

Calculations:

Heat equivalent × cost/unit = cost

Example:

If the heat equivalent is 4,395 kilowatt-hours, and the cost of electricity is $0.15 per kilowatt-hour, then:

4,395 × $0.15/kWh = $659.25

Data Table 1

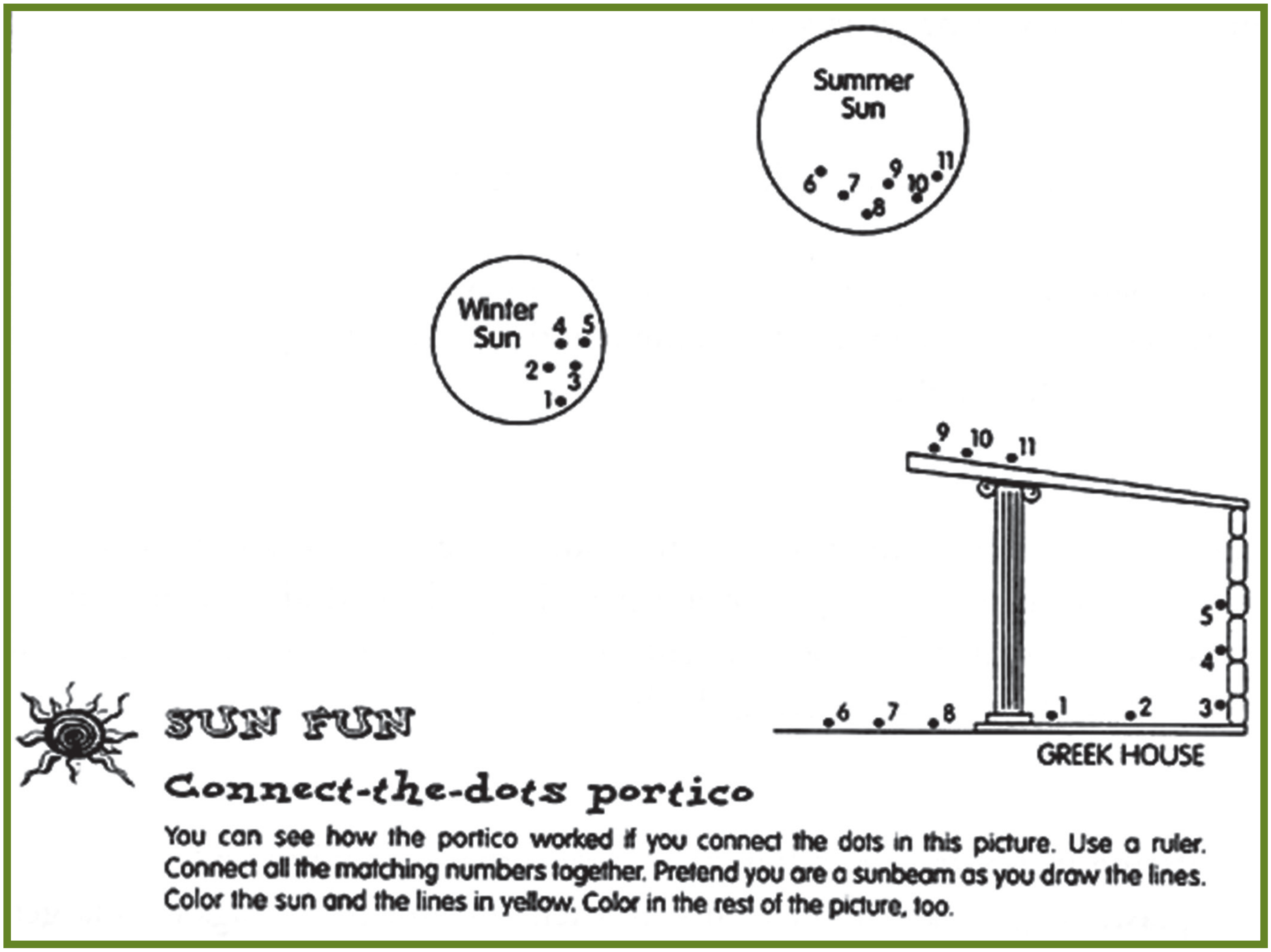
	A	B	C	D	E	F
Window Orientation	Number of windows	Total window area	44° north latitude	Total daily heat gain (Btu)	Total monthly heat gain (Btu)	Winter heat gain for each window orientation
North			Nov–104 Dec–82 Jan–102 Feb–148 Mar–208	Nov Dec Jan Feb Mar	Nov (× 30) Dec (× 31) Jan (× 31) Feb (× 28) Mar (× 31)	Btu
Northeast			Nov–109 Dec–83 Jan–107 Feb–183 Mar–347	Nov Dec Jan Feb Mar	Nov (× 30) Dec (× 31) Jan (× 31) Feb (× 28) Mar (× 31)	Btu
East			Nov–399 Dec–307 Jan–405 Feb–603 Mar–829	Nov Dec Jan Feb Mar	Nov (× 30) Dec (× 31) Jan (× 31) Feb (× 28) Mar (× 31)	Btu
Southeast			Nov–983 Dec–307 Jan–1004 Feb–1148 Mar–1206	Nov Dec Jan Feb Mar	Nov (× 30) Dec (× 31) Jan (× 31) Feb (× 28) Mar (× 31)	Btu
South			Nov–1388 Dec–1292 Jan–1420 Feb–1506 Mar–1342	Nov Dec Jan Feb Mar	Nov (× 30) Dec (× 31) Jan (× 31) Feb (× 28) Mar (× 31)	Btu
Southwest			Nov–983 Dec–307 Jan–1004 Feb–1148 Mar–1206	Nov Dec Jan Feb Mar	Nov (× 30) Dec (× 31) Jan (× 31) Feb (× 28) Mar (× 31)	Btu
West			Nov–399 Dec–307 Jan–405 Feb–603 Mar - 829	Nov Dec Jan Feb Mar	Nov (× 30) Dec (× 31) Jan (× 31) Feb (× 28) Mar (× 31)	Btu
Northwest			Nov–109 Dec–83 Jan–107 Feb–183 Mar–347	Nov Dec Jan Feb Mar	Nov (× 30) Dec (× 31) Jan (× 31) Feb (× 28) Mar (× 31)	Btu
					Total Btu	

Data Table 2

1	2	3
Total Passive Solar Heat Gain	Heat Equivalent	Cost of Heat Equivalent
Total Btu	Cubic Feet of Natural Gas ________________ cubic feet Gallons of Fuel Oil ________________ gallons Kilowatt-hours of Electricity ________________ kWh	Natural Gas @ _______ /cubic foot = $ ________________ Fuel Oil @ _________ /gallon = $ ________________ Electricity @ ________ / kWh = $ ________________

Connect-the-Dots Portico

From Daley, Michael. "Connect-the-Dots Portico" p. 30 in Sun Fun: Amazing Solar Science Activities. Blue Ridge Summit, Penn:



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