Building Science for Energy Modeling and Field Inspection

FSEC Energy Research Center — A Research Institute at the University of Central Florida

UCF

Residential Energy Modeler Track Course Series

This course is part of the Residential Energy Modeler Track Course Series:

1. Building Geometry for Energy Modeling
2. Introduction to HERS and Building Modeling
3. **Building Science for Energy Modeling and Field Inspection** You are here
4. From Blueprints to Energy Code and Ratings
5. EnergyGauge Hands-On Pro

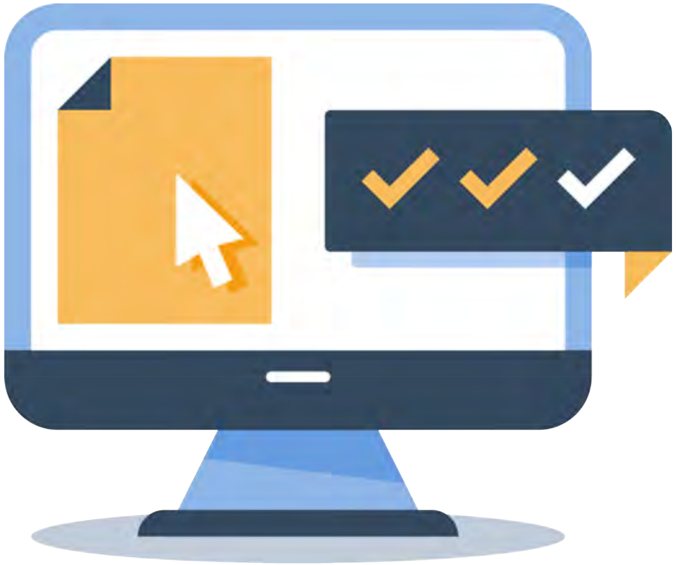
After taking these five online courses, pass the online Energy Modeling test to become an FSEC certified Energy Modeler. You can then go on to become a Residential Energy Auditor and certified HERS Energy Rater.

What This Training Course Covers

This course provides the basics of building science to better understand how to model homes for their energy use. It includes many of the terms and parameters used to characterize the efficiency of buildings.

Lessons

- 1: Heat and Energy
- 2: Temperature and Heat
- 3: Heat Transfer
- 4: Thermal Envelopes Part I
- 5: Thermal Envelopes Part II
- 6: Windows
- 7: Inspecting Insulation
- 8: Moisture Movement
- 9: Uncontrolled Airflow



Lesson Quizzes and Exercises

- At the end of each lesson there will be one to five questions that you will need to answer correctly to continue to the next lesson. If you answer a question incorrectly, go back and review the lesson and answer the question again.
- Lessons include calculation exercises (have a calculator handy).
- After all lessons are completed there will be a final quiz for the course.

Heat and Energy

Heat and Energy

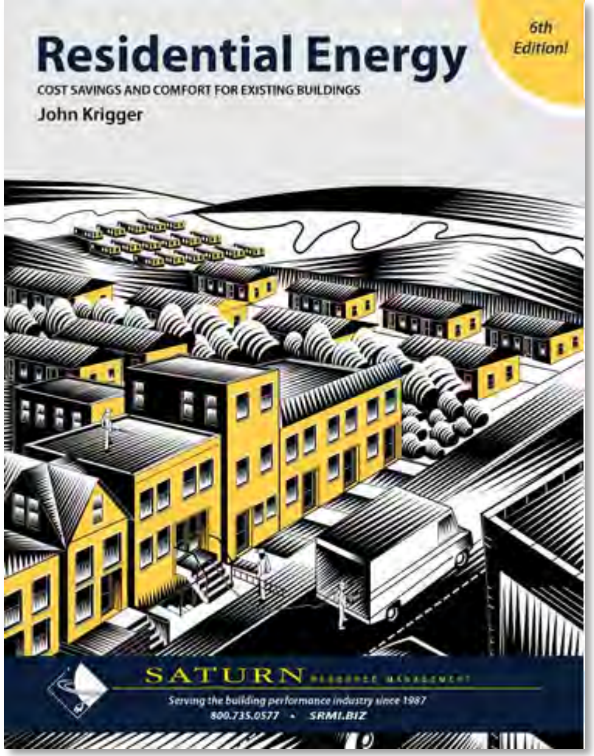
The Heat and Energy lesson will focus on understanding basic heat and energy concepts.

Residential Energy

A paid registration for this course includes a copy of the *Residential Energy* book by John Krigger; email info@fsec.ucf.edu to request your copy (provide the order number for this course and the address you would like the book shipped to).

Students should review *Residential Energy* to reinforce concepts presented in this course and learn valuable additional concepts.

Students who continue on to Home Energy Rater certification training should also familiarize themselves with the book's content and tab its chapters to help prepare for required open-book testing.



Basic Energy Principles

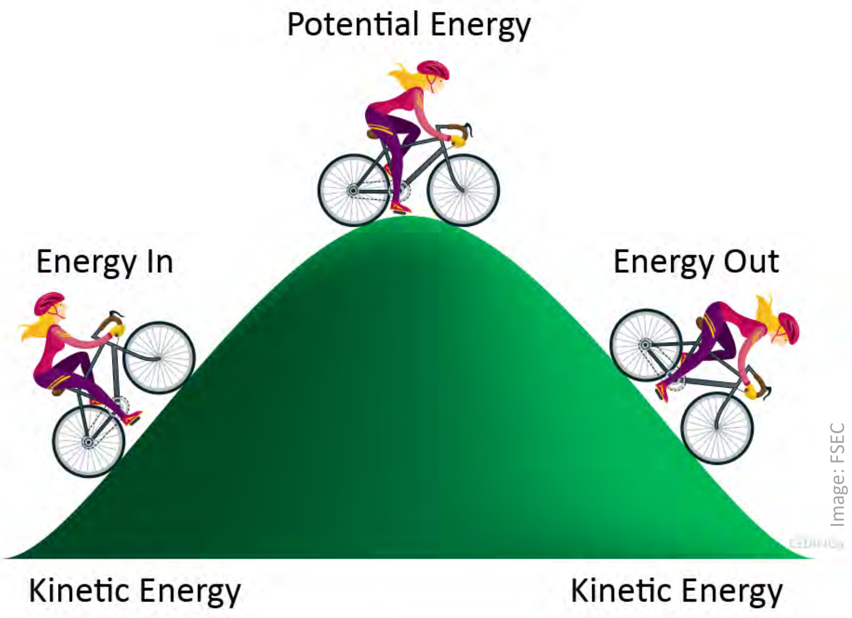
- **Two Laws of Thermodynamics…**
  - The **1st law** of thermodynamics is the conservation of energy, meaning that energy cannot be created nor destroyed; it instead moves from one place to another and changes form.
  - The **2nd law** of thermodynamics states that heat moves from areas of high temperature to areas of low temperature-- never the reverse unless additional energy from an external source is applied.

Derived from *Residential Energy* by J. Krigger and C. Dorsi

Energy

Energy is constant -- neither created nor destroyed

- Energy is the ability to do work
- Energy can change forms
  - **Potential energy is stored energy**
    - A gallon of gasoline
    - A storage battery
  - **Kinetic energy is energy in transition**
    - Burning gasoline
    - Spinning electric motor
  - Potential Energy may be converted into Kinetic Energy and vice versa



For more information: https://www.eia.gov/energyexplained/index.php?page=about_forms_of_energy

Energy Flows

Energy flows naturally from high to low (we'll discuss this more later in the course).

Air:

High air pressure
moves to
Low air pressure

Heat:

Hot
moves to
Cold

Moisture:

Wet
moves to
Dry

CEDU-05b

Image: FSEC

Energy and Power

It is important to understand the difference between energy and power:

- Energy, as previously noted, is the ability to do work
- Power is the rate at which work is performed, or energy divided by time
- One common unit for power applicable to buildings is watts (W) or wattage
- A watt-hour (Wh) is the energy equivalent of a watt operating for one hour.

Application: Light Bulbs

Image: FSEC

How much energy is used by a typical 9 W LED light bulb that is on for 4 hours?

$$9 \text{ W} \times 4 \text{ hours} = 36 \text{ Wh.}$$

We can also convert to the number of kilowatt-hours (kWh) used by dividing by 1,000:

$$36 \text{ Wh} \times \frac{1 \text{ kWh}}{1{,}000 \text{ Wh}} = 0.036 \text{ kWh}$$

Ohms Law and the Power Equation

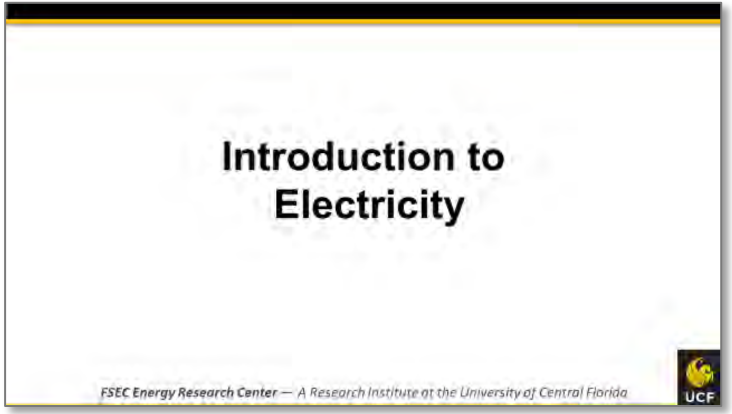
Electricity and electrical power are fundamental home energy use and efficiency concepts.

- Ohm's Law gives us an equation for the basic relationship between electrical voltage (V, units: volts), current (I, units: amps) and resistance (R, units ohms):

$$V = I \times R$$

- A related equation shows the basic relationship between electrical power (P, units: watts), current and voltage:

$$P = I \times V$$



For more information on electricity and electrical power, watch FSEC's *Introduction to Electricity* (click on image above to view in Vimeo).

Heat Energy

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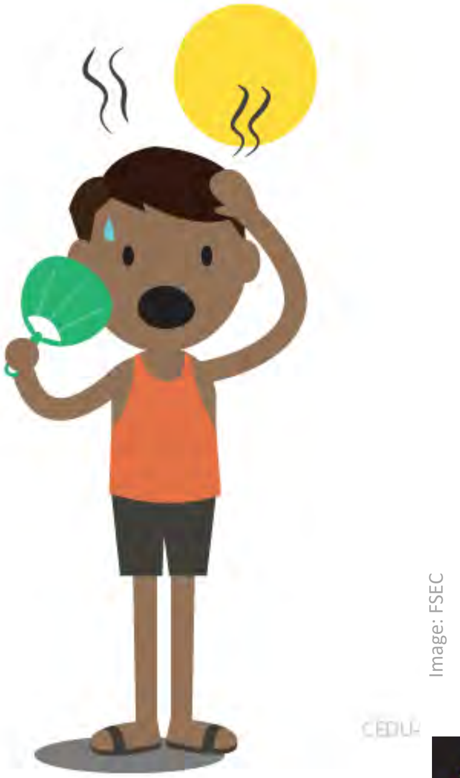
The capacity to increase the molecular activity of a substance increasing its temperature

Heat is a form of Energy

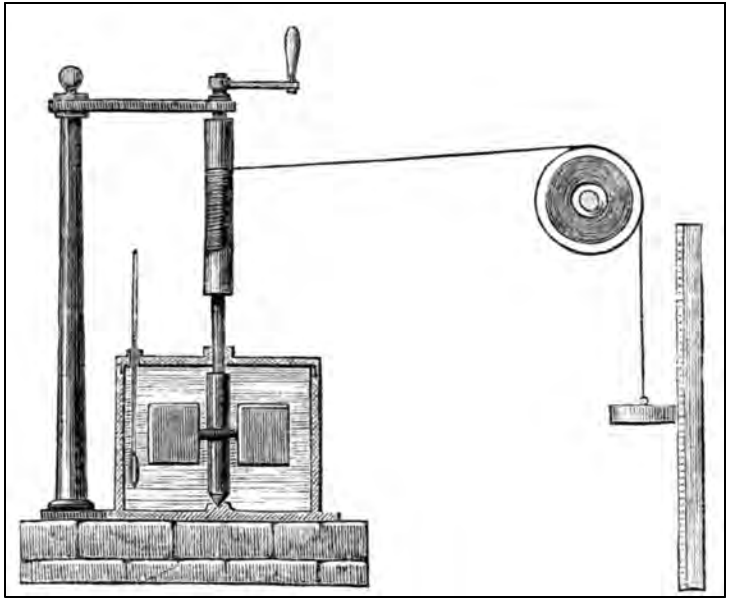
- Heat is created by conversion of other forms of energy:
  - Fuels through combustion
  - Movement and friction
- All objects contain thermal energy (heat)
- Heat energy is measured in the unit British Thermal Unit (Btu) or joule (J), other units for energy are:
  - calorie (cal)
  - foot-pound (ft-lb)



Heat and Mechanical Energy Equivalence

In experiments conducted in the mid-1800's, James Joule demonstrated the equivalence of heat and mechanical energy (work).

- The experiments involved stirring paddles immersed in an insulated water-filled vessel that were attached to a string and weight system that rotated the paddles
- The friction of the stirring paddles moving through the water raised the temperature of the water, demonstrating the relationship between mechanical energy and heat energy.



James Joule's heat and mechanical energy equivalence apparatus.

Btu Definition

1 Btu =

the quantity of heat required to raise the temperature of one pound of liquid water by 1 degree Fahrenheit at the temperature that water has its greatest density (approximately 39 degrees Fahrenheit).

Source: EIA

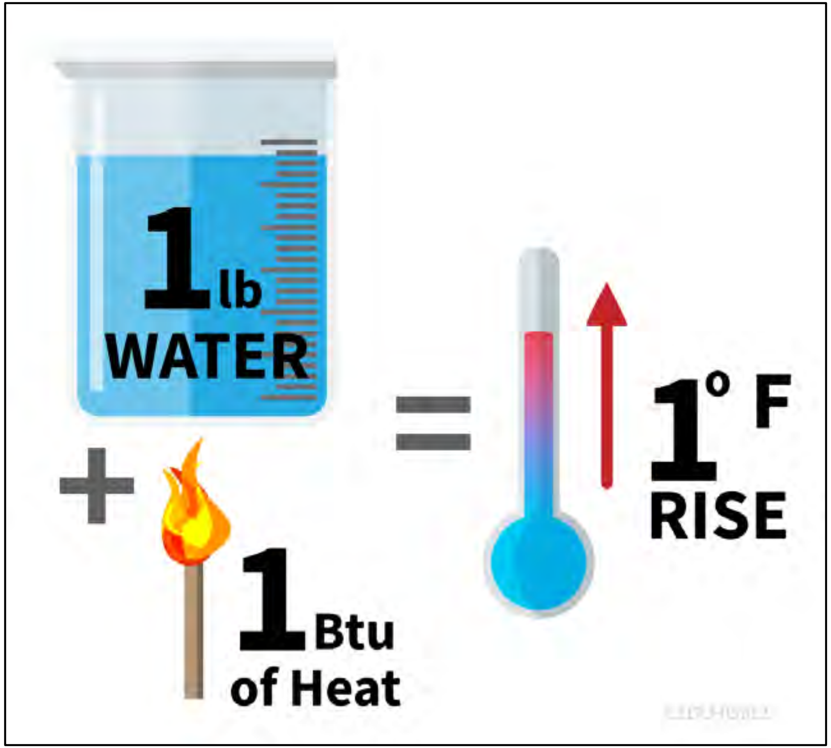


Image: FSEC

For more information: https://www.eia.gov/energyexplained/index.php?page=about_btu

So How Much Heat

- **Btus …**
  - 1 Btu ~ 1 blue-tip kitchen match
  - 1,000 Btus ~ average candy bar or 4/5th of a peanut butter and jelly sandwich
  - 2,000 Btus to make a pot of coffee.

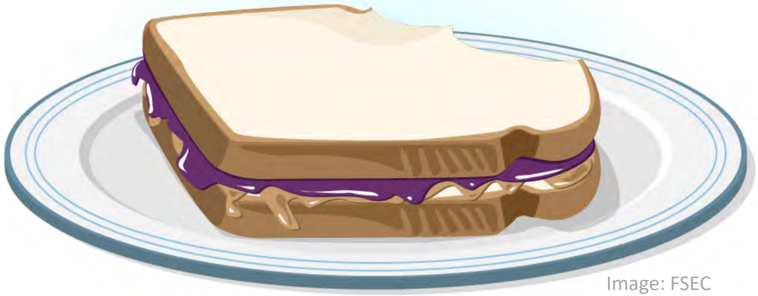


Image: FSEC

CEDU-05d

Energy also can be measured in joules (metric).

- Joules…
  - 1,000 joules = 1 Btu
  - 2 million joules to make a pot of coffee.

