ENERGY PRINCIPLES

ENERGY

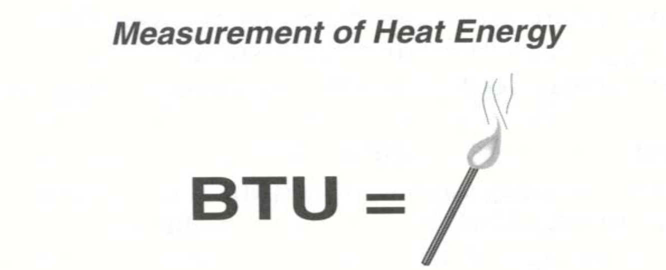
More than 99% of the energy used comes from the sun. The only other significant source is nuclear material in the earth. Plants build their tissues with sunlight, and the composition of all fossil fuels is ancient plant and animal tissue. Fossil fuels are burned to produce heat and work energy.

Energy is a measurable quantity of heat, work, or light. Potential energy is stored energy -- like a cord of wood. Kinetic energy is transitional energy -- like a flame. Energy is called many things. Calories, kilowatt-hours, and therms of natural gas are some measurements of energy. Although energy can take many forms it is all equivalent and can change from one form to another. Energy can flow between objects such as a battery and light or between hot water and skin.

There are two laws of science (thermodynamics) apply to energy in our universe. The first says energy is neither created nor destroyed. Energy merely moves from place to place and changes form. The second says heat moves from high temperature regions to low temperature regions. Heat never naturally moves from low temperature areas to high temperature areas, unless there is an external source of energy.

TEMPERATURE AND HEAT

Temperature is a measure of how fast the molecules in a substance are moving or vibrating. In a thermometer, molecules race around randomly in a fluid. The average speed of travel is actually what a thermometer measures. Heat flows because of a difference in temperature between two areas. Heat is measured in British thermal units (Btu), which is the amount of heat required to raise a pound of water 1°F (equivalent to the amount of heat contained in one wooden kitchen match).

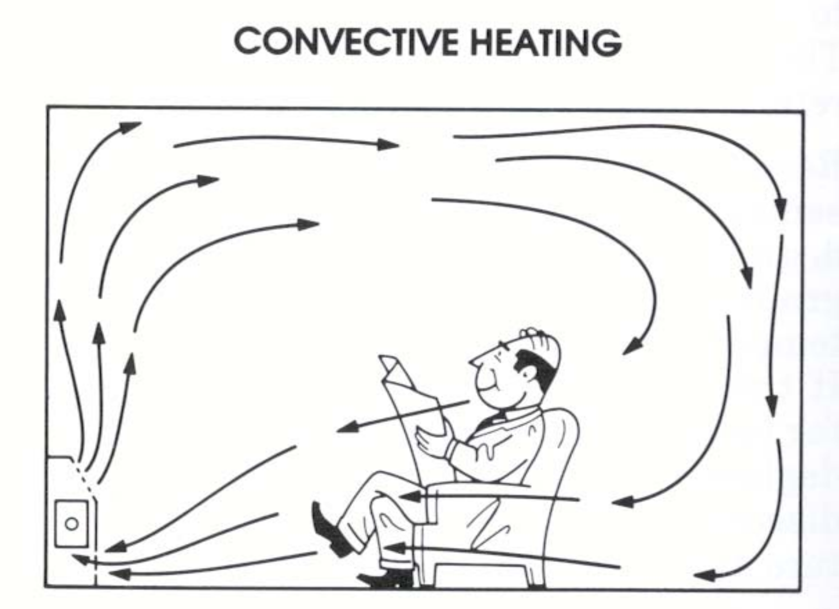


A kitchen match contains about one Btu of heat energy.

Heat travels from area of high temperature to areas of low temperature in three ways: conduction, convection, and radiation.

Conduction is the most familiar and predictable type of heat flow. Heat conducts through solid objects touching one another. An example is when touching something hot, heat is conducted to skin.

Convection is heat transferred by a moving fluid like air or water. Convection happens because of density differences between warmer and cooler parts of the fluid. An example of convection is the hot combustion gases convect against the metal surfaces of the heat exchanger, transferring heat to the metal. Hot air or hot water rises to the top because it is less dense than the cooler air or water, not because heat rises.

