Fundamentals of Building Science: Heat Transfer & Insulation

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Energy Code Resources

Missouri Residential Building Energy Code Construction Practices Study:
https://energy.mo.gov/energy-codes/missouri-residential-building-codes-study
For additional information on other DOE Field Studies and participating states, please visit https://www.energycodes.gov/compliance/energy-code-field-studies.
Additional education resources are available at www.southfaceonlinetraining.org.

www.southface.org => Resources => GA Energy Code Resources

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402.4.1.1 Air sealing checklist (required)

TABLE R402.4.1.1
AIR BARRIER AND INSULATION INSTALLATION*

COMPONENT	AIR BARRIER CRITERIA	INSULATION INSTALLATION CRITERIA
General requirements	A continuous air barrier shall be installed in the building envelope. The exterior thermal envelope contains a continuous air barrier. Breaks or joints in the air barrier shall be sealed.	Air-permeable insulation shall not be used as a sealing material.
Ceiling/attic	The air barrier in any dropped ceiling or soffit shall be aligned with the insulation and any gaps in the air barrier shall be sealed. Access openings, drop down stairs or knee wall doors to unconditioned attic spaces shall be sealed.	The insulation in any dropped ceiling/soffit shall be aligned with the air barrier.
Walls	The junction of the foundation and sill plate shall be sealed. The junction of the top plate and the top of exterior walls shall be sealed. Knee walls shall be sealed.	Cavities within corners and headers of frame walls shall be insulated by completely filling the cavity with a material having a thermal resistance, *R*-value, of not less than R-3 per inch. Exterior thermal envelope insulation for framed walls shall be installed in substantial contact and continuous alignment with the air barrier.
Windows, skylights and doors	The space between framing and skylights, and the jambs of windows and doors, shall be sealed.	—
Rim joists	Rim joists shall include the air barrier.	Rim joists shall be insulated.
Floors, including cantilevered floors and floors above garages	The air barrier shall be installed at any exposed edge of insulation.	Floor framing cavity insulation shall be installed to maintain permanent contact with the underside of subfloor decking. Alternatively, floor framing cavity insulation shall be in contact with the top side of sheathing, or continuous insulation installed on the underside of floor framing; and shall extend from the bottom to the top of all perimeter floor framing members.
Crawl space walls	Exposed earth in unvented crawl spaces shall be covered with a Class I vapor retarder with overlapping joints taped.	Crawl space insulation, where provided instead of floor insulation, shall be permanently attached to the walls.

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402.4.1.1 Air sealing checklist (required)

TABLE R402.4.1.1
AIR BARRIER AND INSULATION INSTALLATION[a]

Shafts, penetrations	Duct shafts, utility penetrations, and flue shafts opening to exterior or unconditioned space shall be sealed.	—
Narrow cavities	—	Batts to be installed in narrow cavities shall be cut to fit or narrow cavities shall be filled with insulation that on installation readily conforms to the available cavity space.
Garage separation	Air sealing shall be provided between the garage and conditioned spaces.	—
Recessed lighting	Recessed light fixtures installed in the building thermal envelope shall be sealed to the finished surface.	Recessed light fixtures installed in the building thermal envelope shall be air tight and IC rated.
Plumbing and wiring	—	In exterior walls, batt insulation shall be cut neatly to fit around wiring and plumbing, or insulation, that on installation readily conforms to available space, shall extend behind piping and wiring.
Shower/tub on exterior wall	The air barrier installed at exterior walls adjacent to showers and tubs shall separate the wall from the shower or tub.	Exterior walls adjacent to showers and tubs shall be insulated.
Electrical/phone box on exterior walls	The air barrier shall be installed behind electrical and communication boxes. Alternatively, air-sealed boxes shall be installed.	—
HVAC register boots	HVAC supply and return register boots that penetrate building thermal envelope shall be sealed to the subfloor, wall covering or ceiling penetrated by the boot.	—
Concealed sprinklers	Where required to be sealed, concealed fire sprinklers shall only be sealed in a manner that is recommended by the manufacturer. Caulking or other adhesive sealants shall not be used to fill voids between fire sprinkler cover plates and walls or ceilings.	—

a. Inspection of log walls shall be in accordance with the provisions of ICC 400.

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Who are you?

A. Weatherization
B. HERS Rater
C. Code official
D. Designer/Engineer
E. Contractor/Builder/Sub
F. Utility
G. Manufacturer/Product Rep
H. Policy / Government
I. Facilities
J. Home Inspector

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Why building science?

