Mechanical Systems

UNIT 1

HVAC Systems

Purpose

Heating, Ventilating, and Air Conditioning (HVAC) systems are designed to provide an adequate level of indoor air quality by: conditioning the air in the occupied space of a building in order to provide for the comfort of its occupants; diluting and removing contaminants from indoor air through ventilation; and providing proper building pressurization.

Commercial heating, ventilating, and air conditioning (HVAC) systems provide the people working inside buildings with “conditioned air” so that they will have a comfortable and safe work environment. People respond to their work environment in many ways and many factors affect their health, attitude and productivity. “Air quality” and the “condition of the air” are two very important factors. By “conditioned air” and “good air quality,” we mean that air should be clean and odor-free and the temperature, humidity, and movement of the air will be within certain acceptable comfort ranges.

ASHRAE, the American Society of Heating, Refrigerating and Air Conditioning Engineers, has established standards which outline indoor comfort conditions that are thermally acceptable to 80% or more of a commercial building’s occupants. Generally, these comfort conditions, sometimes called the “comfort zone,” are between 68°F and 75°F for winter and 73°F to 78°F during the summer. Both these ranges are for room air at approximately 50% relative humidity and moving at a slow speed (velocity) of 30 feet per minute or less.

Design

While there are many different HVAC system designs and operational approaches to achieving proper system functionality, and every building is unique in its design and operation, HVAC systems generally share a few basic design elements (Figure 1):

- Outside air intake
- Air handling unit—a system of fans, heating and cooling coils, air-flow control dampers, air filters, etc.
- Air distribution system
- Air exhaust system

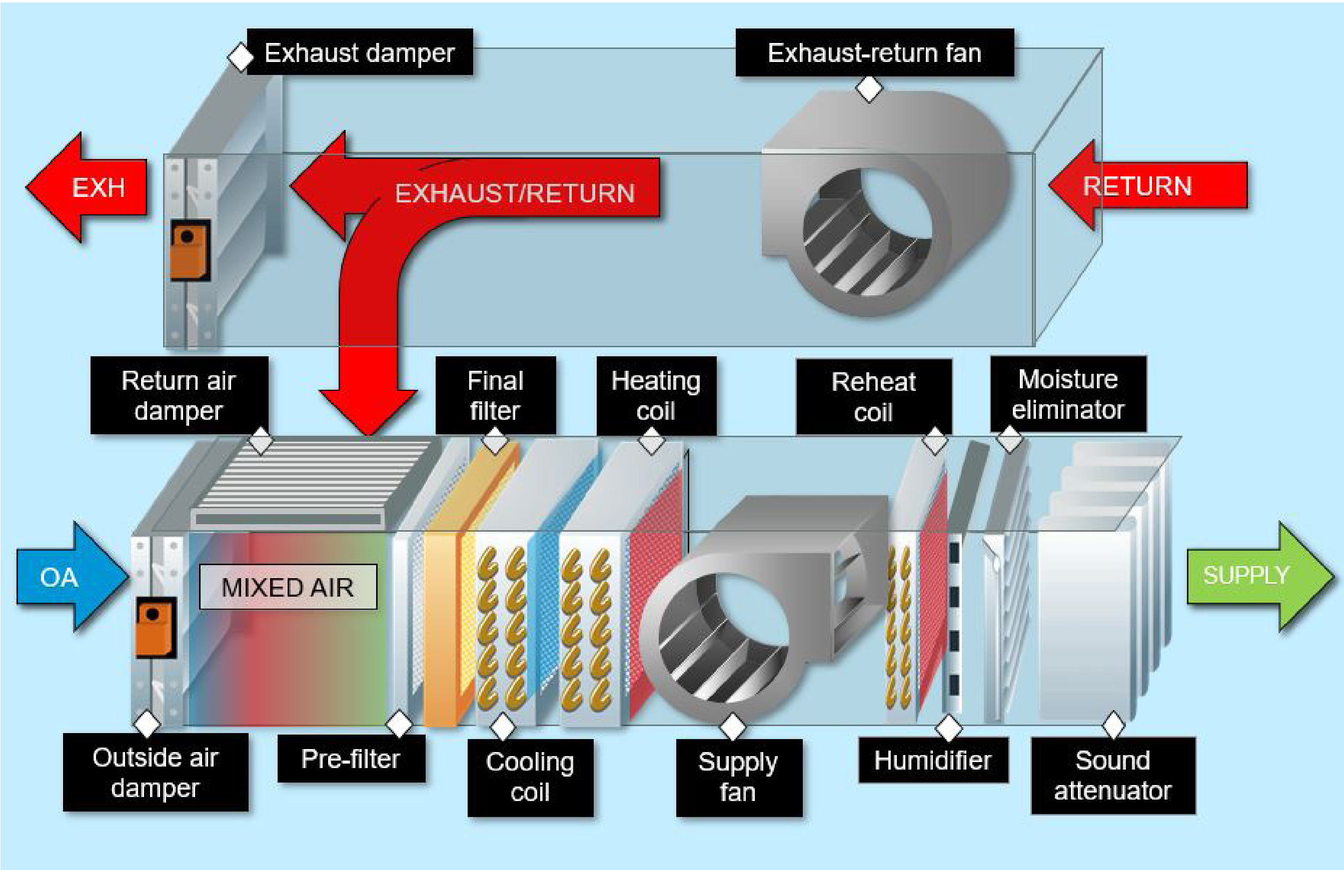


Figure 1. Commercial Forced Air System

Function

Outside ("supply") air is drawn into a building's HVAC system through the air intake by the air handling unit (AHU). Once in the system, supply air is filtered to remove particulate matter (mold, allergens, dust), heated or cooled, and then circulated throughout the building via the air distribution system, which is typically a system of supply ducts and registers.

