HVAC Fundamentals

HVAC Systems

Purpose

Heating, Ventilating, and Air Conditioning (HVAC) systems are designed to provide and control:

- Temperature (heat intensity)
- Enthalpy (heat quantity in the air)
- Humidity (relative, dew point)
- Pressure (atmospheric, building pressurization)
- Air Motion (mechanical, fans, diffusers)
- Ventilation (air freshness, oxygen content)
- Air Quality (pollution, contaminant, odors)

Indoor Air Quality (IAQ)

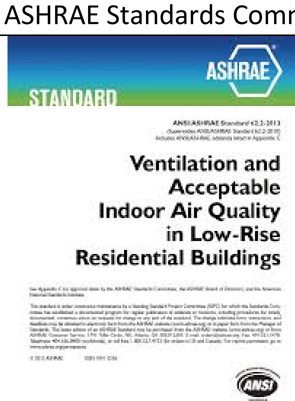
- Refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants.
- Directly affects occupant health, comfort, and productivity.

American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE)

ASHRAE Standard 62.1 Ventilation for Acceptable Indoor Air Quality

	Purpose: The purpose of this standard is to specify minimum ventilation rates and other measures intended to provide indoor air quality that is acceptable to human occupants and that minimizes adverse health effects. *acceptable indoor air quality*: air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.

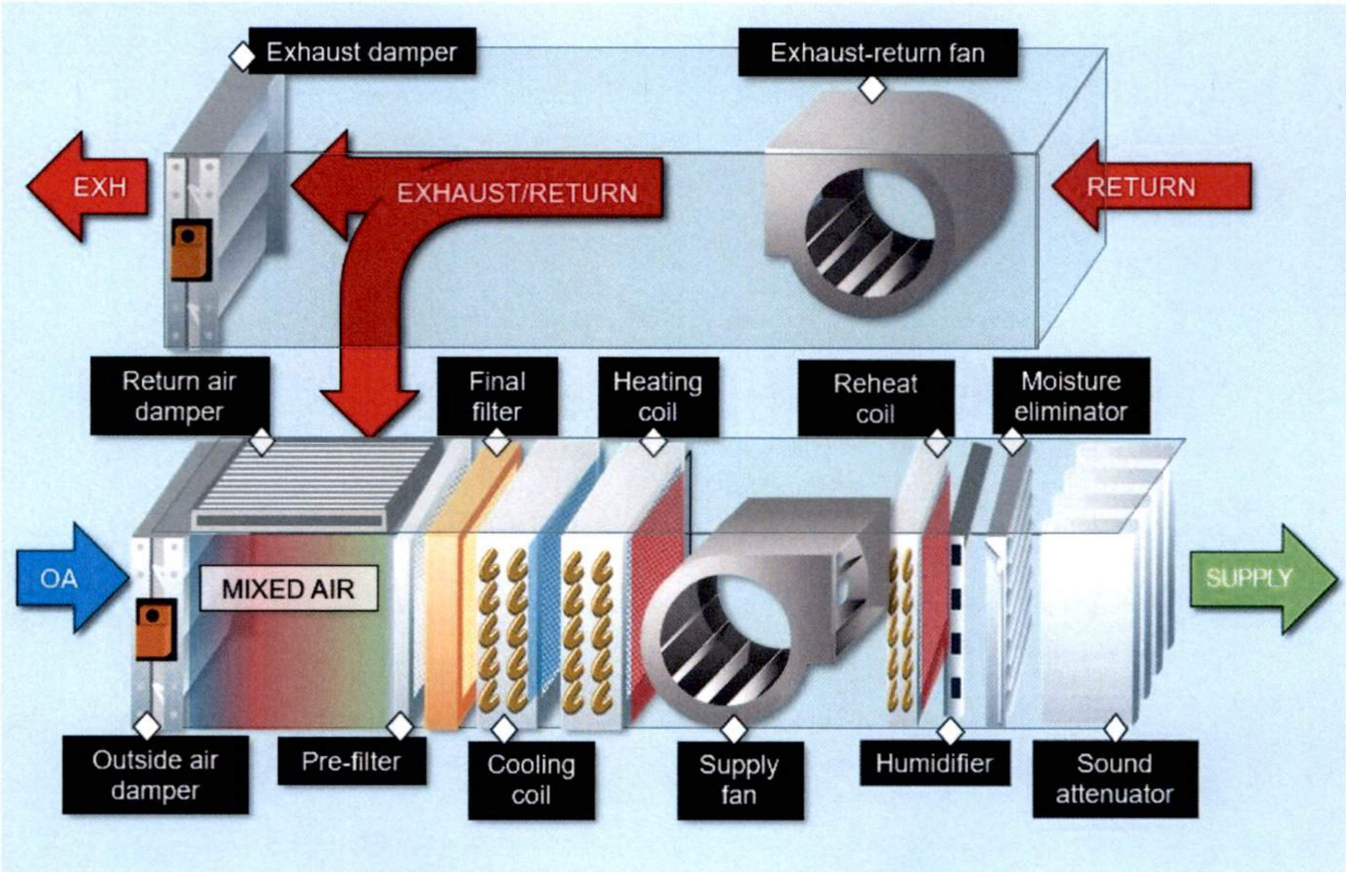
Other ASHRAE Standards Commonly Used for HVAC Design

