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

Building Science

Adventures In Building Science

www.buildingscience.com

"It isn't what we don't know that gives us trouble, it's what we know that ain't so"

Will Rogers

"There are known knowns. These are things we know. There are known unknowns. There are things that we know we don't know. But there are also unknown unknowns. There are things we don't know we don't know.

Donald Rumsfeld

Order of Magnitude

Order of Magnitude

1 to 10

10 to 100

100 to 1000

1000 to 10000

First Order Effects, Second Order Effects….

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

Zeroth Law – Equal Systems

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

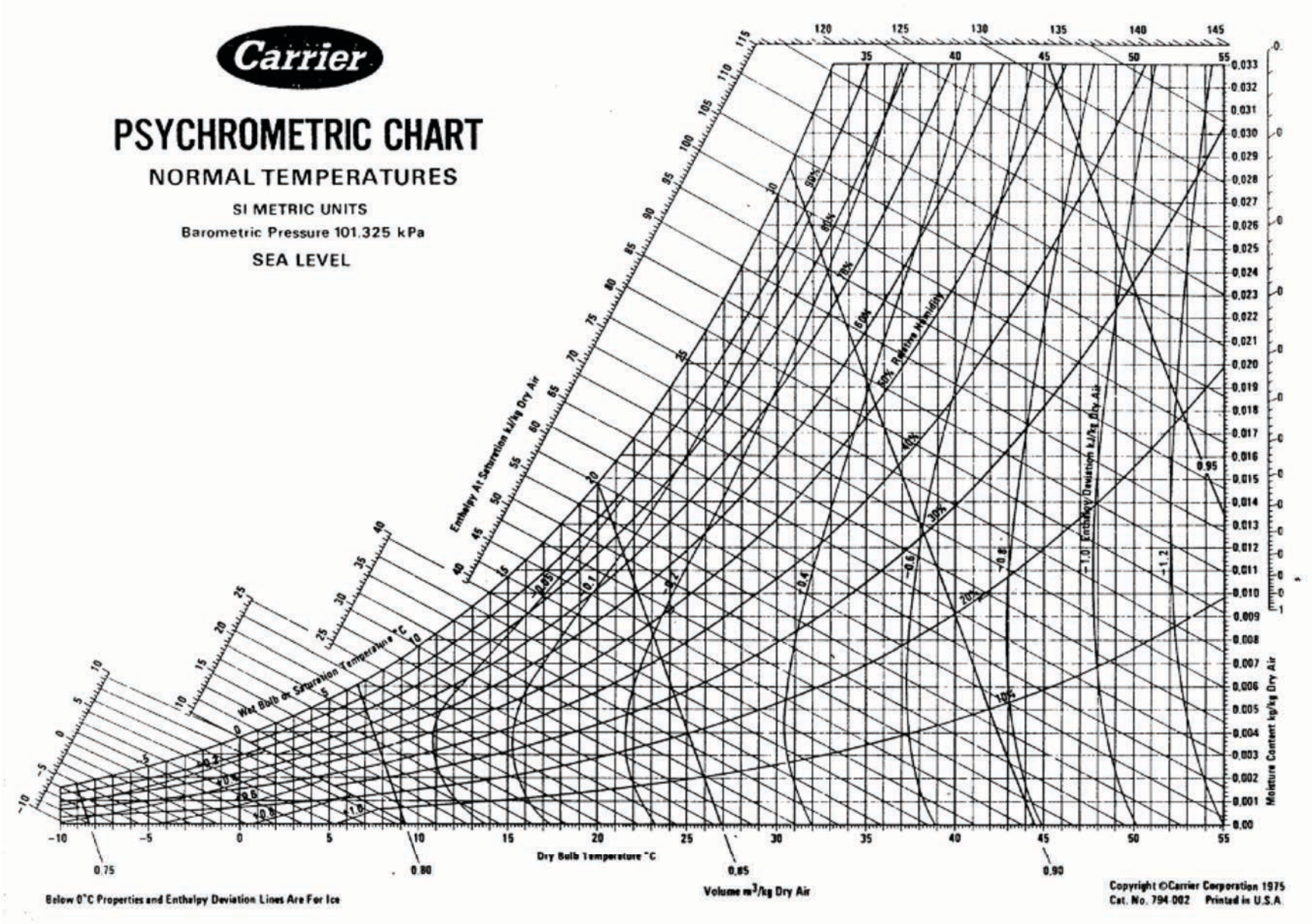
Moisture Flow Is From More To Less

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
50% Relative Humidity
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice
Volume m³/kg Dry Air
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Damage Functions

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…

80 Percent of all Construction Problems are Related to Water

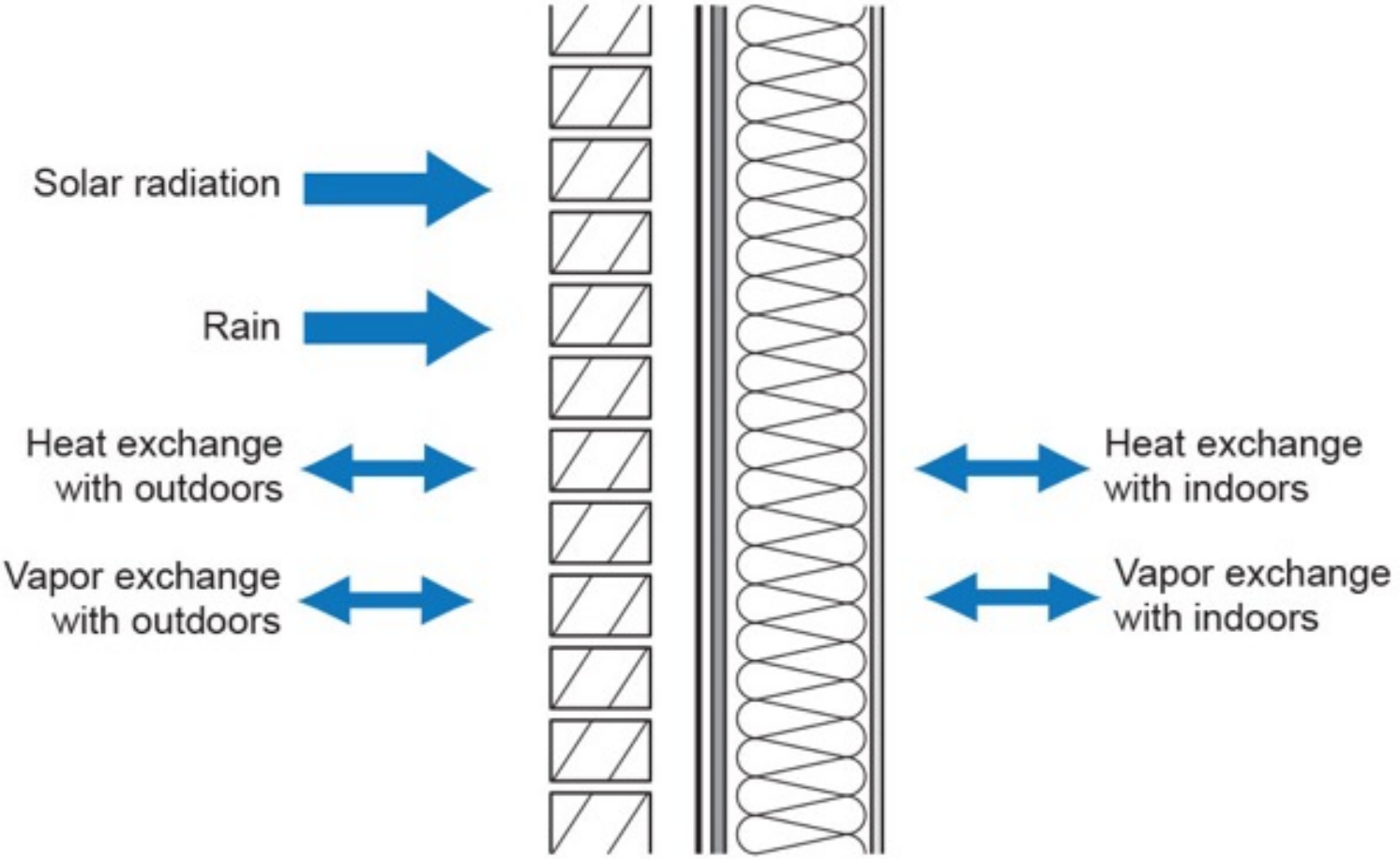
Heat

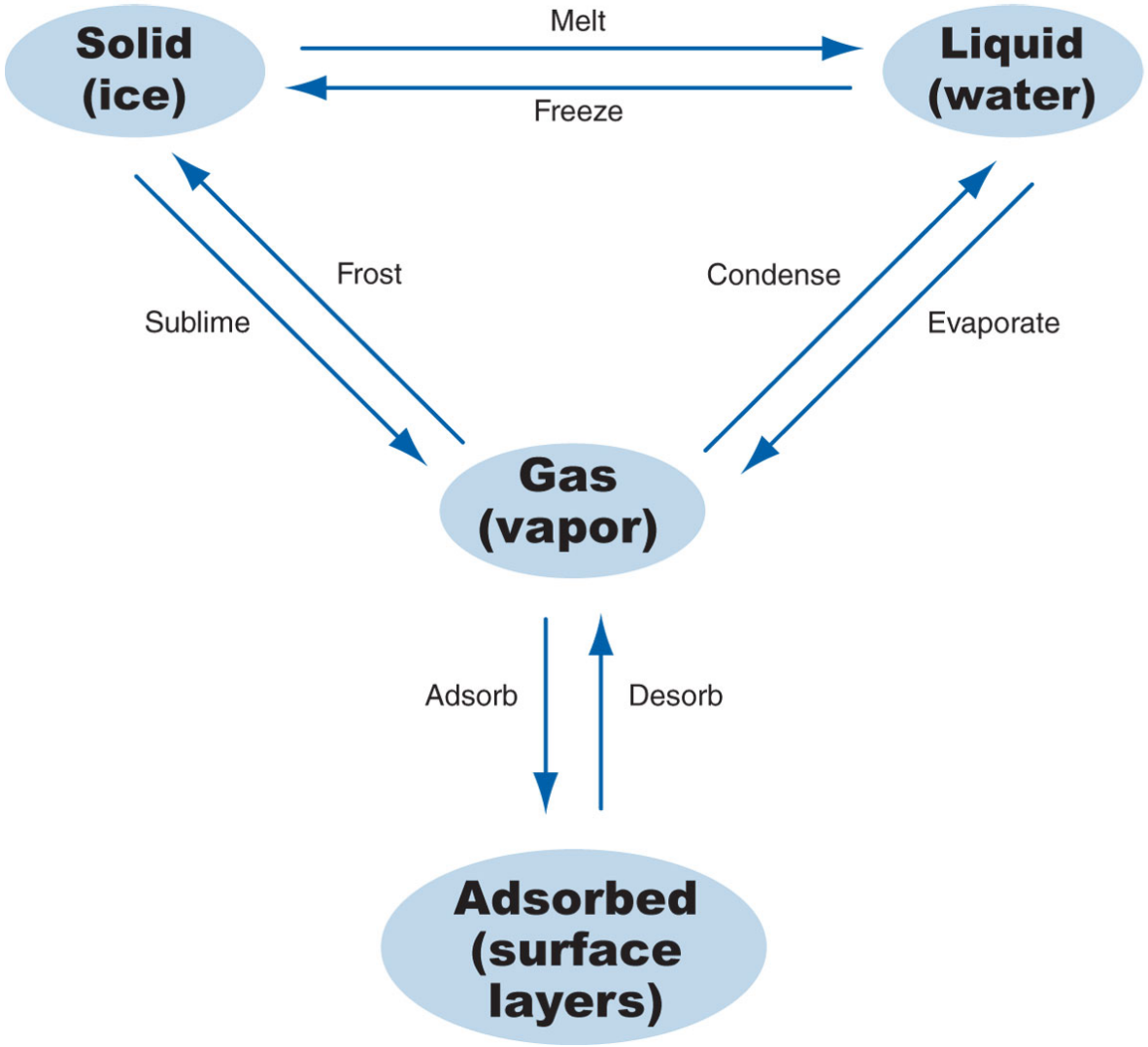
Air

Moisture

HAM

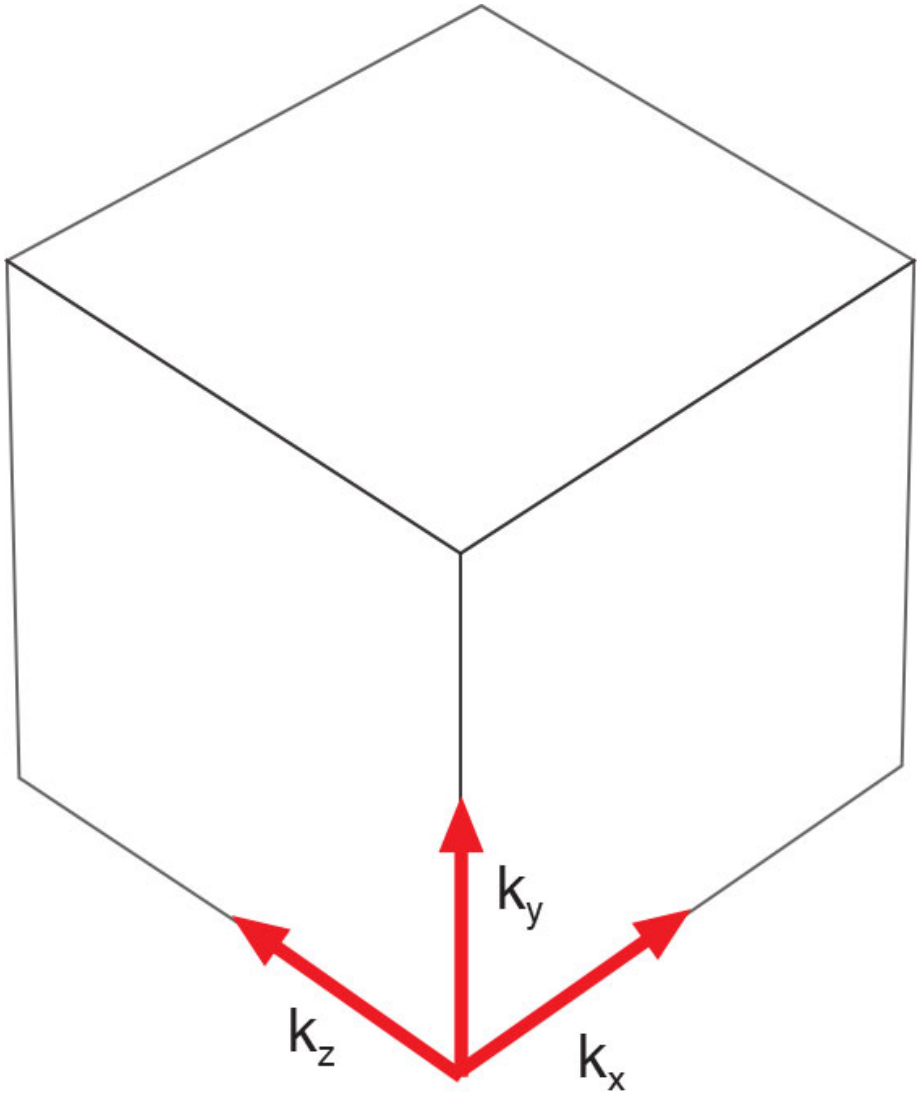
Hygrothermal Analysis

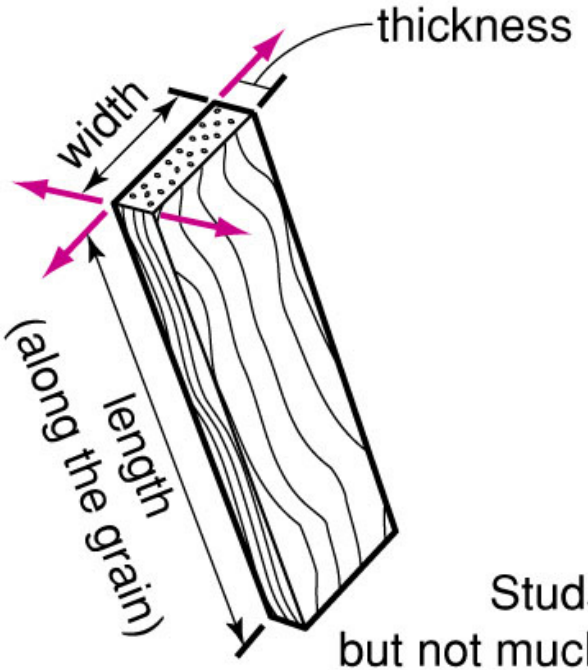

Solar radiation
Rain
Heat exchange with outdoors
Vapor exchange with outdoors
Heat exchange with indoors
Vapor exchange with indoors

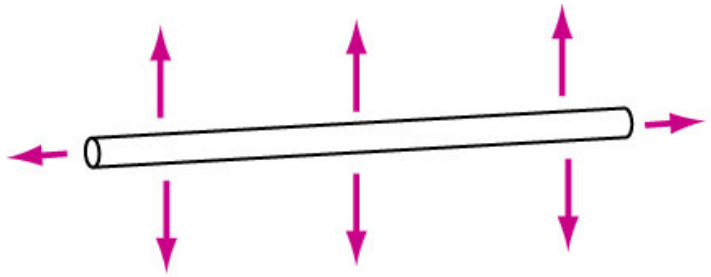

Solid (ice)
Melt
Freeze
Liquid (water)
Frost
Sublime
Condense
Evaporate
Gas (vapor)
Adsorb
Desorb
Adsorbed (surface layers)

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


k_y
k_z
k_x

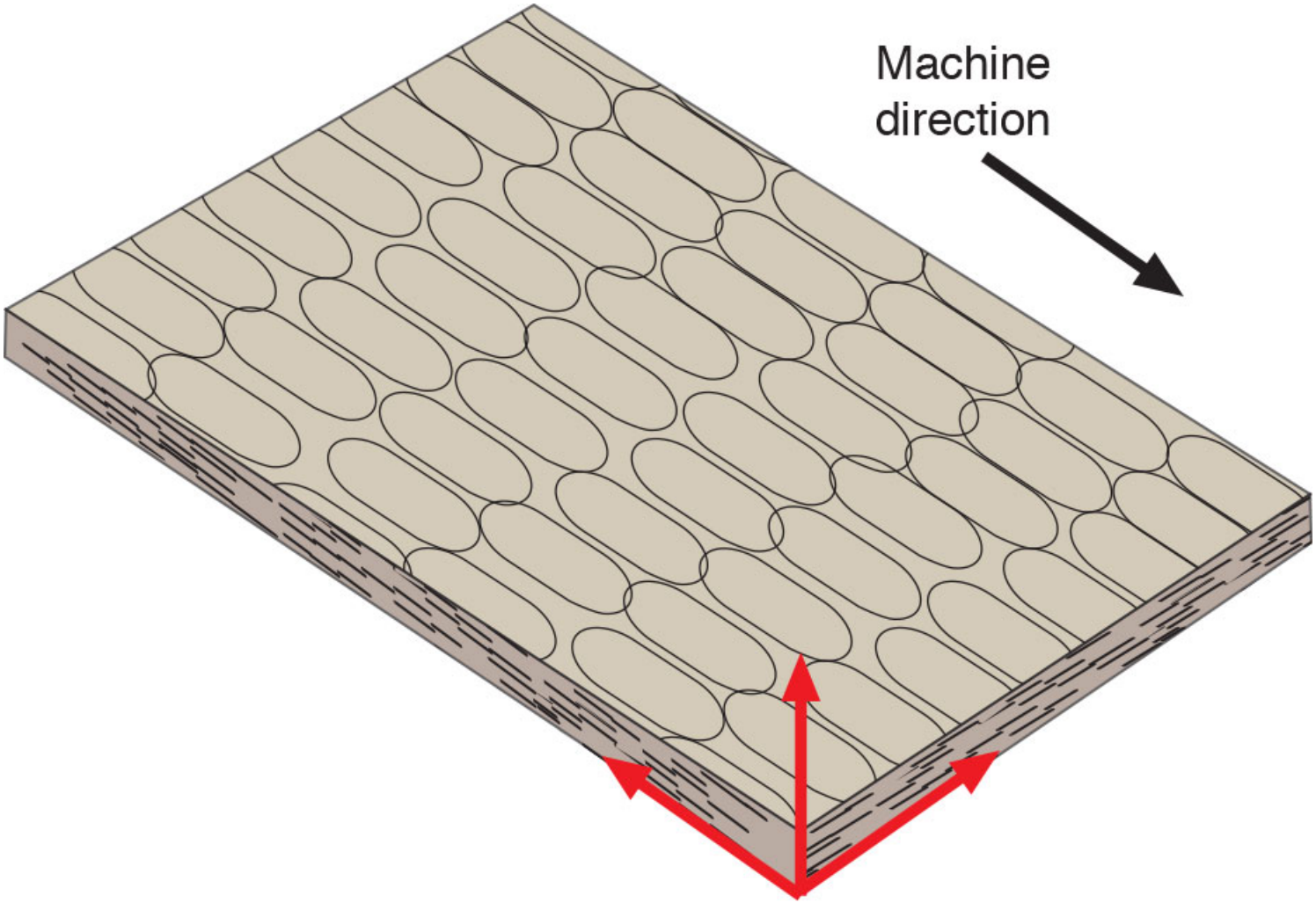


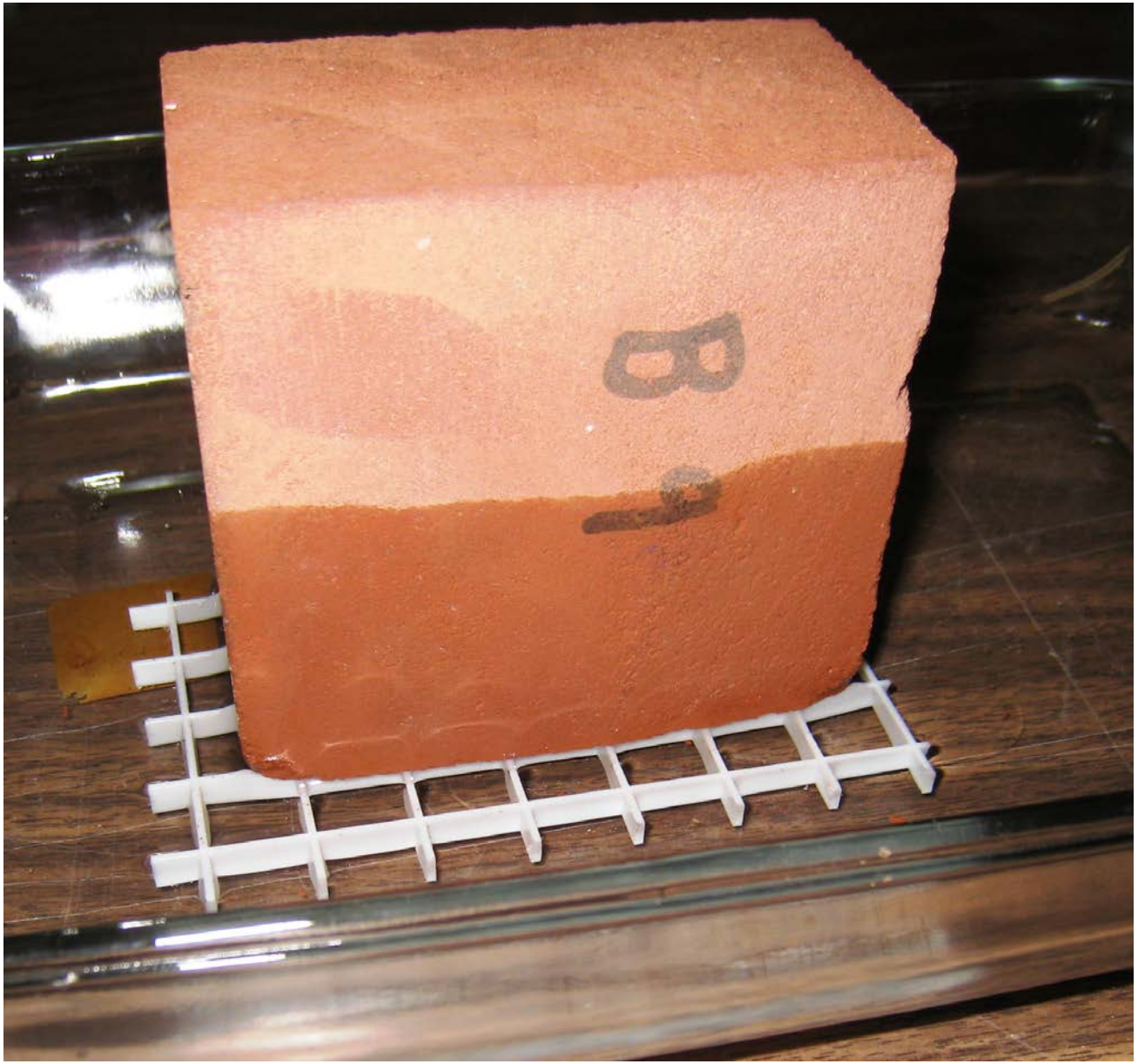


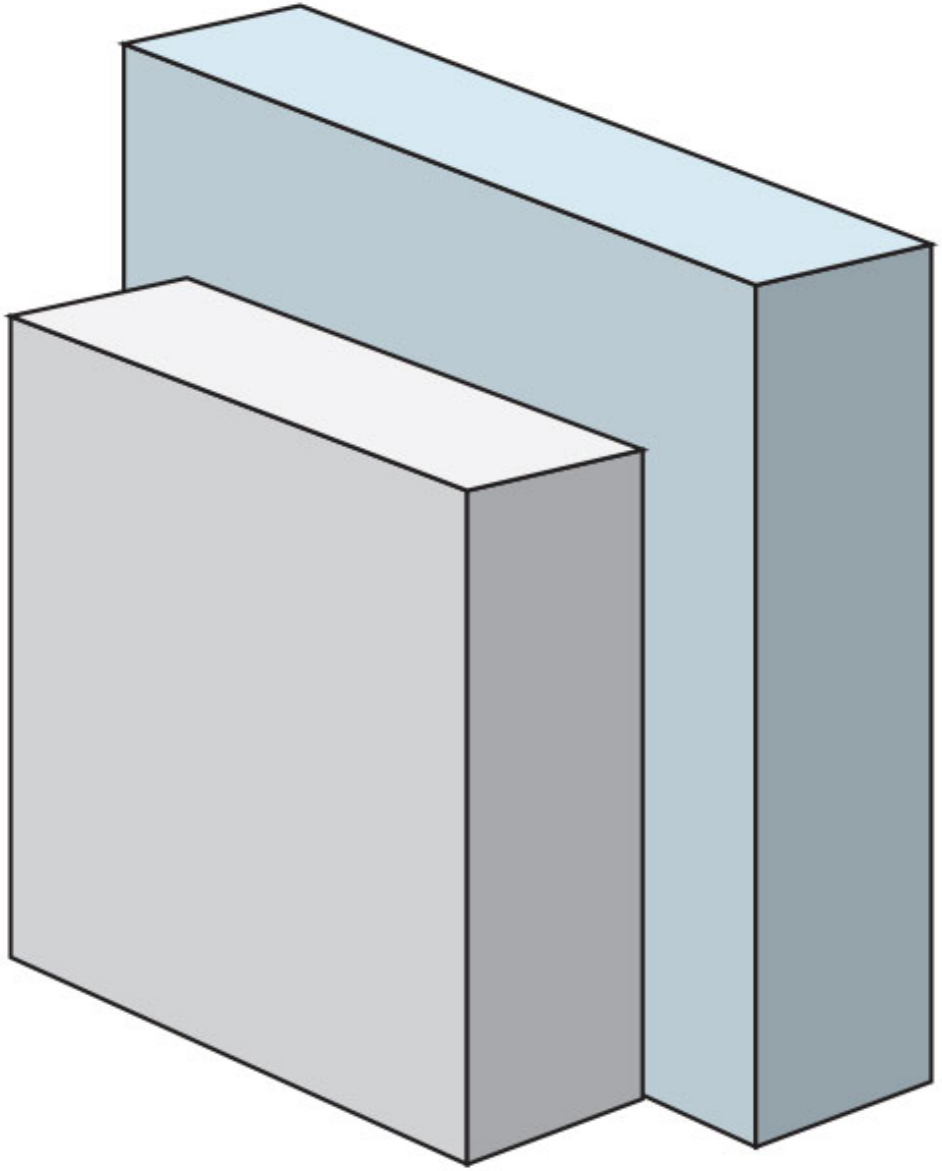
Wood Fiber

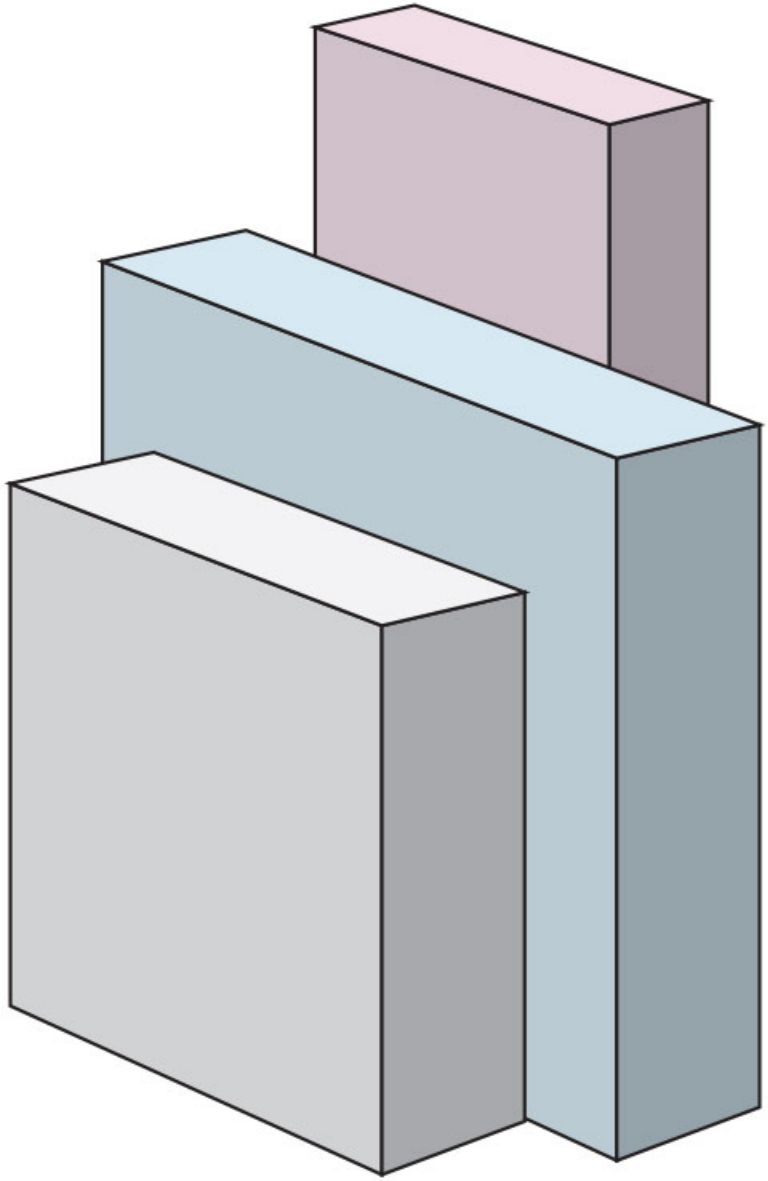
Fibers get much thicker than longer
when they pick up moisture

Studs get much wider and thicker,
but not much longer, when they pick up moisture

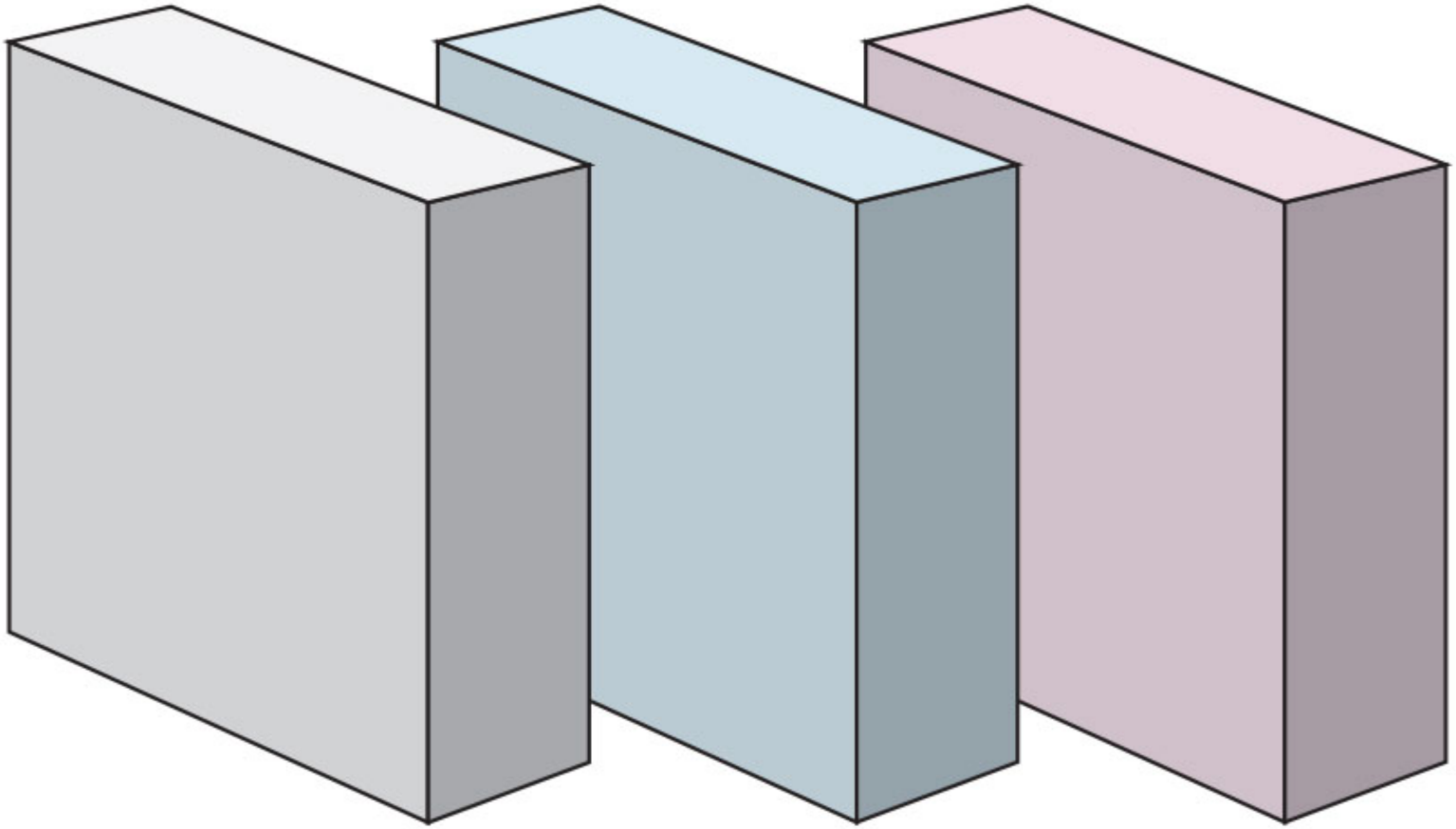

Machine
direction







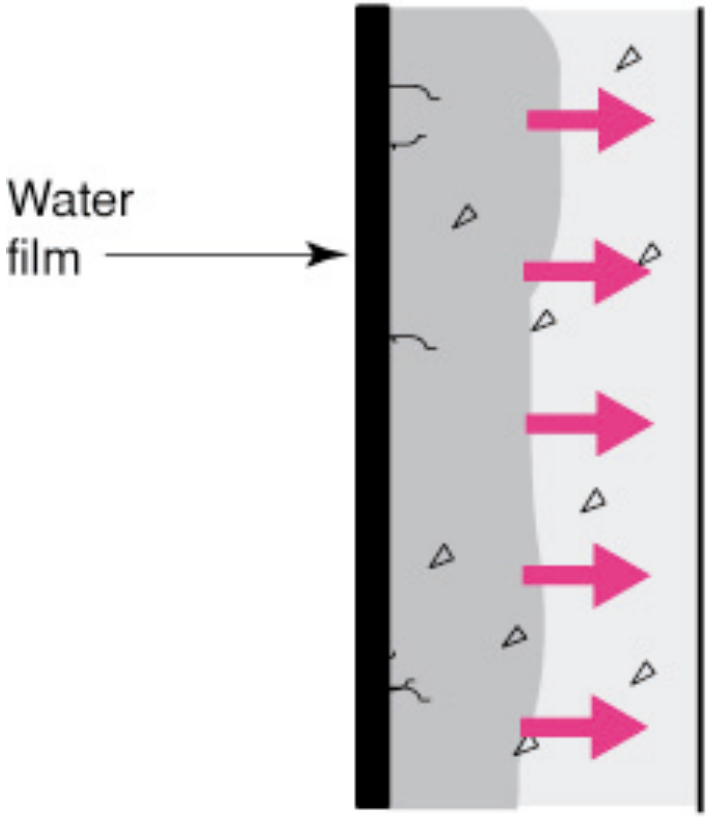
Rain and Airflow Missing



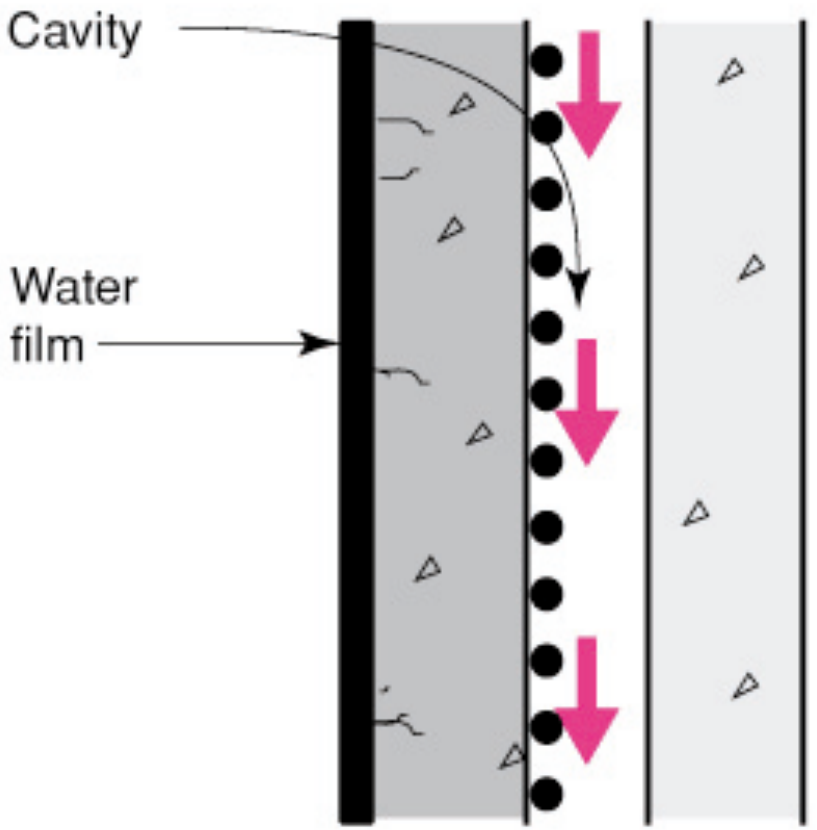
Recall That Rain and Airflow Are Missing

Moisture Transport in Assemblies

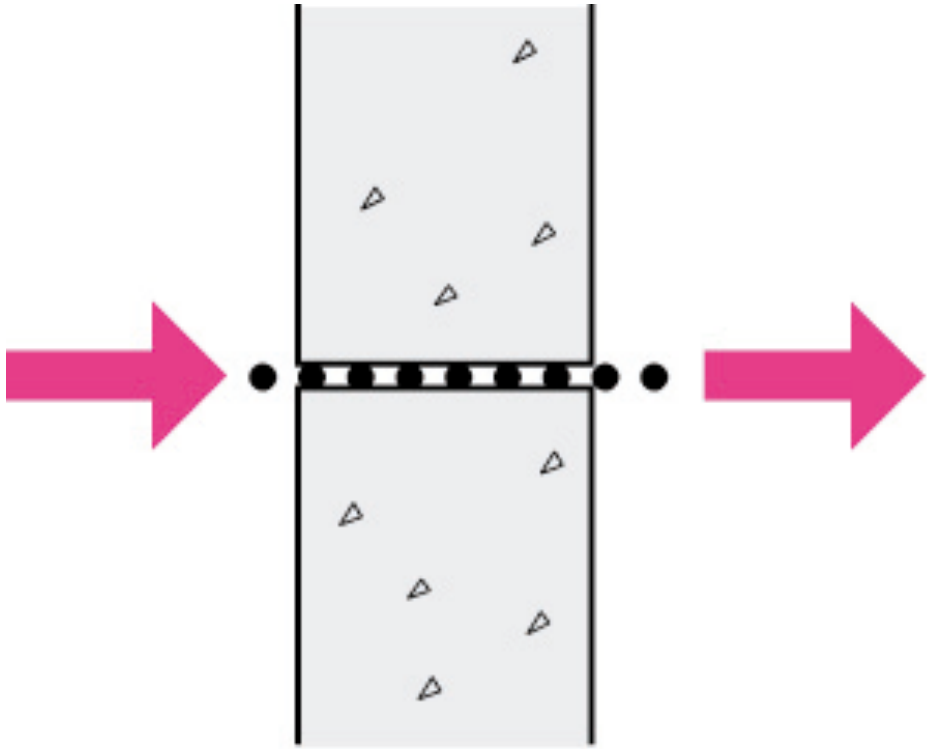
Phase	Transport Process	Driving Potential
Vapor	Diffusion	Vapor Concentration
	Convective Flow	Air Pressure
Adsorbate	Surface Diffusion	Concentration
Liquid	Capillary Flow	Suction Pressure
	Osmosis	Solute Concentration
	Gravitational Flow	Height
	Surface Tension	Surface Energy
	Momentum	Kinetic Energy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



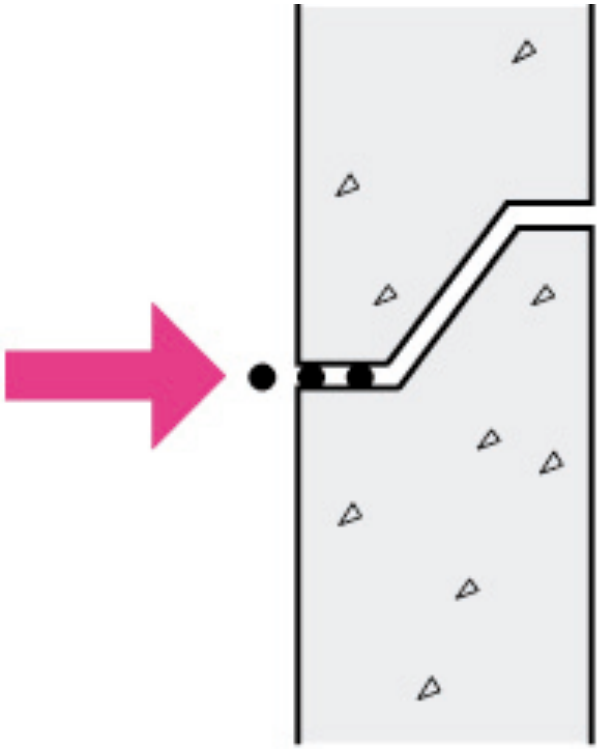
Capillary suction draws water into porous material and tiny cracks



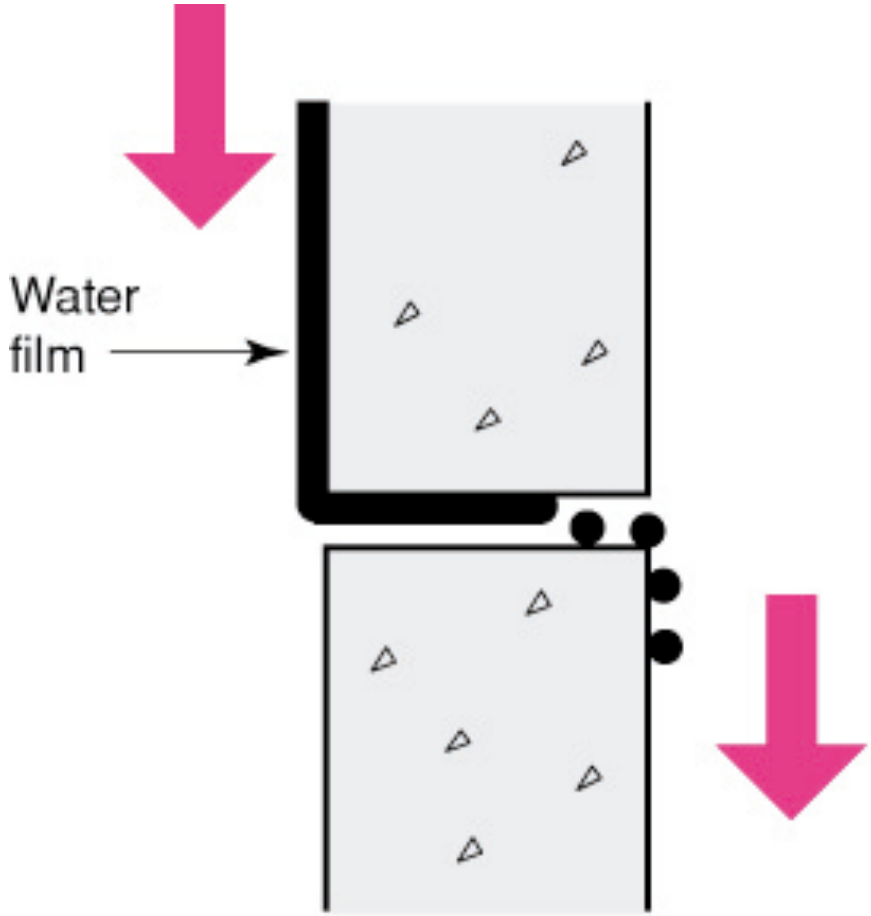
Cavity acts as capillary break and receptor for capillary water interrupting flow



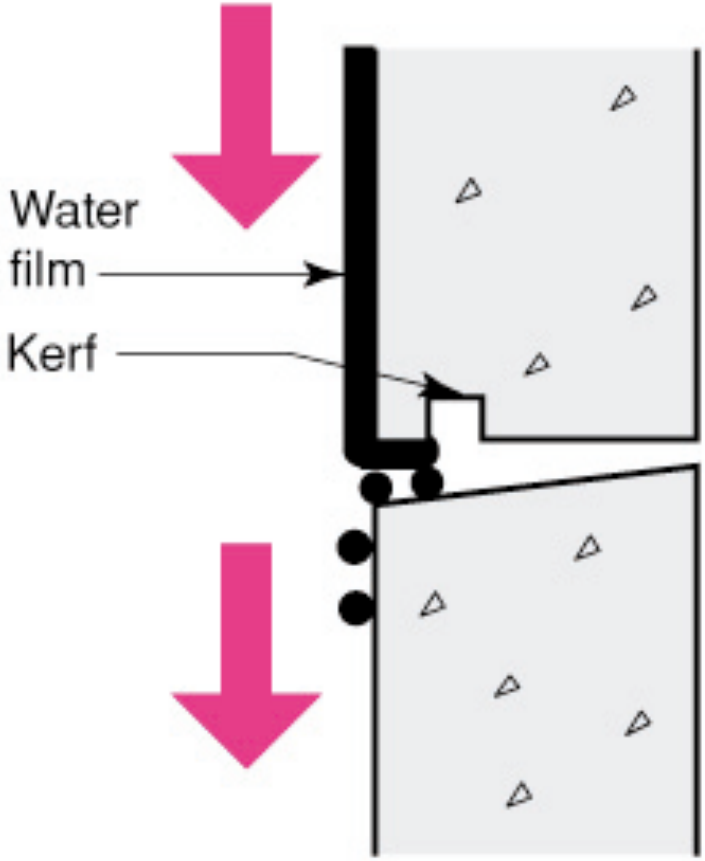
Rain droplets can be carried through a wall by their own momentum



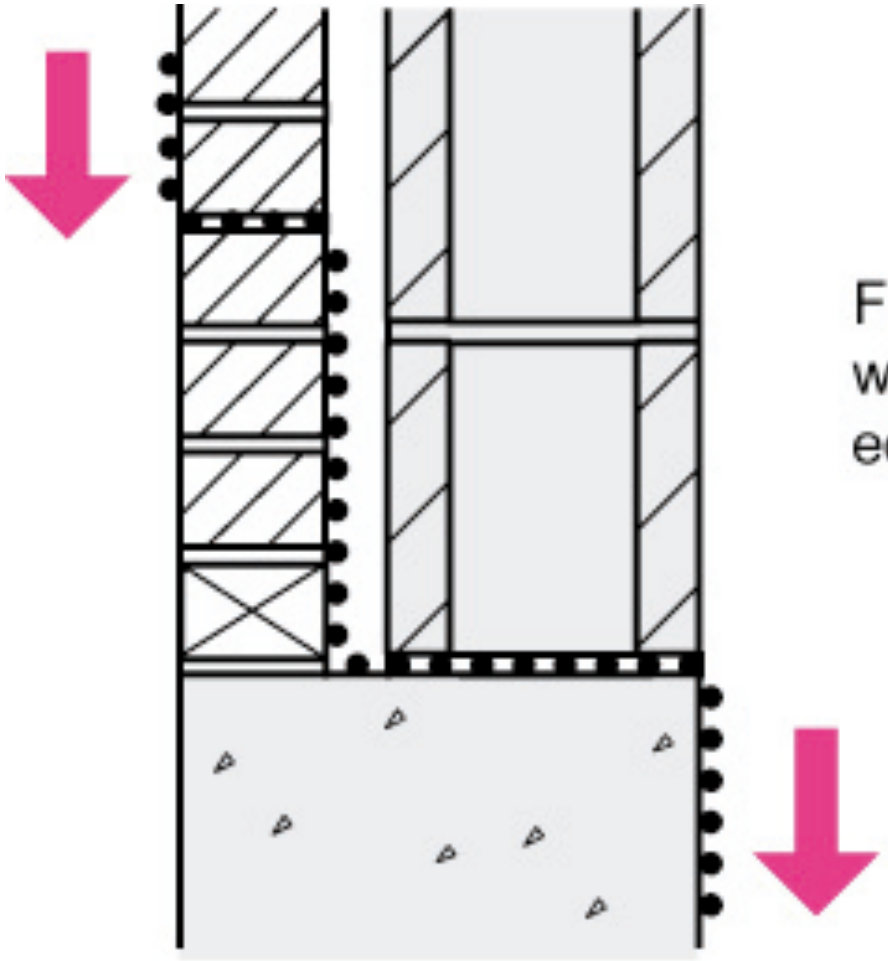
Rain entry by momentum can be prevented by designing wall systems with no straight through openings



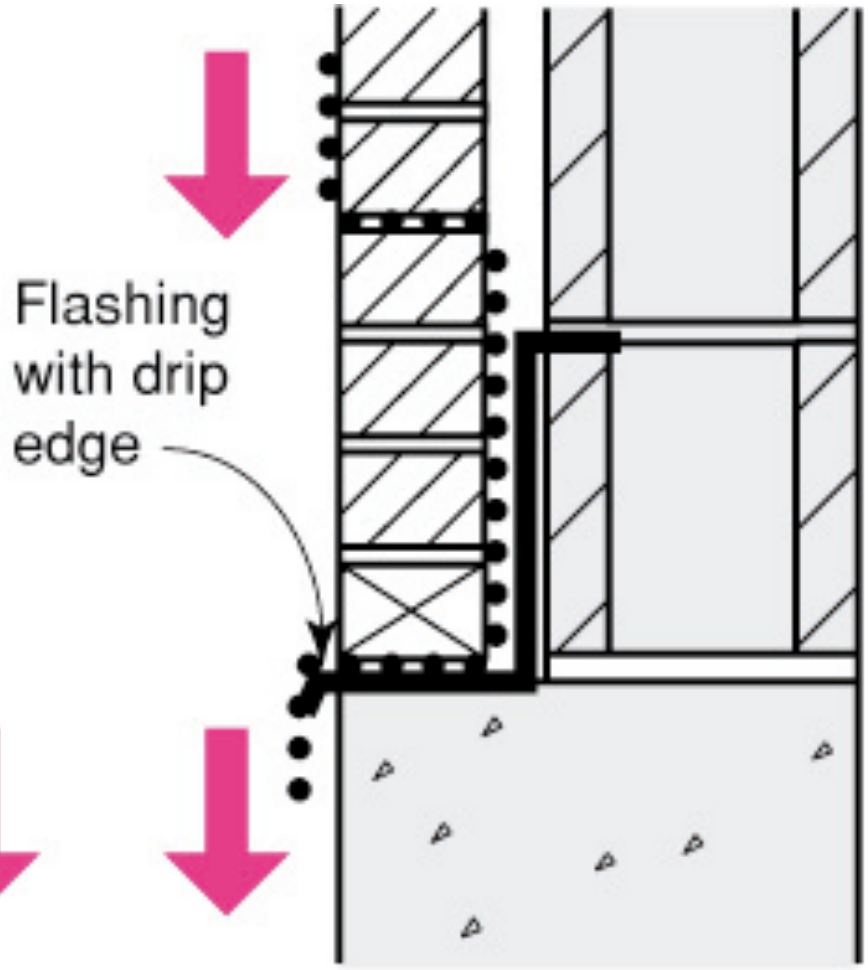
Rainwater can flow around a surface as a result of surface tension



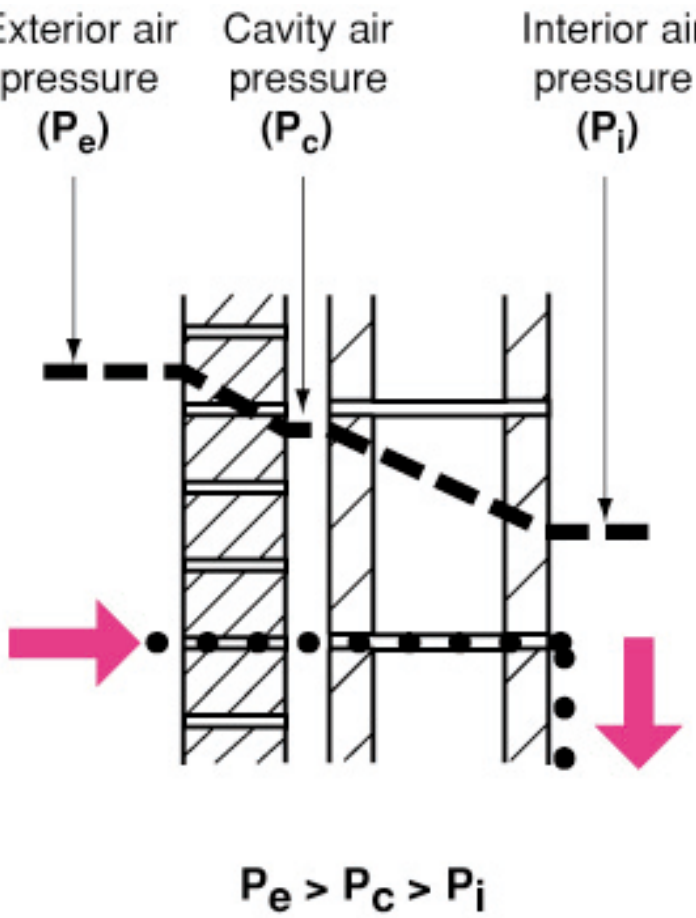
Providing a kerf or drip edge will promote the formation of a water droplet and interrupt flow



