Peter Baker

Building Physics

November 16, 2017

Building Science Corporation

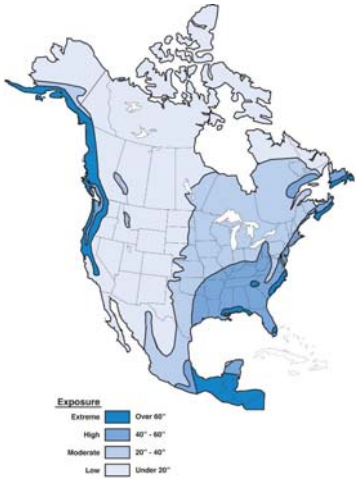
AIA New Hampshire

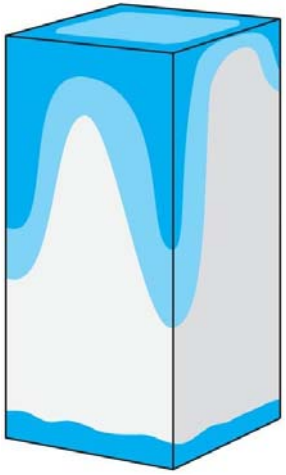
What is a Building?

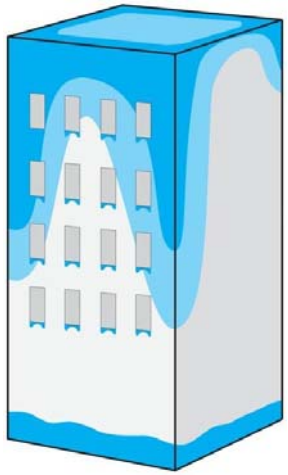
A Building is an Environmental Separator

- Control heat flow
- Control airflow
- Control water vapor flow
- Control rain
- Control ground water
- Control light and solar radiation
- Control noise and vibrations
- Control contaminants, environmental hazards and odors
- Control insects, rodents and vermin
- Control fire
- Provide strength and rigidity
- Be durable
- Be aesthetically pleasing
- Be economical

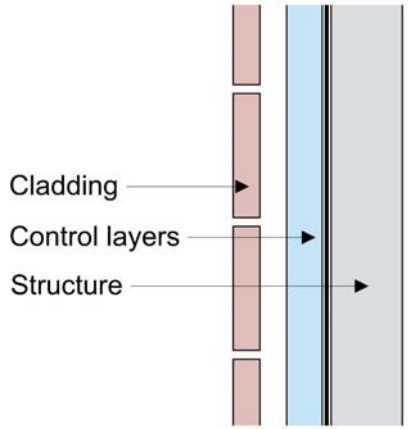
Damage Functions
Water
Heat
Ultra-violet Radiation

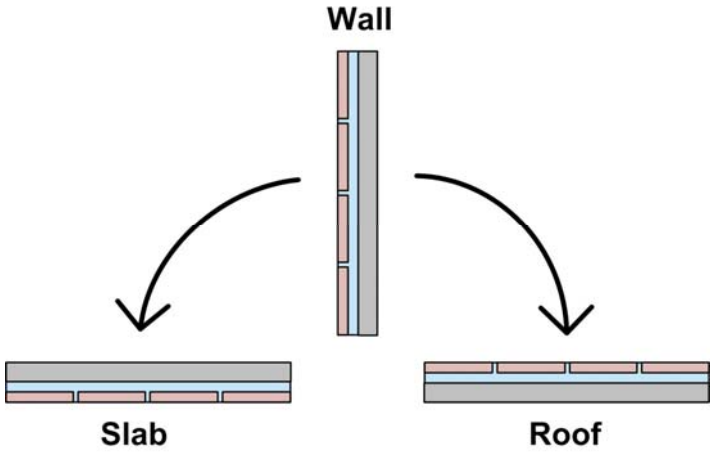


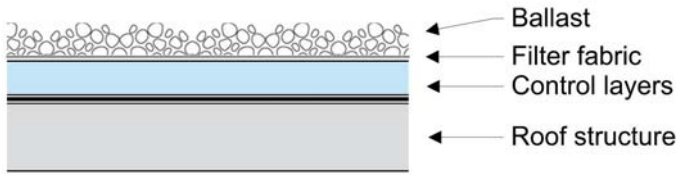




Water Control Layer
Air Control Layer
Vapor Control Layer
Thermal Control Layer







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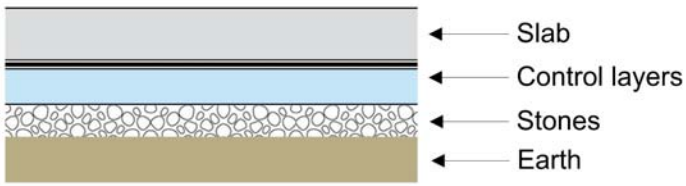