- Employ scientific principles from a variety of fields that govern building performance
- Optimize building performance and understand, prevent and correct building failures
- Systems approach to houses
- Physics of Heat, Air & Moisture

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The house as a system

- A house is a system made up of interrelated parts:
- The building thermal envelope
- Space conditioning
- Ventilation
- Water heating & distribution
- Lighting & appliances

The human factor

- It’s not just about energy efficiency
- Many efficiency measures also improve comfort, health and reduce maintenance
- All efficiency measures should take occupants into account (e.g. air sealing & ventilation)

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Building Science: Heat transfer

- Heat is a form of energy
- Heat moves from hot to cold
- 3 methods of heat transfer:
  - **Radiation:**
    Heat emits from a hot surface or hot object, e.g. hot coals
  - **Conduction:**
    Heat moves through a material by contact, e.g. the grill grates
  - **Convection:**
    Heat energy carried by a fluid, e.g. the air inside the covered grill

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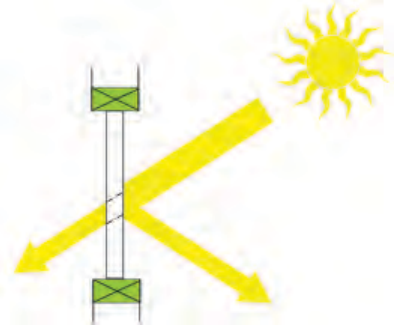
Heat transfer: Radiation



- **Radiation** is the movement of heat from a hot surface to a cooler surface with nothing solid or opaque in between

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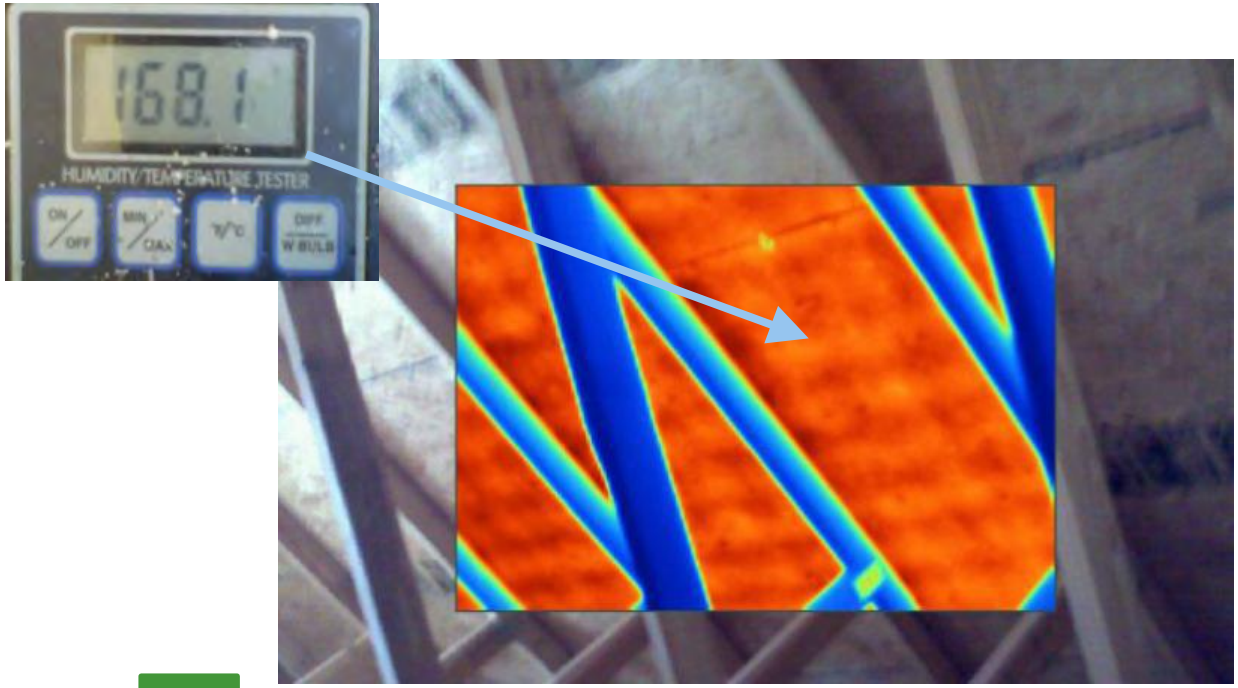
Heat transfer: Radiation

