







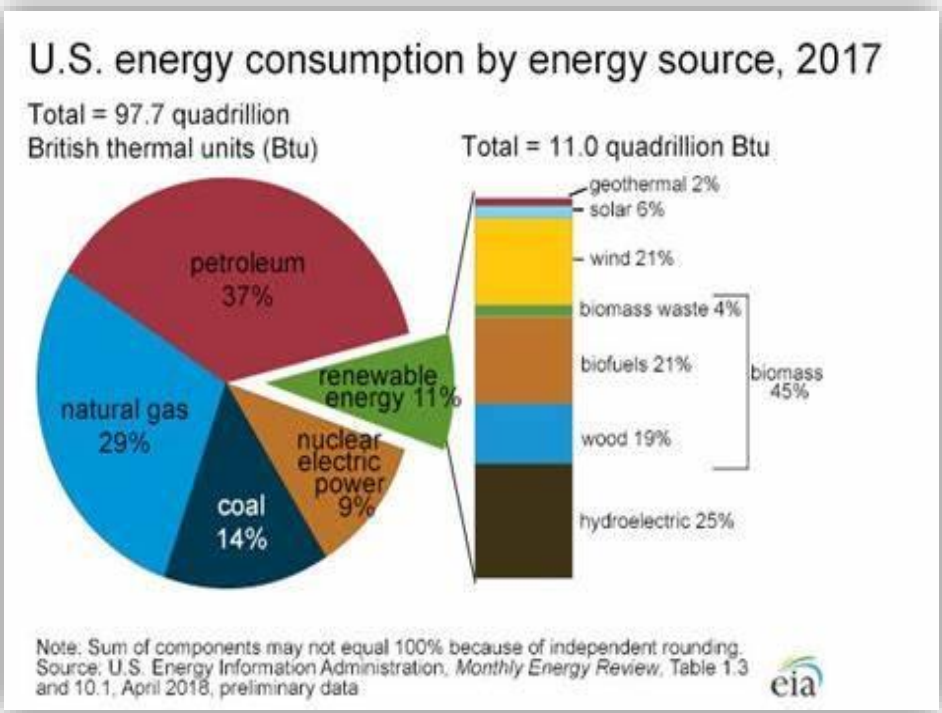
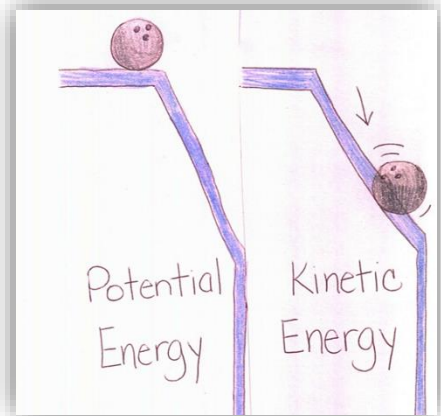


Building Science Basics Key Points Document



The practical purpose of building science is to provide insight to optimizing building performance and sustainability, understand or prevent building failures, and guide the design of new techniques and technologies

-  **solar energy**sunlight
-  **biomass**plants
-  **waterpower**.... flowing water
-  **fossil fuel energy**coal, natural gas, oil
-  **nuclear energy**.....uranium, plutonium, hydrogen
-  **geothermal energy**.....heat from inside the Earth
-  **tidal energy**gravity of the Moon and Sun affects the oceans
-  **wind energy** moving air caused by the sun heating the atmosphere



THE LAW OF CONSERVATION OF ENERGY SAYS THAT ENERGY CAN CHANGE FROM ONE FORM INTO ANOTHER, BUT IT CANNOT BE CREATED OR DESTROYED.

Notes: _____

Energy will **ALWAYS** move in a predictable mannerfrom high to low

– Heat Flow: **hot** always moves to **cold**

– Moisture Flow: **moisture** always moves to **dry**

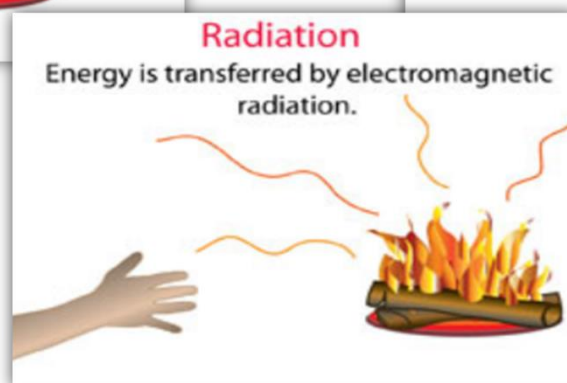
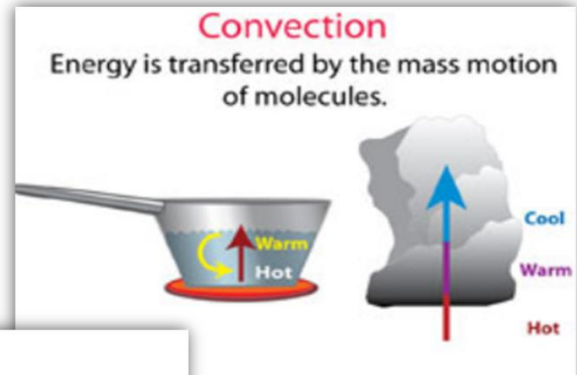
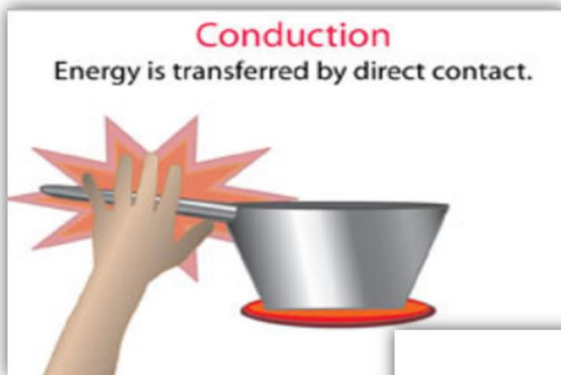
– Air Flow: Air always moves from an area of **high** pressure to an area of **low** pressure



Energy efficiency is using technology that requires less energy to perform the same function. Using a (LED) light bulb requires much less energy than an incandescent light bulb to produce the same amount of light

Energy conservation is any behavior that results in the use of less energy. Turning the lights off when leaving the room and recycling aluminum cans

Heat flow can occur through three mechanisms:



There are four different moisture transport mechanisms that apply to building science:

Bulk moisture movement has the potential to be the most damaging moisture transport mechanism confronted by a building. Typically thought of as rain or snow, bulk moisture movement also includes flowing groundwater.

Capillary action refers to the ability of water to travel against the pull of gravity through a porous material.

Air-transported moisture, water vapor hitchhiking on air, can leak in and out of buildings.

Vapor diffusion, small amounts of moisture in the form of water vapor passing directly through a building's envelope

Dew Point vs. Humidity

Dew point is the temperature the air needs to be cooled to in order to achieve a relative humidity (RH) of 100%. At this point the air cannot hold more water in the gas form. If the air were to be cooled even more, water vapor would have to come out of the air in the liquid form.