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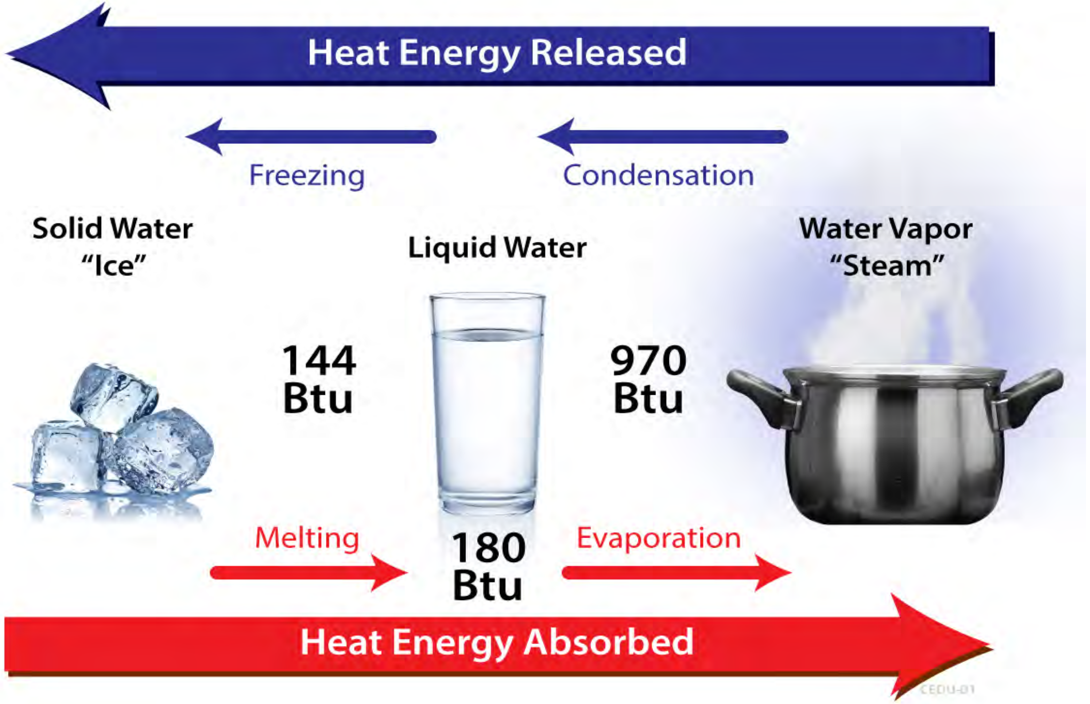
Btus per Pound of Water

It takes 144 Btu to melt a pound of ice at 32ºF (or 144 Btu is released when a pound of water at 32ºF freezes); it takes 180 Btu to raise the temperature of a pound of liquid water from 32ºF to 212ºF (or 180 Btu is released when a the temperature of a pound of liquid water decreases from 212ºF to 32ºF); and it takes 970 Btu to evaporate a pound of 212ºF liquid water (or 970 Btu is released when a pound of water vapor condenses to 212ºF liquid water).



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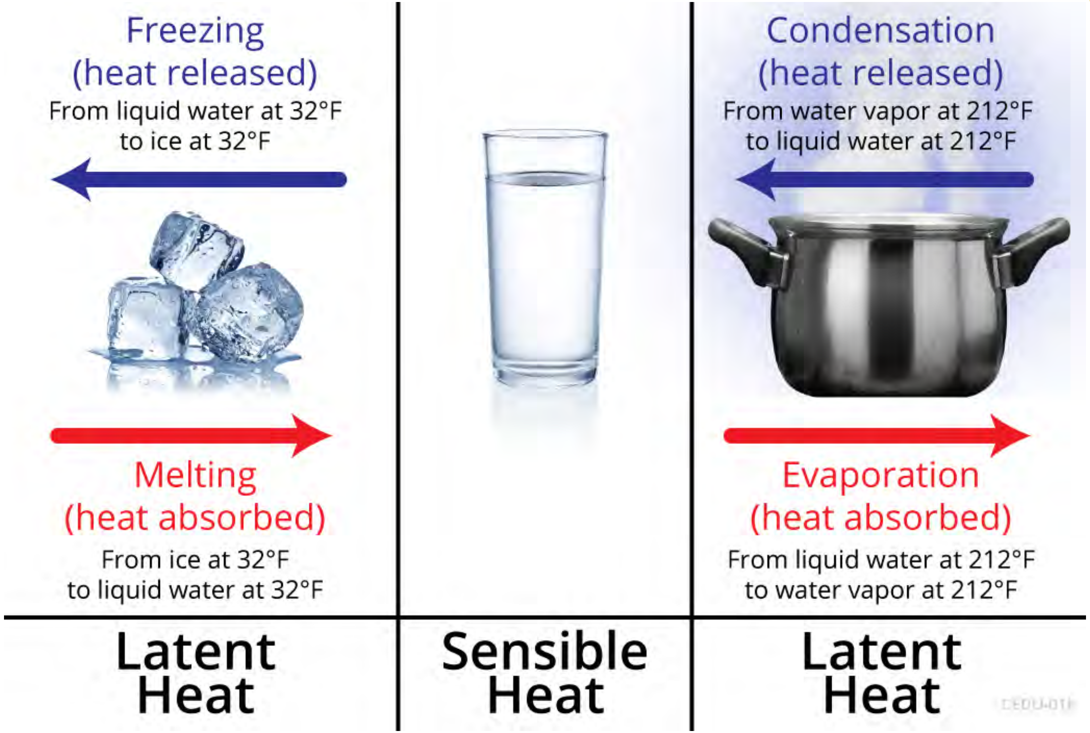
Sensible and Latent Heat

The discussion on the last frame introduces two additional important concepts: *sensible heat* and *latent heat*.

- Sensible heat changes the temperature of a substance without changing its physical state, or phase (e.g. heat added to liquid water in our example to bring it from 32°F to 212°F).
- Latent heat on the other hand changes the physical state of a substance without changing its temperature (e.g. heat absorbed to change 212°F liquid water to 212°F water vapor, or heat released to change 32°F water to 32°F ice).



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Sensible and Latent Heat – Air Conditioners

Drawing air through an air conditioner's cold air handler coil both cools the air by releasing sensible heat, and lowers the moisture content of the air by releasing latent heat as some of the moisture condenses on the coil.

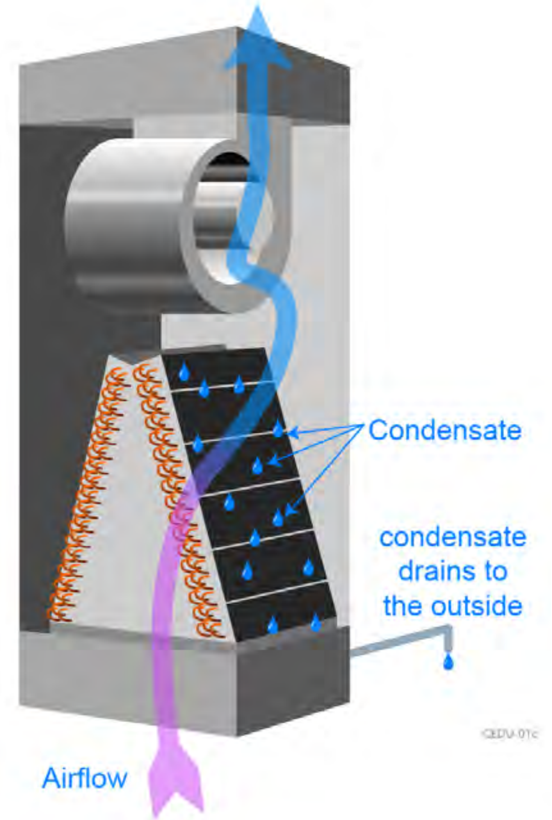

Image: FSEC

Other Conversions

- 1 watt = 3.412 Btu/h
- 1000 Btu/h is 293.1 watt
- 1 "ton of cooling", a common U.S. refrigeration and air conditioning unit, is 12,000 Btu/h.
    - Amount of power needed to melt 2000 lbs of ice at 32ºF in 24 hours
- 1 therm = 100,000 Btu = 100 cf natural gas (1 ccf)

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Temperature and Heat

Temperature

A property of a material that increases as it absorbs heat energy; 1^{o}F is defined as the temperature change of one pound of water heated by one Btu of energy.

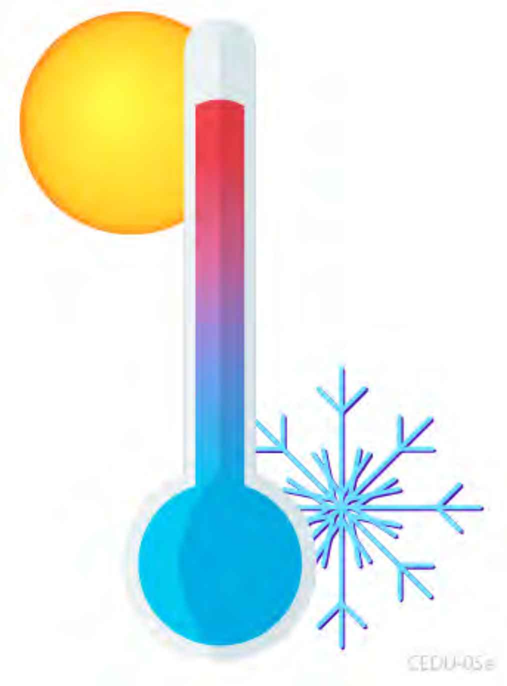


Image: FSEC

What is Temperature?

- Defines the energy state an object is in-- the average kinetic energy of a substance’s molecules
- Not a form of energy
- Will (generally) rise and fall as the energy in an object increases and decreases
- It is the consequence of more or less energy
- Typically measured in Celsius (°C) or Fahrenheit (°F)

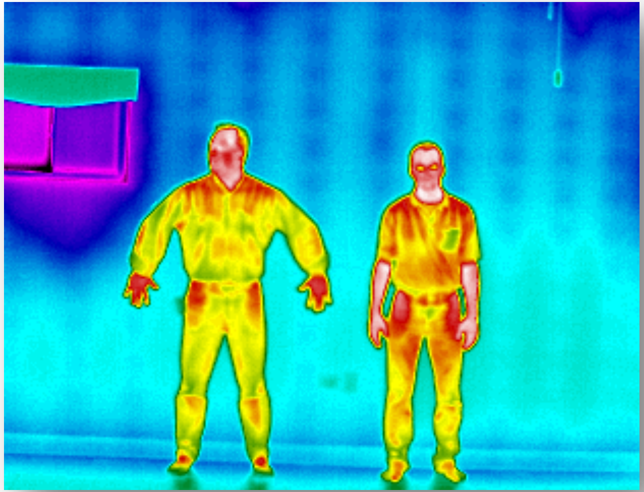
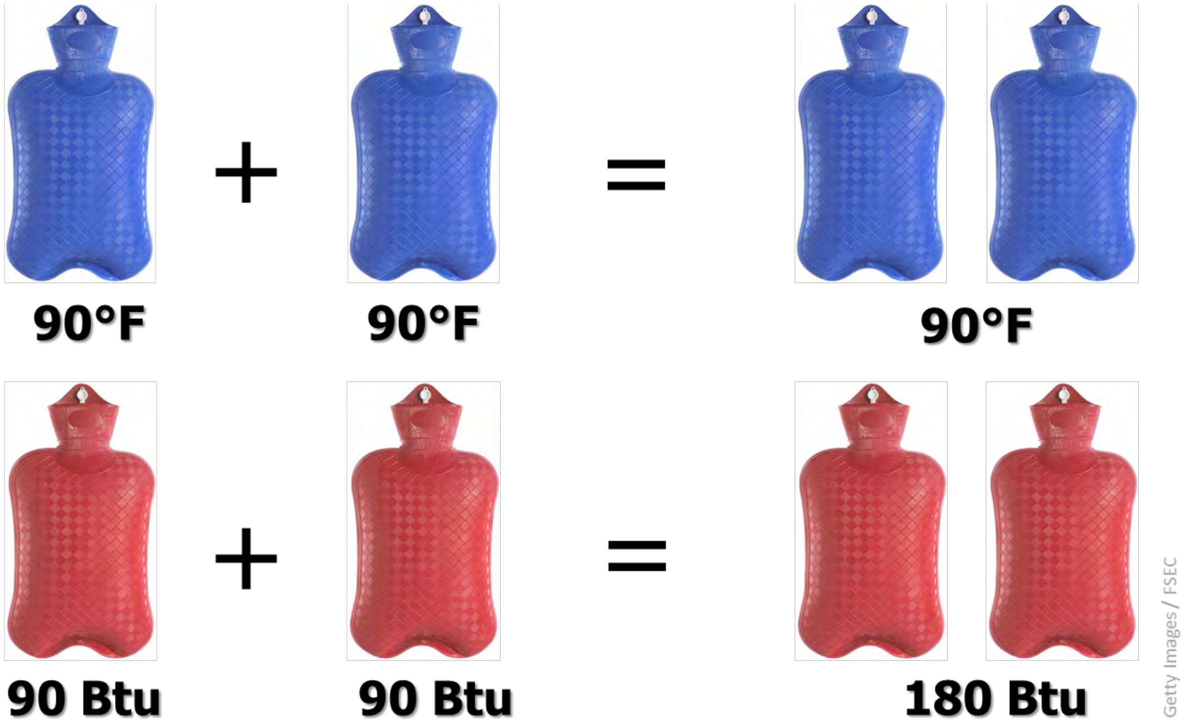


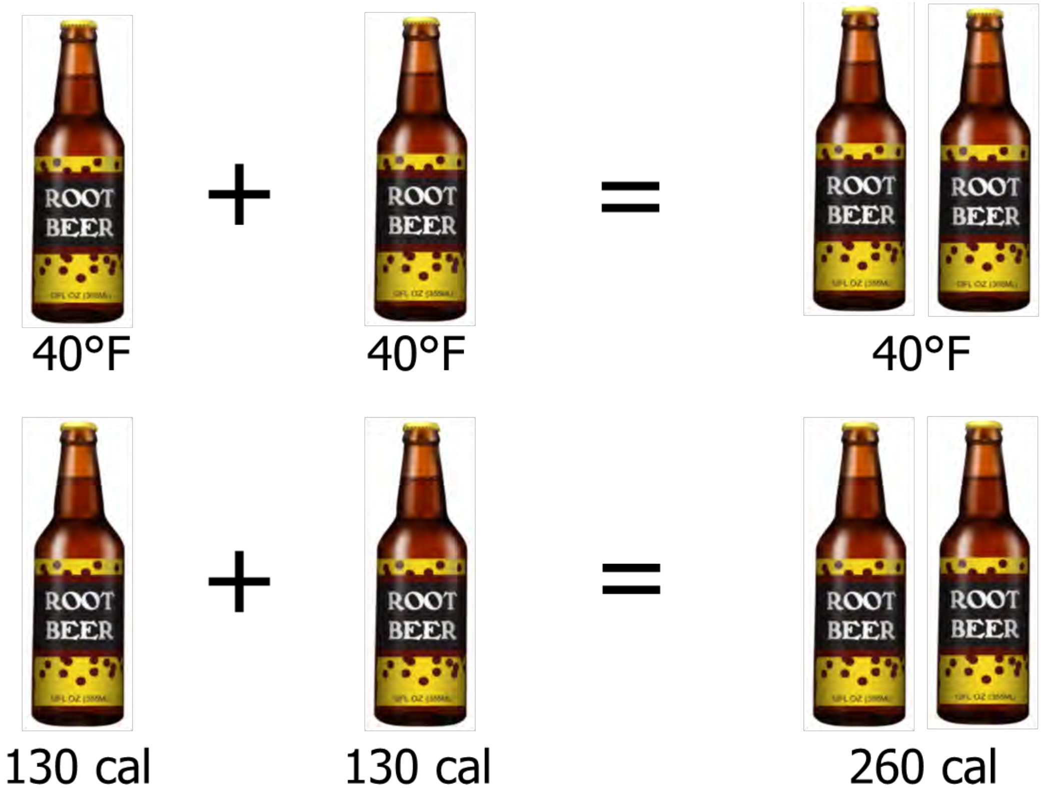
Image: FSEC

Infrared image shows skin as higher temperature than clothing.

Heat vs. Temperature



Heat vs. Temperature



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Delta T (ΔT)

- ΔT is the temperature difference between two zones
- Where there is a temperature difference, heat transfer will occur

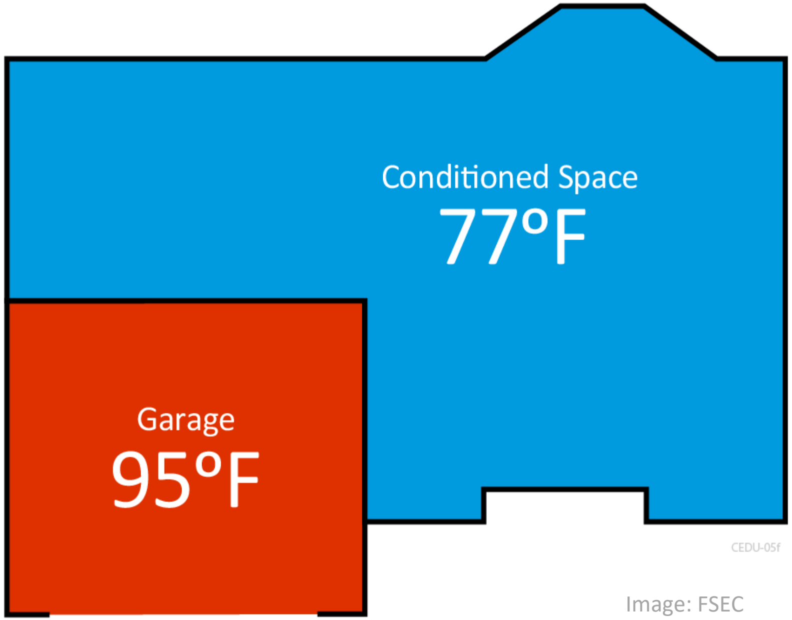


Image: FSEC

The Delta T (ΔT) between this garage and conditioned space is:
95°F – 77°F = 18°F

Specific Heat and Heat Capacity

- Specific heat is the amount of heat required to raise the temperature a single unit of a substance (typically pound or kilogram) one degree (typically Fahrenheit or Celsius).

- "Heat capacity" has a similar definition, but is not for a single unit of a substance; it usually refers to the total amount of the component being used in the building assembly. Also called "thermal capacity."

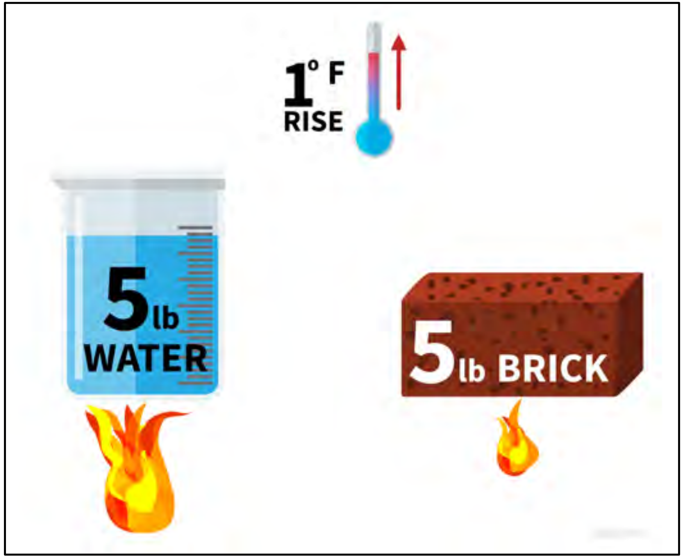


Image: FSEC

It takes more heat to raise the temperature of a given quantity of water than it does to raise the temperature of bricks weighing the same amount because the specific heat of water is higher.

