

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.

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.

How do fluids carry heat from one place to another?

Can air carry heat into and out of a house?

Learning goals

Convection is the flow of fluids carrying heat from one place to another.

Convective heat transfer may be natural (due to density differences between hot and cold fluids) or forced (induced by external forces such as fans or pumps).

Insulating materials are often mostly air that is prevented from moving, that is, convection currents are stopped.

Infiltration is to describe the exchange of air between inside and outside, which can be a major source of heat loss.

Note: This is one section of the “Science of Heat Transfer” chapter of the Engineering Energy Efficiency Project. See: <http://concord.org/engineering>

Natural convection in a cup

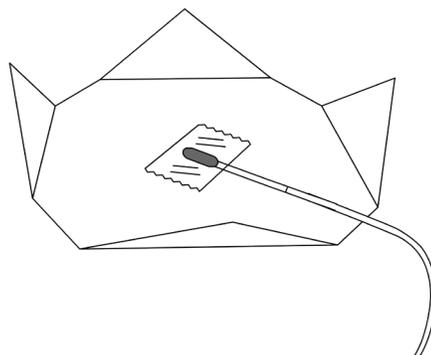
Tools & materials

- Two fast-response temperature sensors (for example, the Vernier surface temperature sensor STS-BTA)
- Computer or other graphing interface for temperature sensors
- 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

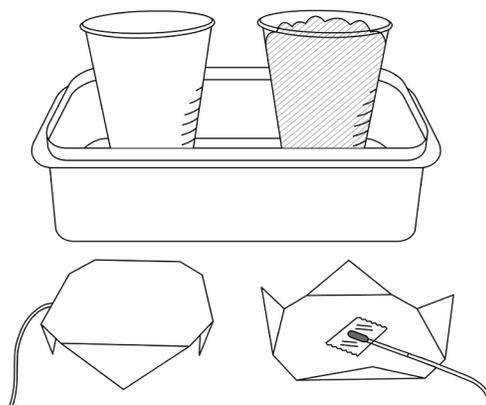
This experiment compares an insulated space to an open air space. Note that any material that inhibits air circulation – tissue paper, cloth, cellulose, packing beads – is worth a try. Although students can't see air circulation, they should be able to describe it in words or draw a diagram.

Procedure & data collection

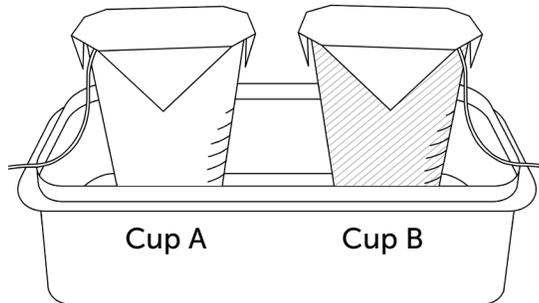
1. Cut out two pieces of cardstock slightly larger than the tops of the two cups.
2. Tape the temperature sensors to the undersides and fold over the corners to fit on the cups.



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



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



- Connect the temperature sensors.
- Start data collection. Wait for a minute or so until the sensors settle at roughly the same temperature.
- Add a small amount of hot water to the pan. If you add too much, the cups will start floating.
- Note the changes in temperature of the two sensors.
- Stop data collection about 30 seconds after you add hot water.
- Record the temperature changes in 30 seconds in the table below.
- 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.

Air heated at the base rises, displacing the colder air at the top, which sinks and is heated and rises in turn.

Give an example where heat is transferred by convection in a house.

warm ceiling; cold floor; warmer upstairs than downstairs; heat rising from a radiator or baseboard heater (no blower); hot gases going up a chimney; water circulating in a pan on a stove

Stopping convection

This experiment is optional but should be quick and more creative than the previous one.

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. Start data collection and wait for a minute or so until the sensors settle at roughly the same temperature.
6. Add a small amount of hot water to the pan.
7. Stop data collection about 30 seconds later.
8. 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

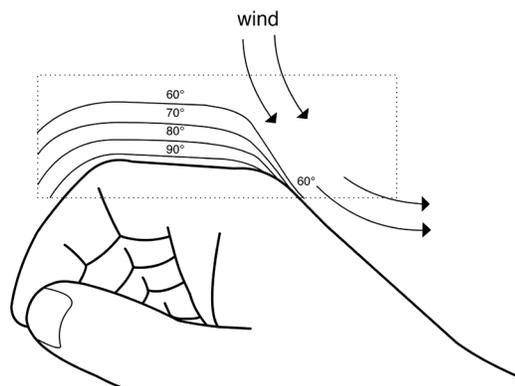
Forced convection refers to motion of a fluid that is not caused by differences in density between warm and cold (“hot air rises”). A fan (air) or a pump (water) is an example of forced convection. It is a very useful way to move heat around. For example, hot-air heating and air conditioning systems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



Be sure all students understand that moving air is not inherently colder than still air. “Wind chill” is due to a temperature difference (air that is colder than our skin) and the stripping away of the thin insulating surface layer of still air next to our skin.