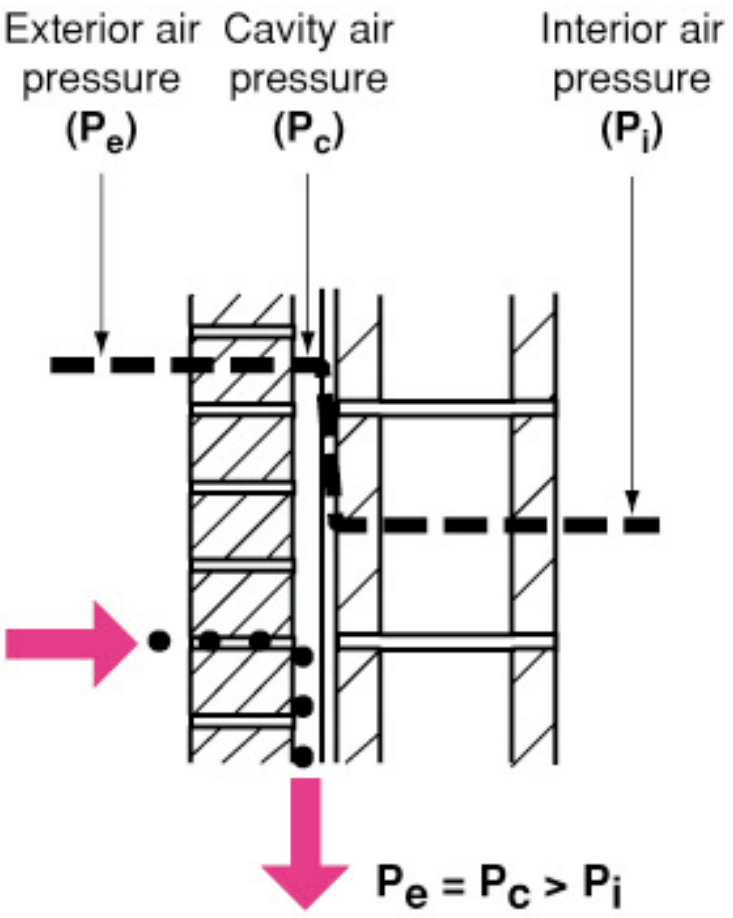
Rainwater can flow down surfaces and enter through openings and cavities



Flashings direct gravity flow rainwater back toward the exterior

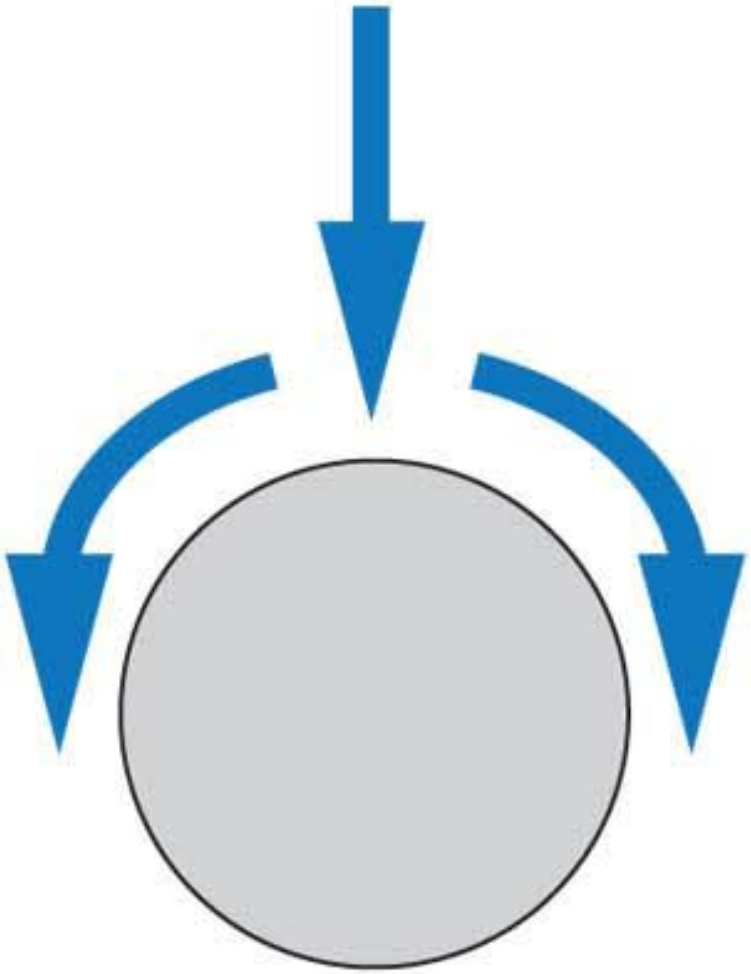


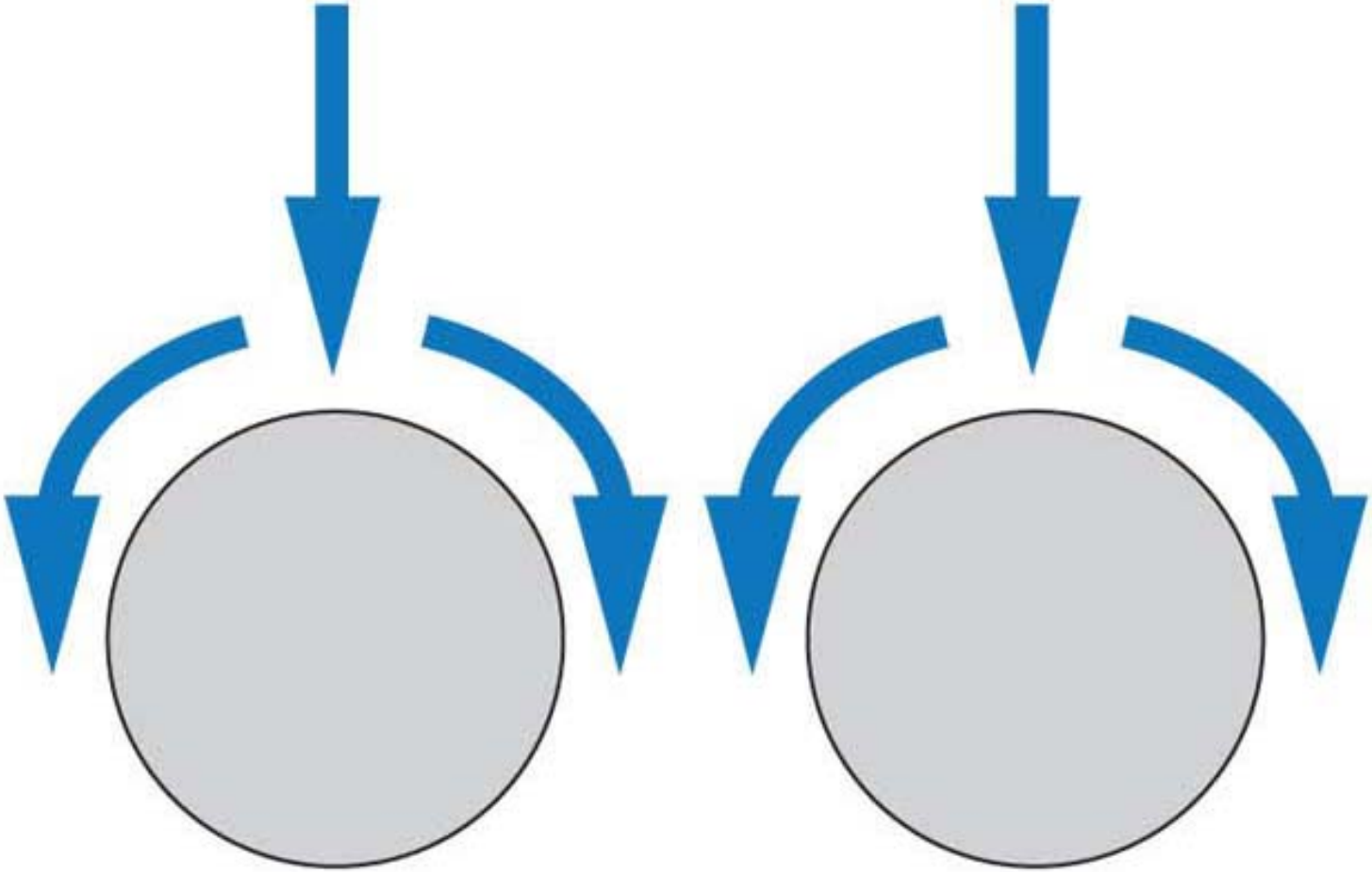
Driven by air pressure differences, rain droplets are drawn through wall openings from the exterior to the interior

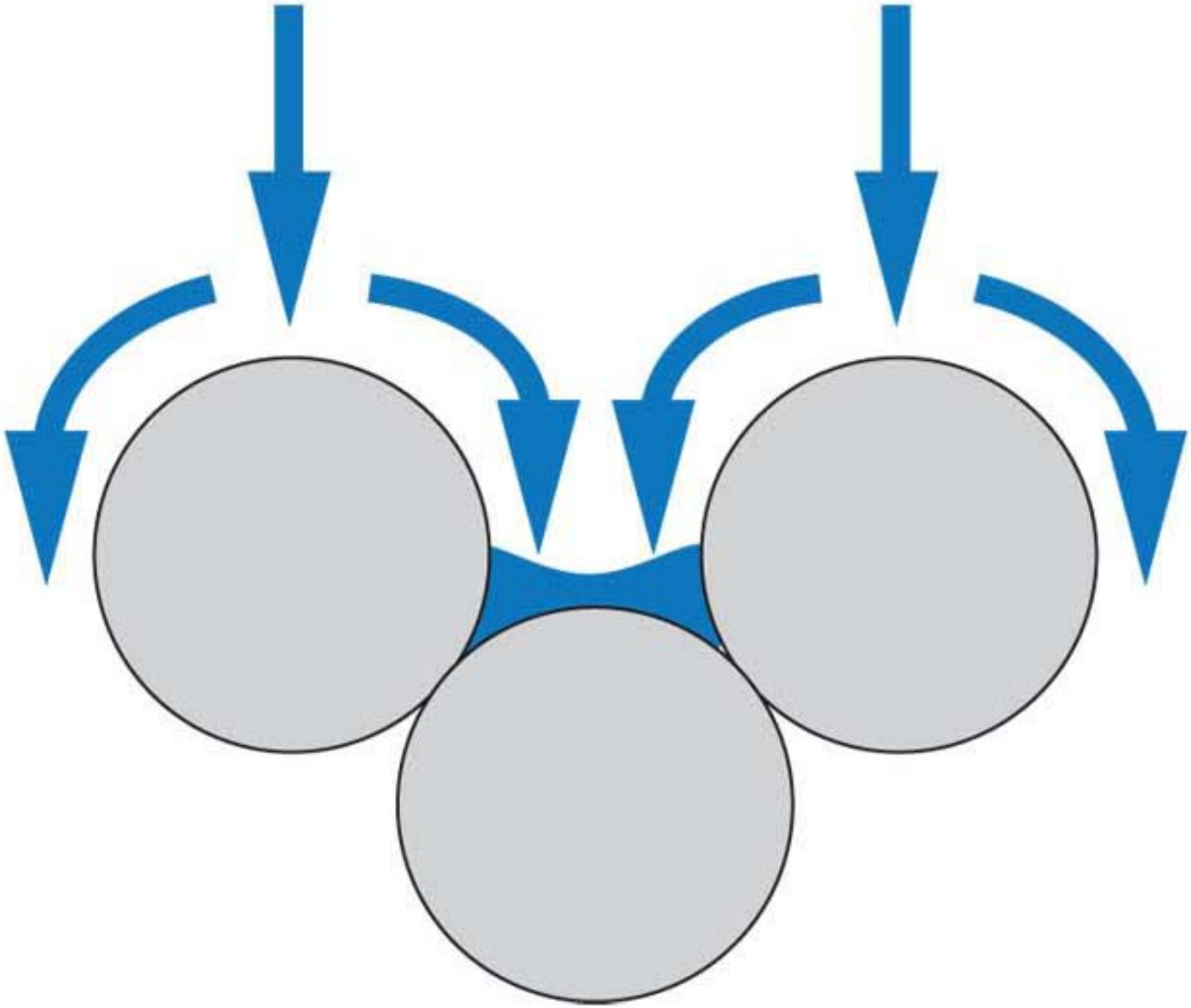


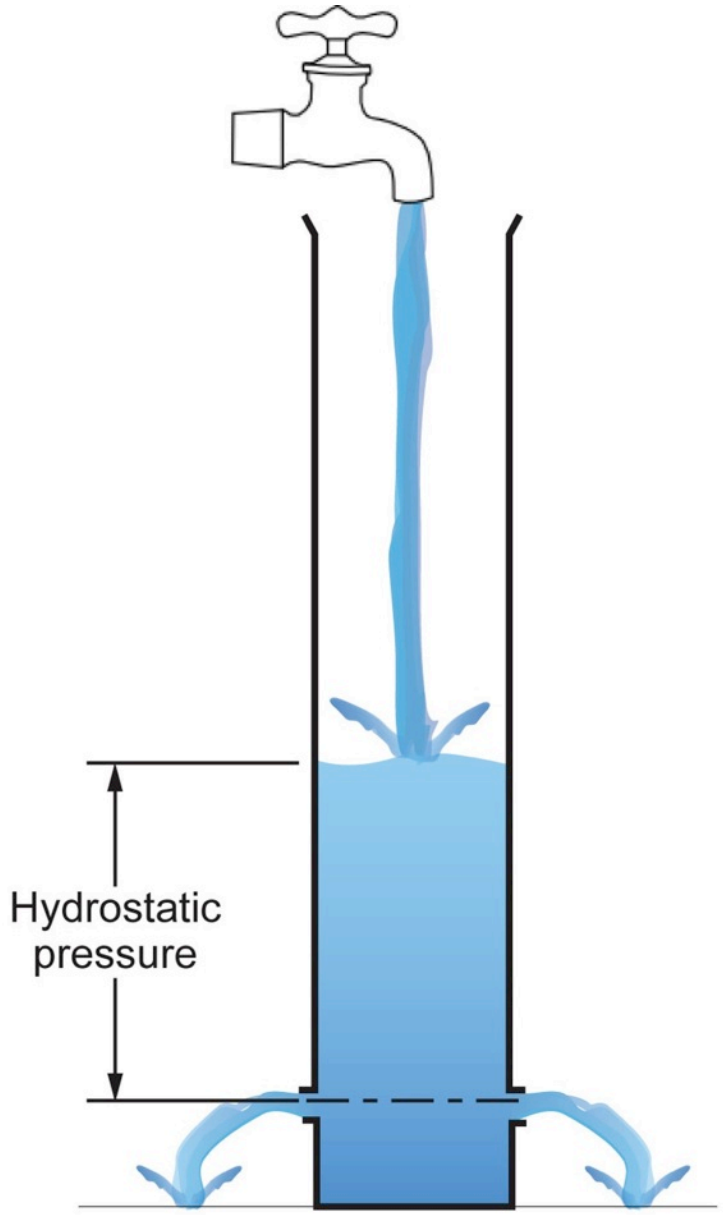
By creating pressure equalization or pressure moderation between the exterior and cavity air, air pressure is diminished as a driving force for rain entry

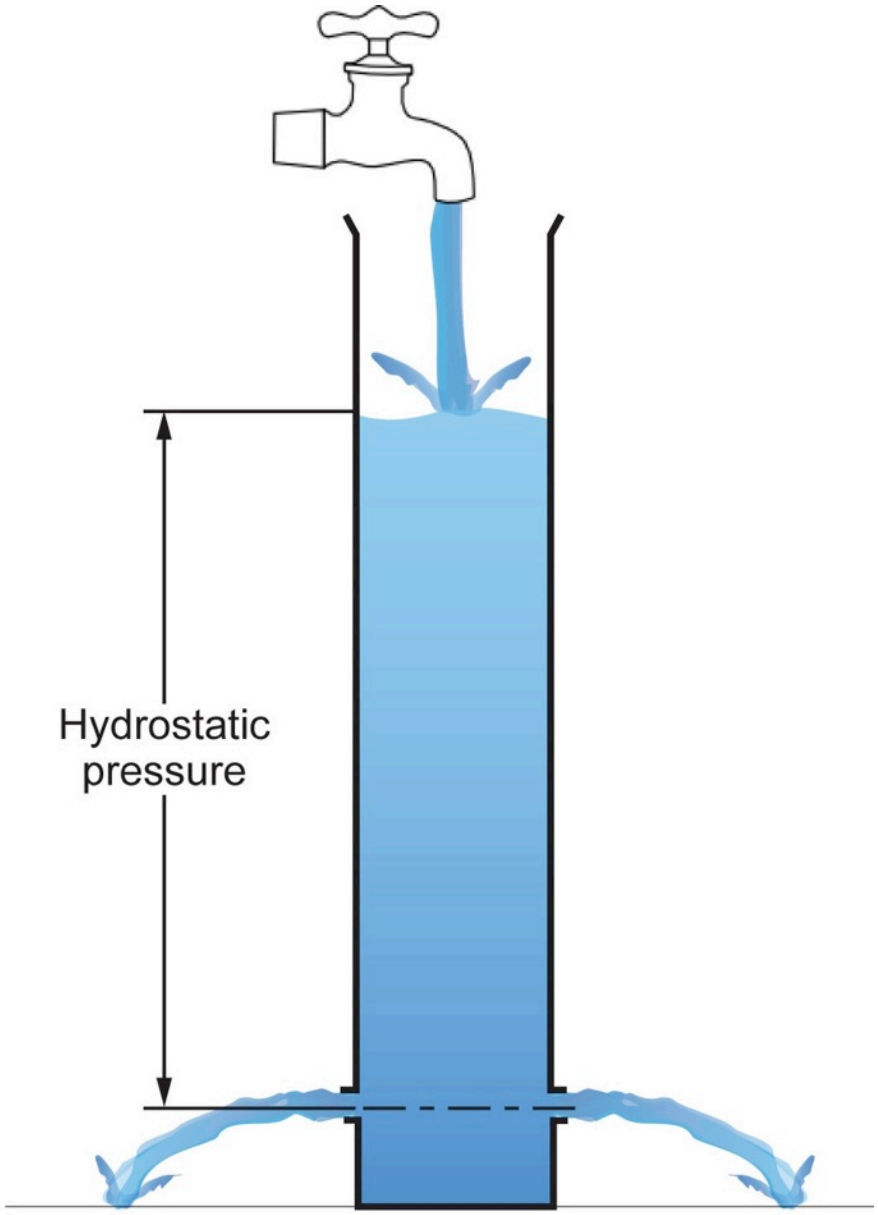

PUBLIC

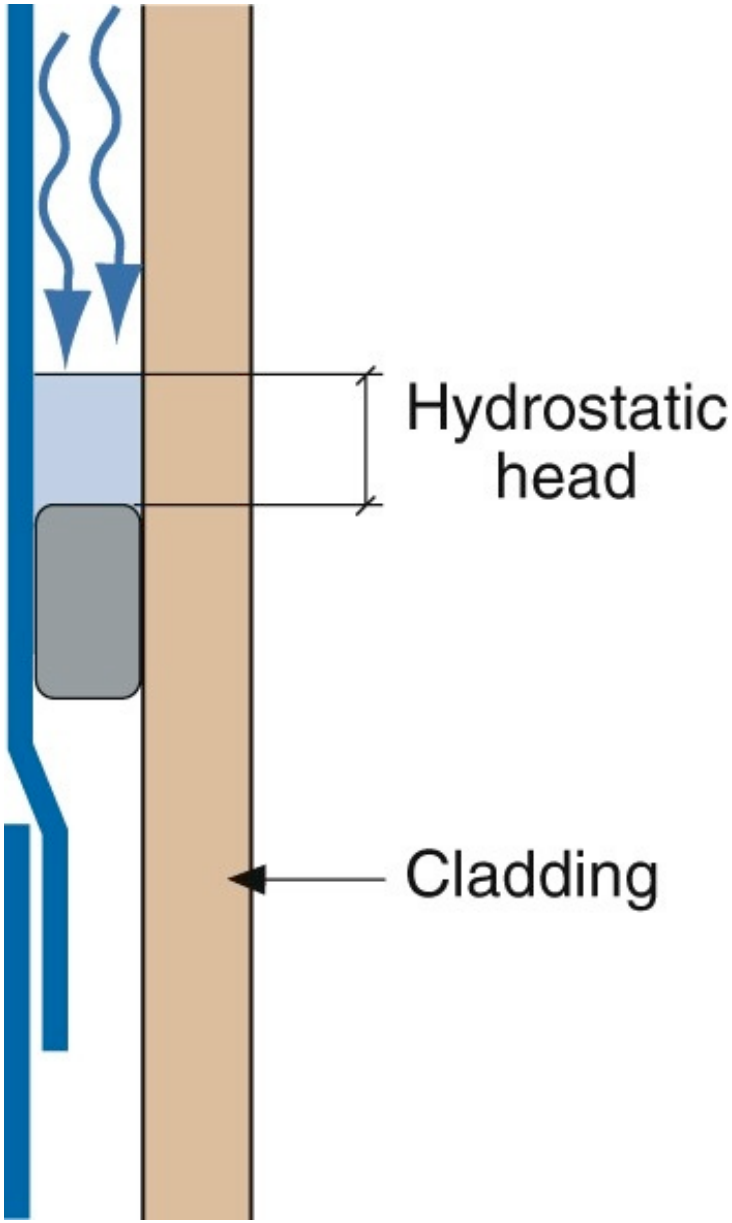


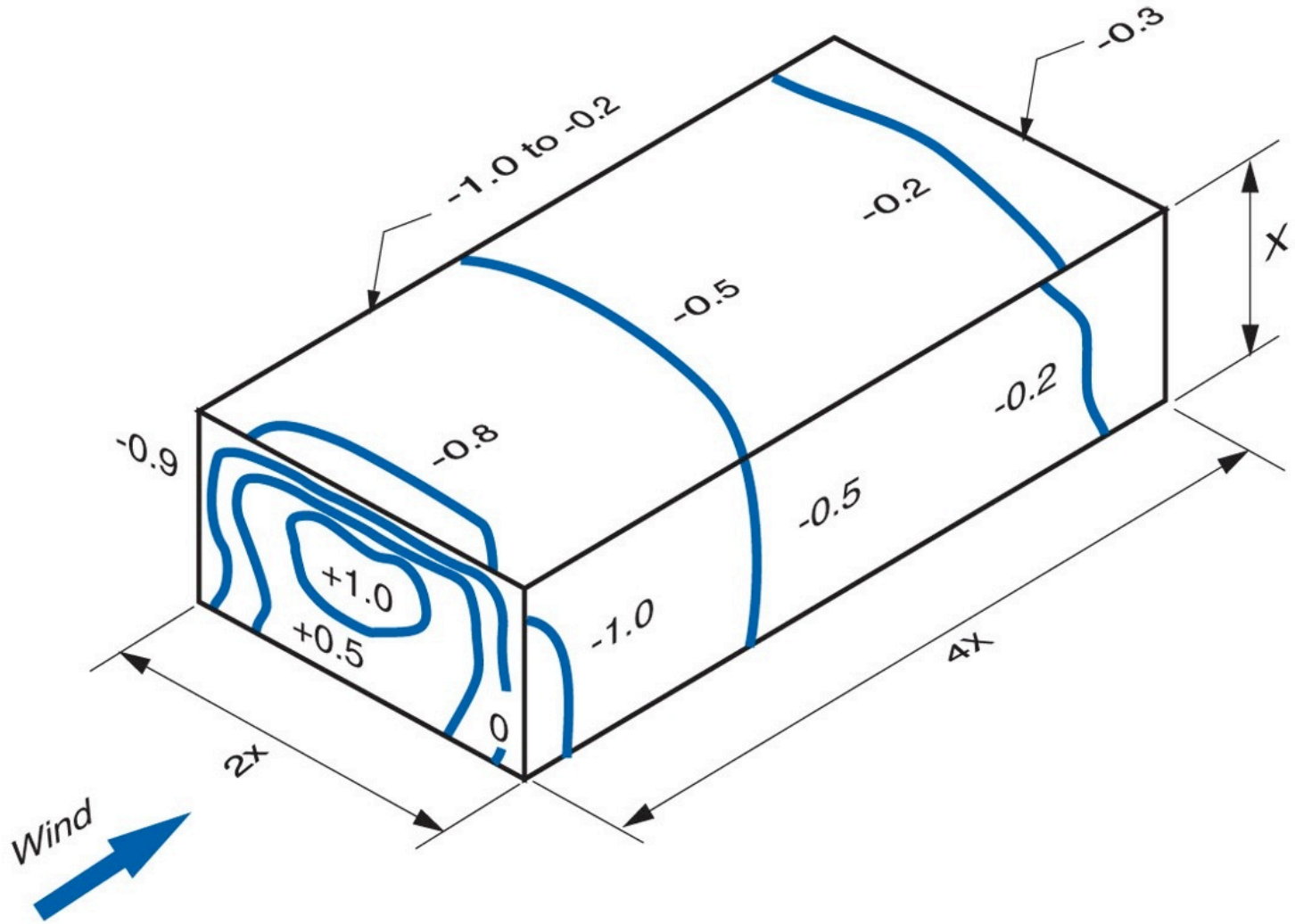




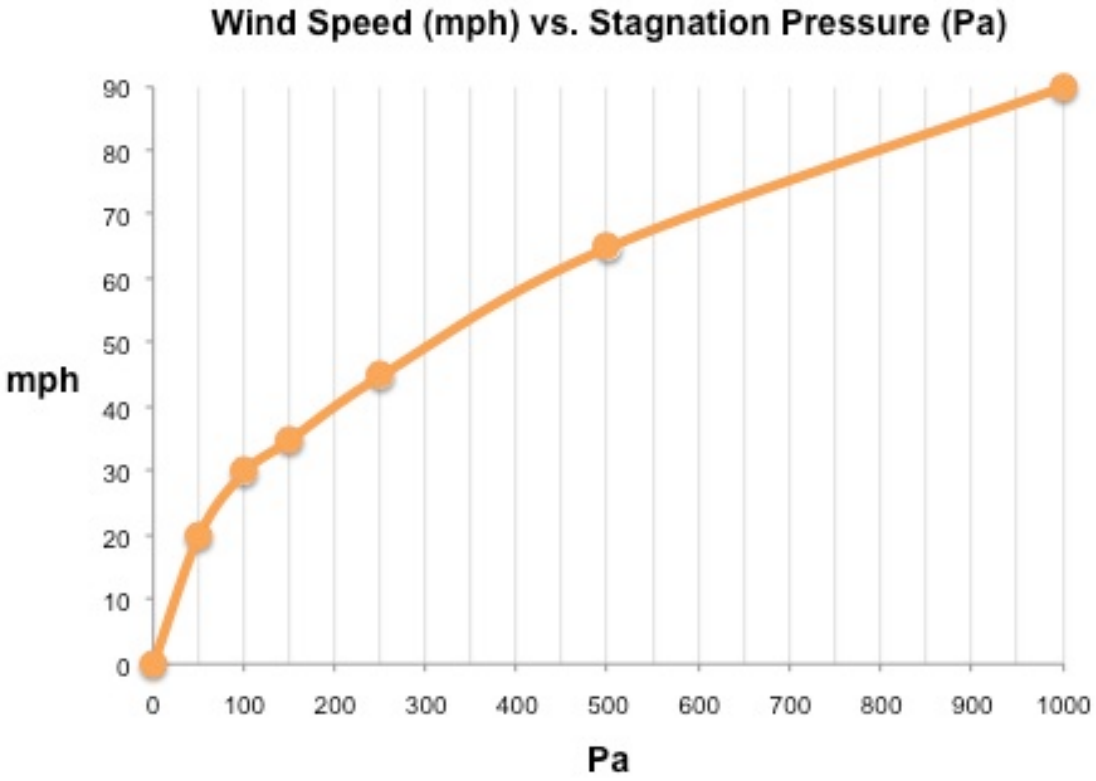

Hydrostatic
pressure


Hydrostatic
pressure


Hydrostatic
head
Cladding

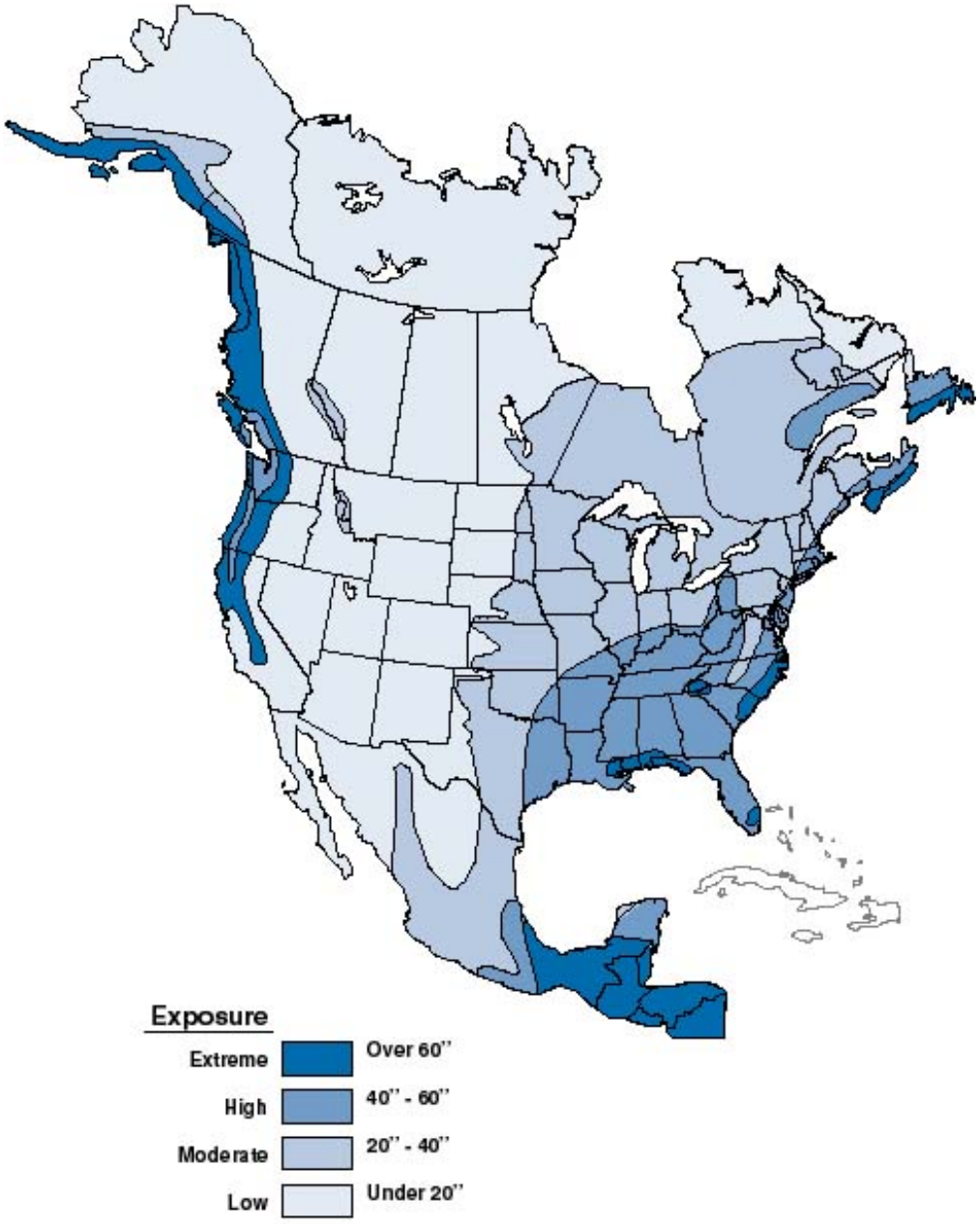

-0.3
-1.0 to -0.2
-0.2
-0.5
-0.2
-0.9
-0.8
-0.5
+1.0
+0.5
-1.0
0
X
2X
4X
Wind

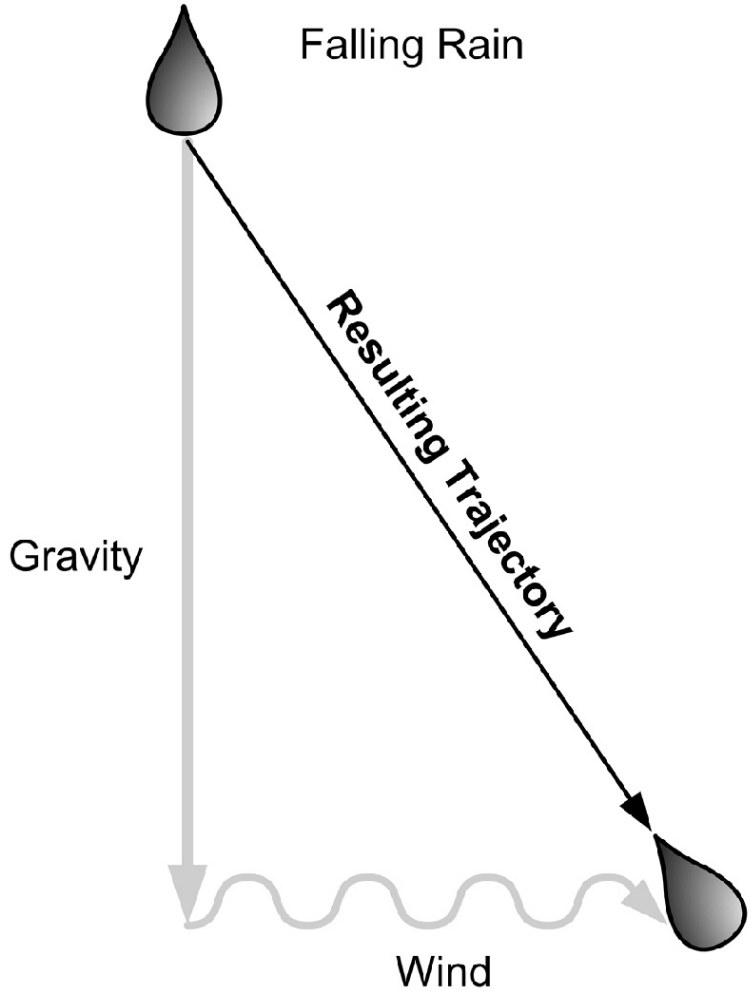
Pascals		mph
50	Pa =	20 mph
100	Pa =	30 mph
150	Pa =	35 mph
250	Pa =	45 mph
500	Pa =	65 mph
1,000	Pa =	90 mph

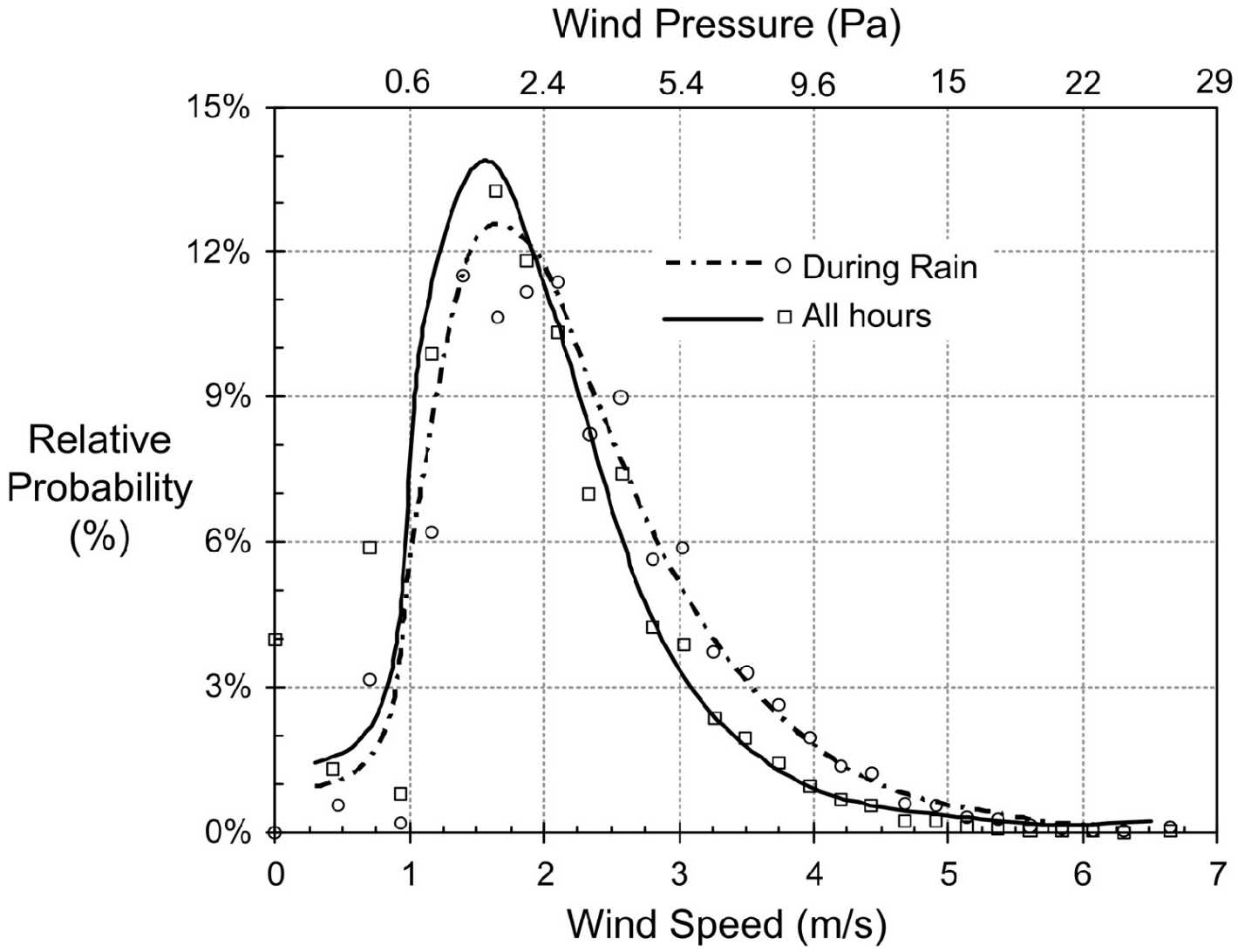


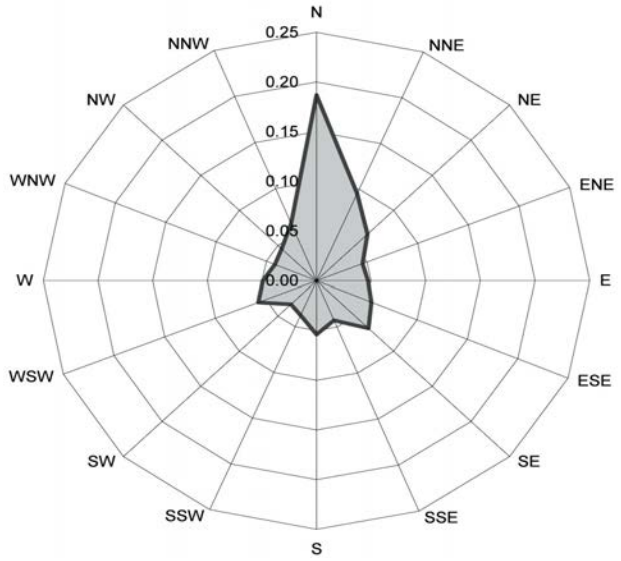
All We Have To Figure Out Is How Much Hits The Wall

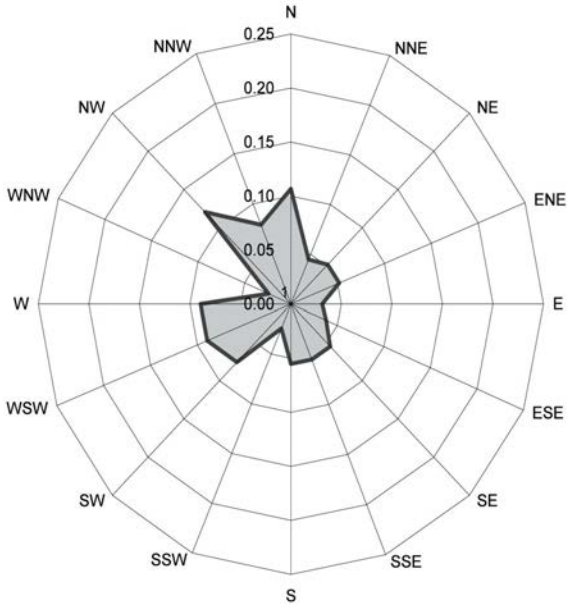
- All We Have To Figure Out Is How Much Hits The Wall
- We Need Straube and Kuenzel

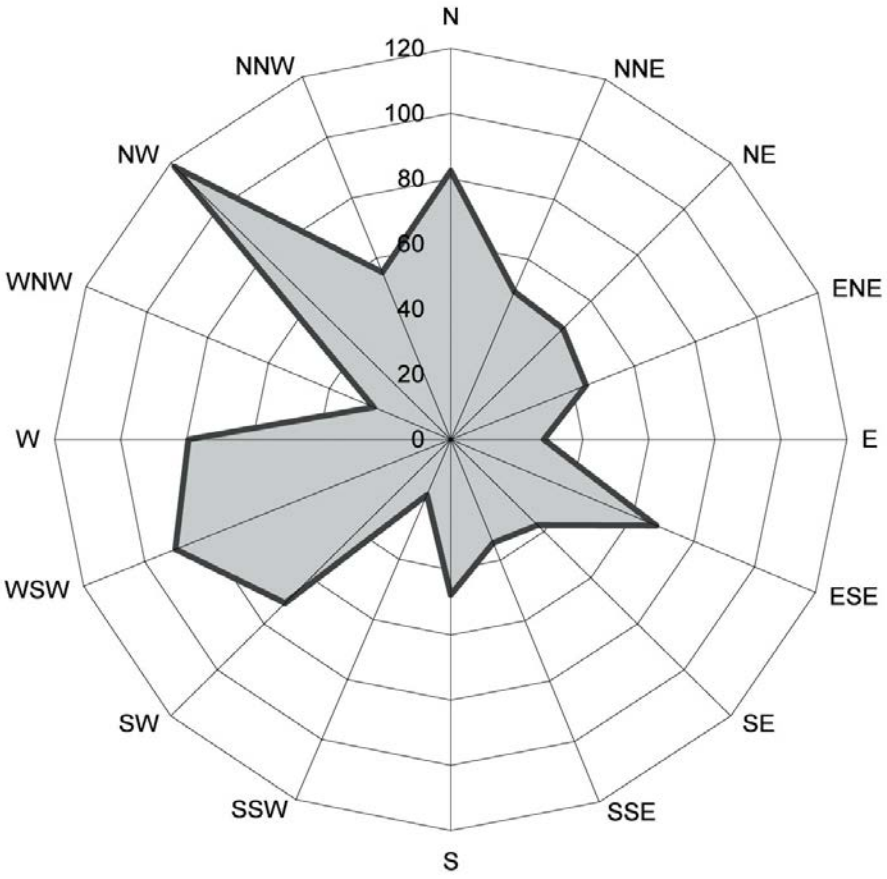

Exposure
Extreme
Over 60''
High
40'' - 60''
Moderate
20'' - 40''
Low
Under 20''

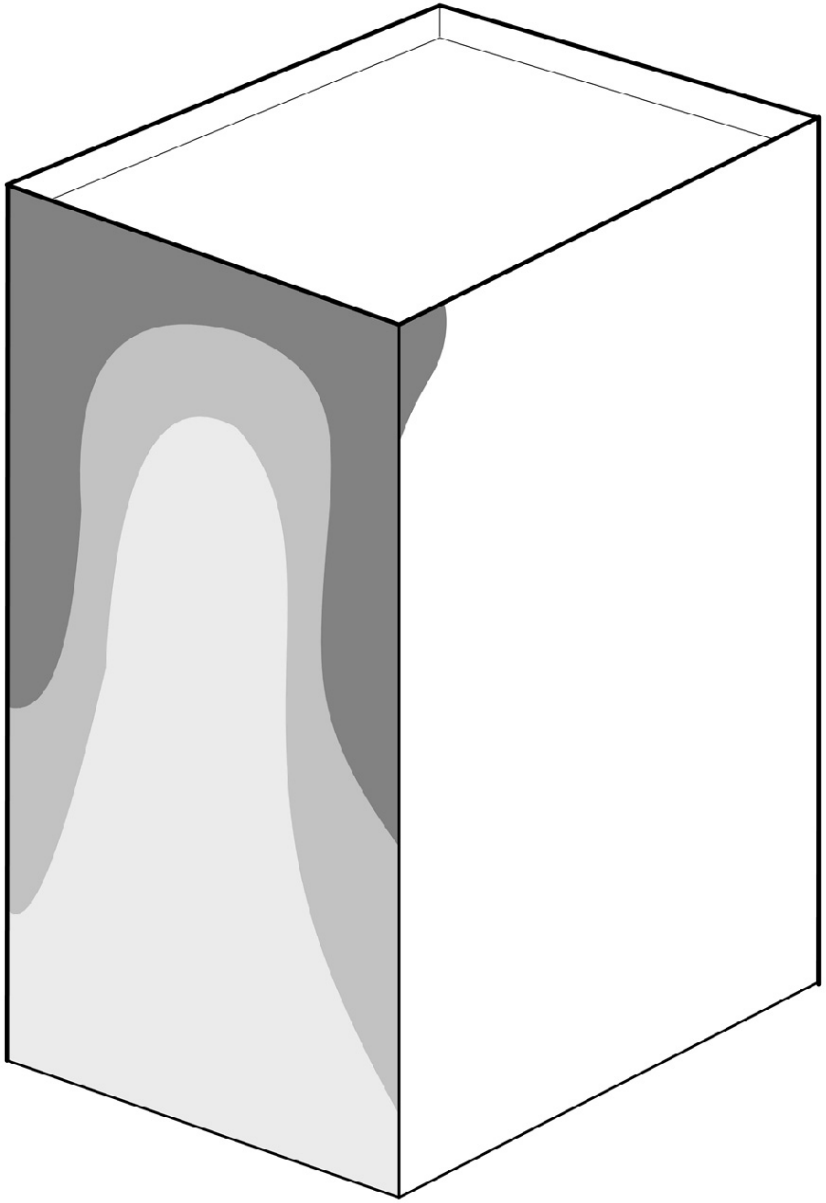

Falling Rain
Resulting Trajectory
Gravity
Wind

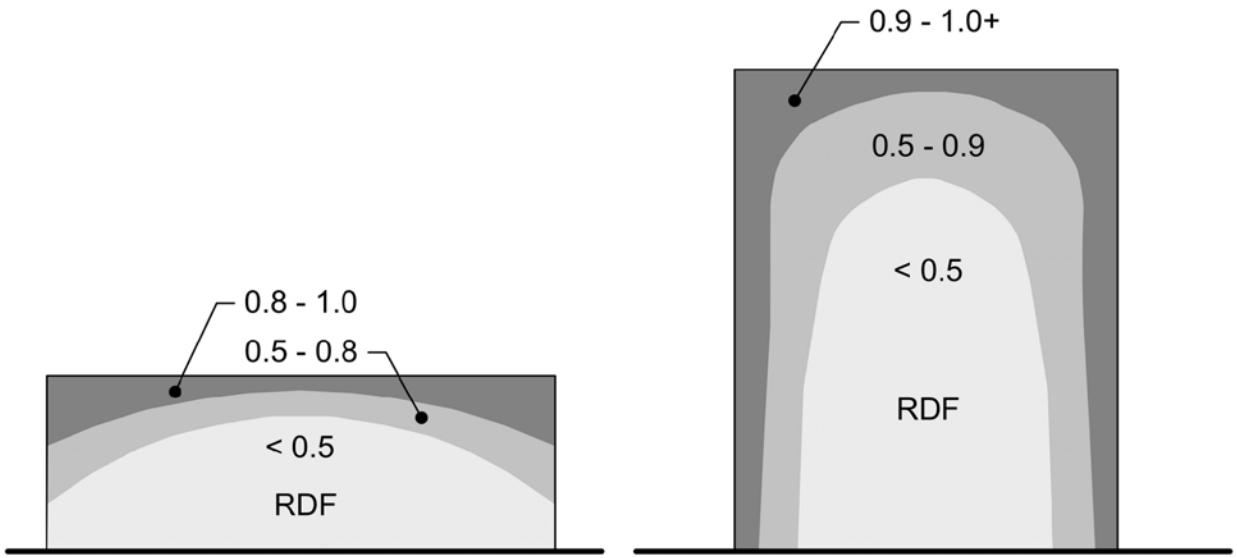

Wind Pressure (Pa)
0.6
2.4
5.4
9.6
15
22
29
15%
12%
9%
6%
3%
0%
Relative Probability (%)
During Rain
All hours
0
1
2
3
4
5
6
7
Wind Speed (m/s)


N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
0.25
0.20
0.15
0.10
0.05
0.00


N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
0.25
0.20
0.15
0.10
0.05
0.00

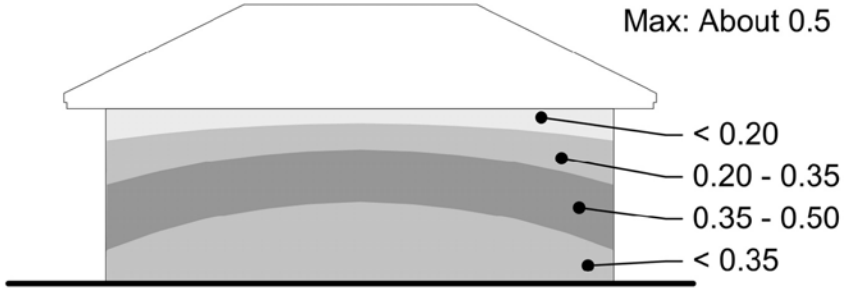

N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
120
100
80
60
40
20
0





Low-rise Building H/W << 1

Tall Building (>10m) H/W >> 1



We use Straube/Kuenzel to determine how much rain water impinges on the wall.

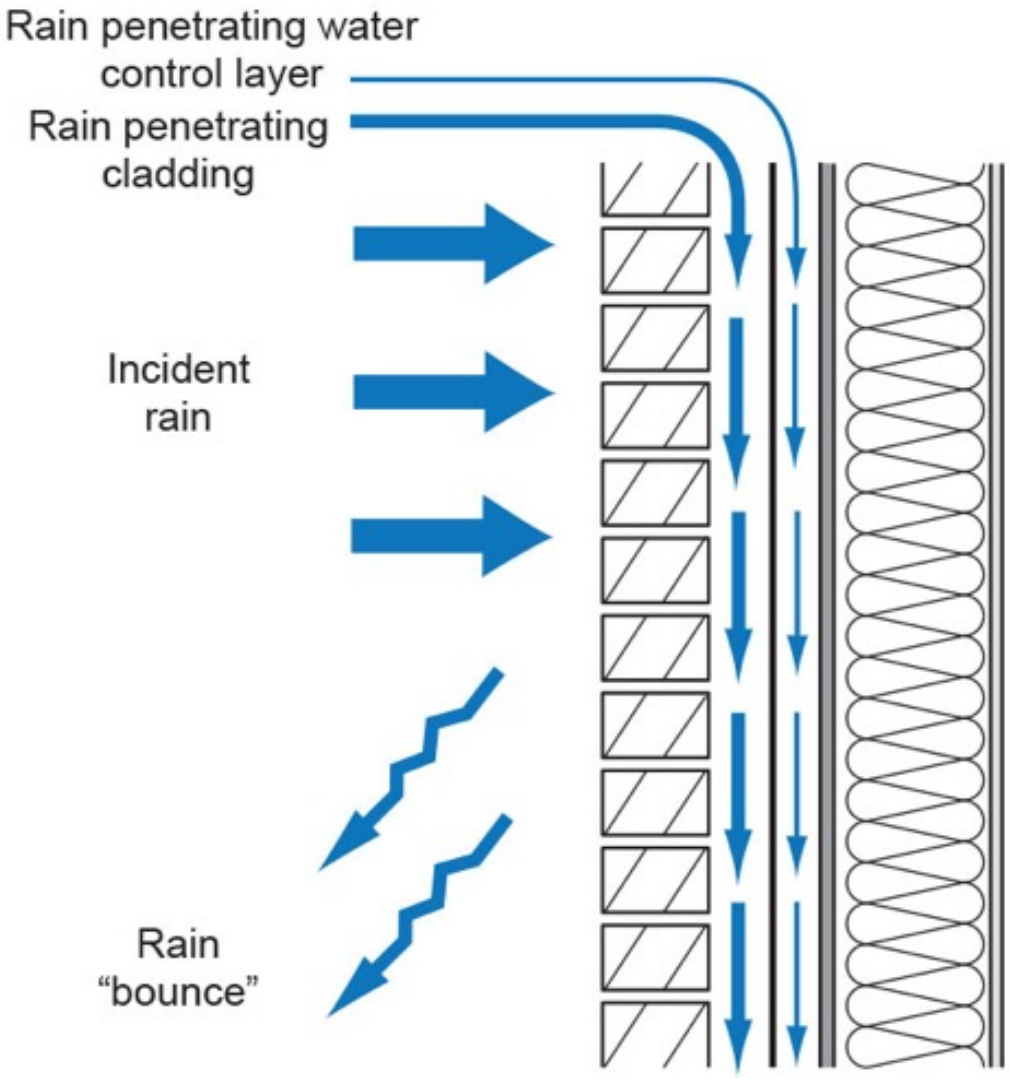
We assume 30% bounces off

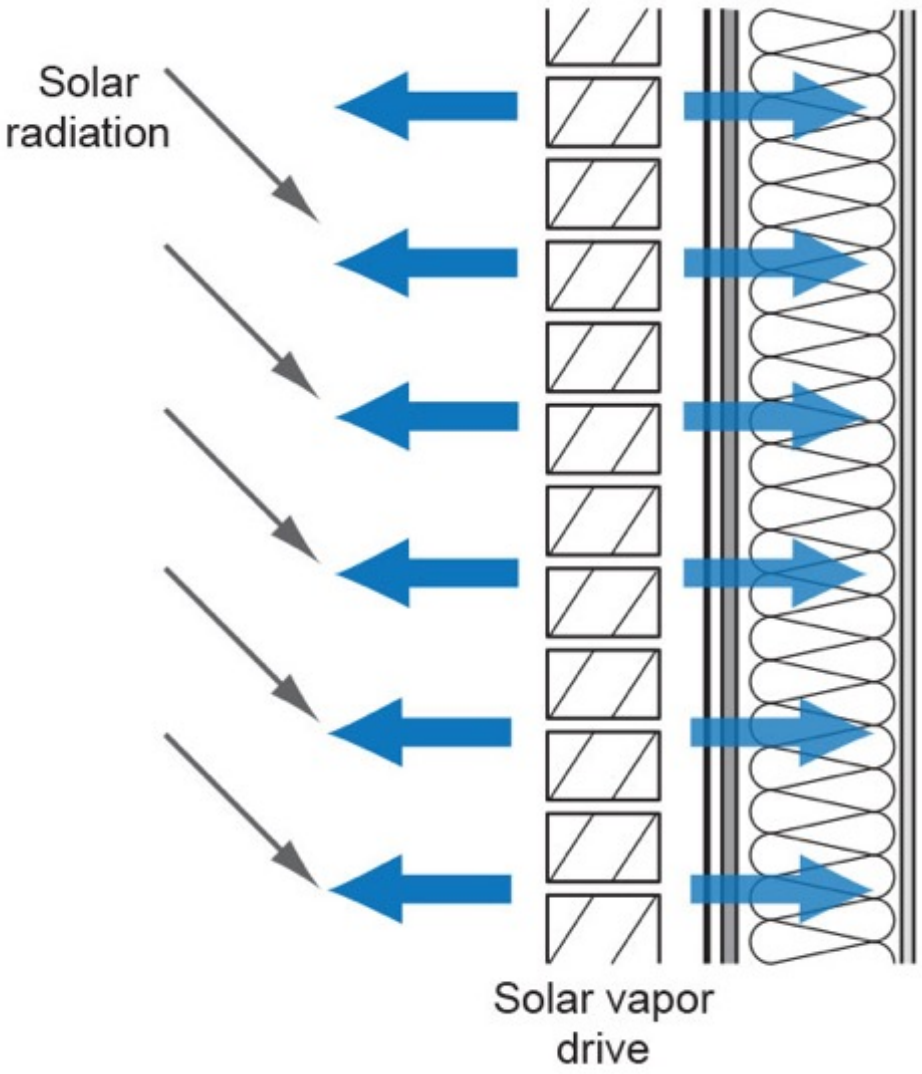
70% stays on the wall.