In many buildings, the air distribution system also includes a return air system so that conditioned supply air is returned to the AHU ("return air") where it is mixed with supply air, re-filtered, re-conditioned, and re-circulated throughout the building. This is usually accomplished by drawing air from the occupied space and returning it to the AHU by: (1) ducted returns, wherein air is collected from each room or zone using return air devices in the ceiling or walls that are directly connected by ductwork to the air-handling unit; or (2) plenum returns, wherein air is collected from several rooms or zones through return air devices that empty into the negatively pressurized ceiling plenum (the space between the drop ceiling and the real ceiling); the air is then returned to the air-handling unit by ductwork or structural conduits.

Finally, some portion of the air within is exhausted from the building. The air exhaust system might be directly connected to the AHU and/or may stand-alone.

Building Pressurization

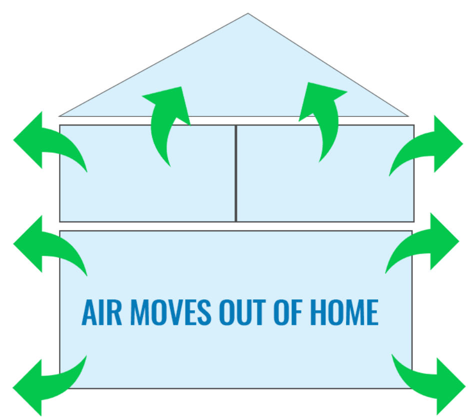
Building pressurization refers to the air pressure relationships that exist between the inside of a building relative to the outside of a building across the building envelope; it also refers to the pressure relationships that exist within different parts of a building relative to each other. Building pressurization is used to limit infiltration, which can lead to indoor air quality problems because air that enters a building via infiltration bypasses the air handling systems and can introduce contaminants into a building and contribute to moisture problems.

Pressurization also can be used to control the movement of air contaminants within a building. Maintaining positive air pressure relative to outside air prevents contaminants in the outside air from entering a building by means of infiltration. Such an approach could reduce the risk of exposure to biological agents from a large-scale outdoor release, provided that air entering the building through the HVAC system is sufficiently filtered to remove contaminants. Whether a building can be pressurized depends upon the building's geometry, HVAC system design, and envelope tightness as well as weather conditions. Building pressurization requires that the HVAC system be able to deliver more air to the occupied space than is being exhausted and lost due to exfiltration. It may not be possible to pressurize a leaky building without first addressing envelope leakage.

Maintaining positive air pressure in one zone of a building relative to another can limit the distribution of an aerosolized biological agent released within that building by means of airflows created by pressure relationships that exist within different parts of the building relative to each other. Such an approach can be used to isolate special-use spaces such as lobbies, parking garages, and mail rooms that may be more vulnerable to an internal release by maintaining them at negative pressure relative to adjacent parts of the building.

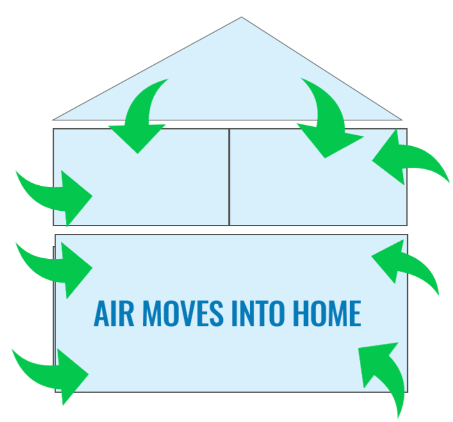
Positive Air Pressure

- Your air pressure inside is greater than pressure outside
- Air gets pushed into walls and insulation



Negative Air Pressure

- When indoor air pressure is lower than pressure outside
- Outside air rushes in to try and balance out the pressure difference



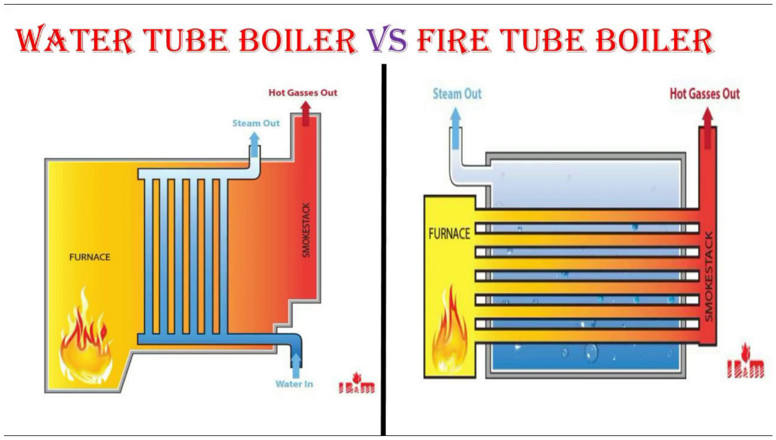
Heating

The overall heat loss in buildings occurs from heat loss due to:
(1) transmission through walls, windows, doors, ceilings, floors, etc.
(2) heat loss caused by ventilation, and
(3) heat loss caused by infiltration.

If the heat loss is significant enough to create an uncomfortable environment for the occupants, the building HVAC system must provide warm air to replace the heat loss. Heat loss is measured in Btu per hour (Btu/h or BTUH).

BTU – British Thermal Unit; the amount of energy required to raise one pound of water one-degree Fahrenheit.

Boilers



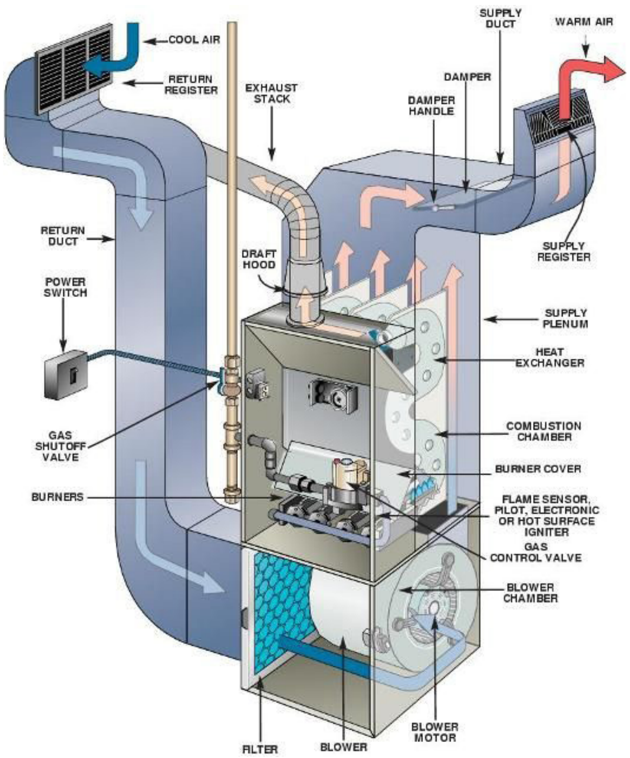
Types of Boilers
— Fire Tube
— Water Tube