- Low-emitting surfaces slow radiation



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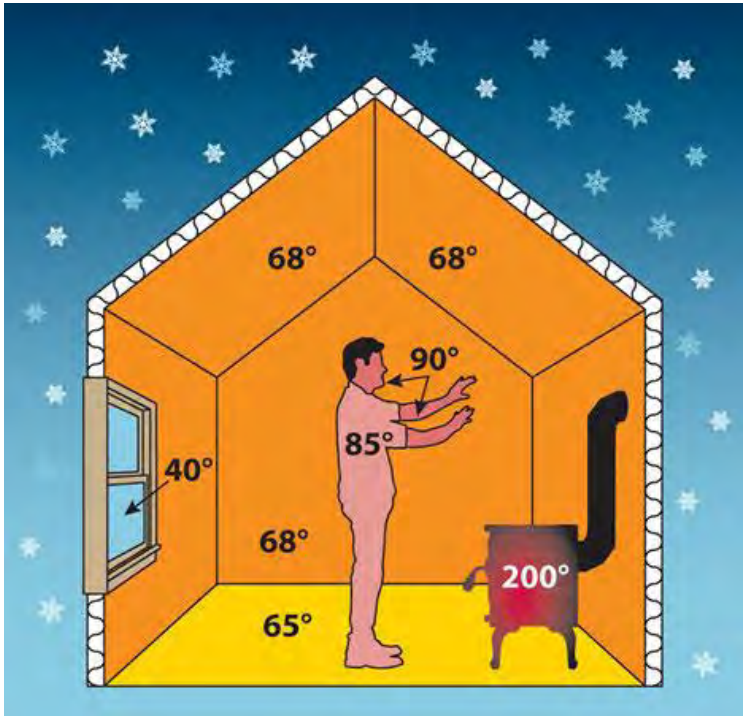
Mean radiant temperature

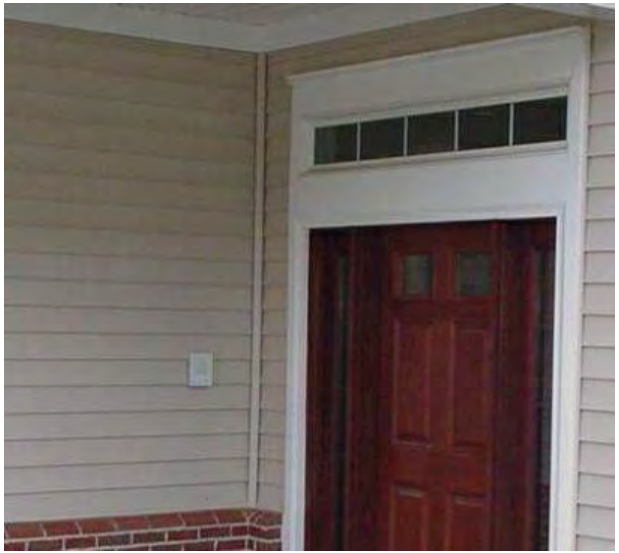


- When the surfaces in the home (walls, floors, ceilings, windows, and doors), are different than the room air temperature, additional body heat can be lost or gained through radiation.
- This can have a major impact on comfort

$(T_H\text{^}4 - T_L\text{^}4) = (660\text{^}4 - 550\text{^}4) = (190\text{Billion} - 91\text{Billion}) = 100\text{Billion}$

Heat transfer: Conduction

- **Conduction** is heat flowing through a solid material (insulation slows conduction)



