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

- 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

Arrhenius Equation

For Every 10 Degree K Rise

Reaction Rate Doubles

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

Damage Functions

Water

Heat

Ultra-violet Radiation

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

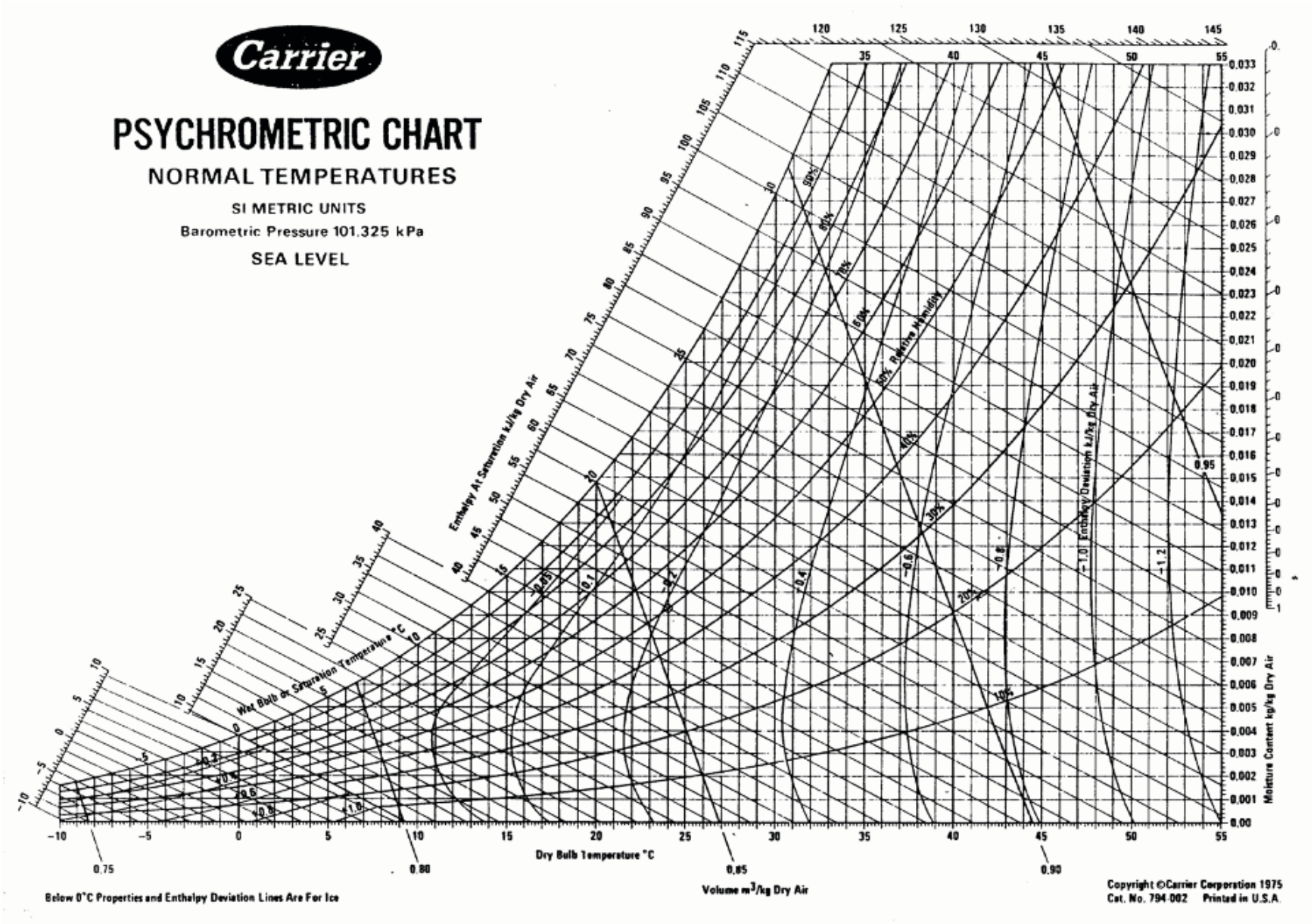
Moisture Flow Is From Warm To Cold

Moisture Flow Is From More To Less

Thermal Gradient – Thermal Diffusion

Concentration Gradient – Molecular Diffusion

Thermodynamic Potential


Carrier
PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101.325 kPa
SEA LEVEL
Wet Bulb or Saturation Temperature °C
Enthalpy At Saturation kJ/kg Dry Air
Dry Bulb Temperature °C
Moisture Content kg/kg Dry Air
50% Relative Humidity
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice
Volume m³/kg Dry Air
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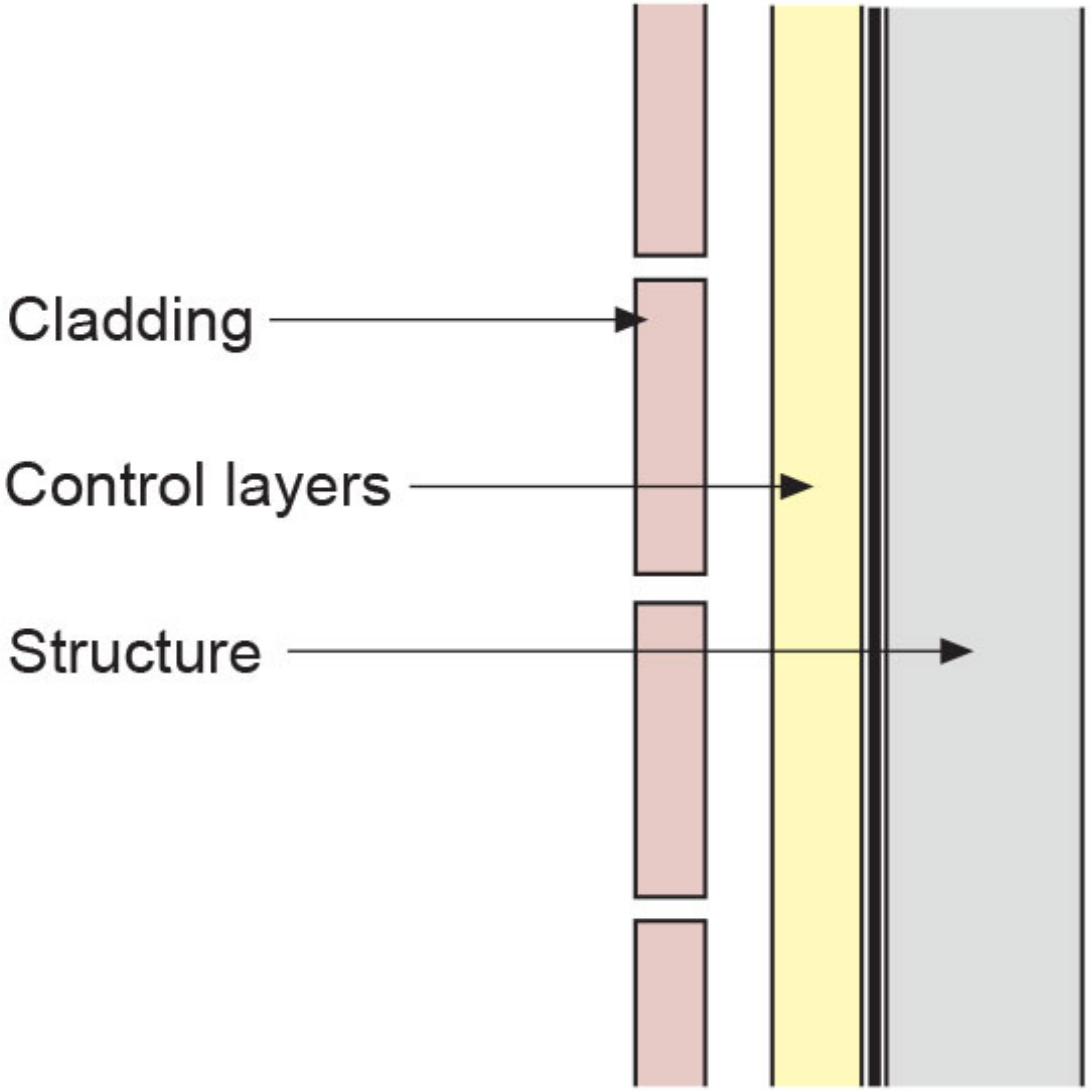
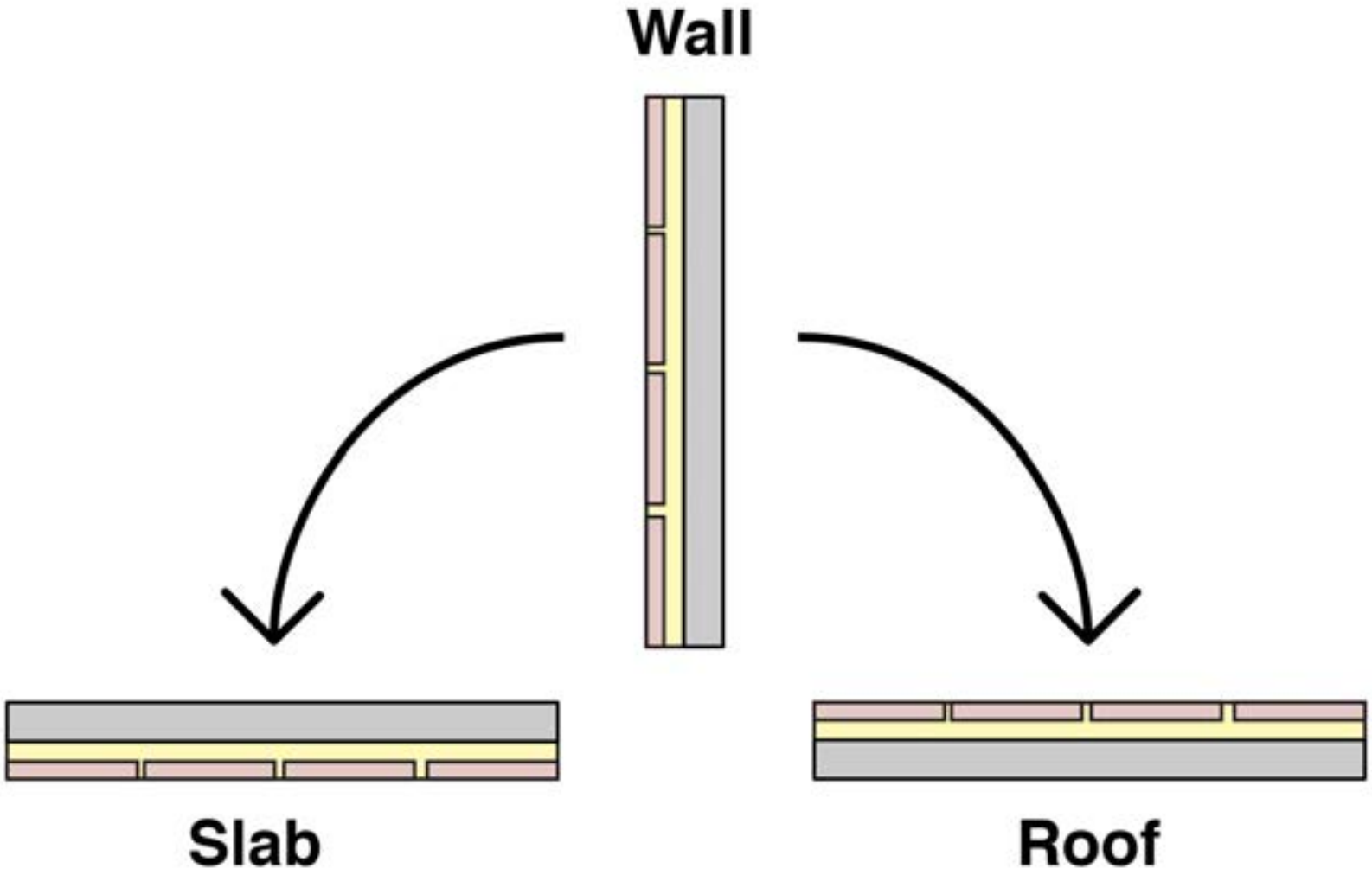
Water Control Layer

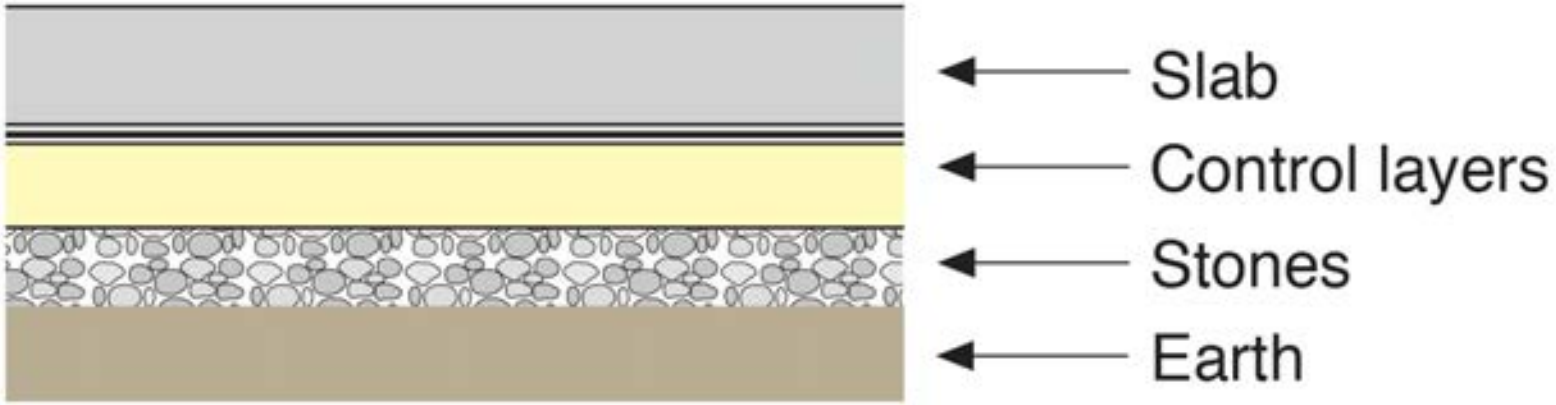
Air Control Layer

Vapor Control Layer

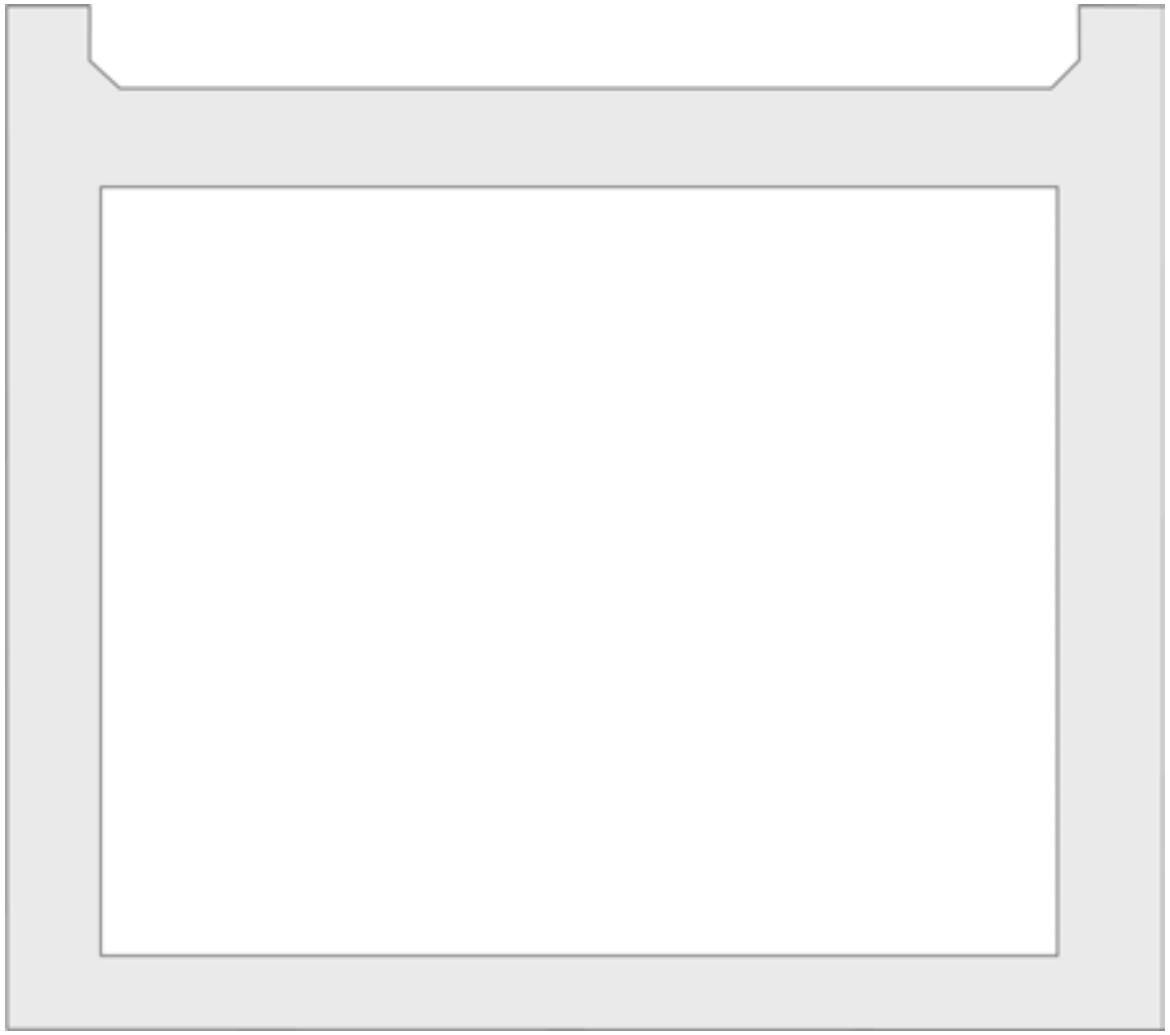
Thermal Control Layer


Cladding
Control layers
Structure

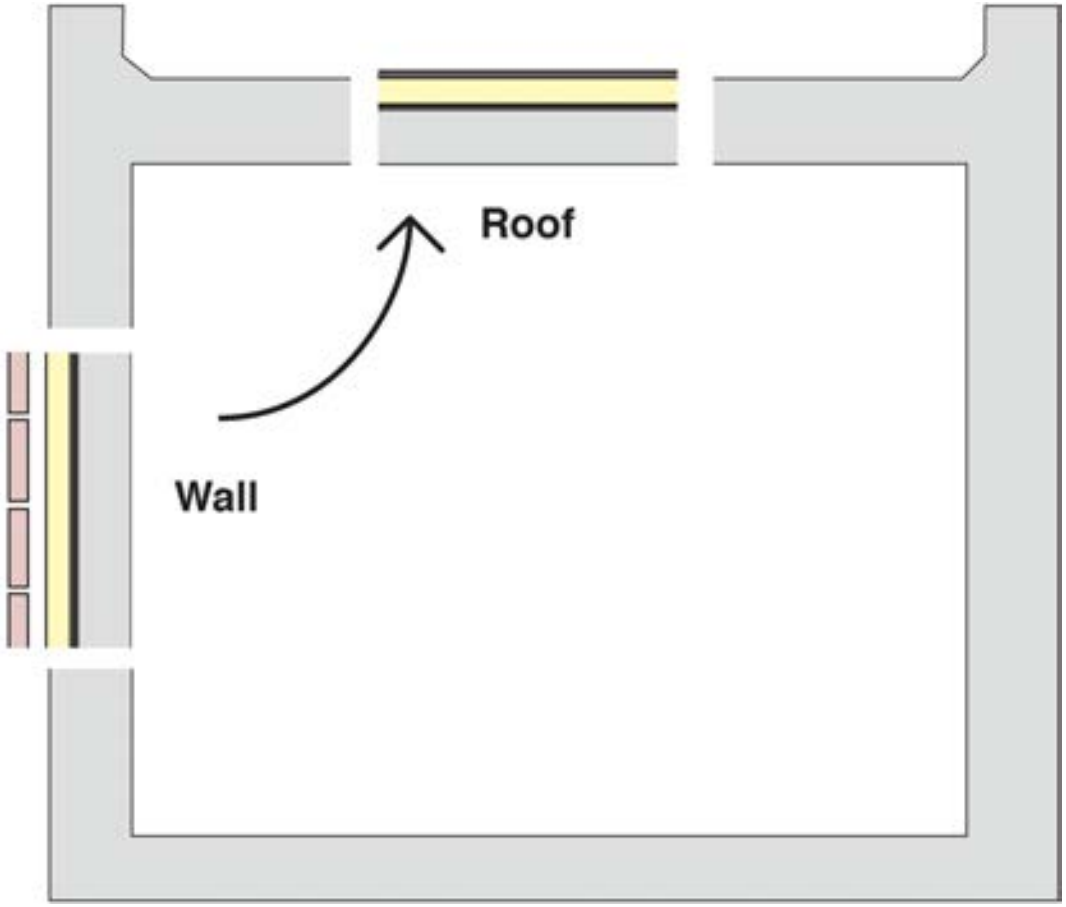

Wall
Slab
Roof

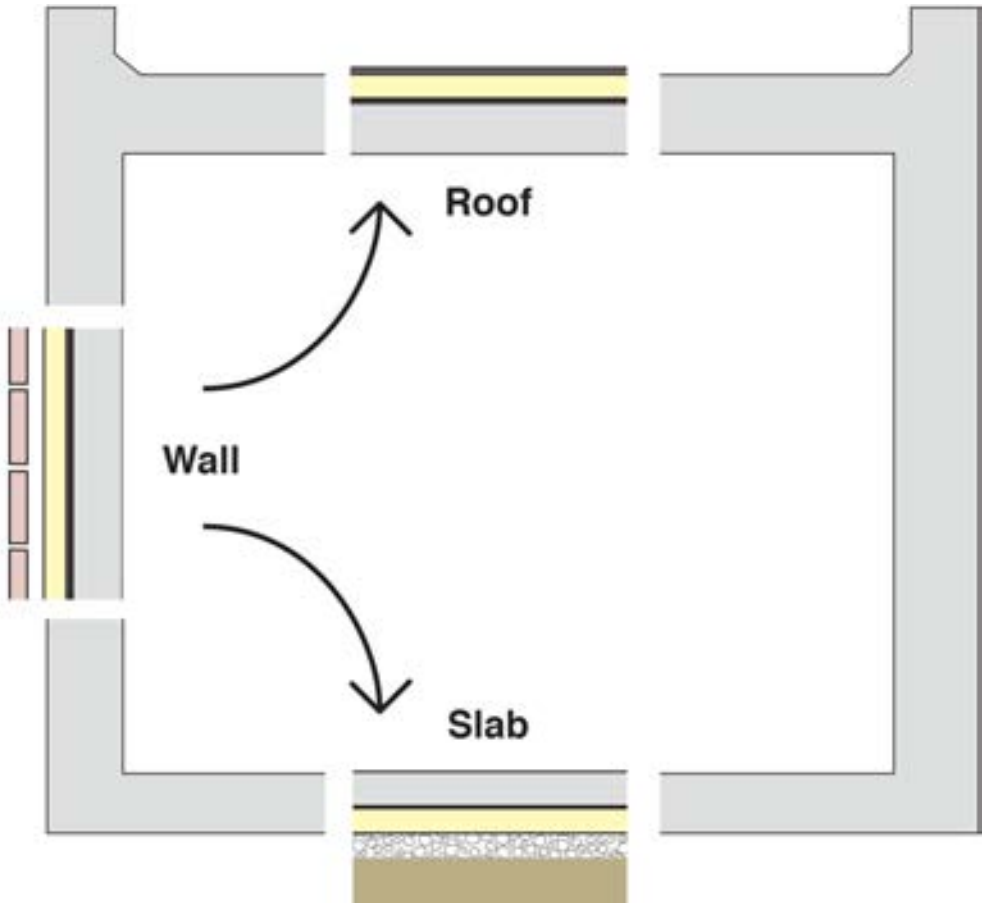

Slab
Control layers
Stones
Earth

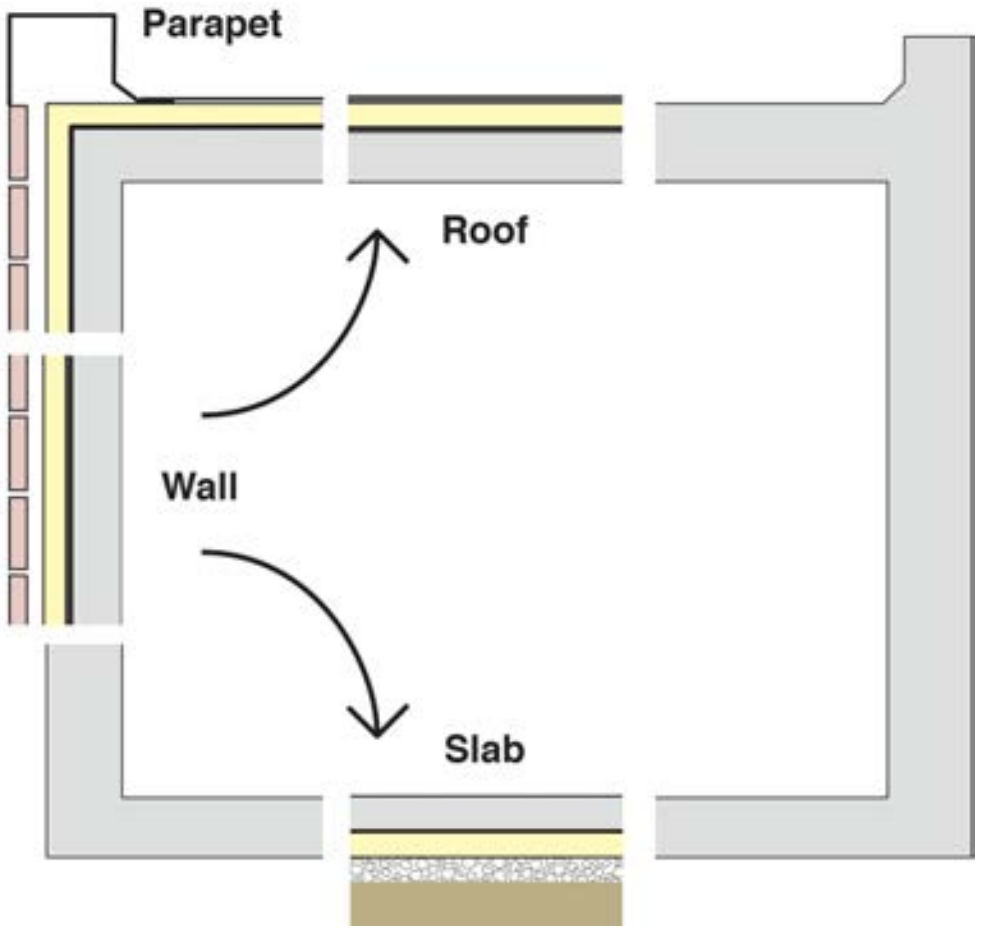

Control layer
Control layer
Roof structure

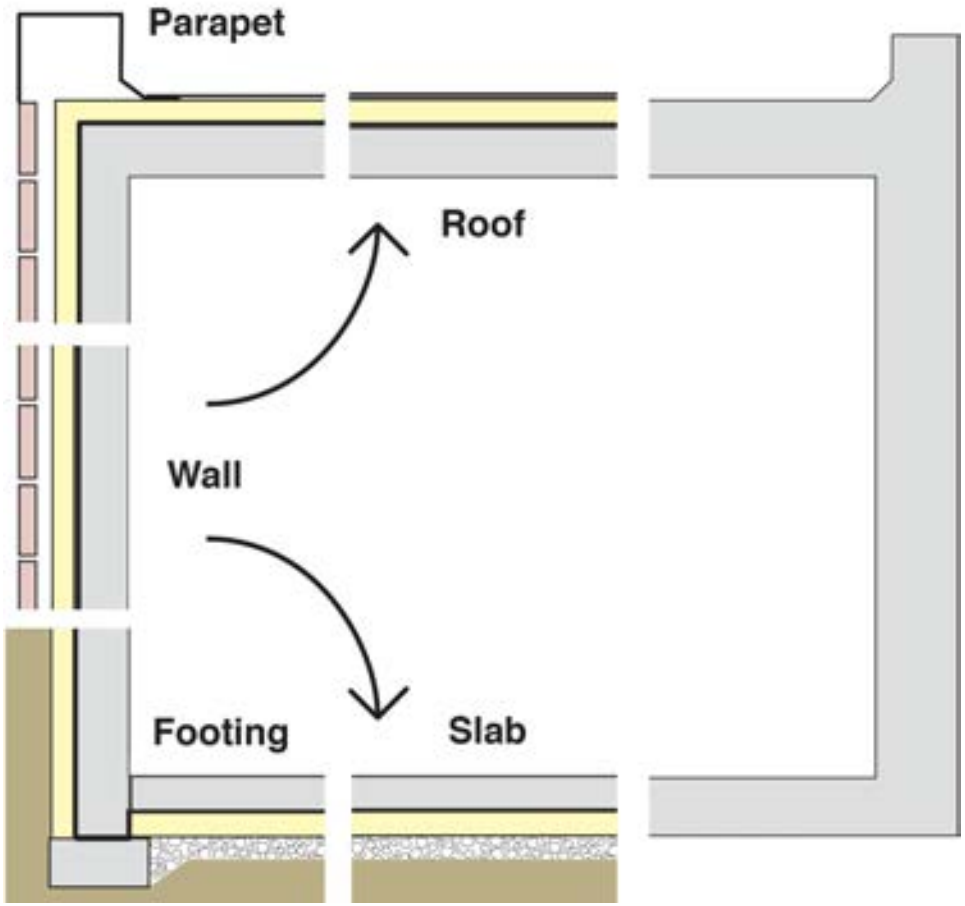


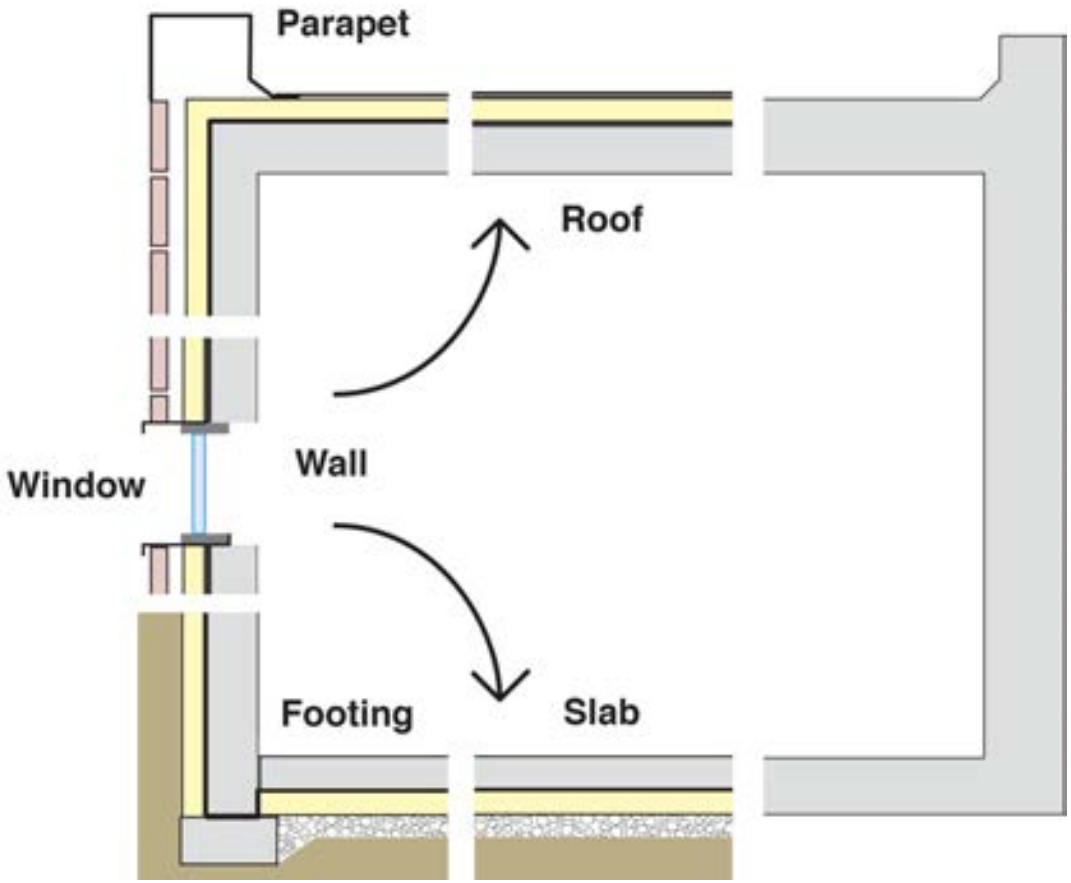

Wall

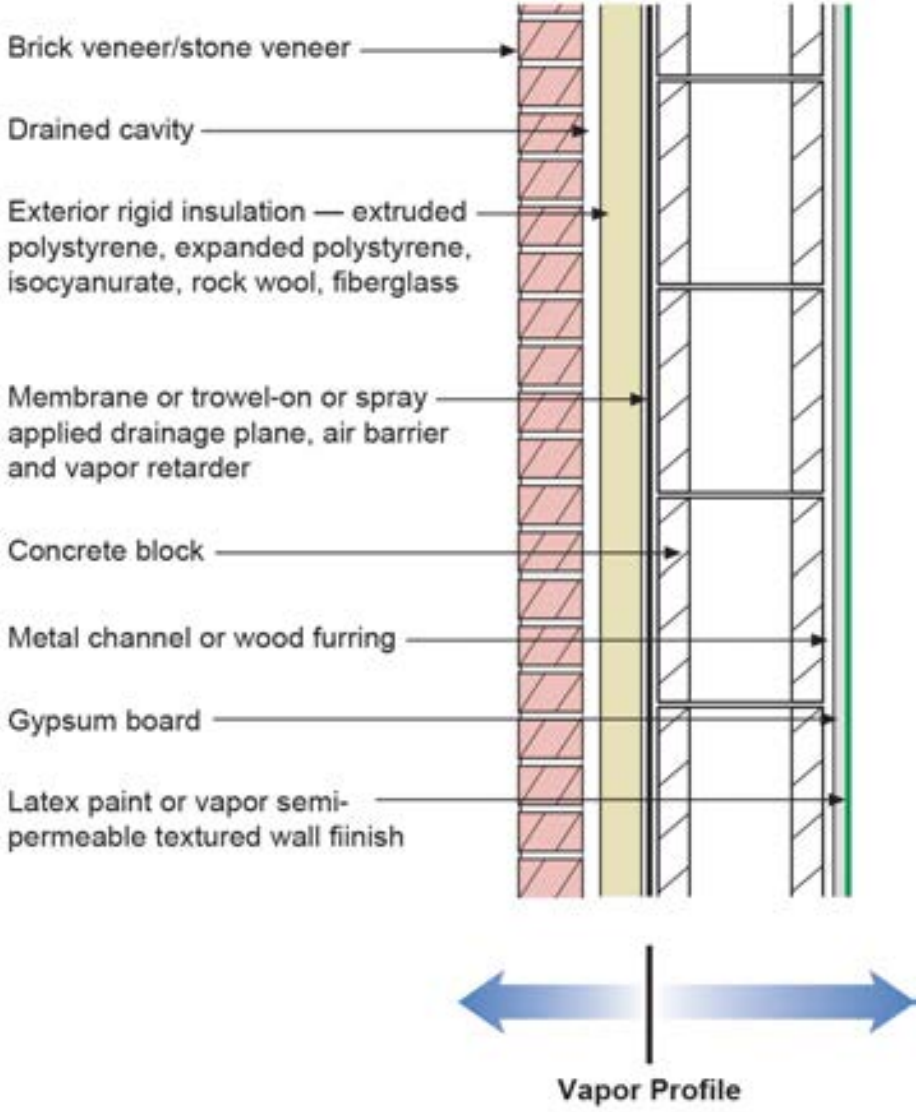

Roof
Wall

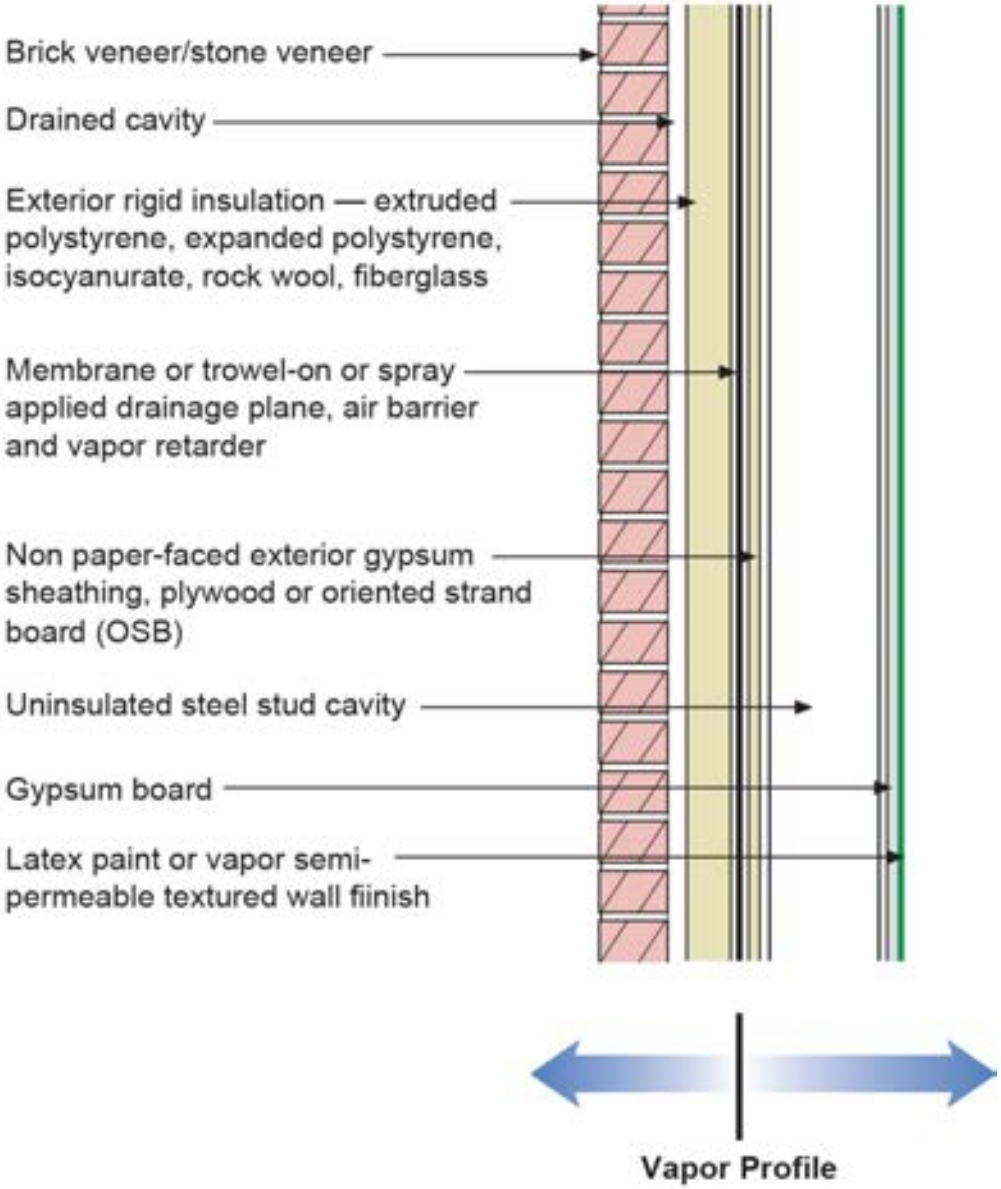

Roof
Wall
Slab

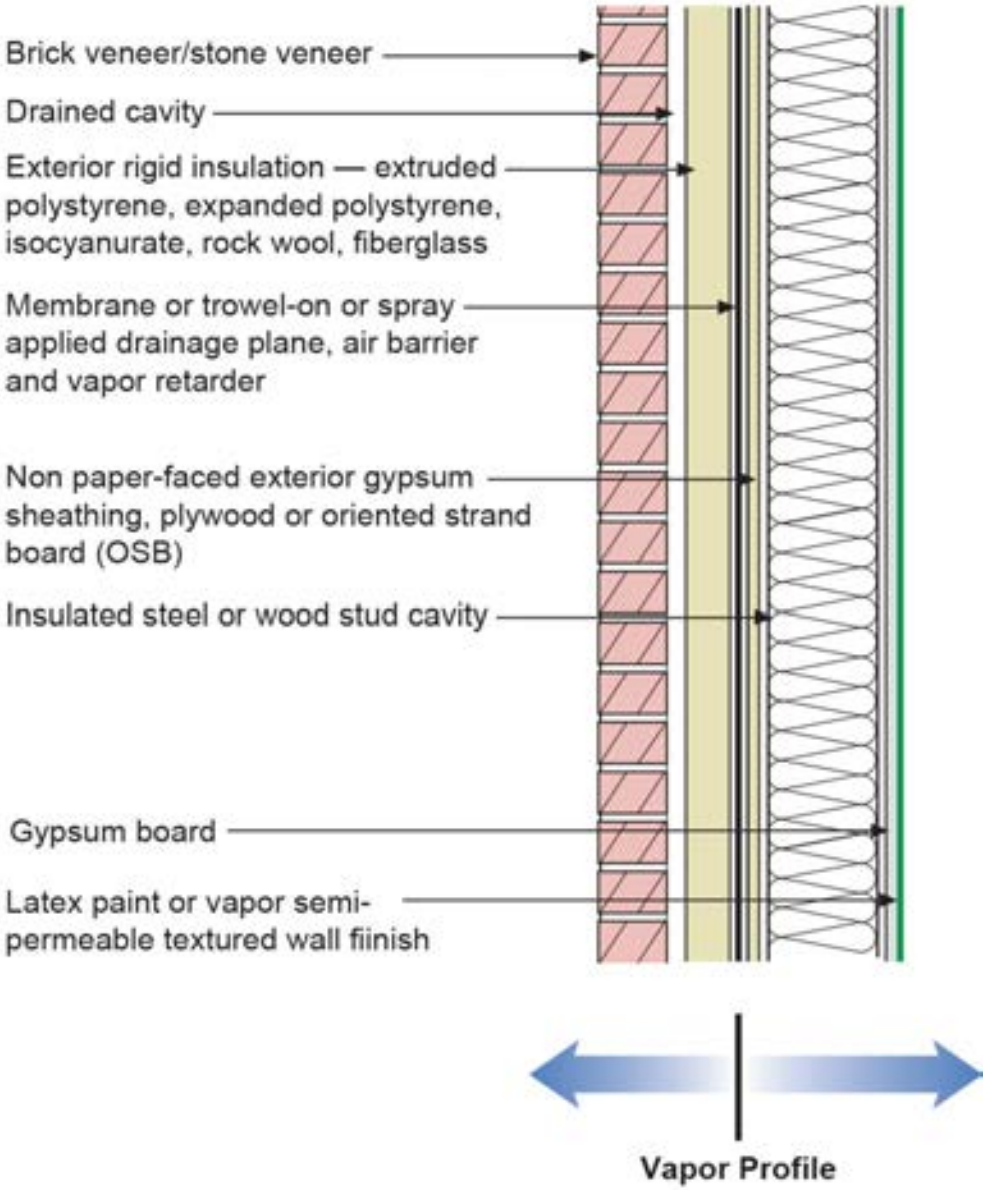

Parapet
Roof
Wall
Slab


Parapet
Roof
Wall
Footing
Slab


Parapet
Roof
Window
Wall
Footing
Slab


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 steel or wood stud cavity
Gypsum board
Latex paint or vapor semi-permeable textured wall fiinish
Vapor Profile