		
ASHRAE Standard 62.2 Ventilation for Acceptable Indoor Air Quality in Low-Rise Residential Buildings	ASHRAE Standard 52.2 Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size	ASHRAE Standard 55 Thermal Environmental Conditions for Human Occupancy

Design

HVAC systems generally share a few basic design elements:

- 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



Function

Outside Air Intake

Outside Air (OA) is brought into the Air Handling Unit (AHU) by the Supply Fan

Air Handling Unit (AHU)

OA also referred to as Supply Air is filtered to remove particulates
Supply Air is conditioned – cooled or heated, by either the Cooling Coil or the Heating Coil
Supply Air Moisture Content – Humidifying (add moisture) or Dehumidifying (remove moisture)

Air Distribution System

Ductwork distributes the conditioned (heated or cooled) air throughout the building before returning it to the AHU

Air Exhaust System

Exhaust/Return Air is forced out of the system by the Exhaust/Return Fan
Exhaust Air – portion of the Return Air pushed outside the building
Return Air – portion sent back to the system to be recirculated
Mixed Air – includes a percentage of Return Air mixed with new Outside Air
100% new Outside Air – all Return Air is exhausted, no recirculated air

Building Pressurization

A building's interior air pressure will be either negative or positive, depending on the airtightness of the building and other forces such as wind, exhaust loads, and amount of make-up air.

Negative indoor air pressure: This occurs when the inside pressure is less than the pressure outside causing air to leak into the building. This is called infiltration.

Positive indoor air pressure: This result's when the inside pressure is greater than the outside pressure. In this case air pushes from inside the building to the outside. This is called exfiltration.

Proper pressurization of buildings and indoor spaces is a crucial component required for the management of:

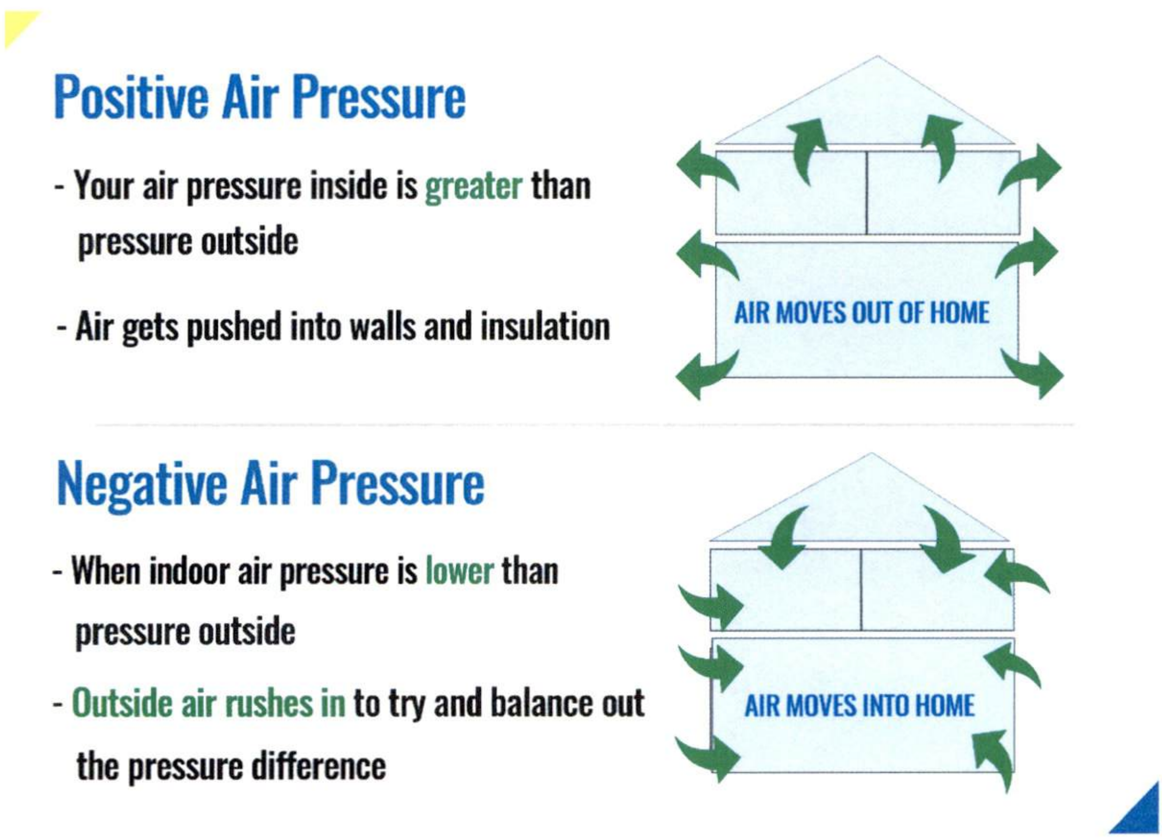
- Indoor air quality
- Maximizing energy efficiency
- Maintaining occupant health and comfort

