Modify Your Solar House

Introduction

Before you begin this chapter, you must have completed "Design and build a solar house."

Now that you have tested your own energy-efficient house design, it's time to modify it and make it work better. A cycle of design, testing, redesign and retesting is an essential part of engineering.

Your success will be measured using the same tests as before:

- keeping the house warm with a heater light bulb (the "no sun" condition)
- reducing the heating requirement using sunshine from a low angle (the "winter sunshine" condition)

You can add other materials from what's available, and also change the design — whatever you think would improve the performance of the house. You can also add "additions" on the outside if you think they will help — solar greenhouses, for example.

Every change *must have a design rationale*, including your theory for why it will help, based on the scientific ideas from the Heat Transfer chapter.

To make your engineering process more systematic, you will be asked to tackle one improvement at a time and measure the effect of that improvement. You will also be asked to do some specific investigations before making your design changes.

Note: If you have your own ideas and prefer to skip over the suggested improvements, make your modifications and then go to page 17 to test your results.

How much can you improve the energy performance of your house?

In this chapter, students explore modifications to reduce their house energy use – adding a ceiling, insulating the walls, and adding a sunspace. If there is time, the changes should be made and tested one at a time. If this is not practical, skip to page 17. Encourage students to apply their scientific knowledge and reasoning to this engineering task.

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.

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

Explore natural convection

Often the most valuable first step in making a house energy efficient is to stop air from leaking in and out. Cold air entering and hot air escaping is a large source of heat loss, in both older and newer construction.

You will conduct a series of experiments to explore convection (the motion of air) in your house and then see how much you can improve its performance.

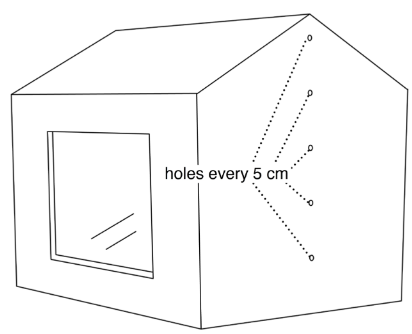
Tools & materials

- Two fast-response temperature sensors (for example, the Vernier surface temperature sensor STS-BTA)
- Computer or other graphing interface for temperature sensor
- Small square of cardboard (5x5 cm)
- Tape
- One 40 W light bulb heater
- Metal ruler
- Your house

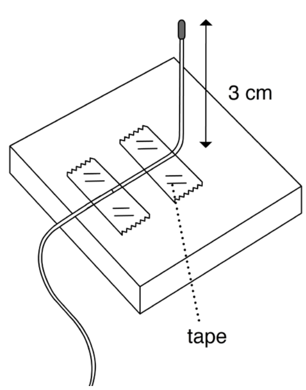
This experiment requires two students working in close c ollaboration. Emphasize that one sensor is a monitor to keep the house 10 °C above room temperature, and the other is movable. Make sure students understand the sample graph before they begin. The top hole can be through the roof if that works better with their design.

Procedure & data collection

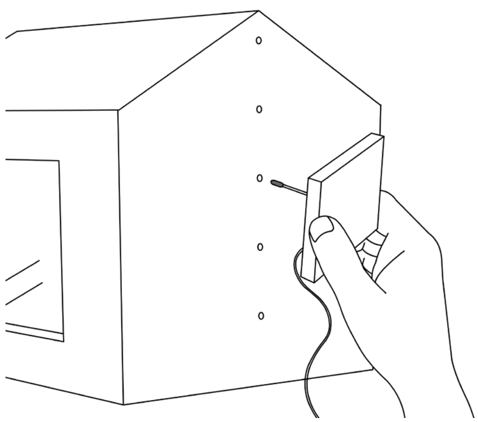
1. Tape one sensor into the hole in your house house at 10 cm. This will be your **fixed monitoring temperature sensor**.
2. Make a series of holes in the end wall opposite the monitoring sensor every 5 cm above the bottom of the house. Use a sharp pen or pencil. The holes should be just large enough so that the movable temperature sensor can be inserted into the house. (The top hole can be through the roof, if your house has a hipped roof.)



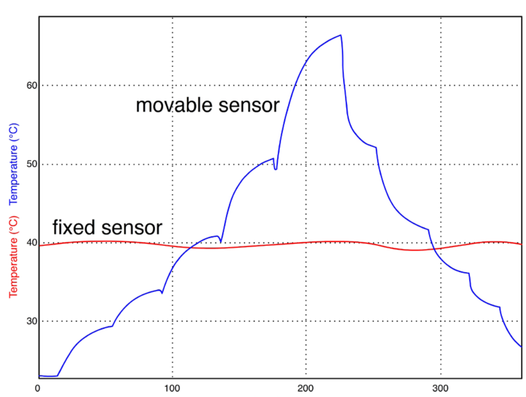
3. Tape the other sensor to a small piece of cardboard (about 5x5 cm) with a bend in the wire so that the end sticks up about 3 cm. This will be your **movable temperature sensor**.