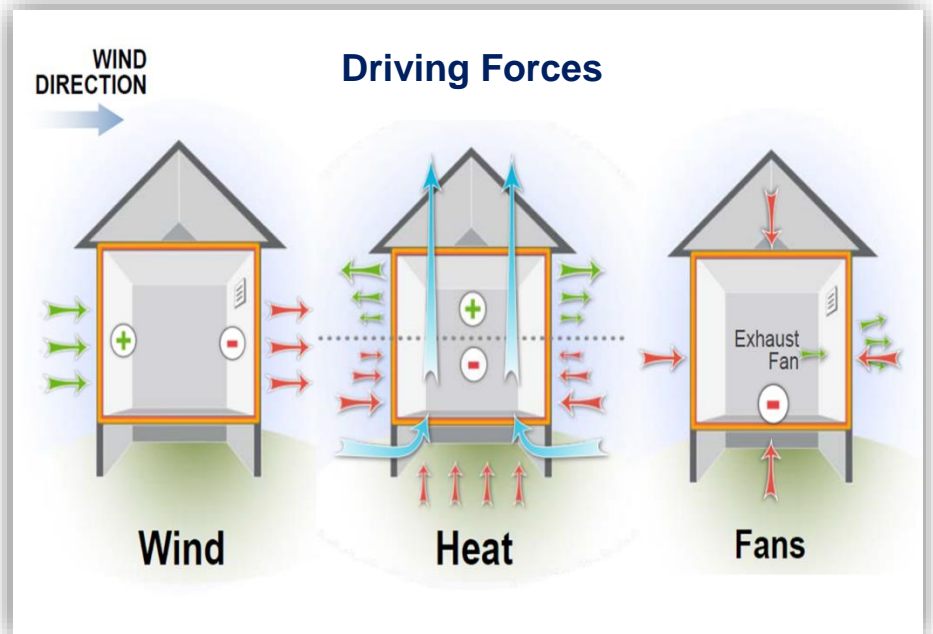


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Notes:

Basics of air flow

- Airflow is measured in cubic feet per minute (CFM), also written as ft^3/min . A cubic foot is a little larger than a basketball.
- 1 CFM out = 1 CFM in – The same volume of air that leaks out of a home also leaks into the home, often at a different location.
- Airflow takes the path of least resistance – Air leakage leads to moisture issues when warm, relatively moist air leaks into colder areas and condenses on building surfaces.
- Air moves from high- to low-pressure areas.
- Air moves from high- to low-temperature areas.

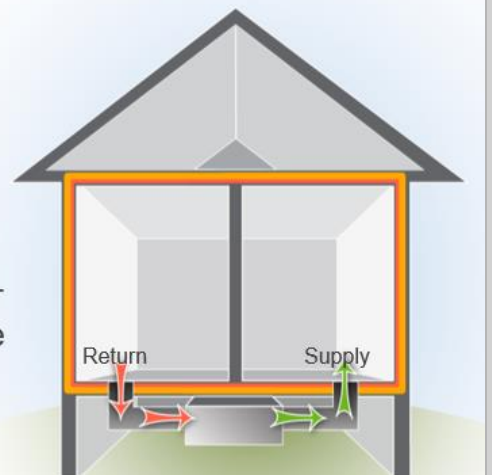


Duct Leakage

Duct leakage can create positive and negative pressures in different areas of the house

The pressures associated with duct leaks can be larger and more important because the driving force is stronger.

All holes are not created equal!



House as a System

A house is a system of interdependent parts.

- The operation of one part affects many others.
- When they all work together, the house is comfortable, safe, efficient, and durable.

A house can experience problems when its parts don't work together properly.

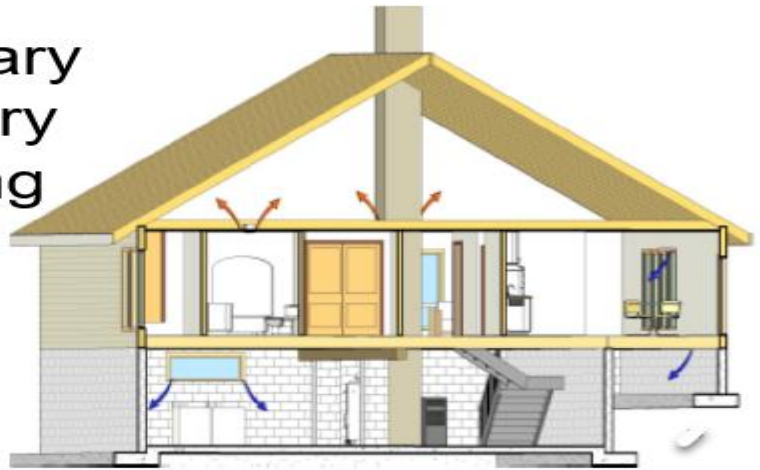
- Some obvious, some invisible.
- Some now, some years later.

A comfortable, safe, and energy-efficient home requires:

- A fully insulated thermal envelope.
- A well-sealed air barrier.
- The thermal and air boundaries to be continuous and in contact with one another.
- Efficient, properly sized equipment to condition the living space and heat water.
- A well-designed and balanced distribution system.
- Healthy indoor air quality.

Houses are made up of multiple systems:

- Pressure Boundary
- Thermal Boundary
- Heating & Cooling
- Ventilation
- Appliances
- Homeowners
- Mother Nature

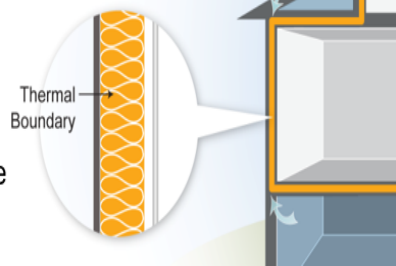


Notes: _____

For maximum efficiency and comfort, the thermal and air barriers must be continuous and in contact with each other

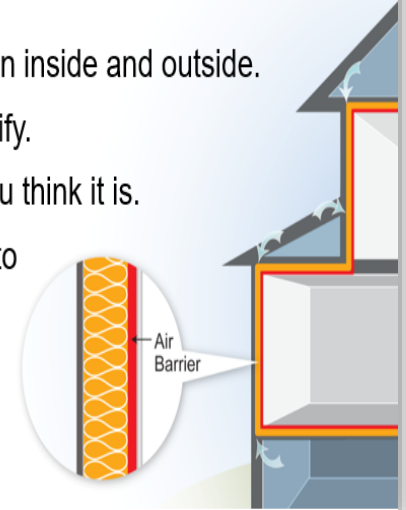
The Thermal Boundary:

- Limits heat flow between inside and outside.
- Easy to identify by presence of insulation.
- The location of insulation in relation to other building components is critical to its effectiveness.
- Even small areas of missing insulation are very important.
- Voids of 7% can reduce effective R-value by almost 50%.



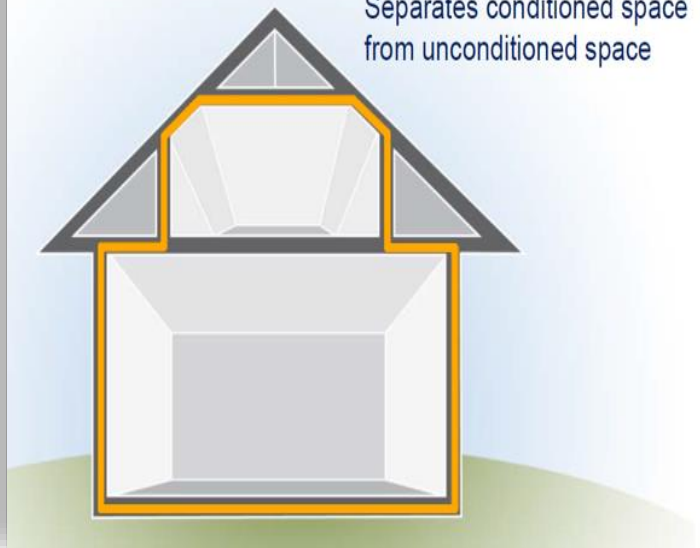
The Air Barrier:

- Limits airflow between inside and outside.
- More difficult to identify.
- Not always where you think it is.
- Blower door is used to locate air barrier.

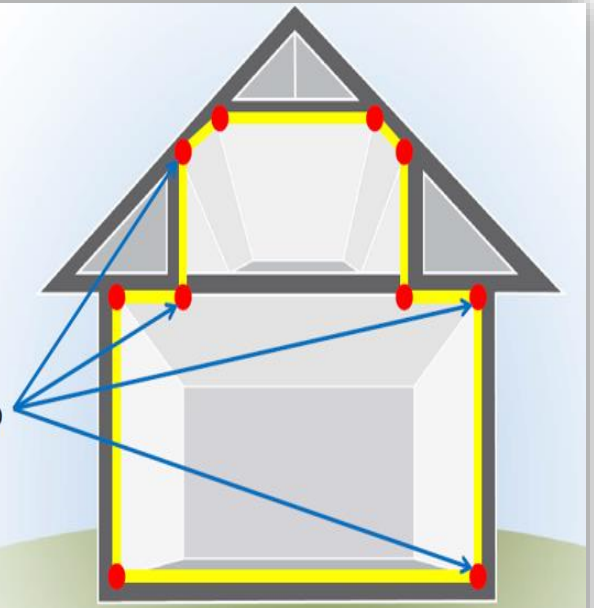


Envelope

Separates conditioned space from unconditioned space



Be sure to address critical junction areas.