Lack of control regarding building pressurization can lead to a host of problems including:

- The infiltration of moisture
- Cold winter or hot summer drafts
- Doors that are difficult to open or slam shut

Which is better?

- In general, a building benefits from having slight positive indoor pressure.
- This is especially true during the heating season because it is expensive to heat the cold air that infiltrates from outside when interior pressure is negative.



HVAC Components

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

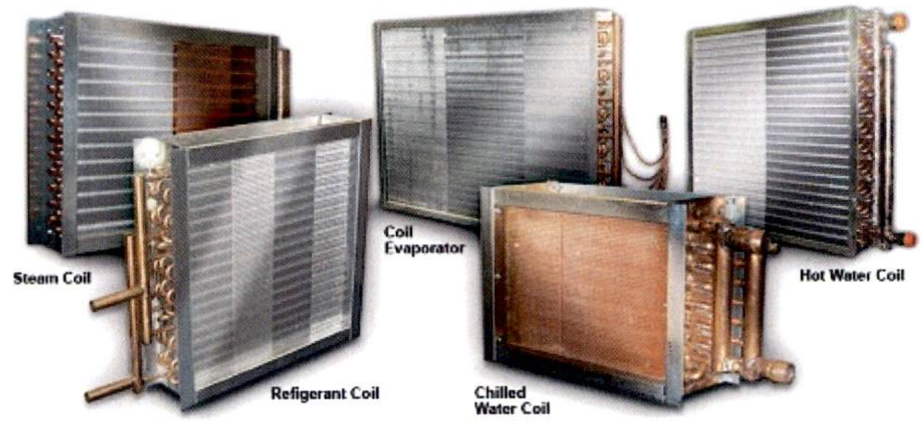
A "forced air" furnace works by blowing heated air through ducts that deliver the warm air to rooms throughout the building via air registers or grills.

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 Heat Exchanger Coils:
Condenser Coils
DX or Evaporator Coils
Cold Water Coils
Hot Water Coils
Steam Coils
Booster Coils
Electric Coils



Ventilation

Indoor Air Quality (IAQ)

- IAQ refers to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants.
- Understanding and controlling common pollutants indoors can help reduce your risk of indoor health concerns.

EPA - IAQ
https://www.epa.gov/indoor-air-quality-iaq

Ventilation Rates

Cubic Feet per minute per person (CFM/person)
Air Changes per Hour (ACH)

The Standards for Ventilation and Indoor Air Quality

ANSI/ASHRAE Standards 62.1 Ventilation for Acceptable Indoor Air Quality for commercial buildings
ANSI/ASHRAE Standards 62.2 Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings for residential buildings

- 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.

