Design and Build a Solar House with Energy3D Software

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.

To download Energy2D software, go to http://energy.concord.org/energy2d/

To run the models in this chapter, go to http://energy.concord.org/htb

Note the video tutorial.

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

Students design and build their own house, based on what they have learned about heat transfer. They use Energy3D to both design and print their finished house. They are asked to come up with three distinct designs and choose the best one.

For each of the three designs, have teams switch who has control of the computer. If a computer lab is available, each student could work individually on a separate design.

Learning goals:

- Explain material and design choices based on constraints or stated goals.
- Justify a design using scientific content knowledge and principles.
- Justify results using scientific content knowledge.

You will be using a computer program, Energy3D, to design and build your house. The process has three steps:

1. Design the house on the computer, using Energy3D. Make three different designs.
2. Review the three designs and choose the best one for building and testing.
3. Print 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.

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

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 not be larger than the 28 x 36 cm platform provided in the software.
- 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.

Be sure students write out a serious design rationale **before** they start designing.

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?

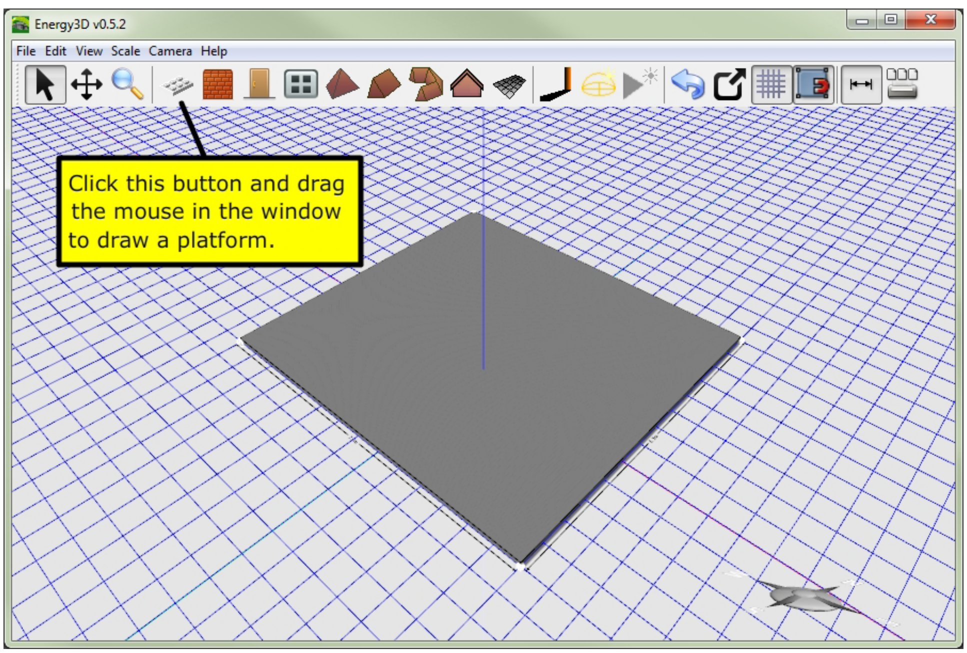
Describe the other features that you would like your house to have in order to meet the design goals.

