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.

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.

Goals

The purpose of this chapter is to provide students with a basic understanding of the physics of heat transfer in everyday situations. They can then apply this understanding to their engineering challenge in the subsequent chapters.

Learning goals

Heat is transferred from higher temperature to lower temperature regions until equilibrium is reached.

Students can explain heat capacity and give everyday examples.

Before you begin this chapter

Each experiment is simple and quick, but student times for setup and analysis may vary quite a bit. Make a rough schedule for the whole chapter and set clear goals for the students so that the pace doesn't lag.
Confirm that the materials are available for each experiment.
Some of the experiments involve hot water. An electric kettle is a great source, but very hot tapwater will also do. Warm tapwater will not be hot enough.

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

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 can be 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.

This chapter addresses the Massachusetts Engineering / Technology standards which require students be able to 1) differentiate among conduction, convection, and radiation in a thermal system; 2) give examples of how conduction, convection, and radiation are considered in the selection of materials for buildings and in the design of a heating system; 3) explain how environmental conditions such as wind, solar angle, and temperature influence the design of buildings; 4) identify and explain alternatives to nonrenewable energies. The MCAS Physical Science exam always has 13% of its questions on heat.

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.

One gallon of oil is 120,000 Btu * (1 kWh/3400 Btu) = 35.3 kWh
At $3.00/gallon, the cost of oil per kWh is: $3.00/35.3 kWh = $0.085/kWh
Electricity is $0.15/kWh, so oil is cheaper for the same amount of energy.

Here's another example. A refrigerator uses 600 watts (a unit of power) when it's running. Over the course of a year it runs 10% of the time on average. How many kilowatt hours (a unit of energy) does it use in one year? What does this cost, if electricity is $0.15/kWh?

The easiest way to do problems like this is to keep canceling units:
600 W x 10/100 x 24 hr/day x 365 days/year x 1 kW/W = 525.6 kWh/year
525.6 kWh/year x $0.15/kWh = about $80/year