Specific Heat of Various Materials

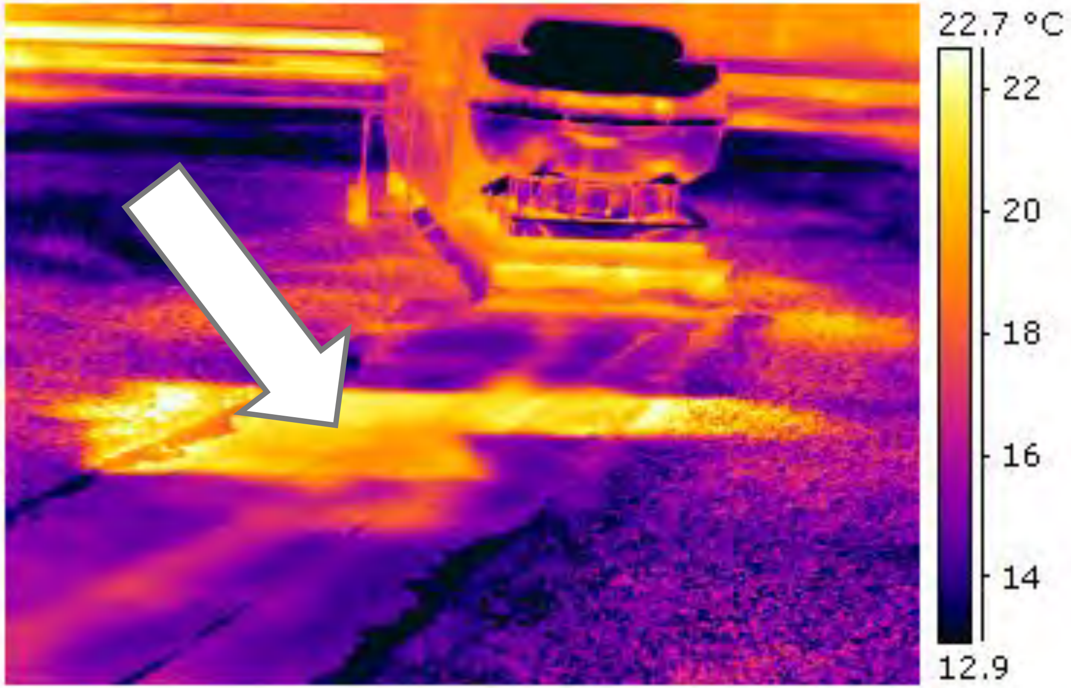
Storage Ability

Image: FSEC

Material	kJ/kg K	Btu/lb F
• Silver	0.235	0.056
• Copper	0.385	0.092
• Aluminum	0.900	0.215
• Steel	0.46	0.11
• Ice	2.0	0.478
• Earth (dry)	1.26	0.301
• Glass (window)	0.84	0.201
• Water	4.18	1.0
• Gypsum board	1.09	0.26
• Brick	0.75	0.179
• Wood	1.8-2.8	0.43-0.67
• Plywood	1.6-2.5	0.38-0.60
• Fiberglass	-	-
• Styrofoam	-	-
• Air (still)	1.0	0.239

Heat Capacity Illustration

Water has higher heat capacity than the roof and stays warm longer



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Heat Transfer

Heat Transfer

The Heat Transfer lesson will focus on the difference between heat and temperature and the three modes of heat transfer: conduction, convection and radiation.

Heat Transfer Principles

- Three modes of heat transfer
  - Conduction
  - Convection
  - Radiation

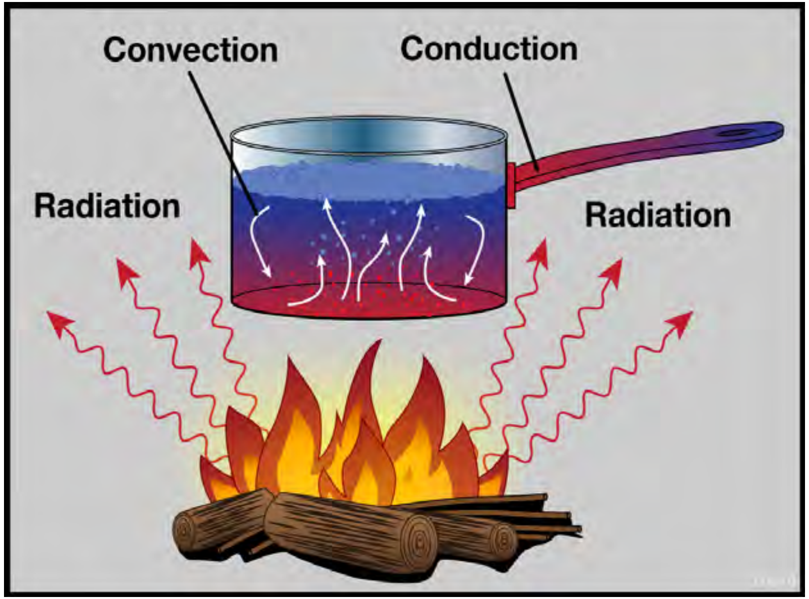

Image: FSEC

A campfire **radiates** heat to a pot. As the bottom of the pot heats up, it **conducts** heat to its sides and handle. Water at the bottom of the pot is heated and carried to the top of the pot via **convection**, and is replaced by cooler water from the top of the pot. If you are upwind of the fire and feel the heat from the fire, that is also **radiation**.

Heat Transfer Principles

- **Conduction:** transfer by vibration of particles colliding with one another and movement of free electrons through the substance (solids)
- **Convection:** transfer by the movement of the particles within a fluid. It only occurs in liquids & gases, either natural (wind-stack) or forced (fans)
- **Radiation:** transfer between surfaces via electromagnetic waves.

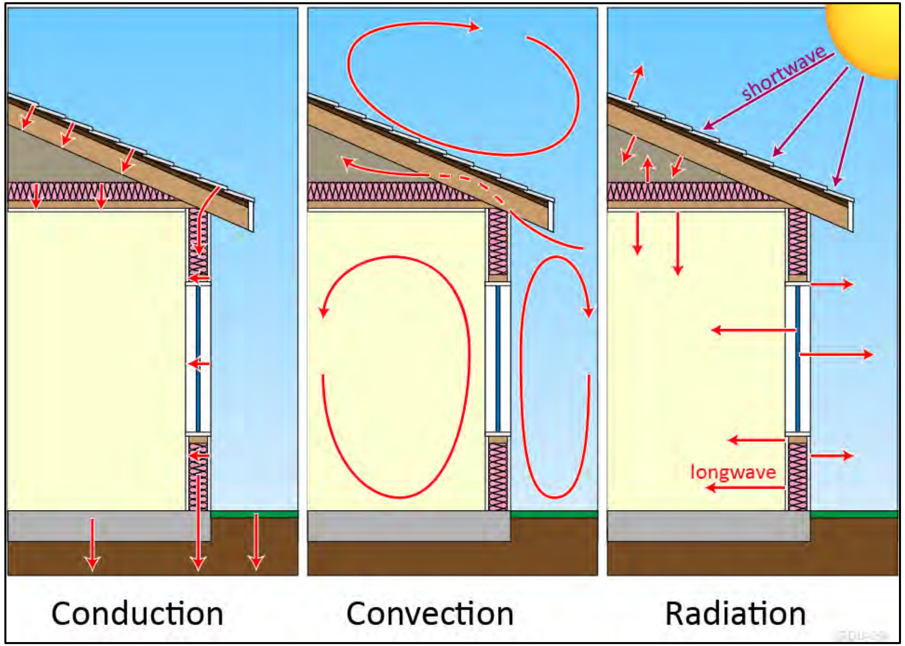

Image: FSEC

Building conduction, convection and radiation heat transfer mechanisms on a summer day.

Conduction

- Energy transfer by direct contact.
- It occurs:
  - when two materials of a different temperature come in direct contact with one another or when there is a difference in temperature within a single material
  - only in solids
  - until equilibrium is reached.
- Never happens in the same place as convection or radiation, but can occur at the same time.

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Conduction Heat Flow

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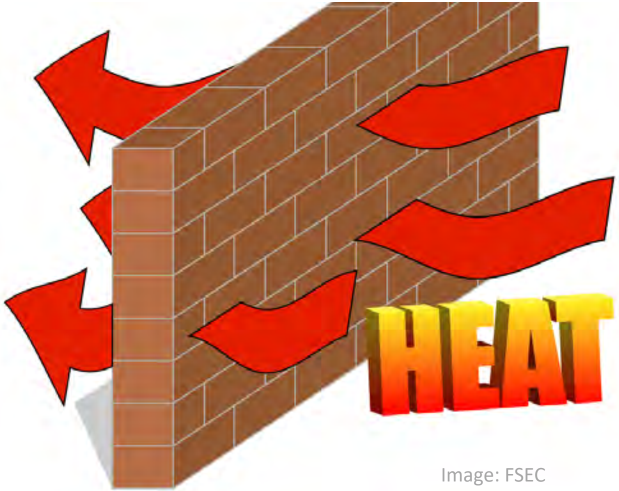

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Amount of heat flow is a function of:

- Cross-sectional Area
- Temperature difference
- Distance traveled
- Material Conductivity

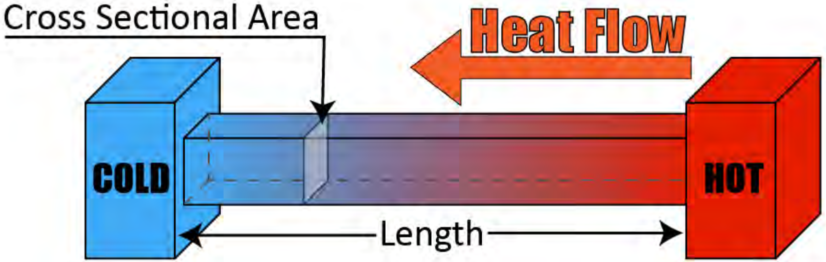


Image: FSEC

Thermal Conductivity

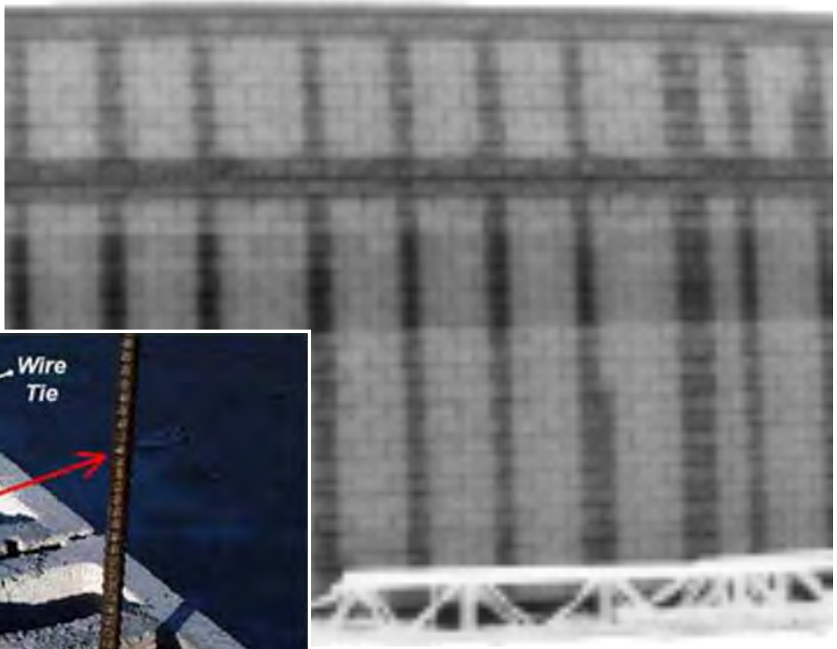
Moving Ability

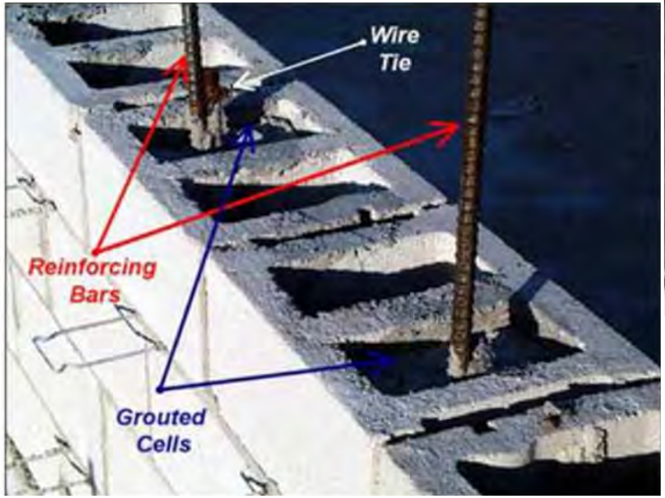
Material	W/mK	Btu/(ft h °F)
• Silver	429	2976
• Copper	401	2782
• Aluminum	237	1644
• Steel	50	346
• Ice	2	13.9
• Earth (dry)	1.5	10.4
• Glass (window)	0.9	6.2
• Water	0.6	4.2
• Gypsum board	0.26	1.80
• Brick	0.18	1.24
• Wood	0.14	0.97
• Plywood	0.13	0.90
• Fiberglas	0.04	0.27
• Styrofoam	0.03	0.2
• Air (still)	0.025	0.17

Material Property that indicates ability to conduct heat

Thermal Conductivity Illustration

Concrete has higher thermal conductivity than air, so the infrared image (upper right) shows a surface temperature difference for block cell cores that are filled with concrete grout (dark lines) vs. air-filled cores (lighter areas).





Images courtesy of Stockton Infrared

Convection

- Natural Convection:
  - Heat transfer in a gas or liquid by the circulation of currents from one area or region to another
  - Warm air rises and is replaced by cooler air
  - Occurs until equilibrium is reached
  - Amount of heat flow is a function of surface area, temperature difference, surface orientation and roughness and fluid velocity.
- Forced Convection:
  - Fluid (gas or liquid) transport caused by an external source (e.g. fan or pump).

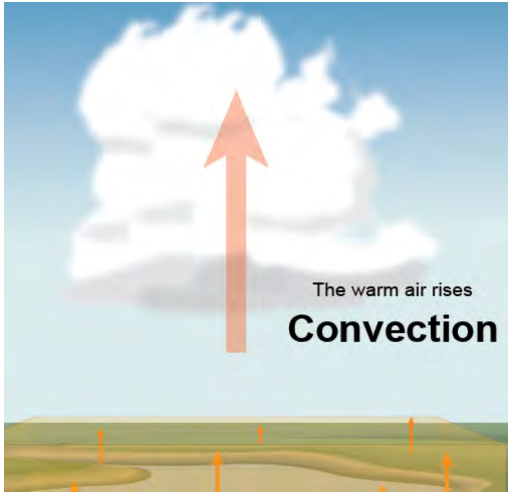


Image: NOAA

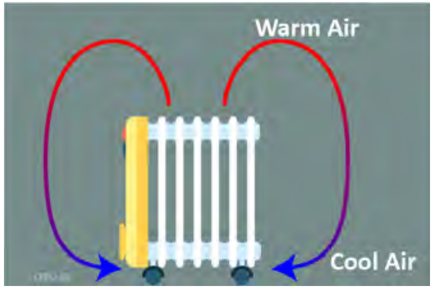
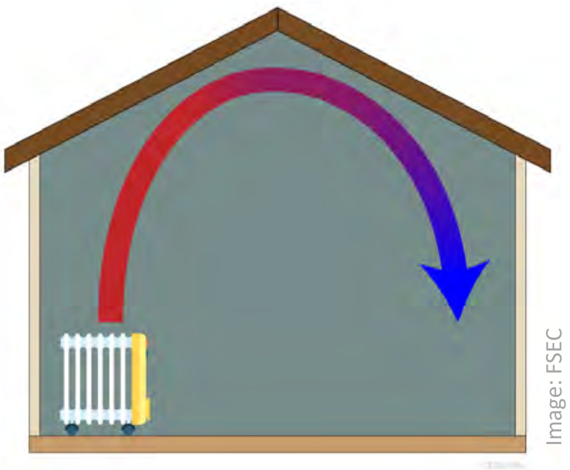


Image: FSEC

Two examples of natural convection.

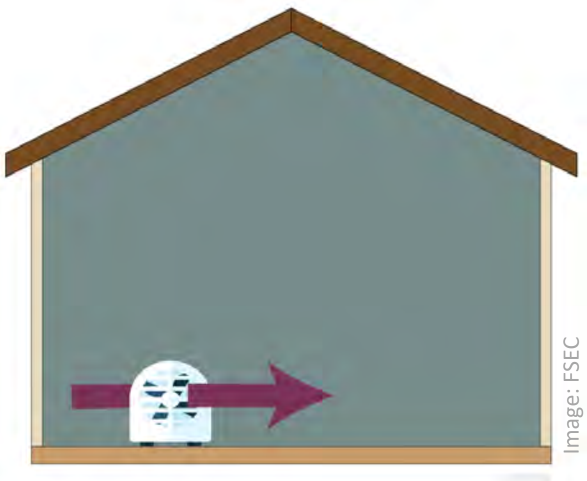
Convection Illustrations

Natural Convection



A radiator heats air which rises, then cools and falls. Air near the radiator is replaced by cooler air, repeating the cycle.

Forced Convection



A portable fan moves air from one area of a room to another.