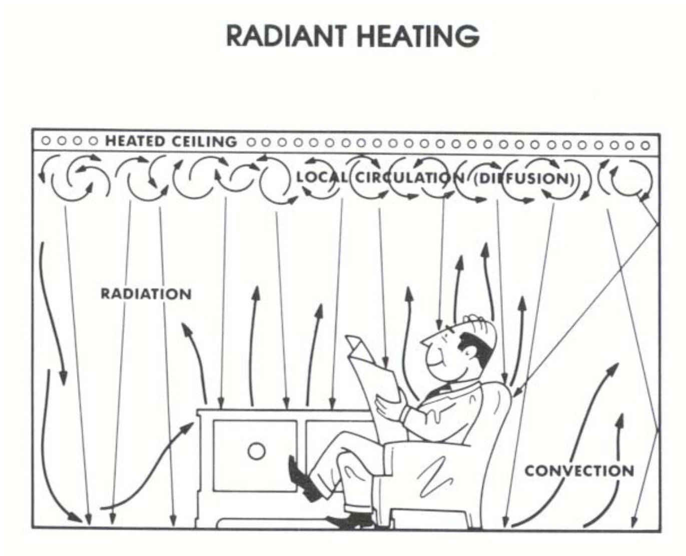


Convection heating devices include:

- Forced warm air- this devices employs a gas, oil or electric burner or heat pump to heat a convector, usually called a heat exchanger. A blower passes air over the convector and through ducts into the heated spaces.
- Hydronic devices- these devices employ a convector heated by hot water. Baseboard units use hot water to heat convector fins with the air passing over them.
- Electric baseboard- in these units, the convector is heated by electric.

Radiation heat flies through space from one object to another. An example is the sun’s radiant heat felt on the skin. There's a continuous unequal exchange of heat radiation between all objects in the universe, with a net heat flow going from high temperature to low temperature as dictated by the second law of thermodynamics.

Radiant heating occurs mainly by radiant heat transfer from the heating surface to one or more of the surfaces in a room.

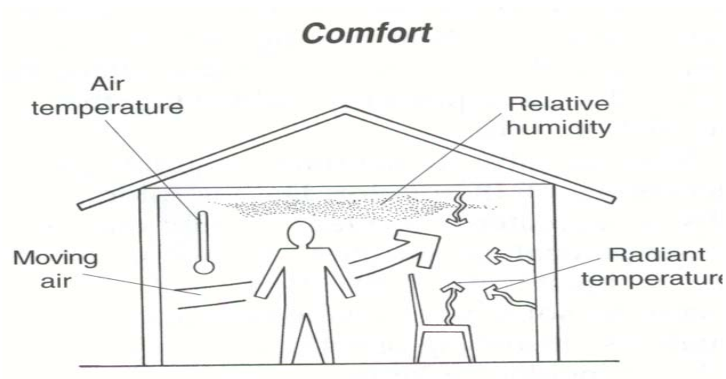


Radiant heating devices include:

- Heat sources in ceilings and floors, such as electric cable, radiant ceiling panels, or pipes heated by hot water or steam.
- Radiant heat with hot water or steam.
- Electric or gas radiant heaters.

COMFORT

Outdoor climate has the most influence on human comfort of any common factor. The temperature, relative humidity, solar radiation, precipitation, and wind affect the immediate comfort of people who are outside. Buildings temper the elements to one degree or another, but the conditions outdoors determine what needs to be done to maintain indoor comfort. Thermal equilibrium with the environment creates comfortable conditions --- the body is losing as much heat as it is gaining from metabolism and from our surroundings. Air temperature is usually the most important factor determining comfort.



Comfort in both winter and summer is related to four factors: air temperature, relative humidity, radiant temperature, and air movement.

Relative humidity is a very important summer comfort factor, since it determines how rapidly sweat can evaporate from the skin. Humid air contains more heat than dryer air, this fact exercises less influence on comfort. Humid air may feel better to the throat and lungs indoors during winter, but there is no heating energy advantage to humidifiers. Moving air is very important for summer comfort. Rapidly moving air increases bodily heat loss through convection and sweat evaporation. Air circulation is important in winter also to avoid air stagnation and large room temperature differences.

