Introduction

Welcome to the Engineering Energy Efficiency Project!

Your design challenge in this project is to build a model house that uses very little energy to keep warm and takes advantage of solar radiation to cut down its energy use even more. Through repeated testing and modifications, you can make your model better and better. In your final report, you will present how well your house performs and what you have learned about energy-efficient design.

Although what you build will just be a model made of paper, clear plastic, and cardboard, and heated by a light bulb, the science and engineering principles are the same as in a real house. The tests of your model would work on a real building. So this project is about a real-world situation and a real-world problem.

A substantial portion of home energy use in the United States is devoted to heating and cooling. The value of improving the energy efficiency of buildings is enormous. Outdated or negligent design and building practices waste vast quantities of fossil fuel that contribute carbon dioxide to the atmosphere. This is unsustainable in the long run. It is also quite unnecessary. We can construct and renovate buildings that are much better! Your generation has the task of making energy efficiency be something that everyone knows and cares about. Some of you will also be the engineers who participate in that transformation.

This is a Concord Consortium research project, but it's also a chance for you to apply your creative energies to an exciting and challenging task, work with your hands, build and test real structures, and have a good time. We look forward to seeing your designs, which we know will be diverse, beautiful, and energy efficient!

Ed Hazzard

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Chapter 1: Build and Test a Standard House

Introduction

Build a model house and measure how much energy is needed to keep it warm.

The overall goal of this engineering project is to design and construct an energy-efficient house that is able to keep a steady inside temperature and can be heated by the sun. You will be working with a model rather than a full-sized house, but the principles are the same. By the end of this project, you will understand the heat transfer basics and design principles that you would need to design an energy-efficient house.

Before you start on your own house design, you will build and test a pre-designed "standard house" to familiarize yourselves with the materials, building methods, and measurements you will use to evaluate your design.

This is called a standard house because everyone will start by building the same one. Also, it will be the standard against which you can compare the performance of your own design later in this project.

The standard house meets the same criteria that you will follow when you build your own design. Your teacher will provide a cutout, which you can trace onto card stock, cut out, fold, and tape together. The windows can be made out of clear acetate.

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 of the house 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 standard house.

As with a real house, what matters is how long 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."

Tools & materials

- Computer
- Logger Lite
- One temperature sensor
- USB Flash drive
- Full-scale cutout of standard house and base for tracing
- Metal ruler (cm)
- Scissors
- Safety utility cutter
- Pencils
- Cardstock sheet, 56 x 71 cm (22 x 28 in)
- Cardboard surface to cut on
- Acetate sheets for windows
- Clear tape
- One 40 W heater light bulb in a socket with an inline switch, covered with aluminum foil
- One sun light bulb in a gooseneck fixture

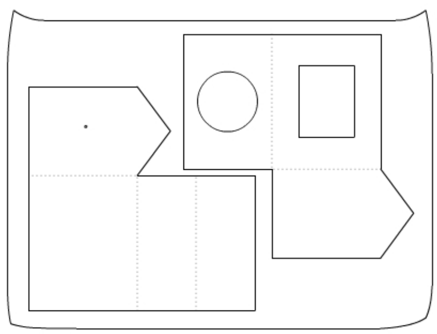
Standard House Description

- The standard house has a floor area of 400 cm^2 (16 x 24 cm) .
- The window is on the south side that faces the sun, and its area is 120 cm^2.
- There is enough room inside for the light bulb (15 cm high) and its base. There is a 12 cm diameter hole in the floor for the heater light bulb.
- Materials for the initial design are limited to cardstock, clear acetate, and tape.
- The house sits on a base, larger than the house. The base is labeled with the directions north, south, east, and west for testing purposes, so that you can picture the house with a real orientation with respect to the sun*.
- One sensor is inserted through the wall of the house.

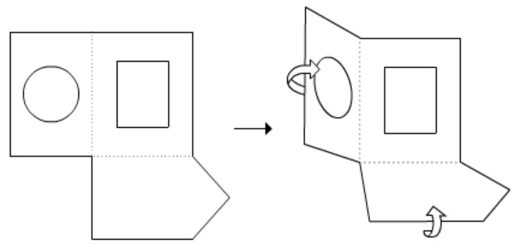
* Note that this workbook is written for a climate at about 40° north latitude that has warm summers and cold winters. Other climates may have quite different design issues, and the sun's path changes in other latitudes.

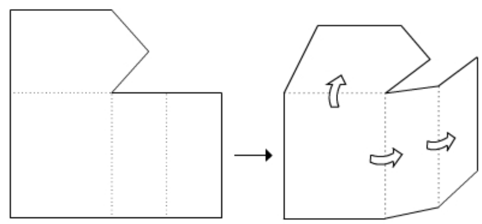
Building Instructions

1. Trace the two pieces of the standard house on a piece of card-stock, using the full-scale template provided by the teacher. Note how they must be arranged to fit on one sheet. Be sure to mark the locations for the sensor as shown on the template.



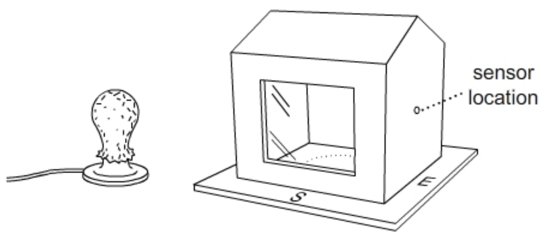
2. Cut out the two pieces, using scissors.
3. Use a sharp pencil to make a hole for putting a temperature sensor in a pre-marked spot. The hole is 10 cm above the floor.
4. Cut out the window and tape a piece of acetate over it on the side of the cardstock that will be inside the house.
5. Cut a circle out of the bottom of the house, as in the template, so that the heater light bulb can fit in. (The circle happens to be the same size as a CD.)
6. Fold the cardboard along the dashed lines. Use the edge of a table to make straight folds.

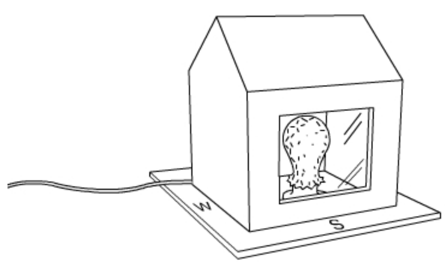




7. Tape the edges together.
8. The teacher will supply a piece for the base of the house (1/4 of a cardstock sheet, about 28 x 35.5 cm).
9. Label the base with directions: North, South, East, West.
10. Place the bulb with foil on the base.
11. Feed the power cord of the bulb through one corner of the house, as in the picture below. Then tape the joints closed around it.

12. Place your house and bulb on the base so that the window faces south and the bulb fits through the hole in the base of the house.
13. Write your team name on the house.
14. Your house will look similar to the house pictured below.





Note the power cord coming out of one corner of the house.

Power and energy

Energy is a special quality in science and engineering. It has many forms – thermal, kinetic, potential, chemical, electrical, nuclear, and radiation. It can change form, but the total amount of energy remains the same. In other words, energy is not created or destroyed; it just changes form. This principle, called the Conservation of Energy, is central to understanding heat flow.

In simple terms, energy is how much, and power is how fast you use it. A car has a certain amount of energy when going 60 mph, regardless of how quickly it reached that speed. A more powerful engine can get up to that speed more quickly. Energy (Q) is measured in joules. Power (P) determines how fast the heat flows or changes. It is measured in watts, which is the same as joules/second.

$$P = Q/t$$

Watts (W) = joules (J) / seconds (s)

We can also say that the amount of heat energy is the power multiplied by the time.

$$Q = Pt$$

Joules (J) = watts (W) * seconds (s)

For example, the power output of a 40 W light bulb is 40 watts. If the bulb is on for one minute it produces 2400 Joules of energy.

2400 J = (40 J / s) (60 s)

In everyday practice, electrical energy is expressed in kilowatt-hours rather than joules.

1 J (1 W-s/J) (1 hr/3600 s) (1 kW/1000 W) = 27.8 x 10^{-6} kWh

1 J = 27.8 x 10^{-6} kWh
1 kWh = 3,600,000 J

As this shows, kilowatt-hours are a more convenient unit because Joules are so small. Also, it's easier to work with hours than with seconds.

What is the power output of a 100 W incandescent bulb?

How much energy does a 100 W bulb use in 24 hr?

How much energy (in kilowatt-hours = 1000 watt-hours) would the bulb use if left on for a year?

How much energy would you save if you replaced the bulb with a 20 W fluorescent, which has about the same light output but uses less energy? (Fluorescent bulbs are more efficient. For the same power input, they produce more light and less heat than incandescent bulbs.)

How much money would you save if electricity costs $0.15/kWh?

Celsius vs. Fahrenheit (optional)

Note to American students: You will use the Celsius scale for these measurements, so here's a quick exercise to remind you about Celsius vs. Fahrenheit. Fill in Table 1.

$$C = 5/9(F - 32)$$

or

$$F = (9/5)C + 32$$

Celsius vs. Fahrenheit		
	Temperature in °C	Temperature in °F
Water freezes		
Water boils		
Room temperature	20	
A hot day		100

For example, suppose the room temperature is 20 °C. The target temperature for the warmed-up house will be 10 °C higher. What will these temperatures be as measured on the Fahrenheit scale? Fill in Table 2.

Experimental conditions		
	Temperature in °C	Temperature in °F
Room temperature	20	
Target house temperature	20 + 10 = 30	
Outdoor temperature if it were 10 °C below room temperature	20 – 10 = 10	

The last calculation is to show that our experimental conditions have the same temperature difference as a house kept at 20 °C when the outdoor temperature is 10 °C (50 °F). It's a cold day, but not freezing.

Keep the house warm

Introduction

Your goal is to warm up your house to 10 °C greater than the air around it. To do this, you will raise the house to the target temperature using the heater light bulb.

As you perform the following steps you will look at the graph generated by Vernier Logger Lite, which will record the time and temperature automatically and represent them graphically.

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 of the house 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 standard house.

As with a real house, what matters is how long 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 is on.

Your goal is to measure how much power it takes to keep your house 10 °C warmer than the air around it. To do this, you will:

- Turn the heater on and off so that the temperature stays within 0.2 °C of the target temperature.
- Record the times when the heater is turned on and off.
- Calculate what percentage of time the heater has to be on to keep the house warm.
- Multiply that percentage by the heater power (40 Watts) to get the average power supplied to the house.

What is the power requirement to keep a house warm on a cold day?

Tools & materials

- Standard house
- One temperature sensor
- Computer
- USB Flash drive
- Logger Lite for plotting temperature
- One 40 W heater light bulb in a socket with an inline switch, covered with foil

Quick Start for Logger Lite

Open the Logger Lite file (.gmbl) that goes with the experiment. (Note: the file name always ends with .gmbl.) It will recognize the sensors that are attached to the computer. It will have the right settings, but you can change them under “Experiment/data collection.”

Use the “collect” button to collect data.

If you have two sensors, touch one very briefly to find out which is which.

Use the “scale” icon to set the size of the graph to match the data.

Drag the axes up and down to expand or shrink the scale.

If the graph stops because the time ends, you can continue by choosing “append to latest” rather than “erase and continue” when you try to collect.

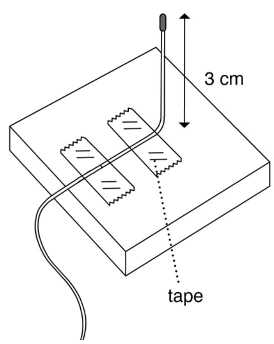
To save a dataset and add another one to the same graph, click on the “store” icon and then start collecting. The previous dataset will change to a thin line.

Use the “examine” button to scan the graph for specific values, which are shown in the data table to the left.

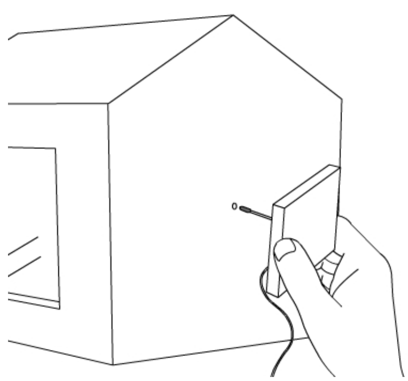
When you save your file, it will be saved as the file you opened. If you want to save another dataset, save it with a different name.