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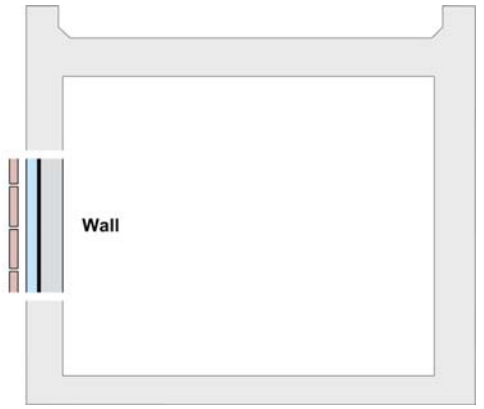

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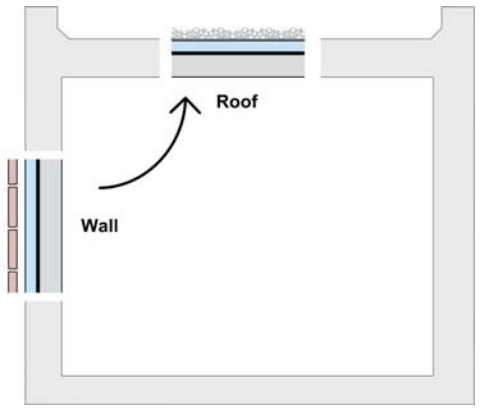

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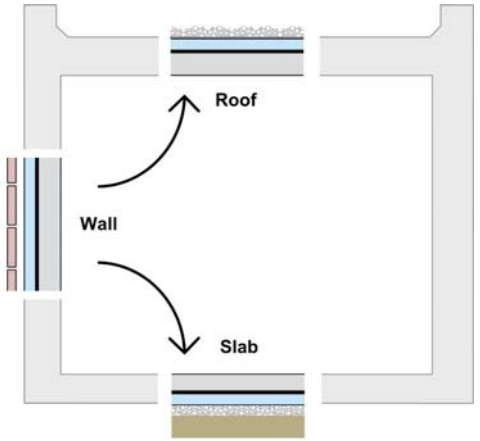
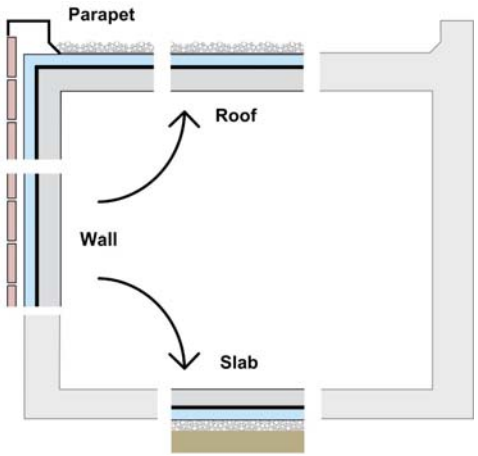
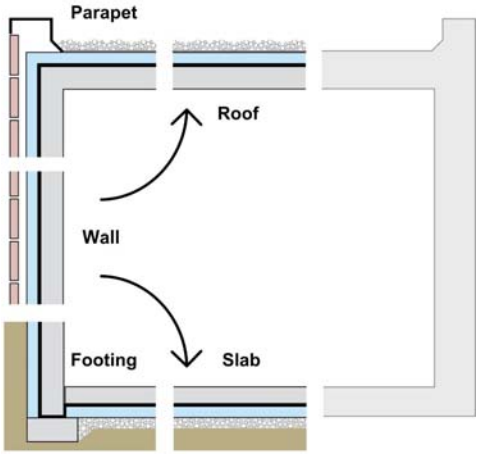


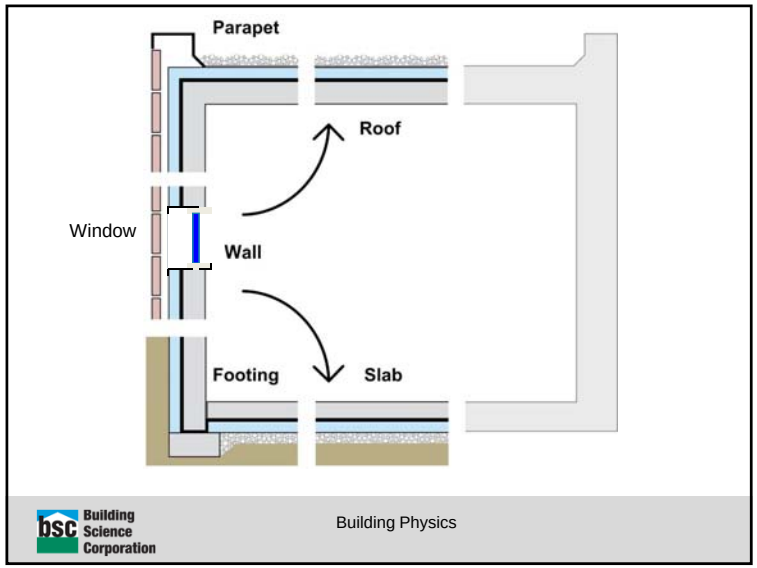
Building Science Corporation Building Physics