Radiation

- All objects radiate electromagnetic energy
- Heat transfer by electromagnetic waves
    - No medium (matter) is required
    - Easily through most gases
    - With difficulty, or is blocked, by liquids and solids

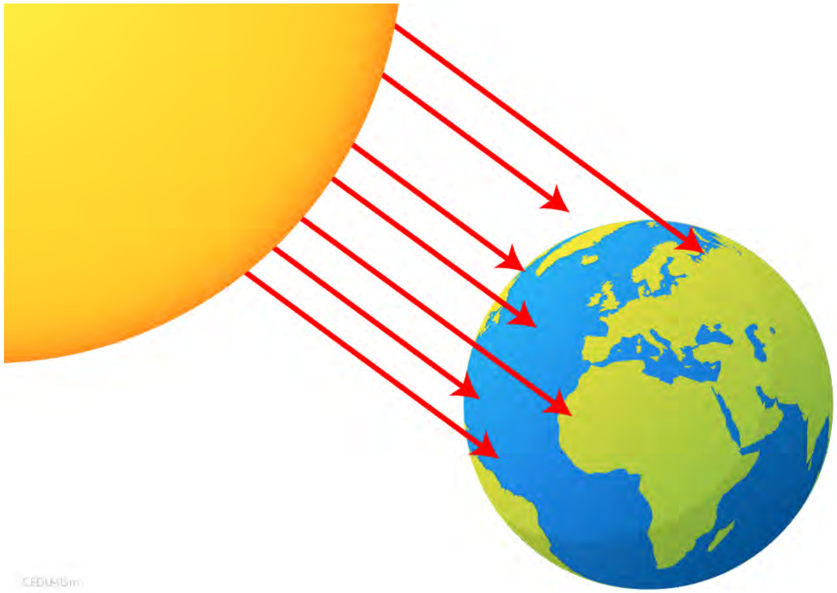
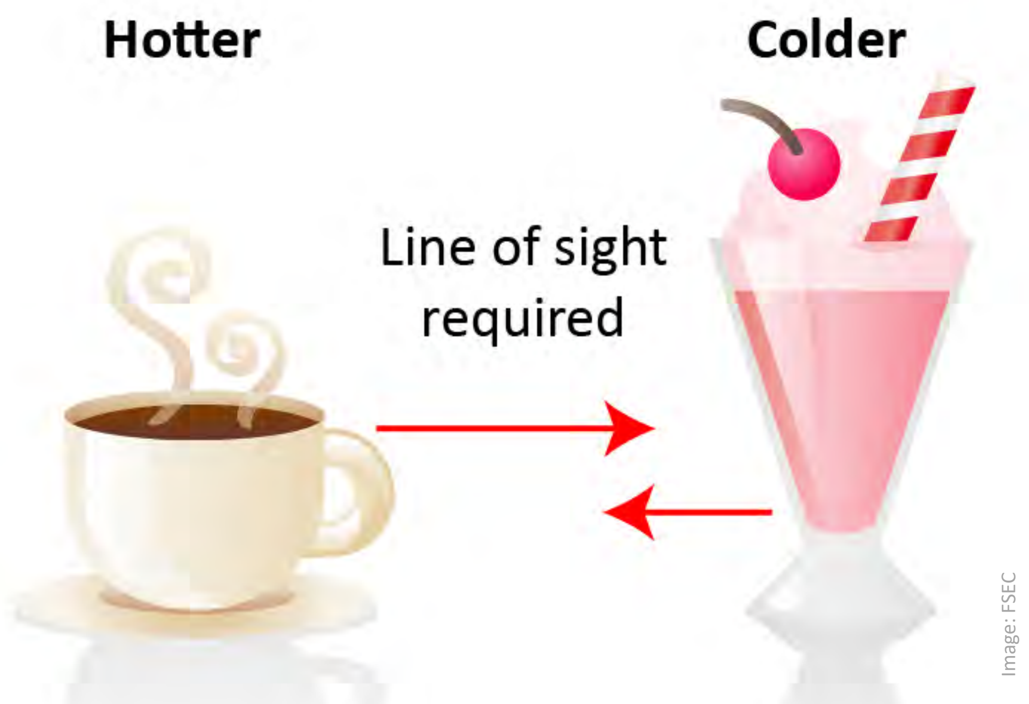


Image: FSEC

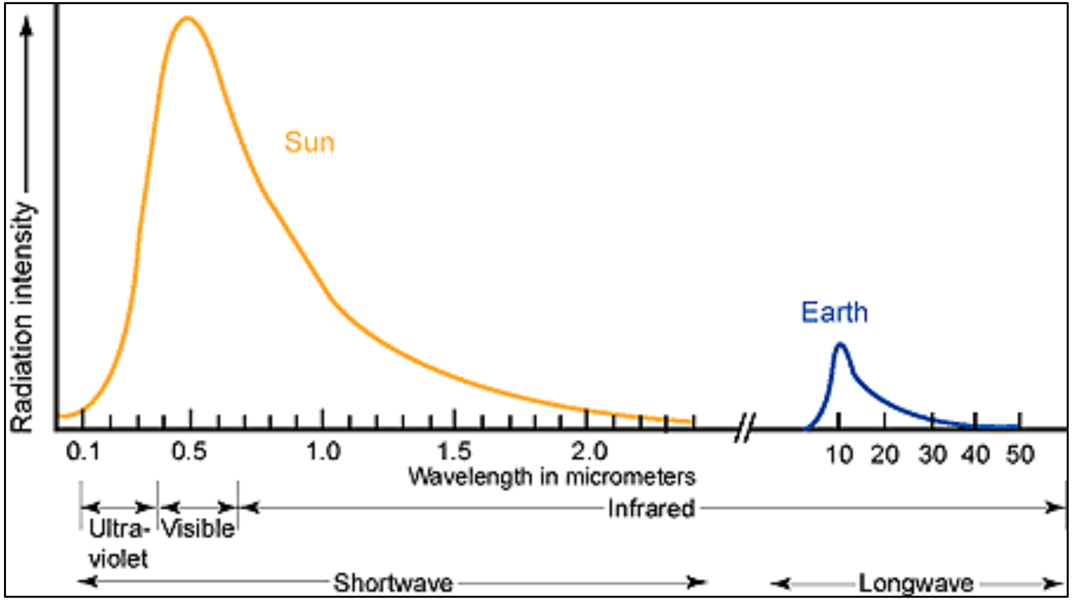
Radiation Heat Transfer

- Heat is transferred by emission and absorption
- Both objects emit and absorb radiation
- The net heat transfer is the difference



Wavelengths

- Materials may absorb radiation at different wavelengths more than at other wavelengths
- Shortwave radiation contains the solar spectrum including ultra-violet, visible and near infrared wavelengths. Note that the visible wavelengths are only part of the solar spectrum
- Longwave radiation is how items on earth exchange heat if they have temperature difference.



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Solar Radiation and Building Surfaces

Solar Absorptance

- Surface's ability to receive energy from solar wavelengths. Value between 0 and 1. Typical dark roof is 0.85 to 0.95

Solar Reflectance

- Surface's ability to reflect energy in the solar spectrum. Typical dark roof is 0.05 to 0.15.

Solar Transmittance

- Energy fraction passing through the object. For wall and roof materials this is 0. For skylights and windows it is higher than 0.

Equation

- Absorptance + Reflection + Transmittance = 1

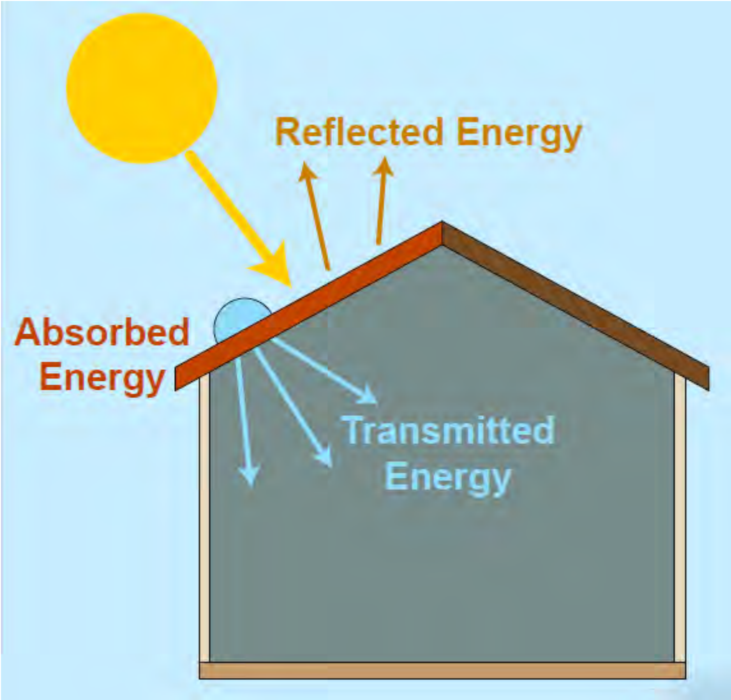

Image: FSEC

Earth/Night Sky Radiation and Building Surfaces

<u>Longwave Emittance</u>

- Surface's ability to receive and radiate energy in longwave spectrum. Value between 0 and 1. Most building surfaces are near 0.90. Radiant barriers are 0.06 or less. Human skin is around 0.98.

<u>Longwave Reflectance</u>

- Surface's ability to reflect energy in the longwave spectrum. Most building materials are around 0.10.

<u>Longwave Transmittance</u>

- Longwave fraction passing through the object. Zero for typical building materials including glass.

<u>Equation</u>

- Emittance + Reflectance + Transmittance = 1

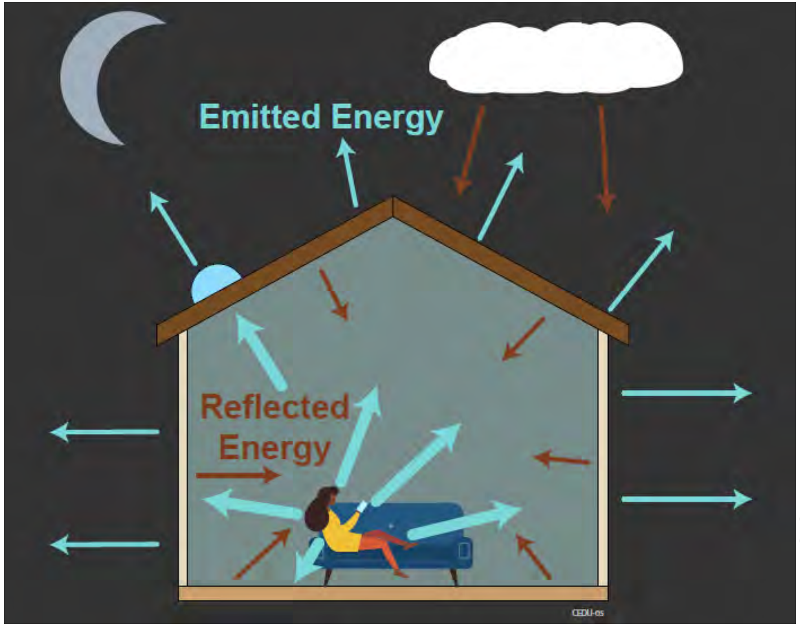

Image: FSEC

Thermal Envelopes
Part 1

Thermal Envelopes

The Thermal Envelopes lesson will focus on how conductive, convective and radiative heat transfer typically occurs in building components.

Wall Cavity Heat Transfer Mechanisms

Un-insulated wall (top illustration) transmits heat…

- Through sheathing by **conduction**
- Through the air space by **radiation** and **convection**

Insulated wall (bottom illustration) transmits heat…

- Through sheathing and insulation almost entirely by **conduction** if there are no air pathways.

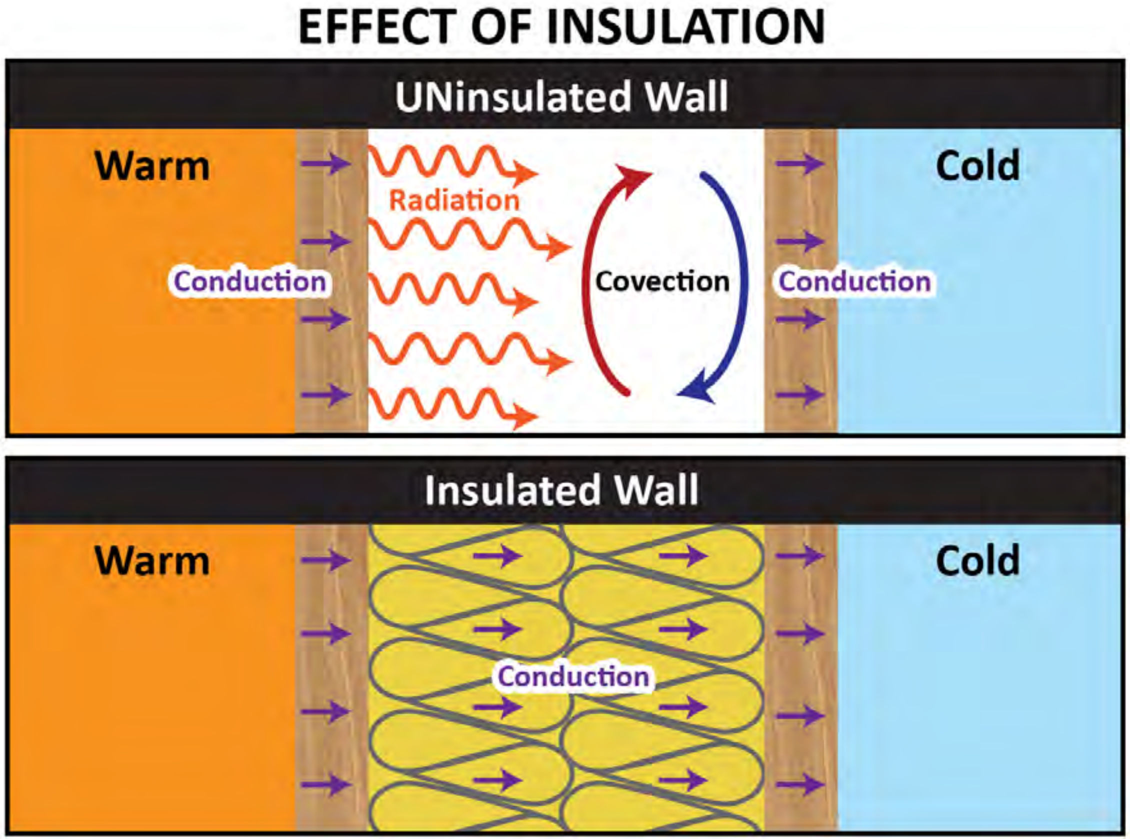

Image: FSEC

Roof and Attic Heat Transfer Mechanisms

Illustration of heat transfer mechanisms in a typical vented attic roof system-- showing simultaneous heat transfer via radiation, convection and conduction.

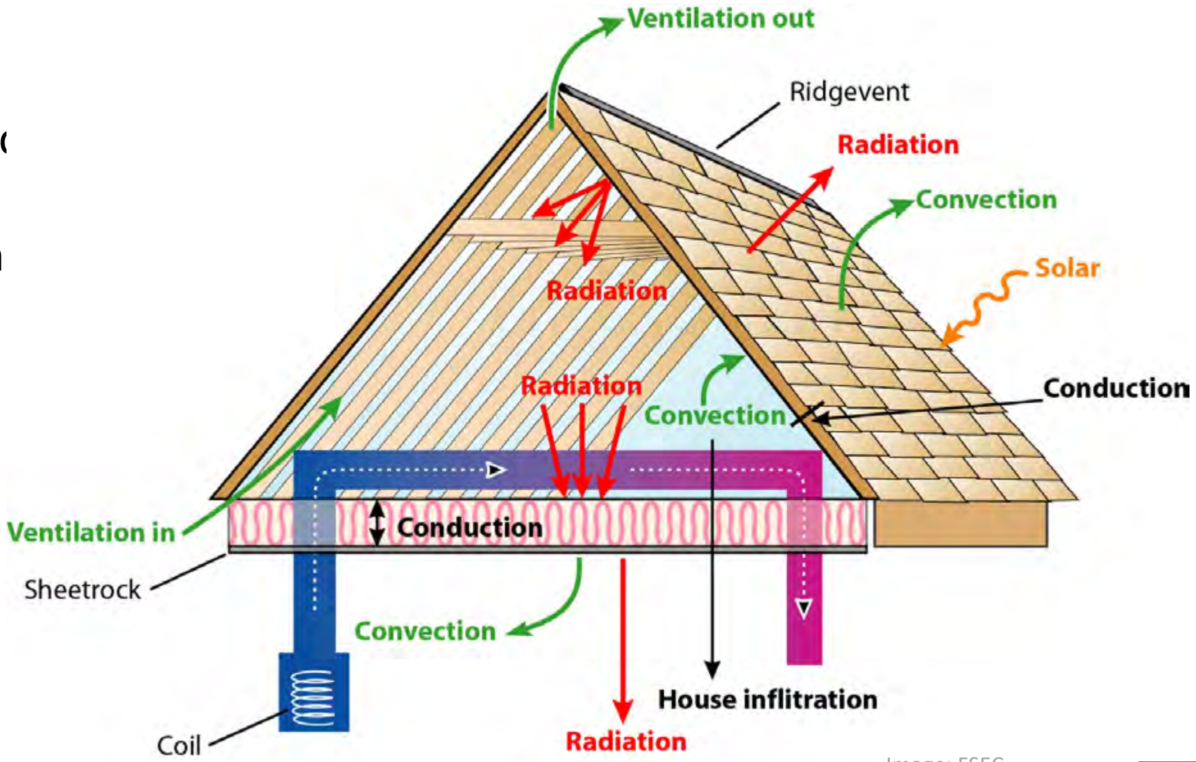

Image: FSEC

Attic Radiant Barriers and Reflective Roofs

A radiant barrier is a high reflectance and low emittance foil product, which when installed facing an attic airspace as illustrated on the right, will reduce radiation from the heated roof deck to the attic insulation and ducts.