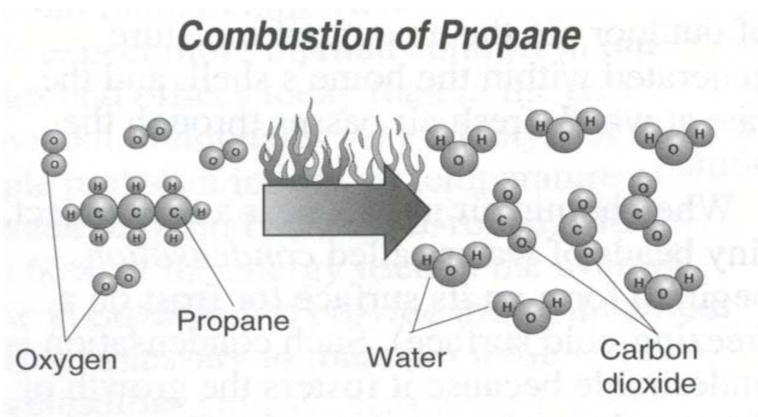
Temperature is the most noticeable characteristic of climate and the most important factor in determining heating energy use. Outdoor temperature is always changing according to the season, the weather, and the time of day. Heating engineers use a unit of measurement called a heating degree-day to describe how long the temperature is below 65°F during each day, month, or year. Cooling degree-days measure the air temperature differences between the outdoors and 78°F over the hot summer season. The temperature from which the degree-day difference is measured is called the balance point. The heating balance point is the outdoor temperature where no heating is needed, usually assumed to be 65°F. A very well insulated home may need no heat even at an outdoor temperature of 50°F, so its balance point is 50°F. The local weather bureau computes the number of degree-days daily by figuring how long the average outdoor temperature is below 65°F. If the high was 30°F and the low temperature was 0°F, then the average temperature for the day is 15°F. Subtract 15°F from the 65°F balance point for a 50°F difference in temperature between indoors and outdoors. The symbol "ΔT" (delta T) is often used to symbolize this temperature difference. Heating degree-days are directly related to heating costs. It will take twice as much fuel to heat a home in Duluth, Minnesota with 10,000 degree-days annually as an identical home in St. Louis, Missouri, where there are 5000 degree-days. Degree-days are abbreviated HDD, for heating degree-days. Cooling degree-days measure the intensity of the summer climate. To find cooling degree-days, calculate how long the average temperature was above the cooling balance point of 78°F by totaling up the daily degree-day values. Cooling degree-days are less reliable as predictor of summer cooing costs than heating degree-days for winter heating costs. Their unreliability is because the amount of shade and relative humidity are often more important than the outdoor air temperature in determining comfort.

The air temperature and amount of water vapor in the air determine how much heat the air contains. The higher the humidity at a given temperature, the more heat the air holds. Relative humidity (rh) measures how saturated the air is with water vapor as a percent. Completely saturated air has 100% rh. Warmer air can hold more moisture than cooler air. The outdoor relative humidity depends on rainfall, nearness to bodies of water, cloudiness, windiness, and other environmental factors. Indoor humidity is governed by the temperature and humidity of outdoor air, the amount of moisture generated within the home's shell, and the rate at which fresh air passes through the home. When humid air moves near a cool object, tiny beads of water called condensation begin to form on its surface (or frost on a freezing-cold surface). Such condensation is undesirable because it fosters the growth of fungus, dust mites, and wood-eating insects. Keeping indoor relative humidity at less than 60% during the summer promotes comfort, and will prevent condensation on cooler surfaces of an air conditioned home. Indoor humidity should be less than 40% during cold weather to prevent condensation on cold windows and other surfaces.

HOME ENERGY USE

Energy is converted from one form to another within a home to provide comfort, water heating, refrigeration, lighting, and other services.

Combustion heating systems convert natural gas, propane, or oil into heat. When the carbon and hydrogen atoms in fuel molecules mix with oxygen and a flame, a chemical reaction called burning starts. Heat is liberated in the chemical process, and this heat is used for space heating and water heating.



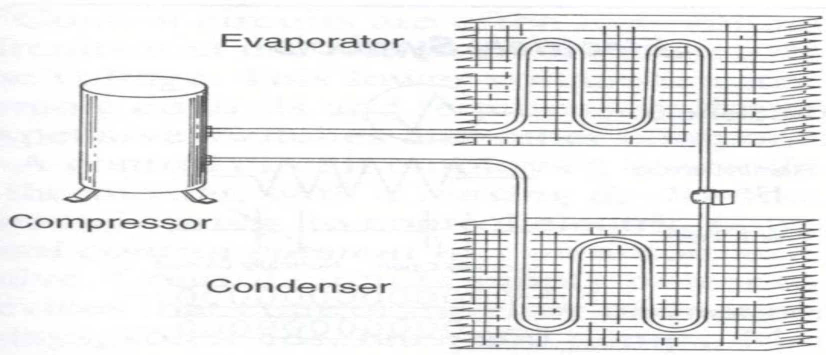
Propane, C_3H_8, combusts by combining with oxygen (O_2) to form water (H_2O) and carbon dioxide (CO_2).