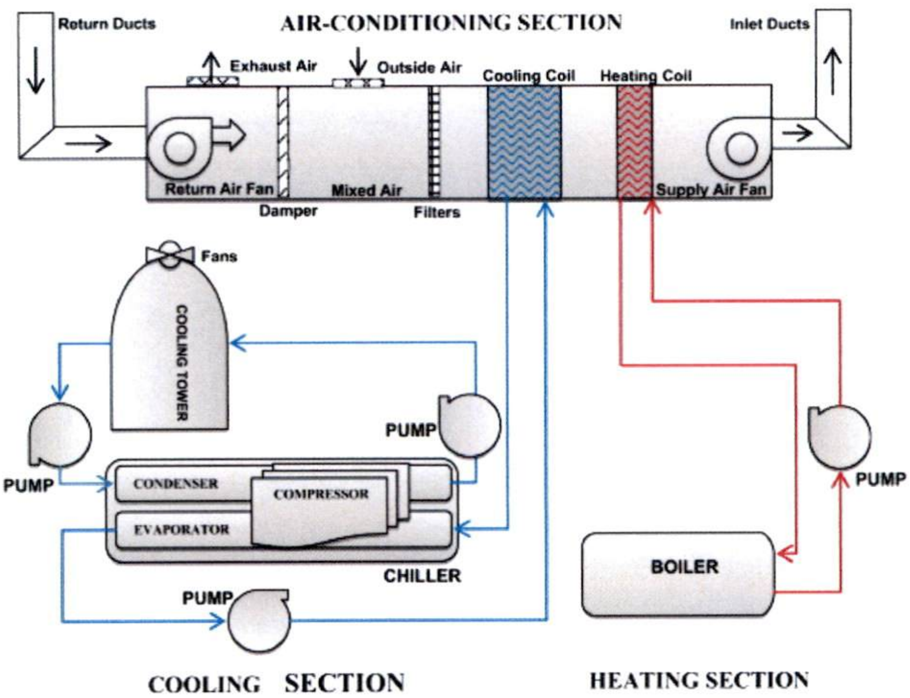
Mechanical Ventilation (Active Ventilation)

Natural Ventilation (Passive Ventilation)

https://www.calacademy.org/efficient-building-design

Air Conditioning

Air Conditioning means comfort cooling with either chilled water systems or refrigerant systems. These systems include cooling coils to remove heat from the air.



AC (Air Conditioning) also means conditioning the air in the following ways:

Temperature (tempering the air)
— Cooling (removing heat)
— Heating (adding heat)

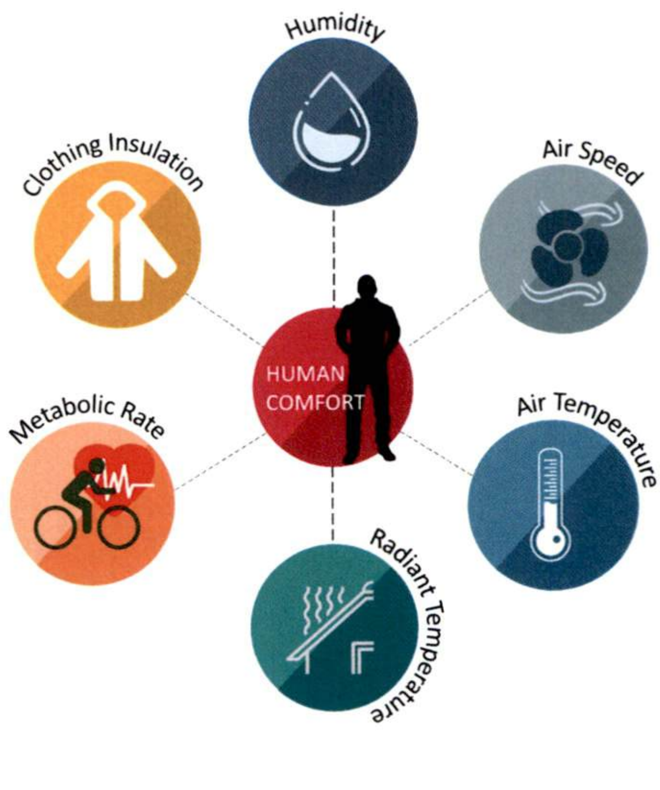
Humidity control
— Dehumidifying (removing moisture)
— Humidifying (adding moisture)

Volume of airflow
— cfm (cubic feet per minute)