The 70% that stays on the wall is addressed by liquid conductivity (capillary flow) and vapor diffusion.

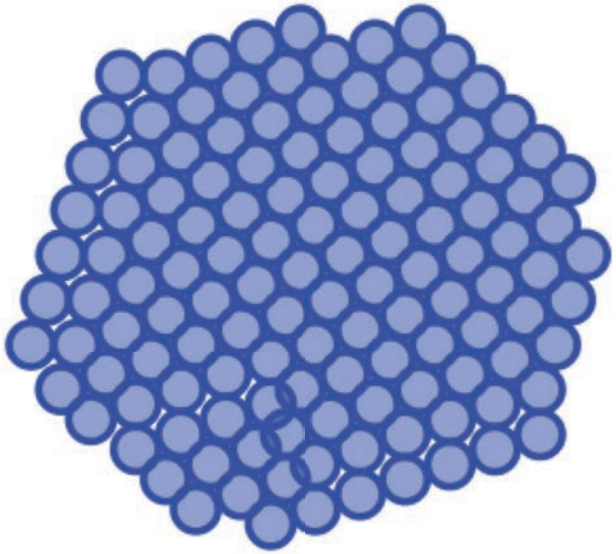
We assume 1% of the 70% penetrates to the back side of the cladding.

We further assume that 1% of the 1% gets past the water control layer into the sheathing.

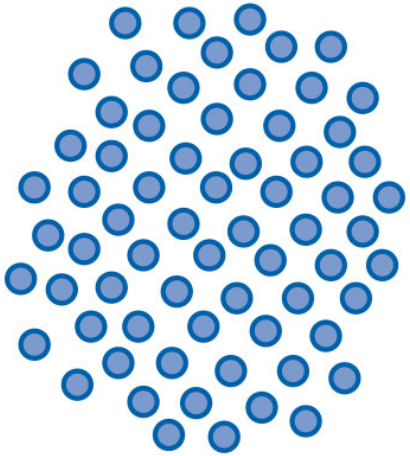

Rain penetrating water control layer
Rain penetrating cladding
Incident rain
Rain "bounce"


Solar
radiation
Solar vapor
drive

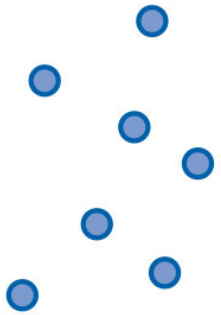
Vapor



Liquid



DIFFUSION



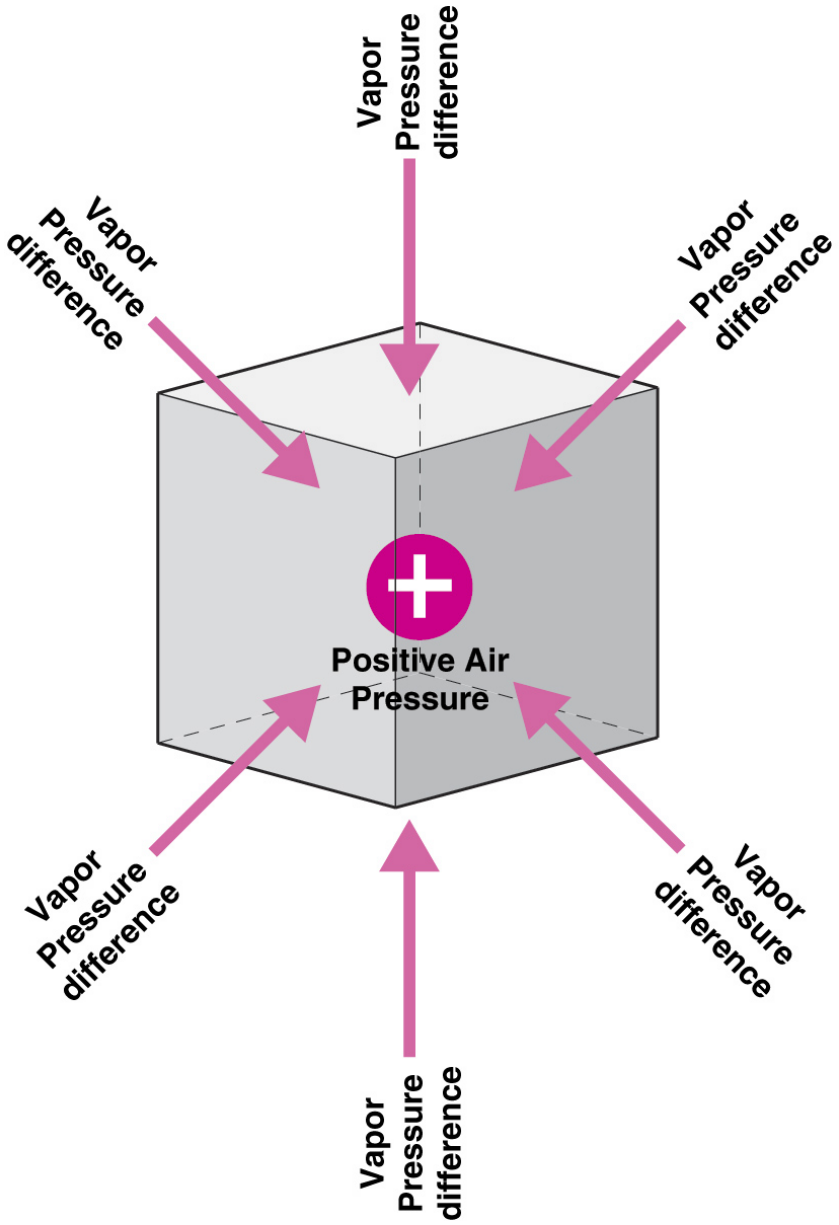
Higher Dewpoint Temperature
Higher Water Vapor Density
or Concentration
(Higher Vapor Pressure)
on Warm Side of Assembly

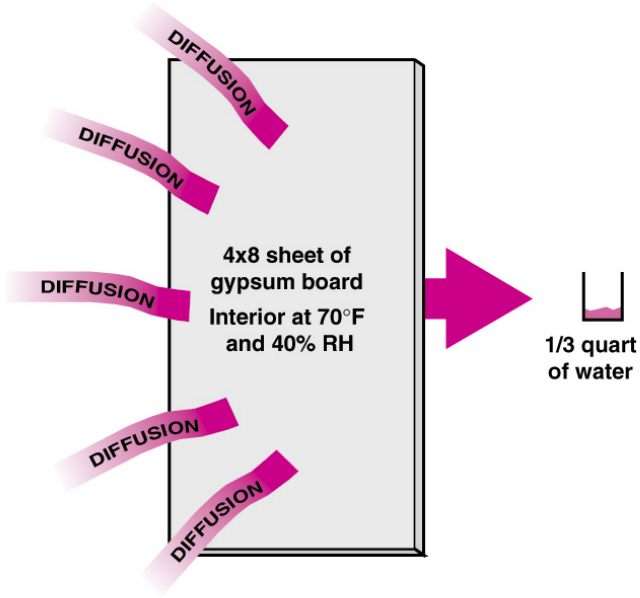
Low Dewpoint Temperature
Lower Water Vapor Density
or Concentration
(Lower Vapor Pressure)
on Cold Side of Assembly

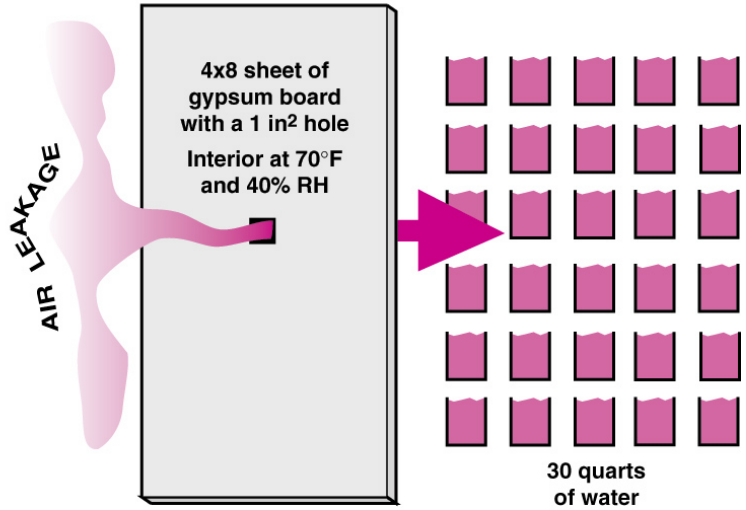
AIR TRANSPORT

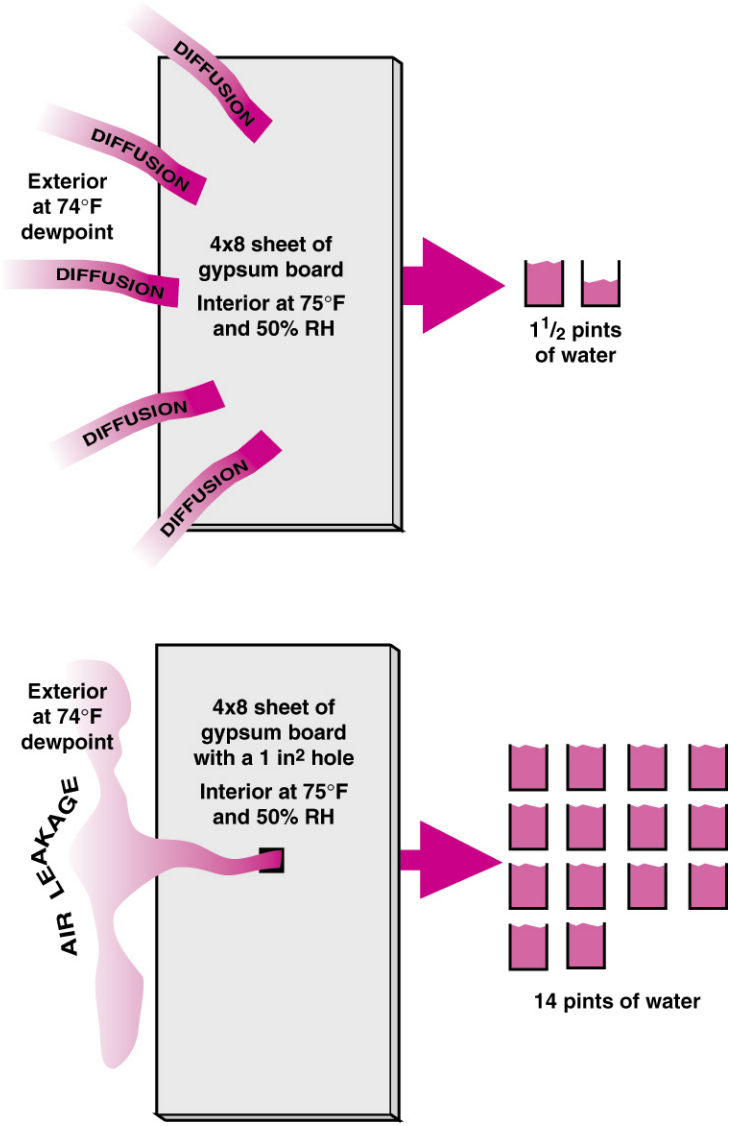
Higher Air
Pressure

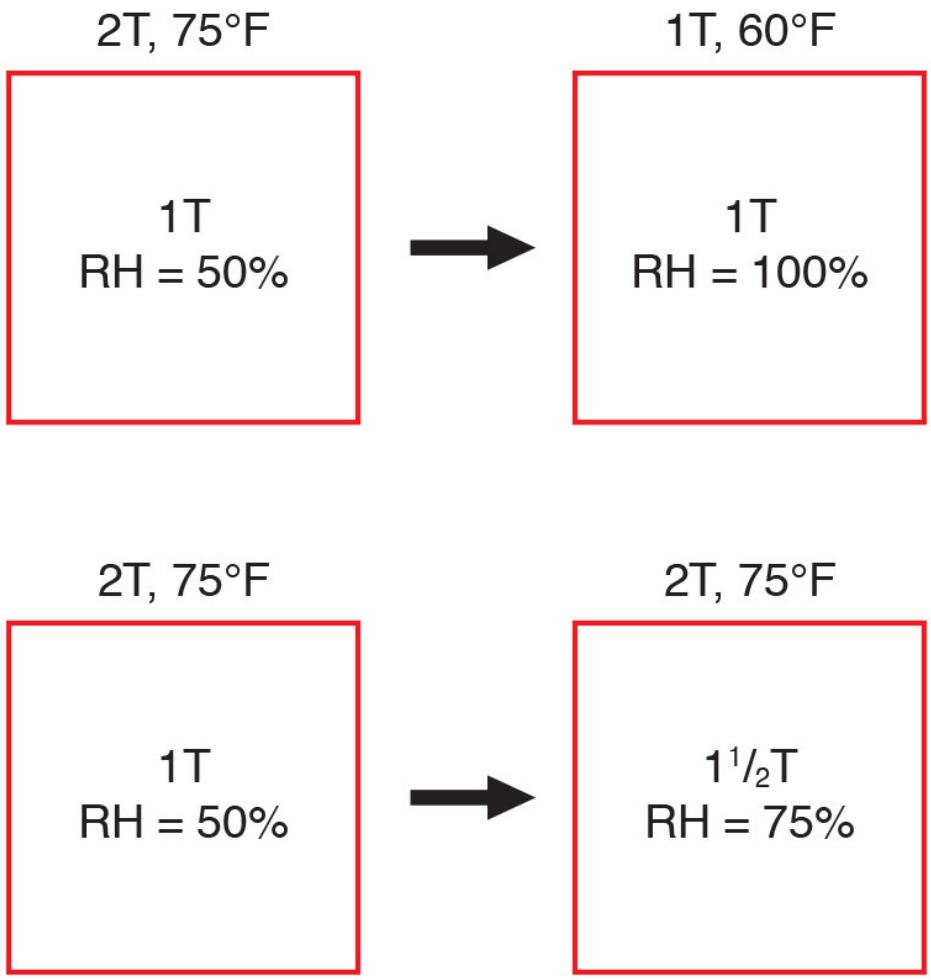
Lower Air
Pressure

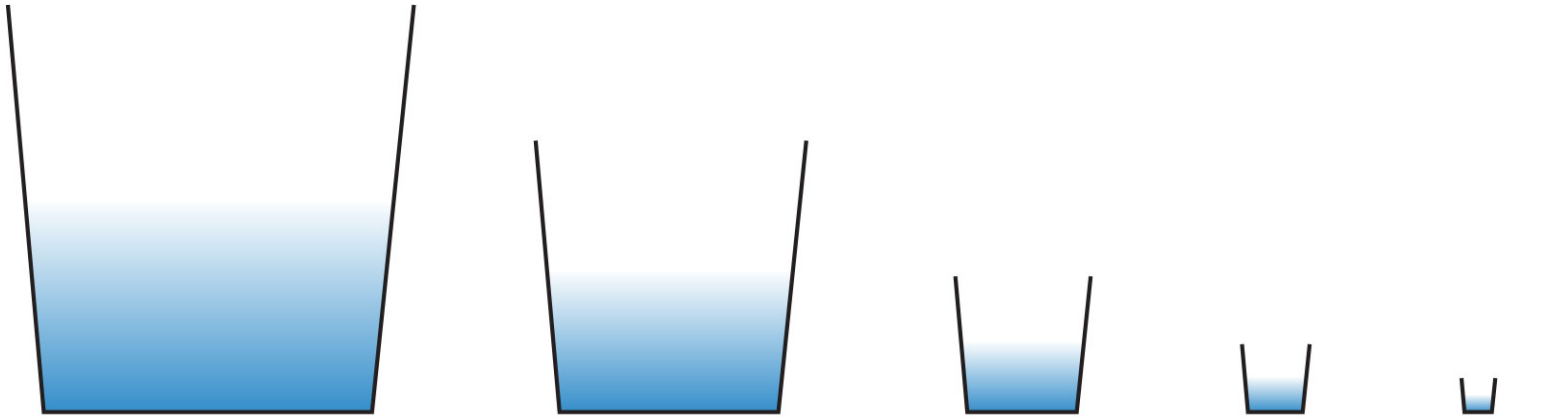

Vapor Pressure difference
Vapor Pressure difference
Vapor Pressure difference
Positive Air Pressure
Vapor Pressure difference
Vapor Pressure difference
Vapor Pressure difference

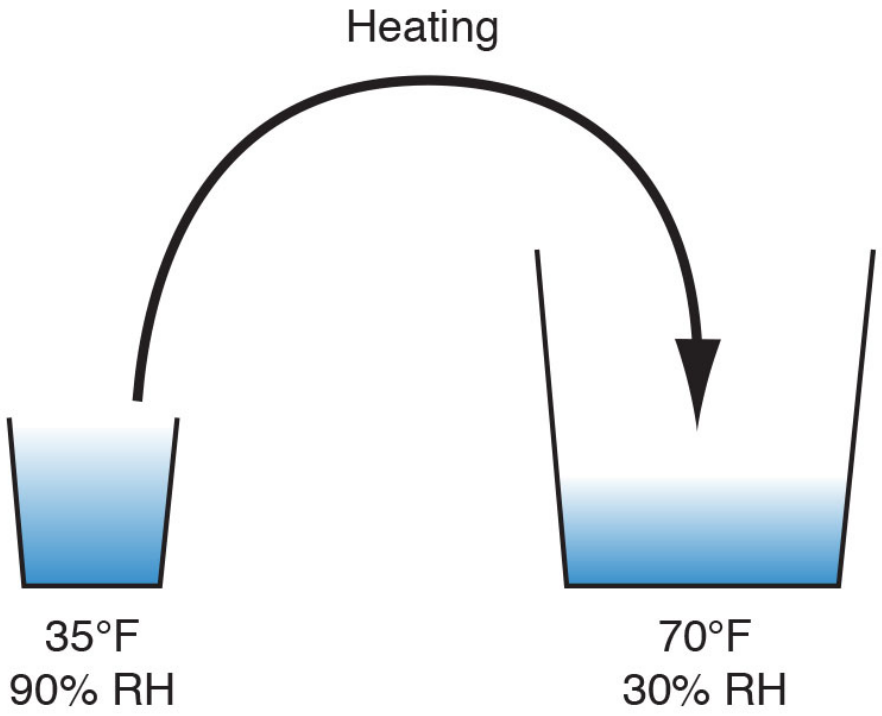

DIFFUSION
DIFFUSION
DIFFUSION
DIFFUSION
DIFFUSION
4x8 sheet of gypsum board
Interior at 70°F and 40% RH
1/3 quart of water

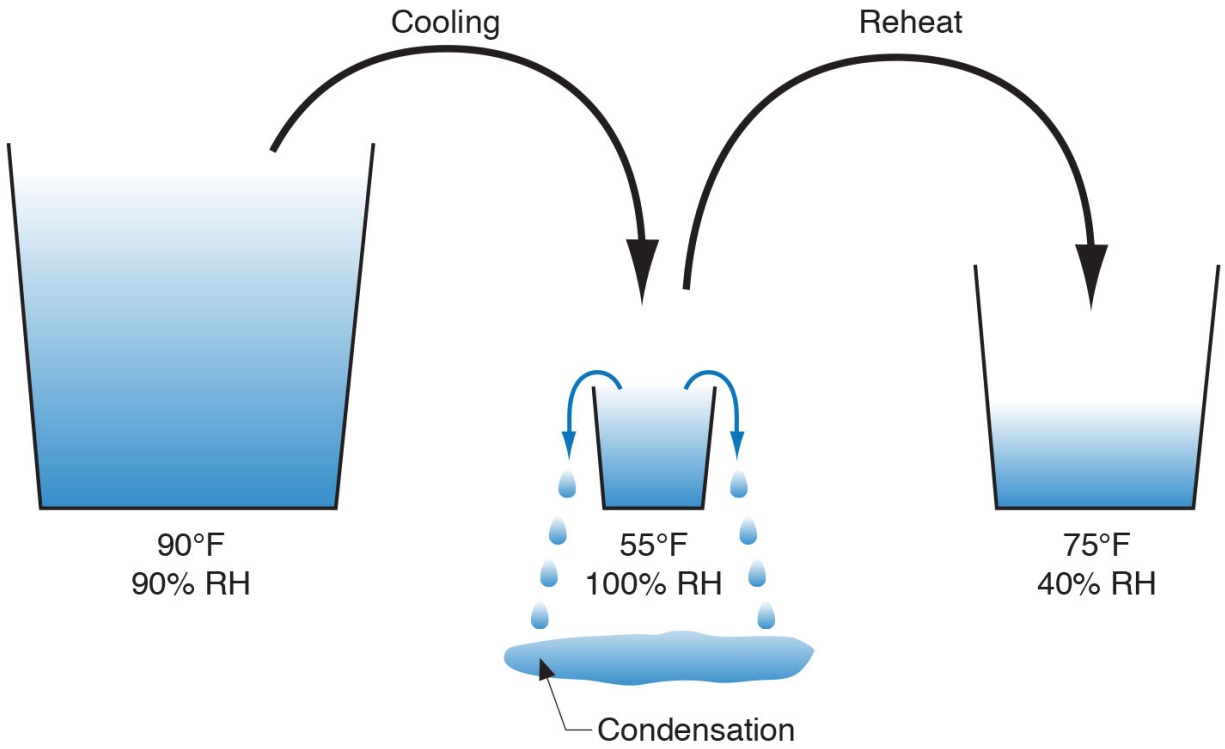

AIR LEAKAGE
4x8 sheet of gypsum board with a 1 in² hole
Interior at 70°F and 40% RH
30 quarts of water

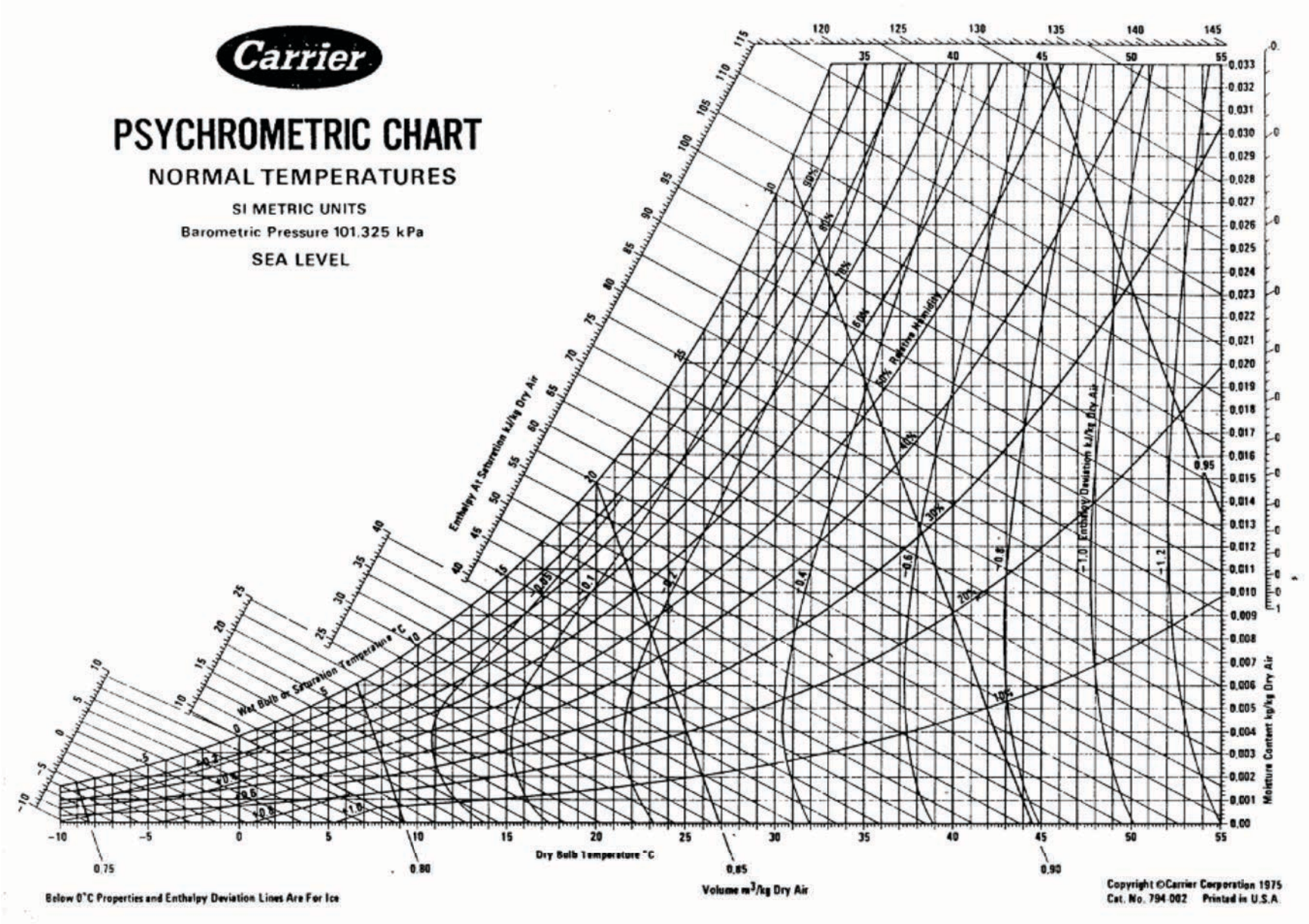

DIFFUSION
DIFFUSION
Exterior
at 74°F
dewpoint
DIFFUSION
4x8 sheet of
gypsum board
Interior at 75°F
and 50% RH
DIFFUSION
DIFFUSION
1 1/2 pints
of water
Exterior
at 74°F
dewpoint
AIR LEAKAGE
4x8 sheet of
gypsum board
with a 1 in2 hole
Interior at 75°F
and 50% RH
14 pints of water

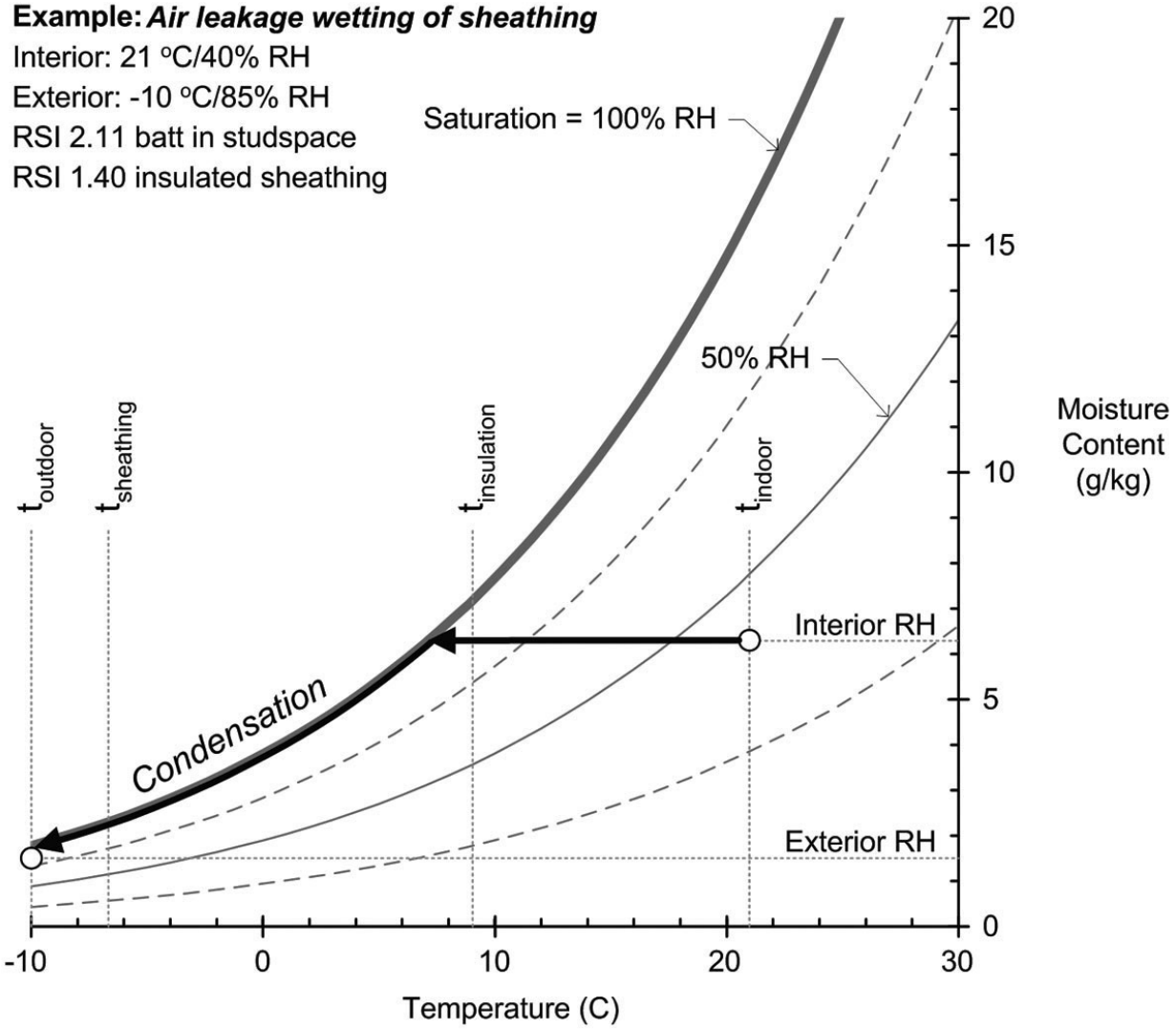

2T, 75°F
1T
RH = 50%
1T, 60°F
1T
RH = 100%
2T, 75°F
1T
RH = 50%
2T, 75°F
1 1/2T
RH = 75%


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

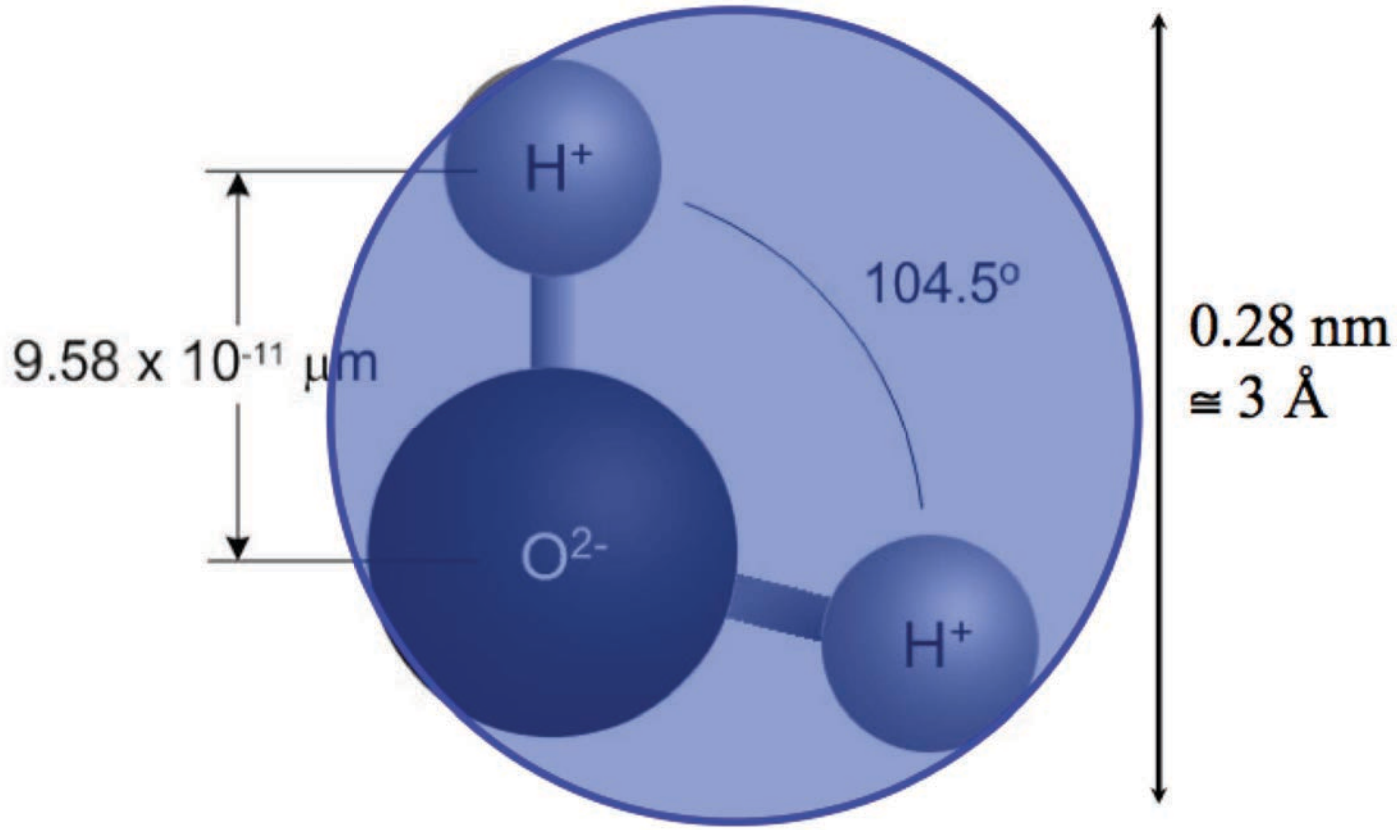

Heating
35°F
90% RH
70°F
30% RH

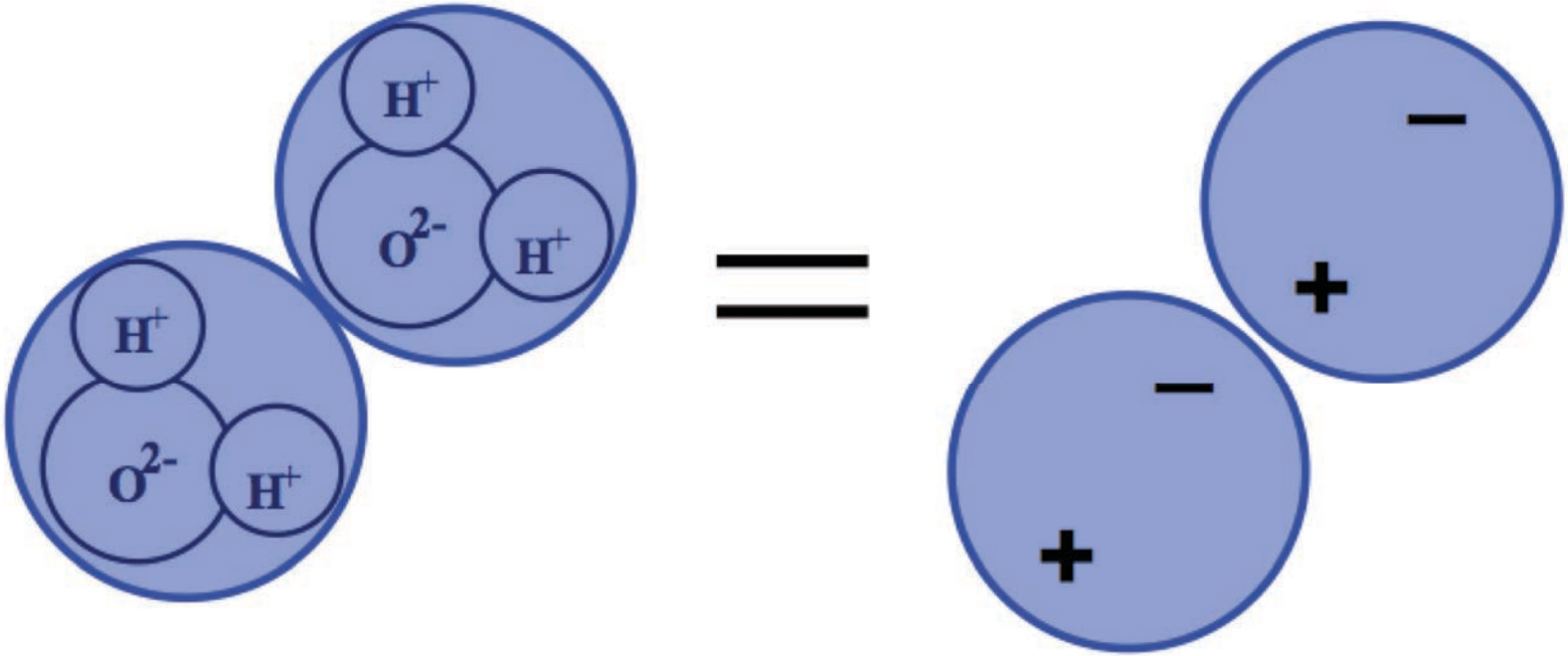

Cooling
Reheat
90°F
90% RH
55°F
100% RH
75°F
40% RH
Condensation

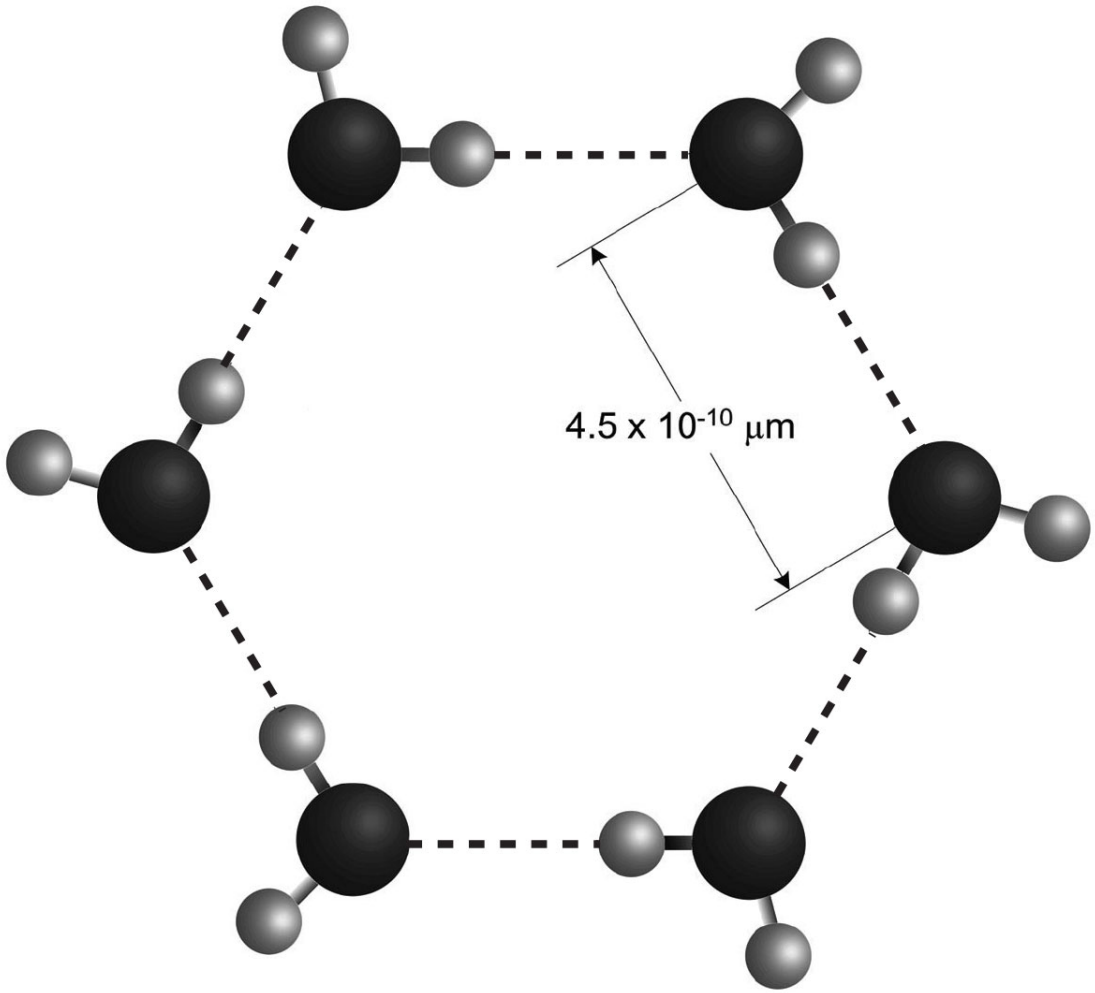

Carrier
PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101.325 kPa
SEA LEVEL
Enthalpy At Saturation kJ/kg Dry Air
Wet Bulb or Saturation Temperature °C
Dry Bulb Temperature °C
Moisture Content kg/kg Dry Air
50% Relative Humidity
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice
Volume m³/kg Dry Air
Copyright ©Carrier Corporation 1975
Cat. No. 794-002 Printed in U.S.A.

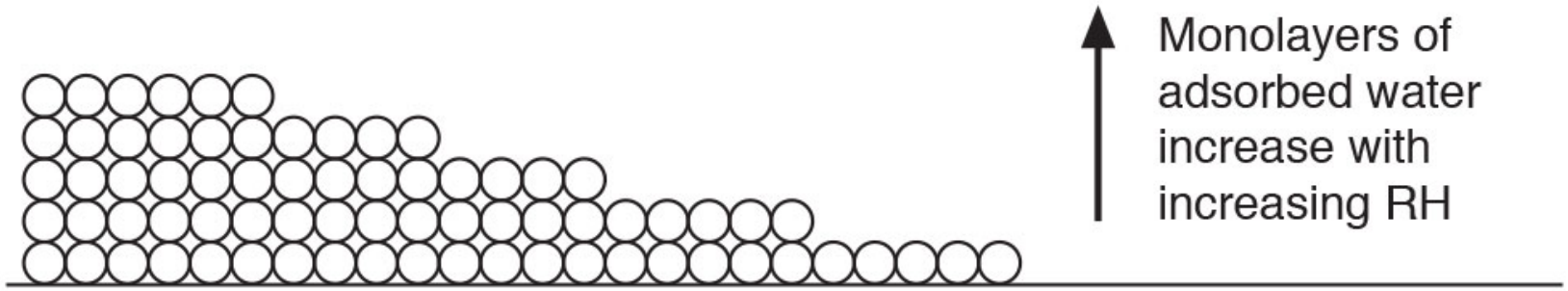


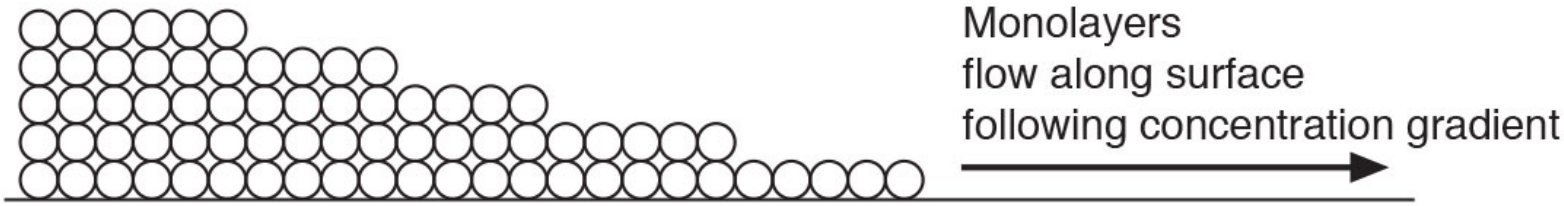
Cooling and condensation
From Straube & Burnett, 2005