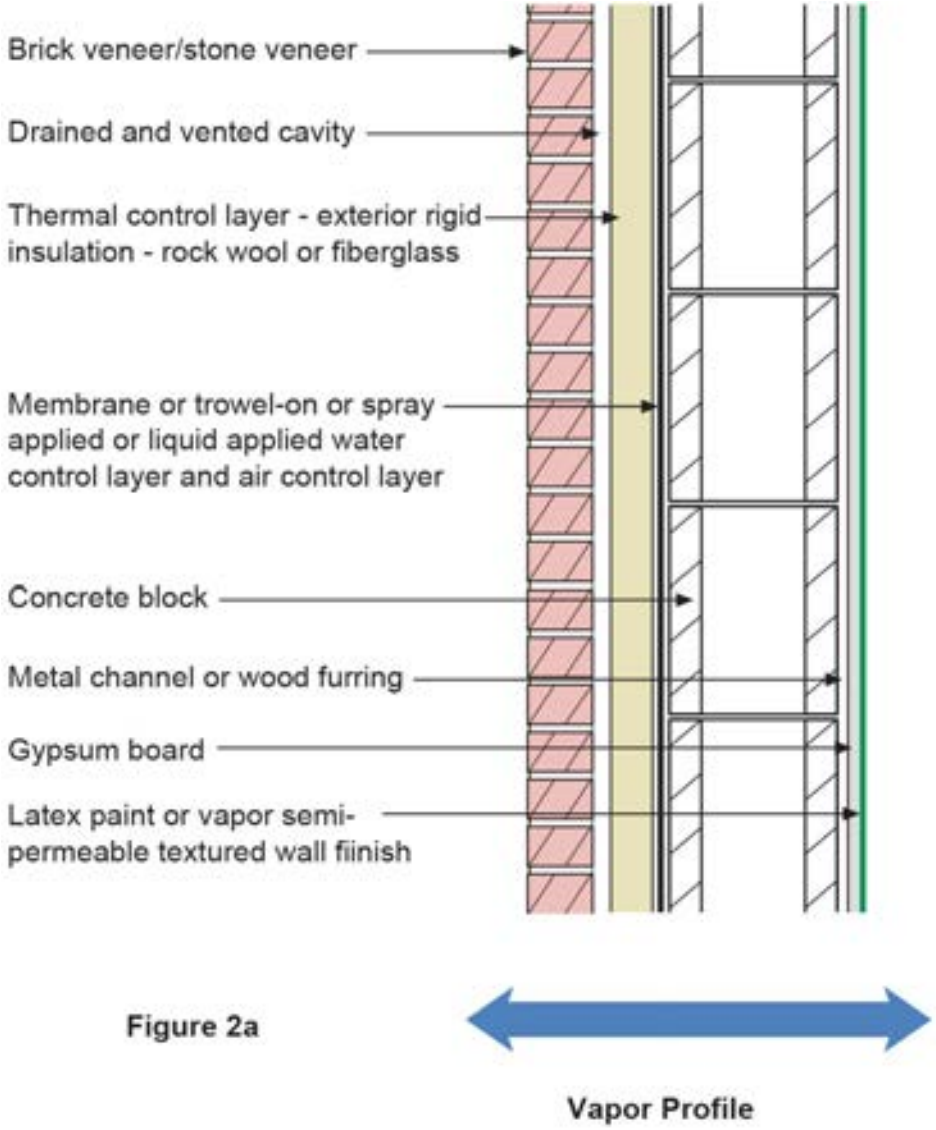

Brick veneer/stone veneer
Drained and vented cavity
Thermal control layer - exterior rigid insulation - rock wool or fiberglass
Membrane or trowel-on or spray applied or liquid applied water control layer and air control layer
Concrete block
Metal channel or wood furring
Gypsum board
Latex paint or vapor semi-permeable textured wall fiinish
Vapor Profile

Figure 2a

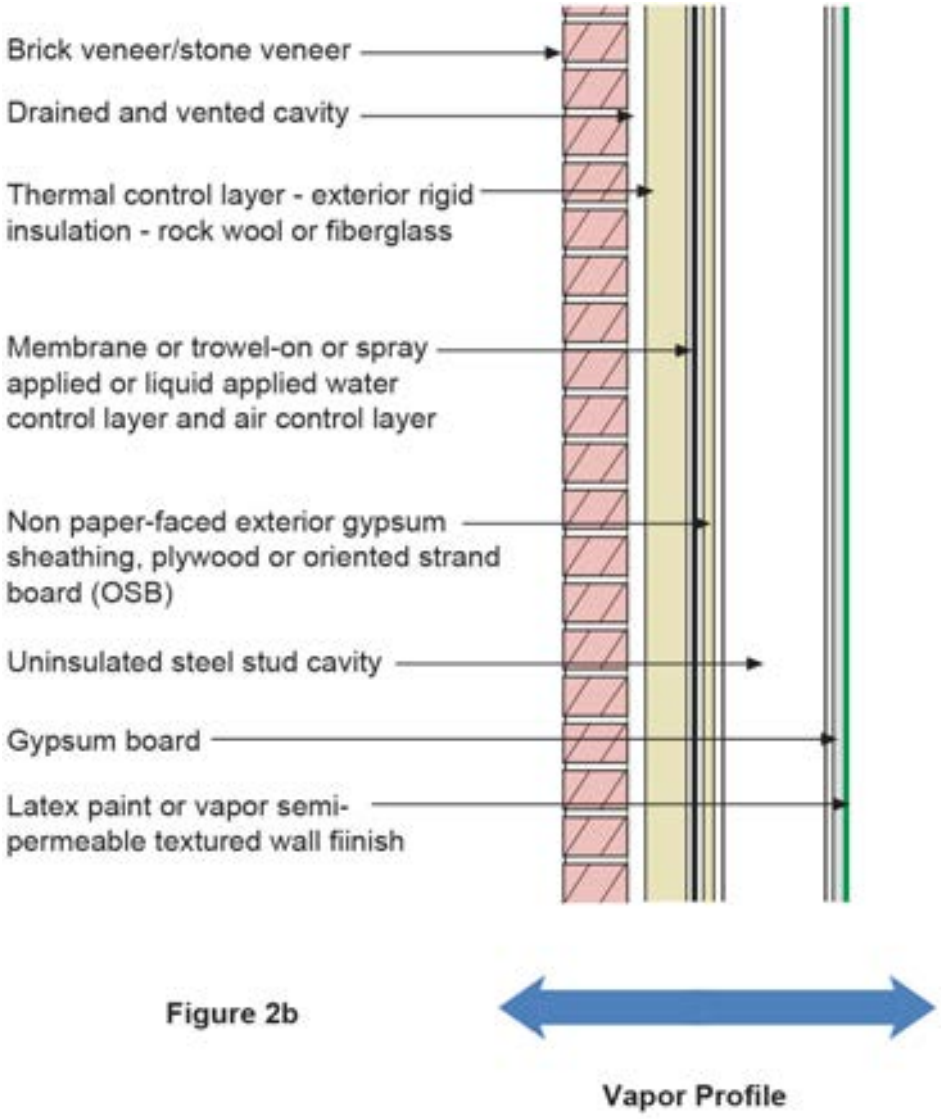

Brick veneer/stone veneer
Drained and vented cavity
Thermal control layer - exterior rigid insulation - rock wool or fiberglass
Membrane or trowel-on or spray applied or liquid applied water control layer and air control layer
Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)
Uninsulated steel stud cavity
Gypsum board
Latex paint or vapor semi-permeable textured wall fiinish
Vapor Profile

Figure 2b

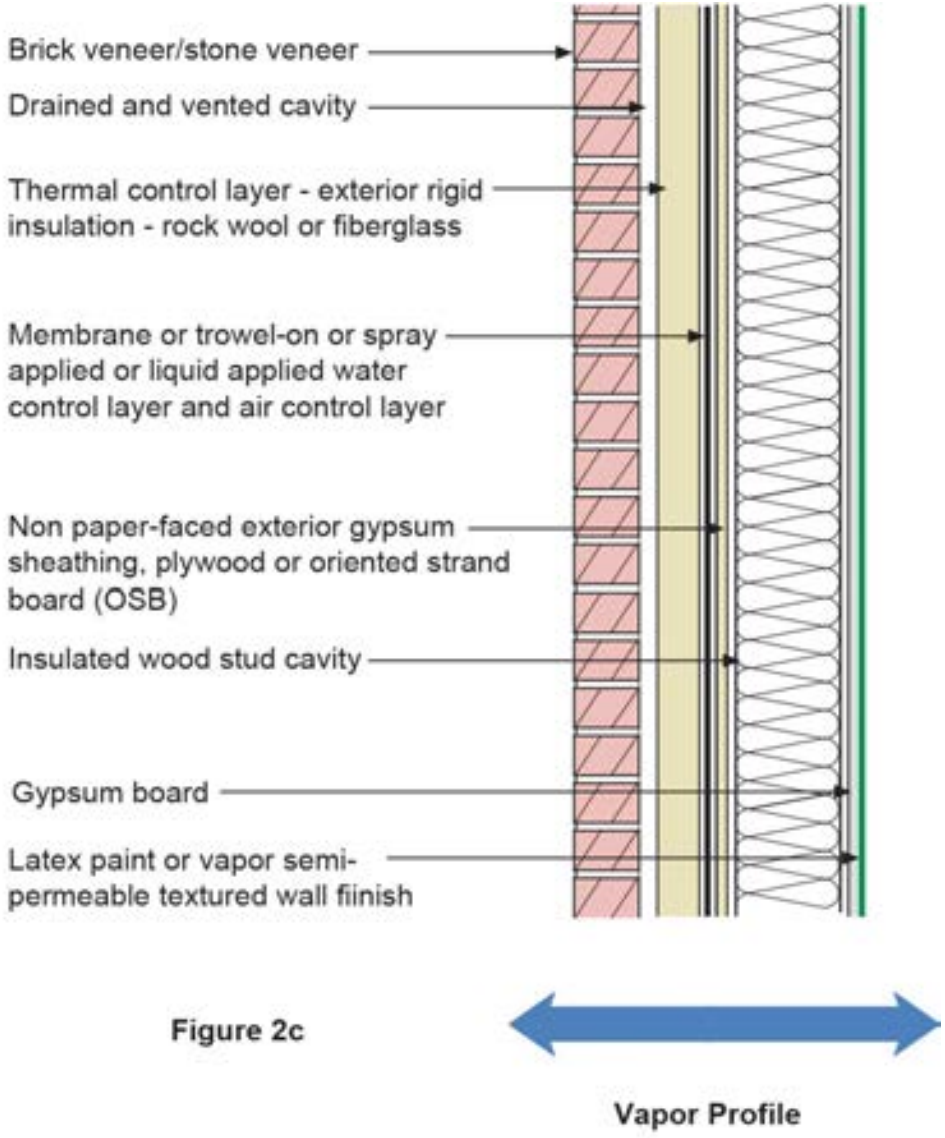
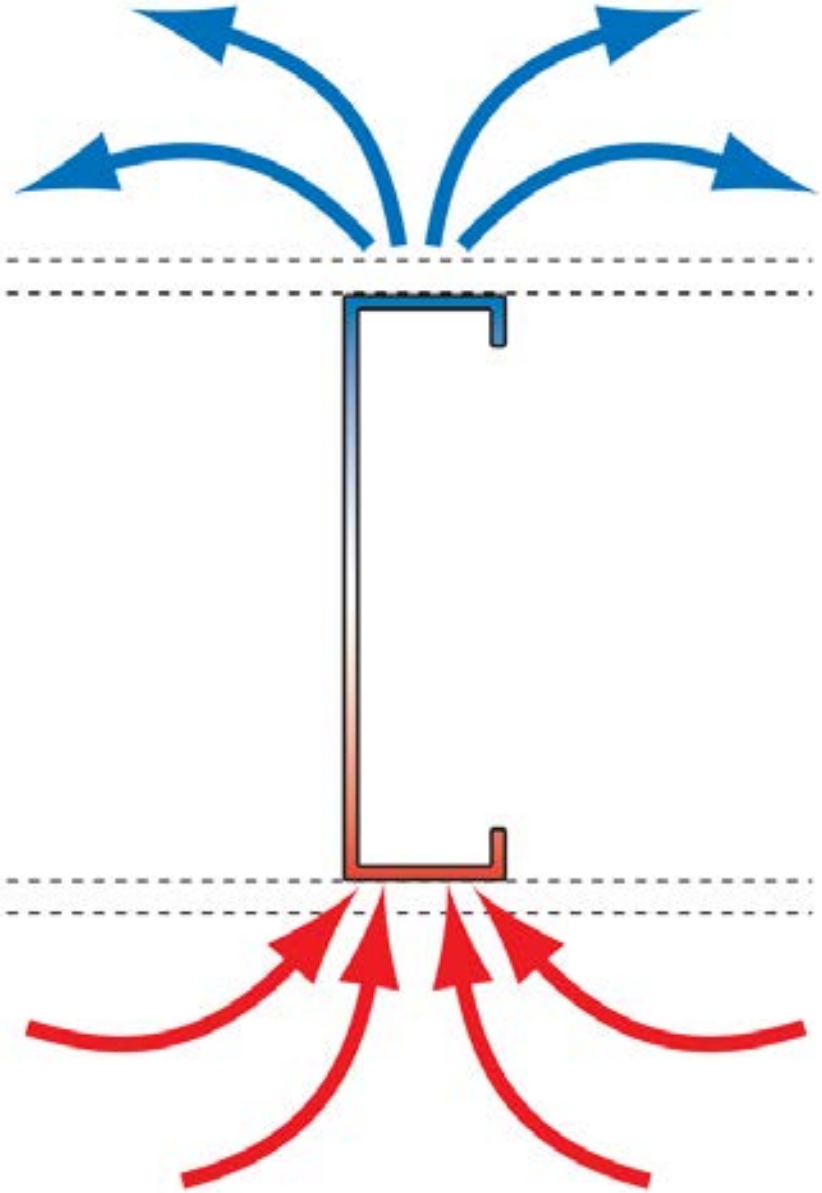
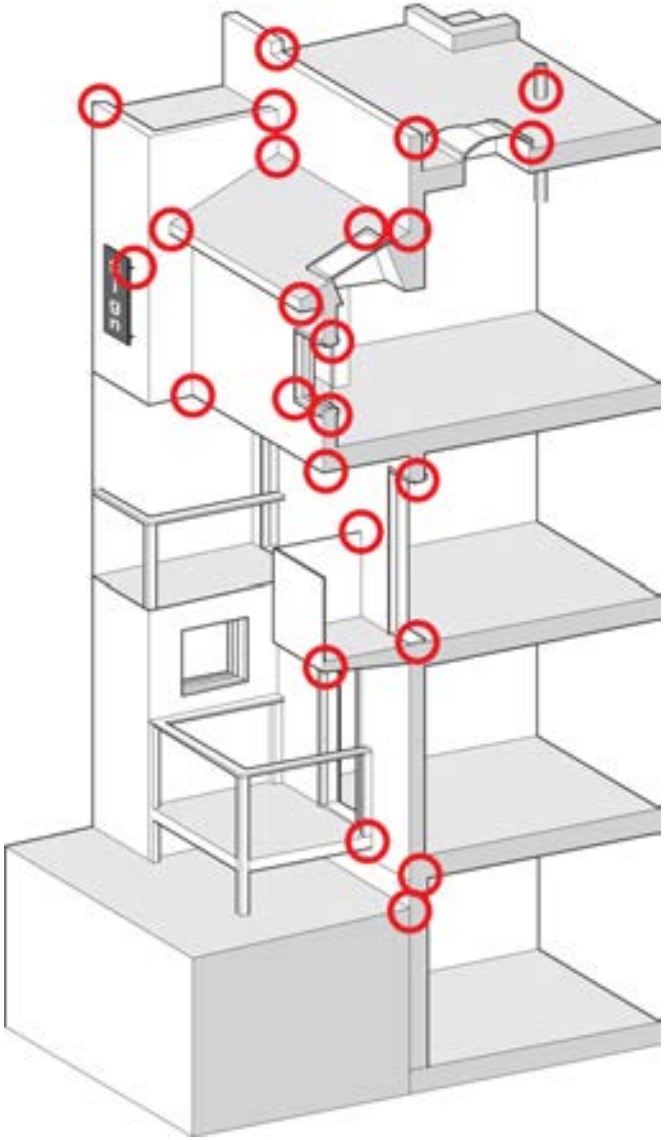

Brick veneer/stone veneer
Drained and vented cavity
Thermal control layer - exterior rigid insulation - rock wool or fiberglass
Membrane or trowel-on or spray applied or liquid applied water control layer and air control layer
Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)
Insulated wood stud cavity
Gypsum board
Latex paint or vapor semi-permeable textured wall fiinish
Vapor Profile

Figure 2c



Commercial Enclosure: Simple Layers

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




GP
DensGlass
Sheathing
Polyguard


DU PONT


Straight Flash


DUPONT
DUPONT


StraightFlash
StraightFlash


J-V-J Co. Inc.
CULLIAN
CONGRESS


HARVARD SCHOOL OF PUBLIC HEALTH


GP
GLASS GOLD

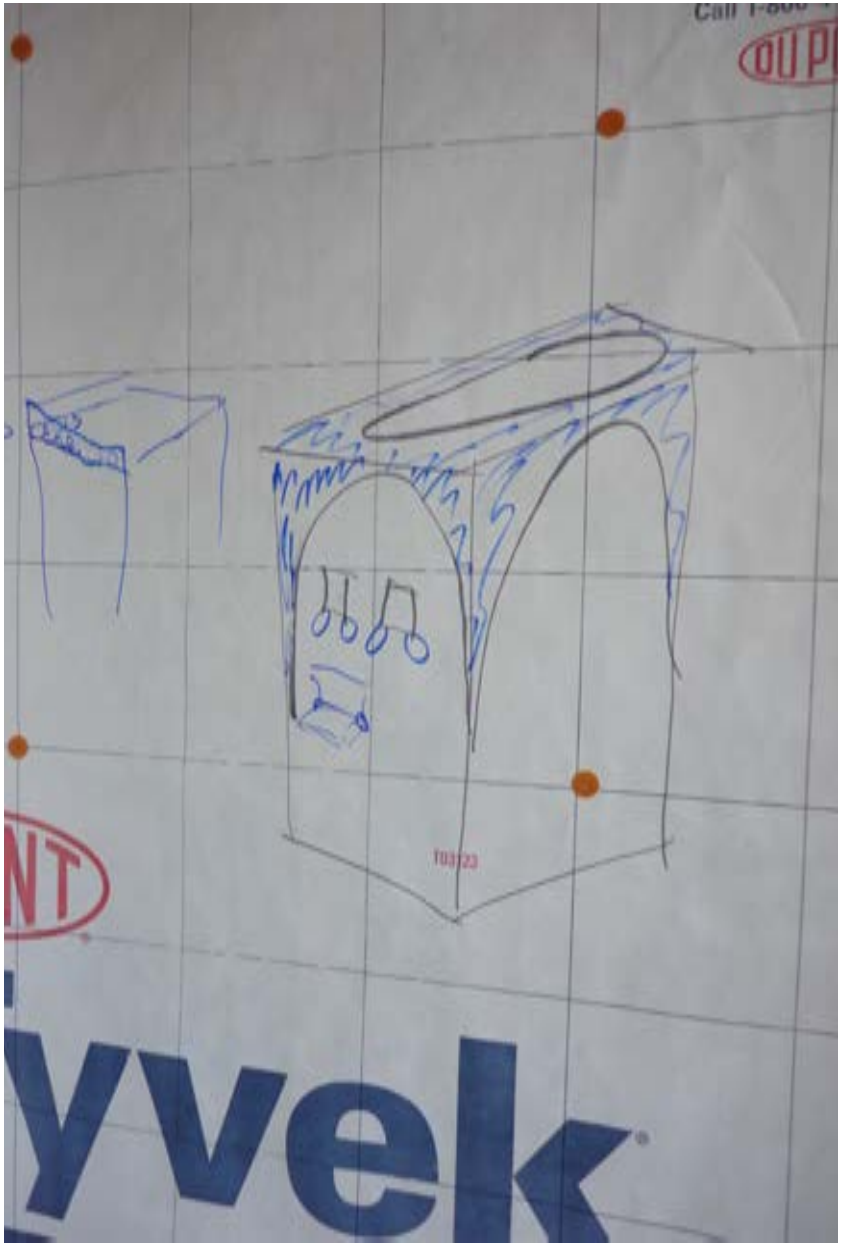

GP
DENSGLASS GOLD
Exterior Sheathing
GP
DENSGLASS GOLD
Exterior Sheathing

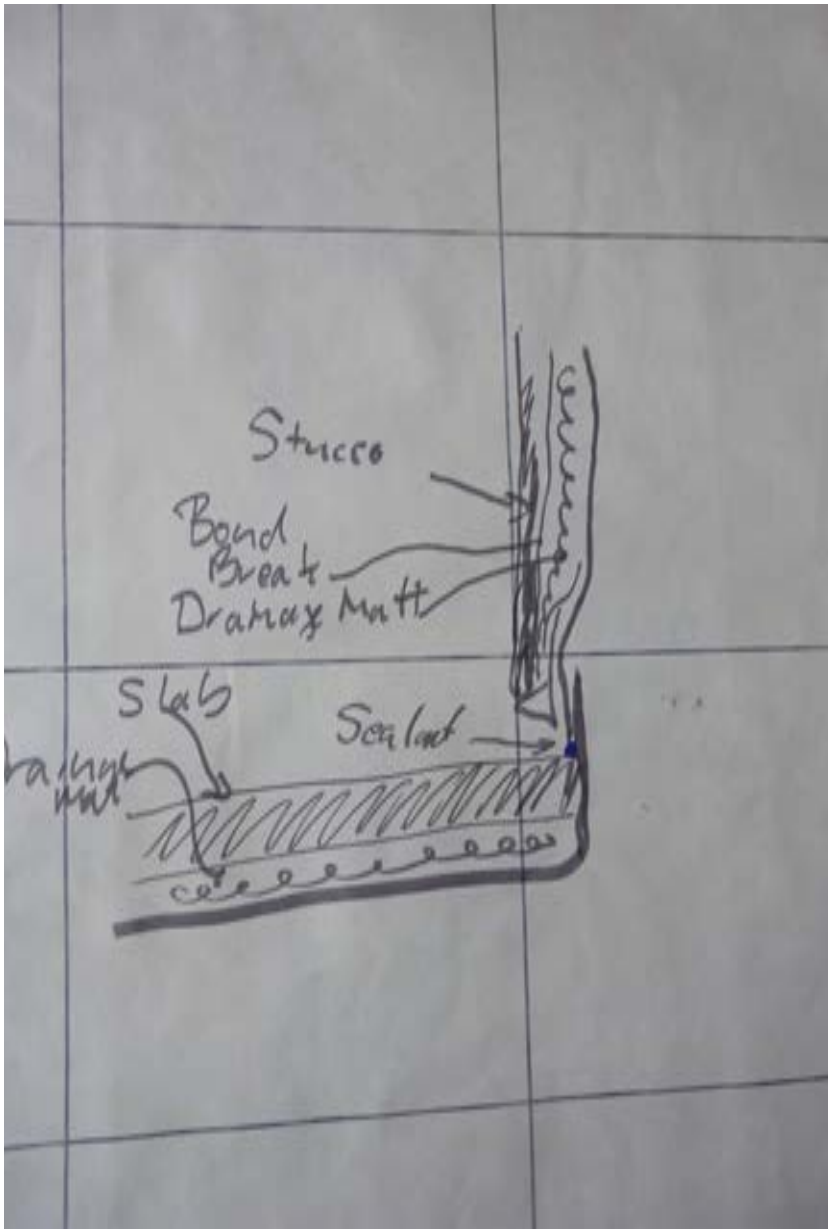

Blueskin


GS-5390
DensGlass
GP


AVAILAB


DensGlass


yvek


Stucco
Bond Break
Drainage Matt
Slab
Sealant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Tyvek
COMMERCIAL WRAP


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DANGER
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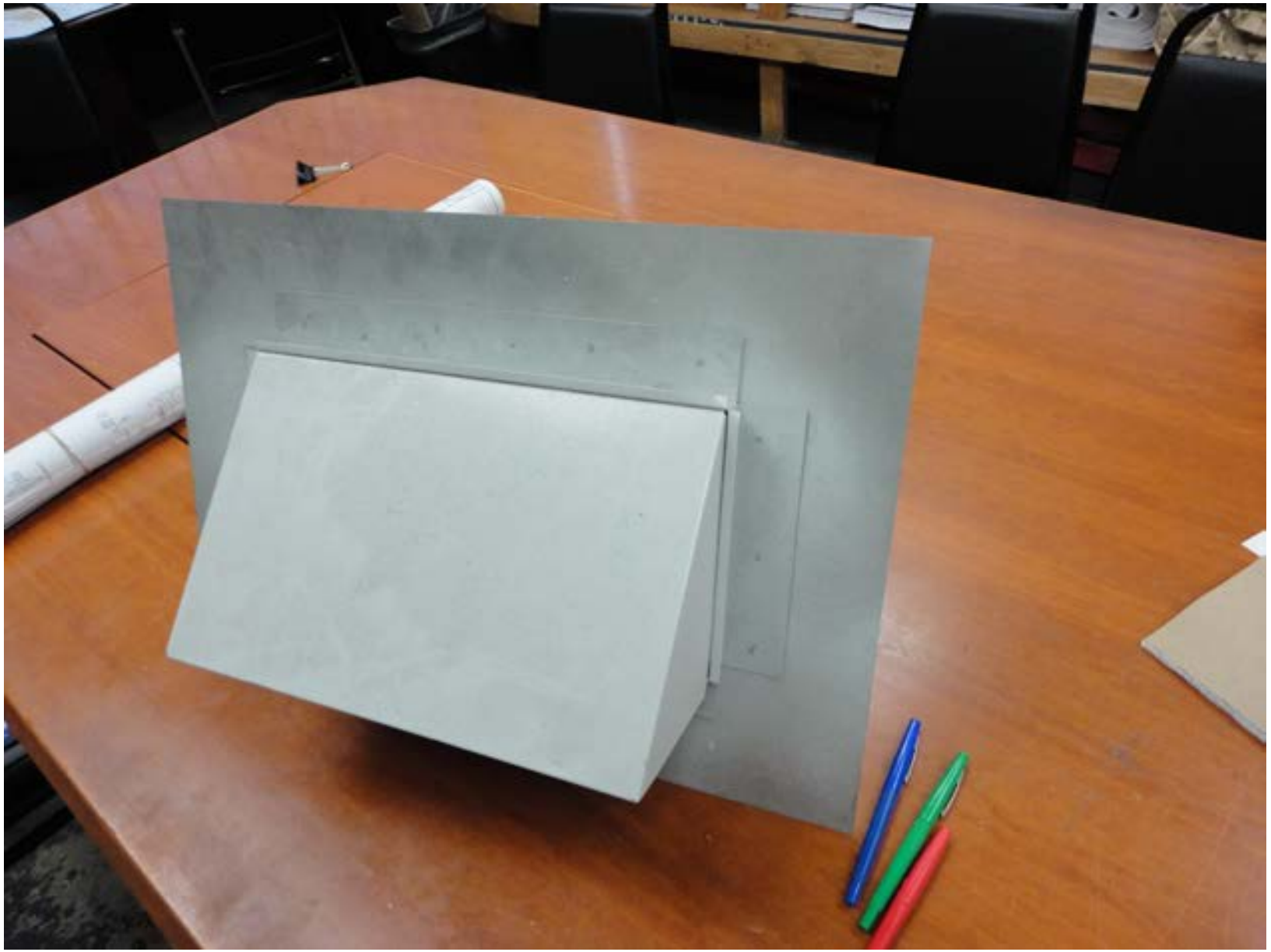
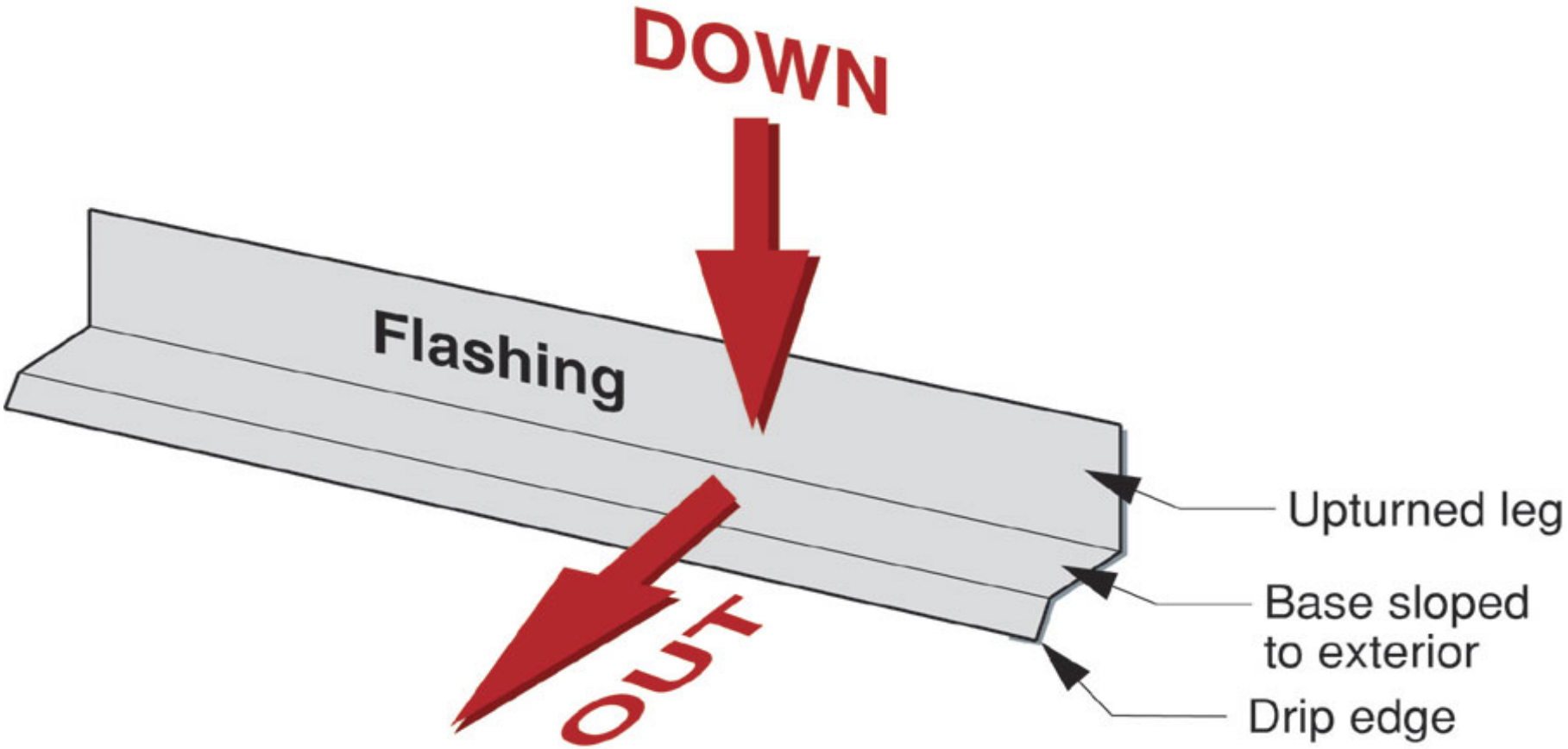
AREA
KEEP OUT

