Joseph Lstiburek, Ph.D., P.Eng, ASHRAE Fellow

Building Science

Adventures In Building Science

www.buildingscience.com

What is a Building?

A Building is an Environmental Separator

Zeroth Law – A=B and B=C therefore A=C

First Law - Conservation of Energy

Second Law - Entropy

Third Law – Absolute Zero

2nd Law of Thermodynamics

In an isolated system, a process can occur only if it increases the total entropy of the system

Rudolf Clausius

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

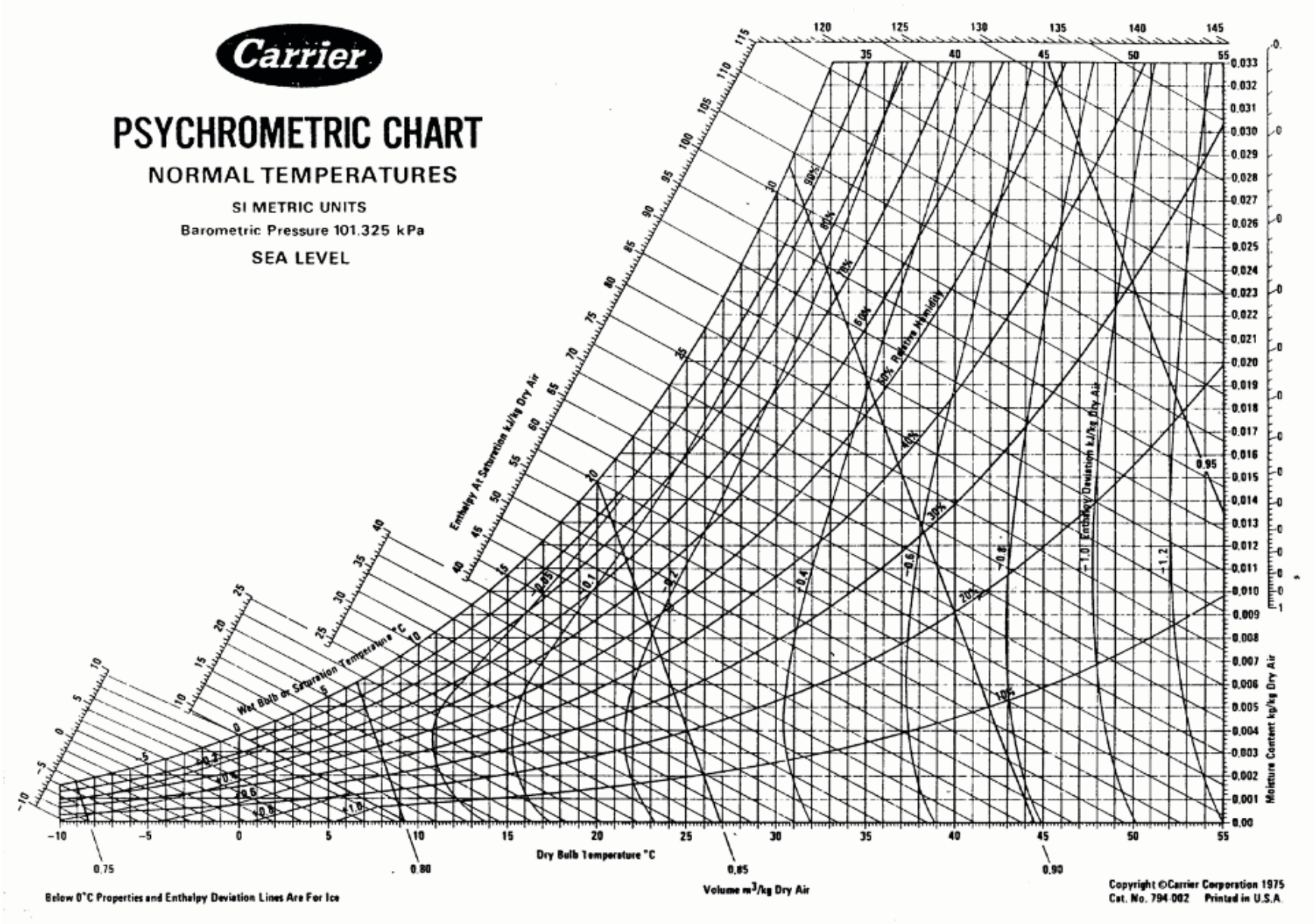
Moisture Flow Is From More To Less

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
Dry Bulb Temperature °C
Wet Bulb or Saturation Temperature °C
Enthalpy At Saturation kJ/kg Dry Air
Moisture Content kg/kg Dry Air
Volume m³/kg Dry Air
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice
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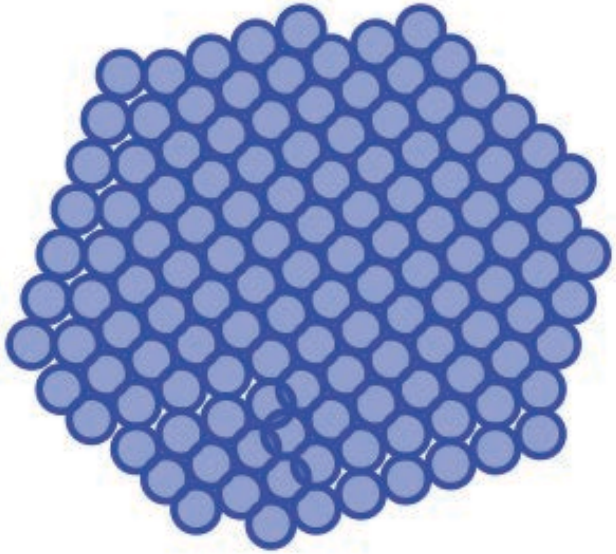
Cat. No. 794-002 Printed in U.S.A.

Size Matters

Vapor



Liquid

DIFFUSION

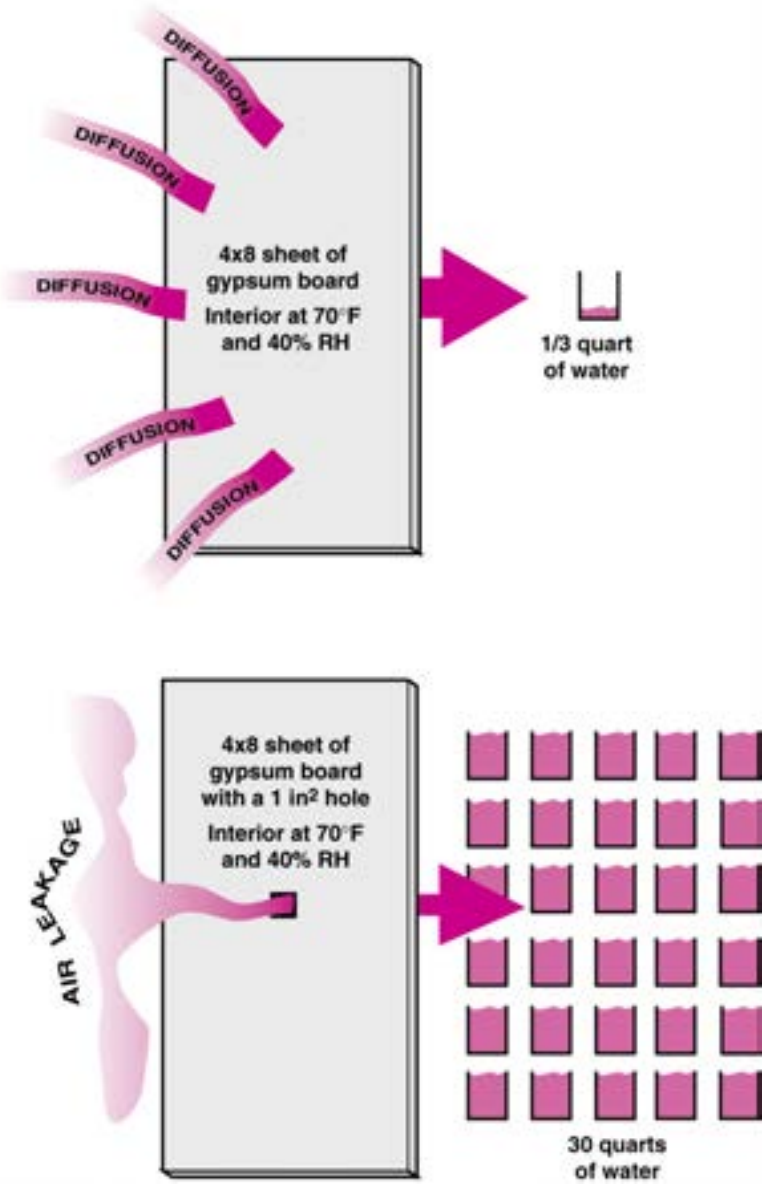
Higher Dewpoint Temperature
Higher Water Vapor Density
or Concentration
(Higher Vapor Pressure)
on Warm Side of Assembly

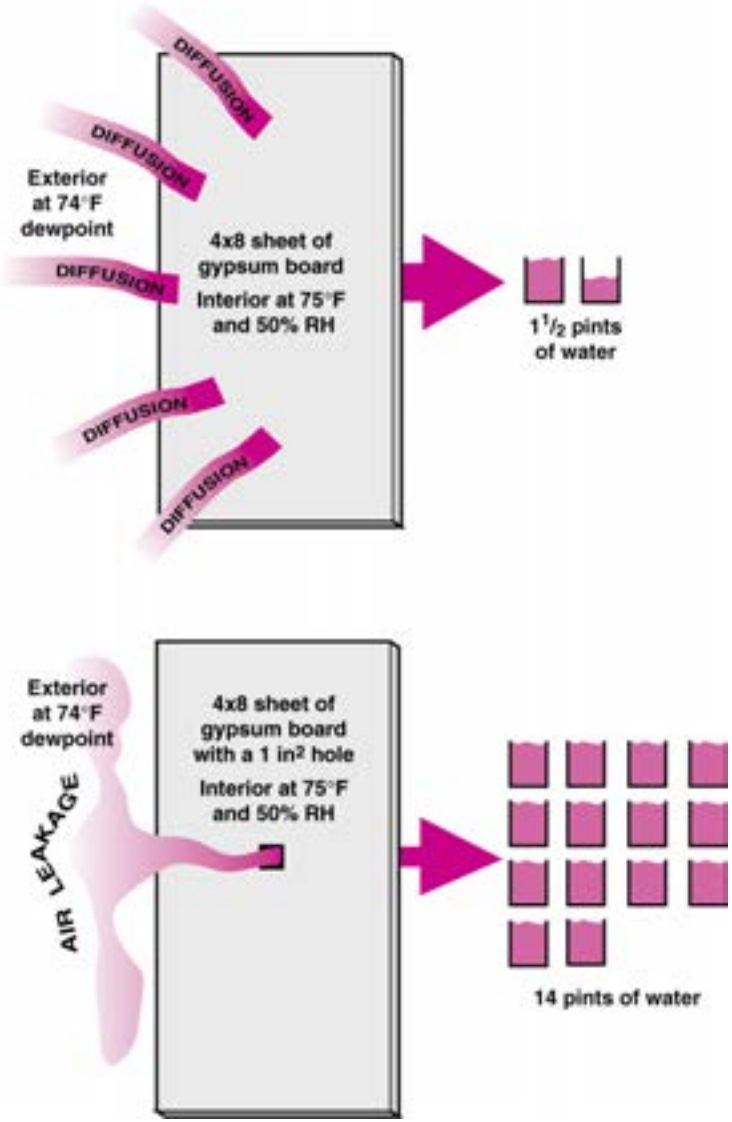
Low Dewpoint Temperature
Lower Water Vapor Density
or Concentration
(Lower Vapor Pressure)
on Cold Side of Assembly

AIR TRANSPORT

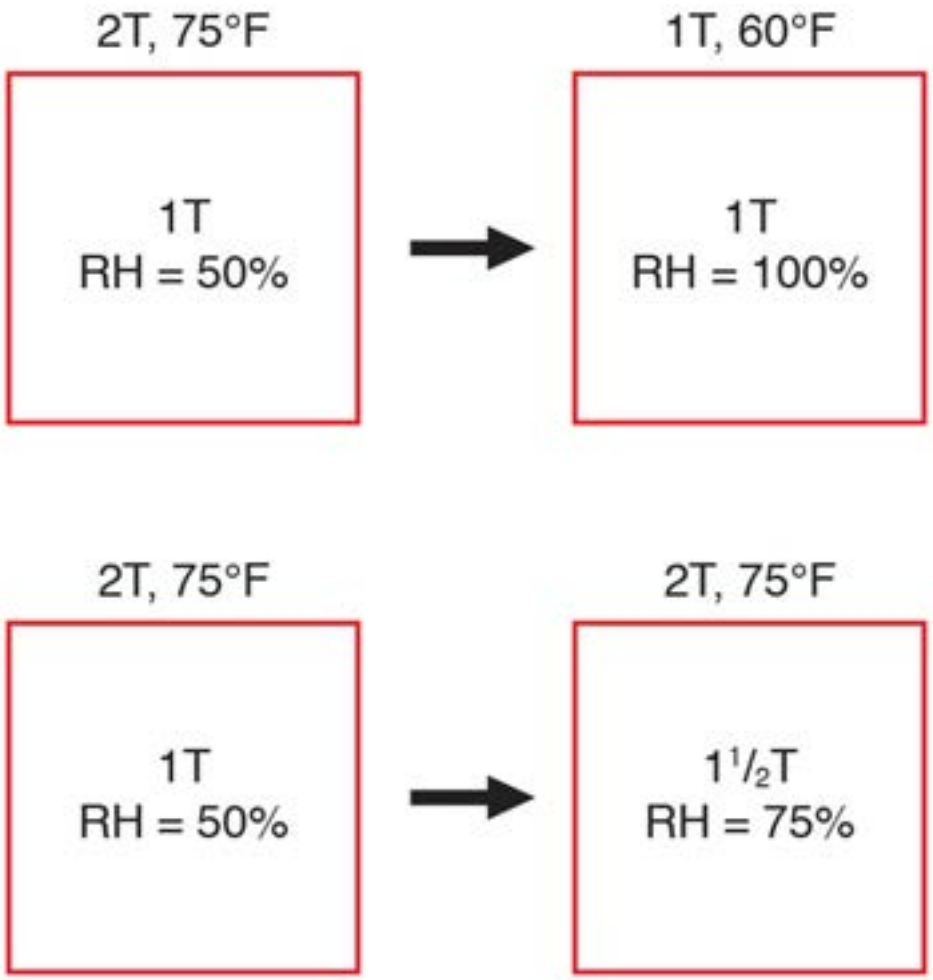
Higher Air
Pressure

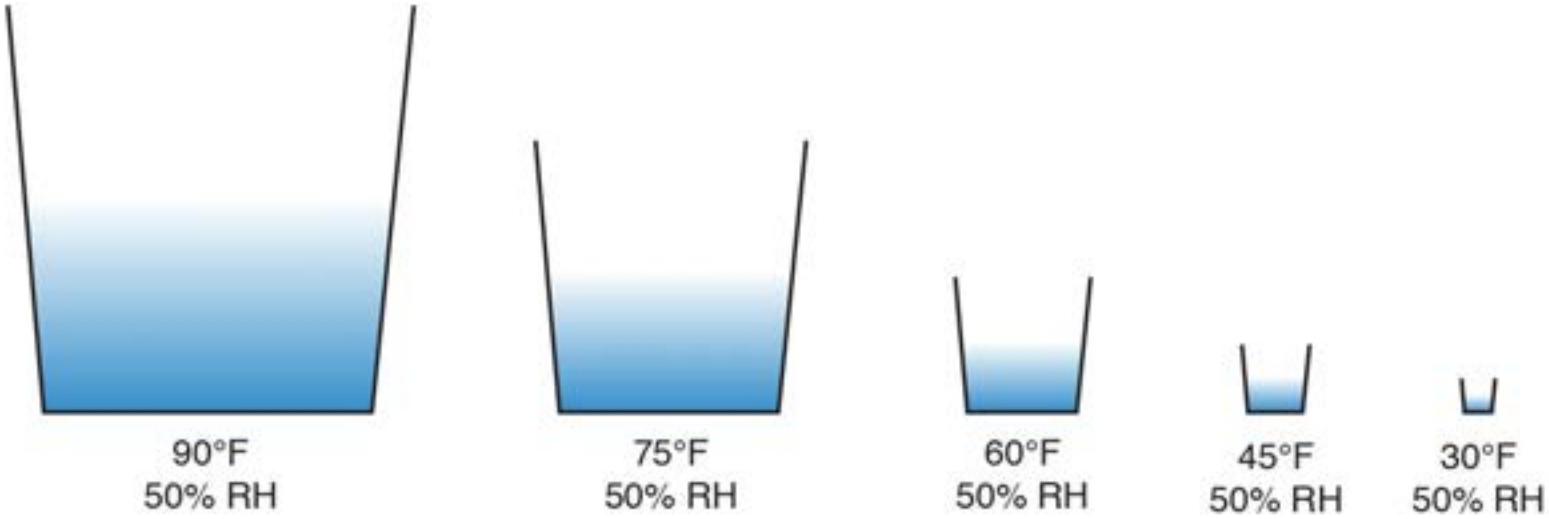
Lower Air
Pressure

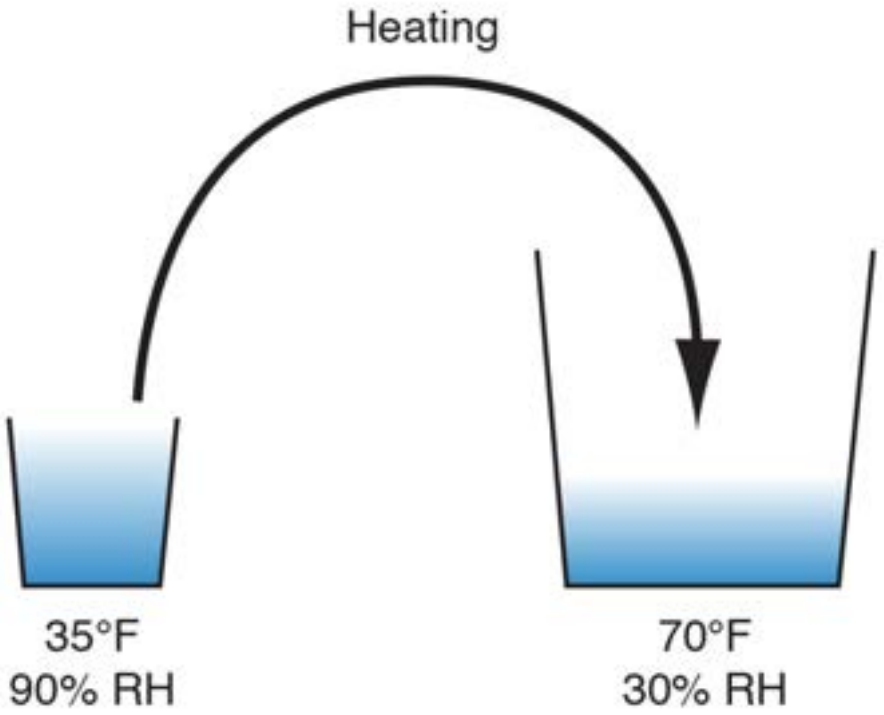

DIFFUSION
DIFFUSION
DIFFUSION
DIFFUSION
DIFFUSION
4x8 sheet of gypsum board
Interior at 70°F and 40% RH
1/3 quart of water
AIR LEAKAGE
4x8 sheet of gypsum board with a 1 in² hole
Interior at 70°F and 40% RH
30 quarts of water

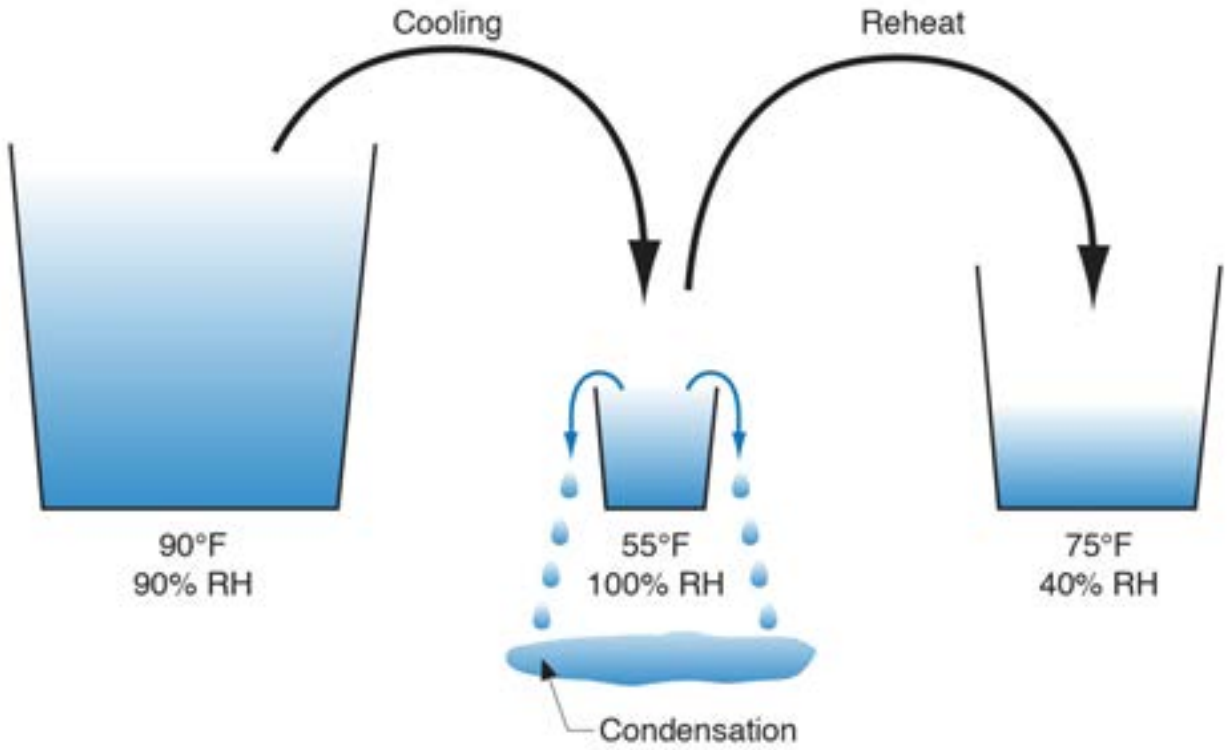

DIFFUSION
DIFFUSION
Exterior
at 74°F
dewpoint
DIFFUSION
4x8 sheet of
gypsum board
Interior at 75°F
and 50% RH
1 1/2 pints
of water
DIFFUSION
DIFFUSION
Exterior
at 74°F
dewpoint
AIR LEAKAGE
4x8 sheet of
gypsum board
with a 1 in² hole
Interior at 75°F
and 50% RH
14 pints of water

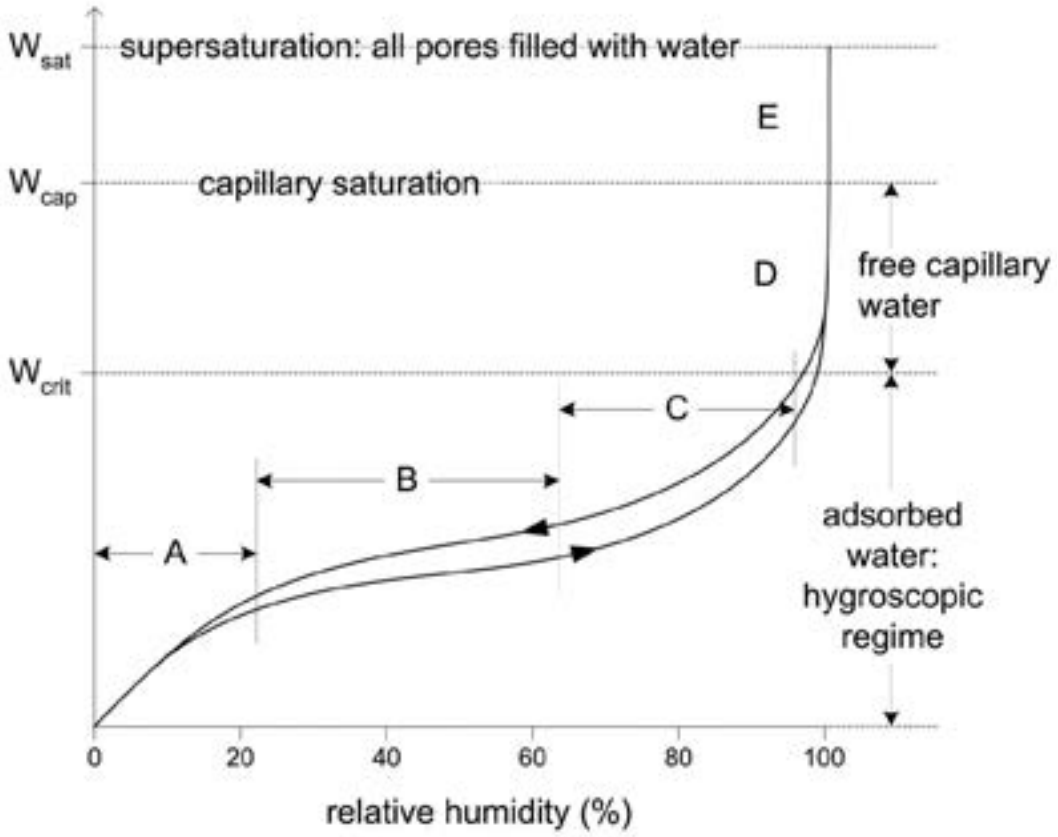
Relative Humidity


2T, 75°F
1T
RH = 50%
1T, 60°F
1T
RH = 100%
2T, 75°F
1T
RH = 50%
2T, 75°F
1 1/2T
RH = 75%


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

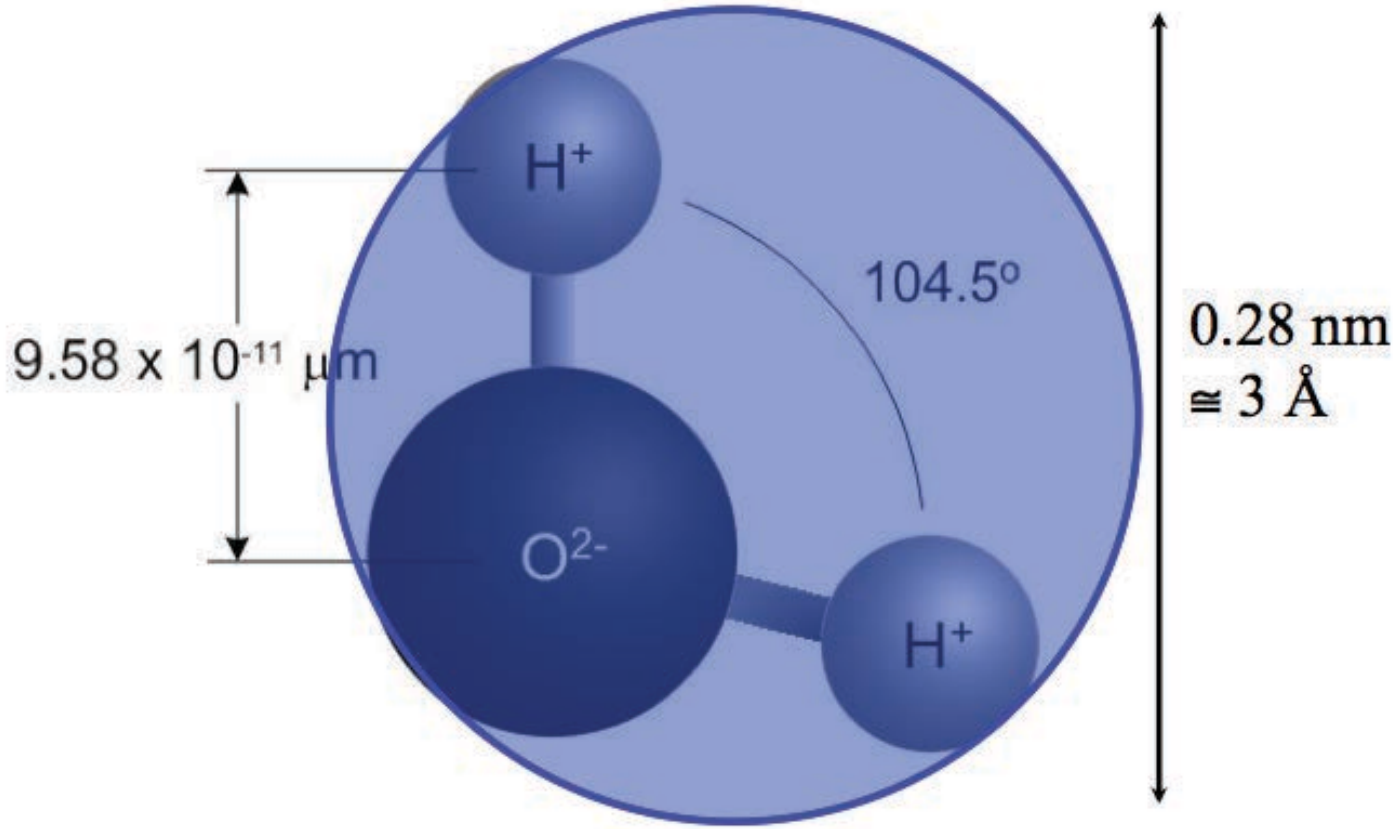

Heating
35°F
90% RH
70°F
30% RH

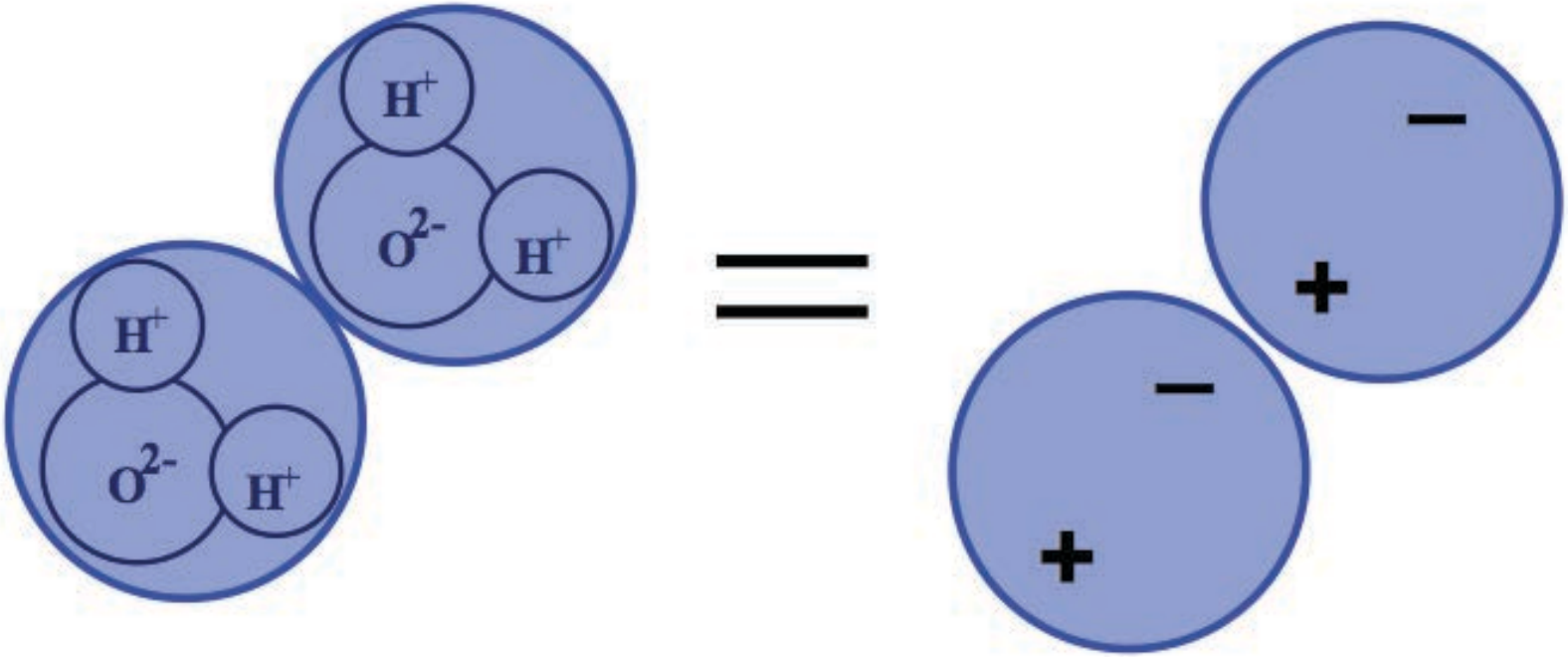

Cooling
Reheat
90°F
90% RH
55°F
100% RH
75°F
40% RH
Condensation

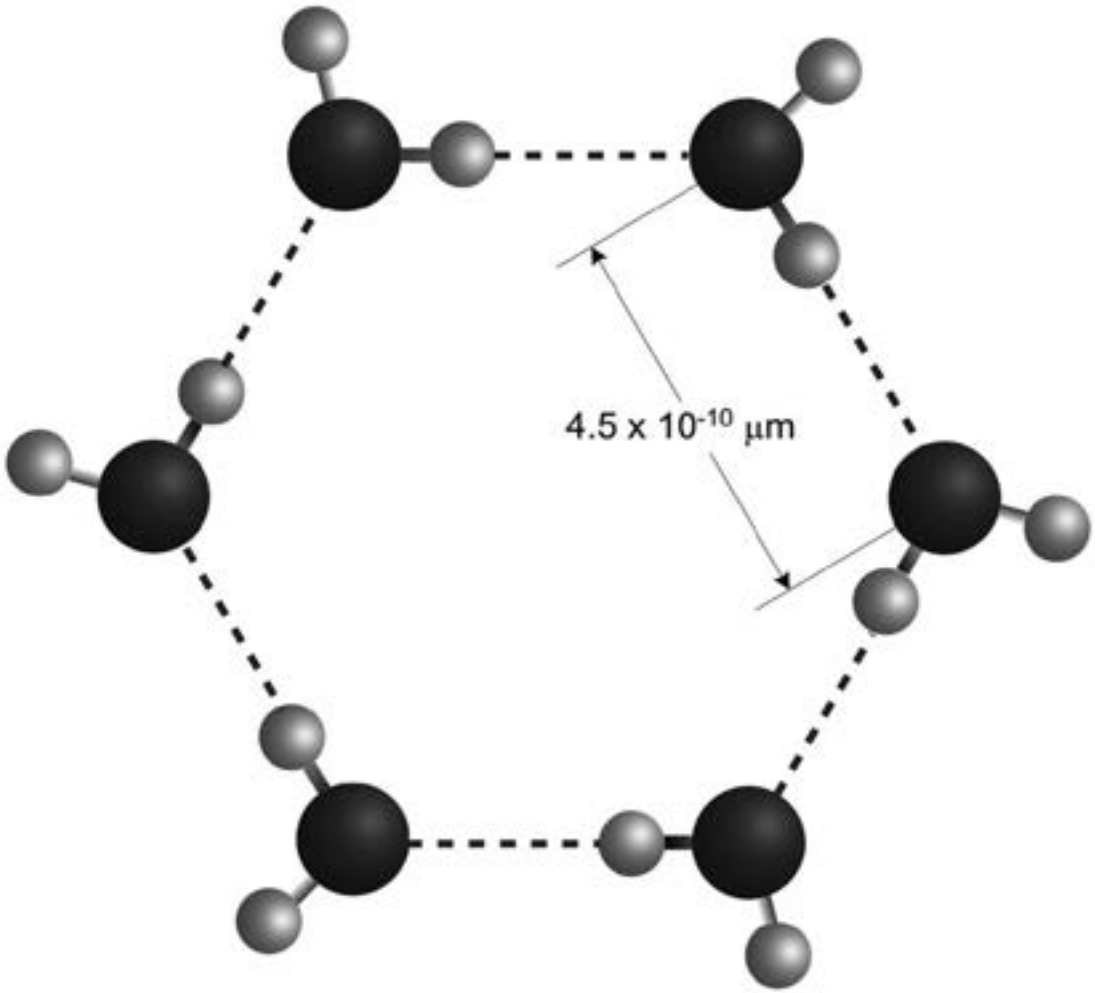


A: Single-layer of adsorbed molecules
B: Multiple layers of adsorbed molecules
C: Interconnected layers (internal capillary condensation
D: Free water in Pores, capillary suction
E: Supersaturated Regime

Regimes of moisture storage in a hygroscopic porous material
From Straube & Burnett, 2005


H+
104.5°
9.58 x 10-11 µm
0.28 nm
≅ 3 Å
O2-
H+


H+
O2-
H+
H+
O2-
H+
=
−
+
−
+


4.5 x 10-10 µm

Arrhenius Equation

For Every 10 Degree K Rise

Activation Energy Doubles

$$k = Ae^{-E_a/(RT)}$$

Damage Functions

Water

Heat

Ultra-violet Radiation

Damage Functions

Water

Heat

Ultra Violet Radiation

Oxidization (Ozone)

Fatigue (Creep)