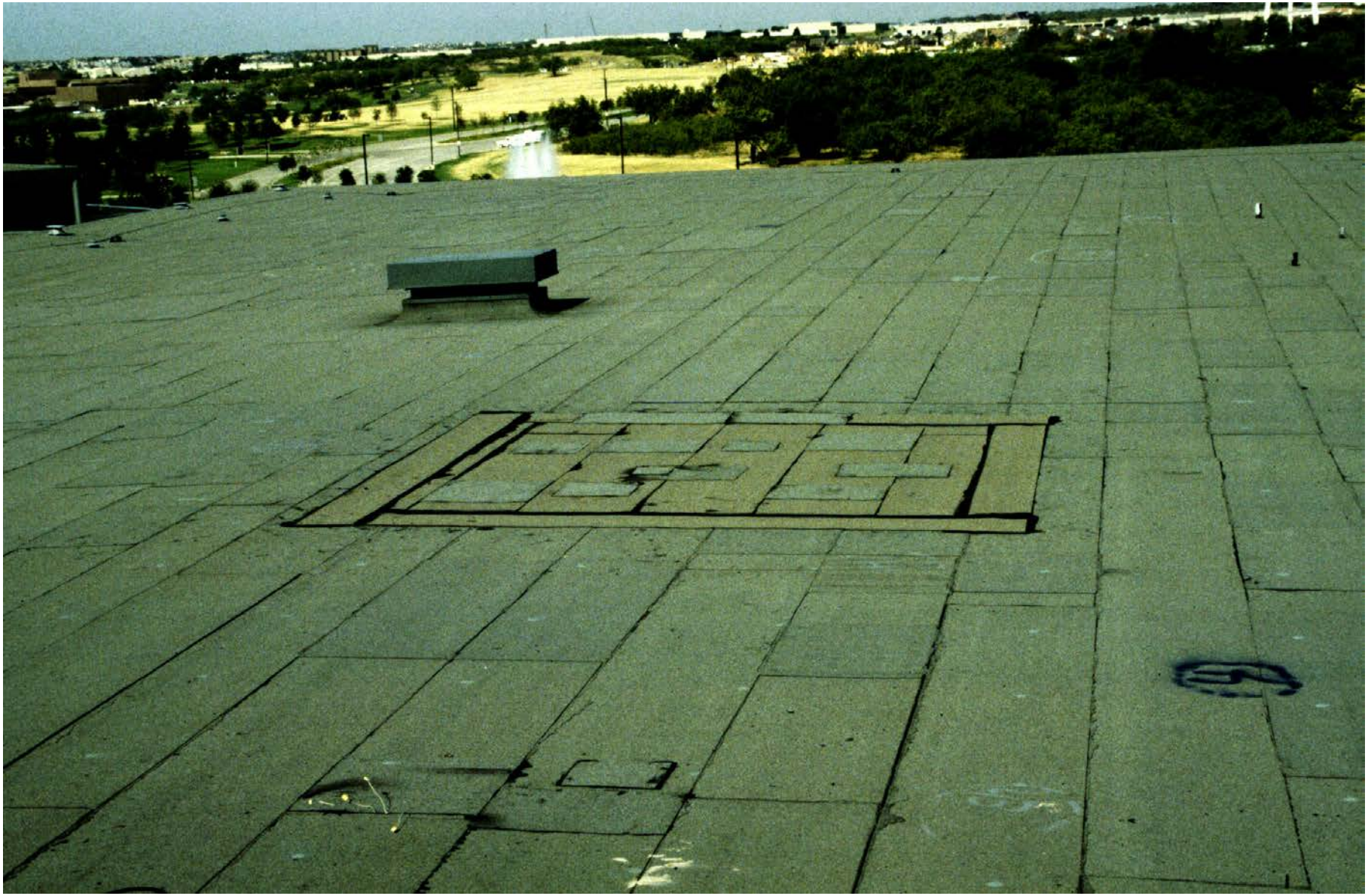

H+
104.5°
9.58 x 10-11 µm
0.28 nm
≅ 3 Å
O2-
H+

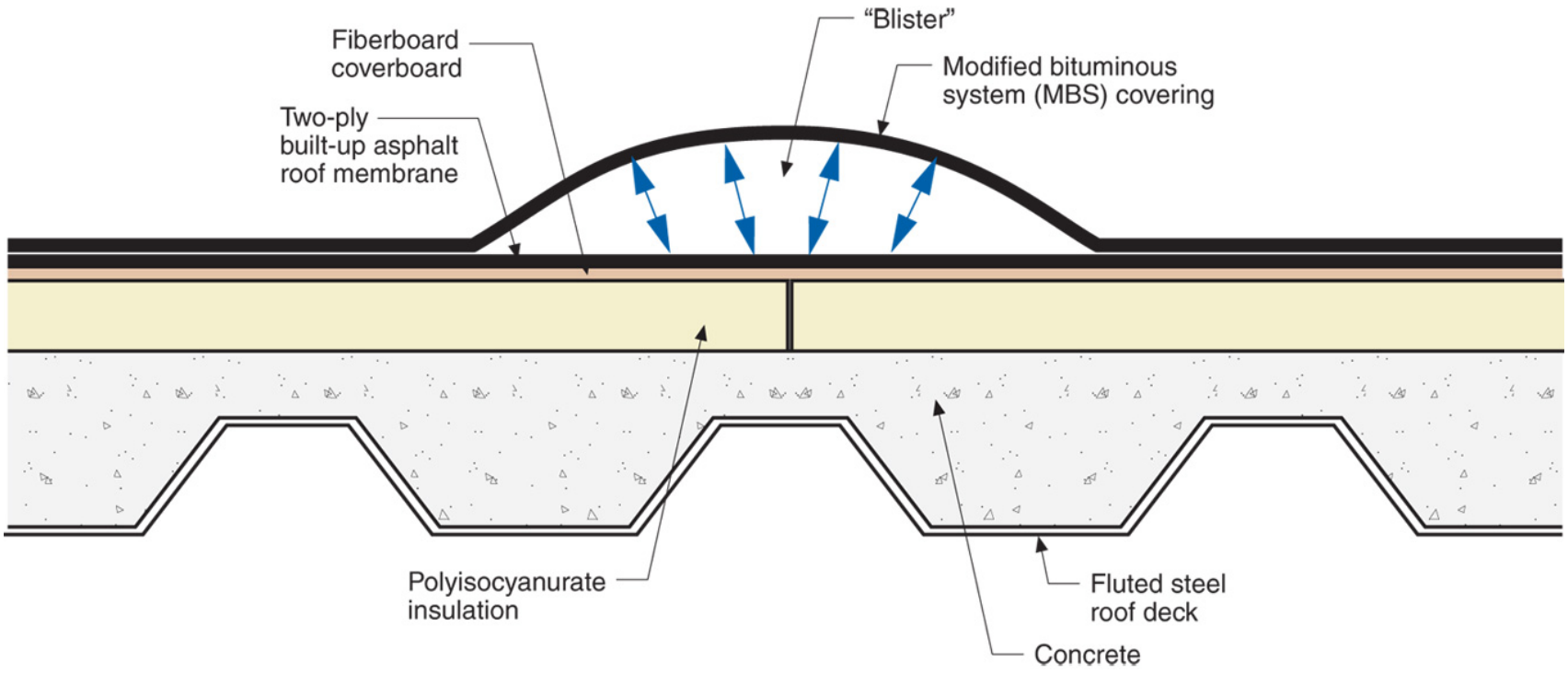

H+
O2-
H+
H+
O2-
H+
=
−
+
−
+

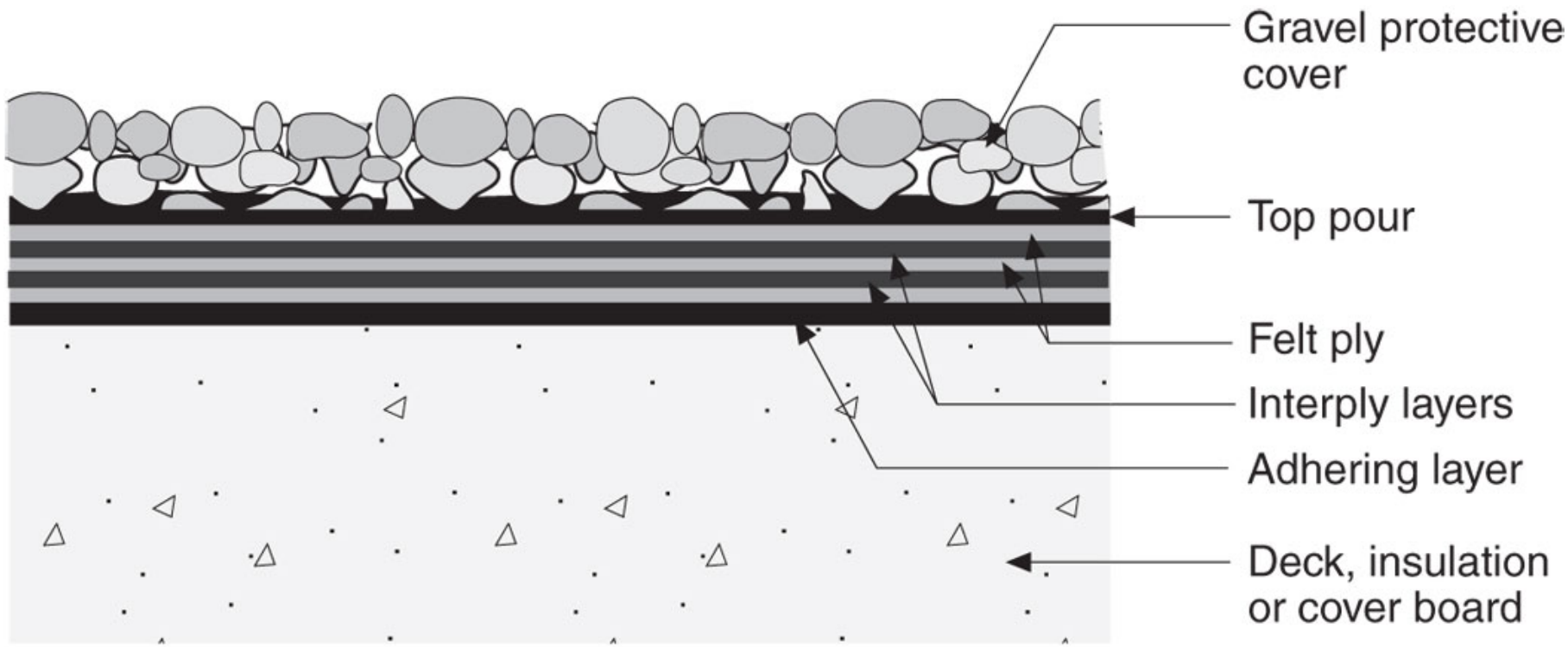

4.5 x 10-10 μm


Monolayers of
adsorbed water
increase with
increasing RH

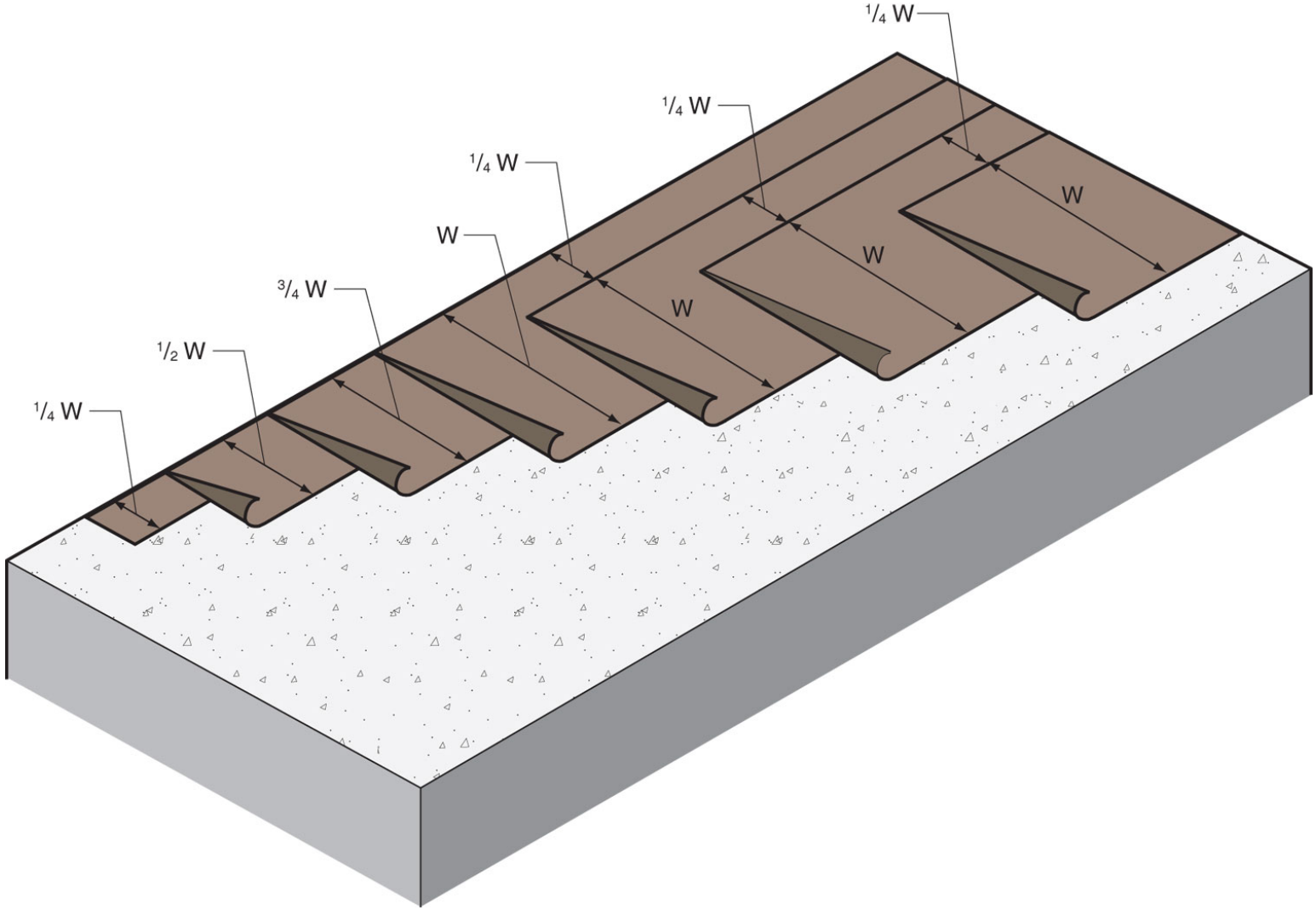

Monolayers
flow along surface
following concentration gradient

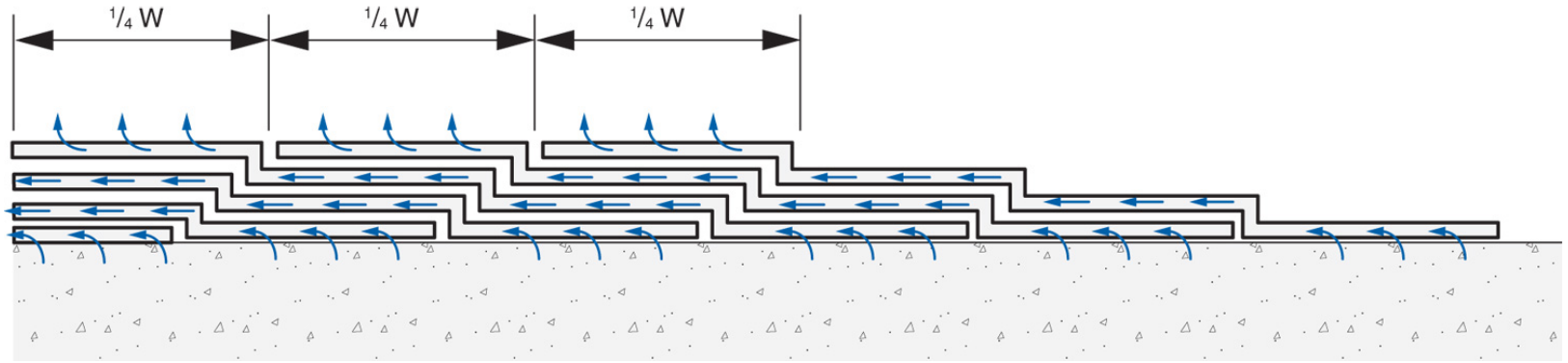


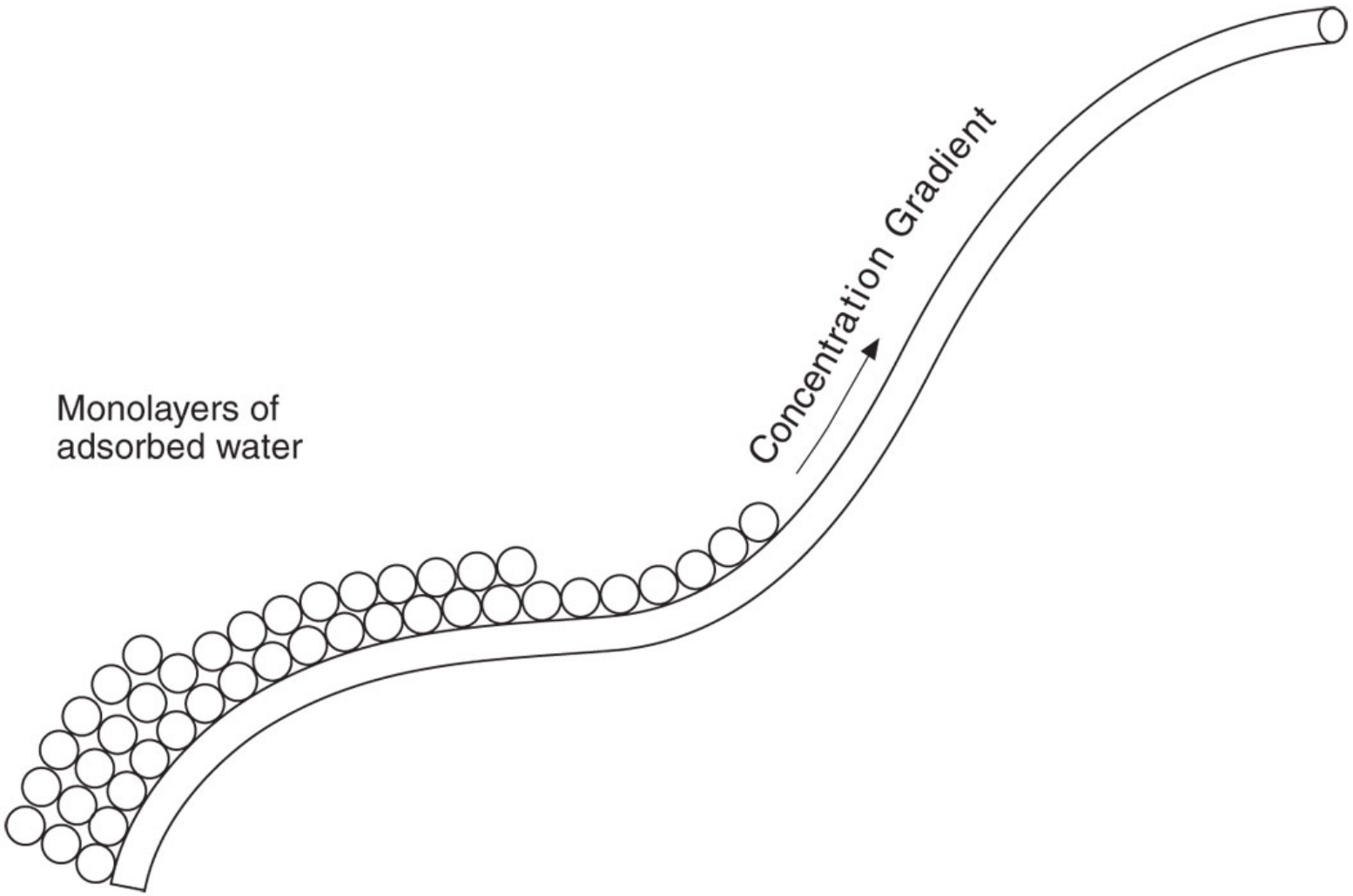

"Blister"
Fiberboard coverboard
Modified bituminous system (MBS) covering
Two-ply built-up asphalt roof membrane
Polyisocyanurate insulation
Fluted steel roof deck
Concrete

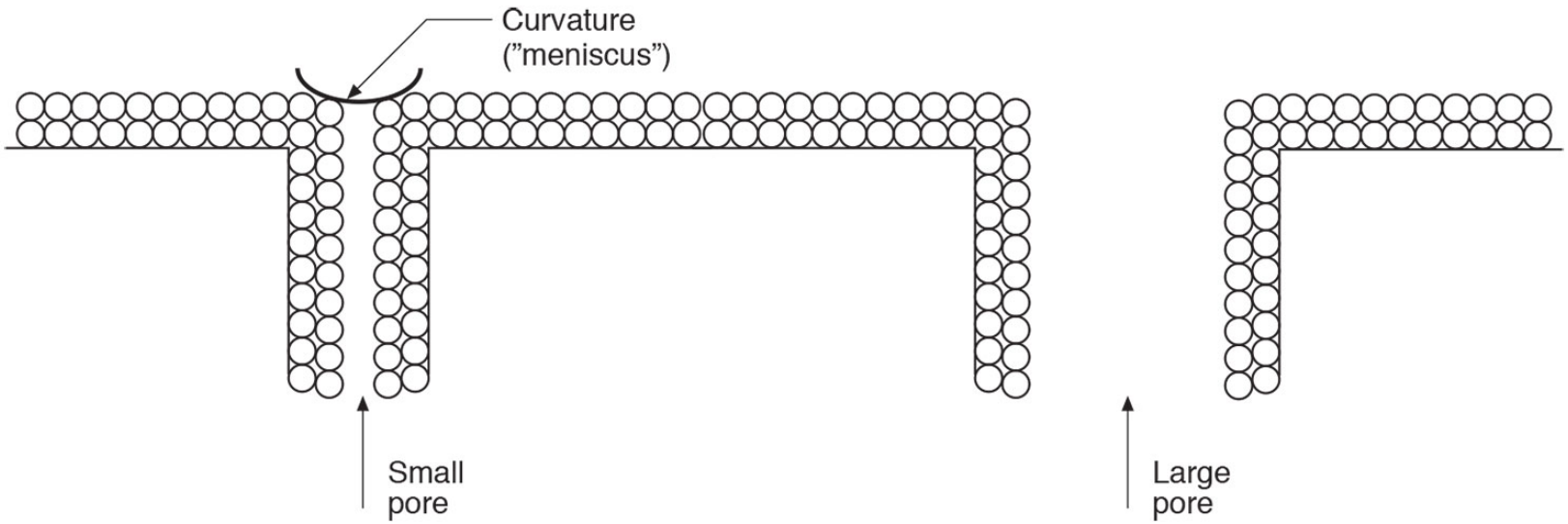


From Baker, M.; Roofs, 1980


1/4 W
1/4 W
1/4 W
W
3/4 W
1/2 W
1/4 W
W
W
W

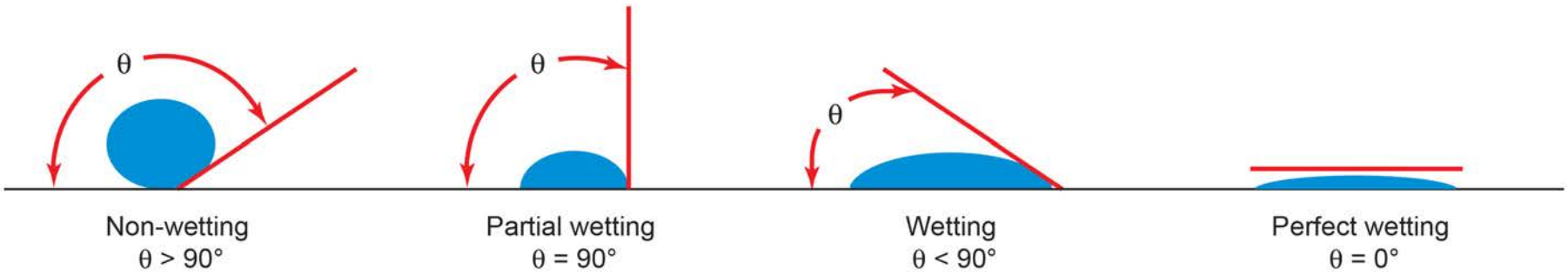

1/4 W
1/4 W
1/4 W

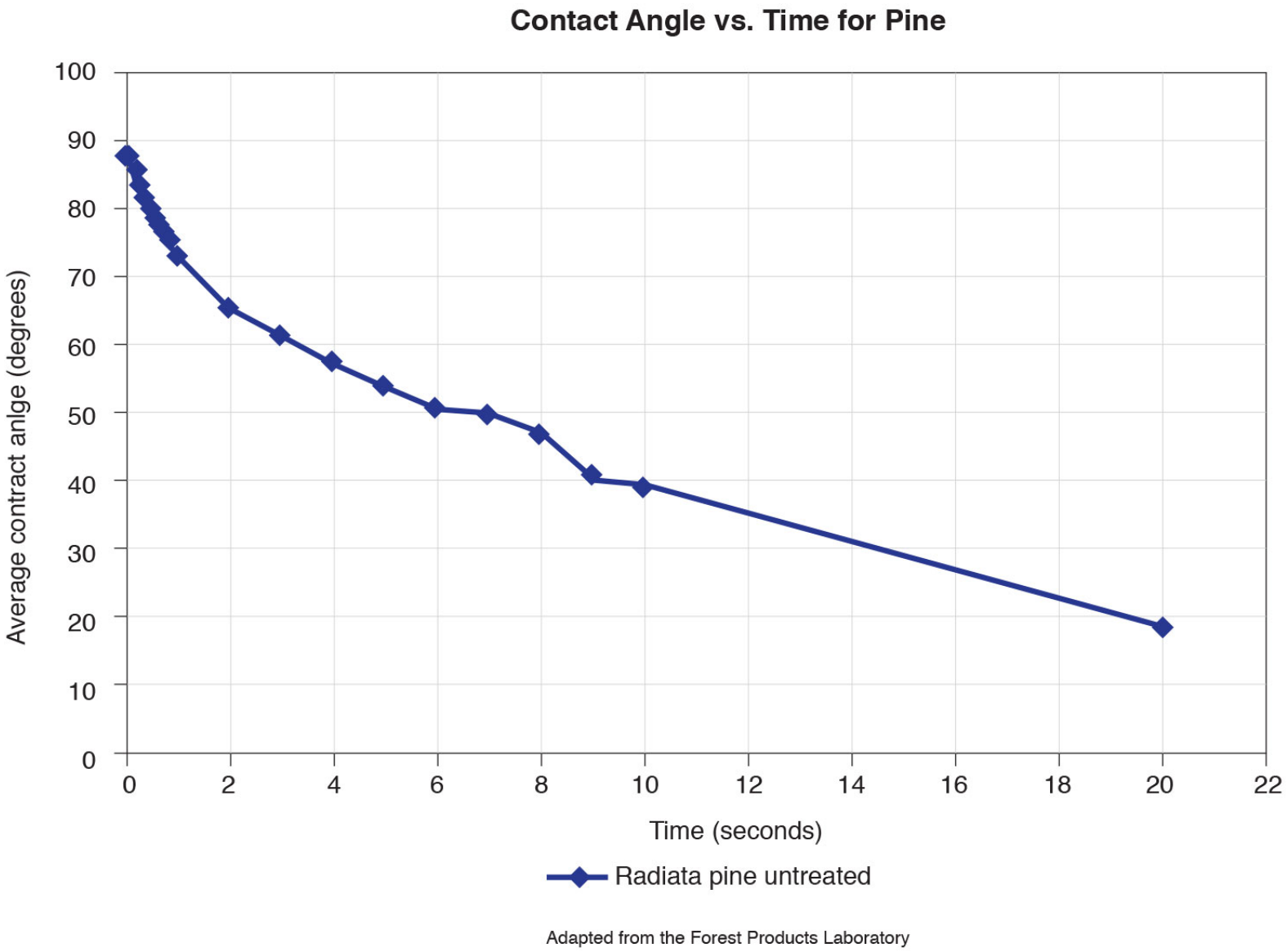

Monolayers of
adsorbed water
Concentration Gradient

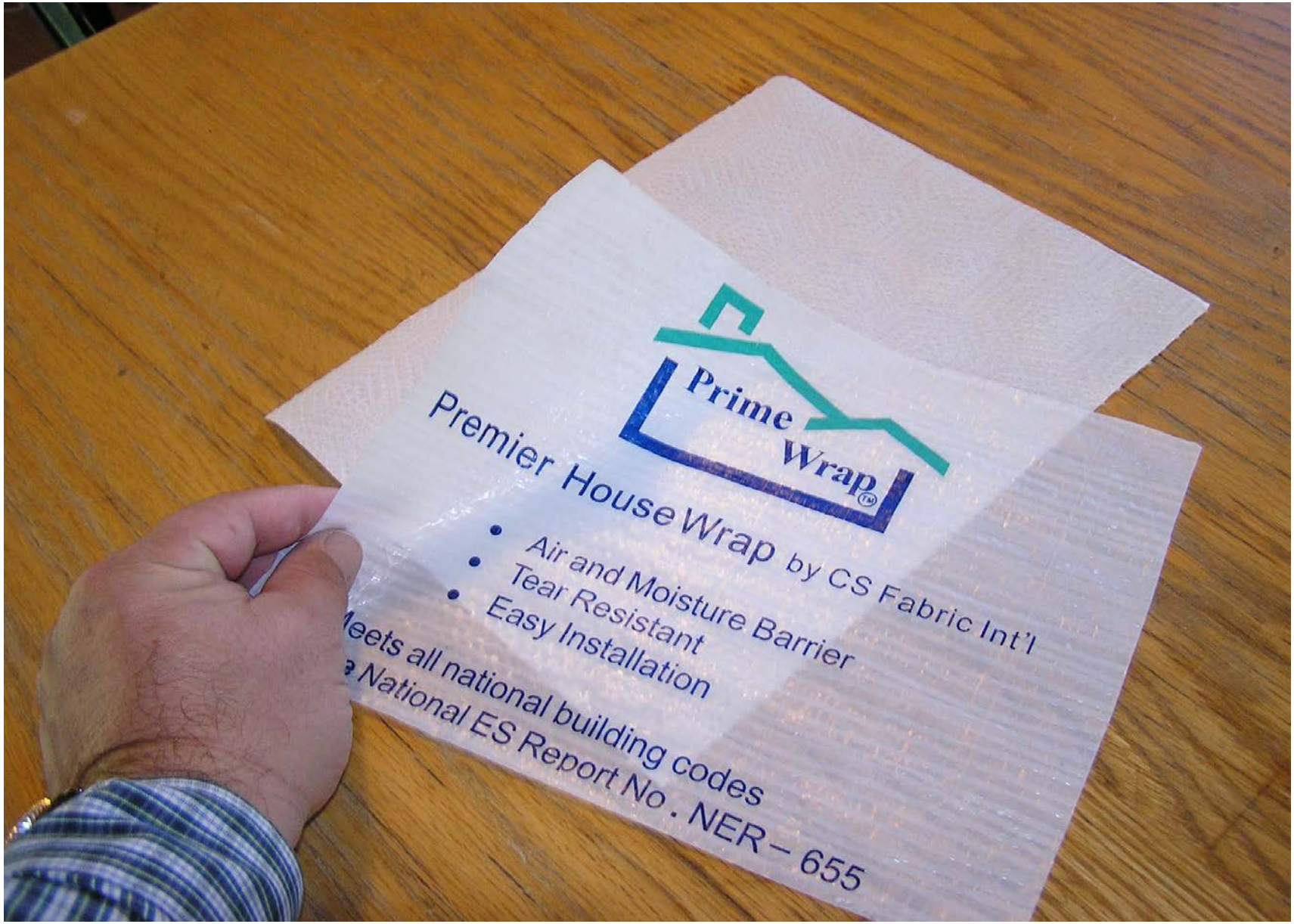

Curvature
("meniscus")
Small
pore
Large
pore

- "non-wetable" surface
- water repellant surface
- hygrophobic surface
- water more attracted to itself than to surface
- surface energy of water greater than surface energy of surface
- water "beads up"
- "greasy" surface
- high contact angle "θ"

- "wetable" surface
- non-water repellant surface
- hygroscobic surface
- water more attracted to surface than itself
- surface energy of surface greater than surface energy of water
- water "spreads out"
- "non-greasy" surface
- low contact angle "θ"


θ
θ
θ
Non-wetting
θ > 90°
Partial wetting
θ = 90°
Wetting
θ < 90°
Perfect wetting
θ = 0°


Contact Angle vs. Time for Pine
Average contract anlge (degrees)
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
18
20
22
Time (seconds)
Radiata pine untreated
Adapted from the Forest Products Laboratory


Prime Wrap
Premier HouseWrap by CS Fabric Int'l
Air and Moisture Barrier
Tear Resistant
Easy Installation
eets all national building codes
National ES Report No . NER – 655

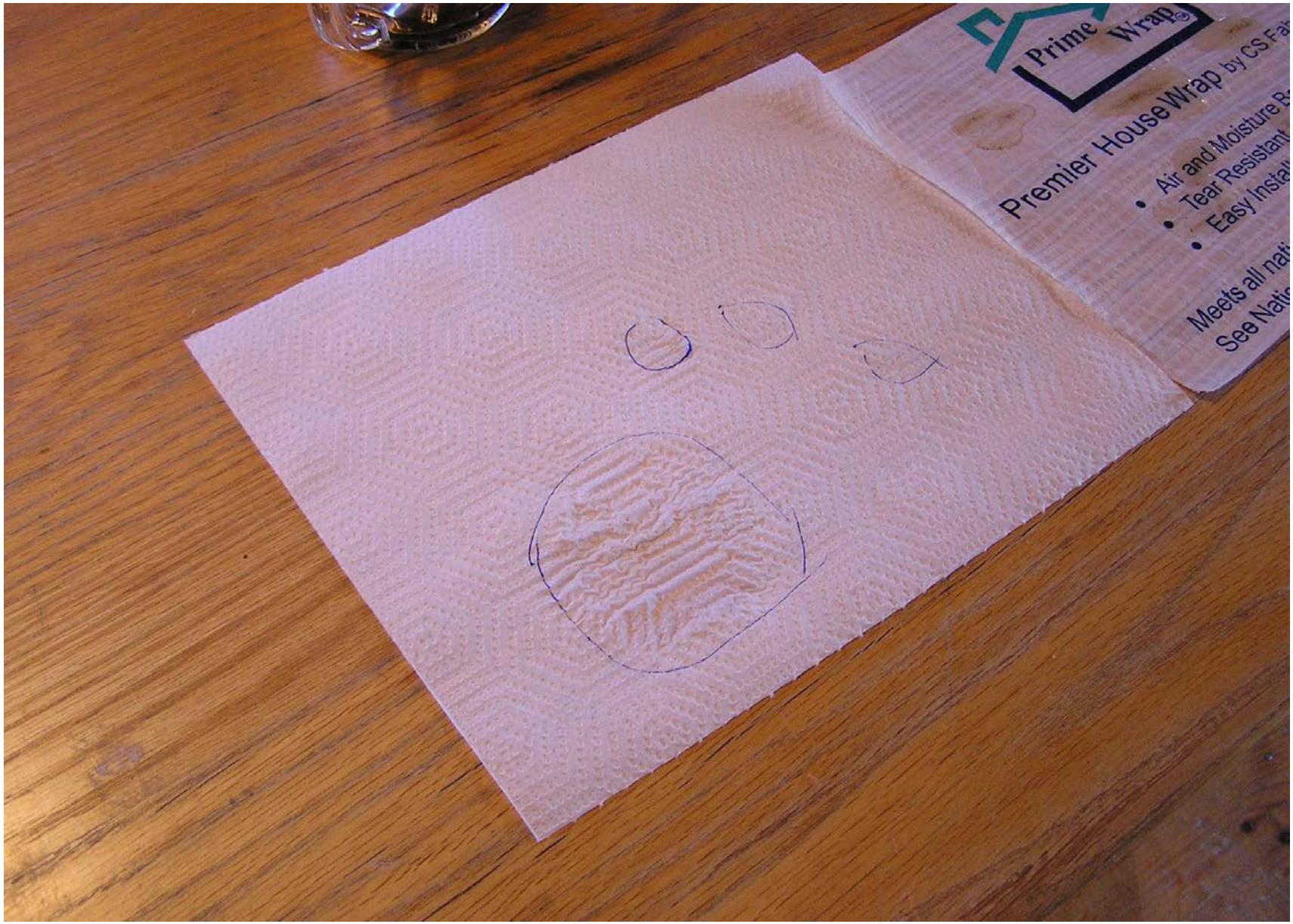

Prime Wrap
Premier HouseWrap by CS Fabric Int'l
• Air and Moisture Barrier
• Tear Resistant
• Easy Installation
Meets all national building codes
See National ES Report No . NER – 655


Prime Wrap TM
emier House Wrap by CS Fabric
Air and Moisture Barrier
Tear Resistant
Easy Installation


Fabric Int'l
d Moisture Barrier
Resistant
codes
Report No . NER– 655


500ml
450
350
250
150
2 CUPS
START


Prime Wrap
Premier HouseWrap by CS Fabric Int'l
Air and Moisture Barrier
Tear Resistant
Easy Installation
Meets all national building codes
See National ES Report No . NER – 655
PYREX

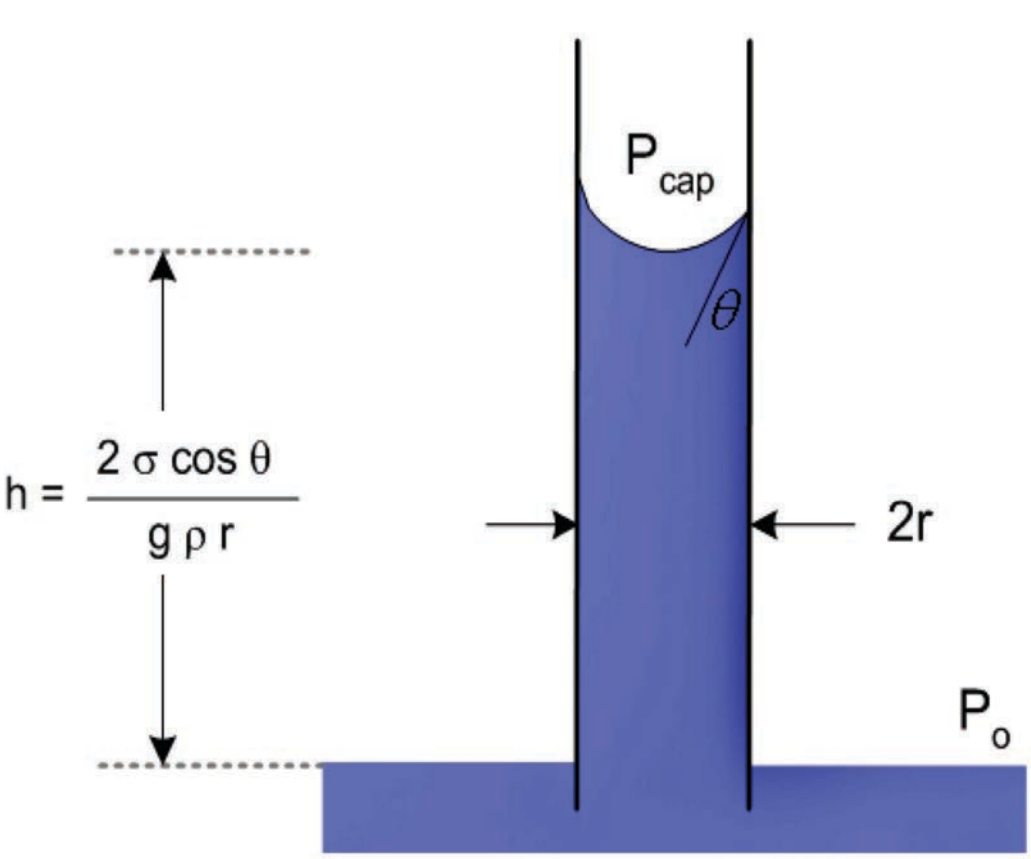

Prime Wrap
Premier HouseWrap by CS
Air and Moisture
Tear Resistant
Easy Instal
Meets all nati
See Natio

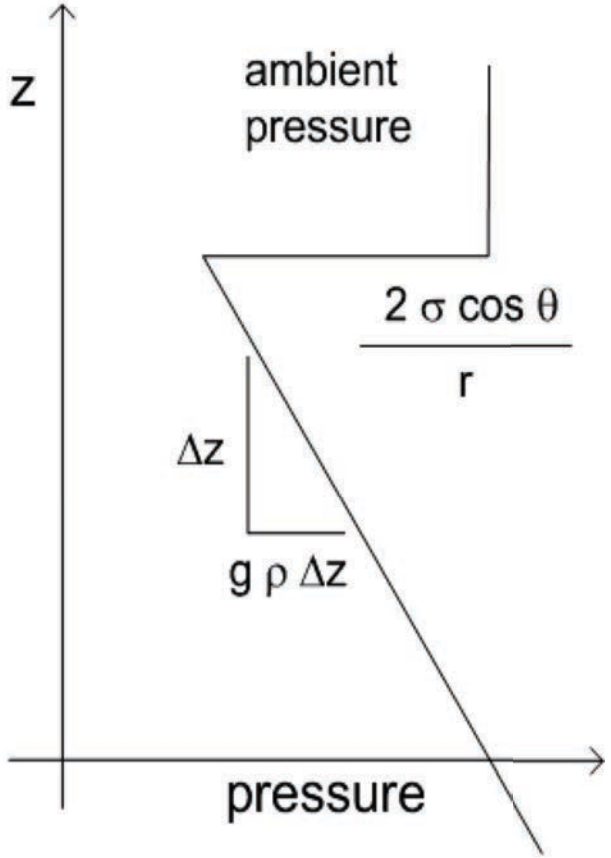

Cambridge
PINKWRAP


TYPAR®
HouseWrap
TYPAR®
HouseWrap

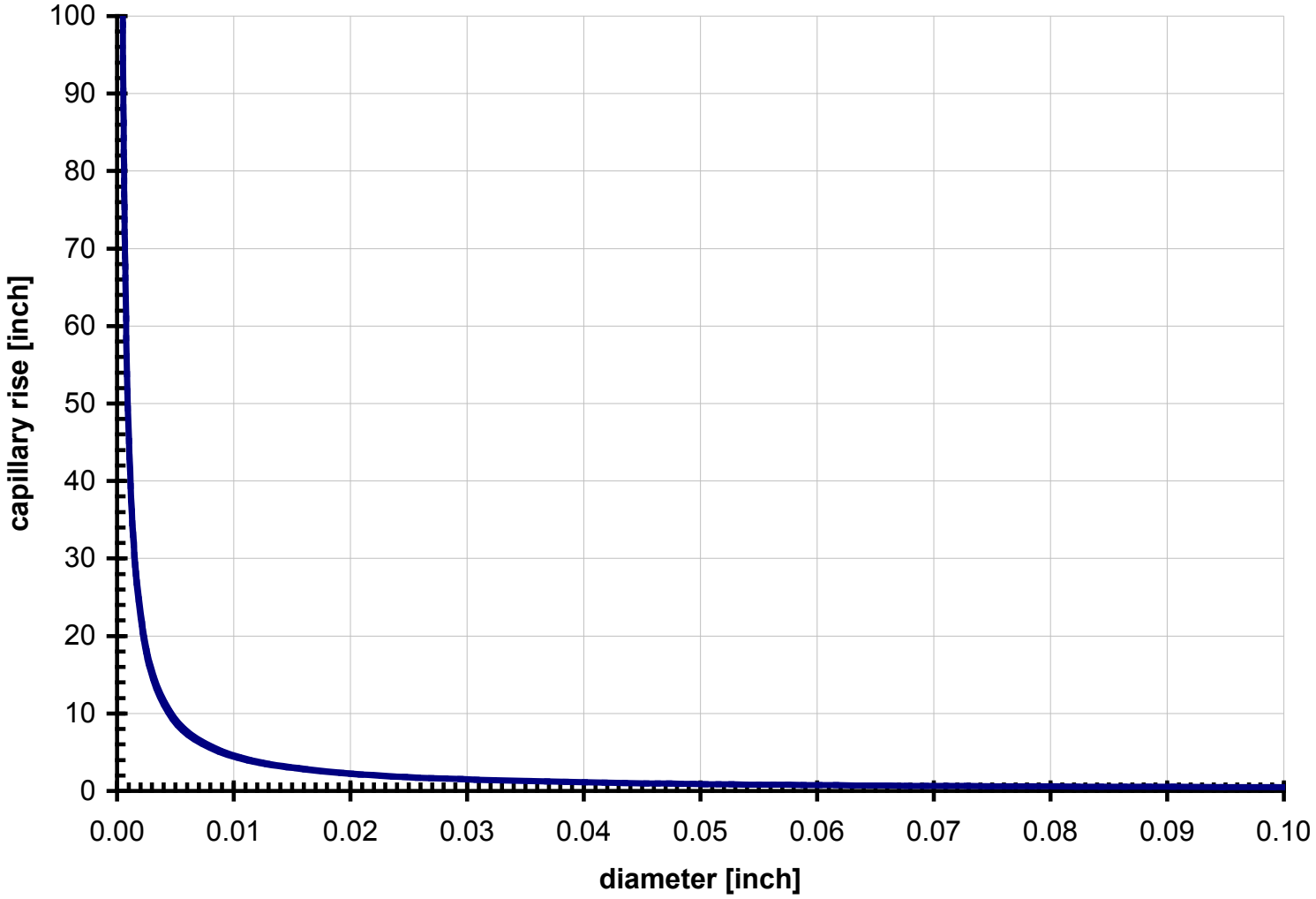
	Surface Energy
Water (20 C)	73 dynes/cm
Water (100 C)	59 dynes/cm
Epoxy	46 dynes/cm
Polyethylene	31 dynes/cm
Soapy water	30 dynes/cm
Paraffin wax	25 dynes/cm
Silicone	24 dynes/cm
Teflon	18 dynes/cm

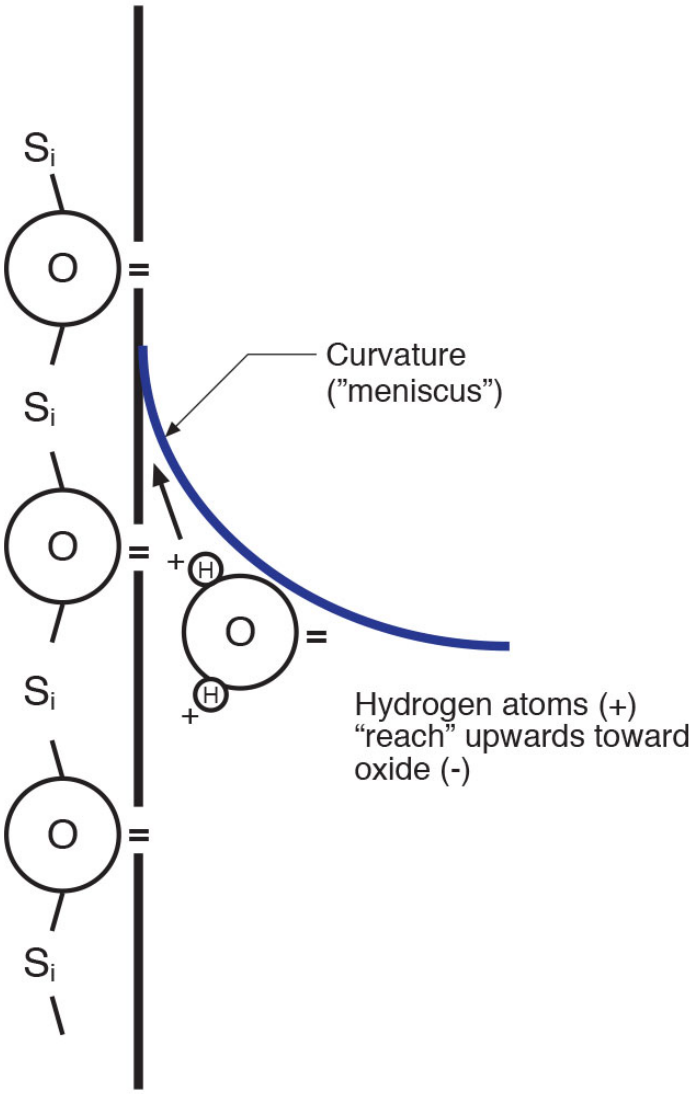
Calculating capillary rise

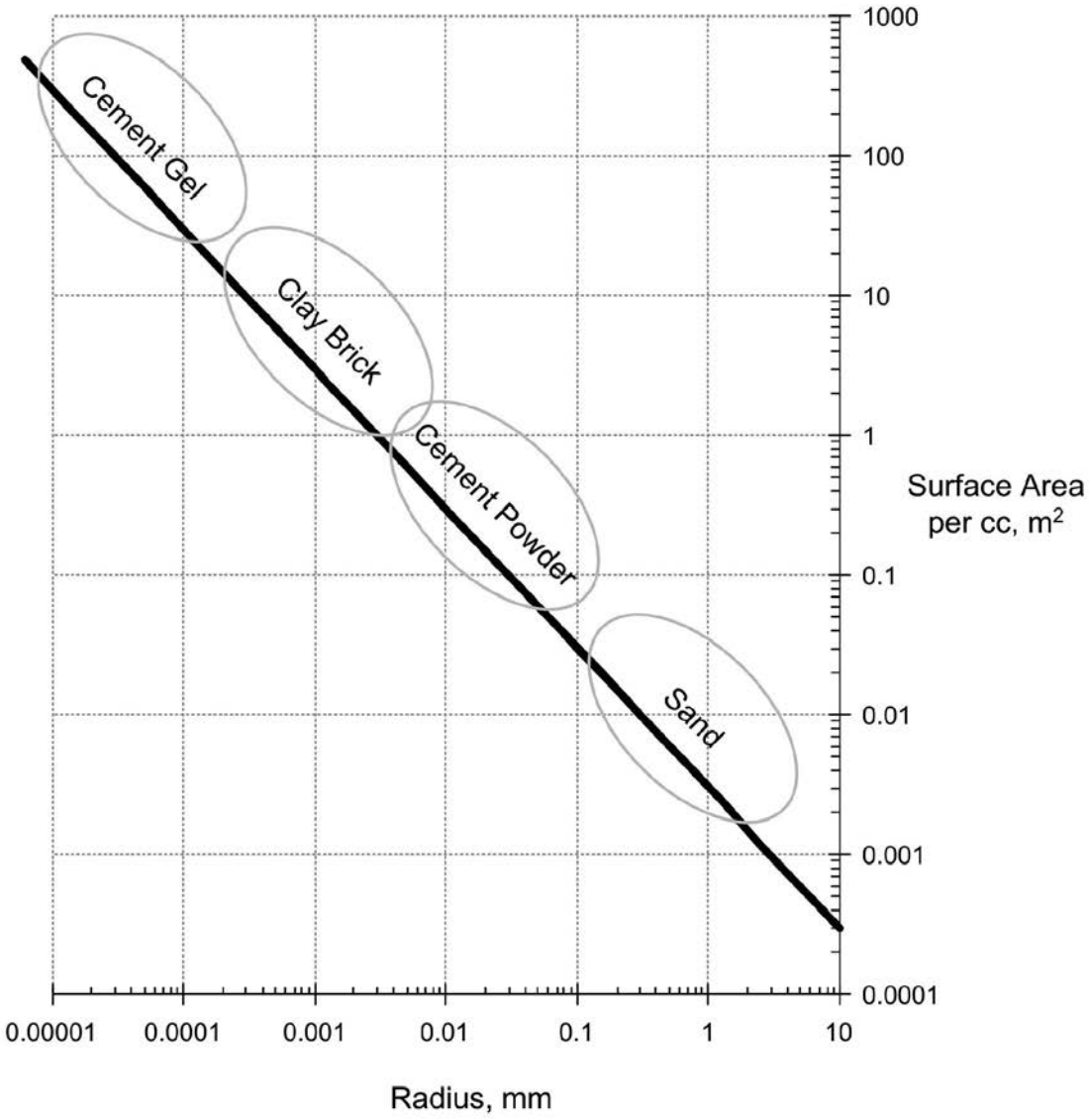




Capillary rise versus diameter




Si
O
Si
O
Si
O
Si
Curvature
("meniscus")
+
H
O
H
+
Hydrogen atoms (+)
"reach" upwards toward
oxide (-)



Surface area vs. particle size
From Straube & Burnett, 2005

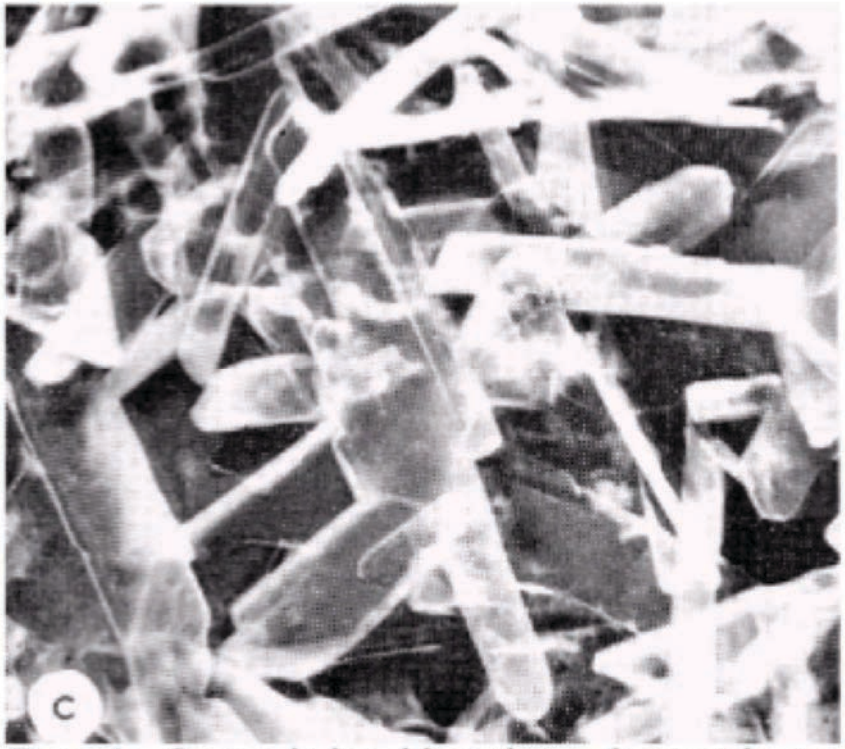


Figure 1c. Gypsum, hydrated from plaster of paris and water, porosity 30 per cent.

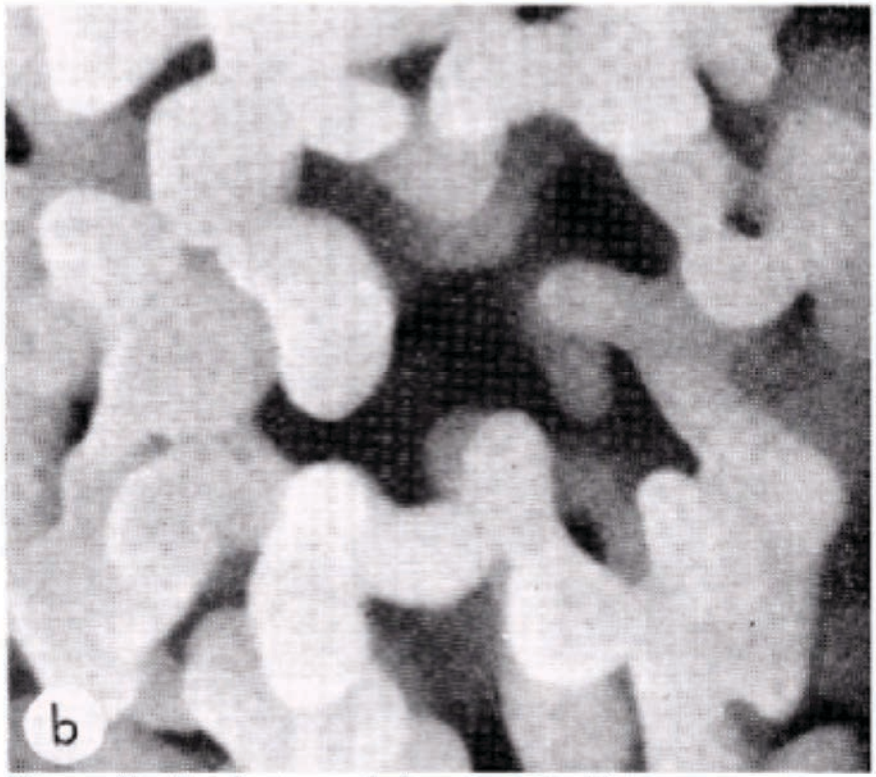
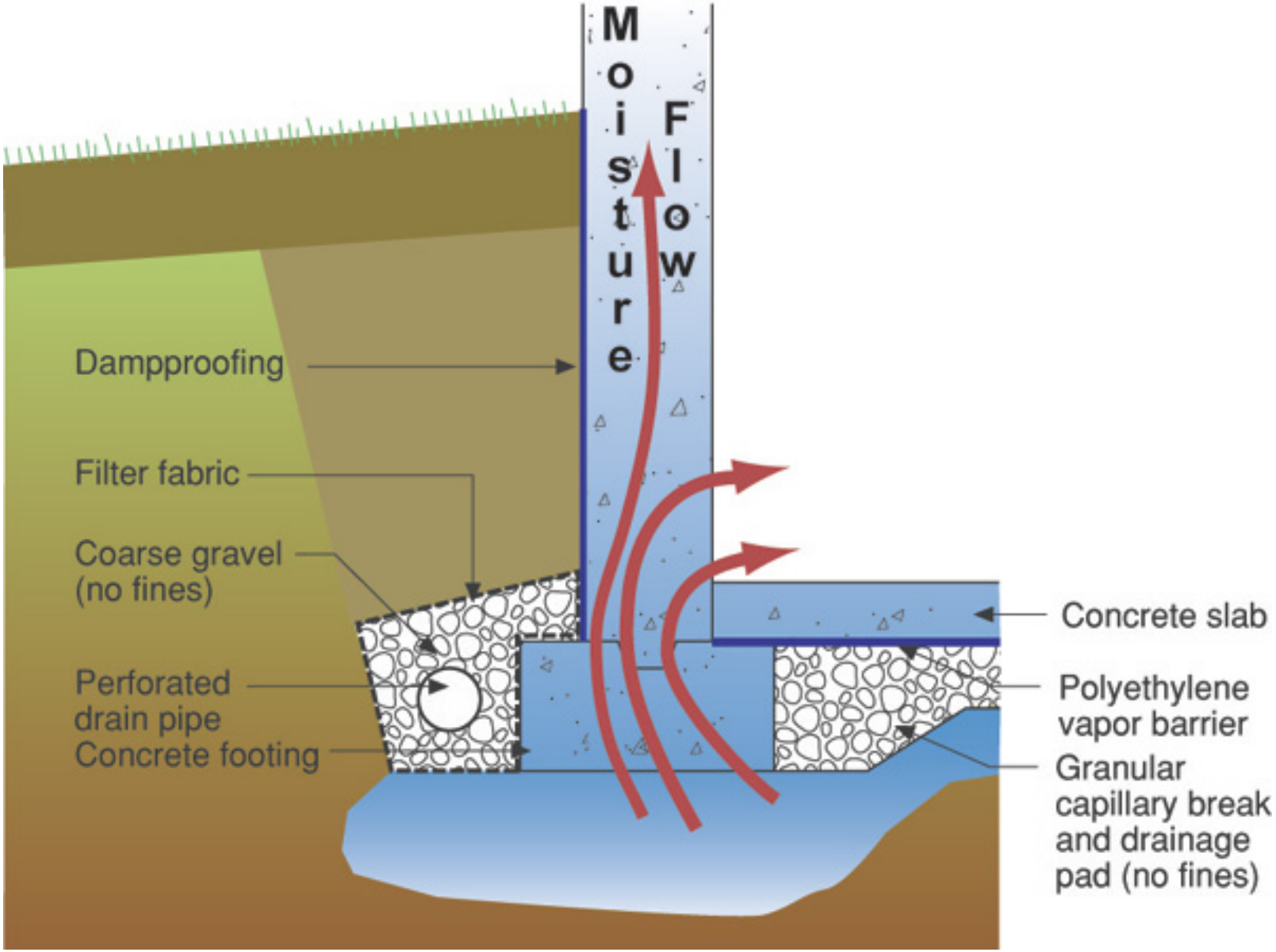
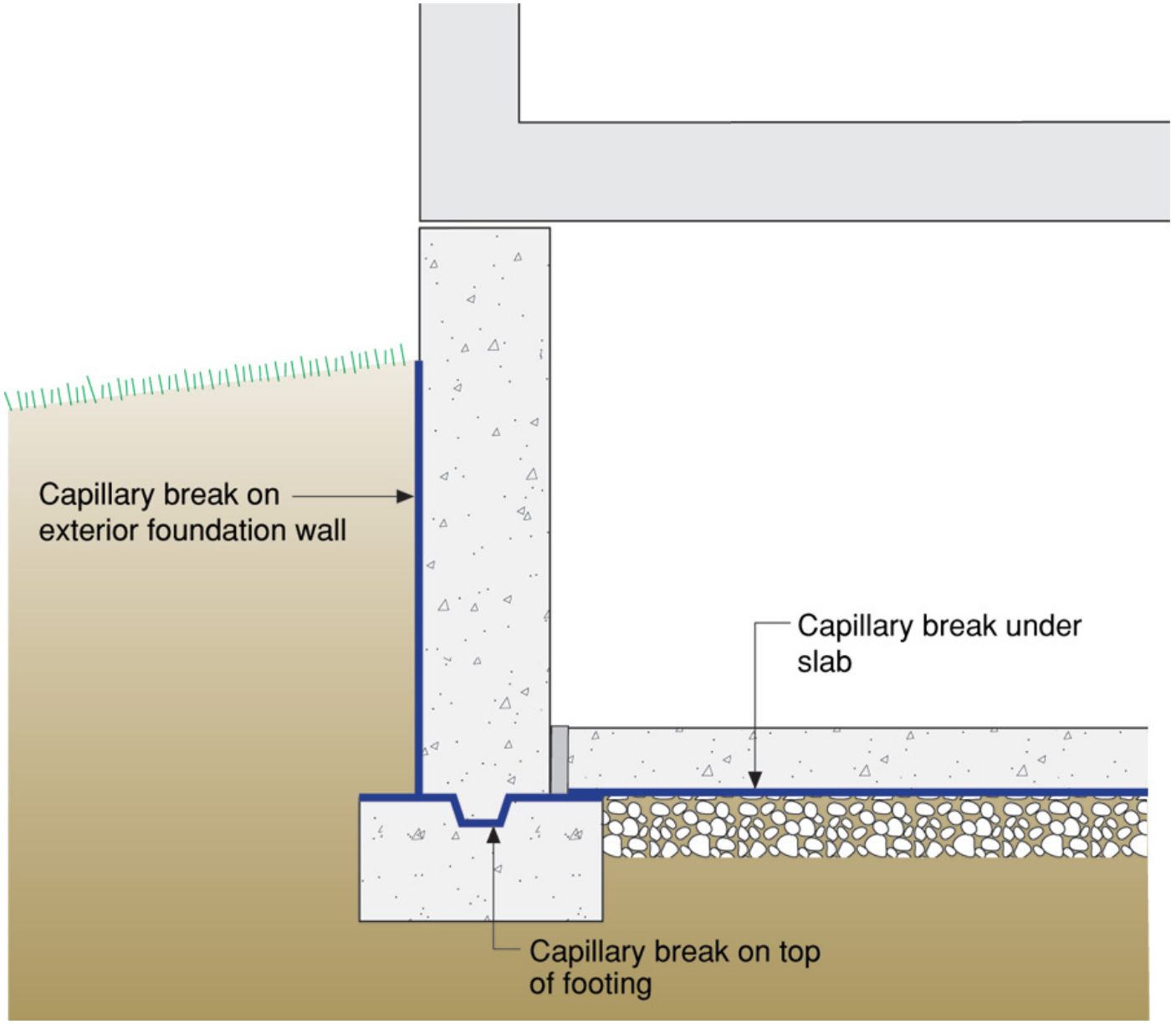
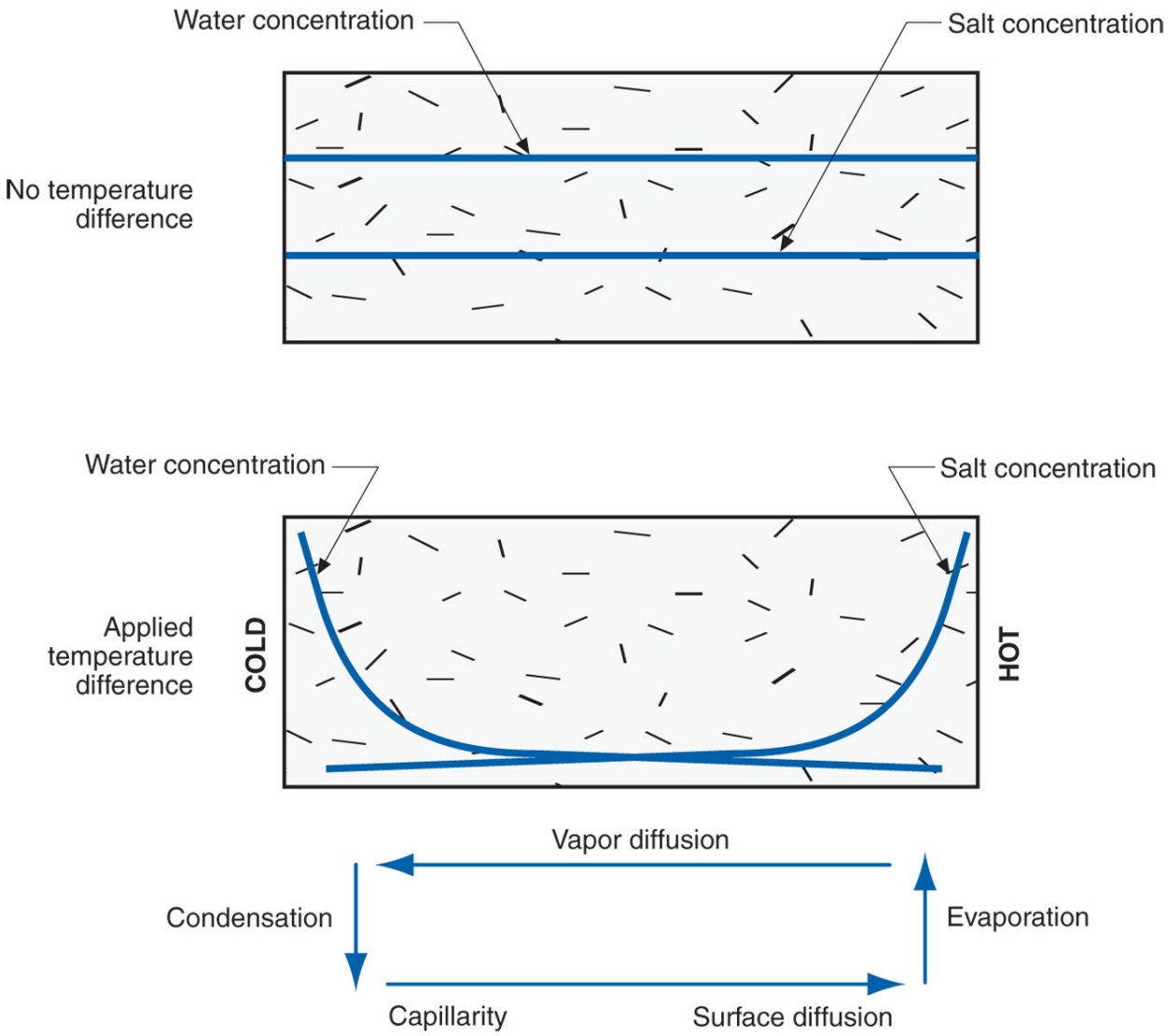


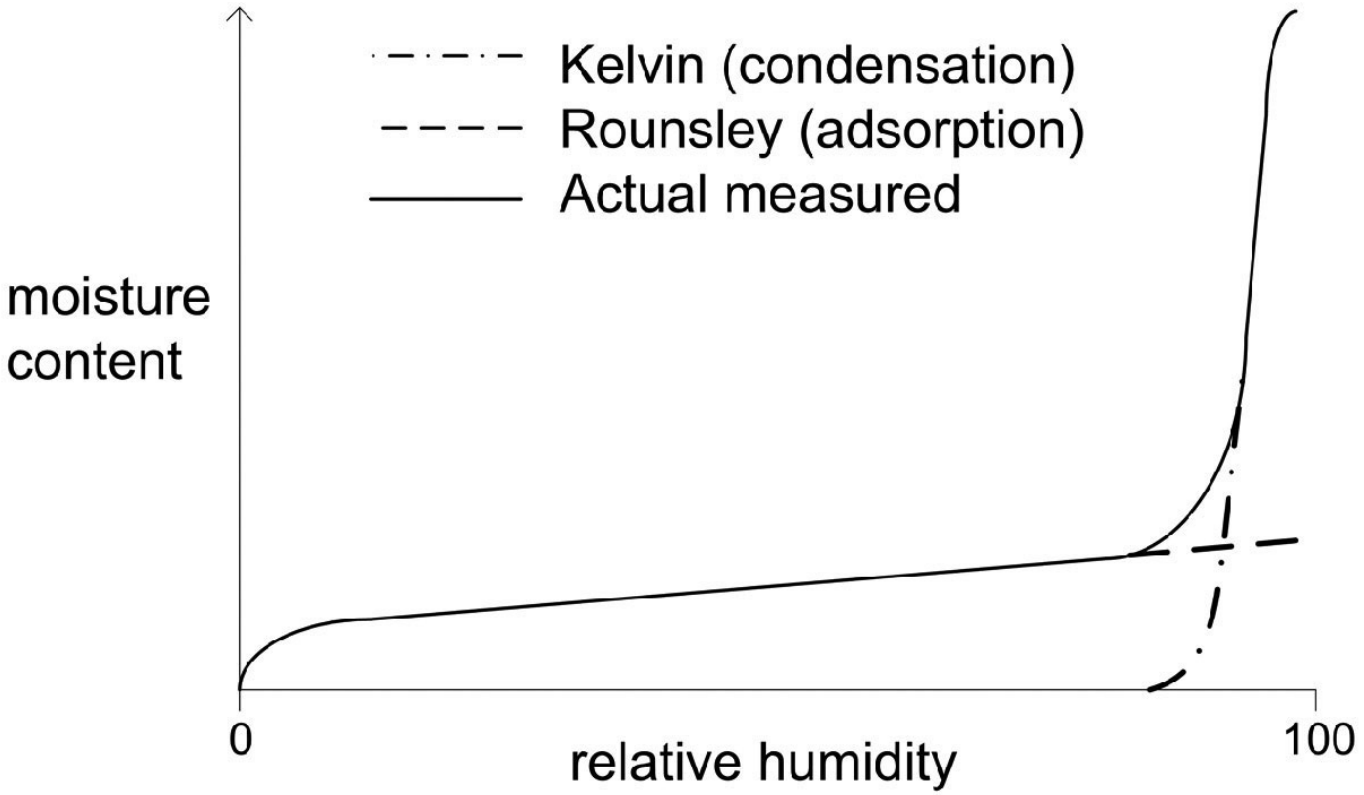
Figure 1b. Brick, sintered clay, porosity 40 per cent.