The heat from the flame and hot gases heats a metal enclosure called a heat exchanger, which then heats the air or water. Pipes or ducts carry the heat or heated water to the building's rooms. Every time heat travels across a metal heat exchanger or through ducts and pipes some of the heat escapes the heating system.

Electric resistance heating changes electricity, usually generated by heat, back into heat. The electric current passes through resistive wires, bars, or plates. Electric heaters are very often located in rooms and provide heat through natural convection and radiation. Electric furnaces blow air through electric resistance coils. Electric water heaters and heating boilers have electric resistance bar surrounded by water, providing heat directly by conduction.

Refrigerators, air conditioners, and heat pumps move heat from one location to another using latent heat. When the liquid refrigerant vaporizes in the evaporator, it absorbs heat from the metal in the evaporator coil, which becomes cold and removes heat from the warm air being blown through the coil. The vaporized refrigerant then carries the heat it has collected from the indoor air to the compressor, where it is pressurized, returning it to its liquid state and releasing its latent heat of vaporization in the process. The condenser coil has a higher temperature than the outdoor air, so the heat flows from the coil to the outdoor air. The liquid refrigerant collects in the condenser and is forced into the liquid receiver with pressure created by the compressor. The liquid flows through the liquid receiver toward the expansion device, which is simply a spray nozzle. The liquid is sprayed back into the evaporator, where it evaporates and heat is again removed from the metal in the evaporator coil, and the cycle begins again.

The Refrigeration Cycle



Refrigerant evaporates in the evaporator absorbing heat from the metal tubes and fins. The compressor compresses the refrigerant, preparing it to condense within the condenser where the refrigerant's latent heat is given to the condenser's tubes and fins and then to the air passing through.

Electricity is converted into lighting via incandescent or fluorescent lighting. In an incandescent light bulb, a tiny metal wire called a filament glows white hot when electric current passes through it. Only 10% of the electricity is converted into light, with the other 90% becoming heat. Fluorescent lights produce light by passing electric current through a metallic gas. The flow of electricity through the gas excites special chemicals called phosphors, causing them to glow or fluoresce. The glowing phosphors coat the inside of the fluorescent tube. Fluorescent lamps convert 80% of the electricity they use into light. Using fluorescent lights instead of incandescent lights can reduce the amount of electricity used for lighting by about 75%.

CALCULATING COMFORT

Heat can be added or removed to maintain comfort in a home. Through calculations and measurements it can be predicted how much heating and cooling will be necessary for comfort, and how much energy will be used.

Heat flowing in and out of the home is a major energy drain. The need for heating, called heating load, is how many Btu's per hour (Btuh) need to be added or removed to provide comfort. Heating load is based on a worst-case temperature difference determined from established weather statistics.

The two main components of the heating load are conduction and air leakage. Heat loss is the number of Btu's flowing through the building annually or some other longer period of time. Heat loss is a measurement of energy expended to heat the building. Heat loss can be calculated from building shell characteristics and then compared with actual energy consumption from the utility bill.

Cooling load is the number of Btuh the cooling system needs to remove during the hottest summer weather, it is used to determine the power of the cooling system needed. Cooling load is completely different from heating load. It is less predictable because of its important variables (solar heat, air leakage, and internally generated heat) differ widely from home to home. Cooling load calculations also include the power needed to remove moisture from the air.

When calculating the heat flow through a wall, floor, or ceiling, pretend the heat flows purely by conduction. In truth it's not all conduction, but convection inside building cavities, and radiation carrying heat across air gaps. However the formulas predict this imperfect heat conduction accurately enough.

Air exchange is a separate component of heating and cooling load consisting of air leakage and ventilation. Air leakage and ventilation intake is heated or cooled by the home's space conditioning equipment. For every cubic foot of air entering a home, a cubic foot of air must leave the home, taking with it the energy used to heat or cool it.