The Three Biggest Problems In Buildings Are Water, Water and Water…

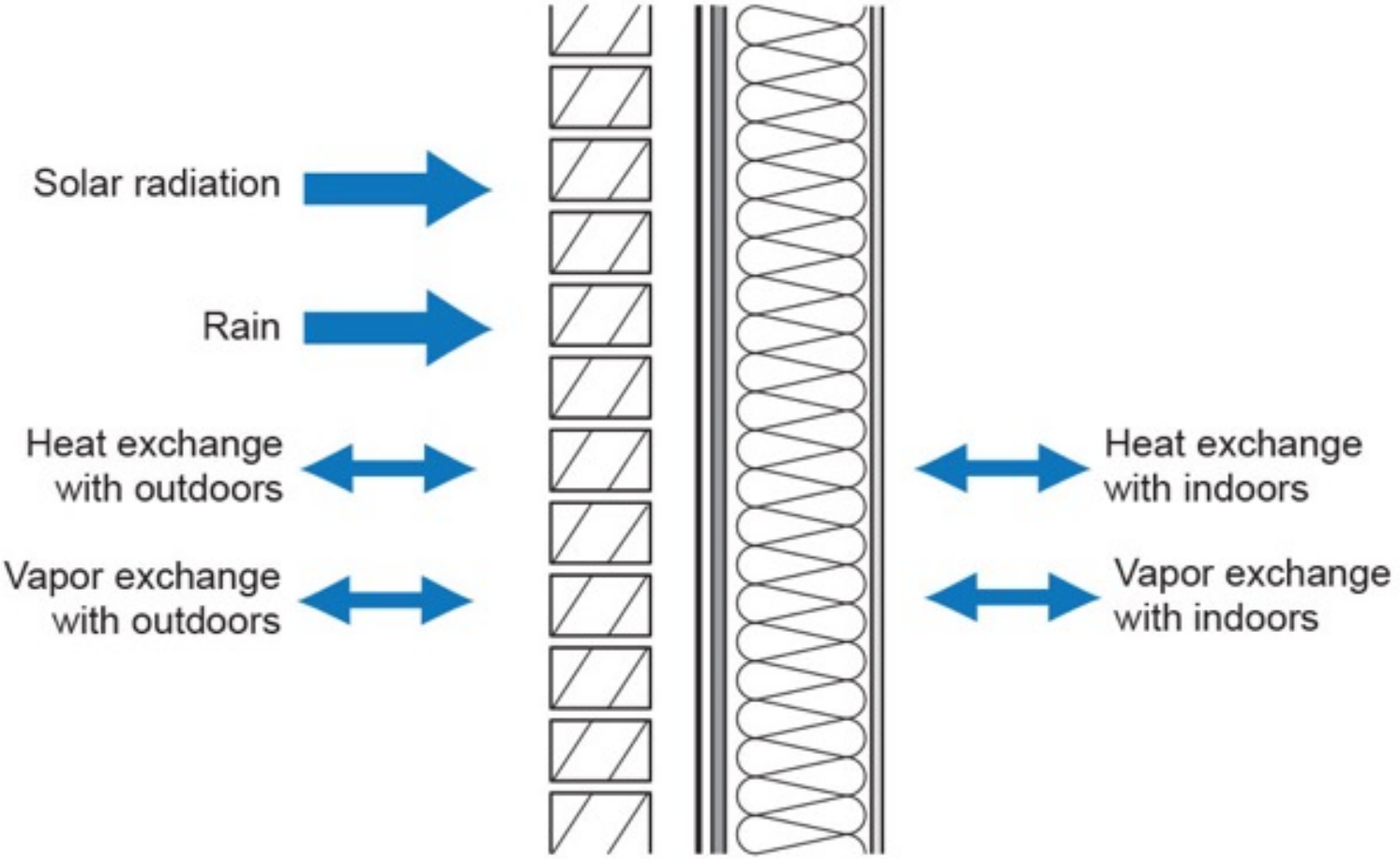
Heat

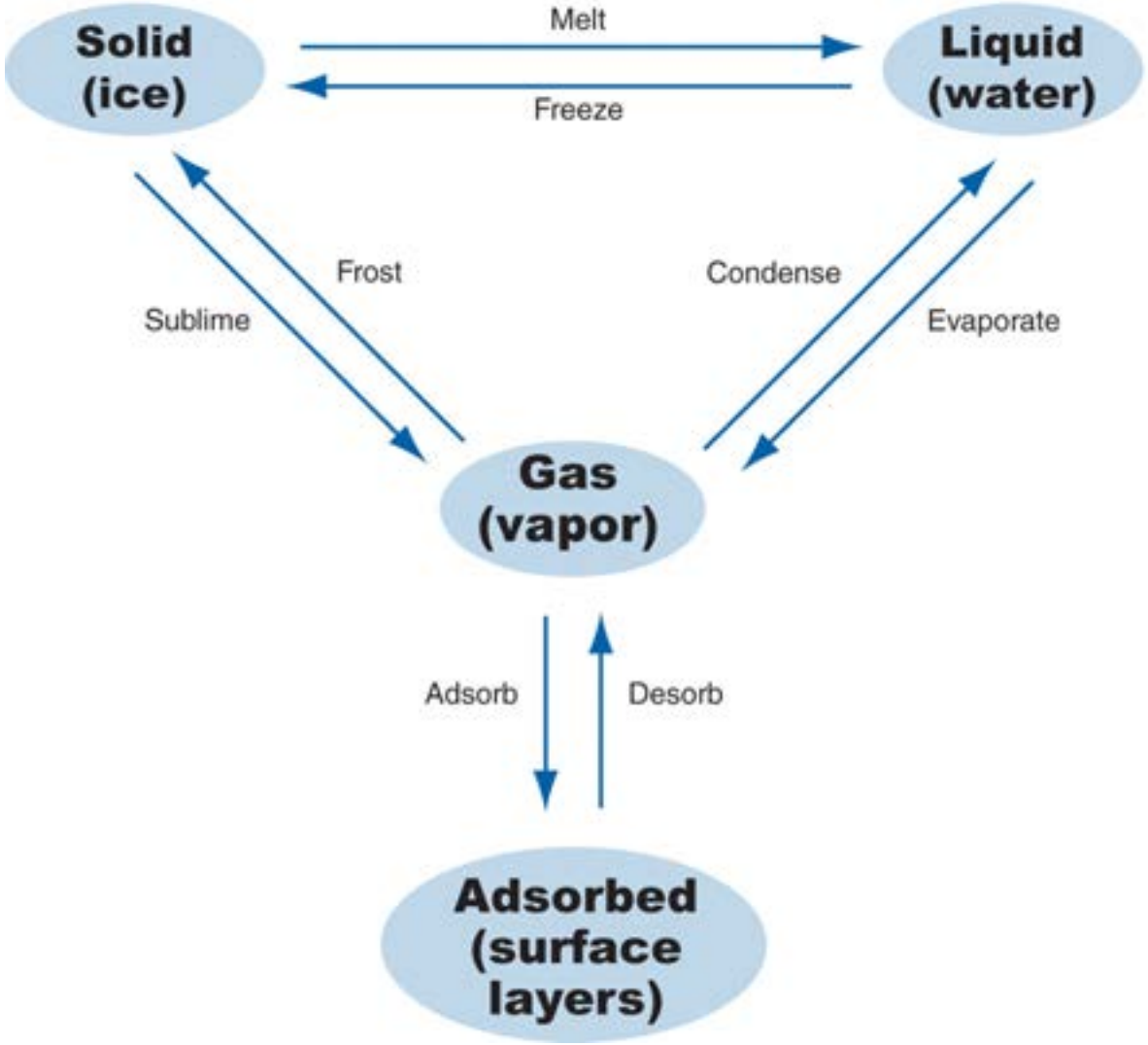
Air

Moisture

HAM

Hygrothermal Analysis


Solar radiation
Rain
Heat exchange with outdoors
Vapor exchange with outdoors
Heat exchange with indoors
Vapor exchange with indoors


Solid (ice)
Melt
Freeze
Liquid (water)
Frost
Sublime
Condense
Evaporate
Gas (vapor)
Adsorb
Desorb
Adsorbed (surface layers)

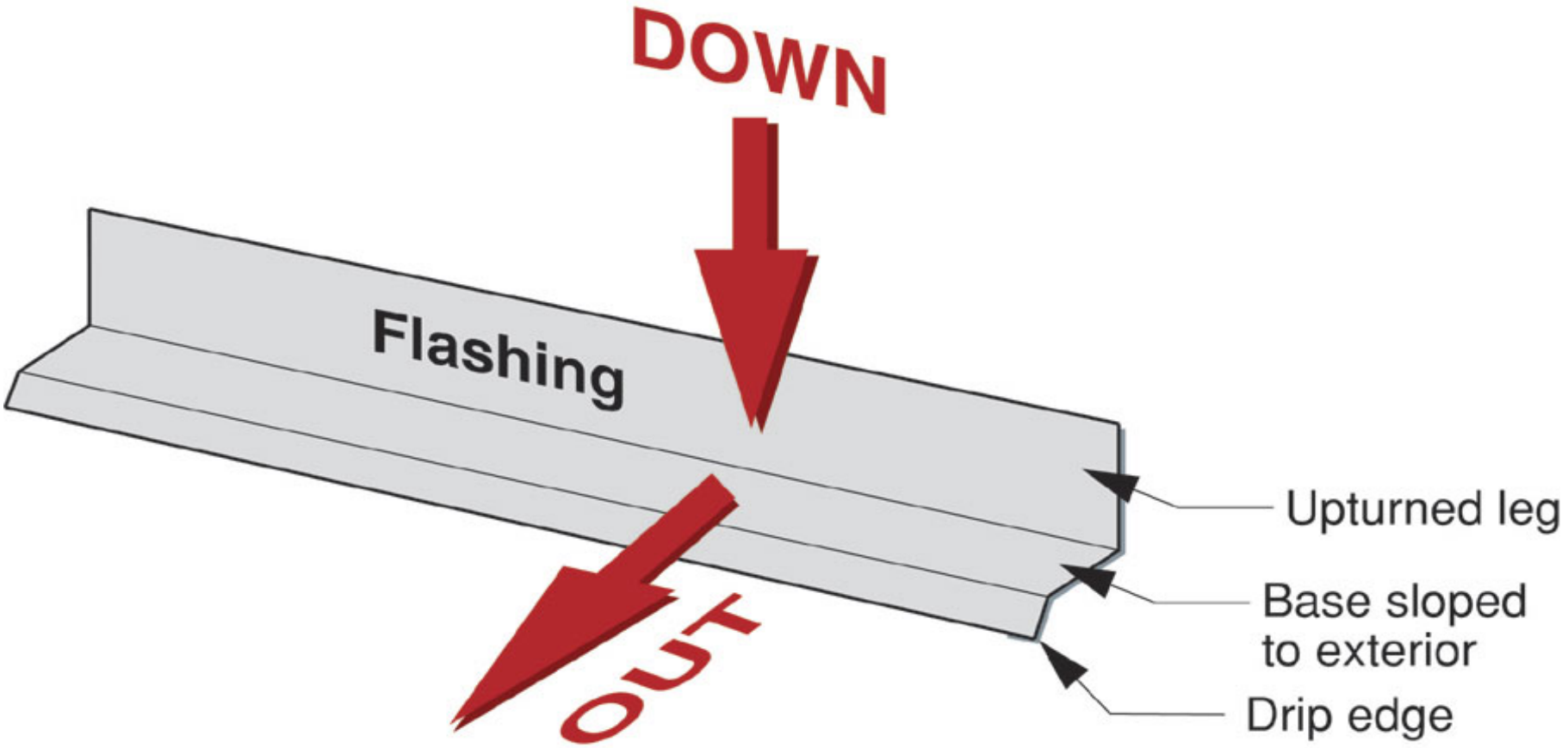
Moisture Transport in Porous Media

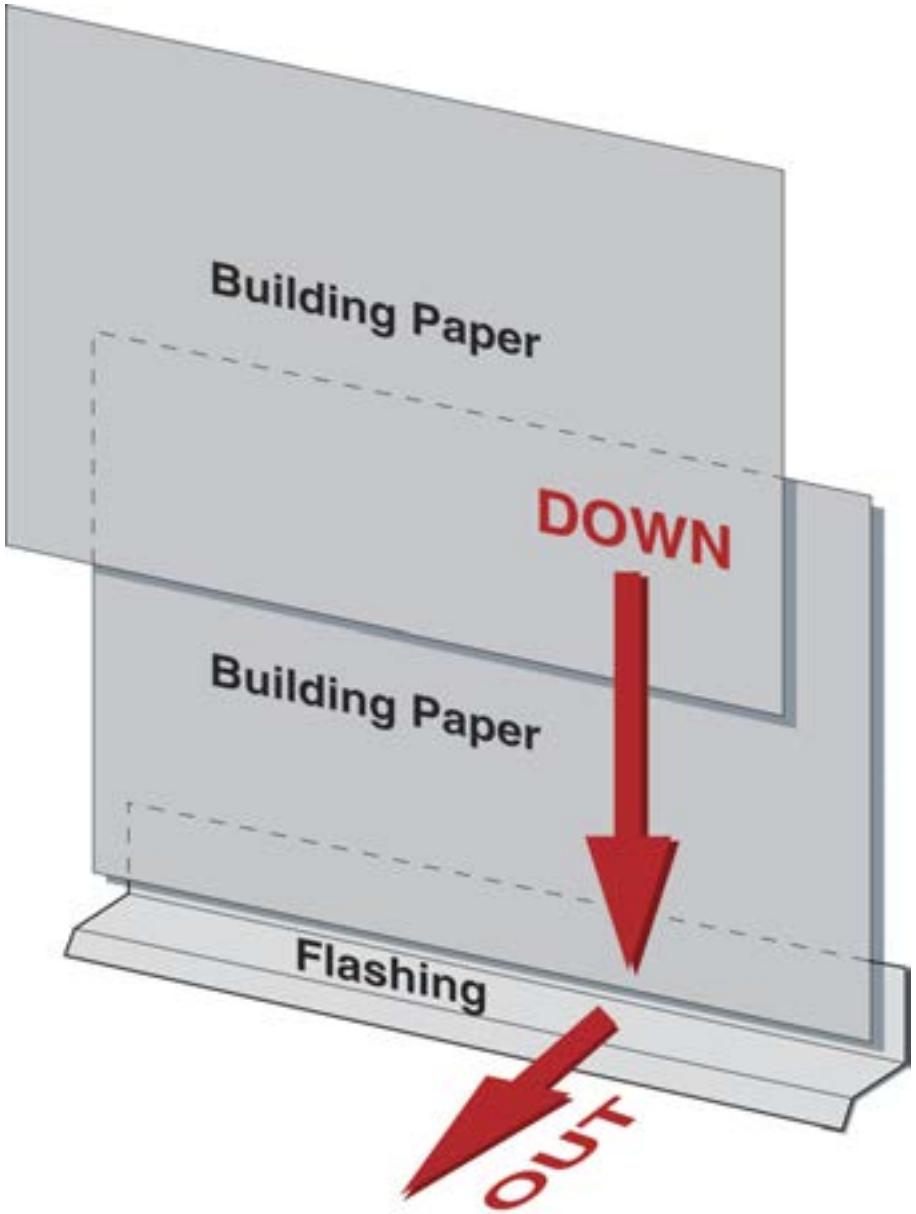
Phase	Transport Process	Driving Potential
Vapor	Diffusion	Vapor Concentration
Adsorbate	Surface Diffusion	Concentration
Liquid	Capillary Flow	Suction Pressure
	Osmosis	Solute Concentration

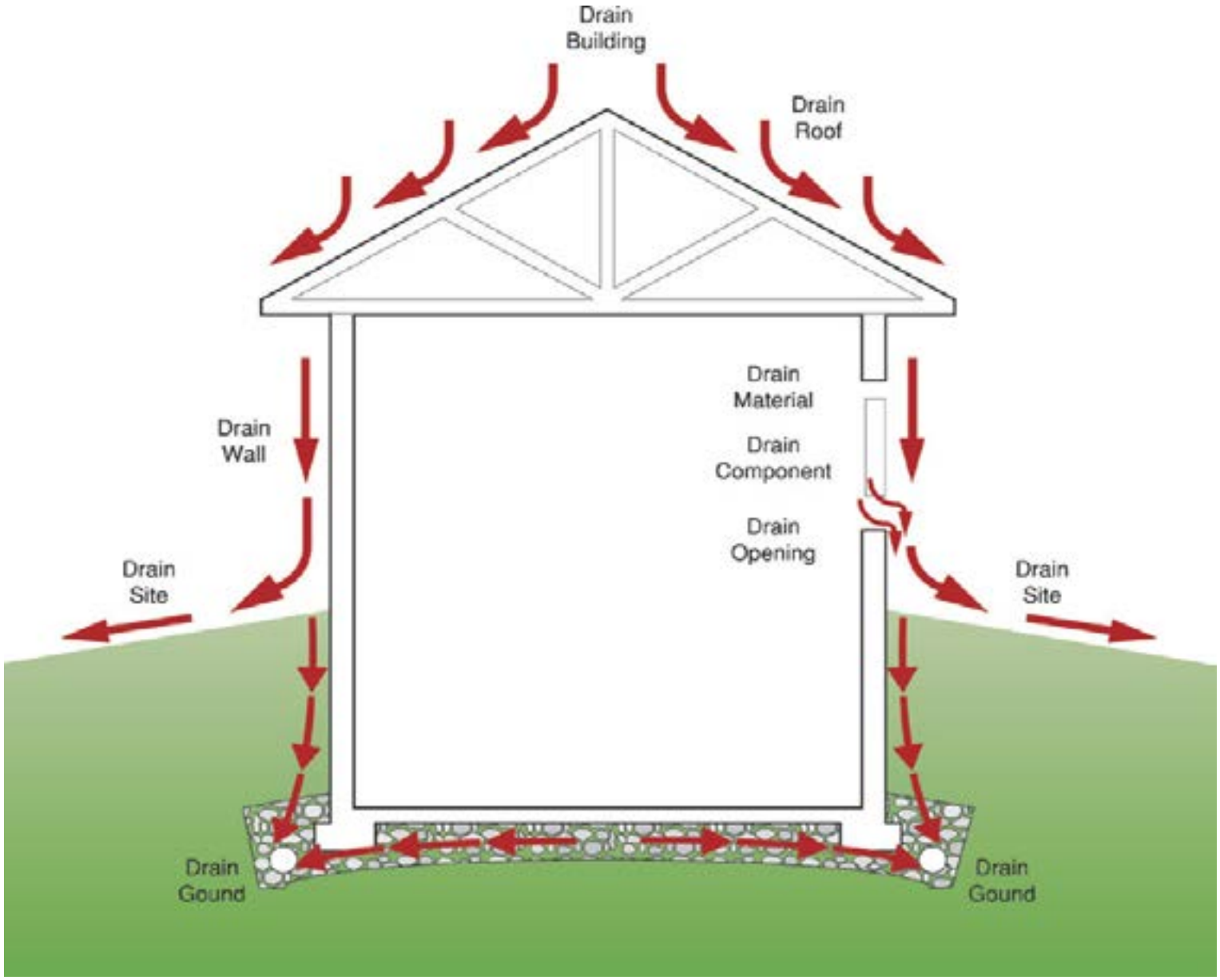
Moisture Transport in Assemblies

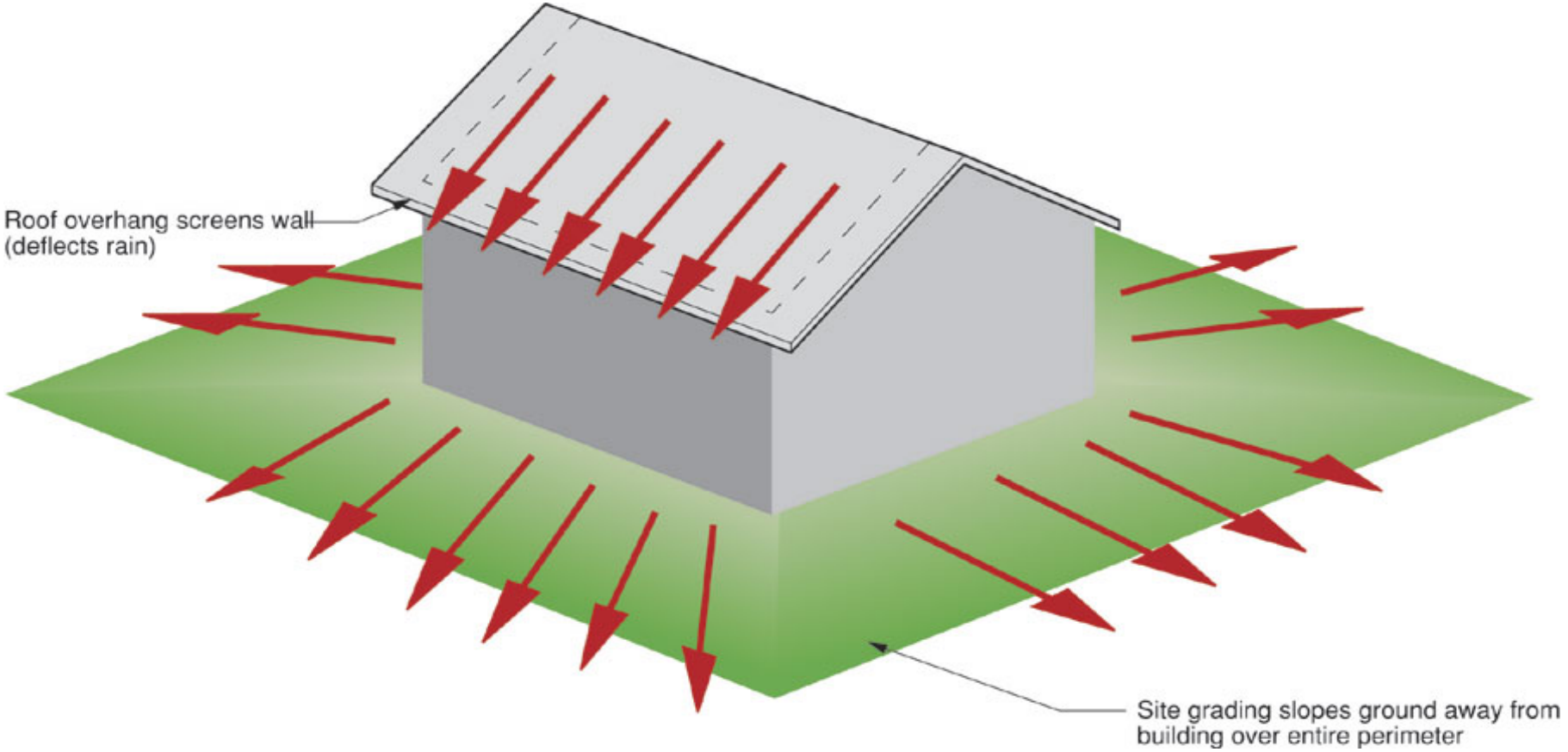
Phase	Transport Process	Driving Potential
Vapor	Diffusion	Vapor Concentration
	Convective Flow	Air Pressure
Adsorbate	Surface Diffusion	Concentration
Liquid	Capillary Flow	Suction Pressure
	Osmosis	Solute Concentration
	Gravitational Flow	Height
	Surface Tension	Surface Energy
	Momentum	Kinetic Energy
	Convective Flow	Air Pressure

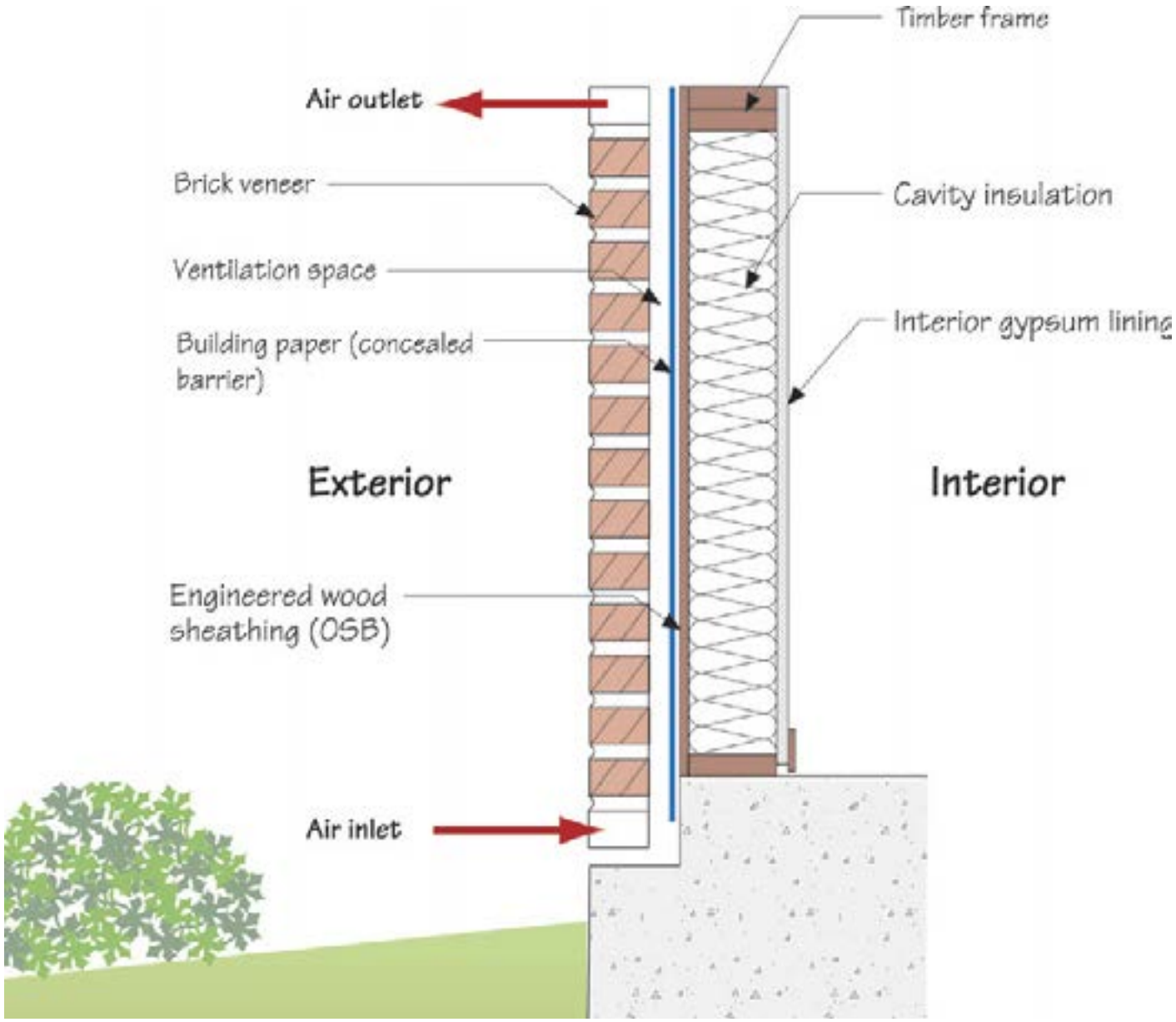
Rain

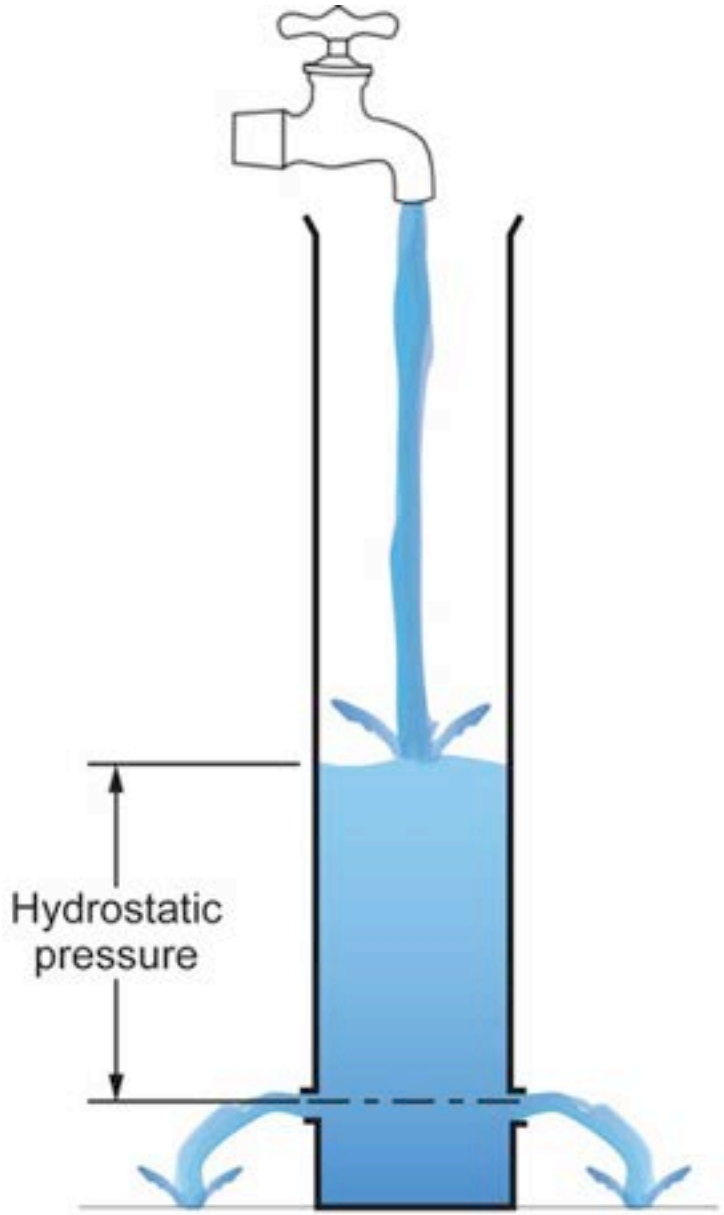

DOWN
Flashing
OUT
Upturned leg
Base sloped
to exterior
Drip edge

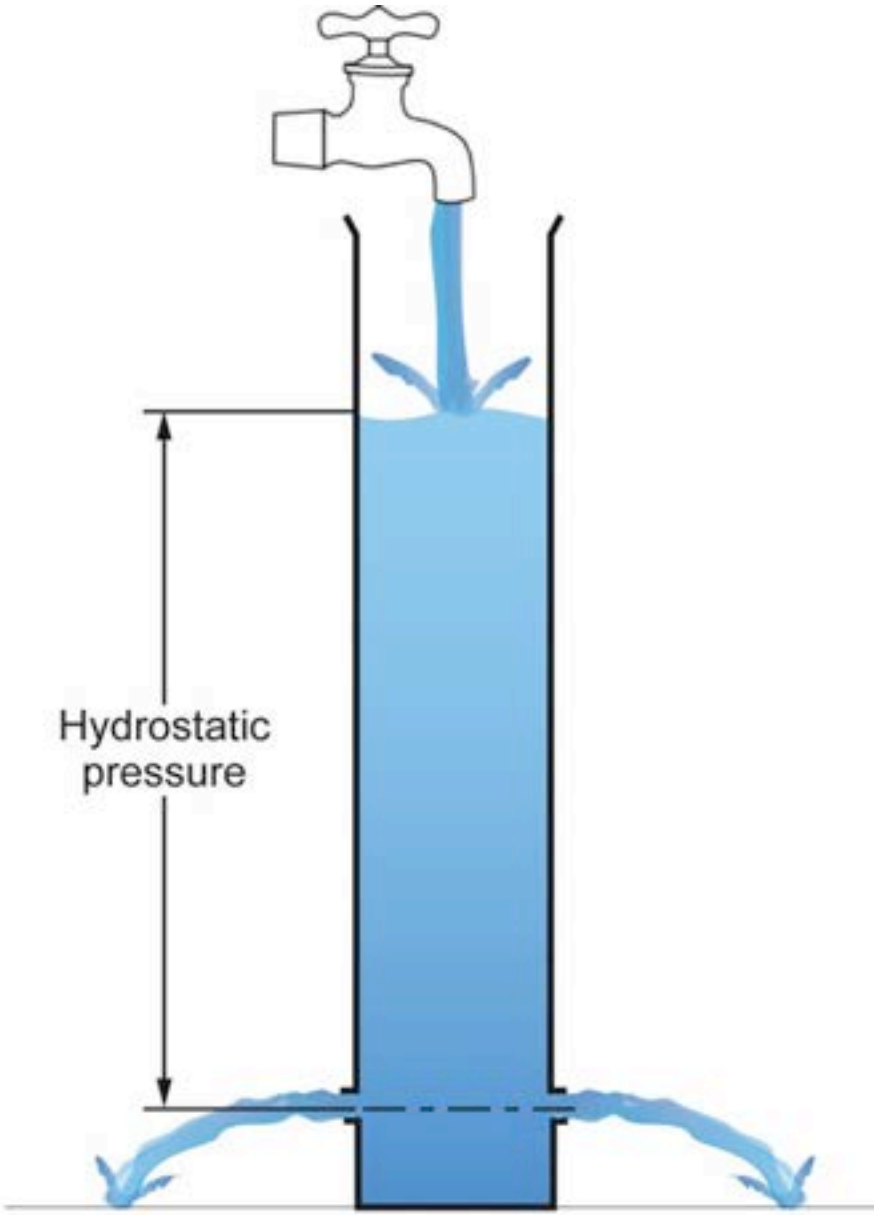

Building Paper
DOWN
Building Paper
Flashing
OUT

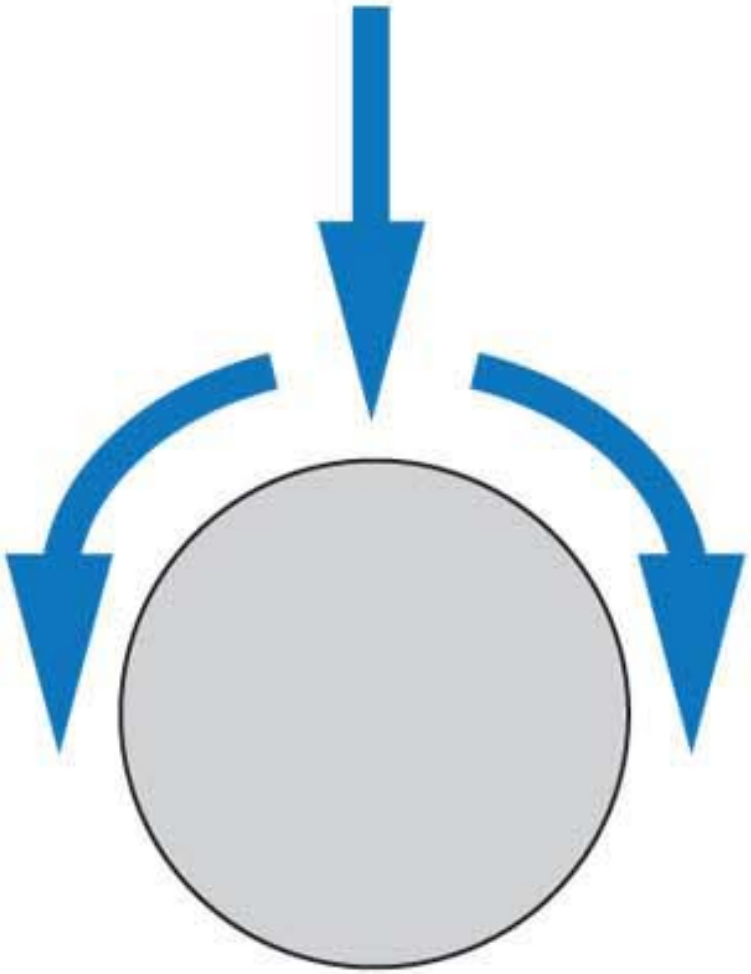

Drain
Building
Drain
Roof
Drain
Material
Drain
Component
Drain
Opening
Drain
Wall
Drain
Site
Drain
Site
Drain
Gound
Drain
Gound

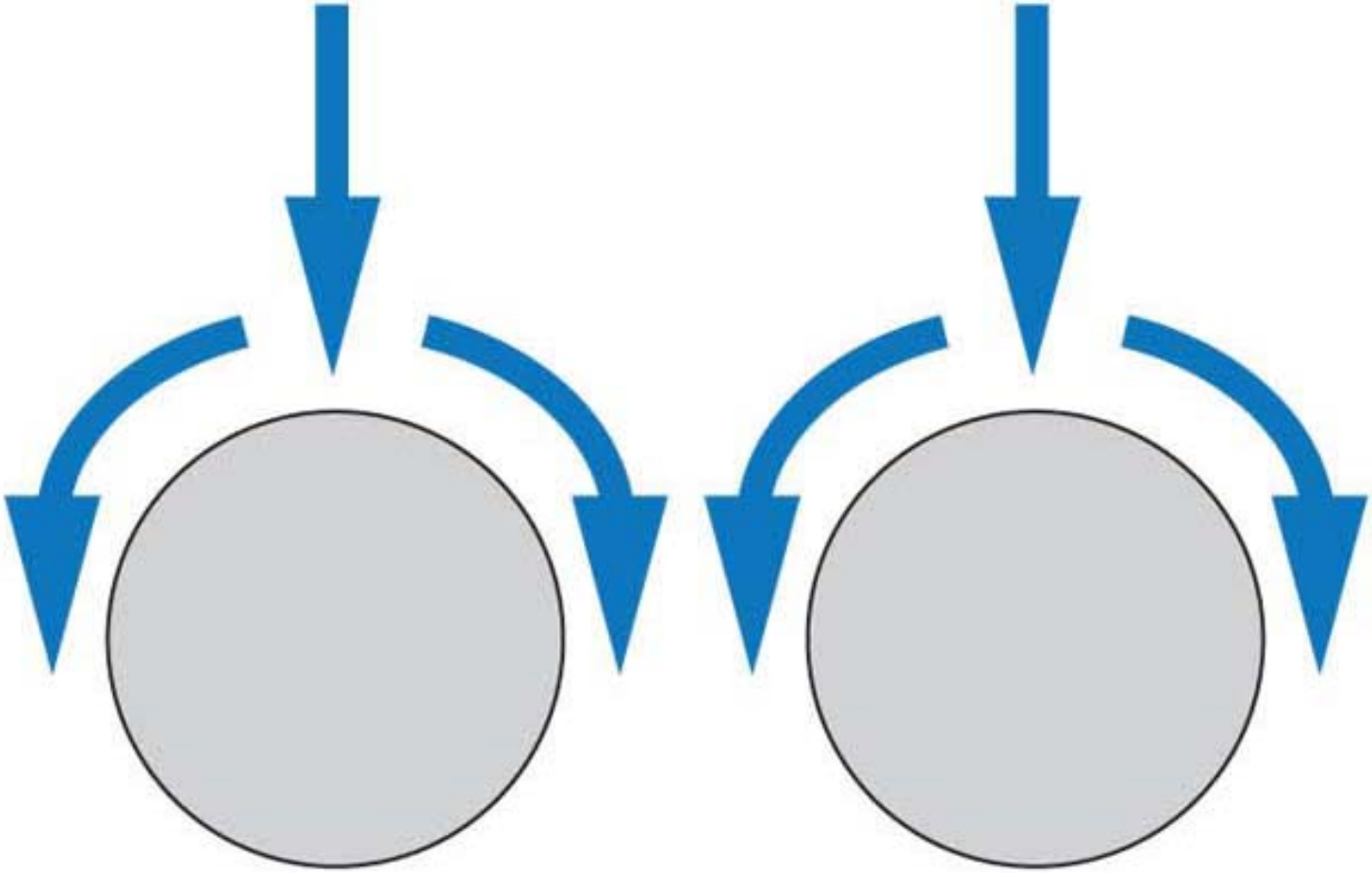

Roof overhang screens wall
(deflects rain)
Site grading slopes ground away from
building over entire perimeter