Building Science Corporation Building Physics



Building Science Corporation Building Physics


Parapet
Roof
Window
Wall
Footing
Slab
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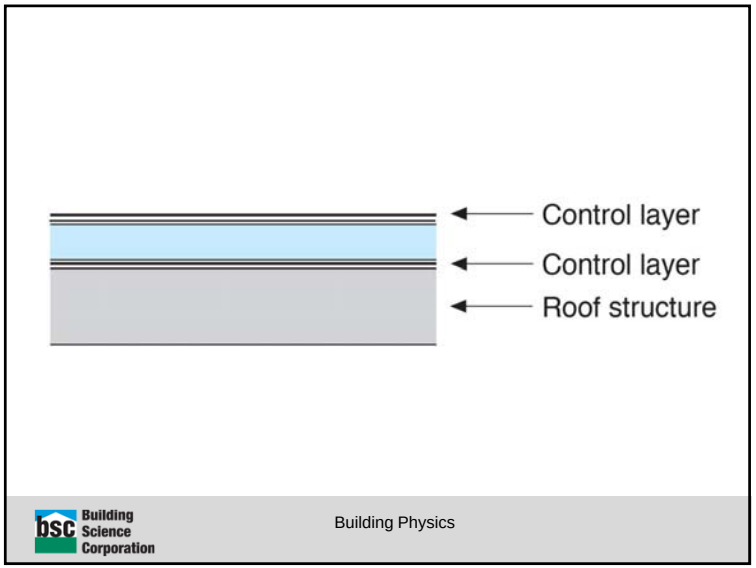
Control layer
Control layer
Roof structure
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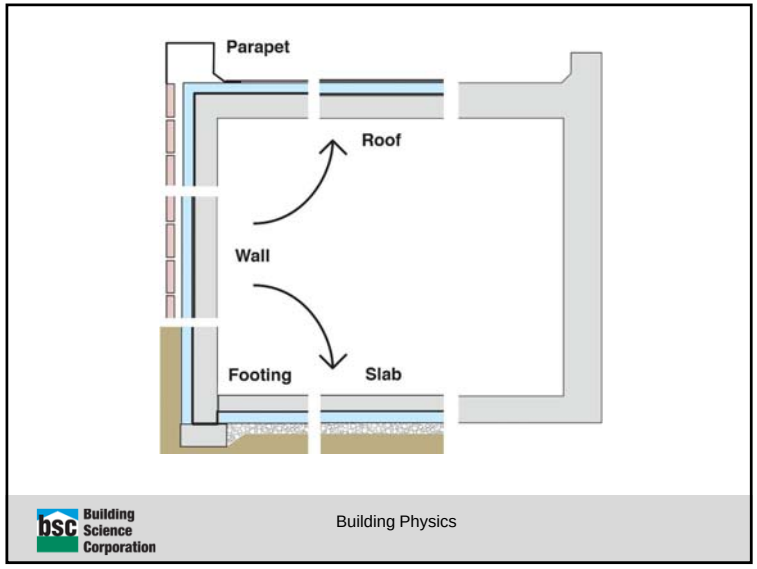
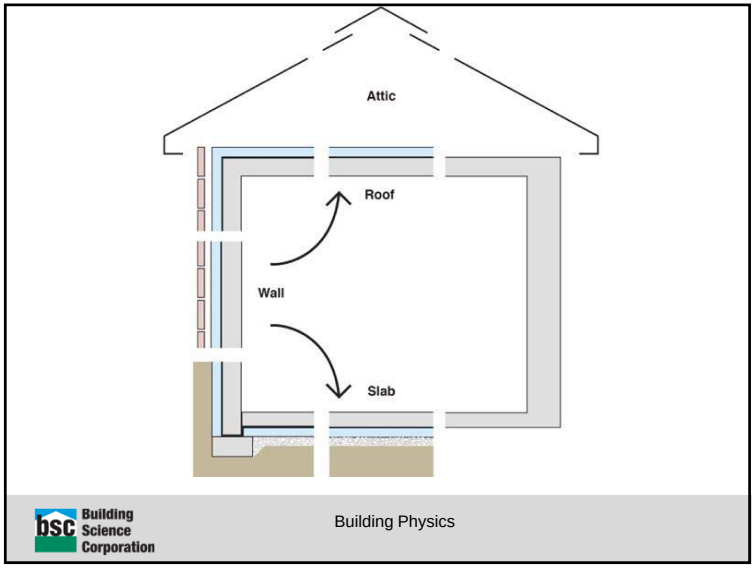
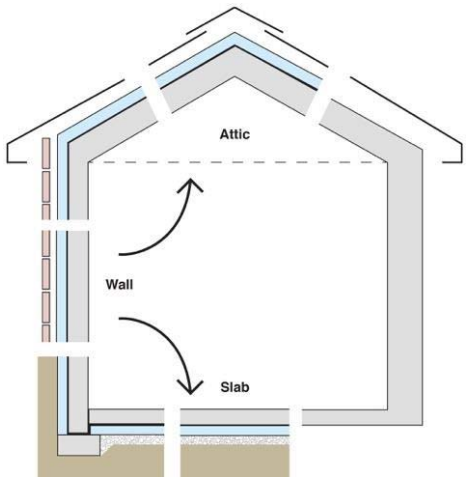
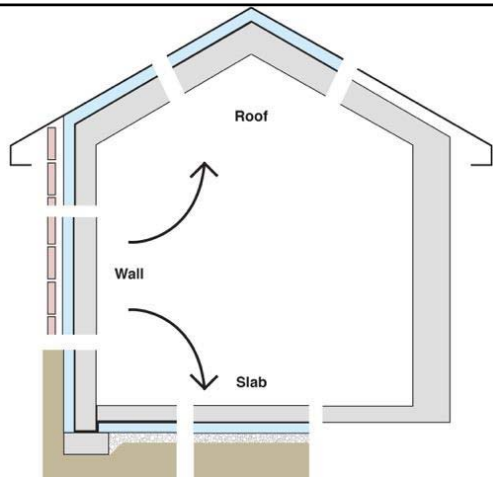