A reflective roof surface (e.g. white metal or tile roof) will reduce solar radiation heating of the roof deck, and in turn also reduce the heating of attic insulation and ducts.

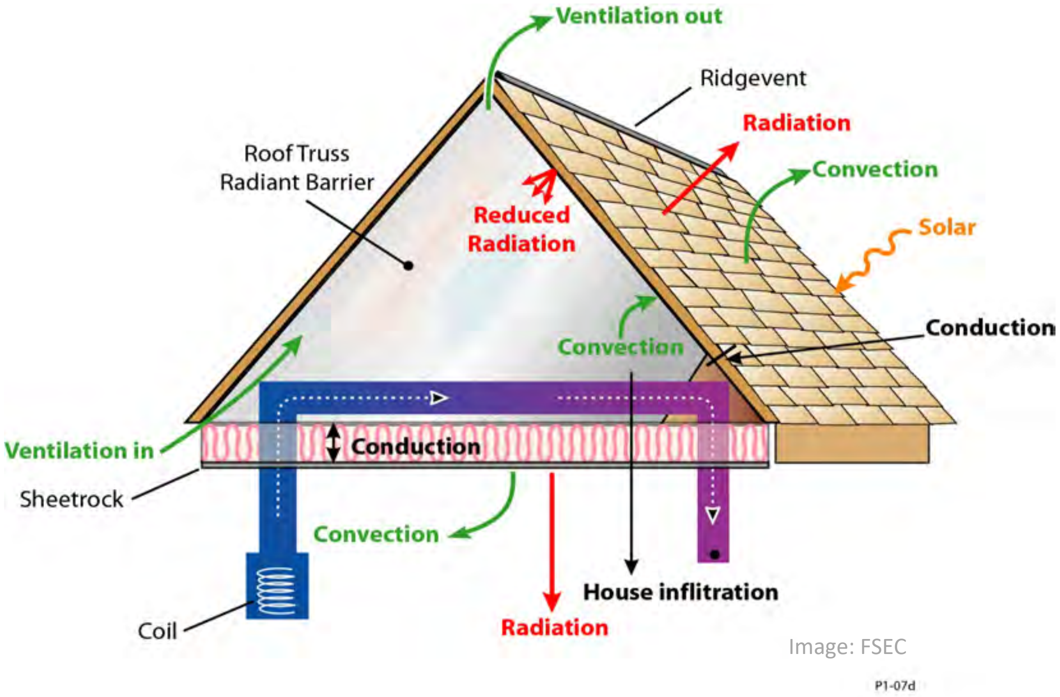

Image: FSEC

U-factor & *R*-value

- *U*-factor (or *U*-value) or "overall heat transfer coefficient" is the rate of heat flow in Btu/h through one square foot when there is a 1 degree F temperature difference (US units are Btu/h-ft^2-^{o}F).
    - A low *U*-factor reduces the transfer of heat relative to a higher *U*-factor.
- *R*-value is the resistance to heat flow through a material.
- *R*-value = 1/*U*-factor (US units are ^{o}F-ft^2-h/Btu).

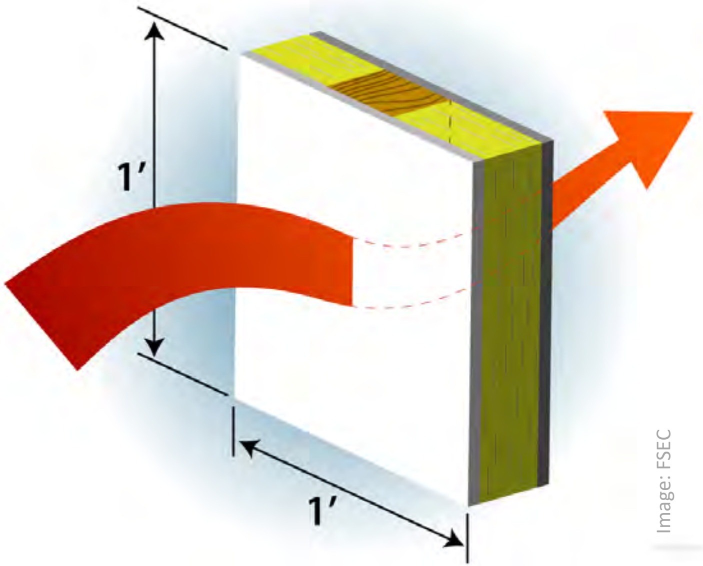

Image: FSEC

R-value

- Resistance of heat flow through a material.
- Higher *R*-value – greater resistance to heat flow.

Getty Images

Material *R*-values

Insulation Material	*R*-value per Inch of Thickness ($^oF\text{-}ft^2\text{-}h/Btu$)
Batt-type	3.1 to 3.5
Loose fill	2.9 to 3.7
Board stock	3.5 to 6.2
Spray-type	3.5 to 6.0

Higher *R*-value = Lower Conductance

Heat Flow in Series

- Flow of thermal energy in sequence through a series of layers as might occur in the construction of a building assembly such as a wall or roof.
  - Each layer adds to the assembly's resistance to heat flow.
- In calculations, the thermal resistances of wall components are added to derive a total resistance to heat flow through the assembly.

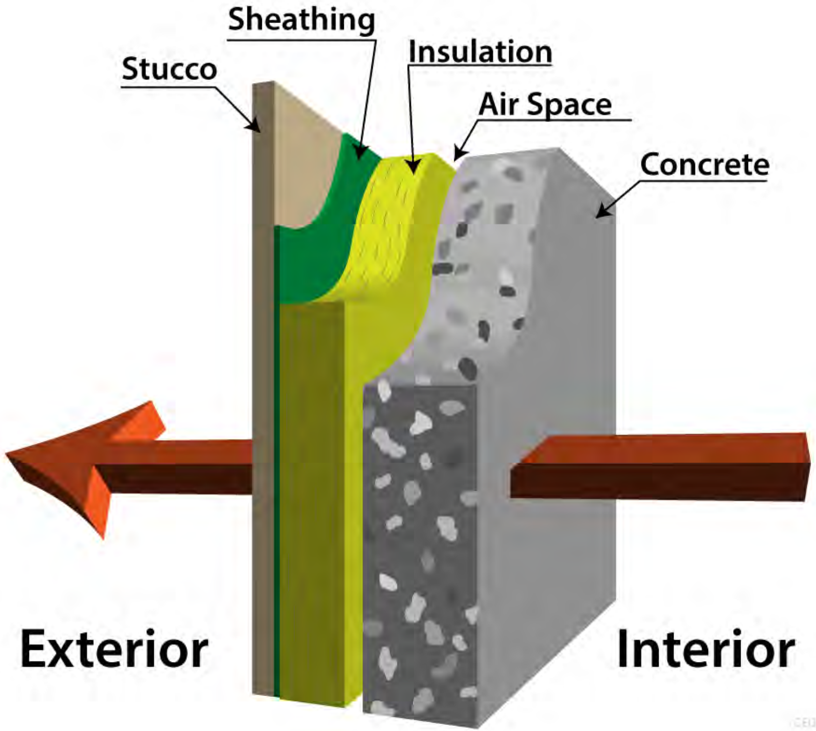

Image: FSEC

Series heat flow through an exterior concrete wall (winter conditions).

Working with *U*-factors and *R*-values

- You may add *R*-values together to get a composite *R*-value for an assembly, however, you **CANNOT** add *U*-factors together to get a composite *U*-factor for an assembly.
- You must convert all to *R*-values then add.
- Then if you want to convert to *U*-factor, just take the reciprocal.

EXAMPLE: *U*-factor for R-19 = 1/19 = 0.053

Now You Try (feedback on next slide)

Given the following wall component *R*-values and *U*-factor, enter the remaining values:

Material	*R*-value	*U*-factor
4” Brick		2.27
8” CMU		0.90
R-5 Insul.	5.00	
½” drywall	0.45	2.22

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Now You Try (feedback)

Given the following wall component *R*-values and *U*-factor, enter the remaining values:

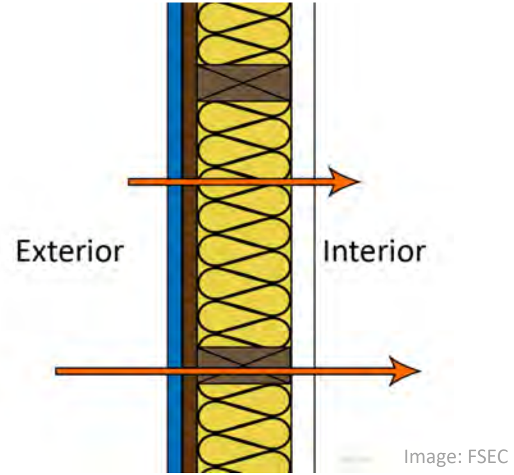
Material	*R*-value		*U*-factor
4” Brick	0.44		2.27
8” CMU	1.11		0.90
R-5 Insul.	5.00		
½” drywall	0.45		2.22
	7.0	→ 1/7	0.143

Thermal Envelopes
Part 2

UCF

Parallel Heat Flow

- Heat flow through simultaneous paths:
  - A frame wall assembly, for example, will have simultaneous heat flow through the framing members and through the cavity insulation
  - A building will have a number of simultaneous heat flows between conditioned space and unconditioned space and the outdoors through its walls, windows, doors, ceilings and floors.
- In calculations, the U-factor of each path is added proportionally to derive the total heat flow rate through the entire assembly.



Parallel summertime heat gain paths through wall stud and insulated sections, showing greater heat flow through stud section than insulated section.

Weighted Averages

Path weighting is used to determine overall *U*-factor for an assembly with parallel heat flow paths (two paths shown below; additional paths can be added).

Example: You are inspecting an existing home. You have determined that the insulation in the ceiling is uneven. The total ceiling area is 1,200 square feet. However, you have determined that 800 sq. ft. of this ceiling has an *R*-value of 19 °F-ft^2-h/Btu and 400 sq. ft. has an *R*-value of 30 °F-ft^2-h/Btu.

Determine the weighted average *U*-factor and *R*-value of the insulation.

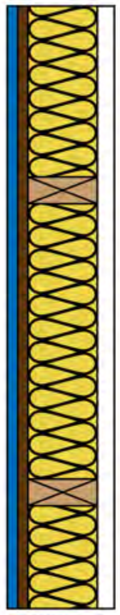
$$\left(\frac{800}{1200}\times\frac{1}{19}\right)+\left(\frac{400}{1200}\times\frac{1}{30}\right)=0.035+0.011=\underbrace{0.046\,\text{Btu/h-ft}^2\text{-}^\circ\text{F}}_{\text{Overall } U\text{-factor}}$$

R-value = 1/U = 1/0.046 = 21.7 °F-ft^2-h/Btu

U-factor & *R*-value Calculation

Combination of series & parallel heat flow paths.

The 23% framing fraction in the example to the right is based on the face area of studs as well as the sill plates, compared to the face area of insulation.



Wall Segment	R_{stud} (°F-ft²-h/Btu)	$R_{insulation}$ (°F-ft²-h/Btu)
outside air film	0.17	0.17
wood siding	0.81	0.81
osb sheathing	0.8	0.8
stud	4.67	---
insulation	---	13
gypsum	0.45	0.45
inside air film	0.68	0.68
***R*-value**	**7.58**	**15.91**
***U*-factor**	**0.132**	**0.063**
Fraction of wall	**.23**	**.77**

$$U = (F_{stud} \times U_1) + (F_{insul} \times U_2)$$

$$U = (0.23 \times 0.132) + (0.77 \times 0.063)$$

$$U = 0.0789 \text{ Btu/h-ft}^2\text{-}^\circ\text{F}$$

$$R = 1/U = 1/0.0789 = 12.7\ ^\circ\text{F-ft}^2\text{-h/Btu}$$

Conductive Heat Flow

Conductive heat flow is calculated using the equation:

$$Q = U \times A \times \Delta T$$

Where:

Q = Heat flow (Btu/hr)

U = Heat transmittance (Btu/ft^2-hr-^{o}F)

A = Area (ft^2)

ΔT = Temperature difference (^{o}F)

What is the conductive heat loss (flow) across this duct under the summertime conditions shown to the right for an R-8 duct that is 48 feet in length and 16 inches in diameter? (See next slide.)

Getty Images / FSEC

Conductive Heat Flow Calculation

$$Q = U \times A \times \Delta T$$

$U = 1/R = 1/8 = 0.125$ Btu/ft^2-hr-^{o}F

A = length x width = $\underbrace{48\text{ft}}_{\text{Length (ft)}} \times \underbrace{3.14}_{\text{pi}} \times \underbrace{16\text{in}/12\text{in}}_{\text{diameter (ft)}} = 201\ \text{ft}^2$

$\Delta T = T_{attic} - T_{supply} = 132^oF - 55^oF = 77^oF$

$Q = 0.125$ Btu/ft^2-hr-^{o}F x 201 ft^2 x 77^{o}F

= 1935 Btu/hr

The conductive heat loss across this duct under these conditions.

Getty Images / FSEC

Now You Try (feedback on next slide)

- Given a 10’ x 20’ frame wall assembly as shown on the right with:
  - 2x6 studs 16” o.c. (*R*-value of studs is 7.34)
  - 20% framing fraction
  - R-19 batt insulation
  - 5% uninsulated (*ignore air films in cavity*)
  - Inside temperature = 76ºF
  - Summer outside temperature = 96ºF and winter outside temperature = 36ºF.
- What are the overall *U*-factor and *R*-value using parallel heat flow?
- What are the summer conditions heat gain and winter conditions heat loss?

Wall Segment	R_{stud}	$R_{insulation}$	$R_{uninsulated}$
outside air film	0.17	0.17	0.17
wood siding	0.81	0.81	0.81
osb sheathing	0.8	0.8	0.8
stud	7.34	---	---
insulation	---	19	0
gypsum	0.45	0.45	0.45
inside air film	0.68	0.68	0.68
Fraction of wall	**0.2**	**0.75**	**0.05**
R-value			
U-factor			

R-values in ºF-ft²-h/Btu

U-factors in Btu/h-ft²-ºF

Now You Try (feedback)

- What is the overall *U*-factor and *R*-value using parallel heat flow?
    - Individual component *R*-values shown in table
    - Overall *U*-factor = (0.2*0.098) + (0.75*0.046) + (0.05*0.344) = 0.071 Btu/ft^2-hr-^{o}F
    - Overall *R*-value = 1/U-factor = 14.1 ^{o}F-ft^2-h/Btu.
- What are the summer conditions heat gain and winter conditions heat loss? Using heat flow equation Q = U x A x ΔT:
    - For 96^{o}F day, heat gain = 0.071*200*(96-76) = 283.7 Btu/h
    - For 36^{o}F day, heat loss = 0.071*200*(76-36) = 567.4 Btu/h.

Wall Segment	R_{stud}	$R_{insulation}$	$R_{uninsulated}$
outside air film	0.17	0.17	0.17
wood siding	0.81	0.81	0.81
osb sheathing	0.8	0.8	0.8
stud	7.34	---	---
insulation	---	19	0
gypsum	0.45	0.45	0.45
inside air film	0.68	0.68	0.68
Fraction of wall	**0.2**	**0.75**	**0.05**
R-value	**10.25**	**21.91**	**2.91**
U-factor	**0.098**	**0.046**	**0.344**

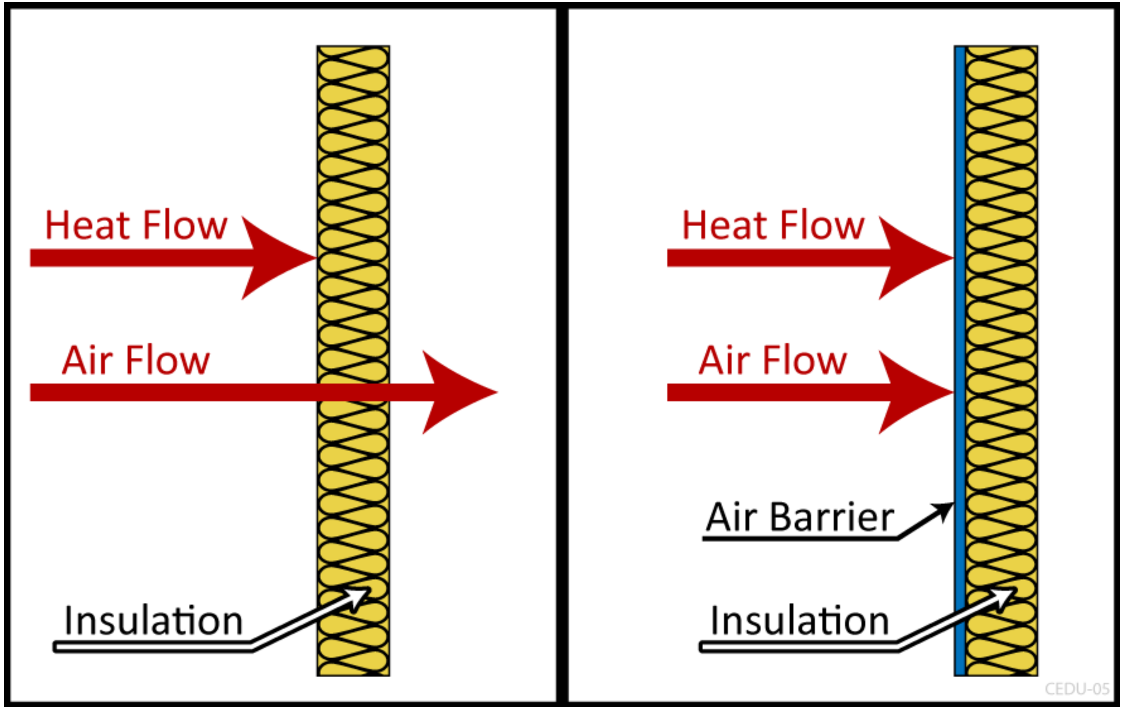
R-values in ^{o}F-ft^2-h/Btu

U-factors in Btu/h-ft^2-^{o}F

Insulation: Resists Heat Flow

- Choose insulation product based on application
- Proper installation of insulation can be more important than its rated performance
- Air movement through insulation greatly degrades its performance.