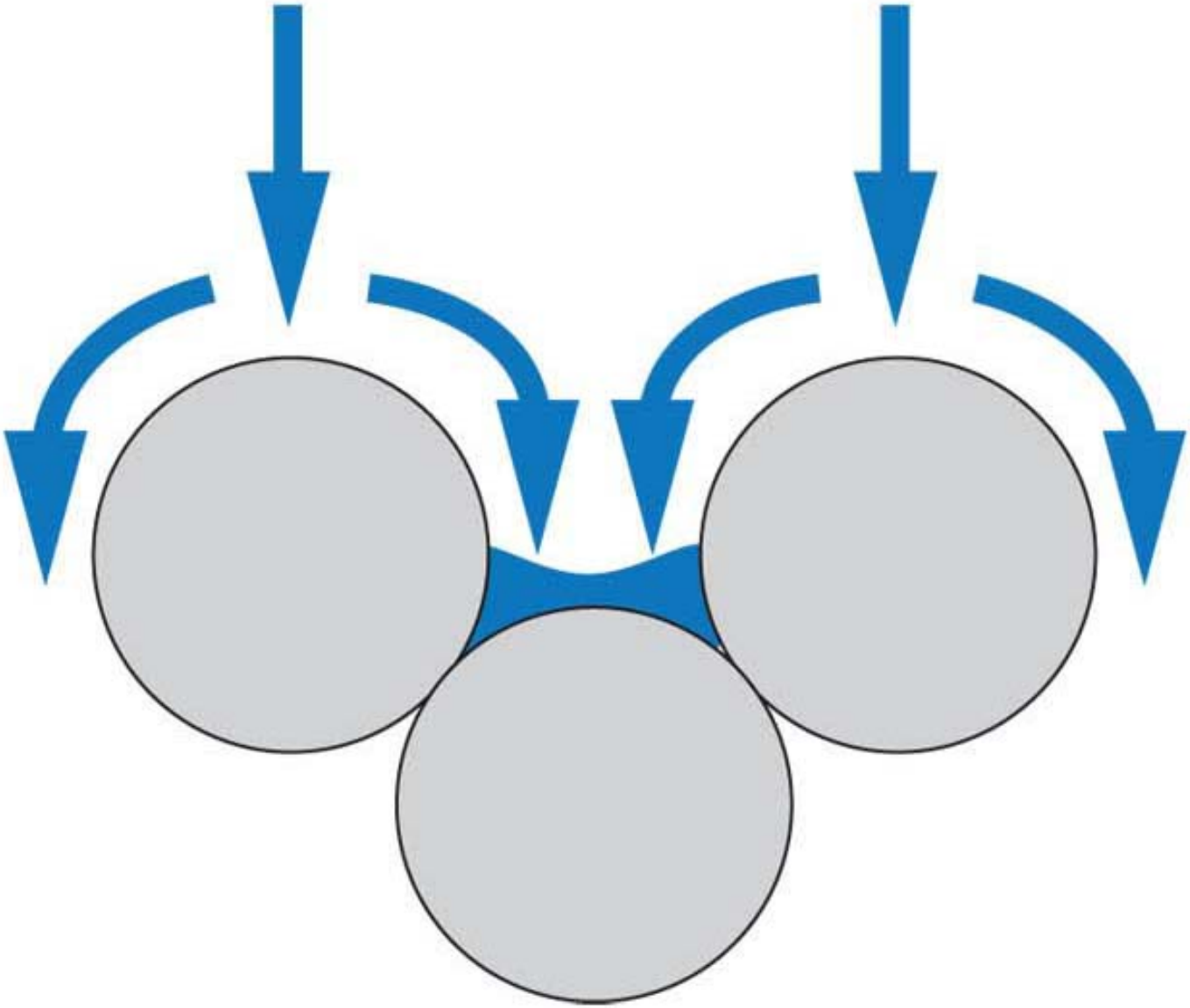

Timber frame
Air outlet
Brick veneer
Cavity insulation
Ventilation space
Interior gypsum lining
Building paper (concealed barrier)
Exterior
Interior
Engineered wood sheathing (OSB)
Air inlet

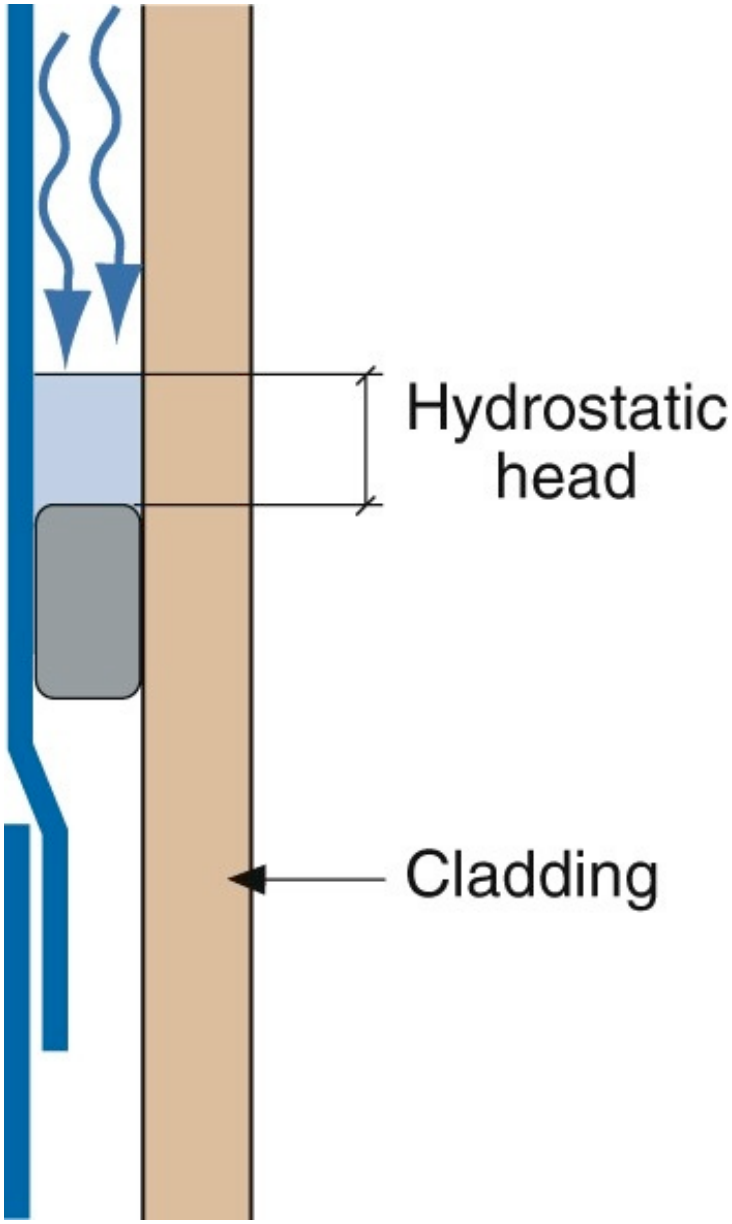

Hydrostatic
pressure

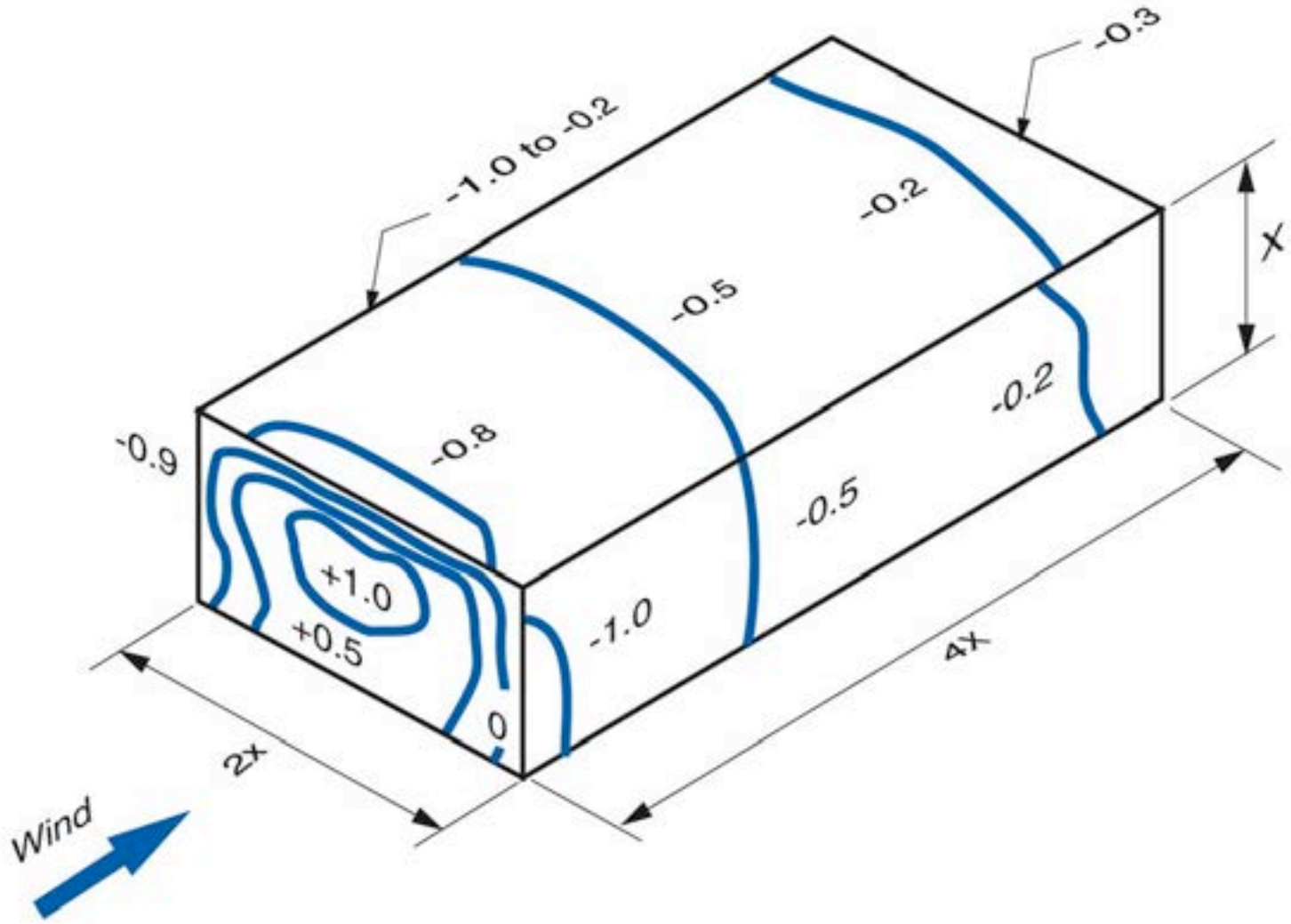

Hydrostatic
pressure



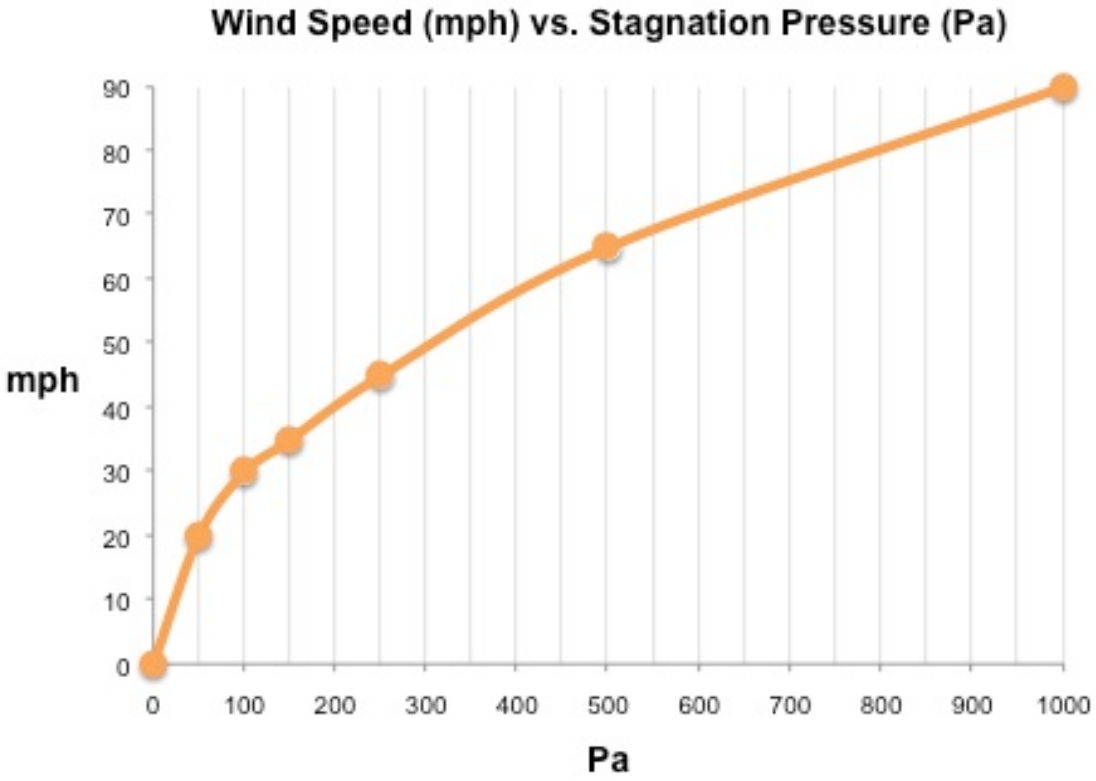





Hydrostatic
head
Cladding

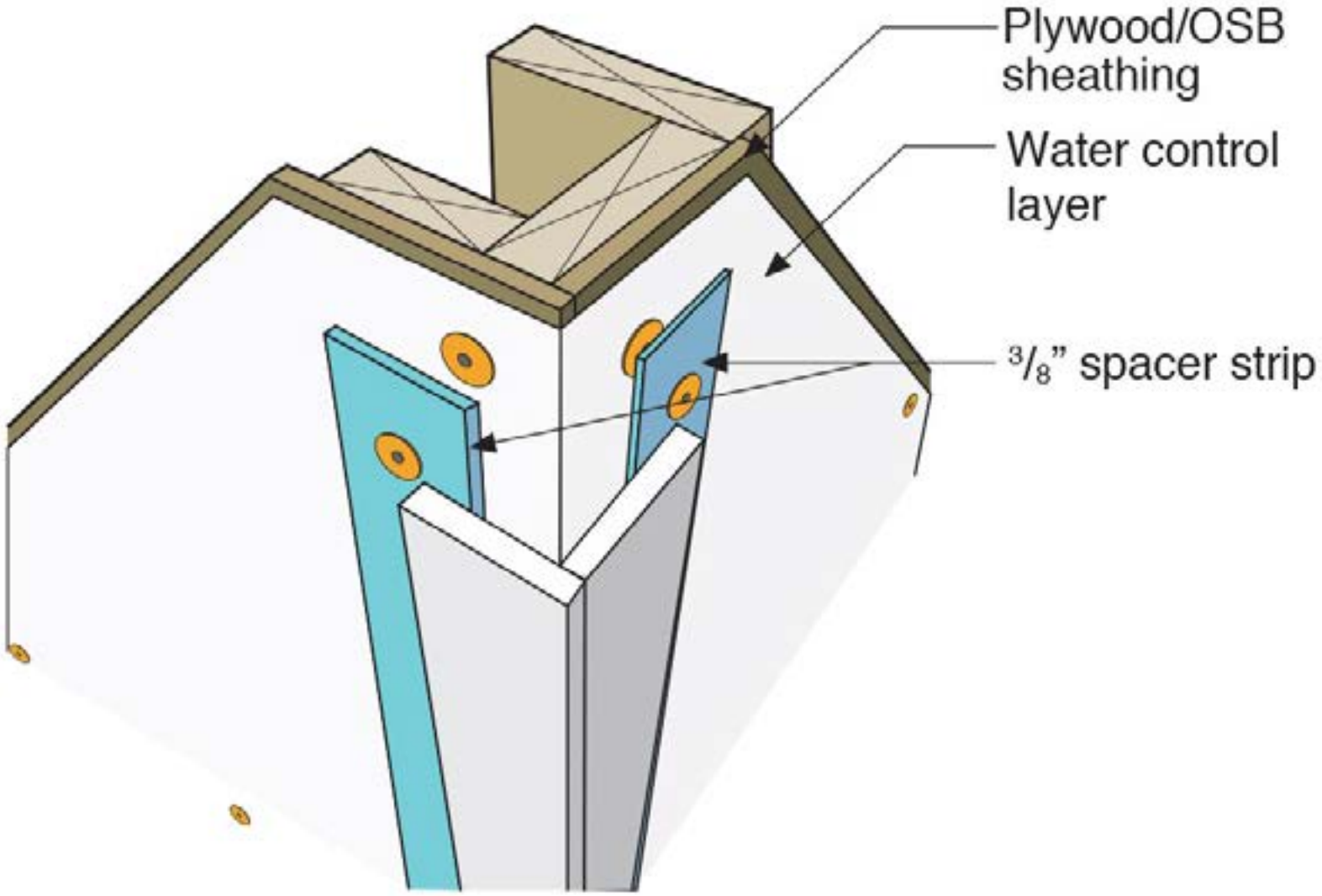

-0.3
-1.0 to -0.2
-0.2
-0.5
-0.2
-0.9
-0.8
-0.5
+1.0
+0.5
-1.0
0
X
2X
4X
Wind

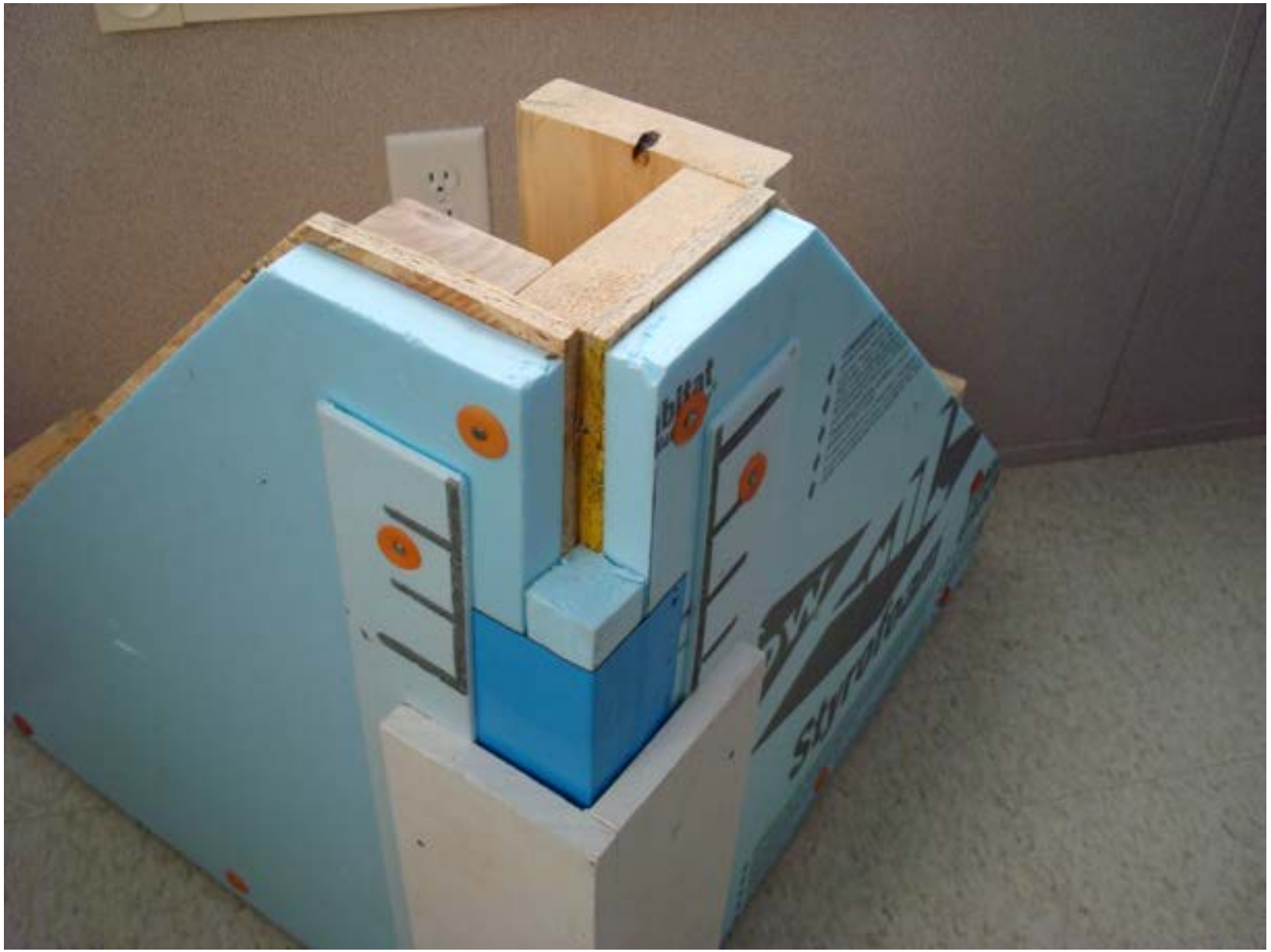
Pascals		mph
50	Pa =	20 mph
100	Pa =	30 mph
150	Pa =	35 mph
250	Pa =	45 mph
500	Pa =	65 mph
1,000	Pa =	90 mph