HEATING LOAD

A combustion heating system has to supply not only the heat lost through the shell but also its own wasted heat. The more heat loss through the shell, the longer the heating system operates and the more heat it wastes because of its own inefficiency.

Insulation and air sealing not only slow the flow of heat through the shell, but they also slow the heating system's heat waste. The heating system also operates for a shorter duration after insulation and air sealing retrofits. This interaction is accounted for by dividing the shell's heating load (output in Btuh) by the heating system's delivered efficiency to find the estimated total heating load (input in Btuh).

Calculations of heat flow through the home's shell are used to estimate the output rating of a building's heating system. To calculate the input rating, divide the output by the heating system's delivered efficiency .

R-value is used to measure thermal resistance of walls, floors, and ceilings. However, U-values are used to calculate power and energy needed for heating. U-values state exactly how much heat conducts through a one-square-foot area of cross-section (wall, floor, or ceiling) in one hour, when there is a 1°F difference in temperature across the two opposite surfaces of the cross-section. U-value is the inverse of R-value, meaning $U = 1 \div R$ and $R = 1 \div U$. Since U-value is the inverse of R-value, when $R = 1$, $U = 1$: when $R = 2$, $U = .5$: when $R = 4$, $U = .25$; and so on. R-values are used to rate the thermal resistance of building components and can be added together. Add R-11 to a wall already insulated to R-3, the wall now has an R-value of R-14. To find the U-value of the wall, divide 1 by 14 (.071).

U-values can't be added together. The amount of heat flowing through a building's cross-section depends on: its U-value: its area: the temperature difference between indoors and outdoors: and the period of time (hour, month, or year) being considered.

A simple heat load (q) calculation is: U-value X Area (surface area) X ΔT. The ΔT is the difference in temperature between the inside and outside the building shell found by subtracting 65°F from the region's design temperature. The design temperature is temperature which is exceeded 97.5% of the time. Mason City, Iowa has design temperature of -10. This calculation can be used to estimate the size of heating unit needed.

Heat loss is the amount of energy lost over a period of time longer than an hour. It is calculated by taking the heating load (Btuh) by the number of hours in the heat loss time period. The primary reason for calculating heat loss is to predict savings from weatherization retrofits. This involves two calculations: one for the current condition and a second for the retrofitted condition. Another reason for calculating heat loss is to compare actual heating costs with predicted ones in order to troubleshoot a building's energy consumption. Heat loss (Q) in Btus over any time period may be calculated by multiplying the following values together: U-value X area X the difference in temperature between inside and outside of the building ΔT and the amount of time during which heat flows (t).

There is a combined measurement for time and temperature called degree-day. It measures the duration and severity of outdoor temperature compared to a balance point temperature. The balance point is the minimum outdoor temperature at which no heating is required. With 72°F as the desired indoor temperature, a building's balance point may be 65°F or less, meaning it doesn't need heat until the outdoor temperature goes below 65°F. If the average temperature outdoors is 30°F on a particular day, the outdoor temperature is 35°F below the 65°F balance point, so there are 35 degree days accumulated for the day. This shortens the calculation for heat loss to U-value X area X heating degree days.

PRINCIPLES OF AIR SEALING

Air leakage requires a hole and a pressure to push air through the hole. The air flow rate through a hole or group of holes depends on two factors: the size of the hole and the difference in pressure. It is nearly impossible to measure the size of the building's holes and cracks, but by measuring pressure and flow, the flow rate may be used to calculate leakage in buildings.

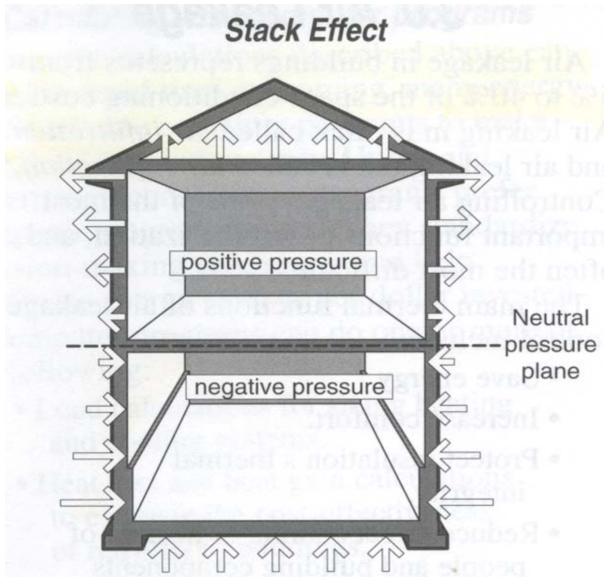
Direct air leaks occur at windows, doors, and seams in the house shell. Indirect leaks occur where air leaks into the shell and flows through the home exiting at a different location. Forces which drive flow can come from: wind, exhaust fans, stack effect, chimneys, and furnace blowers. Chimneys and exhaust fans can create a slight vacuum, often called depressurization. Wind, furnace blower, and stack effect tend to pressurize some areas of the home and depressurize others.