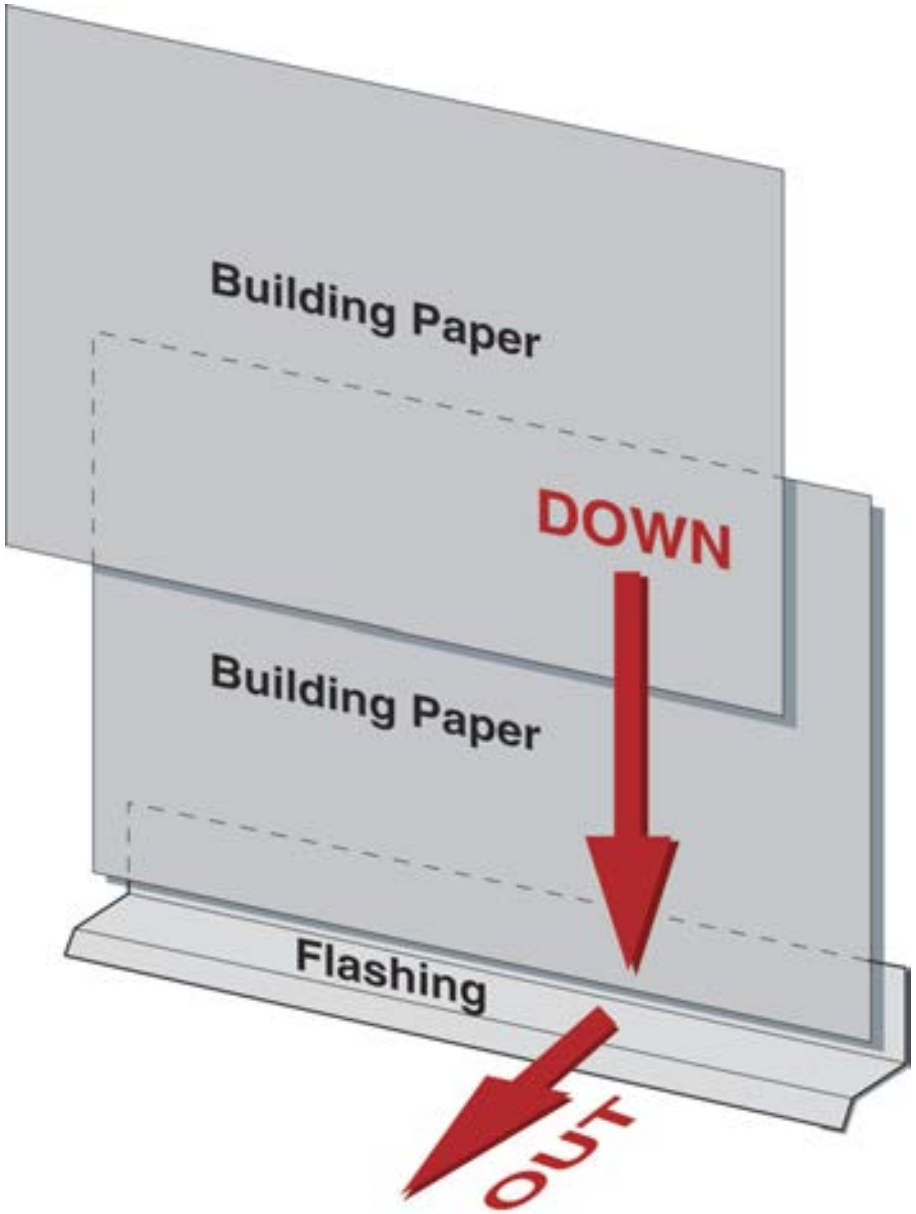


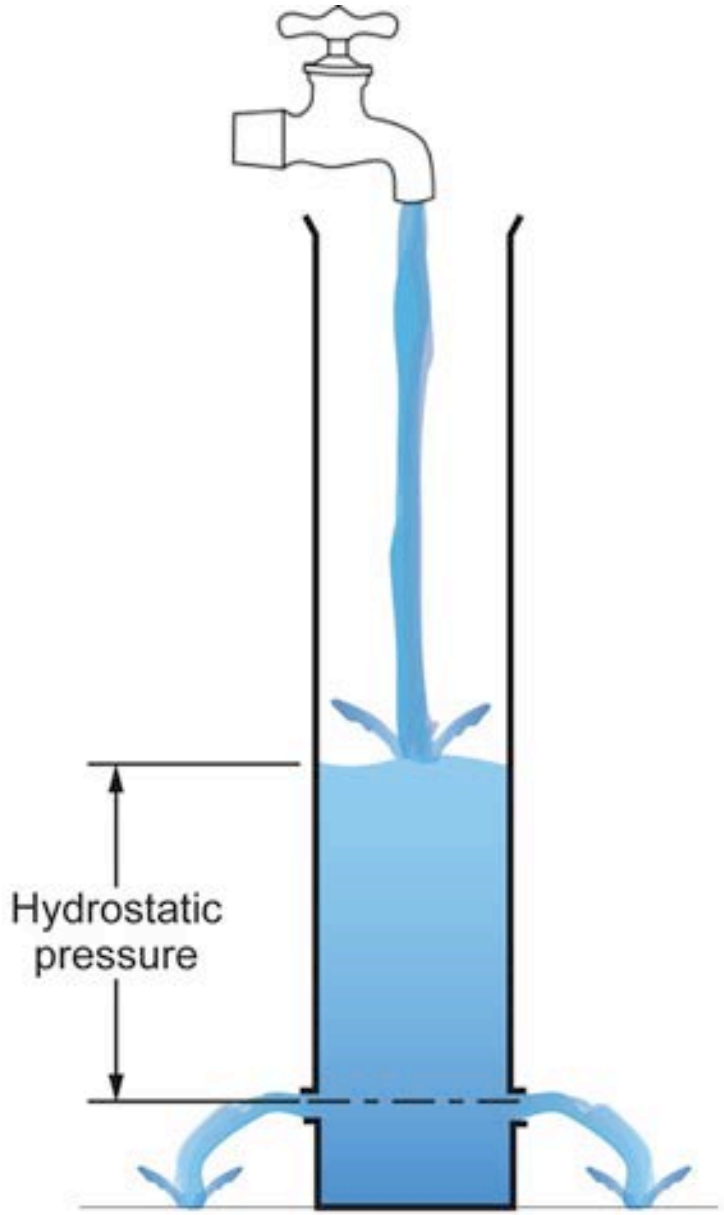

MOISTOP
MOISTOP
MOISTOP
alenco
3700

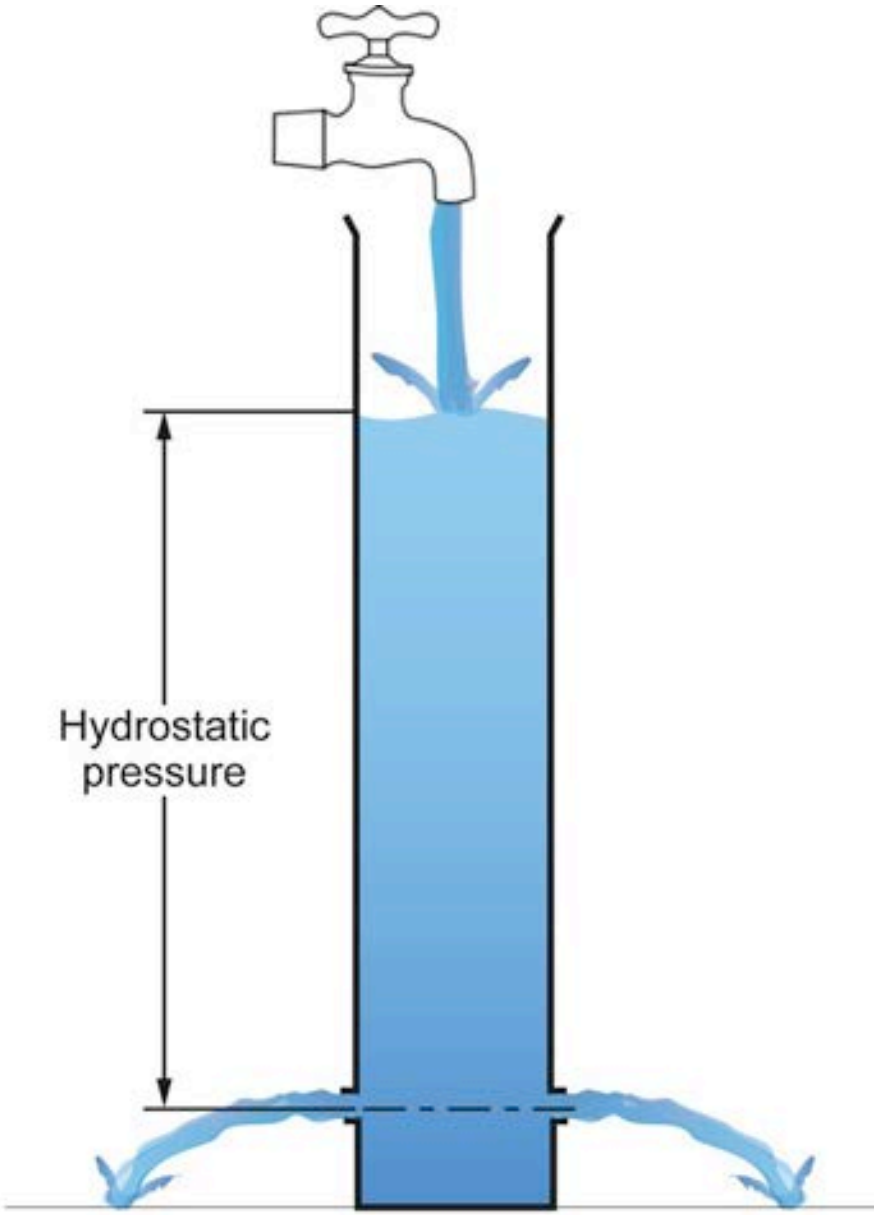

GP
sGlass™
eathing
GP
DensG
Sheathi
THIS SIDE OUT

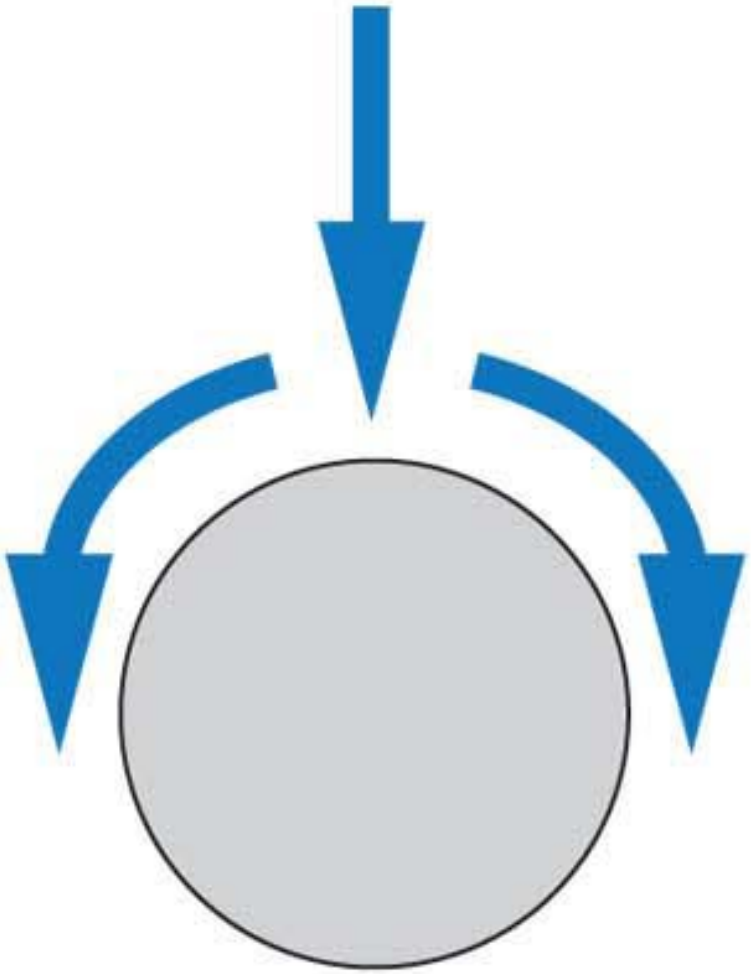

rmax ci
Isolant extérie
Thermax ci
Aislamiento Ext
THERM X ci

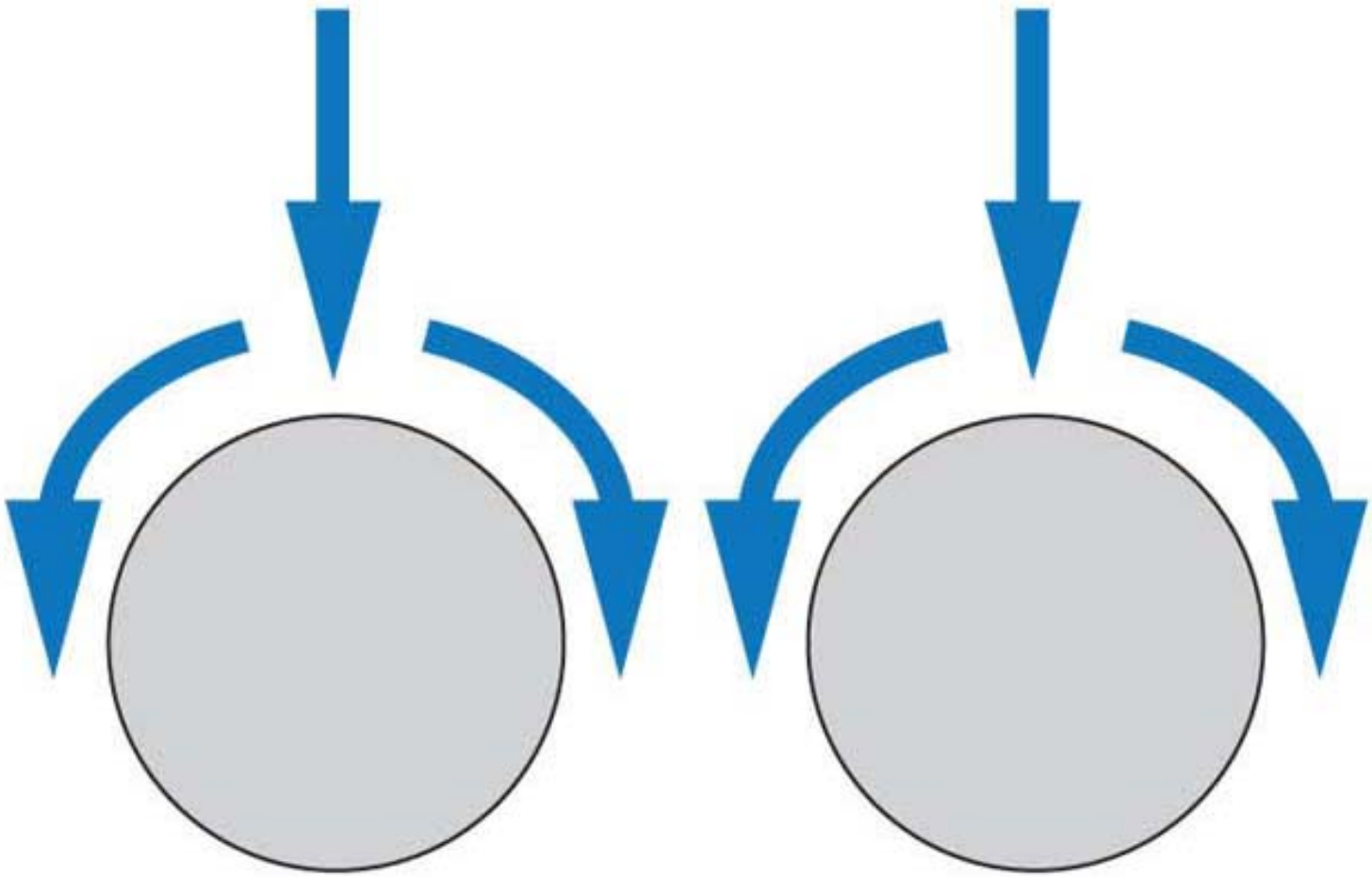

DOWN
Flashing
OUT
Upturned leg
Base sloped
to exterior
Drip edge

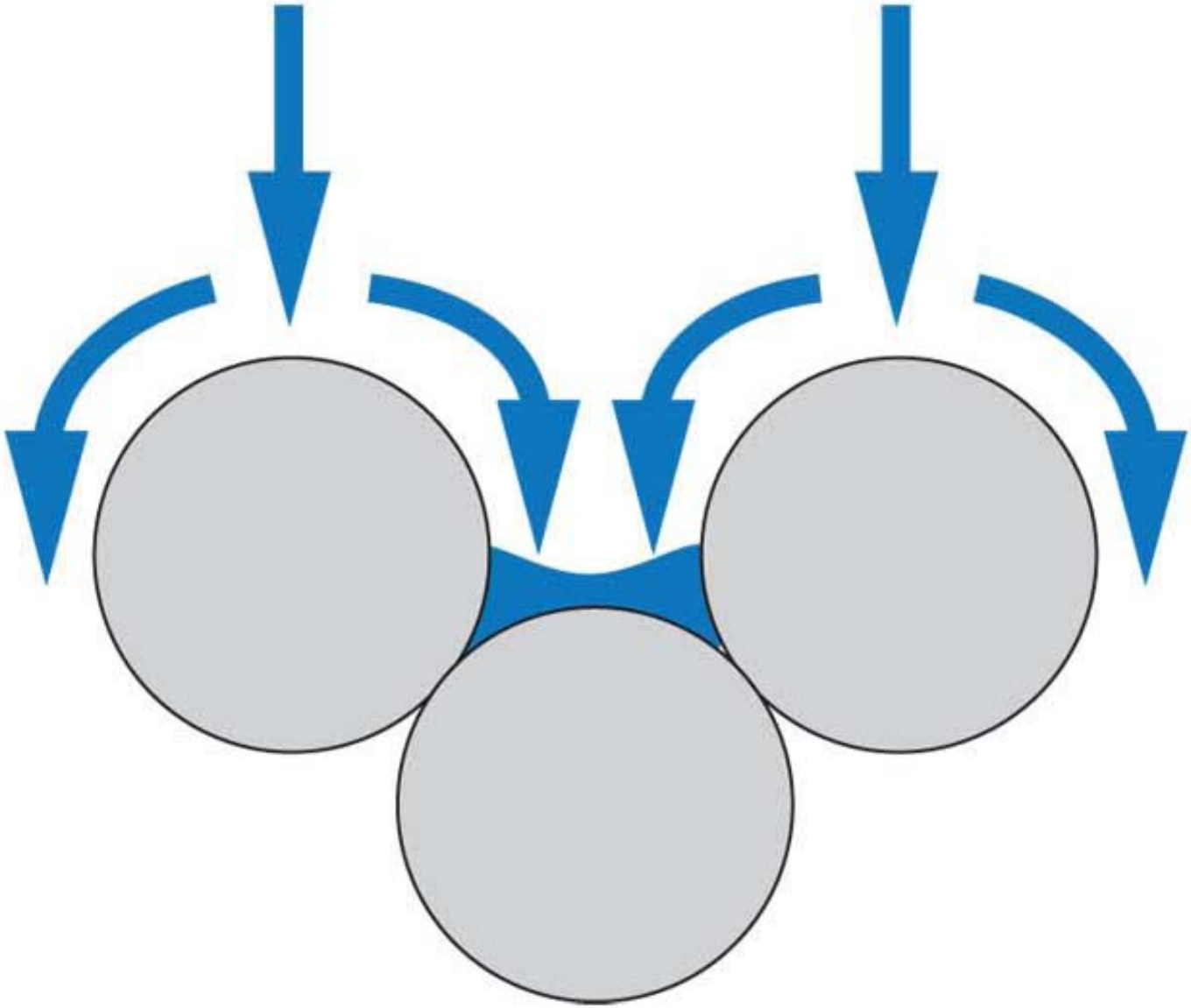

Building Paper
DOWN
Building Paper
Flashing
OUT

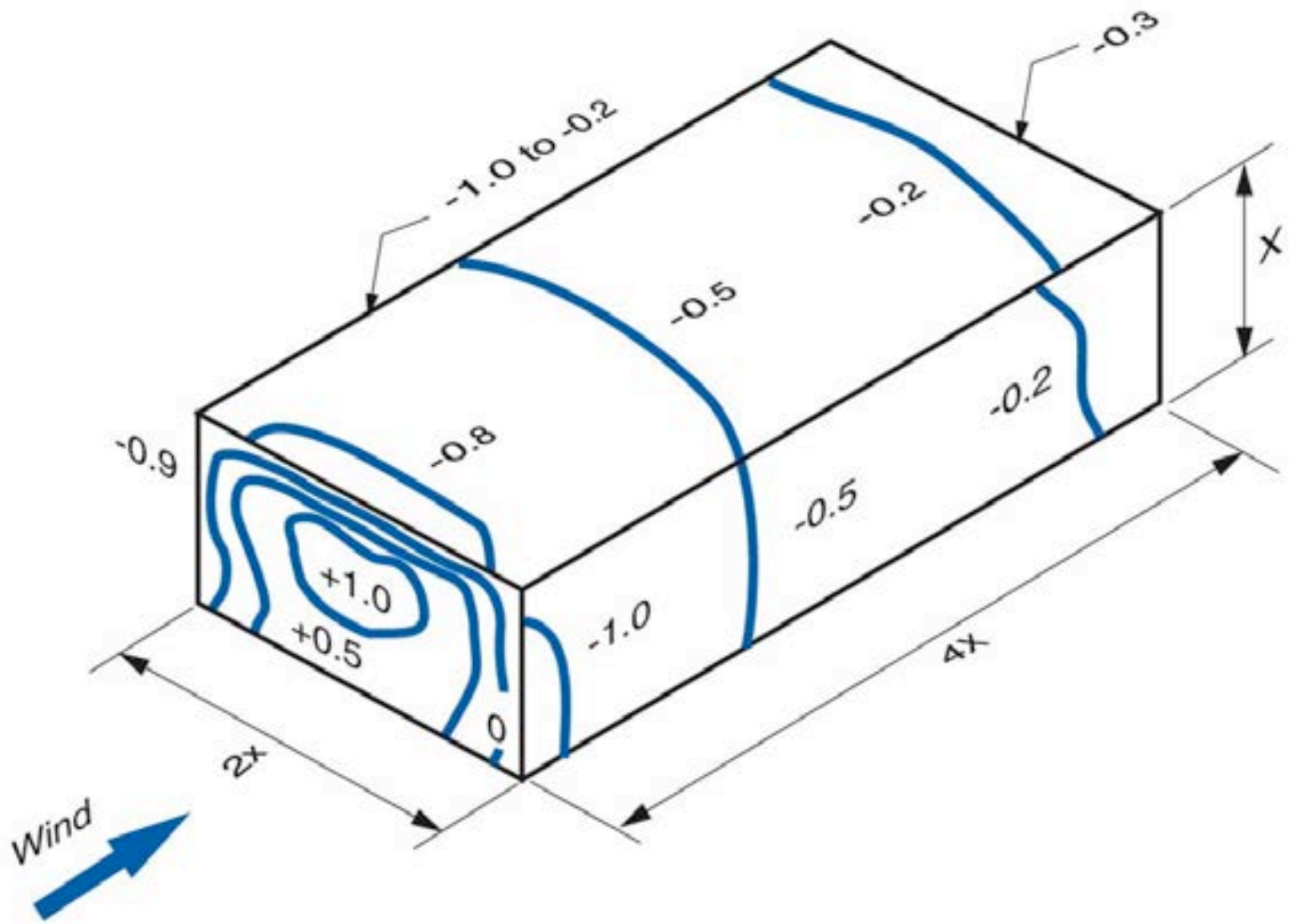

Hydrostatic
pressure


Hydrostatic
pressure

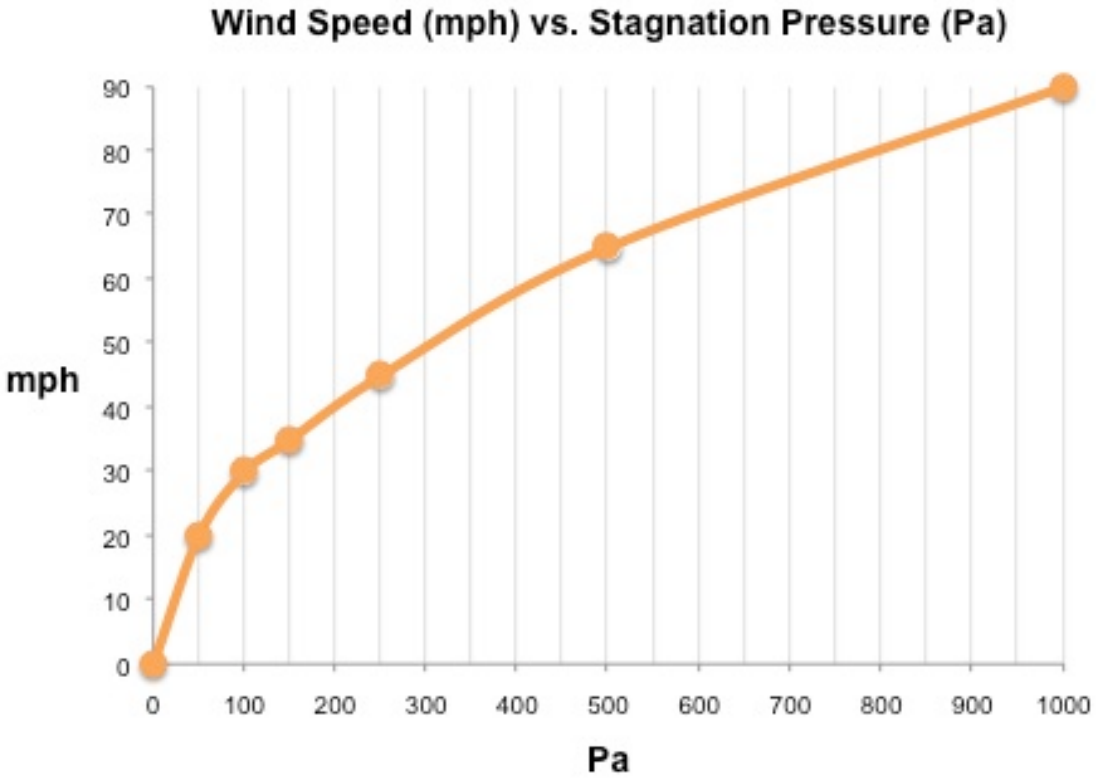







-0.3
-1.0 to -0.2
-0.2
-0.5
-0.2
-0.9
-0.8
-0.5
+1.0
+0.5
-1.0
0
X
2X
4X
Wind

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

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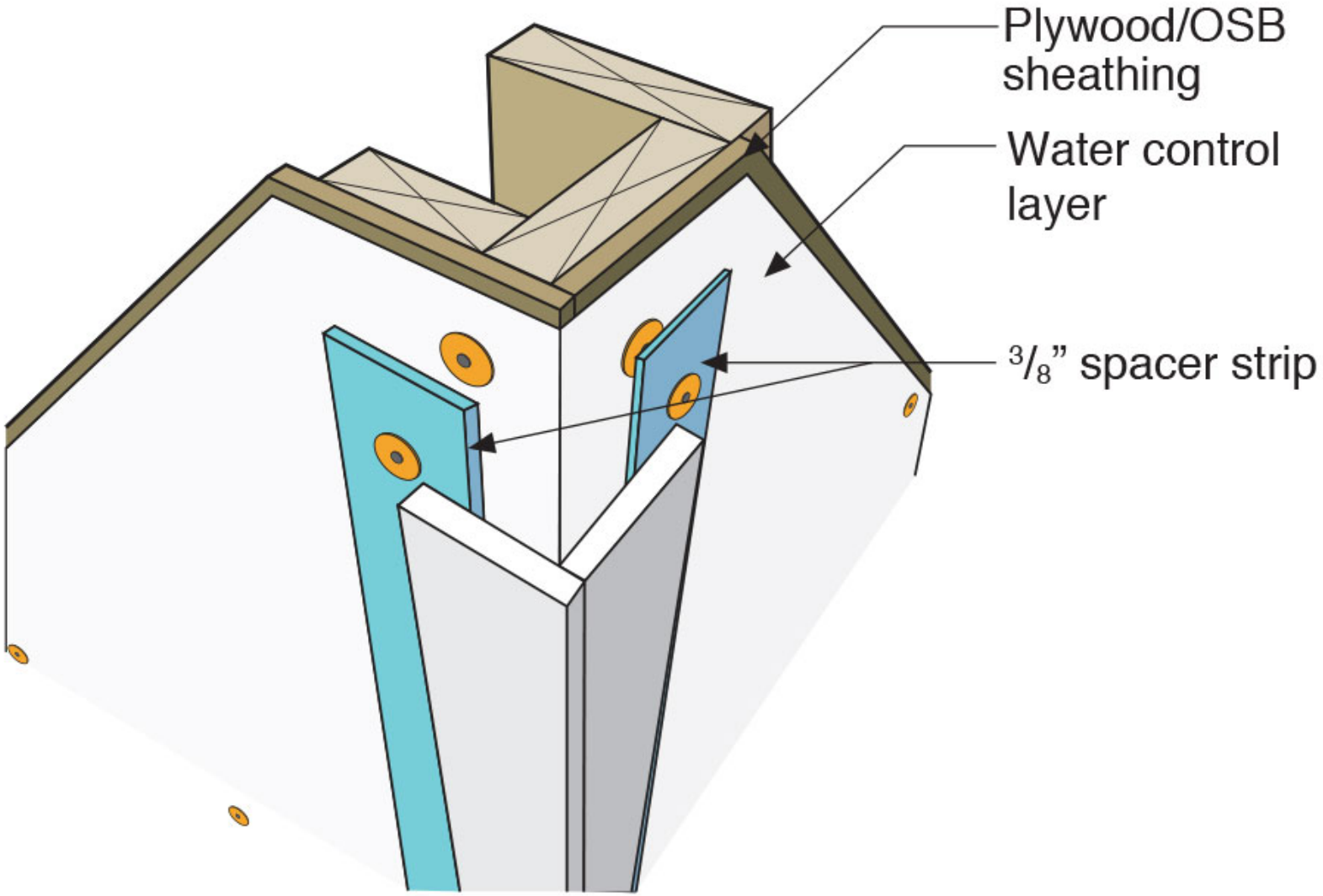
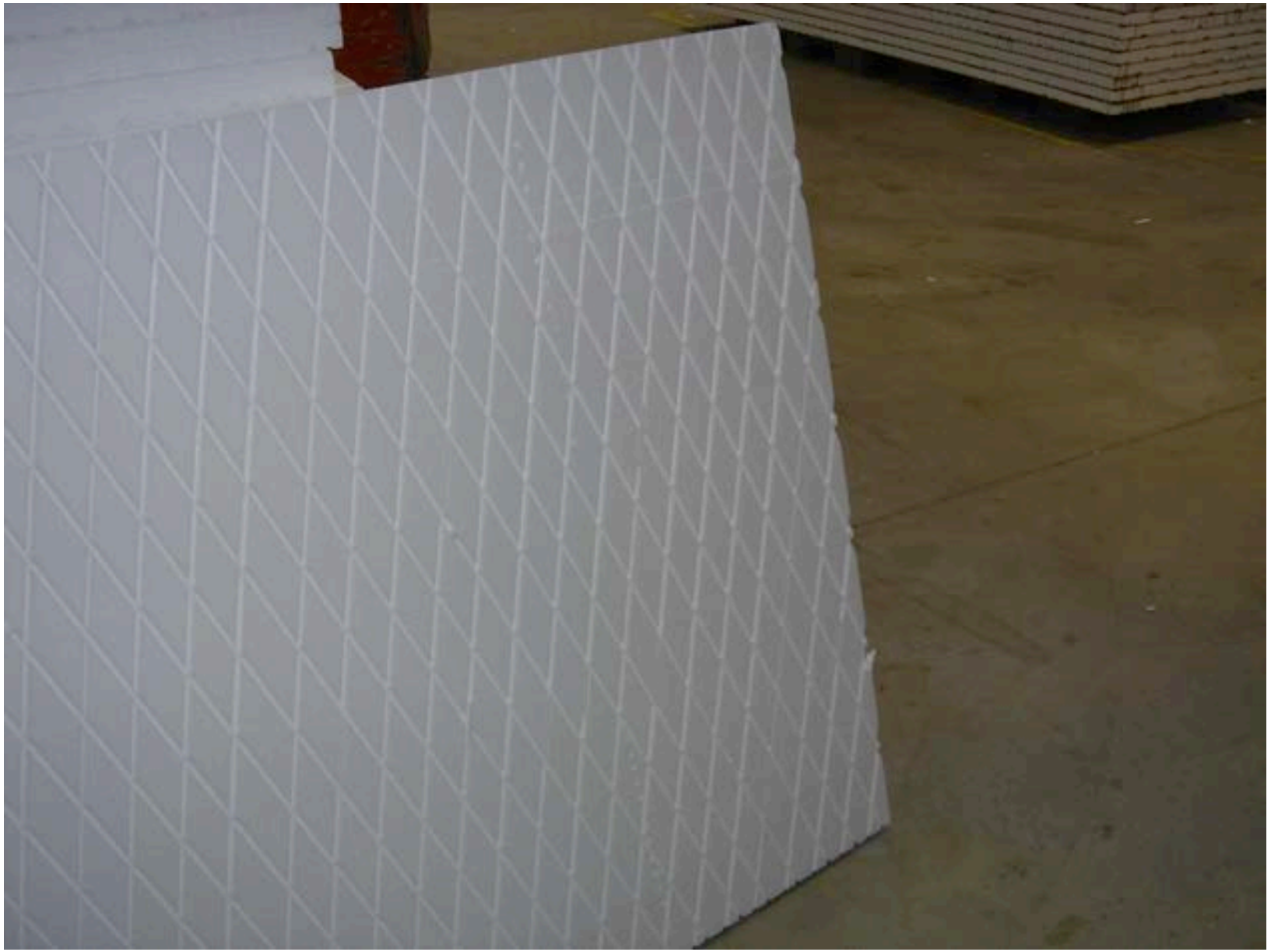
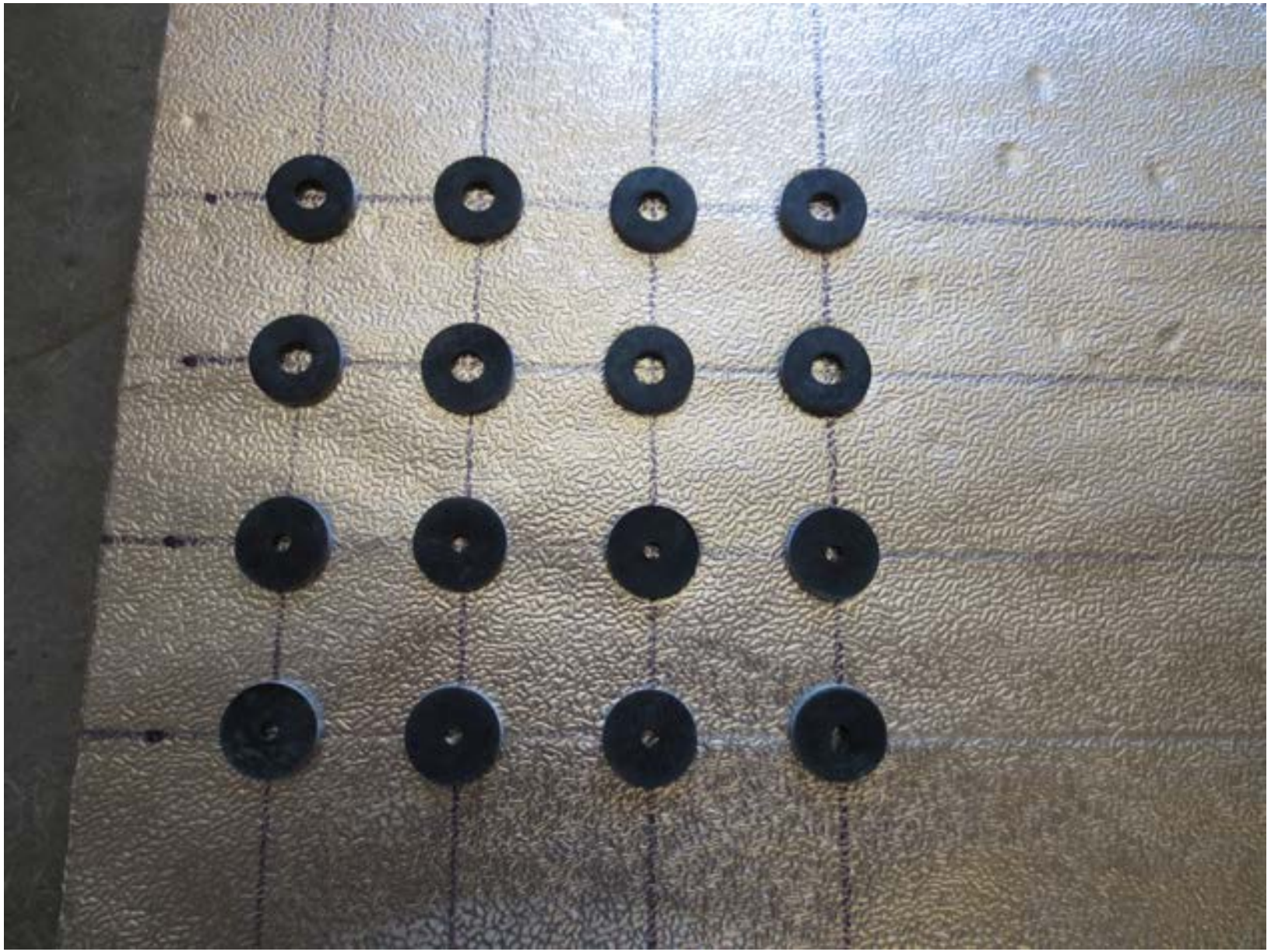

Plywood/OSB sheathing
Water control layer
3/8" spacer strip

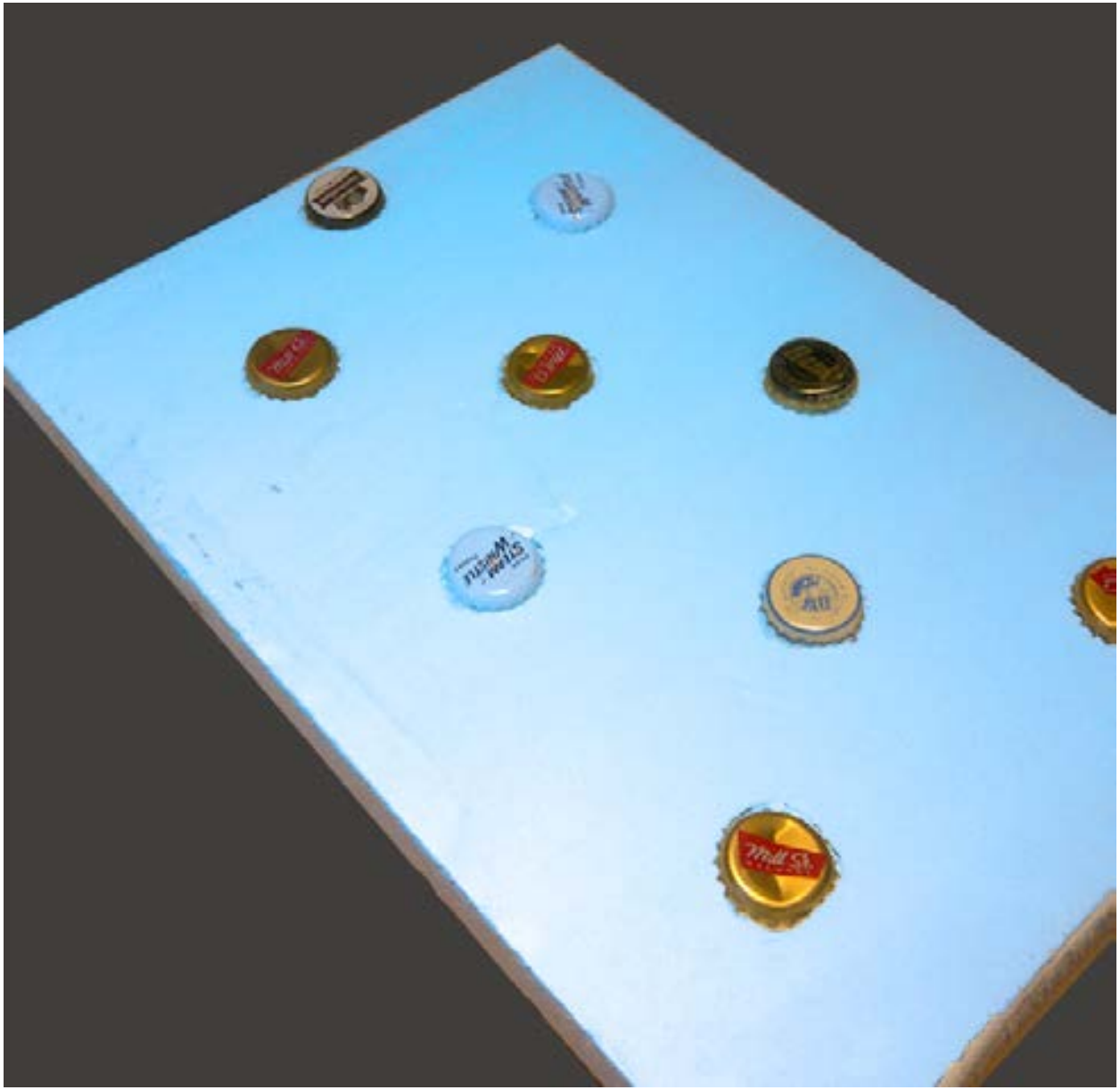

Tyvek
Tyvek

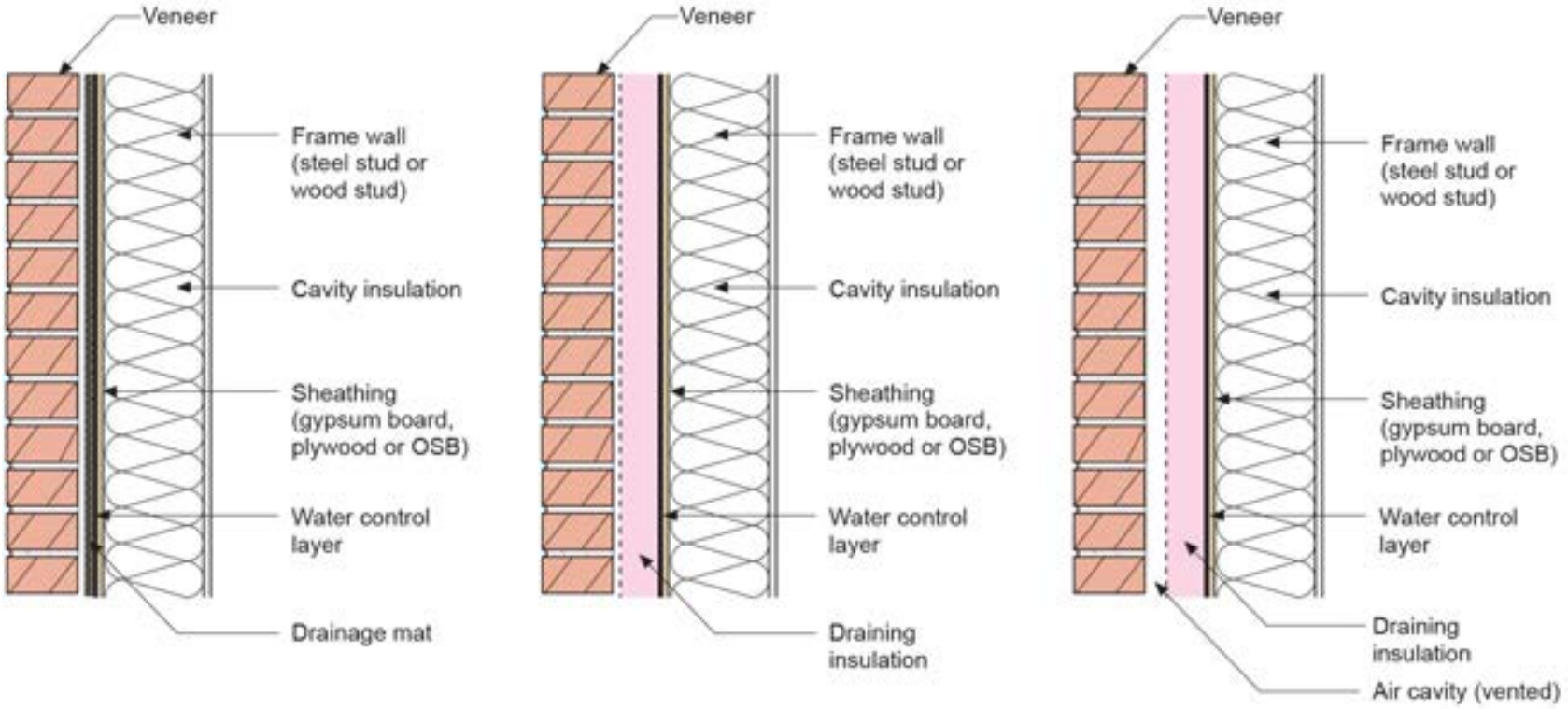


Rain Screen

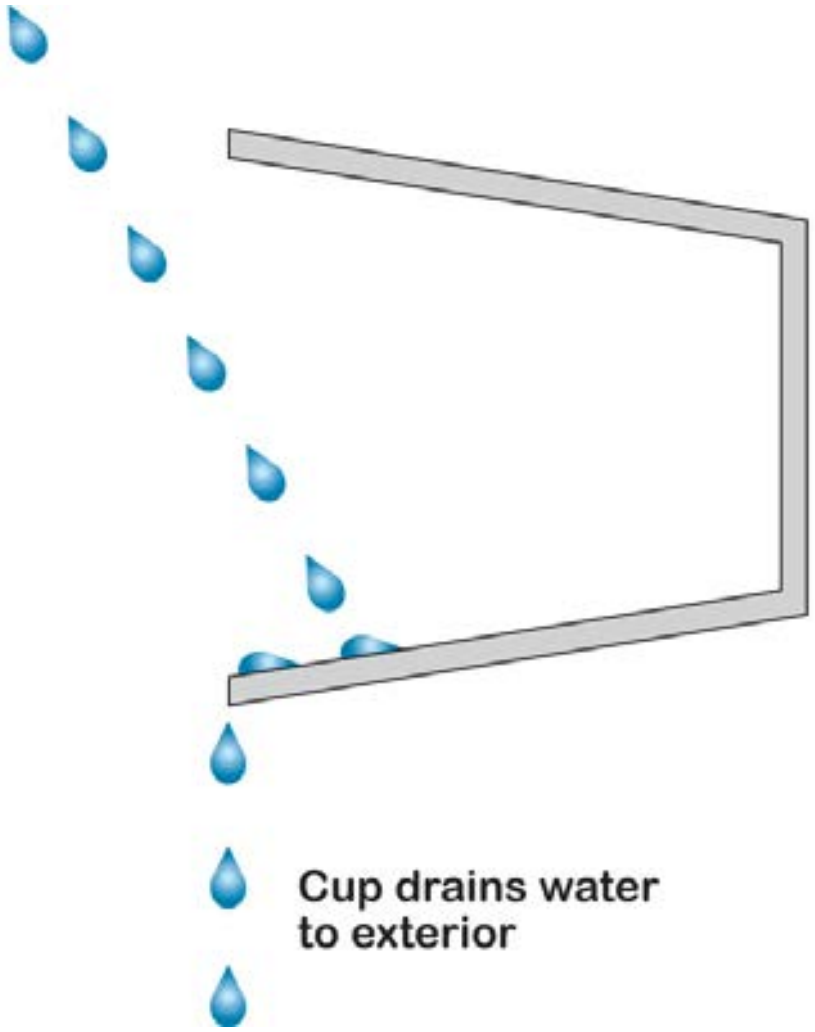


Beer Screen?

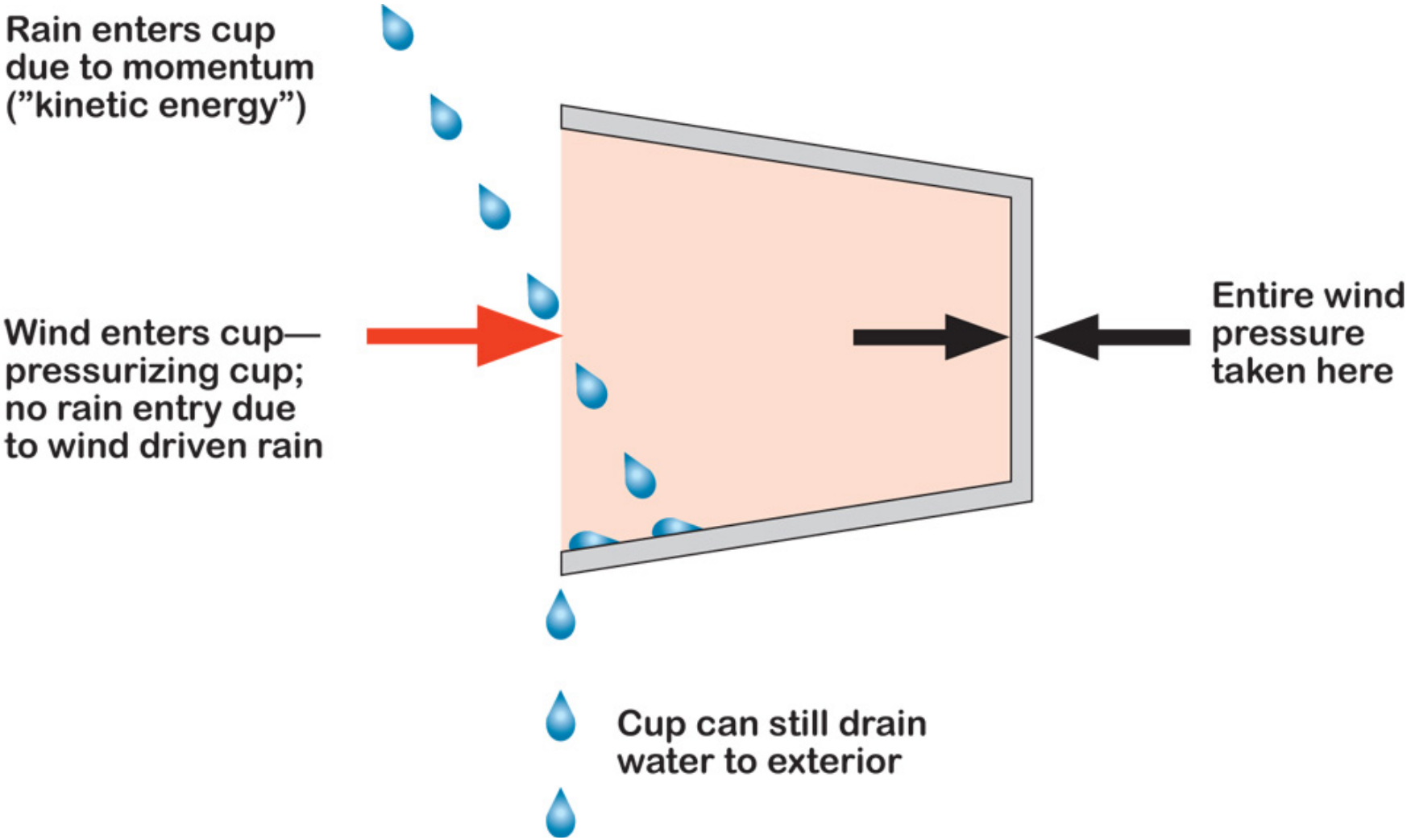


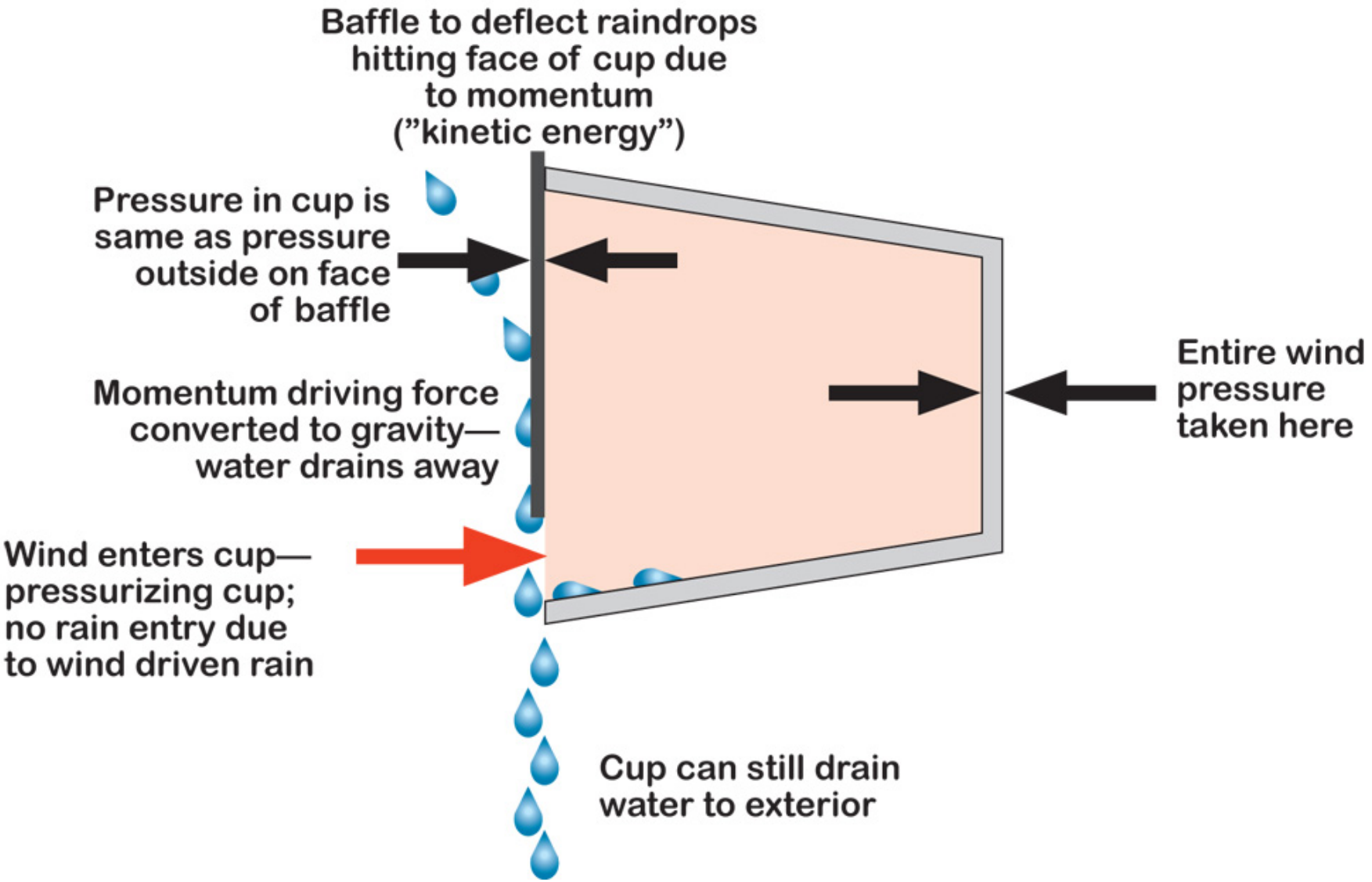

Veneer
Frame wall (steel stud or wood stud)
Cavity insulation
Sheathing (gypsum board, plywood or OSB)
Water control layer
Drainage mat
Veneer
Frame wall (steel stud or wood stud)
Cavity insulation
Sheathing (gypsum board, plywood or OSB)
Water control layer
Draining insulation
Veneer
Frame wall (steel stud or wood stud)
Cavity insulation
Sheathing (gypsum board, plywood or OSB)
Water control layer
Draining insulation
Air cavity (vented)

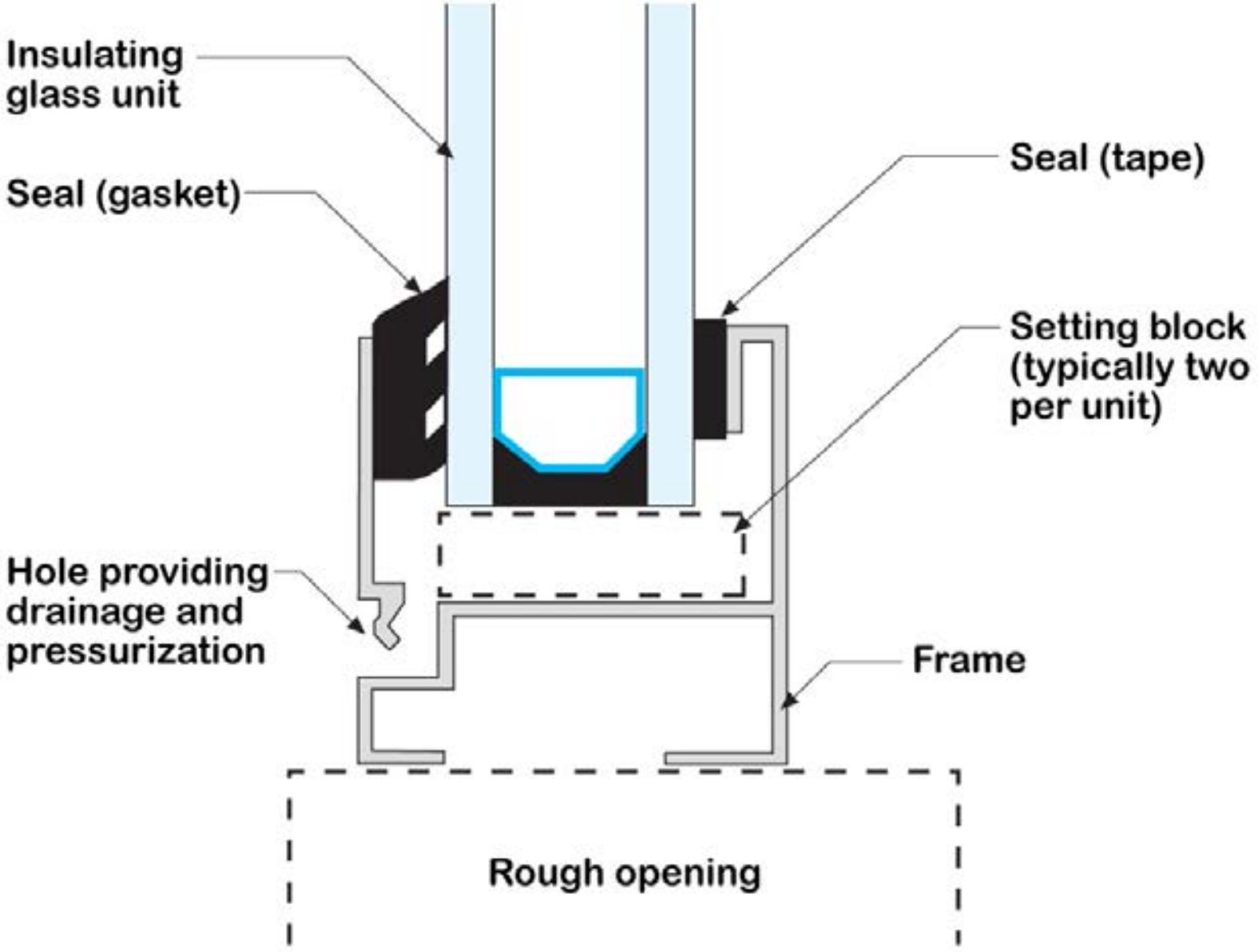
Rain enters cup due to momentum ("kinetic energy")