Boiler Classifications
— high-pressure (operate at >15 psig)
— low-pressure
— steam-boiler
— hot water-boiler

Boiler Fuels
— Natural Gas
— Oil
— Coal
— Electricity

Furnaces

A "forced air" furnace works by blowing heated air through ducts that deliver the warm air to rooms throughout the building via air registers or grills.



Furnace Fuels
— Natural Gas
— Oil
— Coal
— LPG (Liquid Petroleum Gas)
— Electricity

Heating Coils

Water is the most widely used heat transfer medium because it's readily available and low in cost. Water can be used as a heat transfer medium if the temperature range is between 15 degrees Fahrenheit (when mixed with glycol) when cooling and a high of 210 degrees Fahrenheit when heating.

Types of Heating Coils
— Steam
— Water
— Electric

Ventilation

Ventilation is the supply of Outdoor Air (OA) to a building. Outdoor Air is assumed to be fresh, clean air made up of the right combination of oxygen (21%), nitrogen (78%), and other gases (1% hydrogen, argon, carbon dioxide, water vapor). People and all animal life need oxygen to live. Nitrogen and the other gases are inert and not harmful to animal life. People breathe in oxygen and breathe out carbon dioxide. The oxygen level in an enclosed occupied space must therefore be replenished by supplying outdoor air. The outdoor air must be cleaned and filtered before it is supplied.

Ventilation rates vary considerable from building to building and overtime with individual buildings. A major concern for most buildings is Indoor Air Quality (IAQ). Replacing indoor air helps to keep the building air from becoming stale, odorous, or overly contaminated by indoor sources of pollutants. The amount of air (ventilation) that needs to be brought into a building is typically specified by the type of building/purpose and population in cubic feet per minute per person (CFM/person) and/or Air Changes per Hour (ACH).

Minimum ventilation or air change rate requirements, including passive ventilation (e.g. through windows or infiltration) plus provisions for exhaust of known sources of contaminants, are the principal mechanism that building codes use to address indoor air quality concerns. In addition, building codes often address moisture control, which is an important consideration for indoor air quality. Energy codes typically focus exclusively on energy conservation, while provisions in other codes are relied on to protect indoor air quality.

The 2016 California Mechanical Code

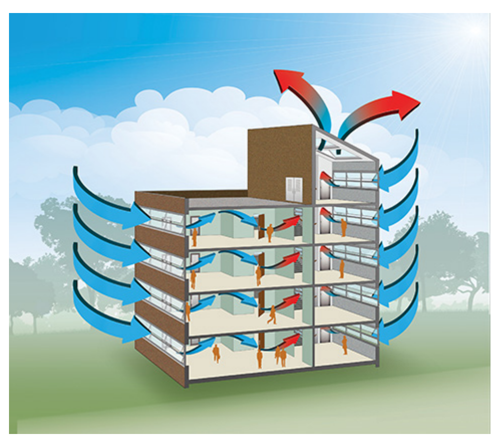
Chapter 4 Ventilation Air

Chapter 4 regulates the minimum requirements for ventilation air supply, exhaust, and makeup air for spaces within a building. Building ventilation is one important factor affecting the relationship between airborne transmission of respiratory infections and the health and productivity of workers. Ventilation air may be composed of mechanical or natural ventilation, infiltration, recirculated air, transfer air, or a suitable combination of that. Providing a comfortable and healthy indoor environment for building occupants is of primary concern. When considering how much ventilation should be supplied, typical and unusual significant sources of indoor pollution need to be controlled. Areas such as kitchens, bathrooms, and laundries are all built to allow specific functions. These spaces produce pollutants such as moisture, odors, volatile organic compounds, particles, or combustion byproducts. The purpose of local exhaust is to control concentrates of these pollutants in the room into which they were emitted in and to reduce the spread of the pollutants into other parts of the occupancy. Local exhaust ventilation is the source control for pollution that is expected in certain rooms. Using local exhaust to extract contaminants before they can mix with the indoor environment is essential.

The Standards for Ventilation and Indoor Air Quality

ANSI/ASHRAE Standards 62.1 Ventilation for Acceptable Indoor Air Quality for commercial buildings and 62.2 Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings for residential buildings are consensus standards and represent the standard of practice for the building industry with respect to ventilation and indoor air quality. Provisions of these standards most often form the basis for ventilation requirements in building codes.

Mechanical Ventilation



Natural Ventilation

Air Conditioning

AC is for Air Conditioning. For most of us, air conditioning means comfort cooling with either chilled water systems or refrigerant systems. Both of these systems include cooling coils to remove heat from the air.