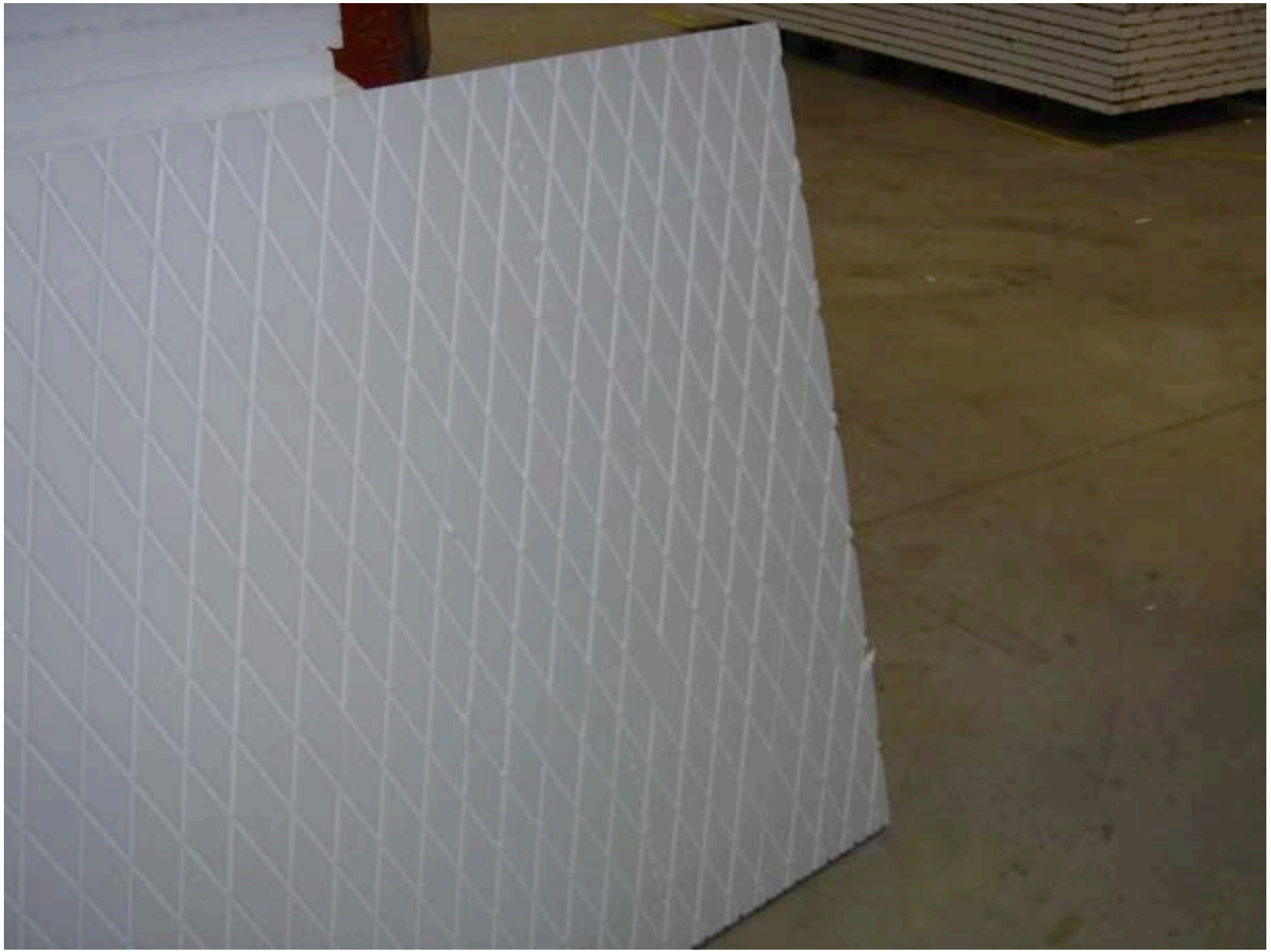

DUPONT


WWW.TYVEK.COM

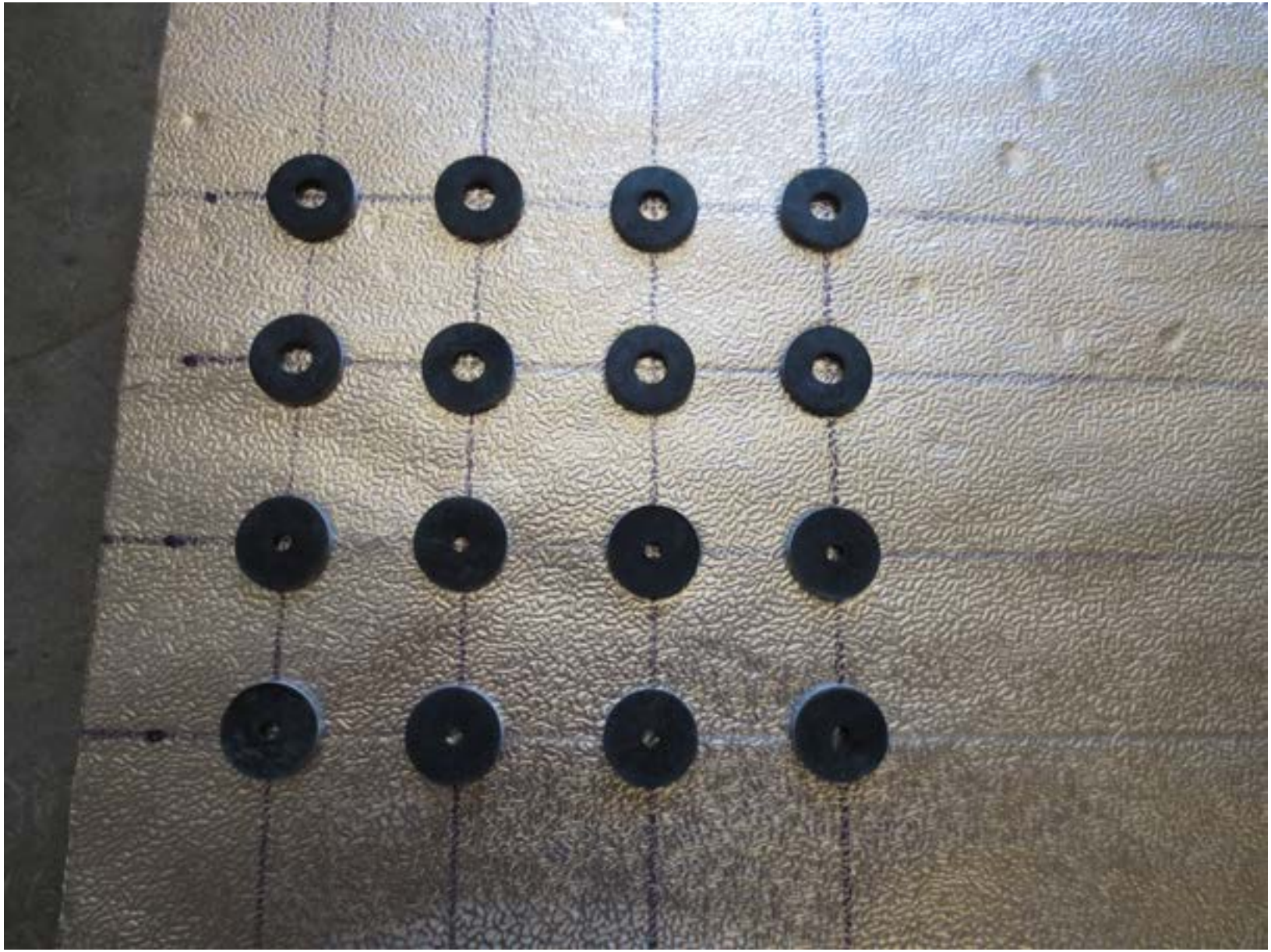

Plywood/OSB sheathing
Water control layer
3/8" spacer strip



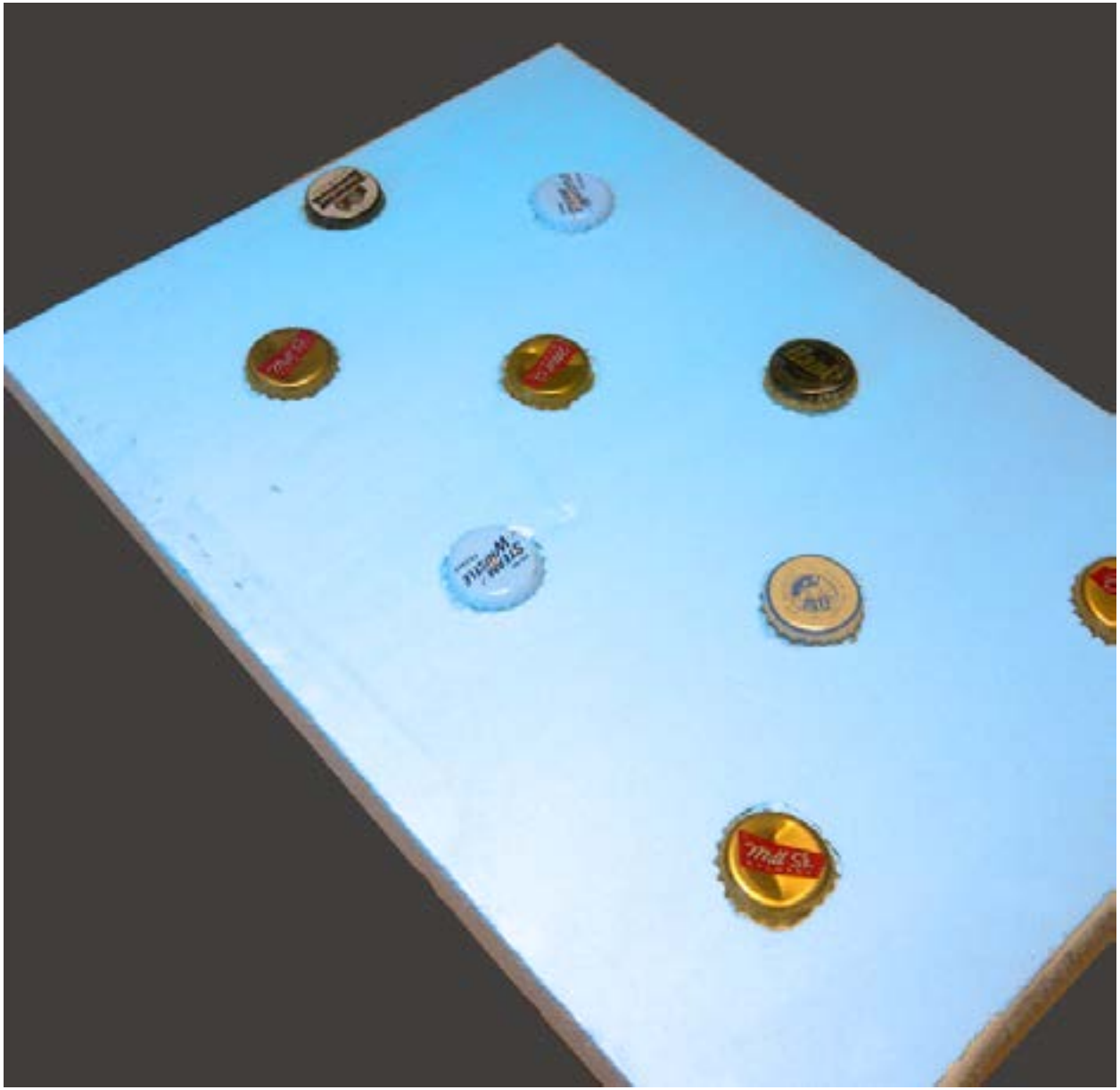

Tyvek
Tyvek



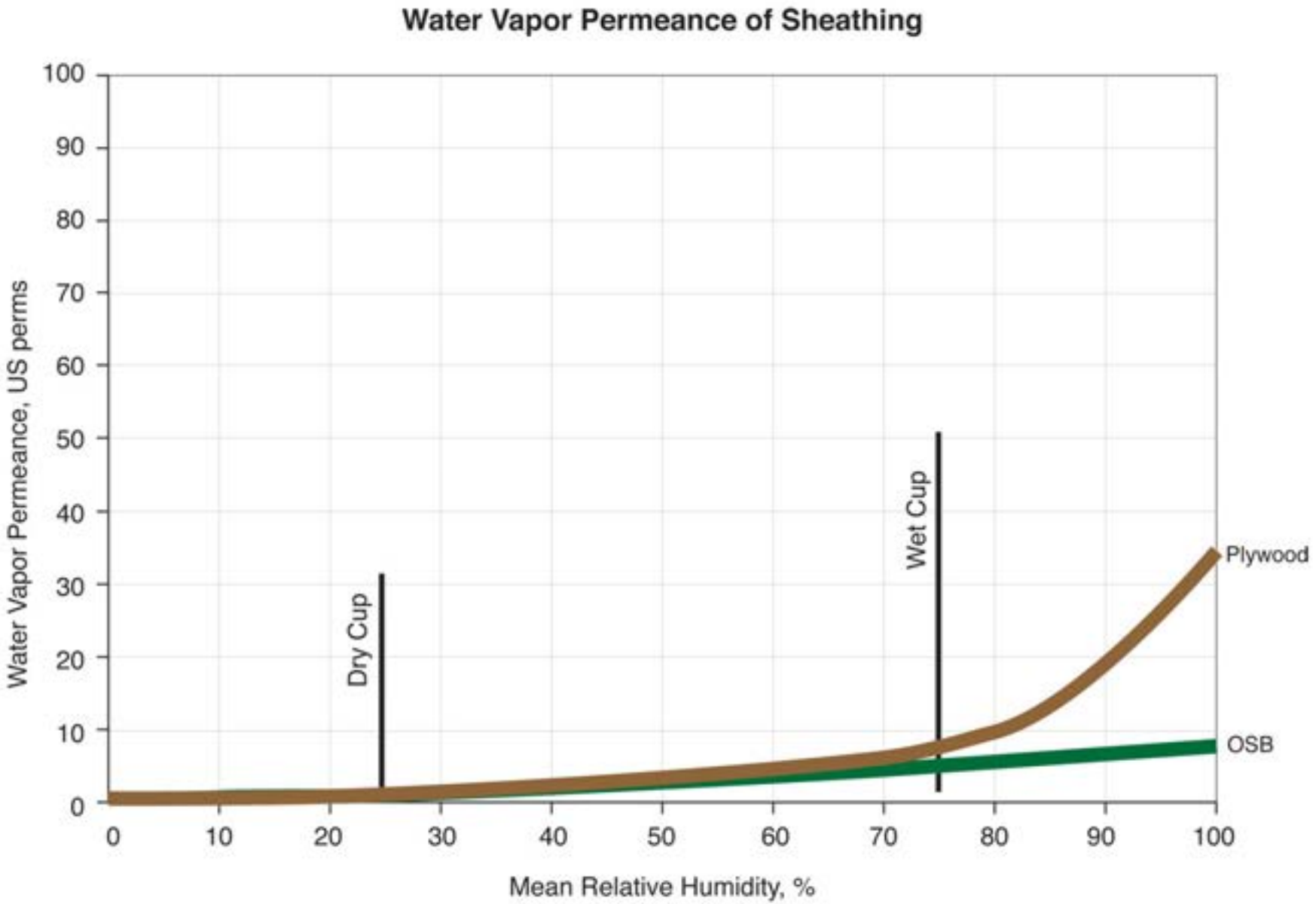
Rain Screen

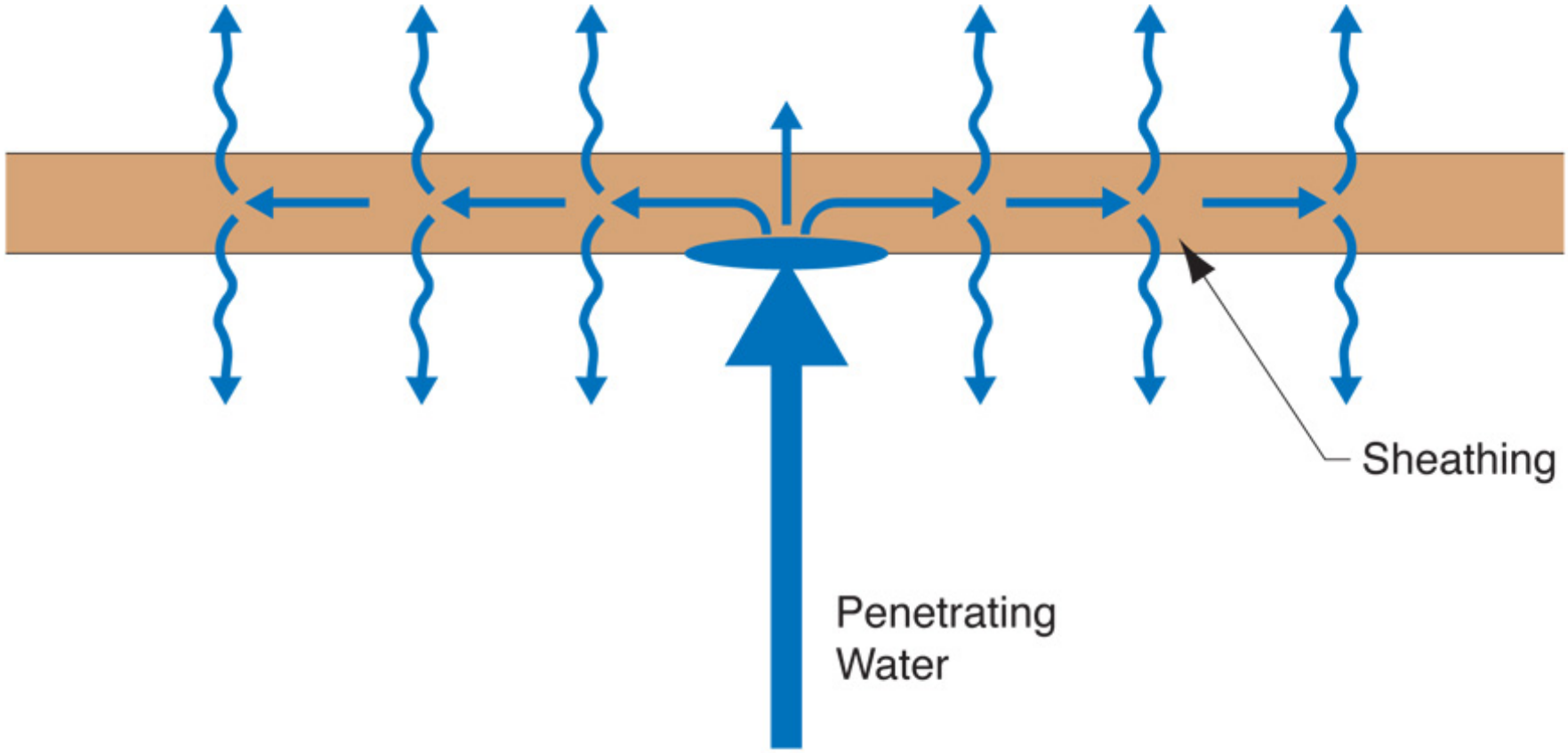


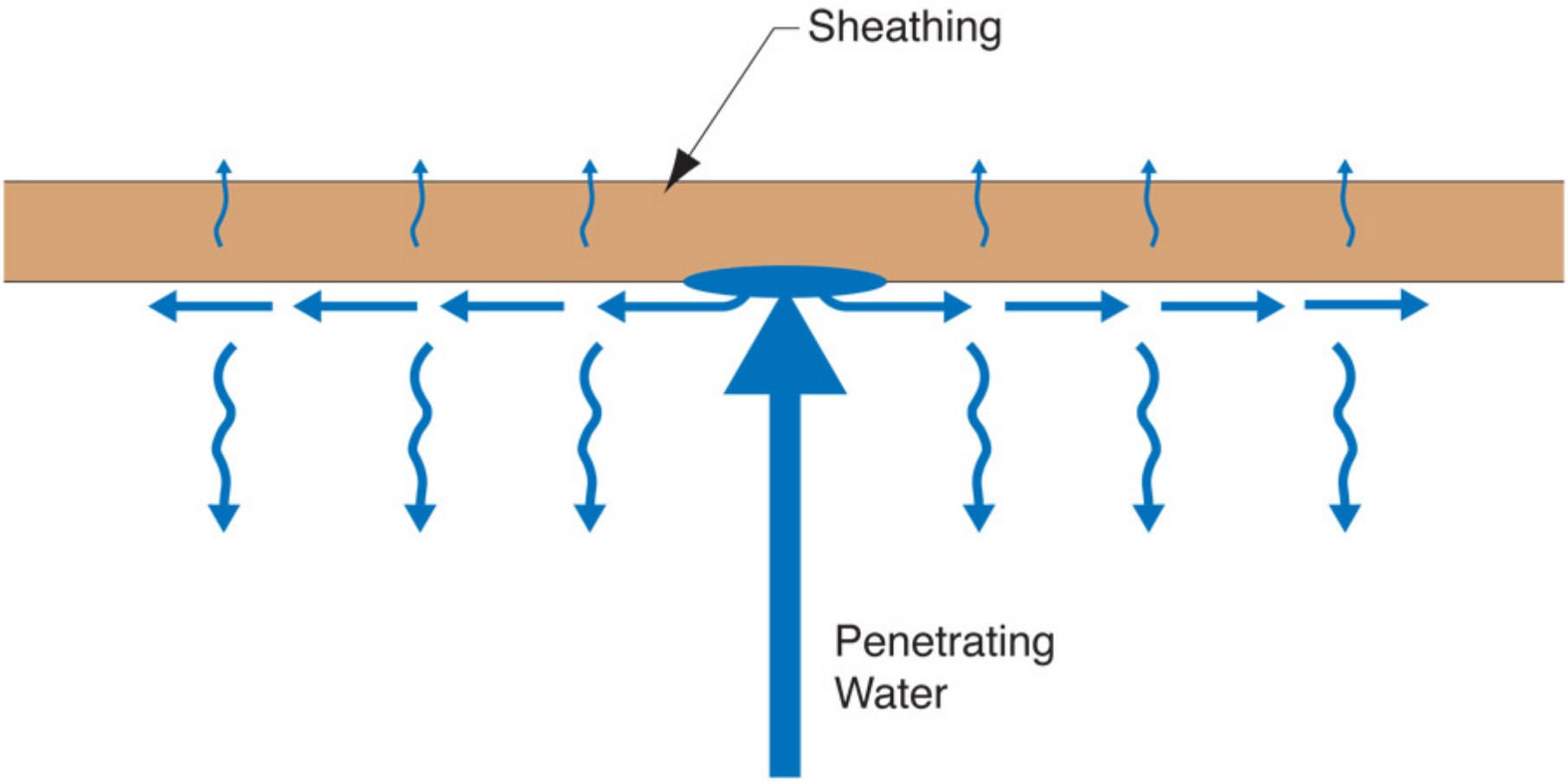
Beer Screen?




BUILT BY
EDDIE EVANS
CONSTRUCTION
1994

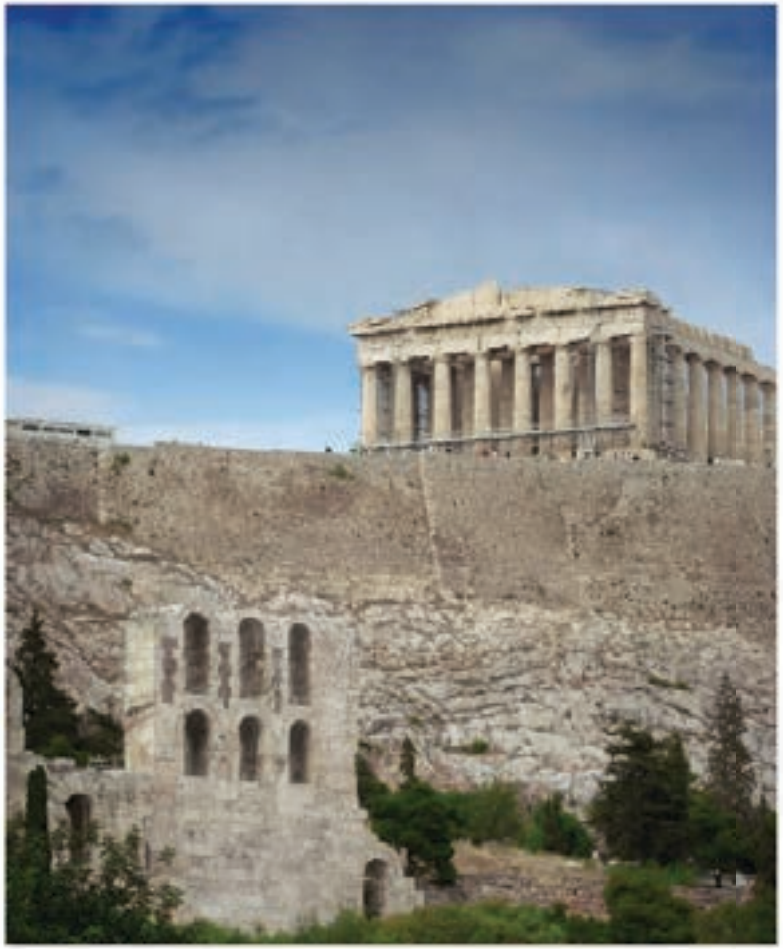

Water Vapor Permeance of Sheathing
Water Vapor Permeance, US perms
100
90
80
70
60
50
40
30
20
10
0
Dry Cup
Wet Cup
Plywood
OSB
0
10
20
30
40
50
60
70
80
90
100
Mean Relative Humidity, %


Sheathing
Penetrating
Water


Sheathing
Penetrating
Water


panago


panago




Tyvek
DrainWrap


N-6
N-7


W1
W3


LOWER
N-2


3514
Finish

What is a Building ?

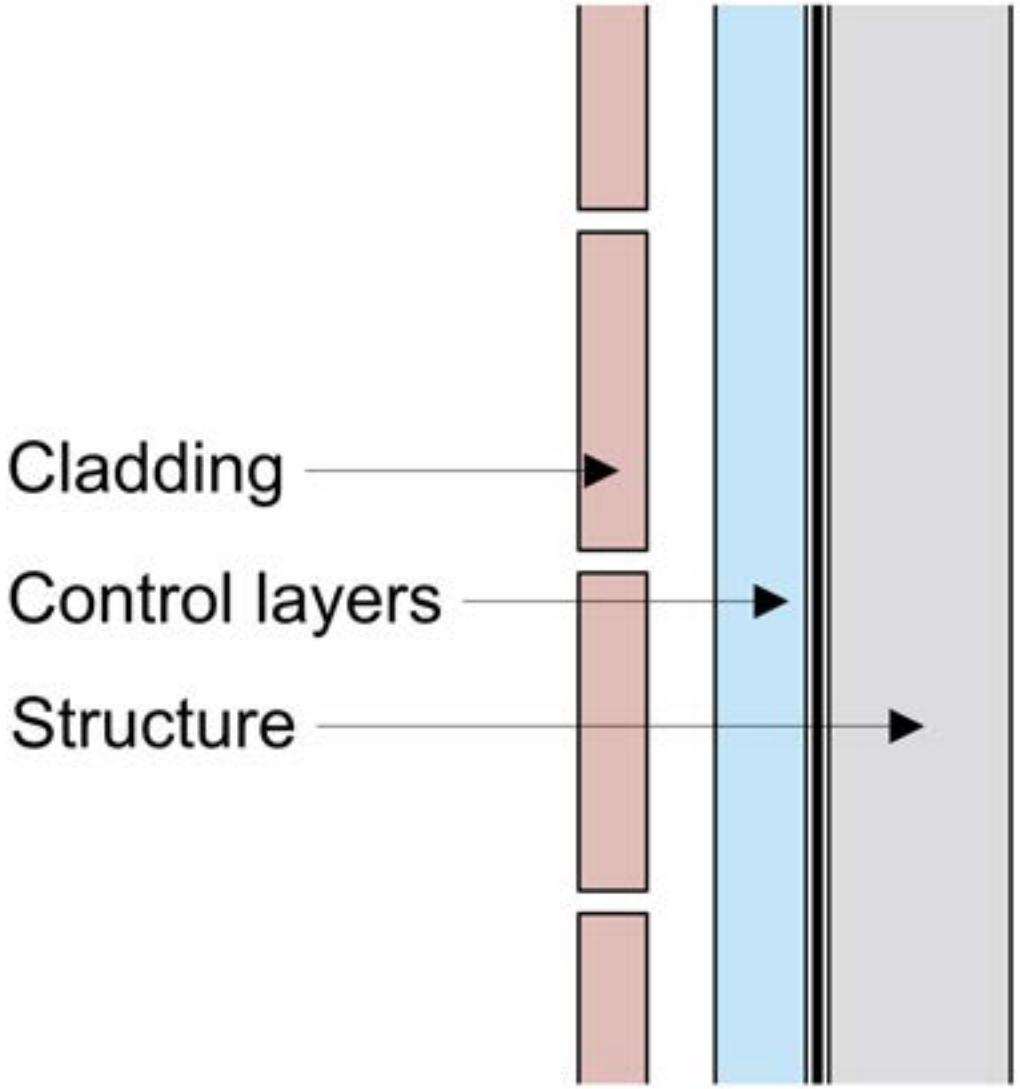
What do We Need?