Procedure

1. Cut a 3x3 cm square of cardstock and tape the sensor to the center of it 3 cm from its tip. Fold the sensor 90° so that it is perpendicular to the card and is 3 cm long.

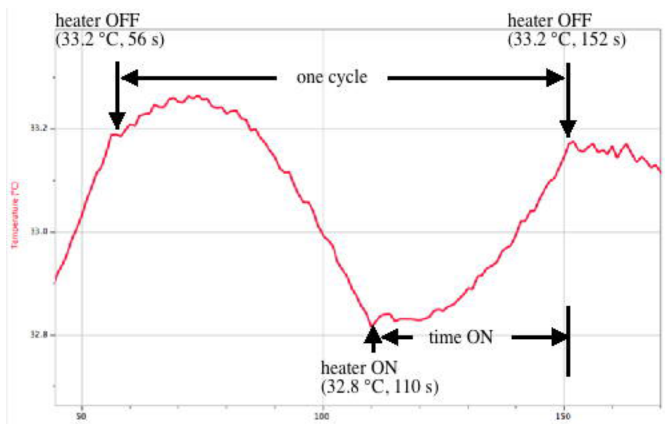


2. Insert the temperature sensor in the hole you made in the middle of the wall of the standard house. The sensor must be pushed through the wall so that it is perpendicular to the wall. Make sure it is not touching the wall. Tape the card to the outside of the house to keep the sensor in place.



Collect data

1. Connect one temperature sensor to your computer.
2. Open the Logger Lite file that goes with this experiment: *std house keep warm.gmbl*. It will open Logger Lite with the proper settings for this experiment.
3. Touch the end of the sensor to make sure it works. You should see the graph go up.
4. Measure the room temperature and record it in the table below. We will assume it stays reasonably constant throughout the experiment.
5. Calculate your target temperature: about 10 °C above room temperature (round it up to a whole number). Record the target temperature in the table below.
6. Turn the heater on.
7. Start collecting data when the sensor is a few degrees below the target temperature.



8. Refer to the sample graph above, which should look roughly like yours. When the sensor reaches 0.2 °C above the target temperature, switch the heater OFF and record the time in the table below (A). Note that the data table in Logger Lite makes it easy to note the current time while data is being collected.

   Note: the temperature may continue to rise for a time. That's OK.

9. 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).

   Note: the temperature may continue to fall for a time. That's OK.

10. 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).

11. Stop collecting data.

12. Click the "scale" icon to fit the graph to your data.

13. Save the Logger Lite file.

14. 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 (point A)	
B. Turn heater ON at lower limit (point B)	
C. Turn heater OFF at upper limit (point C)	
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 W * proportion of time heater is on)	_______ W

How to calculate the power requirement (Row G)

You used the energy provided by the heater to heat up your house and maintain it at your target temperature. The bulb you used as a heater has a power of 40W. This means that it releases 40 joules of energy per second. But since it wasn't on all the time, the house used less than 40 W to stay warm. The average power requirement of your house is:

Power requirement = 40 W * time on / total time

Note that the total time should be a full cycle, from OFF to ON to OFF again.

The steps of the calculation are set out in the table above.

Analysis

In your own words, explain the difference between energy and power.

Which did you measure in this experiment, power or energy?

What are the units for energy? What are the units for power?

The light bulb in this test house is supposed to model the furnace or boiler in your house. Describe how turning the light bulb on and off is similar to a thermostat in your house.

How do you think you could reduce the power needed to maintain the house temperature in this model? Explain what you would do and how it would help.

Homework

(pages 16-17)

Connection to buildings (optional)

Background

The light bulb in the standard house is like the furnace or boiler in your house. It has a fixed output and is on part of the time. Heating units are sized so that they would be on all of the time only on the coldest days, when there would be the greatest temperature differences between inside and outside, and hence the greatest rate of heat loss. If you improved the energy efficiency of your house, the heater would be on less time and use less total energy over the year.

Your house has a thermostat, which does exactly what you did by hand in the experiment: it turns the heater on when the house temperature is below the set temperature, and off when the temperature rises above the set temperature. If you graphed the temperature in your house, it would be a wavy line like the graph in this experiment.

In a real house, the yearly energy requirement would be calculated by looking at the energy bill (for example, 400 gallons of oil multiplied by 130,000 BTU/gallon = 52 million BTU = 15,200 kWh).

Note: in the USA, both kilowatt-hours (kWh) and British Thermal Units (BTU) are in common use as heating energy units. If you want to interpret your energy bill and compare electrical energy to oil or gas energy, you will need to convert from one to the other.

1 kWh = 3412 BTU

Look up your actual heating energy use, following the steps below.

Figure out the amount of energy you use for heating. You probably use electricity, oil, or natural gas.

yearly oil (gal) ____________

yearly gas (therms) ____________

yearly electric (kWh) ____________

Make use of the following *approximate* conversion factors:

1 kWh = 3400 BTU

For oil, 1 gallon = 120,000 BTU (allowing for a boiler effiency of 85%)

For natural gas, 1 Therm = 100,000 BTU

Your annual heating energy use in kWh: ____________

If your boiler heats domestic hot water as well as the house, subtract the average monthly summer use from each winter month (about six months in all) to obtain just the heating energy. If heating and hot water are separate, you can skip this step.

Your average monthly hot water energy use in kWh: ____________

Your hot water energy use for 12 months in kWh: ____________

Your heating energy use (annual heating energy minus annual hot water energy) in kWh: ____________

Solar Heating Test

How does energy provided by the sun reduce the house heating requirement?

Introduction

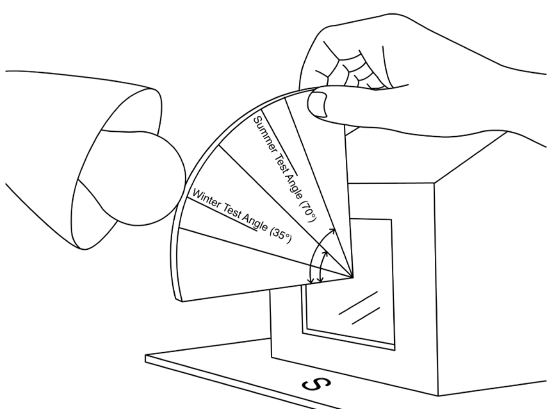
During the last session you built your house and heated it using a heater light bulb. That situation mirrors the nighttime when there is no sunlight.

Now you will add a very bright light bulb (300 W) outside as the "sun." Its position will be roughly that of the sun at noon in winter in the northern United States (40° N). You will use a single temperature sensor to measure the house temperature.

You will turn the heater on and off, but leave the sun on all the time. This will simulate a sunny day with light from the 300 W bulb providing "solar energy."

Set up the sensor

1. Insert the temperature sensor in the hole at the middle of your house.
2. Connect the temperature sensor to your computer.
3. Open the Logger Lite file that goes with this experiment: *std house solar heating.gmbl*
4. Use the room temperature from the previous experiment. It will be approximately the same.
5. Calculate the target temperature (room temperature + 10) and enter it in the table below.
6. Set up the gooseneck lamp with a sun light bulb in it, due south of the building.
7. Place the sun angle template so the corner is in the center of the window.
8. Aim the tip of the light bulb along the “winter test angle” line on the template (see figure below).



Tools & materials

- Standard house
- One temperature sensor
- Computer
- Logger Lite
- USB Flash drive
- One 40 W heater light bulb
- One 300 W sun light bulb in a gooseneck desk lamp
- Template for measuring “sun’s” angle

Procedure - Collect data

1. Switch on the heater light bulb AND the sun light bulb.

NOTE: The 300 W 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.

2. Start collecting data when the sensor is a few degrees below the target temperature.
3. When the 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 throughout the test.**
4. When the sensor reaches 0.2 °C below the target temperature, turn the heater ON. Record the time in the table below (B).
5. 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).
6. Stop collecting data.
7. Click the “scale” icon to fit the graph to your data.
8. Save the Logger Lite file.
9. Calculate the power requirement to keep the house warm by filling out the rest of the table below.

Solar heating test	
Note: Sun is ON for the whole experiment.	
Room temperature: _____°C Target temperature: _____°C Upper limit (target temperature + 0.2): _____°C Lower limit (target temperature – 0.2): _____°C	
Event	Time in seconds (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. Power requirement (40 W * proportion of time heater is on)	_______W
H. Average power requirement without the sun (from previous experiment)	_______W
I. Power supplied by the sun	_______W

Results

Report your results. What is the solar contribution to house heating, in watts and as a percentage of the power requirement?

Analysis

In a real situation, there might be strong sunshine for six hours a day, on average, out of twenty-four. On the other hand, the light would be much more intense than a 300 W light bulb. What might the solar contribution be in that case?

1. **Claim**: Describe a design change that could increase the house's ability to take advantage of energy from the sun.

2. **Evidence**: Use data, results or descriptions of your experiments or model-based activities to show how solar radiation affects the energy usage for the house.

3. **Reasoning**: Use your answer to Question 2 to explain the claim you made in Question 1.

Homework

Connection to buildings (optional)

Explore

Think about your own house and the possibility of using sunshine for heating it.

a. How many south-facing windows does your house have? Measure the area of each and add them up.

south-facing glass m^2 ___________

b. How good is your south-facing exposure? Are there trees or other buildings that cast shade for part of the day?

c. Could you add more south-facing windows?

d. What would you do to increase heat gain during sunny periods, but minimize heat loss at night?

Chapter 2: Heat Transfer

Introduction

As warm-blooded animals, we all care about heat and temperature! Our survival, not to mention comfort, depends on keeping our bodies at a constant temperature, despite huge changes in the environment. The focus here is on buildings, but the same principles apply to our bodies. Every day, we experience conduction (heat transfer through clothes), convection (moving air or water), and radiation (especially sunshine), which are the basic ways that heat is transferred.

What is heat? How is it stored?

In buildings, temperature is a key part of comfort. The more efficiently it can be kept at a comfortable temperature, the better, since a significant part of the nation's energy budget is devoted to the heating and cooling of buildings.

Heat transfer is an important aspect of green building. Heat transfers from warmer to cooler things. This equalizing of temperature occurs in three ways:

Conduction: the transfer of heat through a solid material. Heat is transferred directly in and through the substance. Loss of heat through blankets or transfer of heat through the handle of a hot frying pan to your hand are examples of conduction.

Convection: the transfer of heat by the movement of fluids such as air or water. Hot air rising up a chimney or hot water circulating in a pot on the stove are examples of convection.

Radiation: energy that travels directly through space as electromagnetic waves. It does not require matter for transmission. Most radiation associated with heat is either visible light or infrared radiation, which is not visible. The warmth from a fire is mostly infrared.

In this unit you will explore each means of heat transfer and apply this knowledge to energy efficient house design.

Heat transfer and thermal equilibrium

Thermal energy is the total kinetic energy of the molecules of a substance. It is the energy needed to raise the temperature of the substance from absolute zero, which is -273 degrees Celsius or 0 Kelvin to its actual temperature. It is measured in Joules, kilojoules, or other units of energy.

Heat (Q) is the thermal energy that can be transferred between two systems by virtue of a temperature difference. It is much smaller than the total thermal energy because normal temperature differences are small. For example, when a hot drink cools down, it loses thermal energy or heat to the surroundings due to a difference in temperature. When the liquid reaches room temperature it still has lots of thermal energy, but no more heat is transferred because there is no temperature difference.

Temperature measures the average kinetic energy of the molecules of a substance. Kinetic energy includes all of their motion: vibration, translation, and rotation. Molecules are always moving except at absolute zero, which is defined as the temperature at which all motion stops.

Heat flows from a hotter to a colder body until the two are in equilibrium at the same temperature. The total amount of heat remains the same, unless heat is lost or gained from the system.