Air & Thermal Barrier Alignment



Proper air barrier and thermal barrier alignment (shown at right) reduces energy use by minimizing air currents (convection).

Windows

Heat Flow Through Windows

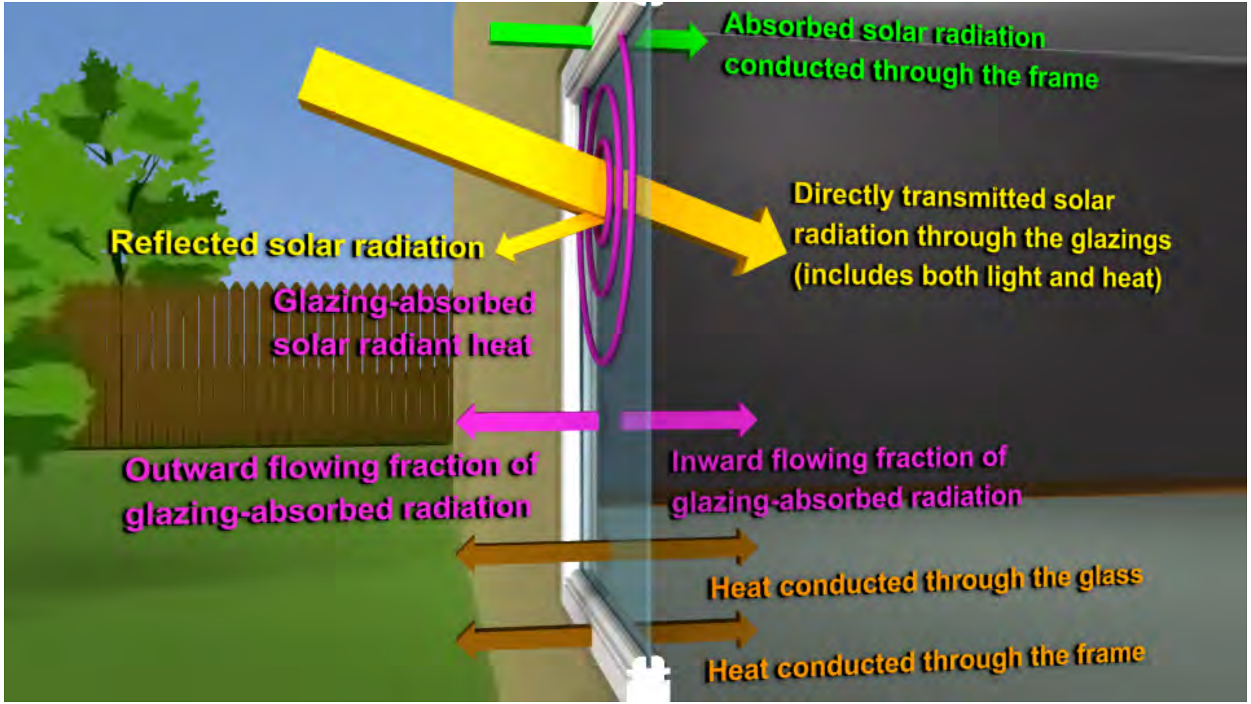


Image: FSEC

Heat flow (gain or loss) through windows is mainly via radiation and conduction.

Reducing Heat Flow Through Windows

Heat flow through windows can be reduced via:

- Coatings that reduce solar radiation gain
- Insulated frames and gas-filled spaces between glass panes to reduce conduction
- Optimized glass pane spacing to reduce convection.

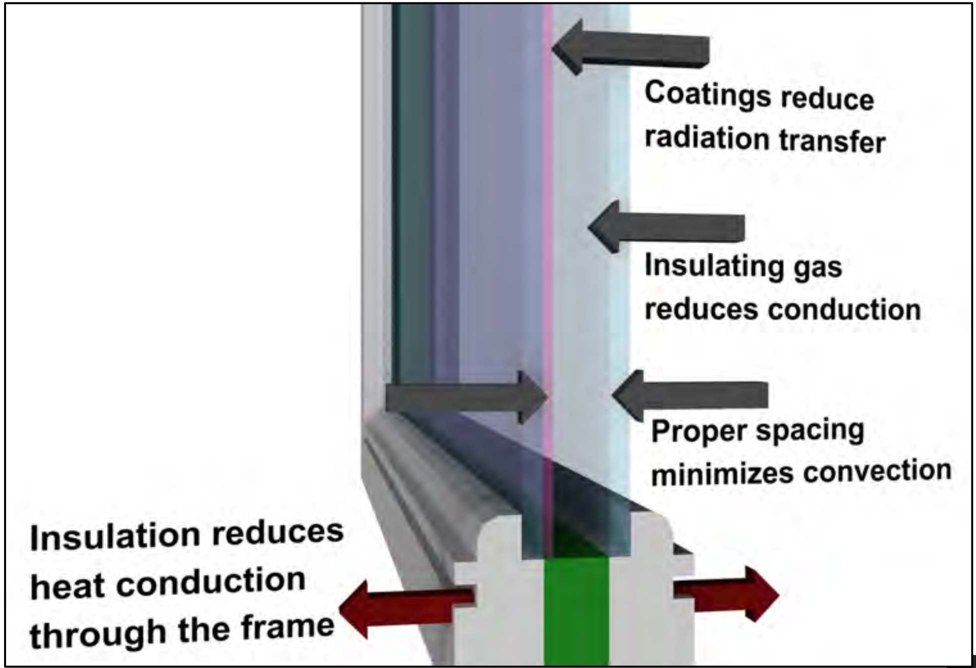


Image: FSEC

Solar Heat Gain Coefficient (SHGC)

- Ratio of the solar heat gain entering a space through a fenestration assembly [e.g. window] to the incident solar radiation*
- Number between 0 & 1
- Lower SHGC transmits less solar heat.

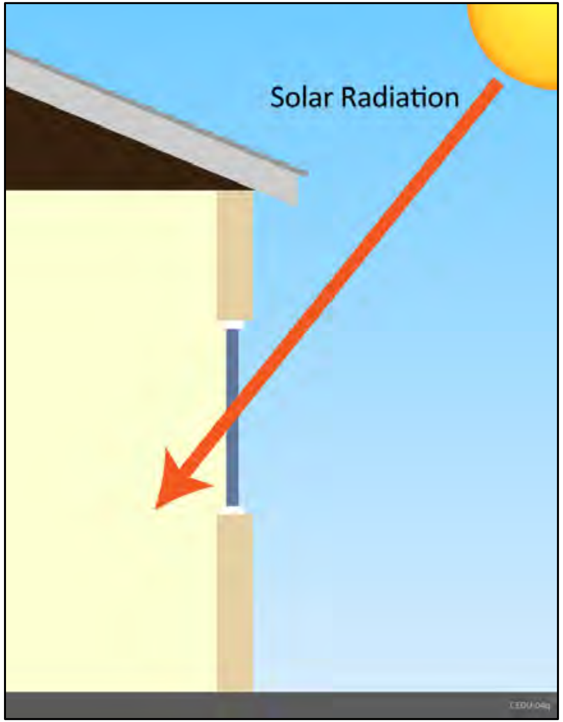


Image: FSEC

* Source: 2017 Florida Building Code, Energy Conservation, Chapter 2 [RE]

Visible Transmittance (VT)

- Ratio of visible light entering a space through a fenestration assembly [e.g. window] to the incident visible light*
- Number between 0 & 1
- Higher VTs maximize daylight and view
- VT is not a rating entry, but a consideration when selecting windows for a project.

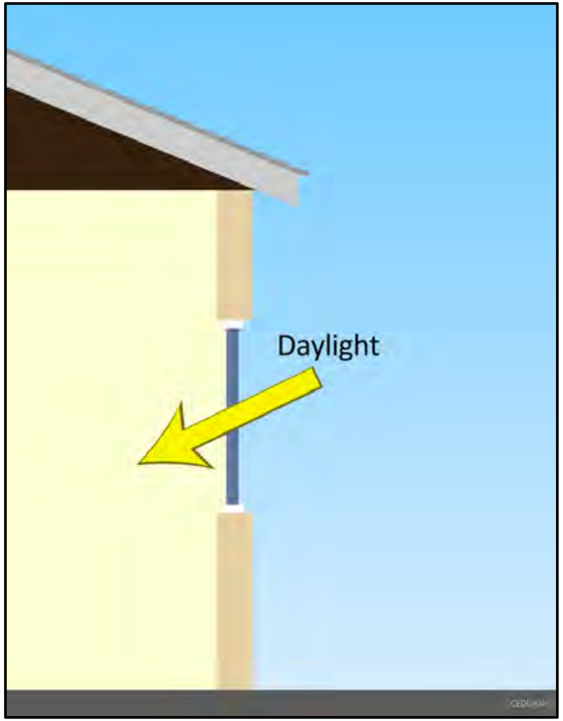


Image: FSEC

* Source: 2017 Florida Building Code, Energy Conservation, Chapter 2 [RE]

Heat Loss (*U*-Factor)

- The coefficient of heat transmission (air to air) through a building component or assembly*
- Low *U*-factor reduces the transfer of heat relative to a higher *U*-factor window.

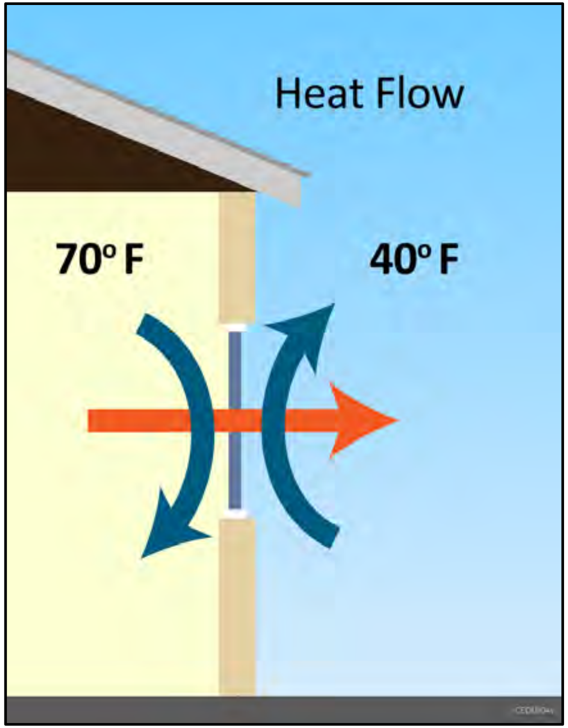


Image: FSEC

* Source: 2017 Florida Building Code, Energy Conservation, Chapter 2 [RE]

Window Performance by Climate Zone

WINDOWS			
CLIMATE ZONE	U-FACTOR[1]	SHGC[2]	
Northern	≤0.27	Any	Prescriptive
	=0.28	≥0.32	Equivalent Energy Performance
	=0.29	≥0.37	
	=0.30	≥0.42	
North Central	≤ 0.30	≤ 0.40	
South Central	≤ 0.30	≤ 0.25	
Southern	≤ 0.40	≤ 0.25	

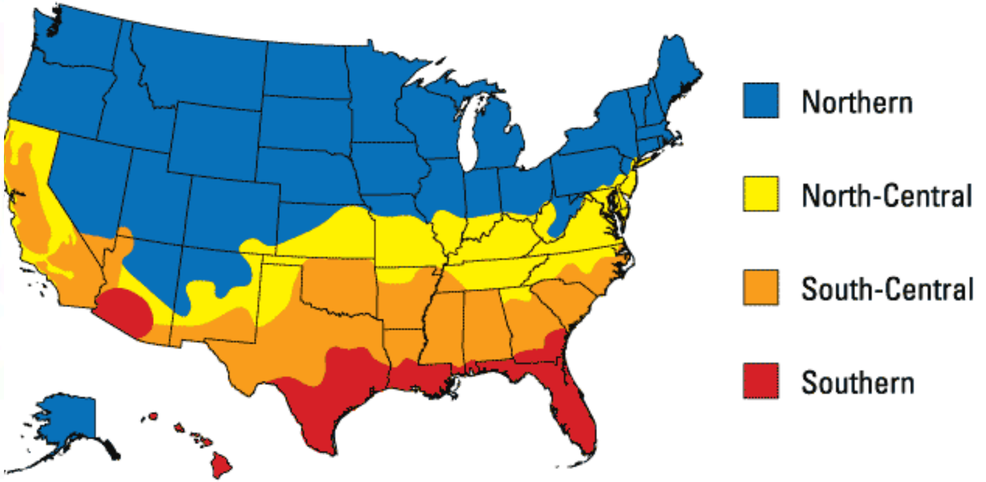


Image: Energy Star

- Windows designed for colder climate have lower U-factor and higher SHGC
- Warm climates windows perform well with higher U-factor and lower SHGC

https://www.energystar.gov/products/building_products/residential_windows_doors_and_skylights/key_product_criteria

* Source: energystar.gov

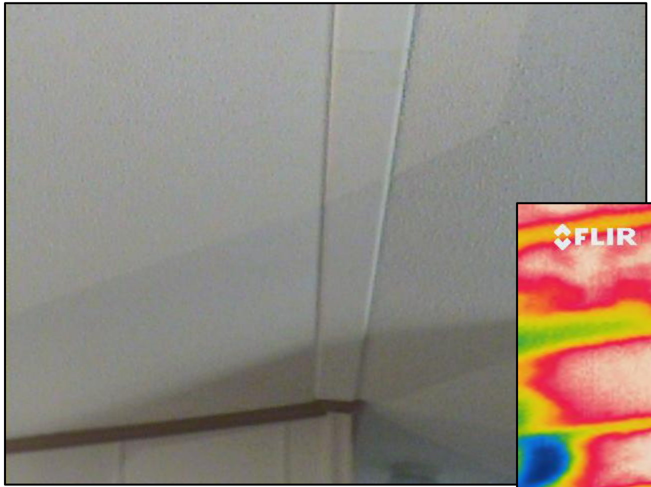
Inspecting Insulation

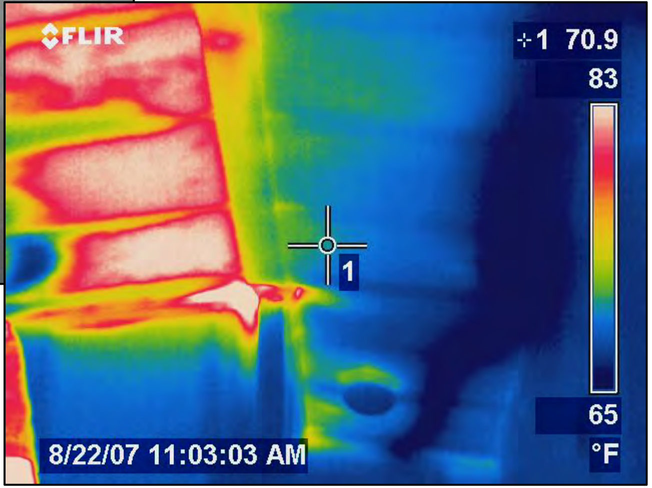
Thermal Barrier Anomalies #1

Images: FSEC

Missing (left) and crushed (right) insulation.

Thermal Barrier Anomalies #2

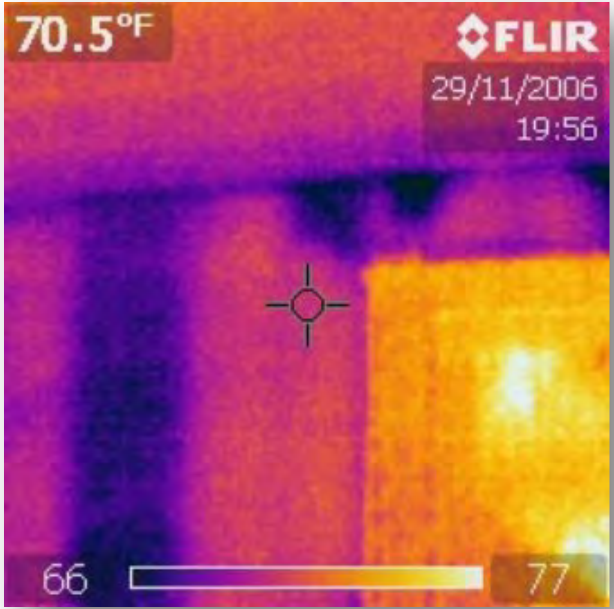




Missing ceiling insulation

Images: FSEC

Thermal Barrier Anomalies #3



Images: FSEC

Missing and crushed insulation (left) and infrared photo indicating insulation anomalies (right)

Thermal Barrier Anomalies #4

Image: U.S. EPA

Insulation misalignment due to compression caused by inset stapling and piping and wiring.

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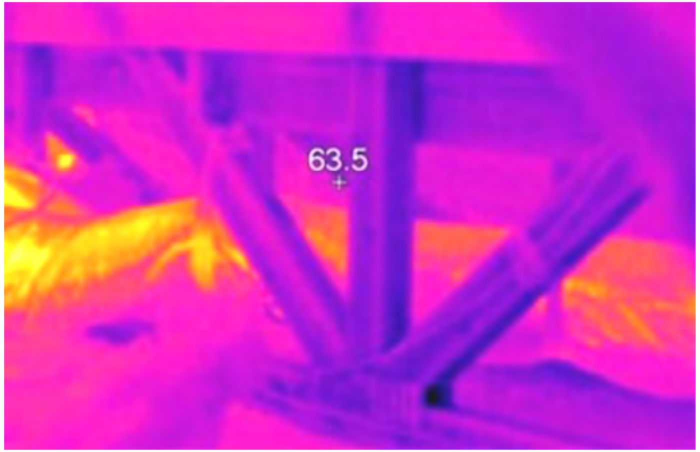
Thermal Barrier Anomalies #5

Image: FSEC

In this case inadequately supported insulation has pulled away from an attic knee wall.