Moisture Flow
Dampproofing
Filter fabric
Coarse gravel
(no fines)
Perforated
drain pipe
Concrete footing
Concrete slab
Polyethylene
vapor barrier
Granular
capillary break
and drainage
pad (no fines)

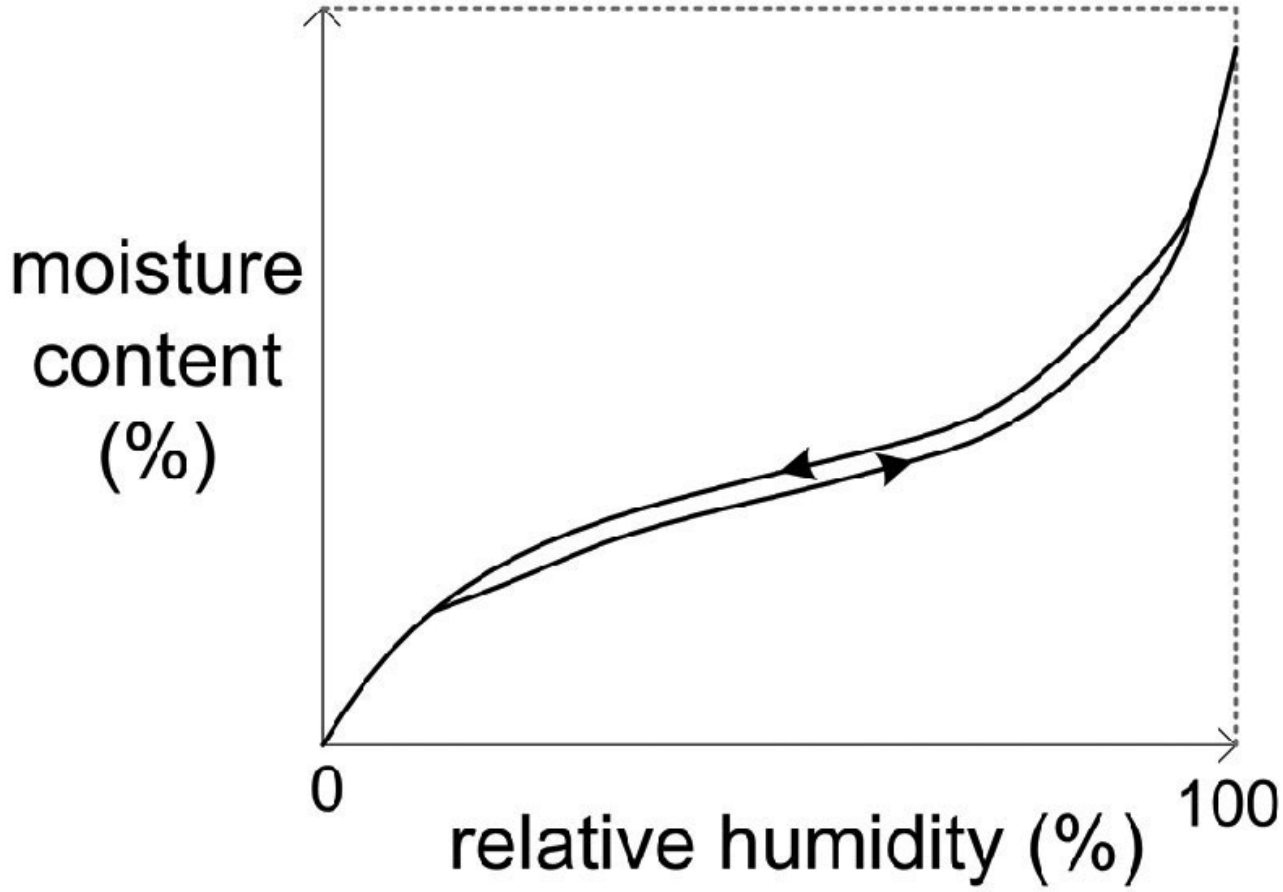

Capillary break on
exterior foundation wall
Capillary break under
slab
Capillary break on top
of footing

Hutcheon-Paxton Experiment



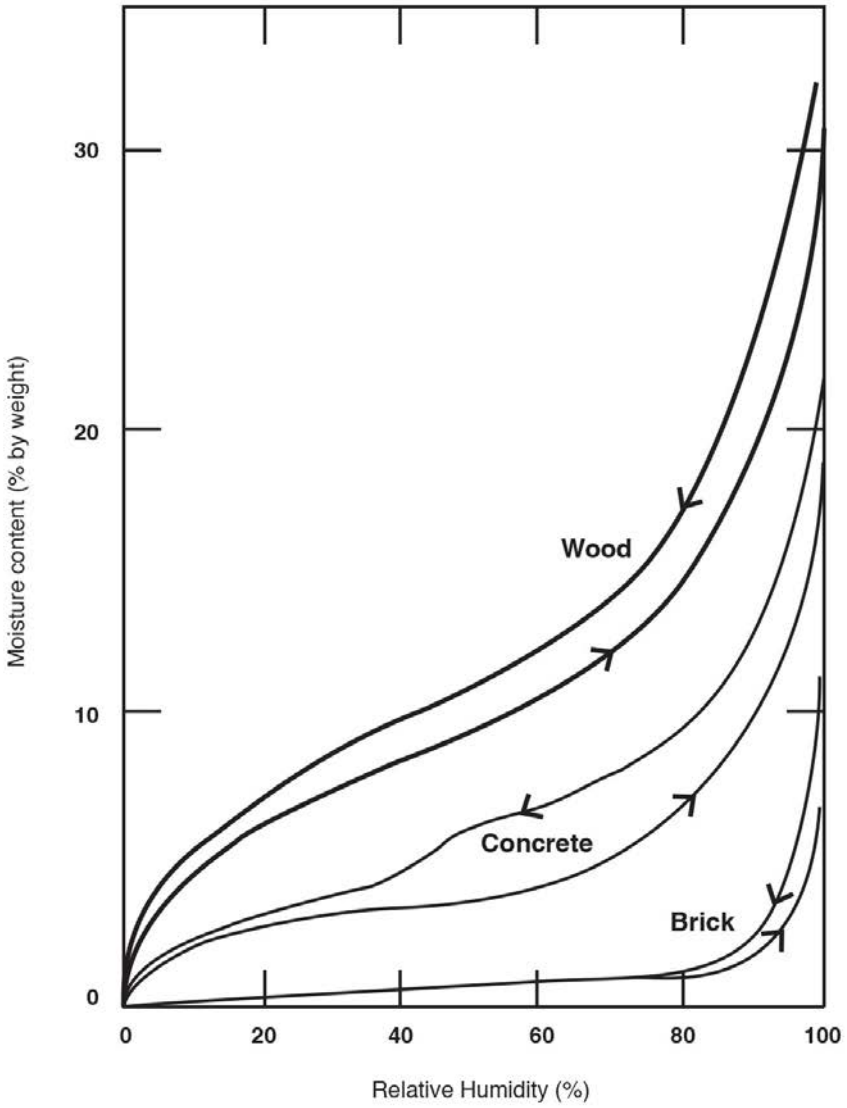


Typical predicted sorption isotherm according to Kelvin equation and modified BET theory
From Straube & Burnett, 2005

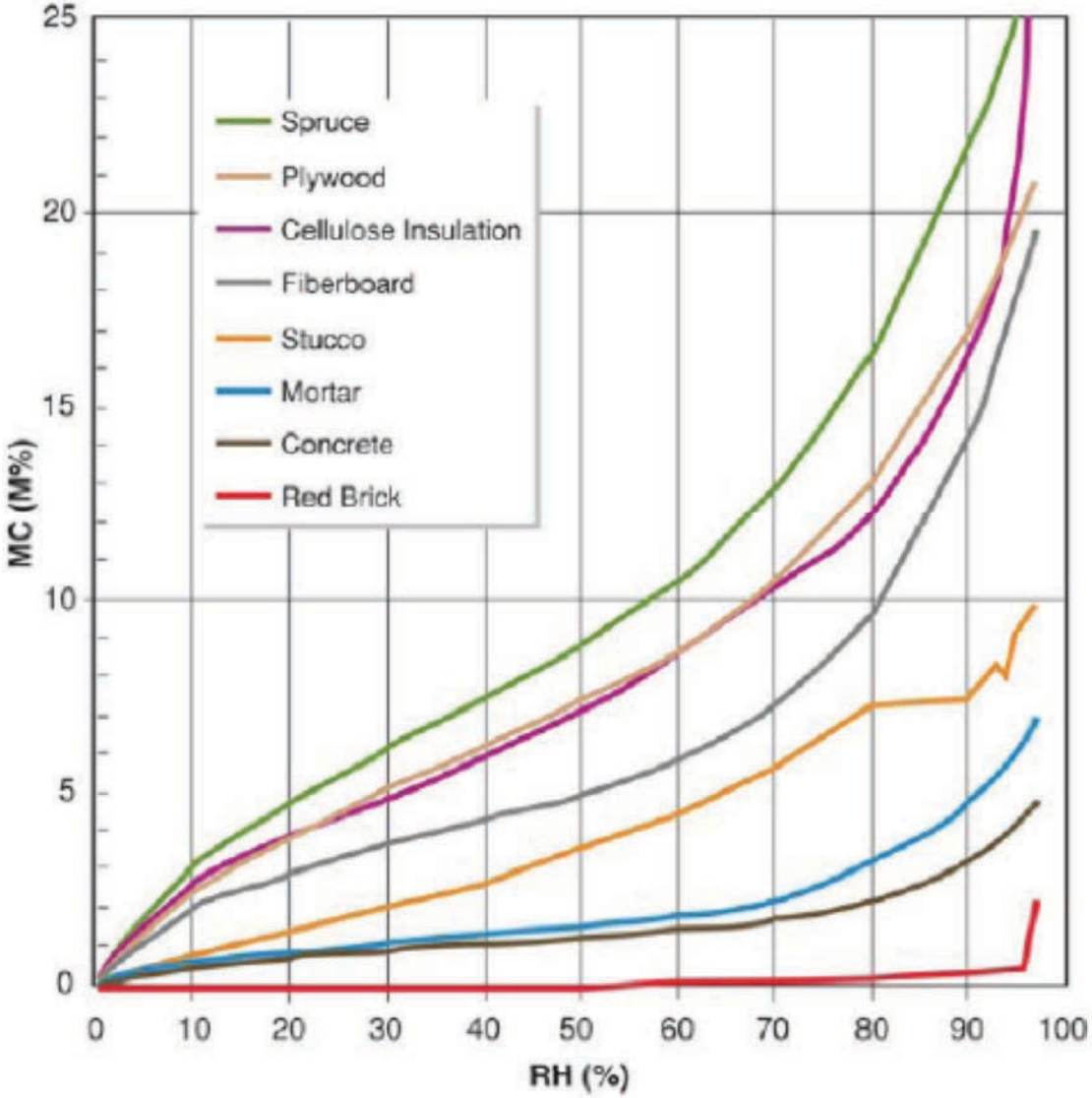


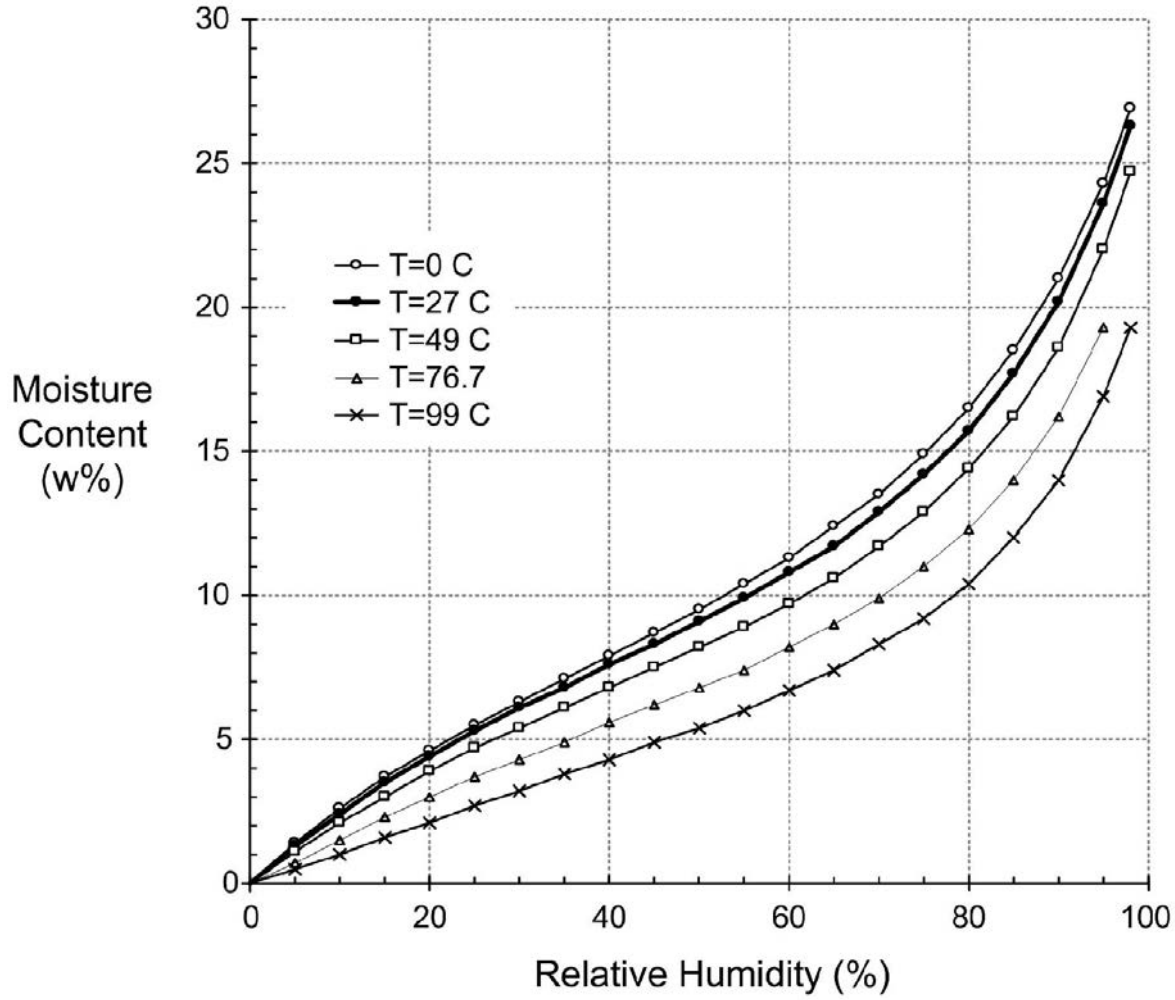
Typical sorption isotherm of a hygroscopic material

From Straube & Burnett, 2005

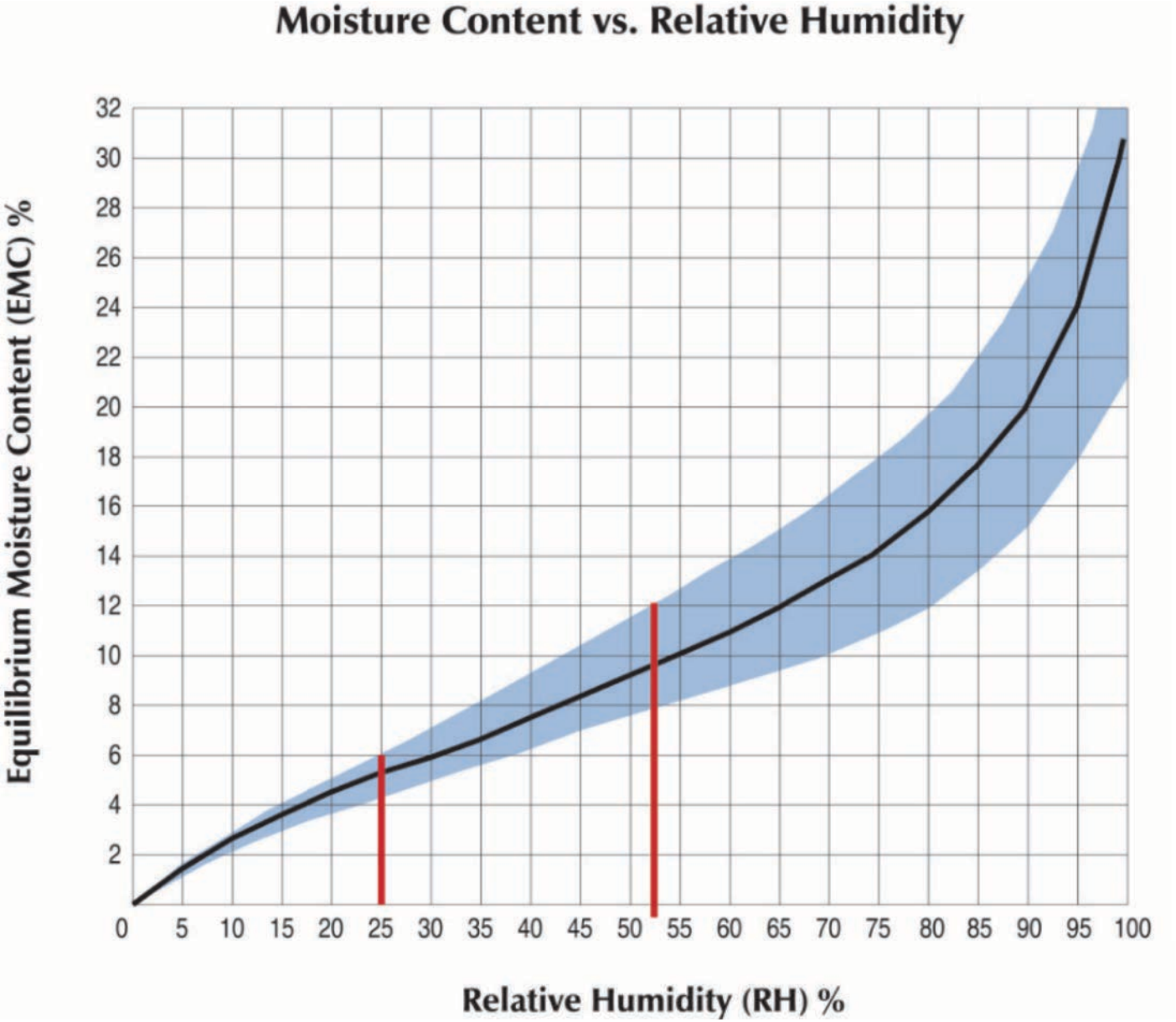


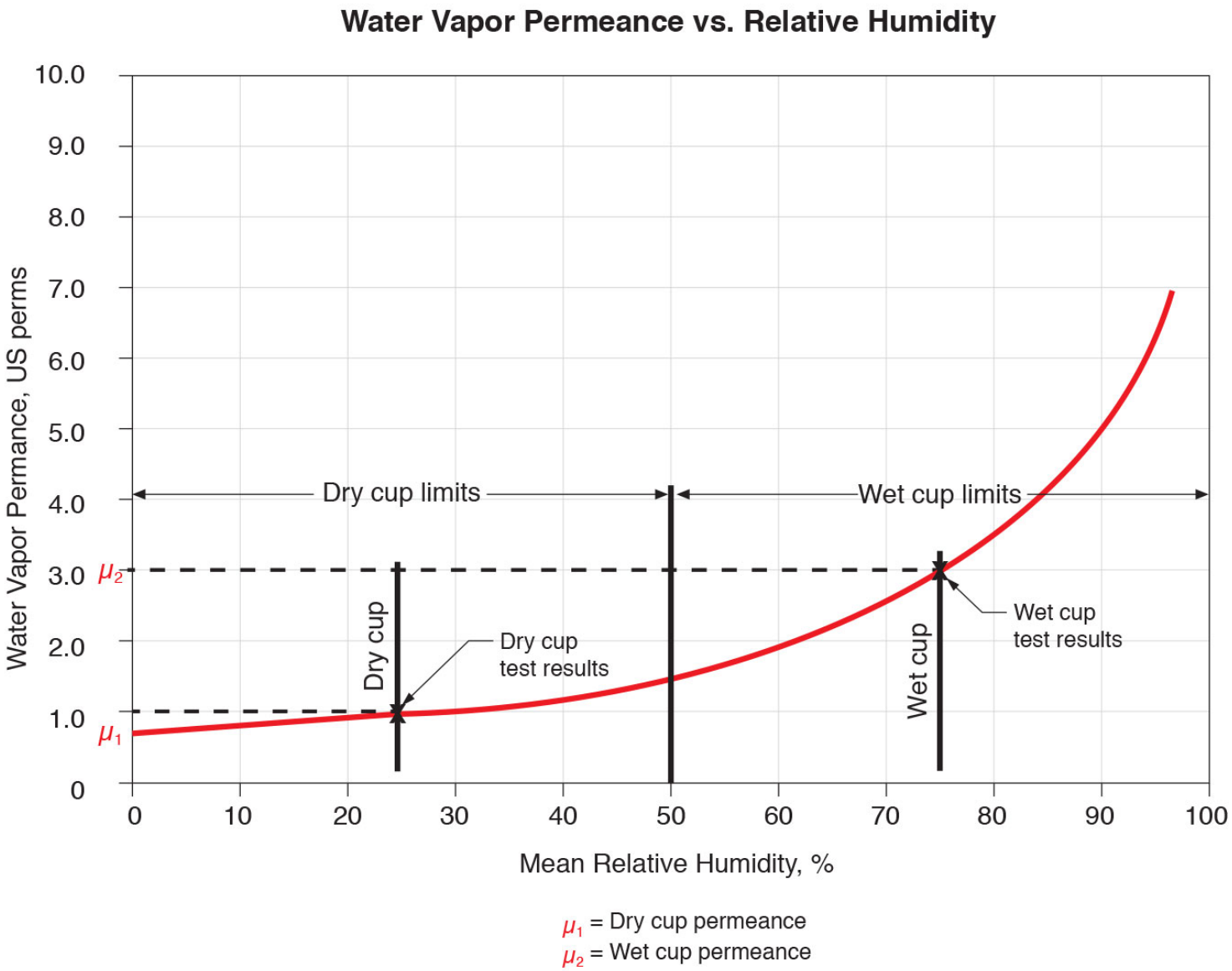
Water held in porous materials at various relative humidities
From Hutcheon & Handegord, 1983


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

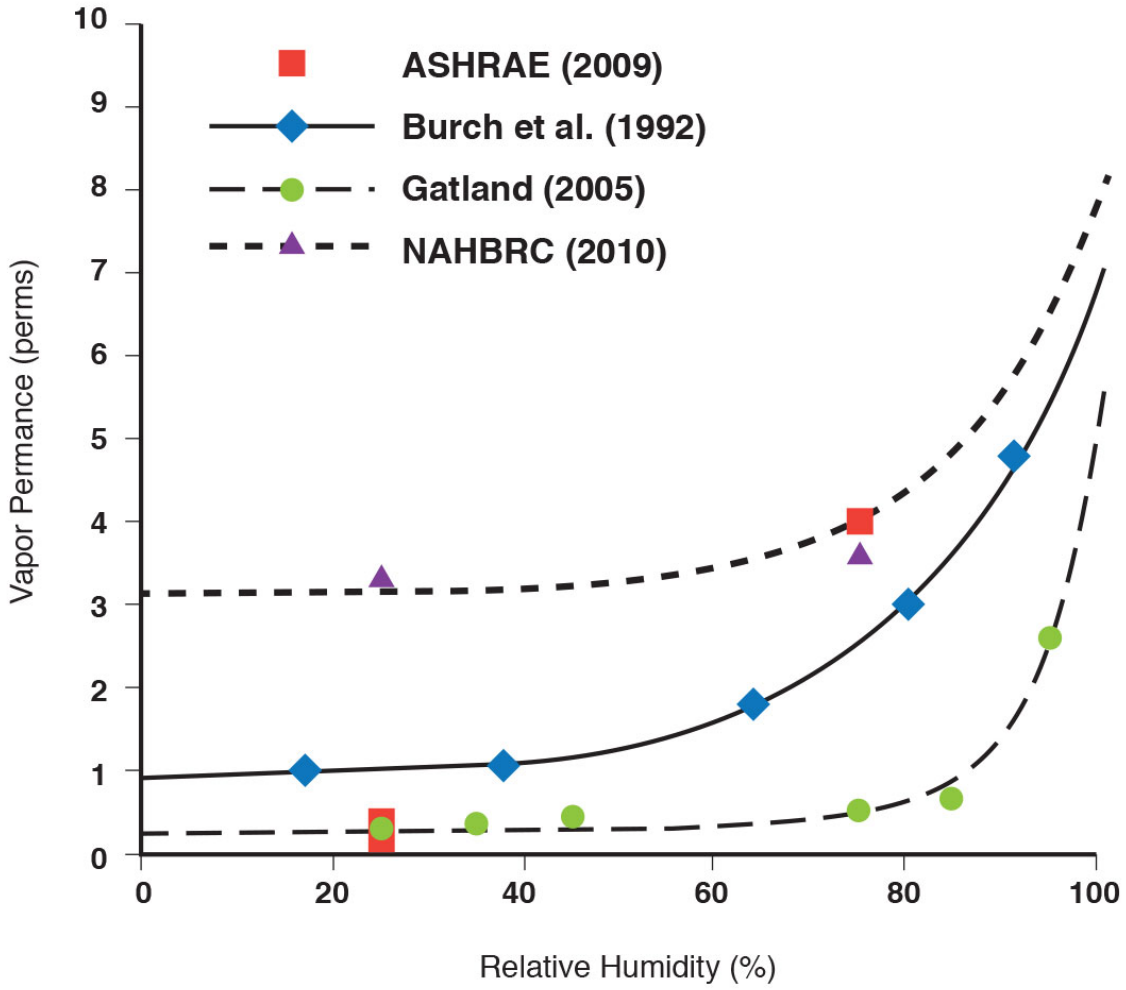


Average sorption isotherm for wood as a function of temperature
From Straube & Burnett, 2005

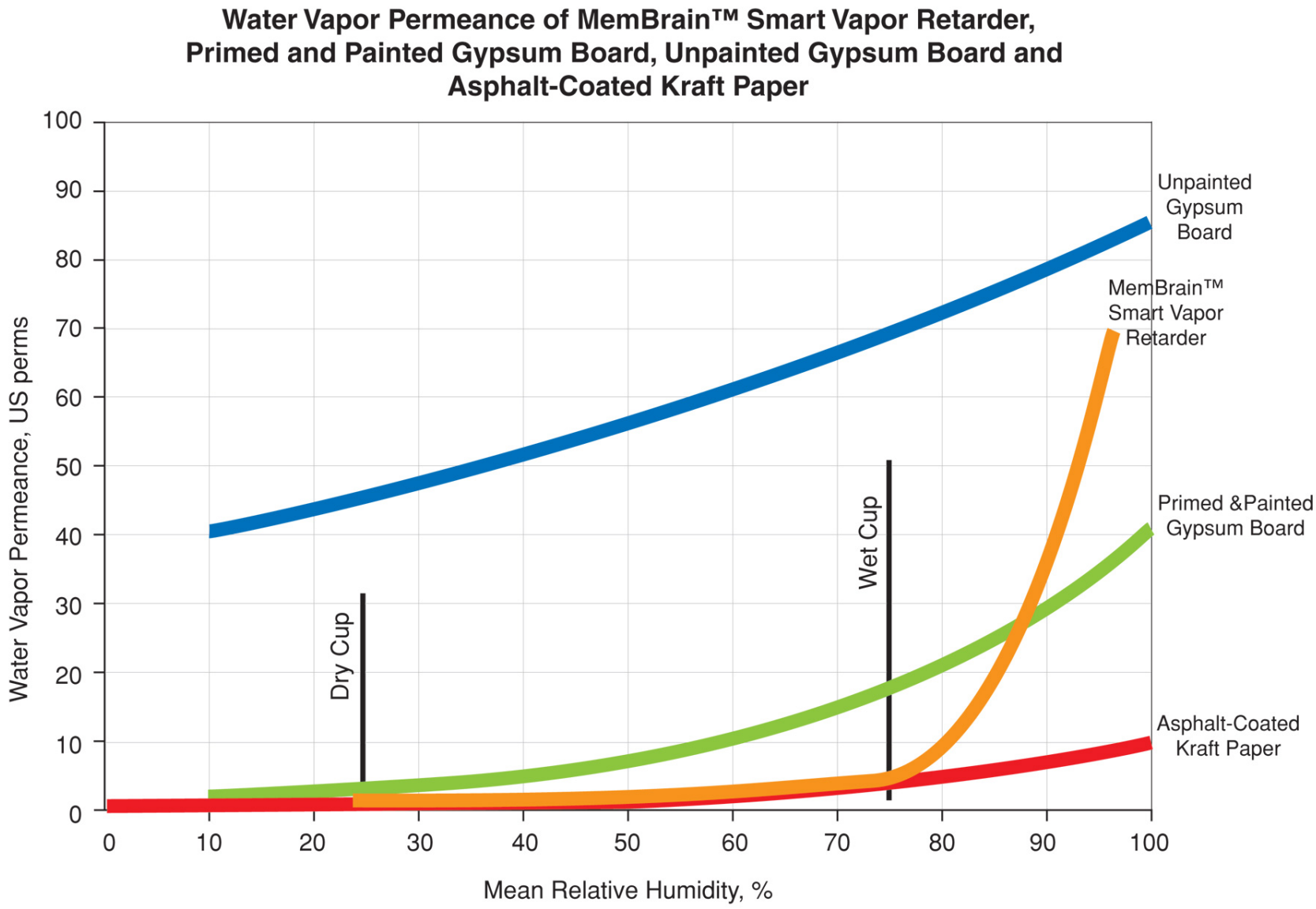

Moisture Content vs. Relative Humidity
Equilibrium Moisture Content (EMC) %
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Relative Humidity (RH) %

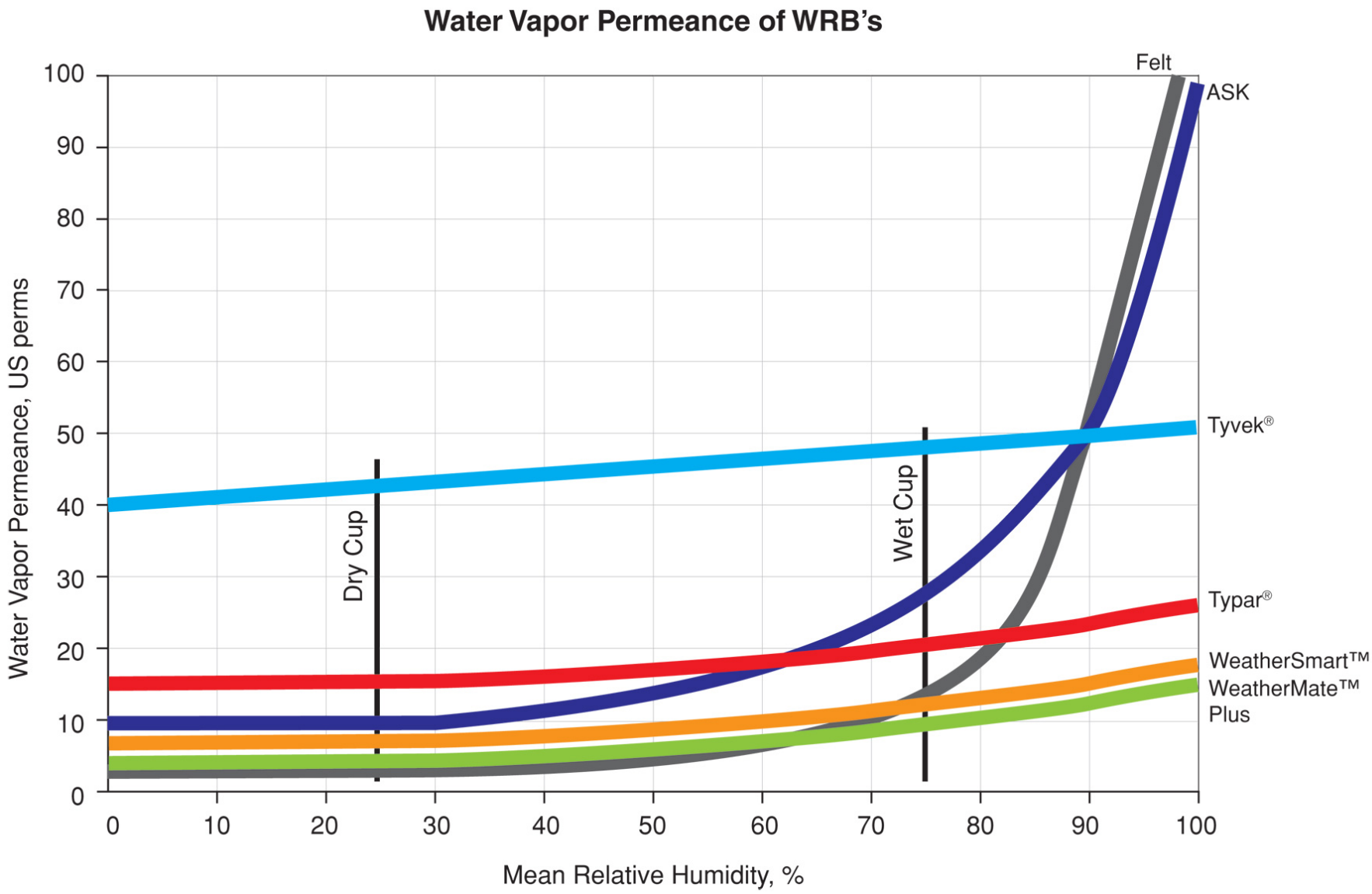

Water Vapor Permeance vs. Relative Humidity
Water Vapor Permance, US perms
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
μ_2
μ_1
Dry cup limits
Wet cup limits
Dry cup
Dry cup test results
Wet cup
Wet cup test results
0
10
20
30
40
50
60
70
80
90
100
Mean Relative Humidity, %
μ_1 = Dry cup permeance
μ_2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

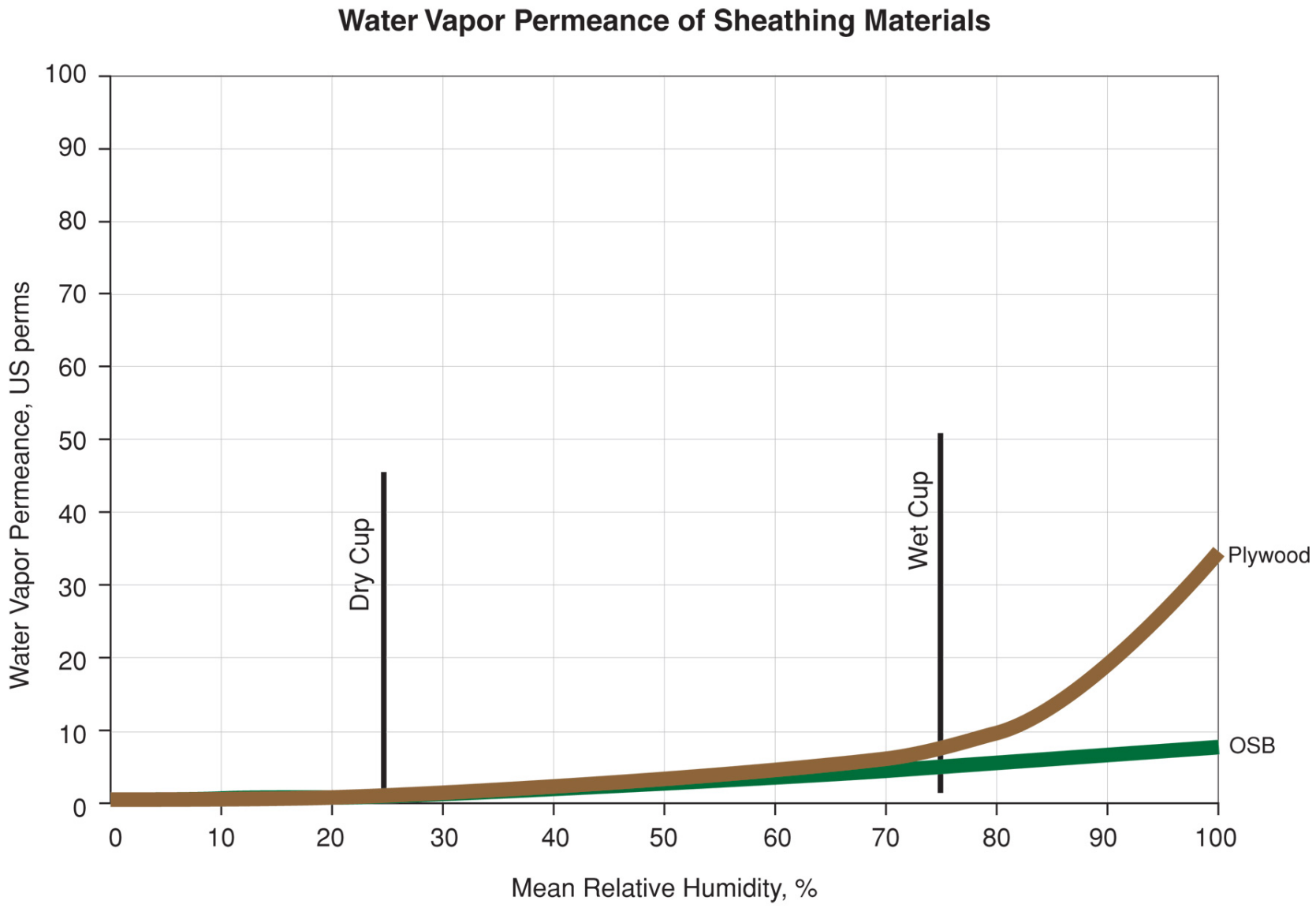

R-11 3½"
OWENS-CORNING
Fiberglas
Building
Insulation
FIBERGLAS
ASSURED THERMAL
PERFORMANCE

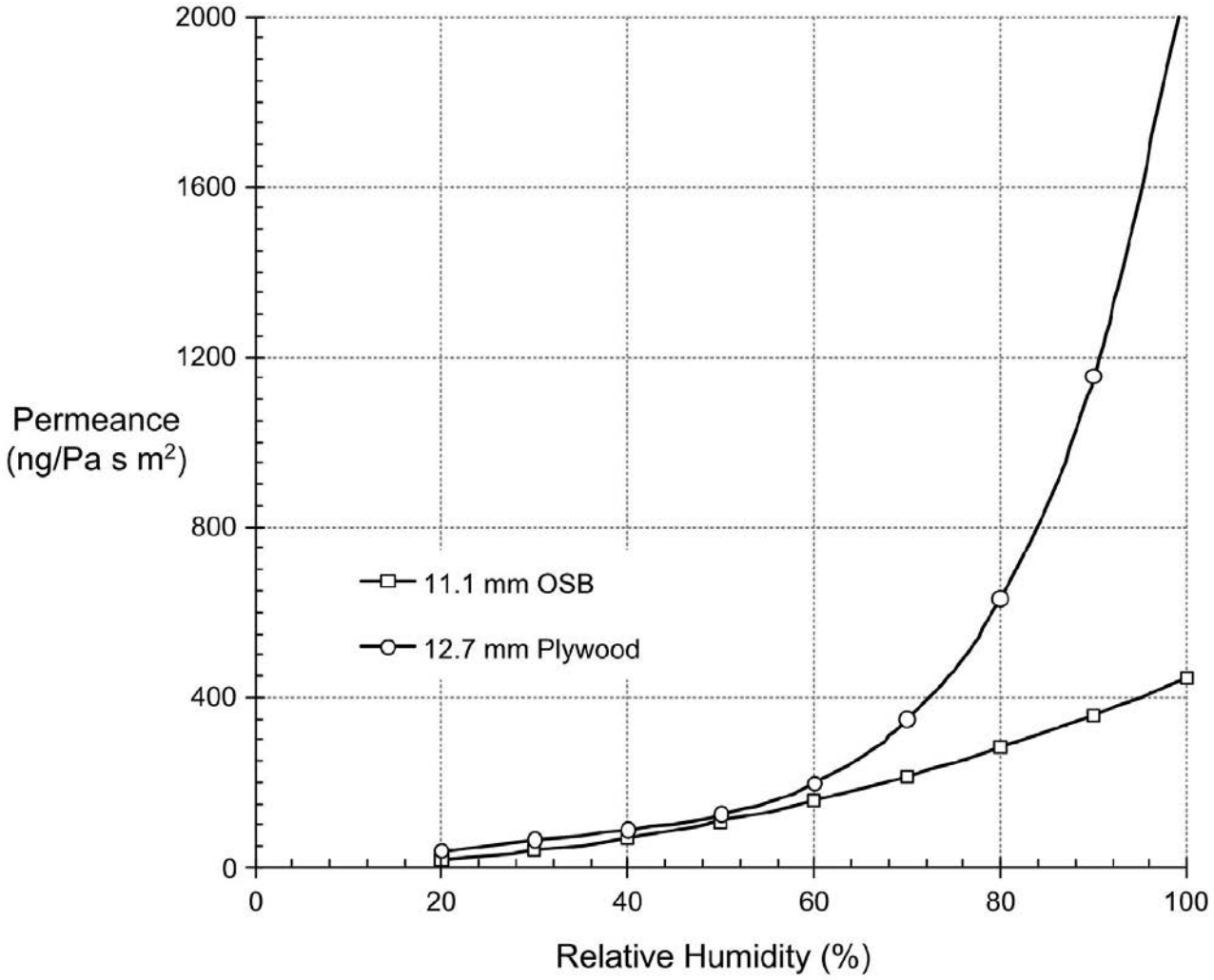


Kraft facing permeance as a function of humidity (Glass 2013)

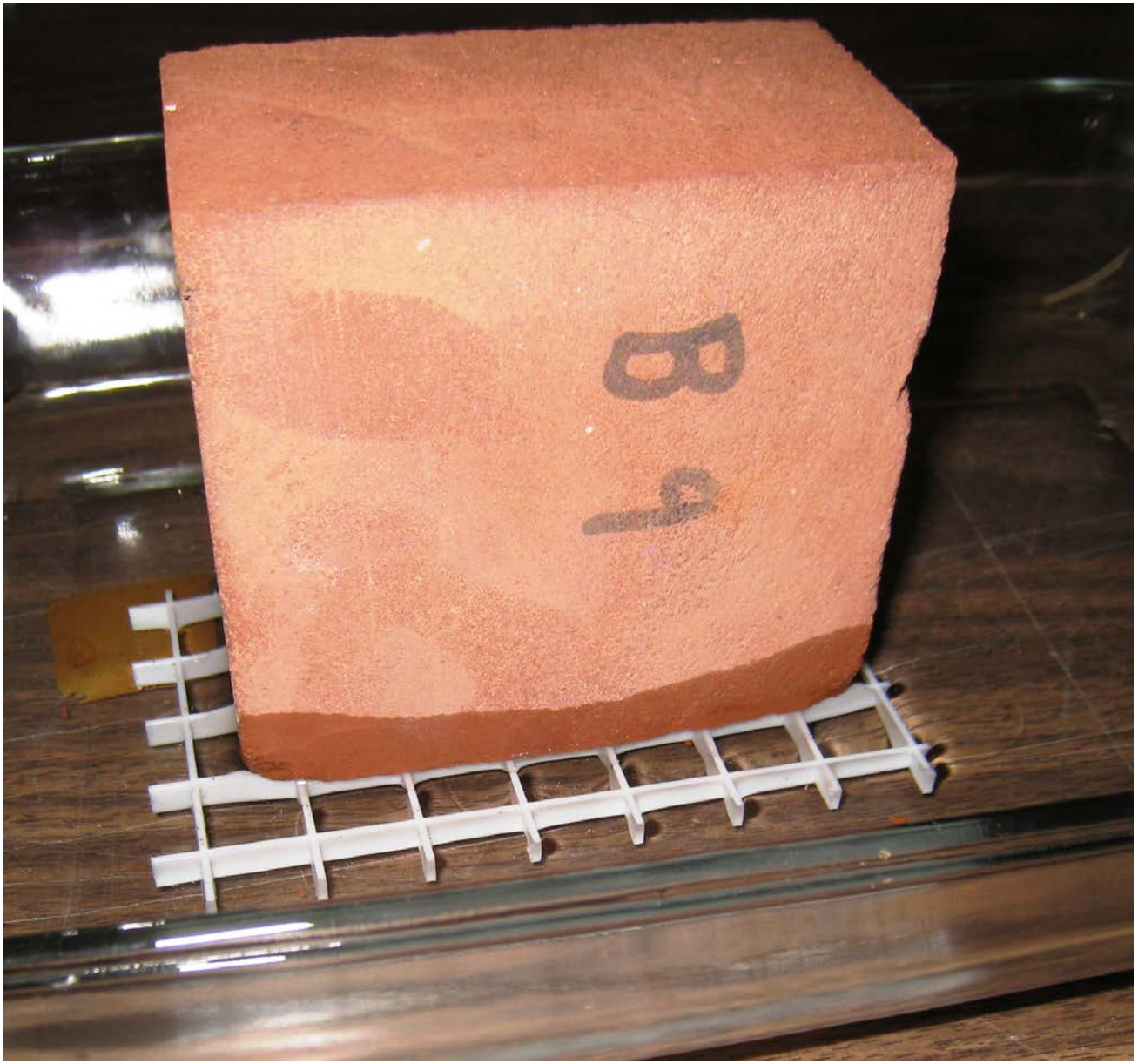

Water Vapor Permeance of MemBrain™ Smart Vapor Retarder, Primed and Painted Gypsum Board, Unpainted Gypsum Board and Asphalt-Coated Kraft Paper
Water Vapor Permeance, US perms
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Mean Relative Humidity, %
Dry Cup
Wet Cup
Unpainted Gypsum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

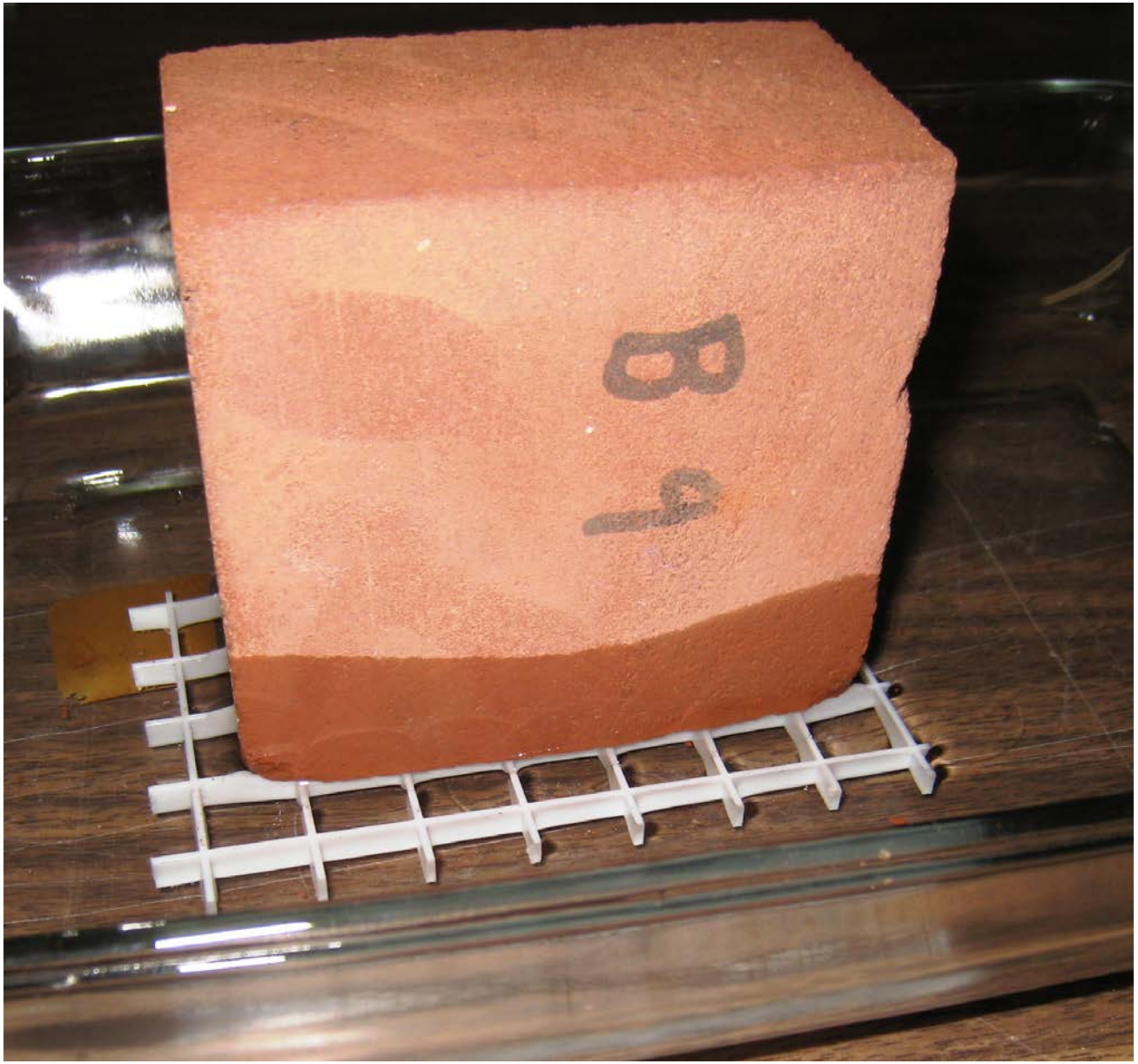

Water Vapor Permeance of WRB's
Water Vapor Permeance, US perms
Mean Relative Humidity, %
0
10
20
30
40
50
60
70
80
90
100
Dry Cup
Wet Cup
Felt
ASK
Tyvek®
Typar®
WeatherSmart™
WeatherMate™
Plus