Notes:

Blower Door and Diagnostic Basics Key Points



BLOWER DOOR TESTING

- Blower door testing is used to locate air leakage by using a fan to depressurize a house.
- Air leakage measured by the blower door is related to the size of the holes in the homes pressure boundary
- Blower door testing is done before and after air sealing to determine the effectiveness of our work.
- Blower door testing gives us an idea of potential for energy savings through air sealing.

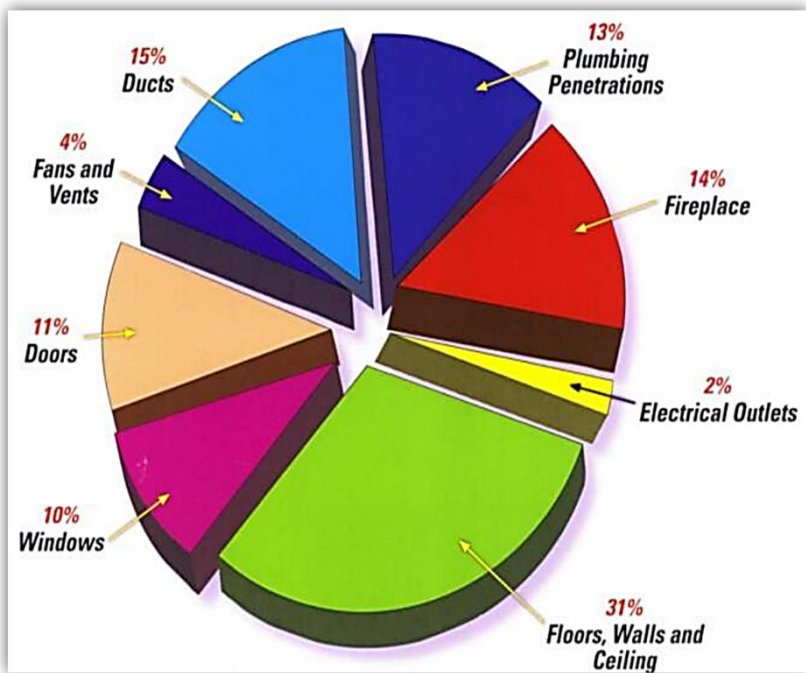
UNITS FOR MEASURING AIRFLOW

Cubic feet per minute (CFM)

- Rate of airflow
- Based on the size of a house and the number of occupants, a house should have a certain amount of fresh air when in winter mode.

CFM₅₀ (standard for blower door)

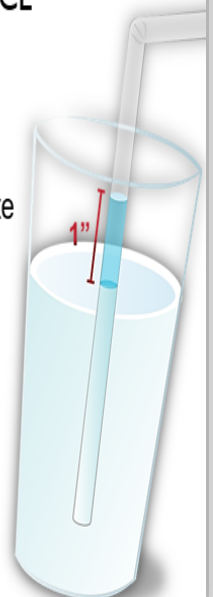
- Blower door measures the rate of airflow in CFM when the pressure difference between the inside of the house with reference to outside is -50 Pascals.



MEASURING PRESSURE DIFFERENCE

Pascal (metric standard)

- 1 Pascal = weight of one Post-It note
- 249 Pascals = 1 in. water column (American standard)
- 1 in. water column = pressure required to suck ½ in. of water up a straw





BLOWER DOOR SETUP

- Set up blower door in an exterior door.
- Put house in winter mode
- Turn off heating/cooling system and gas water heaters.
- Close fireplace dampers.
- Make sure no wood stoves are in use!
- Remove ashes or cover with wet newspaper.

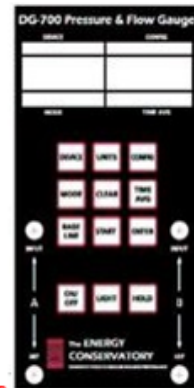
Blower door setup

Blower Door Depressurization Test

- 1) Mode to PR/FL @50PA
- 2) Device to BD 3 (default setting)
- 3) Configure to ring setting as needed
- 4) Baseline

(hit Baseline then start wait 10 seconds hit enter)

Left REF outside



Right INPUT to fan

- With fan cover on, press baseline button, press start button (let baseline settle 10 sec minimum), press enter button (ADJ will appear on channel A under the pressure measurement)
- Once you are comfortable with the reading (nothing within the pressure boundary has changed since setup) Record the reading or save to list if using WIFI adaptor

NOTES: _____

Using a Pressure Pan To Diagnose Duct Leakage



- A pressure pan is a duct leakage diagnostic tool used along with a Blower Door to identify exterior air leaks in forced air duct systems.
- Pressure pans do not directly measure leakage rates, they measure the pressure difference between the house and a duct run during a Blower Door test.
- This pressure reading can be used to estimate the degree to which a duct run is connected to the outside.
- Pressure pan testing involves placing a gasketed pan over each register one at a time, with the air handler fan off.
- The pattern of pressure pan readings allows for quick identification of major leakage sites.
- Pressure pan readings can also be used as a quality control tool to tell technicians if they have done a good job of air sealing the duct system.

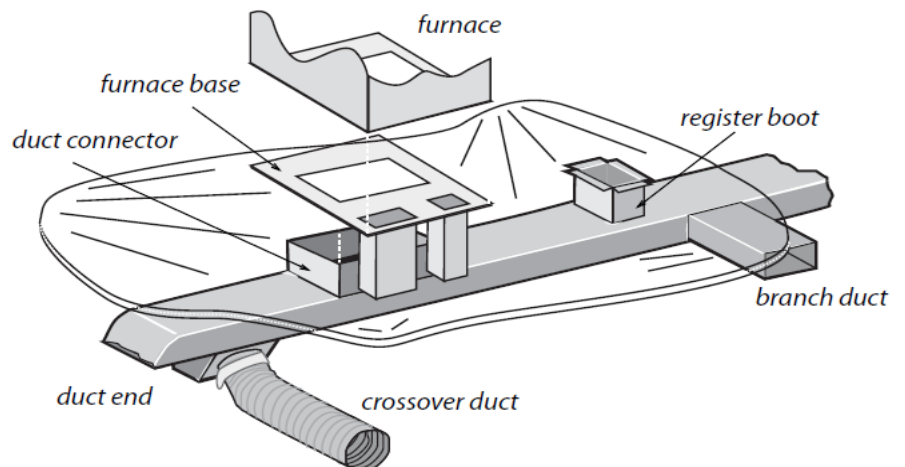
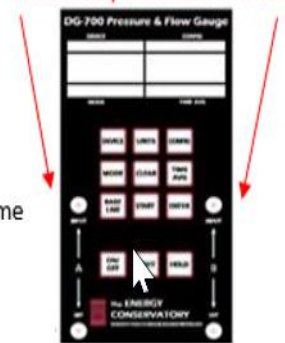
Pressure pan

- 1) Mode to PR/PR on a second DG700
- 2) With blower door @50PA
- 3) Pan can be used over registers, can lights, outlets, anything that way be communicating with outside
- 4) Zonal pressure testing is same without pan and to isolated areas of home

with hose to that's room/area

0 - 10 Pa Inside
11 - 39 Pa Confused
40 - 50 Pa Outside

Hose to input on either side



Mobile home ducts: Mobile home ducts leak at their ends and joints — especially at the joints beneath the furnace. The furnace base attaches the furnace to the duct connector. Leaks occur where the duct connector meets the main duct and where it meets the furnace. Branch ducts are rare, but easy to find, because their supply register isn't in line with the others. Crossover ducts are found only in double-wide and triple-wide homes.

