Peter Baker, P.Eng,

Building Science

Renovation and Rehabilitation

presented by www.buildingscience.com

Presentation Overview

- Building Physics
- Foundations
- Mass Masonry
- Walls
- Roofs

Building Physics

August 8, 2019

What is a Building?

A Building is an Environmental Separator

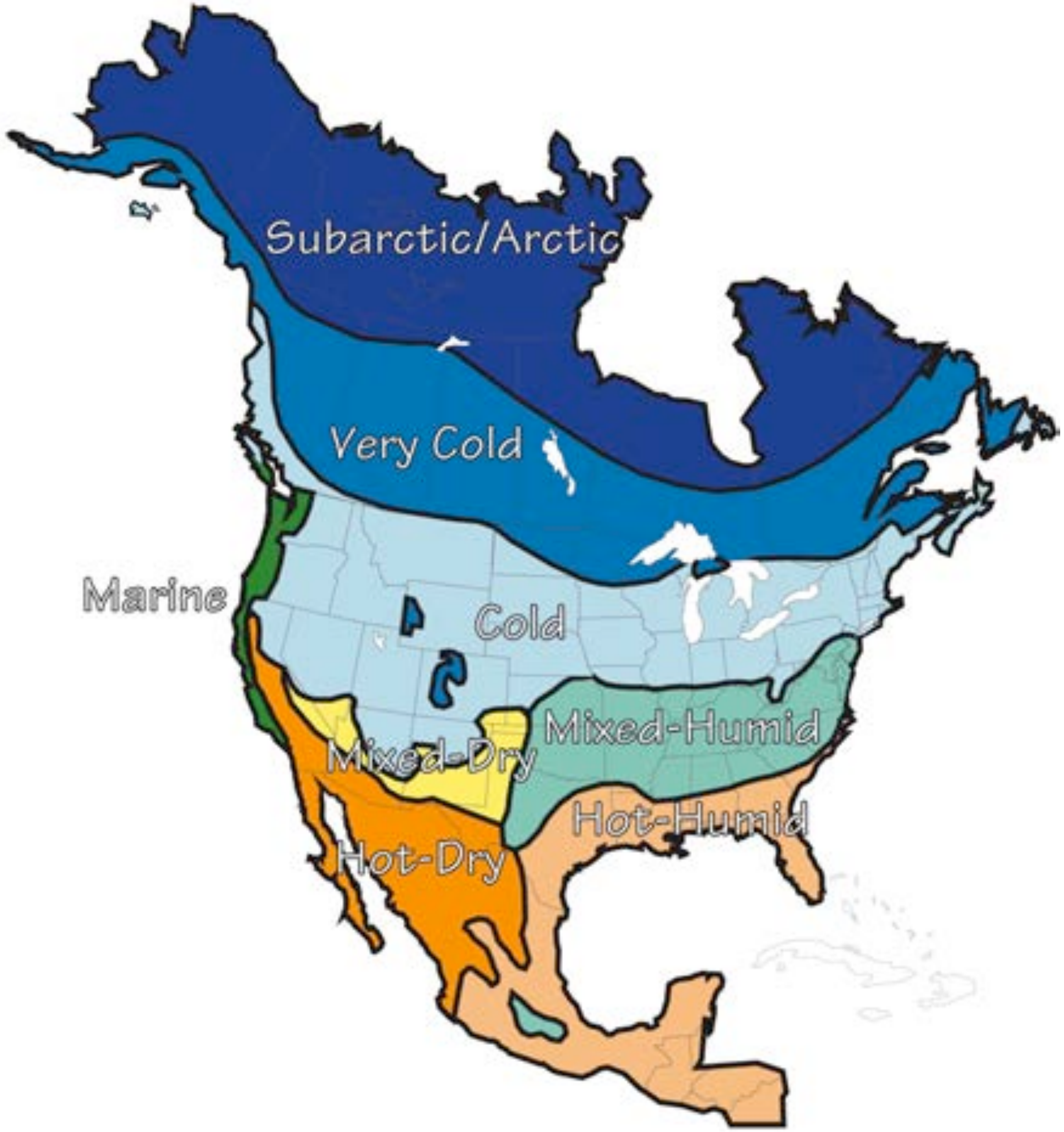
- Control heat flow
- Control airflow
- Control water vapor flow
- Control rain
- Control ground water
- Control light and solar radiation
- Control noise and vibrations
- Control contaminants, environmental hazards and odors
- Control insects, rodents and vermin
- Control fire
- Provide strength and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

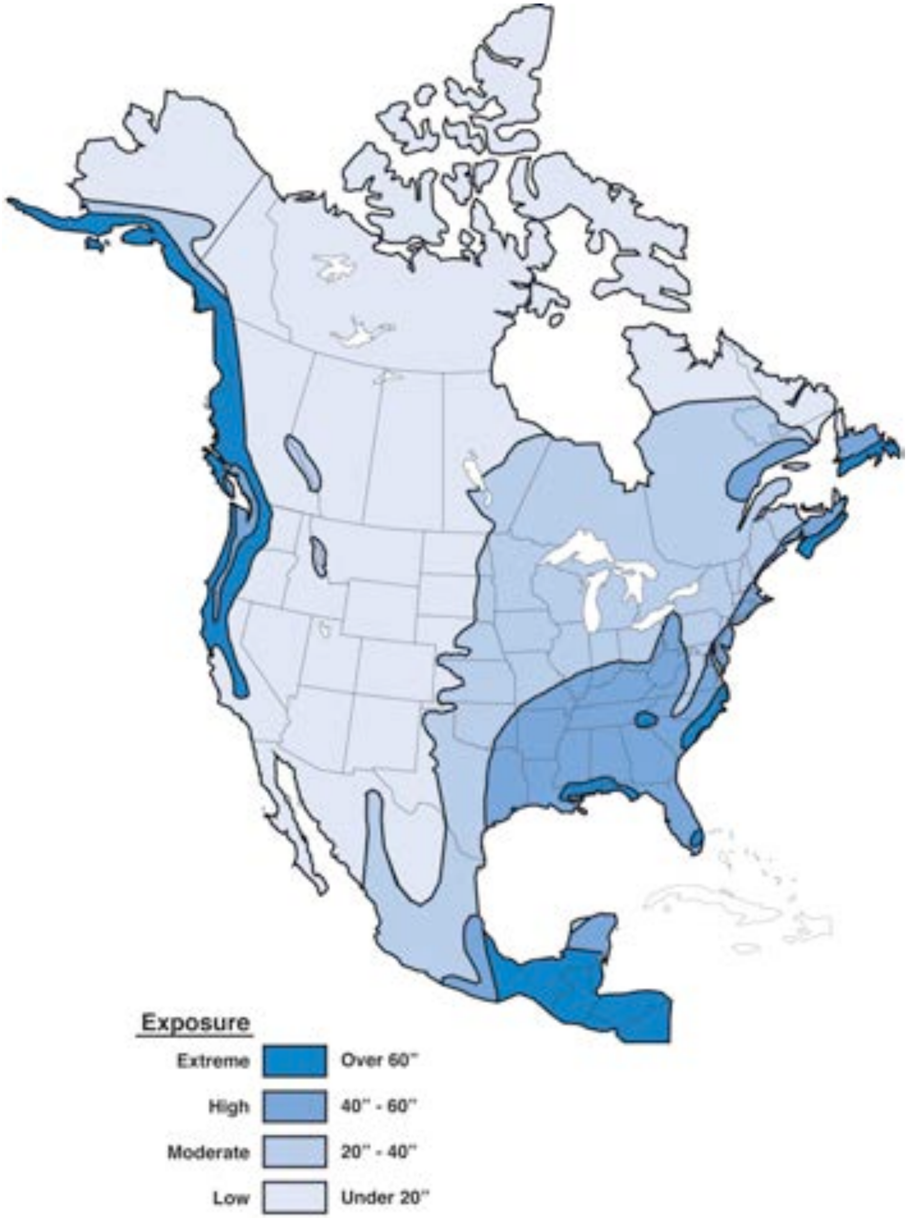
Damage Functions

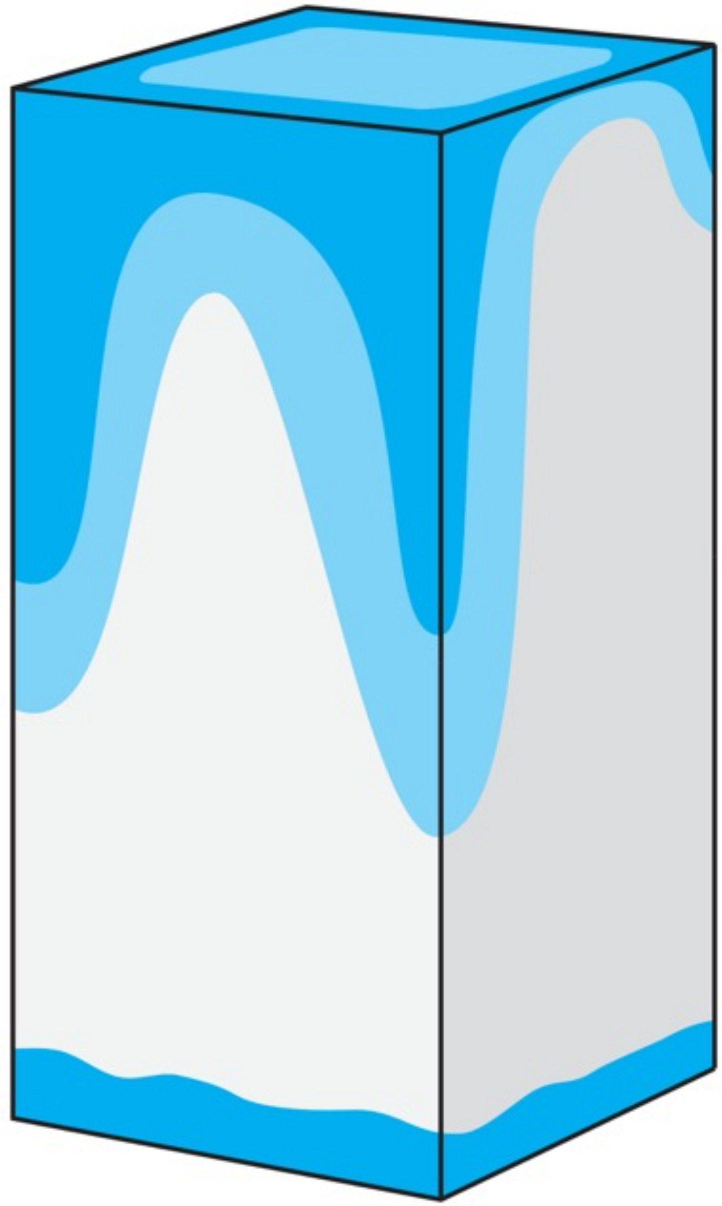
Water

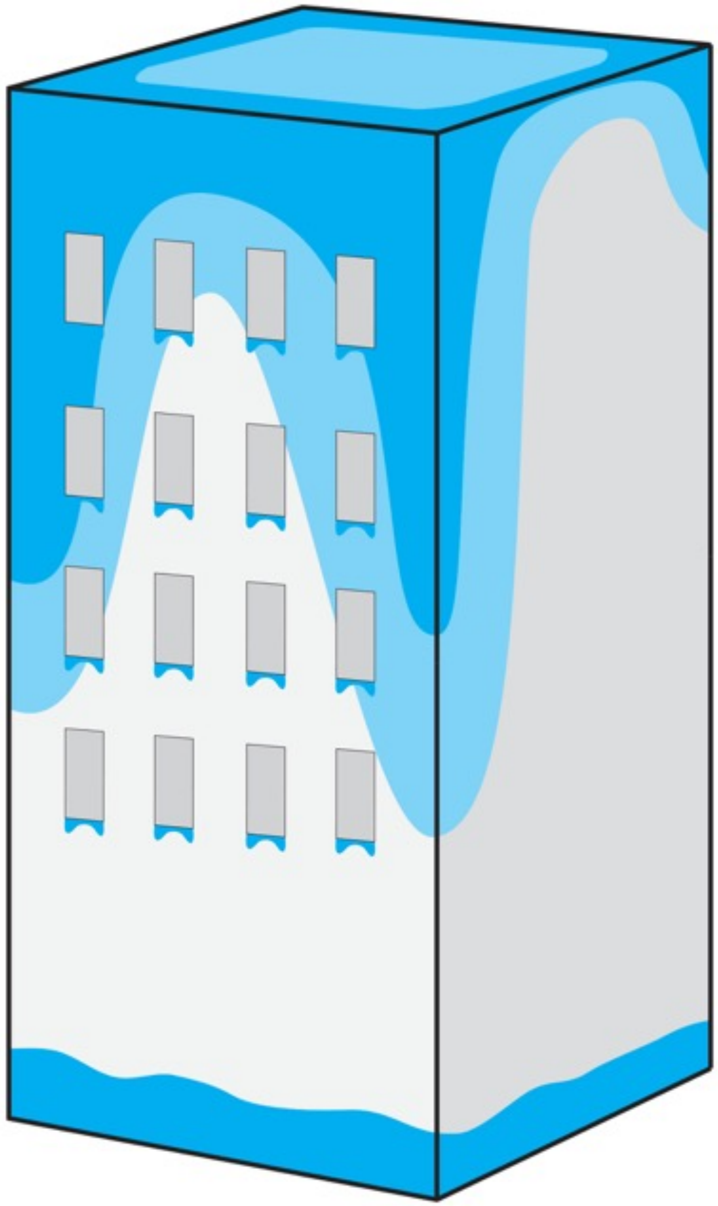
Heat

Ultra-violet Radiation


Subarctic/Arctic
Very Cold
Marine
Cold
Mixed-Humid
Mixed-Dry
Hot-Humid
Hot-Dry


Exposure
Extreme
Over 60"
High
40" - 60"
Moderate
20" - 40"
Low
Under 20"