Heat storage

The heat stored in a material, called its heat capacity or thermal mass, is

$$Q = c_p m \Delta T$$

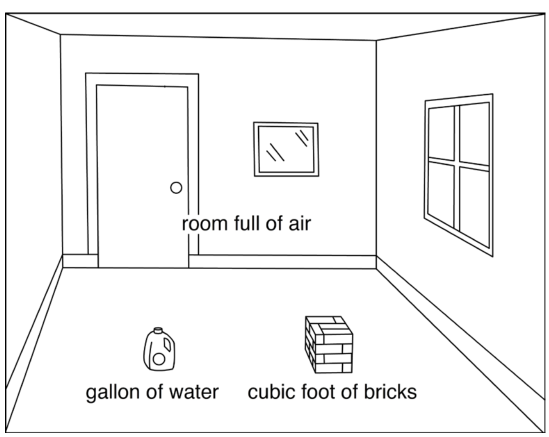
Q = heat (kJ)
c_p = specific heat (kJ/kg K)
m = mass (kg)
ΔT = change in temperature of the material (degrees Kelvin - K, or degrees Celsius - °C)

Expressed in words, this equation says that the heat stored in a material depends on its heat capacity per unit mass (different for different materials), its mass (how much of it there is), and the change in temperature of the object. The symbol (ΔT) means "change in temperature." It could also be written as ($T_2 - T_1$).

Note the units for c_p (kJ/kg K). It is the amount of energy that it takes to raise one kilogram of a material one degree Kelvin (which is the same as one degree Celsius).

Note that heat capacity or thermal mass ($c_p m$) is the total heat per degree of temperature change stored in an object.

Different materials can store different amounts of heat because they have different specific heats. For example, for a given change in temperature, the same amount of heat is stored in a roomful of air, a cubic foot of bricks, or a gallon of water.



Air doesn't hold much heat, and most heat storage in buildings is in the solid materials – plaster walls, concrete floors, etc. Very little of it is in the air, which is quick to heat up, and quick to cool down.

Water has a very high heat capacity, that is, it takes a lot of energy to change the temperature of water a small amount, compared to many other materials. This is very significant in both natural and man-made systems. For example, much more heat is stored in the world's oceans than in its atmosphere, which is important when thinking about climate change. As another example, a much smaller volume of water is needed than air to transport heat from one place to another – say from the furnace to the rooms of a house.

Heat flows from a hotter to a colder body until the two are in thermal equilibrium at the same temperature. The total amount of heat remains the same, unless heat is lost from the system or gained from the outside. This is the principle of Conservation of Energy.

This principle can be used to measure the amount of heat stored in a material. If heat is allowed to flow between two objects at different temperatures, the heat gained by one object (A) is equal to the heat lost by the other one (B).

$$(c_p m\Delta T)_A + (c_p m\Delta T)_B = 0$$

$$(c_p m\Delta T)_A = -(c_p m\Delta T)_B$$

Use this principle to explore the factors that affect heat storage.

Two blocks of aluminum, one at 80° C and the other at 20° C, are placed in contact and surrounded by very good insulation. One is twice as large as the other. What will be the final temperature of each block? Explain how you figured it out.

Power and energy

Here is a quick review of the difference between energy (how much) and power (how fast).

Take an oil-fired boiler as an example. They are rated by their power output (BTU/hr or energy/time), which can also be expressed as gallons per minute of oil used. How fast the oil is used is a power rating. How many gallons of oil you use is an energy rating.

Here's a very common conversion problem. The energy in a gallon of oil is about 120,000 BTU, and a kWh of energy is about 3400 BTU. If oil is $3.00/gal and electricity is $0.15/kWh, which form of energy is more expensive? Show your results.

Connection to buildings

Explore

How would a building with a high heat capacity (masonry) behave differently from a building with a low heat capacity (wood frame)?

When and where is it useful to store heat? Think about different contexts, such as houses, food, cooking, or water and give at least three examples.

Heat Transfer

Conduction

Introduction

Conduction is the transfer of heat through solid materials. Thermal conductivity is the measure of how fast a material conducts heat. The opposite of conductivity is resistivity, or insulating value. Metals, like aluminum or iron, conduct very well, that is, they are good conductors and poor insulators. Materials with air trapped in them, like wool, bedding, or Styrofoam, conduct very slowly; they are good insulators. Most solid materials, like wood, plastic, or stone, are somewhere in between.

How does heat flow through solids?

Factors that affect heat conduction

The rate of heat transferred by conduction depends on the conductivity, the thickness, and the area of the material. It is also directly proportional to the temperature difference across the material. Mathematically, it looks like this:

$$\Delta Q/\Delta t = -kA(\Delta T/L)$$

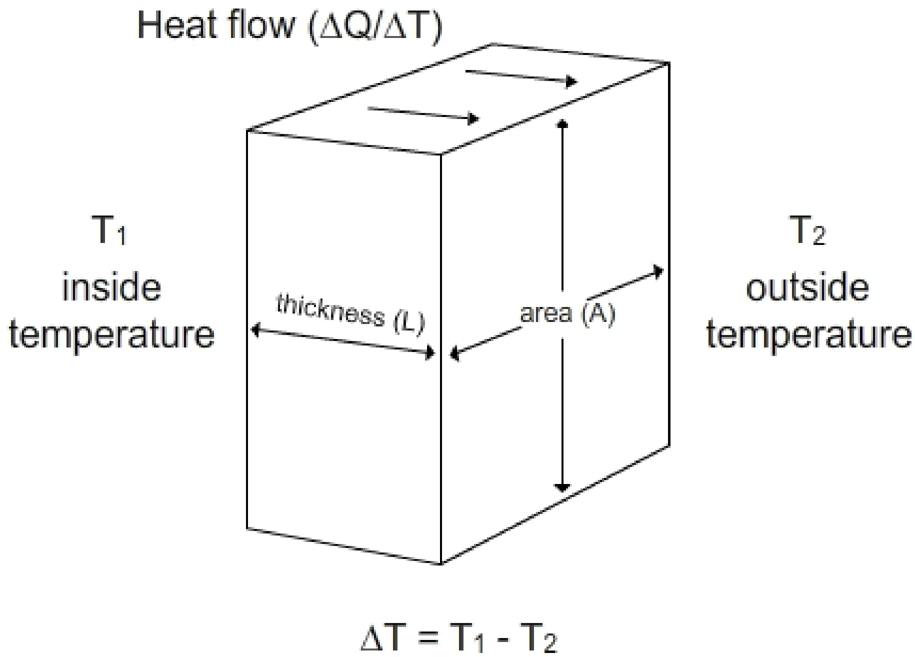
$(\Delta Q/\Delta t)$ **= the rate of heat conduction (kJ/s)**
ΔT **= temperature difference across the material**
L **= thickness of the layer (m)**
A **= area of the material (m^2)**
k **= thermal conductivity of the material per unit thickness (kJ/m/s/°C)**

The symbol Δ (delta) means "change in." It could also be written as follows:

$$\Delta Q/\Delta t = (Q_2 - Q_1)/(t_2 - t_1)$$

$$\Delta T = (T_2 - T_1)$$

Note that $\Delta Q/\Delta t$ is the *rate* of heat flow by conduction, that is, how fast it flows through the material. The *amount* of heat flow is ΔQ.



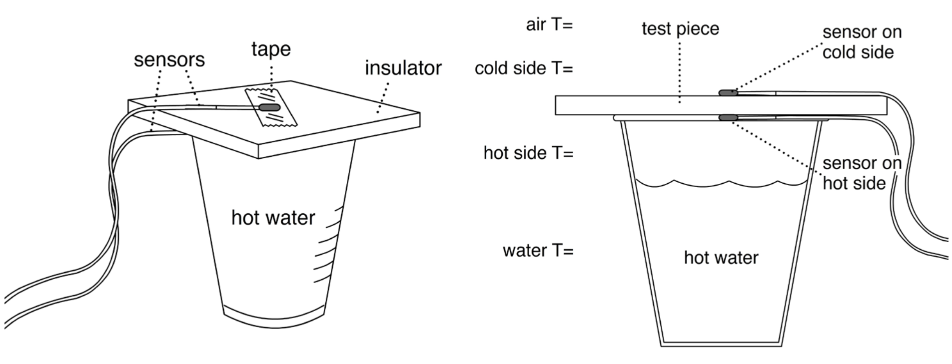
Factors that affect heat conduction through a solid material.

Conductivity of different materials

In this experiment you will measure the relative conductivity of various materials by placing them over a cup of hot water and measuring the temperatures on both sides.

Procedure & data collection

1. Pick a test material from the available collection of sample squares.
2. Attach the two temperature sensors to the computer.
3. Open the Logger Lite file that goes with this experiment: *conduction.gmbl*
4. Fill a foam cup with very hot water and bring it to your work station.
5. Measure the room temperature and the hot water temperature by putting one of the sensors first in air and then in the water in the cup. Record them in Table 1 below.
6. Tape a temperature sensor to each side of a piece of material. The tape should cover the sensor and hold it tightly to the surface.

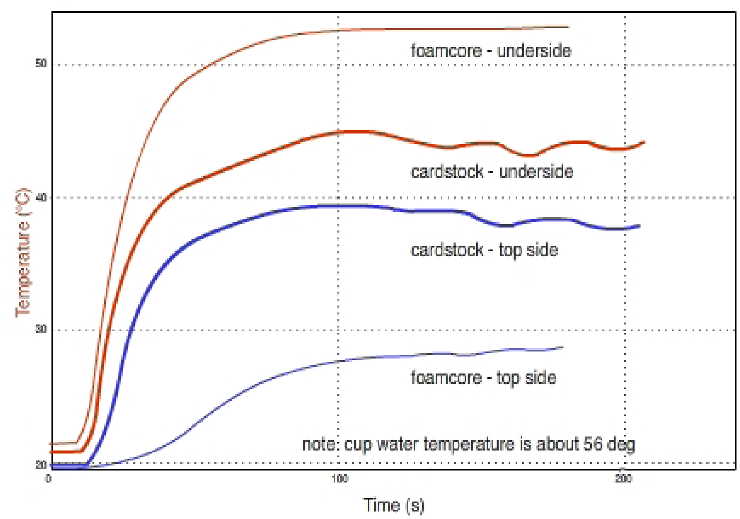


7. and hold it firmly in place, touching only the edges.
8. Observe the temperature graphs. After they stop changing very quickly (about three minutes), stop data collection and scale the graph.
9. Write down the steady state temperatures in Table 1.

Tools & materials

- Two temperature sensors
- Computer
- Hot tap water
- Styrofoam cups
- Squares of different rigid materials (aluminum, card-stock, cardboard, foamcore) large enough to cover the cup
- Clear tape

10. Pick another material and repeat steps 6-9. Record all the data as different runs on the same Logger Lite file. To do this, click on the "store" icon before starting to collect a new dataset. Here's an example. The thicker lines are the current experiment, and the thinner lines are a previous run.



11. Save the Logger Lite file.

Conductivity of materials					
Material	Water temperature	Air temperature	Inside surface temperature	Outside surface temperature	Difference across material
Initial conditions					
Aluminum					
Cardstock					
Foamcore					

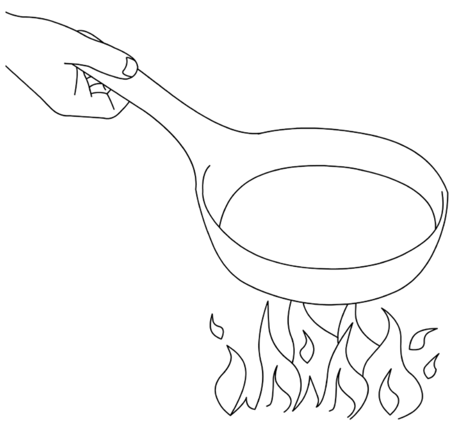
Results

How is the temperature difference related to the thermal conductivity (k)? Explain your reasoning for this.

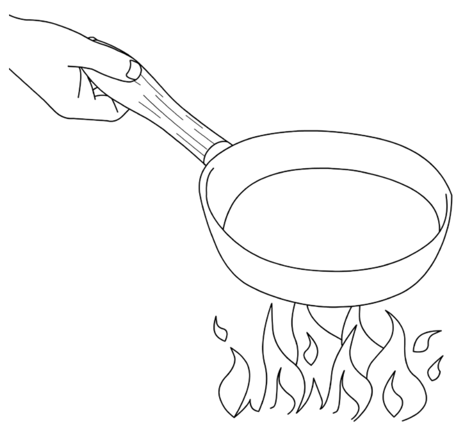
Based on this experiment, what wall construction would you propose for your standard house?

Analysis

The diagrams below show a frying pan over a fire. In each case, indicate which variable in the equation is changed from one drawing to the other, and whether the heat reaching your hand is great for drawing A or drawing B.



