Design and Build a Solar House

Introduction

The goal of this engineering project is to construct and test the energy efficiency and solar heat gain of a model house. You will be working with a model rather than a full-sized house, but the principles are the same. This project uses a standard procedure for measuring the thermal performance of a house. For the house to lose heat, there must be a temperature difference. The interior must be warmer than the outside. Since you can't cool down your classroom to 0 °C, you will warm up your house to 10 °C above room temperature. This is done with a heater light bulb inside the house.

As with a real house, what matters is how much of the time the furnace must be on to keep the house warm. The more it's on, the more energy is used per day and the greater your heating bill. To imitate this situation, you will record what percentage of time the heater light bulb must be on to keep the house at 10° C above room temperature.

Finally, you will perform the same test, but with a bright light shining on the house, imitating sunshine. You can then tell how much your energy bill is reduced by "solar heating."

The setting is the temperate climate of the northern United States: hot summers and cold winters, with moderate spring and fall seasons. There is a fair amount of sunshine all year, but of course the angle of the sun and the length of the day change significantly from season to season.

You have two basic strategies are to cut down on heat loss and to gain some heating from the sun during cold months. You are limited to *passive* solar strategies. Designs that depend on collectors, pumps, and fans are called *active* solar collectors and they are not available in this project.

The initial materials will be cardstock, clear acetate, and tape. You must write down a design rationale before you start building and testing. After you test it, you can start trying other materials and modifications to make it perform better. (See "Modify Solar House.")

Design a model house that uses as little energy as possible to keep it warm.

Note: This is one chapter of a longer engineering project which includes modifying and retesting this house as well as explorations of the various mechanisms of heat transfer—conduction, convection, radiation, and heat capacity—with hands-on or model-based experiments. See: http://concord.org/engineering

1. Design the house using sketches to help you picture it. Make three different designs.
2. Review the three designs and choose the best one for building and testing.
3. Make the pieces for the chosen design and assemble the house.
4. Test the house for energy efficiency.

All of the tools and materials required for this project are described in the “Tools and Materials” Appendix.

Design goals

The design of the house is up to you, but there are specific goals that you should address:

- The house has features that you think will make it energy efficient.
- The interior would be comfortable to be in on a sunny day or a cold night.
- The house should be attractive and have “curb appeal.”

In addition there are geometric limitations:

- The house should fit onto a 28 x 36 cm platform.
- To make room for the heater light bulb, the walls must be at least 20 cm high and there must be room to cut a 12 cm diameter hole (the size of a CD) in the center of the floor.
- The house must be buildable – that is, not too complex and not too many pieces.
- The minimum window area is 50 cm^2.

Note: In your initial design, you are limited to cardstock and clear acetate as basic building materials.

Design rationale

Before you begin designing your house on the computer, brainstorm with your team about the goals and how you will address each one. Then answer the following questions.

What shape and size of the building will contribute to the house's energy efficiency?

What roof shape will contribute to the house's energy efficiency?

How will you orient the building to take advantage of sunlight? What window sizes and placement will be good for solar gain?

Describe the other features that you would like your house to have in order to meet the design goals.

Design #1

Design procedure

Make sketches or scale drawings (whatever works best for you), so that you can picture what your house will look like and communicate your ideas to your team. If you use extra pages, tuck them into the workbook.

Evaluation of Design #1

Now step back and consider as a team how well Design #1 meets your goals. Here is a checklist, but add other goals if you have any.

- Energy efficiency
- Ease of building
- Attractiveness
- Shape
- Simplicity
- Size
- Comfort

Describe how Design #1 successfully met these goals.

Describe how Design #1 was not successful.

Design #2

Don't be satisfied with your first attempt! Try an altogether different design. Again, make sketches to work out your design.

Evaluation of Design #2

Step back and consider how well Design #2 meets your goals.

- Energy efficiency
- Ease of building
- Attractiveness
- Shape
- Simplicity
- Size
- Comfort

Describe how Design #2 successfully met these goals.

Describe how Design #2 was not successful.

Design #3

Try one more altogether different design. Again, make sketches to work out your design.

Evaluation of Design #3

Step back and consider how well Design #3 meets your goals.

- Energy efficiency
- Ease of building
- Attractiveness
- Shape
- Simplicity
- Size
- Comfort

Describe how Design #3 successfully met these goals.