Parapet
Roof
Wall
Footing
Slab
Building Science Corporation
Building Physics

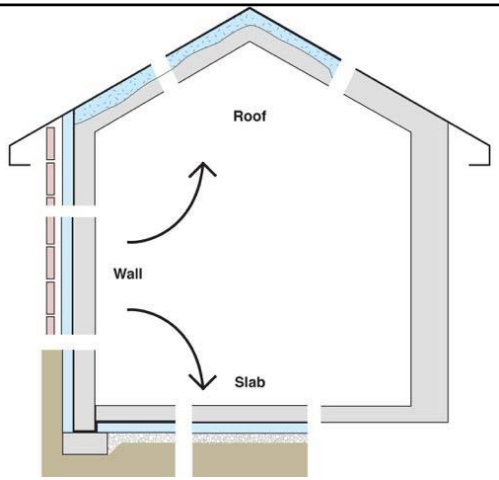

Attic
Roof
Wall
Slab
Building Science Corporation
Building Physics



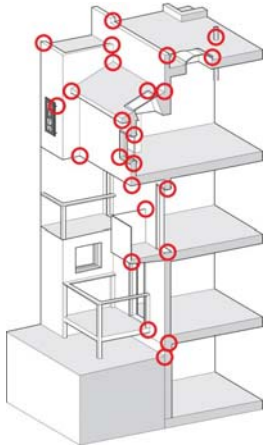
Building Science Corporation Building Physics



Building Science Corporation Building Physics



Building Science Corporation Building Physics



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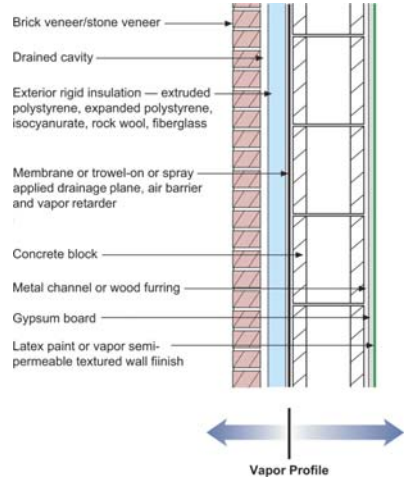
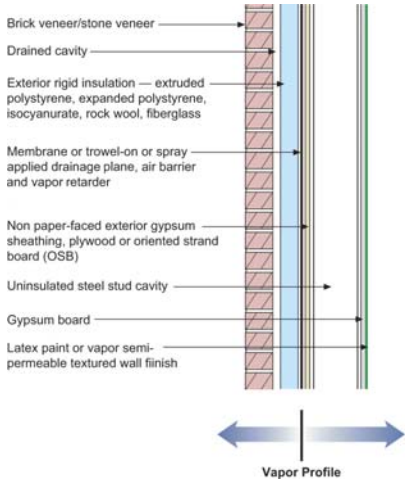
Configurations of the Perfect Wall

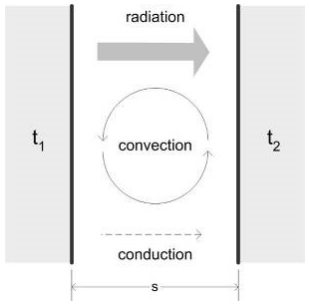




Conduction

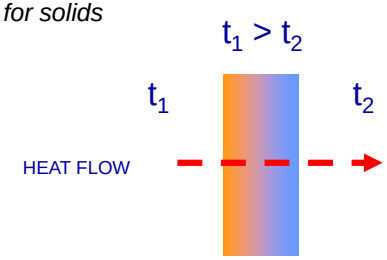
Convection

Radiation



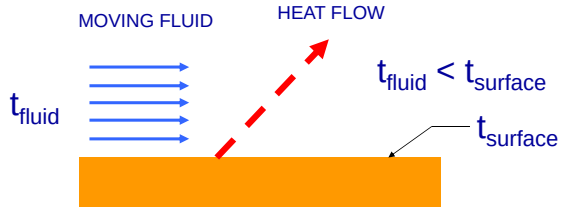
Conduction

- *Heat Flow by direct contact*
- *Vibrating molecules*
- *Most important for solids*