Design instructions

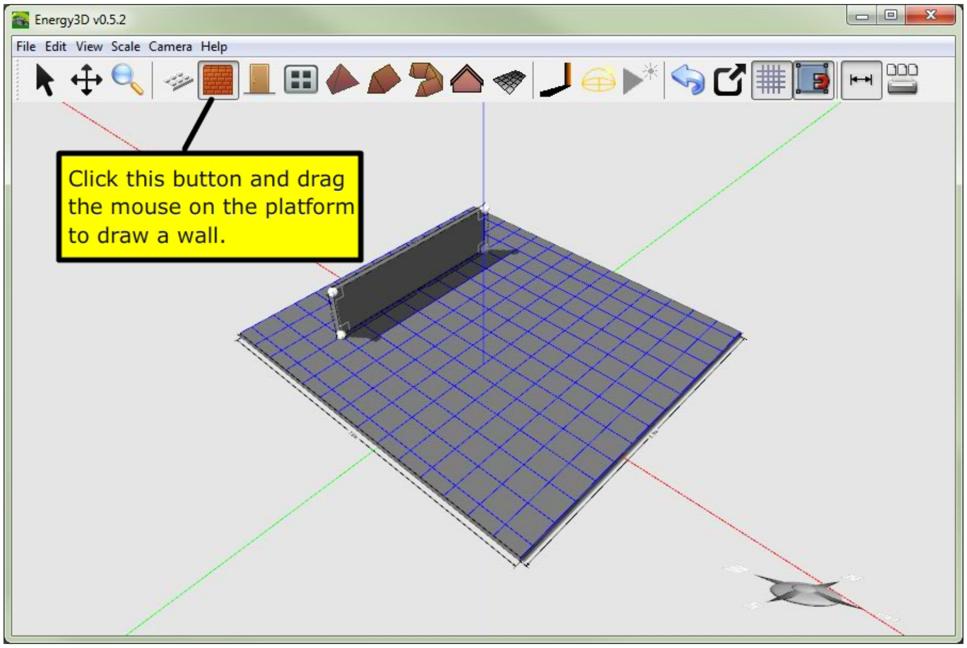
Design procedure

1. Watch the Energy3D movie (Getting Started with Energy3D) at: http://energy.concord.org/energy3d/
2. Construct your house on the computer. Pay attention to the directions, especially which way is south. This should affect many of your decisions.
3. Your house may not look like the example, but it shows a procedure you can follow. It's OK to experiment with different shapes and start over several times if you want to. Keep the house relatively simple. Remember, what you design you must build out of paper!
4. The program will open with a 28 x 36 cm platform. You house must fit within this.

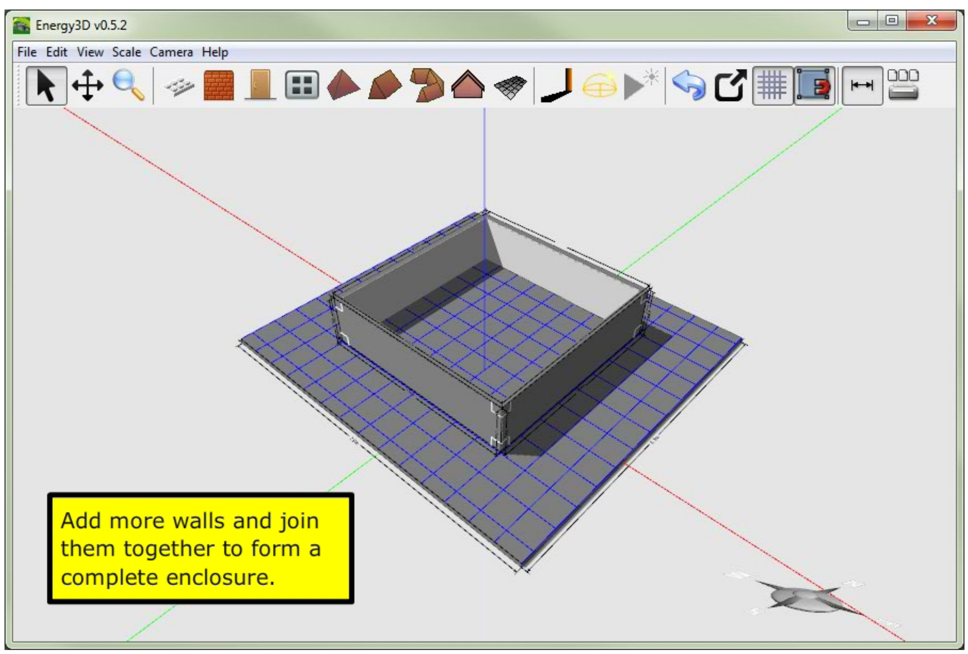
Be sure the teams switch who has control of the computer. Encourage them to come up with a variety of designs.