Describe how Design #3 was not successful.

Select your best design

You now have three designs to choose from. Each one may have features that you like or dislike. Review the design goals and select one of them for building and testing. To help you choose, fill out the rating chart below. 3=excellent, 2=good, 1=fair, 0=bad

Results			
Goal	House #1	House #2	House #3
Energy efficiency			
Ease of building			
Attractiveness			
Shape			
Simplicity			
Size			
Comfort			

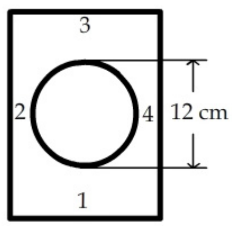
Which design will you select?

Explain why you selected the design that you did.

Construction

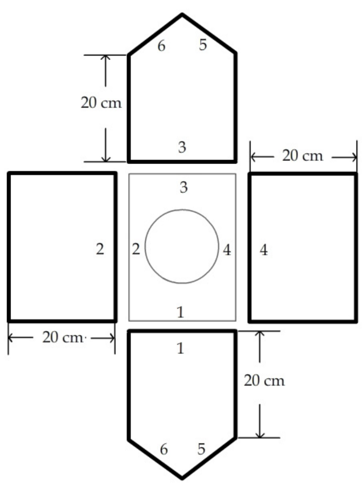
1. You have designed a building with a certain shape and features. Now you need to make all of the pieces and assemble it. The example below shows how you could proceed.

2. Draw the outline (first floor plan) of your house on cardstock. To accommodate the heater light bulb, it must be large enough to place a circle on it with a diameter of 12 cm. It must fit entirely on the base.



3. Cut a circle out of the center of the floor that is 12 cm in diameter (the size of a CD) so that the light bulb heater can fit in.

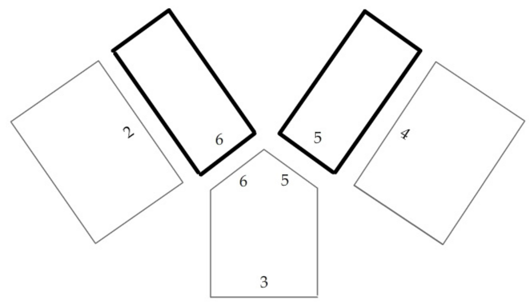
4. Make walls for your house that are 20 cm high and go all the way around the floor plan. Note that if you want a gable roof (see example below), some of the walls will have triangular tops. Use the layout shown below to find the wall lengths from the floor plan. Draw out the walls on cardstock, all next to each other to save materials. Cut out the walls.



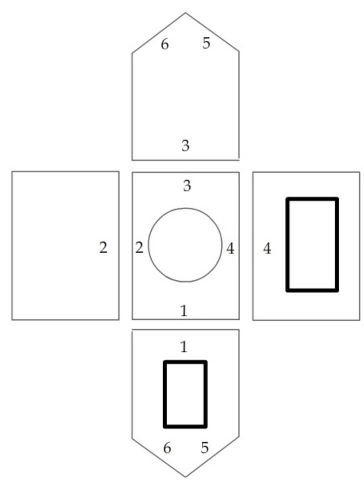
Tools & materials

- Scissors
- Pencils
- Metal ruler (cm)
- Protractor
- Safety utility cutter
- Cardstock (approximately one 20x30 in sheet)
- Acetate sheets (8.5 x 11 in) for windows
- Masking tape and/or clear tape
- 28 x 36 cm platform

5. Decide what kind of roof will work. Try to use a design that is not too hard to build. Draw all of the roof pieces on cardstock. You can use the wall lengths to determine roof dimensions, as shown in the drawing below. If you are uncertain about some dimensions and angles, make them oversized and trim them down to fit.



6. Draw and cut out windows that are in the walls (and roof, if any) and tape pieces of acetate over them on the inside.



7. Tape the edges of your house together. Here is one set of steps that you could follow: It works well to follow these steps:

   a) tape the wall pieces together

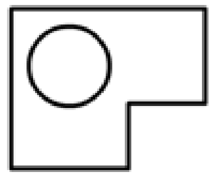
   b) tape the roof pieces together

   c) tape the roof to walls

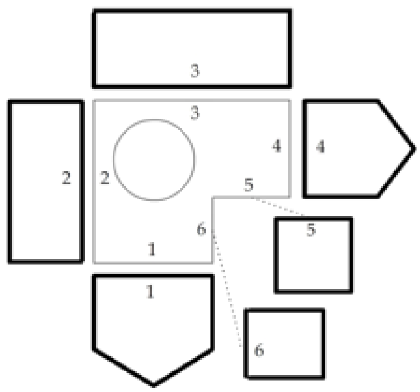
   d) tape the floor to walls

Here is another more complex example – an L-shaped house. Note that the dashed lines on the floor plan (A and B) give the lengths of the roof pieces at the ridge.