Infrared Imaging

BEFORE

AFTER

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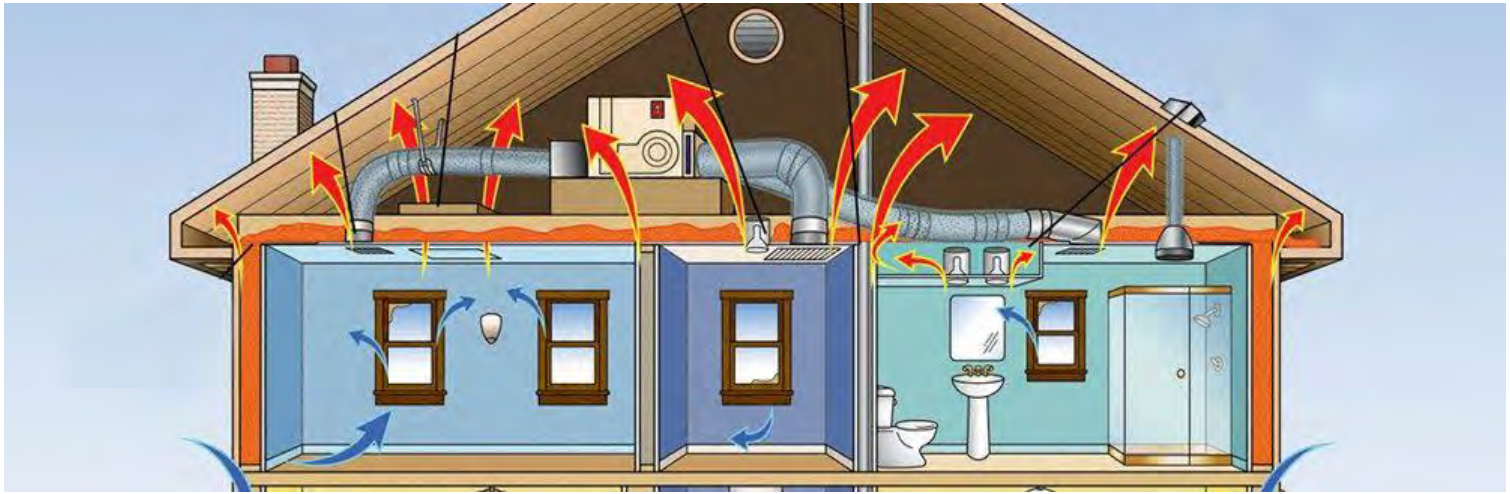
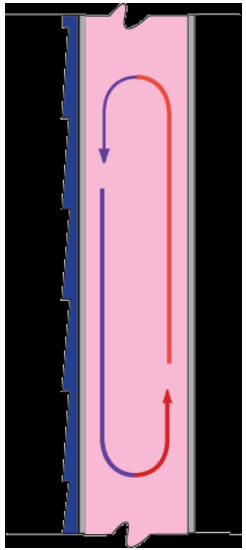
Heat transfer: Convection

Convection is the transfer of heat caused by the movement of a fluid, like water or air (air barriers slow convection)

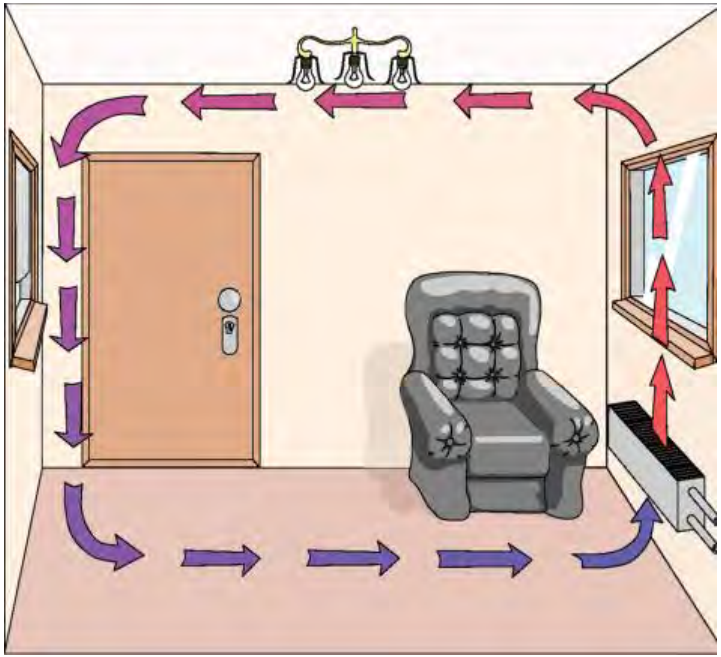


Convective Loop



- Air movement due to temperature and pressure gradients
- Air rises along warm surface and falls along cold surface
- Creates circular movement of air within enclosed space

  (wall cavity, band between floors, even a room within living space!)
- Increases heat flow and can reduce insulation effectiveness