A. metal handle

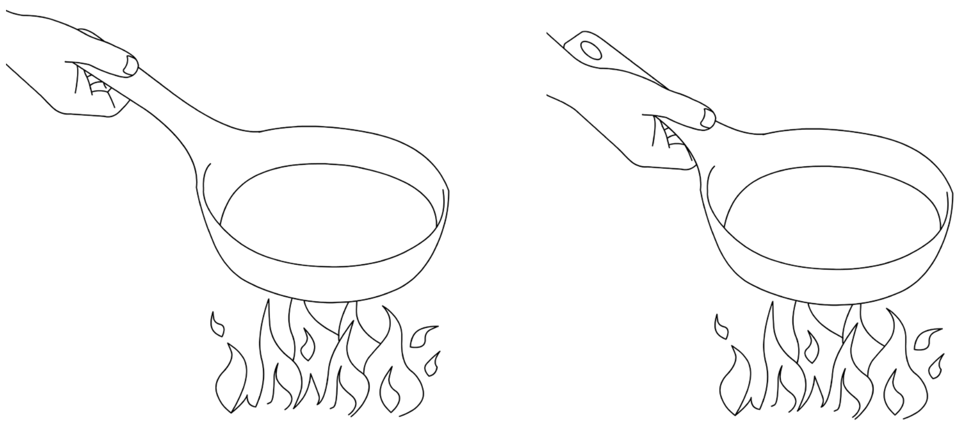


B. rubber handle

In which case, A or B, will the rate of heat reaching your hand be greater?

Which variable in the equation is being changed?

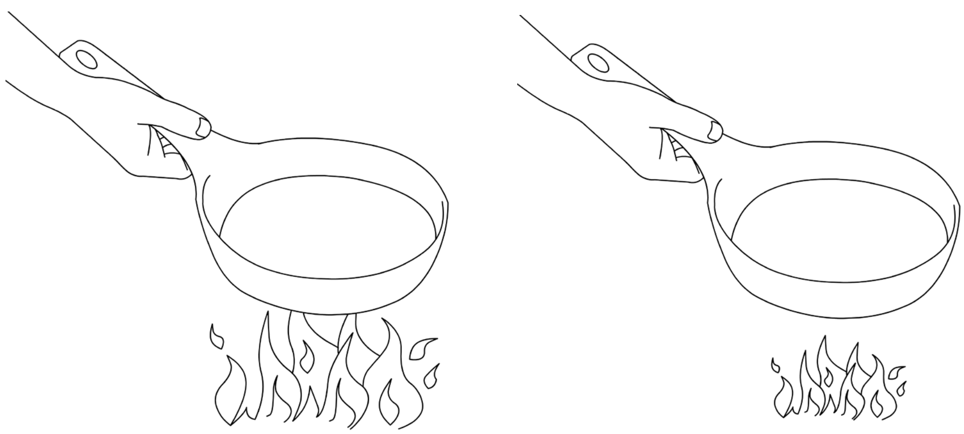
Describe an everyday situation where you have directly experienced the difference in conductivity between two materials.



A. hand farther up the handle   B. hand closer to the pan

In which case, A or B, will the rate of heat reaching your hand be greater?

Which variable in the equation is being changed?



A. more intense heat source   B. less intense heat source

In which case, A or B, will the rate of heat reaching your hand be greater?

Which variable in the equation is being changed?

1. **Claim:** What part(s) of a house lose(s) the most heat by conduction?

2. **Evidence:** Use data, results or descriptions of your experiments or model-based activities to show how thermal conductivity, area, thickness and properties of different materials conduct heat.

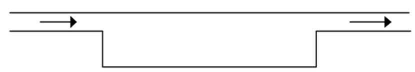
3. **Reasoning:** Use your answer to Question 2 to explain the claim you made in Question 1.

Conductivity and heat capacity combined (optional)

It’s easy to confuse heat capacity (thermal mass) with insulating value. Heat capacity is the ability to *store* heat. An object with more heat capacity takes longer to heat up or cool down because more heat is required to change its temperature.

Conductivity is how easily heat will *flow* from one place to another. A more insulated object takes longer to heat up or cool down because the heat flows more slowly into it or out of it.

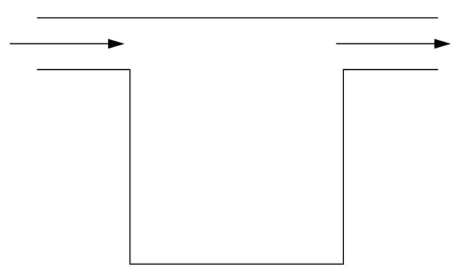
Insulating materials generally have low heat capacity (because they are mostly air) and low conductivity. It takes very little heat to warm them up, but getting the heat into and out of them is slow. So the heat flow looks like this:



insulators

low conductivity = small flow
low heat capacity = small storage

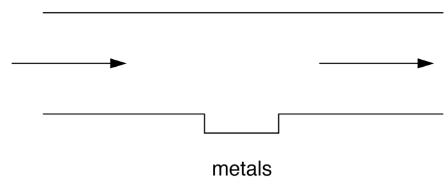
Masonry materials generally have high heat capacity and fairly high conductivity. It may take a lot of heat to warm them up, but once they are “full”, the heat will flow through them quickly. The heat flow looks like this:



masonry

moderate conductivity = medium flow
high heat capacity = large storage

Metals have a low heat capacity and very high conductivity. They are easy to heat up, and heat flows through them easily. The heat flow looks like this:



very high conductivity = large flow
low heat capacity = small storage

Would you insulate a masonry house on the outside or the inside? Describe the difference in terms of heat conductivity and heat capacity of the masonry wall.

Homework

(pages 40-42)

Connection to buildings

Background

In the building trades, the rate of heat loss is called conductivity (U), which is the same as k, seen on page 31. The most common measure of conductivity is its inverse: resistance to heat flow, called R or R-value.

R (thermal resistivity) = 1 / U (thermal conductivity)

The greater the value of R, the more slowly heat is lost. Doubling R-value means the rate of heat loss is cut in half.

The American building trades don't use metric units. For instance, heat flow is measured in British Thermal Units (BTU) per hour, instead of kilojoules per second. Temperatures are in Fahrenheit rather than Celsius. Thickness is in inches, and area is in feet instead of meters.

To do real calculations on a building, you must get used to doing lots of conversions of units! This project will focus on the relative behavior of different materials, rather than exact calculations.

R can be given per inch of material or for the whole assembly. For example, many common insulating materials have an R-value of 3 to 5 per inch, in standard American units. Fiberglass in a 5 ½" wood frame wall adds up to about R-20. Insulation in ceilings and roofs, where there's more room for insulation, is commonly R-30 to R-40.

Windows typically have the lowest R-value in the building envelope: R-1 for single glazed, R-2 for double glazed, and R-3 or 4 for triple or specially treated glazing. So the typical wall is five to ten times as insulating as the typical window. But there is five to ten times as much wall area as window area, so the two elements contribute equally to the total heat loss, roughly speaking.

Note that the true insulating value of a wall or ceiling depends very much on the quality of workmanship. Gaps and voids can radically reduce the nominal R-value.

Material	Approximate R-value in US units
2x4 wall with insulation	12
2x6 wall with insulation	20
12" of attic insulation	45
12" masonry or concrete foundation wall	2
Single sheet of glass	1
Insulated glass	2
High-performance insulated glass	3
Insulated door	5

Masonry is surprising. It has a high thermal heat capacity, but its R-value is low. That is, it stores a lot of heat, but it also conducts heat well. An 8" masonry or concrete wall has only as much R-value as a double-glazed window (about R = 2)!

Connection to buildings

Explore

Describe the advantages of a well-insulated house.

Recall that heat loss is proportional to both the thermal conductivity and the area of a surface such as a wall. If a house had ten times as much wall area as it had window area, and the wall was ten times as insulating, what would be the relative heat loss from wall and window?

Heat Transfer

Convection

Introduction

Convection is defined as the circulation of fluids (liquids or gases), either natural or forced. Hot or cold fluids can add or remove heat. Natural convection is caused by density differences. Hot air rises because it is less dense than cold air, so air will rise above a heater and sink near a cold window. Forced convection refers to fluids being pushed around by outside forces. A fan or a pump are forms of forced convection, which is very useful for moving heat from one place to another.

In this section you will investigate the effects of convection in a house.

How do fluids carry heat from one place to another?

Can air carry heat into and out of a house?

Natural convection

Hot air rises, because it's less dense than cold air. Warm air in a room quickly rises upward, and cold air sinks downward, even if the temperature differences are quite small.

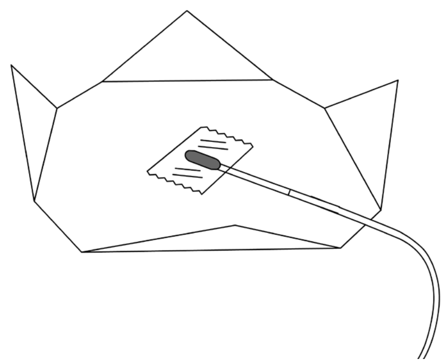
Natural convection in a cup

Tools & materials

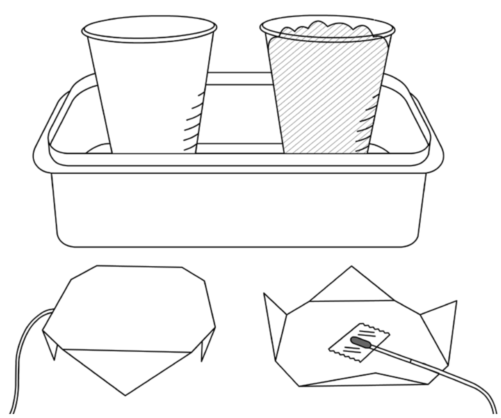
- Two temperature sensors
- Computer
- Logger Lite
- Scissors
- Tape
- Two plastic or Styrofoam cups
- Two pieces of cardstock to cover the cups
- Shallow pan
- Hot water
- Loose insulation such as crumpled paper, foam packing beads, fiberglass, or cellulose, cloth, tissue paper

Procedure & data collection

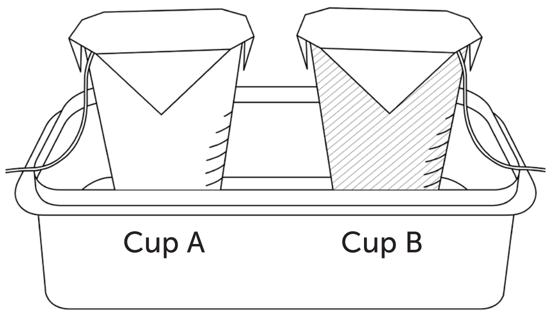
1. Cut out two pieces of cardstock slightly larger than the tops of the two cups.
2. Tape the temperature sensors to the undersides and fold over the corners to fit on the cups.



3. Fill one cup with loose insulation. Leave the other cup empty.
4. Place the cups in a shallow pan.



5. Place the cards on top with the temperature sensors on the lower side.



6. Connect the temperature sensors.
7. Open the Logger Lite file that goes with this experiment: *convection in cup.gmbl*
8. Start data collection. Wait for a minute or so until the sensors settle at roughly the same temperature.
7. Add a small amount of hot water to the pan. If you add too much, the cups will start floating.
8. Note the changes in temperature of the two sensors.
9. Stop data collection about 30 seconds after you add hot water.
10. Record the temperature changes in 30 seconds in the table below.
11. Save your Logger Lite file

Convection in two cups		
	Empty cup A temperature	Insulated cup B temperature
Before hot water		
After 30 seconds		
Change in temperature	_______ °C	_______ °C

Results

Which temperature changed most quickly, the empty cup or the filled cup?

For each cup, about how long did it take for there to be a noticeable difference?

Analysis

Explain how the heat moves from the hot water to the sensor in each case. Draw a diagram of the air flow in each case.

1. **Claim:** Give an example where heat is transferred by convection in a house.

2. **Evidence:** Use data, results or descriptions of your experiments or model-based activities to explain how heat is transferred by convection.

3. **Reasoning:** Use your answer to Question 2 to explain the claim you made in Question 1.

Stopping convection

Introduction

How else could you control convection? For instance, what would be the effect of adding a “ceiling” – a single horizontal circle of paper halfway up the cup? Would this be as effective as insulation throughout the space? What about two or more “ceilings”? What about vertical walls inside the cup?