4. Start collecting data. Record the initial temperature in the table below.
5. Turn the heater on. Let the temperature of the fixed sensor rise until the inside is 10 °C above the initial temperature.
6. Have one team member take responsibility for keeping the reading of the fixed sensor within 0.2 °C or less of the target temperature. Turn the heater off and on to maintain a constant temperature for the fixed sensor.
7. Have another team member measure the temperature at each height by inserting the movable sensor into each hole in turn, from 5 cm to 25 cm, and then back down again.



8. You must wait in each position long enough for the temperature to approach a settled value – about 30 seconds. It's OK not to wait for the exact settled value. The graph will look something like this:



9. Record the temperature values at the different heights in the table below.

10. Calculate the average temperature for each height.

Temperature at different heights			
Initial temperature: _____°C Target inside temperature: _____°C (Initial + 10 °C)			
Height (cm)	Temperature (going up)	Temperature (going down)	Average of two temperatures
5			
10			
15			
20			
25			

Results

What is the maximum temperature difference from bottom to top?

What is the difference between the fixed monitoring sensor and the highest temperature?

Analysis

If the fixed sensor shows a constant temperature, explain what creates the observed temperature pattern seen in the graph of the moveable sensor.

Hot air is less dense than cold air, so it rises from the light. The hotter air therefore is measured close to the roof and cooler air measured close to the floor.

House heating test with a ceiling added

Tools & materials

- One temperature sensor
- Computer
- Cardstock for ceiling
- Small square of foamcore or cardboard (5 x 5 cm)
- Tape
- One 40 W light bulb heater
- Scissors
- Your house

Now test the improvement in overall performance when you add a ceiling. Use the same tests as before to measure how much power it takes to keep your house 10 °C warmer than the air around it.

Construction

1. Trace the floor of the house on a piece of cardstock.
2. Cut this piece out to make a ceiling for the house.
3. Bend the piece a bit so that it can be pushed through the hole in the bottom of the house. Push it up to make a “ceiling” at the tops of the walls, which should be 20 cm high. It should stay roughly in place without tape, but you can add a few small pieces of tape if necessary.

Collect data

1. Connect the temperature sensor to your computer. Use one temperature sensor.
2. Measure the room temperature. Record it in the table below.
3. Calculate your target temperature, 10 °C above room temperature, and record it in the table.
4. Install the sensor in the standard monitoring position, through a hole in the wall 10 cm up and 3 cm into the house.
5. Turn the heater on.
6. When the sensor reaches 0.2 °C above the target temperature, switch the heater OFF and record the time in the table below (A).
7. 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).
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 below.

House heating test with ceiling	
Room temperature: _____°C Target temperature (room temperature + 10): _____°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

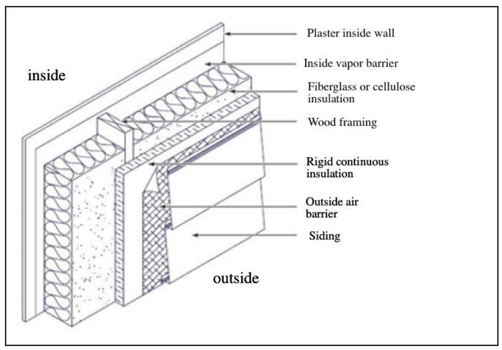
Compare your current house performance with previous experiments.

Summary of results	
Condition	Power requirement
Standard house	
Your model house rom “Build Your Own Solar House” section	
Ceiling added	

Conductivity of the walls

Energy efficient houses are always very well insulated. Often some parts of the building envelope are insulated more than other parts.

Here's a typical well-insulated wall. Each layer has a purpose. The vapor barrier stops moisture from migrating outward. The insulation slows heat flow. The continuous insulation blocks air circulation and thermal bridging through the wood, which is less insulating that the insulation around it. The outside air barrier stops infiltration.



Air spaces inside walls may or may not provide some insulating value. If they are wider than about 2 cm, convection loops form and heat is easily transferred across them. If they are narrower than that, convective loops do not form and they provide insulating value.

Reduce heat loss with insulation

Decide how you will insulate the walls of your house. You may draw from the following materials:

- 1 sheet card stock
- 1 sheet foamcore
- 2 sheets acetate

Here are the rules:

Only use materials that are equally available to all of the teams, unless your teacher decides otherwise.

When possible, apply insulation to the outside of the existing house, so that the interior volume remains about the same.

Do not place any material closer than 5 cm from the heater light bulb.

After you have insulated your house, test its performance.

You may provide other insulating materials, such as more foamcore or aluminum foil, if you wish. The point is for students to try a variety of strategies with limited resources and explain their reasons for doing so.

Collect data

1. Connect the temperature sensor to your computer. Use one temperature sensor.
2. Measure the room temperature. Record it in the table below.
3. Calculate your target temperature, 10 °C above room temperature, and record it in the table below.
4. Install the sensor in the standard monitoring position, through a hole in the wall 10 cm up and 3 cm into the house.
5. Turn the heater on.
6. When the sensor reaches 0.2 °C above the target temperature, switch the heater OFF and record the time in the table (A).
7. When the sensor drops to 0.2 °C below the target temperature, switch the heater ON and record the time in the table (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 (C).
9. Stop collecting data.