Beyond direct air leakage, air can also move around inside building cavities, increasing the rate of heat flow. This is called convective looping. Air convects inside building cavities, carrying heat from one surface to another. Air can wash over the insulation's surface, convecting heat away. Or, air can penetrate beneath the insulation's surface, reducing its thermal resistance. An effective air barrier completely surrounding the building's conditioned space, along with effective air sealing of the building's thermal flaws, reduces these secondary effects.

DRIVING FORCES

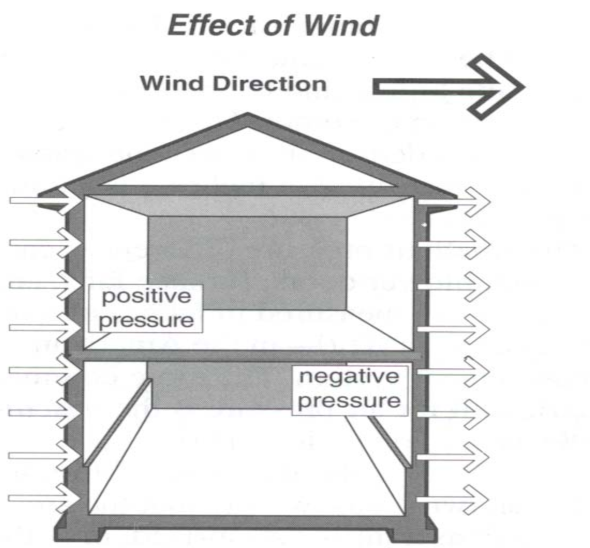
Four major forces which drive air: stack effect, wind effect, exhaust effect, and furnace blower. This is through the process of infiltration and exfiltration.

Stack effect is when the warmer air inside of a home rises and exits the home through openings and cooler air enter the home at a lower level to replace the exiting air. Somewhere near the midpoint of the building height is the point where no air is entering or exiting, this is called the neutral pressure plane. The pressures related to the stack effect are greatest at the highest and lowest points of the home. A hole in the basement will allow more infiltration than a hole at the neutral pressure plan. A hole in the ceiling will exhaust more air than a hole near the mid-point.



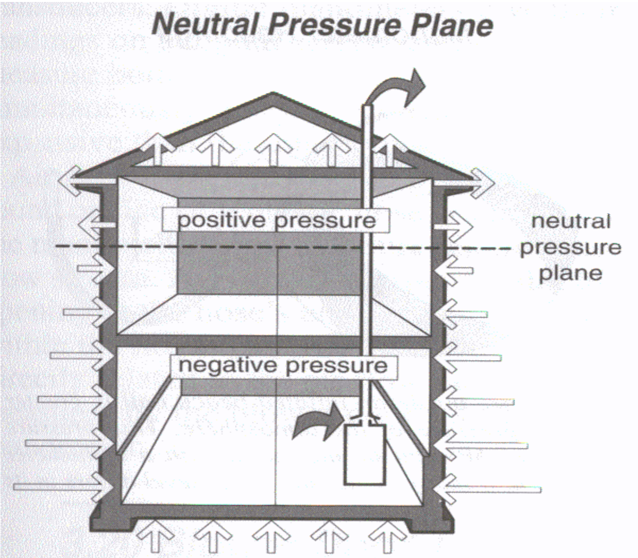
The stack effect is caused by the relative buoyancy of warmer air. Warmer air's upward force exerts an outward pressure. Airflow, through holes in the home's top, creates suction at lower levels, pulling air in. Arrows indicate the direction of positive pressure.

Wind effect is a powerful force. Wind blowing against a wall creates an area of high pressure, driving outdoor air into the windward side of the home. At the same time the leeward side of the home has a negative pressure.



Wind creates a positive pressure on the windward side of the home and negative pressures on other sides. Wind pressures push and pull air through holes in the shell.