Thermal Barrier Anomalies #6

"Wind washing" from missing or misaligned air and thermal barriers between floors or at top plates or band joists.



Images: Chuck Withers, FSEC

Photo and infrared image of cavity between conditioned first and second floor living spaces open to unconditioned attic. Infrared image shows a 63.5°F cavity wood surface temperature taken on a cold morning with lows of ~ 35°F while interior air temperature was 70-72°F.

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Energy Star Thermal Bypass Checklist Guide

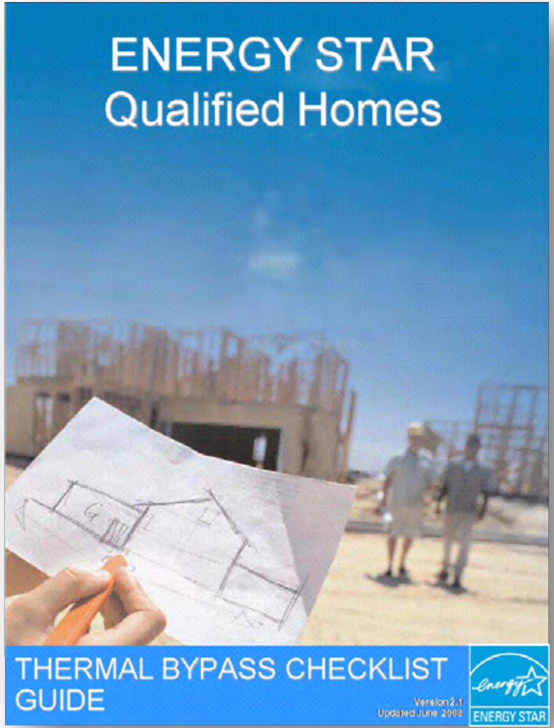

Image: U.S. EPA

ENERGY STAR has an excellent guide showing how to inspect homes for proper air and thermal barrier alignment:

- Walls Adjoining Exterior Walls or Unconditioned Spaces
- Floors Between Conditioned and Unconditioned Spaces
- Shafts
- Attic/Ceiling Interface
- Common Walls
- Thermal Bypass Checklist.

https://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/TBC_Guide_062507.pdf

Insulation Grading

The quality of insulation installation is an important aspect of home efficiency and accurate energy ratings.

The insulation grading discussion on the following frames provides a brief overview of ANSI/RESNET/ICC 301-2019 installation and grading requirements, but each student should review and be able to readily access the full requirements provided in the Standard (link provided below).

RESNET insulation grading requirements are provided in Appendix A of ANSI/RESNET/ICC 301-2019:
http://www.resnet.us/wp-content/uploads/archive/resblog/2019/01/ANSIRESNETICC301-2019_vf1.23.19.pdf.

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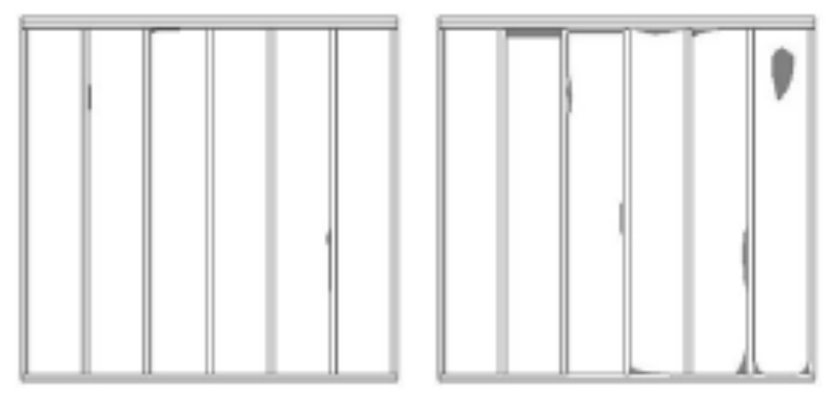
Insulation Grading-- Overview

- Minimum general installation requirements:
  - Installation per manufacturer's recommendations
  - No airspaces allowed between different insulation types or systems (exception for enclosed, reflective airspaces)
  - Installation to the required density and thickness necessary to achieve the labeled R-Value
  - Must fill around obstructions such as framing, blocking, wiring, pipes, etc. without substantial gaps or voids.

Source, and for additional requirements and exceptions see Appendix A of ANSI/RESNET/ICC 301-2019: http://www.resnet.us/wp-content/uploads/archive/resblog/2019/01/ANSIRESNETICC301-2019_vf1.23.19.pdf.

Insulation Grading– Grade I

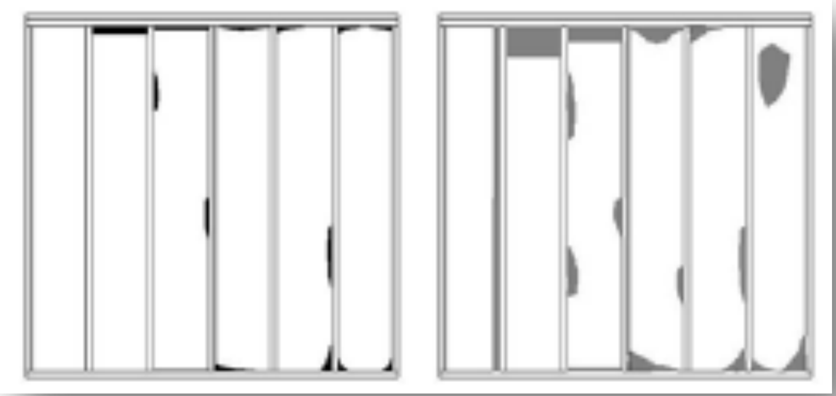
- Grade I (Minor Defects)
  - Complies with min. ASTM standard requirements
  - Batts or loose fill: no more than 2% of total insulated area compressed or containing gaps or voids
  - Spray foam depends on type (open or closed-cell), cavity fill and trimming (see reference below)
  - Insulated sheathing: no interior to exterior voids exceeding 1/8”.



Source, and for additional requirements and exceptions see Appendix A of ANSI/RESNET/ICC 301-2019: http://www.resnet.us/wp-content/uploads/archive/resblog/2019/01/ANSIRESNETICC301-2019_vf1.23.19.pdf.

Insulation Grading– Grade II

- Grade II (Moderate Defects)
  - Does not comply with min. ASTM standard requirements and Grade I requirements
  - Batts or loose fill: no more than 15% of total insulated area compressed or containing gaps or voids
  - Spray foam depends on type (open or closed-cell), cavity fill and trimming (see reference below).



Source, and for additional requirements and exceptions see Appendix A of ANSI/RESNET/ICC 301-2019: http://www.resnet.us/wp-content/uploads/archive/resblog/2019/01/ANSIRESNETICC301-2019_vf1.23.19.pdf.

Insulation Grading– Grade III

- Grade III (Substantial Defects)
  - Does not comply with applicable minimum ASTM standard requirements and Grade I or Grade II requirements.

Source, and for additional requirements and exceptions see Appendix A of ANSI/RESNET/ICC 301-2019: http://www.resnet.us/wp-content/uploads/archive/resblog/2019/01/ANSIRESNETICC301-2019_vf1.23.19.pdf.

Insulation Grading– Other

- Insulation grading criteria is also provided in ANSI/RESNET/ICC 301-2019 Appendix A for:
  - Structural insulated panels (SIPs)
  - Enclosed reflective airspaces
  - Attic radiant barriers
  - Interior Attic Radiation Control Coatings (IRCCs).

Source, and for additional requirements and exceptions see Appendix A of ANSI/RESNET/ICC 301-2019: http://www.resnet.us/wp-content/uploads/archive/resblog/2019/01/ANSIRESNETICC301-2019_vf1.23.19.pdf.

How Bad Is It?

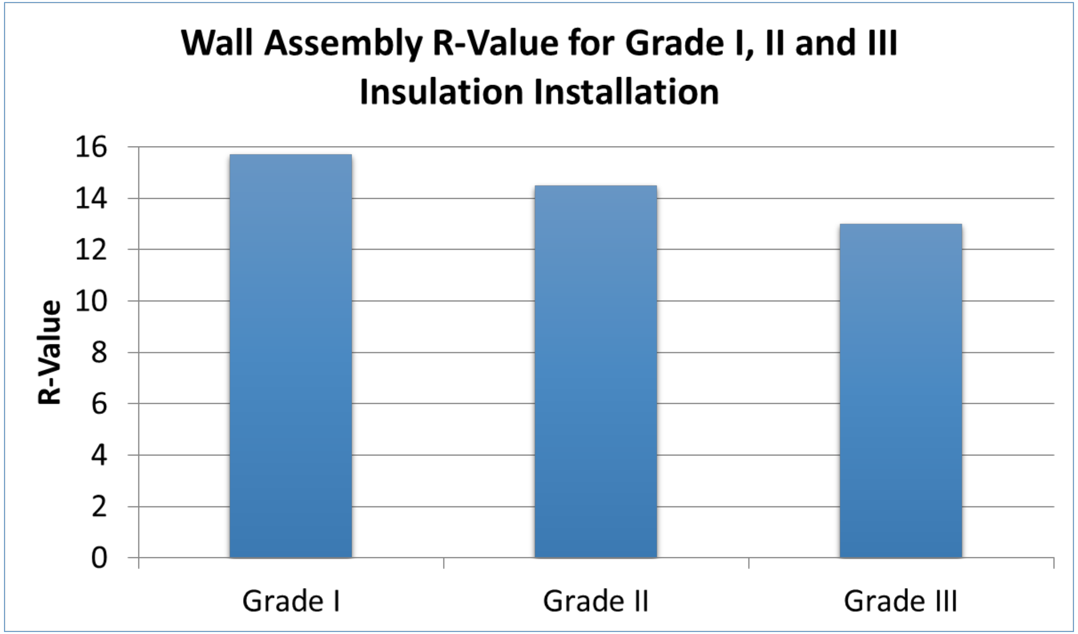


Table shows reduction in overall wall R-value for example 2x6 frame wall with R-19 insulation going from Grade I to Grade II to Grade III insulation. Accounting for framing, the Grade I wall assembly has an overall R-value of R-15.7. Grade II installation reduces the wall's overall R-value to R-14.5, and Grade III to R-13.0.

Source: Insulation Quality & Compliance Assessments -- Bruce Harley

Savings from Improved Insulation Installation

Simulated Energy Savings Going from Grade III to Grade I Ceiling and Wall Insulation for Sample 2,000 sq. ft., 2018 IECC Compliant Homes

	Orlando	Atlanta	St. Louis	Chicago	Minneapolis
IECC Climate	2	3	4	5	6
Annual Heat Gas Savings	5.6 therms	23.9 therms	41.8 therms	48.7 therms	65.5 therms
Annual Cooling Electric Savings	144 kWh	93 kWh	78 kWh	57 kWh	45 kWh
Total Annual Savings	$23	$37	$57	$61	$80

Table: FSEC

Grade 1 Batt Insulation

- Careful installation of all insulating systems are essential for good performance.

Image: U.S. EPA

Faced Fiberglass Batts

Grade 1 Cellulose Insulation

Image: U.S. EPA

Blown Cellulose

Grade 1 Spray Foam Insulation

Image: FSEC

Spray Foam

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Grade 1 Blown Ceiling Insulation

Image: FSEC

Blown Fiberglass

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Insulation Summary

- Maximize R-value
  - Grade I Installations.
- Minimize air movement through insulation
  - All sides need air barrier.

Image: FSEC

Moisture Movement

Moisture Movement

The Moisture Movement lesson will focus on building moisture sources, moisture forms (liquid and vapor) and movement mechanisms.

Building Moisture Sources

- Bulk moisture (i.e., rain water & ground water)
- Internally generated moisture
- Diffusion thru building envelope materials
- Infiltration of moisture-laden outside air
- Ventilation air
- Capillary flows

Mechanisms

Moisture movement occurs in both liquid and vapor forms.

- Liquid form via:
  - Bulk flow
  - Capillary suction
- Vapor form via:
  - Air transport
  - Diffusion

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Bulk Flow

Bulk flow moisture movement is groundwater & rainwater moving under the influence of a driving force such as gravity or air pressure.

Image: FSEC

Capillary Suction

Capillary suction is liquid form moisture movement into porous materials; is a function of pore size and available moisture.

The mold staining shows where standing water was drawn into the drywall behind a bathtub via capillary suction.

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Air Transport

Air Transport is vapor form moisture movement where air that holds moisture moves across a hole by an air pressure difference, carrying the moisture with it.

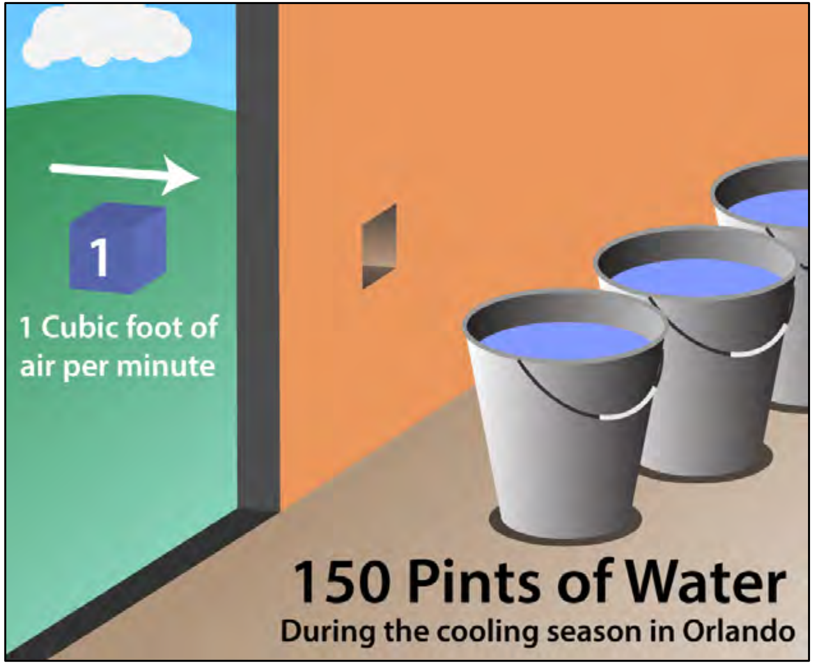
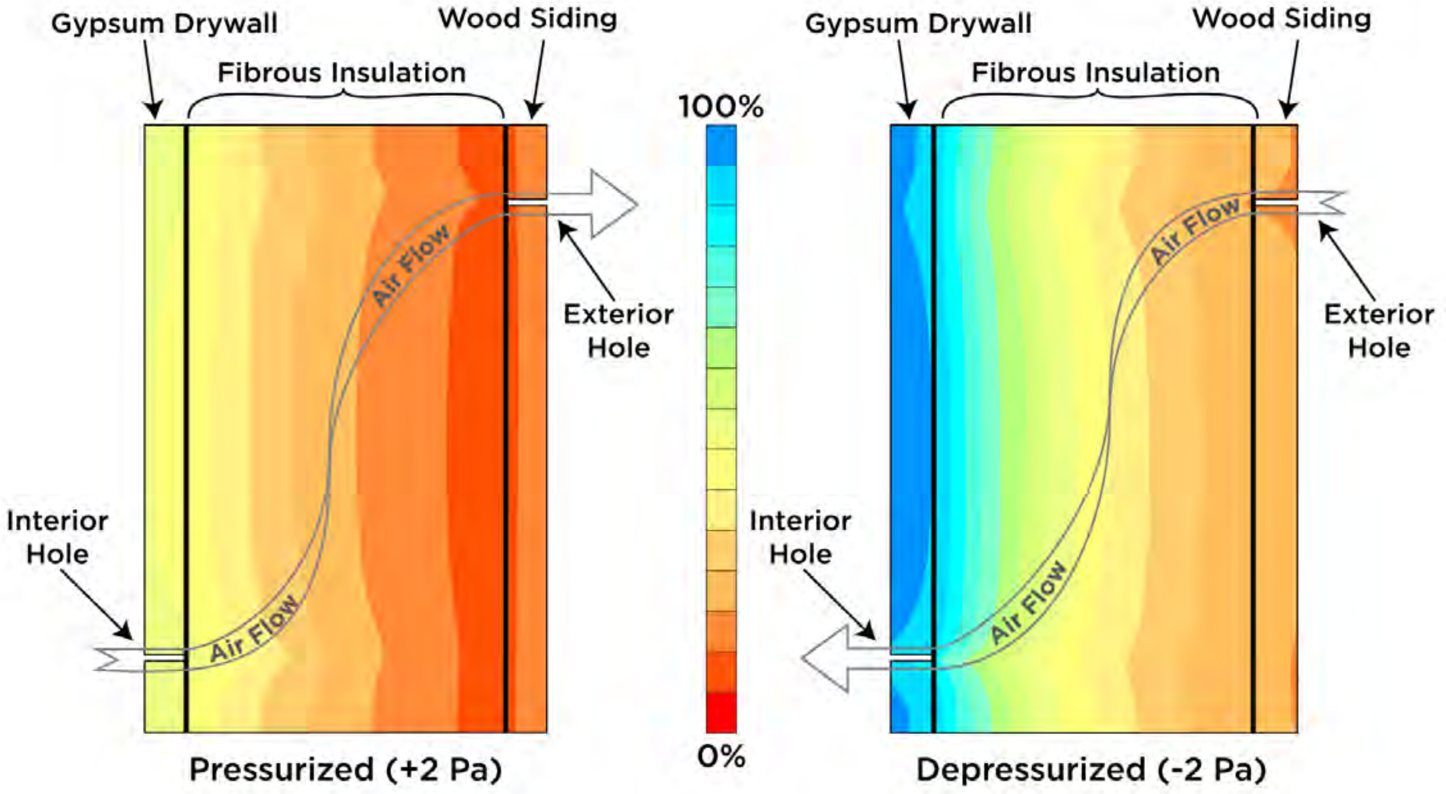


Image: FSEC

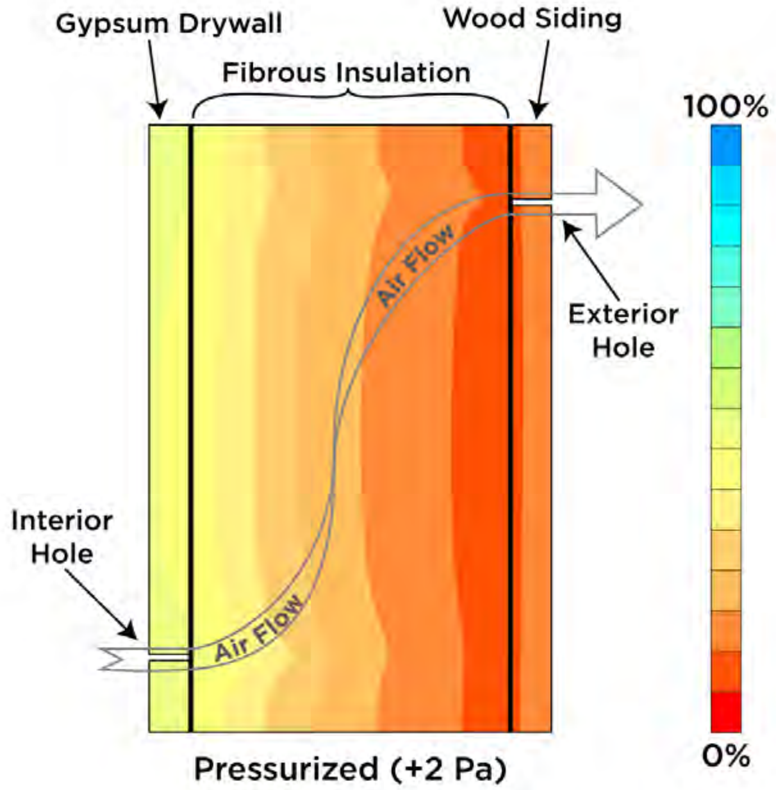
Depending on the climate zone and season, air transport can introduce significant amounts of water into a building.