Procedure & data collection

1. Pick two “convection-stopper” designs that would stop convection, using just paper and tape. Use as little material as possible.
2. Install your designs in the two cups.
3. Place the two cups in a shallow pan as before.
4. Place the cards with temperature sensors attached on top of the cups.
5. Open the Logger Lite file that goes with this experiment: *more convection in cup.gmbl*
6. Start data collection and wait for a minute or so until the sensors settle at roughly the same temperature.
7. Add a small amount of hot water to the pan.
8. Stop data collection about 30 seconds later.
9. Record the temperature changes in 30 seconds in the table below.

Stopping convection

	Cup A	Cup B
Before water is added		
After 30 seconds		
Change in temperature	_______ °C	_______ °C

Results

Describe your "convection-stopper" designs.

Cup A design:

Cup B design:

Compare the arrangements in the table below.

Convection in cups comparison	
Arrangement	Temperature change
Empty cup	
Insulated cup	
Cup A design	
Cup B design	

Explain your results, using diagrams to show how you think the air is moving inside the cup.

Forced convection

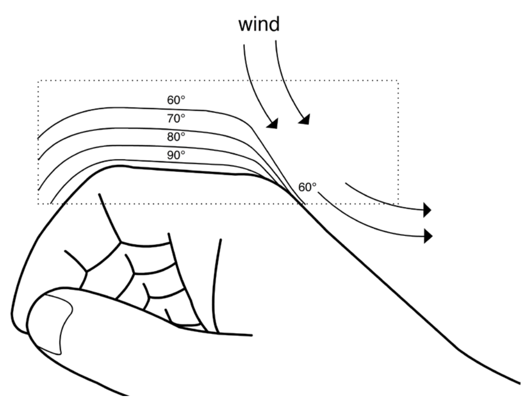
Forced convection refers to motion of a fluid that is not caused by differences in density between warm and cold ("hot air rises"). A fan (air) or a pump (water) is an example of forced convection. It is a very useful way to move heat around. For example, hot-air heating and air conditioning systems use large ducts to transport warm or cold air around a building.

Water can also carry heat from one place to another by being pumped through pipes, that is, by forced convection. The great advantage of water is its enormous specific heat. Large amounts of heat can be transported from the boiler to all corners of the building. It is then transferred to the air in various ways.

Wind chill describes the cooling effect of moving air across a warm surface, such as our skin. The cause of wind chill is simple, and it depends on the difference between conduction and convection. Air is a very good insulator, if it doesn't move. Most good insulators – wool, foam, fiberglass – trap air in tiny pockets so that it can't circulate. Heat conducts very slowly across each little air pocket.

On the other hand, air moves very easily in larger spaces, driven by even the slightest temperature differences. When it moves, warm air carries heat from one place to another. Large air spaces in walls are not good insulation because the air moves freely and carries heat from one side to the other.

Picture a hot surface (such as your skin) with cold air above it. Right next to the surface is a thin layer of still air that provides some insulating value because it is not moving. Imagine what happens when you turn on a fan. Your skin cools off because the still air layer is stripped away, and the skin surface is directly exposed to the cold air.

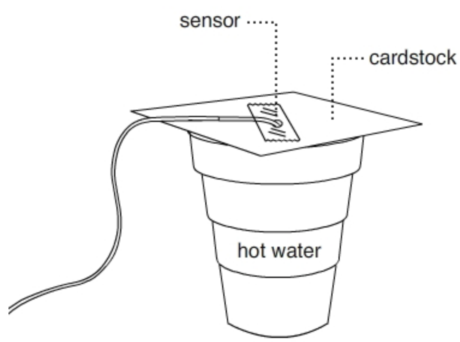


Wind chill (optional)

Procedure & data collection

In this experiment you will measure the effect of moving air on surface temperature.

1. Open the Logger Lite file that goes with this experiment: *wind chill.gmbl*
2. Start data collection. Hold the sensor in front of the fan and compare room temperature with the fan off and the fan on. Record the two temperatures below.
3. Tape the temperature sensor to a piece of cardstock and tape the card down over a Styrofoam cup of hot water so it won't blow away.



4. Start data collection again. Wait for two minutes or so until the sensor settles at a steady temperature.
5. Turn the fan on while continuing to record temperature. If you don't have a fan, use a piece of cardstock to fan air across the sensor. Don't blow – your breath is not at room temperature!
6. Wait until the temperature is stable again and turn the fan off.
7. Wait until the temperature is stable again and stop data collection.
8. Enter the temperature data in the table below.
9. Save your Logger Lite file.

Tools & materials

- One temperature sensor
- Computer
- Standard house with heater light bulb
- Metal ruler (cm)
- Scissors
- Safety utility cutter
- Fan (optional)
- Clear tape
- Styrofoam cup filled with hot water
- A piece of cardstock to cover the cup

Wind chill	
Measurement	Temperature
Room temperature	
Room temperature with fan	
Fan off	
Fan on	
Fan off	
Average difference of fan on vs fan off	

Results

Explain your results. Did the fan change room air temperature? Why?

Did the fan have an effect on the heated sensor? Why?

Explain your results in terms of convection.

Would wind make a house lose heat faster? Explain.

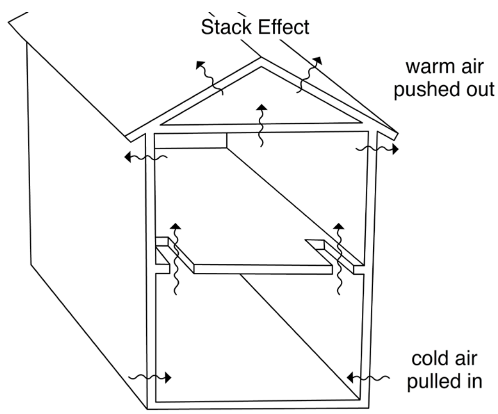
Infiltration

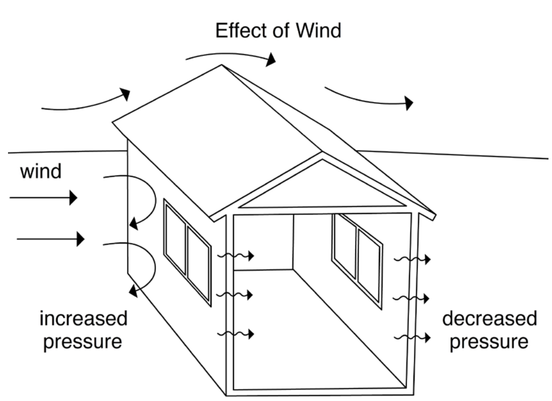
Introduction

Infiltration refers to outside air leaking into a house. This implies that inside air is also leaking out (exfiltration), so infiltration is loosely used to describe the exchange of air between inside and outside. If the inside air is warm and the outside air is cold, lots of heat can be lost, the energy bill will increase, and the house will be drafty and uncomfortable.

Infiltration can be driven by two forces: a) the "stack effect" or the "chimney effect," where rising hot air pushes outward at the top of a building and cold air is drawn inward at the bottom; b) wind, which creates greater pressure on one side of a building than the other, and pushes air through any cracks in the building.

You will explore infiltration further when you test you own model house in Chapter 4.





Connection to buildings

Explore

There are two ways convection might cause a building to lose heat:

1. Hot air leaks out through holes in the building (infiltration driven by the stack effect).
2. Moving air lowers the surface temperature of the building (wind chill effect) and increases the heat loss from the walls and windows. It also enters the building through cracks and holes (infiltration).

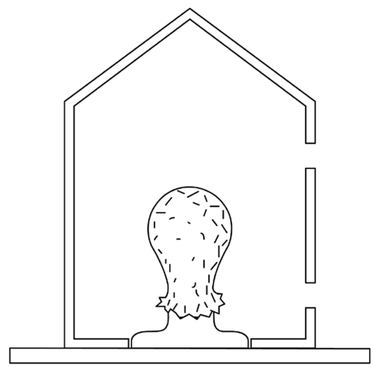
Suggest how you might cut down on these forms of heat loss in a real house.

Have you noticed differences in temperature between different rooms or levels in your house, or between the ceiling and the floor? Explain why in terms of conduction and convection.

Summary

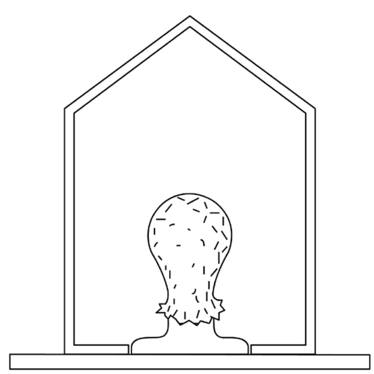
Here is a cross-section of your standard house. There is a leaky joint near the ceiling and another one near the floor. Suppose the average temperature is 40 °C inside and 20 °C outside.

- Draw what you think the heat distribution might be in the house by writing temperature values in five different locations.
- Draw arrows to show what you think the motion of the air might be due to convection.



Now suppose the leaks were sealed up. How would it be different?

- Draw what you think the distribution might be in the house by writing temperature values in five locations.
- Draw arrows to show what you think the motion of the air might be due to convection.



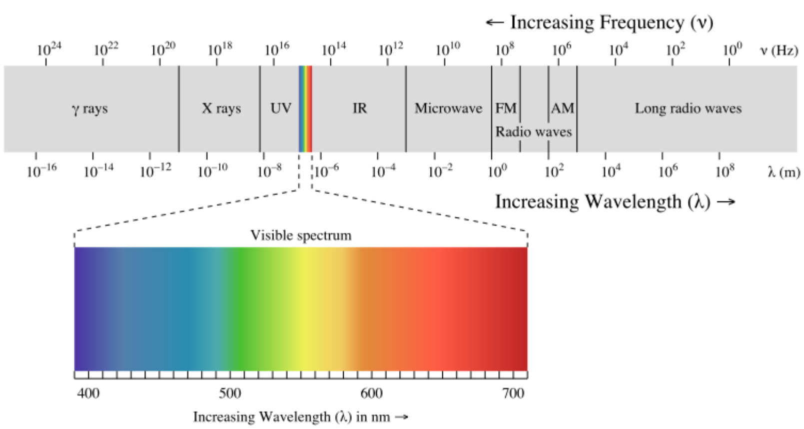
Heat Transfer
Radiation

Introduction

Do objects at room temperature give off radiation?

In this activity you will explore infrared radiation, which you can't see but can feel as heat.

Radiation is the common name for electromagnetic energy traveling through space. It goes very fast (ten times around the earth in one second) and can pass through a vacuum. It doesn't need material to travel in. It has many forms, including visible light, infrared (IR), ultraviolet (UV), X-rays, microwaves, and radio waves. These are all the same form of energy, just with different frequencies and amounts of energy. Different frequencies of radiation interact with matter differently, which makes them seem more different to us than they really are.



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Radiation is not heat. Radiation and heat are two different forms of energy. But one is often transformed into the other in everyday situations. Thermal energy is often transferred by radiation, mostly in the infrared (IR) and visible range. All materials that are warmer than absolute zero (-273 °C) give off radiation due to the fact that their atoms are vibrating. The amount of radiation is proportional to the fourth power of the temperature (T^4), measured from absolute zero. So, the hotter an object, the more radiation it emits.

Also most surfaces absorb radiation and transform it into heat. White surfaces reflect visible light, but absorb infrared. Black surfaces absorb both visible light and infrared.Shiny surfaces reflect both of them.

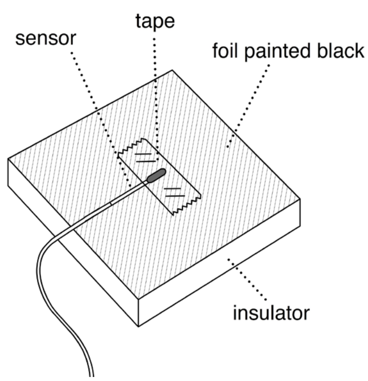
The fact that all objects give off radiation energy is a little surprising. We usually imagine that only “red hot” materials radiate, because we can’t see other wavelengths that aren’t visible light. This experiment will explore radiation from objects at ordinary temperatures. This radiation is mostly in the infrared range, which is right next to visible light but with longer wavelengths. Note the infrared range on the chart above.