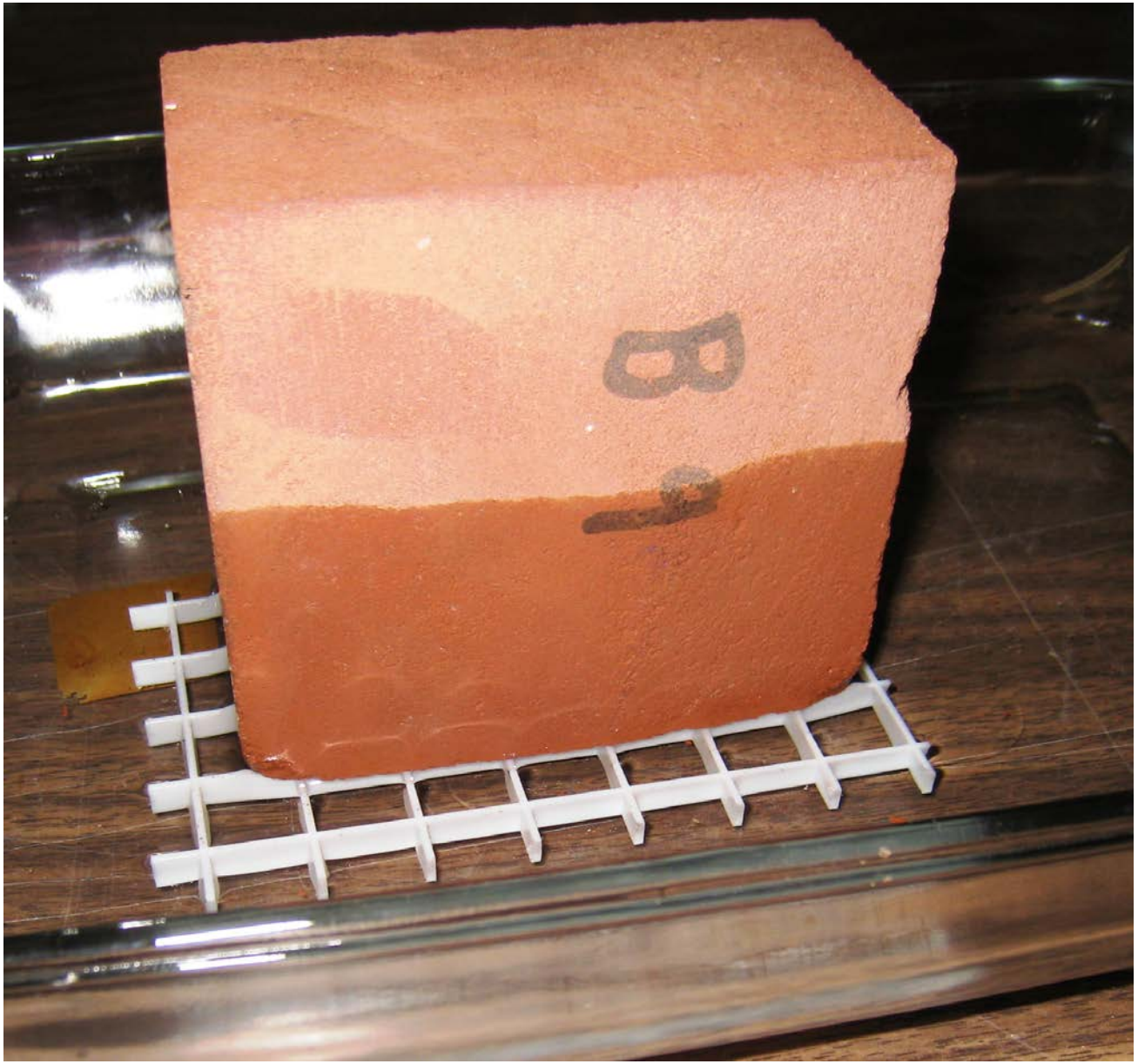

Water Vapor Permeance of Sheathing Materials
Water Vapor Permeance, US perms
100
90
80
70
60
50
40
30
20
10
0
Dry Cup
Wet Cup
Plywood
OSB
0
10
20
30
40
50
60
70
80
90
100
Mean Relative Humidity, %

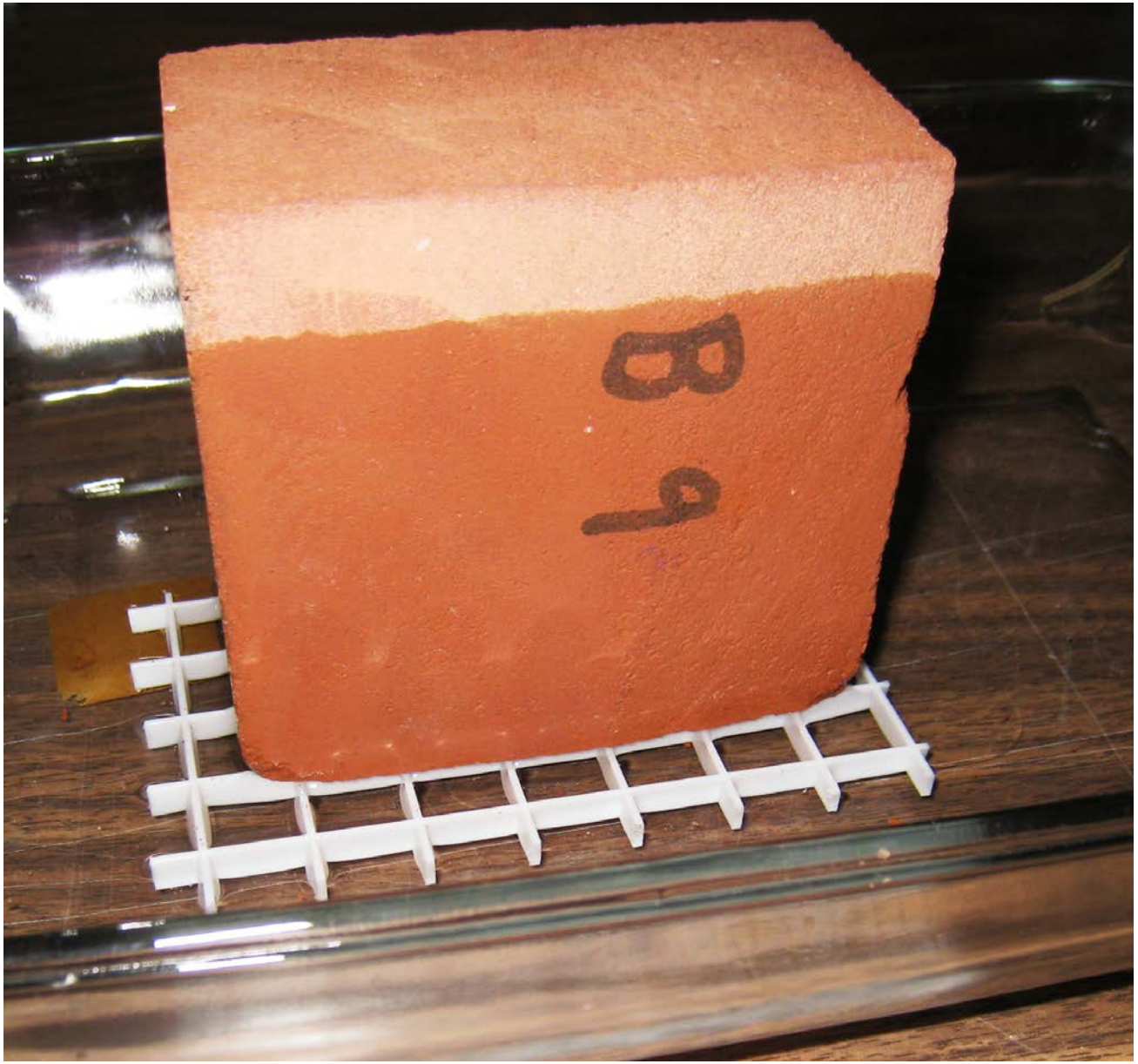


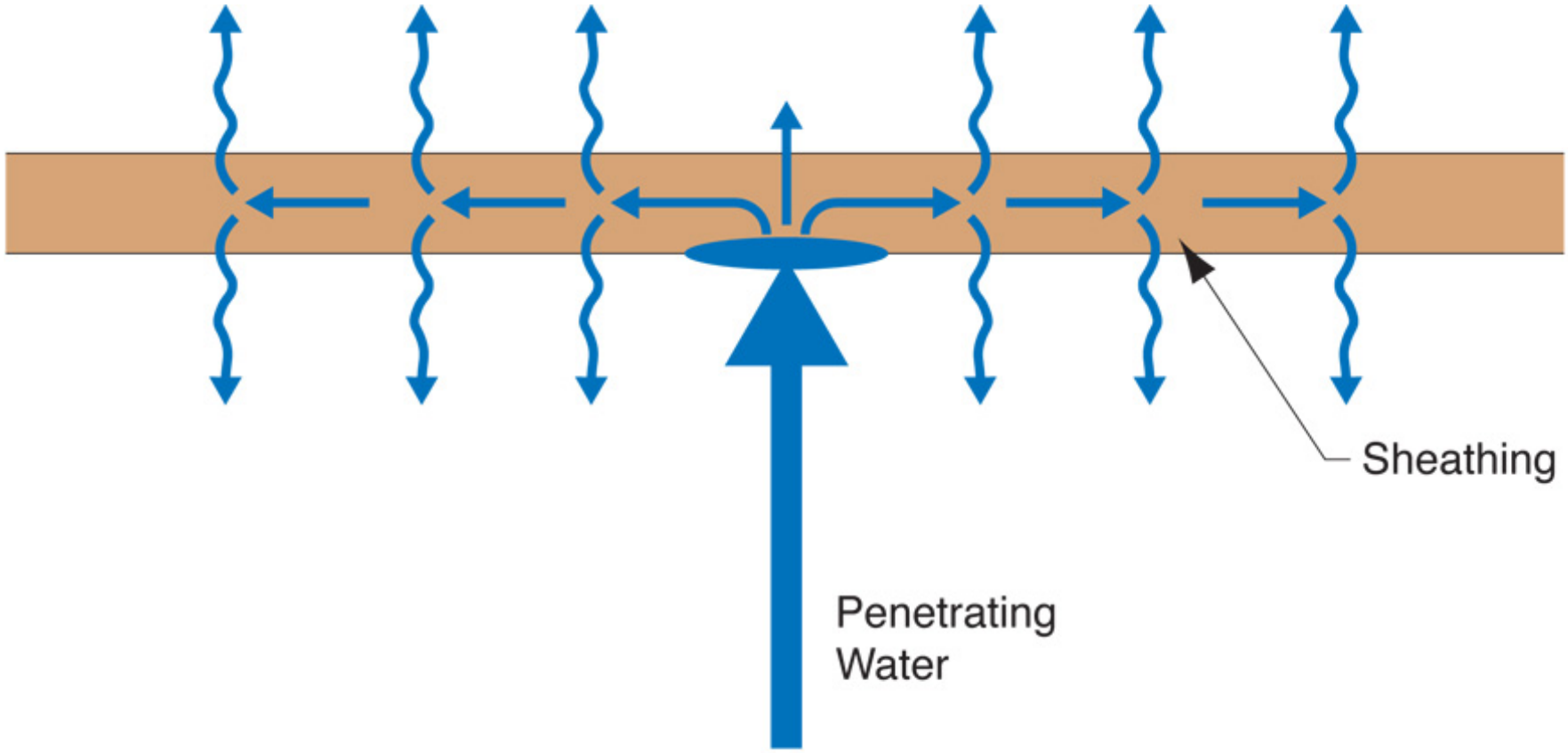
Vapor permeability test results for wood-based products as a function of RH [Kumaran *et al* 2002]
From Straube & Burnett, 2005

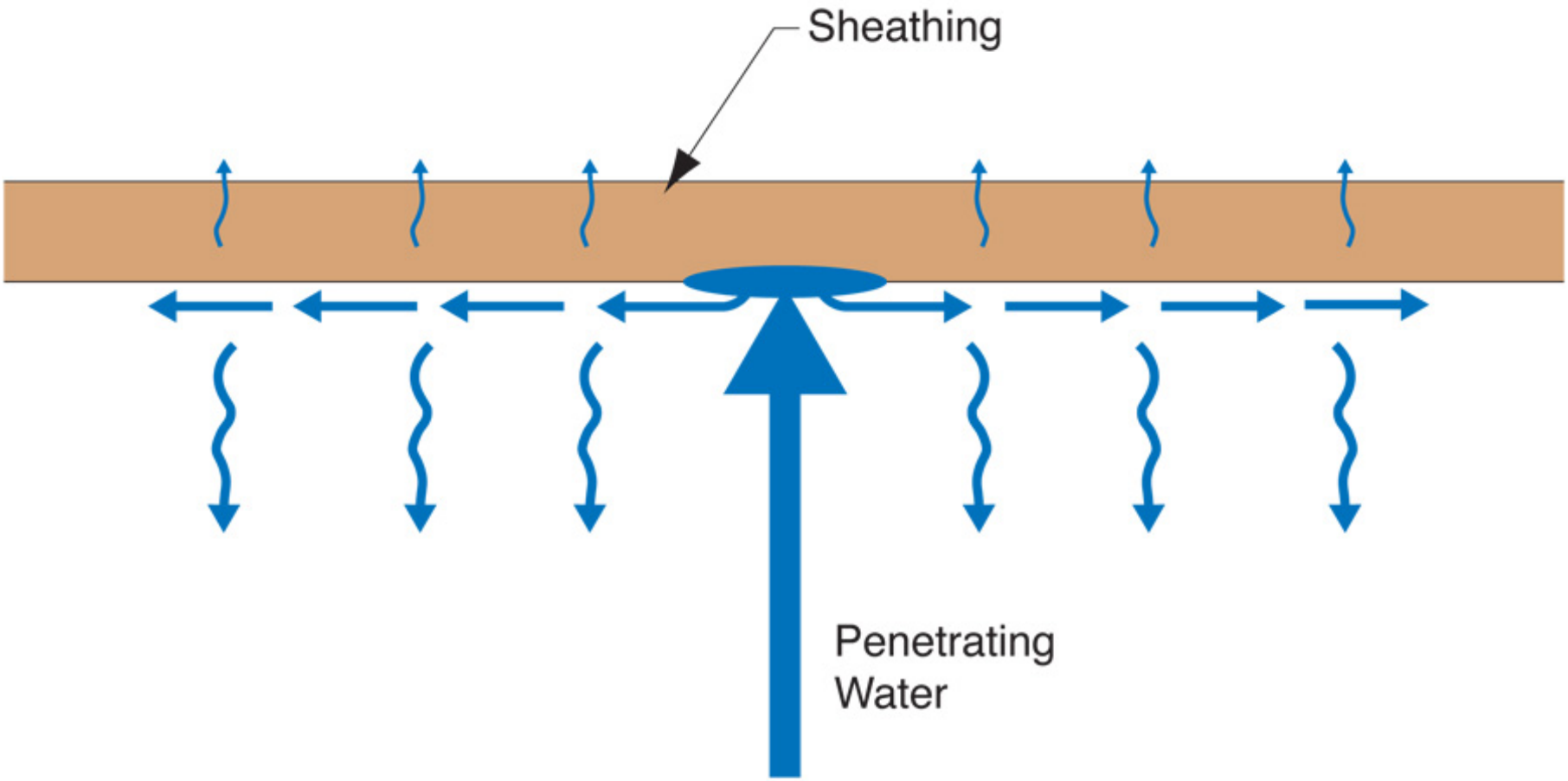

B


B


B

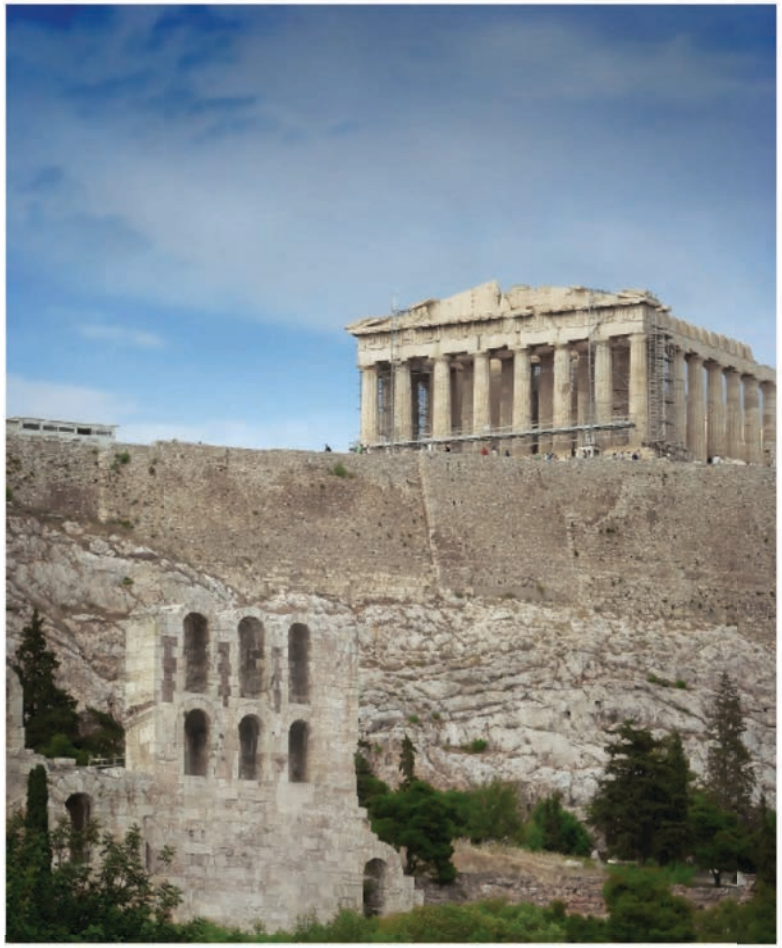

8
9


Sheathing
Penetrating
Water


Sheathing
Penetrating
Water


panago
QUILTED TREASURES


panago
QUILTED TREASURES

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IV-7


W1
W3


LOWER
N-2


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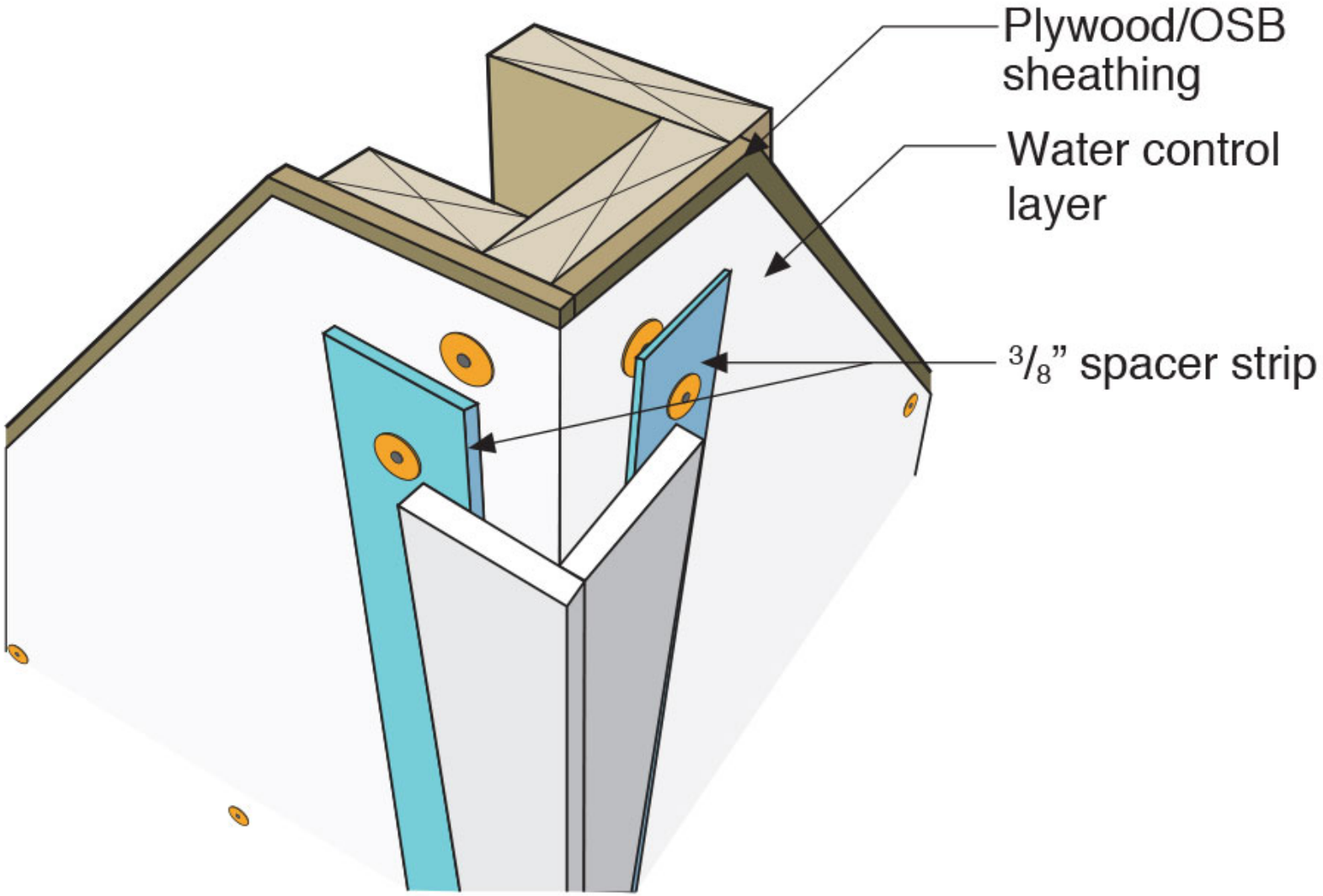
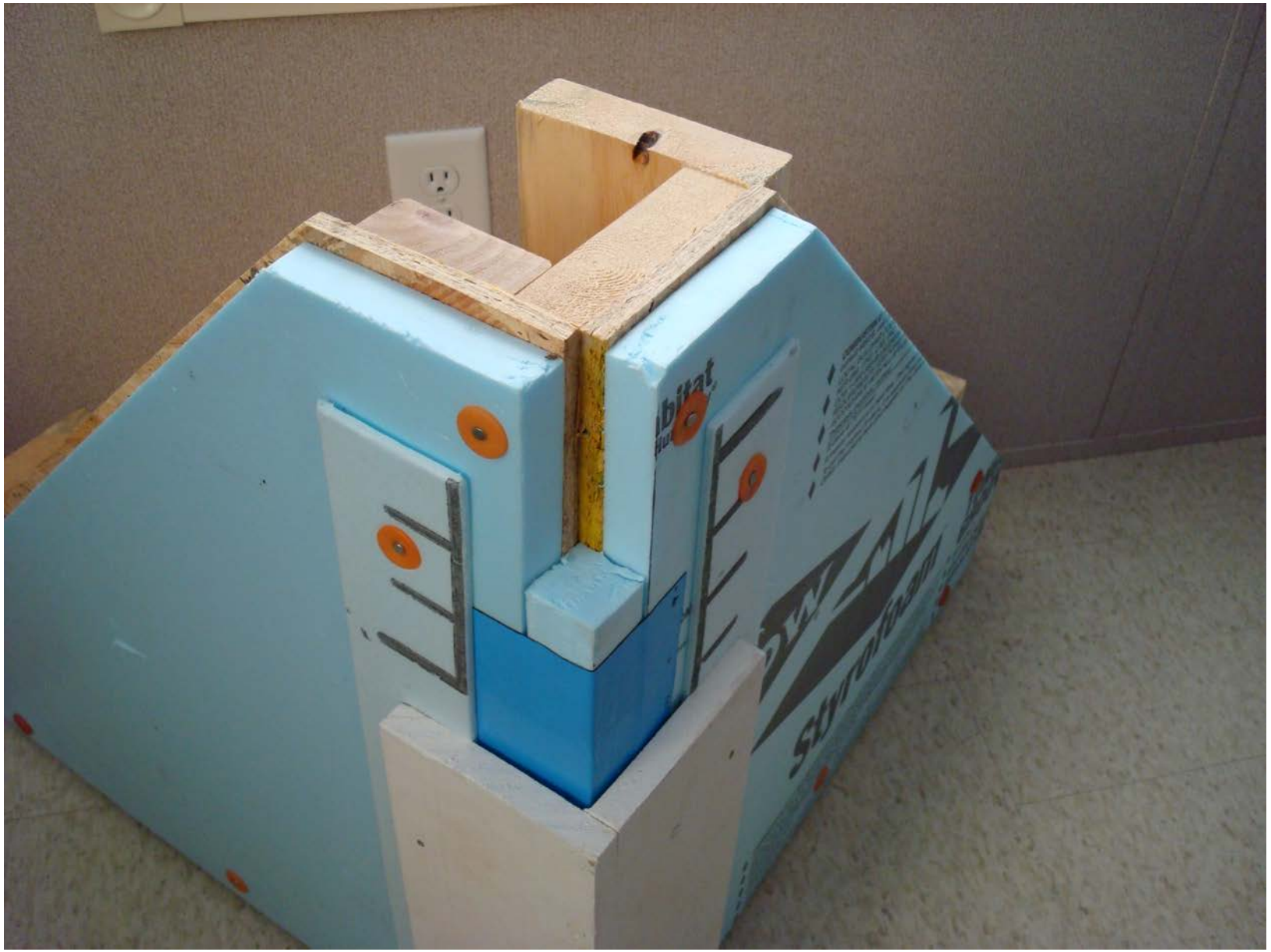
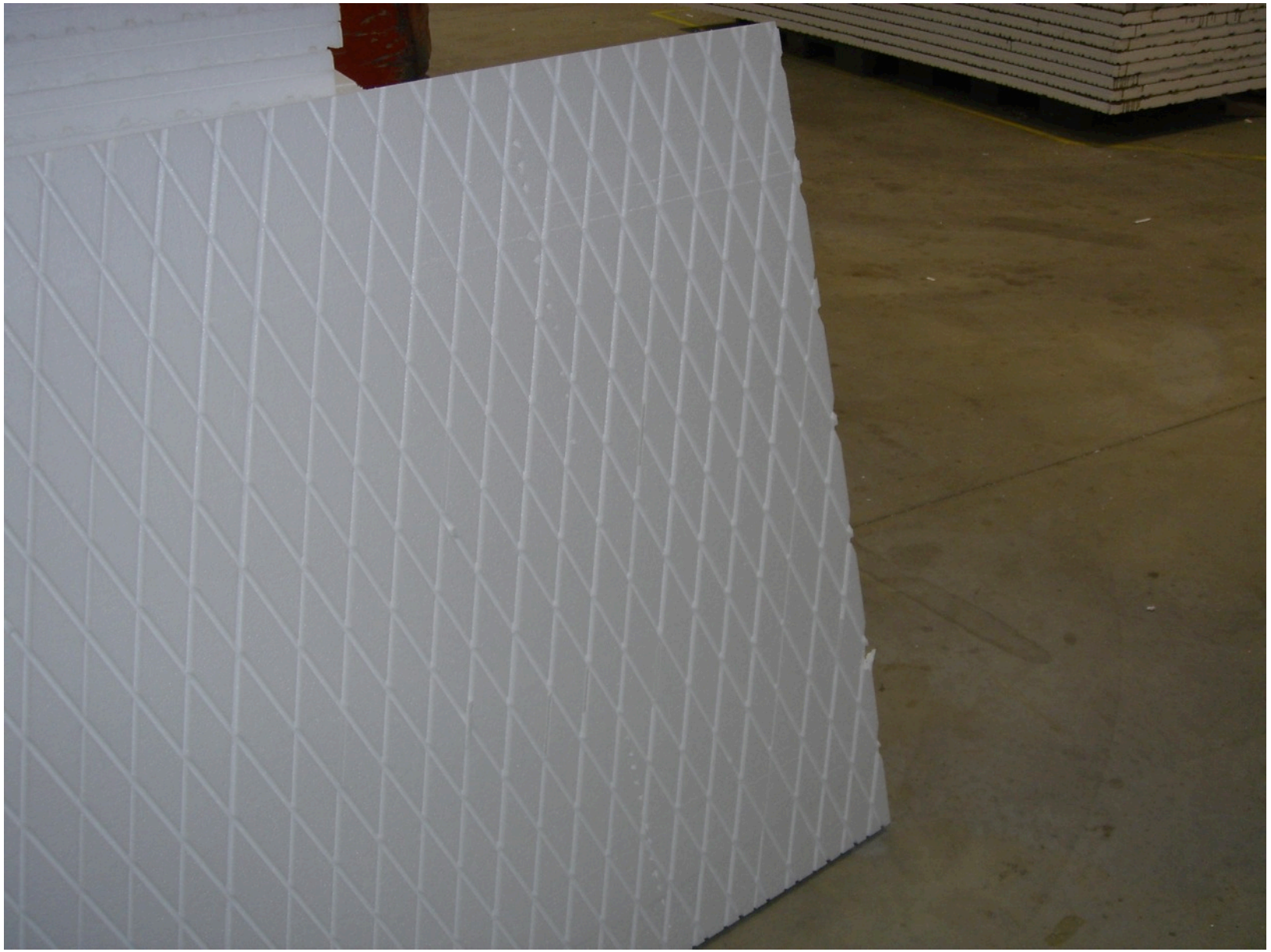
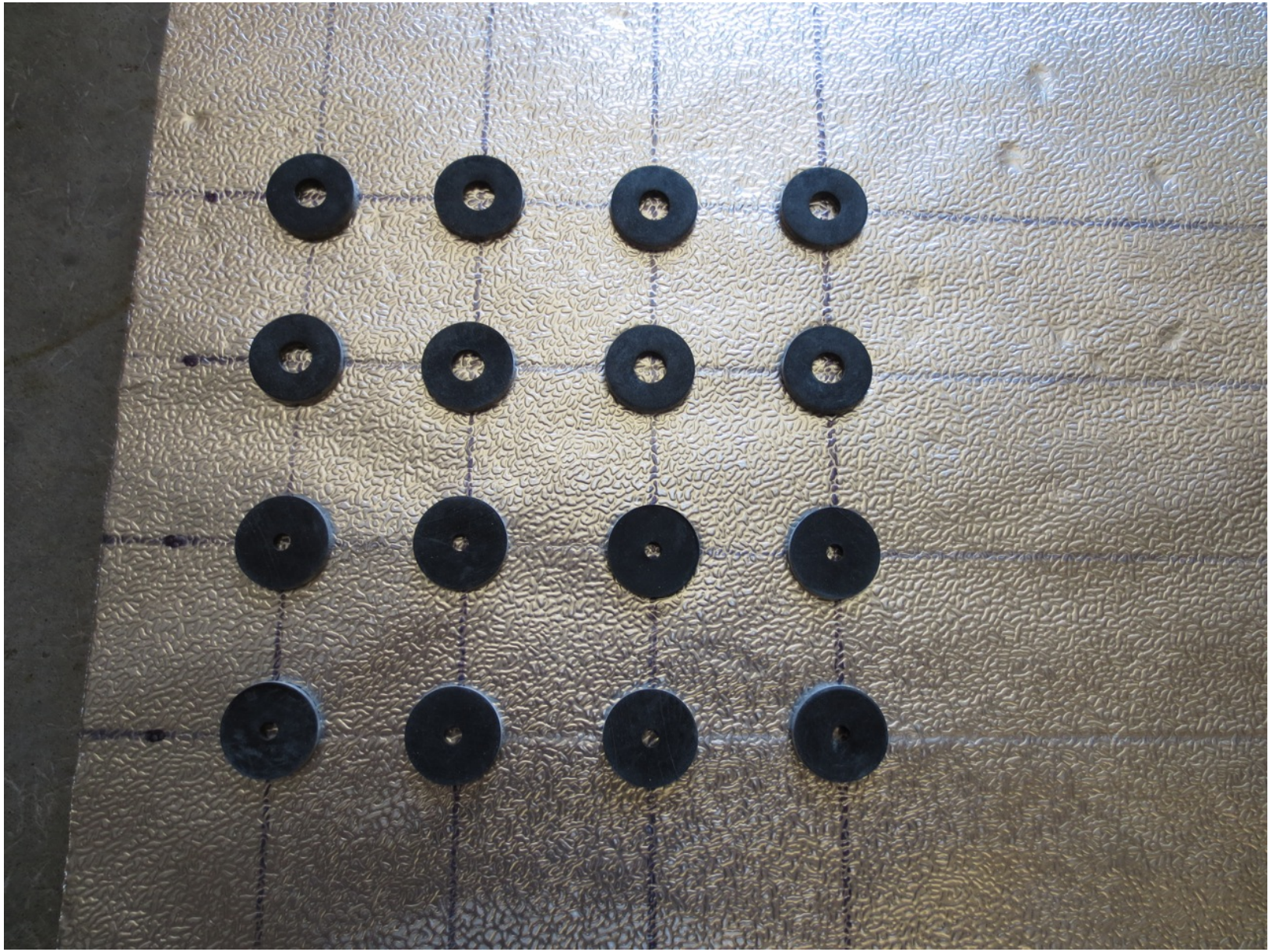

Plywood/OSB sheathing
Water control layer
3/8" spacer strip


Styrofoam

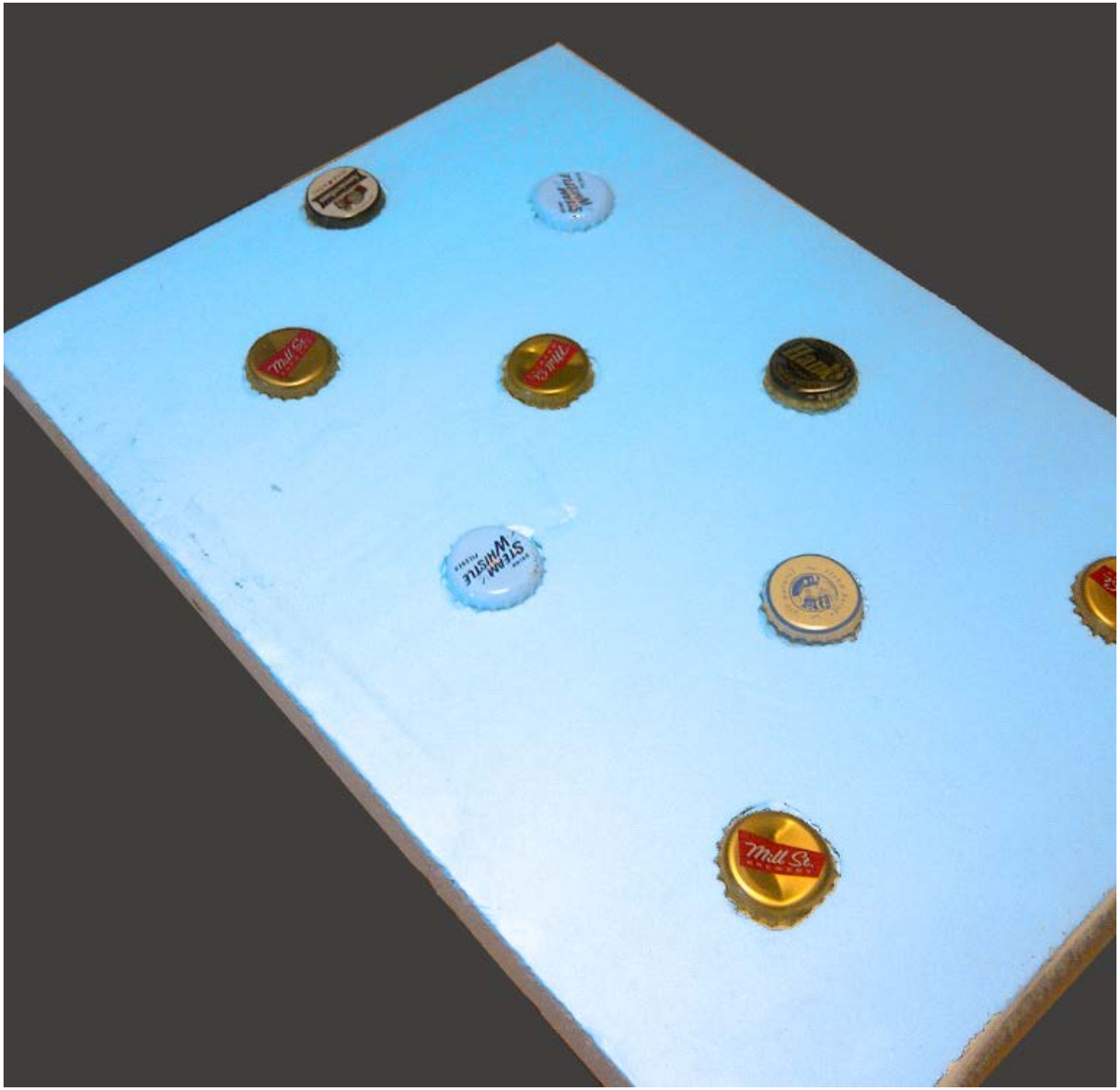

DuPont
Tyvek
Tape
DuPont
Tyvek
Tape

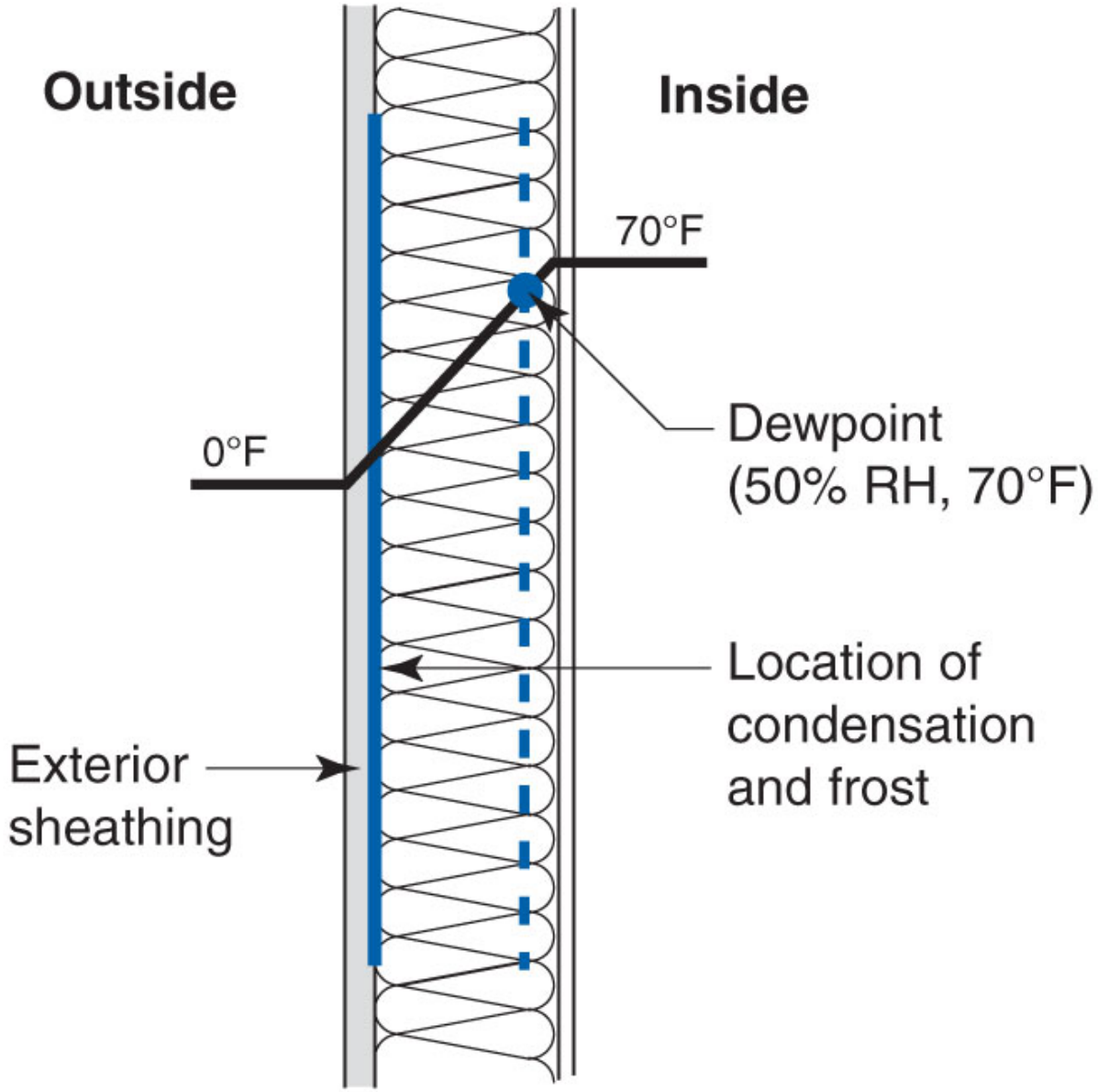


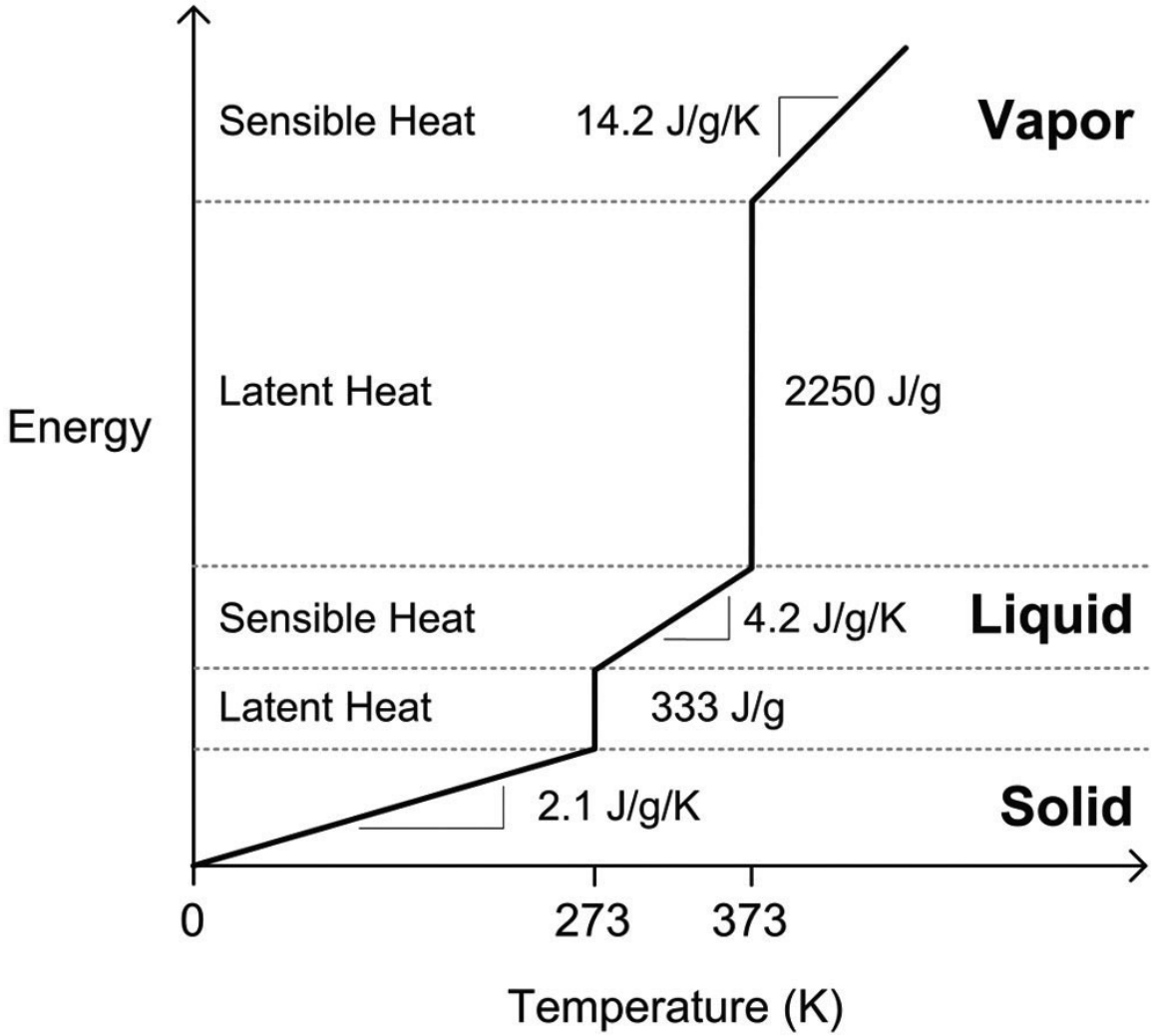
Rain Screen



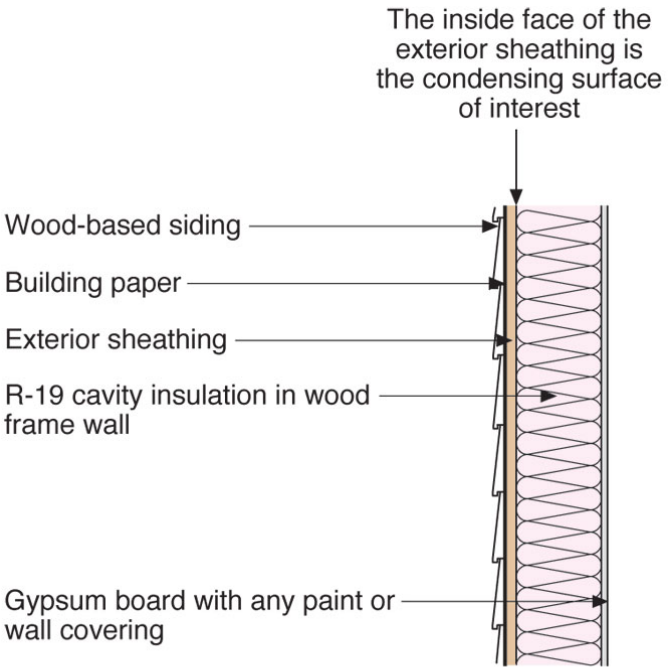
Beer Screen?

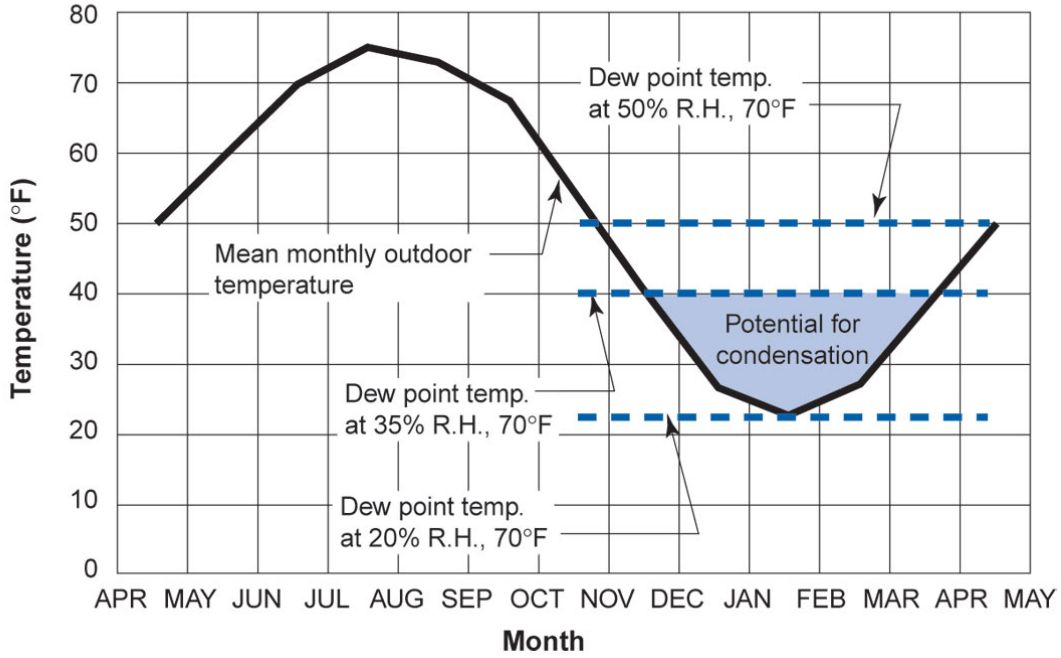

Mill St.
Steam Whistle
Mill St.