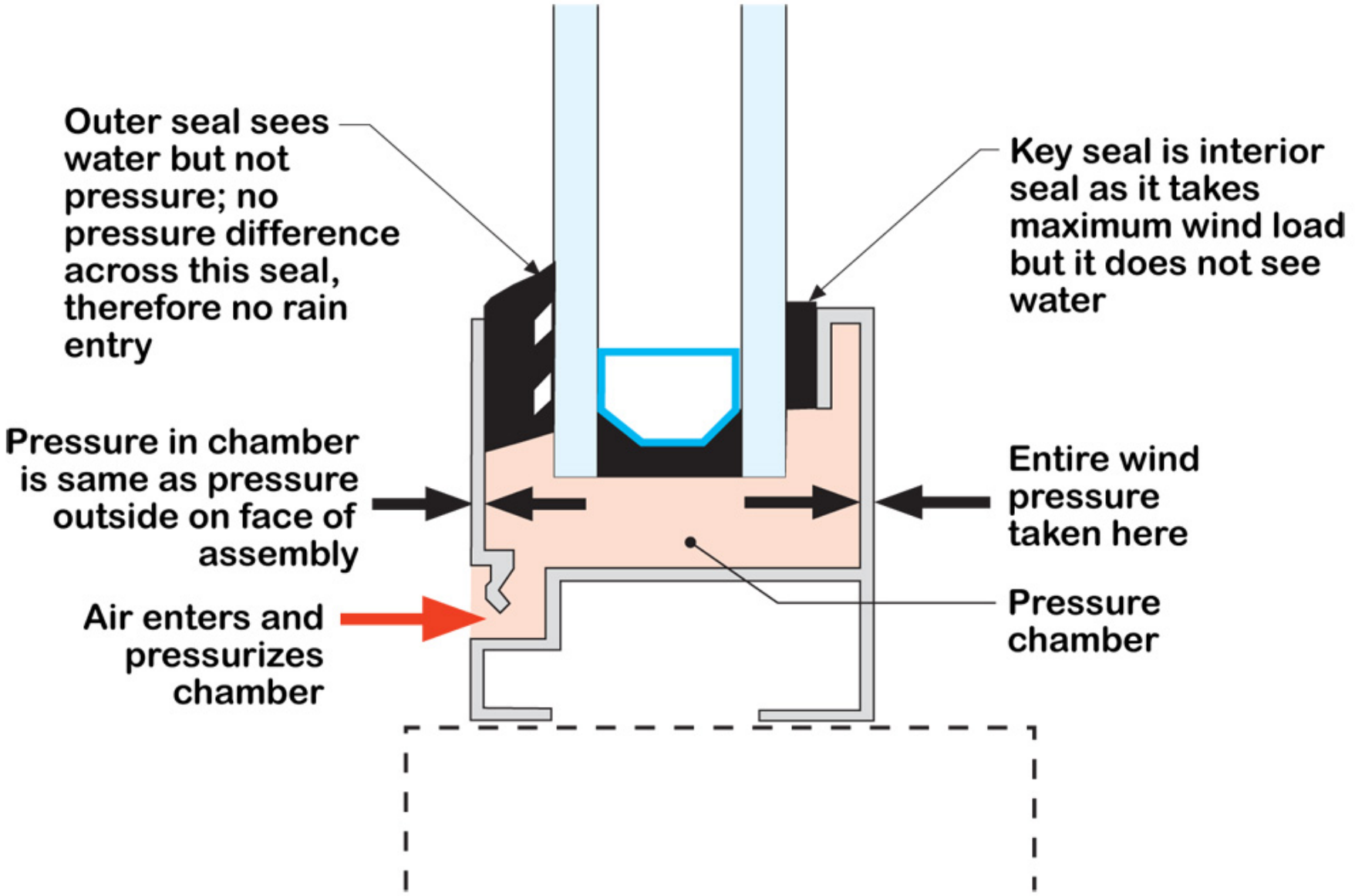


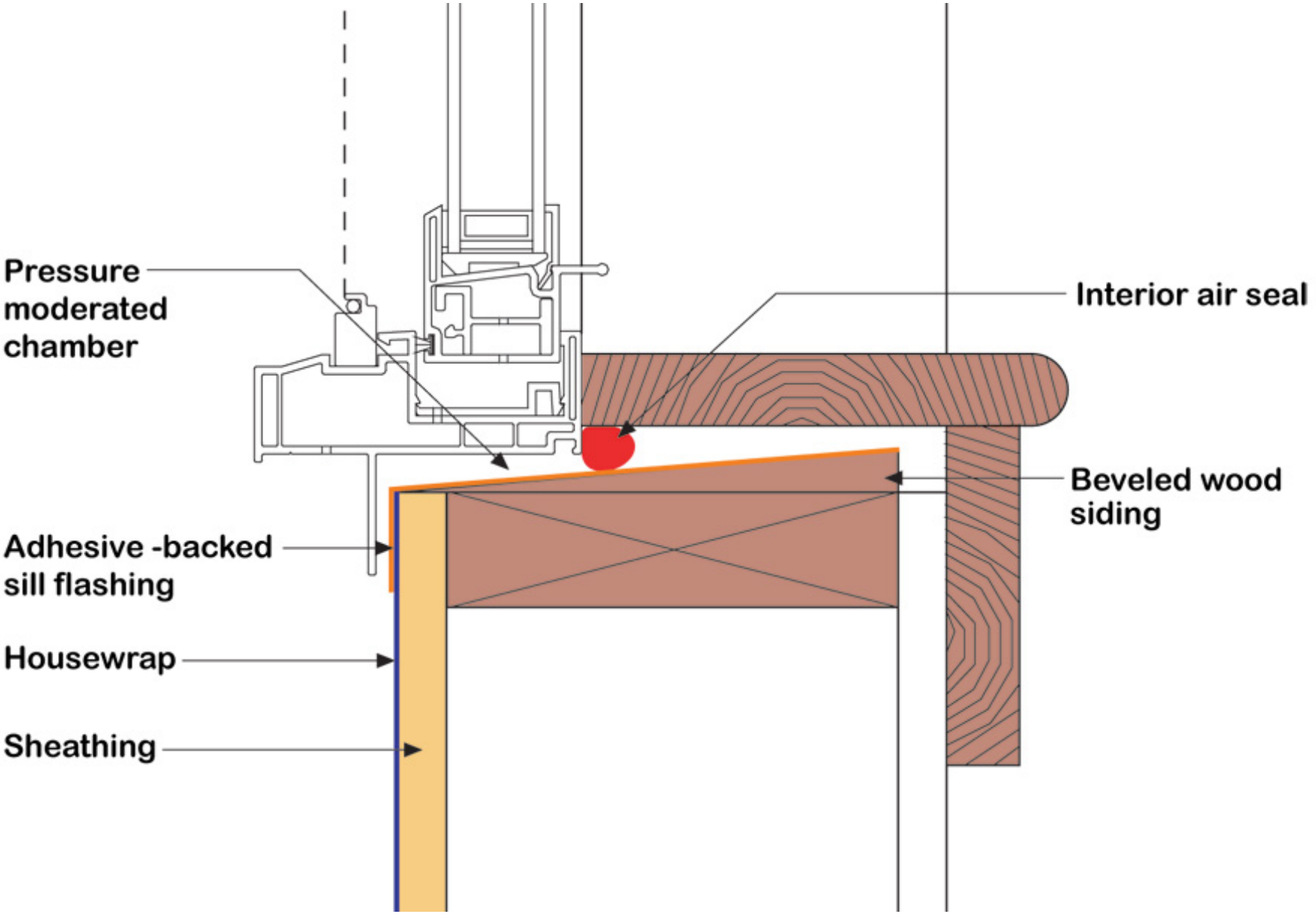
Cup drains water to exterior


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

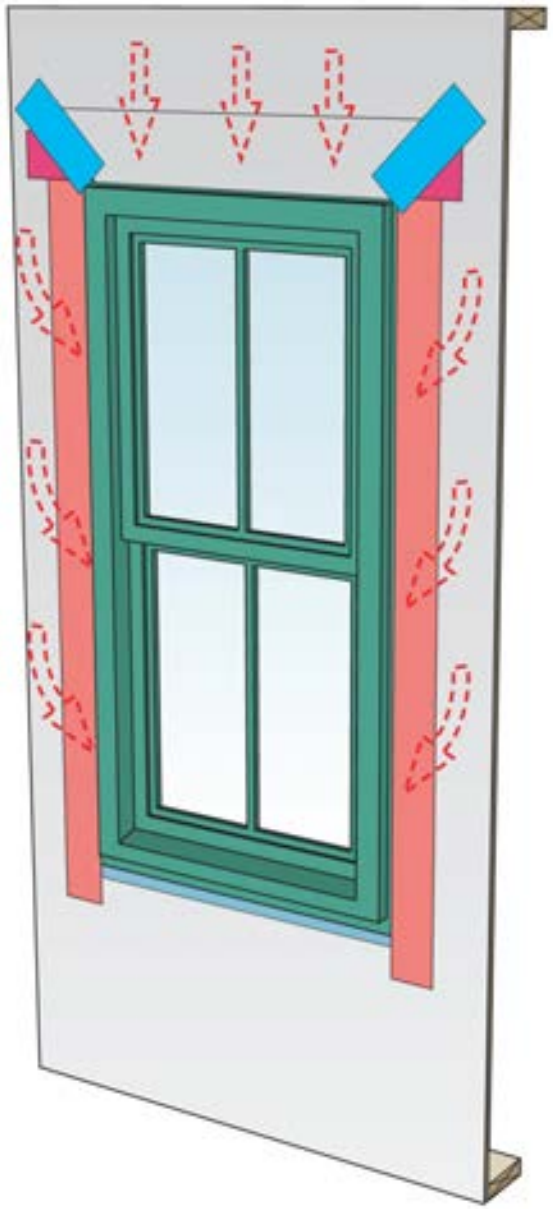

Baffle to deflect raindrops hitting face of cup due to momentum ("kinetic energy")
Pressure in cup is same as pressure outside on face of baffle
Momentum driving force converted to gravity— water drains away
Wind enters cup— pressurizing cup; no rain entry due to wind driven rain
Entire wind pressure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

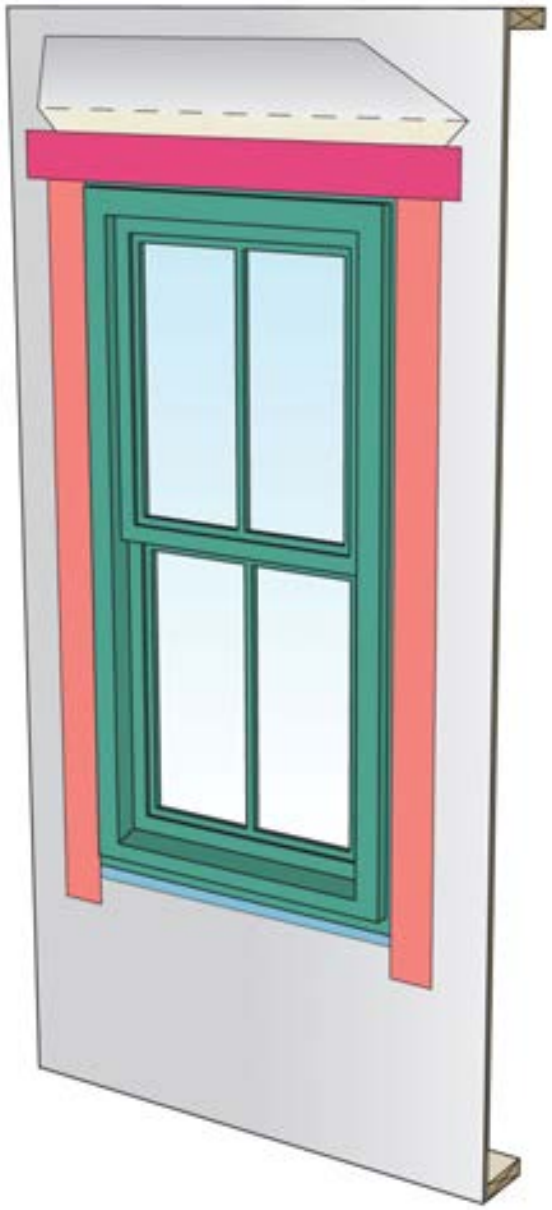

Insulating glass unit
Seal (gasket)
Seal (tape)
Setting block (typically two per unit)
Hole providing drainage and pressurization
Frame
Rough opening

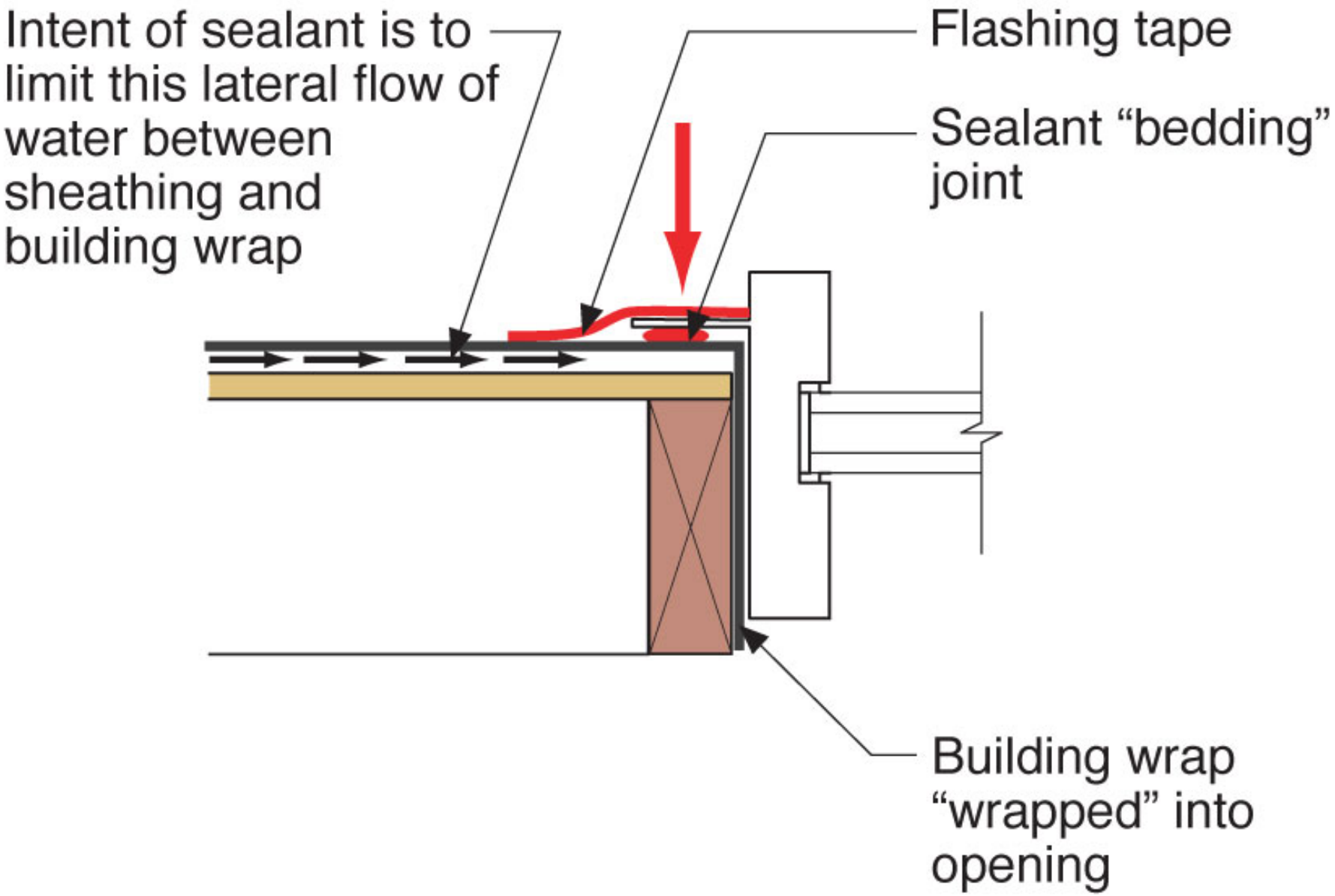

Outer seal sees water but not pressure; no pressure difference across this seal, therefore no rain entry
Key seal is interior seal as it takes maximum wind load but it does not see water
Pressure in chamber is same as pressure outside on face of assembly
Entire wind pressure taken here
Air enters and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

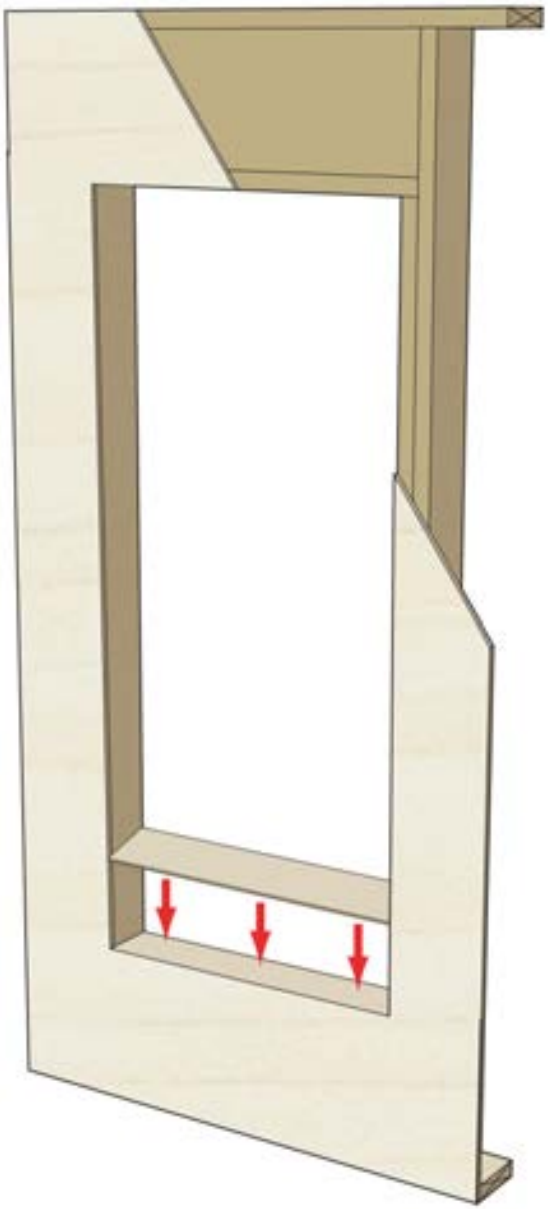

Pressure moderated chamber
Interior air seal
Beveled wood siding
Adhesive -backed sill flashing
Housewrap
Sheathing

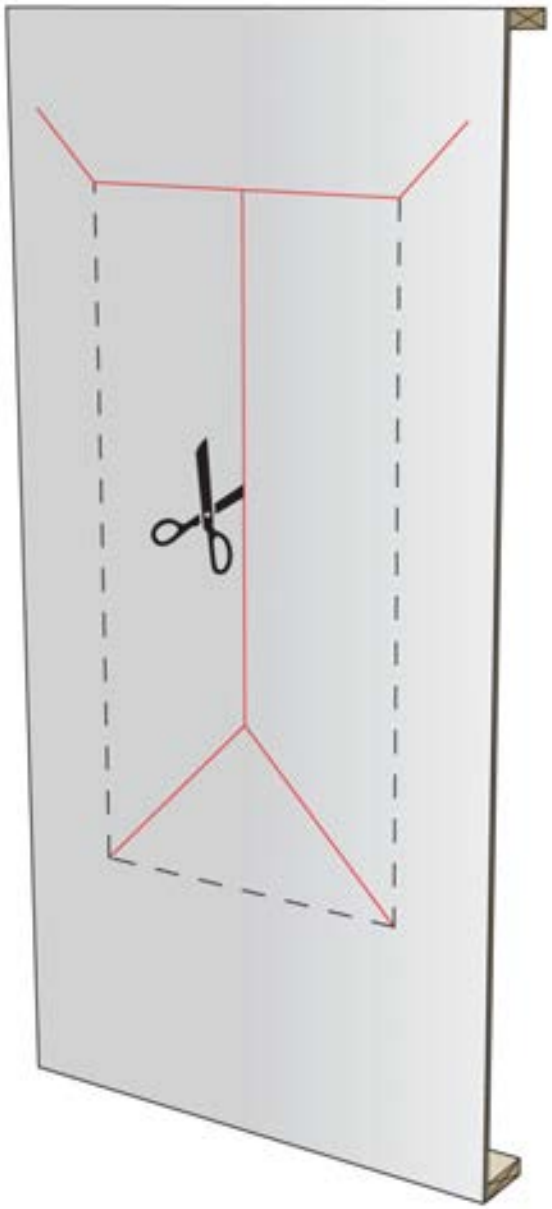

RCI

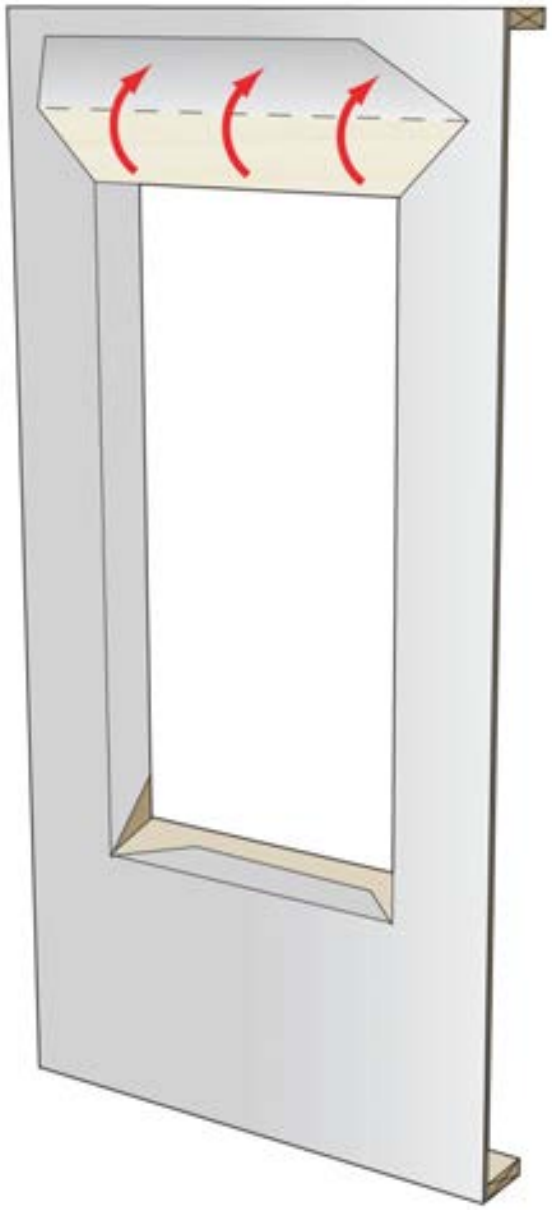


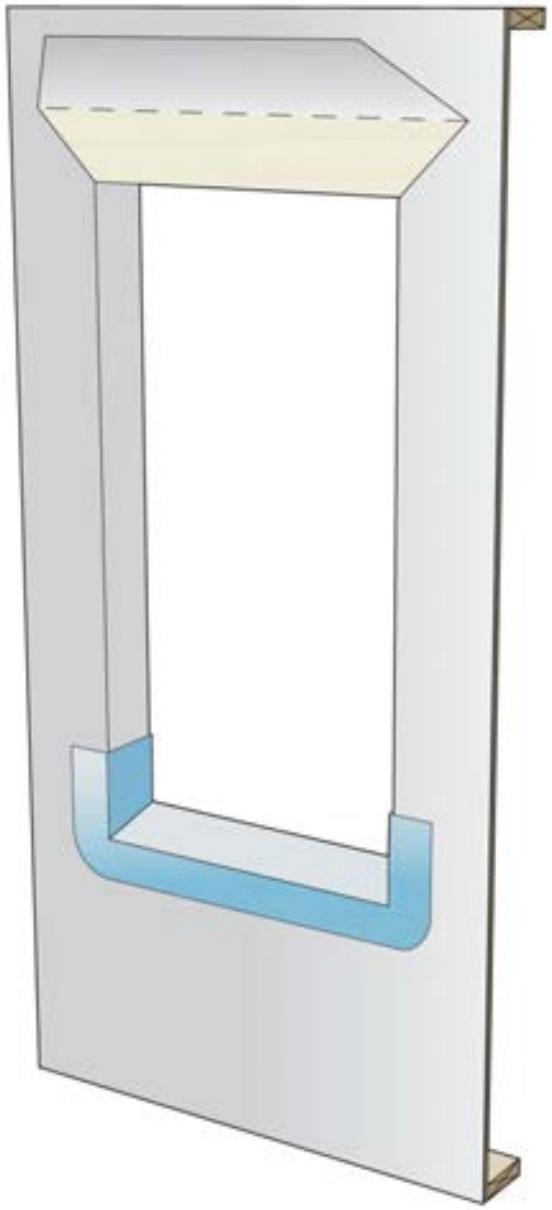


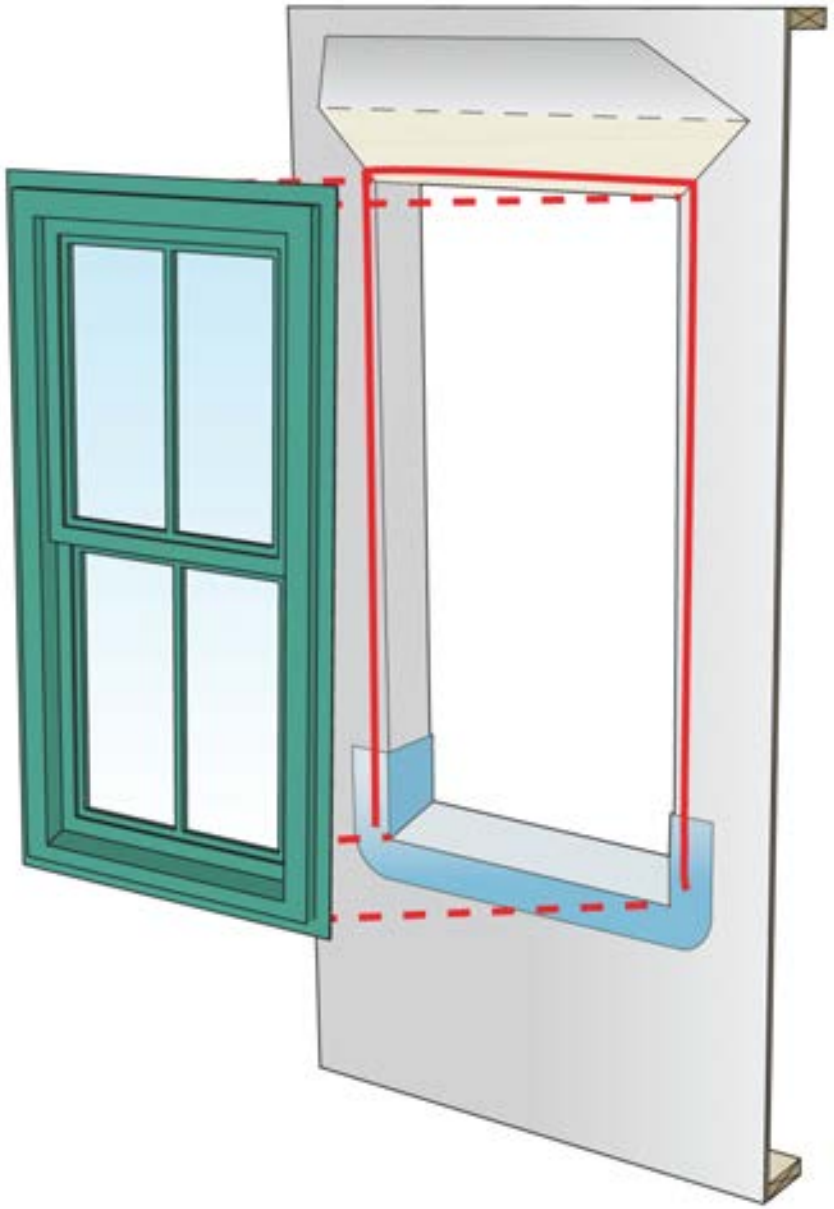

Intent of sealant is to limit this lateral flow of water between sheathing and building wrap
Flashing tape
Sealant “bedding” joint
Building wrap “wrapped” into opening