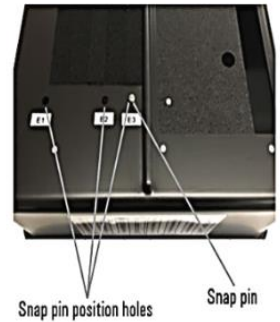
Exhaust Fan Flow Meter™

- The Energy Conservatory's Exhaust Fan Flow Meter is designed to make accurate measurements of air flow through exhaust fans.
- The air flow measurement range for the Exhaust Fan Flow Meter is 10 to 124 CFM with an accuracy of the exhaust fan flow measurement is +/- 10%.
- During the measurement procedure, the Exhaust Fan Flow Meter is placed tightly over the exhaust fan
- The pressure reading is converted to air flow in CFM using a flow table attached to the side of the Metering Box.
- The manometer can also be set up to display air flow readings directly in CFM.
- The Exhaust Fan Flow Meter has 3 calibrated openings to provide an accurate measurement of most exhaust fans.

Set the door position on the metering box

The metering box comes with an adjustable opening which provides three ranges of fan flow measurement.

The door position is determined by the position of the snap pin located on the top of the metering box. The door position can be adjusted by pushing down on the snap pin and sliding the door until the snap pin is in a new position hole.

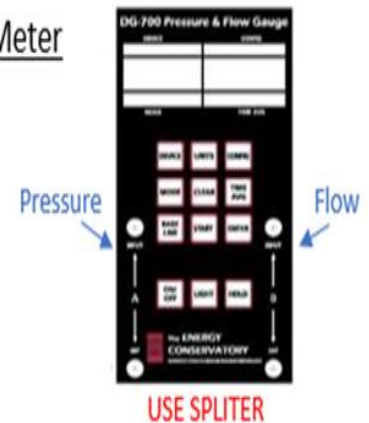


Door Position	Flow Range in CFM
E1	44 - 124
E2	21 - 59
E3	10 - 28

Door Position	CONFIG Icon on DG-700
E1	A1
E2	B2
E3	C3

- 1) Mode to PR/FL
 - 2) Device to EXH
 - 3) Configure to match slide gate setting
 - 4) Put meter up to fan read measurement in CFM
- Cross-reference pressure to chart on flow meter

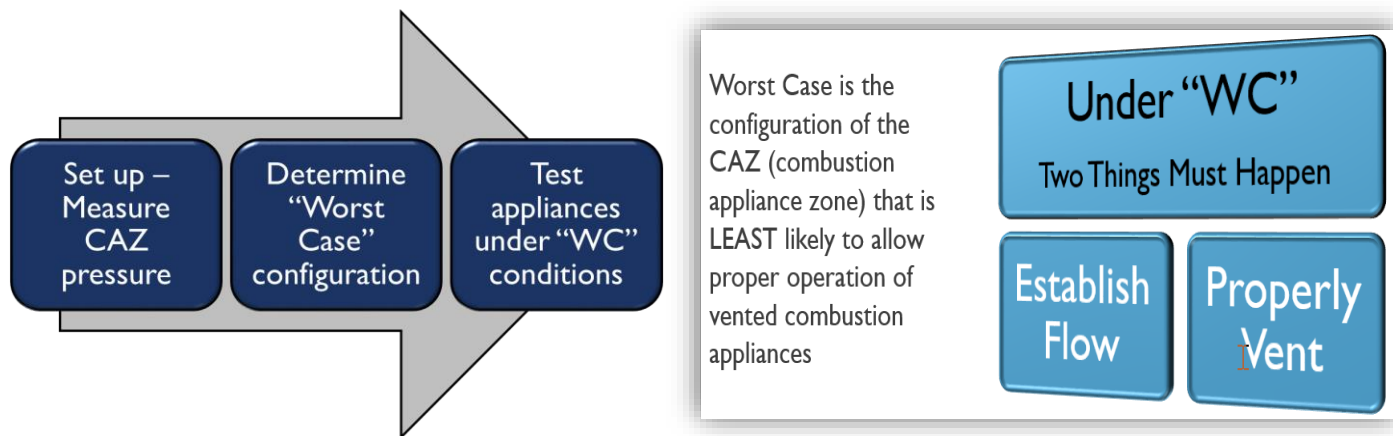
Flow Meter



Notes:

CAZ = Combustion Appliance Zone

- Open combustion heating equipment has the potential to allow Carbon Monoxide and other poisonous combustion by-products into your indoor environment
- A combustion appliance zone test is a method of determining whether this could happen under certain "worst case" or natural conditions,
- A combustion appliance zone test should always be performed when air sealing is done on a home
- We perform CAZ testing in our everyday building performance operations to ensure safety.



CAZ Testing

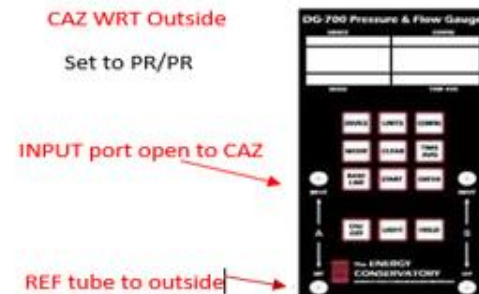
Set up home for CAZ Testing

- ✓ Make sure combustion appliances cannot operate during set-up
- ✓ Remove forced air furnace filter (replace cover)
- ✓ Close all windows, doors and other openings to the exterior of the structure
- ✓ Close fireplace and woodstove dampers

Set up manometer tubing

- Setup gauge to PR/PR
- On channel A
- Input port open to CAZ
- Reference port hose to outside

CAZ Depressurization test



NOTES: _____

There are many variables in testing

When done correctly, these 4 pressure measurements taken from the CAZ WRT outside considers all possible cause scenarios

CAZ Door

Open Closed



■ **Fan Off:** _____ Pa _____ Pa

■ **Fan On:** _____ Pa _____ Pa

What do the numbers mean?

Air Handler	<u>CAZ Door</u>	
	Open	Closed
Off	<ul style="list-style-type: none"> • Exhaust fans 	<ul style="list-style-type: none"> • Exhaust fan either in the CAZ or affecting the CAZ
On	<p><i>Negative number:</i></p> <ul style="list-style-type: none"> • Supply duct leakage to the outside • Interior door closure <p><i>Positive number:</i></p> <ul style="list-style-type: none"> • Return duct leakage to the outside • Interior door closure 	<p><i>Negative number:</i></p> <ul style="list-style-type: none"> • Return duct leak in the CAZ <p><i>Positive number:</i></p> <ul style="list-style-type: none"> • Supply duct leak in the CAZ

Baseline is present in each quadrant – neg or pos

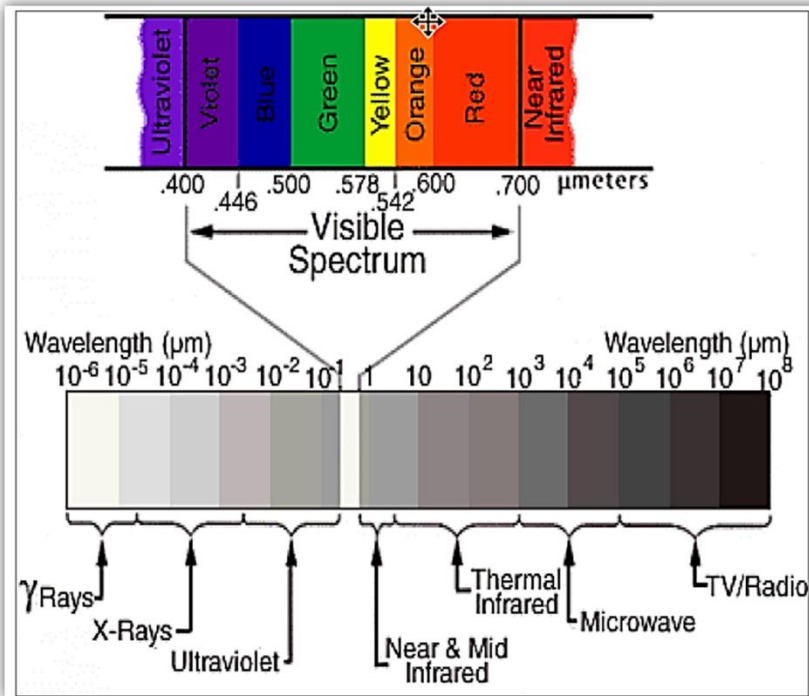
Infrared Thermography Key Points



What is an infrared camera?