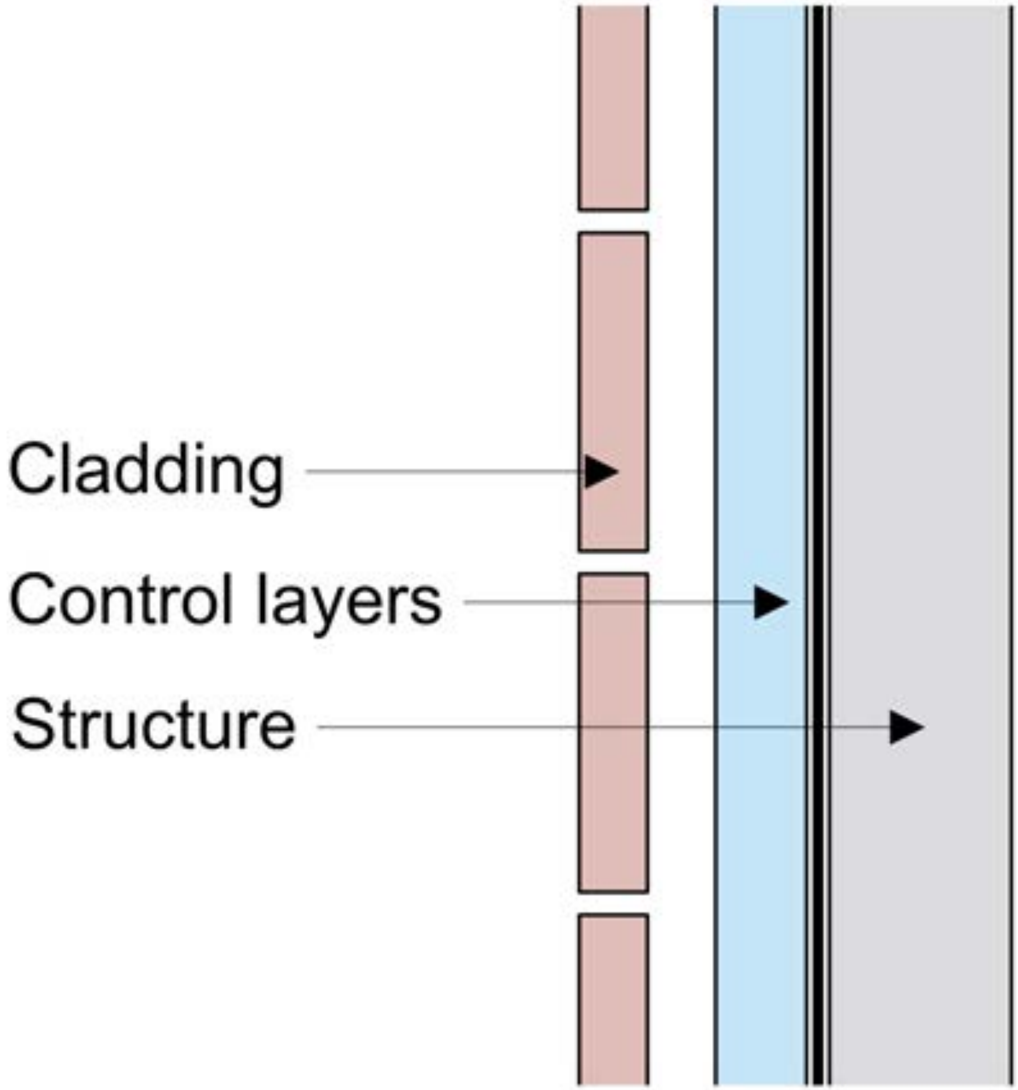


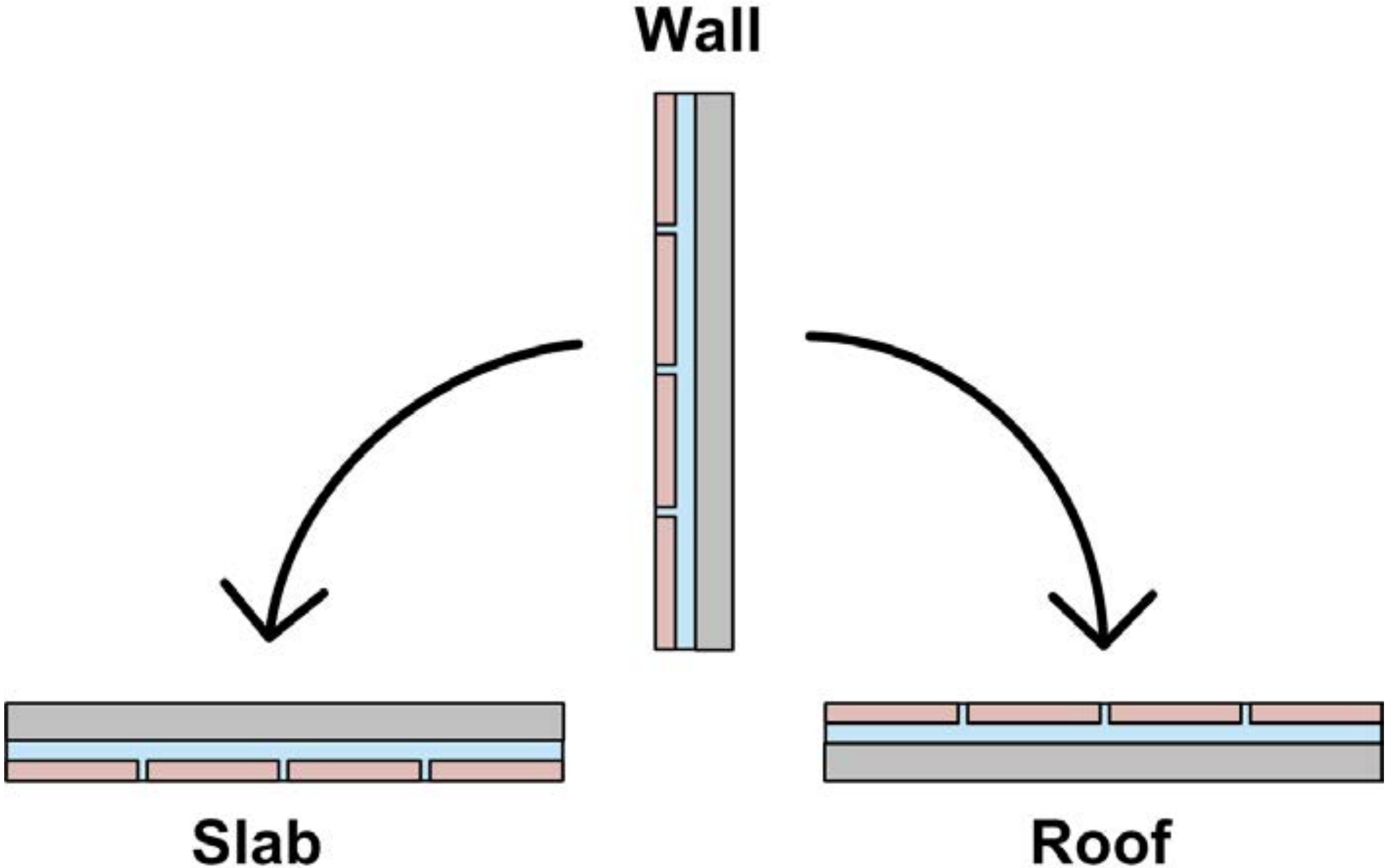
Water Control Layer

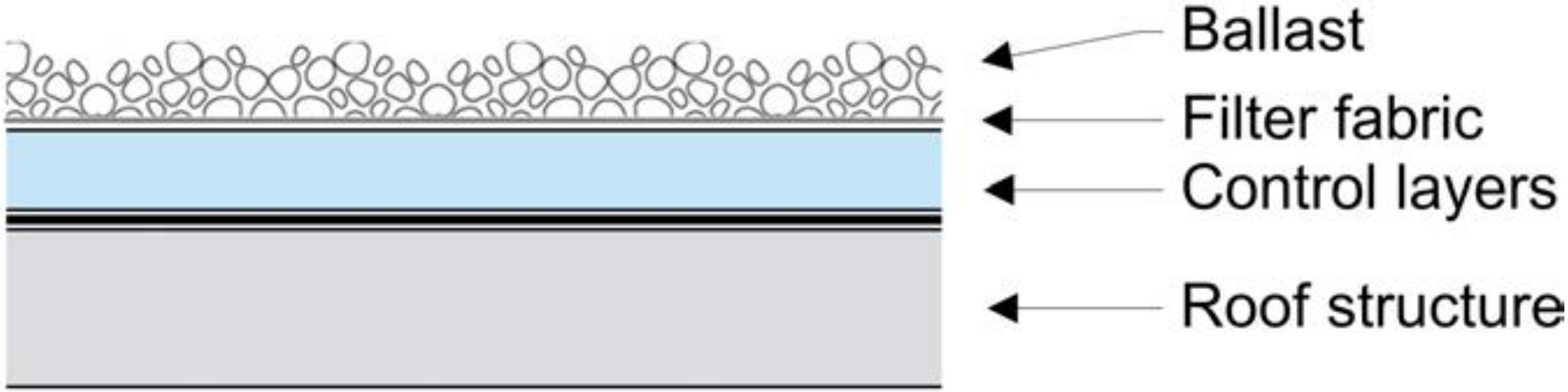
Air Control Layer

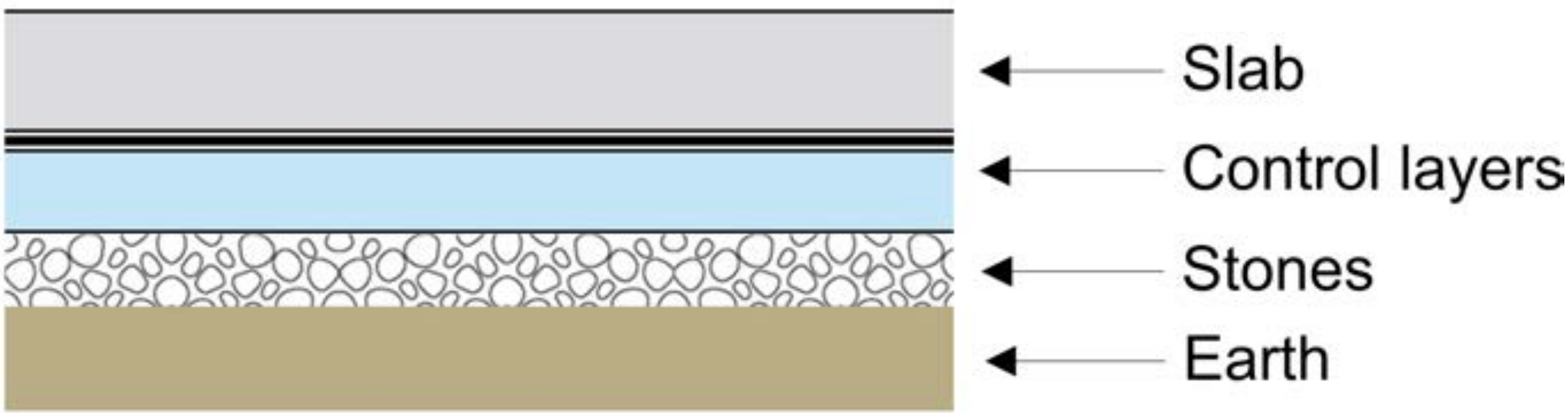
Vapor Control Layer

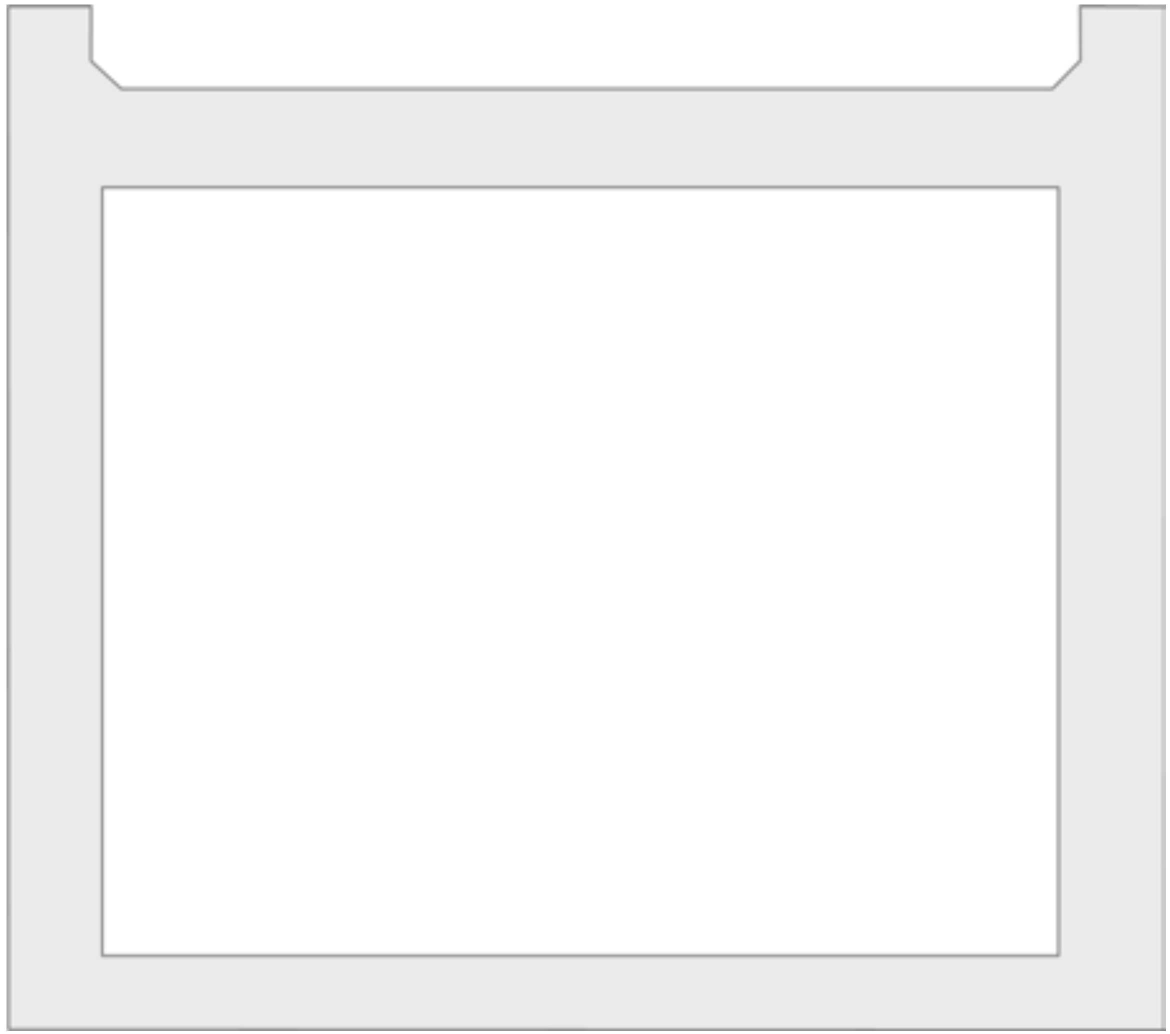
Thermal Control Layer


Cladding
Control layers
Structure

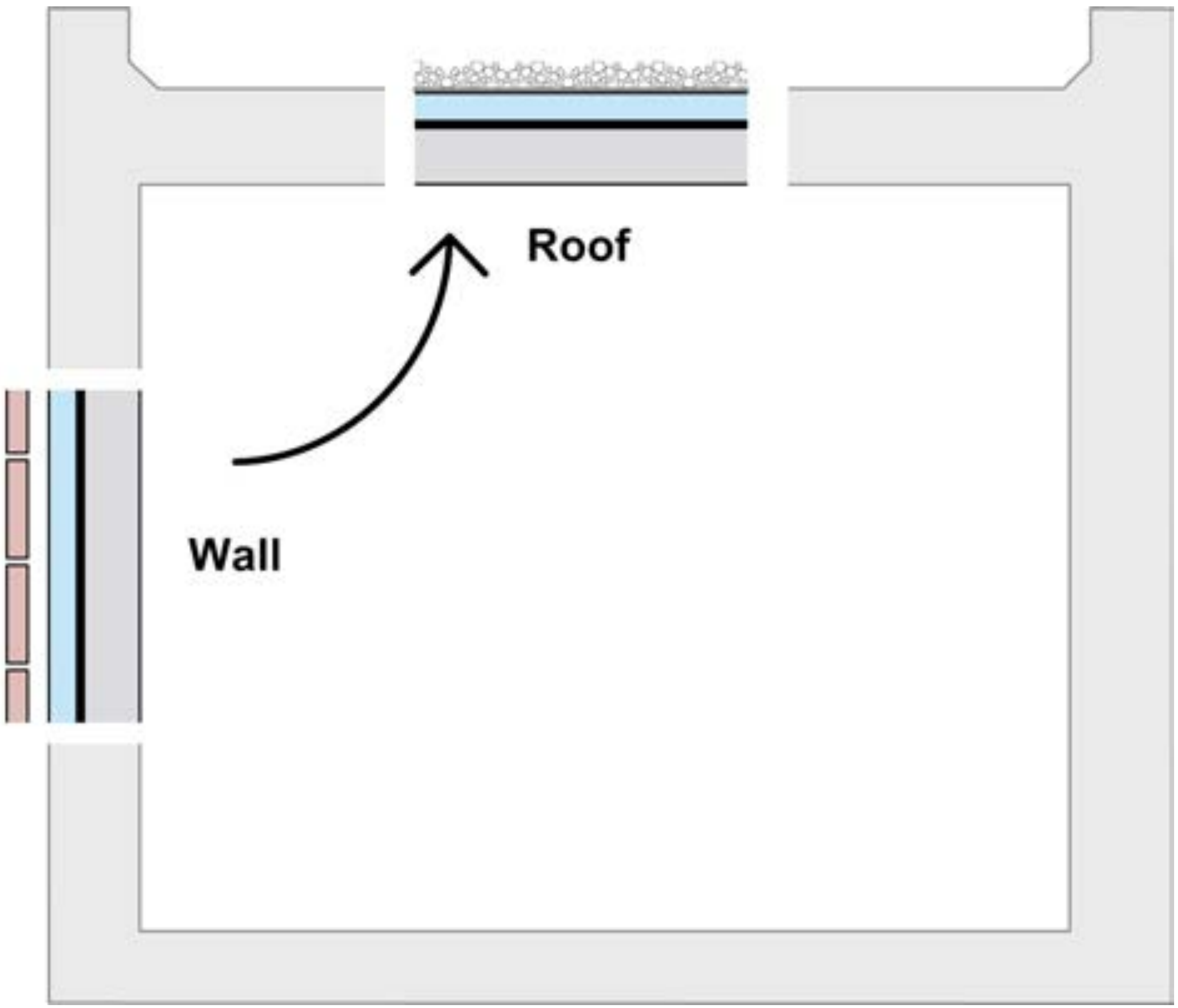

Wall
Slab
Roof

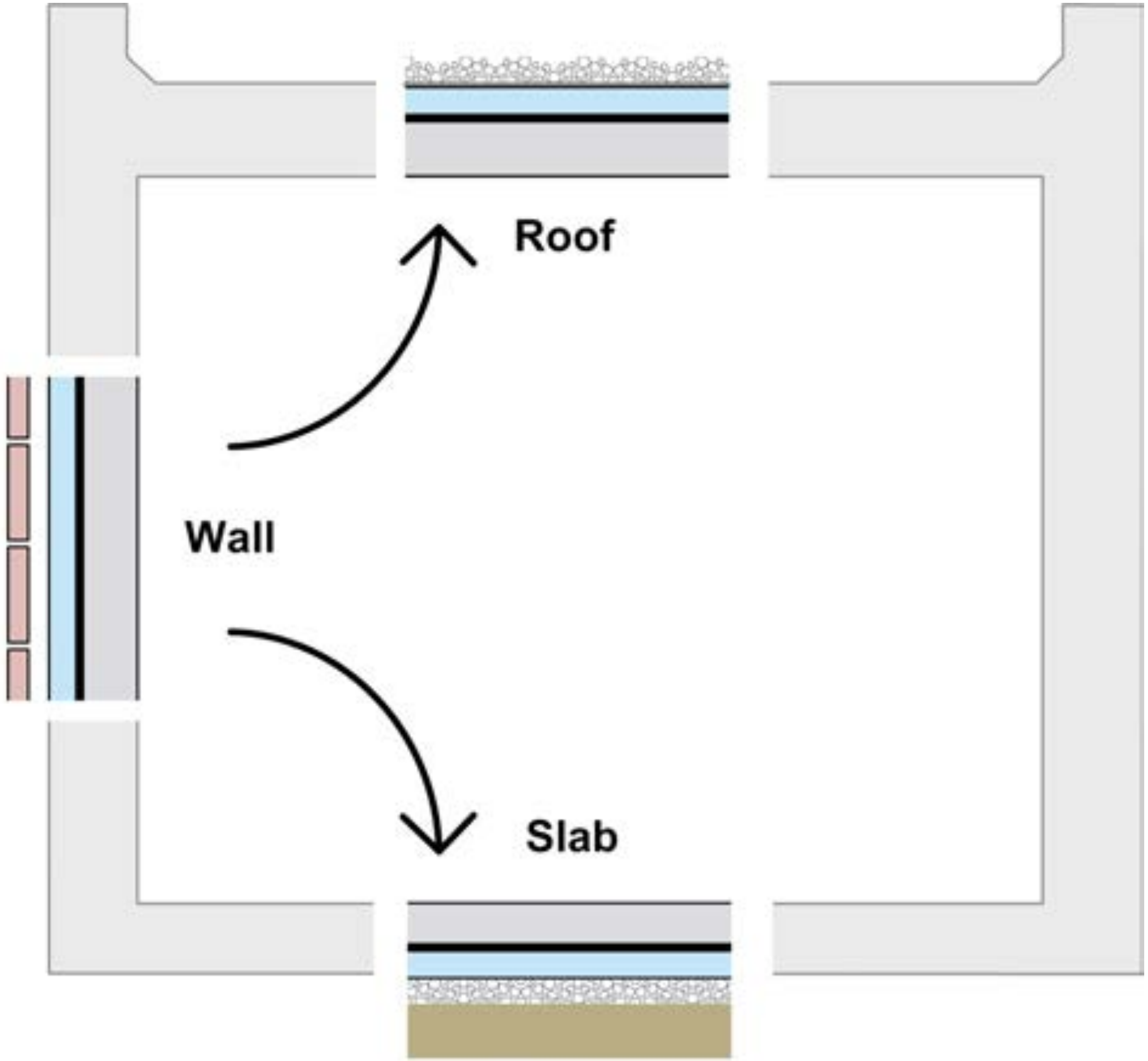

Ballast
Filter fabric
Control layers
Roof structure


Slab
Control layers
Stones
Earth