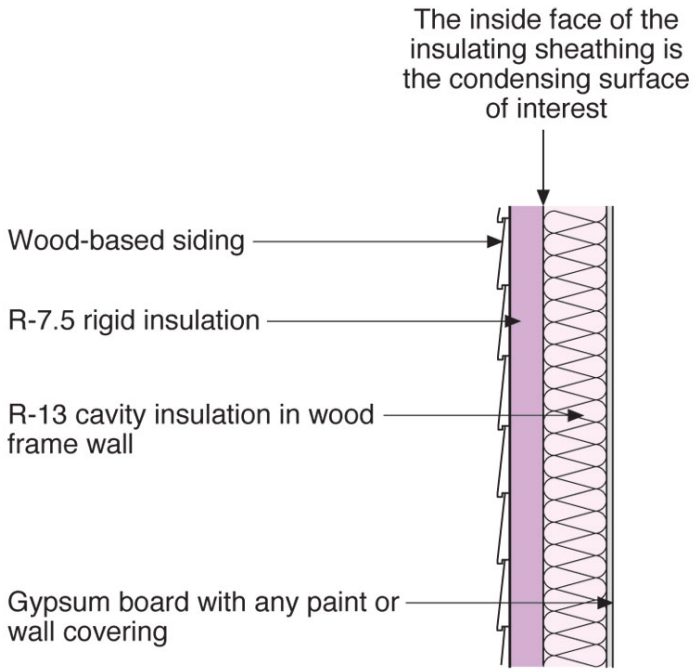

Outside
Inside
70°F
0°F
Dewpoint
(50% RH, 70°F)
Location of
condensation
and frost
Exterior
sheathing

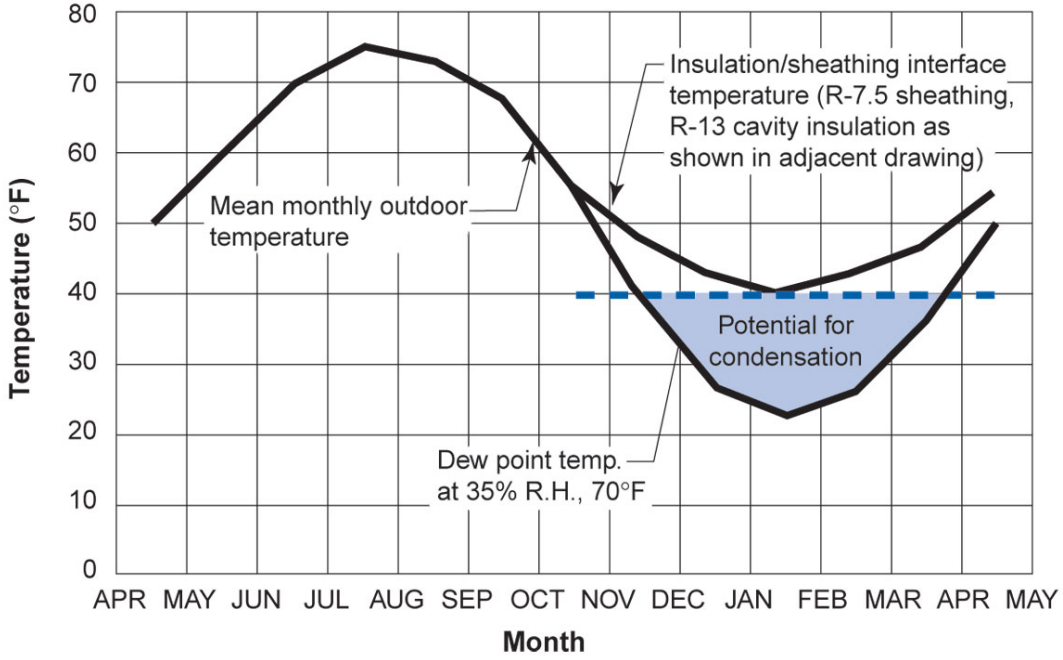


Simple linearized energy-temperature relation for water
From Straube & Burnett, 2005


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
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
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY
Month


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

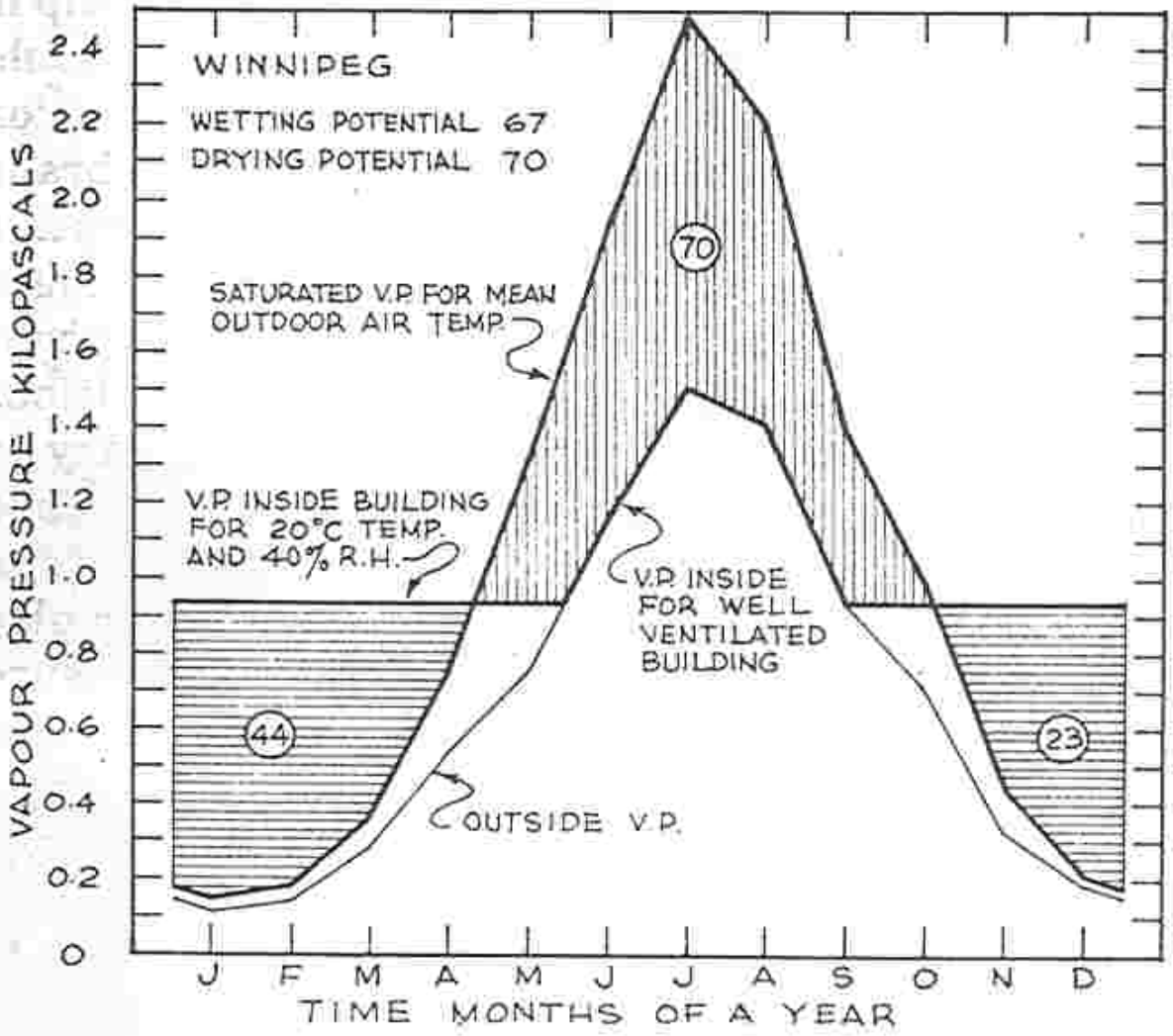
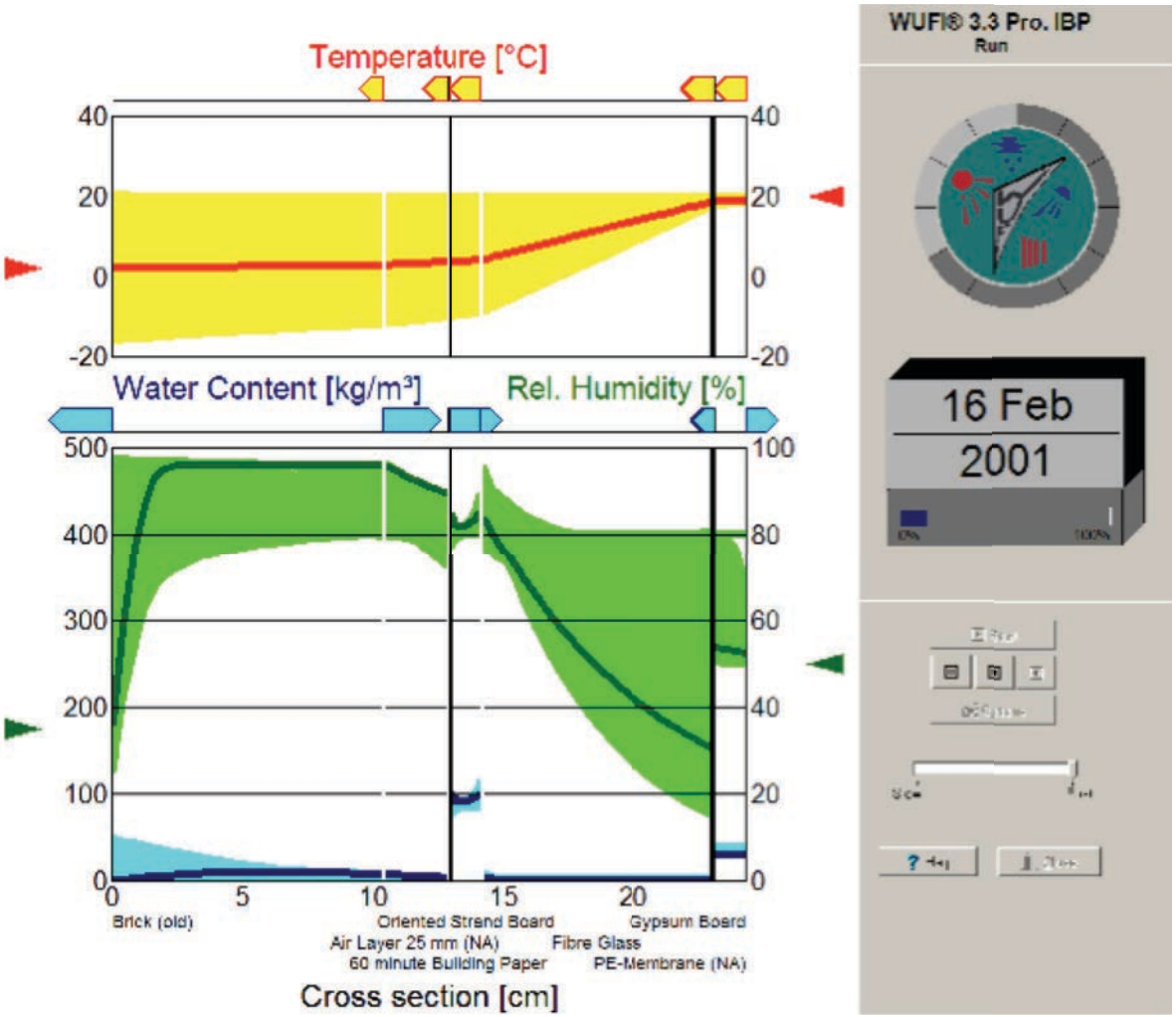
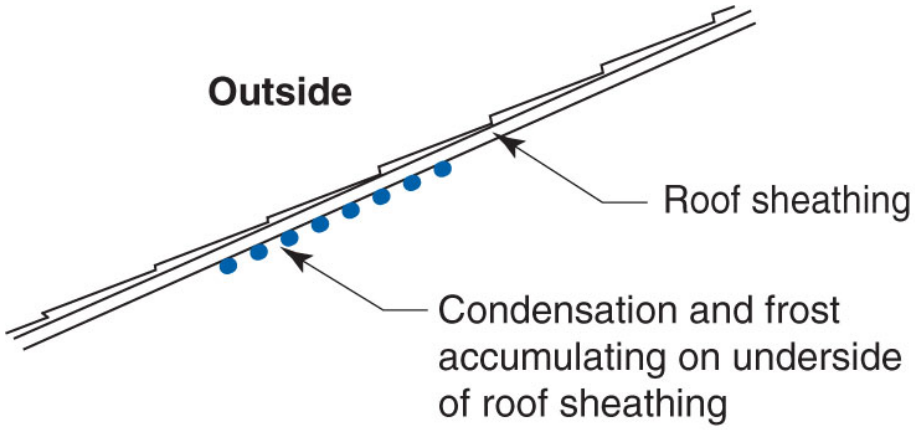
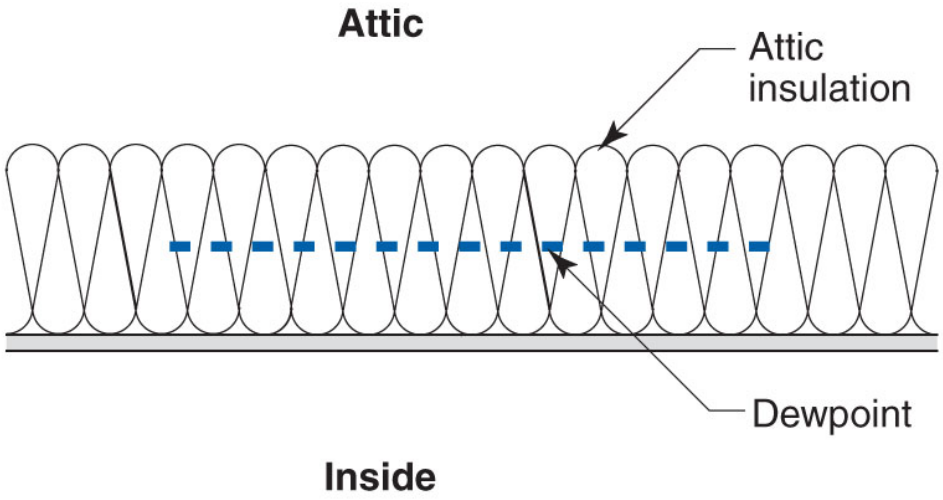
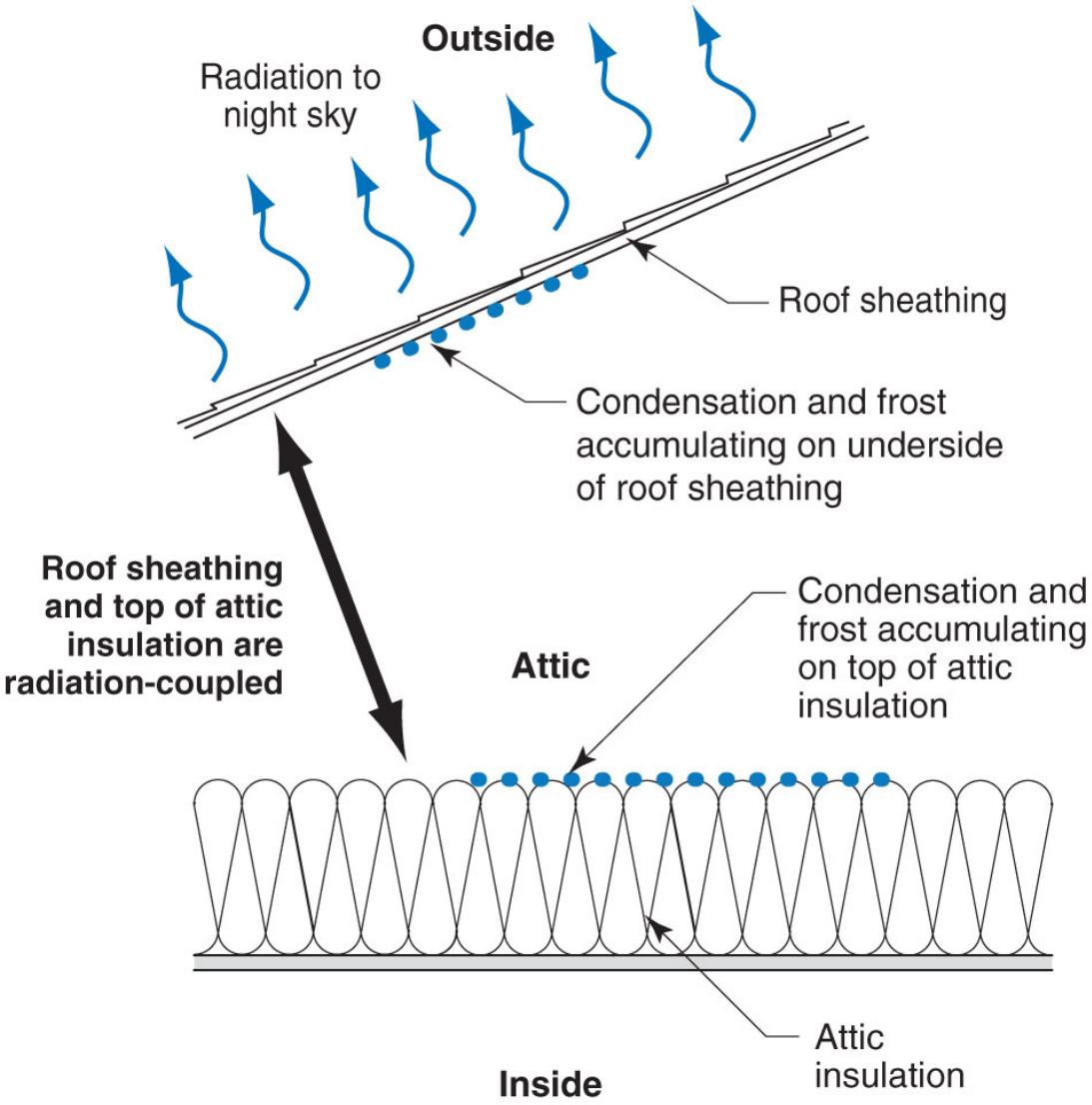


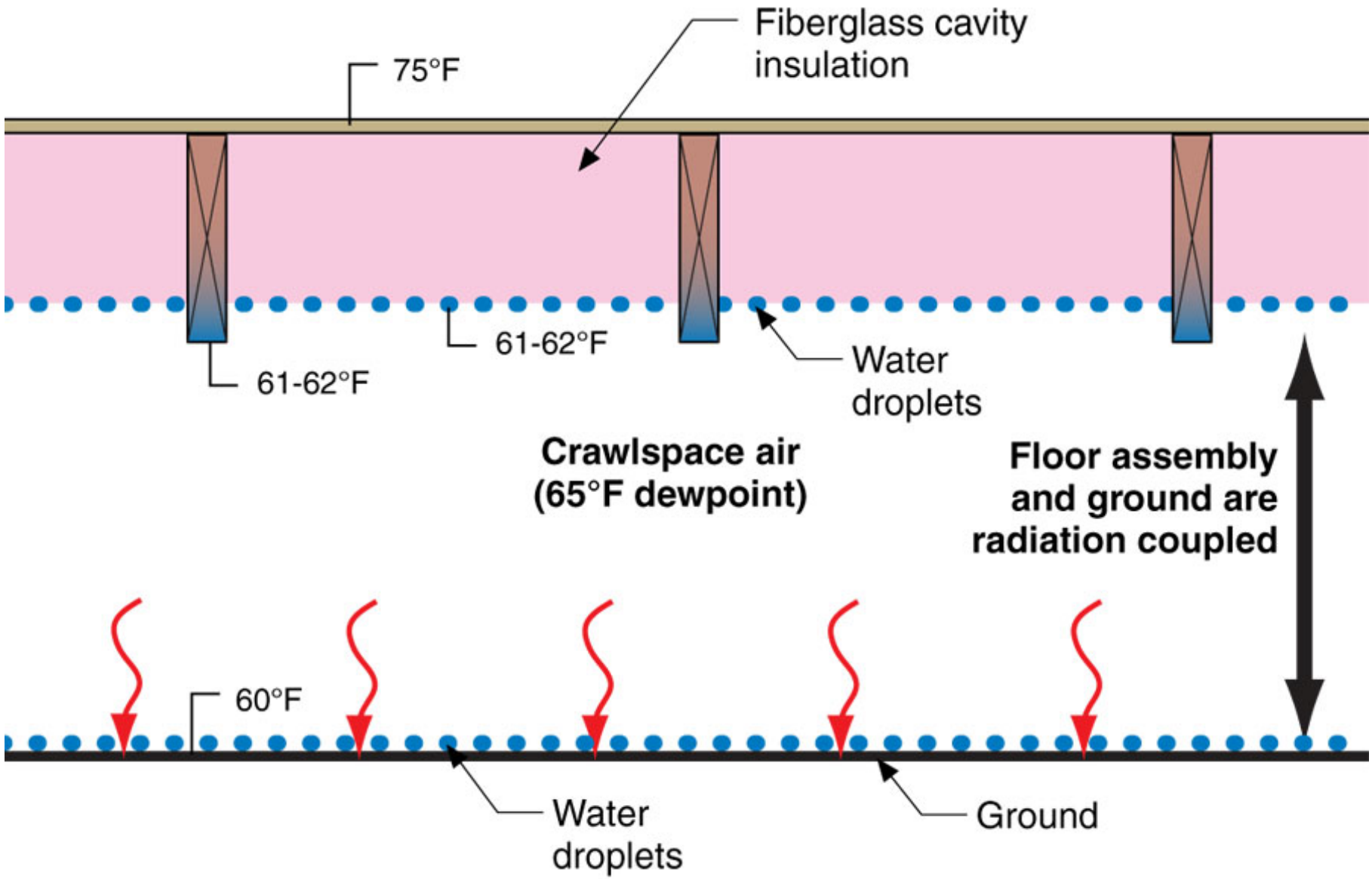
Figure 8-7. Outside vapour pressure, saturated vapour pressure and inside vapour pressure for Winnipeg.

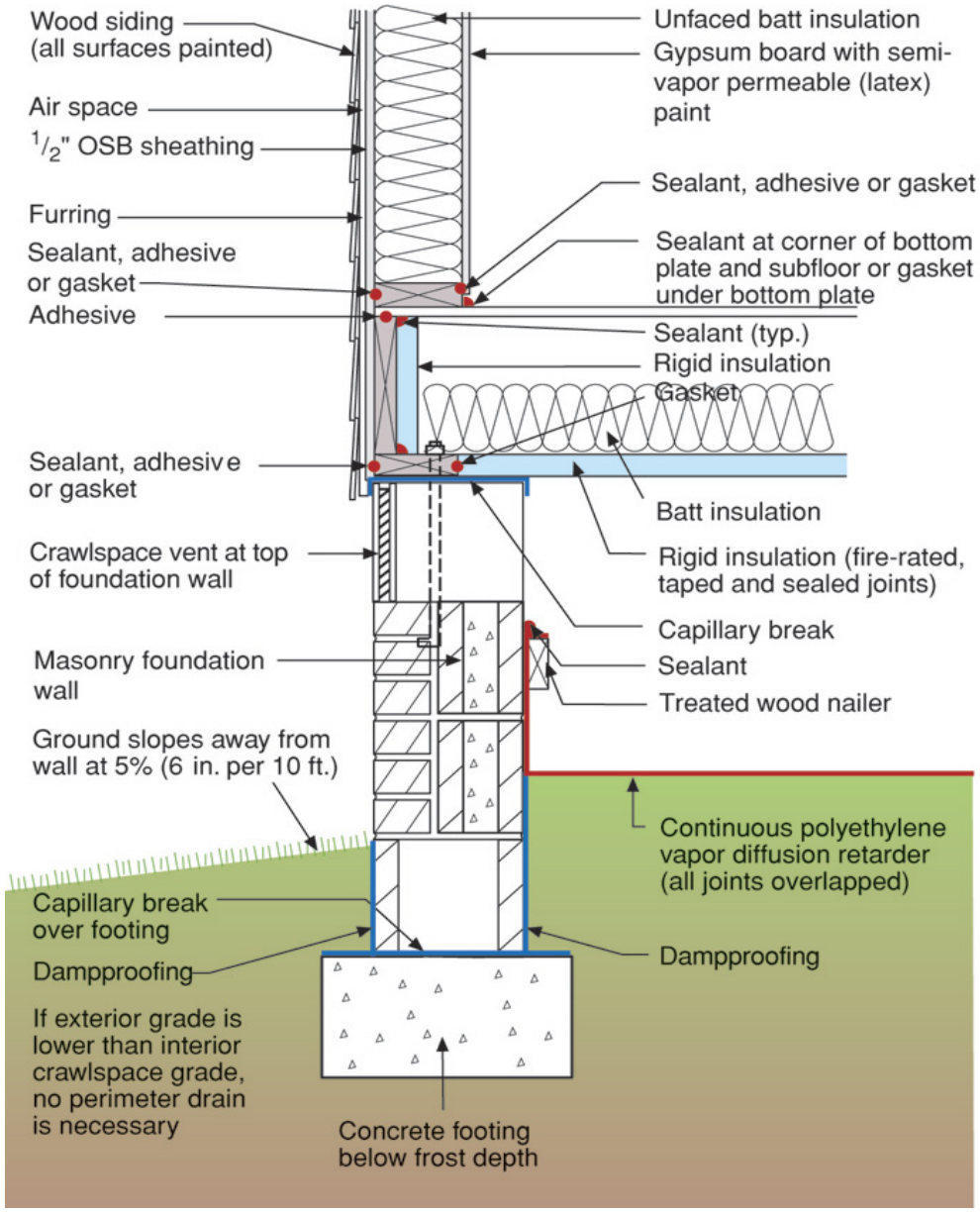

Temperature [°C]
40
20
0
-20
Water Content [kg/m³]
Rel. Humidity [%]
500
400
300
200
100
0
100
80
60
40
20
0
0
5
10
15
20
Brick (old)
Oriented Strand Board
Air Layer 25 mm (NA)
60 minute Building Paper
Fibre Glass
Gypsum Board
PE-Membrane (NA)
Cross section [cm]
WUFI® 3.3 Pro. IBP
Run
16 Feb
2001

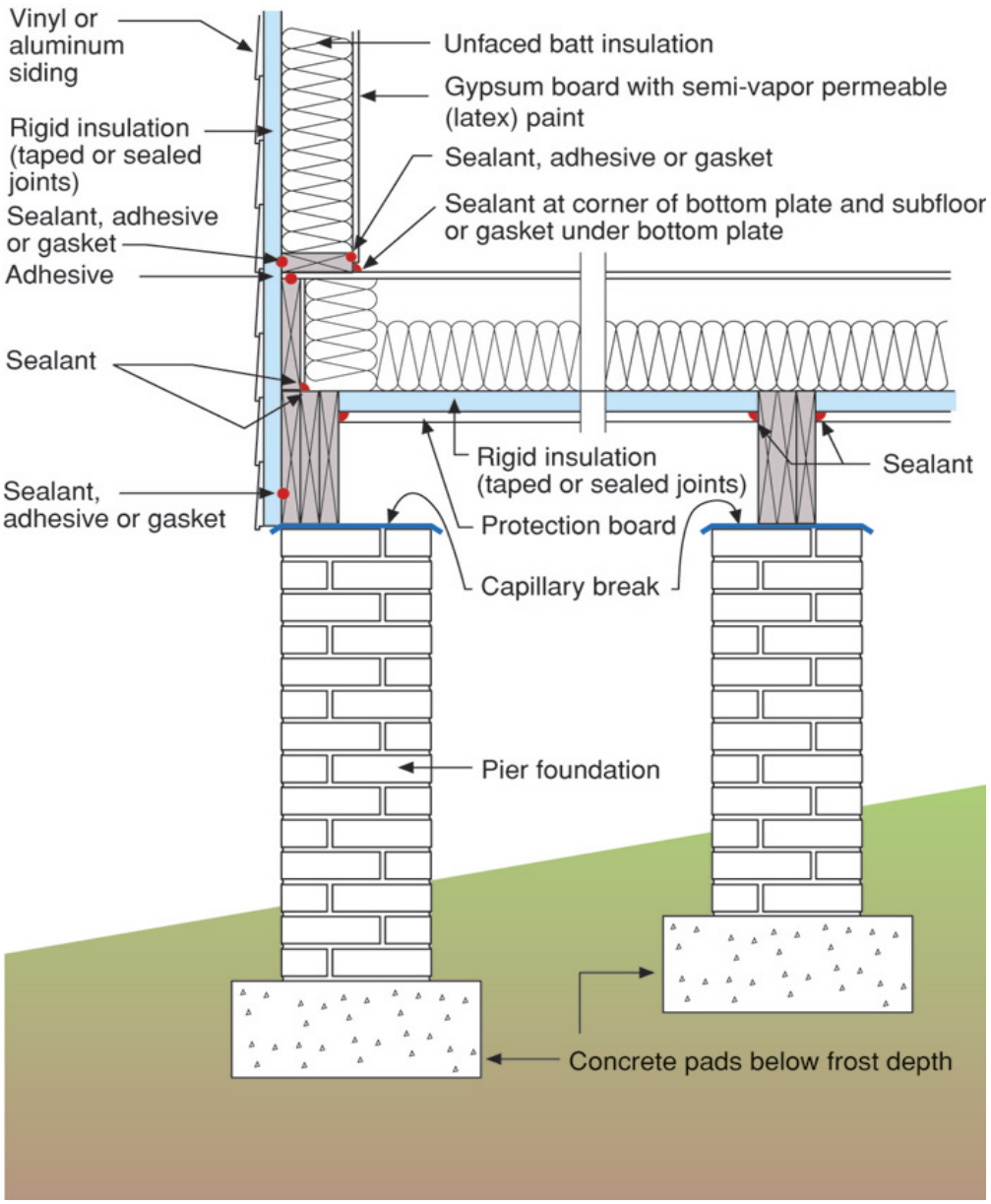

Outside
Roof sheathing
Condensation and frost
accumulating on underside
of roof sheathing

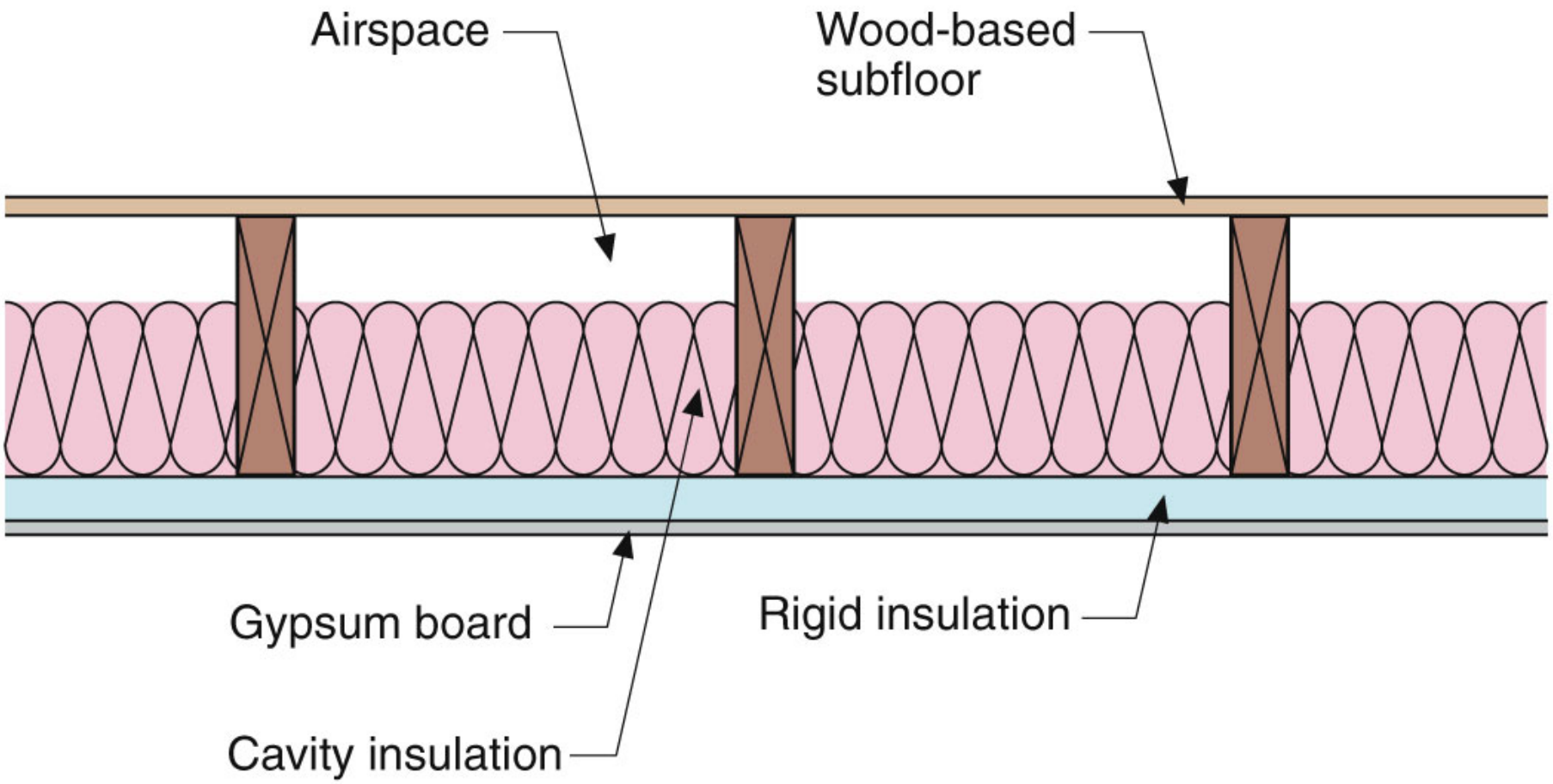

Attic
Attic
insulation
Dewpoint
Inside

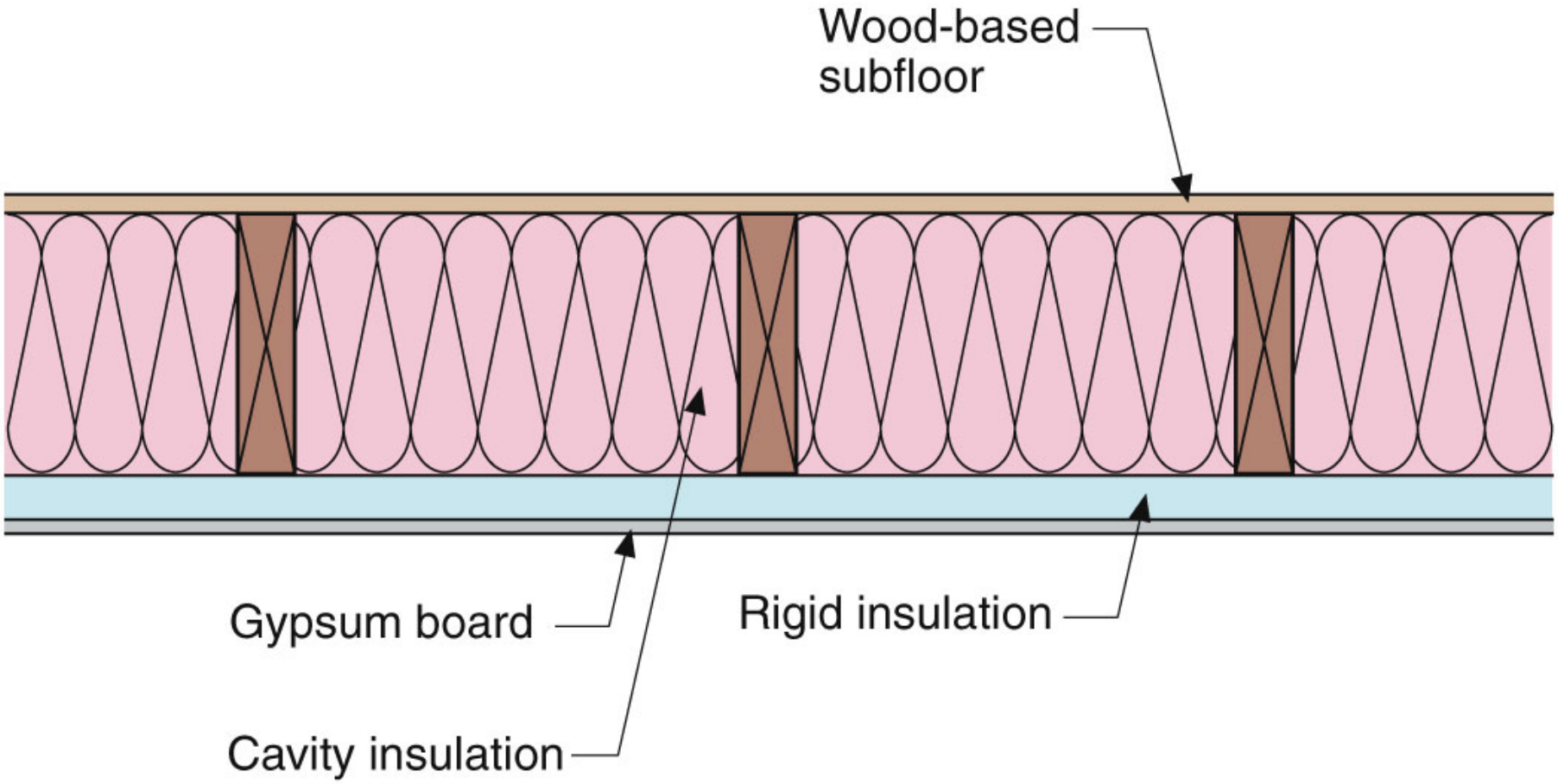

Outside
Radiation to night sky
Roof sheathing
Condensation and frost accumulating on underside of roof sheathing
Roof sheathing and top of attic insulation are radiation-coupled
Attic
Condensation and frost accumulating on top of attic insulation
Attic insulation
Inside

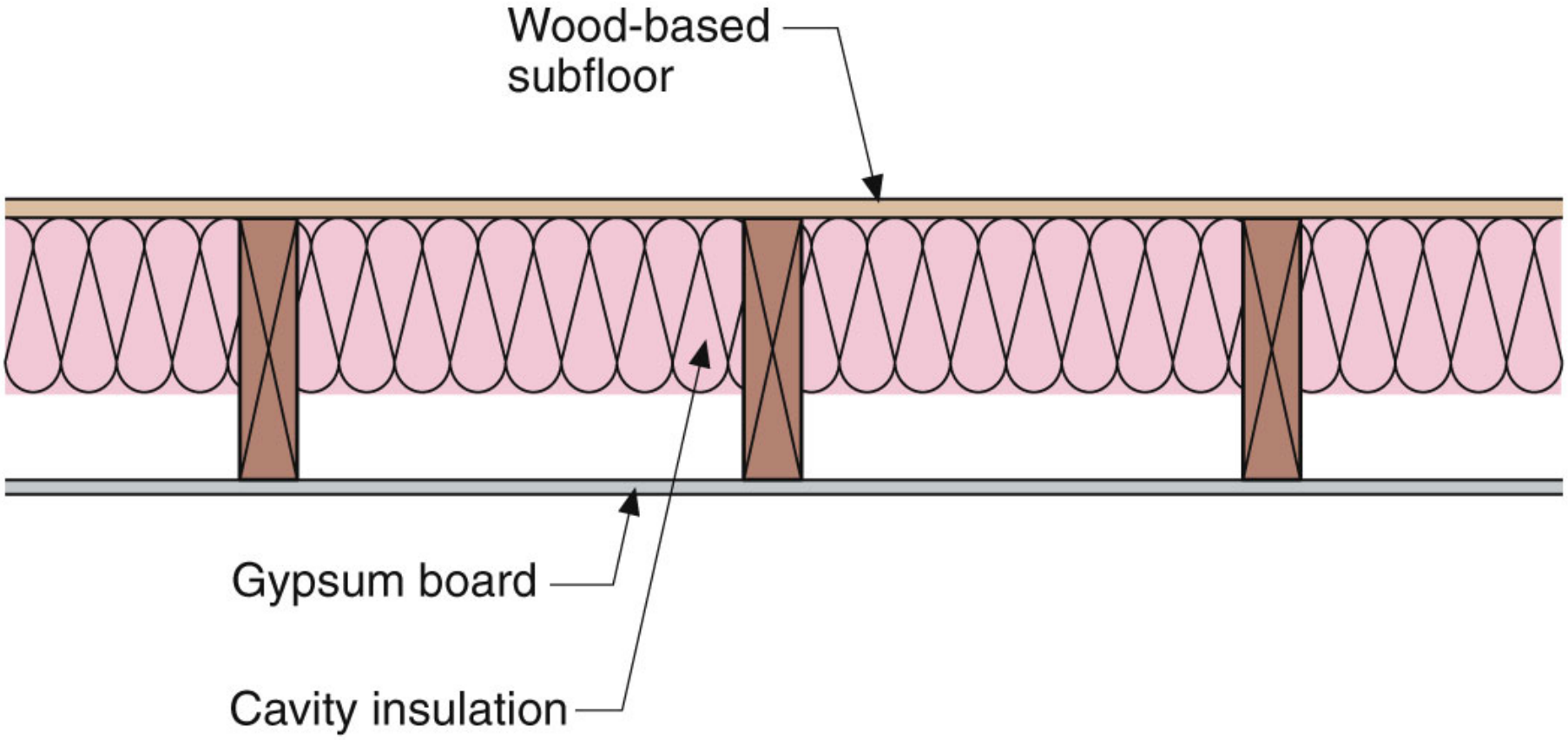

Fiberglass cavity insulation
75°F
61-62°F
61-62°F
Water droplets
Crawlspace air (65°F dewpoint)
Floor assembly and ground are radiation coupled
60°F
Water droplets
Ground

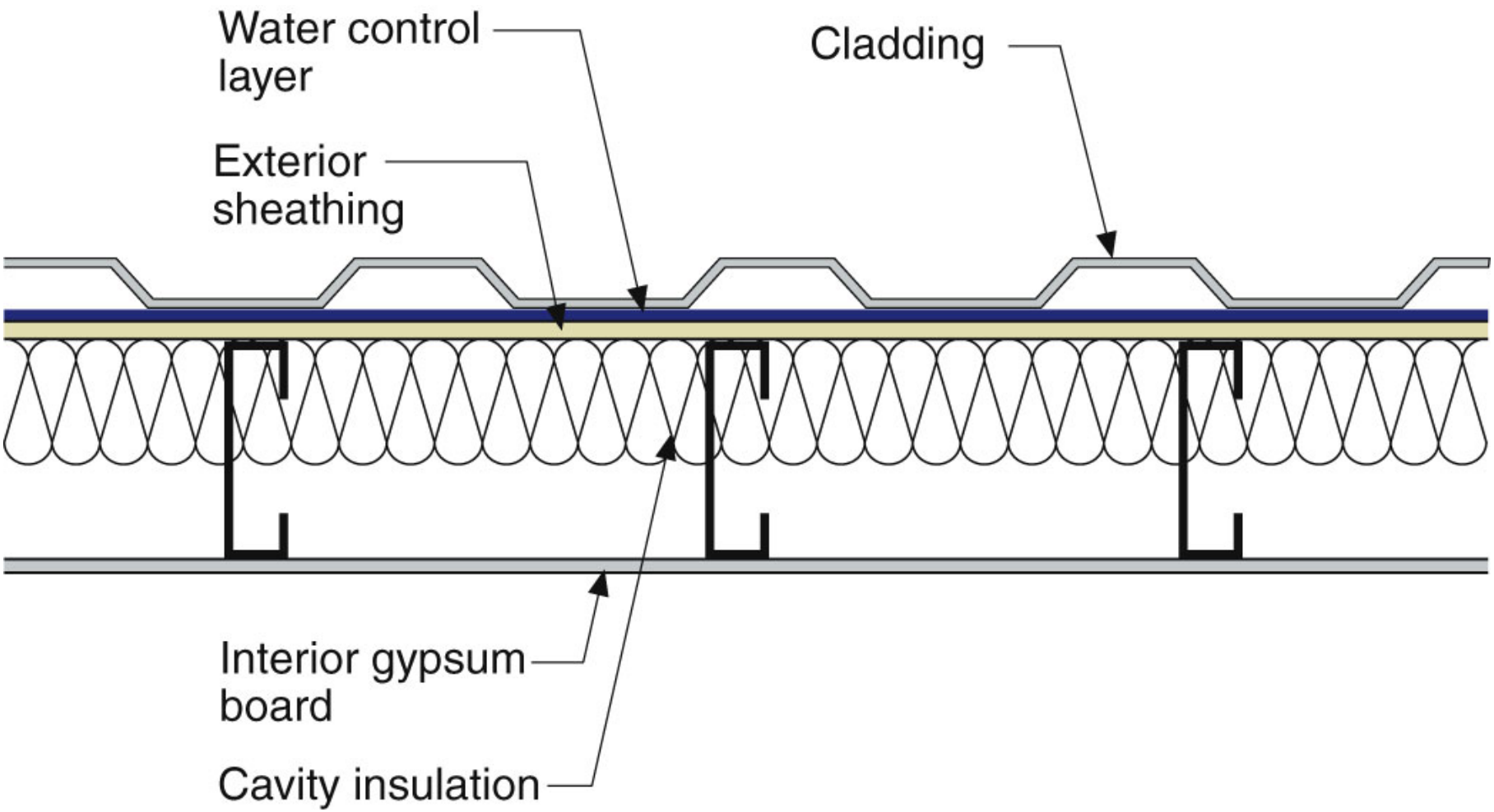

Wood siding
(all surfaces painted)
Air space
1/2" OSB sheathing
Furring
Sealant, adhesive
or gasket
Adhesive
Sealant, adhesive
or gasket
Crawlspace vent at top
of foundation wall
Masonry foundation
wall
Ground slopes away from
wall at 5% (6 in. per 10 ft.)
Capillary break
over footing
Dampproofing
If exterior grade is
lower than interior
crawlspace grade,
no perimeter drain
is necessary
Concrete footing
below frost depth
Unfaced batt insulation
Gypsum board with semi-
vapor permeable (latex)
paint
Sealant, adhesive or gasket
Sealant at corner of bottom
plate and subfloor or gasket
under bottom plate
Sealant (typ.)
Rigid insulation
Gasket
Batt insulation
Rigid insulation (fire-rated,
taped and sealed joints)
Capillary break
Sealant
Treated wood nailer
Continuous polyethylene
vapor diffusion retarder
(all joints overlapped)
Dampproofing

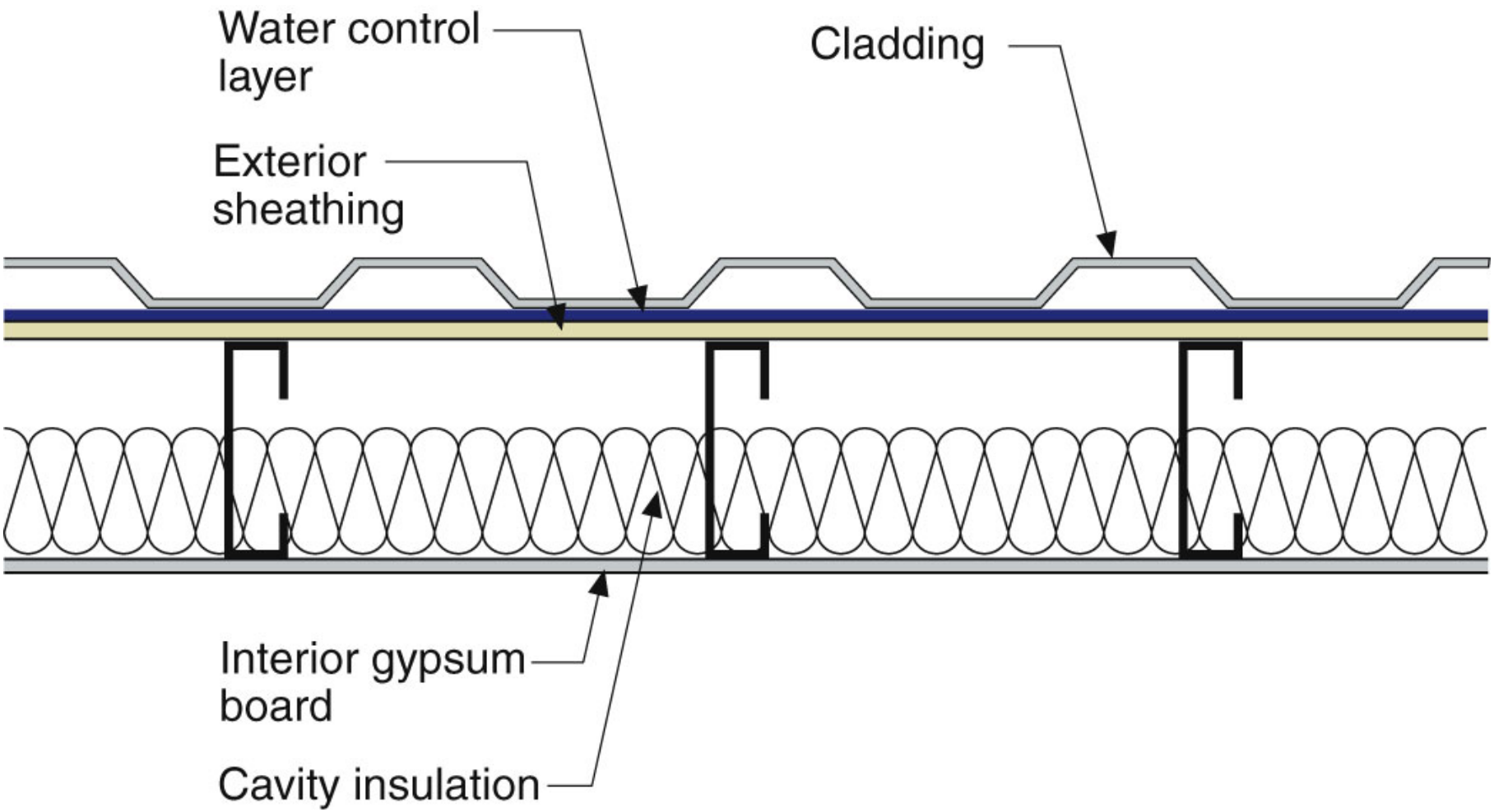

Vinyl or aluminum siding
Rigid insulation (taped or sealed joints)
Sealant, adhesive or gasket
Adhesive
Sealant
Sealant, adhesive or gasket
Unfaced batt insulation
Gypsum board with semi-vapor permeable (latex) paint
Sealant, adhesive or gasket
Sealant at corner of bottom plate and subfloor or gasket under bottom plate
Rigid insulation (taped or sealed joints)
Protection board
Capillary break
Sealant
Pier foundation
Concrete pads below frost depth

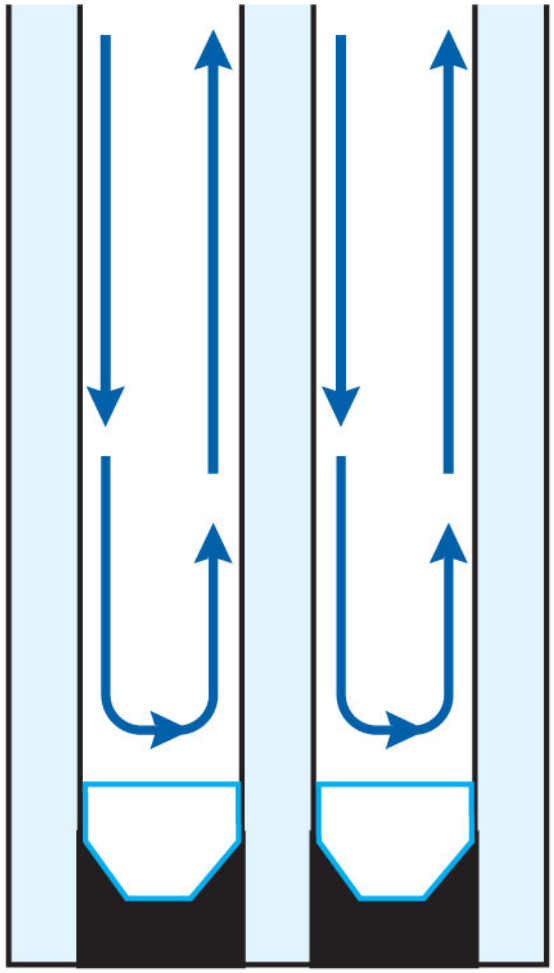

Airspace
Wood-based subfloor
Gypsum board
Rigid insulation
Cavity insulation


Wood-based
subfloor
Gypsum board
Rigid insulation
Cavity insulation

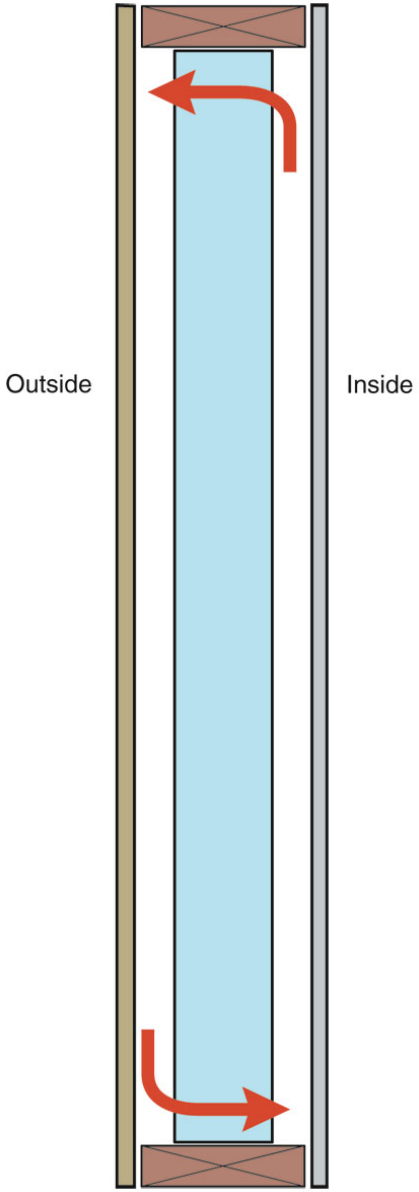

Wood-based
subfloor
Gypsum board
Cavity insulation

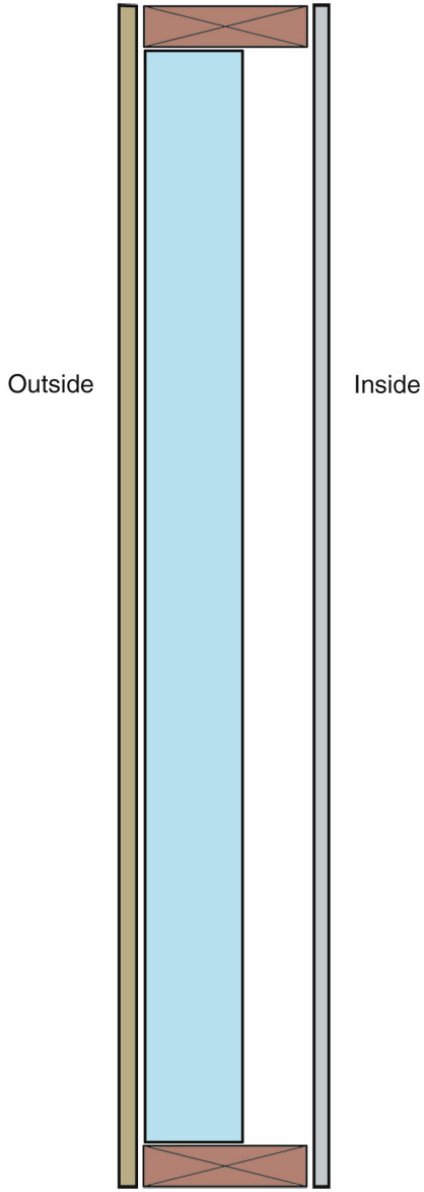

Water control layer
Cladding
Exterior sheathing
Interior gypsum board
Cavity insulation

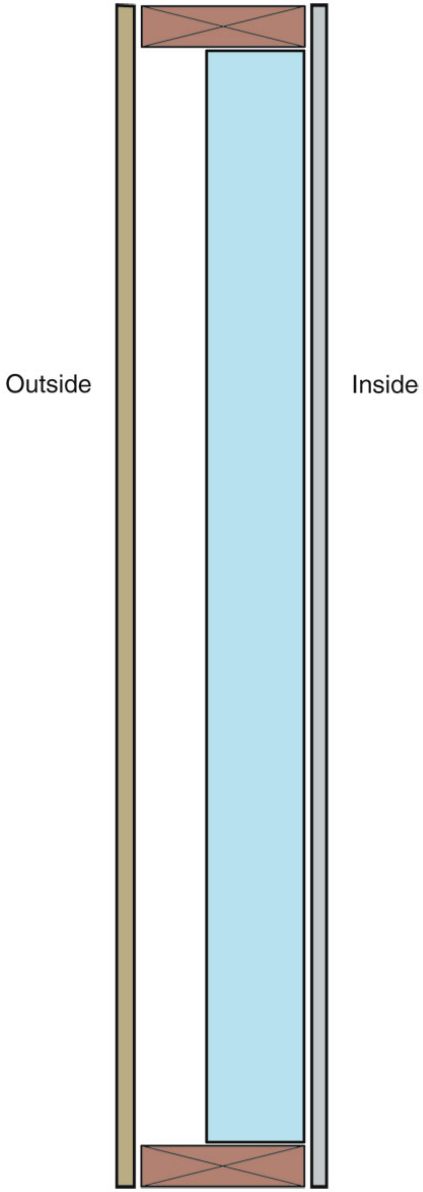

Water control layer
Cladding
Exterior sheathing
Interior gypsum board
Cavity insulation