- IR cameras are non-contact devices that detect infrared energy and then quantify an image, also known as a thermographic camera
- IR cameras use wavelengths longer than visible light to create images even in total darkness
- IR cameras work by detecting the amount of radiation being emitted from an object based on its temperature.
- Standard IR cameras show image intensity based on the color spectrum

Warmer temperature = Intense/brighter
Cooler temperature = dull/darker



Kirchhoff's Law: E+T+R=1

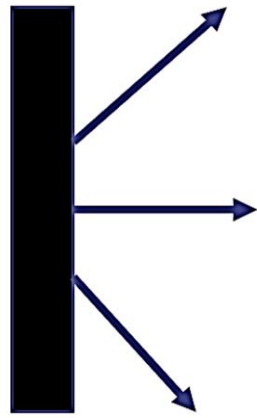
Emitted Energy + Transmitted Energy + Reflected Energy = 1

(in most cases E+R=1)

Good Emitter = Poor Reflector
 Good Reflector = Poor Emitter

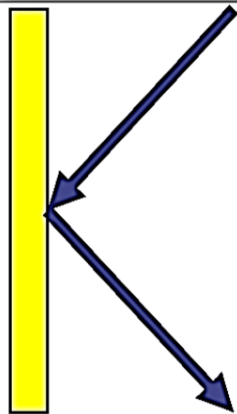


Notes: _____



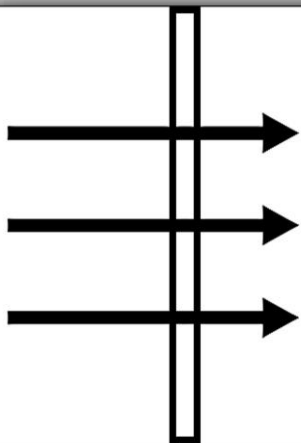
Emittance

- A perfect emitter is referred to as a Black body and $E = 1$.
- All bodies in nature are *colored bodies* and have an $E < 1$.
- Human skin is .98
- A good emitter is a good absorber of energy.



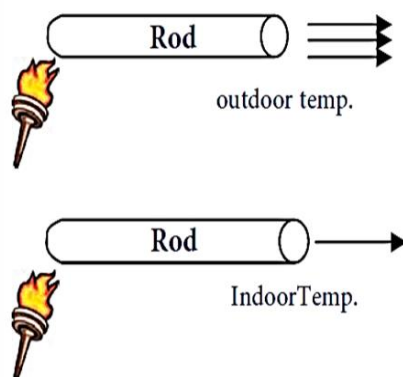
Reflectance

- The amount of light reflected from an object.
- Aluminum tape $R = .98$ $E = .02$
- A first surface mirror is a good reflector.



Transmittance

- The heat transmitted through an object to the camera.
- Thin plastics are transmissive.
- Opaque objects will not transmit energy. (Ex. metals, woods, concrete)



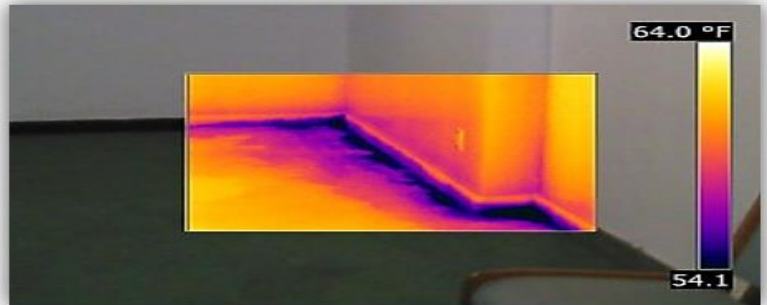
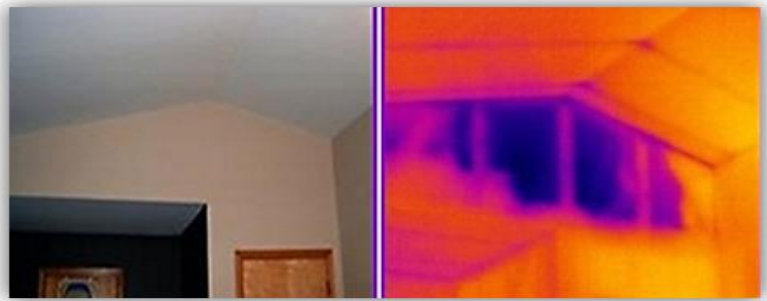
Delta T

- Difference in temperature.
- Increasing temperature differences will increase heat transfer rates.
- The bigger the delta T, the more heat is being transferred.

Infrared Capability

IR cannot see through anything.

- Sees surface temperatures only
- Cannot see color
- Cannot see air

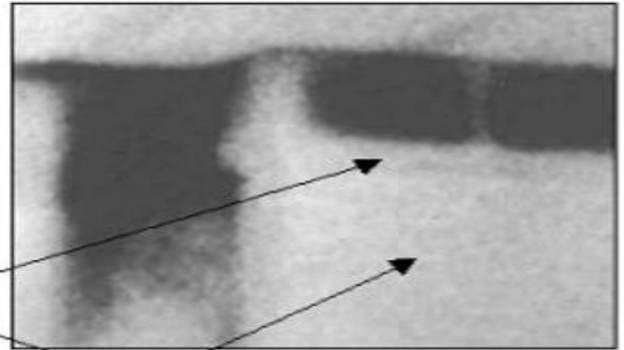
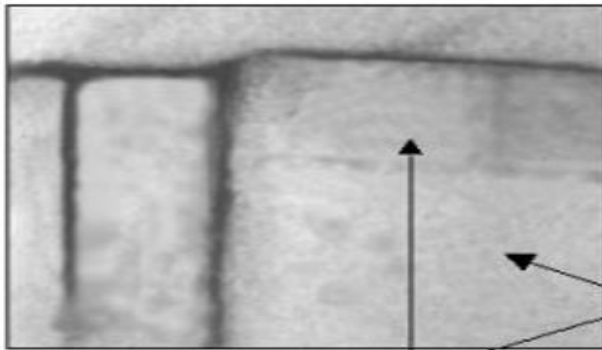


Air Leakage Path investigation

- Blower Door with an Infrared Camera
- View wall before Blower Door Test
- View wall with Blower Door running

Without Blower Door

With Blower Door Running



Kitchen Soffit

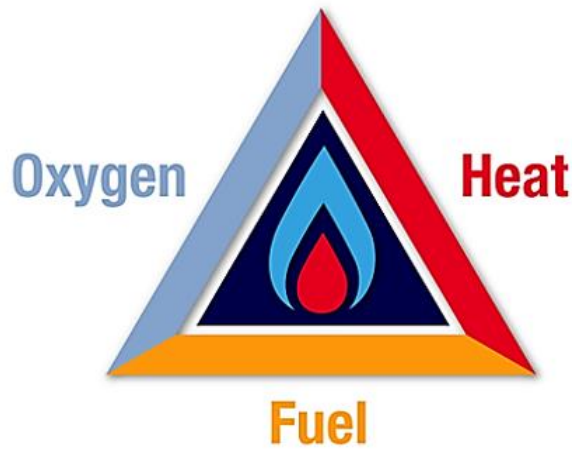
Cabinets

Notes: _____

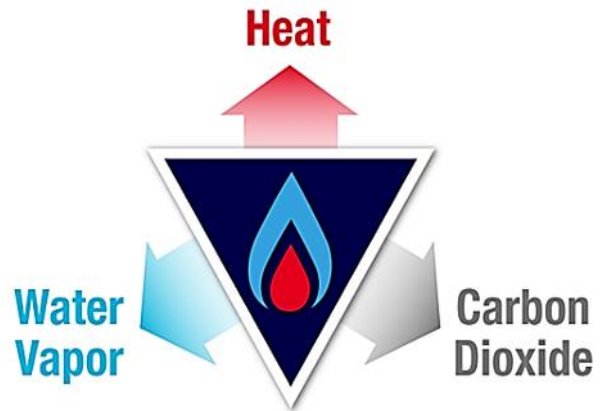
Mechanical and Ventilation System Basics Key Points



Requirements for Combustion:

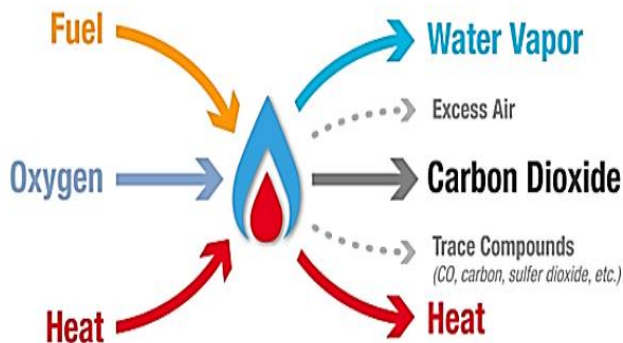


Complete Combustion Results in:



Complete Combustion Occurs...