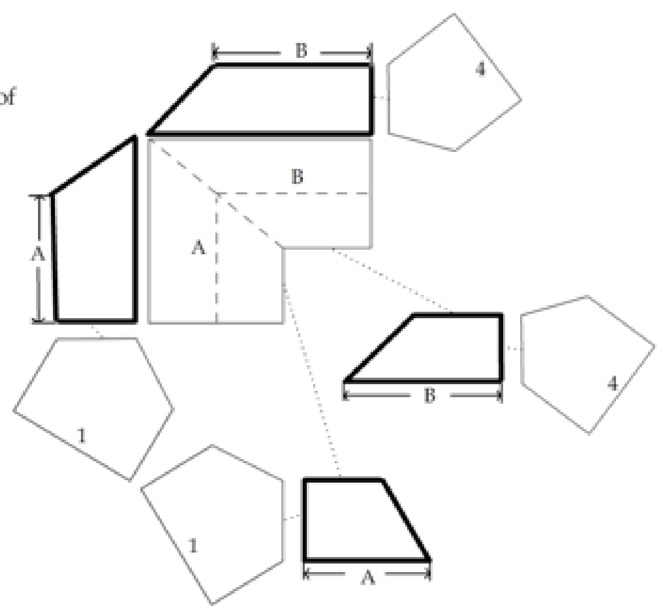
Floor



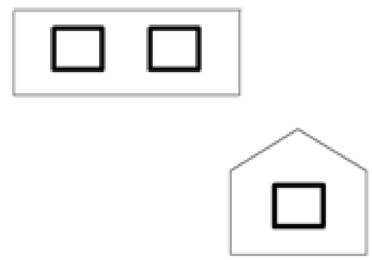
Walls



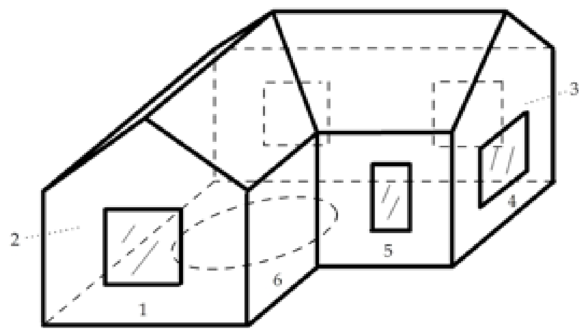
Roof

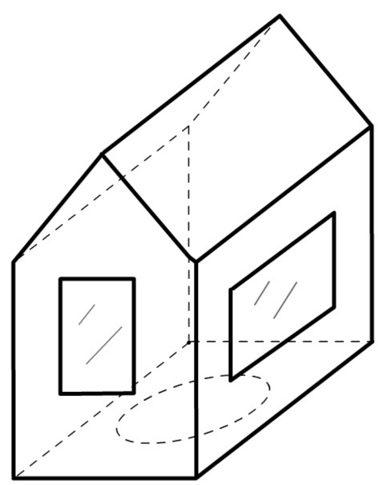


Windows



Assemble





8. Make a hole in one wall for the temperature sensor 10 cm above the floor. Pick the wall that is farthest from the heater light bulb. The sensor will go 3 cm into the house and it must be at least 5 cm from the heater light bulb.

9. Calculate the total floor area and window area of your house. Also calculate the window area that faces south. Your measurements can be rounded to the nearest centimeter. Fill out the table below.

	Your house
Floor area (cm^2)	
Window area (cm^2)	
Window/floor ratio	
South-facing window area (cm^2)	
South window/floor ratio	

House heating test

Your goal in testing your house is to measure how much power it takes to keep your house 10 °C warmer than the air around it.