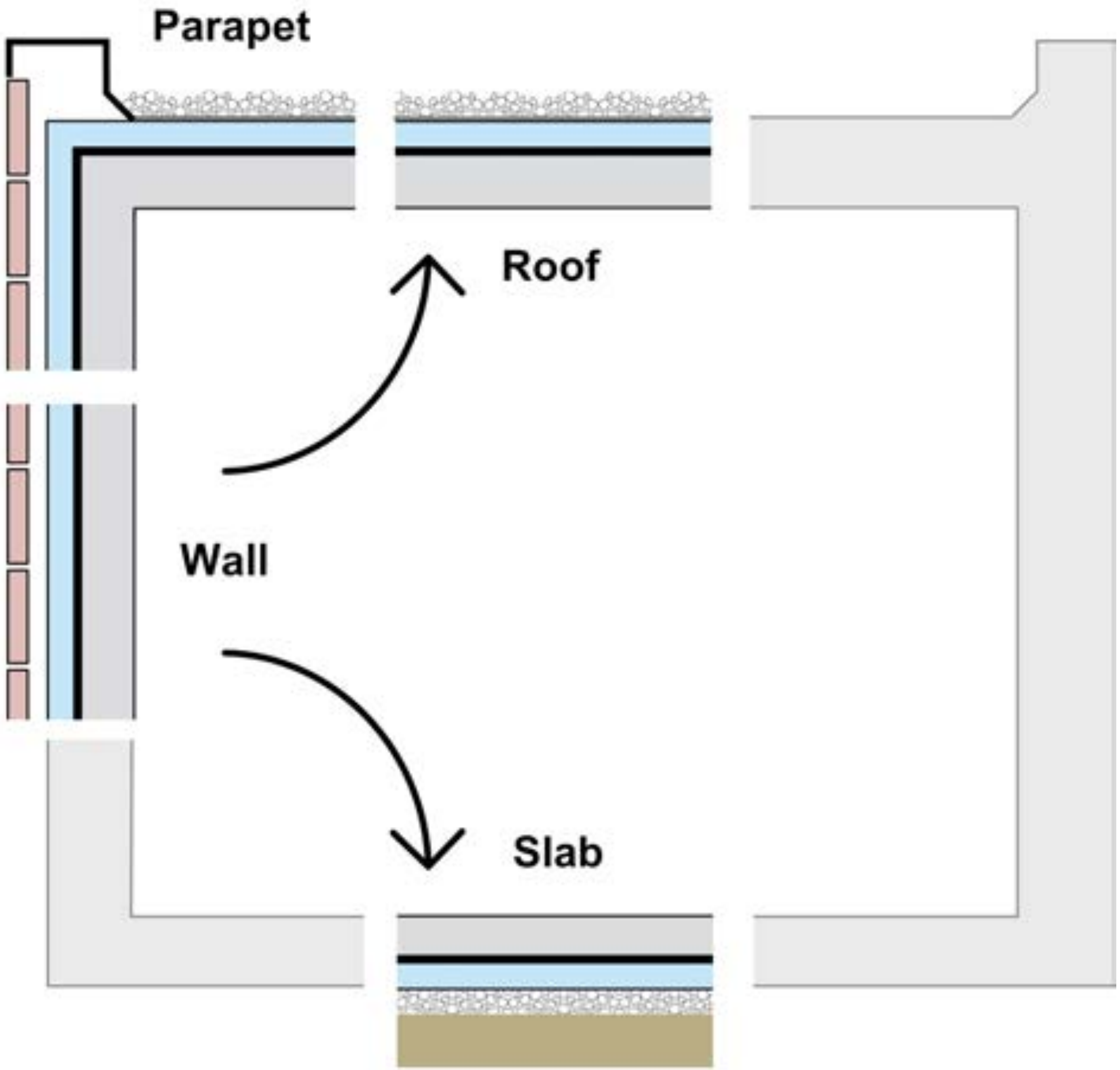


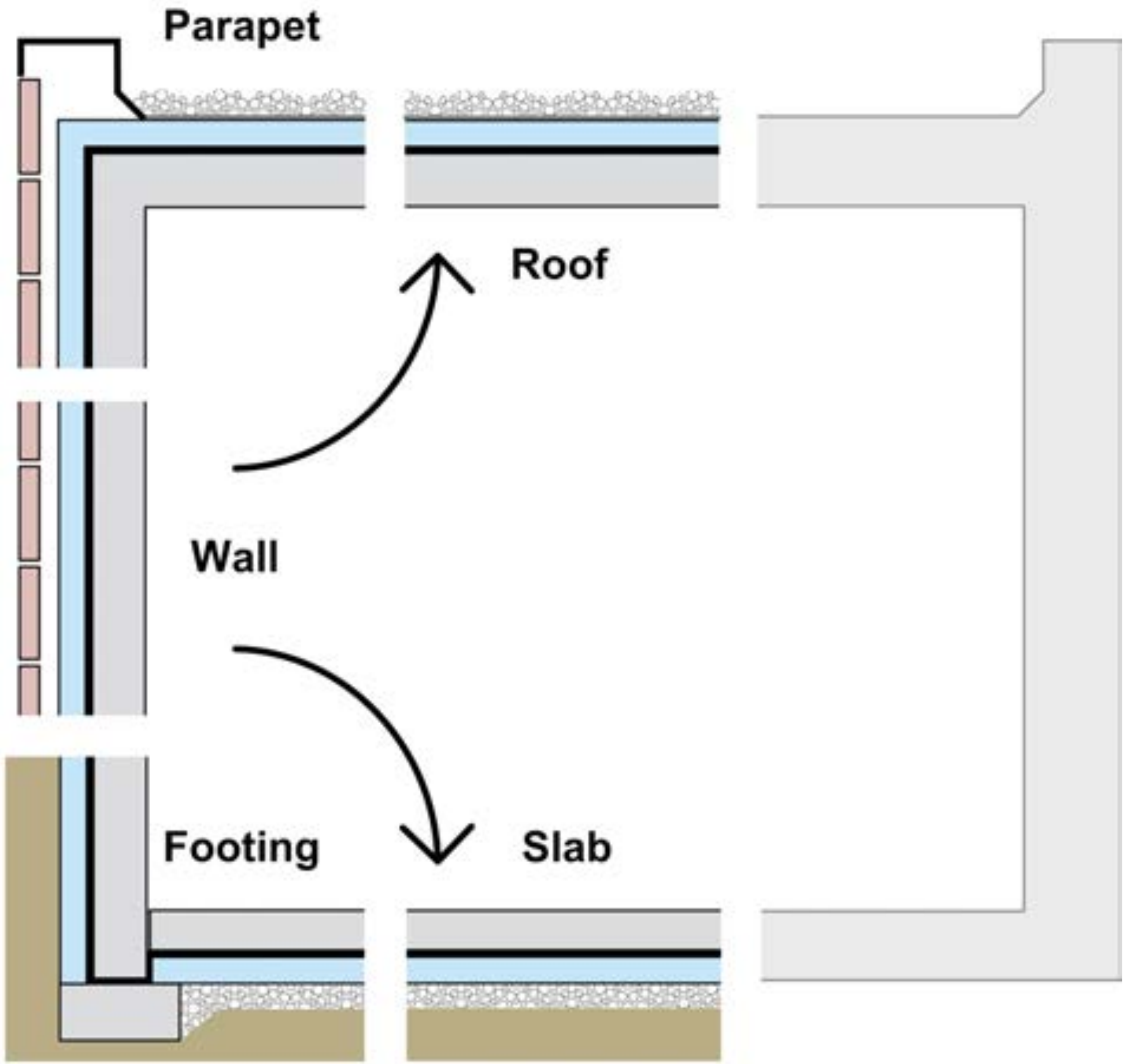

Wall


Roof
Wall

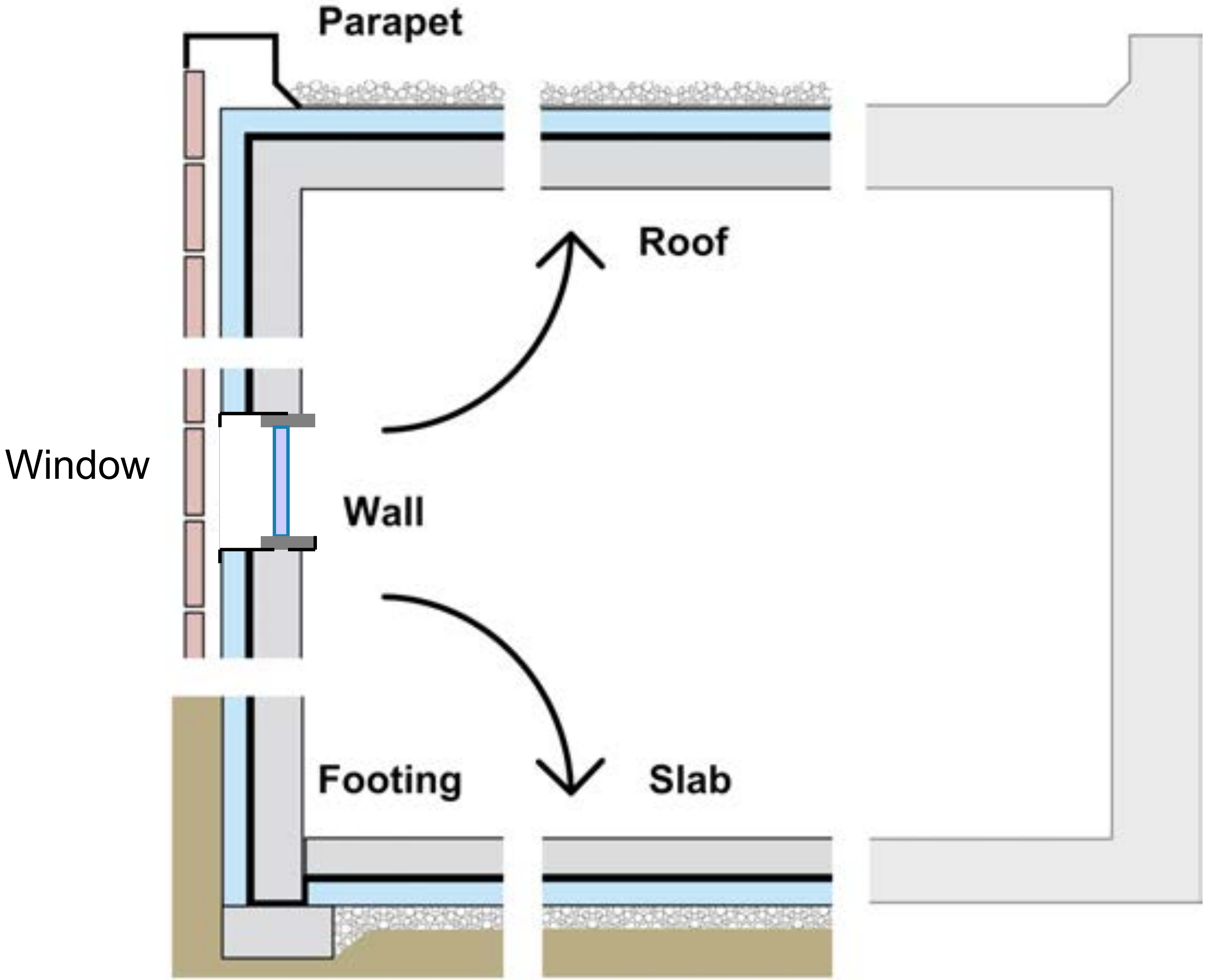


Roof
Wall
Slab

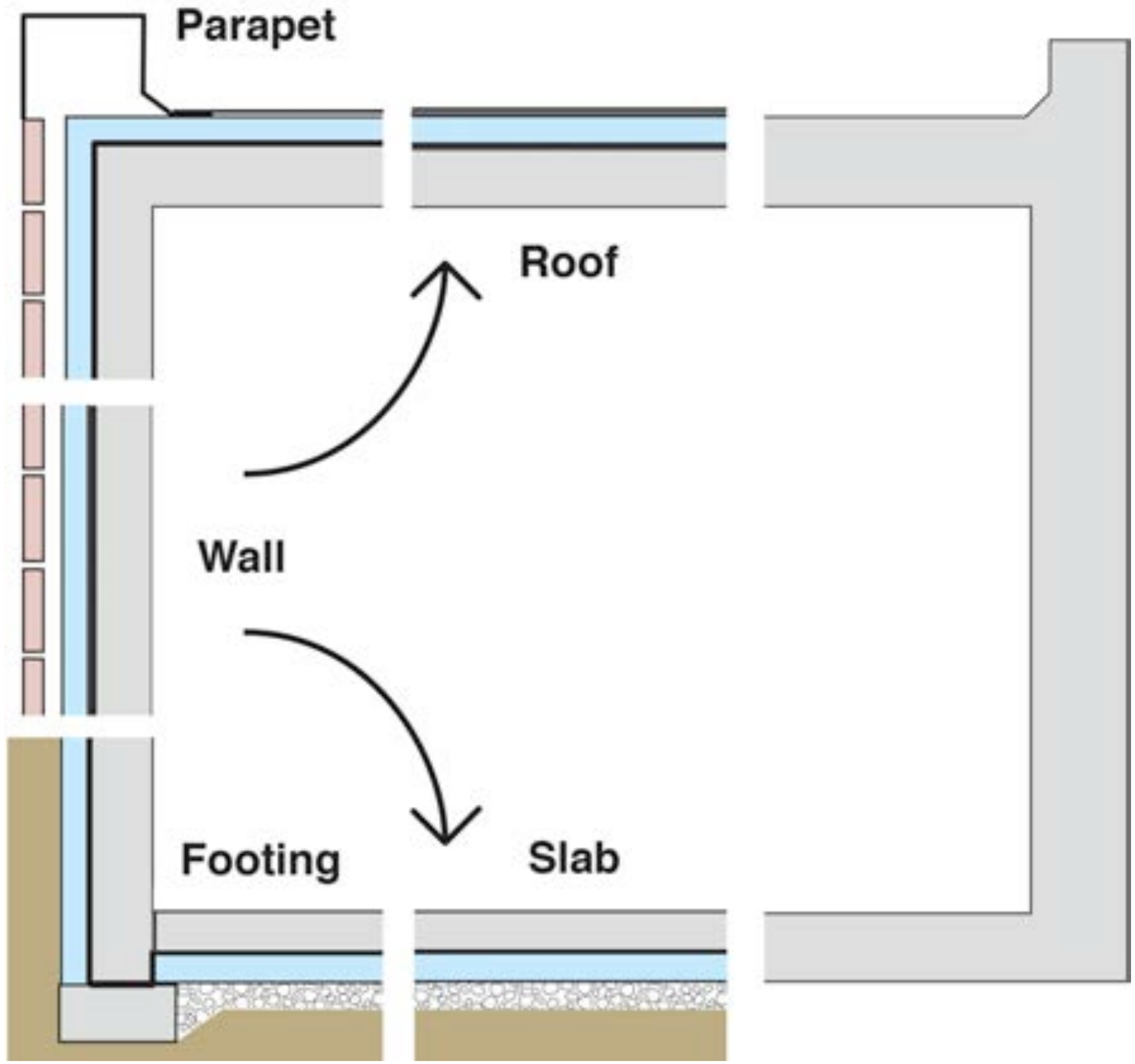

Parapet
Roof
Wall
Slab

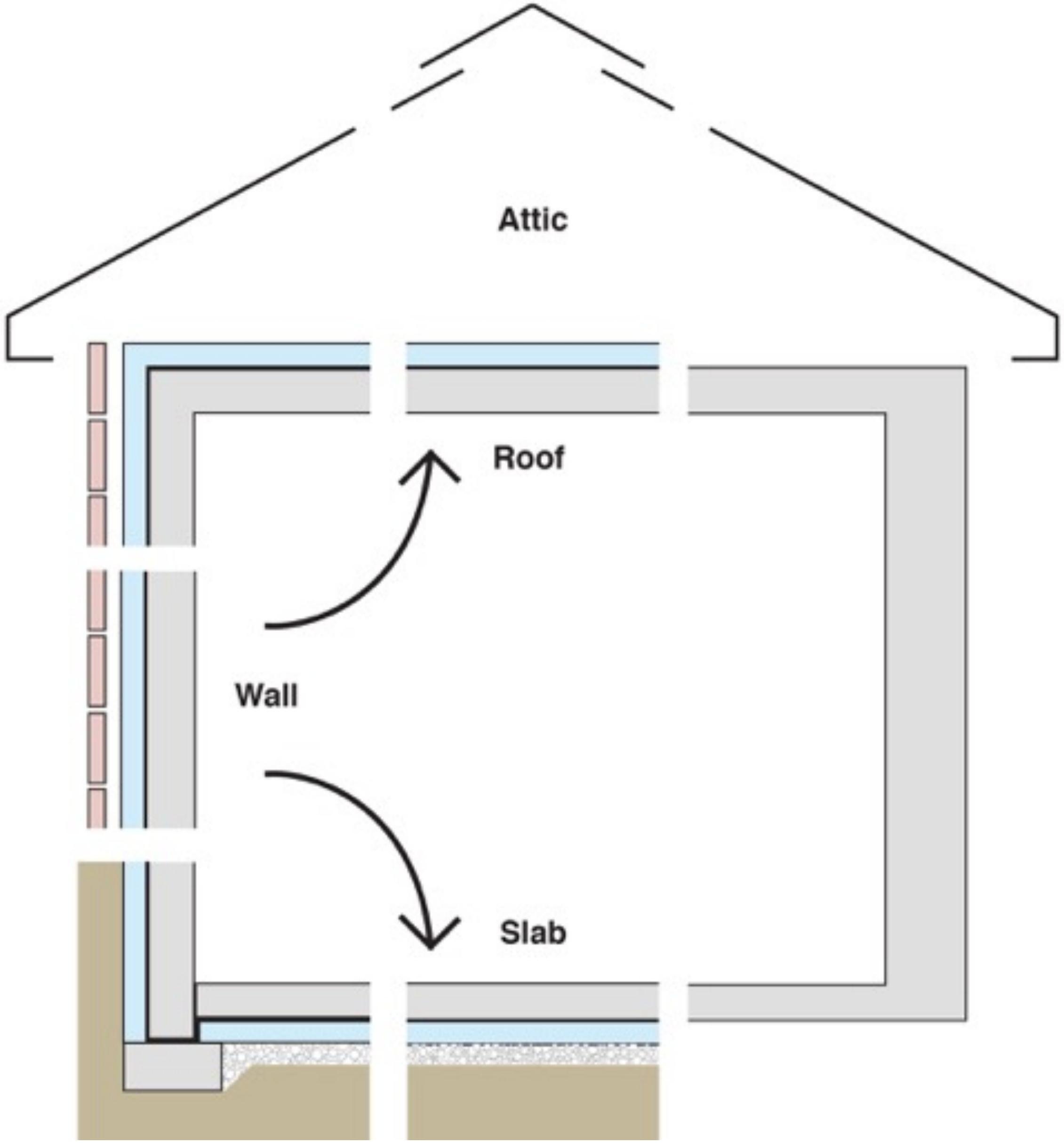


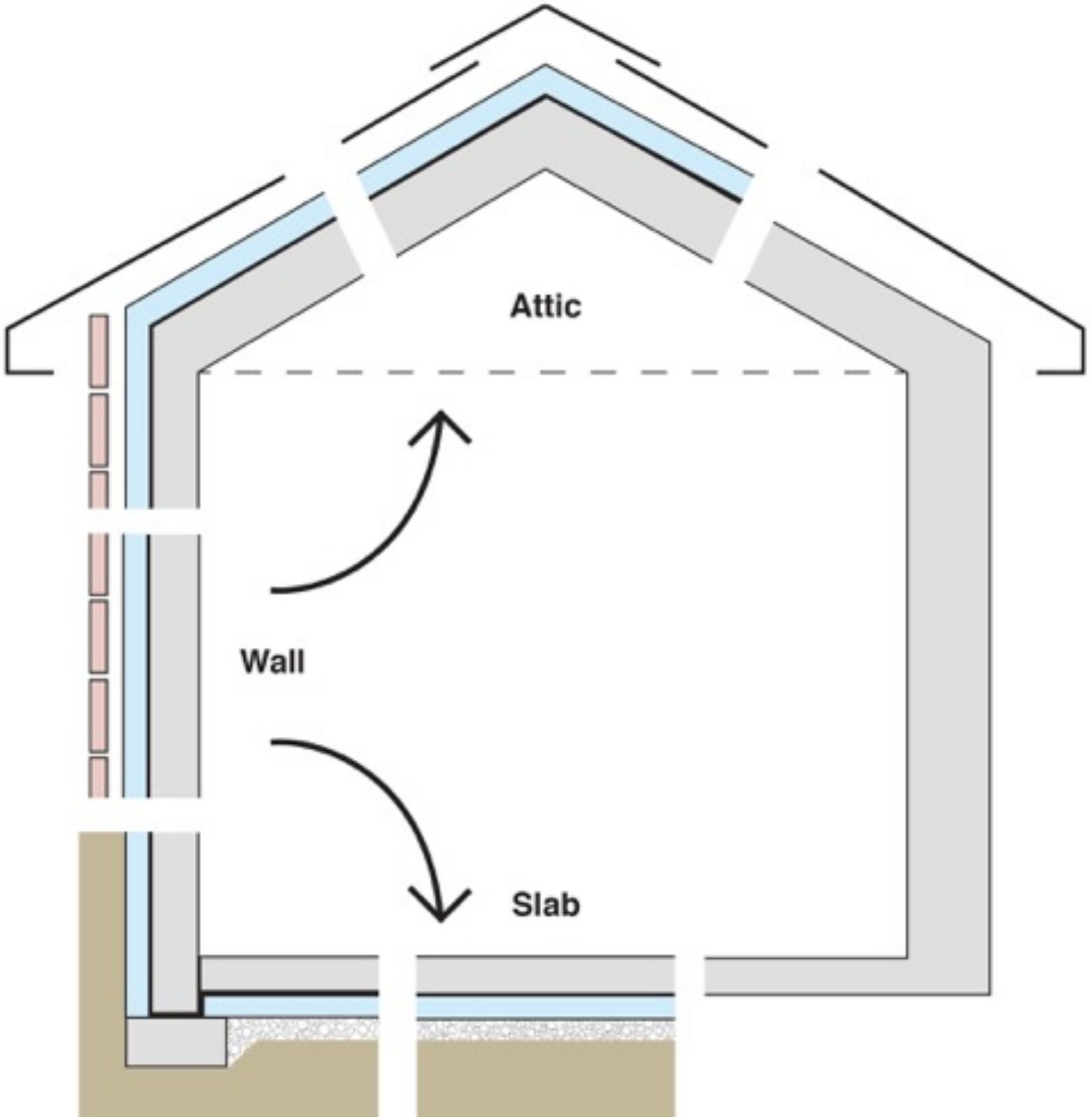
Parapet
Roof
Wall
Footing
Slab

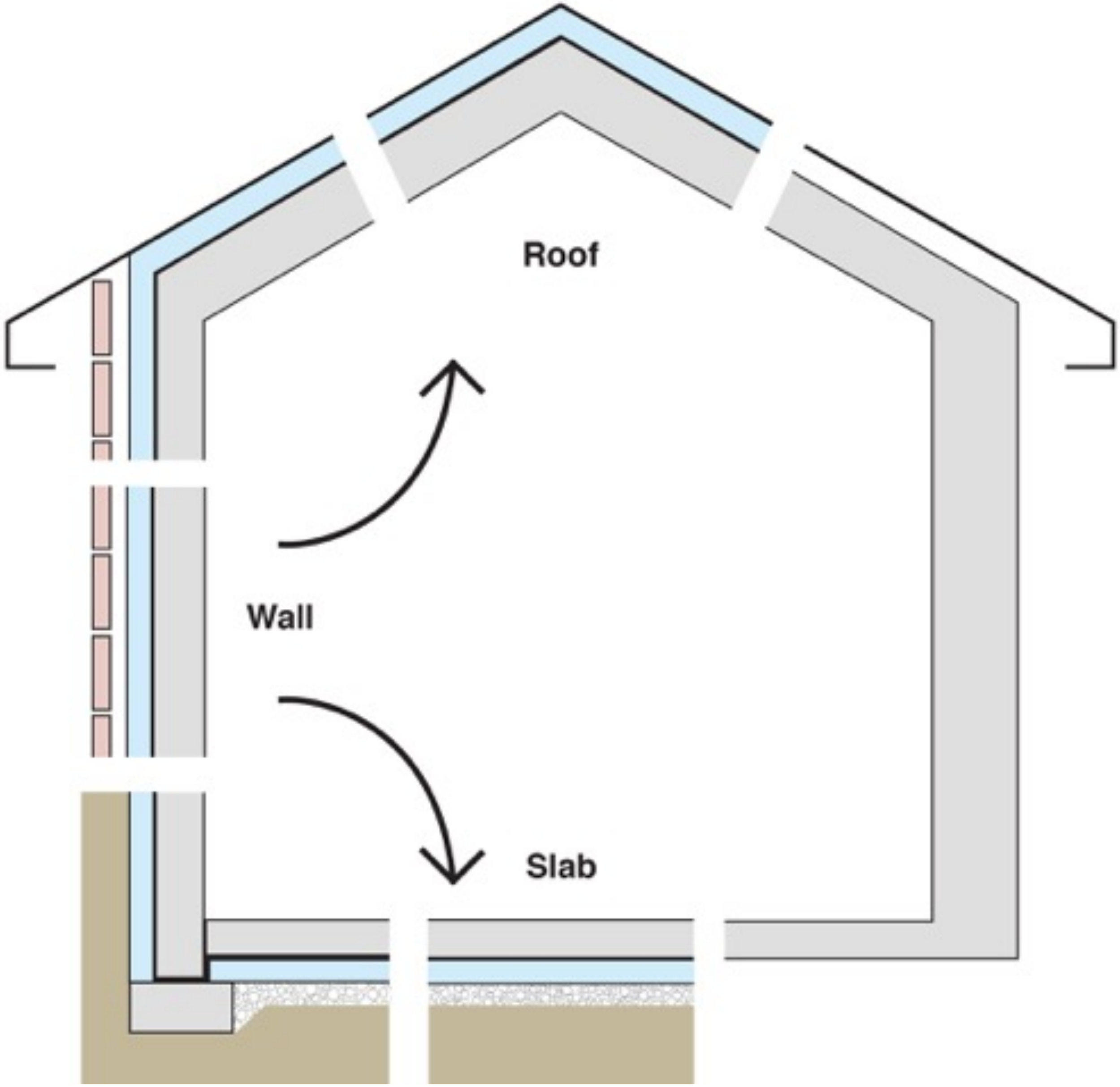

Parapet
Roof
Window
Wall
Footing
Slab

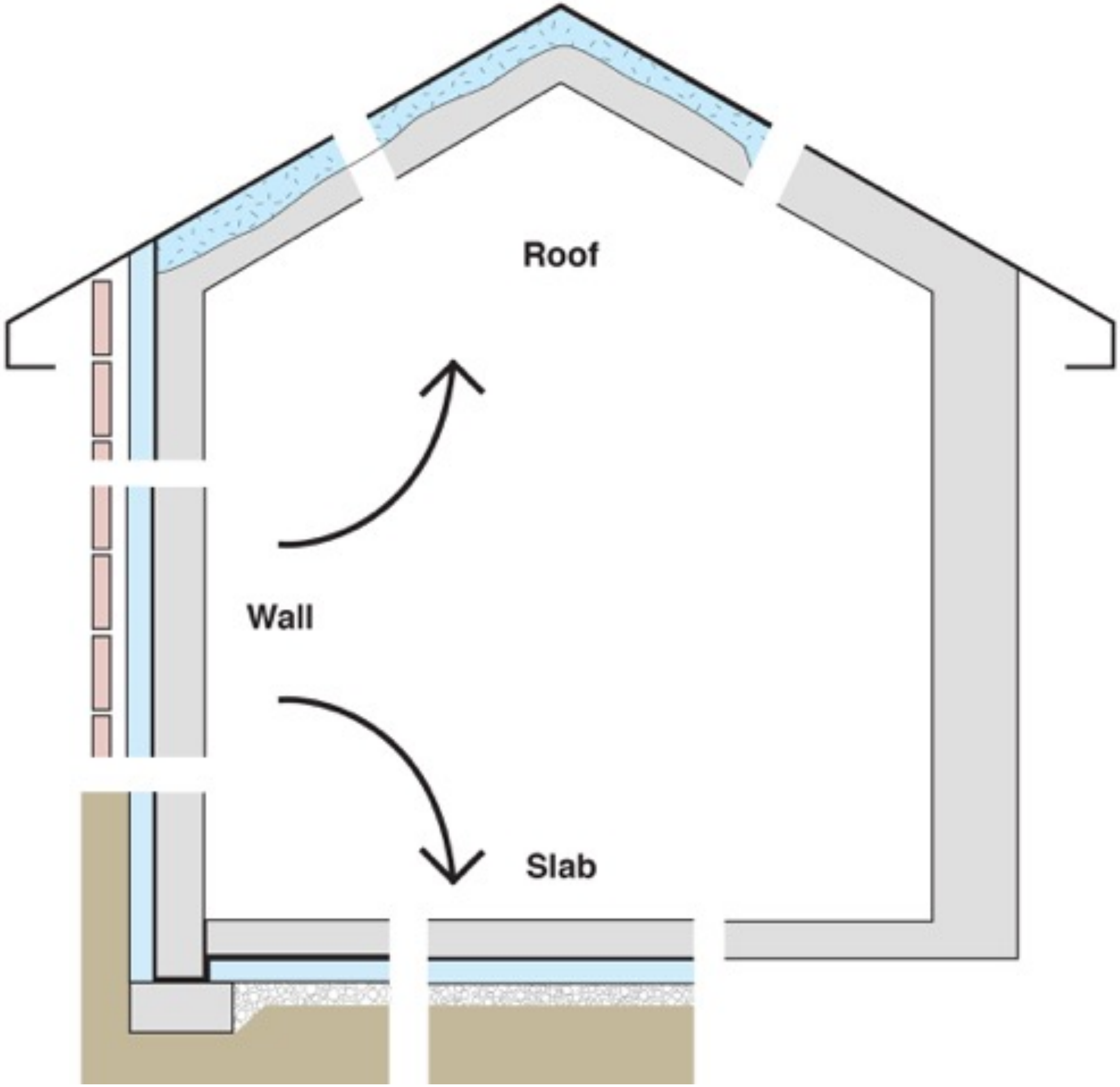

Control layer
Control layer
Roof structure

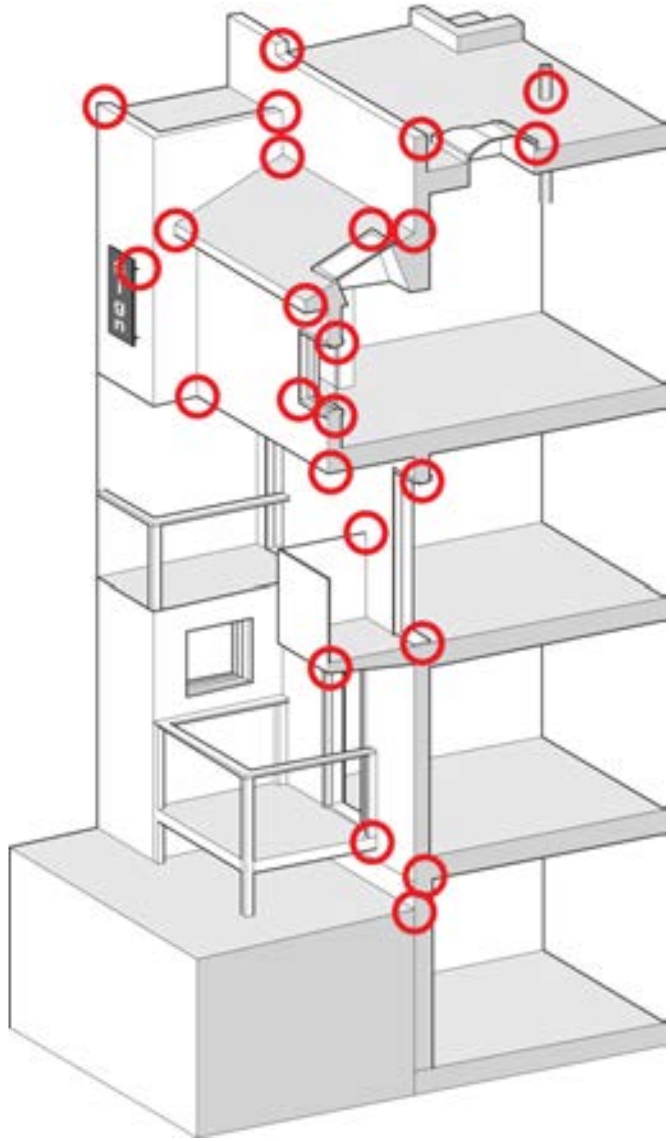