Chilled Water Systems
— Vapor-compression system
— Absorption system

Refrigeration (DX) Systems
— Vapor-compression system

Cooling Coils
— Water coil
— Refrigerant (DX) coil

Air Cooled **Water Cooled**

AC (Air Conditioning) also means conditioning the air in the following ways:
Temperature (tempering the air)
— Cooling (removing heat)
— Heating (adding heat)

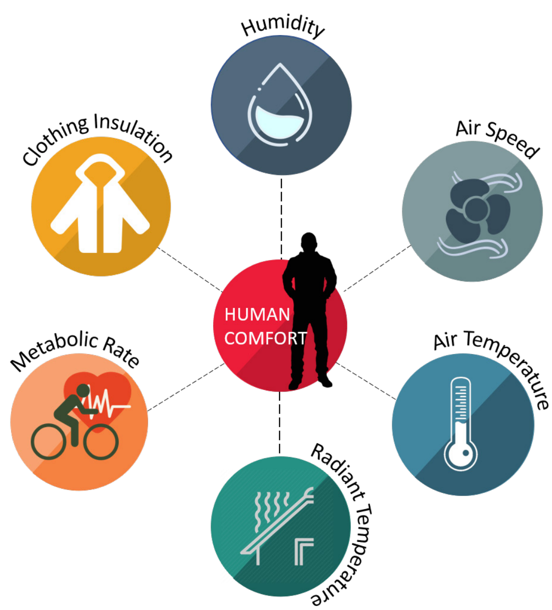
Humidity control
— Dehumidifying (removing moisture)
— Humidifying (adding moisture)

Volume of airflow
— cfm (cubic feet per minute)

Velocity (speed) of airflow
— fpm (feet per minute)

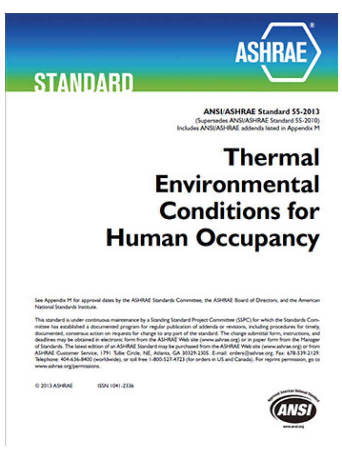
Cleaning
— Filtering

Pattern of airflow
— Direction
  • horizontal
  • vertical



Six Factors of Human Comfort

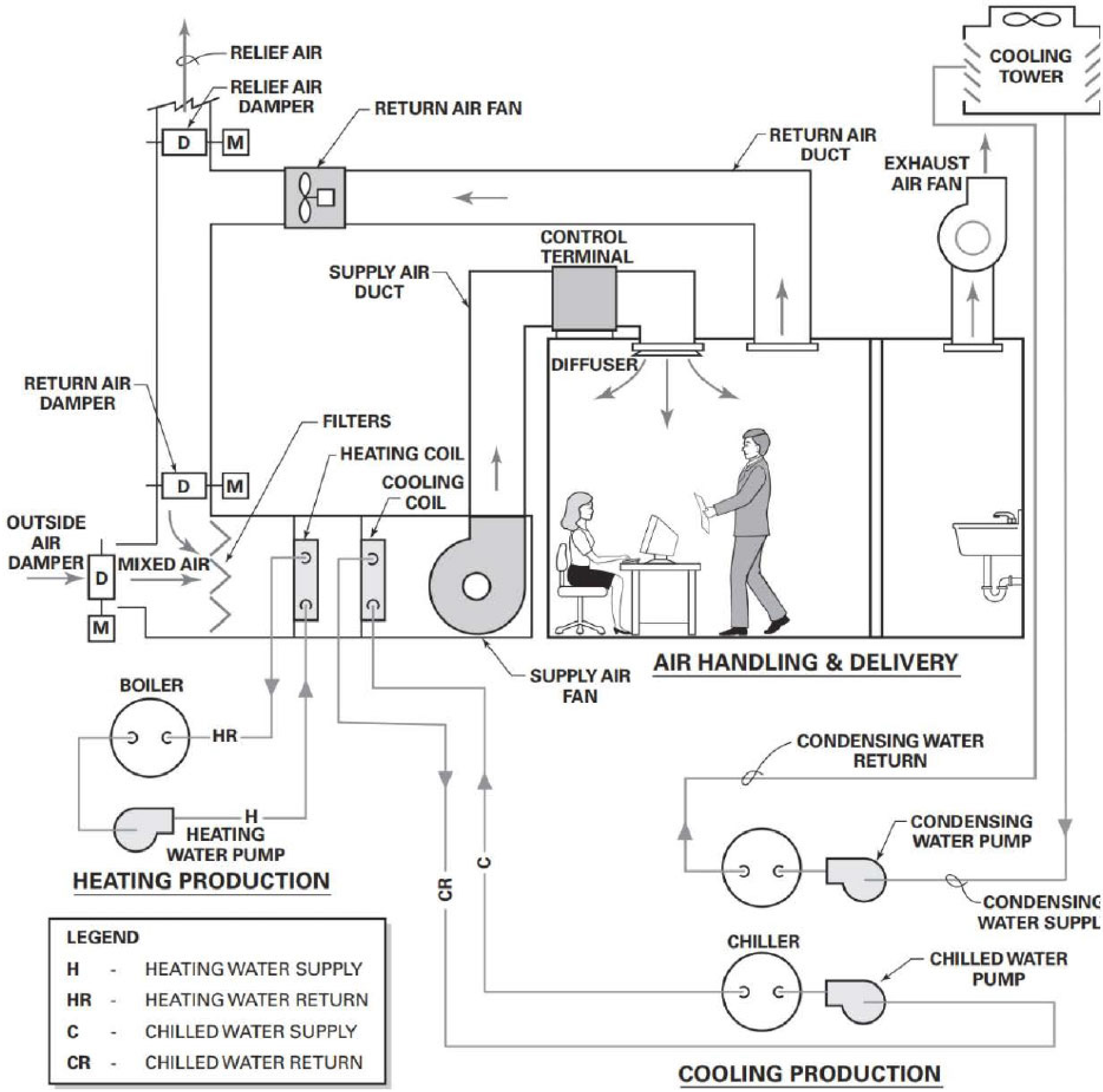
ASHRAE Standard 55 specifies conditions for acceptable thermal environments and is intended for use in design, operation, and commissioning of buildings and other occupied spaces.