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

Cleaning
— Filtering

Pattern of airflow
— Direction
- horizontal
- vertical

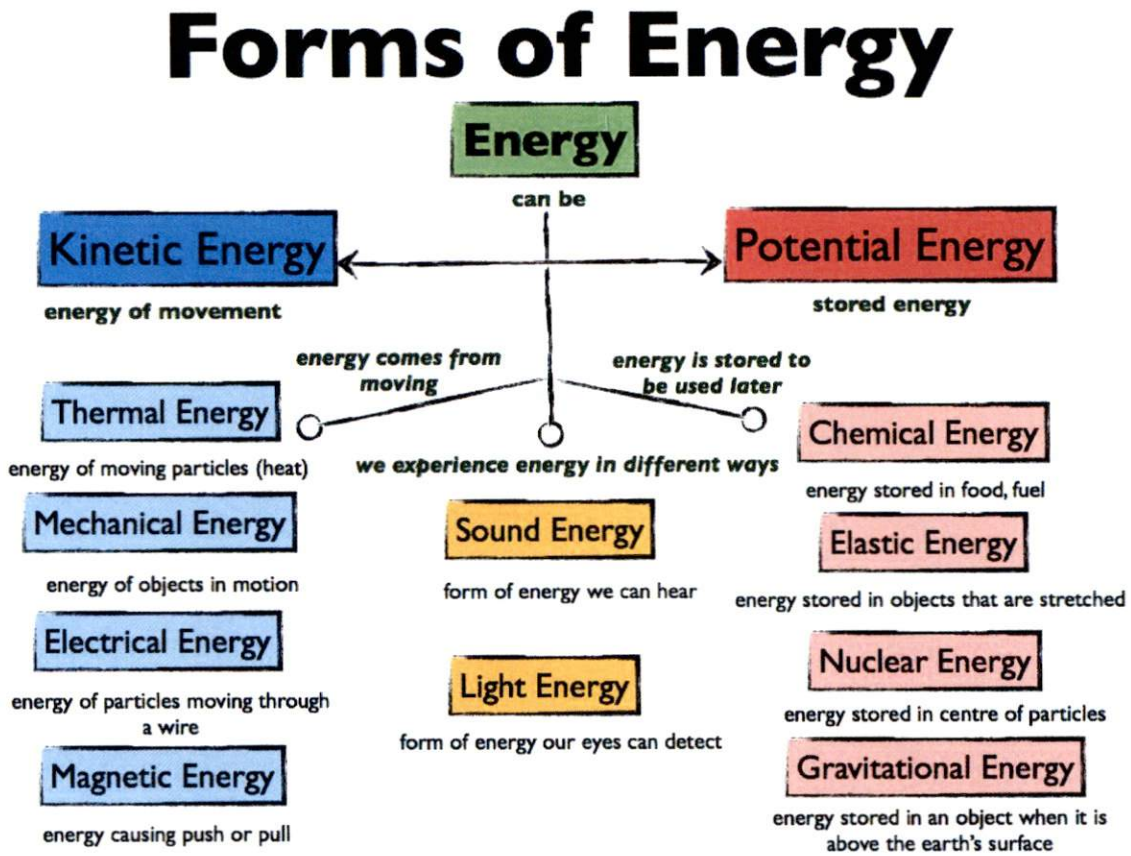


Six Factors of Human Comfort

Basics of Energy

- Energy is the ability to do work.
- Energy is a quantity, such as **Heat**.

All forms of energy fall under two categories:



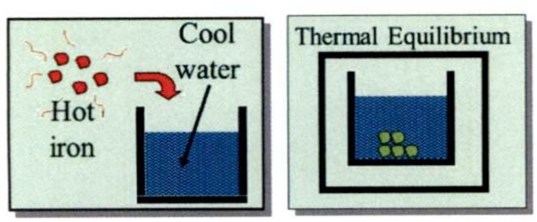
Thermal (Heat) Energy

- 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.
- **Heat** is not something an object has, but rather the <u>energy</u> that it absorbs or gives up.

Conservation of Energy

Whenever there is a transfer of heat within a system, the heat lost by the warmer bodies must equal the heat gained by the cooler bodies:

$$\Sigma \text{ (Heat Losses)} = \Sigma \text{ (Heat Gained)}$$



Units of Heat

Calorie (cal)

One calorie (1 cal) is the quantity of heat required to raise the temperature of 1 g of water 1 ^{o}C

10 calories of heat with raise the temperature of 10 g of water by 10 ^{o}C

One kilocalorie (1 kcal) is the quantity of heat required to raise the temperature of 1 kg of water 1 ^{o}C

British Thermal Unit (Btu)

One British Thermal Unit (1 Btu) is the quantity of heat required to raise the temperature of 1 lb of water 1 ^{o}F

10 Btu will raise the temperature of 10 lb of water by 10 ^{o}F

The British Thermal Unit (Btu) is widely used in the HVAC industry. It is an outdated unit.