Parapet
Roof
Wall
Footing
Slab


Attic
Roof
Wall
Slab

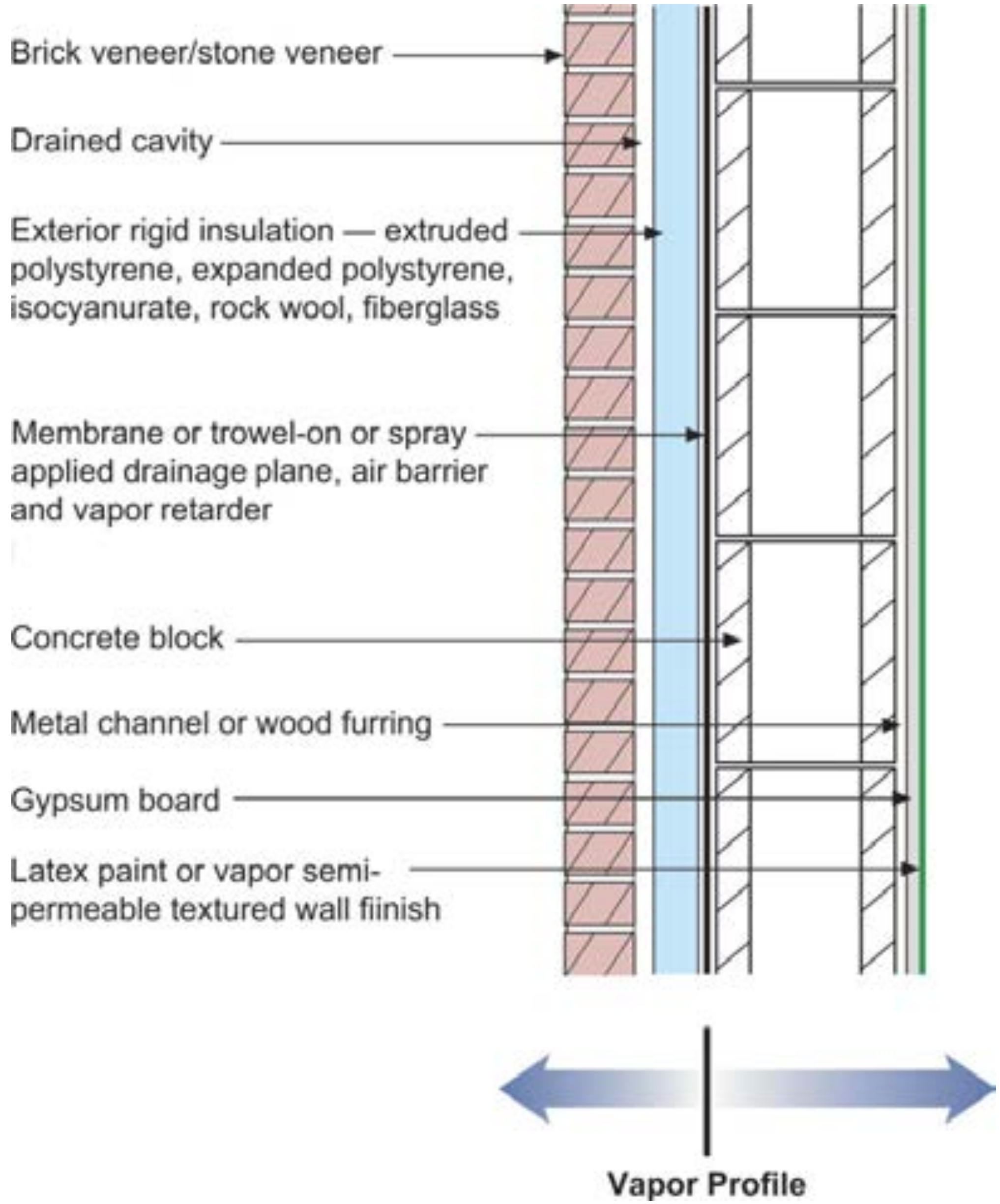

Attic
Wall
Slab

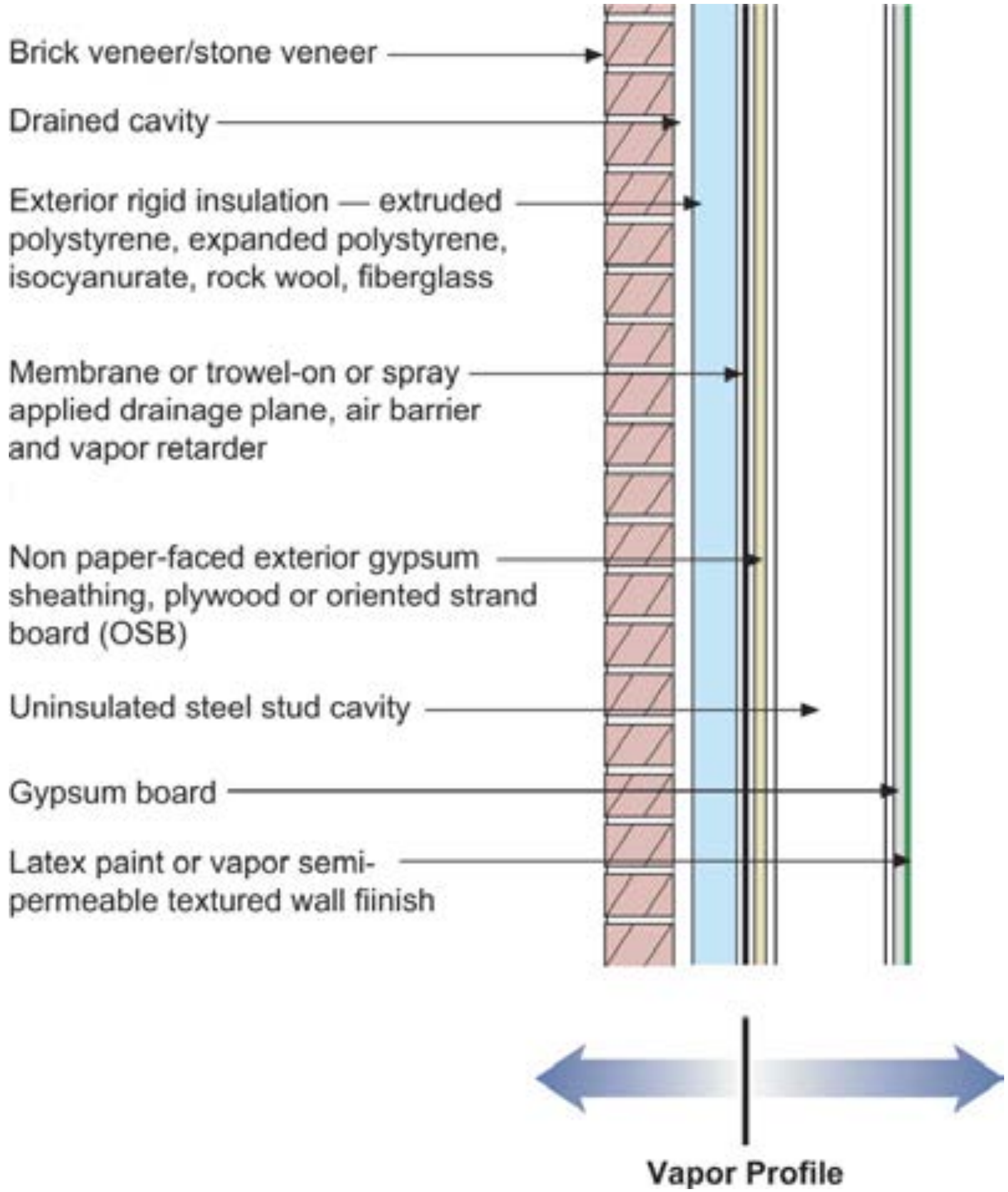

Roof
Wall
Slab


Roof
Wall
Slab



Configurations of the Perfect Wall

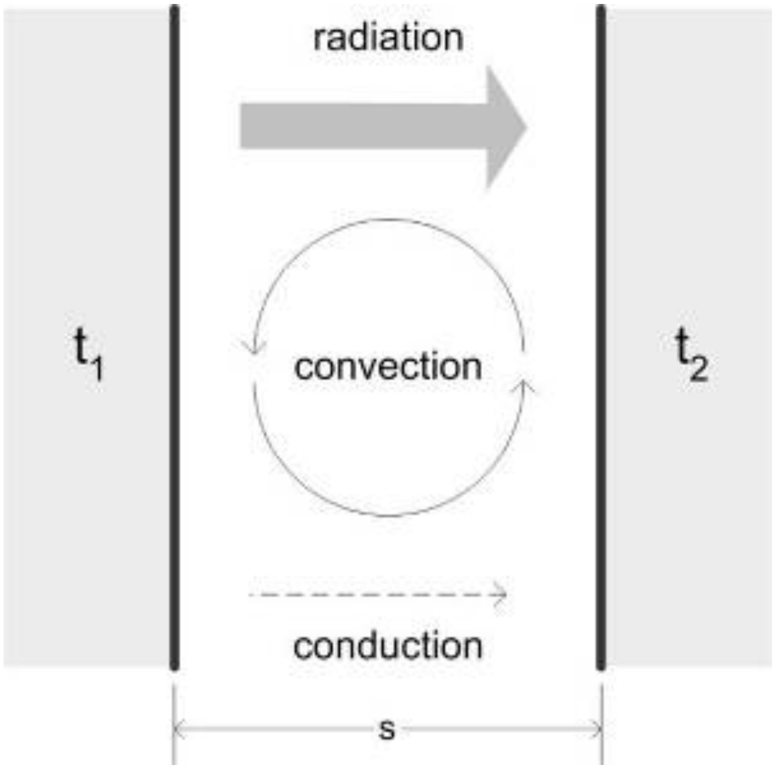

Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied drainage plane, air barrier and vapor retarder
Concrete block
Metal channel or wood furring
Gypsum board
Latex paint or vapor semi-permeable textured wall fiinish
Vapor Profile


Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied drainage plane, air barrier and vapor retarder
Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)
Uninsulated steel stud cavity
Gypsum board
Latex paint or vapor semi-permeable textured wall fiinish
Vapor Profile

Conduction

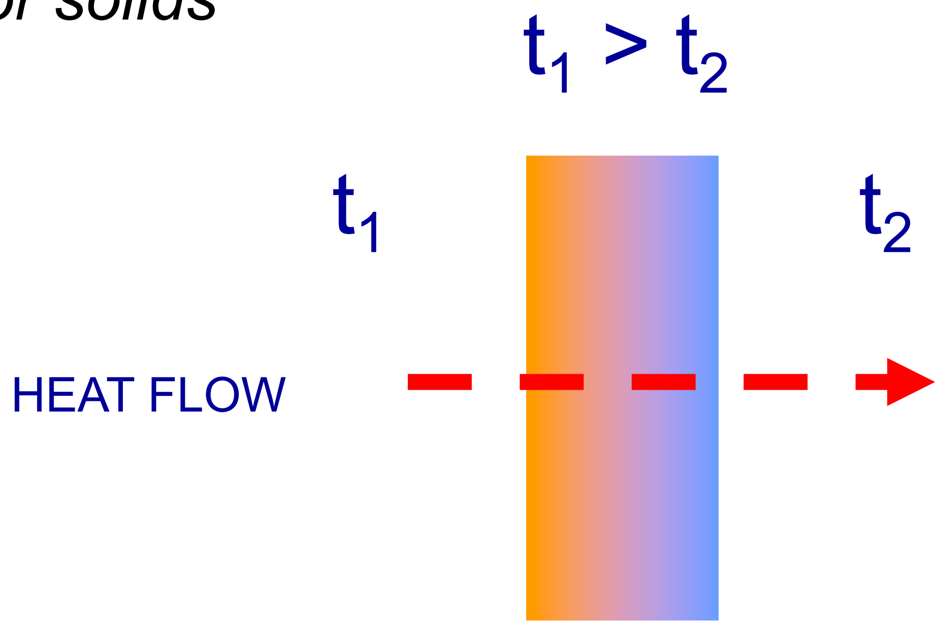
Convection

Radiation



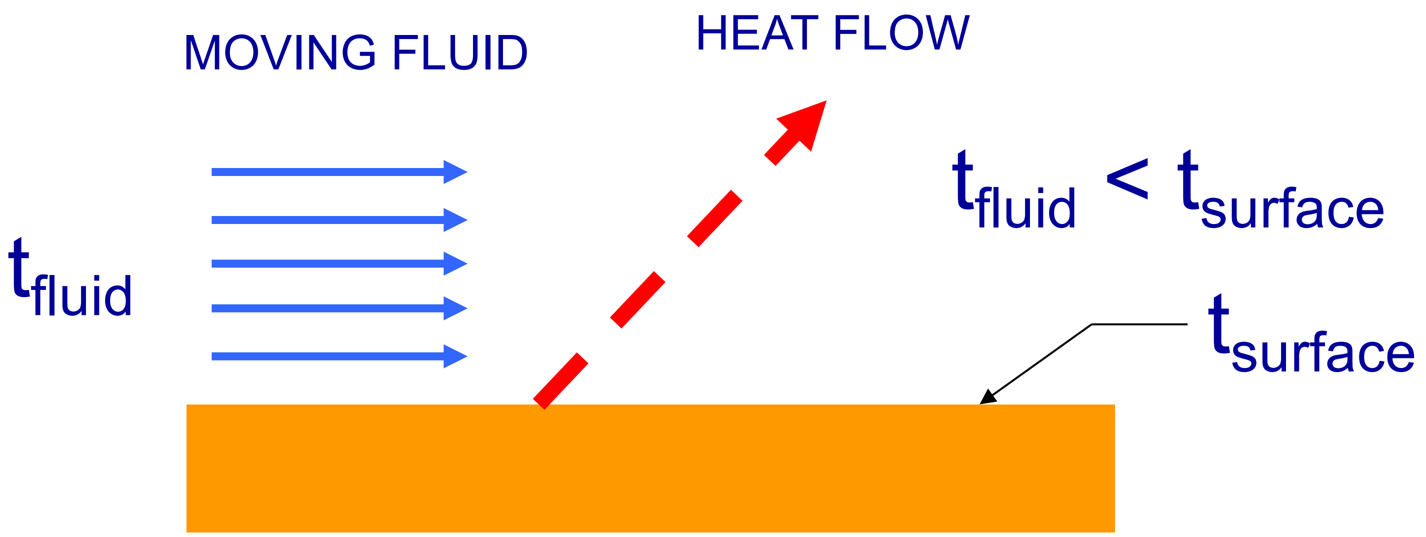
Conduction

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



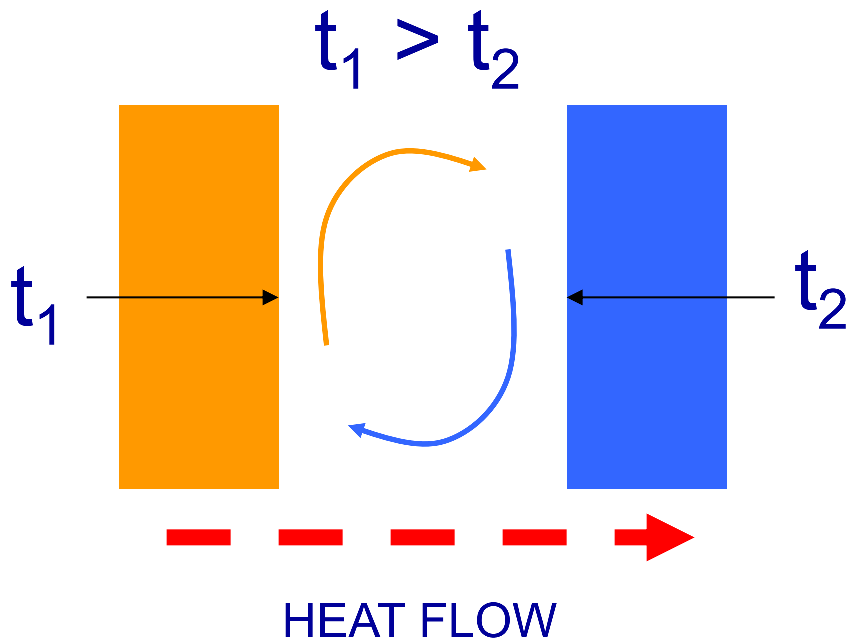
Forced Convection

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



Natural Convection

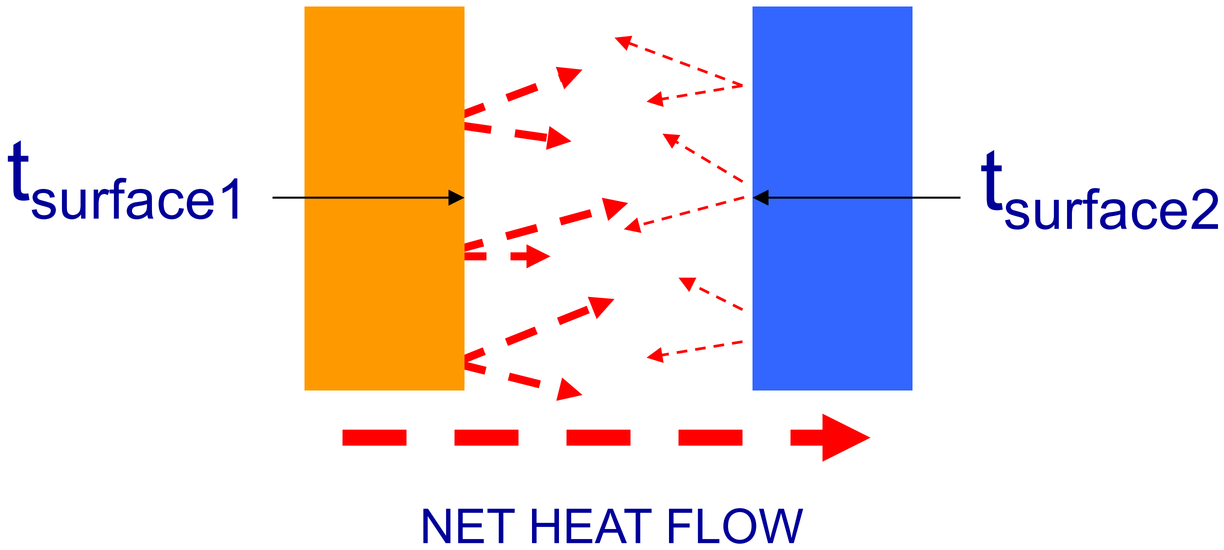
- *Heat Flow by bulk movement of molecules*
- *Most important for liquids and gases*
- *Natural buoyancy drives movement*



Radiation

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

$t_{surface1} > t_{surface2}$

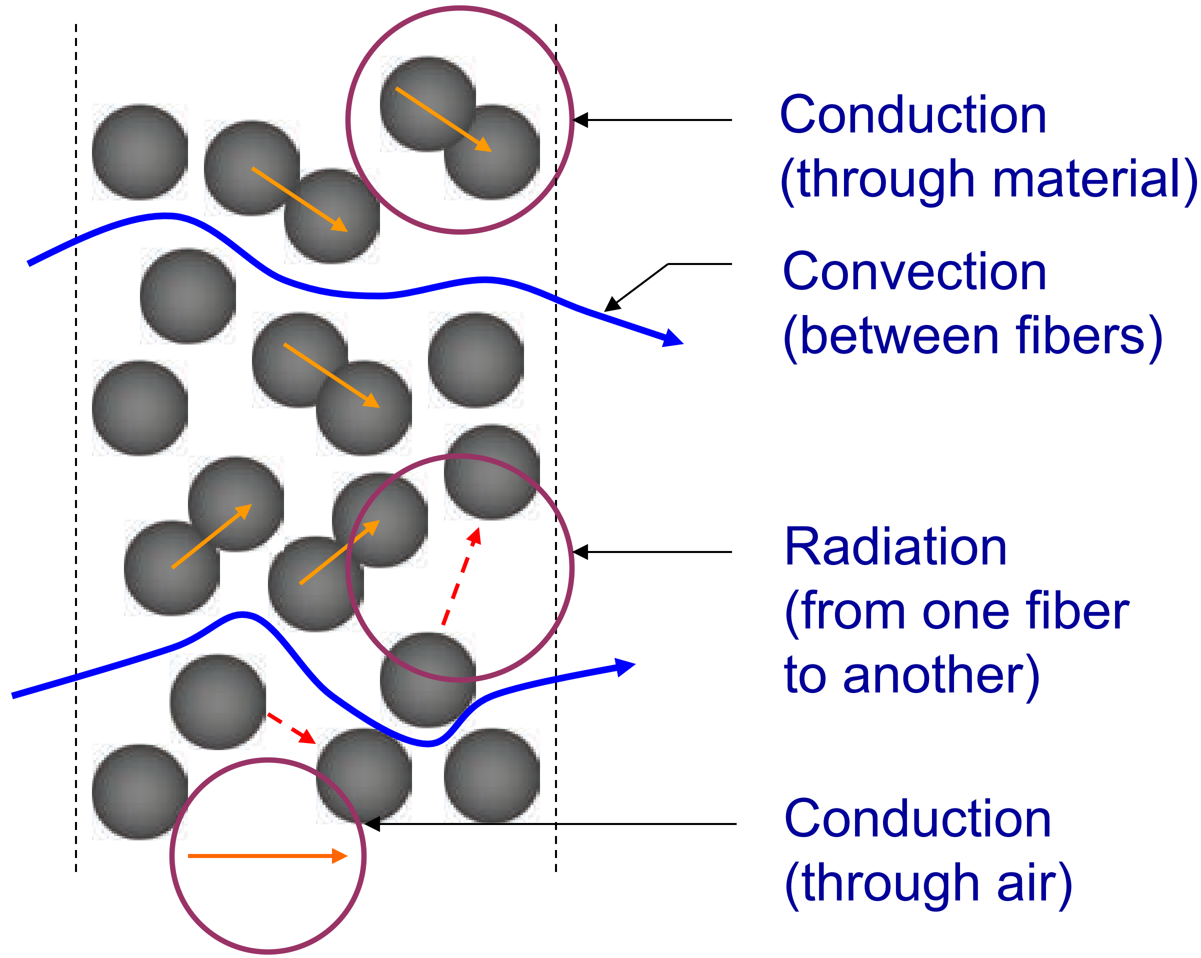


Function of:

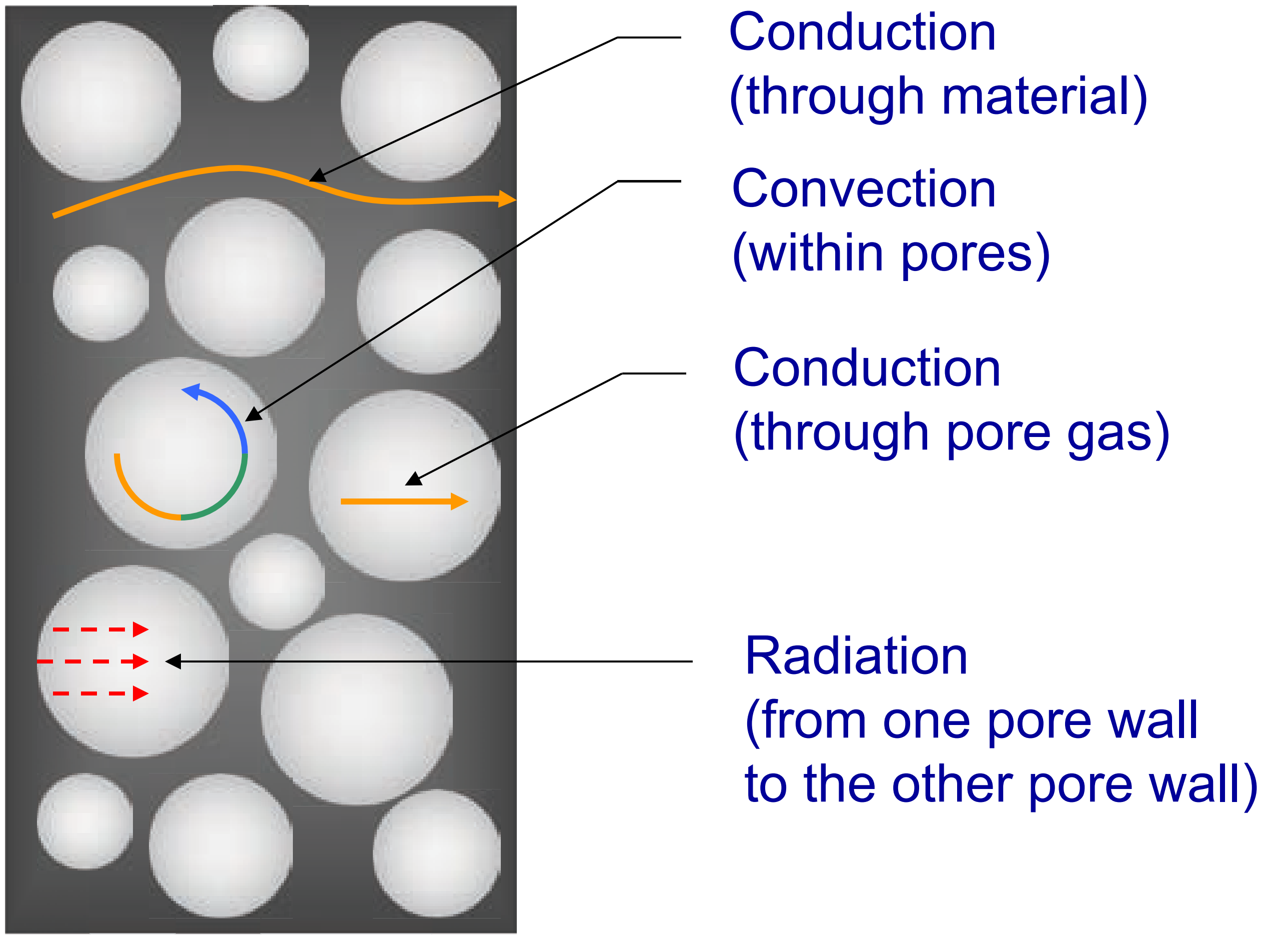
- *Material Type*
- *Density and pore structure*
- *Moisture content*
- *Temperature difference*

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/(ft^2•hr•°F) *or* W/(m^2•K)

Thermal Resistance

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

Formula: Resistance = 1/C

Units: $ft^2 \cdot hr \cdot ° F/ Btu$ *or* $m^2 \cdot K/W$

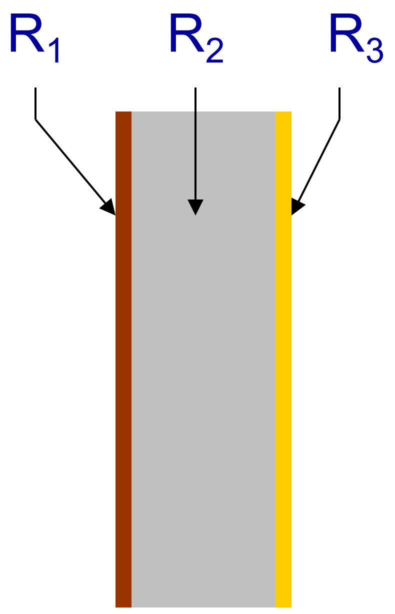
R-Value or RSI

- *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.