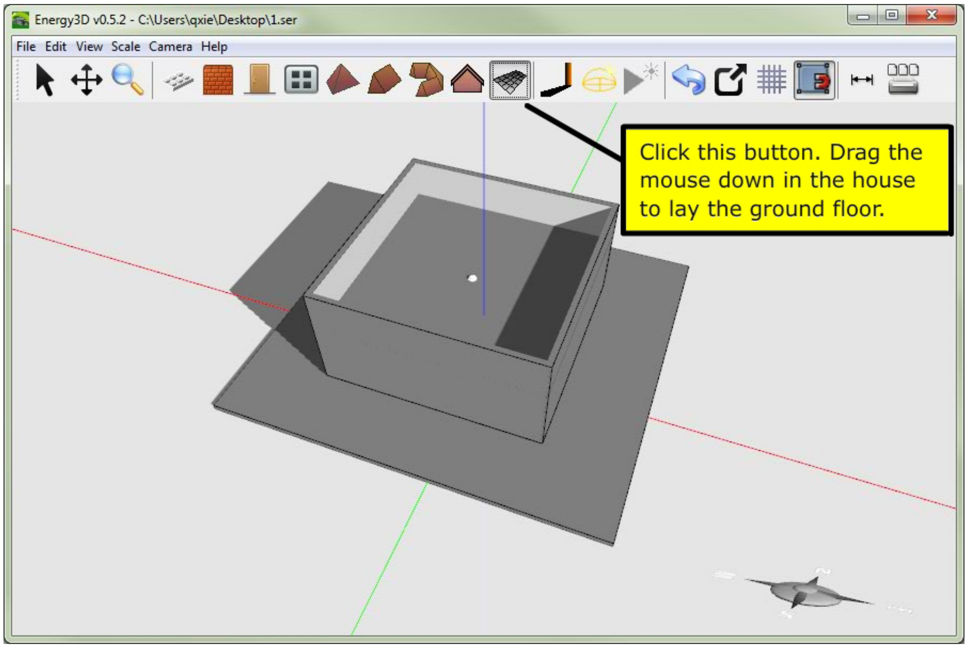
5. Build all of the walls first, one at a time. They should be at least 20 cm high to make room for the heater light bulb.



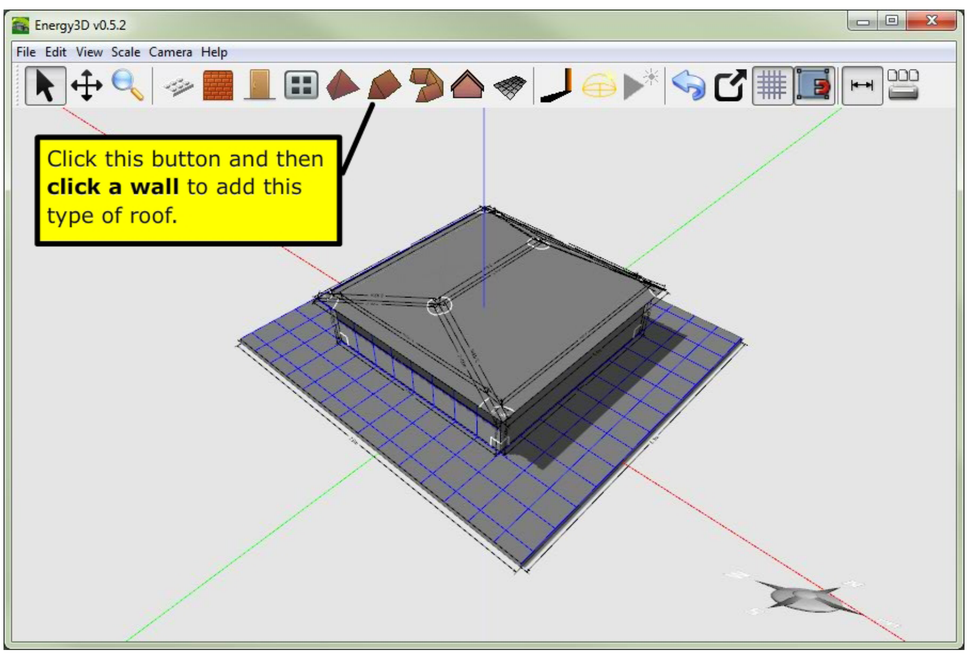
6. Lock the ends of the walls together and make a complete enclosure.