Tools & materials

- One fast-response temperature sensor (for example, the Vernier surface temperature sensor STS-BTA)
- Computer or other graphing interface for temperature sensor
- One 40 W light bulb heater in a socket with an inline switch, covered with foil (page 23)

NOTE: If your house is large or has lots of window area, you may need to change the 40 W heater bulb to 75 W. Be sure to use 75 W instead of 40 W when you calculate the average power requirement on the next page.

Collect data

1. Connect one temperature sensor to your computer. Set up data collection for one reading per second and a total time of 600 seconds.
2. Measure the room temperature. We will assume it stays reasonably constant throughout the experiment. Record temperature in the table below.
3. Calculate your target temperature: 10 °C above room temperature. Record your room and target temperature in the table below.
4. Insert the temperature sensor in the hole you made in the house. It must be pushed through the wall, so that it is 3 cm from the wall.
5. Turn the heater on.
6. Start collecting data when the sensor is a few degrees below the target temperature.
7. When the sensor reaches 0.2 °C above the target temperature, switch the heater OFF and record the time in the table below (A).
8. When the sensor drops to 0.2 °C below the target temperature, switch the heater ON and record the time in the table below (B).
9. When the sensor again reaches 0.2 °C above the target temperature, switch the heater OFF and record the time in the table below (C).
10. Stop collecting data.
11. Click the “scale” icon to fit the graph to your data.
12. Save the data file.
13. Calculate the average power requirement to keep the house warm by filling out the rest of the table below.

House heating test	
Room temperature: _____°C Target temperature: _____°C Upper limit (target temperature + 0.2): _____°C Lower limit (target temperature – 0.2): _____°C	
Event	Time (from data table)
A. Turn heater OFF at upper limit	
B. Turn heater ON at lower limit	
C. Turn heater OFF at upper limit	
D. Total cycle time (C - A)	
E. Total time ON (C - B)	
F. proportion of time the heater is on (C - B) / (C - A)	
G. Average power requirement (40 watts * the proportion of time the heater is on)	_______W

Results

What specific features of your design contributed to or detracted from the energy performance of the house?

Based on your results what design changes would you propose to improve the performance of these design features?

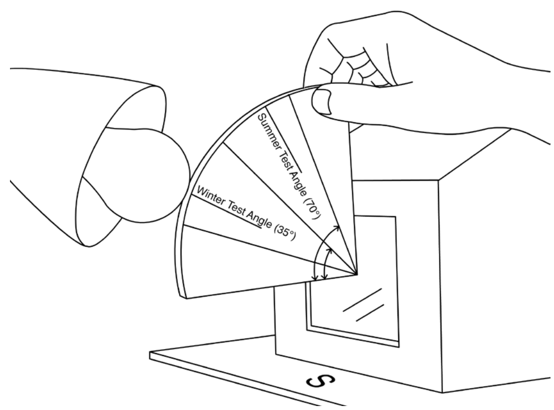
Solar heating test

Tools & materials

- One fast-response temperature sensor (for example, the Vernier surface temperature sensor STS-BTA)
- Computer or other graphing interface for temperature sensor
- One 40 W light bulb heater
- One 300 W sun light bulb in a gooseneck desk lamp (page 23)
- Template for measuring "sun's" angle (page 25)

Collect data

1. Connect the temperature sensor to your computer.
2. Set up data collection for one reading per second and a total time of 600 seconds.
3. Assume that room temperature has not changed. Calculate the target temperature (room temperature + 10 °C) and enter it in the table below.
4. Set up the gooseneck lamp with a 300 W bulb in it, due south of the building. The tip of the bulb should be 20 cm from the house window and aimed downward at about a 35° angle, as if it were noon in winter at 40° North Latitude. Use the template to position the sun.



5. Switch the heater light bulb and the sun light bulb on.

   NOTE: The bulb is very hot. Be careful not to touch it, and wait until it cools down to move or store it. Turn it off except while doing the experiment.

6. Start collecting data when the sensor is a few degrees below the target temperature.
7. When the upper sensor reaches 0.2 °C above the target temperature, switch the heater OFF and record the time in the table below (A). Leave the sun on.
8. When the upper sensor reaches 0.2 °C below the target temperature, turn the heater ON. Record the time in the table below (B).
9. When the sensor again reaches 0.2 °C above the target temperature, switch the heater OFF and record the time in the table below (C).
10. Stop collecting data.
11. Click the “scale” icon to fit the graph to your data.
12. Save the data file.
13. Calculate the average power requirement to keep the house warm by filling out the rest of the table.