When working with the Btu, the pound unit is actually a unit of mass, not weight.

SI Unit of Heat

Joule - the SI unit of work or energy, equal to the work done by a force of one newton when its point of application moves one meter in the direction of action of the force.

Comparison of Heat Units:

1 cal = 4.186 J	1 Btu = 778 ft lb
1 kcal = 4186 J	1 Btu = 252 cal
	1 Btu = 1055 J

Heat Formula

Heat flows from the point of higher temperature to one of lower temperature.

The heat content, Q, is given by the equation:

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

Where

Q = heat absorbed (or released) (Btu)

M = mass (lb)

C = heat capacity (often called "specific heat") (Btu/lb ^{o}F)

ΔT = temperature increase or decrease, ^{o}F

Example 1.

A 12 ft X 20 ft concrete patio is 6 in thick. If the slab is warmed by the sun to 90°F during the day and cools to 45°F overnight, how much heat is stored and released by the floor on a daily basis?

Solution.

For Concrete, $C = 0.21 \frac{Btu}{lb\ ^{o}F}$

$W = \rho v$

$\rho = 144 \frac{lb}{ft^3}$ (density)

Heat Storage

$$Q = \left(12\,ft \times 20\,ft \times 6\,in \times \frac{1\,ft}{12\,in}\right) \times 144 \frac{lb}{ft^3} \times 0.21 \frac{Btu}{lb\ ^{o}F} \times (90^{o}F - 45^{o}F)$$

$$= 17,280\ lb \times 0.21 \frac{Btu}{lb\ ^{o}F} \times 45\ ^{o}F$$

$$= 163,296\ Btu$$

Heat Capacity

The heat capacity of a substance is the heat required to raise the temperature a unit degree.

Substance with a low specific heat capacity warm quickly because they need less heat energy for a given change in temperature. They also give up their heat quickly.

Substances with a high specific heat capacity take a long time to warm up and they retain their heat for a long time.

Density and Heat Capacity for many common materials are listed in the table below.

Material	Density (lb/ft^3) (ρ)	Heat Capacity (Btu/lb°F) (c)
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 2.

How much heat (Btus) will be stored in a 100-ft^2 concrete wall 8-in thick if it is warmed from 55°F to 85°F by exposure to sunlight?

Solution.

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

$$= \left(100\ ft^2 \times 8in \times \frac{1ft}{12in}\right) \times \frac{144\ lb}{ft^3} \times \frac{0.21\ Btu}{lb\ °F} \times (85°F - 55°F)$$

$$= \underline{\underline{60,480\ Btu}}$$

Converting Between U.S. and S.I.

Quantity	U.S.	S.I.
Q (heat supplied or released)	Btu	kJ (kilo Joule)
M (unit mass)	lb	kg
C (specific heat)	Btu/lb °F	kJ/kg °C , kJ/kg °K
ΔT (temperature increase or decrease)	°F	°K, °C

$$\frac{1\ \text{Btu}}{\text{lb °F}} = \frac{4{,}186.8\ \text{J}}{\text{Kg °K}} = \frac{1\ \text{kcal}}{\text{kg °C}}$$

Example 3 – Heat Aluminum

2 kg of Aluminum (AL) is heated from 20°C to 100°C. The specific heat of AL is 0.91 kJ/kg °C and the heat required can be calculated as:

Q = M x C x ΔT

$$= 2\ kg \times 0.91\ \frac{KJ}{kg\ °C} \times (100°C - 20°C)$$

$$= 145.6\ KJ$$

How many Btu's? rapidtables.com 138 BTU

Example 4 – Heating Water

One litre of water is heated from 0°C to boiling (100°C). Specific heat of water is 4.19 kJ/kg °C and the heat required can be calculated as:

Q = M x C x ΔT

$$= 1\ litre \times \frac{1\ kg}{1\ litre} \times 4.19\ \frac{KJ}{kg\ °C} \times (100°C - 0°C)$$

$$= 419\ KJ$$

How many Btu's? 397 BTU rapidtables.com

Convert from SI to US

$Q = 419\ KJ = 419{,}000\ J$

$1\ J = 0.000948\ BTU$

$1000\ J = 0.948\ BTU$

$$= 419\ KJ \times 0.948\ \frac{BTU}{KJ} = 397\ BTU$$

Using US Units

1 litre = ? lb? Can't compare!