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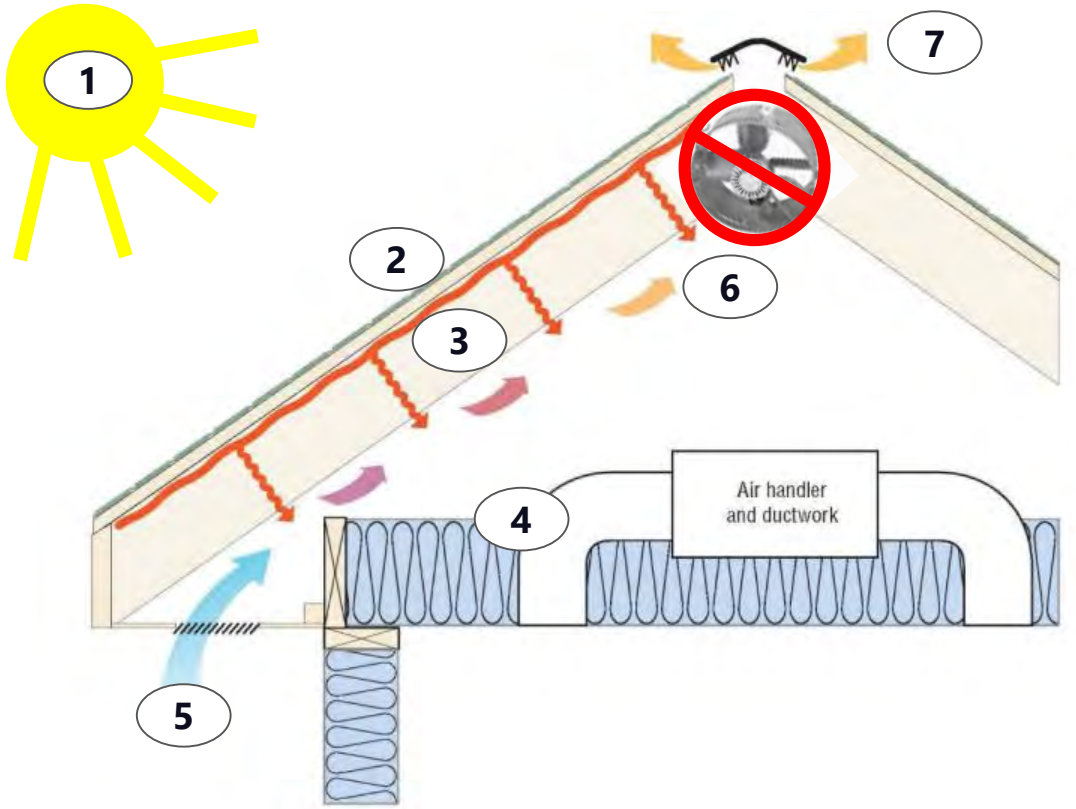
Heat Transfer Problem



Your Choices:

Radiation

Conduction

Convection

1 → 2 = Radiation

2 → 3 = Conduction

3 → 4 = Radiation

5 → 6 → 7 = Convection

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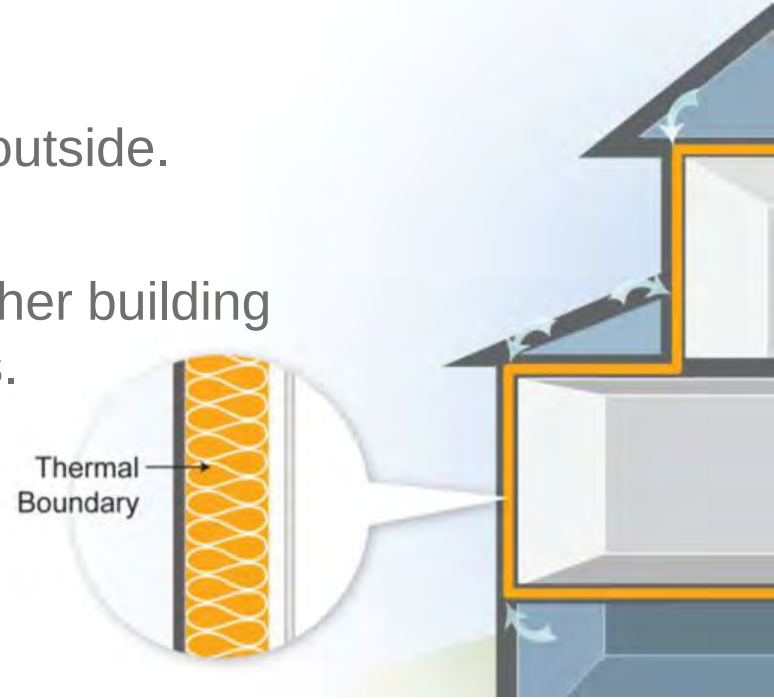
Graphic developed for the US DOE WAP Standardized Curricula

Thermal Boundary

- Limits heat transfer between inside and outside.
- Identified by the 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 half.



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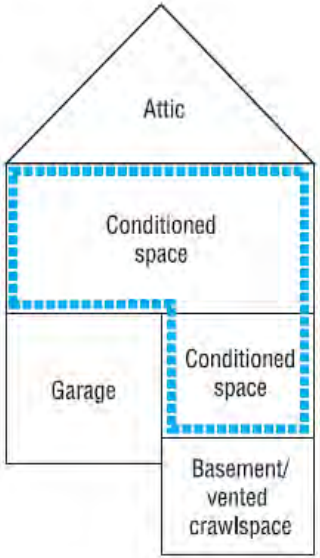
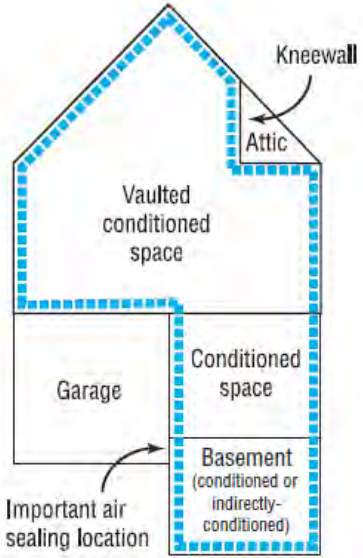
Building Thermal envelope