Air Transport: Pressurized vs Depressurized



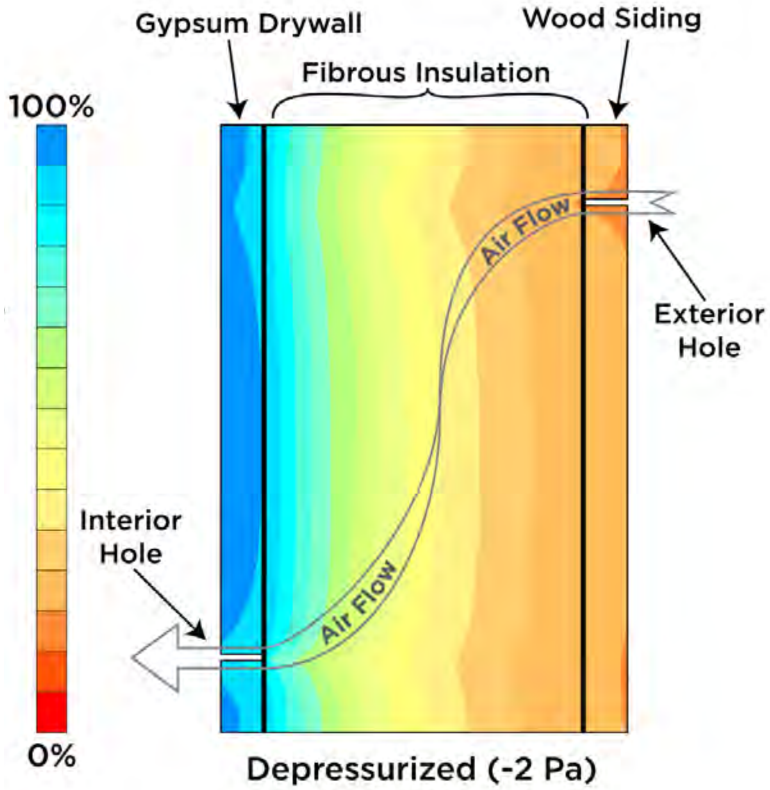
Condition 1 *Condition 2*

Pressurized



Condition 1

Depressurized



Condition 2

Moisture Movement: Diffusion

Diffusion is vapor form moisture movement through a material. It is a function of material permeability and vapor pressure differential.

Image: FSEC

Moisture diffusion through this drywall resulted in mold growth when the vinyl wallpaper (vapor barrier) kept it inside the wall.

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Moisture Control

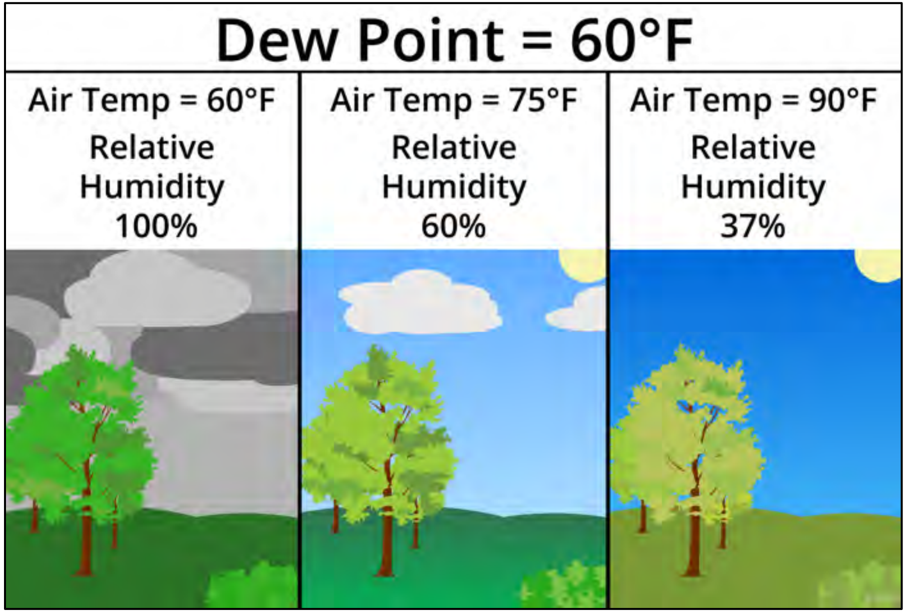
- **Moisture** must be available
- There must be a **pathway**
- There must be a **force** to cause movement
- **Materials** must be susceptible to damage

- Theory-- totally **eliminate** any one of the above for complete control
- Reality-- take **control** of as many as possible and to the extent possible.

Relative Humidity and Dew Point

Two important, related moisture concepts are relative humidity and dew point:

- Relative humidity (RH) is the amount of water vapor present in the air relative to the highest amount of water vapor that the air can hold at the same temperature
  - Relative humidity changes as the air temperature changes (see illustration).
- Dew point is the temperature at which water vapor is saturated, and below which it begins to condense
  - The air temperature cannot go below the dew point– if the air temperature is the same as the dew point, the RH is 100%.



Warmer air can hold more moisture, so if there are no changes to the actual moisture content of the outdoor air, the relative humidity will decrease as the air temperature increases and increase as the air temperature decreases.

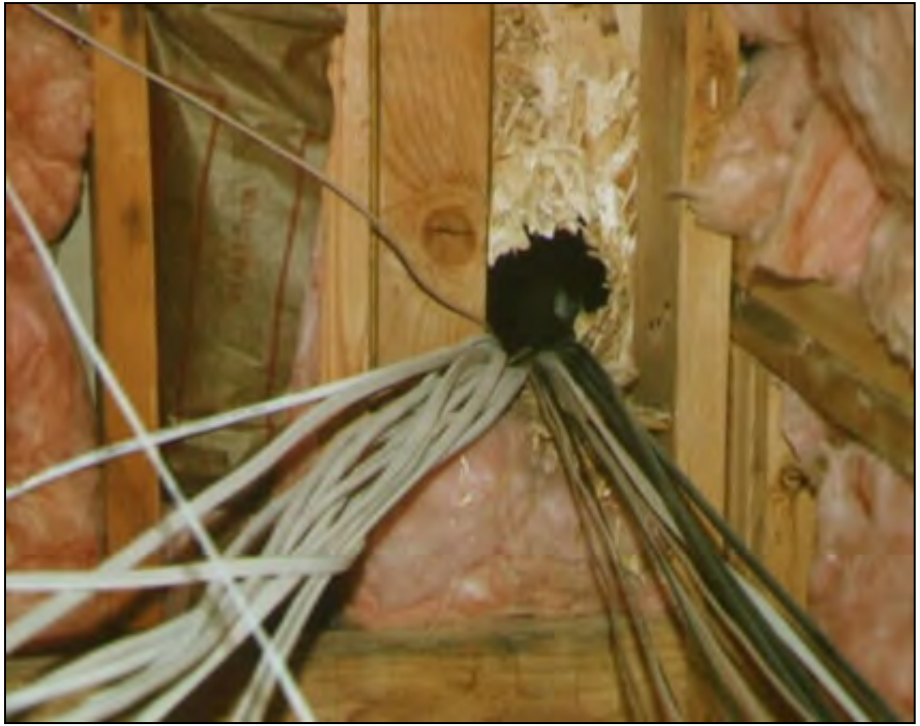
Uncontrolled Airflow

Uncontrolled Airflow (UAF)

The Uncontrolled Airflow lesson will focus on defining uncontrolled airflow, how it occurs in buildings, and building failure issues associated with it. The lesson will also discuss the “building as a system” concept.

Uncontrolled Airflow Definition

Uncontrolled airflow is air moving across the building envelope or between zones or cavities of the building, where the pathways of flow, the direction of flow, and the origin of the air are unknown, unspecified, or unintended.



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Types of UAF: Example 1

Duct leakage, such as this branch duct collar separating from a main trunk, is a form of uncontrolled airflow.

Types of UAF: Example 2

Discoloration of insulation indicates attic air is being pulled into a return side duct leak.

Types of UAF: Example 3

Photo and infrared image of wall with return plenum and air handler behind it; infrared image shows hot air from the attic being drawn down the wall cavity into the return air.

Image: FSEC

Types of UAF: Example 4

Uncontrolled airflow can also be caused by pressure differences inside a house resulting from closing interior doors when doing so restricts the air supplied to a room via a forced air system from returning to a central air handler.

Image: FSEC

Researcher measuring the air pressure between a den and the main body of a house with a forced air system.

Moisture

In addition to causing higher energy use and decreased comfort, uncontrolled air flow can also create building durability and health and safety issues. Here interior drywall in a manufactured home is buckling due to moisture issues resulting from failure to connect an air duct between the two halves of the home.

Image: FSEC

Mold/Mildew

Image: FSEC

Here mold/mildew contamination is caused by the return side of a forced air system depressurizing wall cavities which brought unconditioned outside air into the cavities which then condensed as it came in contact with a vinyl wall surface.

Flame Rollout

Image: FSEC

An atmospherically vented gas water heater shows evidence of flame rollout caused by uncontrolled airflow which significantly depressurized the area where the water heater is located relative to the outside.

Pressure Relief

Uncontrolled airflow caused by interior door closure can be reduced or eliminated by providing pressure relief via door undercuts, transfer ducts and ducted returns.

Image: FSEC

Ceiling mounted transfer duct providing pressure relief between a bedroom (left side of photo) and the main body of the house (right side).

The Building as a System

An important concept to understand related to uncontrolled airflow is that a building is a system– meaning that there are numerous interactions within the building envelope and between the envelope and equipment installed in a building.

We'll use forced air system duct leakage as an example to further explore these interactions, contrasting a system with little leakage to systems with significant supply or return leaks.

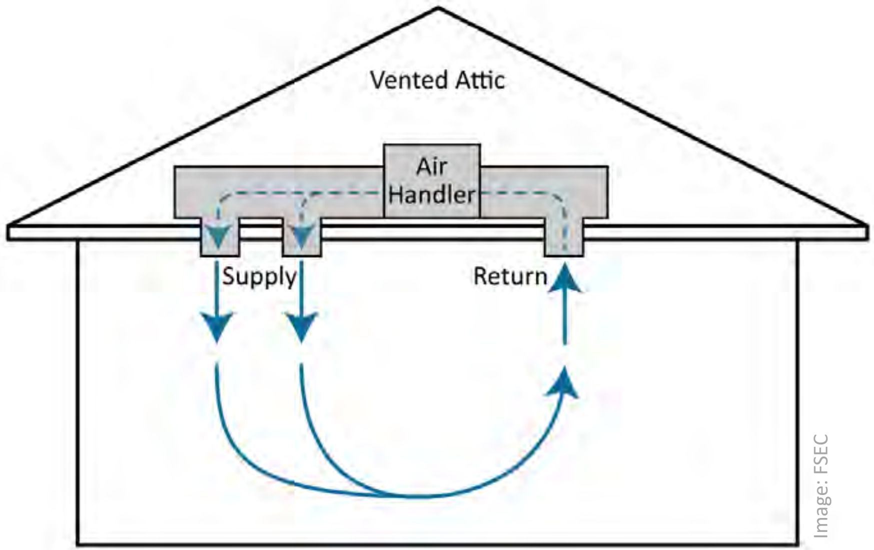
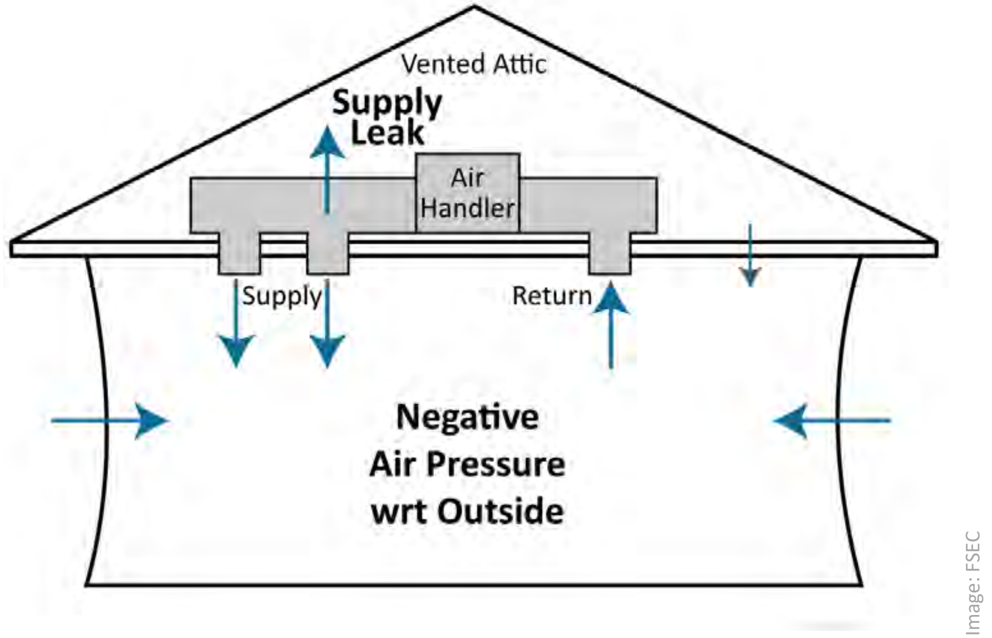


Image: FSEC

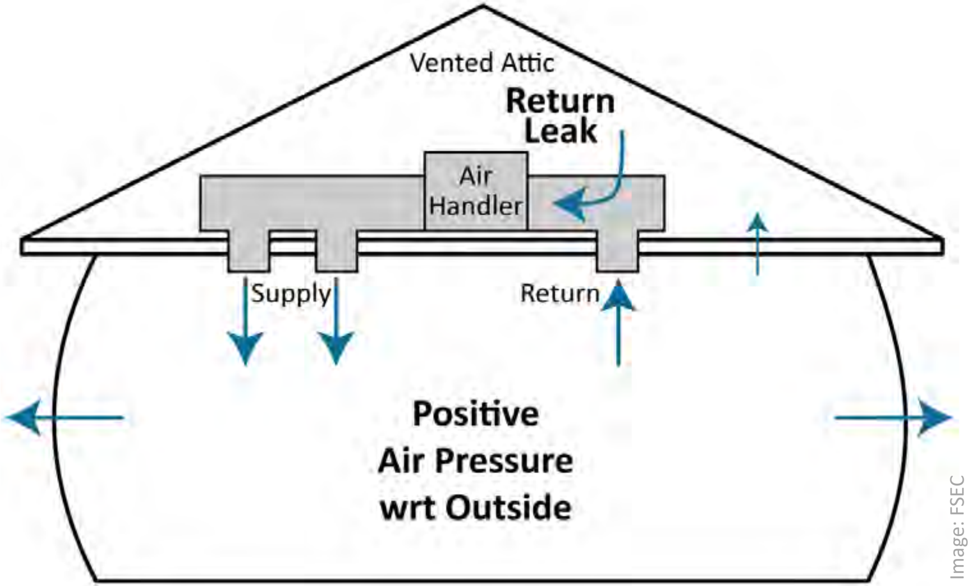
A forced air system with minimal door closure restrictions and duct air leakage allows an uninterrupted air flow loop. Such a system creates only minimal pressure changes in the building with respect to outside, in turn not significantly increasing indoor to outdoor air exchange (infiltration).

Supply Leak



In the case of supply side duct leaks, some air is not delivered to conditioned space while the return side continues to draw the same amount of air from the space, so the house is depressurized with respect to (wrt) the outside, increasing outside air infiltration through cracks and gaps in the building envelope.

Return Leak



Return side duct leaks result in outside (and/or garage or attic) air being brought into the forced air system's distribution loop. This excess air source means not as much air is being pulled from conditioned space, causing the main body of the house to pressurize wrt the outside, increasing leakage of conditioned air through cracks and gaps in the building envelope.

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Performance Testing Training

Uncontrolled airflow can be difficult to identify and measure without specialized training and tools, often leading to at best ineffective “Band-Aid” mitigation measures.

Energy raters are trained to perform pressure measurements and building and duct air leakage tests which can quantify uncontrolled airflow and when needed, provide a first step toward proper mitigation.

Image: FSEC

A building air leakage test underway.

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