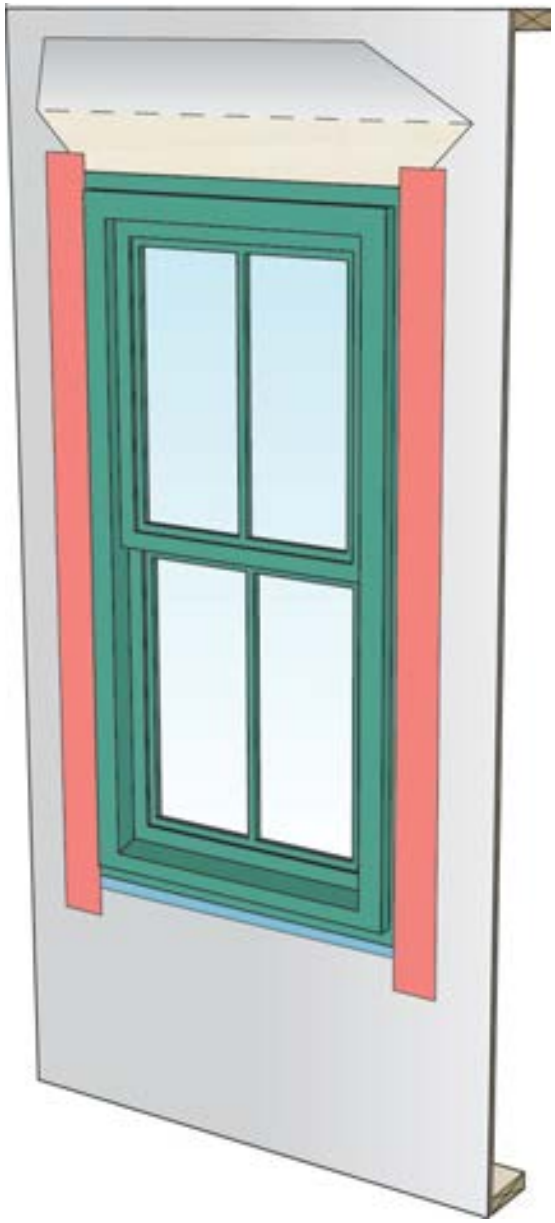


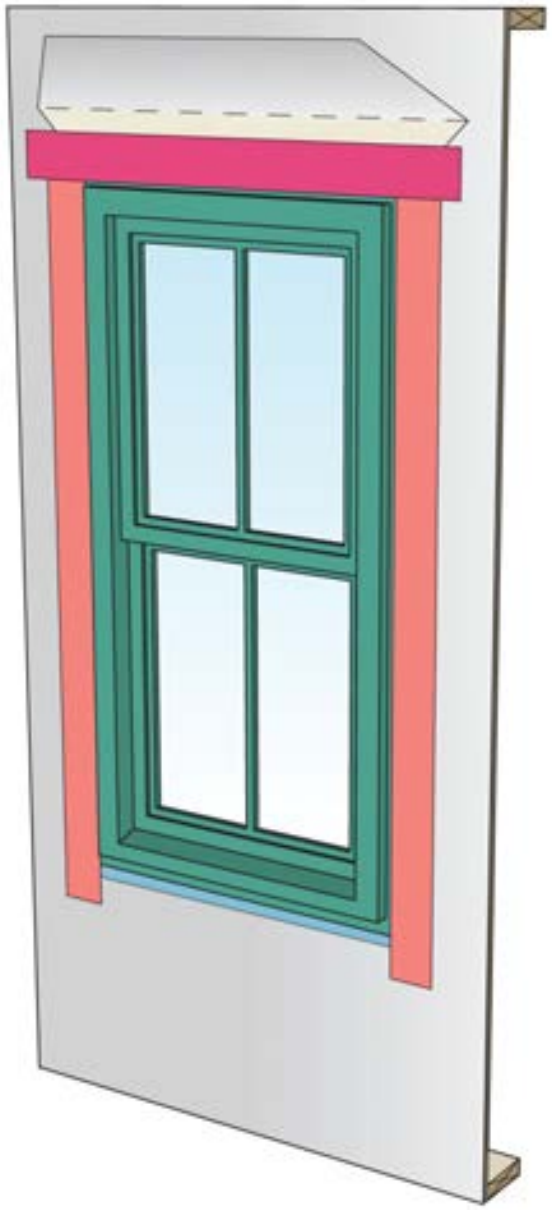


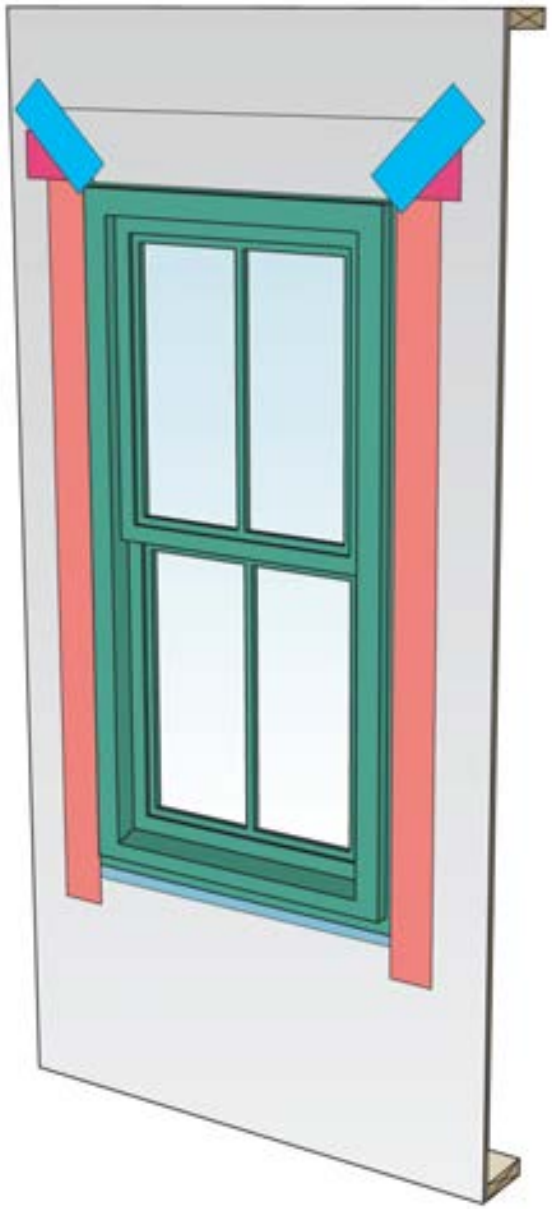


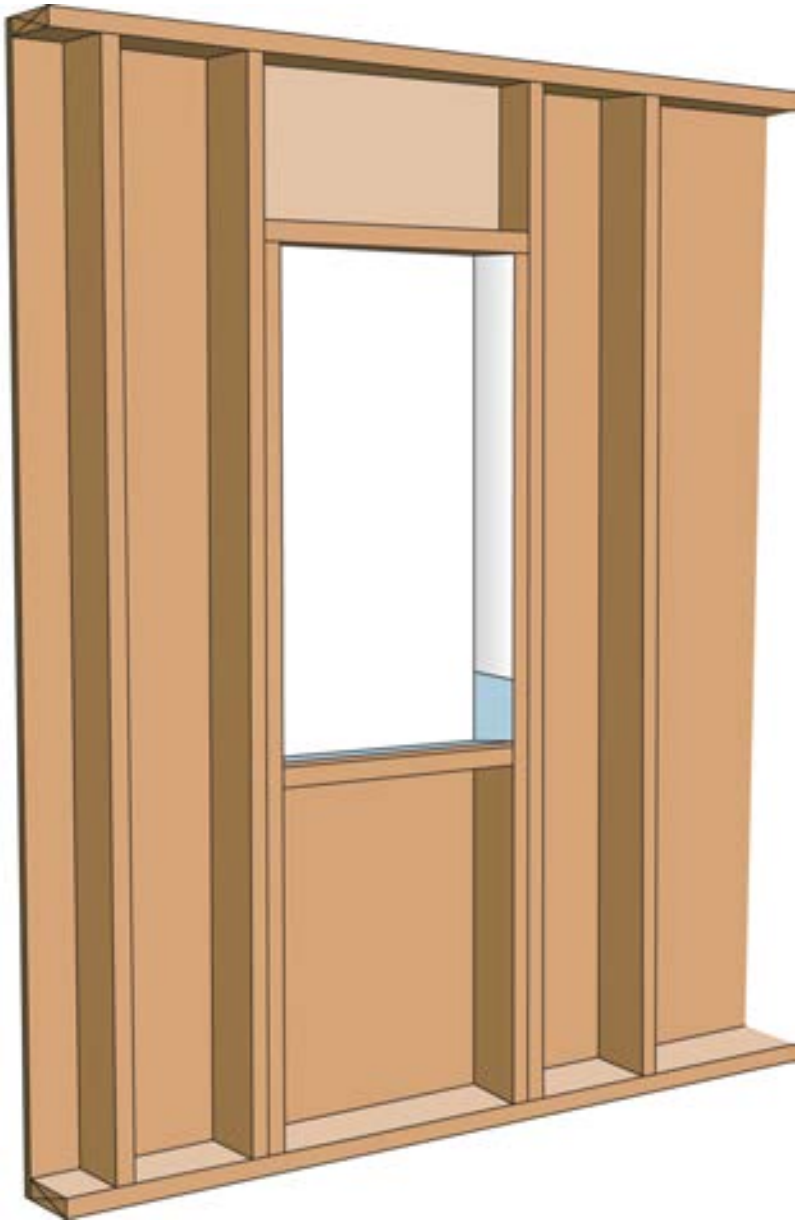


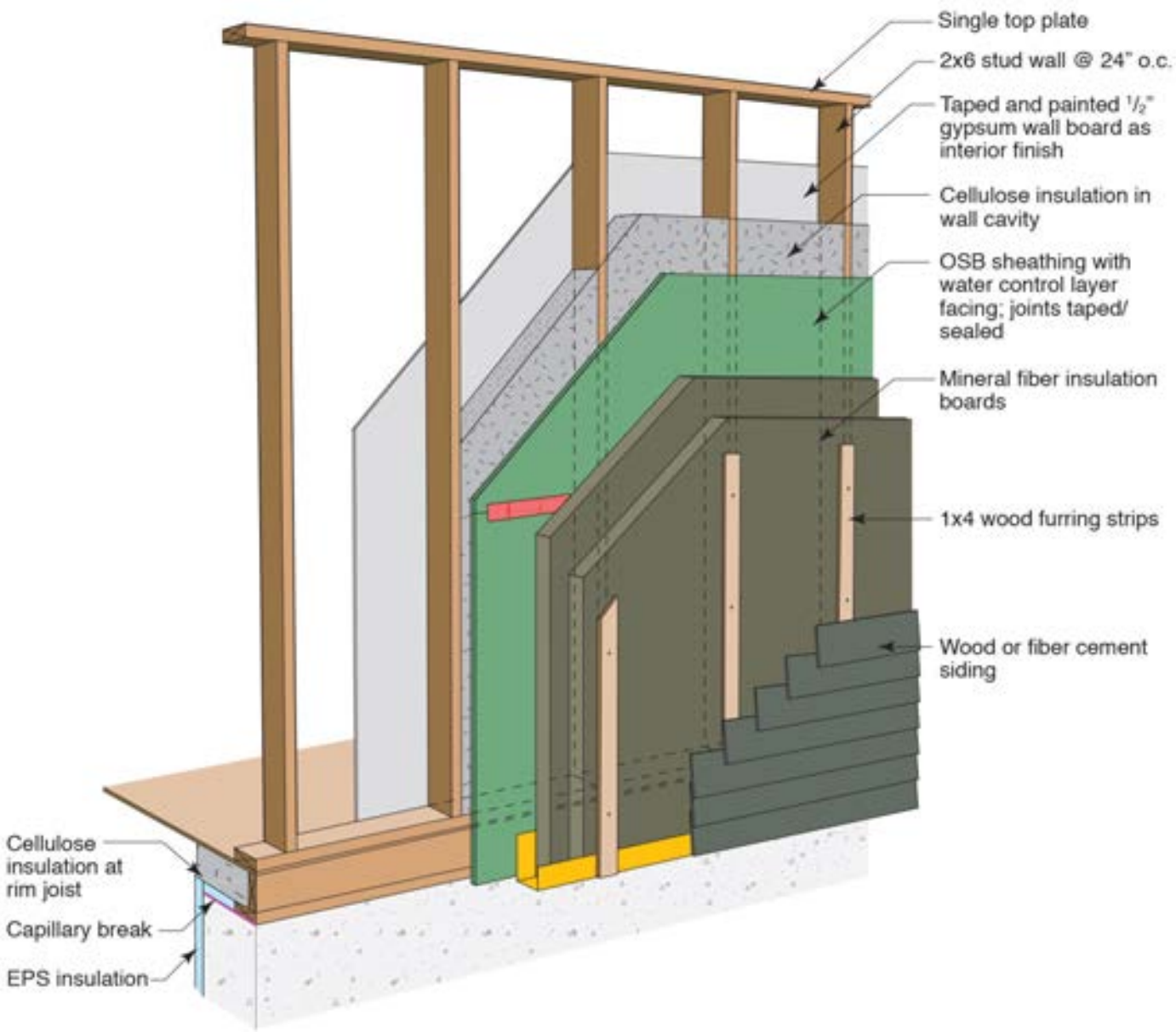


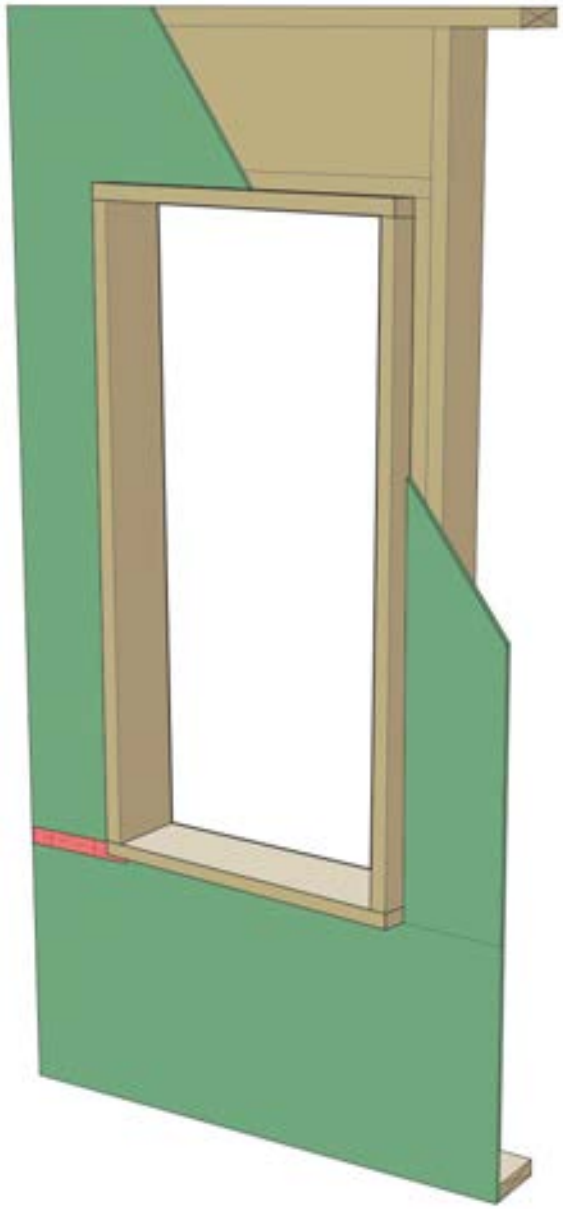


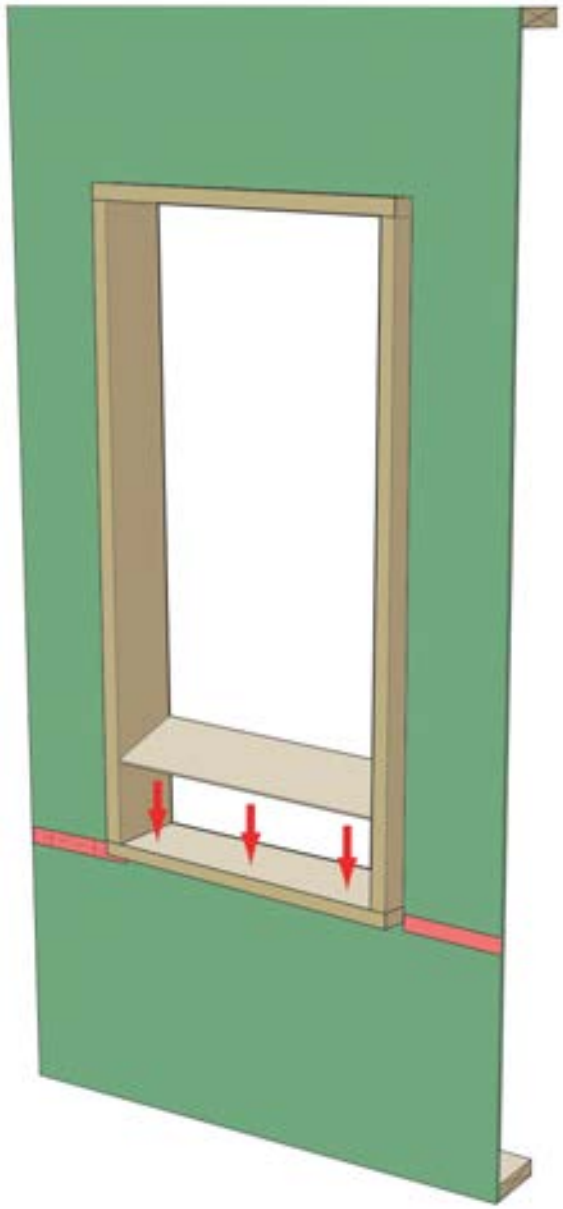


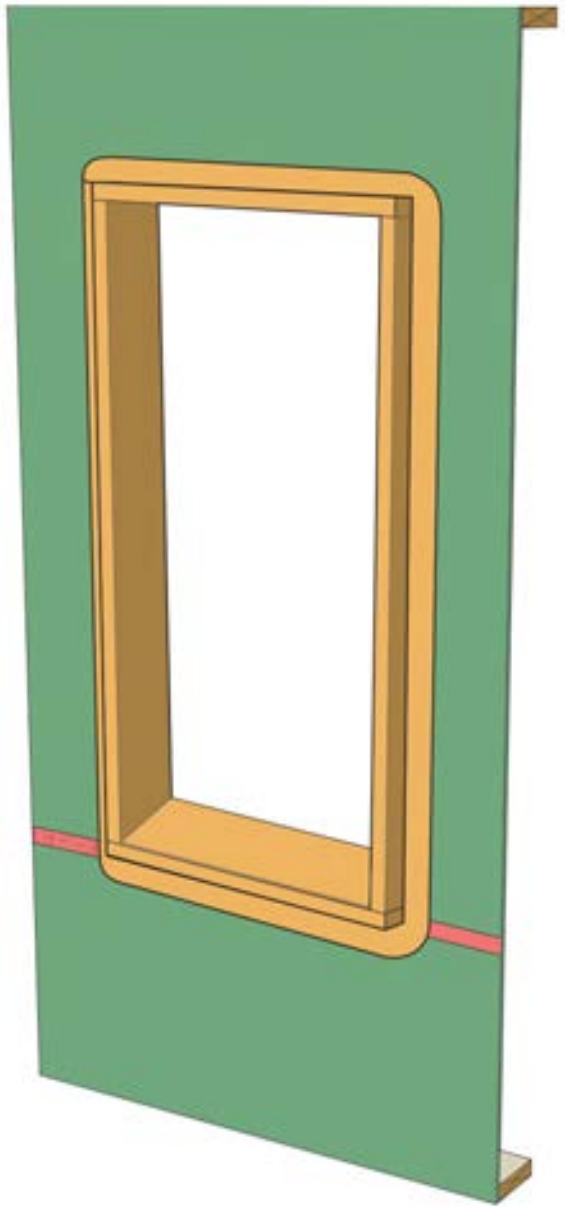


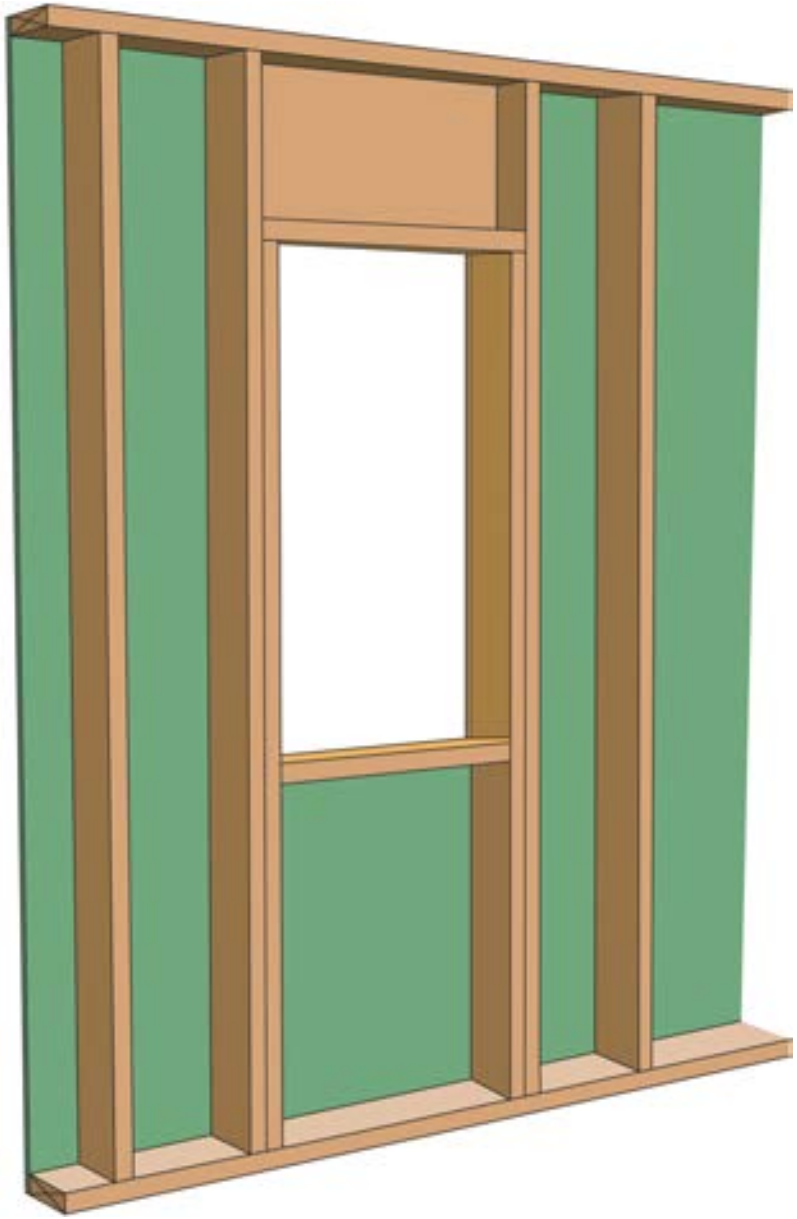


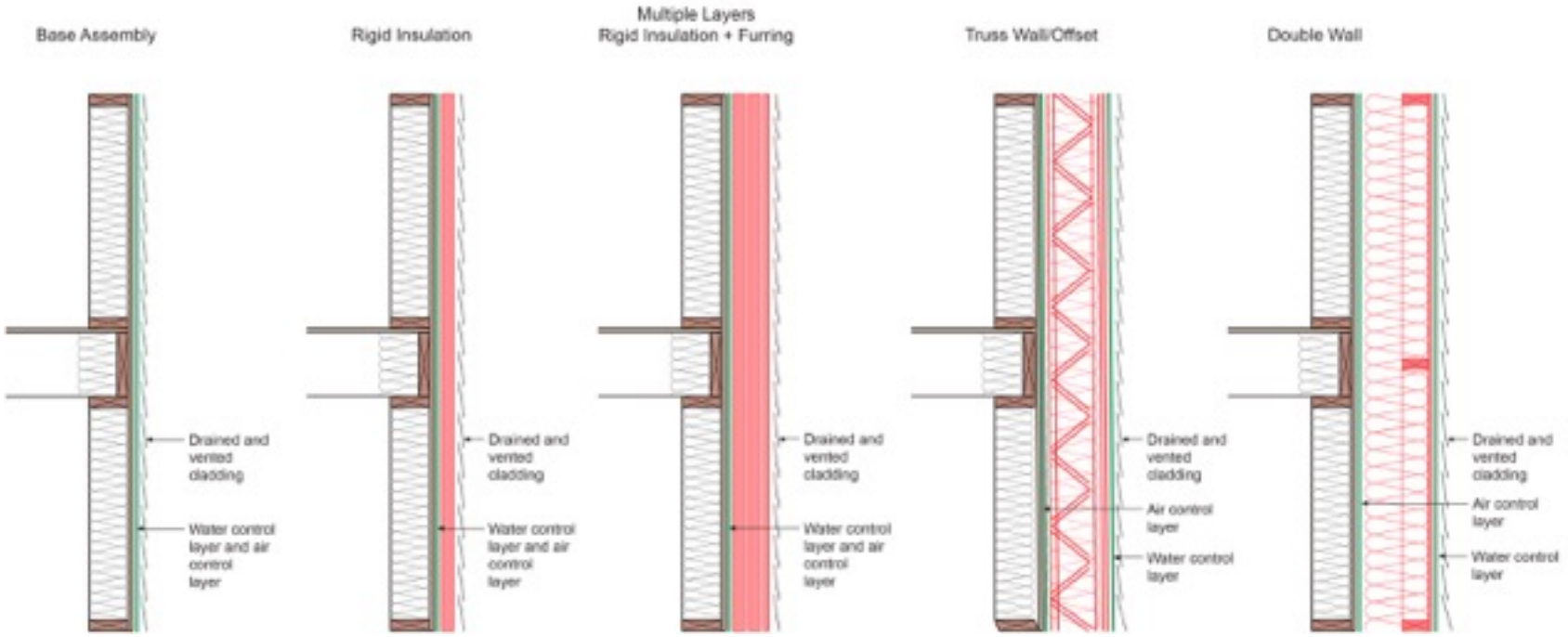

Single top plate
2x6 stud wall @ 24" o.c.
Taped and painted ½" gypsum wall board as interior finish
Cellulose insulation in wall cavity
OSB sheathing with water control layer facing; joints taped/ sealed
Mineral fiber insulation boards
1x4 wood furring strips
Wood or fiber cement siding
Cellulose insulation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







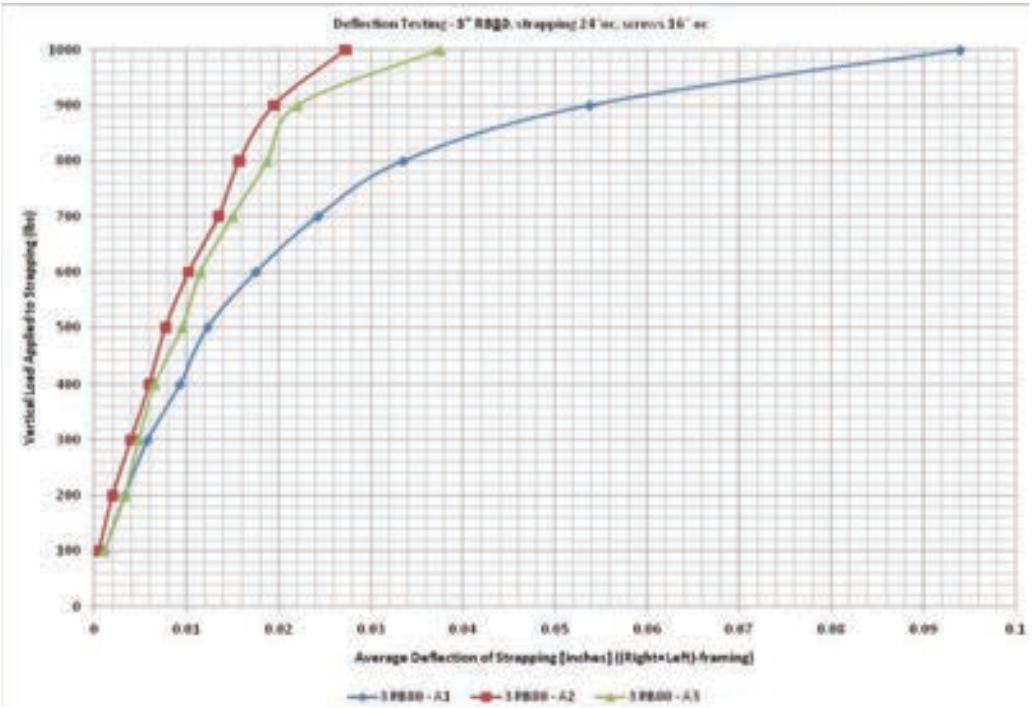


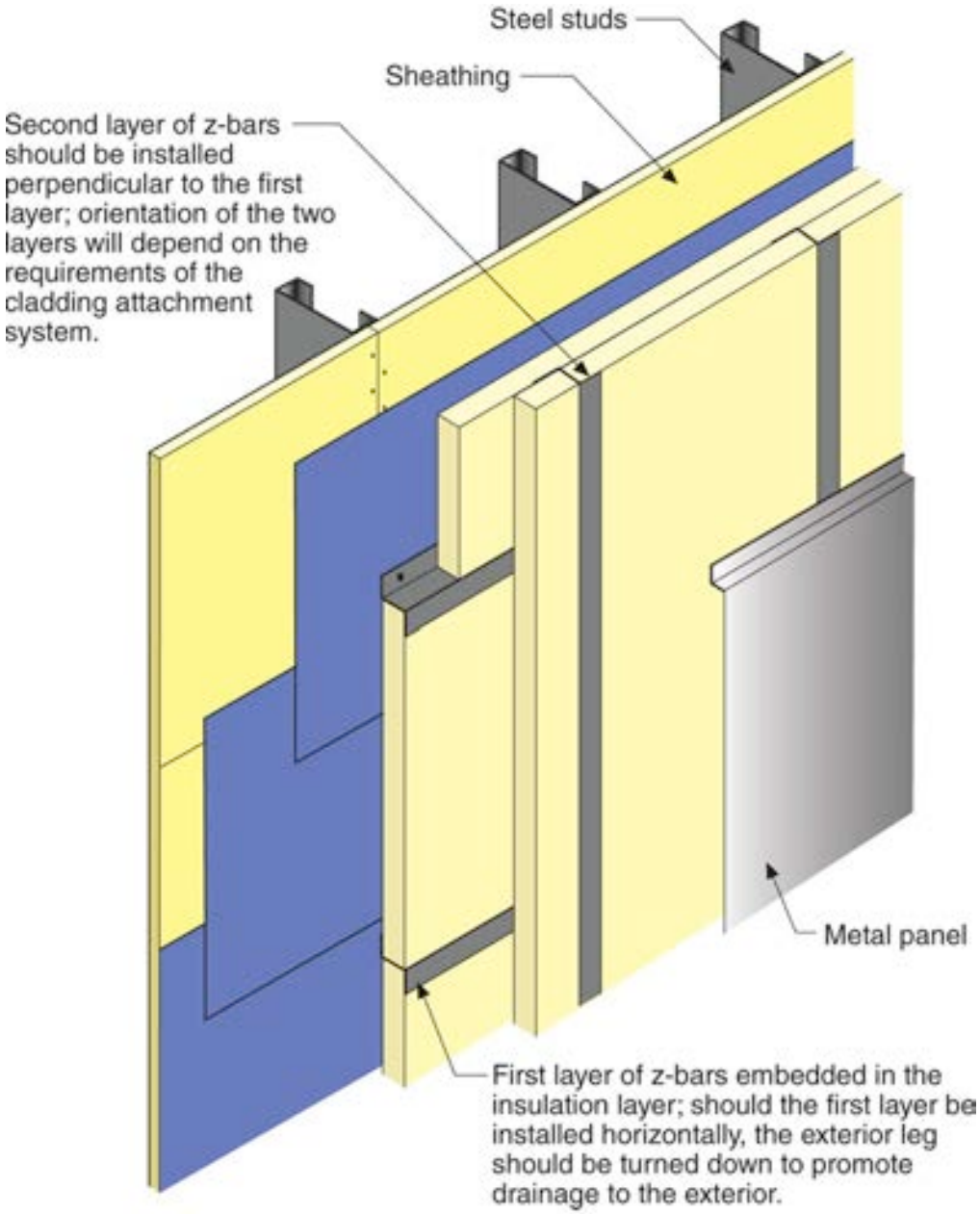

Base Assembly
Drained and vented cladding
Water control layer and air control layer
Rigid Insulation
Drained and vented cladding
Water control layer and air control layer
Multiple Layers
Rigid Insulation + Furring
Drained and vented cladding
Water control layer and air control layer
Truss Wall/Offset
Drained and vented cladding
Air control layer
Water control layer
Double Wall
Drained and vented cladding
Air control layer
Water control layer

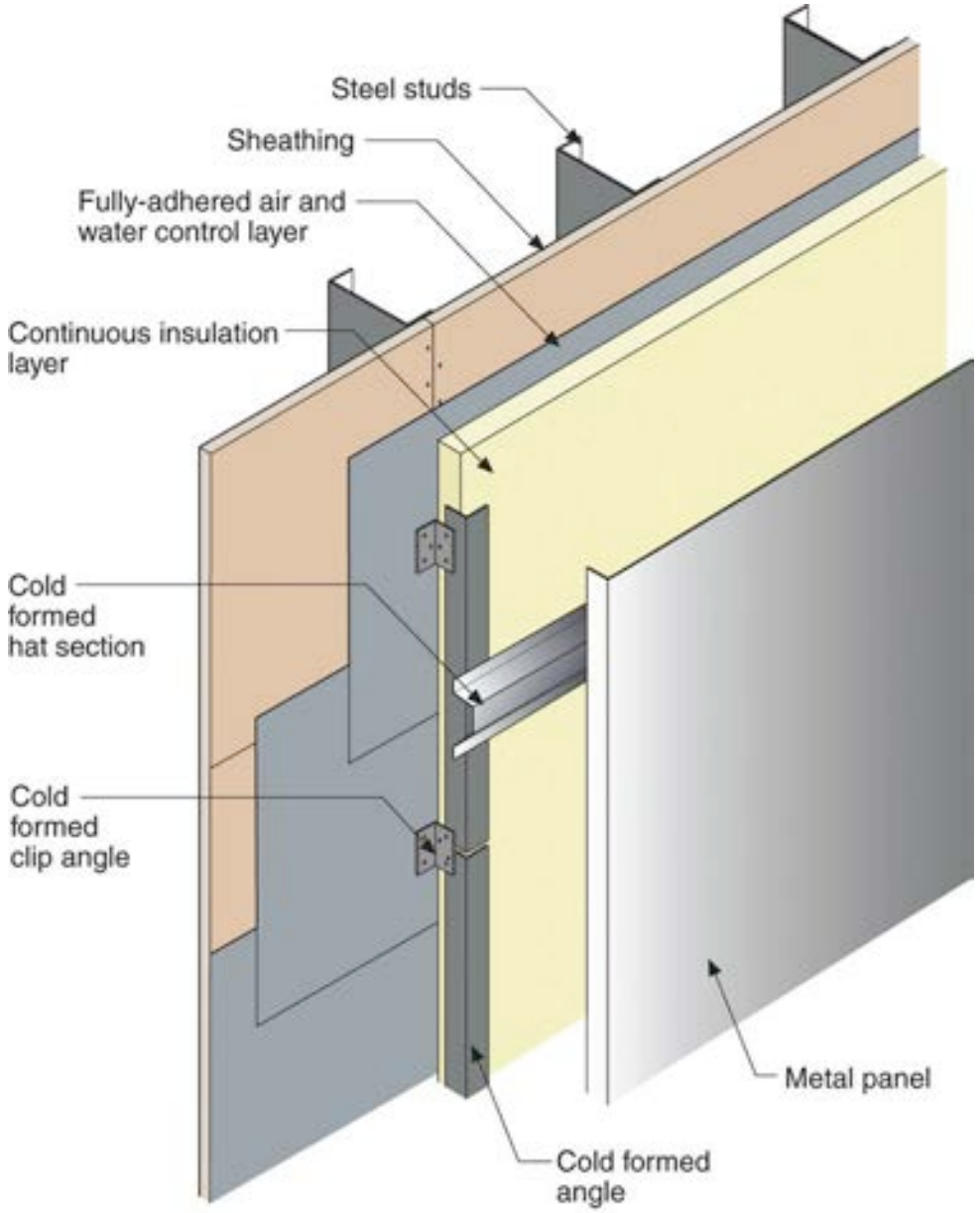

PlastiSpan HD
R8
EcoLogic

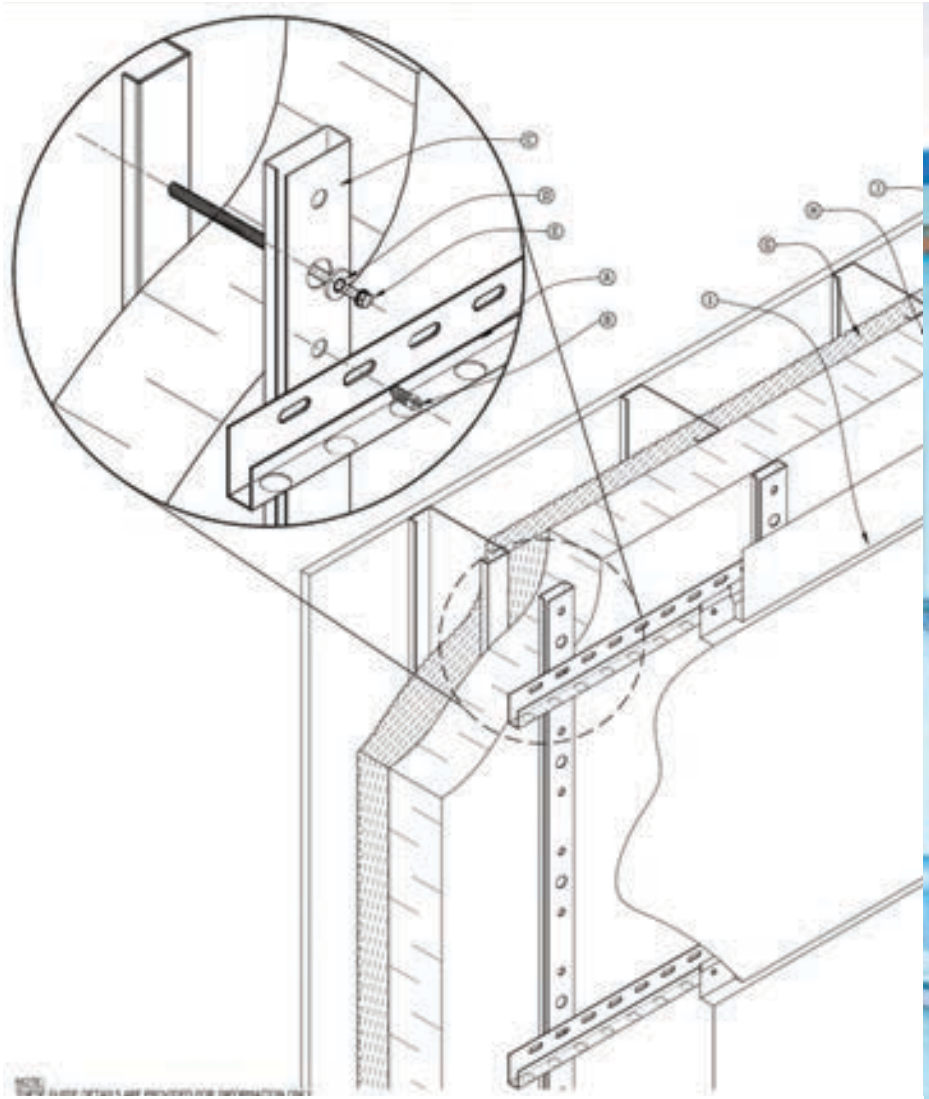
Rockwool

1x3 furring @ 24” o.c.
#10 screws @ 16” o.c. vertically
Result: 20 psf cladding weight
with < 2/100” deflection

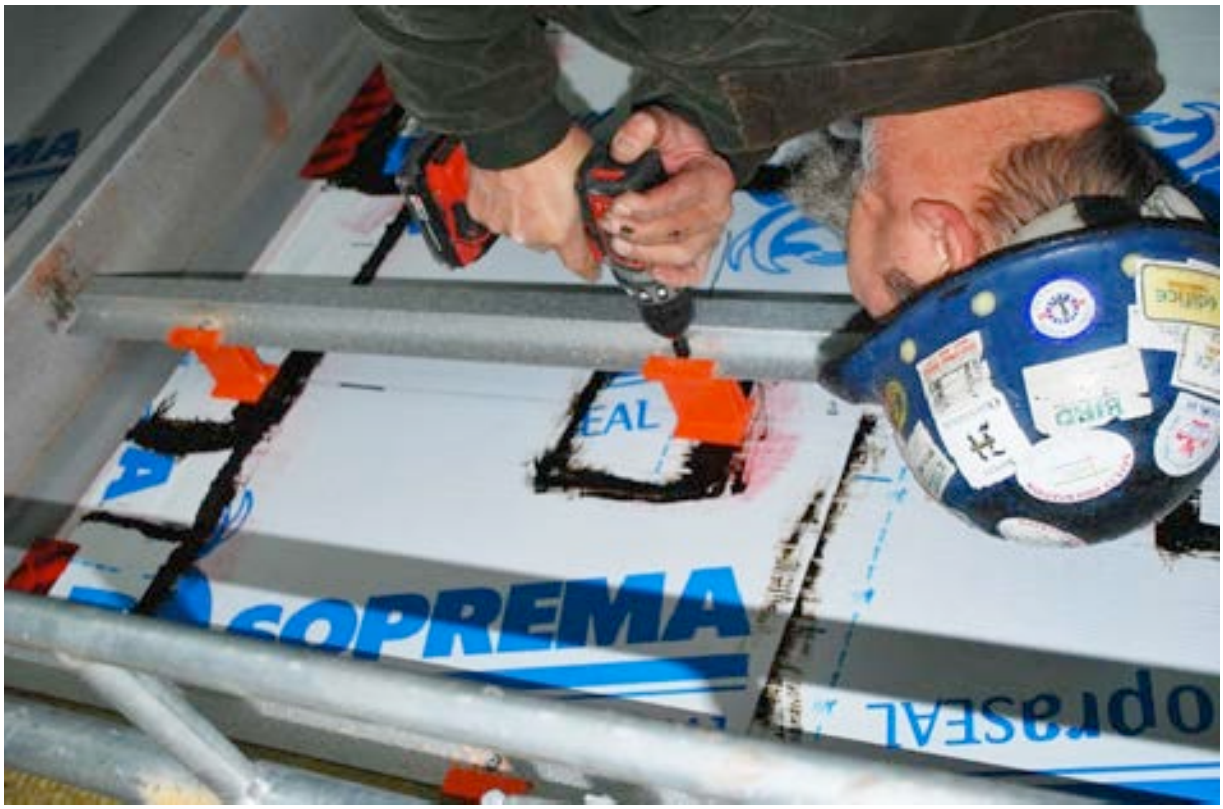



Steel studs
Sheathing
Second layer of z-bars should be installed perpendicular to the first layer; orientation of the two layers will depend on the requirements of the cladding attachment system.
Metal panel
First layer of z-bars embedded in the insulation layer; should the first layer be installed horizontally, the exterior leg should be turned down to promote drainage to the exterior.

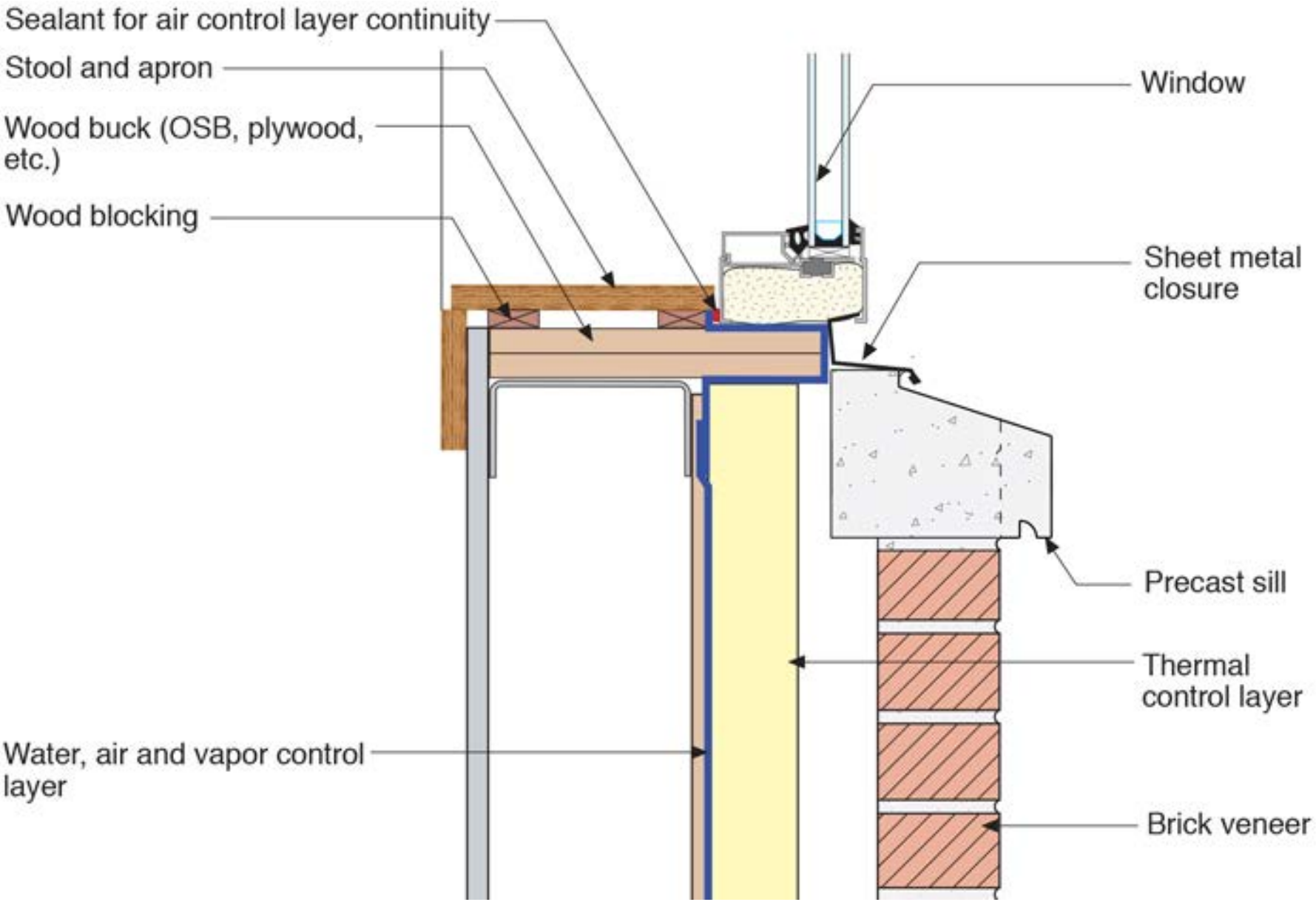

Steel studs
Sheathing
Fully-adhered air and water control layer
Continuous insulation layer
Cold formed hat section
Cold formed clip angle
Metal panel
Cold formed angle

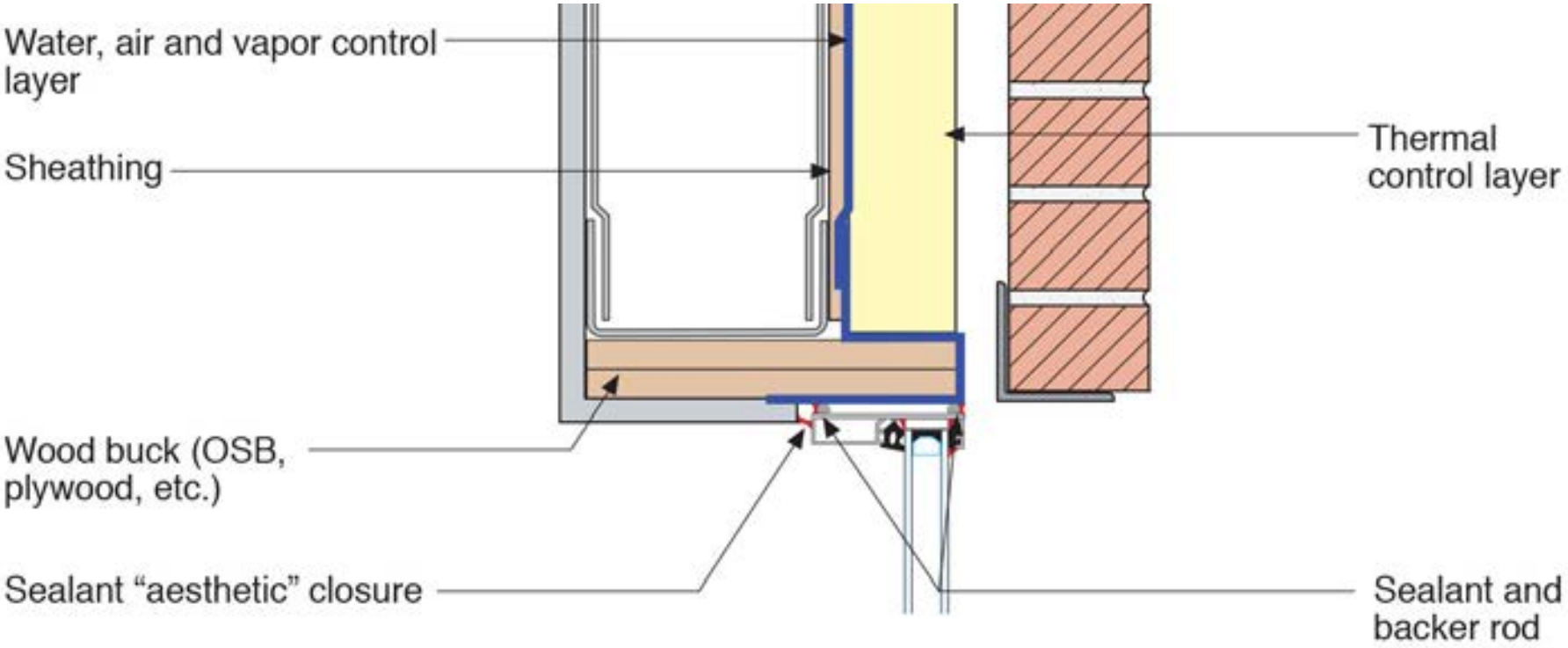



DOW
Thermax ci
Exterior Insulation

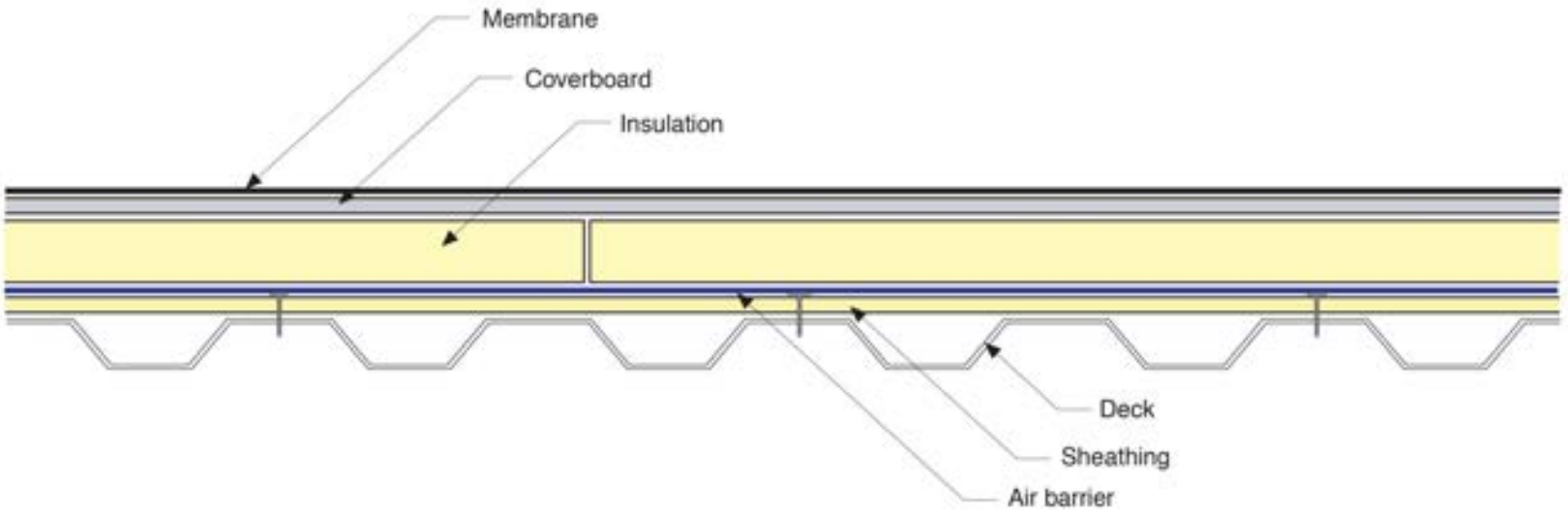

SOPREMA

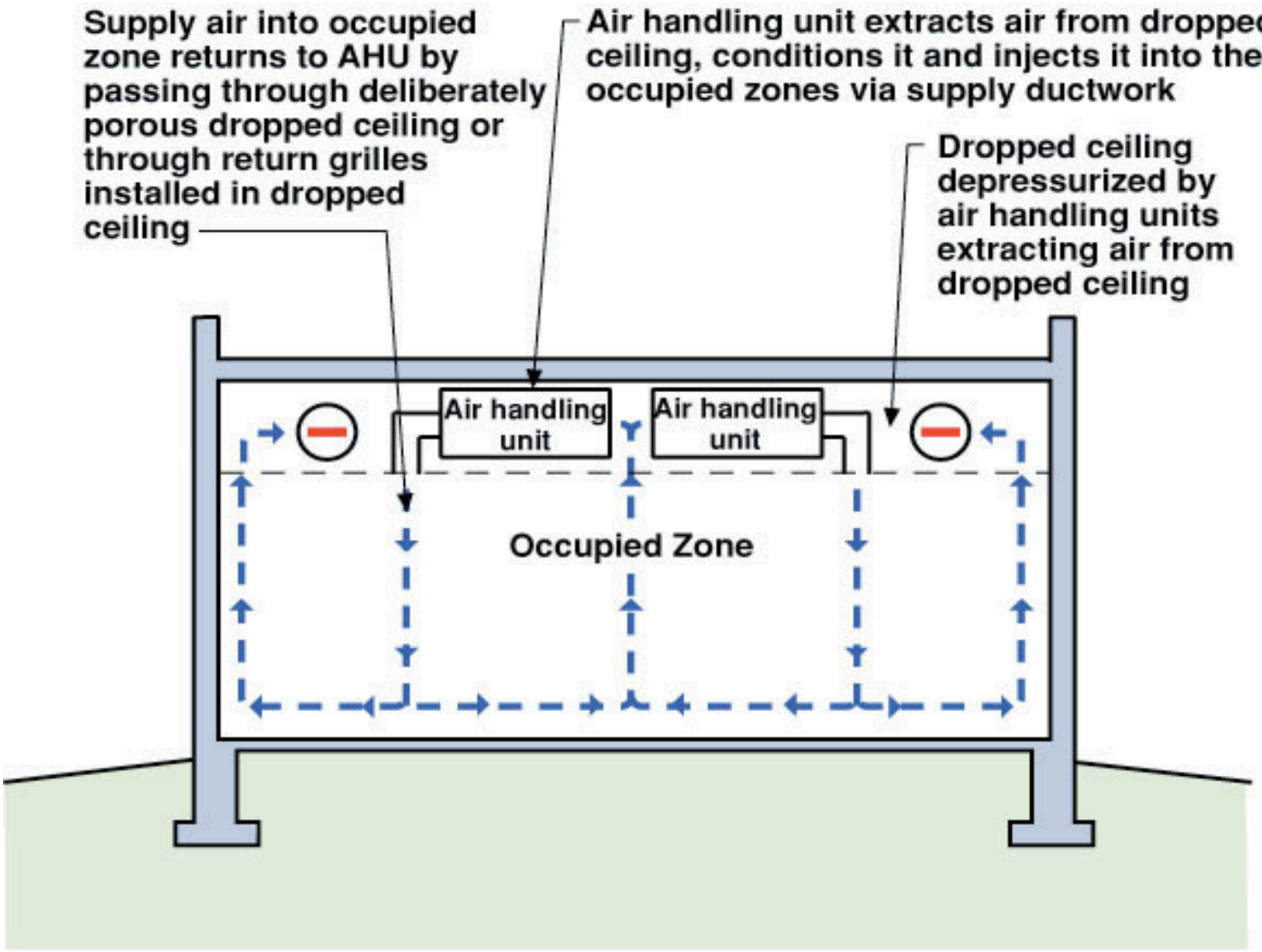

THIS SIDE
THIS SIDE

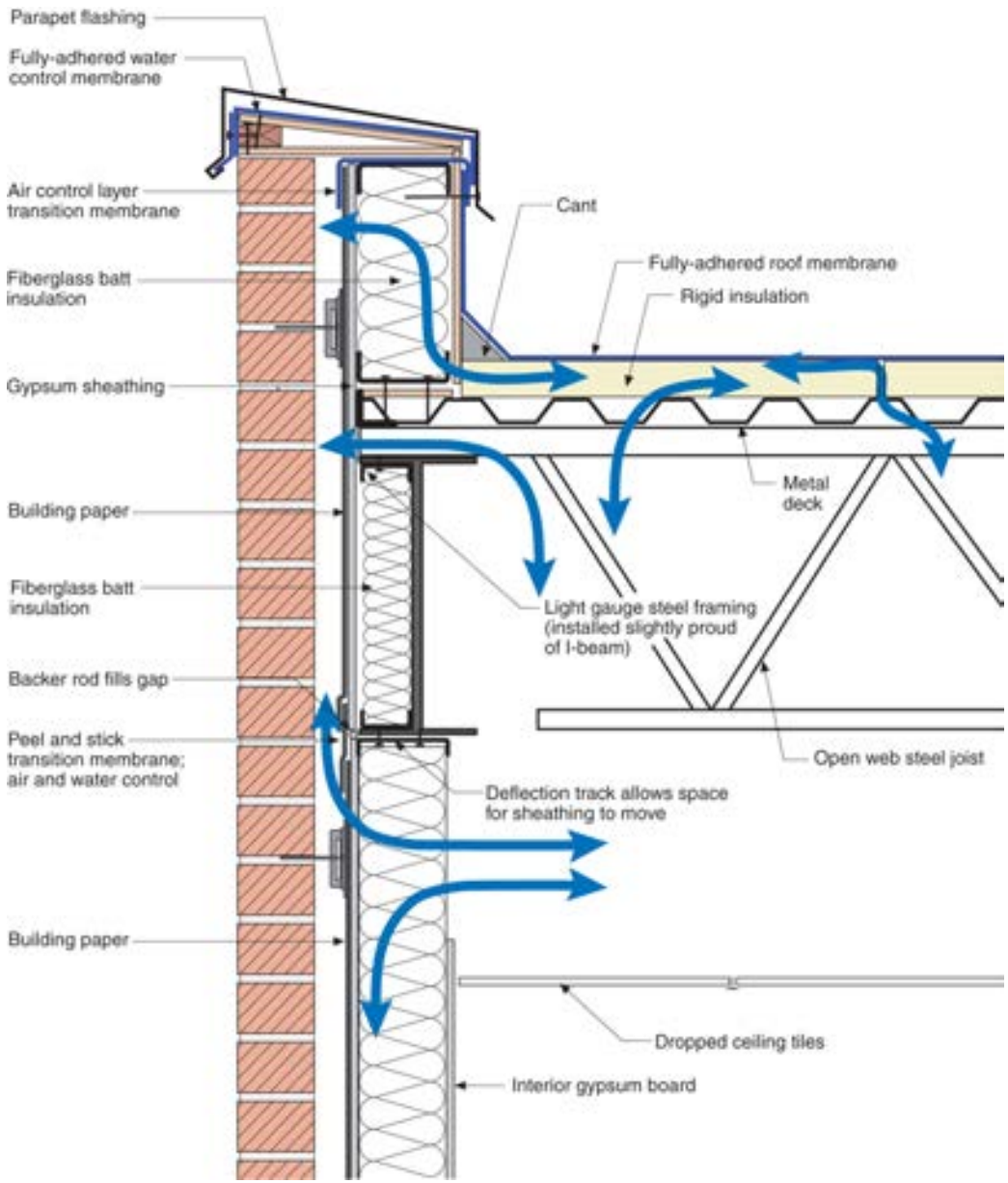

Sealant for air control layer continuity
Stool and apron
Wood buck (OSB, plywood, etc.)
Wood blocking
Window
Sheet metal closure
Precast sill
Thermal control layer
Water, air and vapor control layer
Brick veneer