When all the fuel is burned with enough oxygen to produce carbon dioxide and water vapor.



Notes: _____

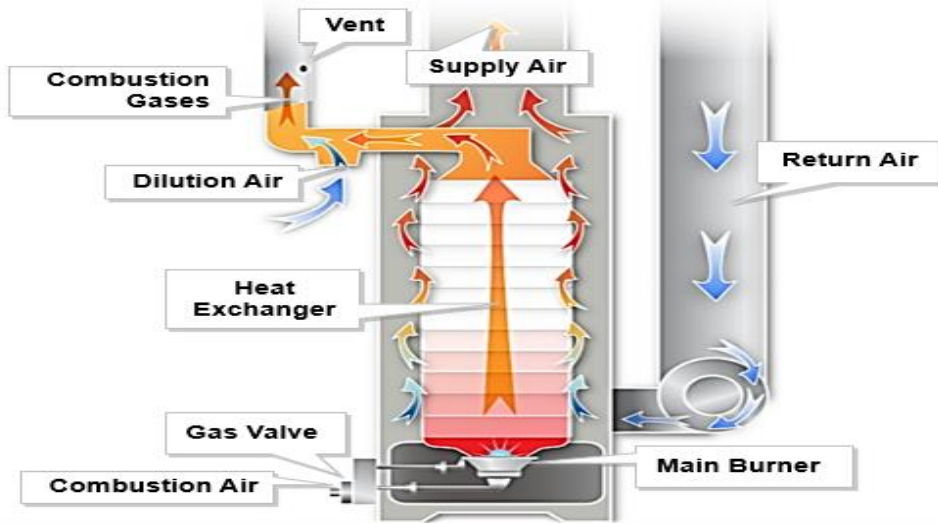
CO OCCURS WHEN:

- The ratio of fuel to oxygen is either too high to permit the complete formation of CO₂ or...
- The temperature is too low to permit complete burning to occur.

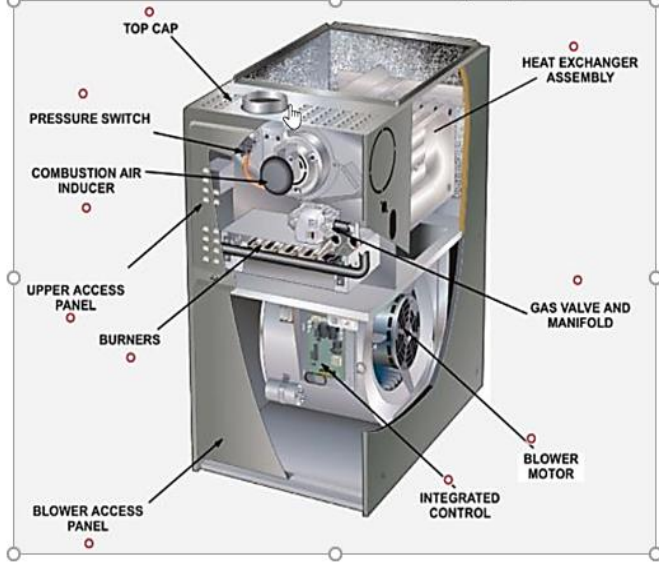
IT IS CAUSED BY:

- Too much fuel for the amount of oxygen.
- Not enough oxygen for the amount of fuel.
- Not enough heat (flame impingement).

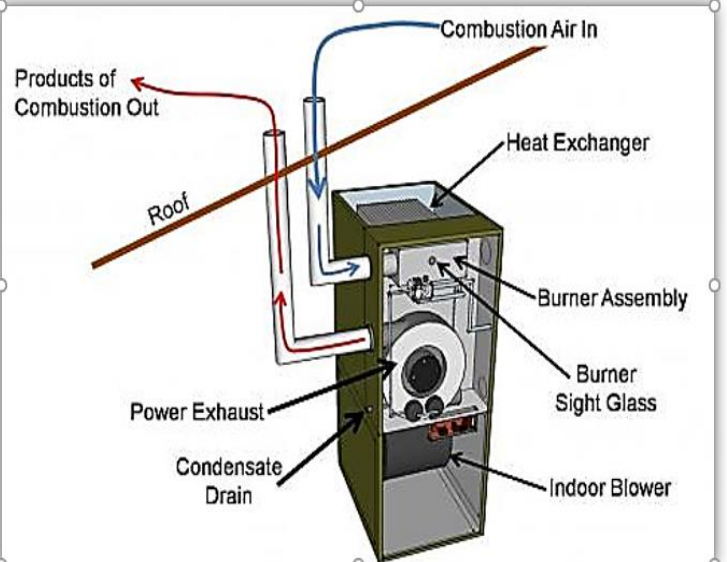
Natural draft forced air heating system 70%



Draft inducer forced air heating system 80%



Sealed combustion forced air heating system 90%+

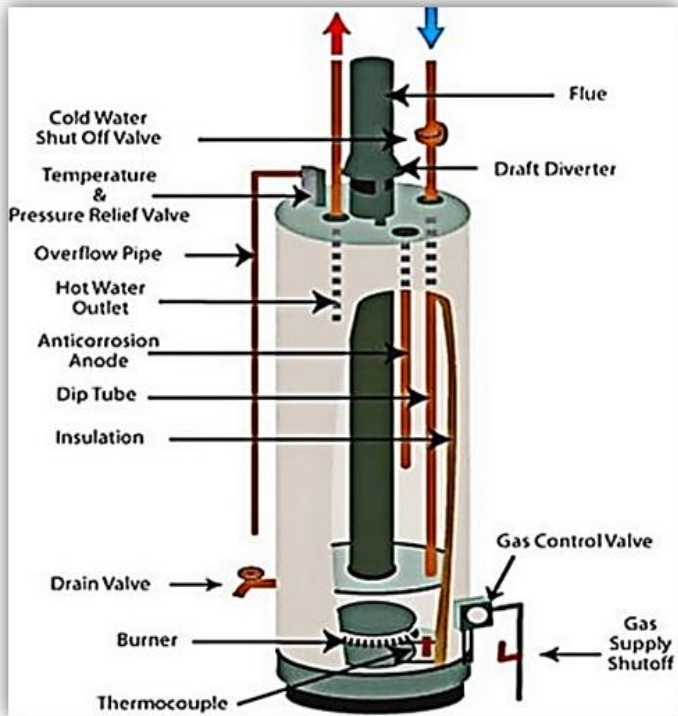


Furnace concerns:

- Fuel leaks
- Vent pipes
- Wiring
- Heat exchanger
- Distribution systems
- Combustion air



Gas-fired domestic hot water tank



Electric domestic hot water tank



DHW concerns:

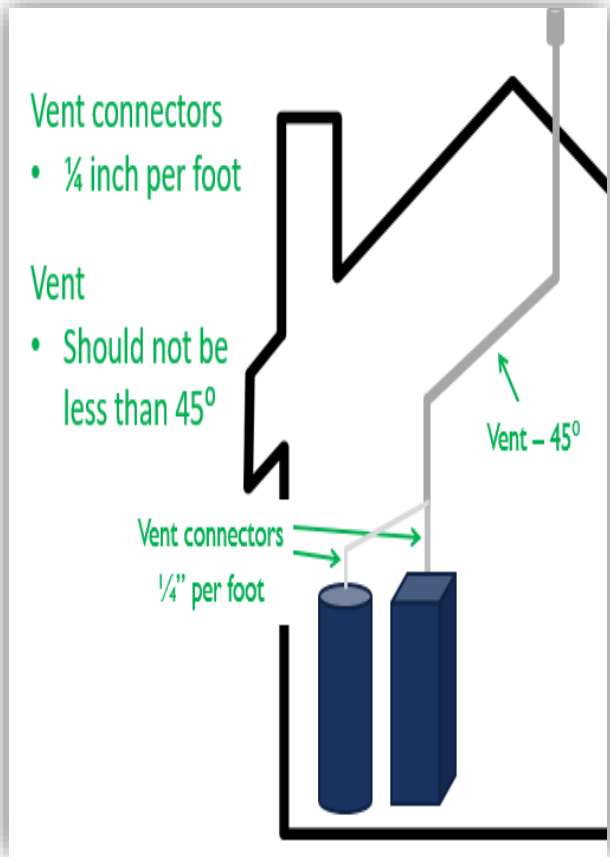
- Fuel leaks
- Vent pipes
- Wiring
- Flame quality
- Combustion air
- Water leaks
- P&T discharge line



Notes: _____

Chimneys and vents should:

- Be connected and unblocked.
- Not have holes in the chimney or vent.
- Have a sound liner.
- Rise no less than 1/4" per linear foot in the direction of the outlet.
- Be the appropriate type and size for the combustion appliances.
- Be at least the same diameter as the exhaust port of the combustion appliance.



Vent pipe driving forces

Temperature

- (ΔT) The difference in temperature between the flue products and outside

Height

- (ΔP) The difference in pressure between the bottom and the top of the vent



Notes: _____



ANSI/ASHRAE Standard 62.2

The purpose of this standard is to define “...the roles of and minimum requirements for mechanical and natural ventilation systems in the building envelope intended to provide acceptable indoor air quality (IAQ) in residential buildings.”

ASHRAE 62.2 refers to two types of ventilation systems:

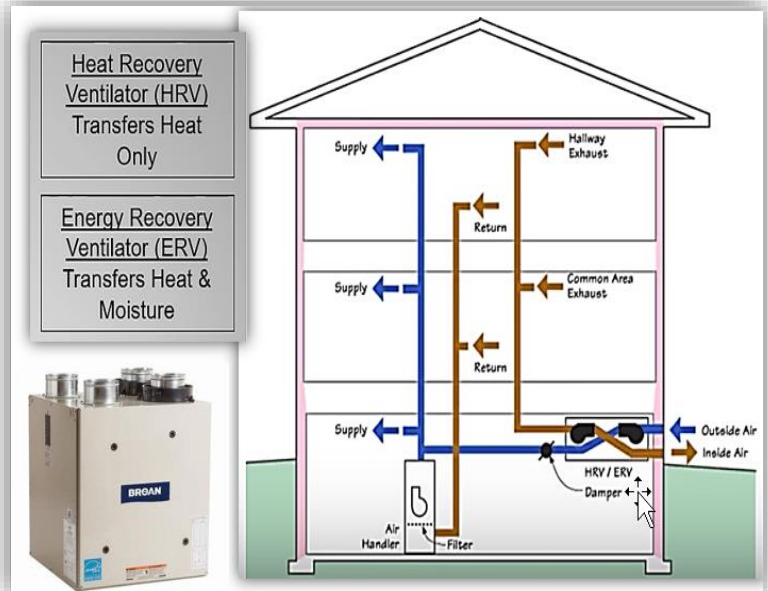
natural ventilation: ventilation occurring as a result of only natural forces, such as wind pressure or differences in air density, through intentional openings such as open windows and doors.

mechanical ventilation: the active process of supplying air to or removing air from an indoor space by powered equipment such as motor-driven fans and blowers but not by devices such as wind-driven turbine ventilators and mechanically operated

ASHRAE general requirements:

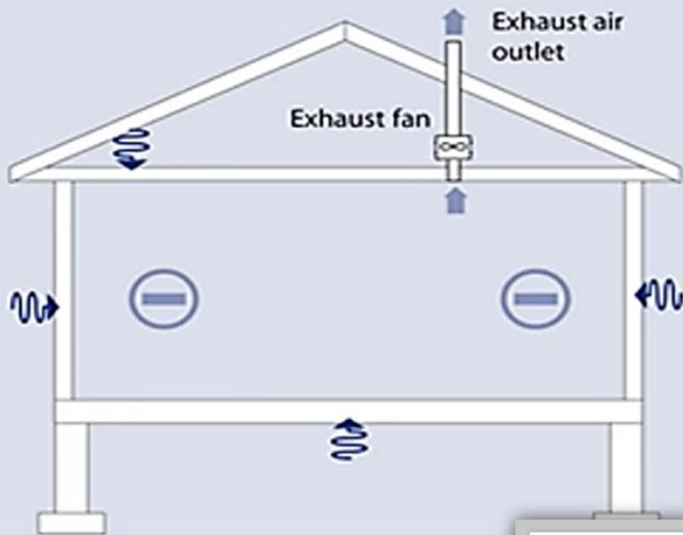
System designs:

- Can be an exhaust system, supply system, or a combination of both (balanced)
- Must be designed for automatic operation
- Can run continuously or intermittently, as long as it provides (on-average) the calculated air exchange rate



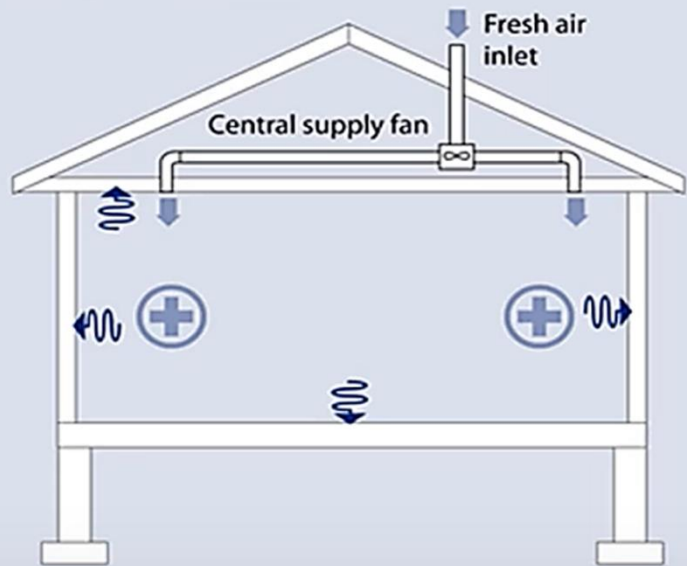
Notes: _____

Exhaust Ventilation



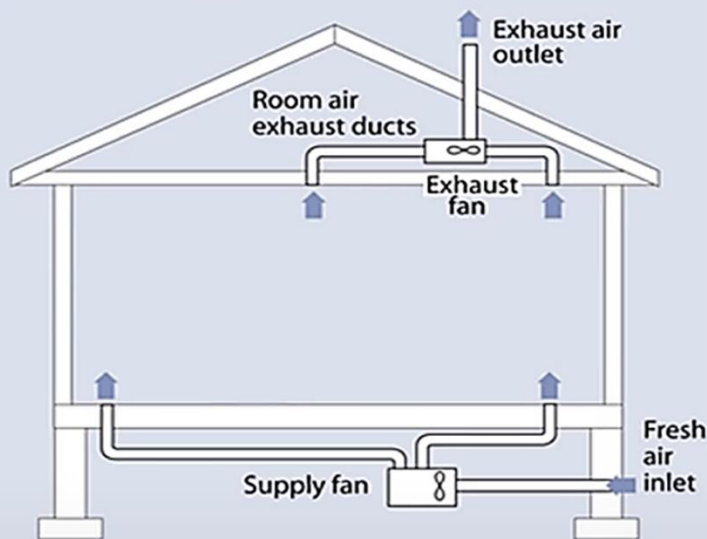
Most common

Supply Ventilation



Cooler climate issues

Balanced Ventilation



Can be expensive

Baseloads, Energy Saving, and SIR Key Points



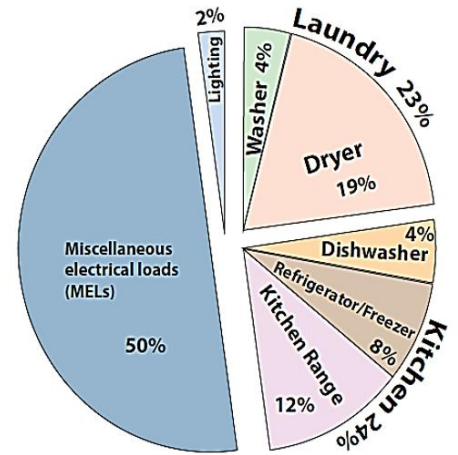
Base Load:

The energy used by electric or gas appliances in a home that is not energy used for space conditioning.