2016 California Mechanical Code

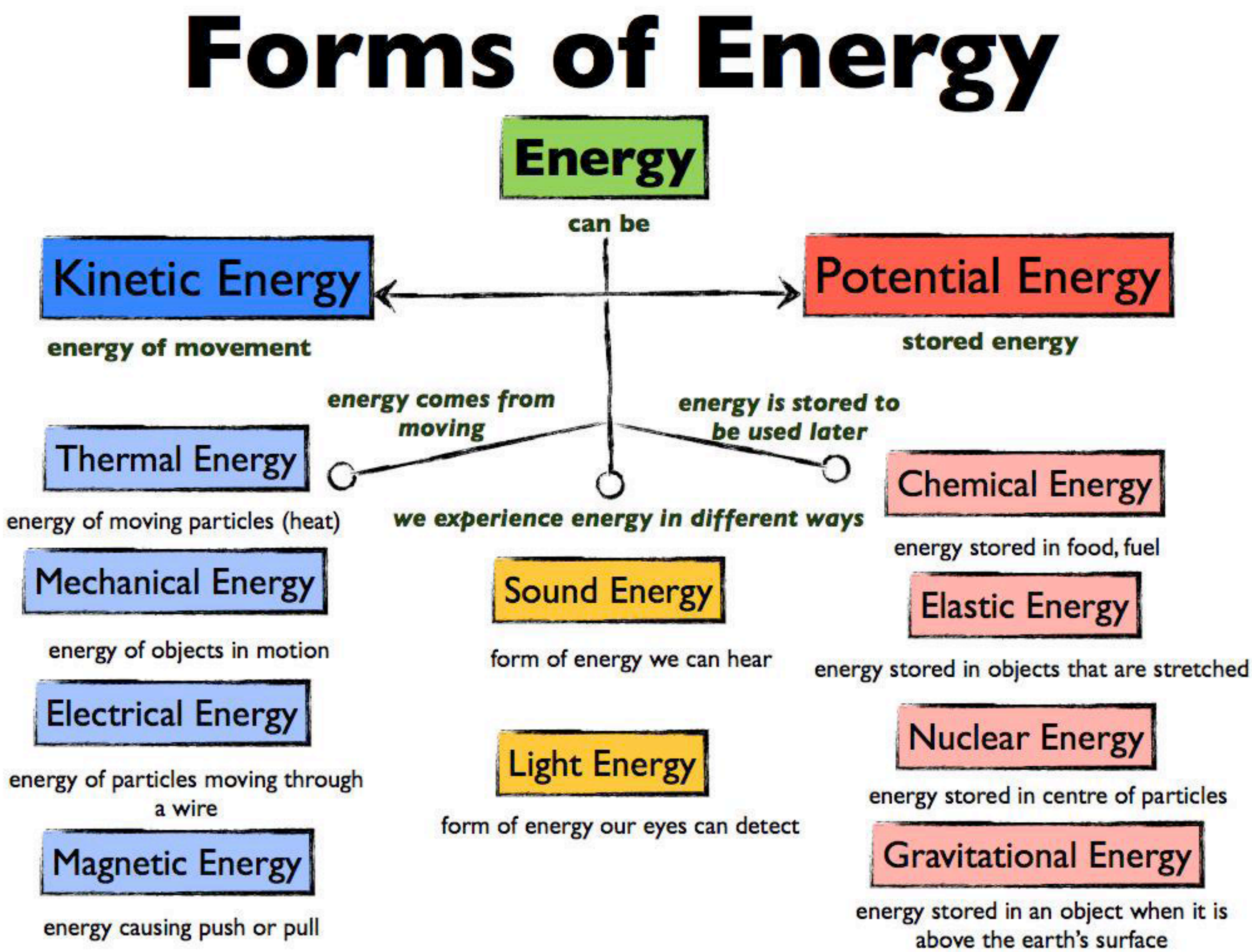
1105.0 General Requirements.

1105.1 Human Comfort. Cooling systems used for human comfort shall be in accordance with the return-air and outside-air provisions for furnaces in Section 904.7 and Section 904.8. Cooling equipment used for human comfort in dwelling units shall be selected to satisfy the calculated loads determined in accordance with the reference standards in Chapter 17 or other approved methods. Refrigerants used for human comfort shall be in accordance with Section 1104.6.



Components of a large HVAC System (based on hot-chilled water system)

Energy
Energy is the ability to do work.
All forms of energy fall under two categories:



MEP systems in buildings use and convert energy and move fluids to make buildings habitable and functional. Energy forms applicable to building systems depends on what the system is designed to do. For example, HVAC systems in buildings use thermal energy (add or remove heat), mechanical energy (motors and pumps), electrical energy (fans, blowers), etc.

Thermal Energy
Thermal Energy, called heat, is the energy of any object with a temperature above absolute zero, due to the kinetic energy of its molecules. For a given quantity of material, the higher its temperature, the more thermal energy it has.

Thermal energy is measured in British Thermal Units (Btu). A Btu is the amount of heat required to raise 1 lb of water 1°F. Stated another way, if we heat 1 lb of water (about a pint) 1°F, the water will have absorbed 1 Btu. If we heat a pound of water 2°F, we will need 2 Btu. Pound for pound, water will absorb much more heat than most other materials for a given temperature rise. Only 0.21 Btu will be necessary to raise 1 lb of concrete 1°F. If we normalize the heat-absorbing capacity of water at 1.0, the heat capacity (C) of concrete will be 0.21.

These relationships can be combined into the following equation:

$$Q = M \times C \times \Delta T \qquad \text{[Equation 1]}$$

where,
Q = heat absorbed (or released) (Btu)
M = mass (lb)
C = heat capacity (often called "specific heat") (Btu / lb °F)
ΔT = temperature increase or decrease, °F

Density or mass density (ρ) of a substance is the mass per unit volume. Density is expressed in units of pounds per cubic foot (lb/ft^3). The quantity C, heat capacity or specific heat, is expressed in Btu per pound degree farenheit (Btu/lb°F). Density and Heat Capacity for many common materials are listed in the table below.

Material	**Density (lb/ft^3)**	**Heat Capacity (Btu/lb°F)**
Water	62.4	1.0
Wood	45	0.57
Foam Insulation	2.5	0.34
Air	0.075	0.24
Concrete	144	0.21
Steel	489	0.12
Aluminum	169	0.215

Example 1.
A 10 ft x 12 ft x 4 in. concrete slab is warmed in the sun during the day to 90 °F and cools to 62 °F overnight, how much heat is stored and released by the slab in a day?