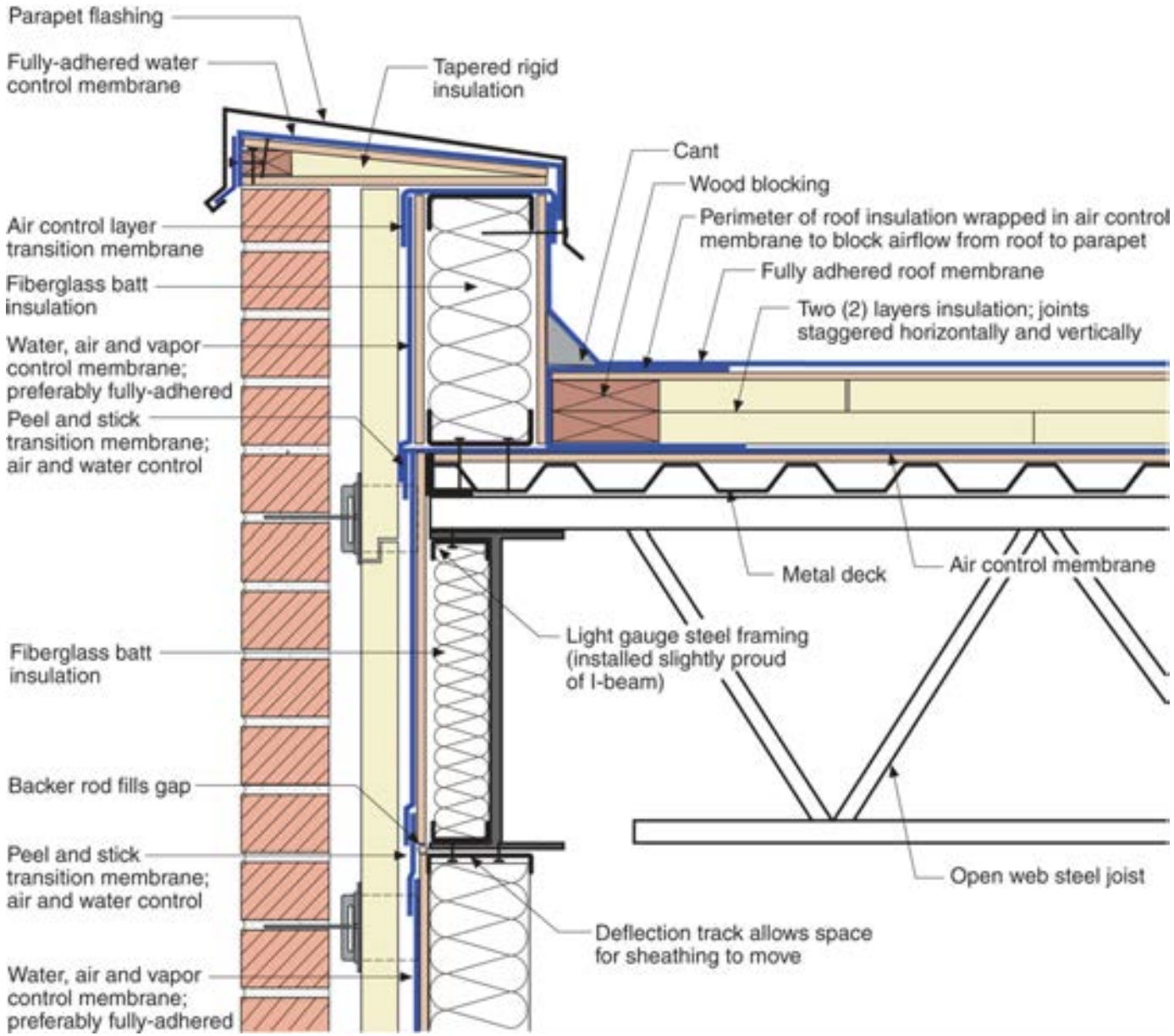

Water, air and vapor control layer
Sheathing
Wood buck (OSB, plywood, etc.)
Sealant “aesthetic” closure
Thermal control layer
Sealant and backer rod

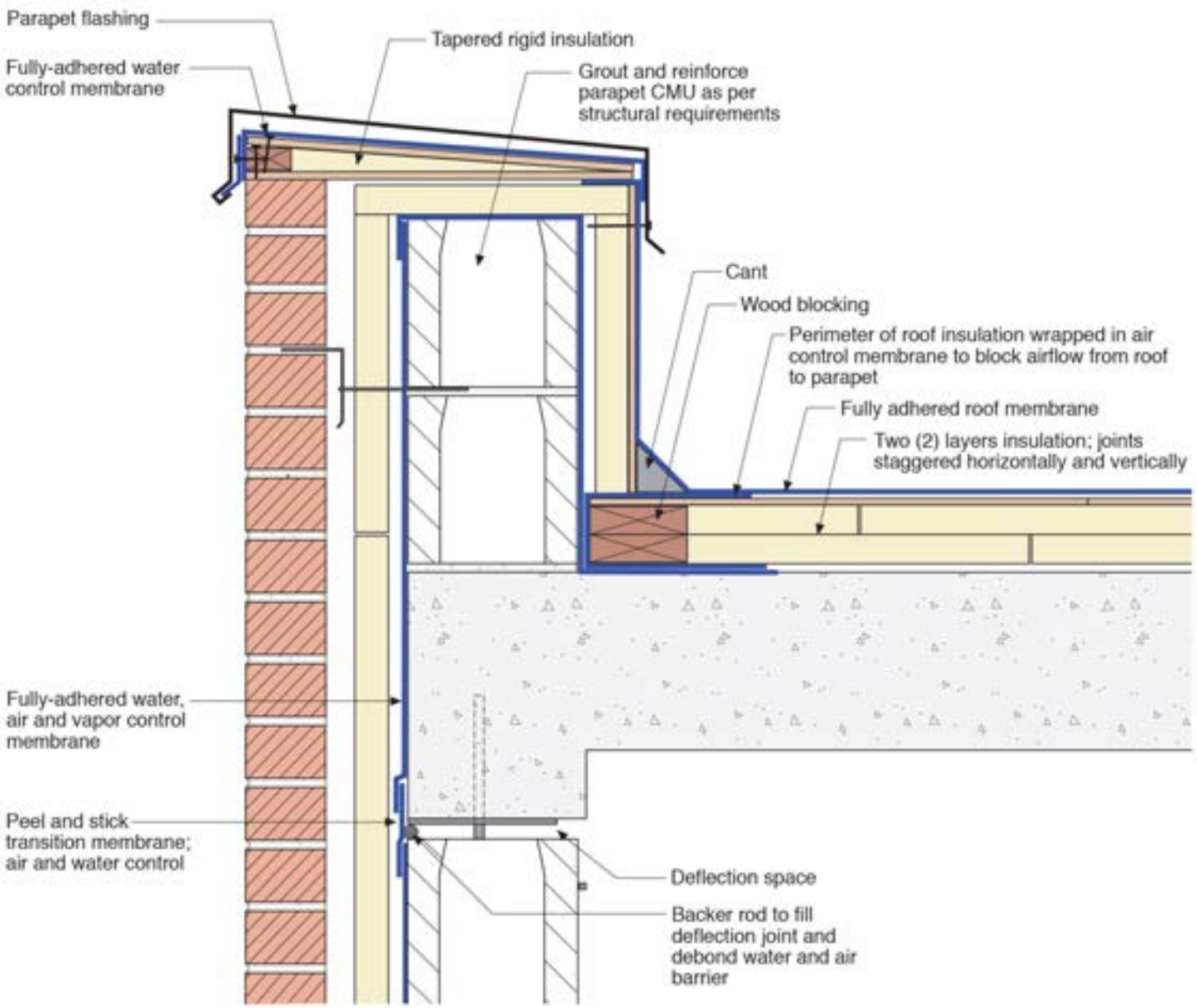
Air Leakage

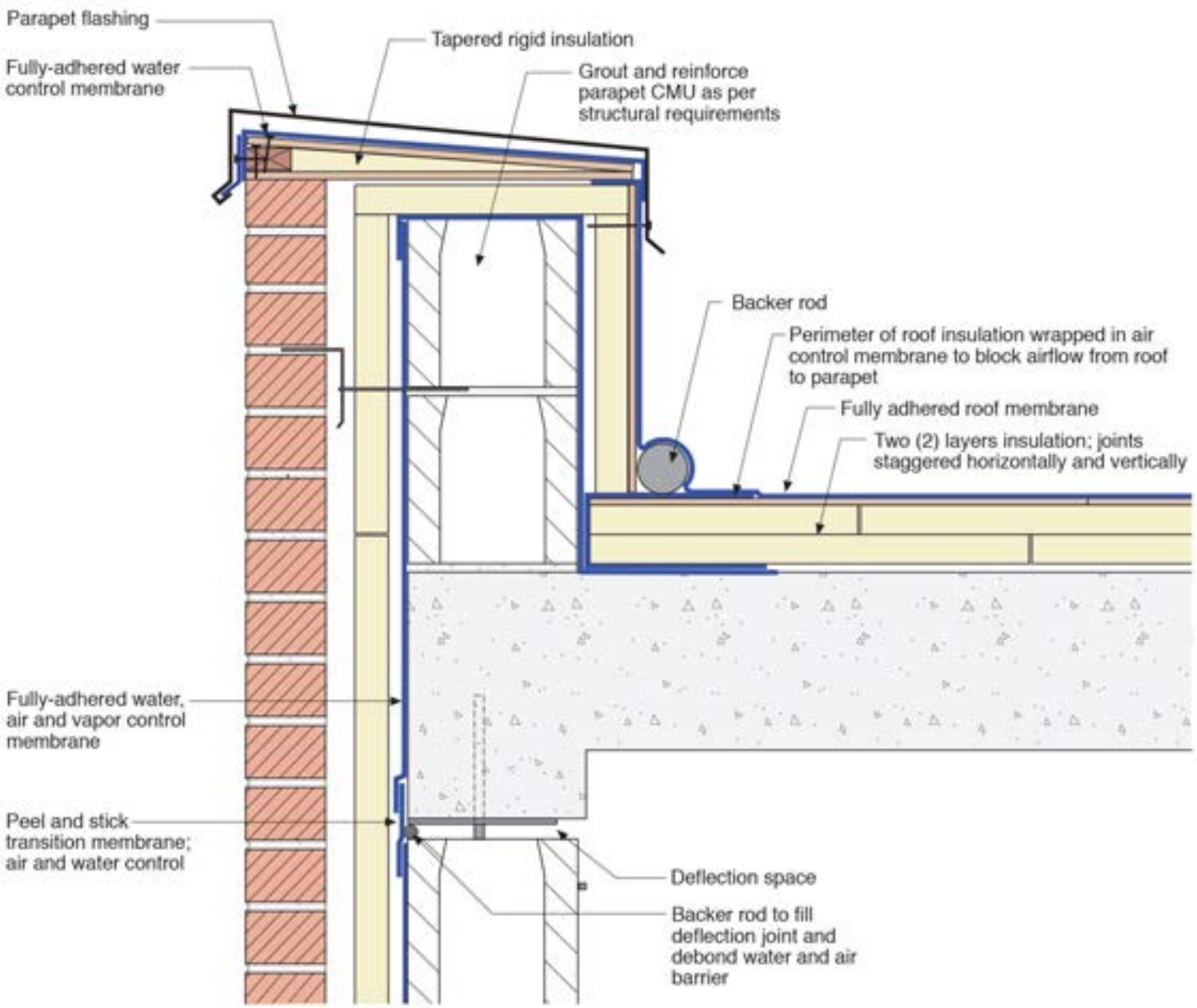

Membrane
Coverboard
Insulation
Deck
Sheathing
Air barrier

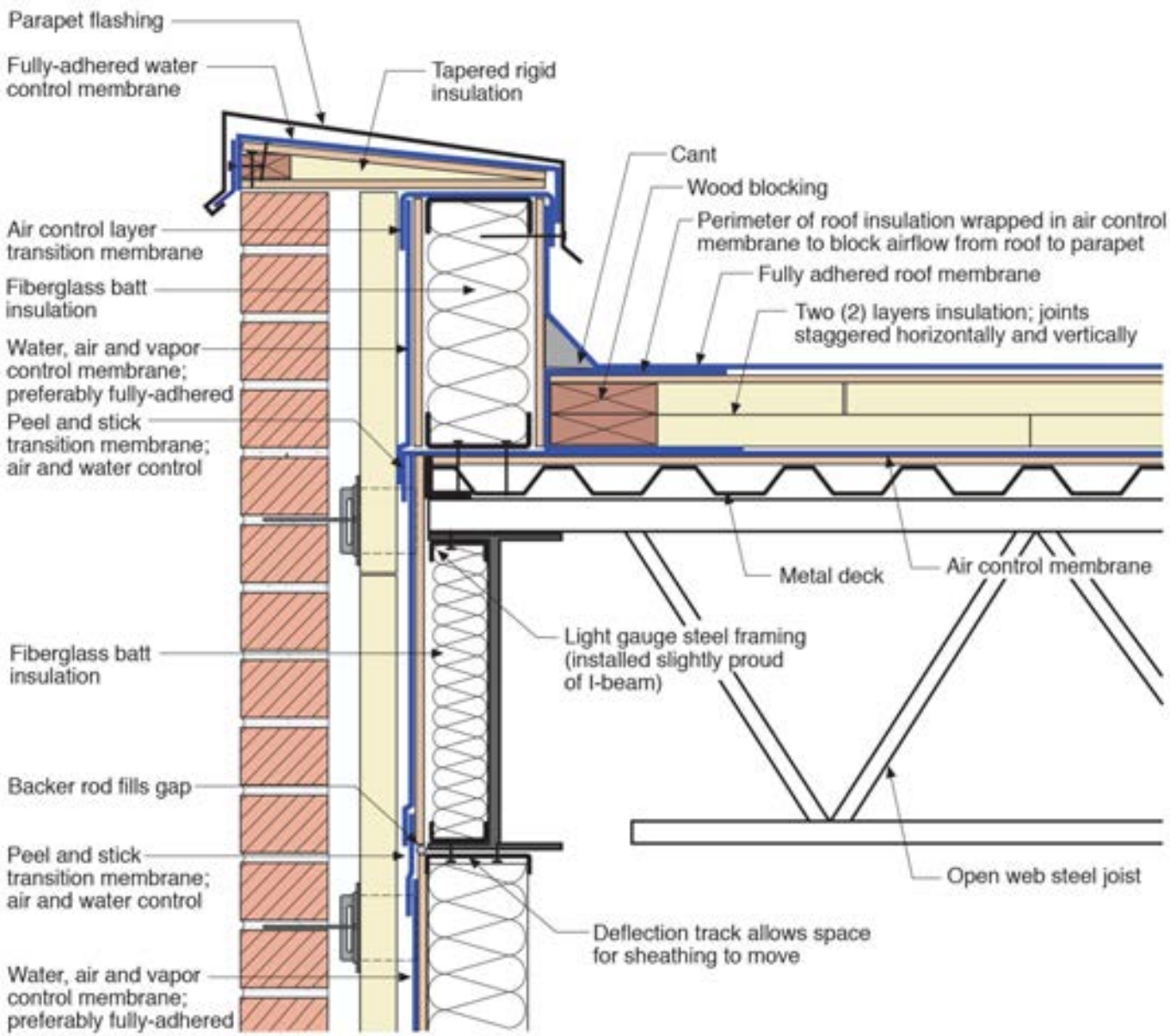

Supply air into occupied zone returns to AHU by passing through deliberately porous dropped ceiling or through return grilles installed in dropped ceiling
Air handling unit extracts air from dropped ceiling, conditions it and injects it into the occupied zones via supply ductwork
Dropped ceiling depressurized by air handling units extracting air from dropped ceiling
Air handling unit
Air handling unit
Occupied Zone

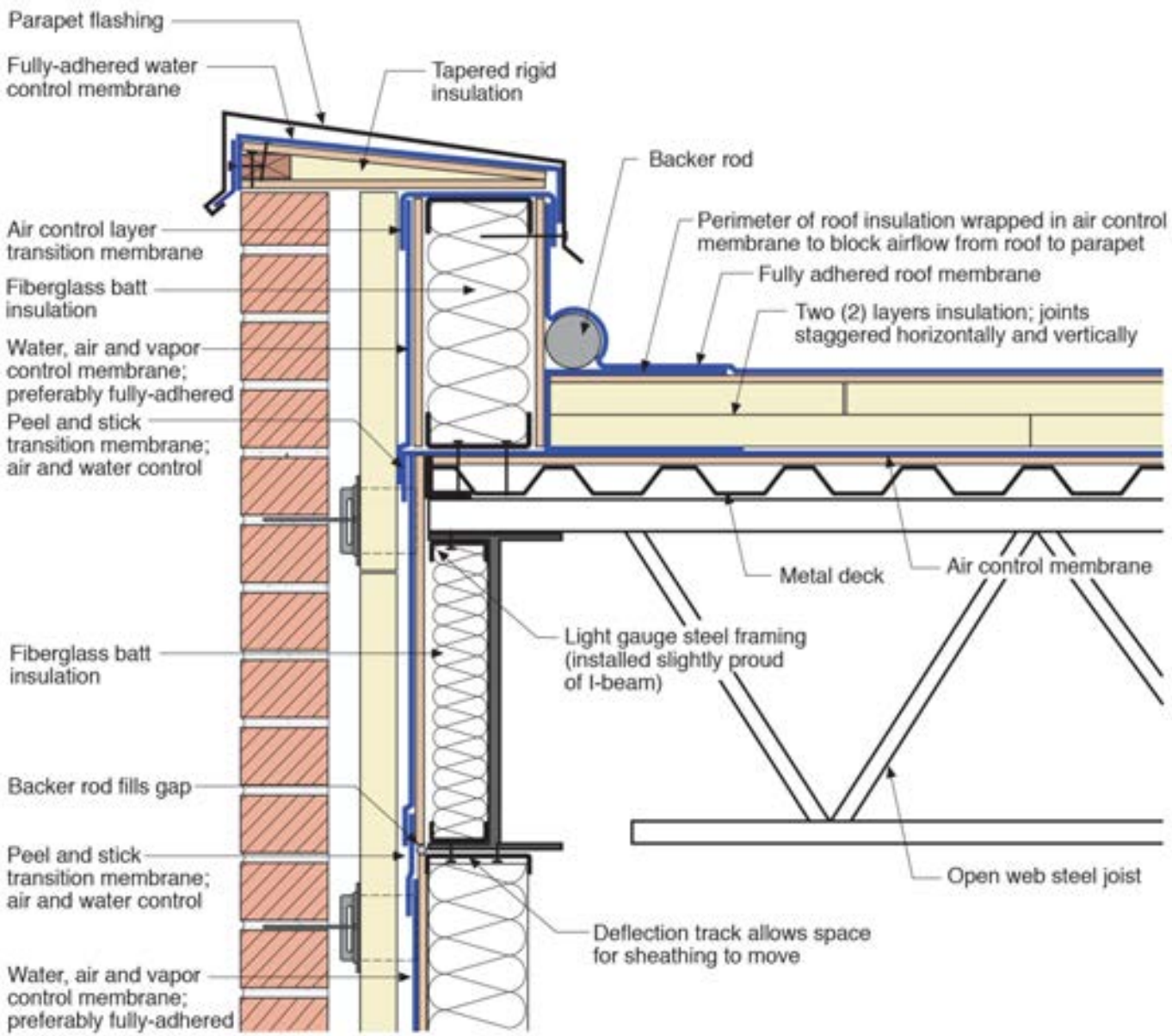

Parapet flashing
Fully-adhered water control membrane
Air control layer transition membrane
Fiberglass batt insulation
Gypsum sheathing
Building paper
Fiberglass batt insulation
Backer rod fills gap
Peel and stick transition membrane; air and water control
Building paper
Cant
Fully-adhered roof membrane
Rigid insulation
Metal deck
Light gauge steel framing (installed slightly proud of I-beam)
Open web steel joist
Deflection track allows space for sheathing to move
Dropped ceiling tiles
Interior gypsum board

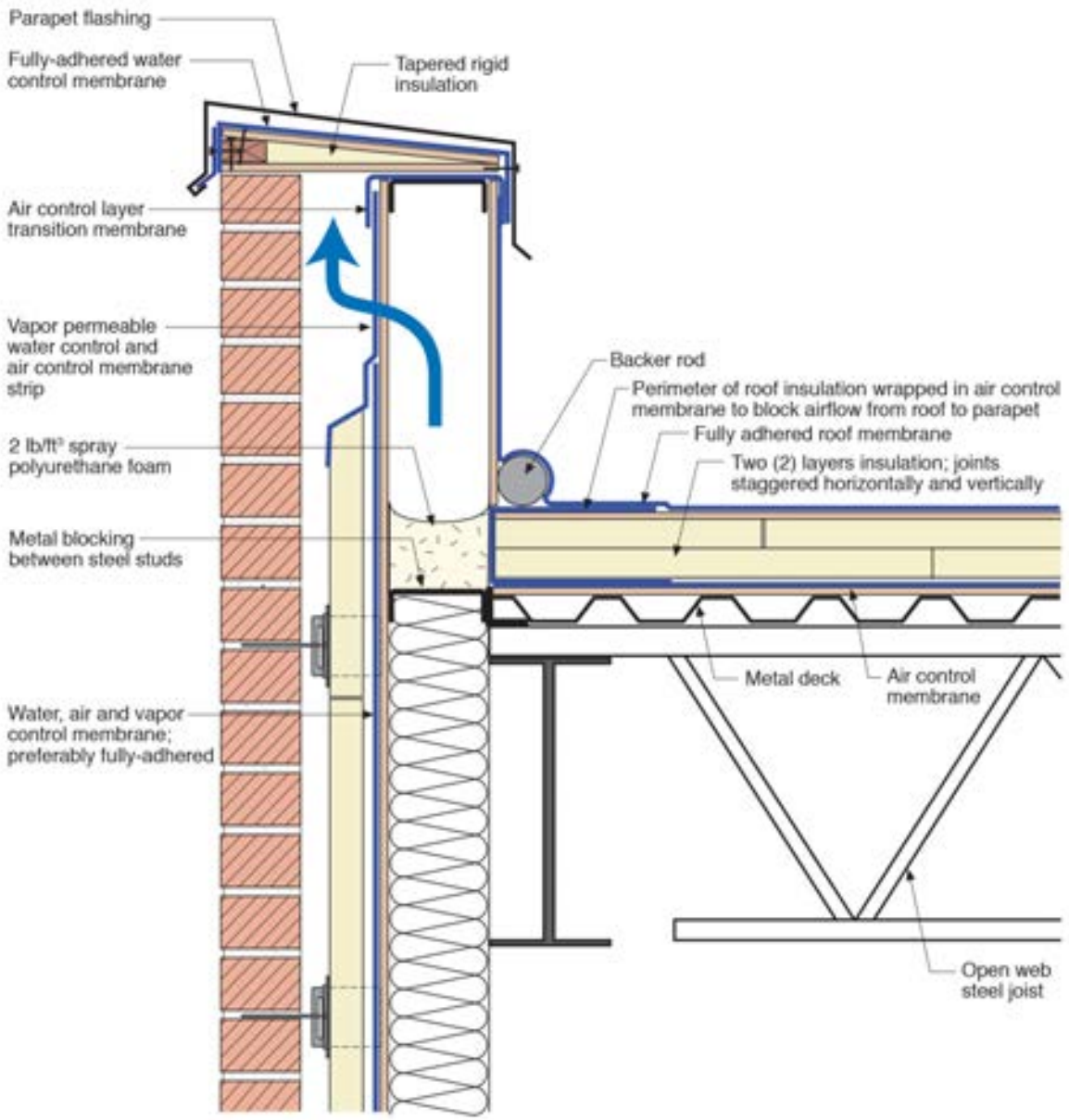

Parapet flashing
Fully-adhered water control membrane
Tapered rigid insulation
Cant
Wood blocking
Perimeter of roof insulation wrapped in air control membrane to block airflow from roof to parapet
Fully adhered roof membrane
Two (2) layers insulation; joints staggered horizontally and vertically
Air control layer transition membrane
Fiberglass batt insulation
Water, air and vapor control membrane; preferably fully-adhered
Peel and stick transition membrane; air and water control
Metal deck
Air control membrane
Light gauge steel framing (installed slightly proud of I-beam)
Fiberglass batt insulation
Backer rod fills gap
Peel and stick transition membrane; air and water control
Open web steel joist
Deflection track allows space for sheathing to move
Water, air and vapor control membrane; preferably fully-adhered

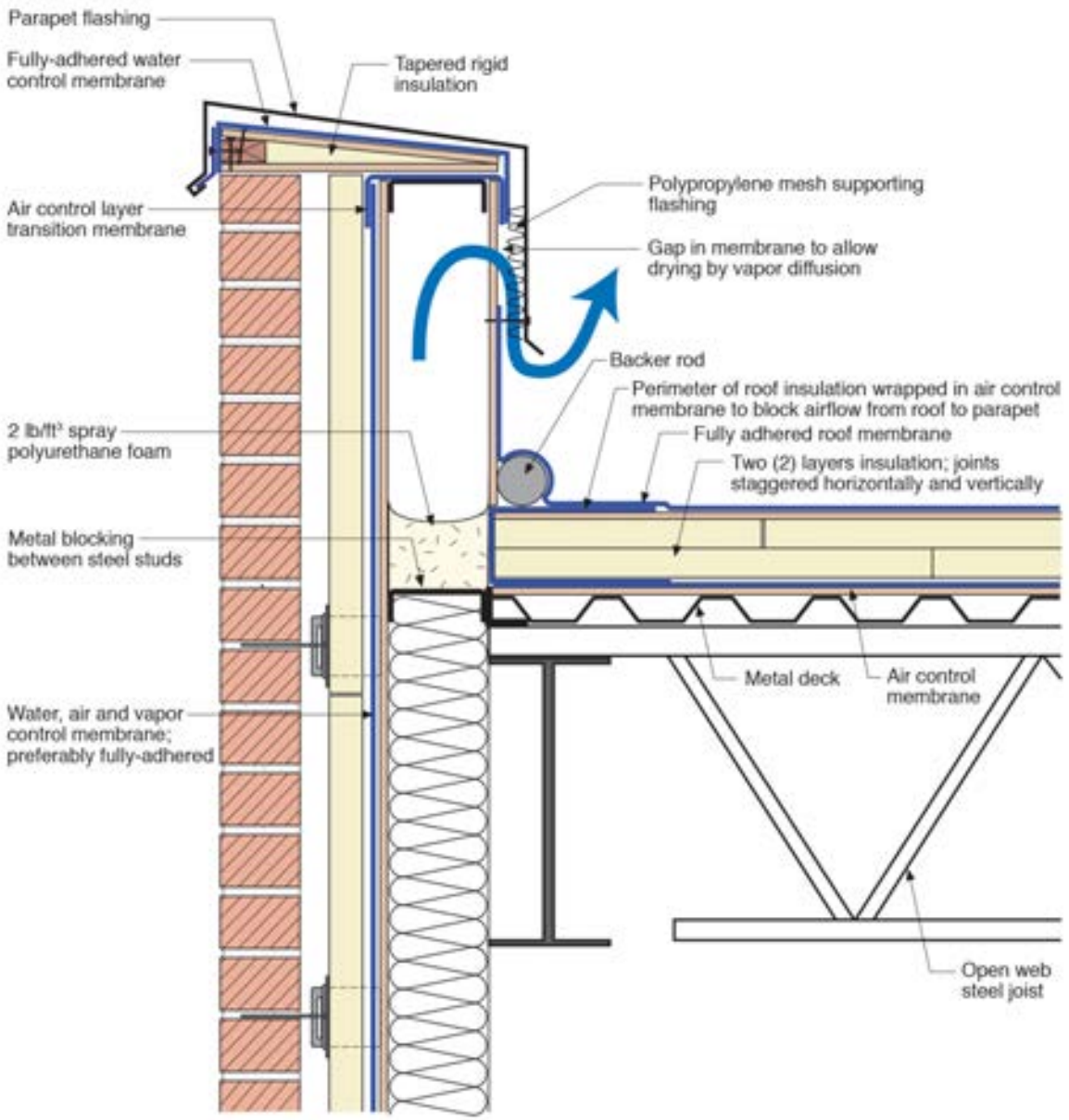

Parapet flashing
Fully-adhered water control membrane
Tapered rigid insulation
Grout and reinforce parapet CMU as per structural requirements
Cant
Wood blocking
Perimeter of roof insulation wrapped in air control membrane to block airflow from roof to parapet
Fully adhered roof membrane
Two (2) layers insulation; joints staggered horizontally and vertically
Fully-adhered water, air and vapor control membrane
Peel and stick transition membrane; air and water control
Deflection space
Backer rod to fill deflection joint and debond water and air barrier

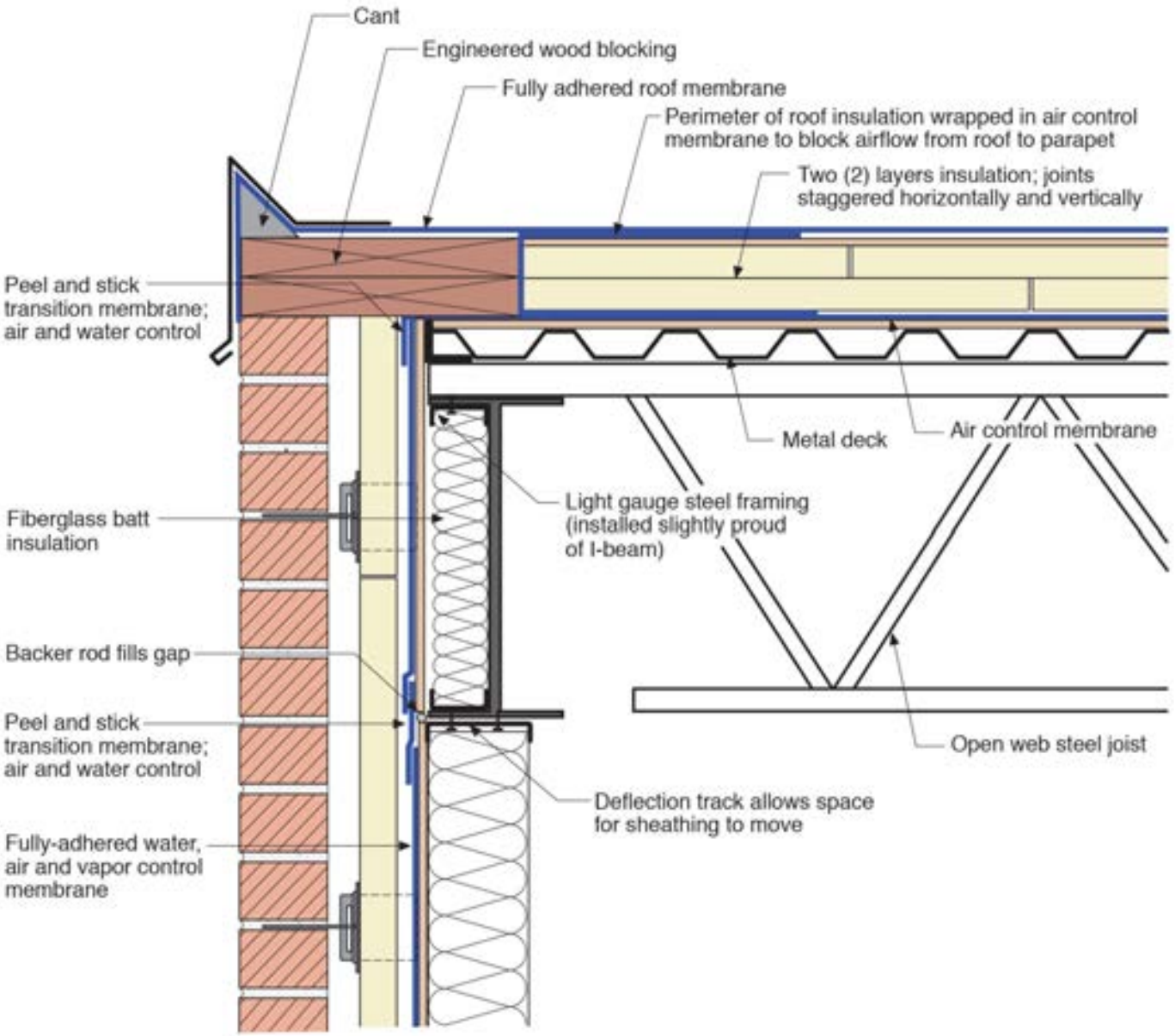

Parapet flashing
Fully-adhered water control membrane
Tapered rigid insulation
Grout and reinforce parapet CMU as per structural requirements
Backer rod
Perimeter of roof insulation wrapped in air control membrane to block airflow from roof to parapet
Fully adhered roof membrane
Two (2) layers insulation; joints staggered horizontally and vertically
Fully-adhered water, air and vapor control membrane
Peel and stick transition membrane; air and water control
Deflection space
Backer rod to fill deflection joint and debond water and air barrier

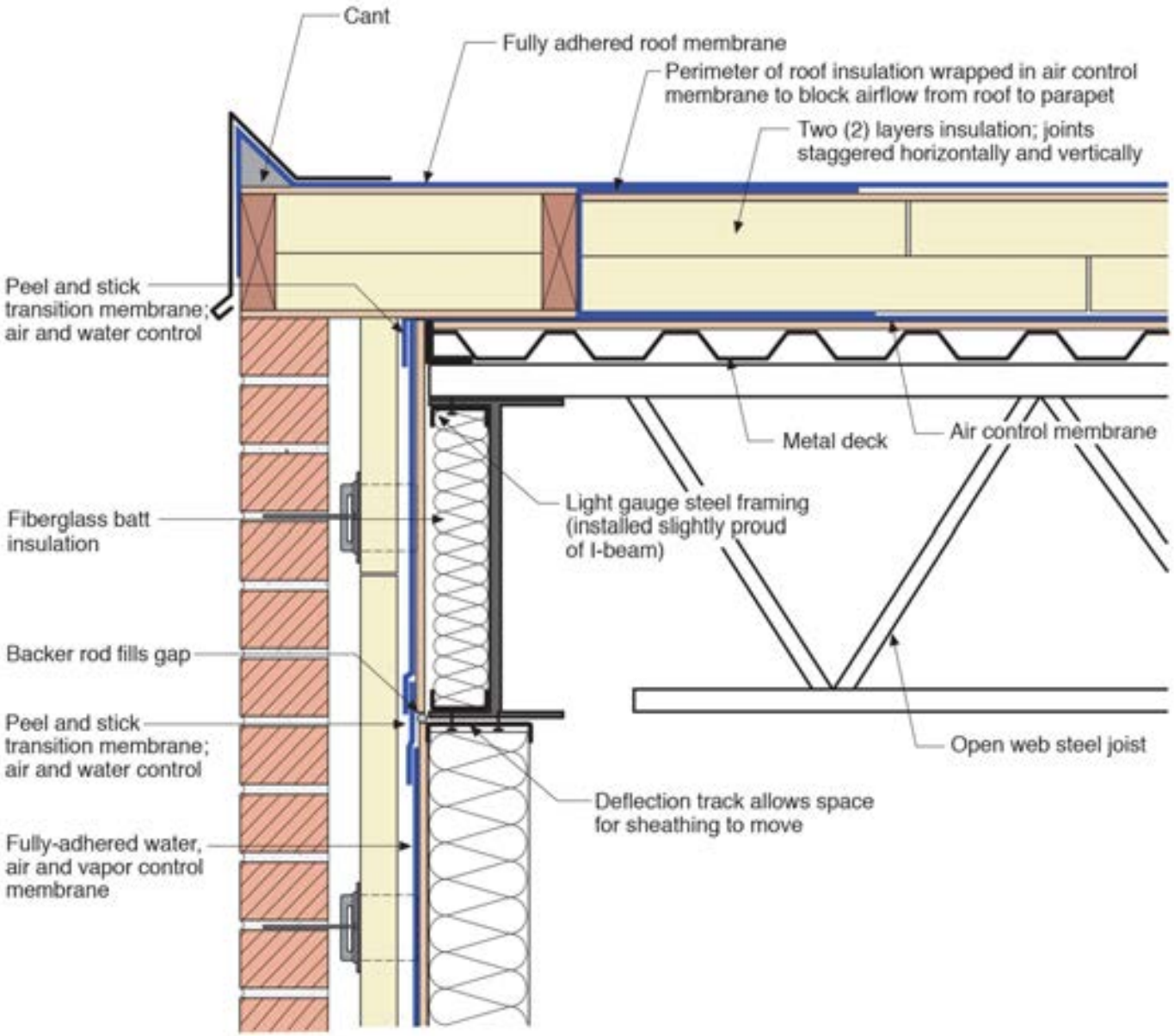

Parapet flashing
Fully-adhered water control membrane
Tapered rigid insulation
Cant
Wood blocking
Perimeter of roof insulation wrapped in air control membrane to block airflow from roof to parapet
Fully adhered roof membrane
Two (2) layers insulation; joints staggered horizontally and vertically
Air control layer transition membrane
Fiberglass batt insulation
Water, air and vapor control membrane; preferably fully-adhered
Peel and stick transition membrane; air and water control
Metal deck
Air control membrane
Light gauge steel framing (installed slightly proud of I-beam)
Fiberglass batt insulation
Backer rod fills gap
Peel and stick transition membrane; air and water control
Open web steel joist
Deflection track allows space for sheathing to move
Water, air and vapor control membrane; preferably fully-adhered


Parapet flashing
Fully-adhered water control membrane
Tapered rigid insulation
Backer rod
Perimeter of roof insulation wrapped in air control membrane to block airflow from roof to parapet
Fully adhered roof membrane
Two (2) layers insulation; joints staggered horizontally and vertically
Air control layer transition membrane
Fiberglass batt insulation
Water, air and vapor control membrane; preferably fully-adhered
Peel and stick transition membrane; air and water control
Metal deck
Air control membrane
Light gauge steel framing (installed slightly proud of I-beam)
Fiberglass batt insulation
Backer rod fills gap
Peel and stick transition membrane; air and water control
Open web steel joist
Deflection track allows space for sheathing to move
Water, air and vapor control membrane; preferably fully-adhered


Parapet flashing
Fully-adhered water control membrane
Tapered rigid insulation
Air control layer transition membrane
Vapor permeable water control and air control membrane strip
2 lb/ft³ spray polyurethane foam
Metal blocking between steel studs
Water, air and vapor control membrane; preferably fully-adhered
Backer rod
Perimeter of roof insulation wrapped in air control membrane to block airflow from roof to parapet
Fully adhered roof membrane
Two (2) layers insulation; joints staggered horizontally and vertically
Metal deck
Air control membrane
Open web steel joist


Parapet flashing
Fully-adhered water control membrane
Tapered rigid insulation
Air control layer transition membrane
Polypropylene mesh supporting flashing
Gap in membrane to allow drying by vapor diffusion
Backer rod
Perimeter of roof insulation wrapped in air control membrane to block airflow from roof to parapet
Fully adhered roof membrane
Two (2) layers insulation; joints staggered horizontally and vertically
2 lb/ft³ spray polyurethane foam
Metal blocking between steel studs
Metal deck
Air control membrane
Water, air and vapor control membrane; preferably fully-adhered
Open web steel joist


Cant
Engineered wood blocking
Fully adhered roof membrane
Perimeter of roof insulation wrapped in air control membrane to block airflow from roof to parapet
Two (2) layers insulation; joints staggered horizontally and vertically
Peel and stick transition membrane; air and water control
Metal deck
Air control membrane
Light gauge steel framing (installed slightly proud of I-beam)
Fiberglass batt insulation
Backer rod fills gap
Peel and stick transition membrane; air and water control
Open web steel joist
Deflection track allows space for sheathing to move
Fully-adhered water, air and vapor control membrane