Exhaust effect comes from chimneys and exhaust fans which create a vacuum indoors because they exhaust air out of the building. An exhaust fan or chimney blowing air out of the home moves the neutral pressure plane up because most of the holes would be admitting air. The incoming replacement air (make up air for exhaust appliances, or combustion air for combustion appliances) will come into the building following the path of least resistance. This make up air may even come down the chimney, backdrafting the combustion appliance. The chances of backdrafting become greater with the number of exhaust appliances the home has.



The neutral pressure plane is the area of the home where positive pressures and negative pressures meet. The furnace's chimney exhausts air from the home, putting more of the home under negative pressure.

The furnace blower circulates air through the furnace, into a system of supply and return ducts and through their outlets, called registers. Supply registers blow air into a room, pressurizing nearby areas of the room. Return registers suck air out of rooms, depressurizing these nearby areas. If the ducts are leaky or return air is restricted, rooms may have high positive or negative pressures. These pressures can become large enough to double or triple the building shell's air leakage compared to when the furnace blower is off.

Air pressure, airflow, and the size of air leaks are directly related to each other. An increase in pressure on opposite sides of a hole causes an increase in airflow through the hole. Make the hole bigger and airflow increases again. Pressure and airflow can be measured by instruments, called manometers. Manometers come in three types: U-shaped transparent tube, a round gauge with a needle indicating the pressure or amount, or a digital gauge.

The air inside an inflated beach ball is denser than the atmosphere outside. This pressure difference can be measured by attaching a manometer to the beach ball's valve. The lighter atmosphere presses on one side of the liquid, and the denser beach ball air presses on the other. The distance the beach ball's denser air moves the water column, measured in inches, is a unit of air pressure. Smaller air pressures are measured in inches of water column. In the weatherization program pressures are measured in Pascals. There are 250 Pascals per one inch of water column. When talking about pressure differences between two areas, the area having denser air is pressurized, or is the high-pressure area. The area with less dense air is depressurized, is under vacuum, or is the low-pressure area.

Another type of manometer is a round gauge with an arc-shaped scale for measuring either pressure (Pascals) or airflow (CFM, cubic feet per minute). This gauge has two pressure taps: the high-pressure tap and the low-pressure tap. If the gauge is physically located in the low pressure area, as with typical blower door testing, the low pressure tap is open to the area, and a hose is used to expose its high pressure tap to the high pressure area (outdoors).

The digital manometer measures pressure by way of sensors, called pressure transducers. Digital manometers give their readings on a digital screen, and some can measure both house pressure and flow simultaneously. They are considerably more expensive than the other types.

Airflow is then measured by putting the round orifice of a plastic hose connected to the manometer's low pressure tap into the air flow stream. Air flowing perpendicular to the opening at the hose's end creates vacuum within the hose. This vacuum's strength is directly related to the airflow rate as measured by the blower door's airflow manometer.

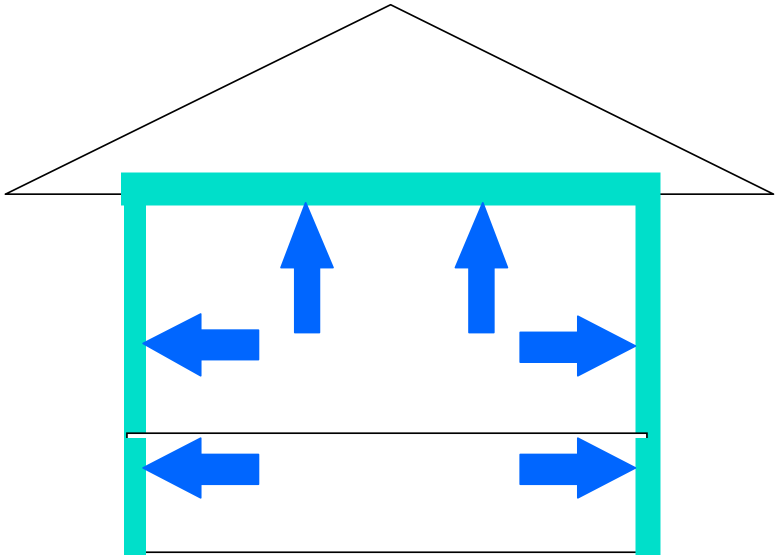
The blower door measures the total air leakage of the pressure boundary of a building.