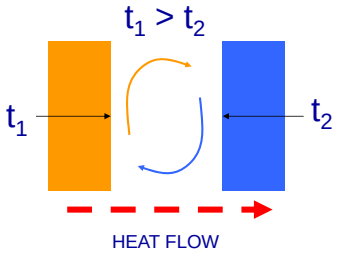
Forced Convection

- *Heat Flow by bulk movement of molecules*
- *Most important for liquids and gases*
- *Movement driven by fans or wind*



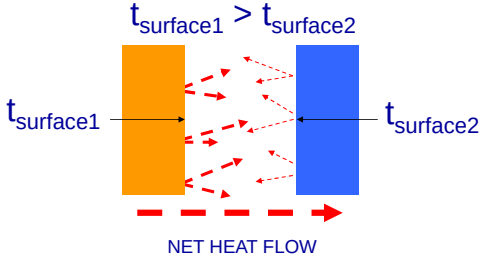
Natural Convection

- *Heat Flow by bulk movement of molecules*
- *Most important for liquids and gases*
- *Natural buoyancy drives movement*



Radiation

- *Heat flow by electromagnetic waves*
- *Heat radiates from all materials, e.g. campfire*
- *Passes through gases and vacuum (NOT Solid)*

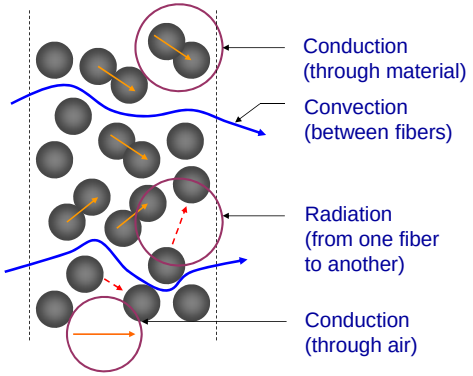


Function of:

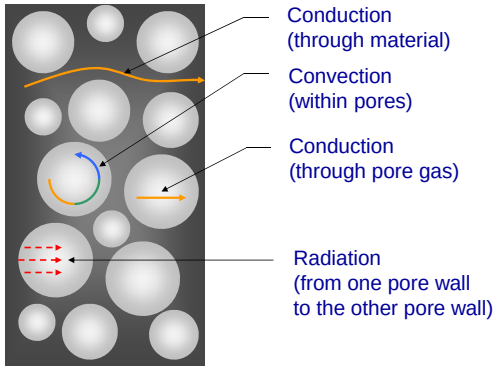
- *Material Type*
- *Density and pore structure*
- *Moisture content*
- *Temperature difference*

Combination of:

- *Conduction through material and air (or other gas)*
- *Convection in pores*
- *Radiation through pores*



HYPOTHETICAL FIBEROUS MATERIAL



HYPOTHETICAL POROUS MATERIAL

Thermal Conductivity (k)

- *Material property*
- *Time rate of heat flow through a unit thickness and unit area of material under a unit temperature difference*

Units: Btu•in/(ft^2•hr•°F) *or* W/(m•K)

Thermal Conductance (C)

- *Layer property*
- *Time rate of heat flow through a unit area of a material layer (or the conductivity of a material for a given thickness)*

Formula: C = k/L
Units: Btu/(ft²•hr•°F) *or* W/(m²•K)

Thermal Resistance

- *Layer property*
- *Reciprocal of conductance*
- *A measure of how well a material resists heat flow*

Formula: Resistance = 1/C
Units: ft²•hr•°F/ Btu *or* m²•K/W

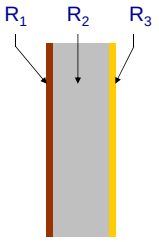
R-Value or RSI

- *Gives heat flow as "equivalent conductance"*
- *Includes all three modes of heat transfer*
- *Rarely includes thermal bridging or three dimensional heat flow*
- *Never intended to include airtightness or mass*

Conductance through the enclosure assemblies

Total thermal resistance R_T is a sum of the thermal resistance of all the materials in the enclosure assembly.

Materials such as gypsum, plywood, OSB, wood studs, metal studs all contribute to the overall thermal resistance.

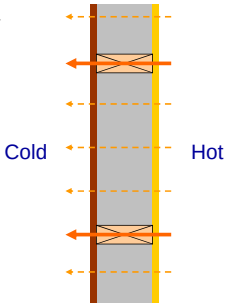


$R_T = R_1 + R_2 + R_3$

Conductance through the enclosure assemblies

Materials of lower thermal resistance create pathways of increased conductance losses, or "thermal bridges" through layers of greater thermal resistance

Thermal bridging can reduce the effective R-value of a wall assembly.

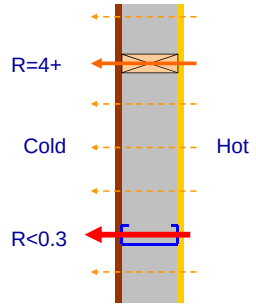


A 2x6 wood stud wall 16" OC with R-19 Fiberglass Batt = effective R-13 wall assembly.