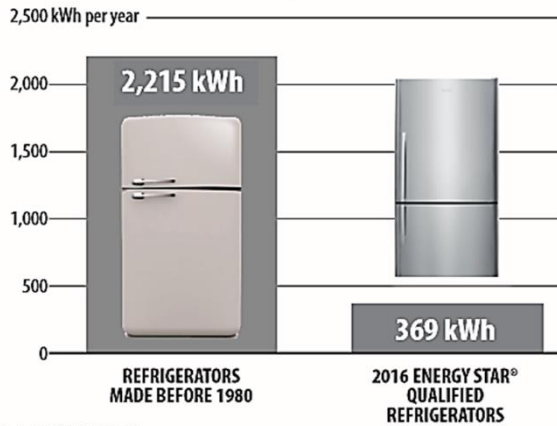
Typical Measures:

- Lighting retrofits.
- Refrigerator replacement.
- Water heater modification.
- Low-flow fixtures.

Baseload Energy Consumption: These baseload usage percents are, of course, different for every dwelling unit. However this chart gives an idea of a typical distribution. Miscellaneous electrical loads or MELs can be up to half of total baseload consumption.



Refrigerator Efficiency



Data: ENERGY STAR®

CLEAN REFRIGERATOR COIL

Even if replacement is not an option, some savings are possible.

	Average	High
Energy Savings	36 kWh/yr	200 kWh/yr
\$ Savings*	\$3.96/yr	\$22.00/yr
Frequency of coil cleaning	Once/year, 3% savings	Never been cleaned

* Savings based on \$0.11/kWh

WAP Refrigerator Replacement

- Will be cost cost-effective, Based on metering or recognized database
- Will be 40% more efficient than the minimum federal standards or be labeled ENERGY STAR.
- Refrigerators that are replaced go to a facility that is licensed to reclaim refrigerant and recycle the unit.
- No refrigerator, taken out of service, may be returned to service by sale, barter, or for free.

Notes: _____

Standby power

- Also called, **vampire draw**, **phantom load**, **ghost load** refers to the way electric power is consumed by electronic and electrical appliances while they are switched off or in standby mode
- This occurs because some devices claimed to be "switched off" on the electronic interface, but are in a different state from switching off at the plug, or disconnecting from the power point
- These devices draw power 24 hours a day, often without the knowledge of the consumer
- typically 5-10% of residential electricity use

Lighting

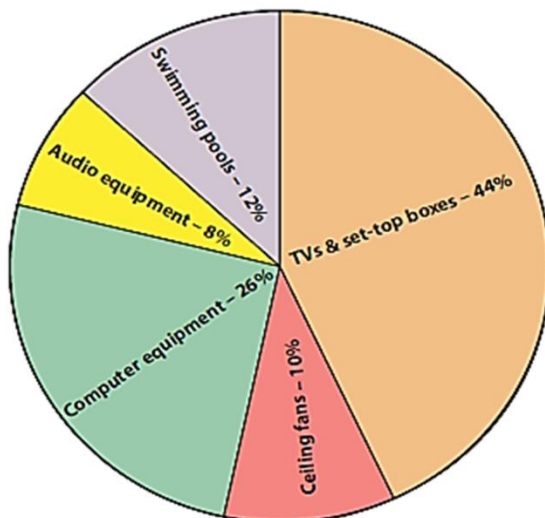
Some homes still use the traditional incandescent light bulbs invented by Thomas Edison. These bulbs convert only 10 percent of the electricity they use to produce light; the other 90 percent is converted into heat.

- Lighting can account for up to **5%** of total home energy use.
- LED retrofits, can cut that by **80%**.
- Overall energy reduction of **5%** for the home.



LED lighting is different than other light sources

- LED lighting differs from incandescent and fluorescent in several ways. When designed well, LED lighting is more efficient, versatile, and lasts longer
- LEDs are “directional” light sources, which means they emit light in a specific direction, unlike incandescent and CFL, which emit light and heat in all directions
- However, it also means that advanced engineering is needed to produce an LED light bulb that shines light in every direction
- Common LED colors include amber, red, green, and blue. To produce white light, different color LEDs are combined or covered with a material that converts the color of the light to a familiar “white” light used in homes



Miscellaneous Electrical Loads (MELs): MELs consume from 1000 to 3000 kWh per household, a huge increase over households 20 or even 10 years ago. The explanation is more TVs with set-top boxes, computers, and electronic entertainment.

Notes: _____

WATER-HEATING ENERGY SAVINGS

The most important tasks in evaluating hot water energy savings are determining the water heater's insulation level, measuring the shower's flow rate, and measuring the water temperature.



INSTALLATION CAN ALSO CAUSE



Some manufacturers set water heater thermostats at 140°F, most households usually only require them to be set at 120°F, which also slows mineral buildup and corrosion in your water heater and pipes. Water heated at 140°F also poses a safety hazard—scalding.

insulating hot water heaters is an easy and inexpensive way to improve energy efficiency

- reduces standby heat losses by 25%–45%
- saves about 7%–16% in water heating costs

- *Make connections in the direction of exhaust flow*

Number of Residents	Annual kWh	Annual Therms	Gallons Per Day
1	2700	180	25
2	3500	230	40
3	4900	320	50
4	5400	350	65
5	6300	410	75
6	7000	750	85

Notes: _____

Water Conservation Devices

Our clients use water in their homes at several outputs.

- Showers
- Kitchen sink
- Bathroom faucets
- Toilets

Each of these points of water use has opportunities for water conservation.

Showers

Low flow shower heads reduce water consumption from as much as 4.0 GPM to as little as 1.5 GPM. The Evolve Shower head is not only low flow, it has a hot water shut off mechanism where a homeowner can leave the hot water running in a shower and once the water becomes hot, the shower head will automatically close shut until the valve is released ready for use.

Kitchen sink and Bathroom faucets

Low flow aerators reduce kitchen sink water consumption from 2.0 - 3.0 GPM to 1.5 GPM. Low flow aerators can be installed in bathroom faucets to reduce flow to as low as 1.0 GPM.

Toilets

Dual flush toilets reduce the amount of water per use from 3.0 gallons per flush to 1.0 gallons per flush. Although weatherization generally does not replace toilets, there are other options that go along with client education.

Notes: _____



SAVINGS TO INVESTMENT RATIO (SIR)

A calculation that determines a ratio or cost effectiveness of a weatherization measure

Actual SIR calculations supported by NEAT, MHEA, and other approved audit tools account for the Present Value (PV) of money and fuel escalation rates over the lifetime of the measures to arrive at more accurate savings numbers.

SIRs of greater than one are considered cost effective according to DOE WAP.

The highest SIRs are at the top of the modeling software list for a particular home.

Payback and SIR

Payback is simply the number of years it takes for the energy savings from an improvement to equal the upfront cost

$$\text{Cost} \div \text{Savings} = \text{Payback (in years)}$$

$$\text{Savings} \times \text{Life} \div \text{Cost} = \text{SIR}$$

Notes: _____