Solution. The specific heat of concrete is 0.21 Btu / lb °F. The density of concrete is approximately 144 lb / ft^3.

Heat Storage is:

$Q = M \times C \times \Delta T$

$= (10 \text{ ft} \times 12 \text{ ft} \times 4/12 \text{ ft}) \times 144 \text{ lb} / \text{ft}^3 \times 0.21 \text{ Btu} / \text{lb °F} \times (90 \text{ °F} - 62 \text{ °F})$

$= 33{,}869$ Btu

Example 2.
How much heat (BTUs) is required to warm 40 gallons of water from 50°F to 120°F?

Solution.

$Q = M \times C \times \Delta T$

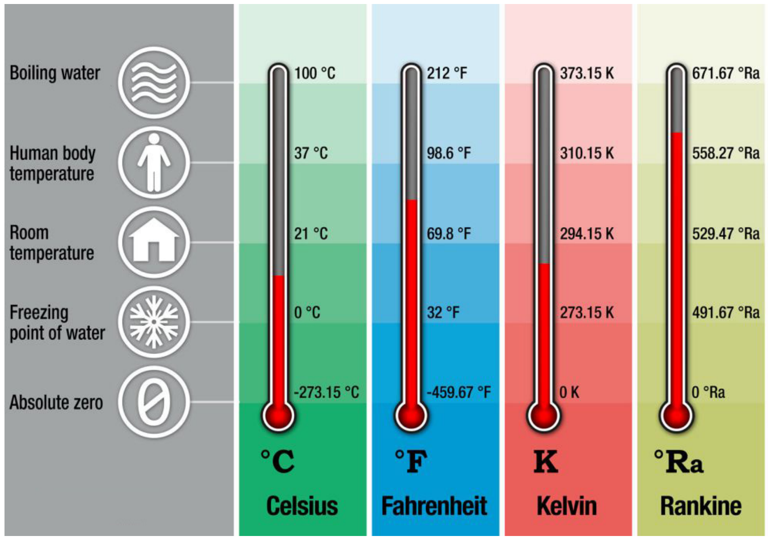
$= (40 \text{ gal} \times 8.34 \text{ lb/gal}) \times 1 \text{ Btu/lb°F} \times (120\text{°F} - 50\text{°F})$

$= 333.6 \text{ lb} \times 1 \text{ Btu/lb°F} \times (70\text{°F})$

$= 23{,}352$ Btu

Sensible and Latent Heat

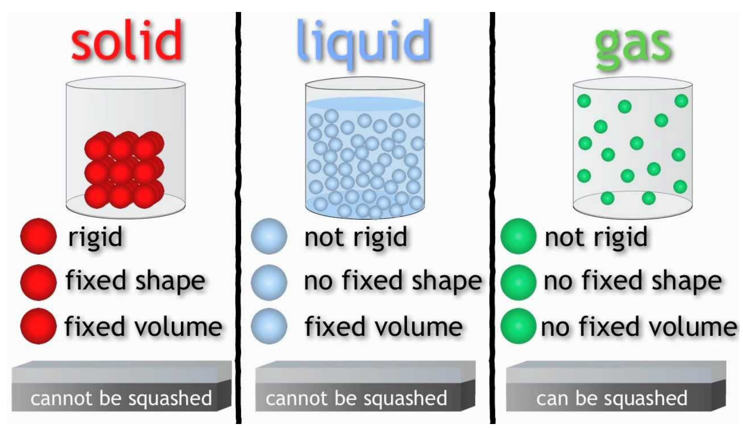
Temperature is a physical quantity expressing hot and cold. It is measured with a thermometer calibrated in one or more temperature scales. The most commonly used scales are the Celsius scale (formerly called centigrade) (denoted °C), Fahrenheit scale (denoted °F), and Kelvin scale (denoted K).



Sensible heat is that which causes a change in temperature when heat is added or removed. Sensible heat is related to changes in temperature of a liquid, gas, or object with no change in phase. Sensible heat can be measured by a thermometer.

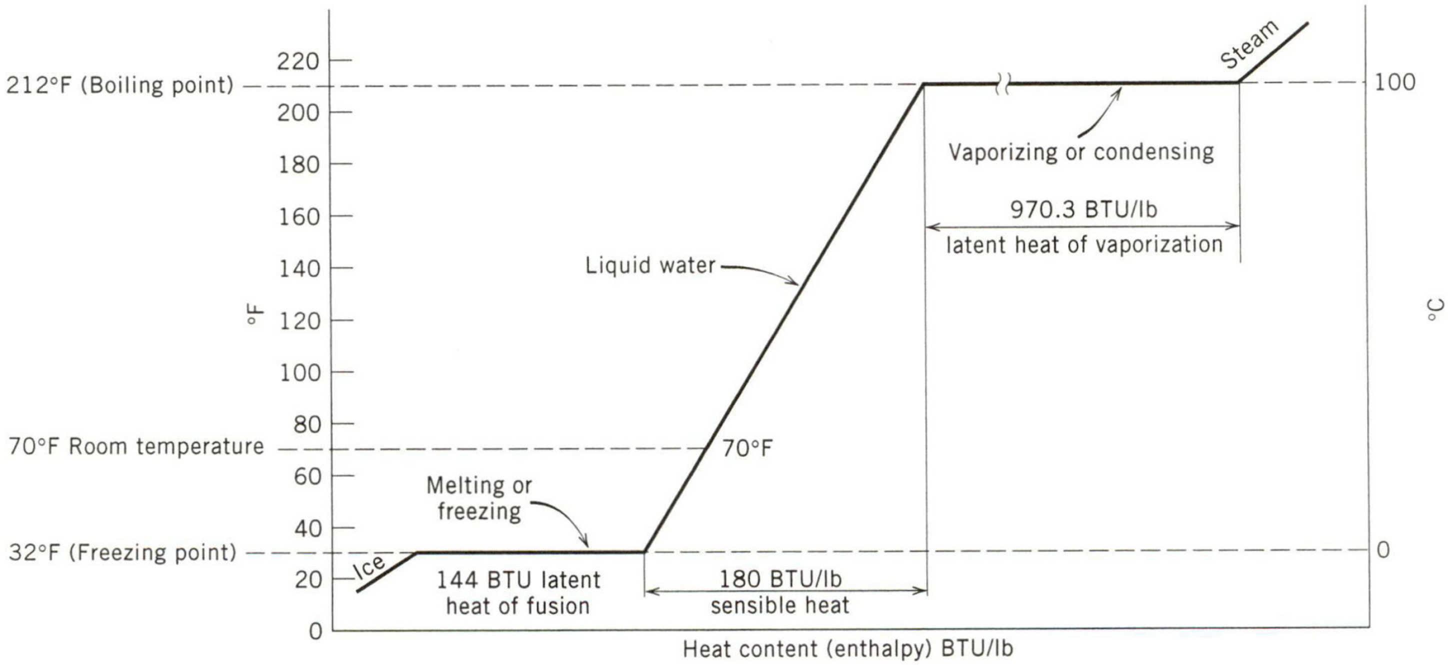
Latent heat is that which causes a change in state in the substance or matter, as for instance a solid to liquid or liquid to gas while the temperature remains constant. Water can be one of three phases: solid, liquid or gas.