Conductance through the enclosure assemblies

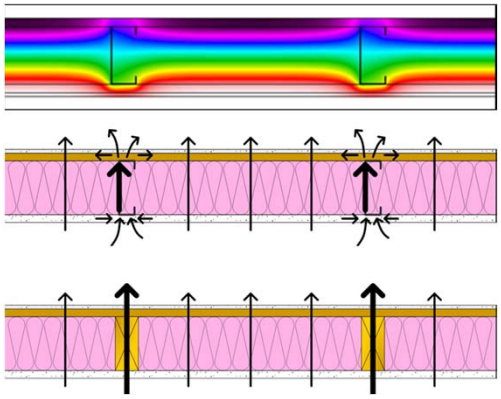
Steel is 400 times more conductive than wood

Steel studs are about 40 times thinner

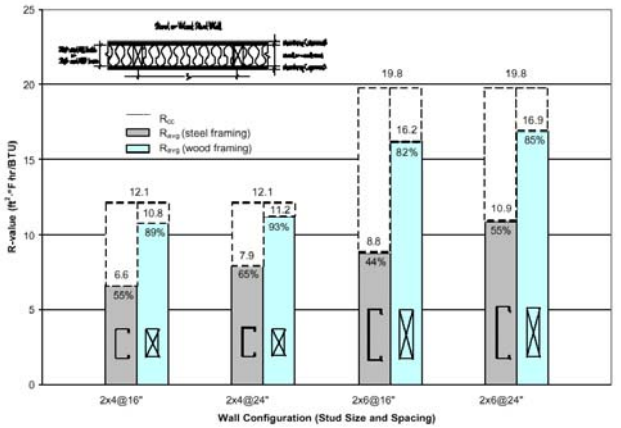


A 2x6 steel stud wall 16" OC with R-19 Fiberglass Batt = effective R-9 wall assembly.

Conductance through the enclosure assemblies



Conductance through the enclosure assemblies



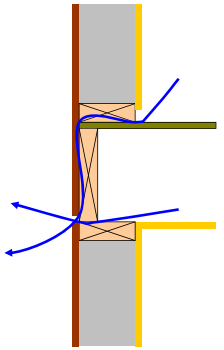
Conductance through the enclosure assemblies

Convection through the enclosure assemblies

Commonly referred to as "Air Leakage"

Driven by air pressure differences
- *wind*
- *mechanical*
- *stack effect*

Large energy impacts (can account for 30% of the heating and cooling energy)



Convection within the enclosure assemblies

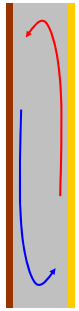
Commonly referred to as "Convective Loops"

Driven by natural buoyancy - warm air will rise

Short circuits insulation

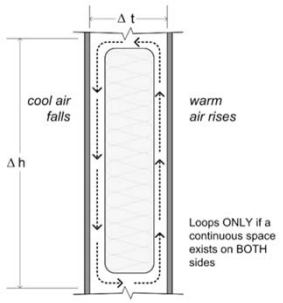
R-value does not take into account the potential of movement of air within an assembly.

Cold

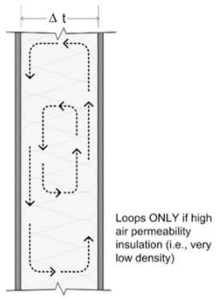


Hot

Convection within the enclosure assemblies



A: Air Loops Around Insulation

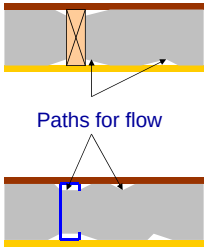


B: Air Loops Through Insulation

Convection within the enclosure assemblies

Spaces for flow from:

- *Compressing batts*
- *Inset stapling*
- *Difficulty in filling steel studs*



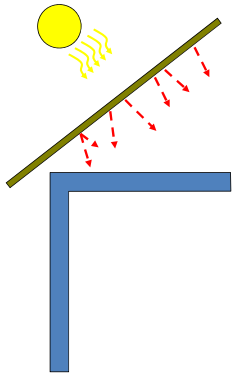
Convection within the enclosure assemblies

Radiation from surfaces within the enclosure assemblies

Net radiant flow across a clear cavity

Emissivity is expressed as a fraction of energy emitted when compared to the radiation from a black body

Common in attics



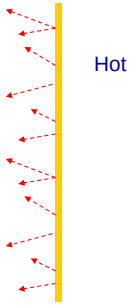
Radiation from surfaces within the enclosure assemblies

Radiation from surfaces within the enclosure assemblies

Must have an airspace for radiant products to work

While low emitting, radiant products are often highly conductive

Energy will be conducted to other materials in contact with radiant product (framing, dirt)



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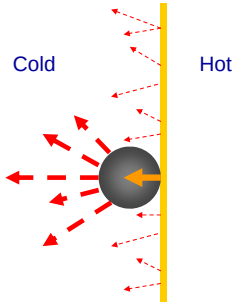