Discussion question: why does putting our hand in hot or cold water feel so much hotter or colder than air of the same temperature?

Answer: The water has a much higher heat capacity, so it warms or cools the skin much more quickly by carrying more heat.

Tools & materials

- One fast-response temperature sensor (for example, the Vernier surface temperature sensor STS-BTA)
- Computer or other graphing interface for temperature sensor
- 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

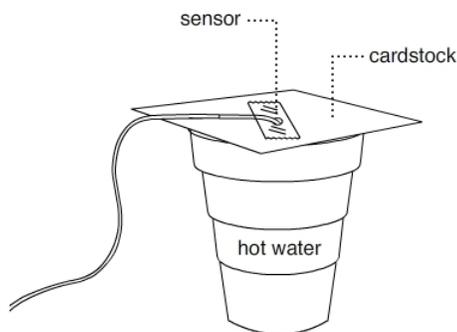
If students don't do the wind chill experiment, have them record what they think would happen and discuss it.

Wind chill

Procedure & data collection

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

1. 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.
2. 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.



3. Start data collection again. Wait for two minutes or so until the sensor settles at a steady temperature.
4. 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!
5. Wait until the temperature is stable again and turn the fan off.
6. Wait until the temperature is stable again and stop data collection.
7. Enter the temperature data in the table below.

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

Be sure all students understand that moving air is not inherently colder than still air. "Wind chill" is due to a temperature difference (air that is colder than our skin) and the stripping away of the thin insulating surface layer of still air next to our skin.

Discussion question: why does putting our hand in hot or cold water feel so much hotter or colder than air of the same temperature?

Answer: The water has a **much** higher heat capacity, so it warms or cools the skin much more quickly by carrying more heat.

Results

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

No. The air is moving but that doesn't change its temperature.

Did the fan have an effect on the heated sensor?

Yes. The sensor was closer in temperature to the moving air, because the insulating air layer next the sensor was blown away.

Explain your results in terms of convection.

Convection strips away the heated air and replaces it with cooler room air next to the sensor.

Would wind make a house lose heat faster? Explain.

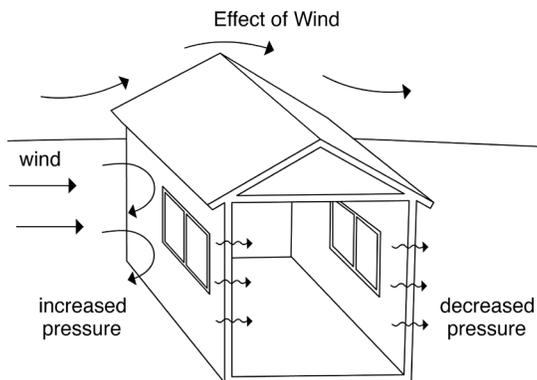
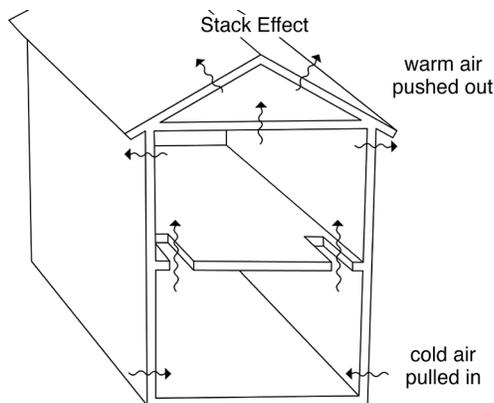
Yes, for the same reason as above. It might also increase infiltration.

Infiltration

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 can explore infiltration further when you test you own model house in the section called “Modify your solar house.”



Connection to buildings: Convection heat loss

Application

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.

To cut down on infiltration, seal all of the possible holes or cracks in the house – around pipes, outlets, and basement walls. Make tighter windows and doors.

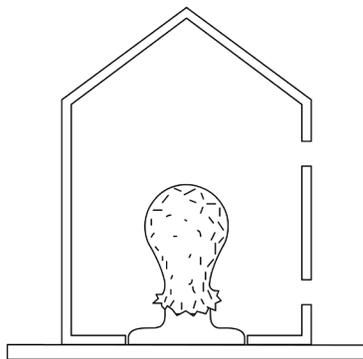
Have you noticed differences in temperature between different rooms or levels in your house, or between the ceiling and the floor? Explain why in terms of conduction and convection.

Different rooms on the same level: Rooms might have the following differences: Different number of windows (conduction), different insulation (conduction) more exposed exterior walls (conduction), sides more exposed to the wind (convection). Different levels: heat would rise and tend to make upper floors warmer. Cold air flows in at the lower levels, being drawn in by convection.

Summary

Here is a cross-section of a one-room house. There is a leaky joint near the ceiling and another one near the floor. Suppose the average temperature is $40\text{ }^{\circ}\text{C}$ inside and $20\text{ }^{\circ}\text{C}$ 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.