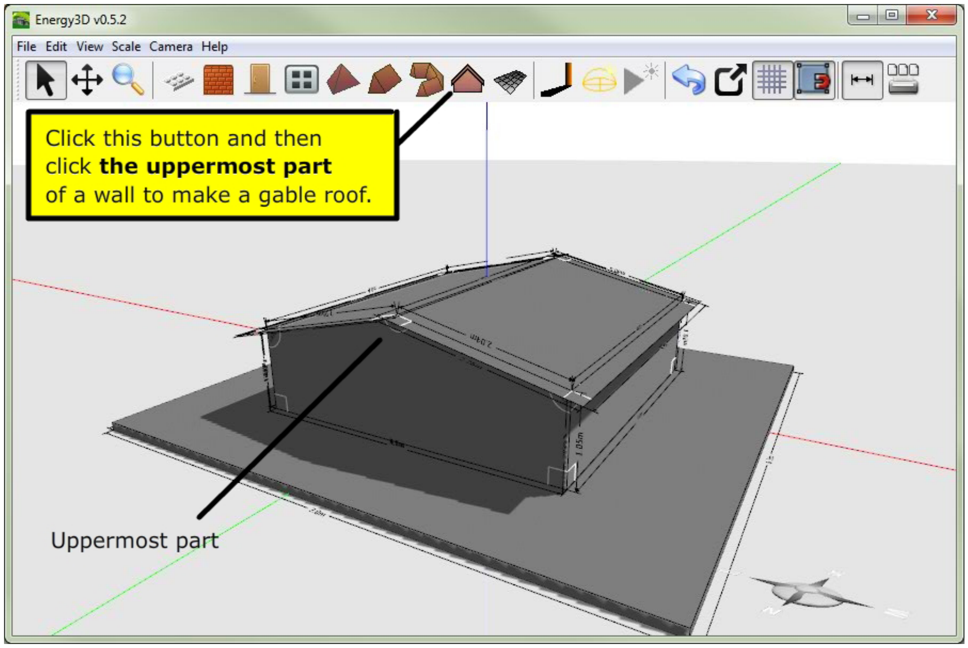
7. Create a floor inside the house. This will help you assemble it.



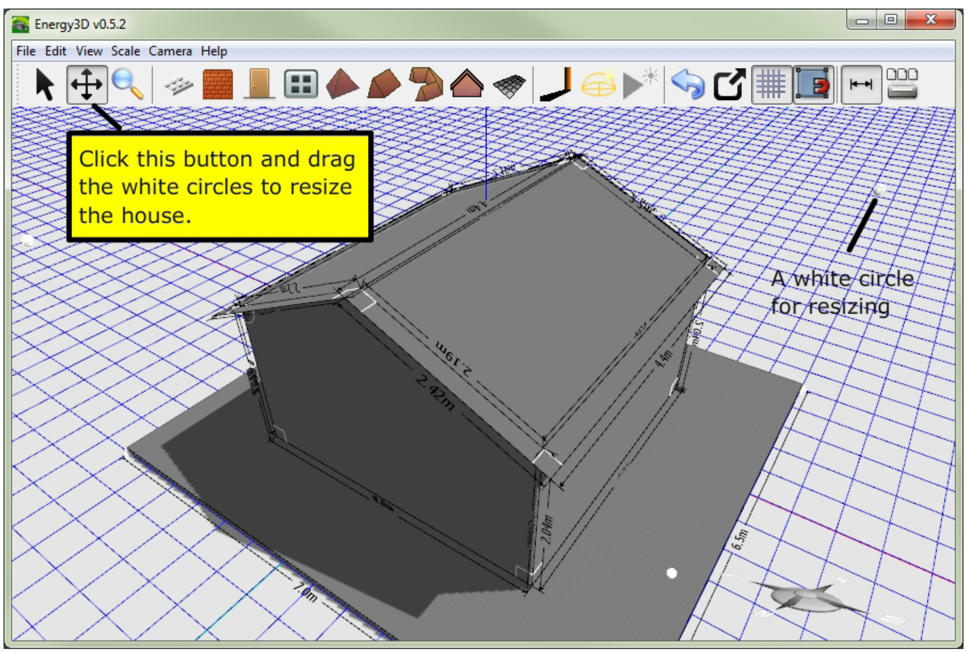
8. Add the roof last, after you have made the basic shape and size of the house.