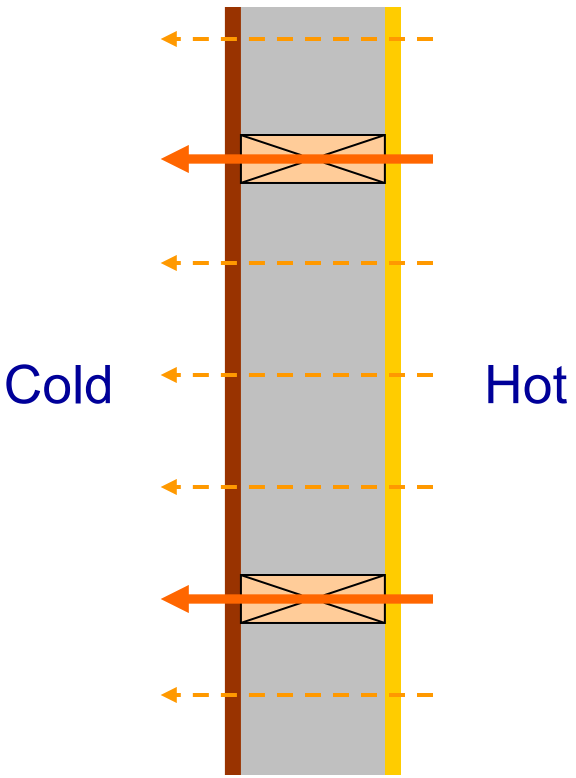


$$R_T = R_1 + R_2 + R_3$$

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.

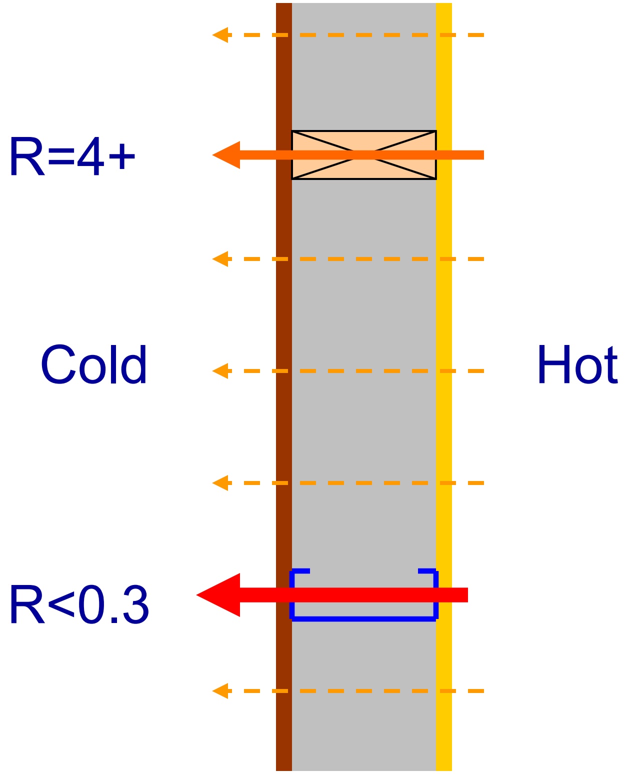


A 2x6 wood stud wall 16" OC with R-19 Fiberglass Batt = effective R-13 wall assembly.

Conductance through the enclosure assemblies

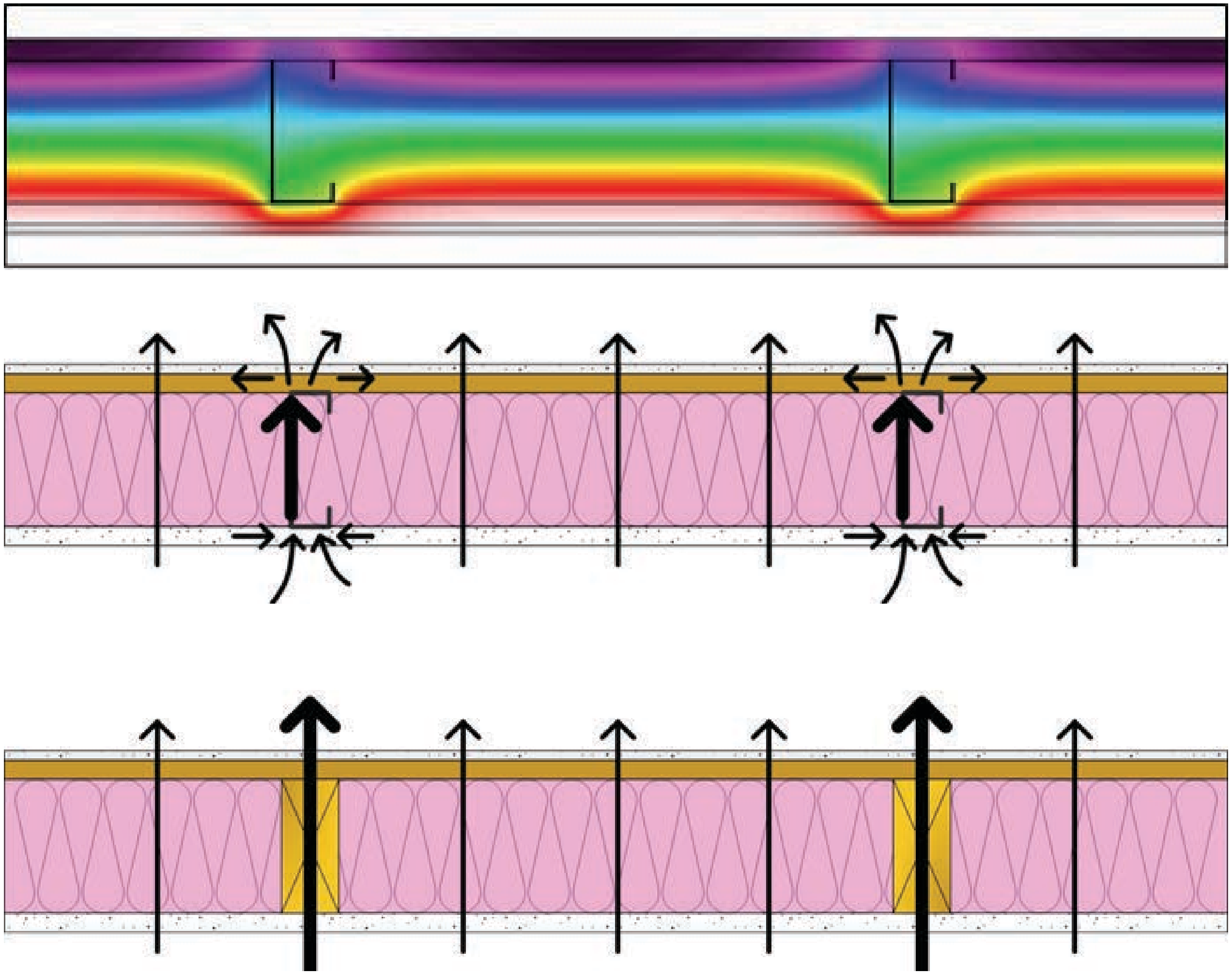
Steel is 400 times more conductive than wood

Steel studs are about 40 times thinner

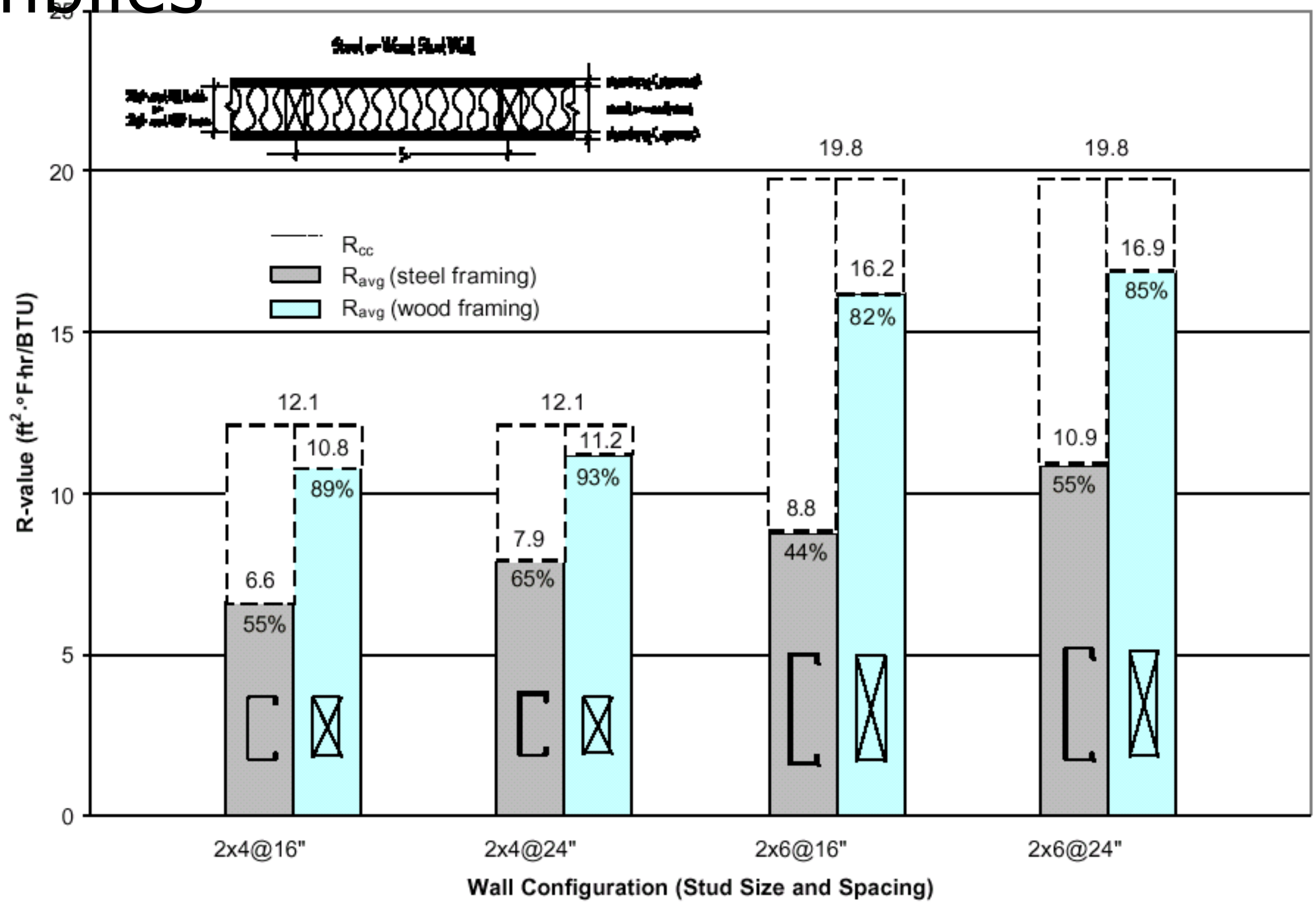


A 2x6 steel stud wall 16" OC with R-19 Fiberglass Batt = effective R-9 wall assembly.

Conductance through the enclosure assemblies



Conductance through the enclosure assemblies



Conductance through the enclosure assemblies

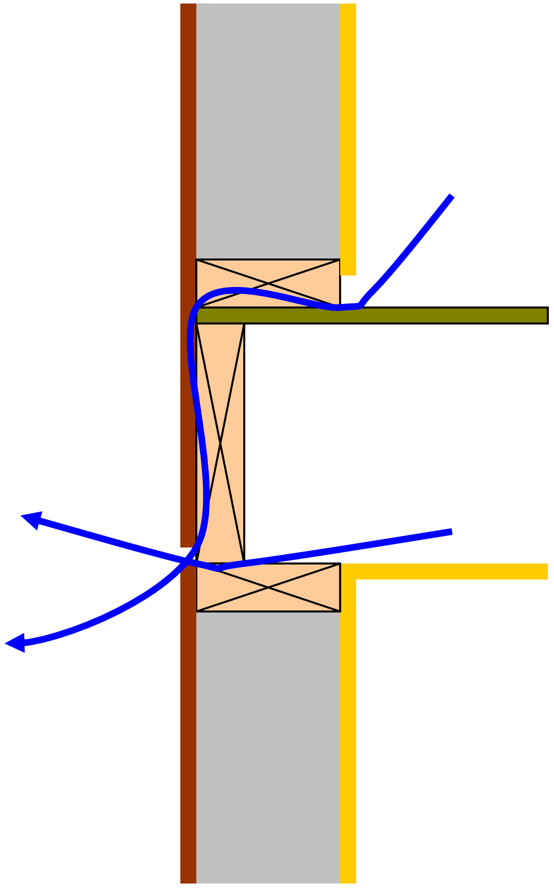
Convection through the enclosure assemblies

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)



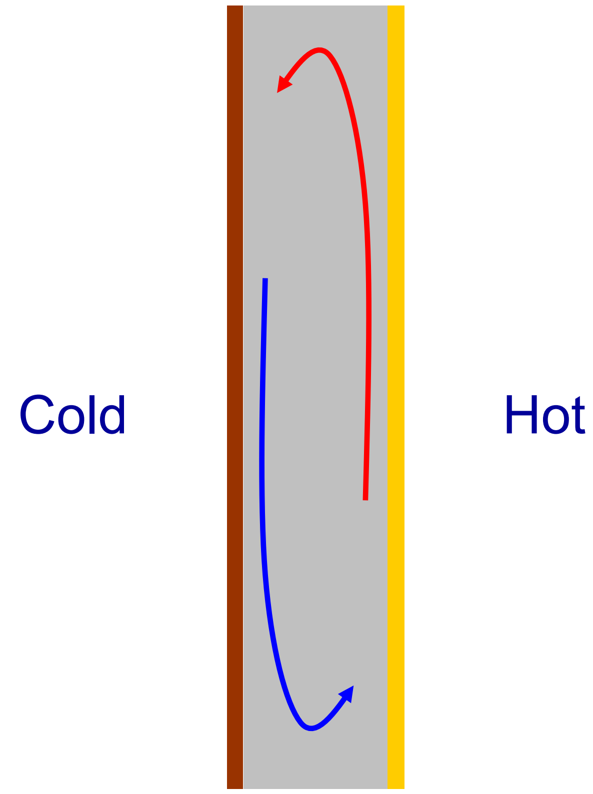
Convection within the enclosure assemblies

Commonly referred to as "Convective Loops"

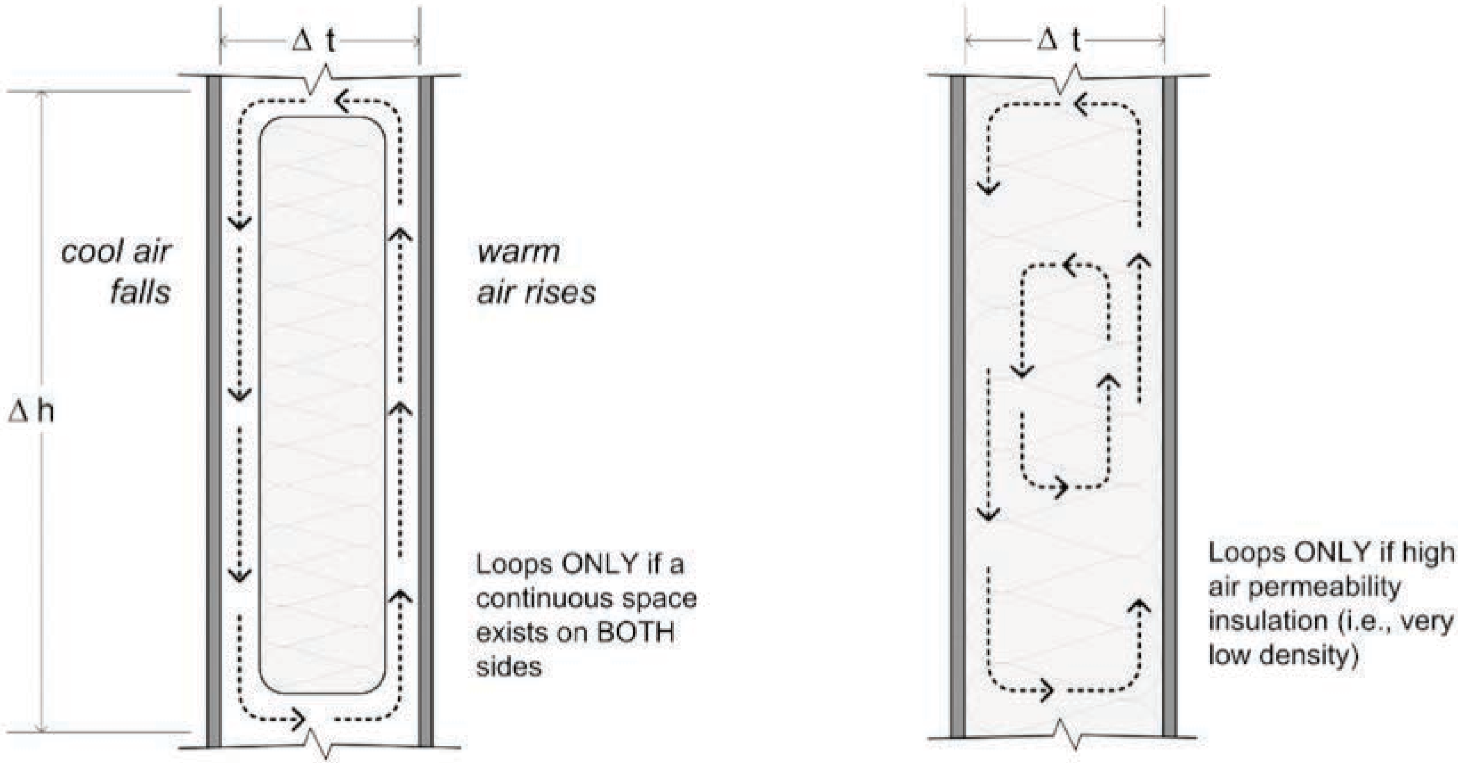
Driven by natural buoyancy - warm air will rise

Short circuits insulation

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



Convection within the enclosure assemblies



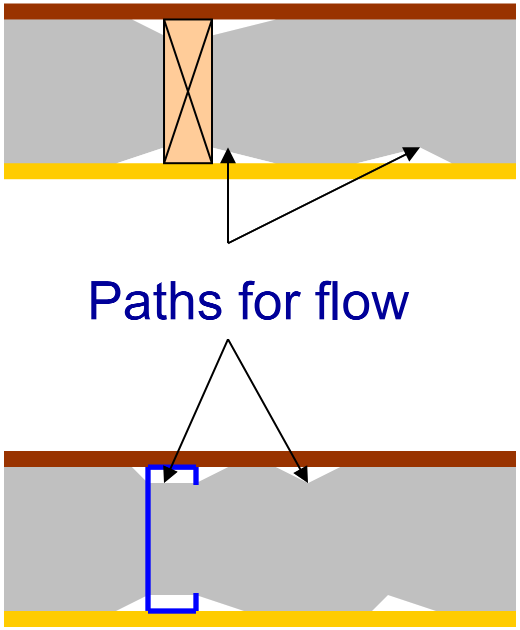
A: Air Loops Around Insulation

B: Air Loops Through Insulation

Convection within the enclosure assemblies

Spaces for flow from:

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



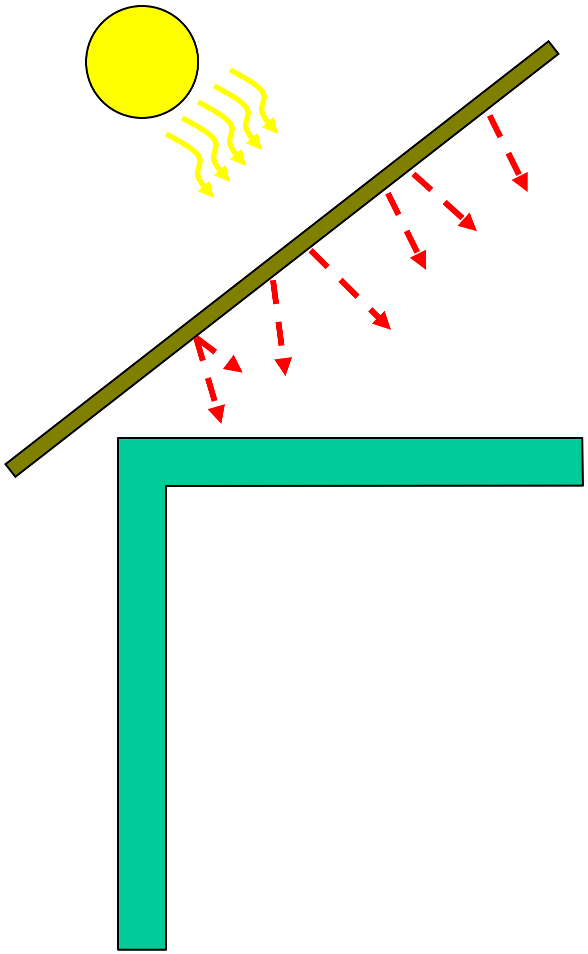
Convection within the enclosure assemblies

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



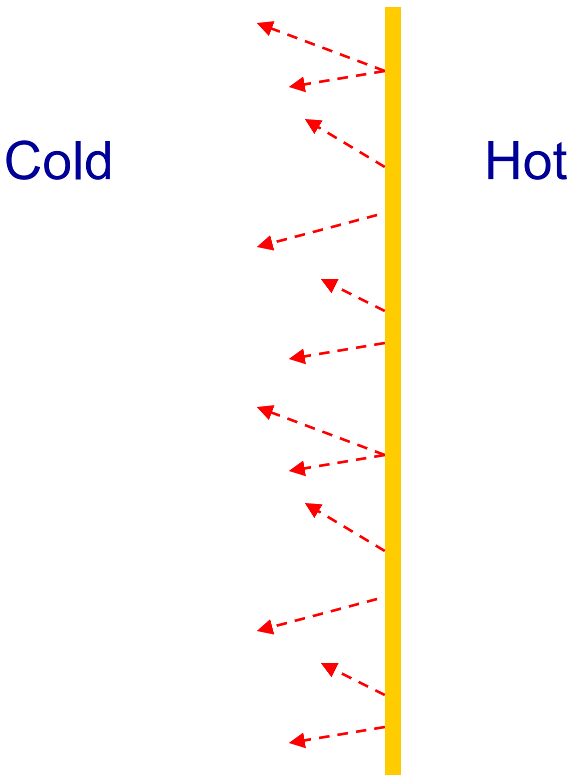
Radiation from surfaces within the enclosure assemblies

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)



Radiation from surfaces within the enclosure assemblies

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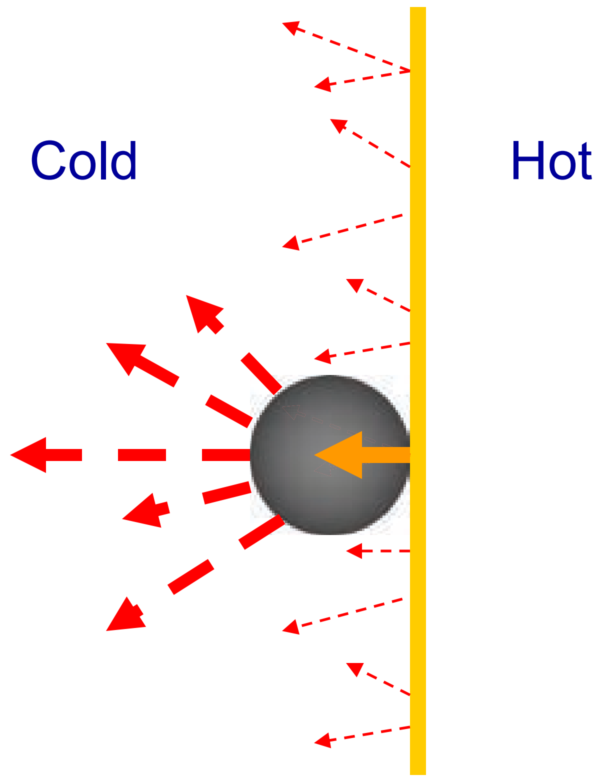


Heat Flow Is From Warm To Cold

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

Moisture Flow Is From Warm To Cold

Moisture Flow Is From More To Less

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

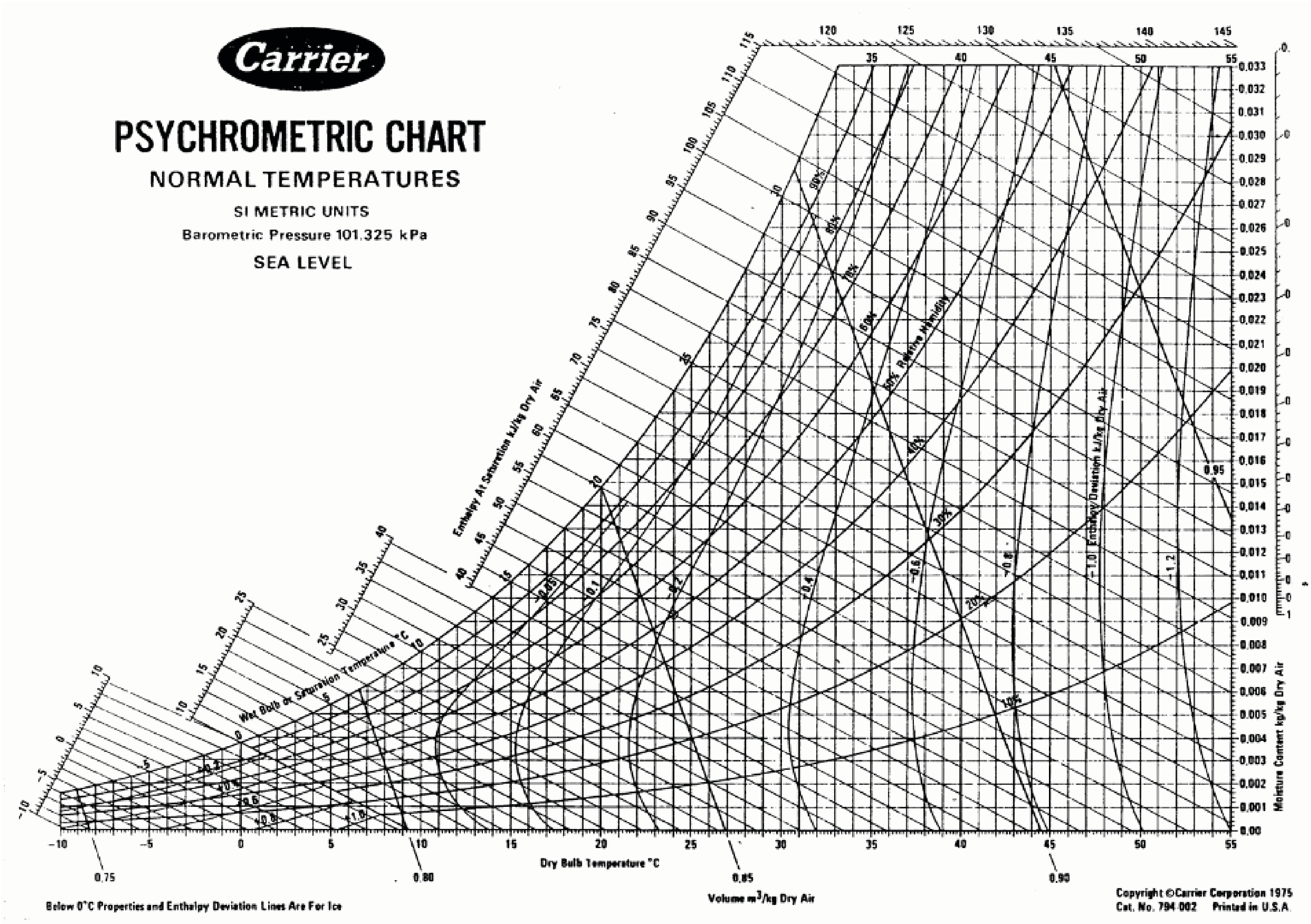
Moisture Flow Is From More To Less

Thermal Gradient – Thermal Diffusion

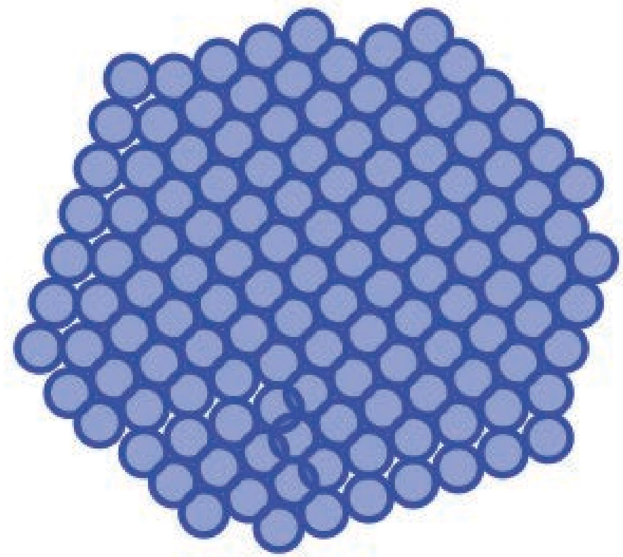
Concentration Gradient – Molecular Diffusion

Vapor Diffusion

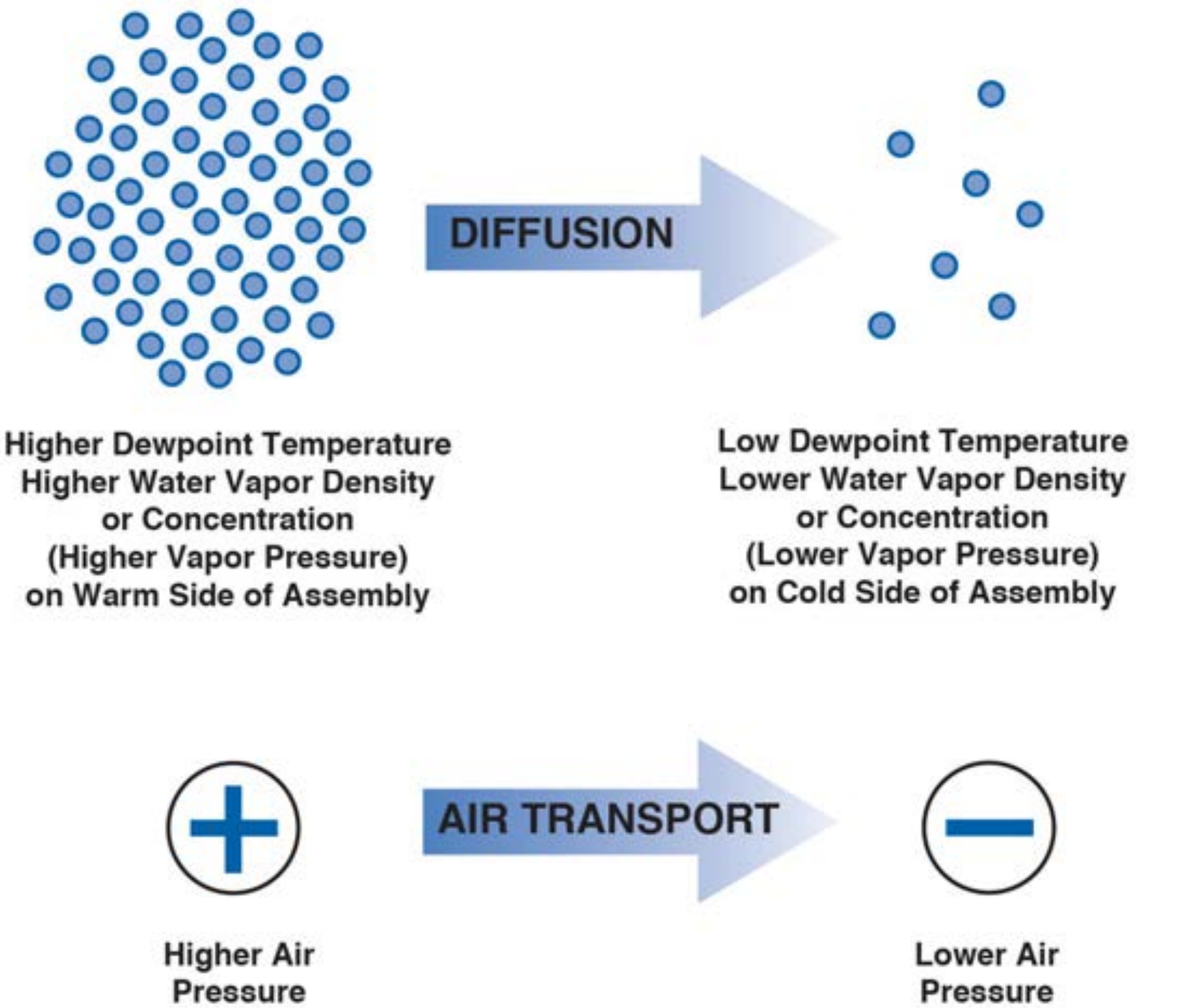
Thermodynamic Potential

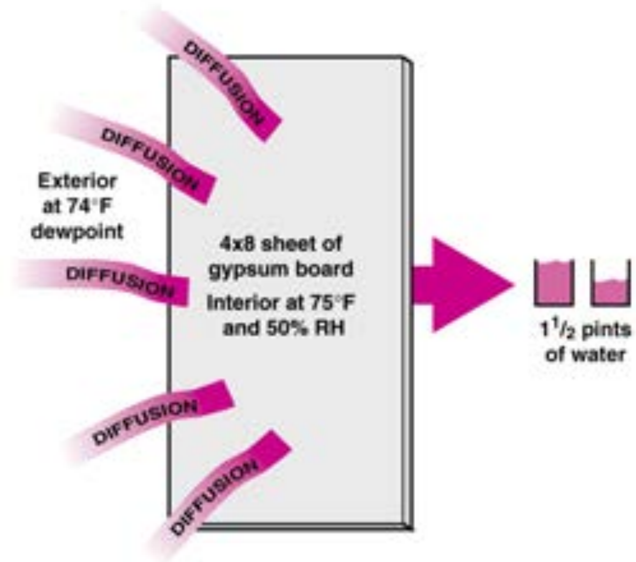

Carrier
PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101.325 kPa
SEA LEVEL
Enthalpy At Saturation kJ/kg Dry Air
Wet Bulb or Saturation Temperature °C
Relative Humidity
Enthalpy Deviation kJ/kg Dry Air
Moisture Content kg/kg Dry Air
Dry Bulb Temperature °C
Volume m³/kg Dry Air
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice
Copyright ©Carrier Corporation 1975
Cat. No. 794-002 Printed in U.S.A.