A blower door can, by itself: measure total leakage rate, indicate the potential for air leakage reduction in a building, provide an estimate of the natural infiltration for a building, and assist in finding air leakage locations.

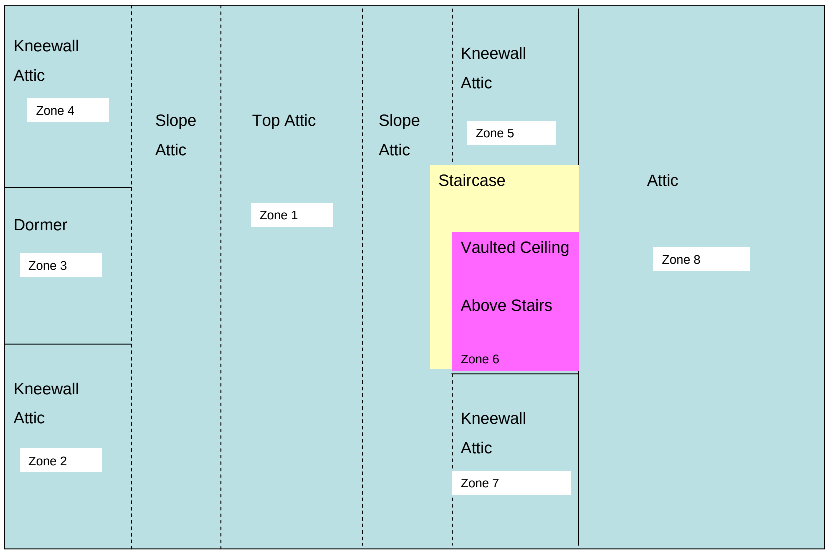
A blower door test by itself does not determine: the location of the pressure boundary, the interconnections between leaks (which are the most important), the relationship of the pressure boundary and the thermal boundary, and the best location to seal an air leakage site.

Zone pressure testing can help align the thermal and pressure boundary. If these are aligned, the amount of surface area through which heat loss can occur can be reduced, increase the effectiveness of the air reduction work, increase the motivation of field staff, increase the performance of the thermal insulation, and increase the energy saving and comfort in a building.

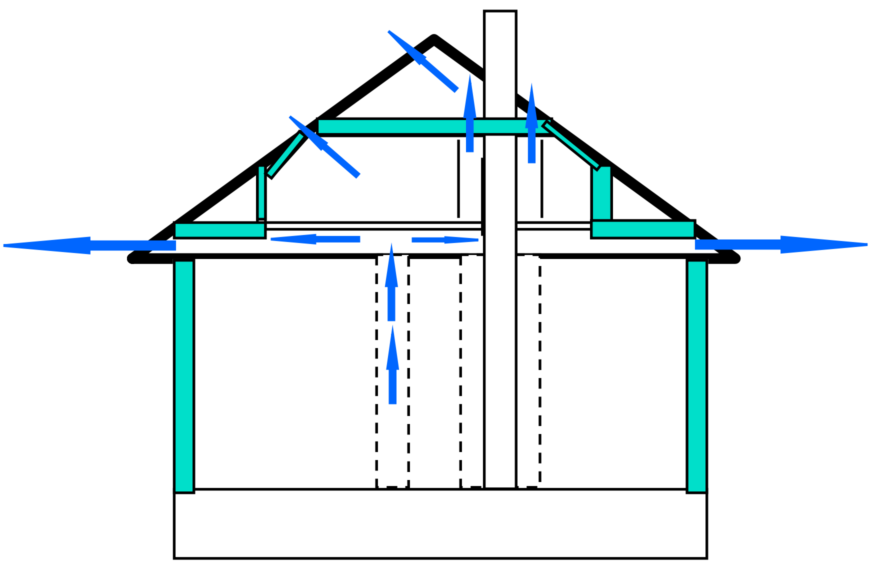
The thermal boundary is the insulation. With insulation in the attic, walls and floor, the thermal boundary of the house will look like this.



To find pressure boundaries identify the thermal boundary and the buffer zones.



When the thermal boundary and the pressure boundary are not aligned, air escapes through breaks in the pressure boundary, making the insulation less effective. It can also cause moisture problems and ice dams.



The buffer zone is a space in a building separating the heated interior of the building from the outside. Buffer zones include kneewalls, crawlspaces, garages, attics, and floored cavities.