Latent heat is the energy absorbed by or released from a substance during a phase change from a gas to a liquid or a solid or vice versa. If a substance is changing from a solid to a liquid, for example, the substance needs to absorb energy from the surrounding environment in order to spread out the molecules into a larger, more fluid volume. If the substance is changing from something with lower density, like a gas, to a phase with higher density like a liquid, the substance gives off energy as the molecules come closer together and lose energy from motion and vibration.



For example, when water is boiled over a stove, energy is absorbed from the heating element and goes into expanding the water molecules into a gas, known as water vapor. When liquid water is put into ice cube trays and placed in the freezer, the water gives off energy as the water becomes solid ice. This energy is removed by the freezer system to keep the freezer cold.

In Example 2, the heat (Btu) required to raise the temperature of the water was just sensible heat. Water is a liquid at 50°F and at 120°F and heating the water did not involve a phase change. Latent heat only occurs when there is a phase change as shown by the chart below.



Heat content (enthalpy) chart of water in Btu per pound.
At the 32 °F (0 °C) lower change-of-state point, freezing water loses 144 Btu/lb and melting ice gains 144 Btu/lb of latent heat.

At the 212 °F (100 °C) upper change-of-state point, vaporizing water absorbs (gains) 970 Btu/lb and condensing steam releases (loses) 970 Btu/lb of latent heat.

In the liquid state between 32 °F and 212 °F, water gains or loses 1 Btu of sensible heat per pound, for each 1 °F of temperature change, that is, 180 Btu/lb for the 180 °F temperature change between 32 °F and 212 °F.

Example 3.
A block of ice, ½ ft³ in volume, is taken from a freezer where it was stored at 32°F (0°C).
How many BTU of heat will be required to convert the ice to water at 75°F?

Solution.

Weight of the ice	Weight of water at 32°F = 62.41 lb/ft³ W = ½ ft³ x 62.41 lb/ft³ = 31.205 lb
Latent Heat is involved since there is a phase change from solid (ice) to liquid (water) 32°F to Melted	Q = 144 Btu/lb x 31.205 lb = 4,493.52 Btu
Sensible Heat needed to raise the temperature from melted @32°F to 75°F	Q = M x C x ΔT = 31.205 lb x 1 Btu/lb°F x (75°F - 32°F) Q = 1,341.815 Btu
Total Heat (Enthalpy)	Q = Latent Heat + Sensible Heat Q = 4,493.52 Btu + 1,341.815 Btu Q = 5835 Btu

Heat Transfer: Conduction, Convection, Radiation

When bodies of unequal temperatures are placed near each other, heat leaves the hotter body and is absorbed by the colder one until the temperatures are equal to each other. The rate by which the heat is absorbed by the colder body is proportional to the difference of temperature between the two bodies ➔ the greater the difference in temperature, the greater the rate of flow of the heat.

Heat is transferred from one body to another at lower temperature by any one of the following means:

1. Conduction
2. Convection
3. Radiation

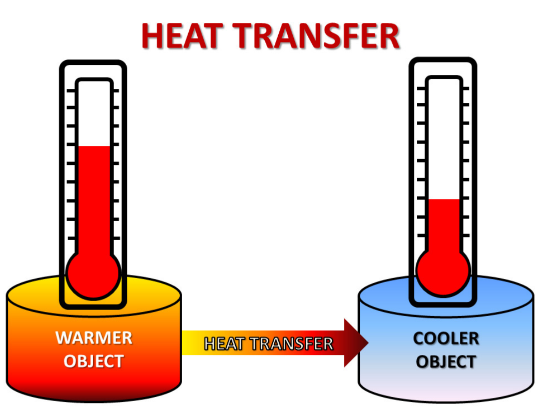
Conduction is how heat transfers through direct contact with objects that are touching. Any time that two objects or substances touch, the hotter object passes heat to the cooler object.

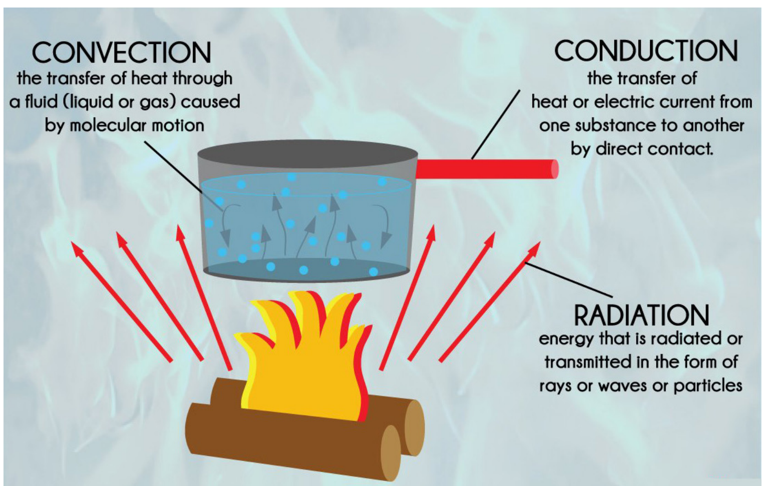
Convection is how heat passes through fluids. A fluid is anything that has loosely moving molecules that can move easily from one place to another. Liquids and gases are fluids.