A litre is a unit of volume

A pound is a unit of weight

0°C + 100°C SI

32°F to 212°F US

1 litre weighs 1 kg

There are 2.2 lb/kg

∴ 2.2 lb water

Q = M x C x ΔT

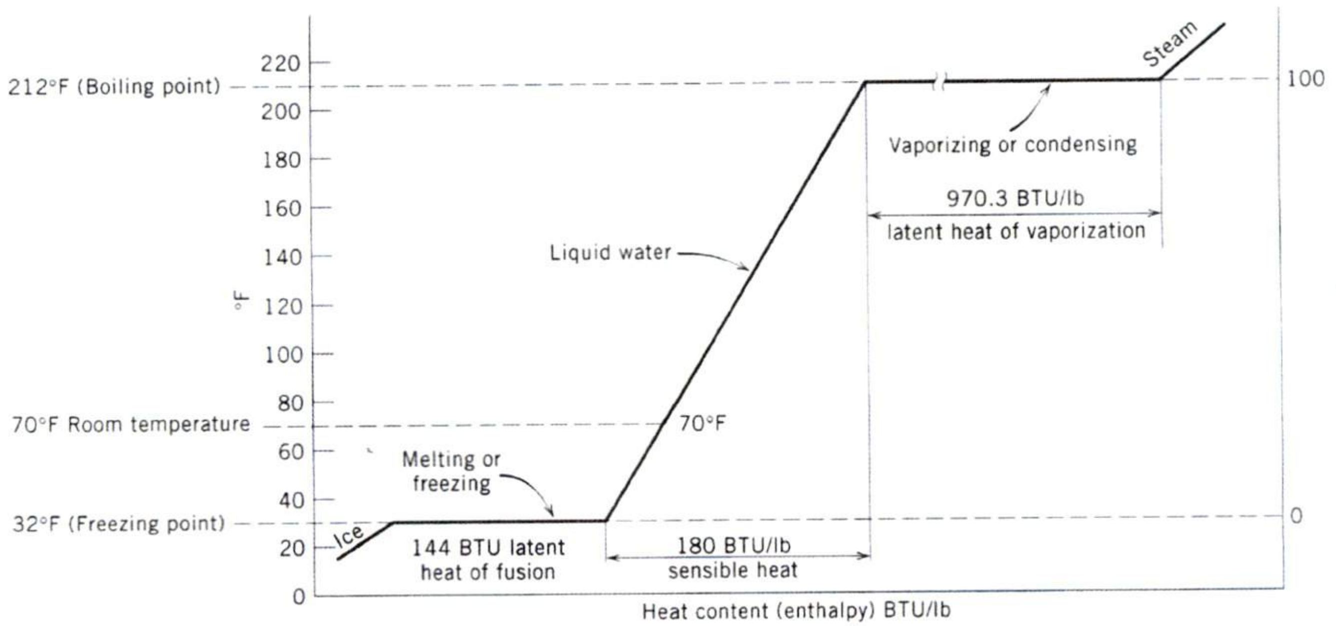
$$= 2.2\ lb \times \frac{1\ BTU}{lb\ °F} \times (212°F - 32°F)$$

$$= 397\ BTU$$

Sensible and Latent Heat

Sensible Heat
Causes a change in temperature of substance when heat is added or removed. Can be measured by a thermometer.

Latent Heat
Causes a change of state in the substance when heat is added or removed. Changing a solid to a liquid or a liquid to a gas while the temperature remains constant.



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 5.
How much heat must be added to a 1 lb of water at room temperature (70^{0}F) to bring it to the boiling point?

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

$$= 1\,lb \times \frac{1\,BTU}{lb\,^{\circ}F} \times (212^{\circ}F - 70^{\circ}F)$$

$$= \underline{\underline{142\ BTU}}$$

Example 6.
A block of ice, 1 ft^3 in volume, is taken from a freezer where it was stored at 20°F (0°C). How many BTU of heat will be required to convert the ice to water at 60°F?

Solution.