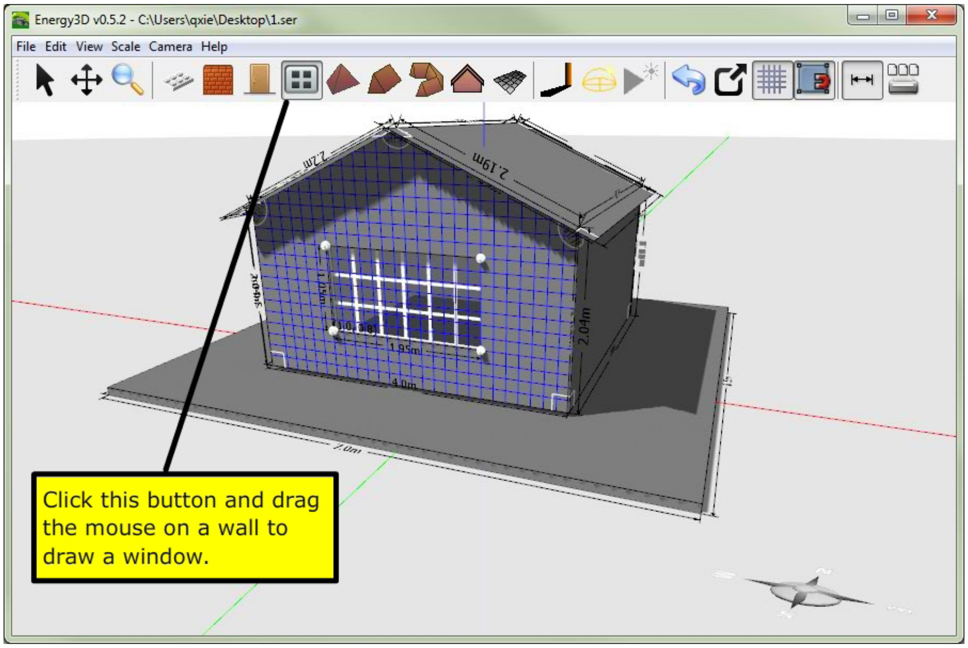
9. After the roof is added, you can change it from a hip roof (above) to a gable roof (below) if you wish.



10. The walls must be at least 20 cm high. You can resize them all at once. You can also resize the house in other directions if you need to.



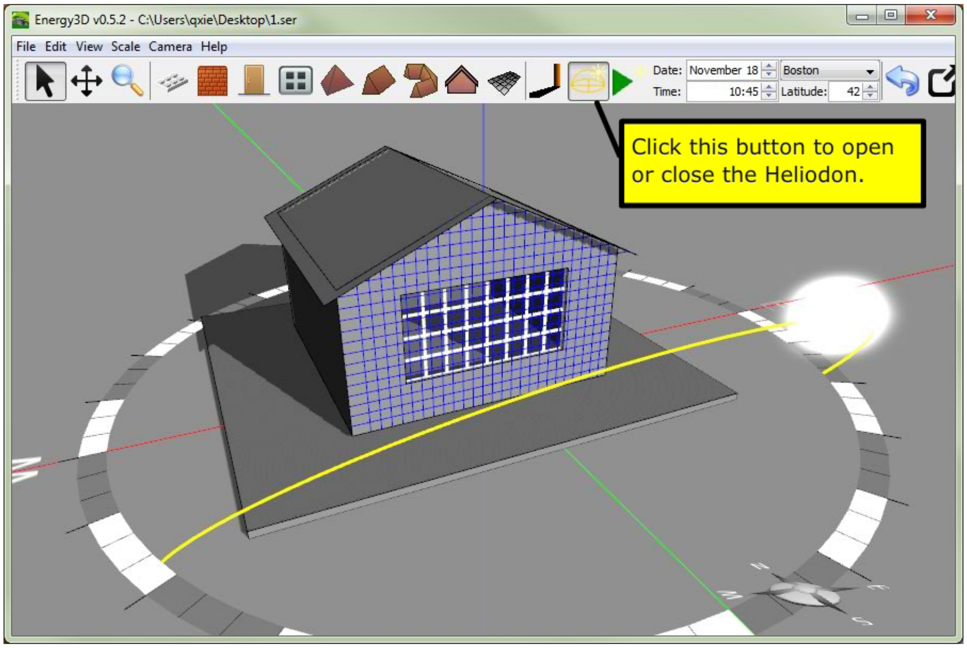
11. Add windows. Pay attention to which direction they face.