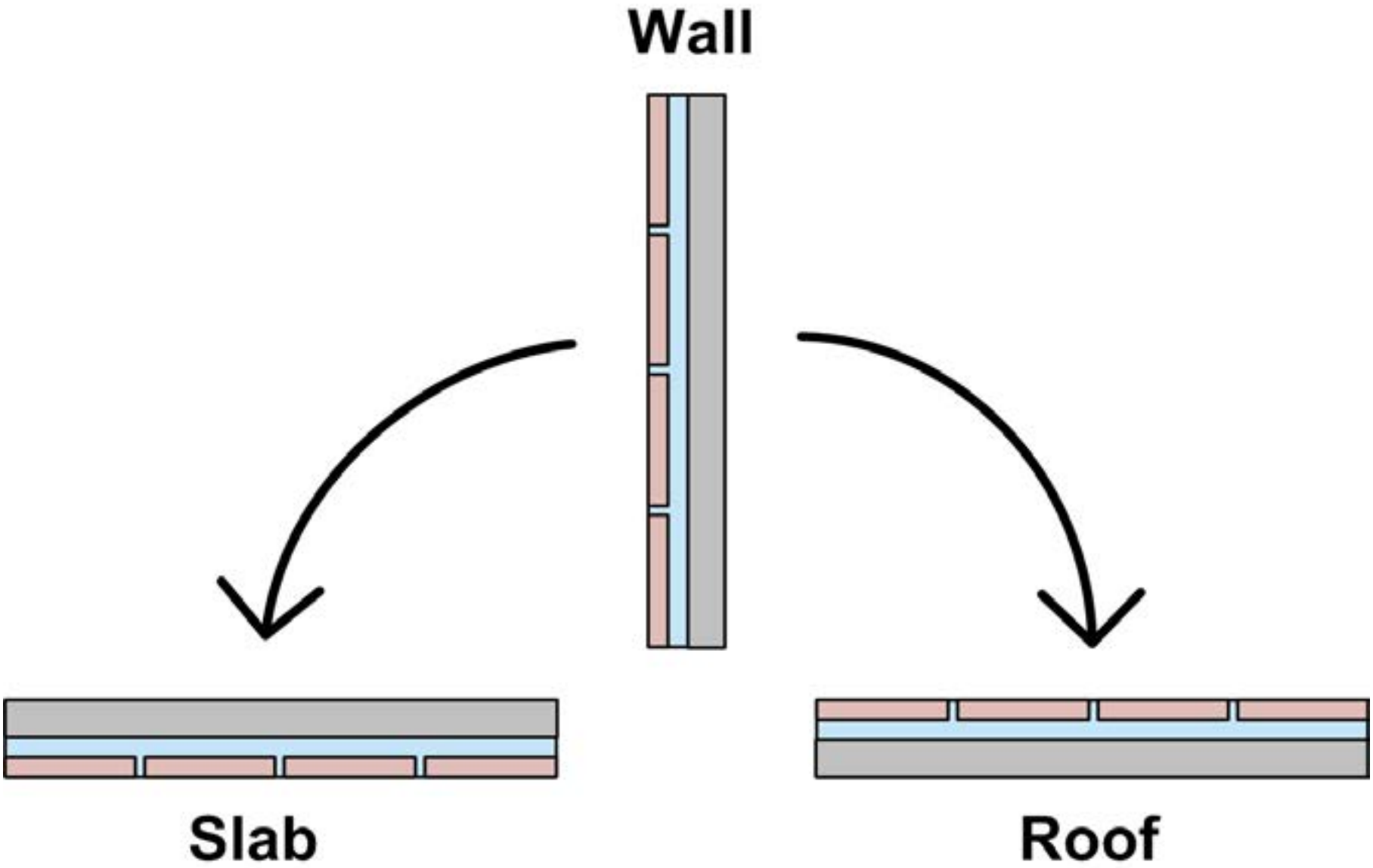
Water Control Layer

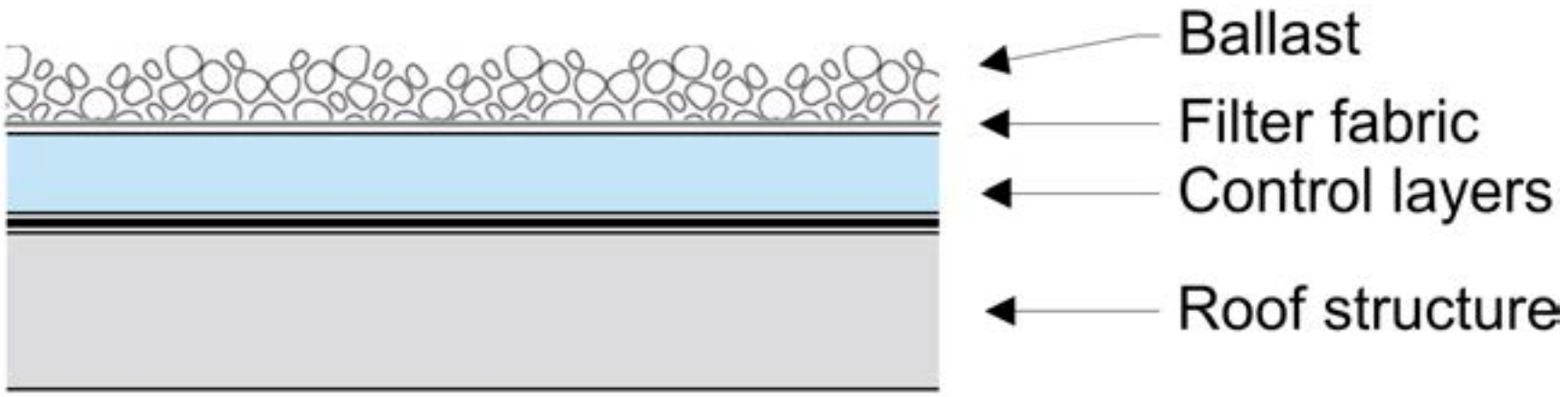
Air Control Layer

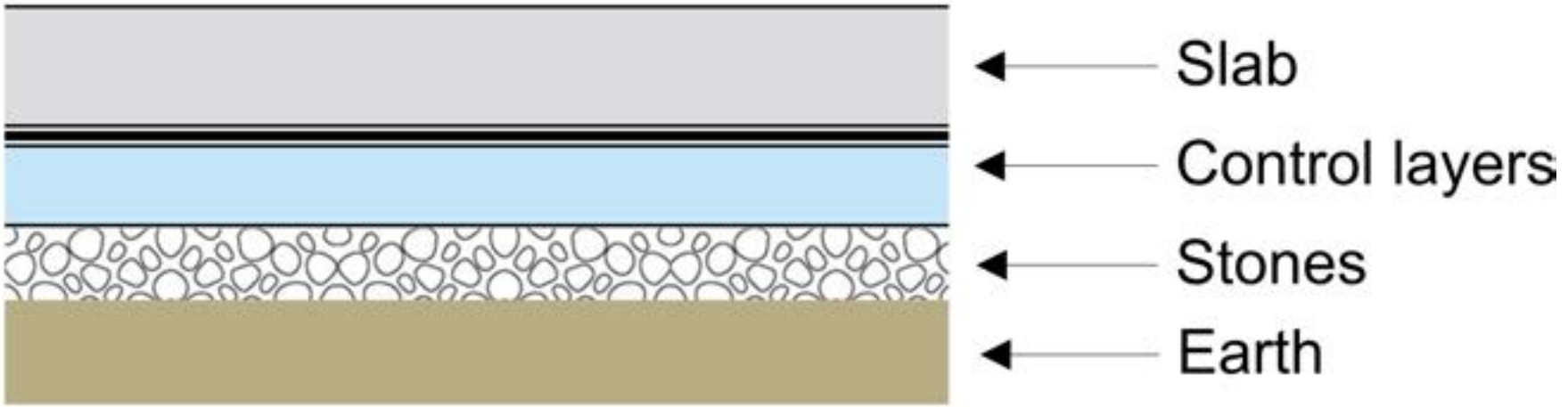
Vapor Control Layer

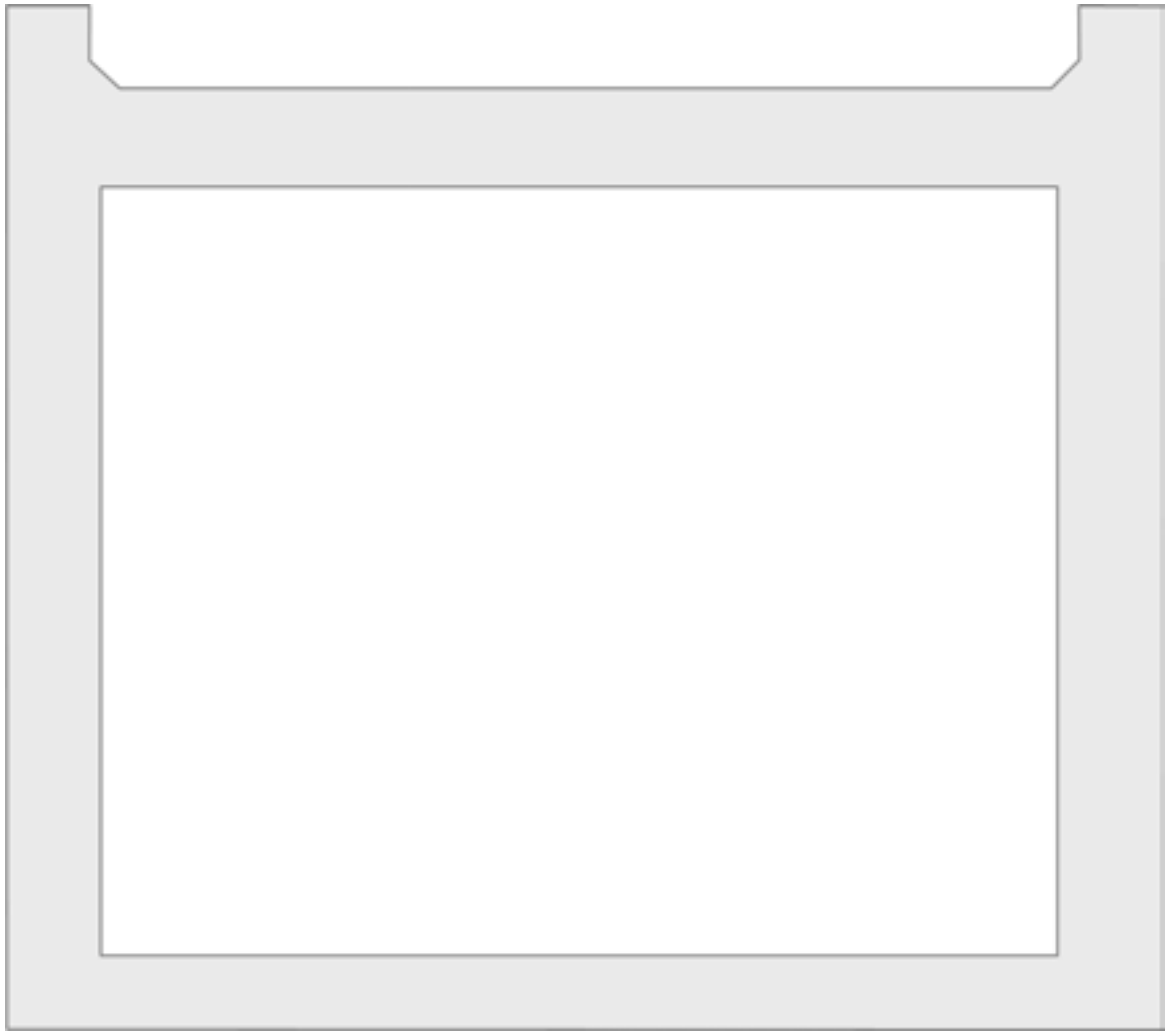
Thermal Control Layer


Cladding
Control layers
Structure

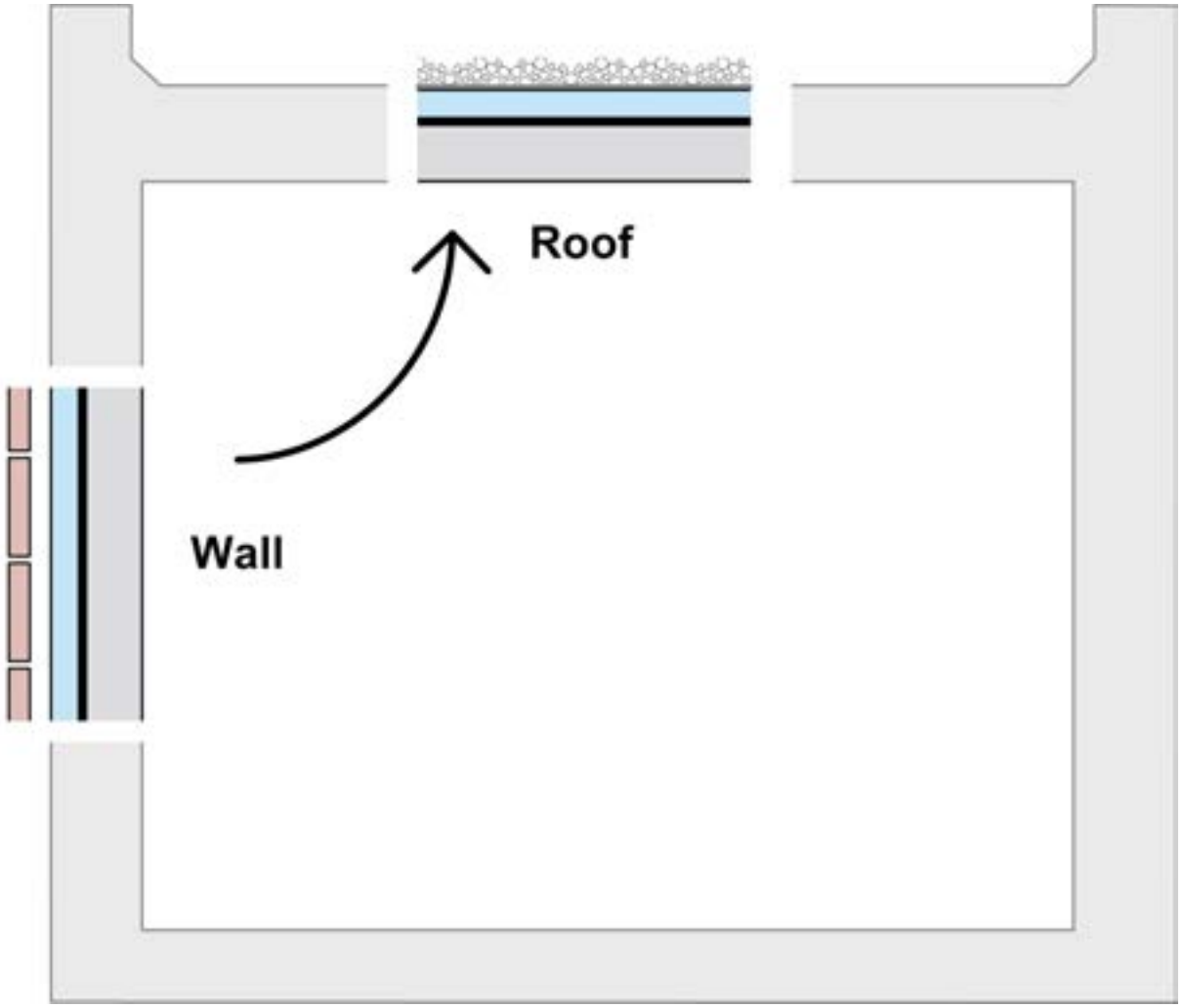

Wall
Slab
Roof

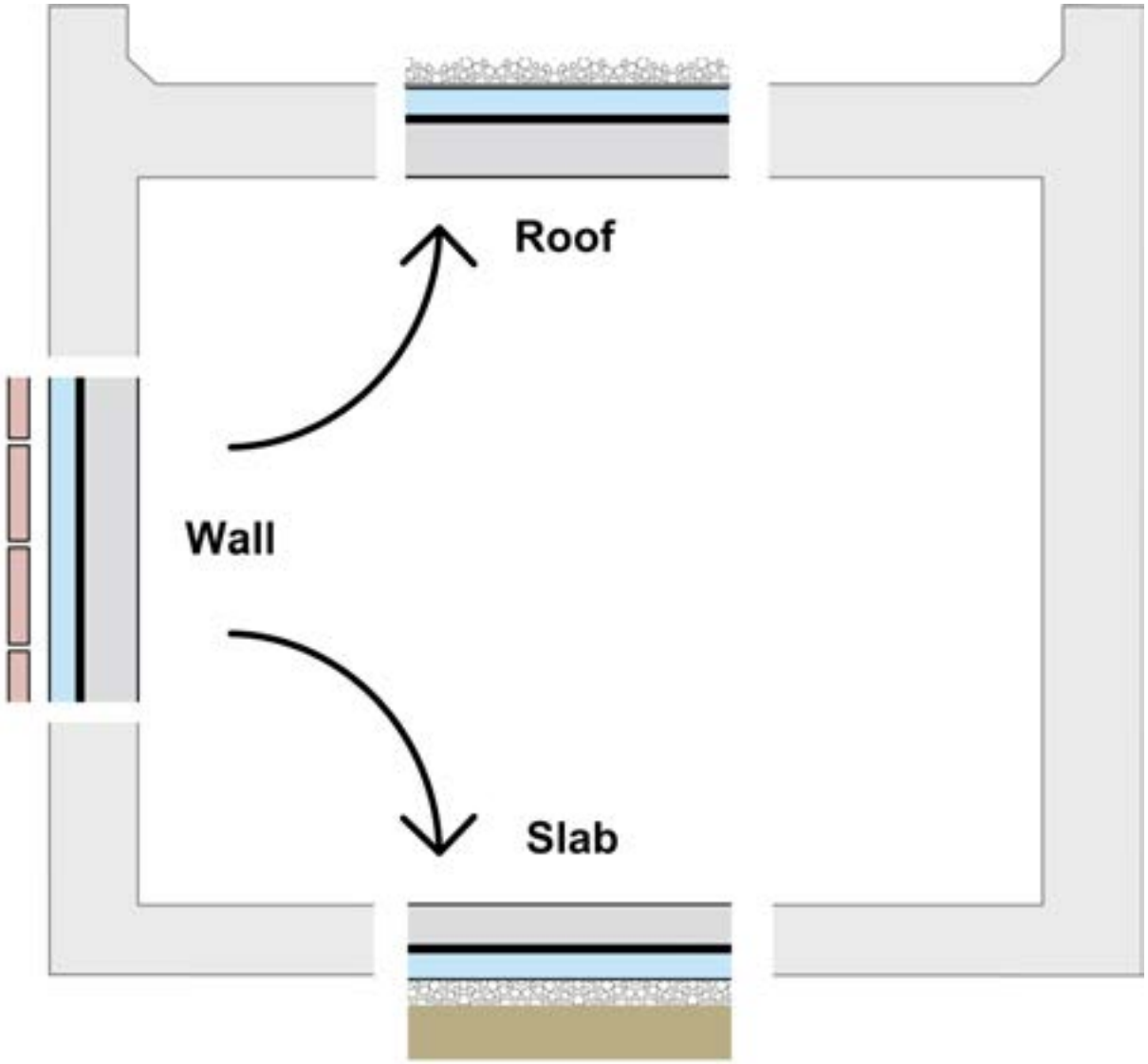

Ballast
Filter fabric
Control layers
Roof structure

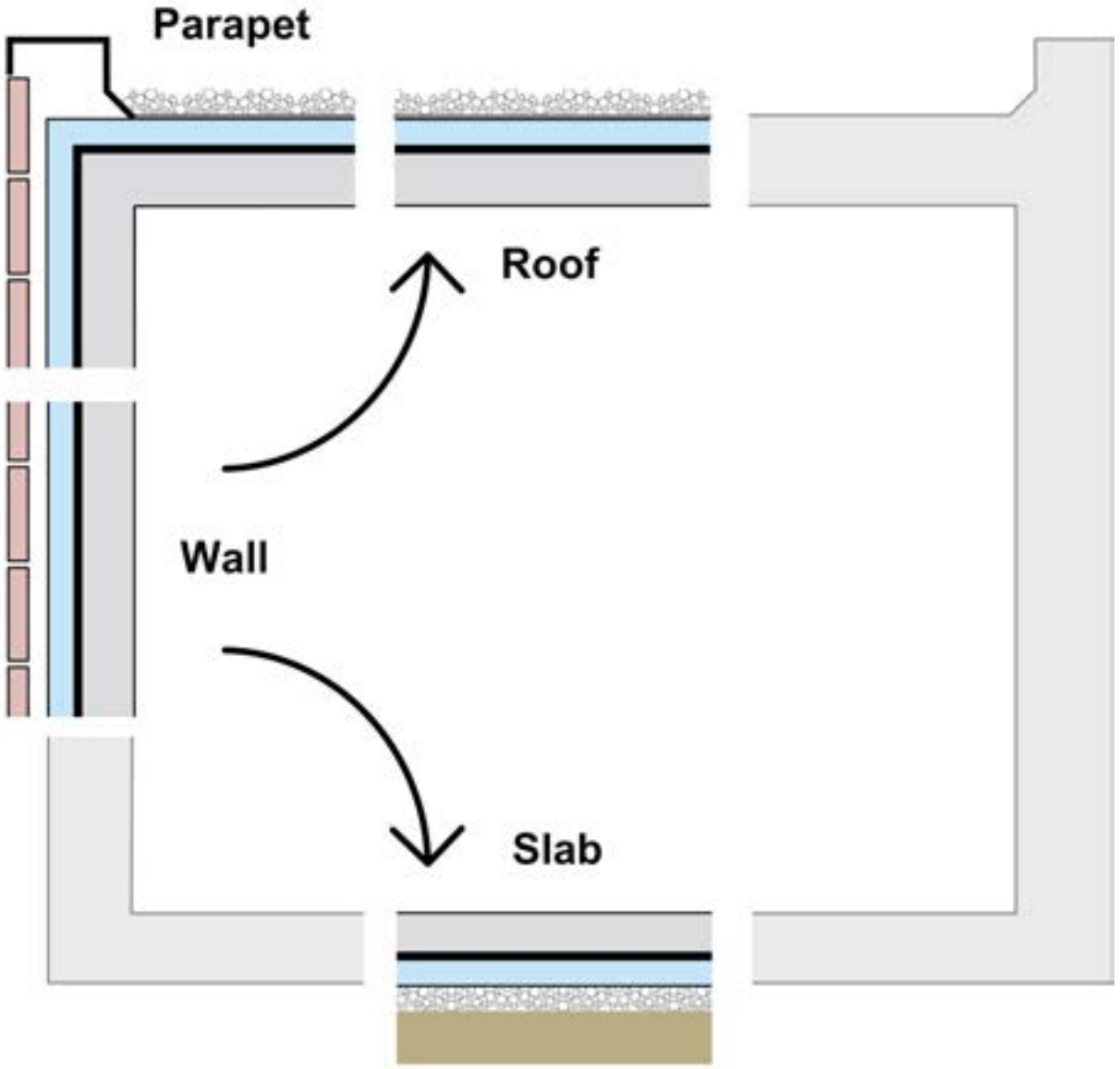

Slab
Control layers
Stones
Earth

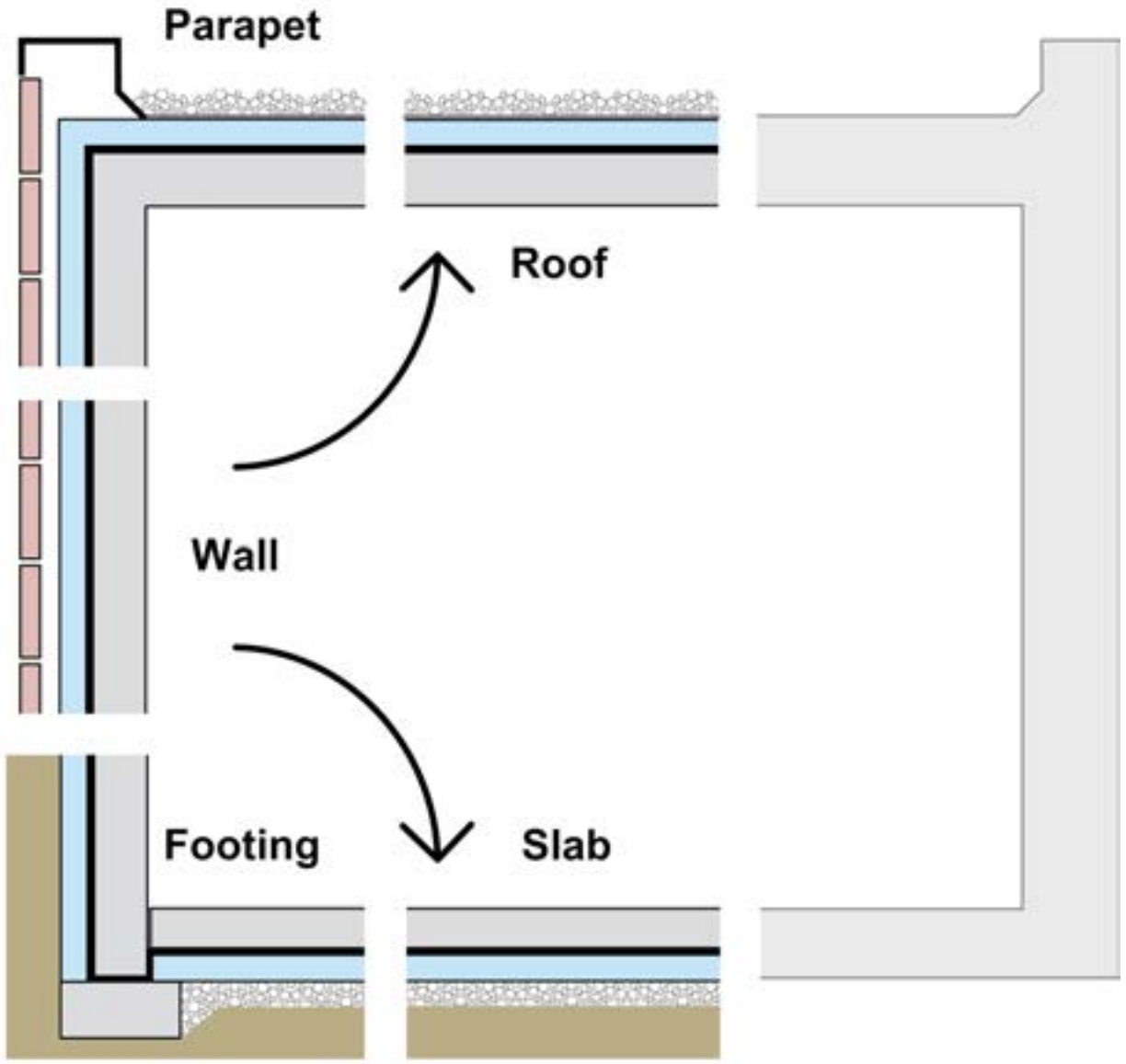


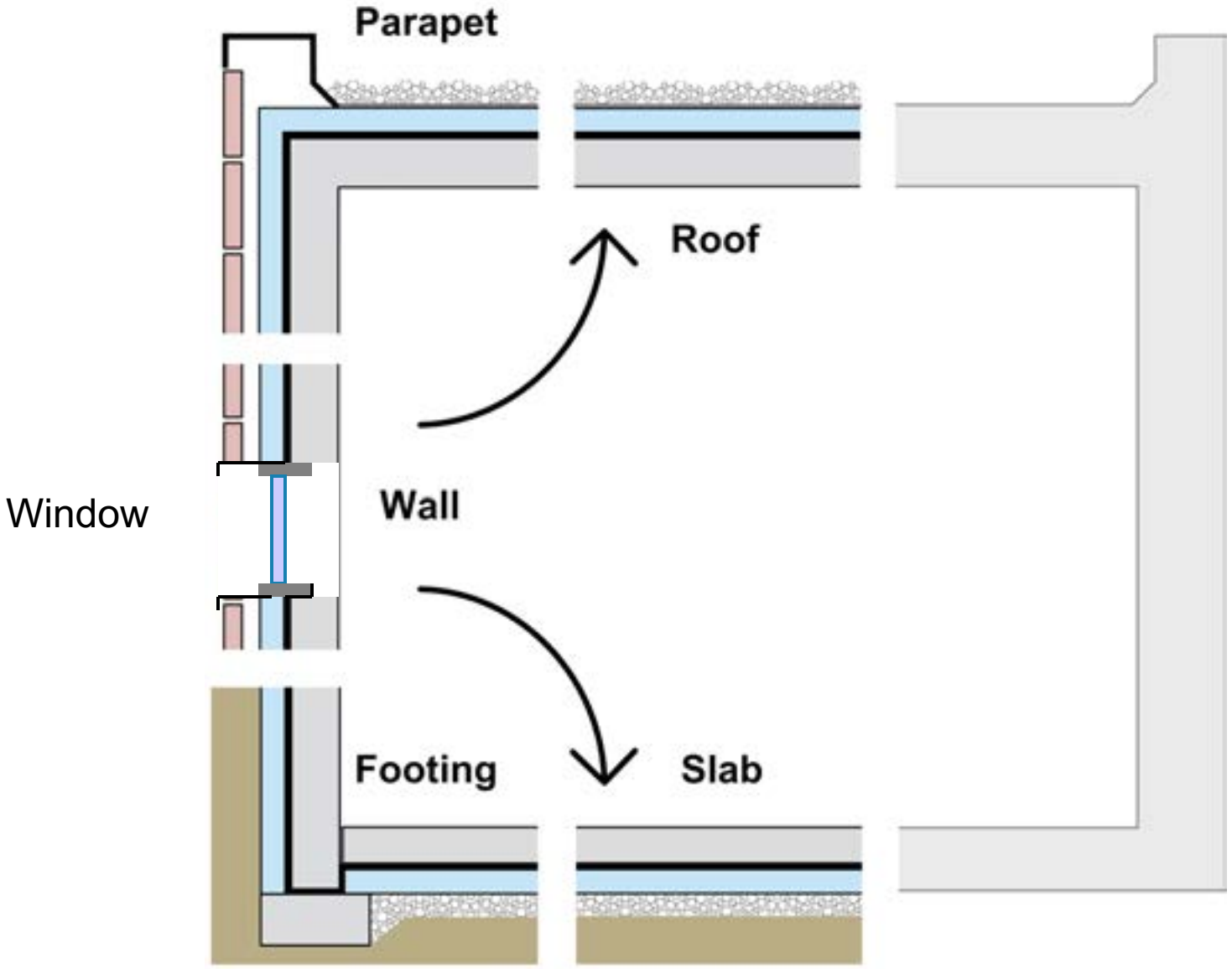

Wall

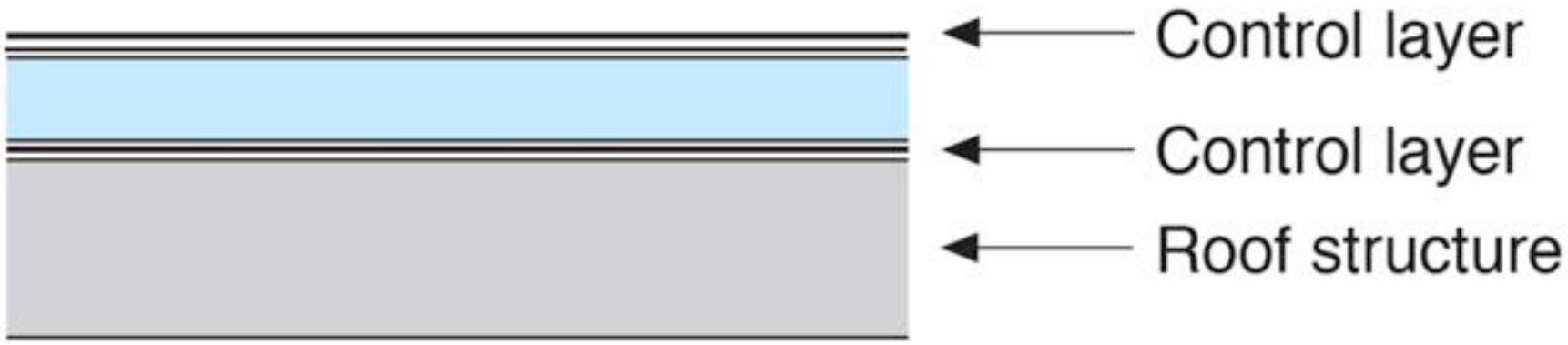

Roof
Wall

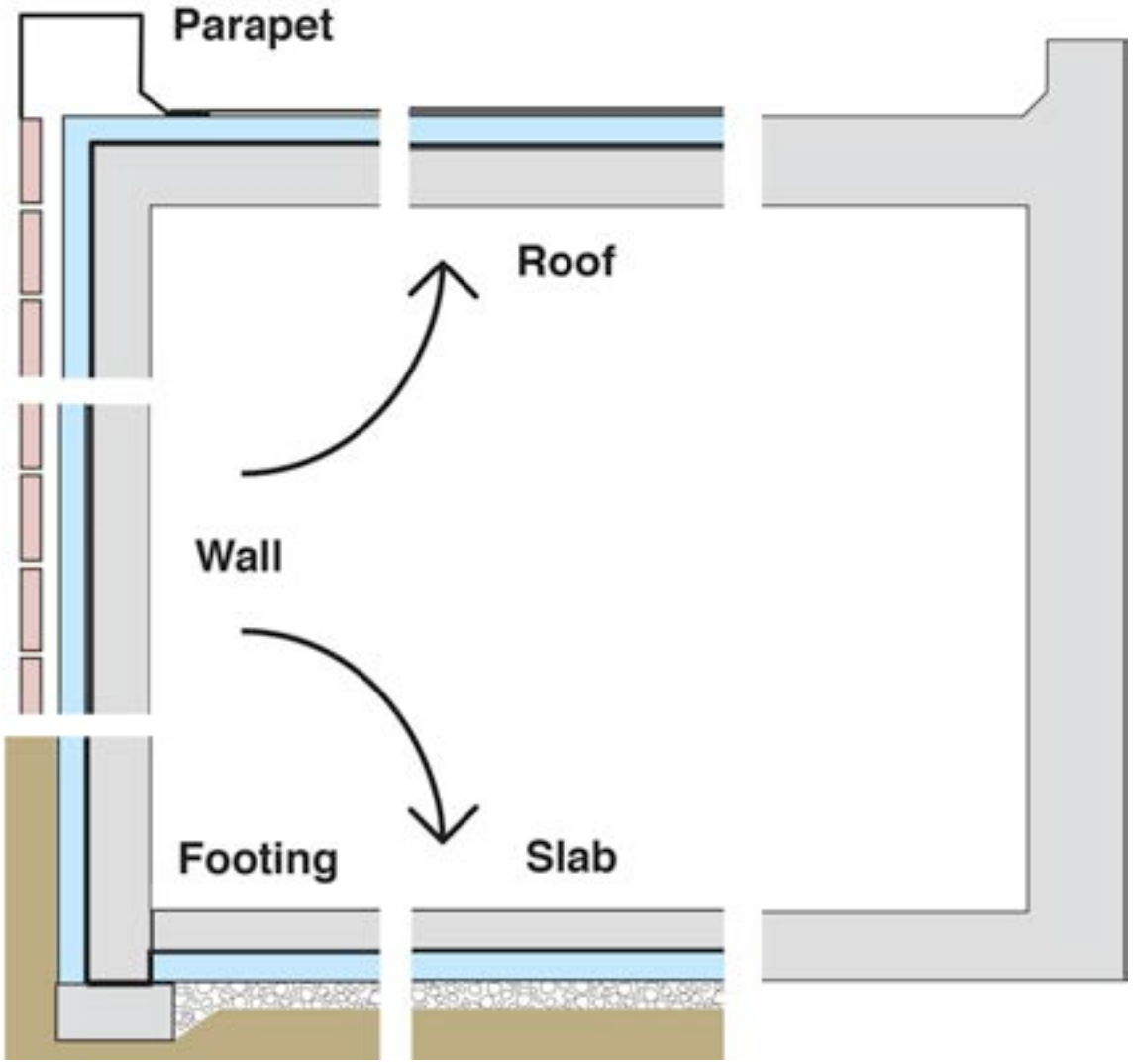

Roof
Wall
Slab

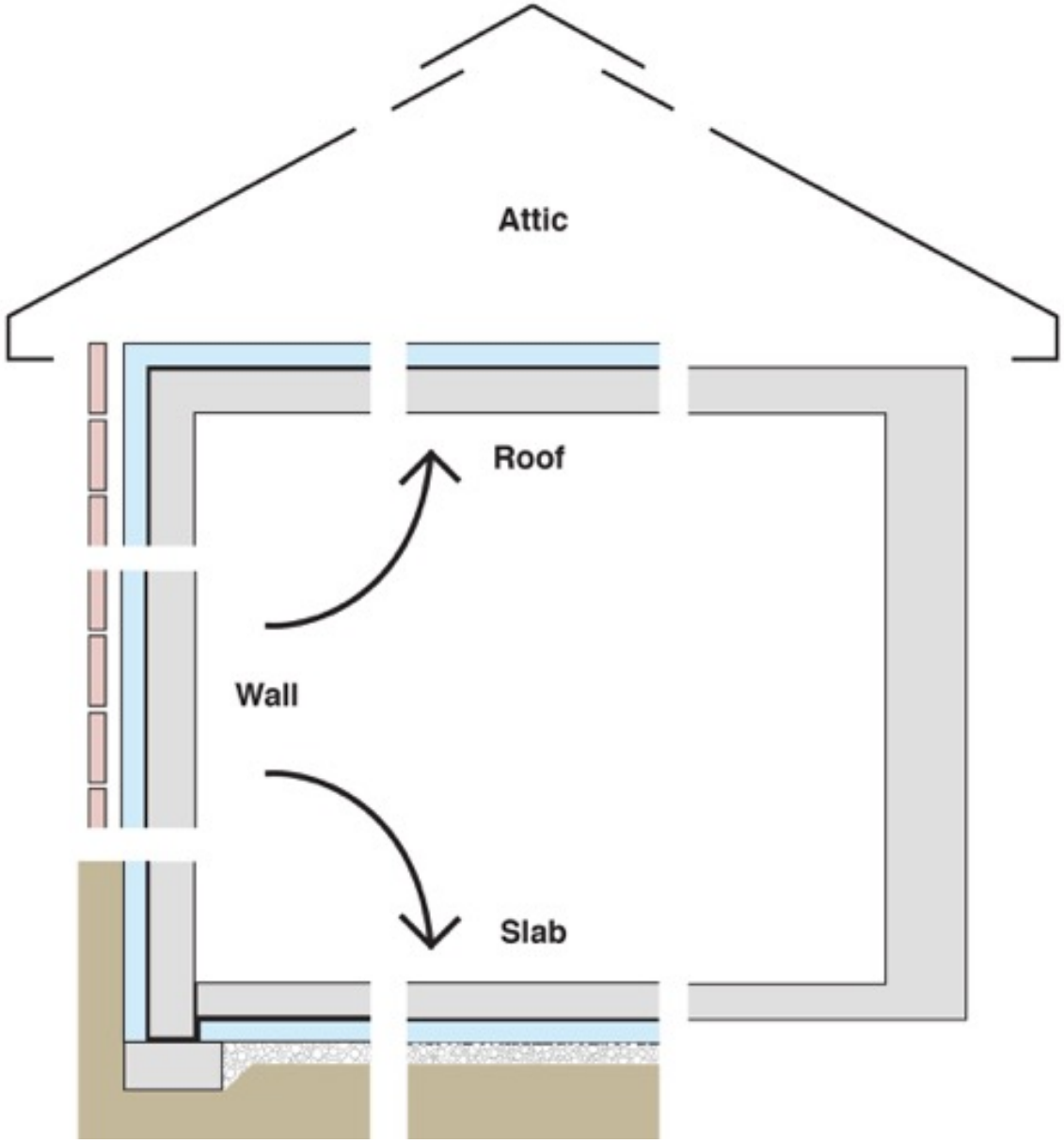

Parapet
Roof
Wall
Slab

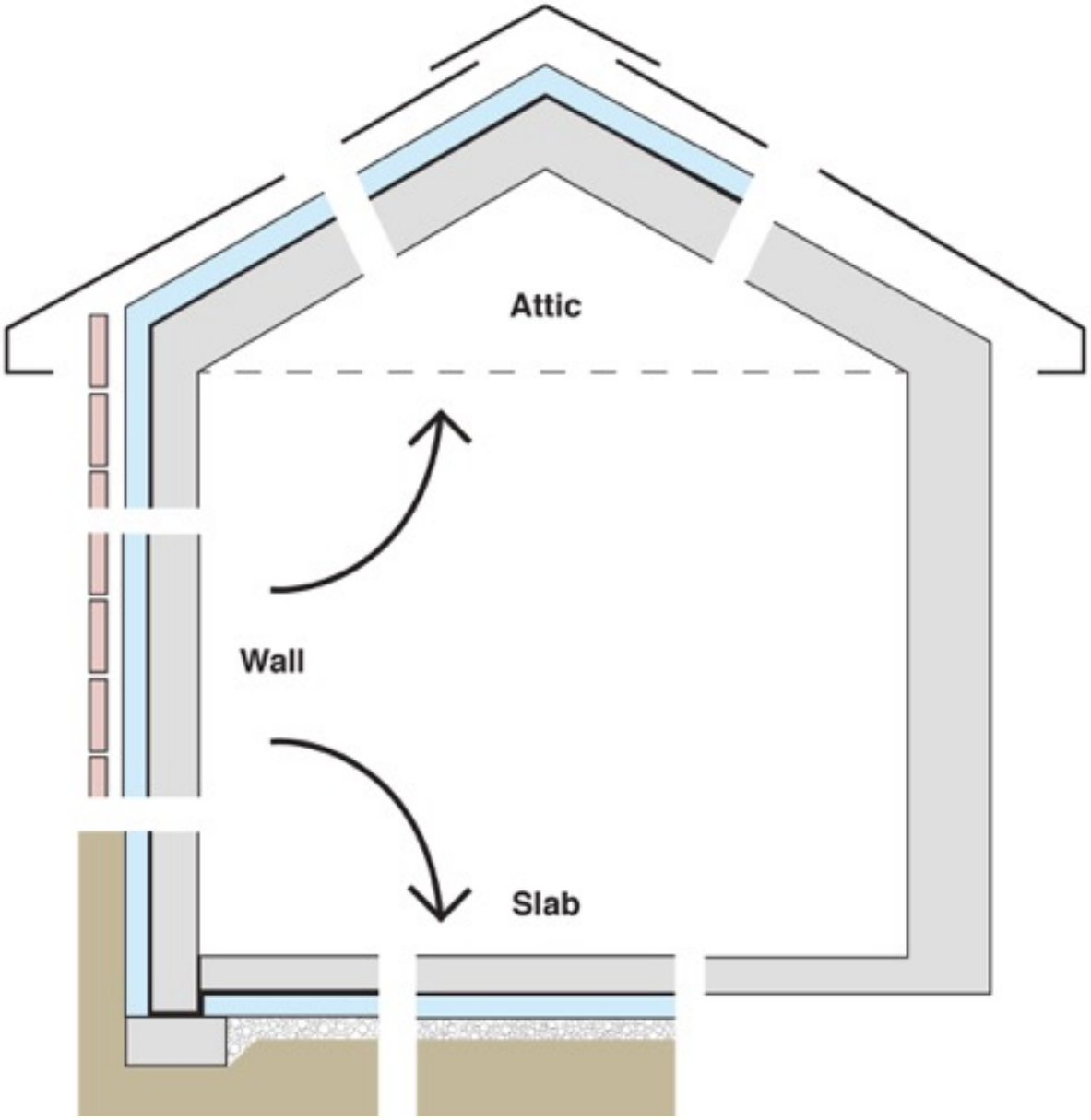

Parapet
Roof
Wall
Footing
Slab


Parapet
Roof
Window
Wall
Footing
Slab


Control layer
Control layer
Roof structure


Parapet
Roof
Wall
Footing
Slab


Attic
Roof
Wall
Slab


Attic
Wall
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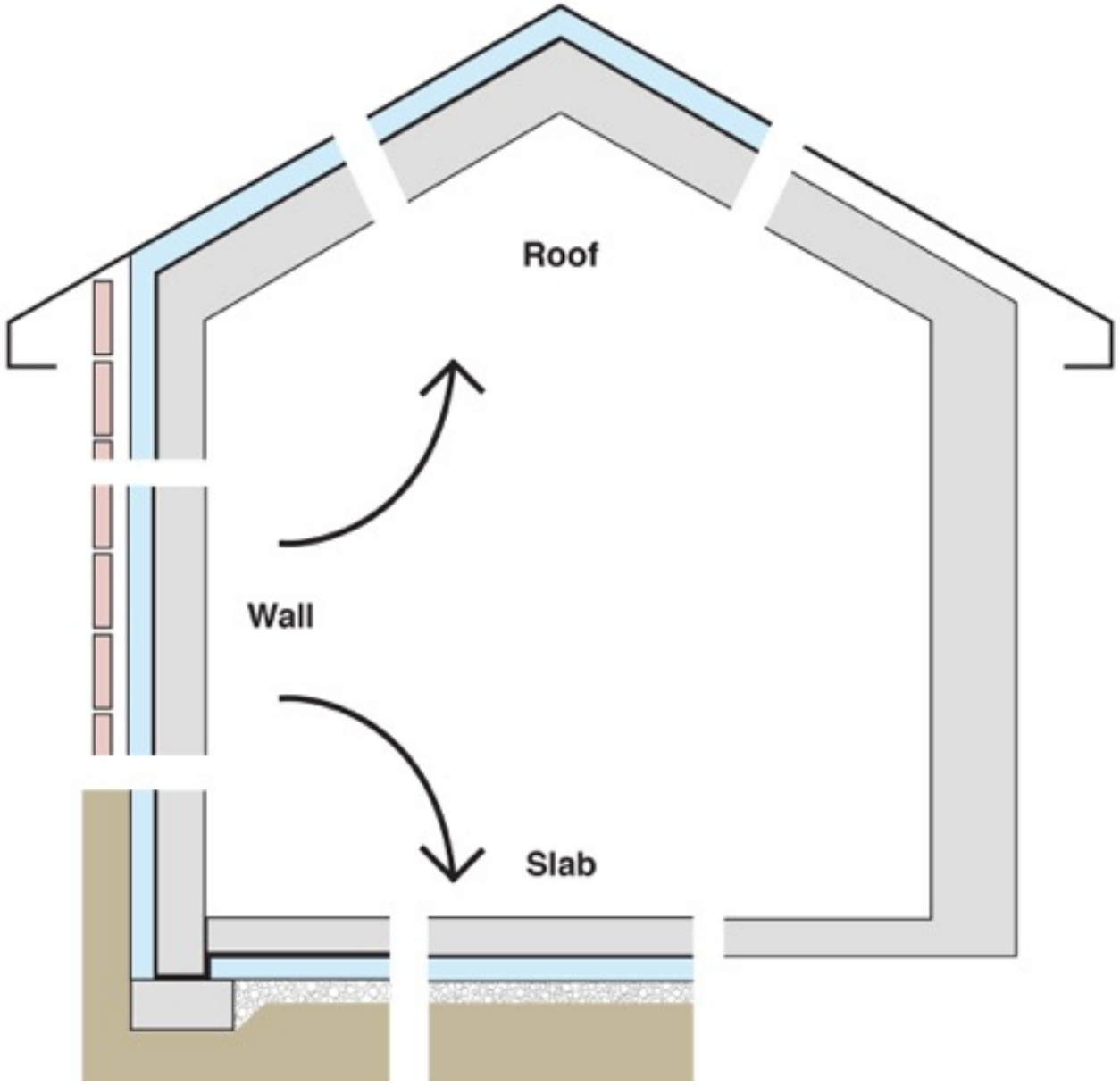
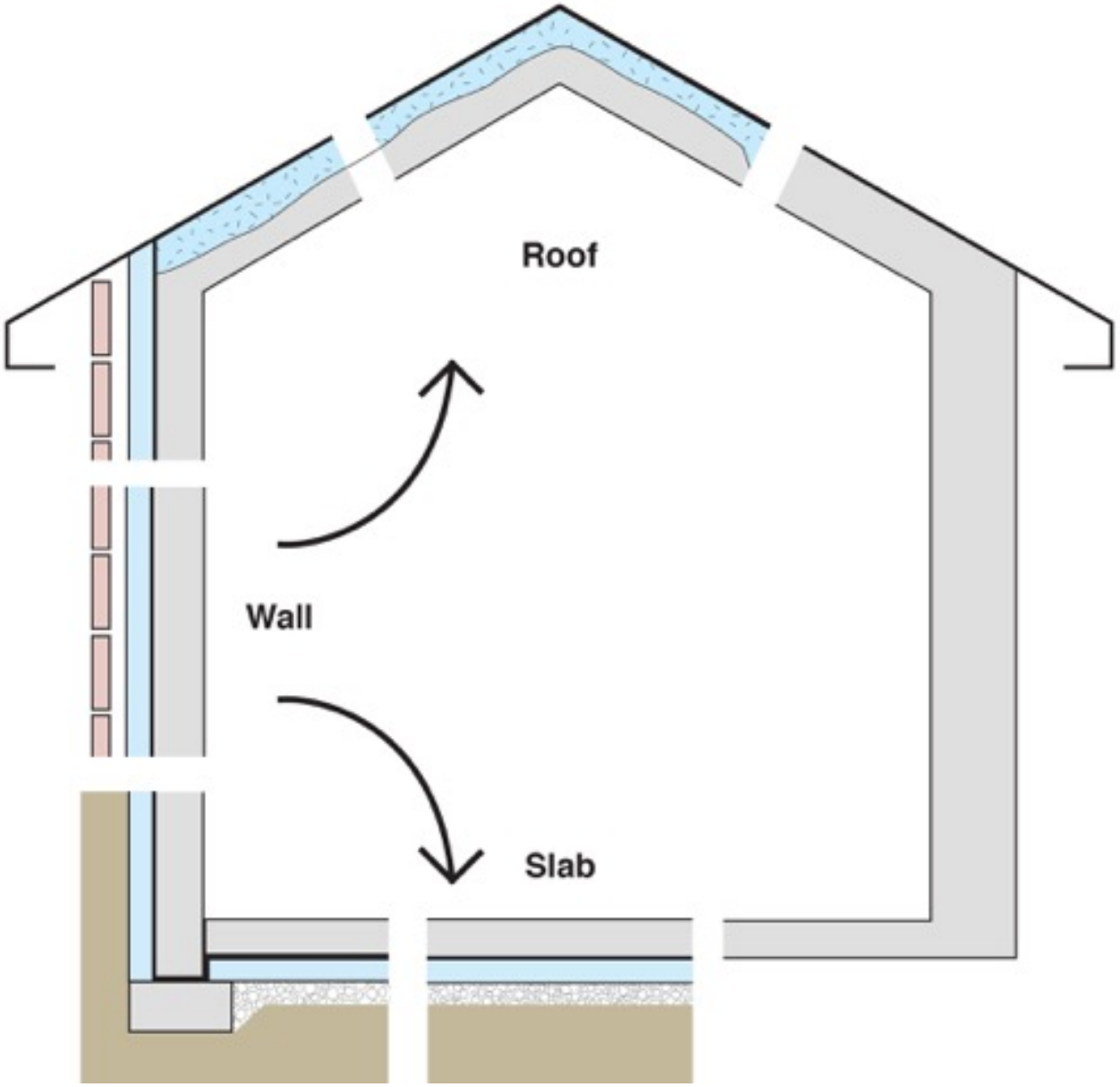
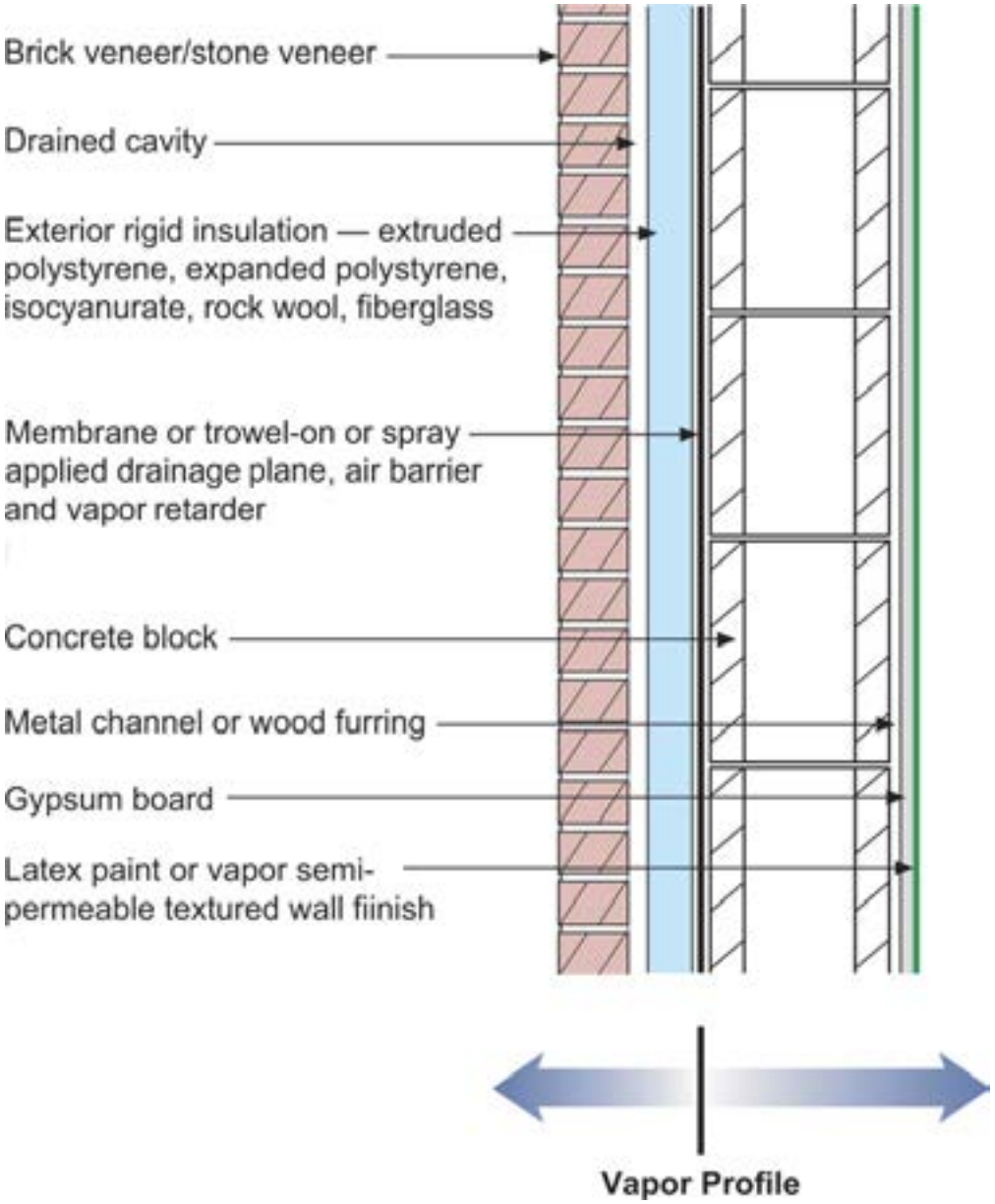
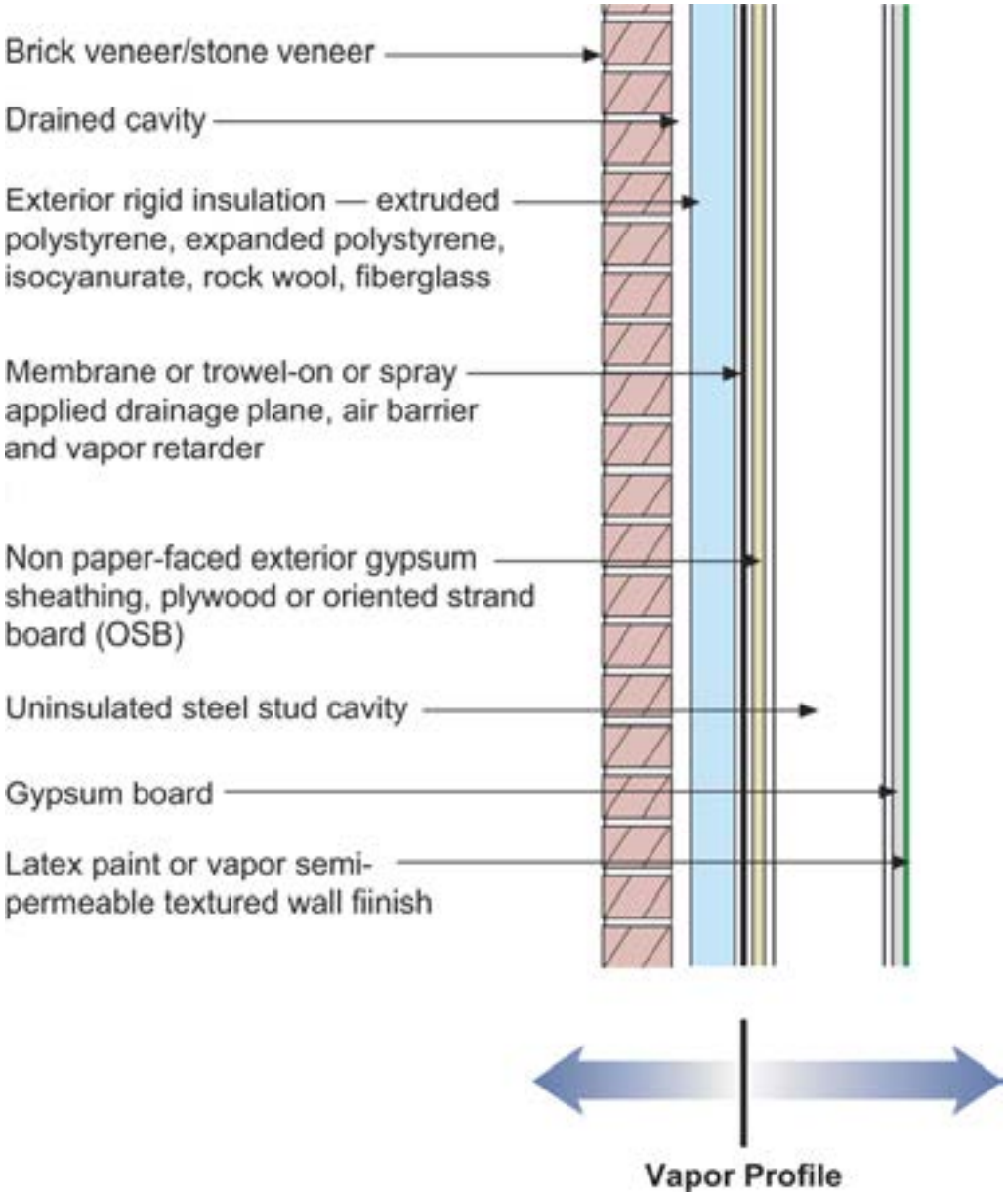
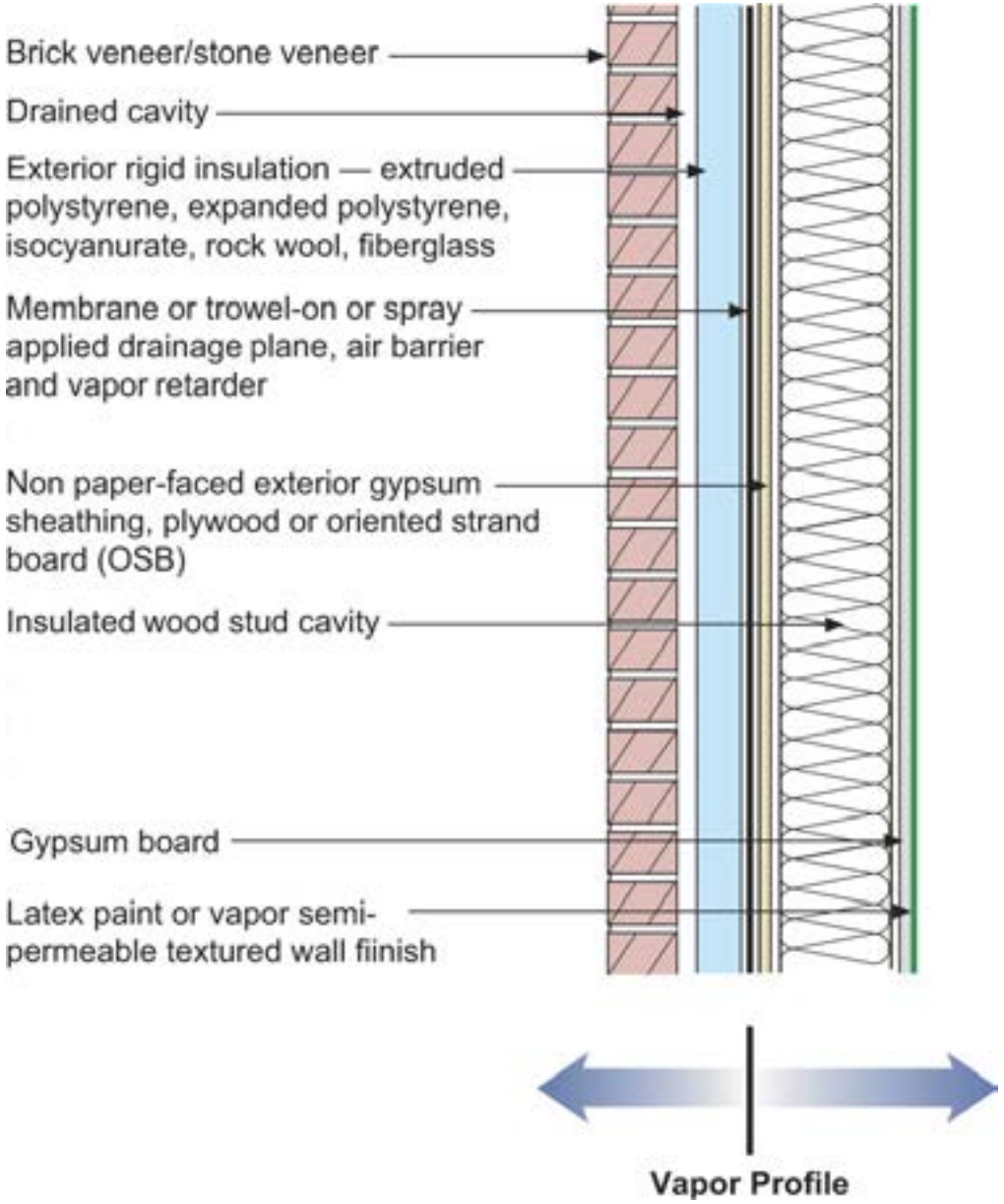