Note that a test without the sun is followed immediately by the same test with the sun. The house does not need to cool down in between tests.

10. Click the "scale" icon to fit the graph to your data. Enter the data in the "without sun" column below.

11. Save the data file.

12. Set up the sun light bulb at the winter test angle, turn it on, repeat this experiment. Enter the data in the "with sun" column below. Save the data file.

13. Calculate the average power requirement to keep the house warm, with and without the sun, by filling out both columns in the table below.

House heating test with insulation	
Room temperature: _____°C Target temperature (room temperature + 10): _____°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

Summary of results	
Condition	Power requirement
Standard house	
Your model house rom "Build Your Own Solar House" section	
Insulation added	

Sunspace addition

Sunspace, sunrooms, or greenhouses can be used to collect sunshine for heating. They are also pleasant spaces in the winter, although they have drawbacks as well. Build a sunspace addition to your house. Explore the temperatures in it and how it affects your house heating requirement.

What are the temperatures in a sunspace?

Can a sunspace contribute heating energy to a house?

Construction

Build a sunspace addition, following these guidelines:

- You can use acetate, cardstock, and tape.
- The house should form one wall of the sunspace. That is, the sunspace should be against the house.
- The sunspace can be on any side of the house, but remember that your goal is for it to gain solar heating in the winter.
- The sunspace floor area should be **one-half the area of the house or smaller.**

Tools & materials

- One temperature sensor
- Computer
- Acetate
- Cardstock
- Tape
- One 40 W heater light bulb
- One 300 W sun light bulb in a gooseneck desk lamp
- Scissors
- Sun angle template (page 20)
- Your house

The sunspace is meant to be a more open design challenge. Students should feel free to try a variety of arrangements, materials, and shapes for a sunspace – against the south wall, as an addition to the east or west, square or sloping, all acetate or partly insulated.

Since the sunspace will probably heat up more than the house, the challenge is to get the heat from the sunspace into the house while the sun shines. It may prove to be quite difficult. Students should try various strategies and justify them.

Collect data

1. Place one sensor in the house at the standard monitoring position, 10 cm up and 3 cm in.
2. Slip the other sensor into the sunspace about 10 cm up and near the wall of the house.
3. Tape a piece of paper on the outside of the sunspace so that it casts a shadow on the sunspace sensor. This will make sure the sensor measures the air temperature and is not heated directly by radiation.
4. Record the room temperature in the table below.
5. Calculate your target temperature, 10 °C above room temperature, and record it in the table below.
6. Turn on both the heater light bulb and the sun light bulb. Start collecting data.
7. When the monitor 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 monitor 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 monitor 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.
14. Start collecting data. Turn on both the heater light bulb and the sun light bulb. Heat up the house to about 10 °C above room temperature. This will be your house target temperature.

15. Keep the house within 0.2 °C of the target temperature by turning **both** the heating bulb and the sun bulb on and off. Observe at least two on-off cycles.

16. Scale the data with the “scale” button.

17. Save your data.

House heating test with sunspace #1	
Room temperature: _____°C	
Target temperature (room temperature + 10): _____°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. Previous requirement without sun	_______W
I. Sunspace contribution (G-H)	_______W

Results

Compare the graphs of the two sensors – inside the house and inside the sunspace. How are they the same and different?

Analysis

How could you explain the differences?

Improve the solar heating contribution from the sunspace

See if you can improve the construction of the sunspace.

Your design must accomplish two things:

- The sun light bulb must heat up the sunspace.
- The heat must be transported into the house.

Repeat the test each time as as you refine the sunspace. Note that two tables have been provided. Describe your experimental conditions in each case. Try at least two improvements and take data for each. For example:

- Connect the sunspace to the house with cutout openings, so the heat can flow from the sunspace to the house.
- Add black paper inside the sunspace to increase solar absorption.

After you have made improvements, test your house again, using the table on the next page. Also fill out the “Summary of results.”

House heating test with sunspace #2

Room temperature: _____°C

Target temperature (room temperature + 10): _____°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

Summary of results

Description of experiment	Power requirement
Before sunspace is added – no sun	
Sunspace added	
Improvement:	

Procedure for standard house heating test

If you skipped over the suggested improvements and did your own, use the steps below to measure the results. 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. This is the same test you used with the standard house.

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.

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.

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
H. Power requirement before improvements	_______W

Connection to buildings: Lessons learned

Application

What lessons or guidelines did you learn from these experiments that would apply to real buildings?

a) adding a ceiling

b) insulating the walls

c) adding a sunspace

This open-ended question has many possible answers, such as:

- Hot air rises to the top and settles there, so ceilings and less tall rooms are easier to heat.
- Insulation makes a very large difference in heating energy requirements, so insulate as well as possible.
- Sunspaces can contribute solar gain, but only if there is an effective way to move the sunspace heat into the house and close off the sunspace at night.
- Window and sunspace orientation toward the south is important.
- Heat-absorbing surfaces (black paper) help in a sunspace.
- Foil acts as an insulator by reflecting IR back into the room.

CUT OUT THE QUARTER-CIRCLE
& GLUE IT TO CARDSTOCK