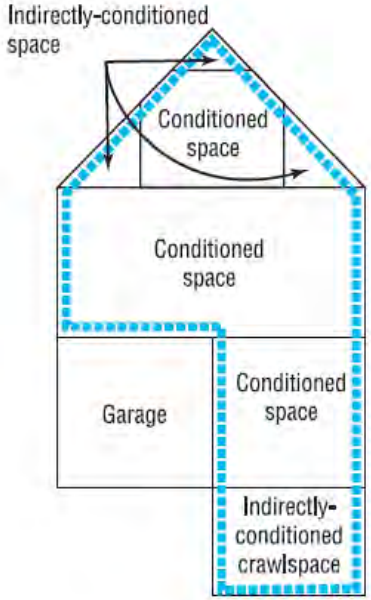
Example 1



Example 2



Example 3



- Although these three homes look identical from the outside, each has defined the building thermal envelope differently

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Spray foam rooflines

There are multiple ways of defining the building thermal envelope.

What's the advantage when a home's envelope is defined by the roof, not the flat ceiling?

Heat Flow Calculations

Convection Heat Flow

- Heat transfer through a fluid (liquid or gas) – usually air. For air, the formula for calculating convective heat transfer is

$$q = 1.08 \times CFM \times \Delta T$$ = convective heat flow (Btu/hr)

- CFM = Cubic Feet per Minute of air being transported
- ΔT = temperature difference of entering air and ambient air (°F)

  Example:
  A supply fan delivers 50 cfm of OA into a 75°F home when the ambient is 90°F.
  Sensible heat added is q = 1.08 x 50 x (15) = 810 Btu / hr

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Conduction Heat Flow Calculations

- Heat transfer through a solid object: the formula for calculating transmission heat loss is:
  - **$q = U \times A \times \Delta T$**
- q = heat flow (Btu/hr)
- U = inverse of R-Value [U=1/R, R=1/U] (Btu/hr ft^2°F)
- U is referred to as the *Conductance* or *Thermal Transmittance*
- A = area (square feet)
- ΔT = temperature difference across component (°F)

Btu = British Thermal Unit

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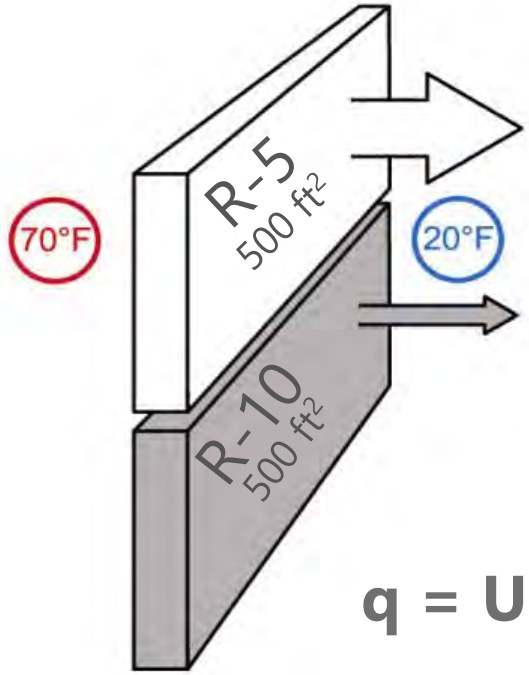
Conduction Example



q = U x A x ΔT

Low R-value (R-5)

- (1/5) x 500 x (70-20) = 5,000 Btu/hr

High R-value (R-10)