12. Save your design.

Evaluation of Design #1

1. Open the Heliodon tool. Set it to your latitude. Turn on the Shadows tool right next to it.



2. Study how sunlight enters your house at different times of day and different times of year. Do you think your windows are effective passive solar collectors? Explain.

3. Zoom **inside** your house. Study the path of sunlight from your various windows. Do you think this would be a comfortable room on a sunny day? Explain.

4. 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.

5. Based on your review, modify your design and save it again as a new file.

Design #2

1. Now that you have some experience with Energy3D, try another altogether different design. Don't be satisfied with your first attempt!

2. Close and re-open Energy3D. Design a new house from scratch.

3. Save your design.

Evaluation of Design #2

1. Open the Heliodon tool. Set it to your latitude. Turn on the Shadows tool.

2. Study how sunlight enters your house at different times of day and different times of year. Examine the house both from the outside and the inside.

3. Step back and consider how well Design #2 meets your goals. Refer back to your checklist.

Describe how Design #2 successfully met these goals.

Describe how Design #2 was not successful.

4. Based on your review, modify your design and save it again as a new file.

Design #3

1. Try to come up with one more altogether different design.

2. Close and re-open Energy3D. Design a new house from scratch.

3. Save your design.

Evaluation of Design #3

1. Open the Heliodon tool. Set it to your latitude. Turn on the Shadows tool.

2. Study how sunlight enters your house at different times of day and different times of year. Examine the house both from the outside and the inside.

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

Describe how Design #3 successfully met these goals.

Describe how Design #3 was not successful.

4. Based on your review, modify your design and save it again as a new file.

After each team selects their preferred design, have them present it to the whole class and explain the virtues and drawbacks of their design choices.

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

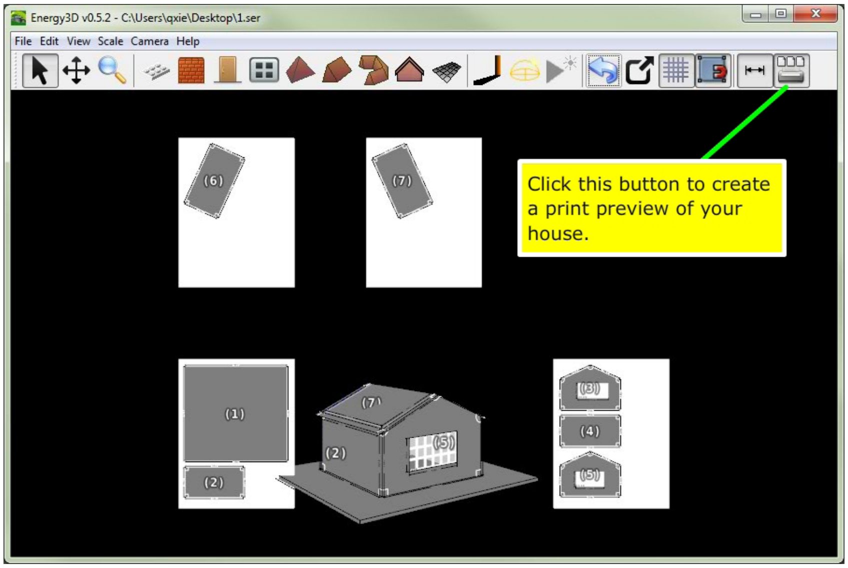
Results			
Goal	House #1	House #2	House #3
Energy efficiency			
Ease of building			
Attractiveness			
Shape			
Simplicity			
Size			
Comfort			

Which design will you select?