Roof
Wall
Slab


Roof
Wall
Slab

Configurations of the Perfect Wall

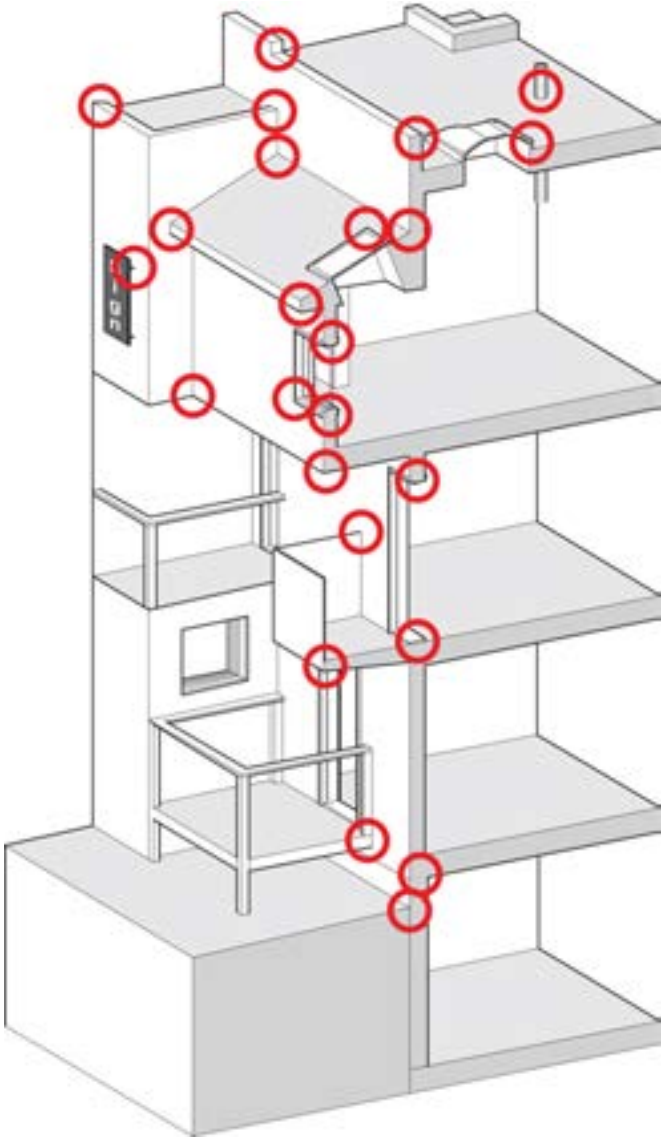

Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied drainage plane, air barrier and vapor retarder
Concrete block
Metal channel or wood furring
Gypsum board
Latex paint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

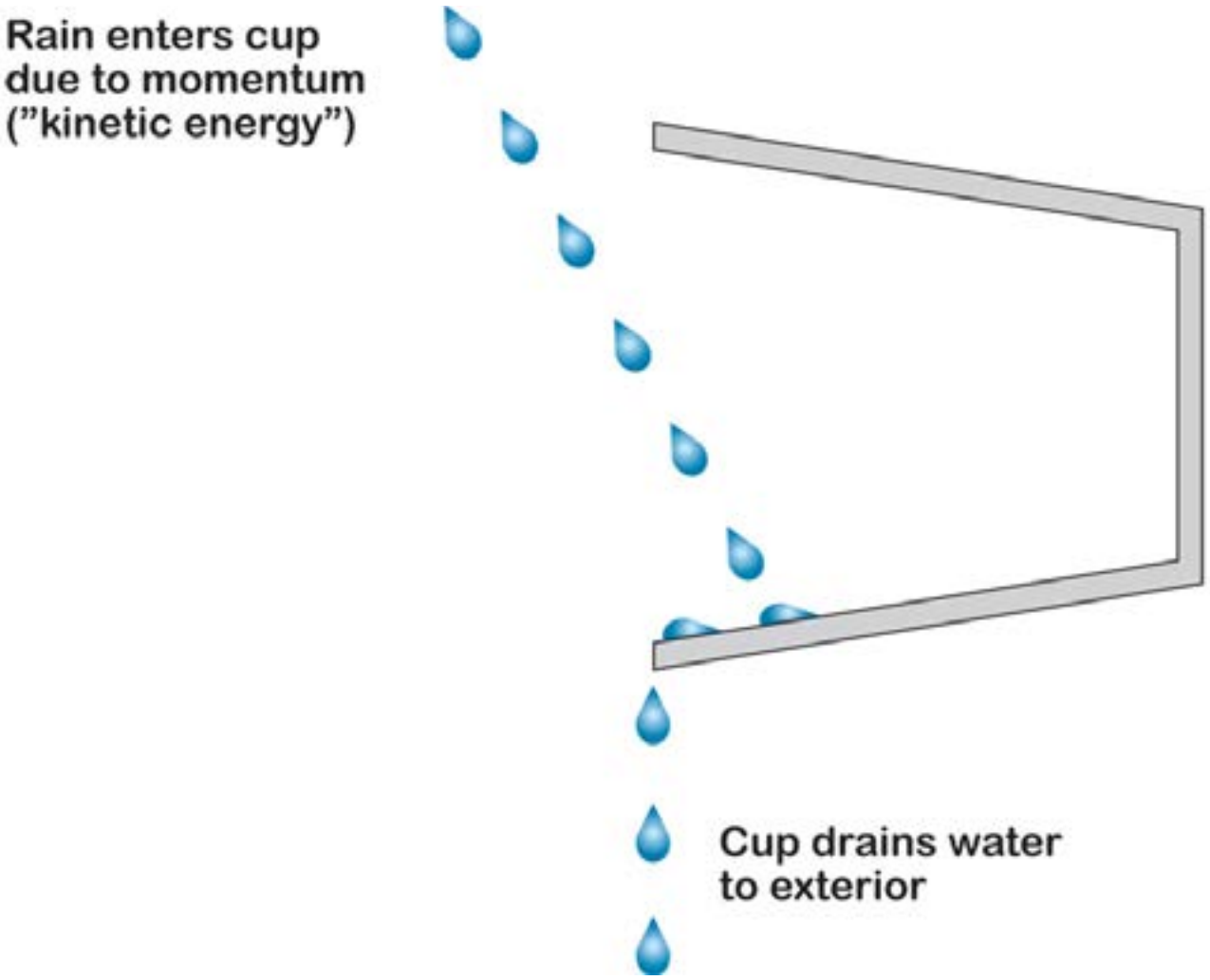

Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied drainage plane, air barrier and vapor retarder
Non paper-faced exterior gypsum sheathing, plywood or oriented strand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

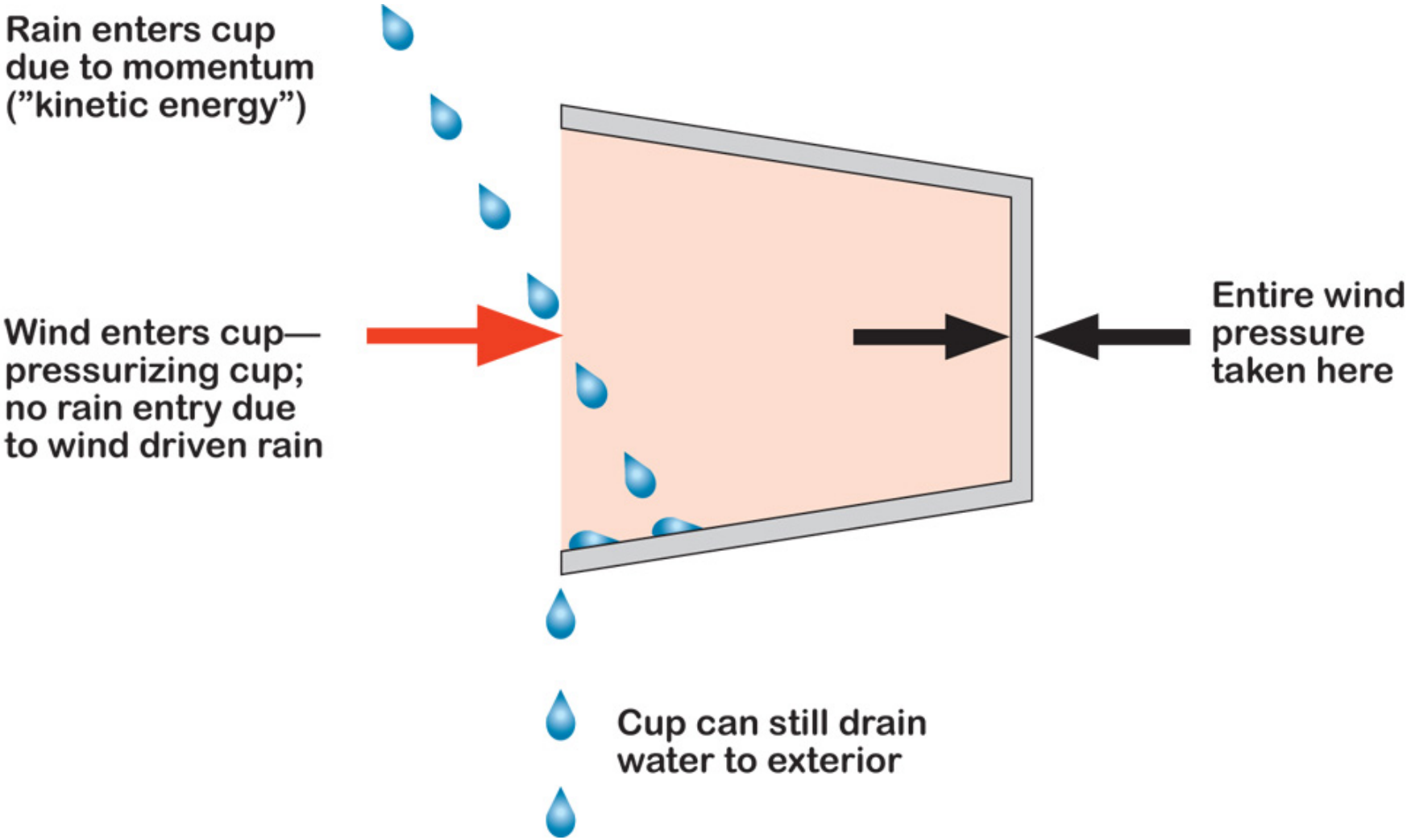

Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied drainage plane, air barrier and vapor retarder
Non paper-faced exterior gypsum sheathing, plywood or oriented strand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

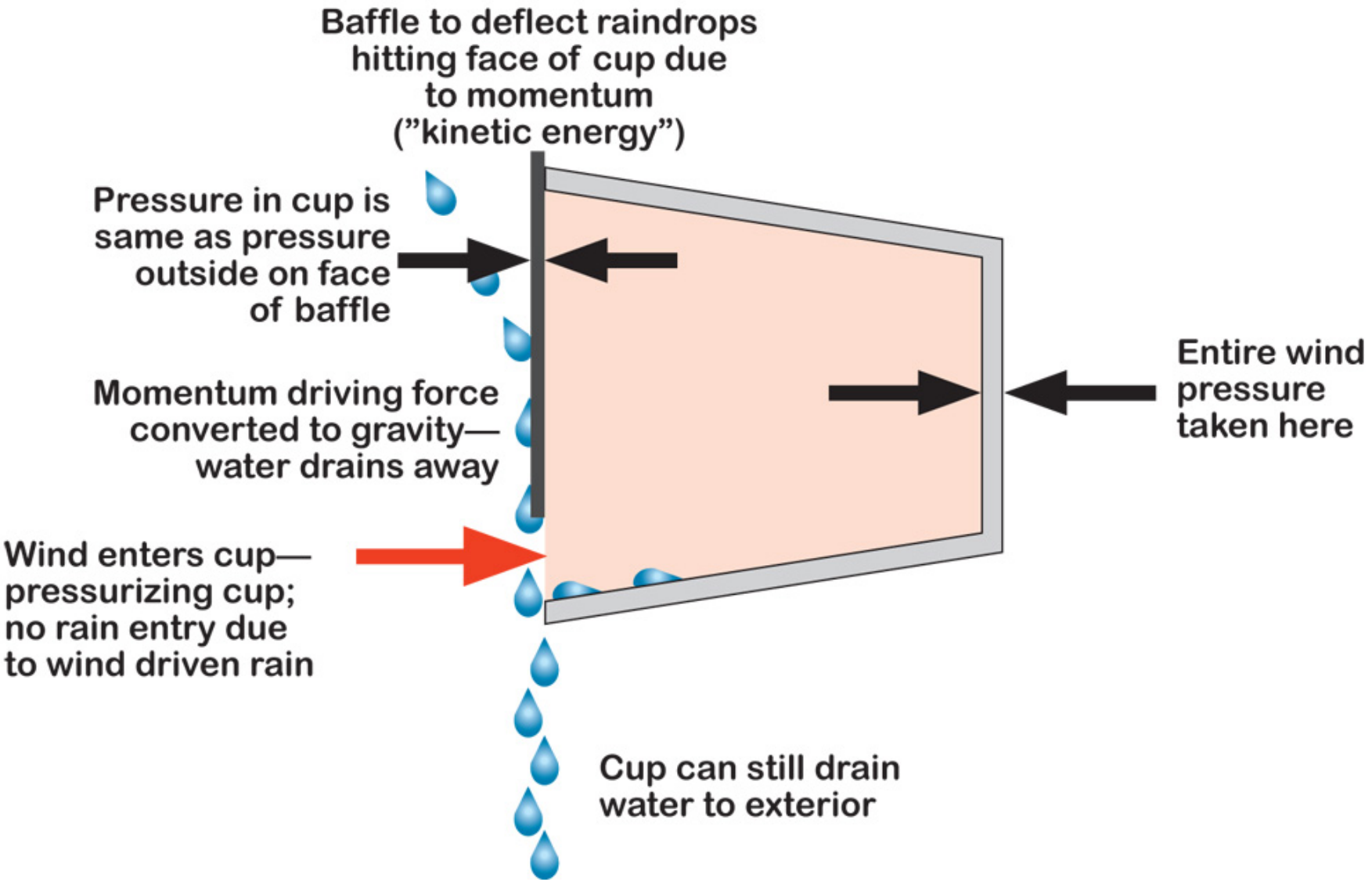
Commercial Enclosure: Simple Layers

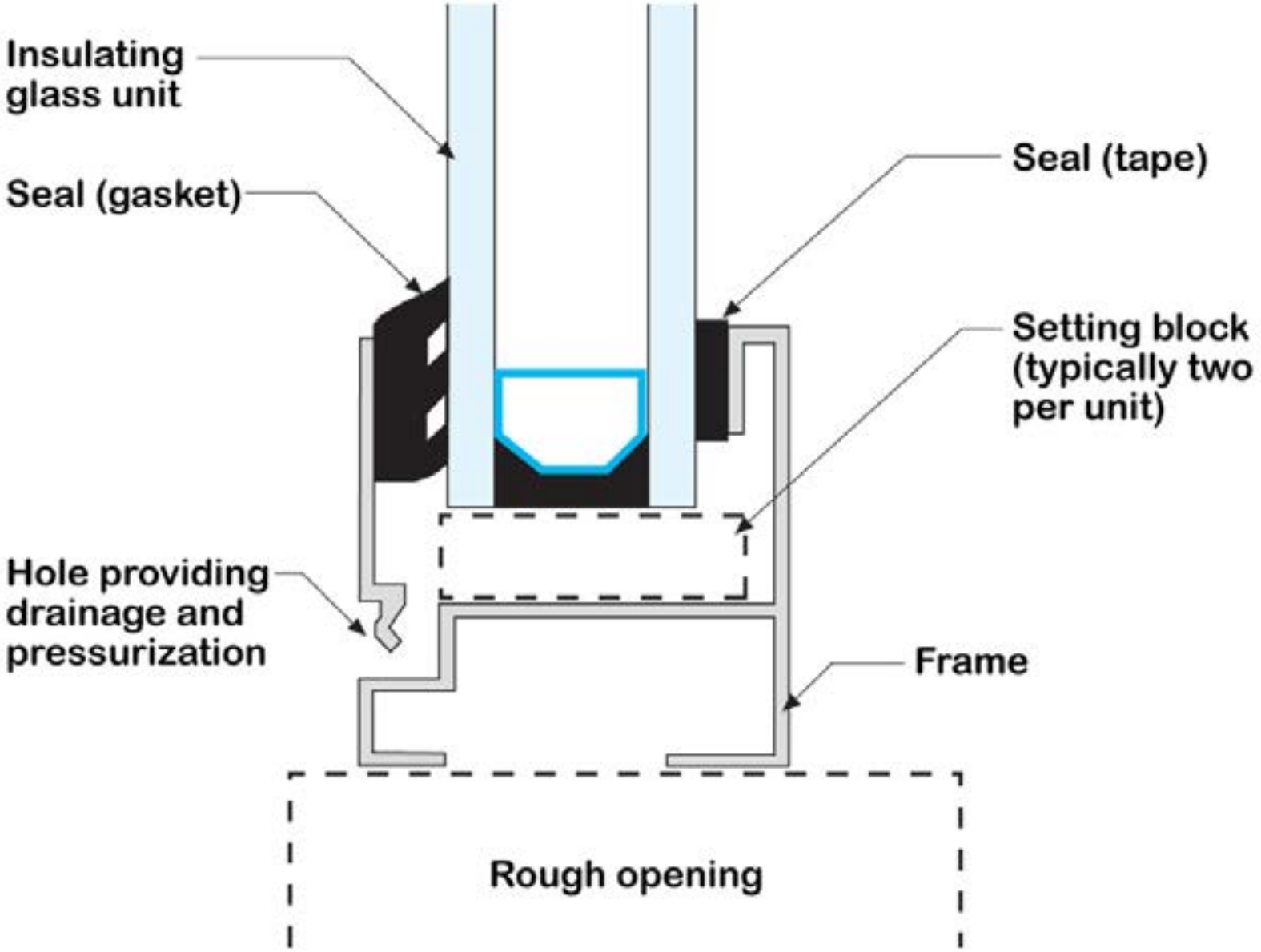
- Structure
- Rain/Air/Vapor
- Insulation
- Finish

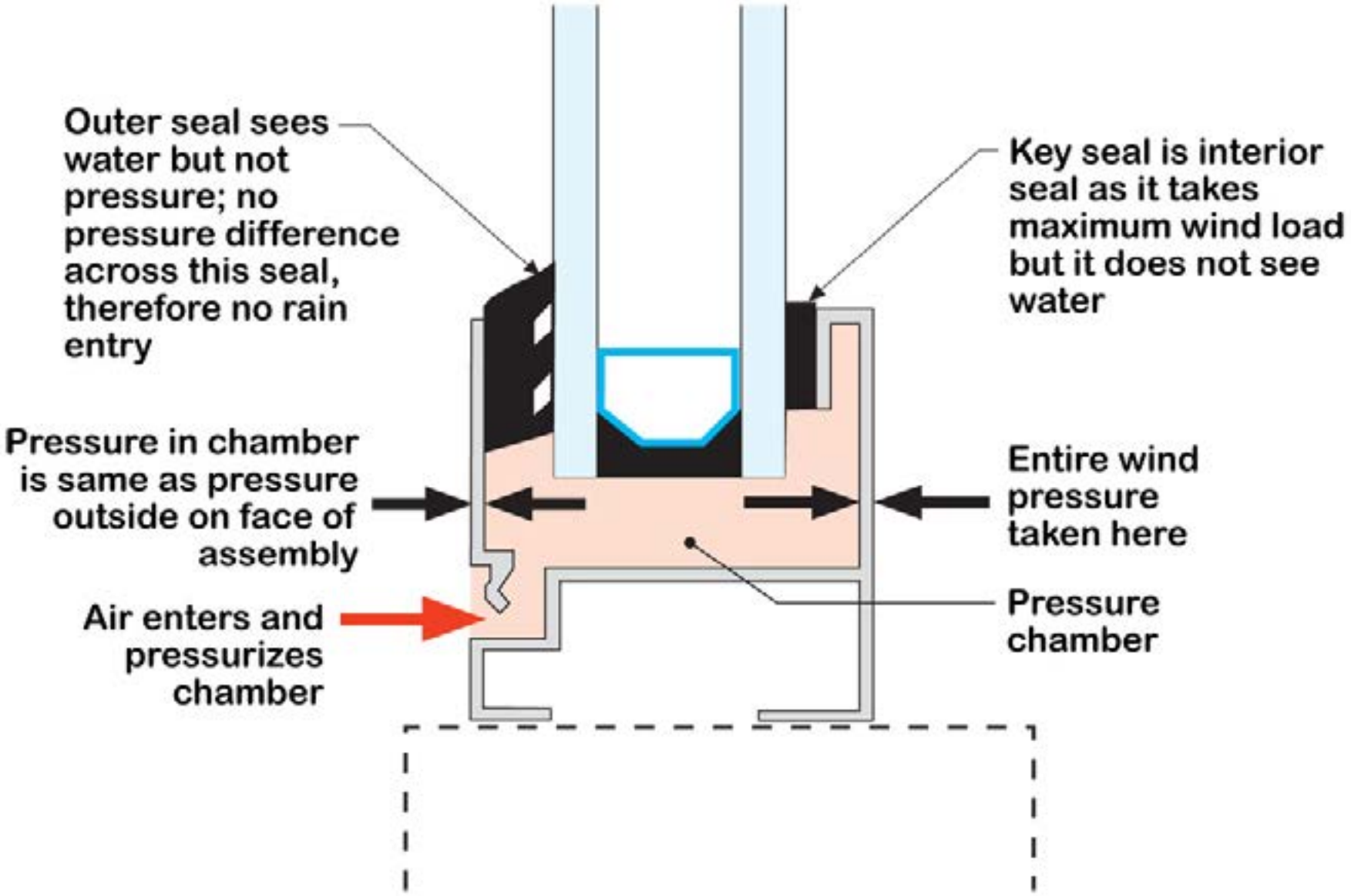


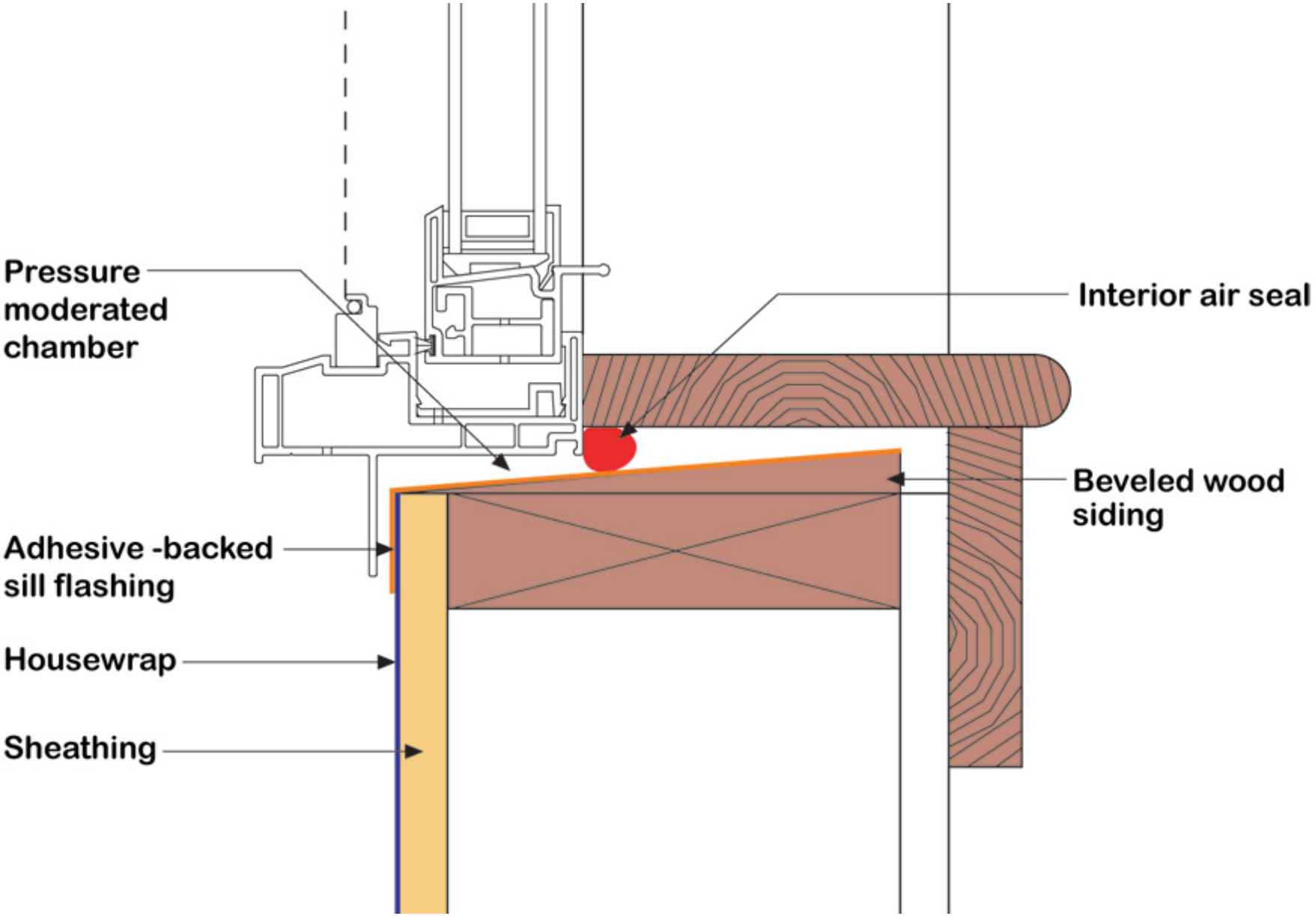

Rain enters cup due to momentum ("kinetic energy")
Cup drains water to exterior

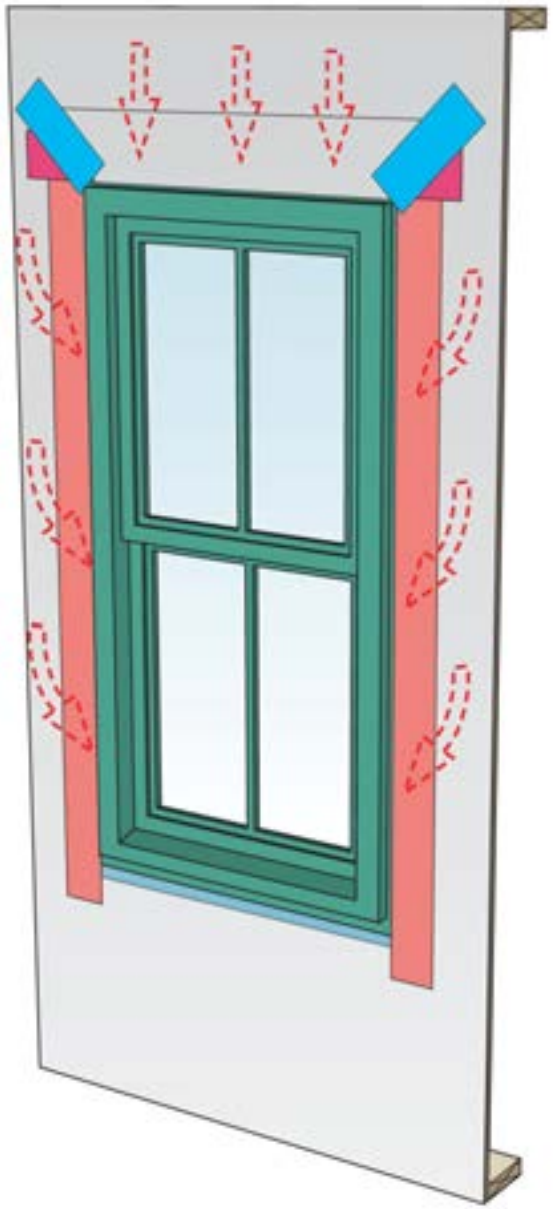

Rain enters cup due to momentum ("kinetic energy")
Wind enters cup— pressurizing cup; no rain entry due to wind driven rain
Entire wind pressure taken here
Cup can still drain water to exterior

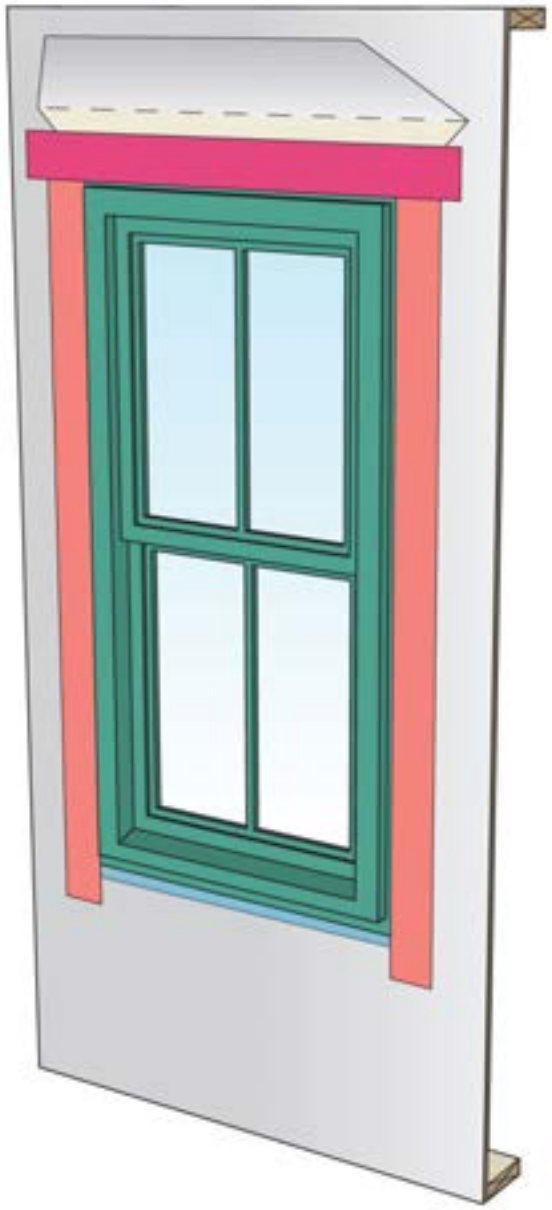

Baffle to deflect raindrops hitting face of cup due to momentum ("kinetic energy")
Pressure in cup is same as pressure outside on face of baffle
Momentum driving force converted to gravity— water drains away
Wind enters cup— pressurizing cup; no rain entry due to wind driven rain
Entire wind pressure taken here
Cup can still drain water to exterior

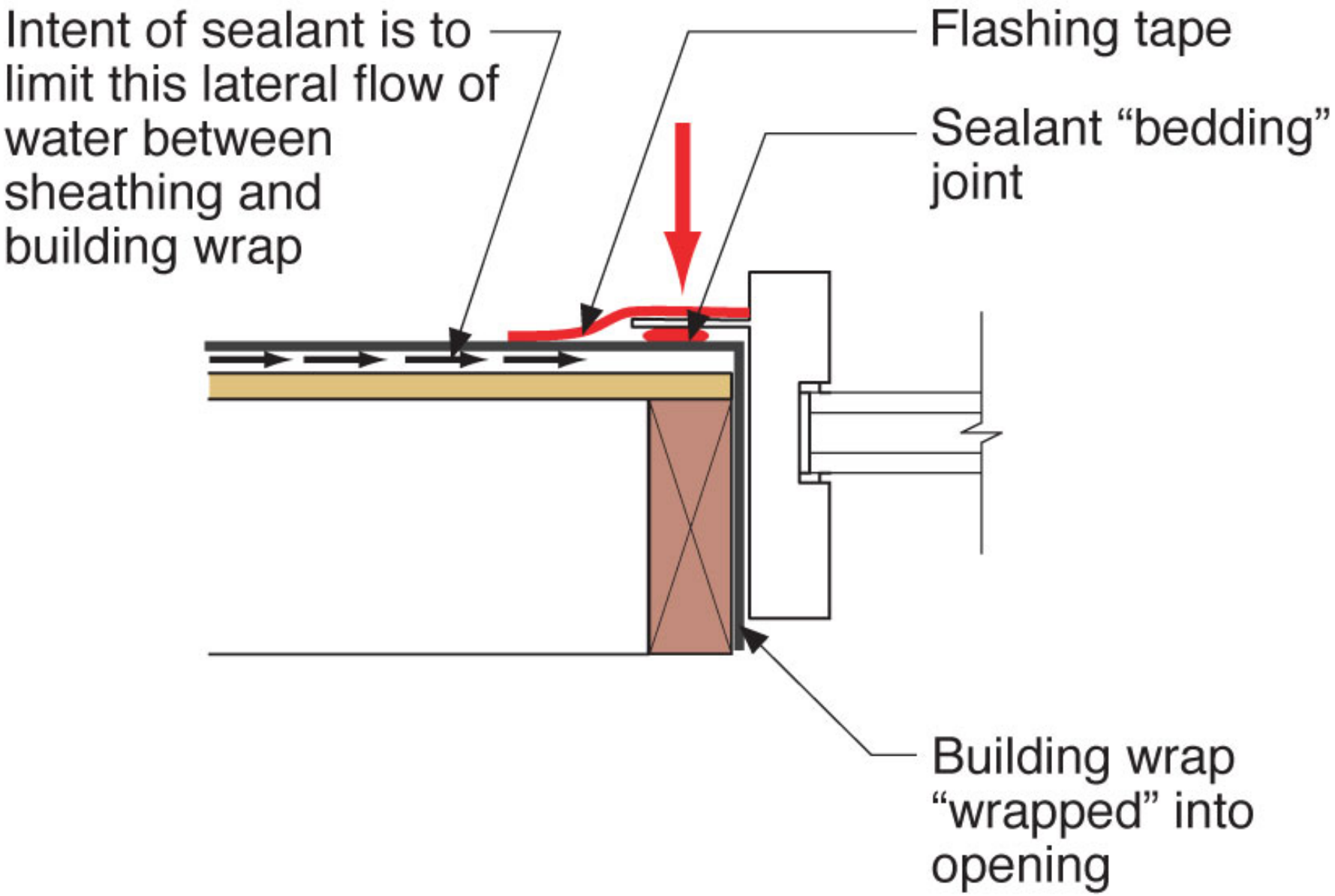

Insulating glass unit
Seal (gasket)
Seal (tape)
Setting block (typically two per unit)
Hole providing drainage and pressurization
Frame
Rough opening

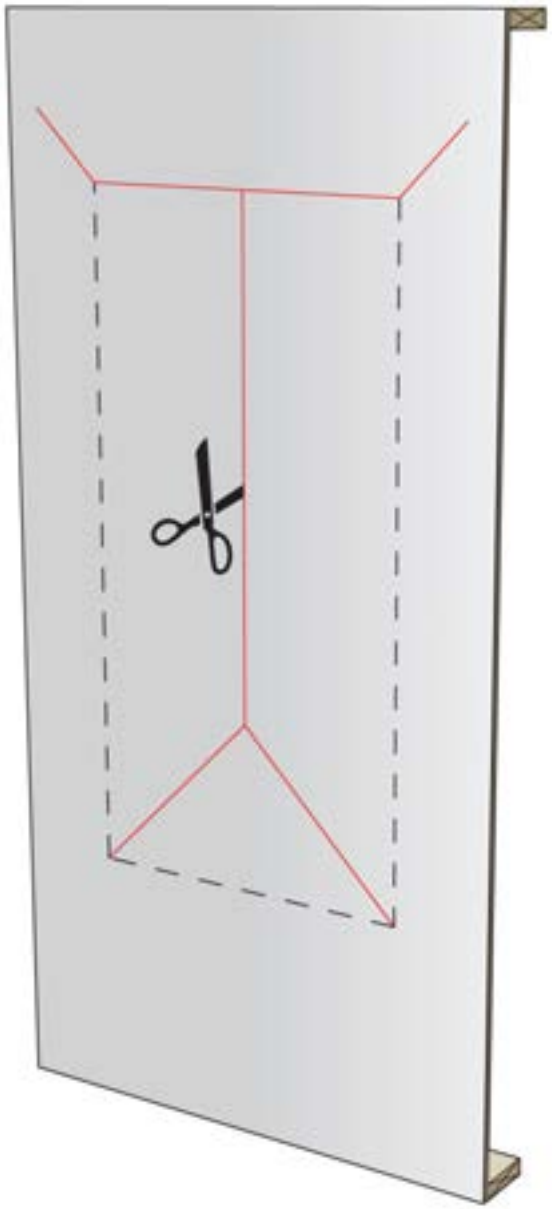

Outer seal sees water but not pressure; no pressure difference across this seal, therefore no rain entry
Key seal is interior seal as it takes maximum wind load but it does not see water
Pressure in chamber is same as pressure outside on face of assembly
Entire wind pressure taken here
Air enters and pressurizes chamber
Pressure chamber

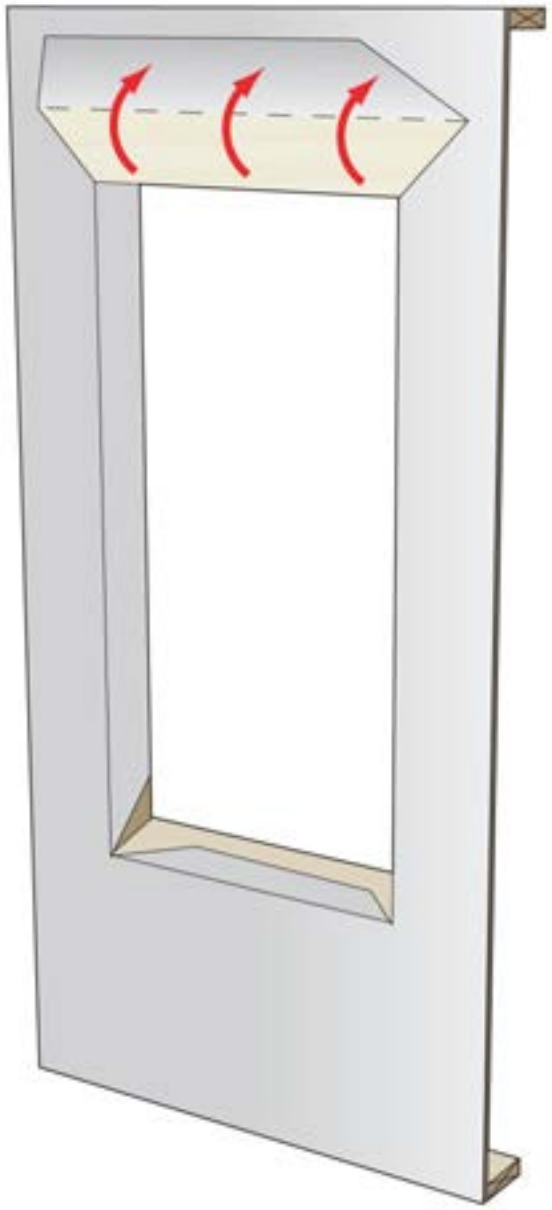

Pressure moderated chamber
Interior air seal
Beveled wood siding
Adhesive -backed sill flashing
Housewrap
Sheathing