Infrared radiation detection

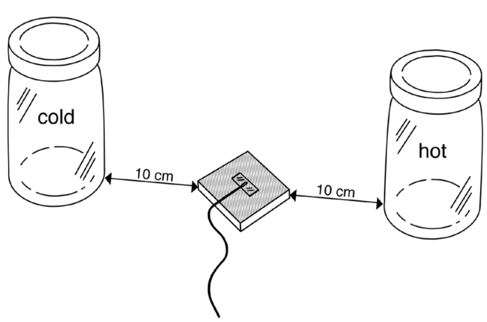
In this experiment you will use a "radiation meter"– a temperature sensor taped to a thin layer of aluminum foil that is glued to a piece of insulation and painted black. Radiation that strikes this surface will be absorbed and will quickly heat up the foil and the sensor. If the sensor temperature is different from the air temperature around it, you have detected heating from radiation.

Procedure & data collection

1. Tape your temperature sensor to a "radiation meter." Your teacher will provide this. The clear tape should cover the sensor so that it is held tight against the black surface.



2. Open the Logger Lite file that goes with this experiment: *radiation.gmbl*
3. Fill a jar with hot water (close to boiling if possible – be careful! You may need cloth or paper towels to pick it up) and another jar with cold water (ice water). The jars should have tops so they won't spill.
4. Place the two jars on a table and the radiation meter between them, with the radiation meter facing upward.

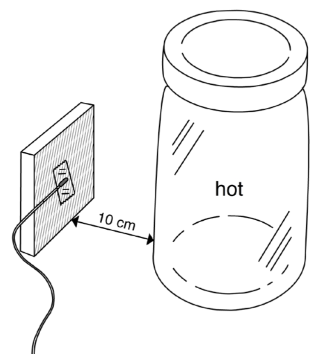


Tools & materials

- Temperature sensor
- Computer
- "Radiation meter": foil-faced rigid insulation, about 5 cm square, painted black
- Logger Lite
- USB Flash drive
- Ruler (cm)
- Clear tape
- Hot water jar (plastic or glass)
- Cold water jar (plastic or glass)

5. Start measuring. Let the sensor settle down to room temperature. Be careful not to touch it! If you do, wait until it goes back down to room temperature. It should remain unchanged (to 0.1 °C) for at least ten seconds. Record the room temperature in the table below.

6. Face the sensor toward the hot water jar. It should be 10 cm away. Wait for the sensor to settle down and then record the temperature in the table below. Note: your hands radiate IR too. Keep them away from the front of the meter!



7. Face the sensor toward the cold water jar and repeat the measurement. Record the temperature in the table below.

8. Save your Logger Lite file.

9. Calculate the change from room temperature.

Infrared heating		
Measurement	Temperature °C	Change from room temperature
Room temperature		
Toward hot water		
Toward cold water		

Results

Summarize your results, which compared the radiation meter facing the room (straight up), the hot jar, and the cold jar.

Could the radiation meter show a different temperature than the air immediately around it? Why?

Analysis

The radiation meter you used was black so that it would absorb radiation. What if it were white or shiny?

If the hot and cold jars influenced the temperature of the radiation meter, how did they do it? Explain in terms of conduction, convection, and radiation. Include specific evidence for your explanation.

Does the cold jar “radiate cold,” or does it “radiate less heat”? Why?

Describe a real-world situation where you have felt radiation from something hot and something cold even though they were not visibly hot or cold.

1. Claim: Explain why it is uncomfortable to sit near windows on a cold night even if they are tightly sealed and don’t let cold air in.

2. Evidence: Use data, results or descriptions of your experiments or model-based activities to describe what your experiments showed about radiation energy?

3. Reasoning: Use your answer to Question 2 to explain the claim you made in Question 1.

Connection to buildings

Homework

Background

Passive solar heating consists of letting in sunlight energy (mostly visible light) and stopping heat loss, some of which is IR radiation outward from the warm building. There's a trade-off between the two processes. Larger windows gain more sunlight, but they also lose much more heat than walls. There have been considerable technical advances over the years to make windows that are transparent (let light in), but also have a high insulating value (keep heat in).

For example:

- two layers of glass (three layers in northern climates), with an air space between
- argon gas in the air space, which is less conducting than regular air
- "low-emissivity" coatings on the glass surfaces, which reduces the emission of radiation from the glass itself. If you coated the jar of hot water in this way, the radiation meter would not show a temperature rise when it faced the jar.

Picture a room with large windows on one wall and a steam radiator on the opposite wall. Steam radiators are large cast-iron objects that get very hot — almost too hot to touch. At night, or when the sun is not shining, show all of the ways that the heat from the steam radiator becomes distributed throughout the room.

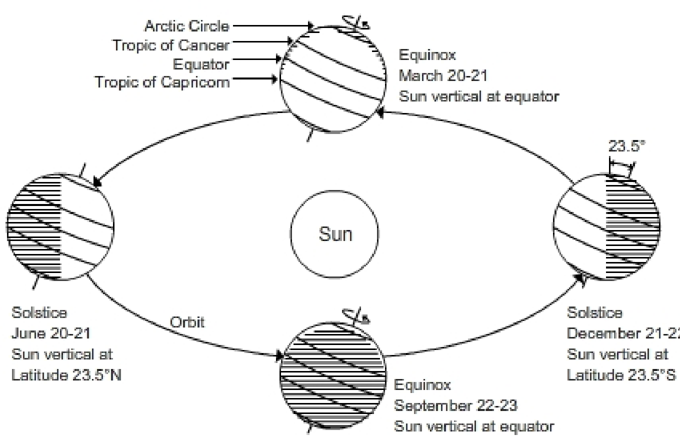
Heat Transfer
Energy from the Sun

Introduction

The sun rises in the east and sets in the west, but its exact path changes over the course of the year, which causes the seasons. In order to use the sun's energy in a building, we need to know where it is in the sky at different times of the year.

There are two ways to think about the sun's path in the sky. One way is to study the tilted Earth traveling around the sun viewed from outer space and figure out where the sun would appear in the sky at your latitude at different times of the day and year. If you have time, give this a try with your class.

Walk around a light source, real or imagined, with a globe that's tilted at the right angle. Turn the globe at different positions (times of the year). Try to picture the length of the day and the angle of the sun.

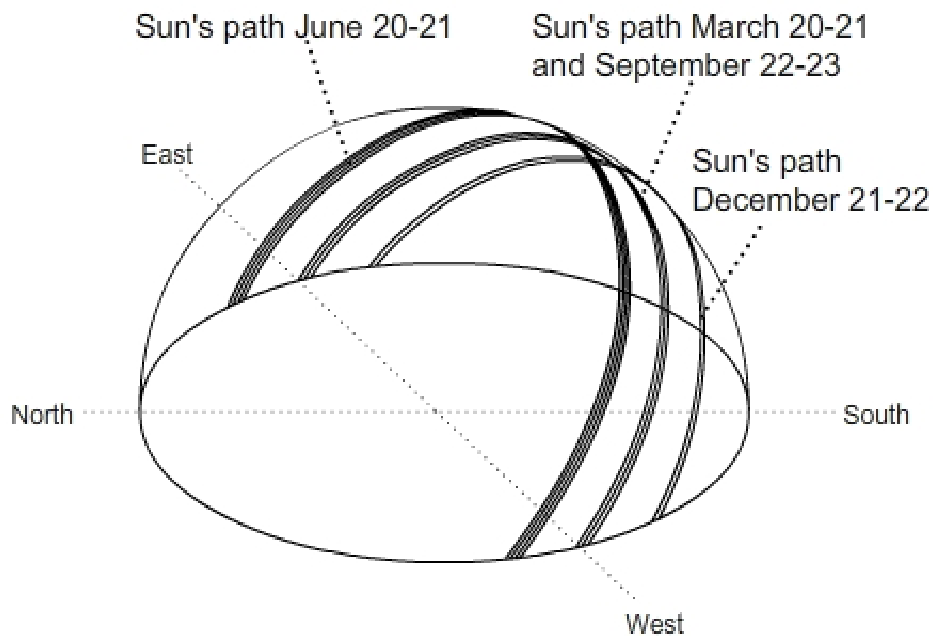


The other way is to stand on the Earth and plot the path of the sun from your point of view on the ground. This is easier to apply to a building, although, of course, the two ways give the same results.

We will use the earth-centered approach in this workbook.

Here is a diagram of the sun's path in the sky at different times of the year. It is roughly correct for a northern latitude of 40°. Note the three lines showing the sun's path. One is the summer solstice, one is the spring and fall equinoxes, and one is the winter solstice.

One is the summer solstice (June 21), one is the spring and fall equinoxes (March 20 and September 23), and one is the winter solstice (December 21). The exact dates change a little bit from year to year.



Homework

Learn the basic facts about the sun's path at your latitude. Use the above diagram, your background knowledge, and class discussion to fill out the following table. Here are some hints.

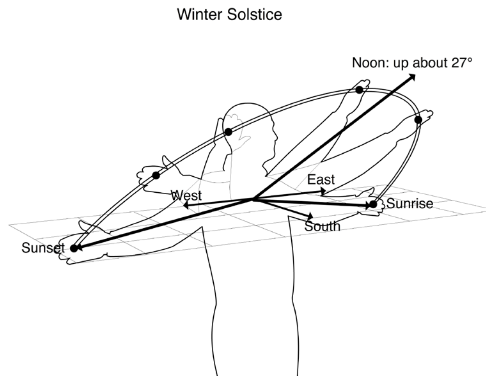
a) At the equinox at noon, the angle of the sun above the horizon is (90° minus the latitude). For example, at the equator this is 90°; at the pole this is 0°.

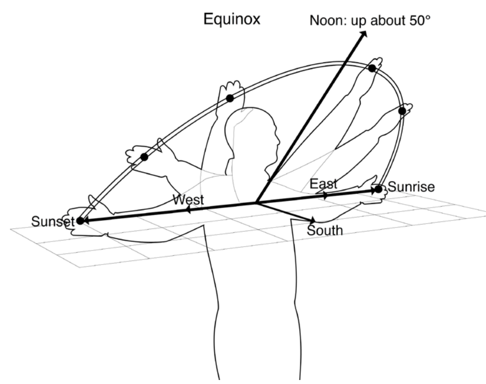
b) At the two solstices, the angular height of the sun at noon either increases or decreases by 23.5°– the tilt of the earth's axis – compared to the equinox.

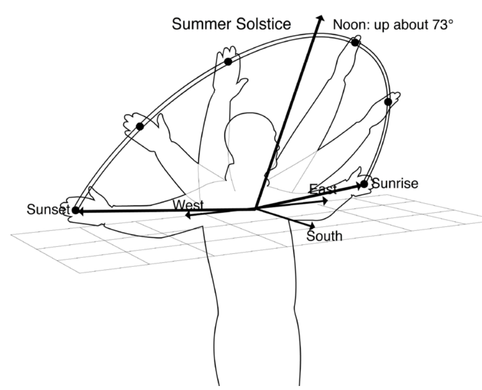
c) For the length of the day, do some Internet research. Many sites give the times of sunrise and sunset. (For 40°N, daylight is about 3 extra hours in summer and 3 fewer hours in winter.)

Sun's path throughout the year					
Your latitude:					
Event	Date	Length of day	Height of sun at noon	Sun rises in what direction?	Sun sets in what direction?
Winter solstice					
Spring equinox					
Summer solstice					
Fall equinox					

Before you continue, the teacher will lead a discussion on the Sun's Path Calisthenics so that this diagram makes more sense.



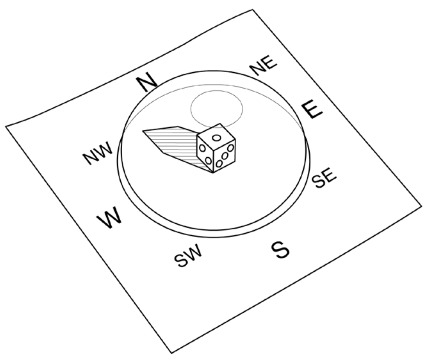




Represent the sun's path through the sky

Procedure & data collection

1. Place the plastic dome lid on a piece of paper.
2. Place a small cube under the center of the dome, as if it were your house.
3. Tape the dome to hold it in place.
4. Draw the directions N, S, E, W around the dome. Then add NE, SE, SW, and NW.