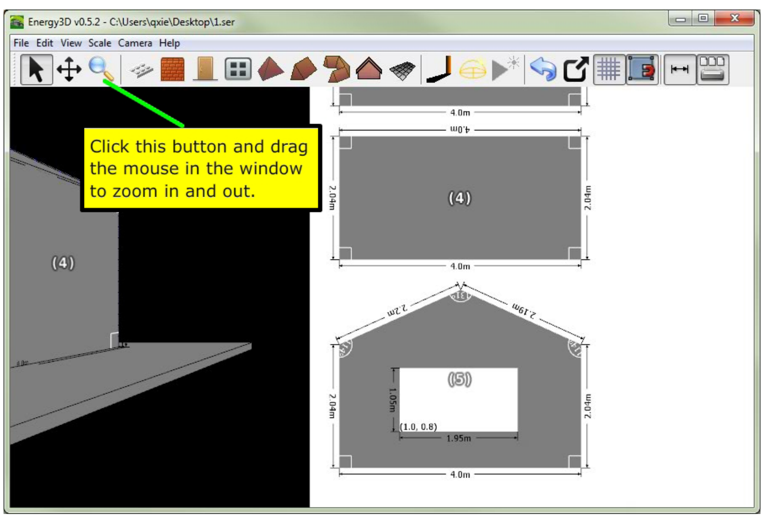
Explain why you selected the design that you did.

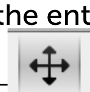
Print your design

1. View the print preview, which displays the house and all of its pieces as they will be printed on regular-size paper. Make sure you have included a floor.



2. You can zoom into a sheet and see the dimensions of each piece.



3. Print all of the pieces on heavy paper. Under "file," you have two choices: "scale to fit paper" or "exact size on paper." To print exact size, you will probably need to use a 11"x17" printer. If your house is too big to print, scale the entire thing down to a manageable size with the scale button. 

Before students print, be sure they have included a floor. It is needed to hold the house together. If, however, the floor is too large to print, they can make it by hand.

Use the special 13x19 paper and printer provided. Note that one page at a time can be printed if needed.

A large printer and 11x17 or even 13x19 paper are best for this. If this is not available, the pieces can be tiled.

Tools & materials

- Scissors
- Pencils
- Metal ruler (cm)
- Protractor
- Safety utility cutter
- Cardstock that matches your printer size
- Acetate sheets (8.5 x 11 in) for windows
- Masking tape and/or clear tape

Construction

1. Cut out the pieces with scissors.
2. Cut out the window openings with scissors or a utility knife and tape pieces of acetate over them on the inside.
3. Cut a circle in the floor (12 cm diameter, the size of a CD) for the heater light bulb.
4. Tape the house pieces together. Use the 3D house view in "print view" as a guide. Note that the pieces are numbered. 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
5. 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.
6. 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.

Collect data

1. Connect the temperature sensor to your computer. Use one temperature sensor.
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.

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 (see “Light bulb heater” in Appendix) in a socket with an inline switch, covered with foil

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.

This is the basic house heating test. Point out that the students are acting as a “human thermostat.” Review how it is analogous to a real house furnace, which turns on and off to keep the house at a constant temperature. The furnace output (power) multiplied by the percentage of time it is on (percent) is the average power requirement to keep the house warm.

Once the room temperature has been measured, the whole class can use the same value throughout the project unless a large change (more than 2-3 °C) is noticed. Then students don't need to wait for their house to cool down between experiments. This will save considerable time.

Note: the house does not need to cool down between this and the next experiment (page 22) so students can save time by doing them both together.

Make a table of everyone's results so that they can be compared and discussed. Include the floor and window areas, which may help explain some of the differences.