Solar heating test	
Room temperature: _____°C	
Target temperature: _____°C	
Upper limit (target temperature + 0.2): _____°C	
Lower limit (target temperature – 0.2): _____°C	
Event	Time (from data table)
A. Turn heater OFF at upper limit	
B. Turn heater ON at lower limit	
C. Turn heater OFF at upper limit	
D. Total cycle time (C - A)	
E. Total time ON (C - B)	
F. Proportion of time the heater is on (C - B) / (C - A)	
G. Average power requirement (40 watts * proportion of time heater is on)	________W
H. Power requirement without sun	________W
I. Solar contribution	________W

Results

How did this solar-heated house perform compared to the house without sunlight?

What specific features of your design contributed to or detracted from its performance as a passive solar house? Include the evidence from your tests that support your claims.

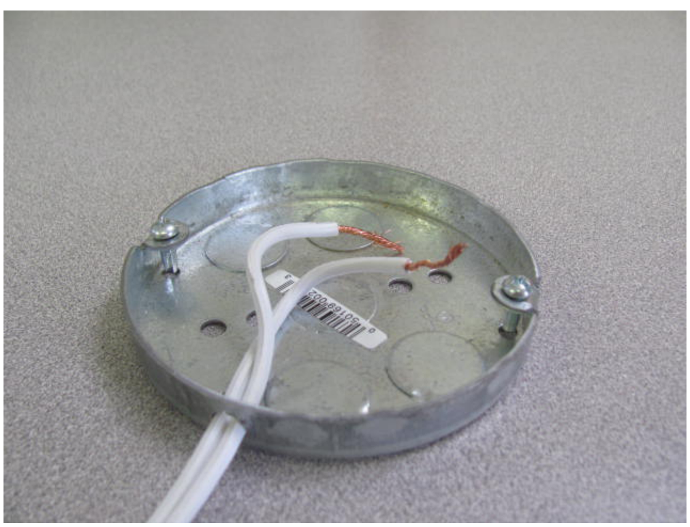
Based on your results what design changes would you make to improve its performance?

What are the advantages and disadvantages of having large south-facing windows?

Fabricating a light bulb heater

Procedure

1. Cut off the outlet end of the extension cord. Strip the wires.
2. Install the inline switch in the extension cord. Note that the common (ground) wire has ribs and the live (hot) wire is smooth. Make sure the switch interrupts the hot wire.
3. Drill a 5/16″ (8 mm) hole through the side of the pancake box and insert the cord.

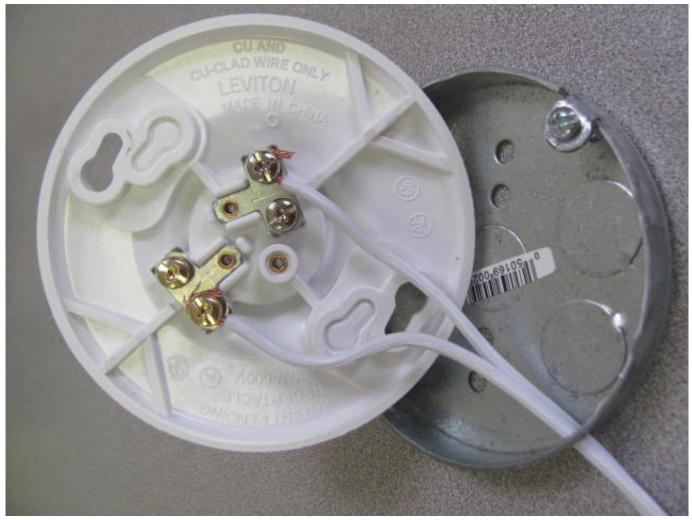


Tools & materials

The required parts, available at any hardware store, are:

- keyless socket (plastic or ceramic)
- 6' extension cord
- inline switch
- metal pancake box
- 40 W light bulb
- aluminum foil

4. Attach the wires to the keyless socket. The ribbed (ground) wire is attached to a silver screw and the smooth (hot) wire is attached to a brass-colored screw.



5. Screw the socket to the pancake box. Cover the bulb with a layer of foil to cut down on radiation.

CUT OUT THE QUARTER-CIRCLE
& GLUE IT TO CARDSTOCK