5. Draw the path of the sun in the sky on the dome at the spring equinox, using the marker. Do this by drawing points for the sun's position at sunrise, noon, and sunset at the equinox, using what you recorded on the table above. Estimate the angles, knowing that a right angle is 90°. Then connect the points with a smooth arc.
6. Draw the path of the sun in the sky at the summer solstice, the winter solstice, and the fall equinox, using the same procedure.

Tools & materials

- Clear dome lid
- Clear tape
- Marker
- Die or small cube
- Piece of white paper

Analysis

The sun always travels at the same speed across the sky (15° per hour). If that’s true, why does the length of the day change from summer to winter?

How would the path on the dome lid appear if you were on the equator?

How would the path on the dome lid appear if you were at the North Pole?

Based on your sun’s path diagram, explain why it’s warmer in summer than in winter when you are not near the equator.

Solar radiation through windows (optional, pages 71-73)

Introduction

Now that you know the path of the sun in the sky at different times of year, how can you use this information to use solar energy for heating your house?

The simplest form of solar space heating is windows that face the sun. Sunlight passes through the windows and is absorbed by surfaces within the house. There are no moving parts and no mechanical systems. **This is called passive solar heating.**

In this experiment you will investigate the best orientation for windows for passive solar heating by measuring how much the radiation meter is heated up by the gooseneck light at different orientations.

Procedure & data collection

Part I: Winter

1. Place the radiation meter on a table facing straight up.
2. Use the solar angle template to position the sun light bulb 20 cm away from the radiation meter at the winter sun angle. Picture the direction of the light as being south at noon in the winter.
3. Open the Logger Lite file that goes with this experiment: *window angle winter.gmbl*
4. Turn on the light and start collecting data.
5. Every 30 seconds, change the angle of the radiation meter, in the following sequence:

Winter sun angle		
Time	Orientation of radiation meter	Ending temperature
0-30 s	Horizontal	
30-60 s	Vertical facing NORTH	
60-120 s	Vertical facing EAST	
120-180 s	Vertical facing SOUTH	
180-240 s	Perpendicular to light rays	

6. In 30 seconds, the temperature will approach a new value but not quite stop changing. After you have finished the sequence, stop collecting data and write down the temperature for each orientation at the end of its 30 seconds.

7. Save your data.

Part II: Summer

8. Open the Logger Lite file that goes with this experiment: *window angle summer.gmbl*

9. Reposition the sun light bulb to the summer test angle, using the sun angle template. Repeat the sequence and fill out the following table.

Summer sun angle		
Time	Orientation of radiation meter	Ending temperature
0-30 s	Horizontal	
30-60 s	Vertical facing NORTH	
60-120 s	Vertical facing EAST	
120-180 s	Vertical facing SOUTH	
180-240 s	Perpendicular to light rays	

Results

Compare winter and summer by filling out the following table. Rank the various orientations from most to least solar heating.

Summer vs. winter solar heating		
Solar heating	Orientation (winter)	Orientation (summer)
5 (most)		
4		
3		
2		
1 (least)		

What is the best orientation for windows so that a building will gain heat in the winter but not in the summer?

Explain a strategy for using shades or overhangs to control winter heat loss and summer heat gain.

What area should they have? What are the advantages and the drawbacks of passive solar heating?

Summary

Think about a house you'd like to design. What directions and slopes (vertical, sloped, horizontal) would you choose for large windows? What directions and slopes would you choose for smaller windows? Why?

Chapter Summary

Explain the difference between conduction, convection, and radiation. Give an example of each process.

Chapter 3: Design and Build Your Own House

Introduction

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

Now that you have some background about heat transfer and some experience with taking measurements, it's time to design and build your own energy-efficient house.

Your success will be measured using the same tests that you did with your standard house:

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

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.

As you have seen with your standard house experiments, the 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 the same as for the standard house: 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 Chapter 4).

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.

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 is room to cut a 12 cm diameter hole 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 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.

What evidence from your experiments in Chapter 2 are you using to determine these features?

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.

- The house has features that you think will make it energy efficient.
- The house is attractive and has "curb appeal."
- The interior would be comfortable to be in on a sunny day or a cold night.
- The house is not larger than the 28 x 36 cm platform.
- To make room for the heater light bulb, the walls must be at least 20 cm high and you can cut a 12 cm diameter hole in the center of the floor.
- The house is buildable – that is, not too complex and not too many pieces.
- The minimum window area is 50 cm^2.

Describe how Design #1 successfully met these goals.

Describe how Design #1 was not successful.

Tools & materials

- Scissors
- Pencils
- Metal ruler (cm)
- Protractor
- Safety utility cutter
- Cardstock (one 20x30 in sheet)
- Acetate sheets for windows
- Masking tape and/or clear tape
- Temperature sensor
- Computer
- One 40 W heater light bulb in a socket, covered with foil
- One 300 W sun light bulb in a gooseneck desk lamp
- Pre-cut 28 x 36 cm platform

Design #2

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. Refer back to your checklist.

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. Refer back to your checklist.

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

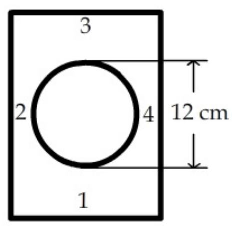
Results			
Goal	House #1 (version B)	House #2 (version B)	House #3 (version B)
Energy efficiency			
Ease of building			
Attractiveness			
Shape			
Simplicity			
Size			
Comfort			

Which design will you select?

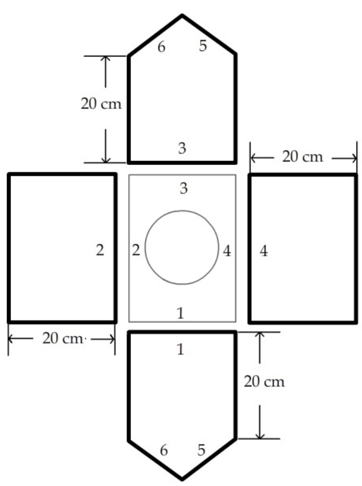
Explain why you selected the design that you did.

Construction

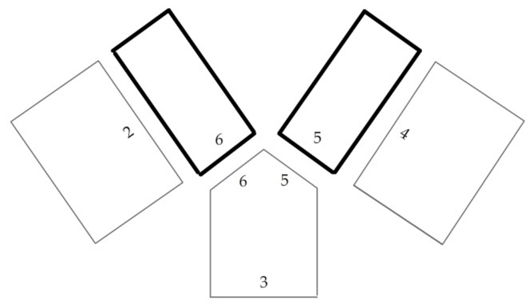
1. You have designed a building with a certain shape and features. Now you need to make all of the pieces and assemble it.
2. Draw the outline (first floor plan) of your house on cardstock. To accommodate the heater light bulb, it must be large enough to place a circle on it with a diameter of 12 cm. It must fit entirely on the base.



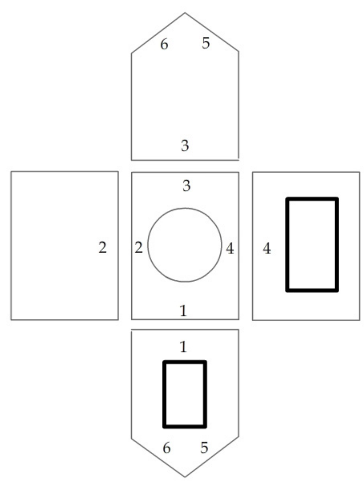
3. Cut a circle out of the center of the floor that is 12 cm in diameter (the size of a CD) so that the light bulb heater can fit in.
4. Make walls for your house that are 20 cm high and go all the way around the floor plan. Note that if you want a gable roof (see example below), some of the walls will 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.



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. The dashed line on the floor plan gives the length of the roof at the ridge. If you are uncertain about some dimensions and angles, make them oversized and trim them down to fit.

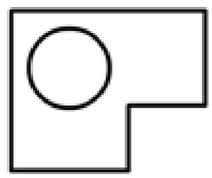


6. Draw and cut out windows that are in the walls (and roof, if any) and tape pieces of acetate over them on the inside.

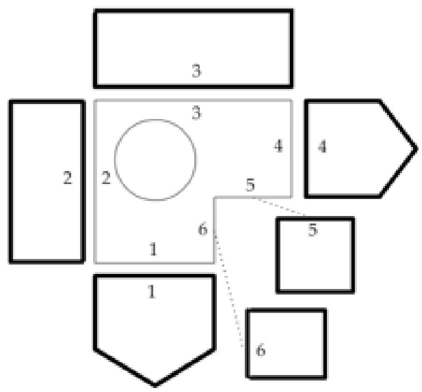


Here is another more complex example – an L-shaped house. Note that the dashed lines on the floor plan (A and B) give the lengths of the roof pieces at the ridge.

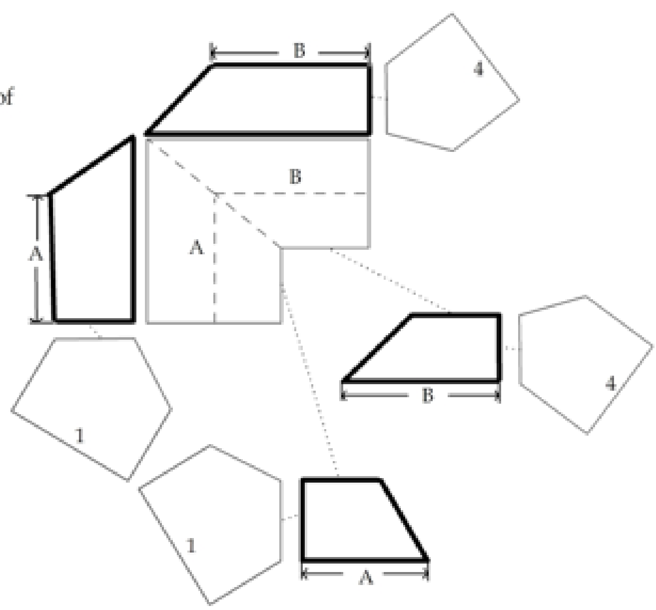
Floor



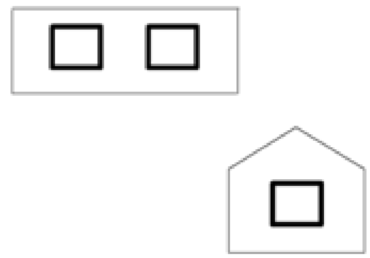
Walls



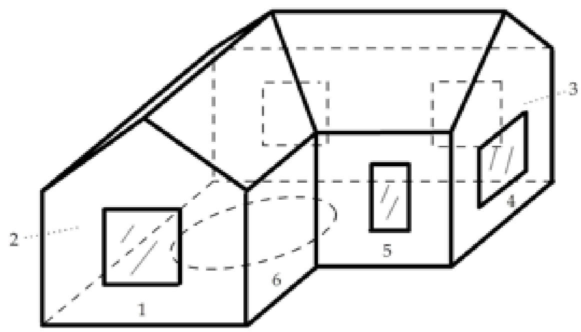
Roof



Windows



Assemble



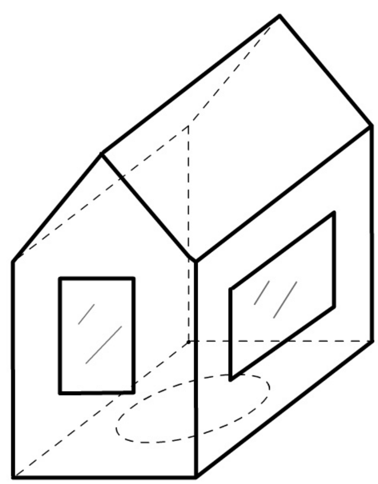
7. Tape the edges of your house together. Here is one set of steps that you could follow: It works well to follow these steps:

   a) tape the wall pieces together

   b) tape the roof pieces together

   c) tape the roof to walls

   d) tape the floor to walls



8. Write your team name and your team members' names on the house.

9. 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.

10. 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. The measurements for the standard house are included for comparison.

	Standard house	Your house
Floor area (cm^2)	16x24=384	
Window area (cm^2)	10x12=120	
Window/floor ratio	120/384 = .31	
South-facing window area (cm^2)	120	
South window/floor ratio	.31	

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. This is the same test you used with the standard house.