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

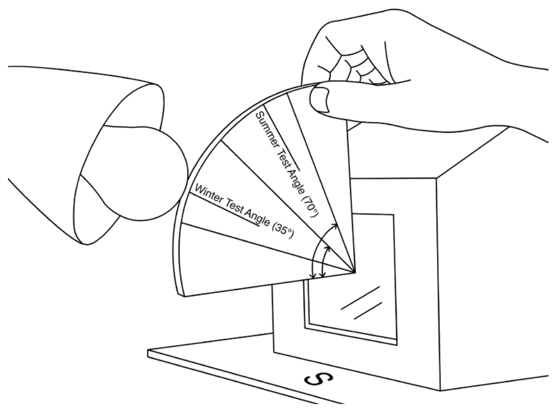
Tools & materials

- 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 (page 27)
- One 300 W sun light bulb in a gooseneck desk lamp
- Template for measuring "sun's" angle (page 29)

Insist that students be very careful with the light bulbs, turning them off when not in use.

Collect data

1. Connect the temperature sensor to your computer.
2. Assume that room temperature has not changed. Calculate the target temperature (room temp + 10 °C) and enter it in the table below.
3. 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. Use the template provided by the teacher to position the sun.



4. 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.

5. Start collecting data when the sensor is a few degrees below the target temperature.

6. 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.
7. When the upper sensor reaches 0.2 °C below the target temperature, turn the heater ON. Record the time in the table below (B).
8. 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).
9. Stop collecting data.
10. Click the “scale” icon to fit the graph to your data.
11. Save the data file.
12. Calculate the average power requirement to keep the house warm by filling out the rest of the table.

Add these results to the shared table for discussion.

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?

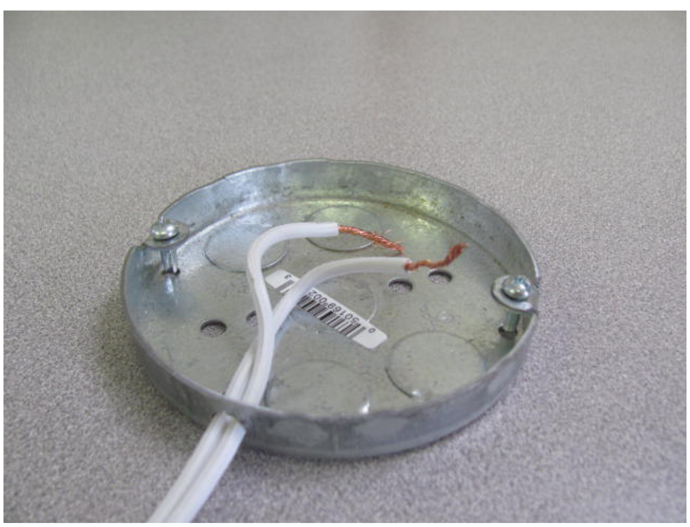
What are the advantages and disadvantages of having large south-facing windows?

Advantages: more solar gain in winter, less in summer. Cold surface in winter.
Disadvantages: large conductive loss in winter, conductive gain in summer.

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.

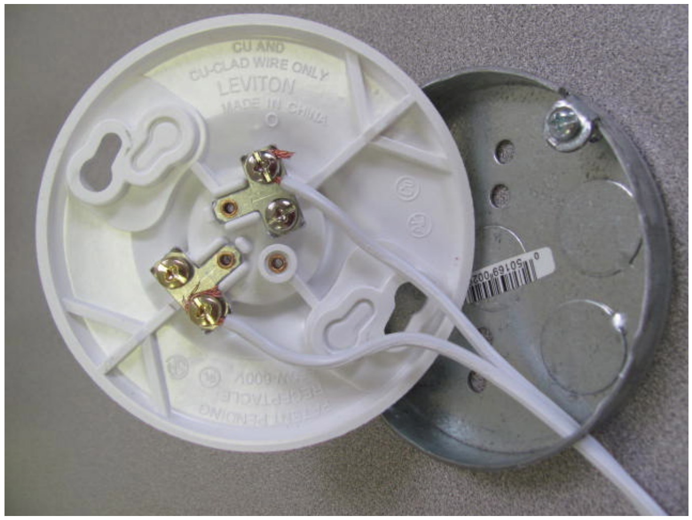


Tools & materials

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