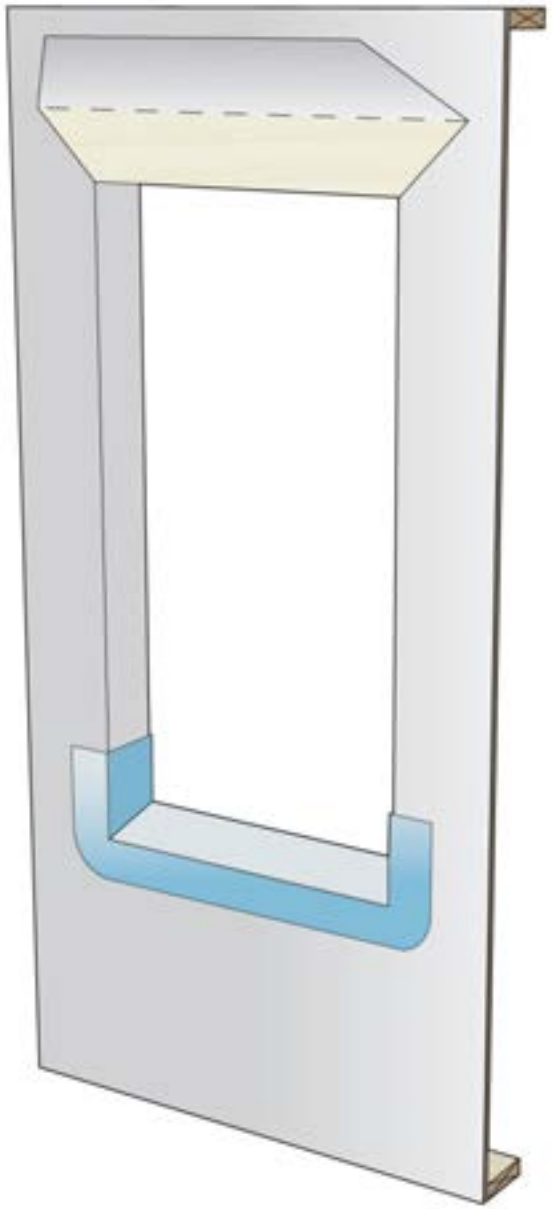


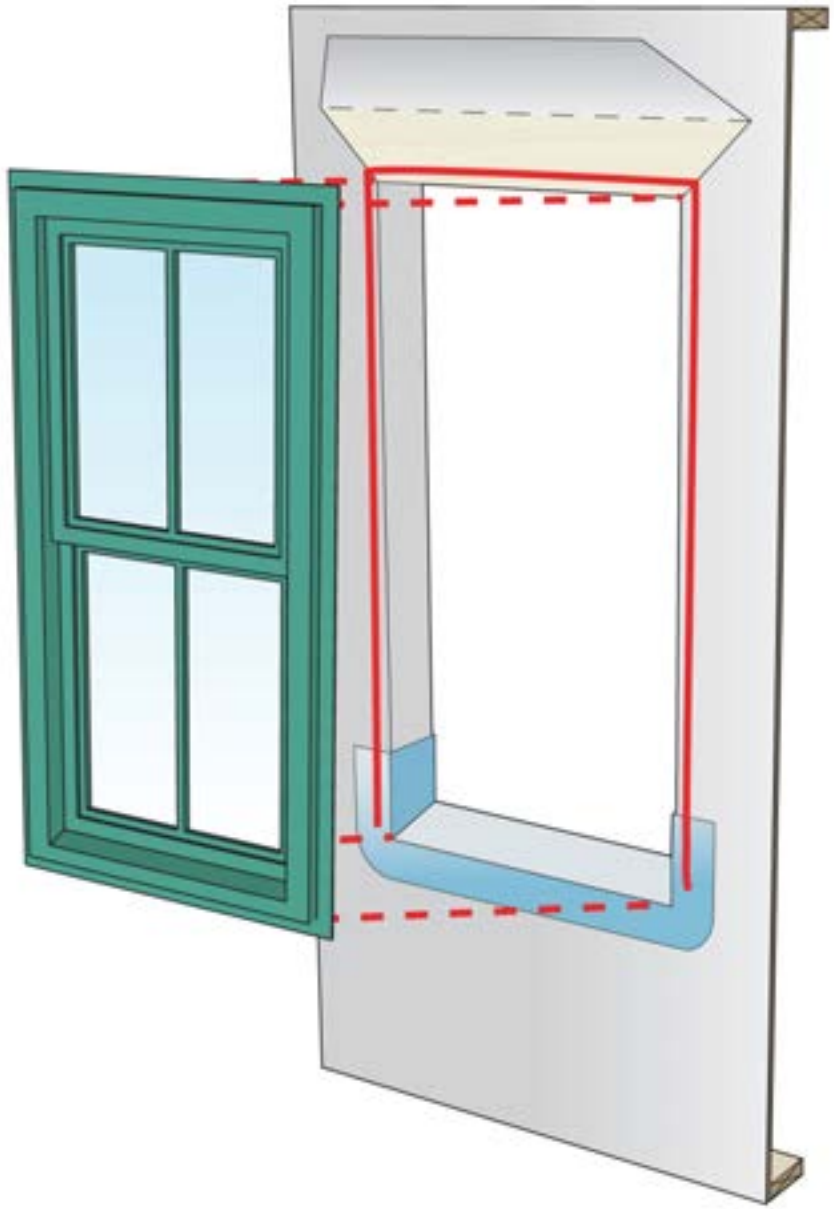


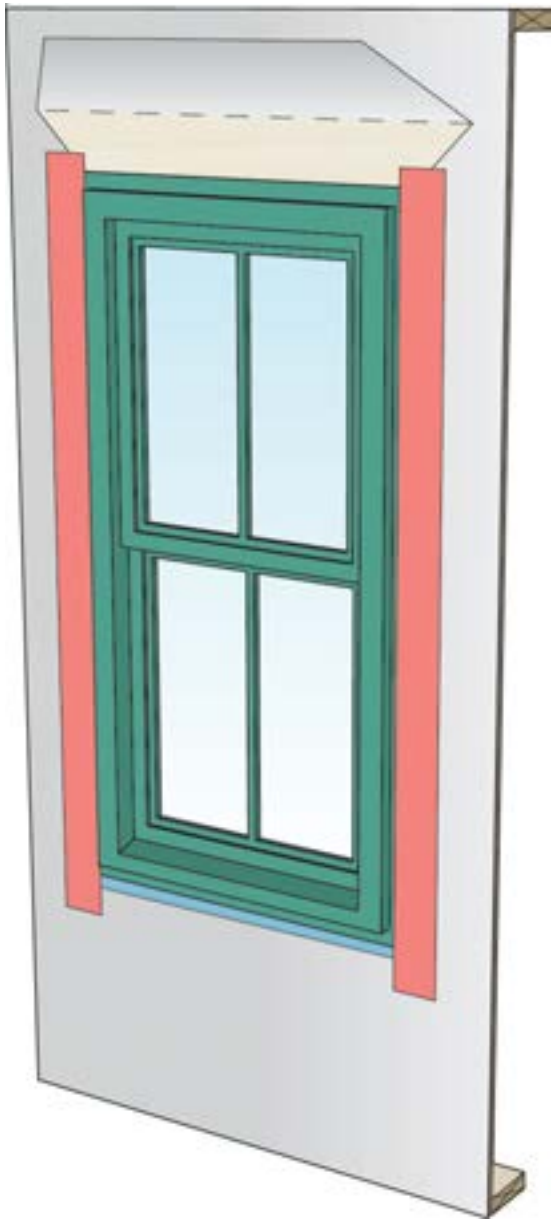

Intent of sealant is to limit this lateral flow of water between sheathing and building wrap
Flashing tape
Sealant “bedding” joint
Building wrap “wrapped” into opening

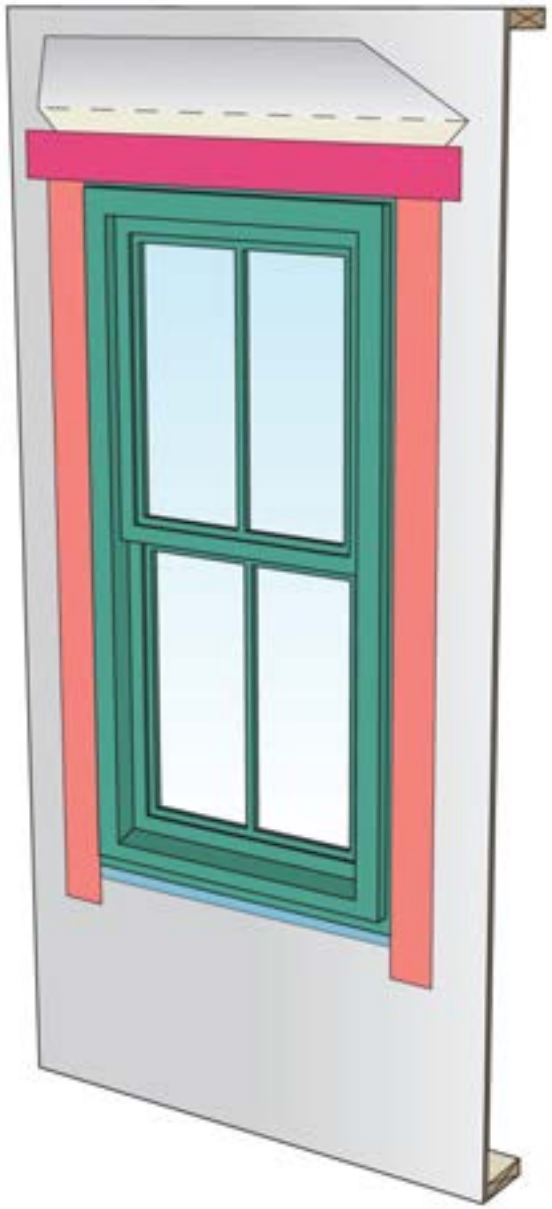


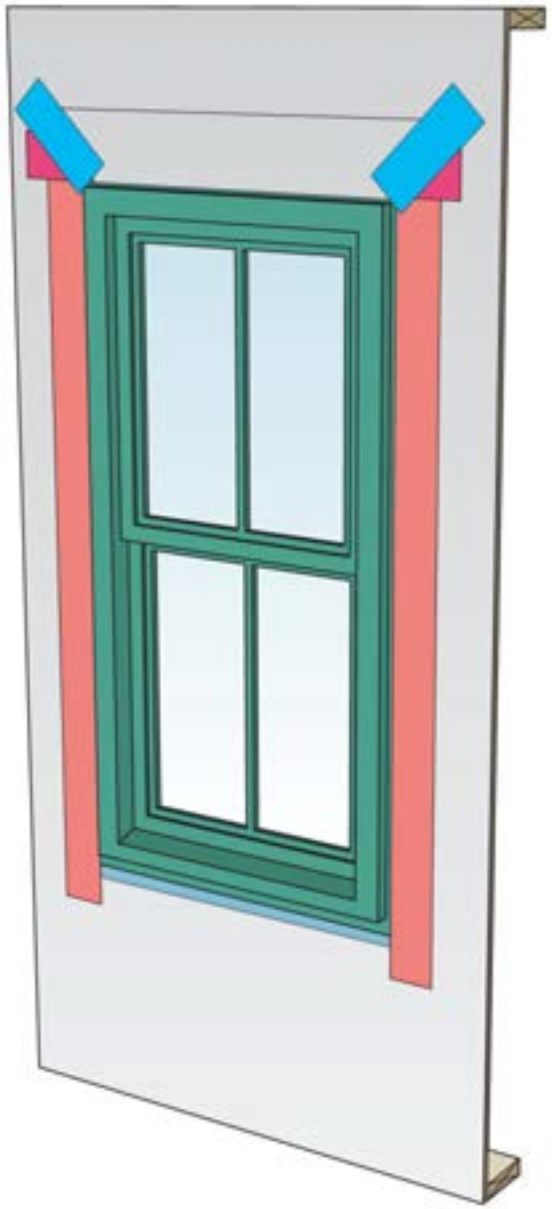


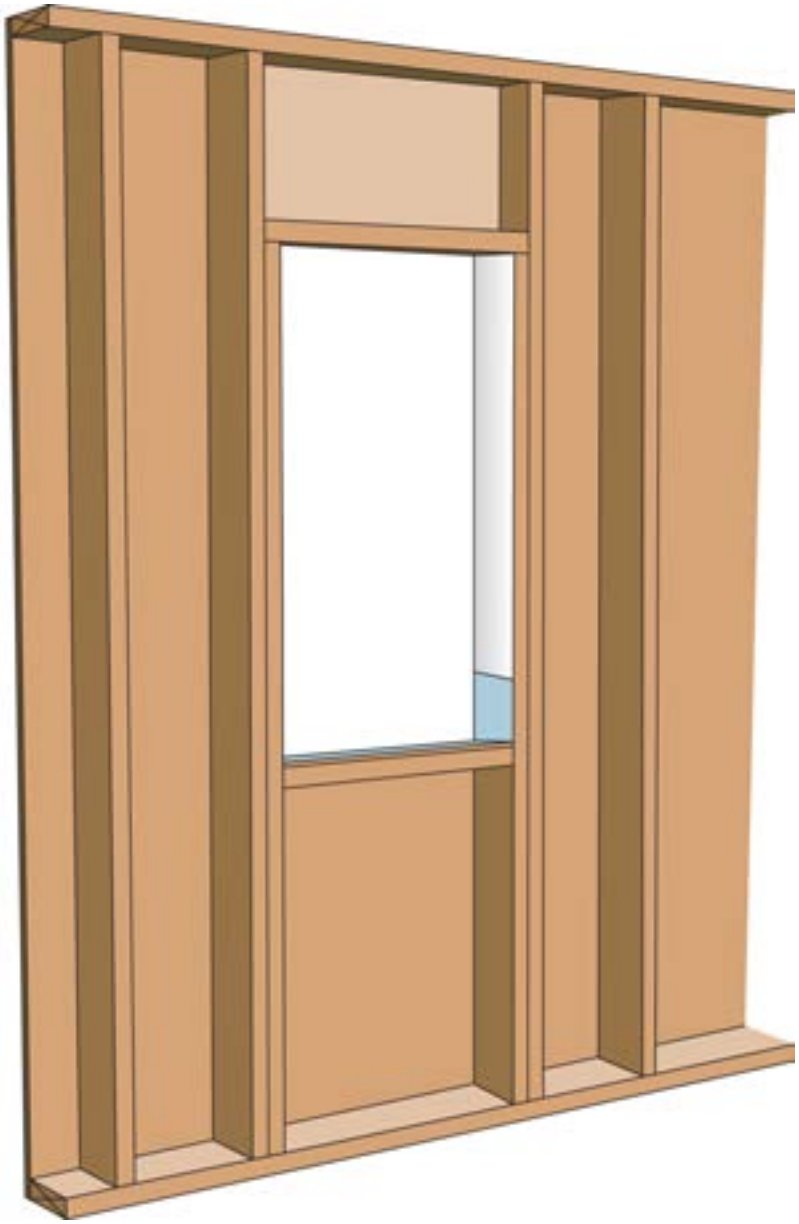


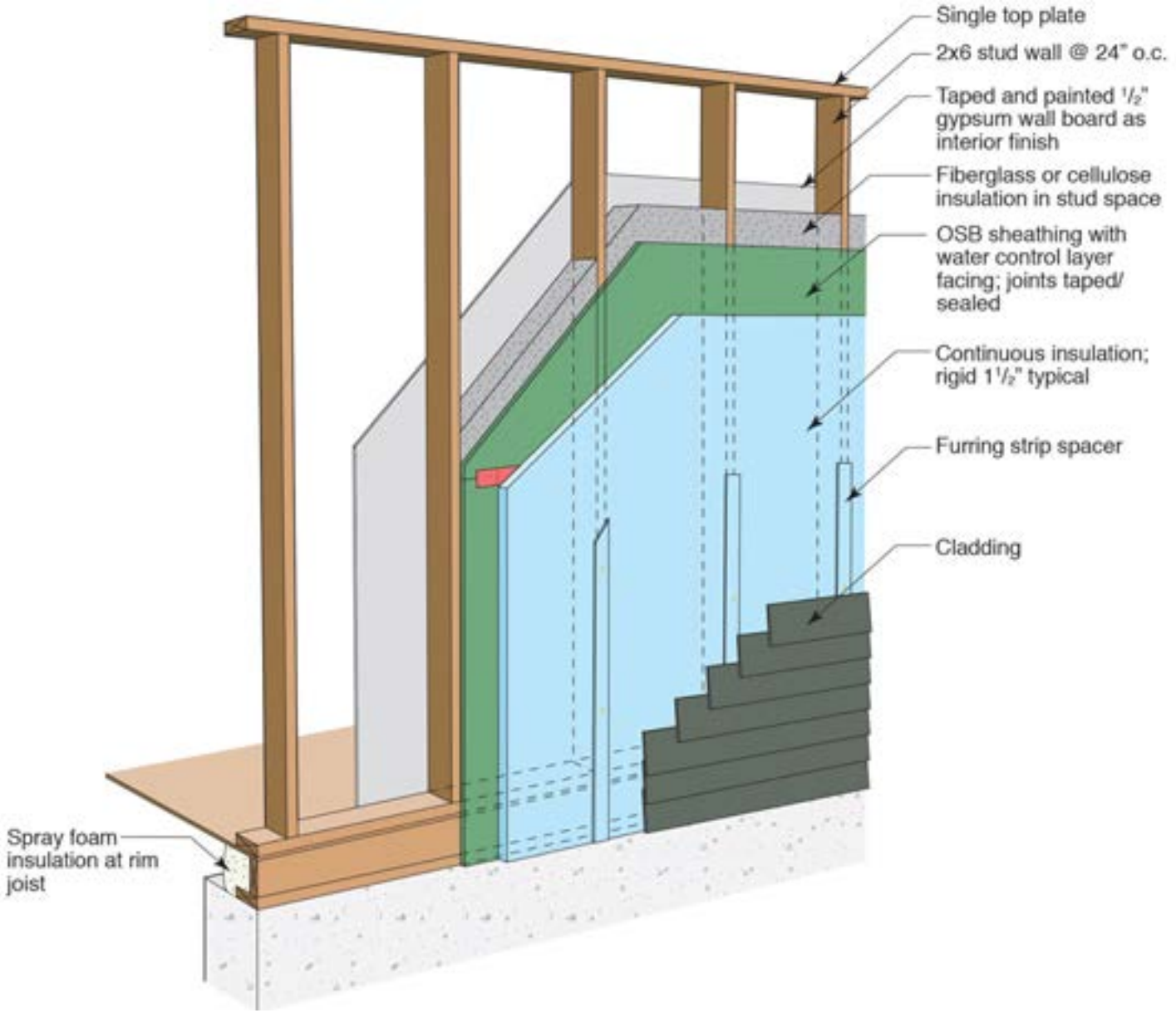


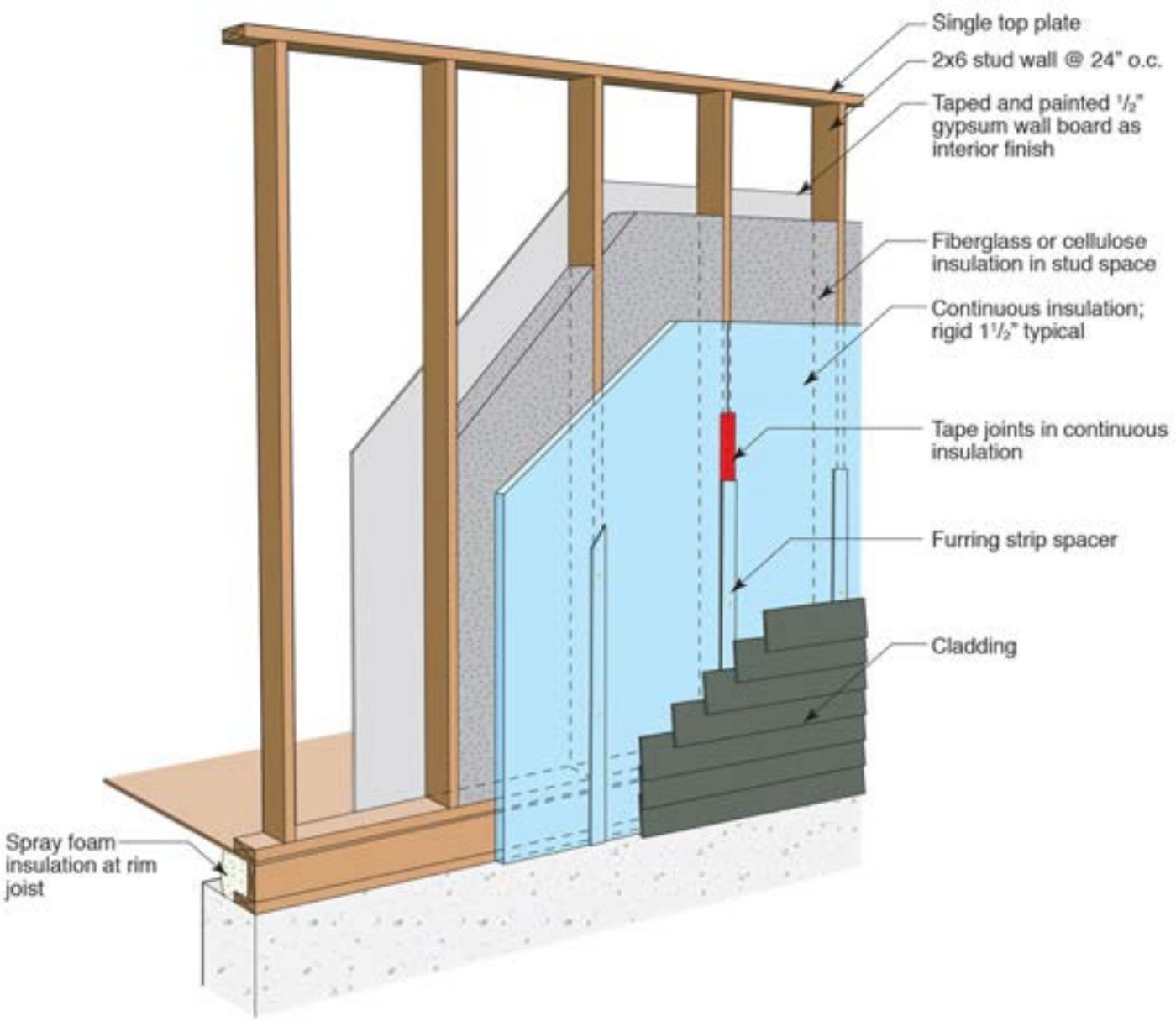









Single top plate
2x6 stud wall @ 24" o.c.
Taped and painted 1/2" gypsum wall board as interior finish
Fiberglass or cellulose insulation in stud space
OSB sheathing with water control layer facing; joints taped/ sealed
Continuous insulation; rigid 1 1/2" typical
Furring strip spacer
Cladding
Spray foam insulation at rim joist


Single top plate
2x6 stud wall @ 24" o.c.
Taped and painted ½" gypsum wall board as interior finish
Fiberglass or cellulose insulation in stud space
Continuous insulation; rigid 1½" typical
Tape joints in continuous insulation
Furring strip spacer
Cladding
Spray foam insulation at rim joist

Where Is The Water Control Layer?

Where Is The Water Control Layer?

Behind The Continuous Insulation?

Or The Face of The Continuous Insulation?

Where Is The Water Control Layer?

Behind The Continuous Insulation?

Or The Face of The Continuous Insulation?

Where Is The Window?

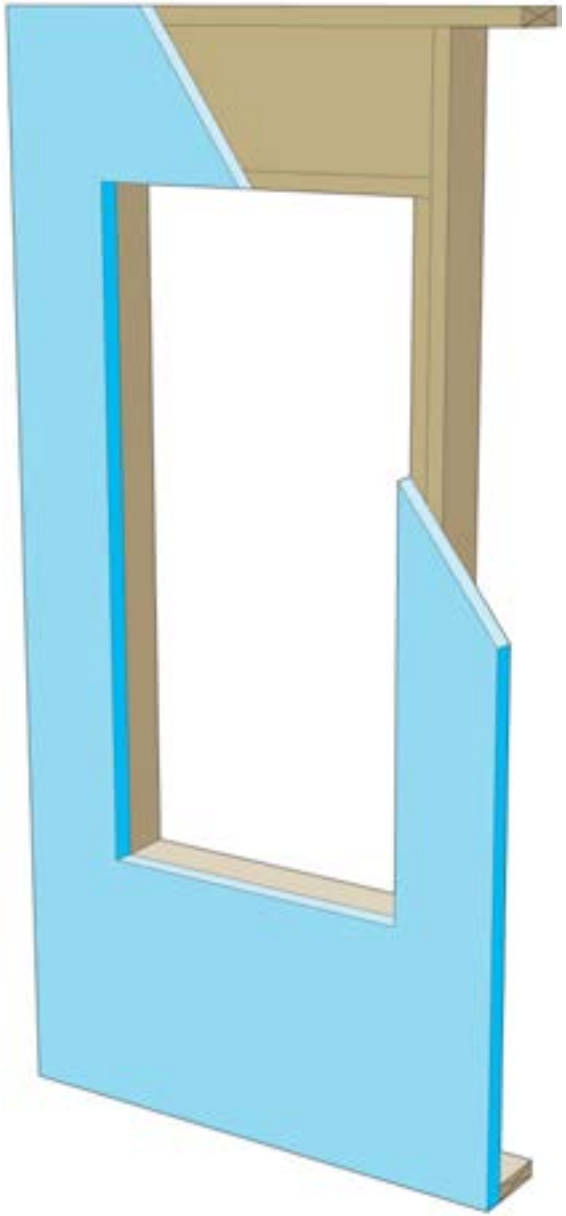
Where Is The Water Control Layer?

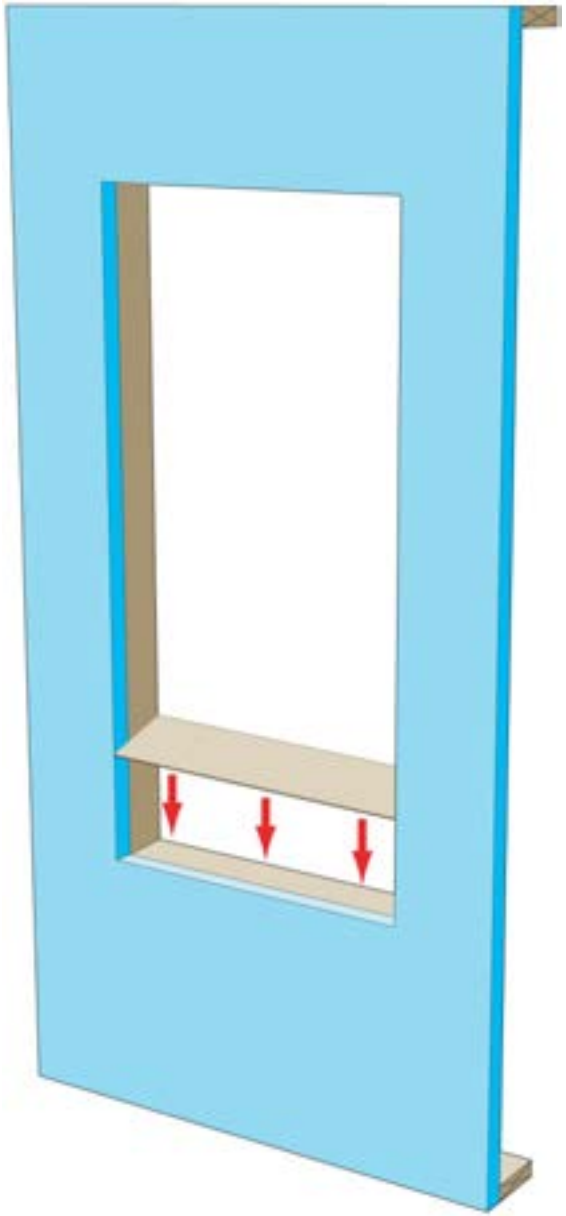
Behind The Continuous Insulation?

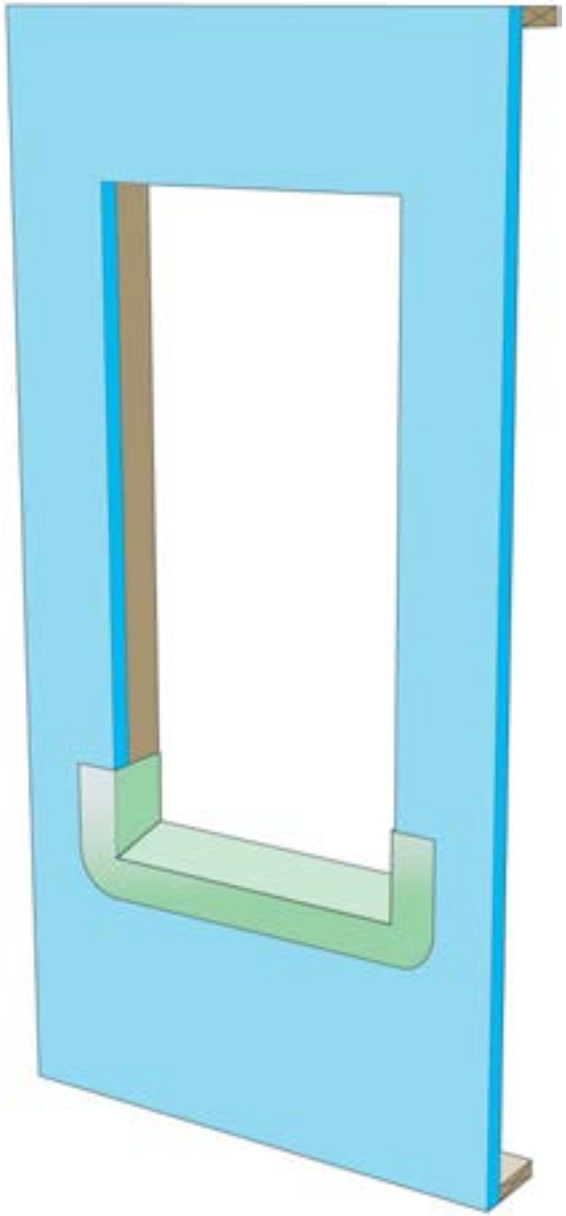
Or The Face of The Continuous Insulation?

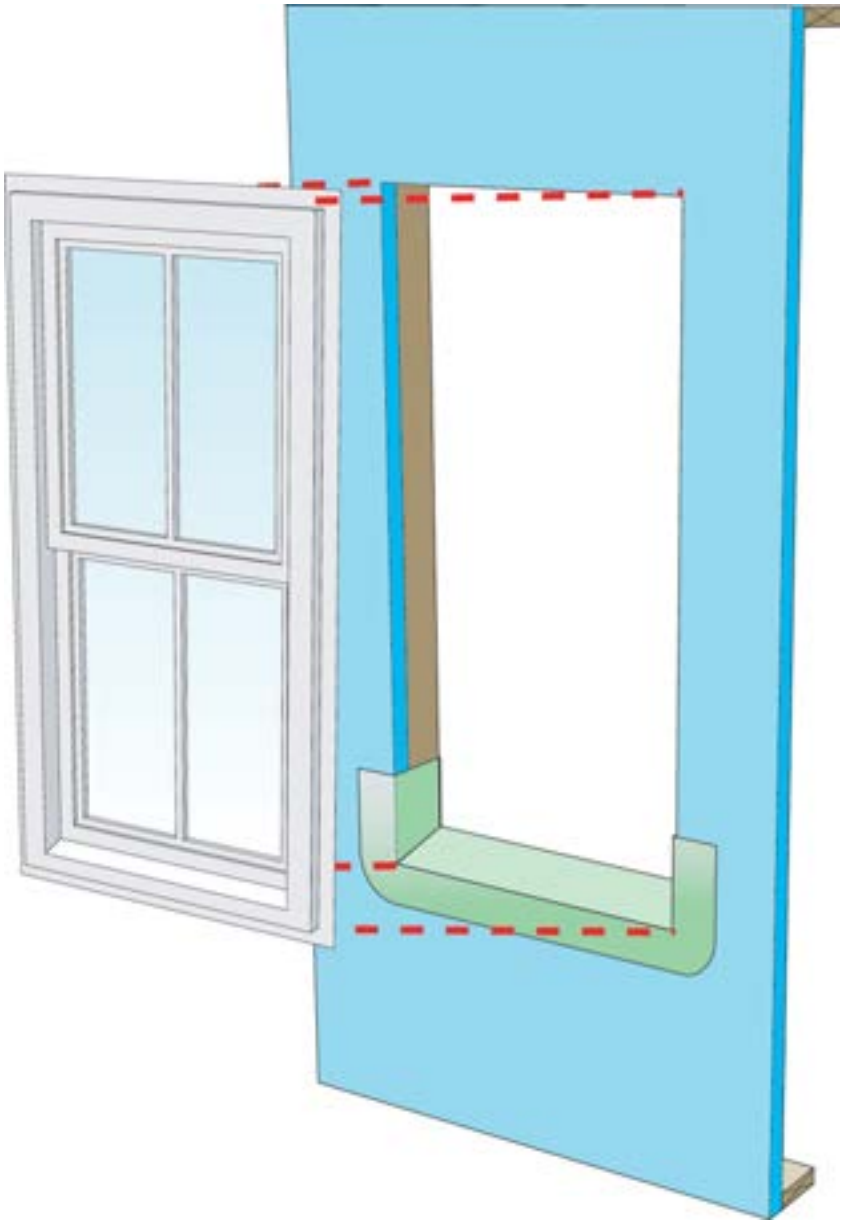
Where Is The Window?

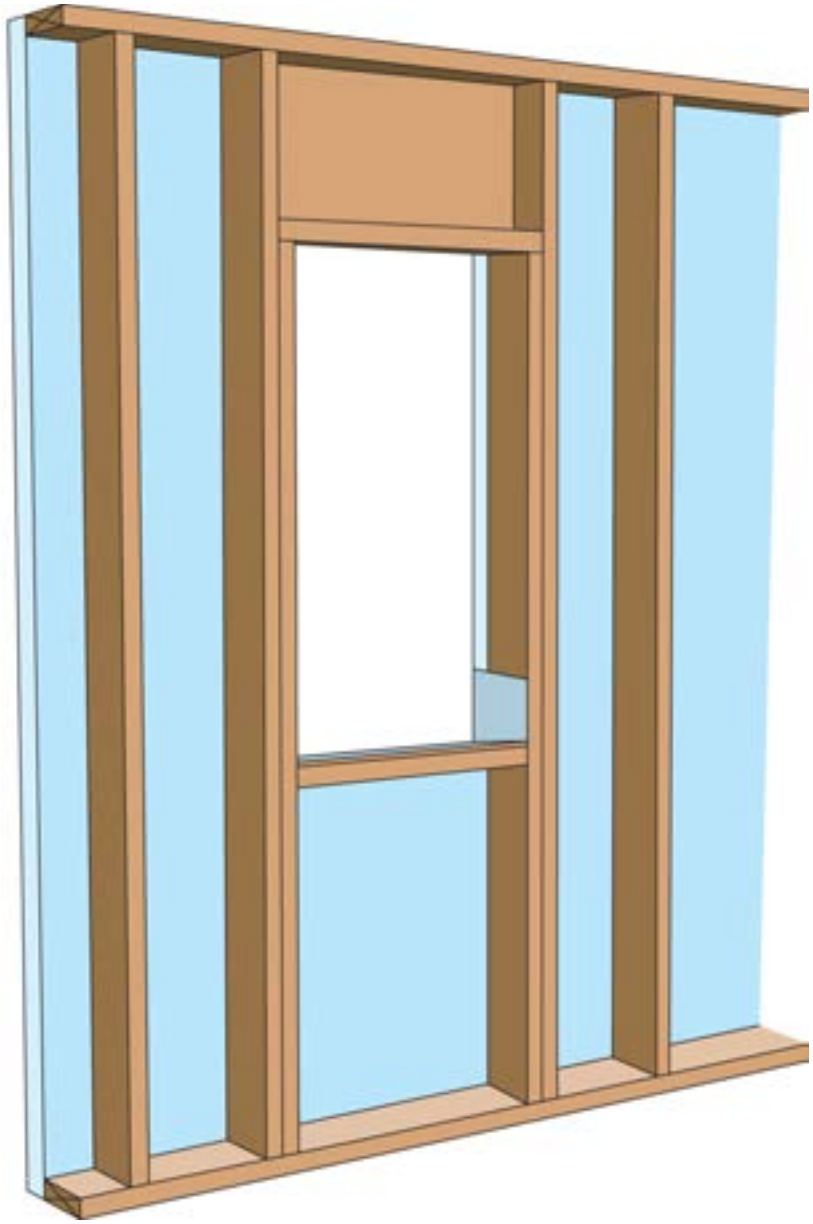
Is It An Innie Or Outie Or Tweeny?