Collect data

1. Connect the temperature sensor to your computer. Use one temperature sensor.
2. Open the Logger Lite file that goes with this experiment: *own house keep warm.gmbl*
3. Measure the room temperature. We will assume it stays reasonably constant throughout the experiment. Record temperature in the table below.
4. Calculate your target temperature: 10 °C above room temperature. Record your room and target temperature in the table below.
5. 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. Use the same 3x3 cm cardstock sensor holder you used in Chapter 1.
6. Turn the heater on.
7. Start collecting data when the sensor is a few degrees below the target temperature.
8. When the sensor reaches 0.2 °C above the target temperature, switch the heater OFF and record the time in the table below (A).
9. 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).
10. 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).
11. Stop collecting data.
12. Click the “scale” icon to fit the graph to your data.
13. Save the LoggerLite data file.
14. 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

How did this house perform compared to your standard house?

Your teacher will make a summary chart of the performance of each team's house. How did your house perform compared to other teams?

What did you learn from other teams' designs that could help you improve your house?

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

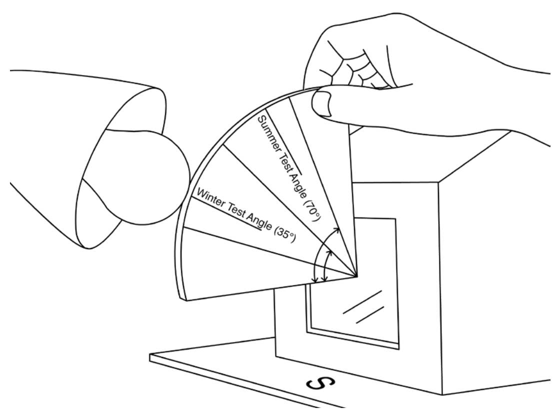
Results: What evidence do you have from the test to support your claim?

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

Solar heating test

Collect data

1. Connect the temperature sensor to your computer.
2. Open the Logger Lite file that goes with this experiment: *own house solar heating.gmbl*
3. Assume that room temperature has not changed. Calculate the target temperature (room temp + 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. Use the template provided by the teacher 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 LoggerLite data file.
13. Print your LoggerLite graph and make a copy for each team member to put in their workbook.
14. 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?

How did your house performance compare to other teams?

Feature: What specific features of your design contributed to or detracted from its performance as a passive solar house?

Results: What evidence do you have from the test to support your claim?

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

1. Claim: What are the advantages and disadvantages of having large south-facing windows?

2. Evidence: Use data, results or descriptions of your experiments or model-based activities to explain the role of passive solar heating on a house. (You can include results from Chapter 2.)

3. Reasoning: Use your answer to Question 2 to explain the claim you made in Question 1.

Chapter 4: Modify Your House

Introduction

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.

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

Tools & materials

- Two temperature sensors
- Computer
- Small square of cardboard (5x5 cm)
- Tape
- One 40 W heater light bulb
- Metal ruler
- Logger Lite
- Your house

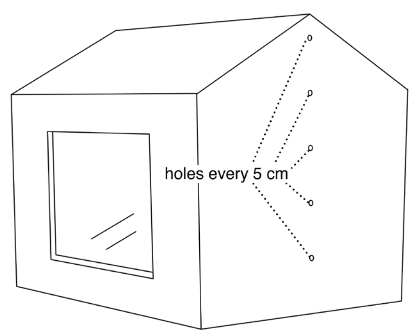
Explore convection

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.

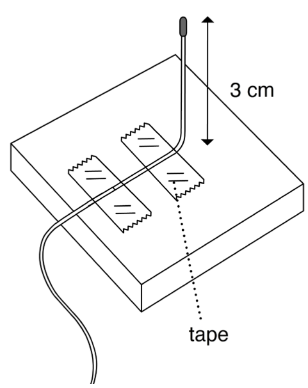
You will conduct a series of experiments to explore convection (the motion of air) in your house and then see how much you can improve its performance.

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**.



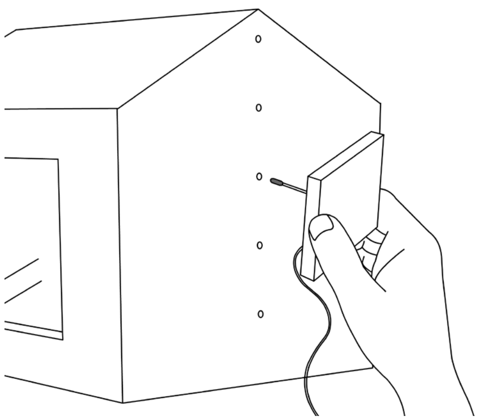
4. Open the Logger Lite file that goes with this experiment: *house convection.gmbl*

5. Start collecting data. Record the initial temperature in the table below.

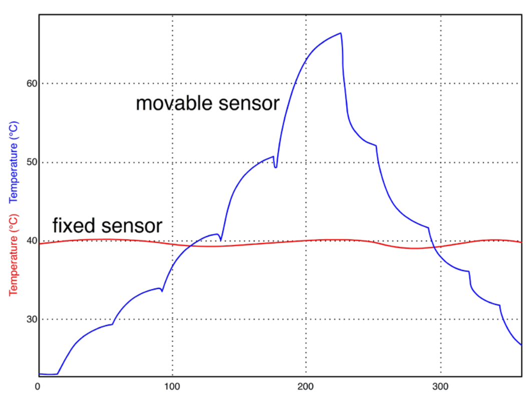
6. Turn the heater on. Let the temperature of the fixed sensor rise until the inside is 10 °C above the initial temperature.

7. 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.

8. 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.



9. 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:



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

11. 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.

Tools & materials

- Two temperature sensors
- Computer
- Cardstock of file folder card the size of the house (16 x 24 cm)
- Small square of foamcore or cardboard (5 x 5 cm)
- Tape
- One 40 W heater light bulb
- Scissors
- Your house

House heating test with a ceiling added

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. Open the Logger Lite file:
   own house with ceiling.gmbl
3. Measure the room temperature. Record it in the table below.
4. Calculate your target temperature, 10 °C above room temperature, and record it in the table.
5. Install the sensor in the standard monitoring position, through a hole in the wall 10 cm up and 3 cm into the house.
6. Turn the heater on.
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 LoggerLite 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 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 (ch. 1)	
Your model house (ch. 3)	
Ceiling added	

Analysis

Your teacher will make a summary chart of the performance of each team's house. Consider your house performance compared to other teams. Why do you think it did better or worse than other designs? Be specific and give scientific explanations.

1. Claim: How do ceilings change the natural convection patterns in a house?

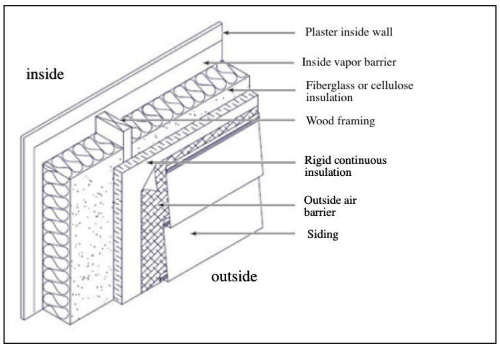
2. Evidence: Use data, results or descriptions of your experiments or model-based activities to explain natural convection patterns in a house? (You can include results from Chapter 2 and this chapter.)

3. Reasoning: Use your answer to Question 2 to explain the claim you made in Question 1.

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 add 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.

Collect data

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

10. Stop collecting data.

11. Click the “scale” icon to fit the graph to your data. Enter the data in the “without sun” column below.

12. Save the LoggerLite data file.

13. Now, open the Logger Lite file: *insulated house solar heating.gmbl*

14. 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.

15. 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		
Room temperature: _____°C Target temperature (room temperature + 10): _____°C Upper limit (target temperature + 0.2): _____°C Lower limit (target temperature – 0.2): _____°C		
	Without sun	With sun
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	_______W

Feature: Describe how the wall materials affect the heat flow of the house?

Results: What evidence do you have from the test to support your claim?

Modification: Based on your results, what design changes in wall construction would you propose to improve performance even more?

Sunspace addition

What are the temperatures in a sunspace?

Can a sunspace contribute heating energy to a house?

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.

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.**

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. Open the Logger Lite file that goes with this experiment: *sunspace test.gmbl*
5. Record the room temperature in the table below.
6. Calculate your target temperature, 10 °C above room temperature, and record it in the table below.
7. Turn on both the heater light bulb and the sun light bulb. Start collecting data
8. 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).
9. 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).
10. 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).
11. Stop collecting data.
12. Click the “scale” icon to fit the graph to your data.
13. Save the LoggerLite data file.
14. Calculate the average power requirement to keep the house warm by filling out the rest of the table below.

15. 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.
16. 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.
17. Scale the data with the “scale” button.
18. 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 (optional)

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.

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

House heating test with sunspace #3

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:	
Improvement:	

1. Claim: What is a key design feature of a sunspace that helps it contribute to heating a home?

2. Evidence: Use data, results or descriptions of your experiments or model-based activities to show how a sunspace contributes to the heating of a house.

3. Reasoning: Use your answer to Question 2 to explain the claim you made in Question 1.

Connection to buildings

Explore

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

Chapter 5: Final Report

Introduction

A new energy-efficient housing development is looking for a project engineer. The project engineer will be responsible for all design and construction decisions related to heating and cooling energy use. The project involves a variety of house designs that all need to be energy efficient.

This final report will be used to persuade a review committee that you have the understanding and inventiveness to apply what you have learned to the entire housing project.

Your project was a preliminary study to identify the most important features of an energy-efficient house. The committee will be looking at the energy performance of your model house as one indication of your skill. It will also look at the design ideas and materials you used to accomplish this. Equally important, however, you must demonstrate that you understand the science behind the energy-efficient designs and would be able to make further improvements and develop other designs.

Complete all of the sections below. If you write this on a computer, save your work on a USB memory stick.

Here is the outline of your report:

Summary

House performance: experimental data

Explanation of house performance and design choices

Heat flow analysis

Conclusion

Energy-Efficient House Project: Final Report

Name:

Name of team:

Names of team members:

House dimensions

Floor area (cm^2):

Total window area (cm^2):

Total surface area (cm^2):

SUMMARY

Write a summary paragraph describing the house you designed, its special energy-efficent features, and what makes it a great energy-efficient house for this climate.

HOUSE PERFORMANCE: EXPERIMENTAL DATA

Gather the results of your experimental data in the table below.

Summary of experimental data			
Winter heating	Power requirement (W)	Percentage of power requirement compared to the standard house*	Page reference
Standard house, no sun condition (page 13)		= 100%	
Standard house, winter sun condition (page 21)			
Own house, no sun condition (page 89)			
Own house, winter sun condition (page 94)			
Own house, with all modifications, no sun condition (page 109)			
Own house, with all modifications, winter sun condition (page 103)			
Own house, sunspace added (page 113)			

* For example, if the standard house requires 20 W and "own house, no sun condition" requires 15 W, the percentage is 15/20 = 75%.

Did your modifications give you the improvement you expected?

Under what conditions did your house perform the best?

EXPLANATION OF HOUSE PERFORMANCE AND DESIGN CHOICES

House design

Describe the major features of your design (for example, the shape of the house, placement of windows, material choices). In each case, describe the feature, how it functions, and your evidence that it works that way. Use scientific explanations from the Heat Transfer unit to explain how each of these features affects energy efficiency. Refer to your experimental data to support your claims.

Modifications

What did you learn from your experiments that guided your design choices? Explain what features were added after initial experiments, what features were modified, and how they affected the energy performance of the house. Include evidence from your experiments.

HEAT FLOW ANALYSIS

Describe where and how heat is lost from your house and how different modifcations changed the rate of heat loss. Use evidence from the Heat Transfer Basic units to describe the process.

Draw a picture of your house in vertical cross section, which is a slice through the center in the North-South direction. Label the wall, window, and roof materials. Label North and South.

On your drawing show your best guess for the temperature distribution throughout the house. Write down what you think are likely values of temperatures in various locations, assuming the outside temperature is 5 °C, the heater temperature is 40 °C, and the average temperature in the house is about 25 °C.

Draw arrows to show how you think heat flows around inside your house as well as in and out of your house.

CONCLUSION

Given what you know now, if you were starting again from scratch and could make a completely different design, what materials and design features would you choose for your house? Why?