Cant
Fully adhered roof membrane
Perimeter of roof insulation wrapped in air control membrane to block airflow from roof to parapet
Two (2) layers insulation; joints staggered horizontally and vertically
Peel and stick transition membrane; air and water control
Metal deck
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Light gauge steel framing (installed slightly proud of I-beam)
Fiberglass batt insulation
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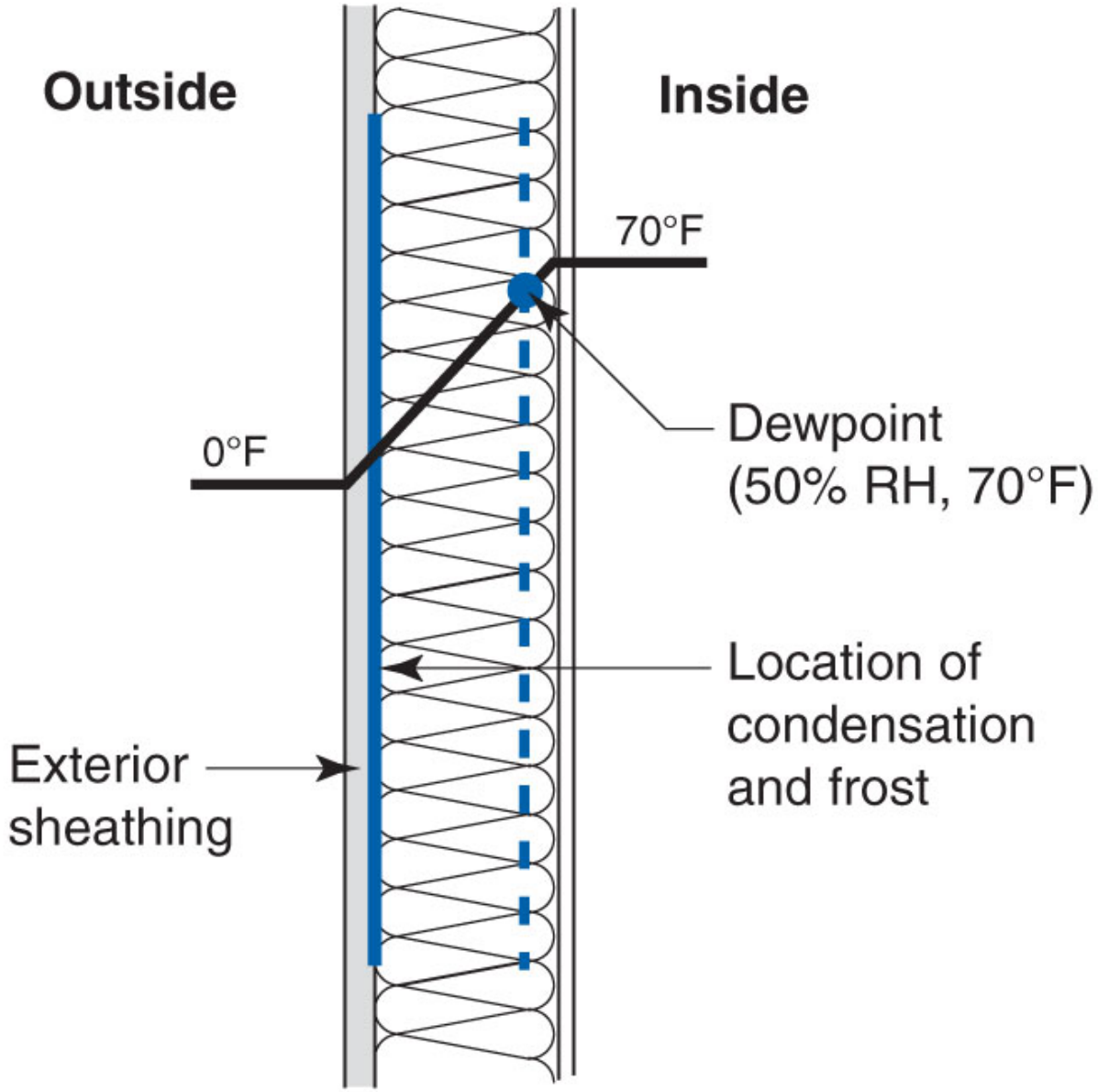
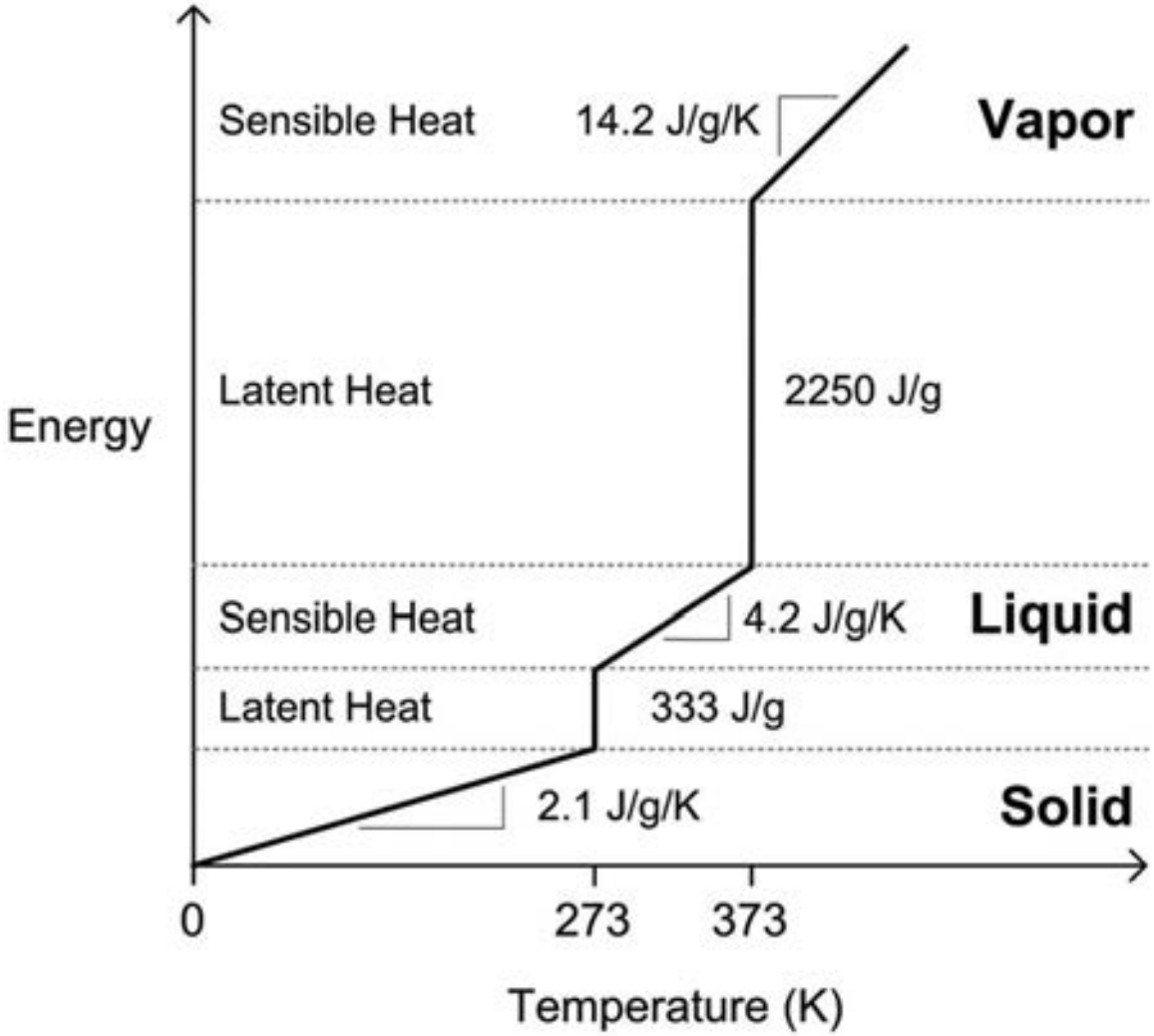
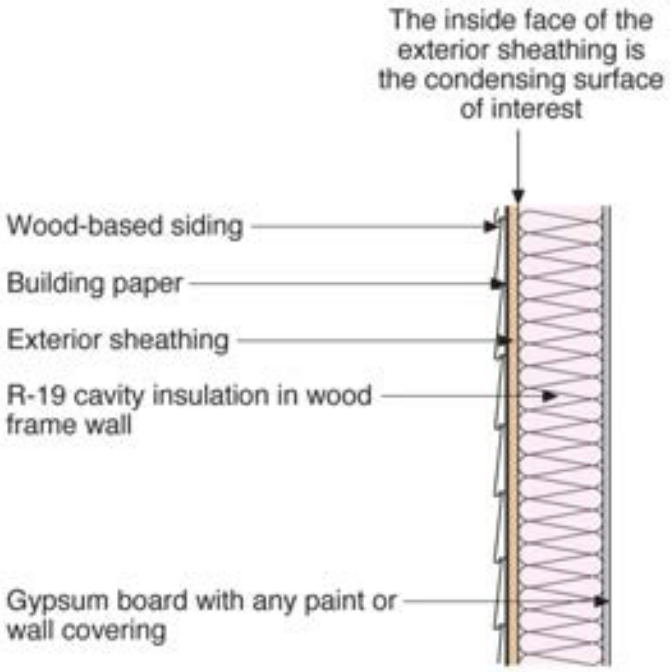
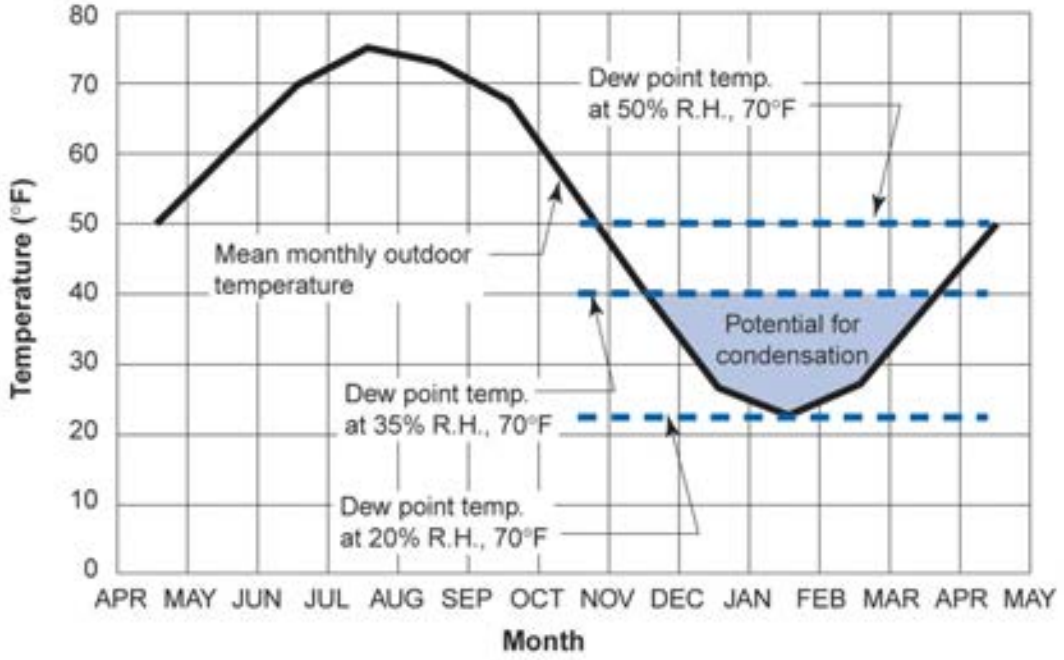
Open web steel joist
Deflection track allows space for sheathing to move
Fully-adhered water, air and vapor control membrane

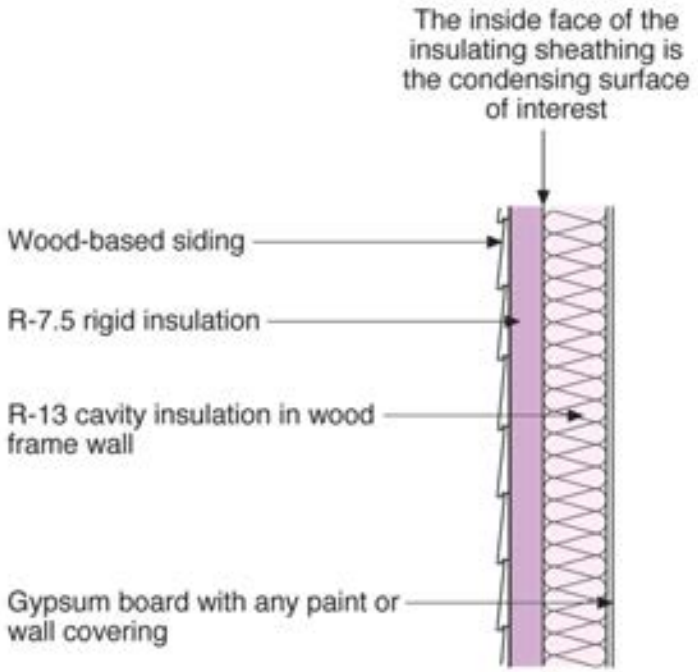

Outside
Inside
70°F
0°F
Dewpoint
(50% RH, 70°F)
Location of
condensation
and frost
Exterior
sheathing

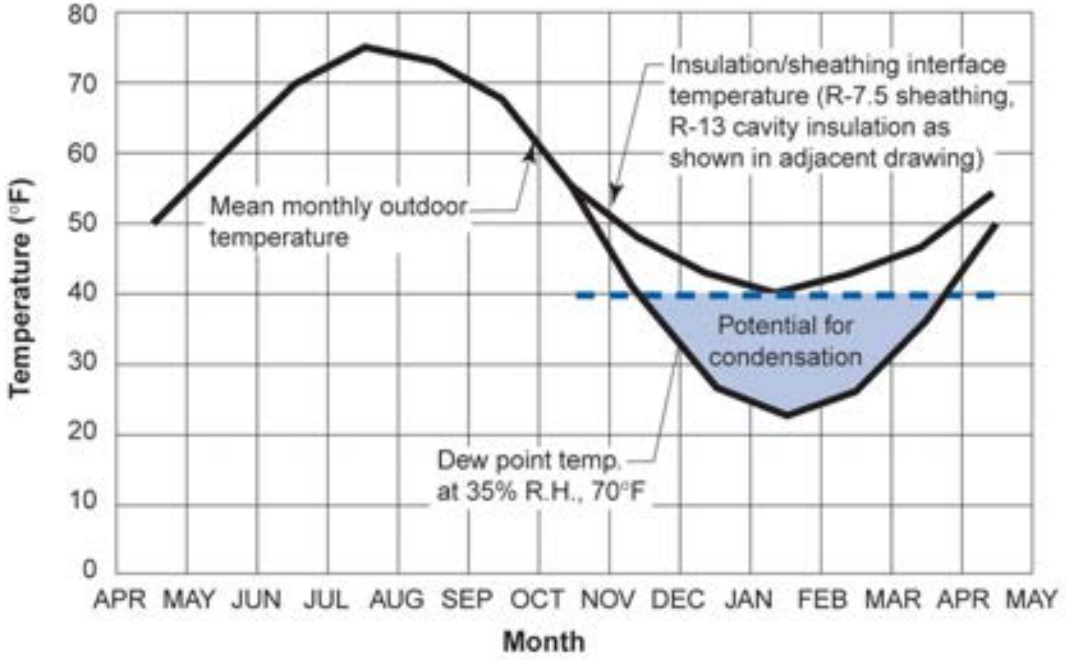


Simple linearized energy-temperature relation for water
From Straube & Burnett, 2005


The inside face of the exterior sheathing is the condensing surface of interest
Wood-based siding
Building paper
Exterior sheathing
R-19 cavity insulation in wood frame wall
Gypsum board with any paint or wall covering


Temperature (°F)
80
70
60
50
40
30
20
10
0
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
Month
Dew point temp. at 50% R.H., 70°F
Mean monthly outdoor temperature
Potential for condensation
Dew point temp. at 35% R.H., 70°F
Dew point temp. at 20% R.H., 70°F


The inside face of the insulating sheathing is the condensing surface of interest
Wood-based siding
R-7.5 rigid insulation
R-13 cavity insulation in wood frame wall
Gypsum board with any paint or wall covering


Temperature (°F)
80
70
60
50
40
30
20
10
0
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
Month
Insulation/sheathing interface temperature (R-7.5 sheathing, R-13 cavity insulation as shown in adjacent drawing)
Mean monthly outdoor temperature
Potential for condensation
Dew point temp. at 35% R.H., 70°F

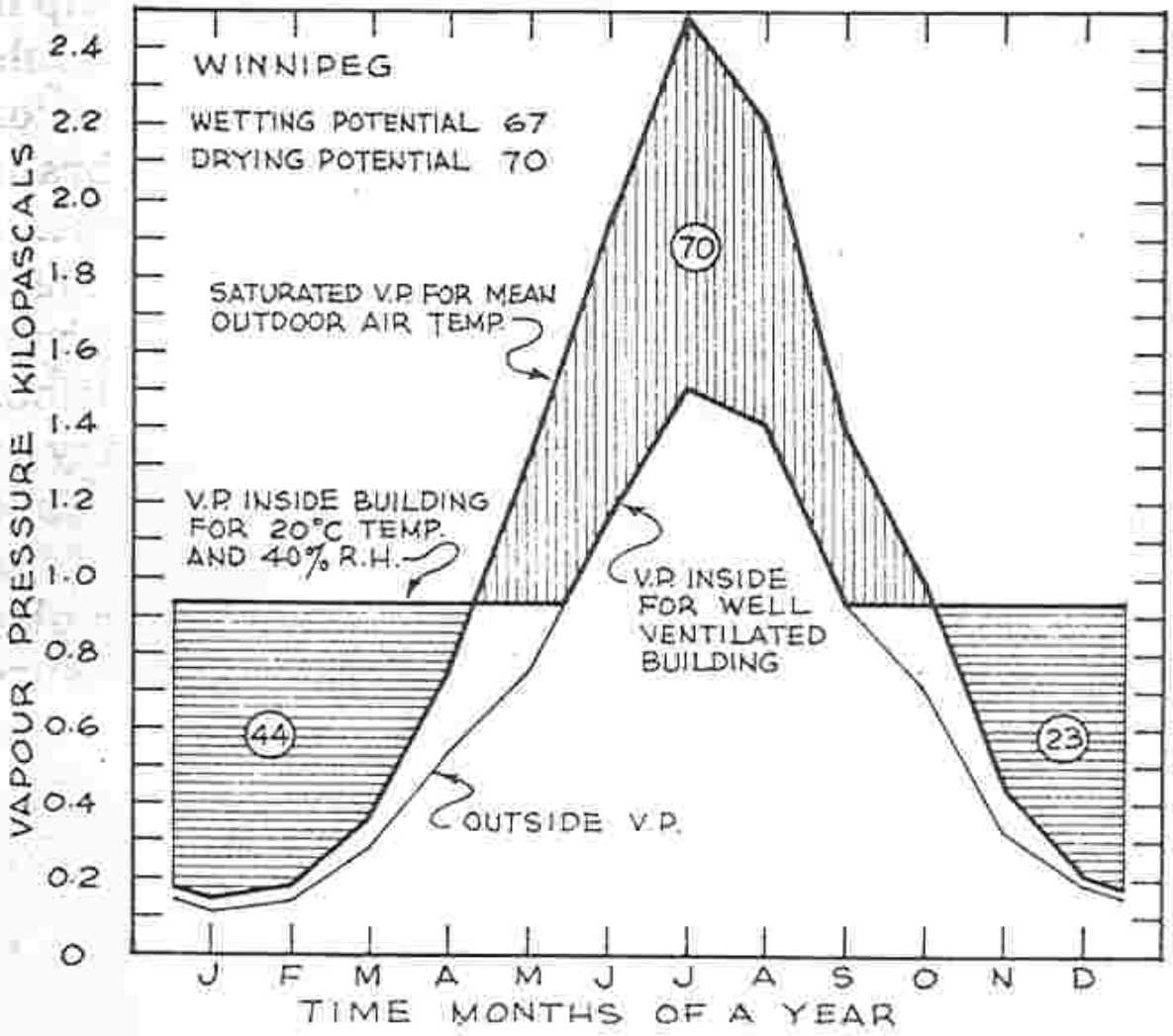
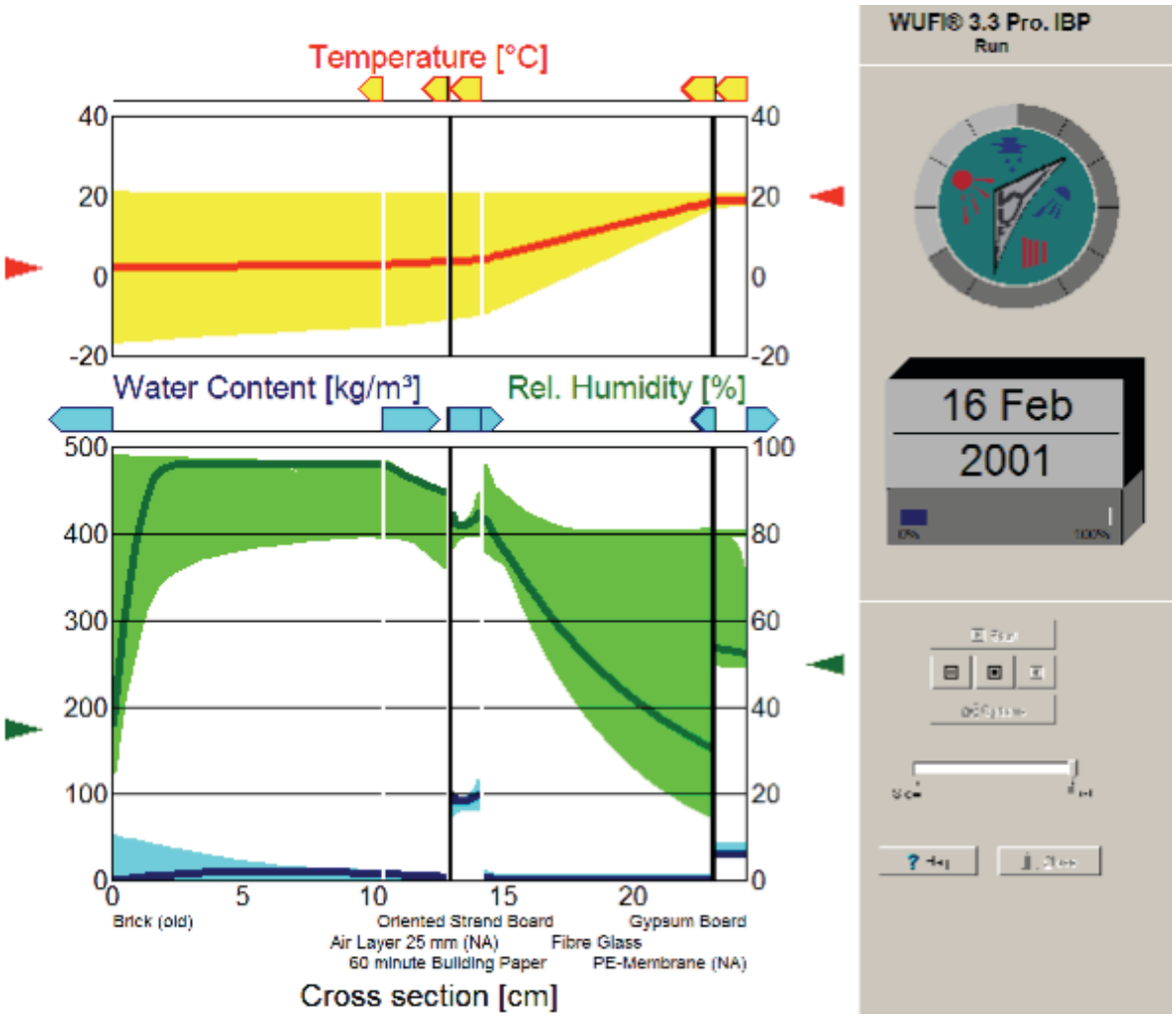
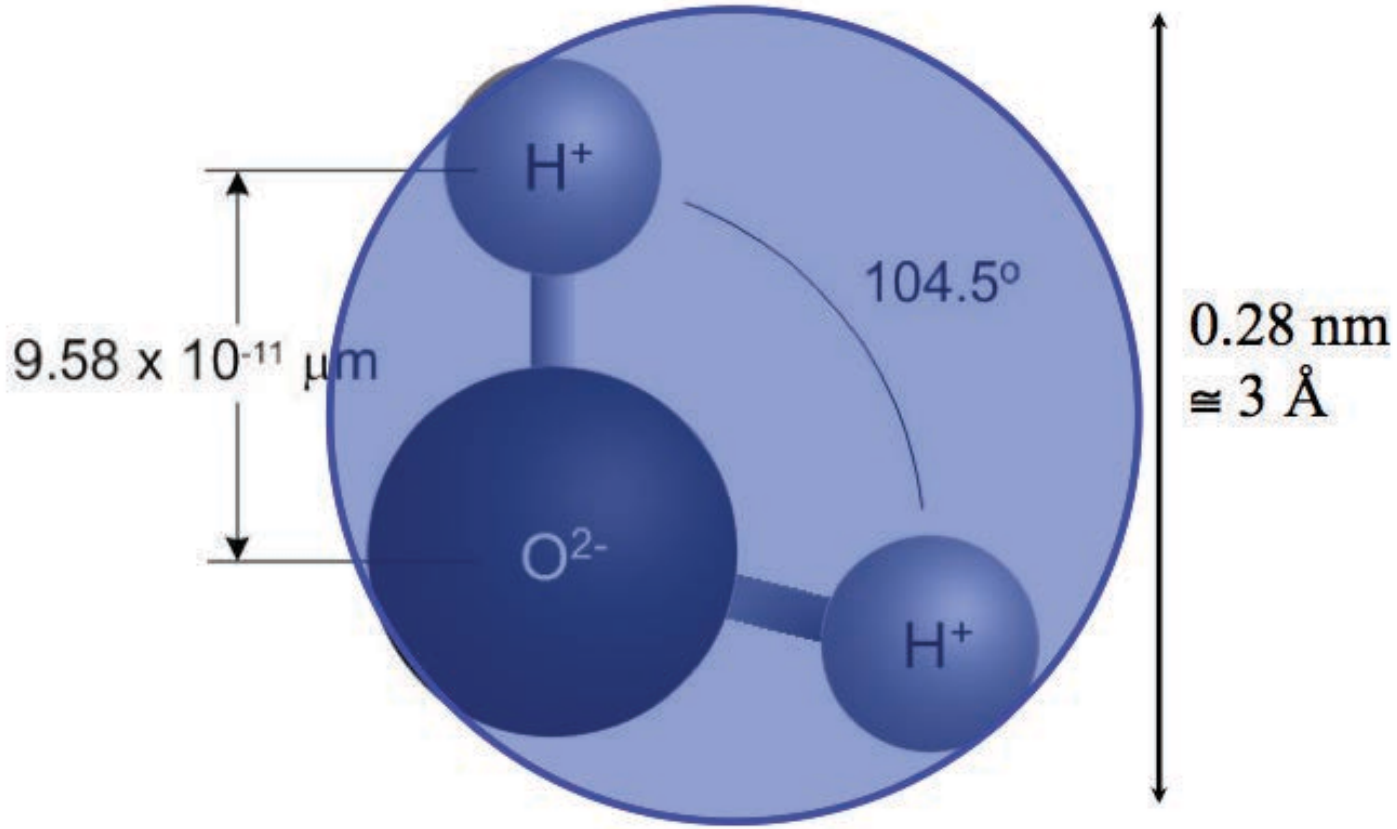


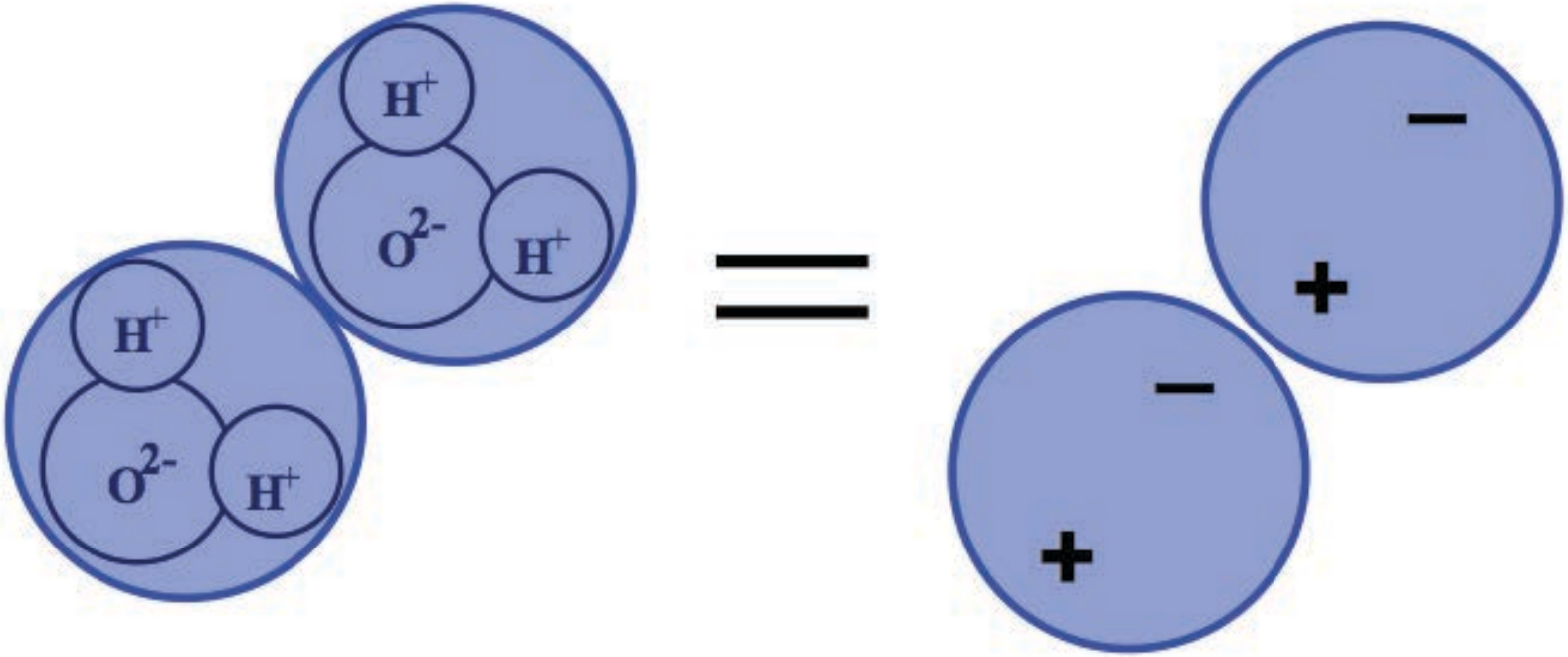
Figure 8-7. Outside vapour pressure, saturated vapour pressure and inside vapour pressure for Winnipeg.


Temperature [°C]
40
20
0
-20
Water Content [kg/m³]
Rel. Humidity [%]
500
400
300
200
100
0
100
80
60
40
20
0
0
5
10
15
20
Brick (old)
Air Layer 25 mm (NA)
60 minute Building Paper
Oriented Strand Board
Fibre Glass
PE-Membrane (NA)
Gypsum Board
Cross section [cm]
WUFI® 3.3 Pro. IBP
Run
16 Feb
2001

Water Molecules

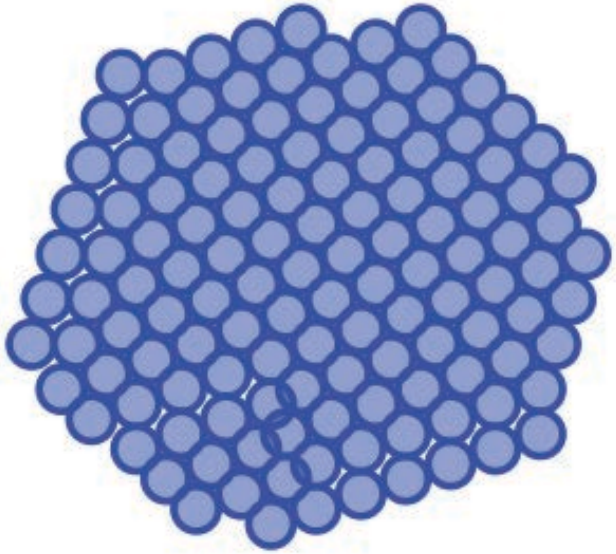

H+
104.5°
9.58 x 10-11 µm
0.28 nm
≅ 3 Å
O2-
H+

Polar Molecule


H+
O2-
H+
H+
O2-
H+
=
−
+
−
+

Size Matters

Vapor



Liquid

DIFFUSION

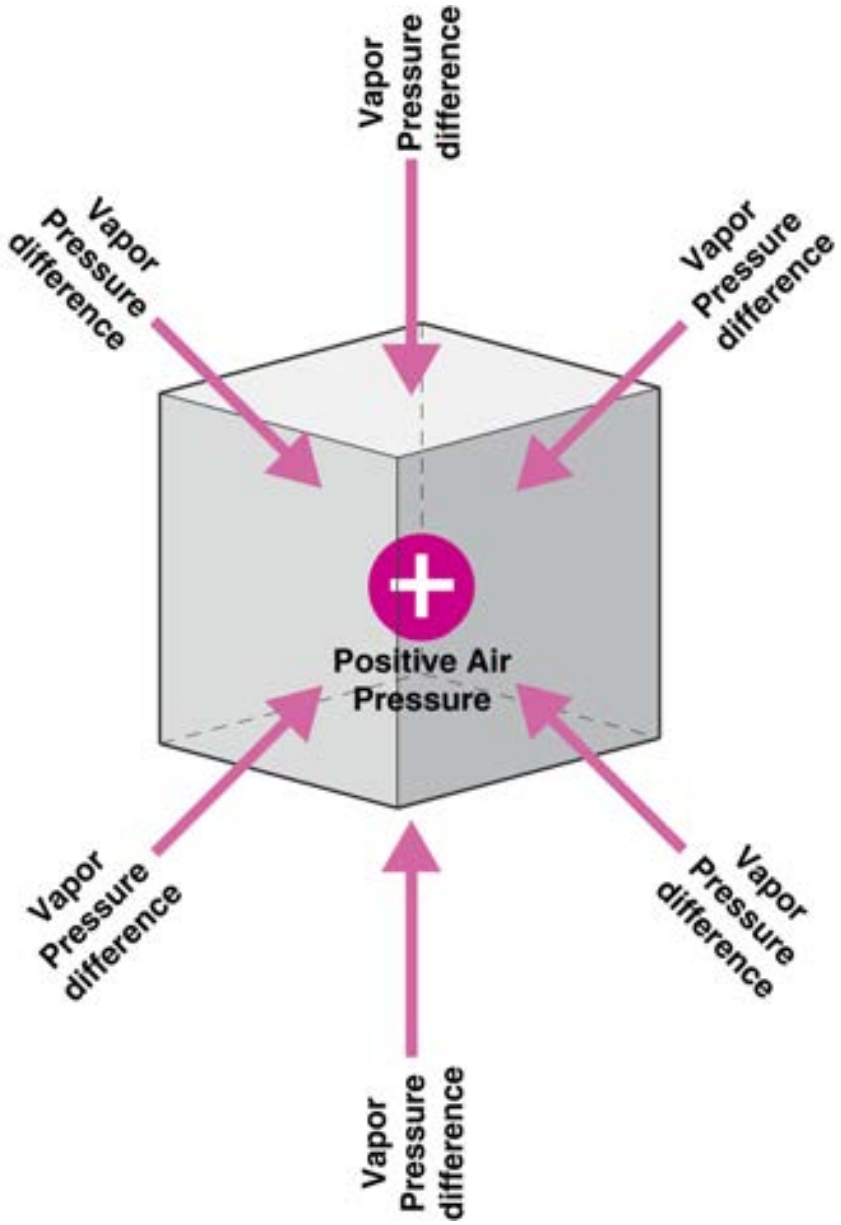
Higher Dewpoint Temperature
Higher Water Vapor Density
or Concentration
(Higher Vapor Pressure)
on Warm Side of Assembly

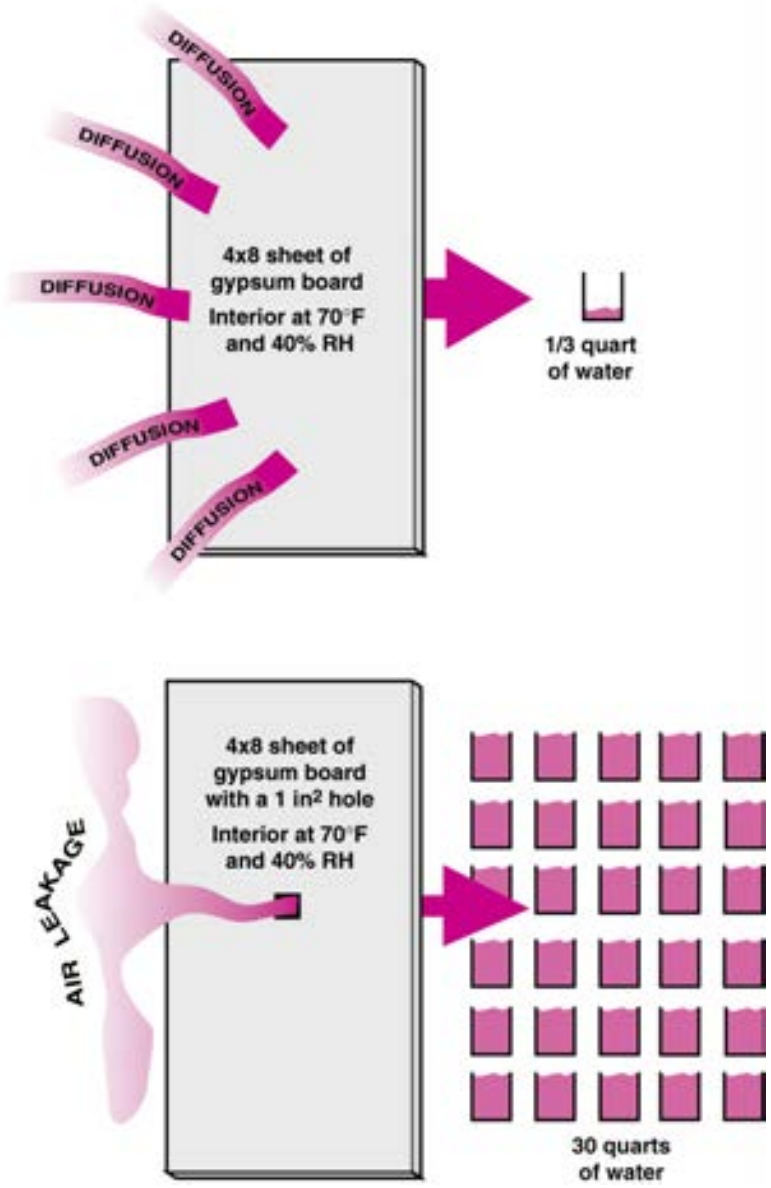
Low Dewpoint Temperature
Lower Water Vapor Density
or Concentration
(Lower Vapor Pressure)
on Cold Side of Assembly

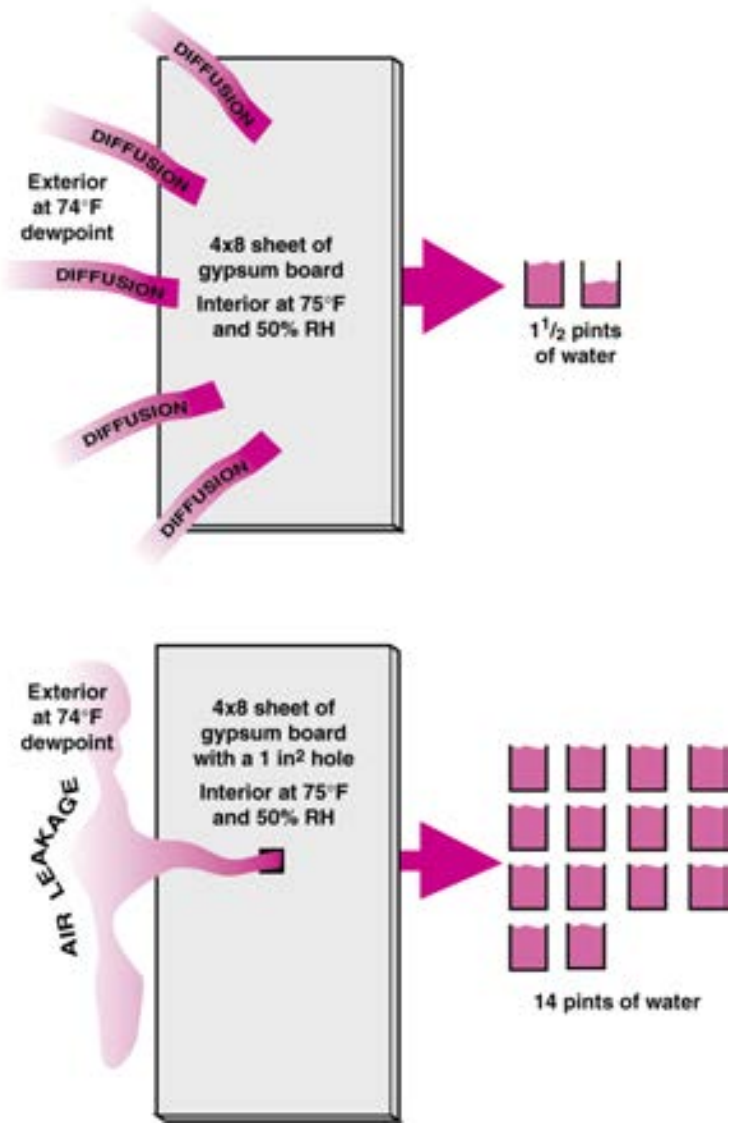
AIR TRANSPORT

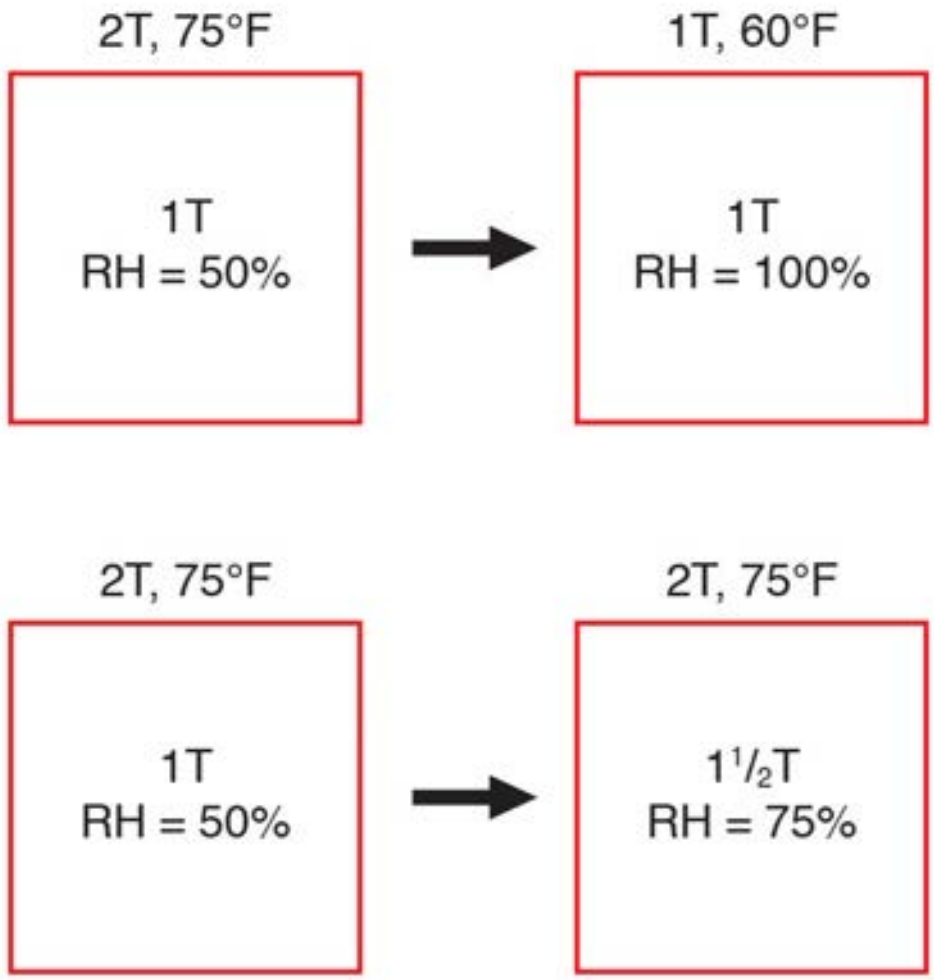
Higher Air
Pressure

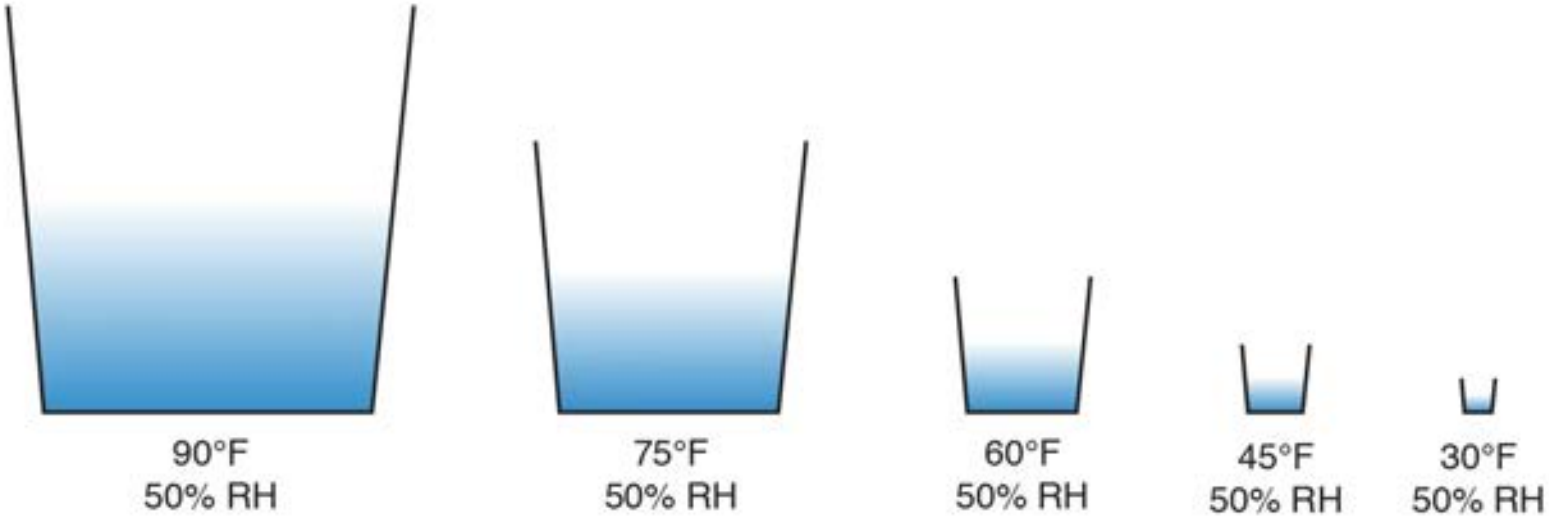
Lower Air
Pressure

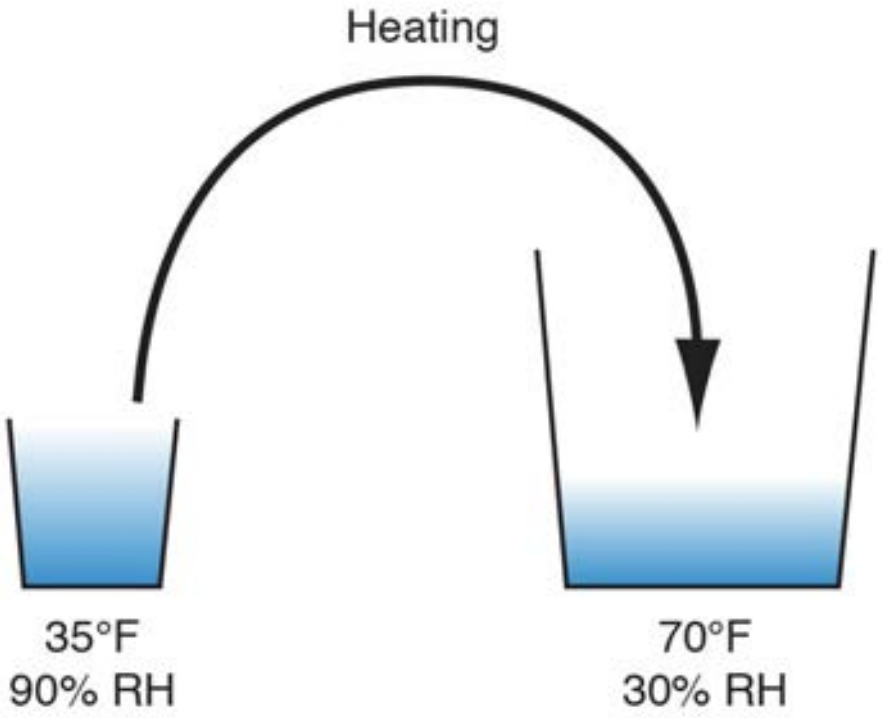

Vapor Pressure difference
Vapor Pressure difference
Vapor Pressure difference
Positive Air Pressure
Vapor Pressure difference
Vapor Pressure difference
Vapor Pressure difference