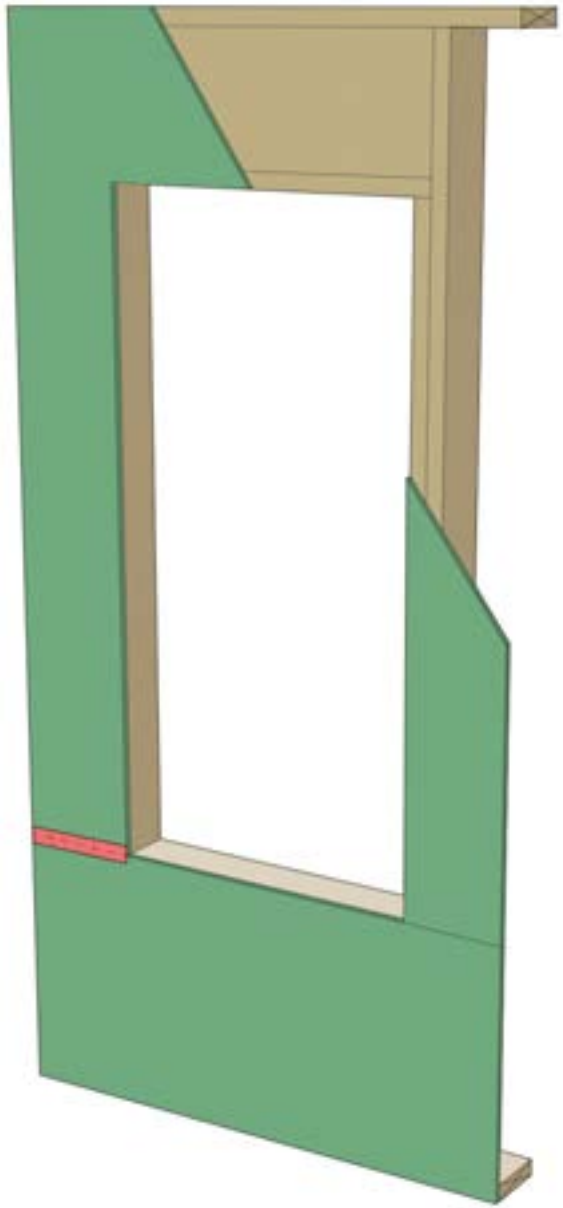


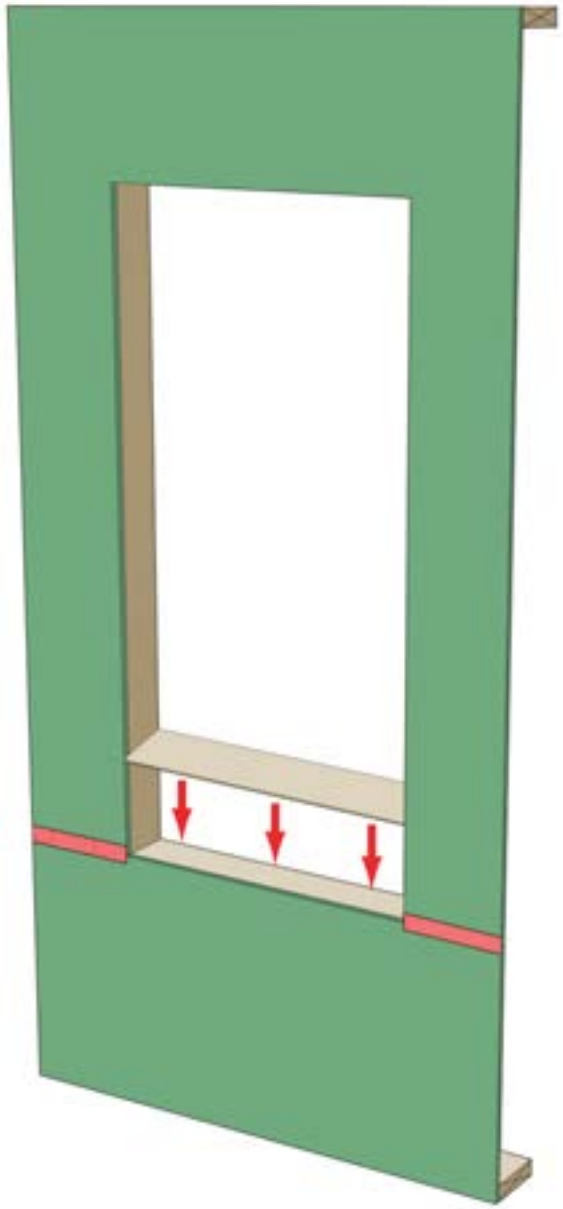


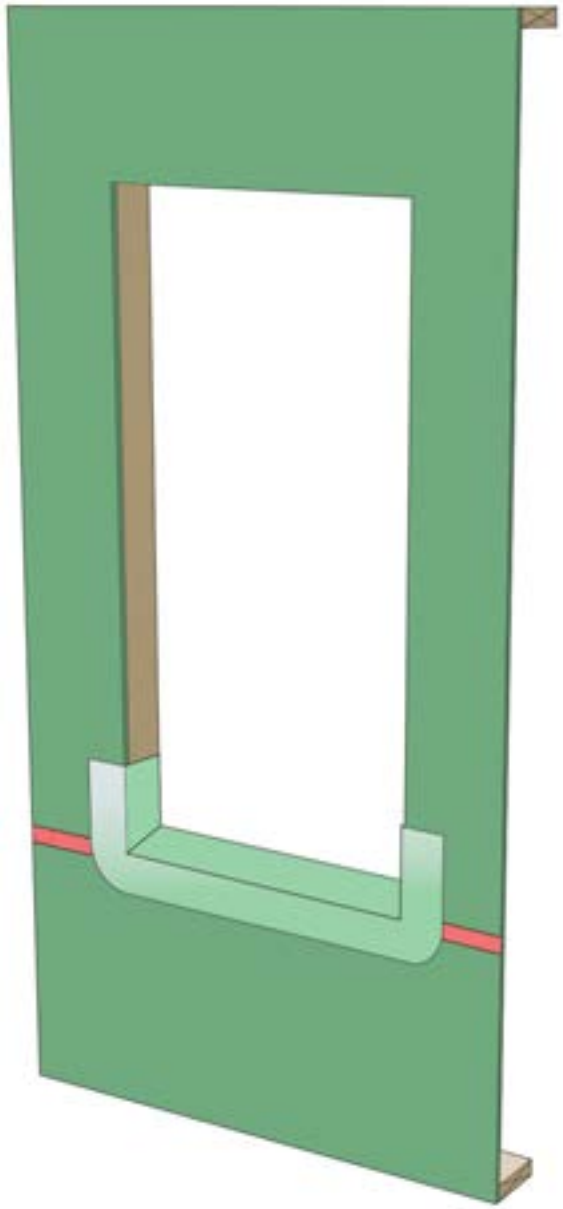


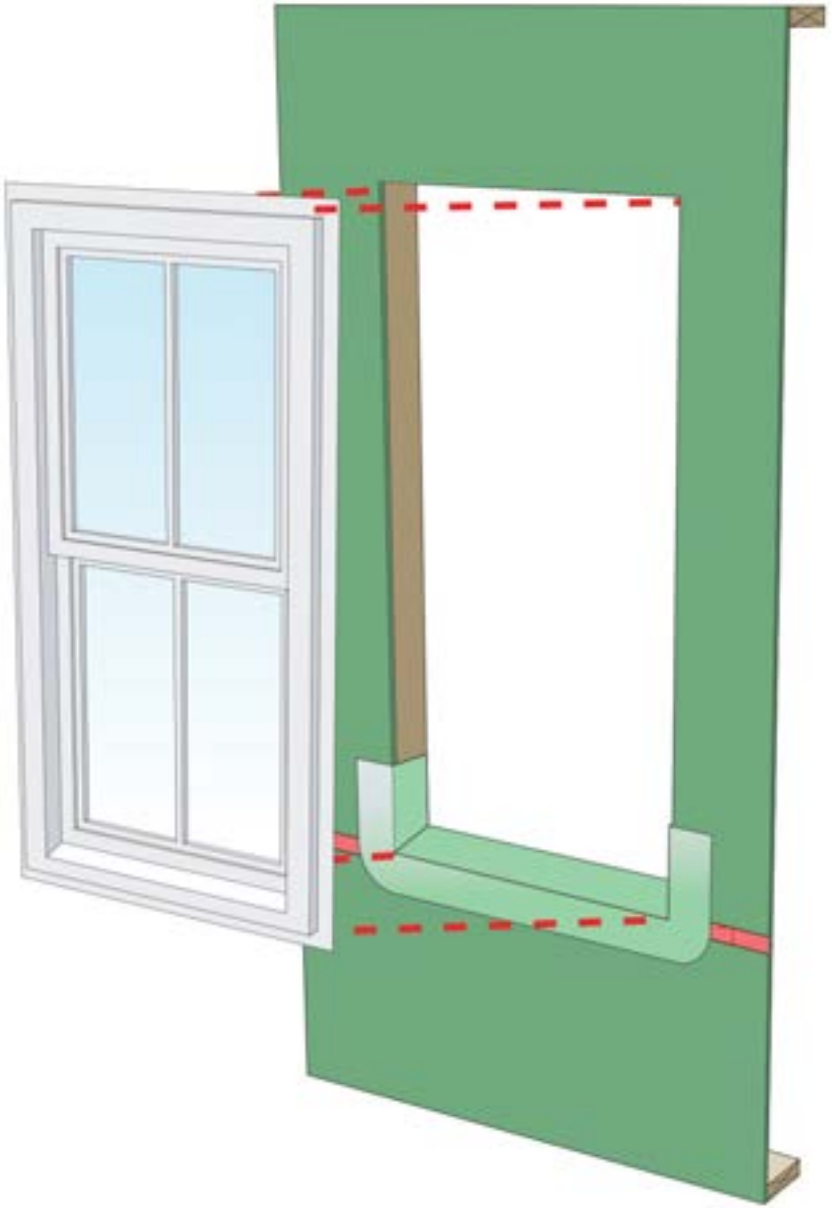


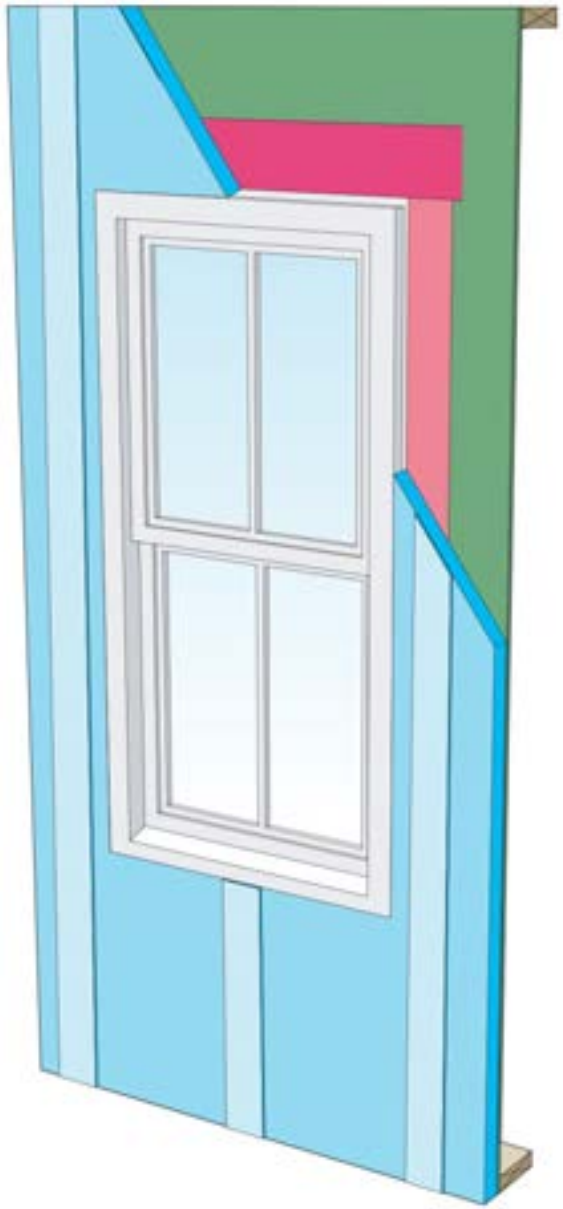


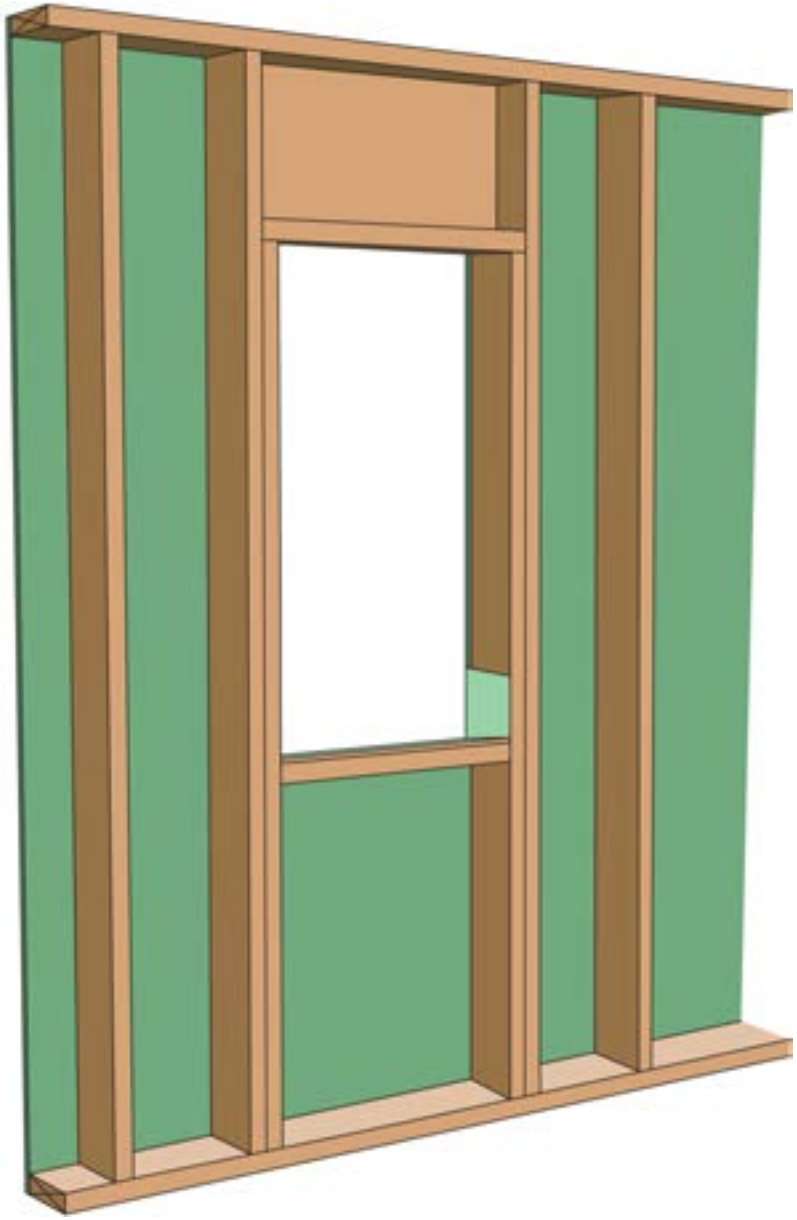


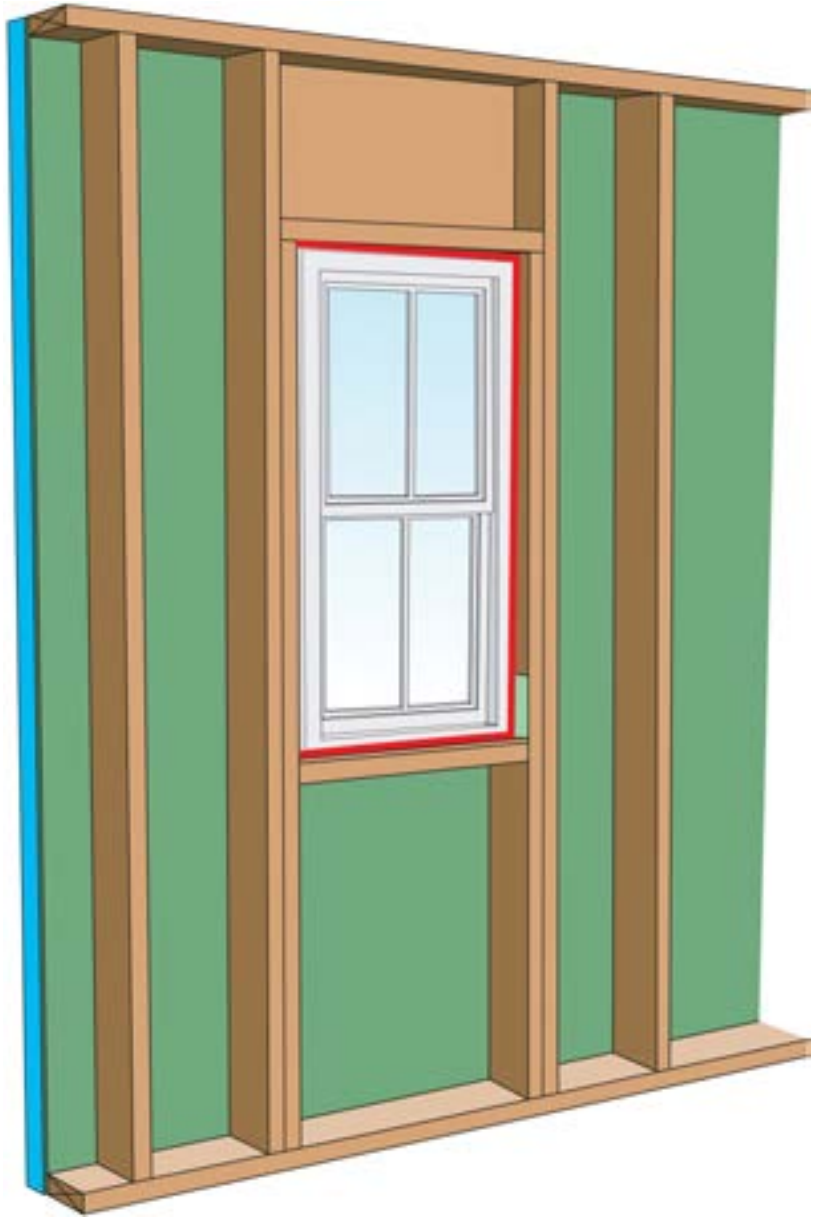


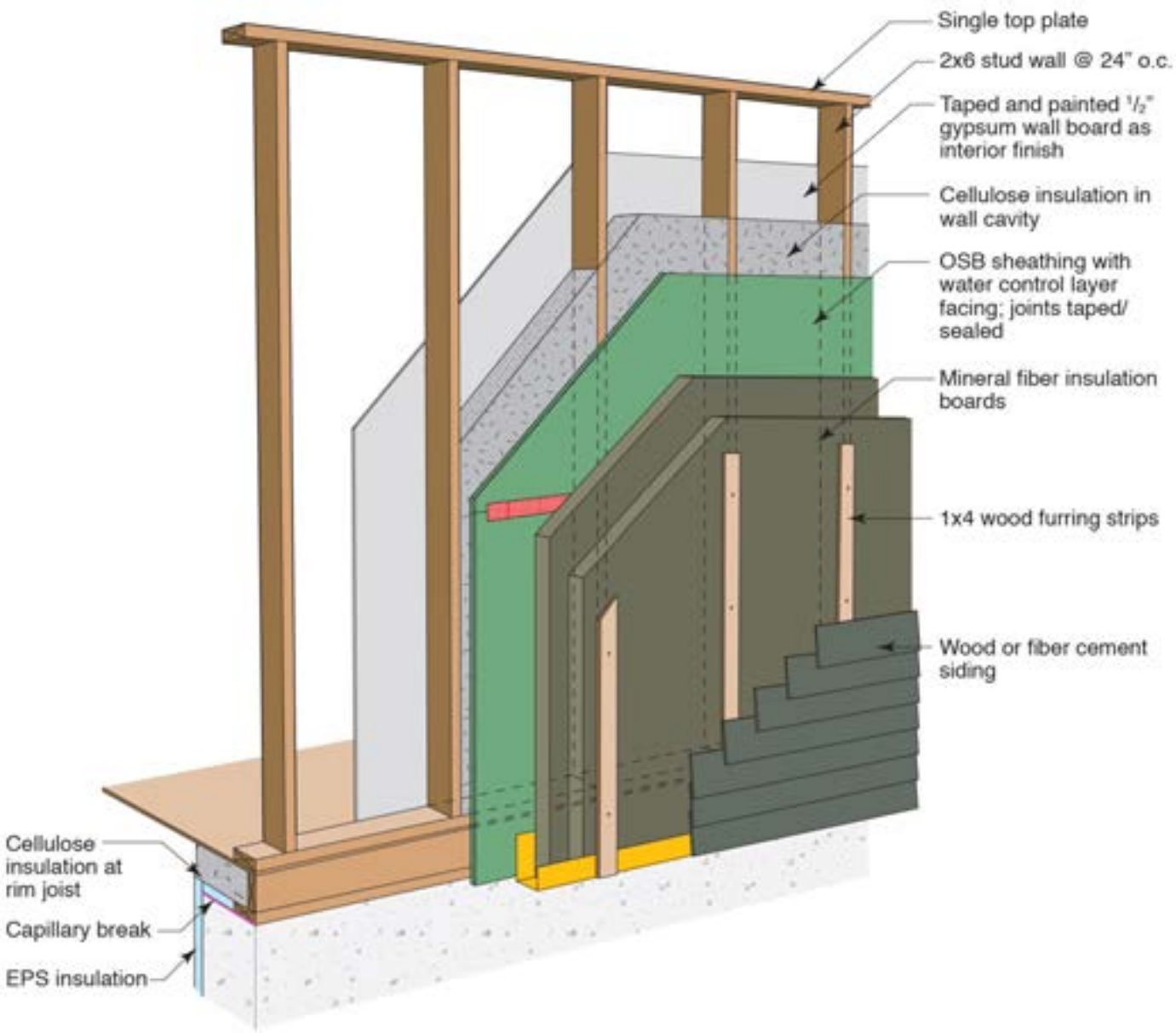


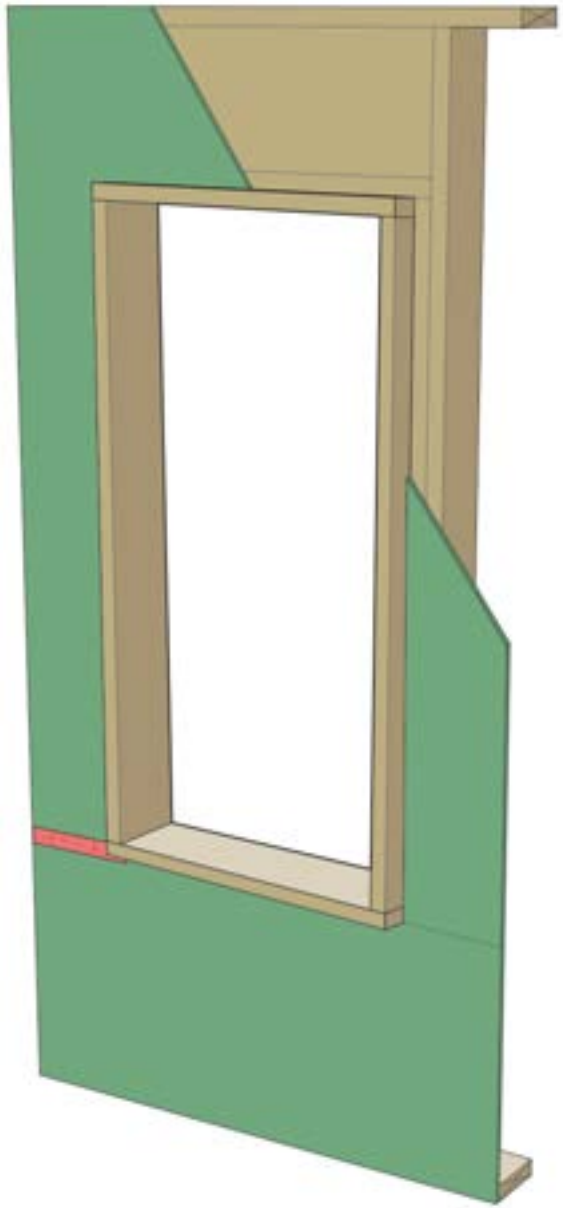


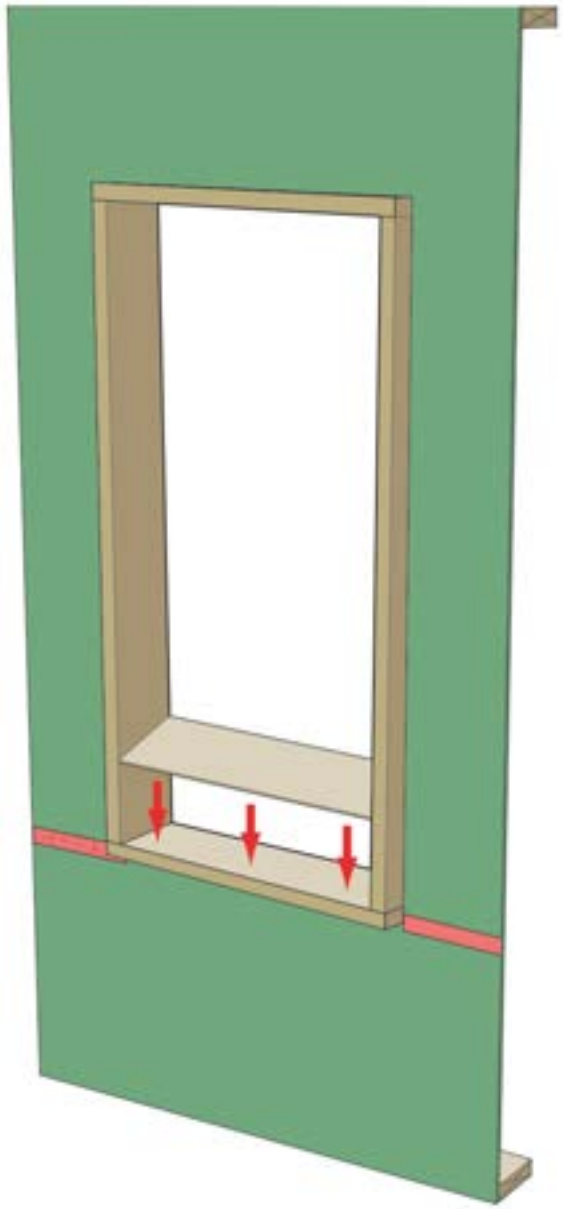


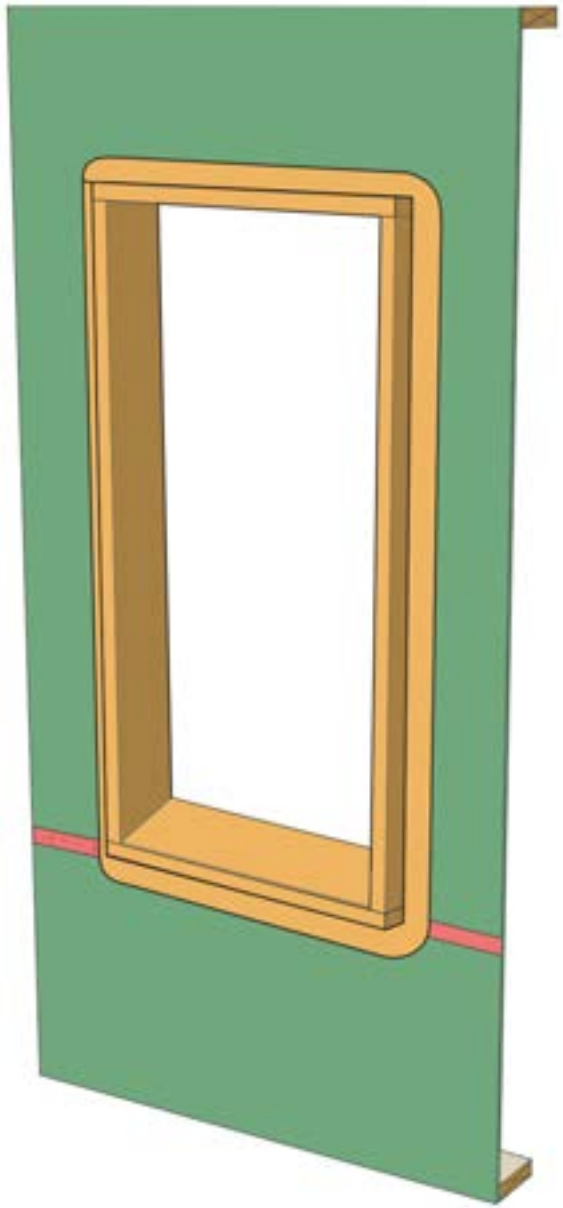


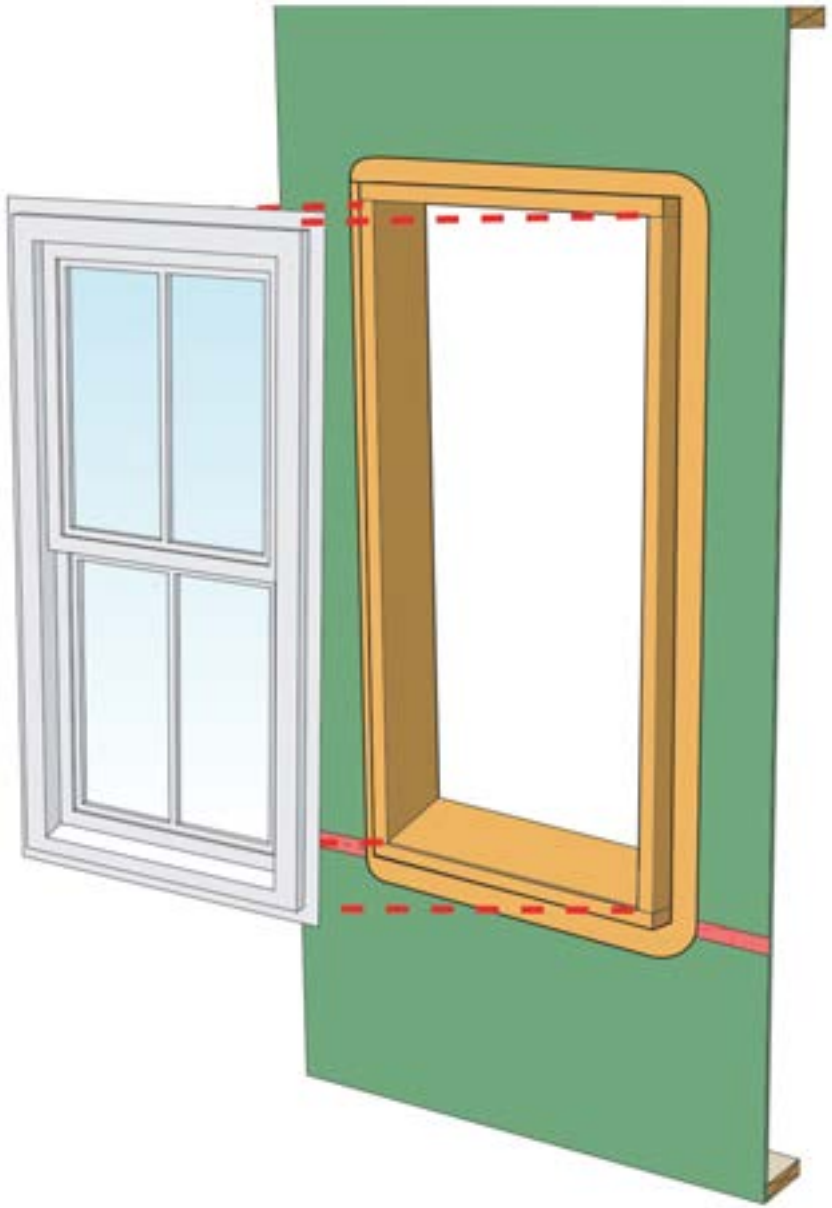


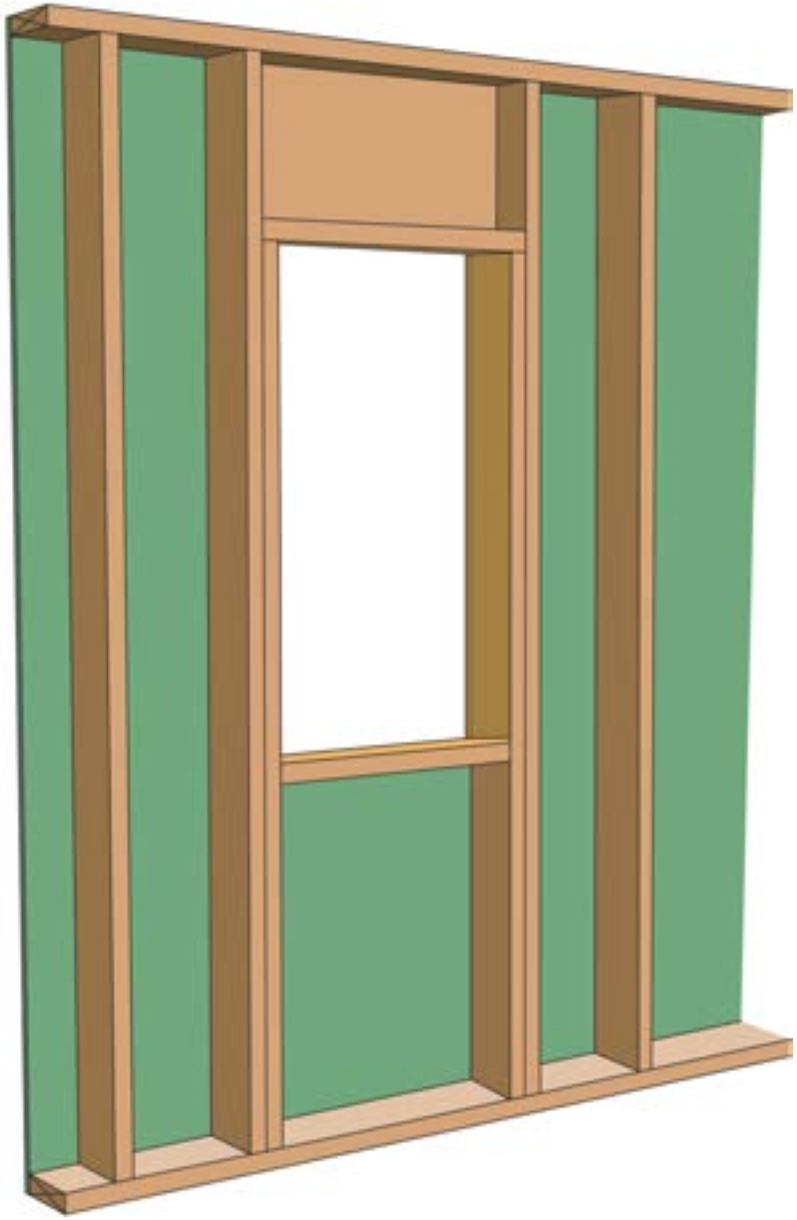

Single top plate
2x6 stud wall @ 24" o.c.
Taped and painted ½" gypsum wall board as interior finish
Cellulose insulation in wall cavity
OSB sheathing with water control layer facing; joints taped/ sealed
Mineral fiber insulation boards
1x4 wood furring strips
Wood or fiber cement siding
Cellulose insulation at rim joist
Capillary break
EPS insulation

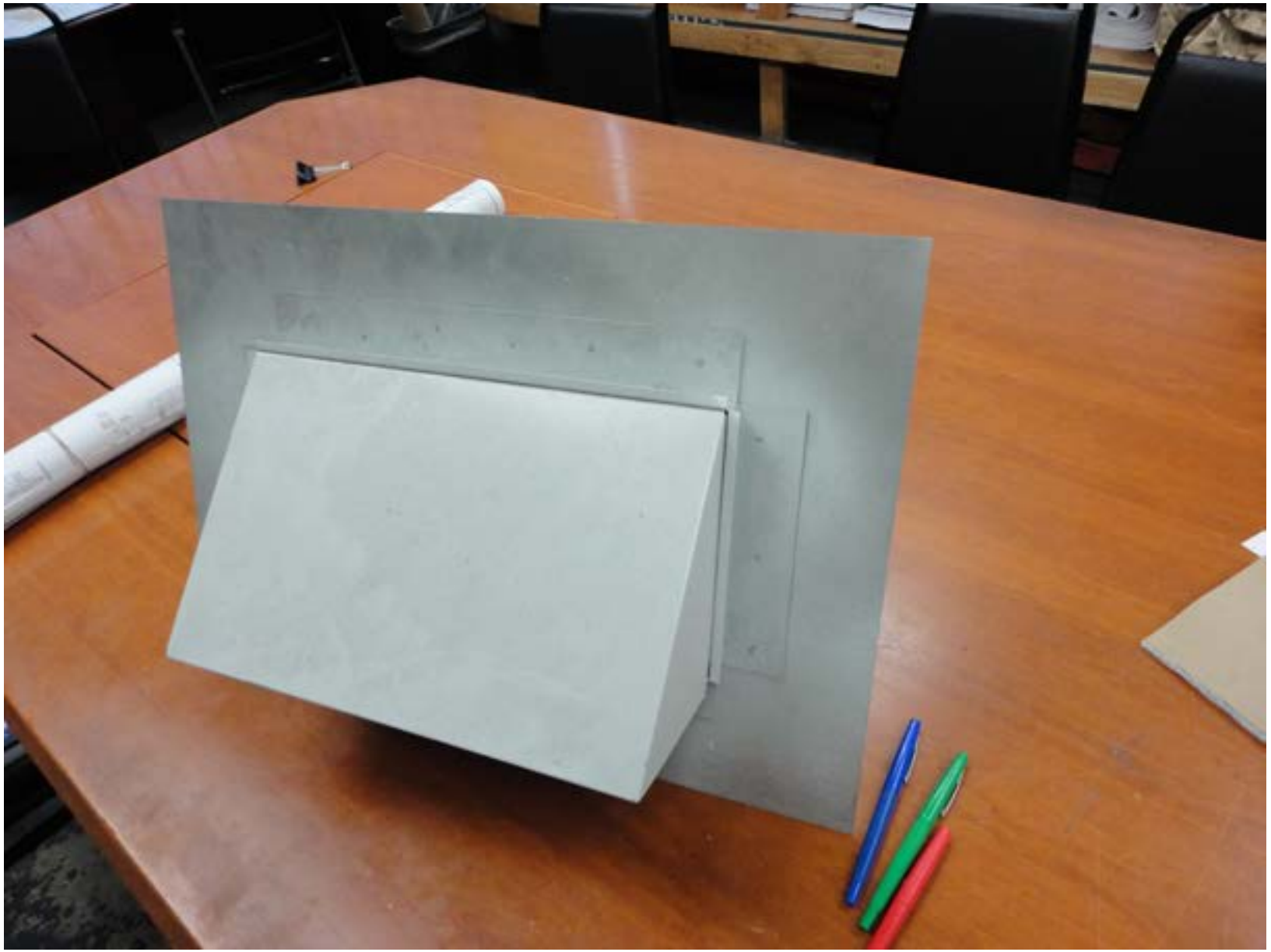










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THERMAX ci


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GROOVE
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TONGUE &
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