One important property of fluids is that they rise when heated. That's because the molecules spread out and move apart when they get hot. The hot fluid becomes less dense and rises up. Cooler fluid is more dense and so it sinks down. This up-and-down motion creates what are called convection currents. Convection currents are circular movements of heated fluids that help spread the heat.

Radiation is how heat moves through places where there are no molecules. Radiation is actually a form of electromagnetic energy. Electromagnetic energy moves in waves. Radiation is heat moving in waves. Radiation does not need molecules to pass the energy along.

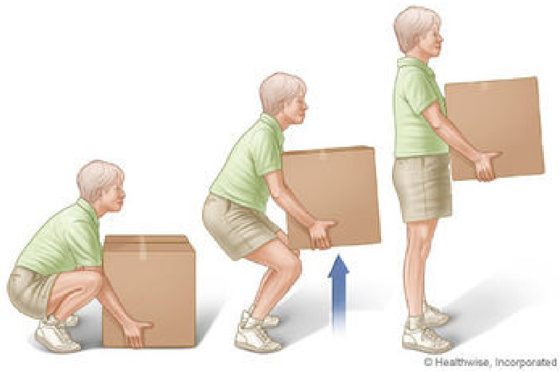
All objects radiate heat, but some radiate much more heat than others. The biggest source of radiation is the Sun – it sends a huge amount of heat to Earth through electromagnetic waves. A good way to remember radiation is that it is how you can feel heat without touching it. Heat passes through the empty space until it reaches your hand. That's radiation! A fire is another example of radiation. Even you are an example. Your body gives off heat. (That's why a classroom gets warm when there are a lot of people sitting in it and the HVAC system is not adequately designed to remove the extra heat.)





Power

Energy and power are closely related but are not the same physical quantity. Energy is the ability to cause change; power is the rate energy is moved, or used.



Picking up a box requires a specific amount of energy, no matter how quickly the box is picked up.

Picking it up faster will change the amount of power but not the amount of energy.

Working Faster = More Power

Power is how fast energy is used or transmitted - power is the amount of energy divided by the time it took to use the energy. Its unit is the watt, which is one joule per second of energy used. A circular saw will draw a certain amount of power to run, and how quickly power is drawn from a battery determines how long its stored energy will last.

$$P = \frac{\Delta E_{sys}}{\Delta t}$$

P is the average power output, measured in watts (W)
ΔE_{sys} is the net change in energy of the system in joules (J) - also known as work.
Δt is the duration - how long the energy use takes - measured in seconds (s)

Multiplying a value of power and the period of time over which it is used gives an amount of energy. This is why a kilowatt is a unit of power but a kilowatt-hour (1 kilowatt times 1 hour) is a unit of energy.

Tasks (like lifting a box) take a certain amount of energy (a certain number of joules), but the faster the task is done (the smaller Δt), the more power it takes (more watts).

The basic unit of energy is the joule. Lifting the box will take a certain number of joules regardless how quickly the box is lifted.

The unit of energy for heat is Btu. The unit of power for heat will be Btu per hour, abbreviated Btuh. This unit is used in quantifying the amount of heating gained or lost by a structure (load) and the amount of heating or cooling capacity required by the equipment to offset the heat or load.

For all forms of energy the following equations will apply, but units will depend on energy form:

Power = Energy / Time

or

Energy = Power x Time

Electric power is measured in watts (W) or kilowatts (1000 W or kW). These are power units. If power is applied over time, energy is the product.

Electric Energy (kilowatt-hours, or kWh) = Electric Power (kilowatts, or kW) x Time (hours)

Electrical energy is useful because it can be converted into mechanical energy in a motor, to light in a lamp, or to heat in a resistance heater.

Forms and Units of Energy and Power

Energy Form	Unit of Measure: Energy	Unit of Measure: Power	Conversion to Btu
Heat	British Thermal Unit (Btu)	British Thermal Unit per hour (Btuh)	1.00
Electric	Watt-hour (Wh)	Watt (W)	3.41
	Kilowatt-hour (kWh)	kilowatt (kW)	3,412
Mechanical	Horsepower-hour (hp-hr)	Horsepower (hp)	2,545

Example 4.
A 200 ft^2 x 4 in. concrete slab is in full sun all day and absorbed 56,000 Btu of heat energy. If the absorbed heat is released during the night between 10:00 pm and 6:00 am, what is the average capacity of the slab over this period to assist in heating the building?

Solution.

Power = Energy / time

Power = 56,000 Btu / 8 hr = 7,000 Btuh

Example 5.
A 60 W incandescent bulb produces 800 lumens and an 8 W LED bulb produces 800 lumens. How much energy will each bulb use in a year's time if each bulb is on for 10 hours per day?

Solution.

<u>60 W incandescent Bulb</u>
Energy = Power x time = 60 W x 10 hr / day x 365 day / yr = 219,000 watt-hours = 219 kWh / yr

<u>8 W LED Bulb</u>
Energy = Power x time = 8 W x 10 hr / day x 365 day / yr = 29,200 watt-hours = 29.2 kWh / yr

If a kWh cost $0.22 how much money will you save annually by using the LED bulb in place of the incandescent bulb?

<u>60 W incandescent Bulb Cost</u>
Annual Energy Cost = 219 kWh x $0.22 / kWh = $48.18 / yr

<u>8 W LED Bulb Cost</u>
Annual Energy Cost = 29.2 kWh x $0.22 / kWh = $6.24 / yr

Annual Cost Savings = $48.18 - $6.24 = $41.94 / yr