- (1/10) x 500 x (70-20) = 2,500 Btu/hr

Total = 7,500 Btu/hr

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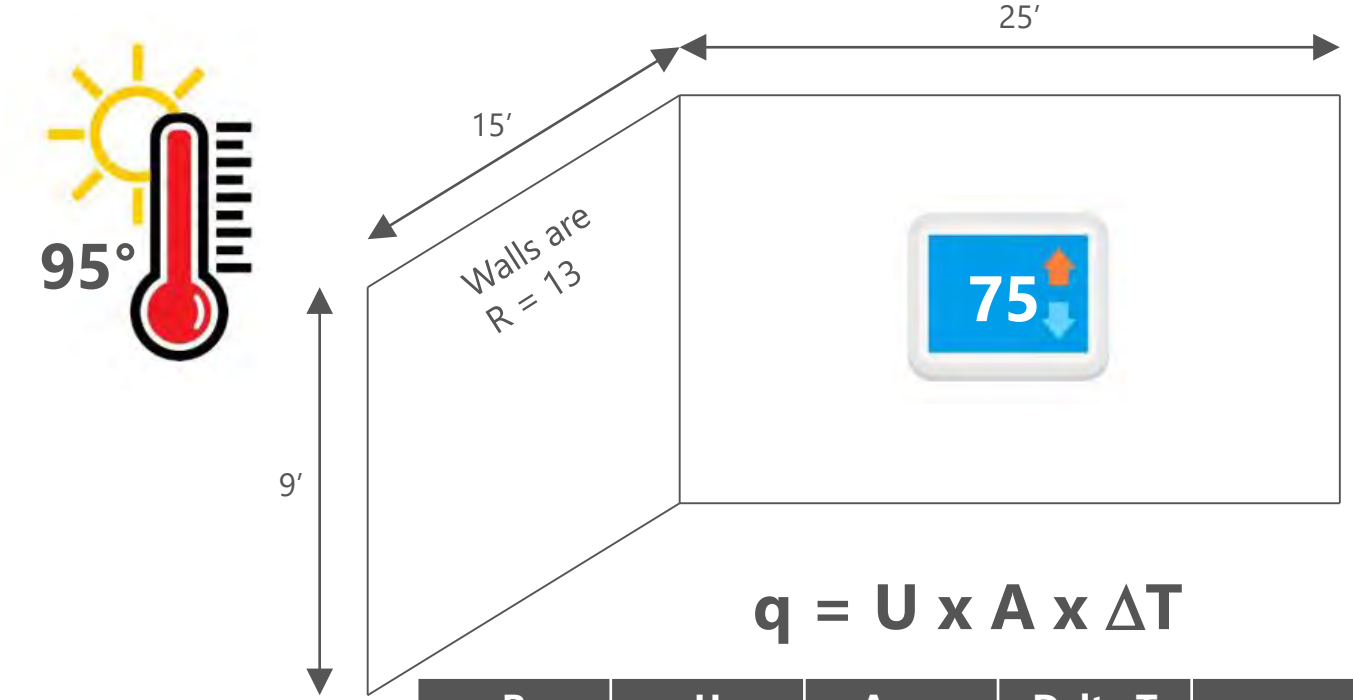
Gross Wall Area Example



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

R	U	Area	Delta T	q
13	.077	360	20	554 Btu/hr

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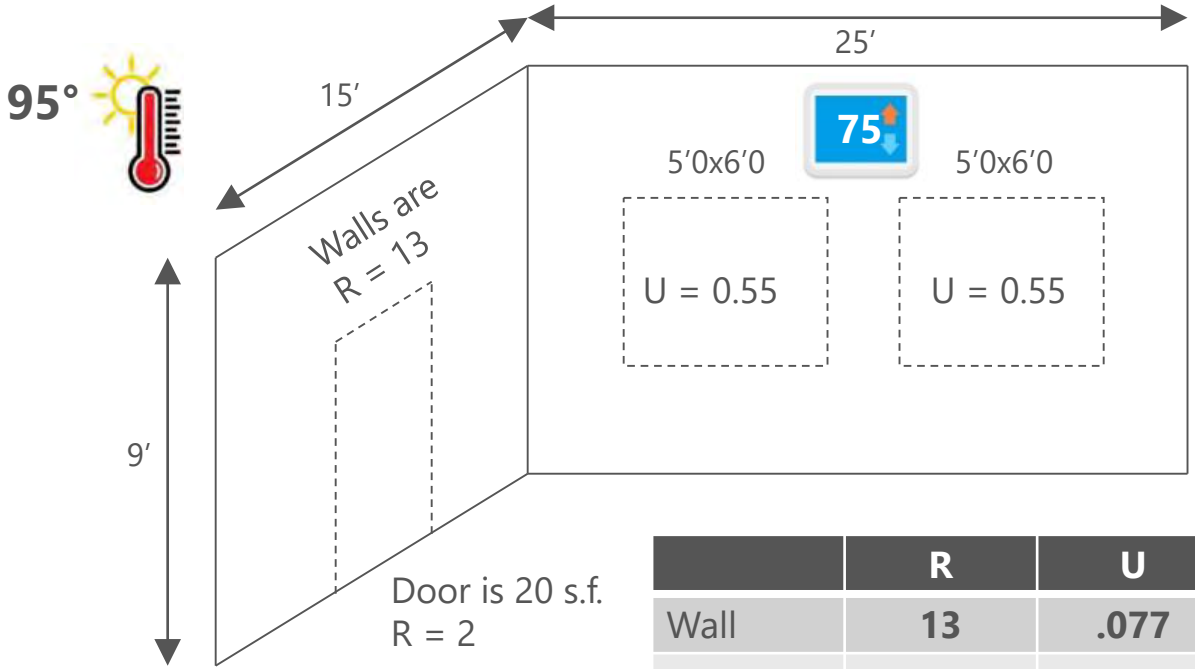