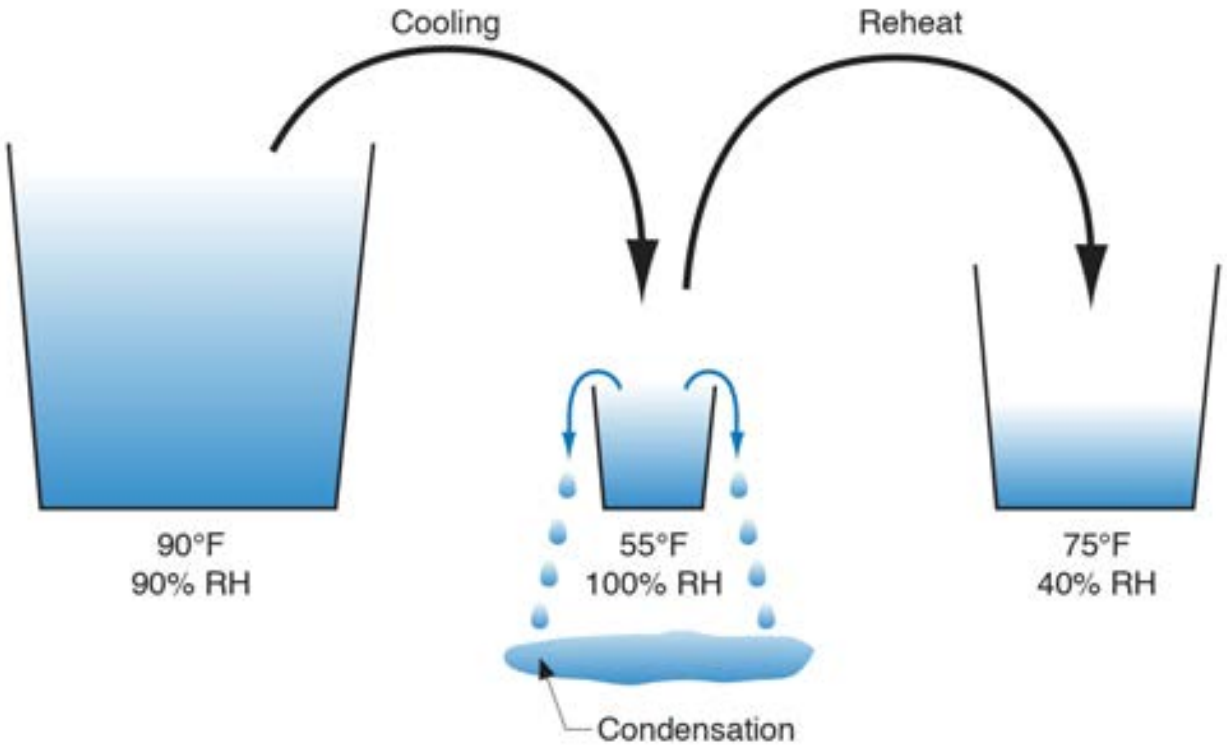

DIFFUSION
DIFFUSION
DIFFUSION
DIFFUSION
DIFFUSION
4x8 sheet of gypsum board
Interior at 70°F and 40% RH
1/3 quart of water
AIR LEAKAGE
4x8 sheet of gypsum board with a 1 in² hole
Interior at 70°F and 40% RH
30 quarts of water

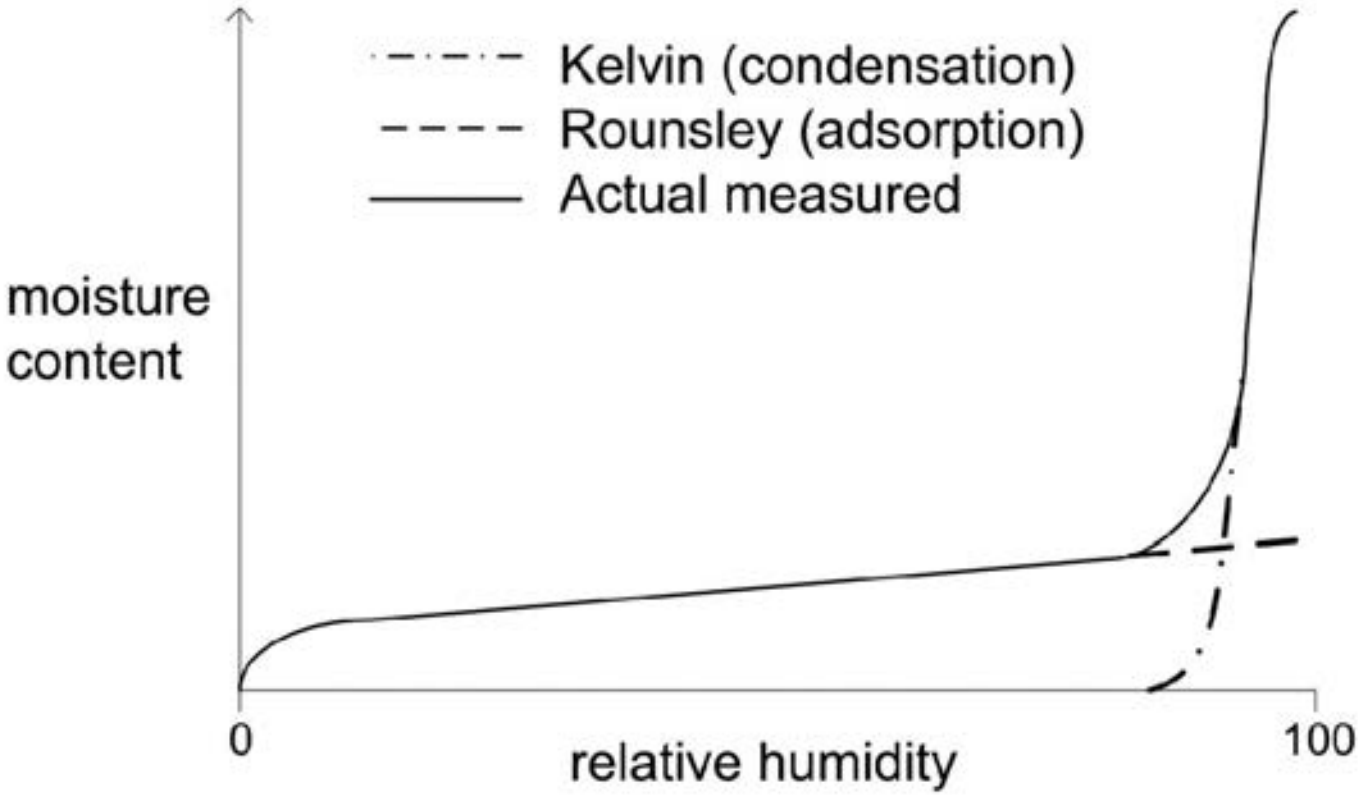

DIFFUSION
DIFFUSION
Exterior
at 74°F
dewpoint
DIFFUSION
4x8 sheet of
gypsum board
Interior at 75°F
and 50% RH
1 1/2 pints
of water
DIFFUSION
DIFFUSION
Exterior
at 74°F
dewpoint
AIR LEAKAGE
4x8 sheet of
gypsum board
with a 1 in² hole
Interior at 75°F
and 50% RH
14 pints of water


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%

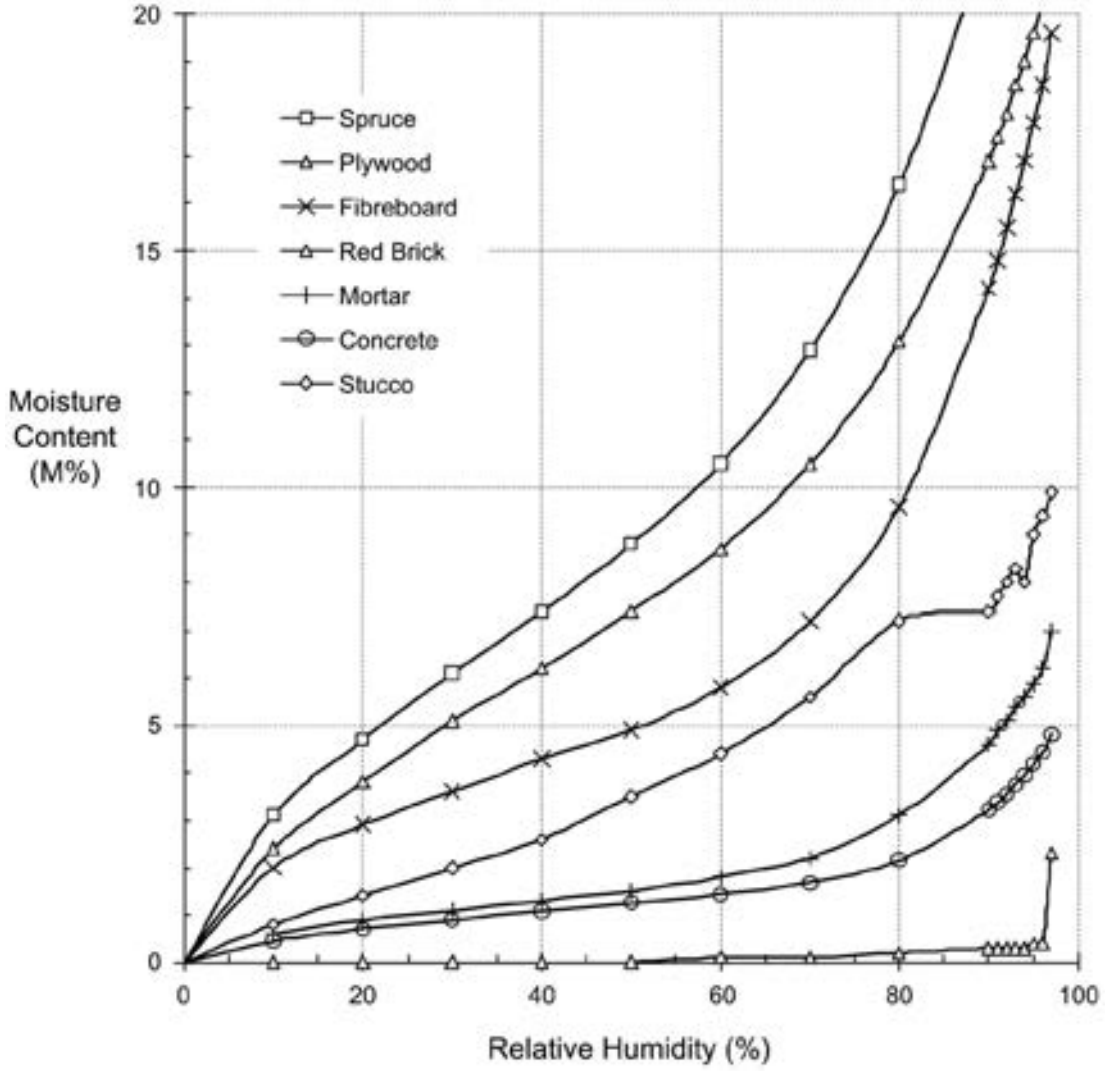

90°F
50% RH
75°F
50% RH
60°F
50% RH
45°F
50% RH
30°F
50% RH


Heating
35°F
90% RH
70°F
30% RH

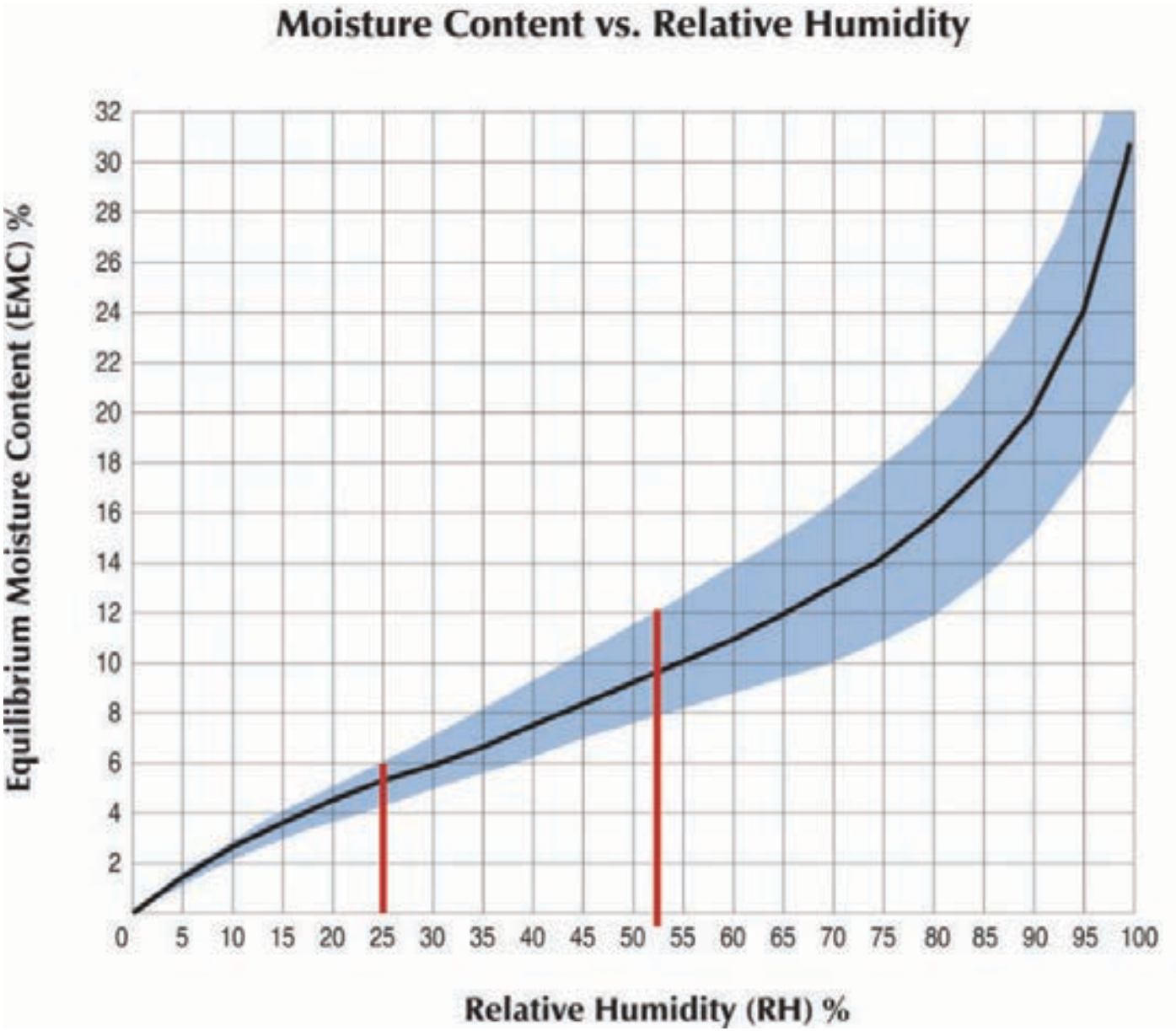

Cooling
Reheat
90°F
90% RH
55°F
100% RH
75°F
40% RH
Condensation

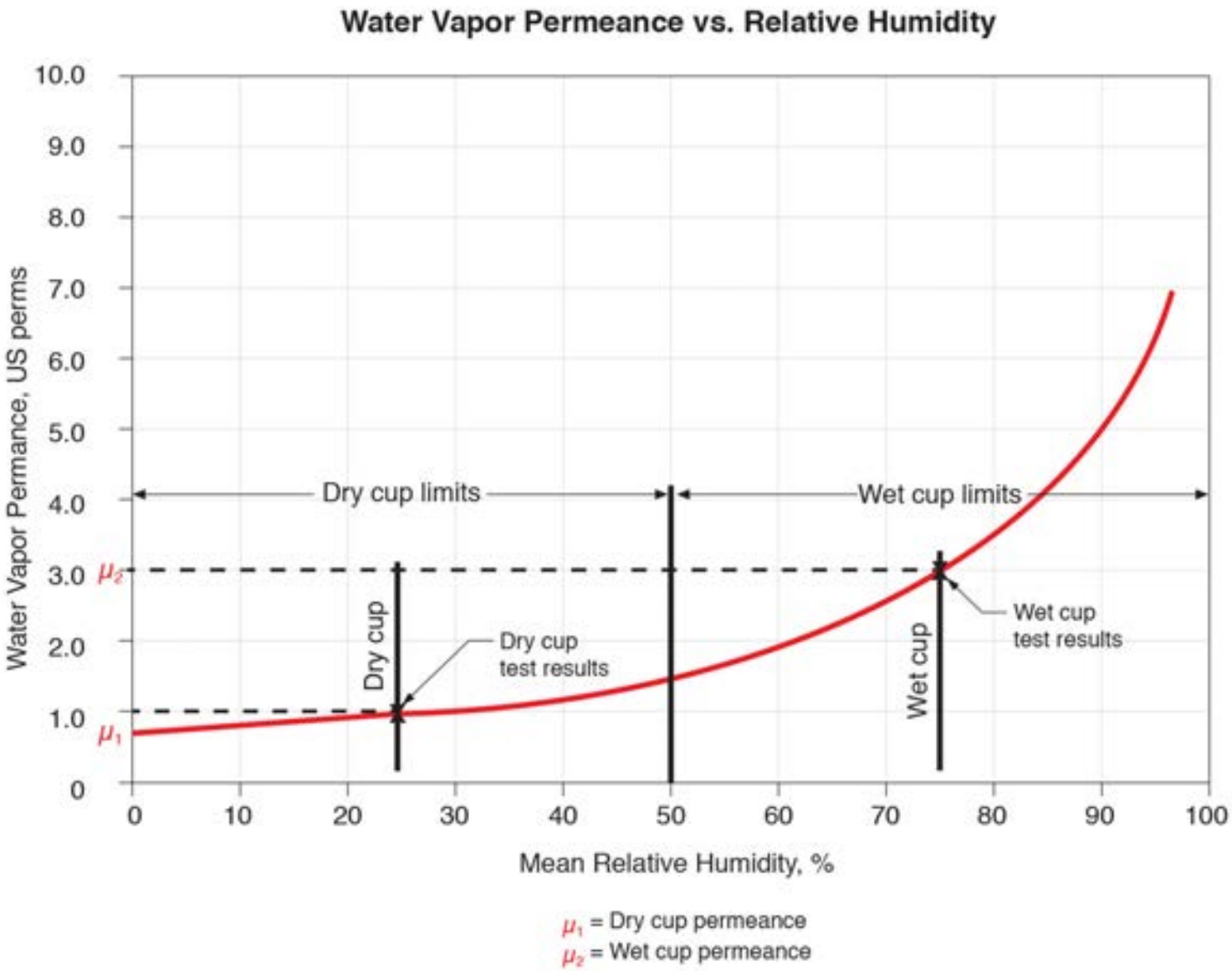


Typical predicted sorption isotherm according to Kelvin equation and modified BET theory
From Straube & Burnett, 2005

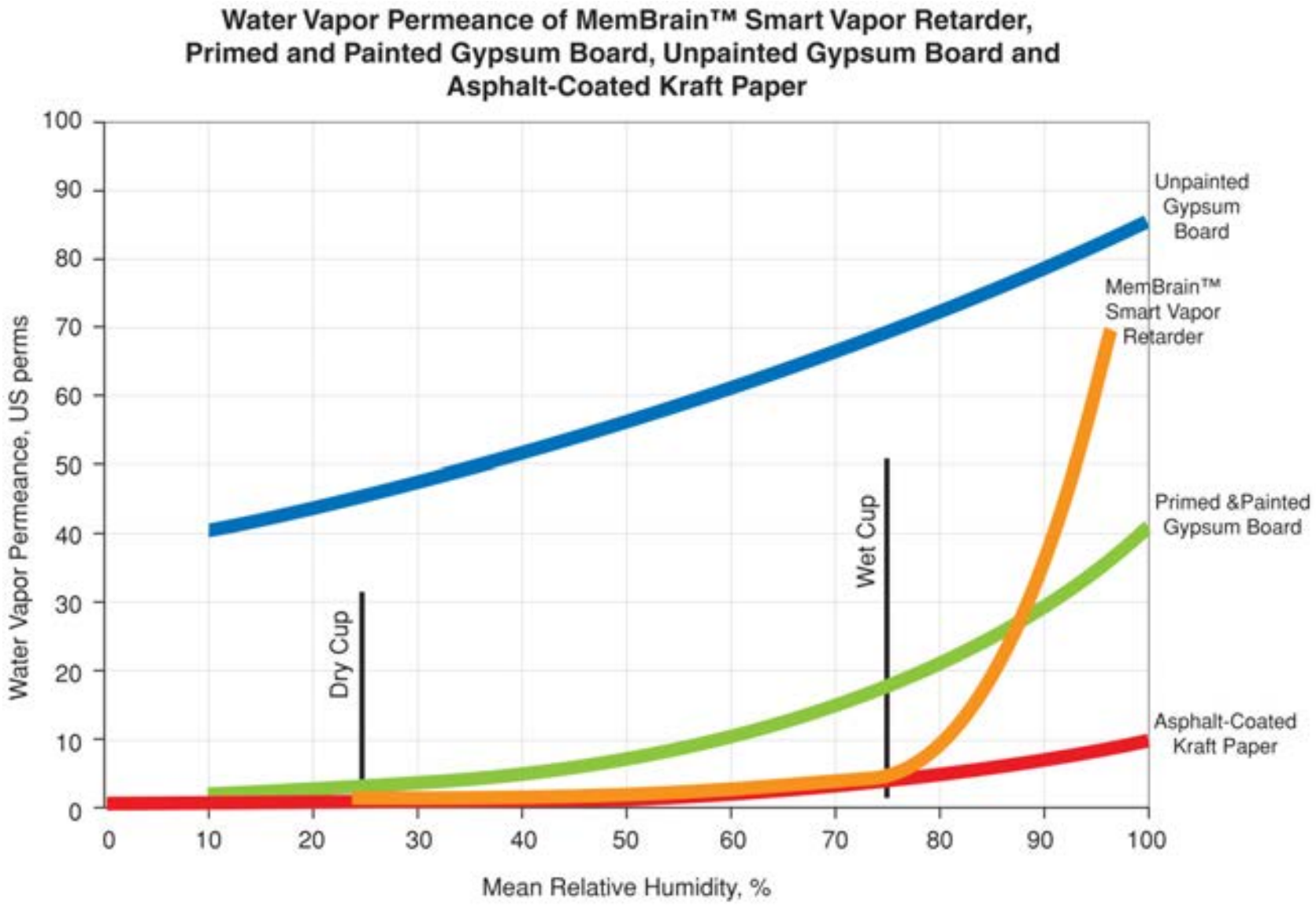


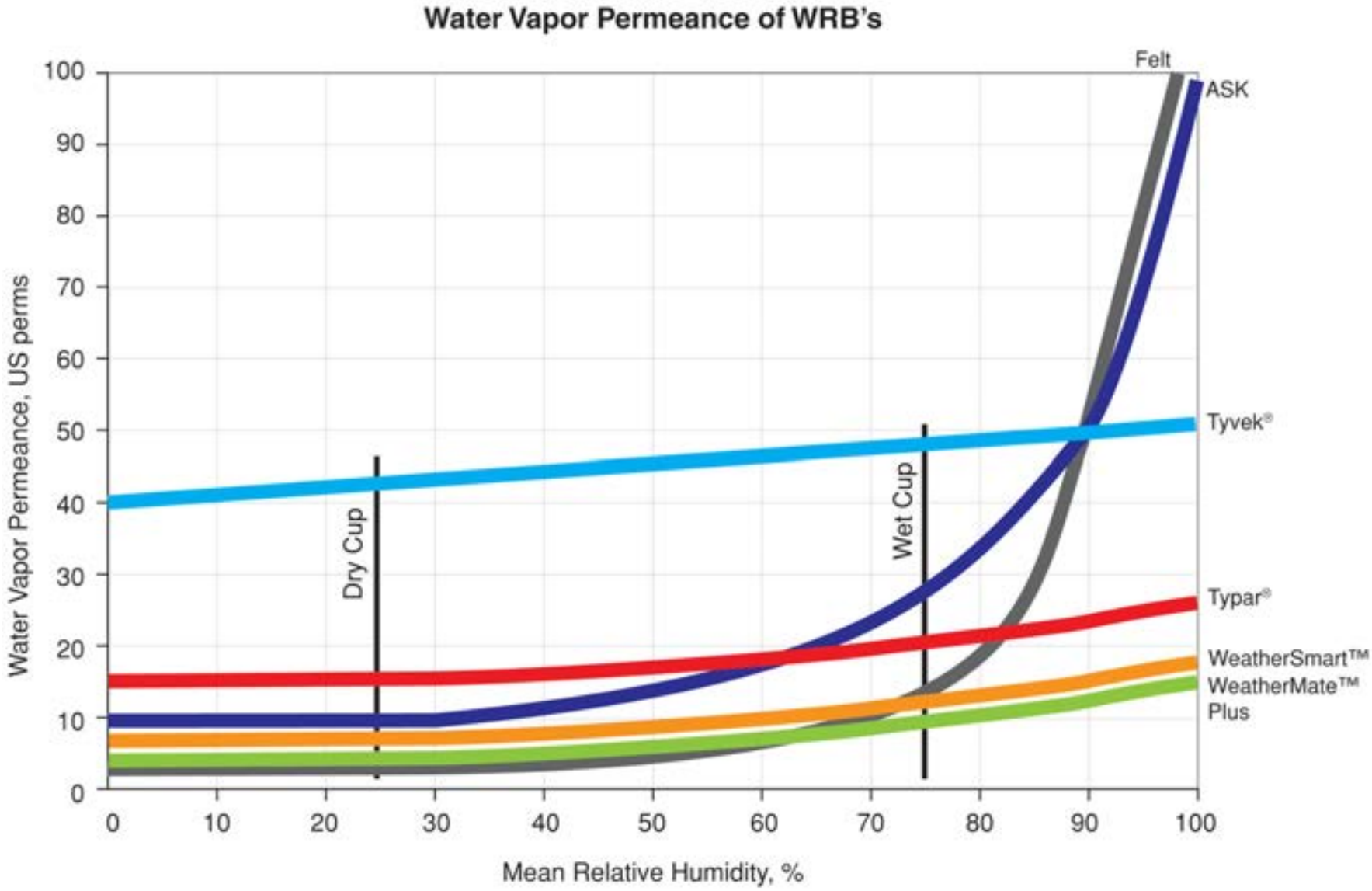
Sorption isotherm for several building materials [Kumaran 2002]
From Straube & Burnett, 2005

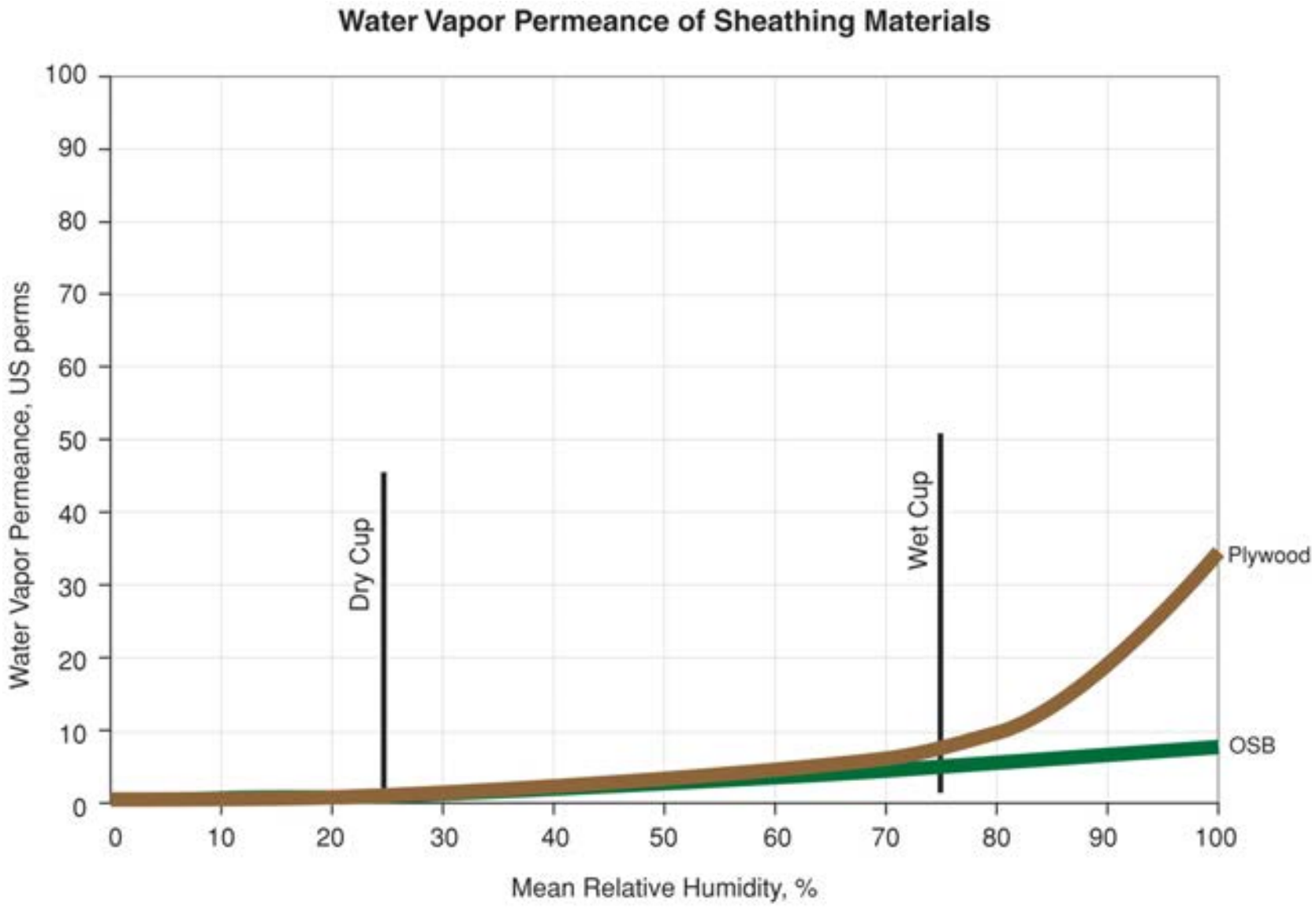

Moisture Content vs. Relative Humidity
Equilibrium Moisture Content (EMC) %
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Relative Humidity (RH) %

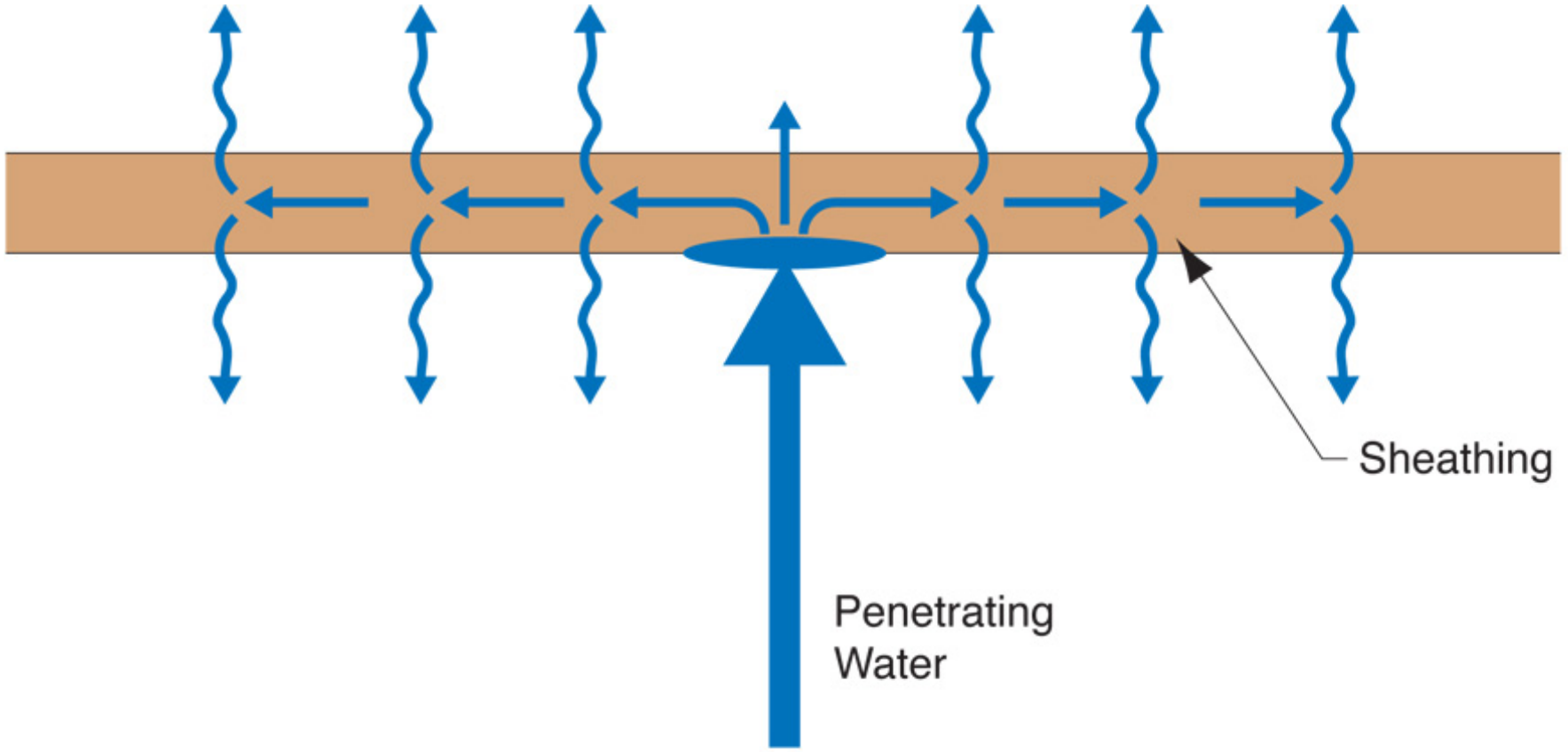

Water Vapor Permeance vs. Relative Humidity
Water Vapor Permance, US perms
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
μ_2
μ_1
Dry cup limits
Wet cup limits
Dry cup
Dry cup test results
Wet cup
Wet cup test results
0
10
20
30
40
50
60
70
80
90
100
Mean Relative Humidity, %
μ_1 = Dry cup permeance
μ_2 = Wet cup permeance

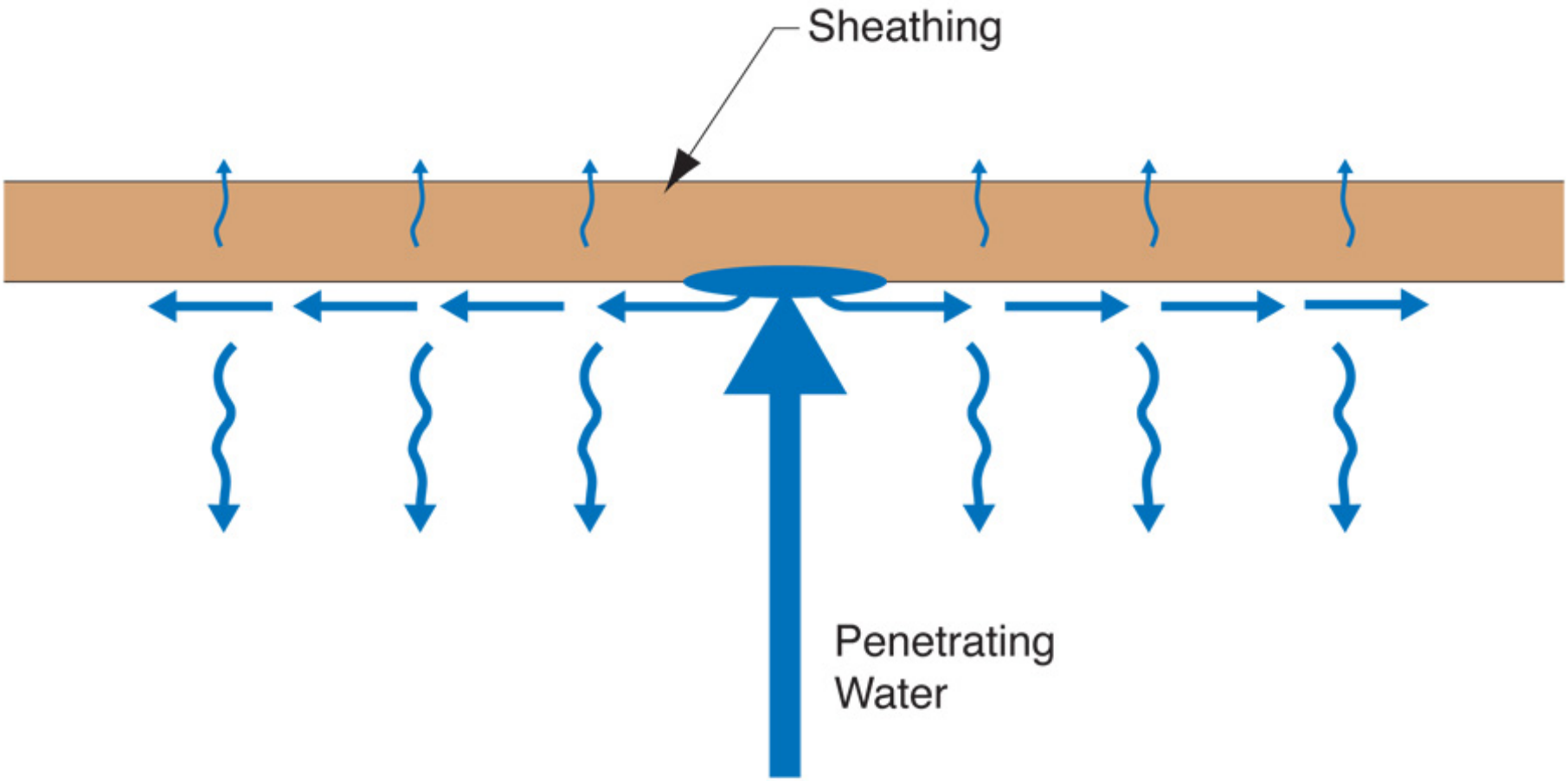

R-11 3½
OWENS-CORNING
Fiberglas
Building
Insulation
ASSURED THERMAL
PERFORMANCE
R-11 3½
OWENS-CORNING
Fiberglas
Building
Insulation
R-11 3½
OWENS-CORNING
Fiberglas
Building
Insulation
R-11 3½
OWENS-CORNING
Fiberglas
Building
Insulation


Water Vapor Permeance of MemBrain™ Smart Vapor Retarder, Primed and Painted Gypsum Board, Unpainted Gypsum Board and Asphalt-Coated Kraft Paper
Water Vapor Permeance, US perms
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Mean Relative Humidity, %
Dry Cup
Wet Cup
Unpainted Gypsum Board
MemBrain™ Smart Vapor Retarder
Primed &Painted Gypsum Board
Asphalt-Coated Kraft Paper


Water Vapor Permeance of WRB's
Water Vapor Permeance, US perms
Mean Relative Humidity, %
0
10
20
30
40
50
60
70
80
90
100
Dry Cup
Wet Cup
Felt
ASK
Tyvek®
Typar®
WeatherSmart™
WeatherMate™
Plus

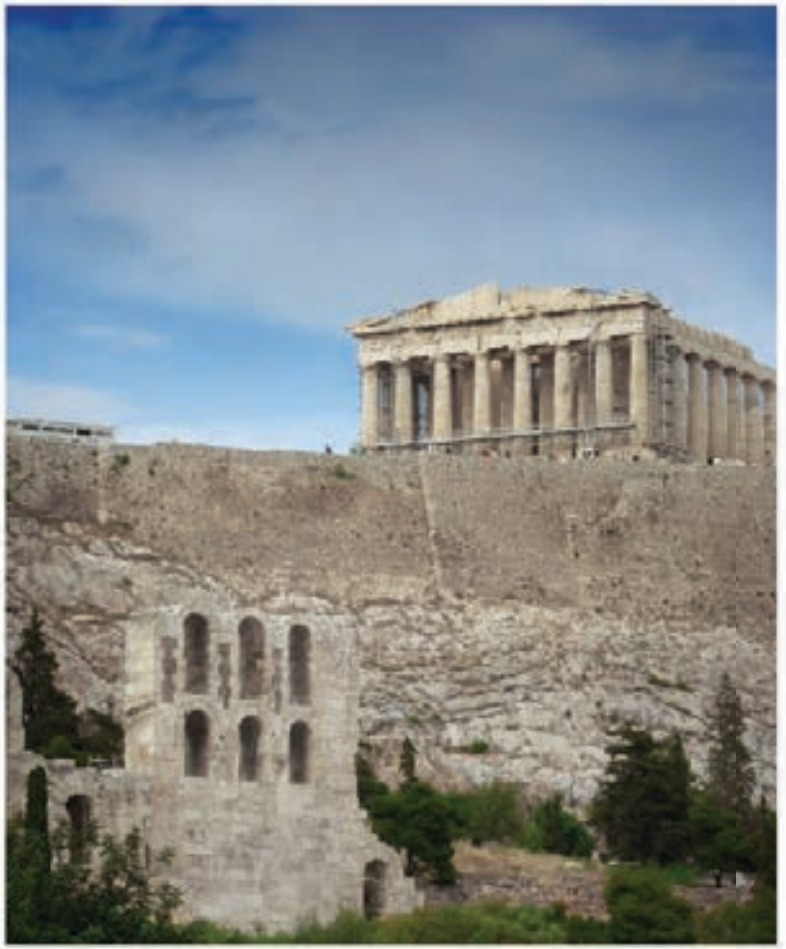

Water Vapor Permeance of Sheathing Materials
Water Vapor Permeance, US perms
100
90
80
70
60
50
40
30
20
10
0
Dry Cup
Wet Cup
Plywood
OSB
0
10
20
30
40
50
60
70
80
90
100
Mean Relative Humidity, %


Sheathing
Penetrating
Water


Sheathing
Penetrating
Water


panago


panago




Tyvek
DrainWrap


N-6
N-7


W1
W3


LOWER
N-2