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- Heat Flow Is From Warm To Cold
- Moisture Flow Is From Warm To Cold
- Moisture Flow Is From More To Less
- Air Flow Is From A Higher Pressure to a Lower Pressure
- Gravity Acts Down

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- Moisture Flow Is From Warm To Cold
- Moisture Flow Is From More To Less

Building Science Corporation Building Physics

Moisture Flow Is From Warm To Cold
Moisture Flow Is From More To Less

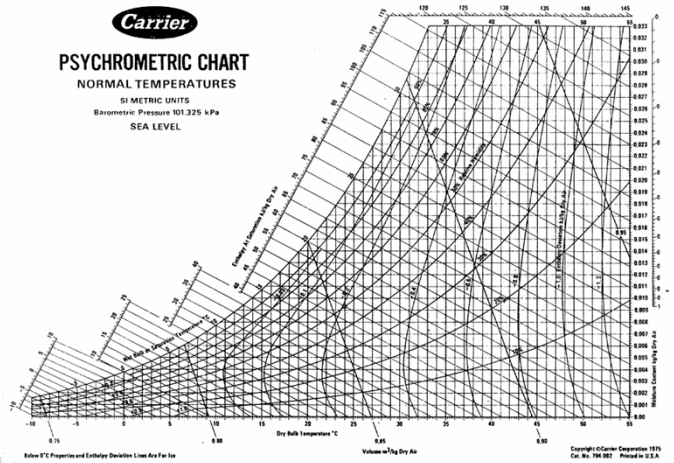
Thermal Gradient – Thermal Diffusion
Concentration Gradient – Molecular Diffusion

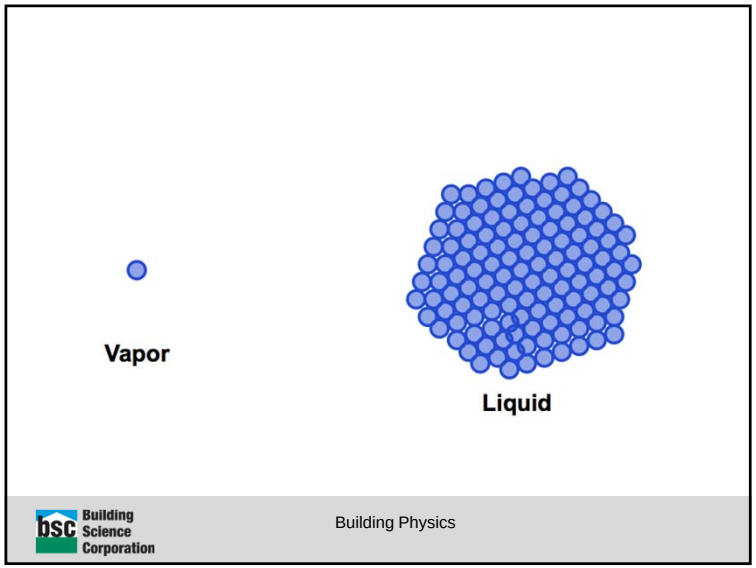
Moisture Flow Is From Warm To Cold
Moisture Flow Is From More To Less

Thermal Gradient – Thermal Diffusion
Concentration Gradient – Molecular Diffusion