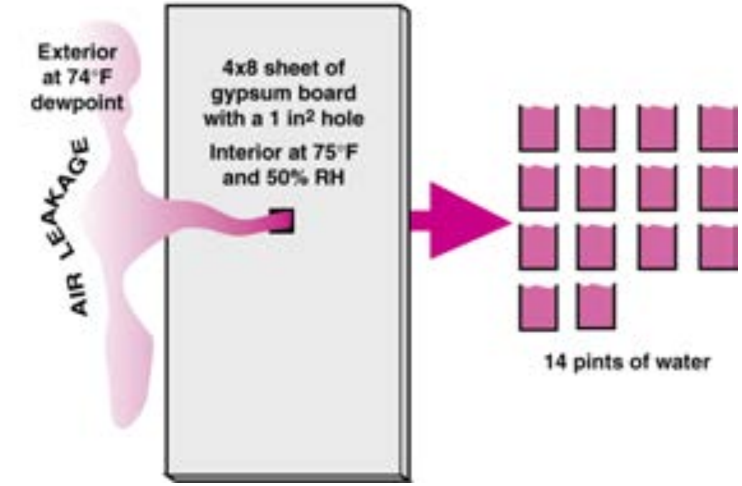
Vapor

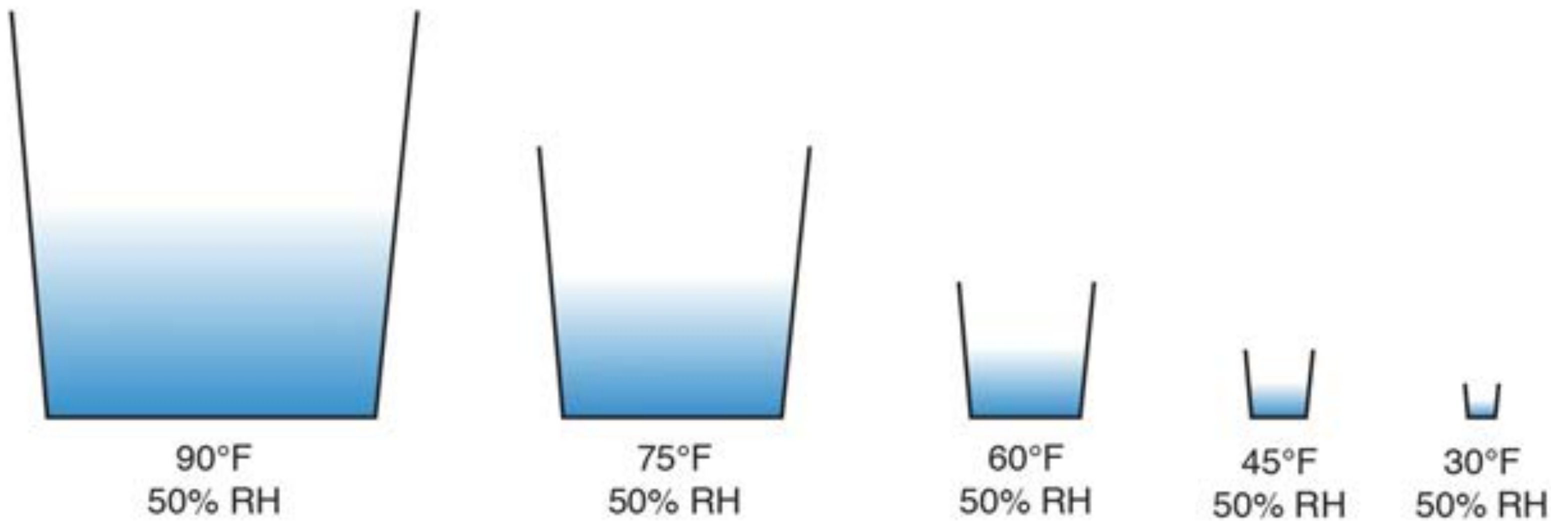


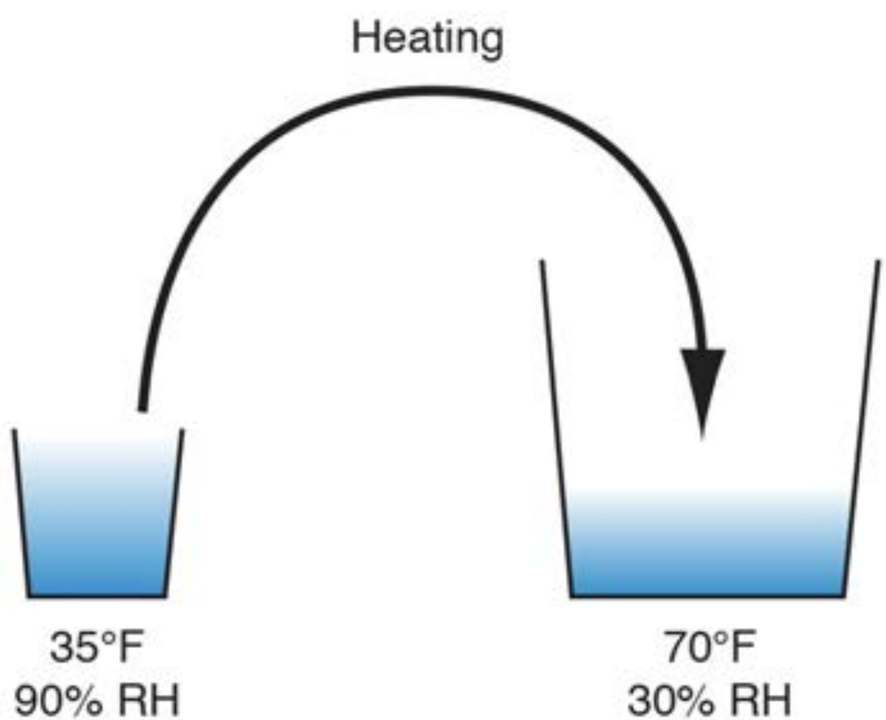
Liquid

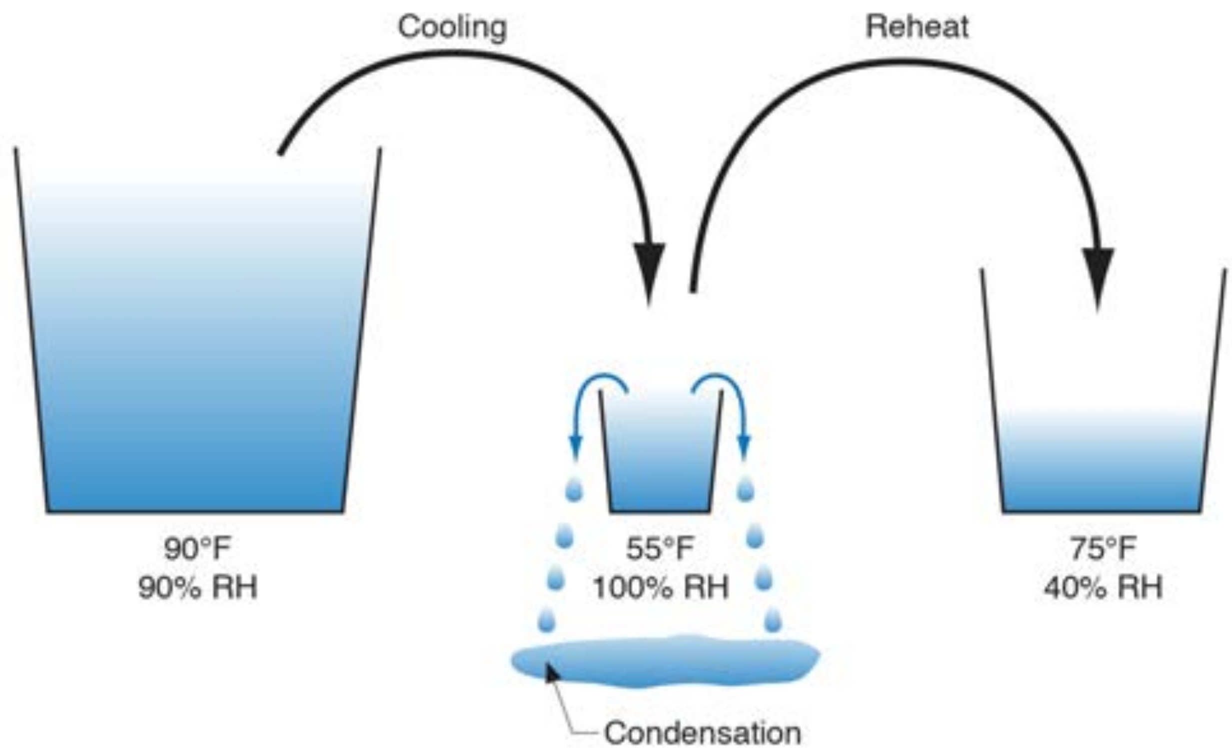

DIFFUSION
Higher Dewpoint Temperature
Higher Water Vapor Density
or Concentration
(Higher Vapor Pressure)
on Warm Side of Assembly
Low Dewpoint Temperature
Lower Water Vapor Density
or Concentration
(Lower Vapor Pressure)
on Cold Side of Assembly
AIR TRANSPORT
Higher Air
Pressure
Lower Air
Pressure


DIFFUSION
DIFFUSION
Exterior
at 74°F
dewpoint
DIFFUSION
4x8 sheet of
gypsum board
Interior at 75°F
and 50% RH
1 1/2 pints
of water
DIFFUSION
DIFFUSION

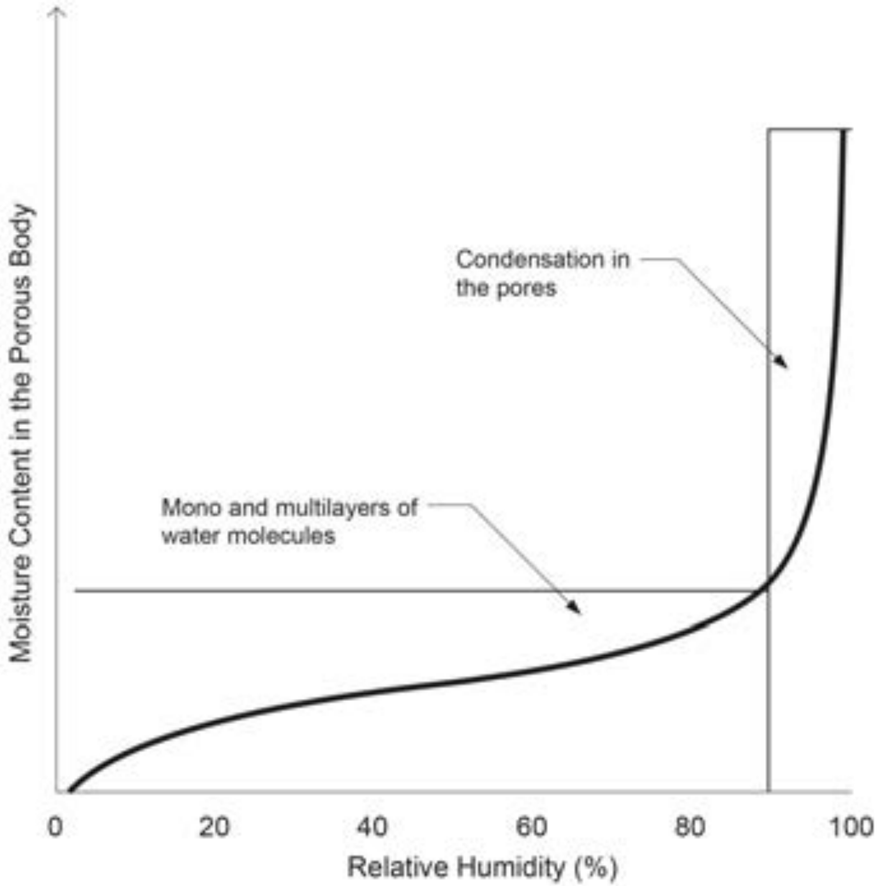

Exterior
at 74°F
dewpoint
4x8 sheet of
gypsum board
with a 1 in² hole
Interior at 75°F
and 50% RH
AIR LEAKAGE
14 pints of water


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

Sorption Isotherms

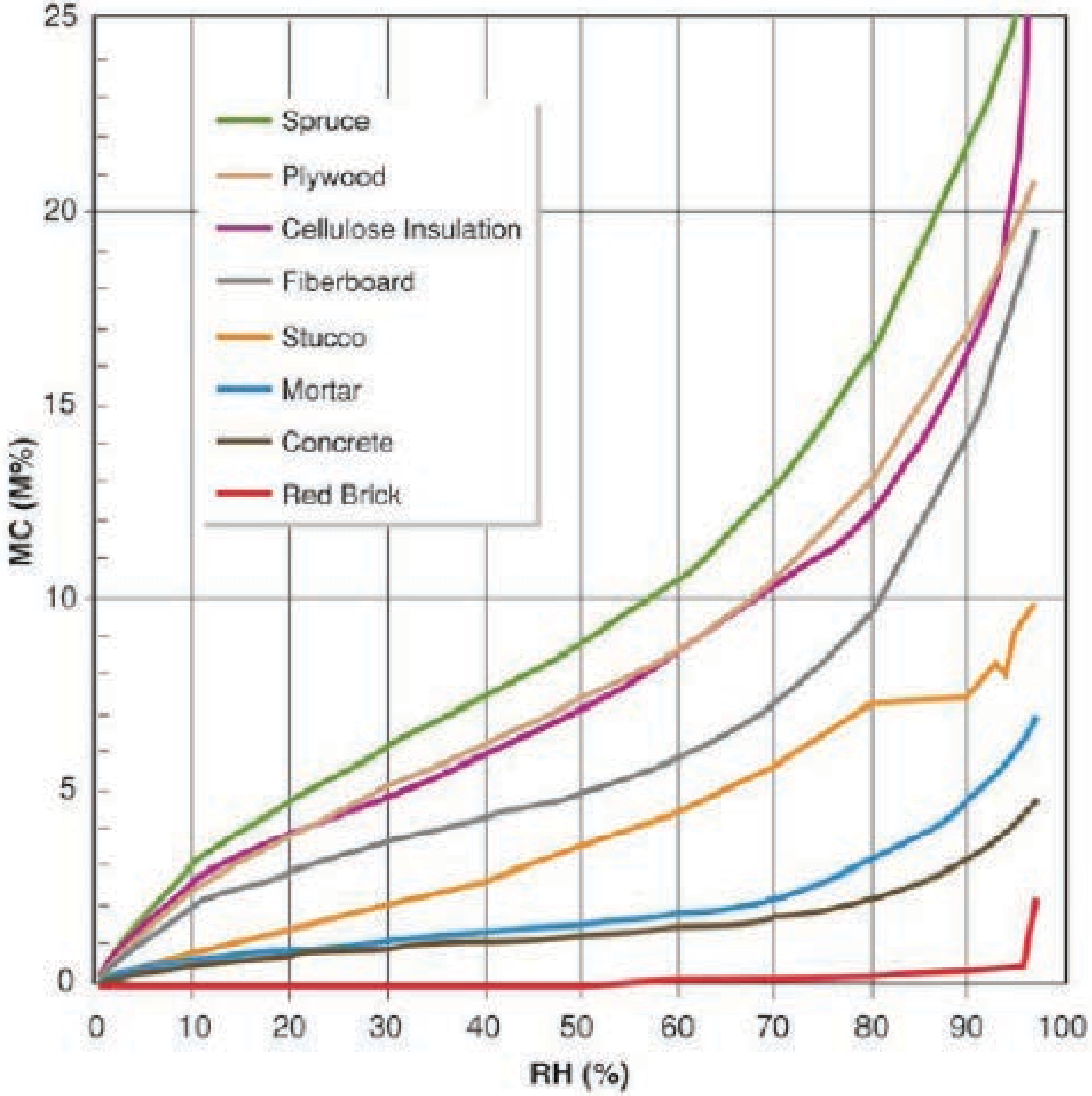


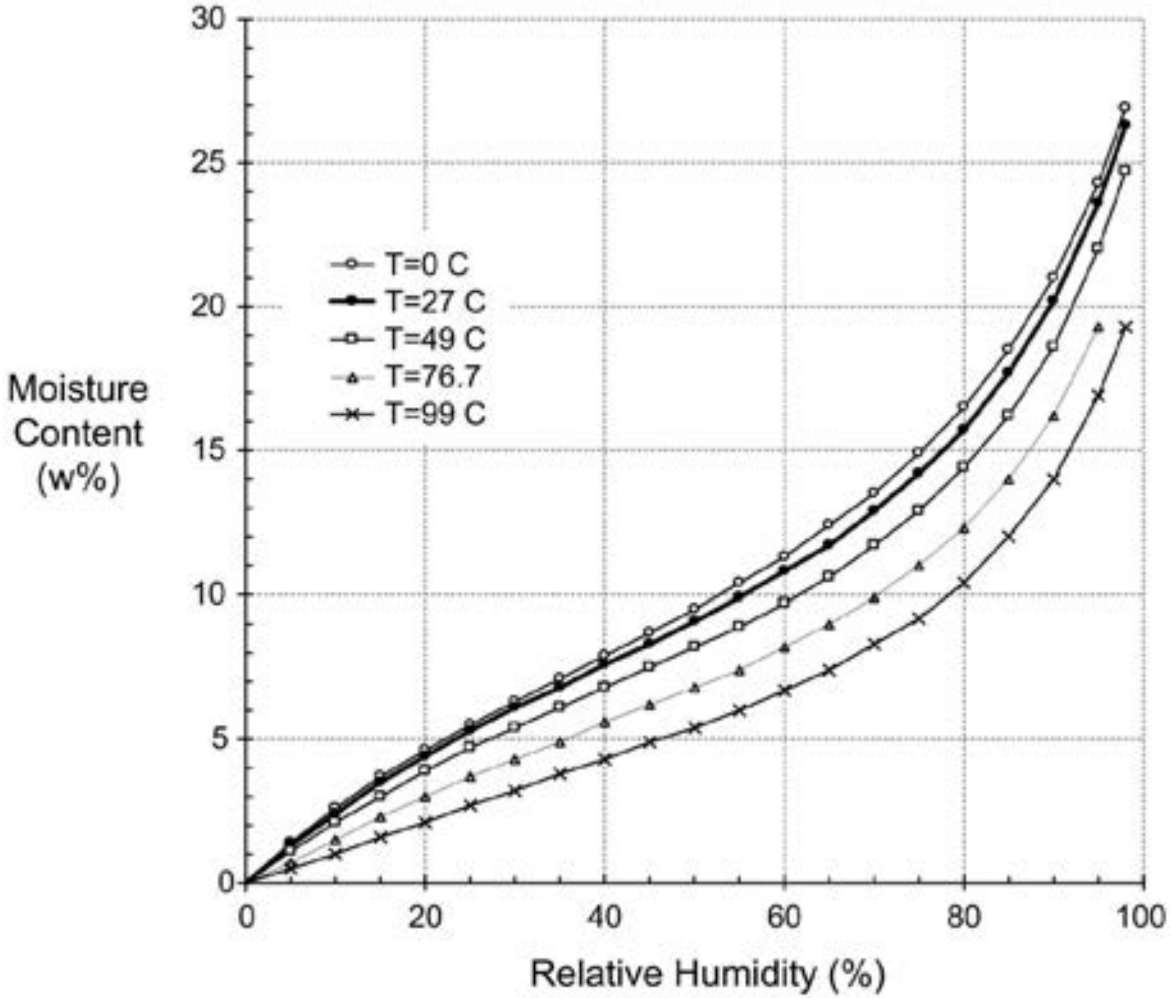
Partial Pressure of Water Vapor

Change in the storage of moisture in a porous building material as the partial pressure of water vapor in the ambient air increases from zero to full saturation value at a given temperature.

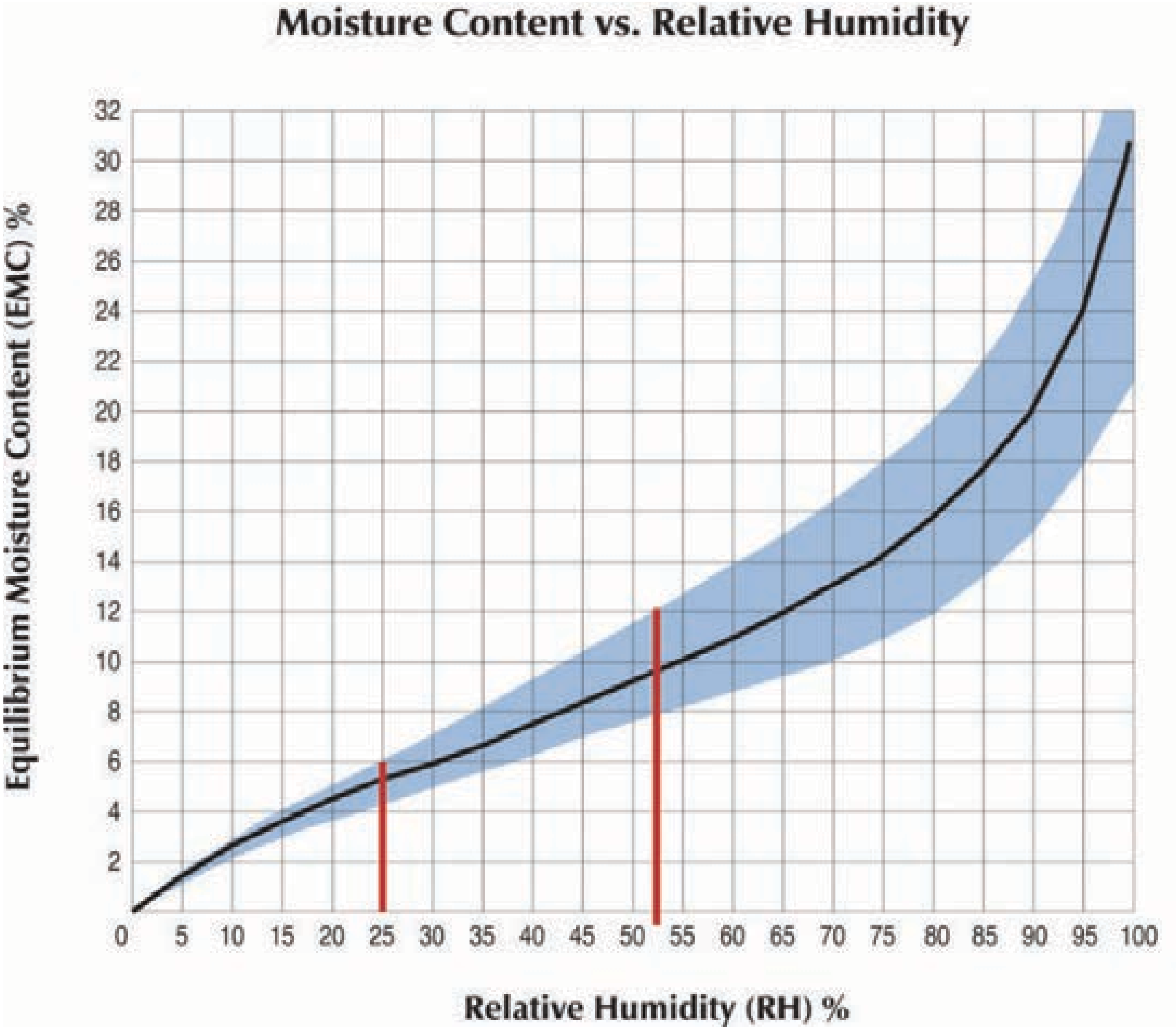
Sorption Curve

From M.K. Kumaran, ASTM MNL 18-2nd Edition, Moisture Control in Buildings, 2009


Spruce
Plywood
Cellulose Insulation
Fiberboard
Stucco
Mortar
Concrete
Red Brick
MC (M%)
RH (%)
0
5
10
15
20
25
0
10
20
30
40
50
60
70
80
90
100



Average sorption isotherm for wood as a function of temperature
From Straube & Burnett, 2005



Moisture Content vs. Relative Humidity
Equilibrium Moisture Content (EMC) %
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Relative Humidity (RH) %