Weight of the ice

$$M = 1\ ft^3 \times 62.41\ \frac{lb}{ft^3} = 62.41\ lb$$

Sensible Heat needed to raise the temperature from 20°F to 32°F

$$Q = 62.41\ lb \times \frac{1\ Btu}{lb\ ^\circ F} \times (32^\circ F - 20^\circ F) = 748.92\ BTU$$

Latent Heat in involved since there is a phase change from solid (ice) to liquid (water)

32°F to Melted

$$Q = 144\ \frac{Btu}{lb} \times 62.41\ lb = 8,987.04\ BTU$$

Sensible Heat is needed to raise the temperature from melted @ 32°F to 60°F

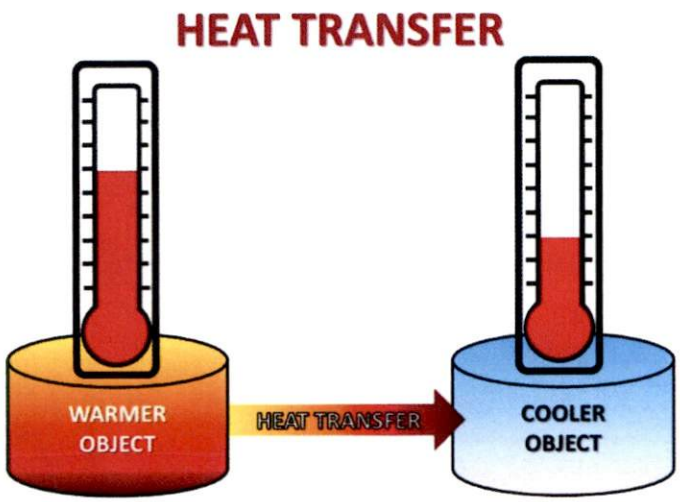
$$Q = 62.41\ lb \times \frac{1\ Btu}{lb\ ^\circ F} \times (60^\circ F - 32^\circ F) = 1,747.48\ Btu$$

Total Heat (Enthalpy) = Latent Heat + Sensible Heat

= 748.92 Btu + 8987.04 Btu + 1747.48 Btu

= **11,483 BTU**

Heat Transfer: Conduction, Convection, Radiation



1. Conduction
2. Convection
3. Radiation

Conduction
Transfer of heat between substances that are in direct contact with each other. The better the conductor, the more rapidly heat will be transferred.

Examples:
- A cold cast iron skillet is placed onto a stovetop. When the stove is turned on, the skillet becomes very hot due to the conduction of heat from the burner to the skillet.
- A cube of ice placed in your hand.

Convection
Thermal energy is transferred from hot places to cold places by convection. Convection occurs when warmer areas of a liquid or gas rise to cooler areas in the liquid or gas. Cooler liquid or gas then takes the place of the warmer areas which have risen higher. This results in a continuous circulation pattern.

Example:
- Boiling water - The heat passes from the burner into the pot, heating the water at the bottom. Then, this hot water rises and cooler water moves down to replace it, causing a circular motion.

Radiation
Transfer of heat through space from a mass at a higher temperature to a mass at a lower temperature via electromagnetic waves.

Examples:
- Sun warms your body
- Heat from a fire

Mean radiant temperature (MRT) is a measure of the average temperature of the surfaces that surround a point, with which it will exchange thermal radiation.

Power

The rate of energy flow is "power".

$-\frac{Btu}{hr}$ or $\frac{BTU}{h}$

The unit of power for thermal energy is in Btus per hour, abbreviated Btuh (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 equipment to offset the heat or load.

TABLE 1.1 Forms and Units of Energy and Power

	Unit of Measure		
Energy Form	**Energy**	**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)	3,413
Mechanical	Horsepower-hour (hp-hr)	Horsepower (hp)	2,545

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

Power = Energy /time

or

Energy = Power X time

Example 7.

A 50 ft^2 x 6 in. concrete slab is in full sun all day and absorbed 72,000 Btu of heat energy. If the absorbed heat is released during the night between 11:00 pm and 5:00 am, what is the average capacity of the slab over this period to assist in heating the building?

$$\text{Power} = \frac{\text{Energy}}{\text{time}}$$

$$= \frac{72{,}000 \text{ Btu}}{6 \text{ hr}}$$

$$= 12{,}000 \frac{\text{Btu}}{\text{hr}} = \underline{\underline{12{,}000 \text{ Btuh}}}$$