(1/13) x 360 x 20 = **554**

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

	R	U	Area	Delta T	q
Wall	13	.077	280	20	431Btu/hr
Door	2	.5	20	20	200Btu/hr
Window	1.8	.55	60	20	660Btu/hr

1291 Btu/hr

Net Wall Area Example

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Poll Question

- Which of these is NOT needed to calculate heat transfer?

a) Area

b) Delta T

c) U-Factor

d) Material Density

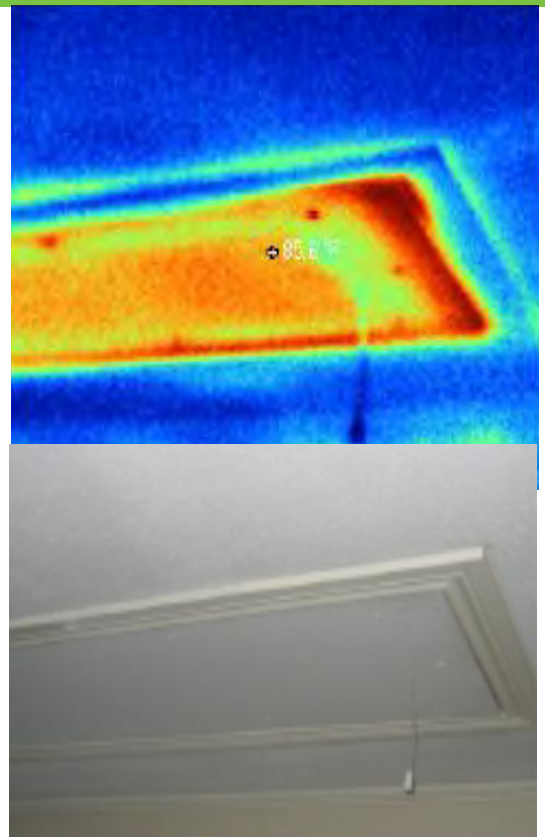
Insulation Coverage is key!

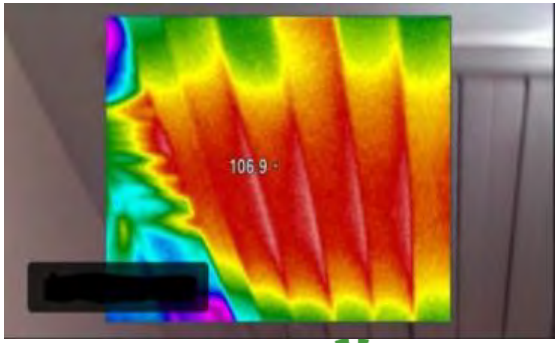
- If 990 s.f. of R-38 is installed with 10 s.f. of uninsulated attic access (R-1), it effectively yields the same heat transfer as R-28!

$$U_{avg} = \frac{U_1 \times A_1 + U_2 \times A_2 + U_3 \times A_3}{A_{total}}$$

$$U_{avg} = \frac{0.026 \times 990 + 1 \times 10}{1000}$$

$$U_{avg} = \mathbf{0.036} \qquad \mathbf{R = 27.7}$$





Insulation Coverage is Key!

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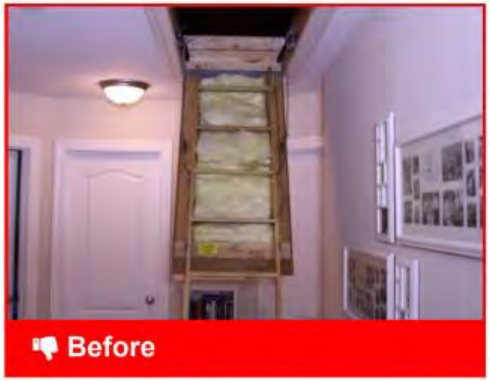
Attic Pull-down stairs



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- Access Doors and Hatches

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