Vapor Diffusion

Thermodynamic Potential




Vapor
Liquid
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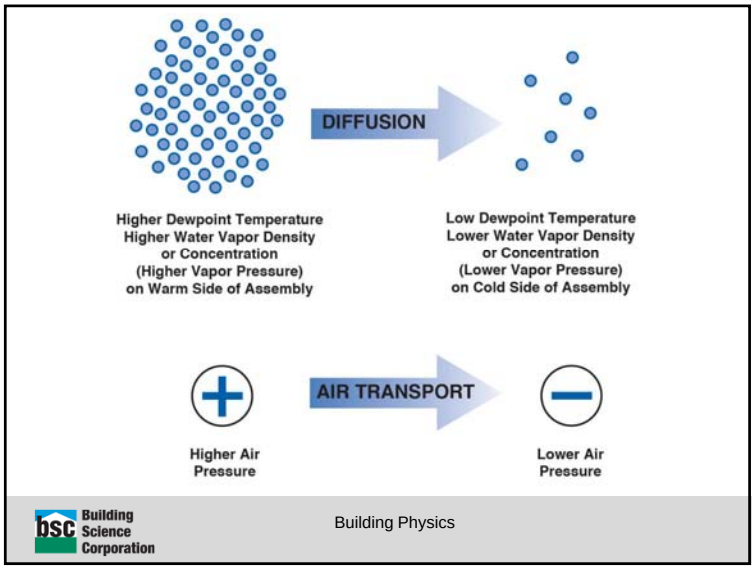
DIFFUSION
Higher Dewpoint Temperature
Higher Water Vapor Density
or Concentration
(Higher Vapor Pressure)
on Warm Side of Assembly
Low Dewpoint Temperature
Lower Water Vapor Density
or Concentration
(Lower Vapor Pressure)
on Cold Side of Assembly
AIR TRANSPORT
Higher Air Pressure
Lower Air Pressure
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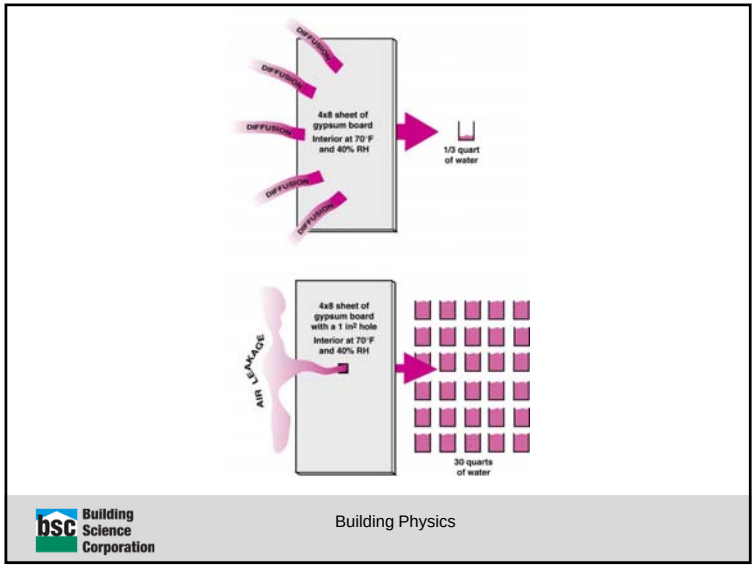
DIFFUSION
4x8 sheet of gypsum board
Interior at 70°F and 40% RH
1/3 quart of water
AIR LEAKAGE
4x8 sheet of gypsum board with a 1 in² hole
Interior at 70°F and 40% RH
30 quarts of water
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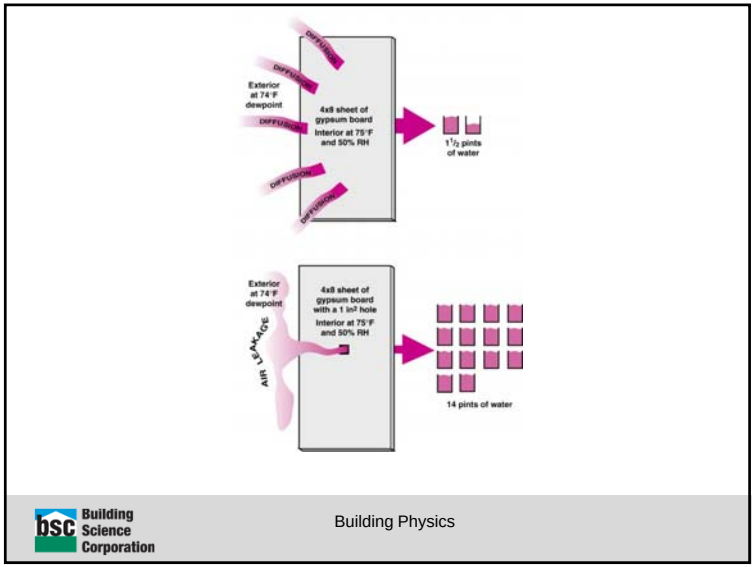
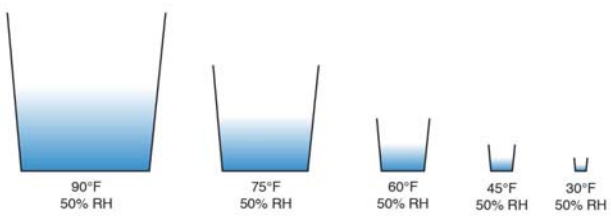
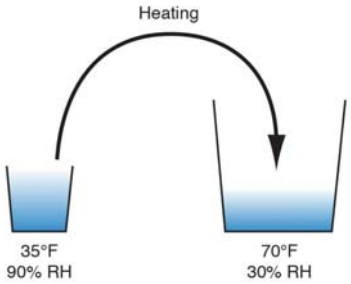
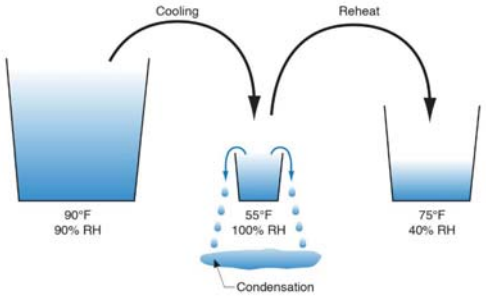

Exterior at 74°F dewpoint
4x8 sheet of gypsum board
Interior at 75°F and 50% RH
1½ pints of water
AIR LEAKAGE
4x8 sheet of gypsum board with a 1 in² hole
Interior at 75°F and 50% RH
14 pints of water
Building Science Corporation
Building Physics


90°F
50% RH
75°F
50% RH
60°F
50% RH
45°F
50% RH
30°F
50% RH


Heating
35°F
90% RH
70°F
30% RH


Cooling
Reheat
90°F
90% RH
55°F
100% RH
75°F
40% RH
Condensation