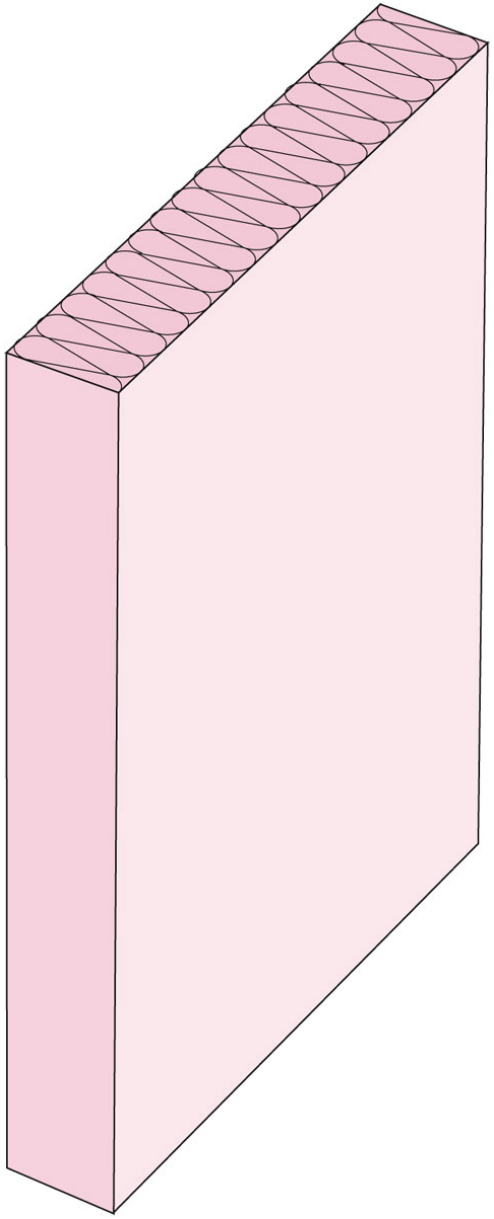


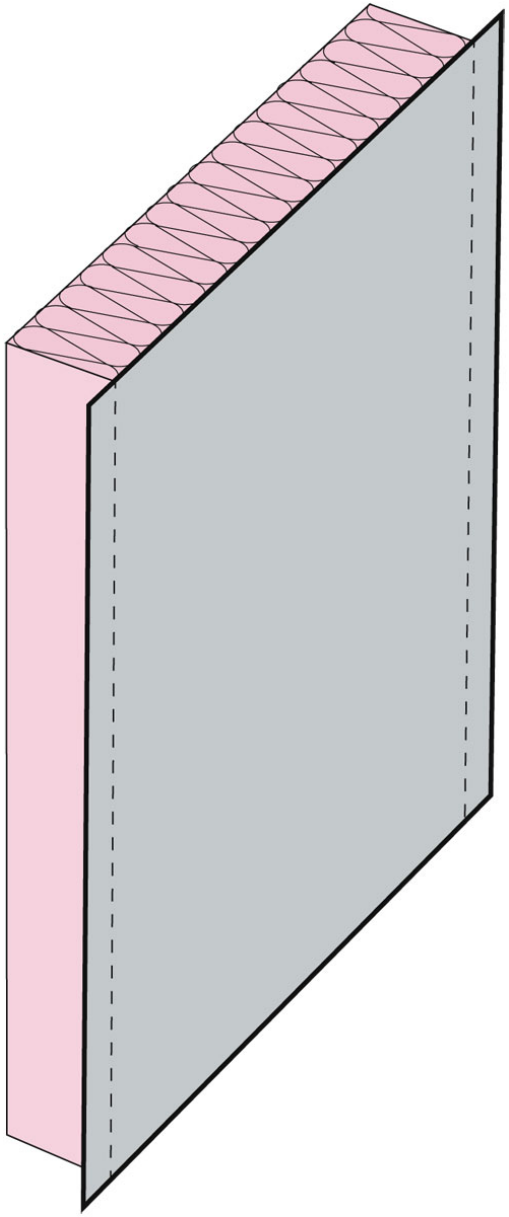
Insulated
glazing unit

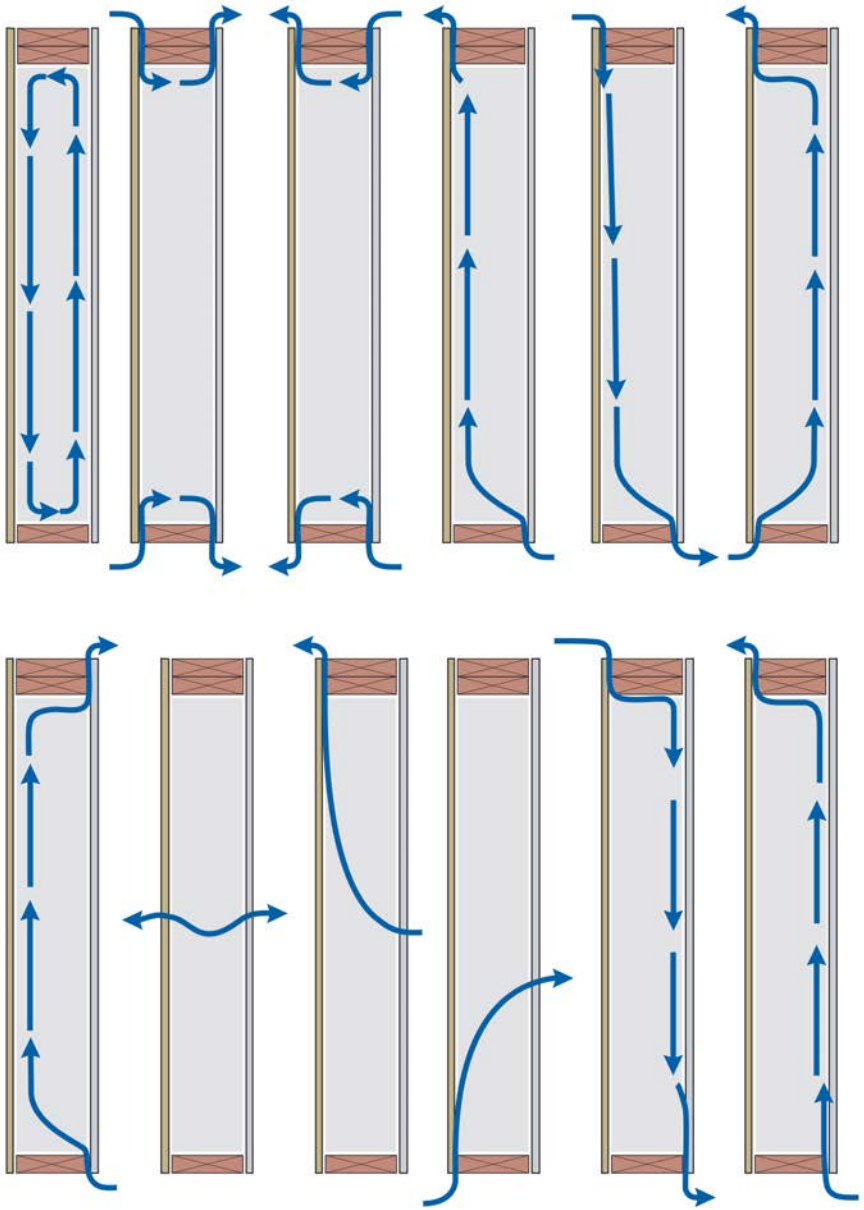

Outside
Inside

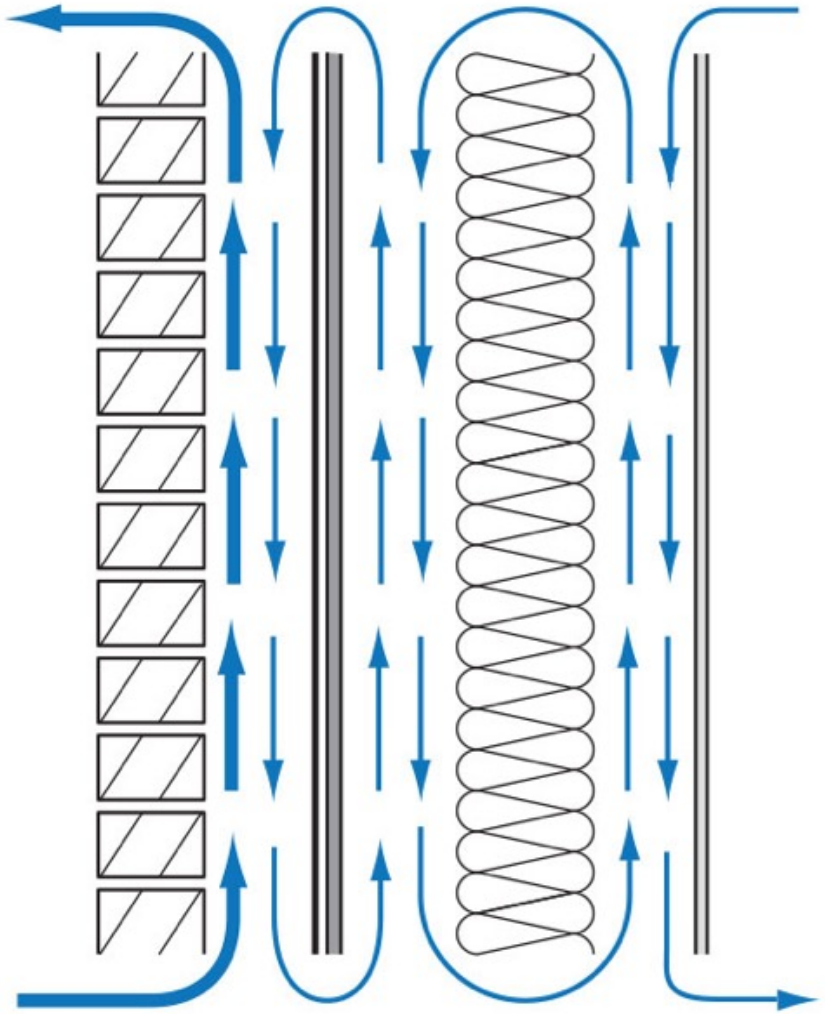

Outside
Inside

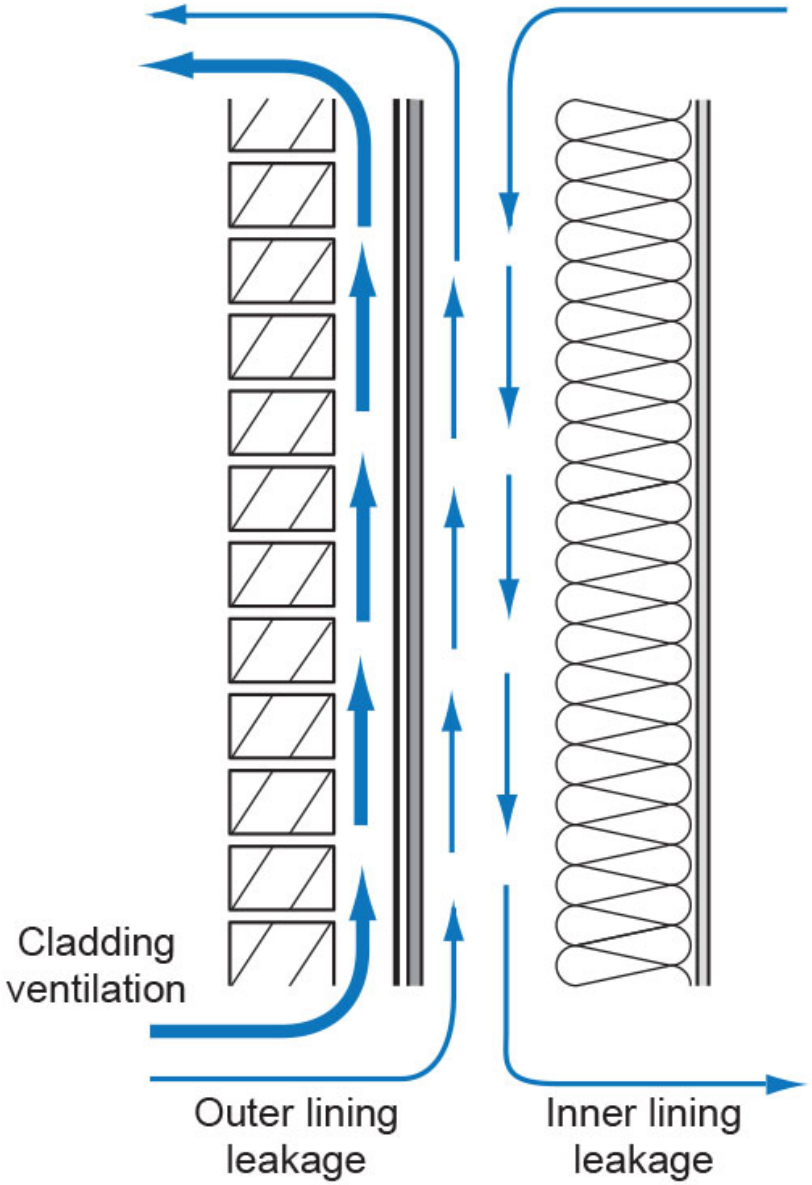

Outside
Inside

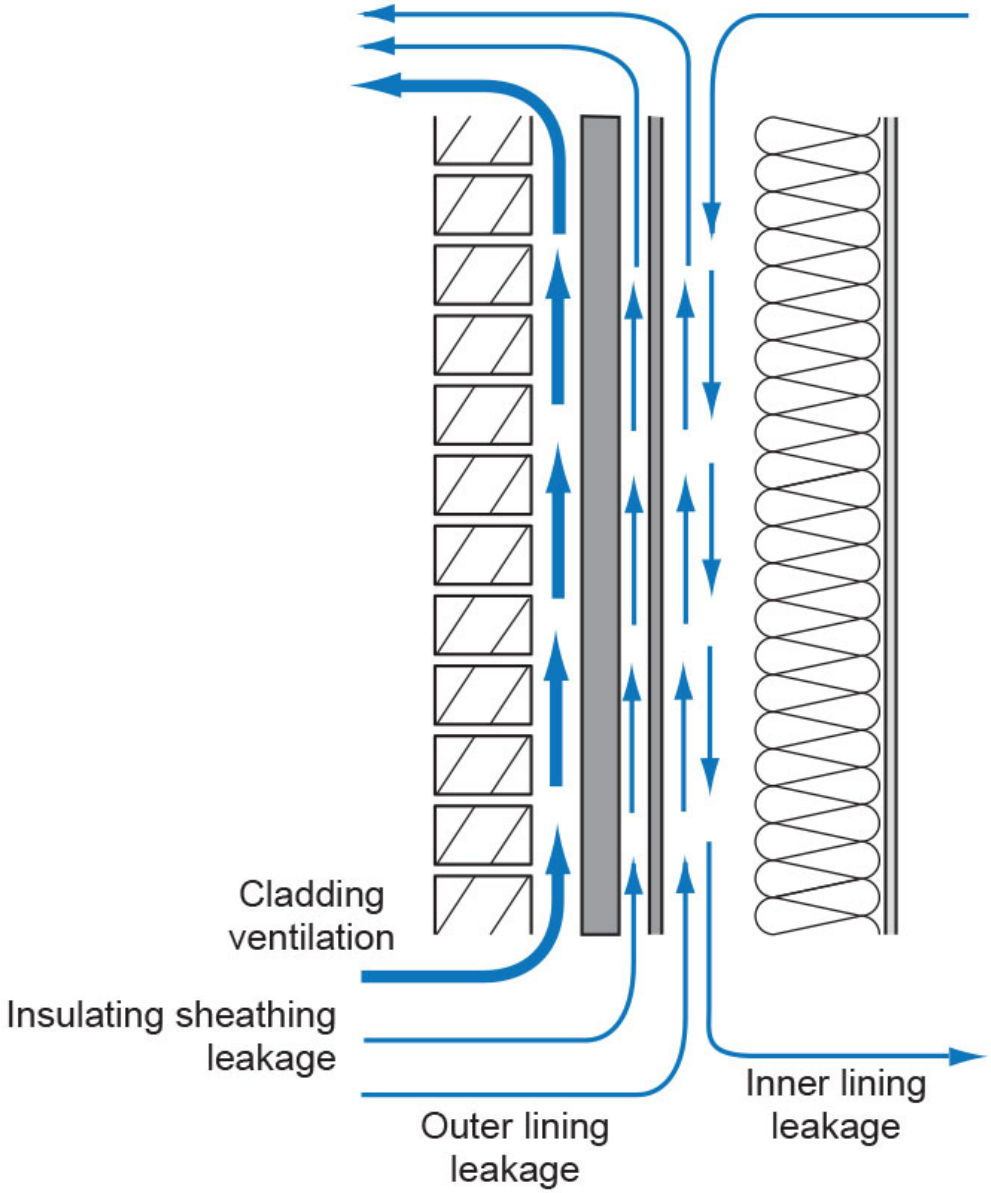






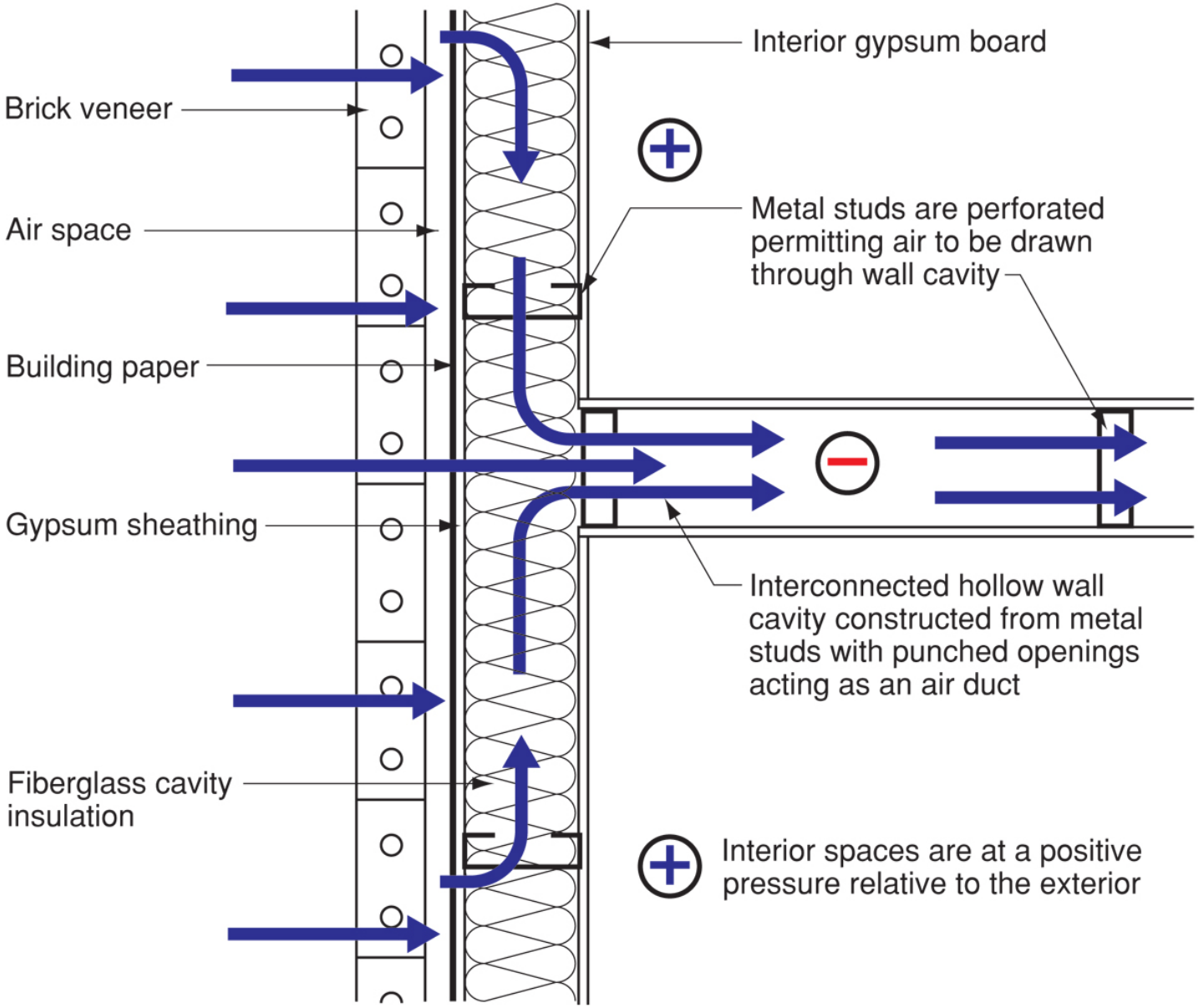


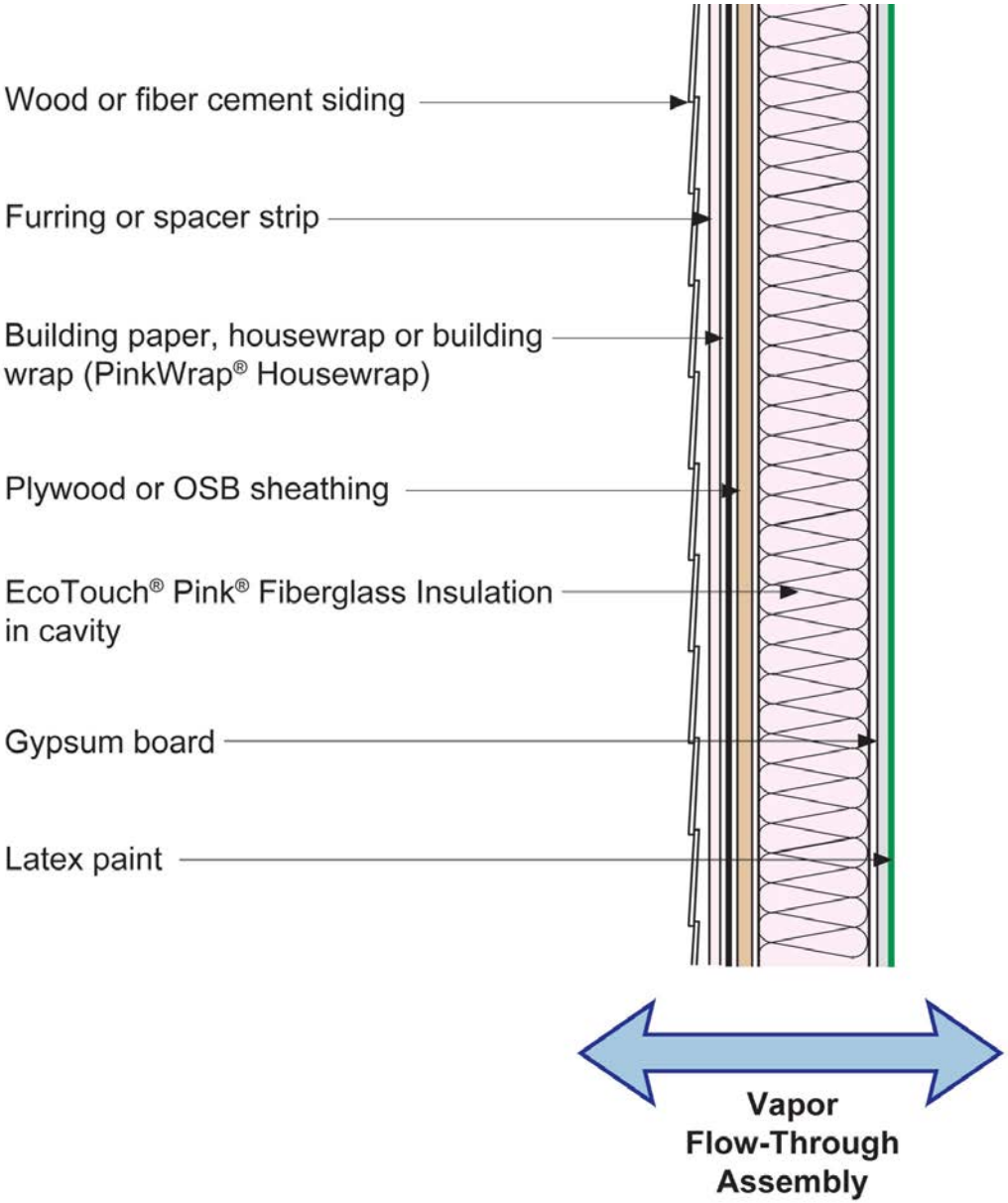

Cladding
ventilation
Outer lining
leakage
Inner lining
leakage

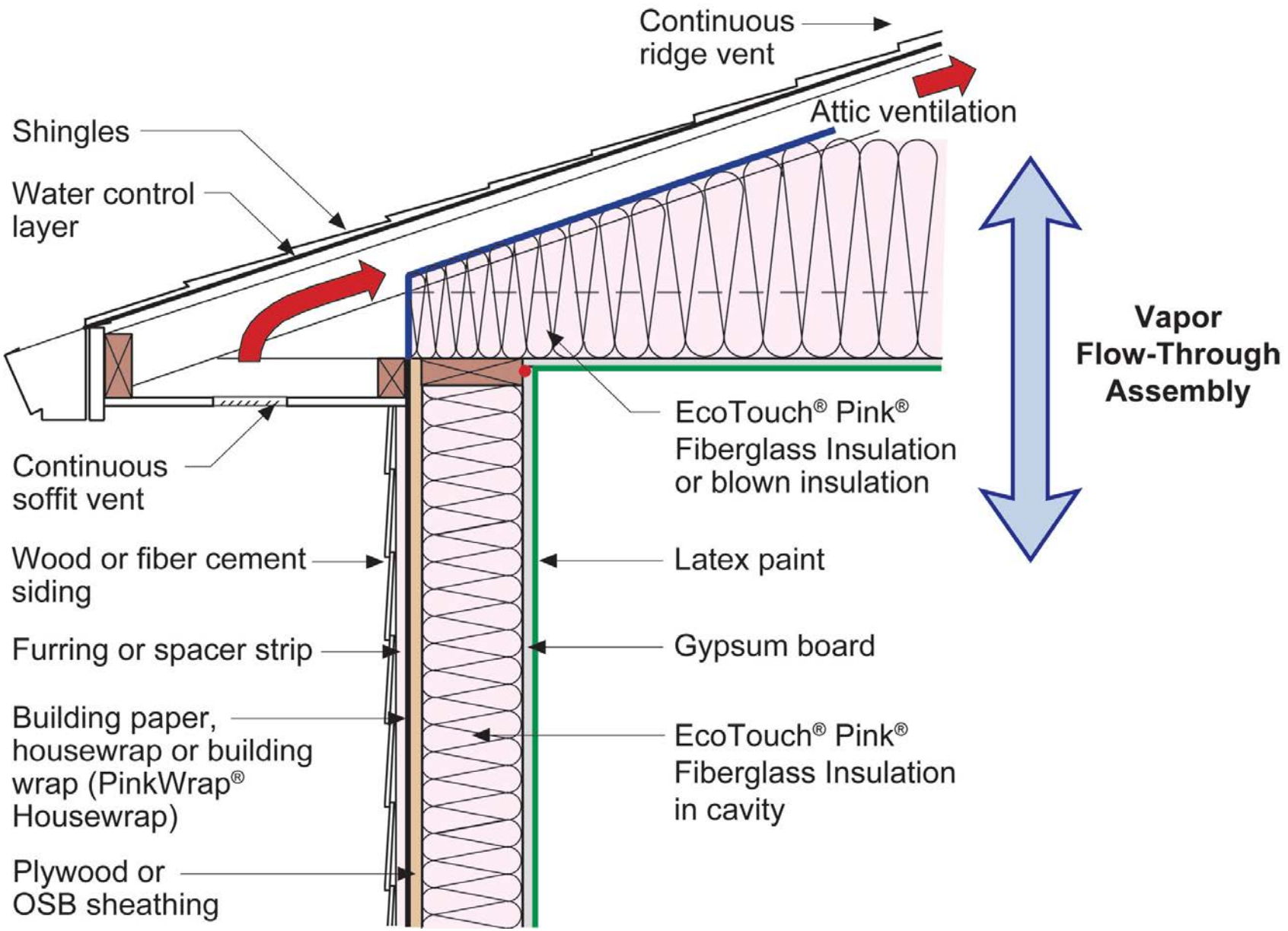

Cladding
ventilation
Insulating sheathing
leakage
Outer lining
leakage
Inner lining
leakage

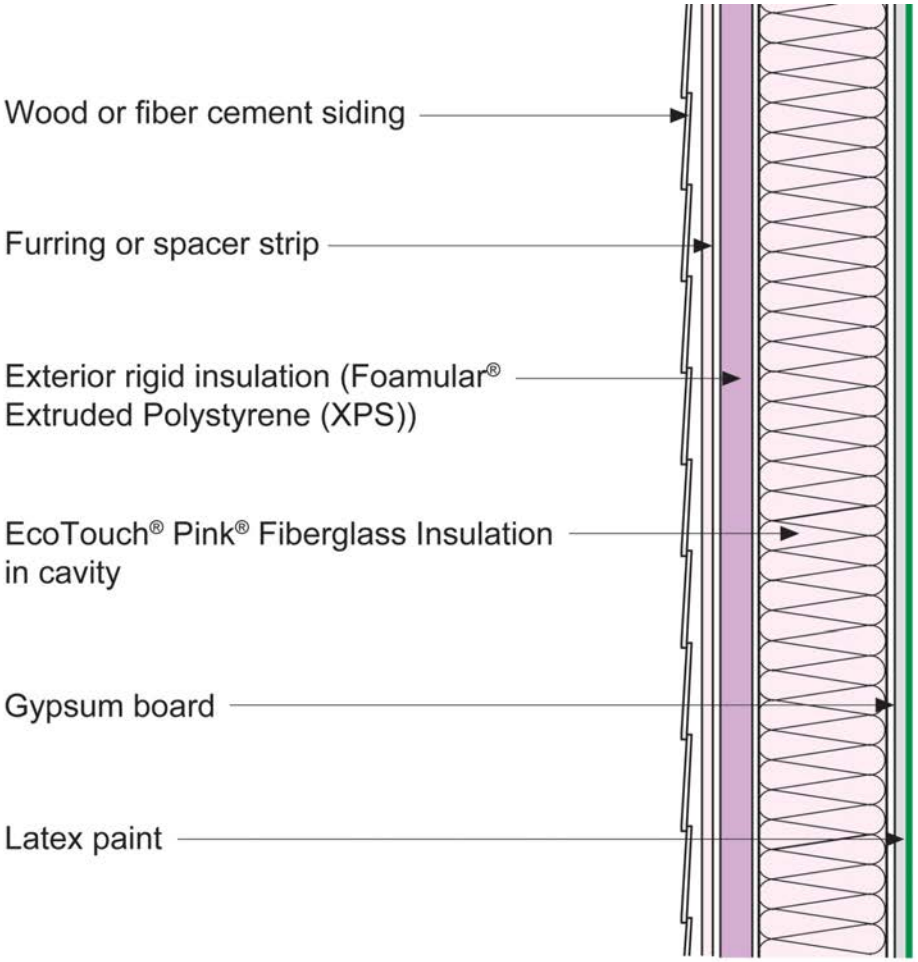
Cladding Ventilation/ Sheathing Ventilation

	Flow Rate	Gap	ACH
Wood Siding	0.1 cfm/sf	3/16"	20
Vinyl Siding	0.5 cfm/sf	3/16"	200
Brick Veneer	0.15 cfm/sf	1"	10
Stucco (vented)	0.1 cfm/sf	3/8"	10
Stucco (direct applied)	none	none	0
Sheathing flanking flow	0.05 cfm/sf	3/16"	10

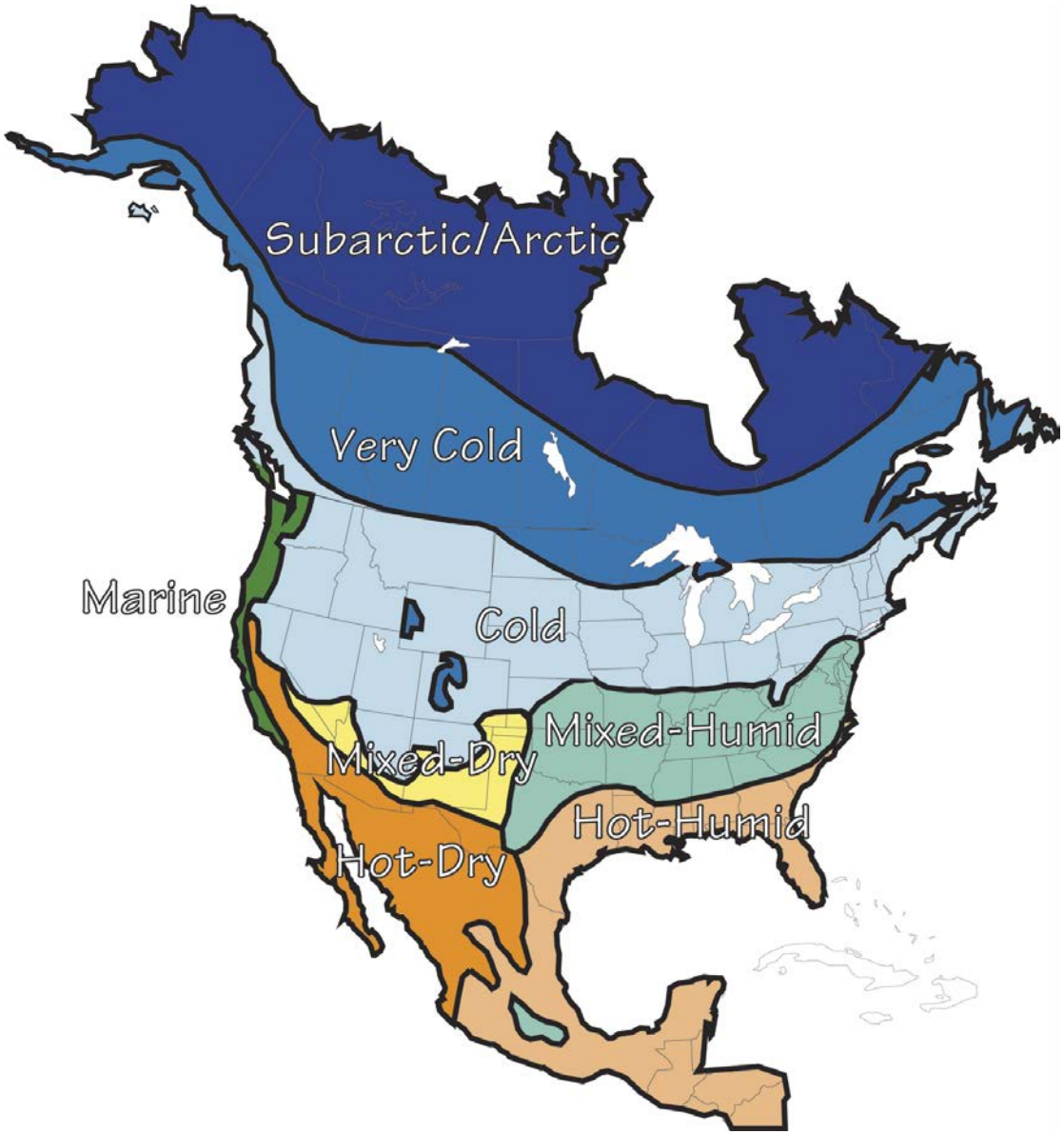

Brick veneer
Air space
Building paper
Gypsum sheathing
Fiberglass cavity insulation
Interior gypsum board
Metal studs are perforated permitting air to be drawn through wall cavity
Interconnected hollow wall cavity constructed from metal studs with punched openings acting as an air duct
Interior spaces are at a positive pressure relative to the exterior

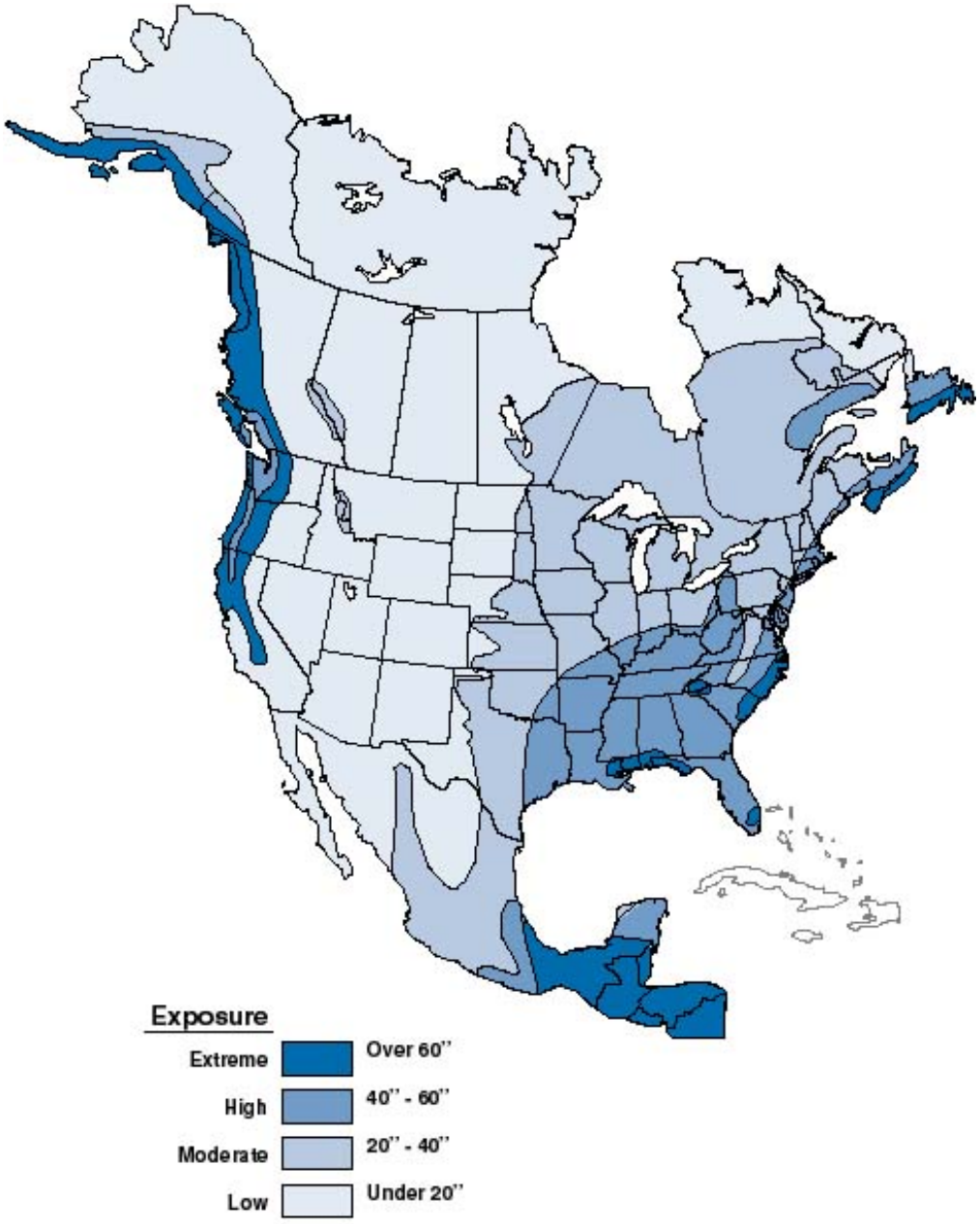

Wood or fiber cement siding
Furring or spacer strip
Building paper, housewrap or building wrap (PinkWrap® Housewrap)
Plywood or OSB sheathing
EcoTouch® Pink® Fiberglass Insulation in cavity
Gypsum board
Latex paint
Vapor Flow-Through Assembly

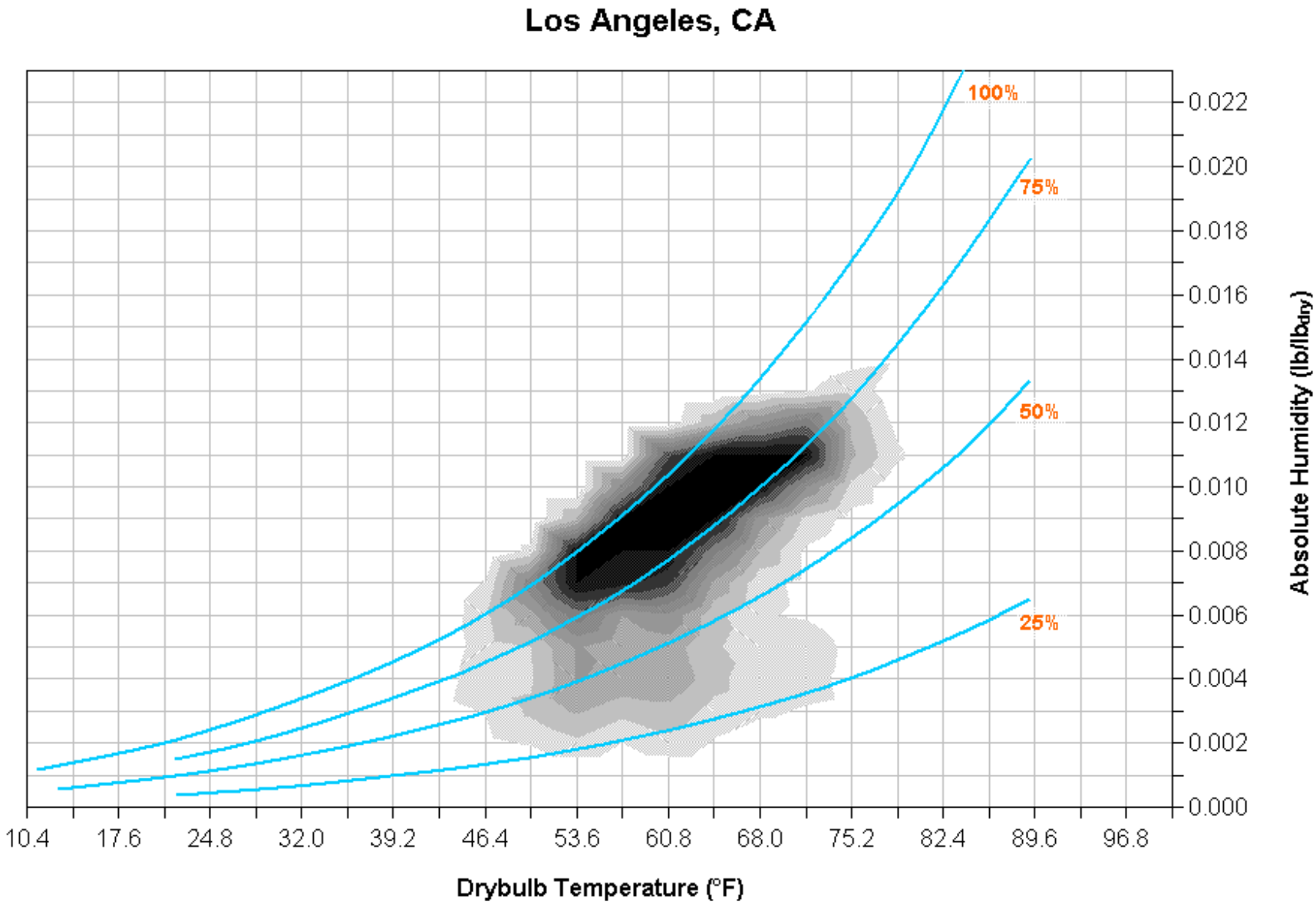

Continuous ridge vent
Attic ventilation
Shingles
Water control layer
Vapor Flow-Through Assembly
EcoTouch® Pink® Fiberglass Insulation or blown insulation
Continuous soffit vent
Wood or fiber cement siding
Latex paint
Furring or spacer strip
Gypsum board
Building paper, housewrap or building wrap (PinkWrap® Housewrap)
EcoTouch® Pink® Fiberglass Insulation in cavity
Plywood or OSB sheathing

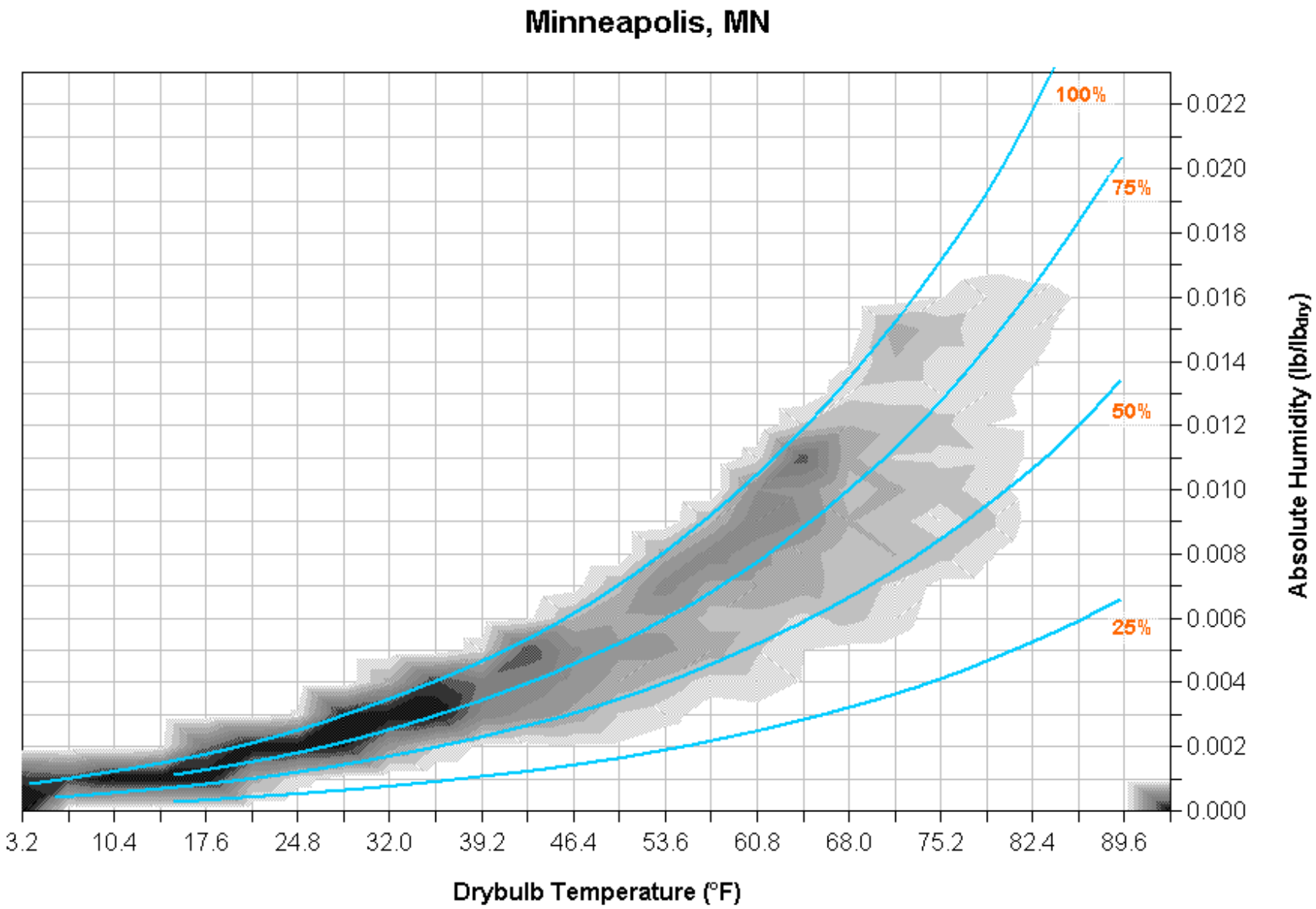


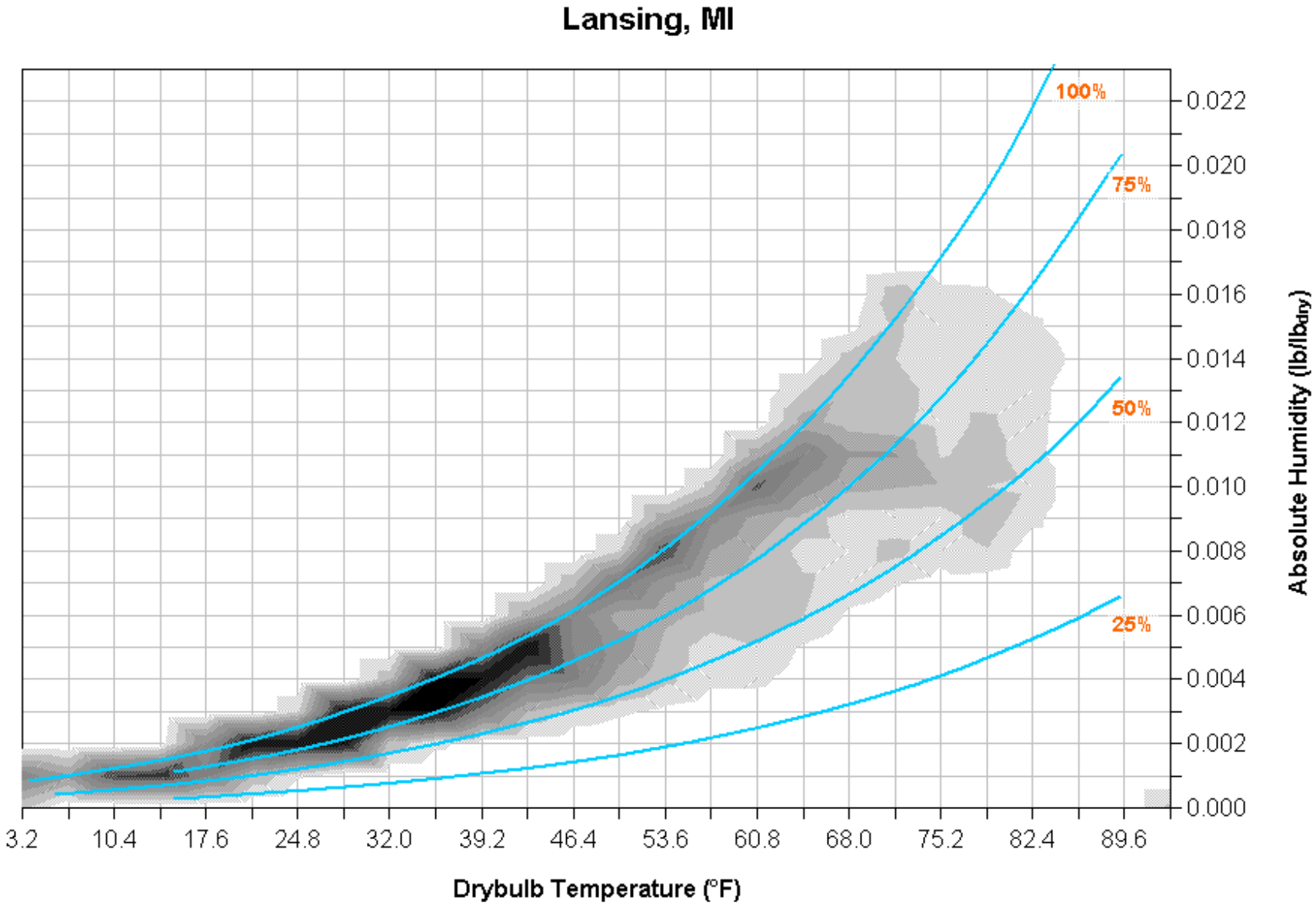
Control of Condensing Surface Temperature Assembly

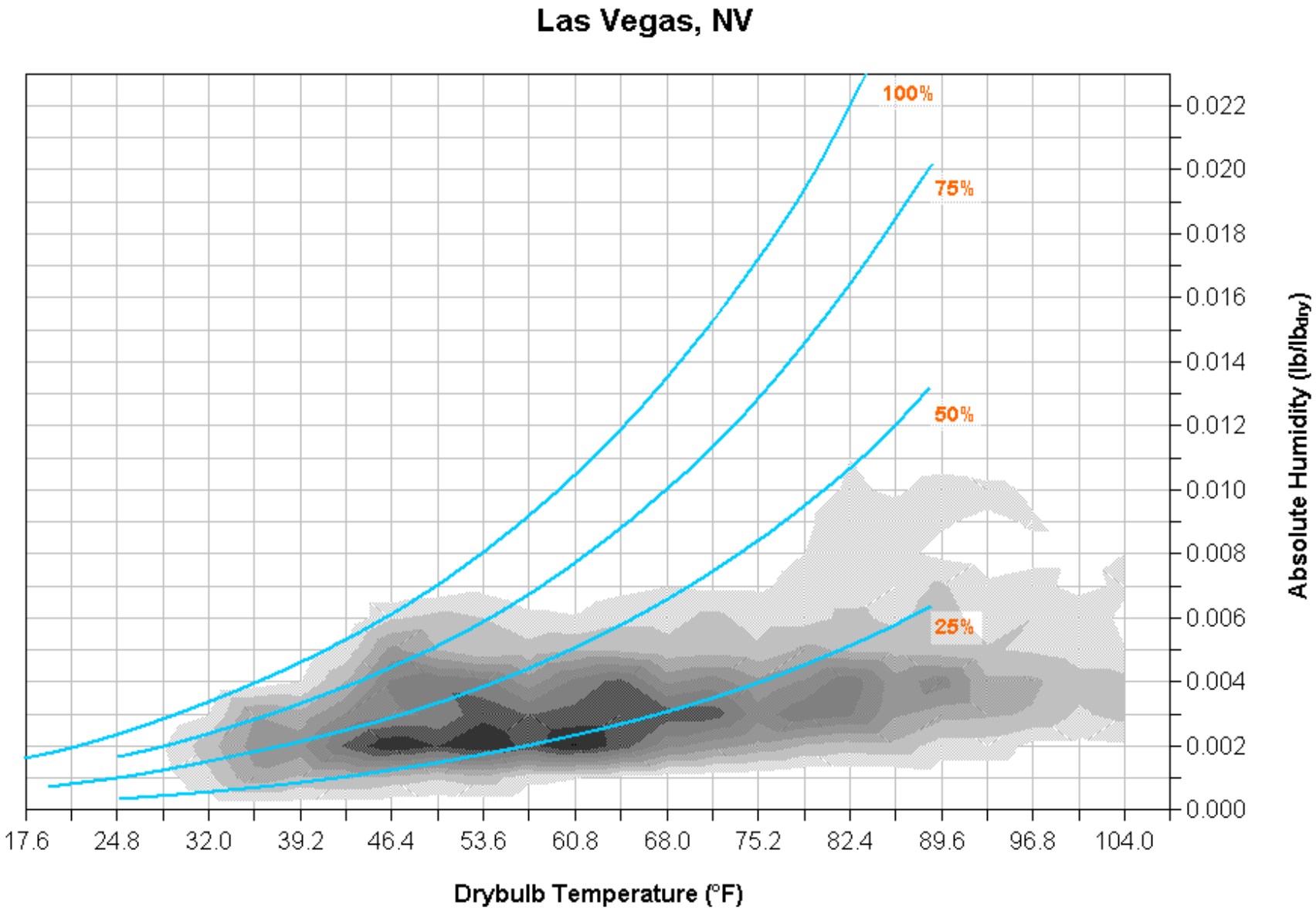

Subarctic/Arctic
Very Cold
Marine
Cold
Mixed-Humid
Mixed-Dry
Hot-Humid
Hot-Dry

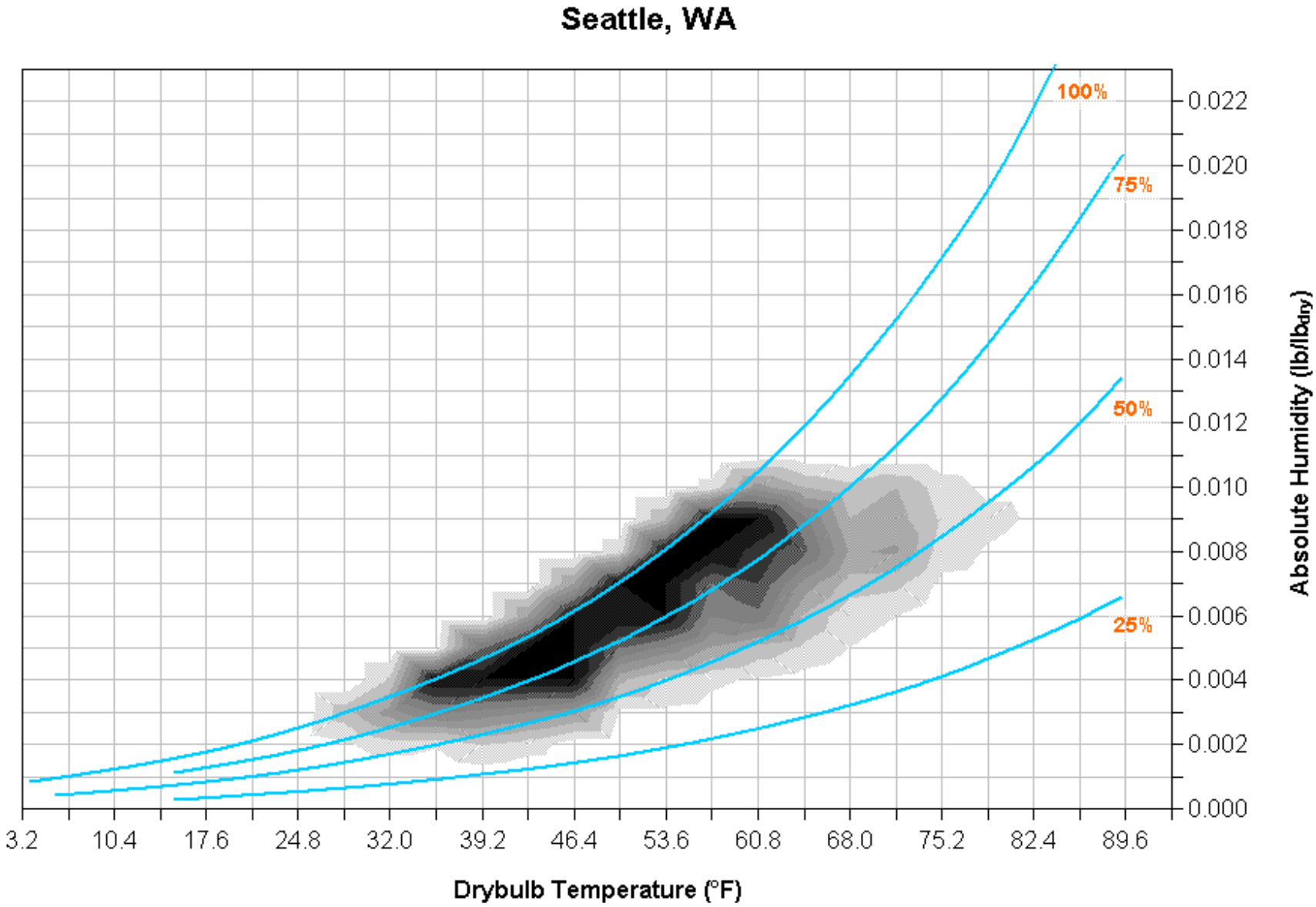

Exposure
Extreme
Over 60''
High
40'' - 60''
Moderate
20'' - 40''
Low
Under 20''


Los Angeles, CA
100%
75%
50%
25%
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Absolute Humidity (lb/lbdry)
10.4
17.6
24.8
32.0
39.2
46.4
53.6
60.8
68.0
75.2
82.4
89.6
96.8
Drybulb Temperature (°F)


Minneapolis, MN
100%
75%
50%
25%
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Absolute Humidity (lb/lbdry)
3.2
10.4
17.6
24.8
32.0
39.2
46.4
53.6
60.8
68.0
75.2
82.4
89.6
Drybulb Temperature (°F)

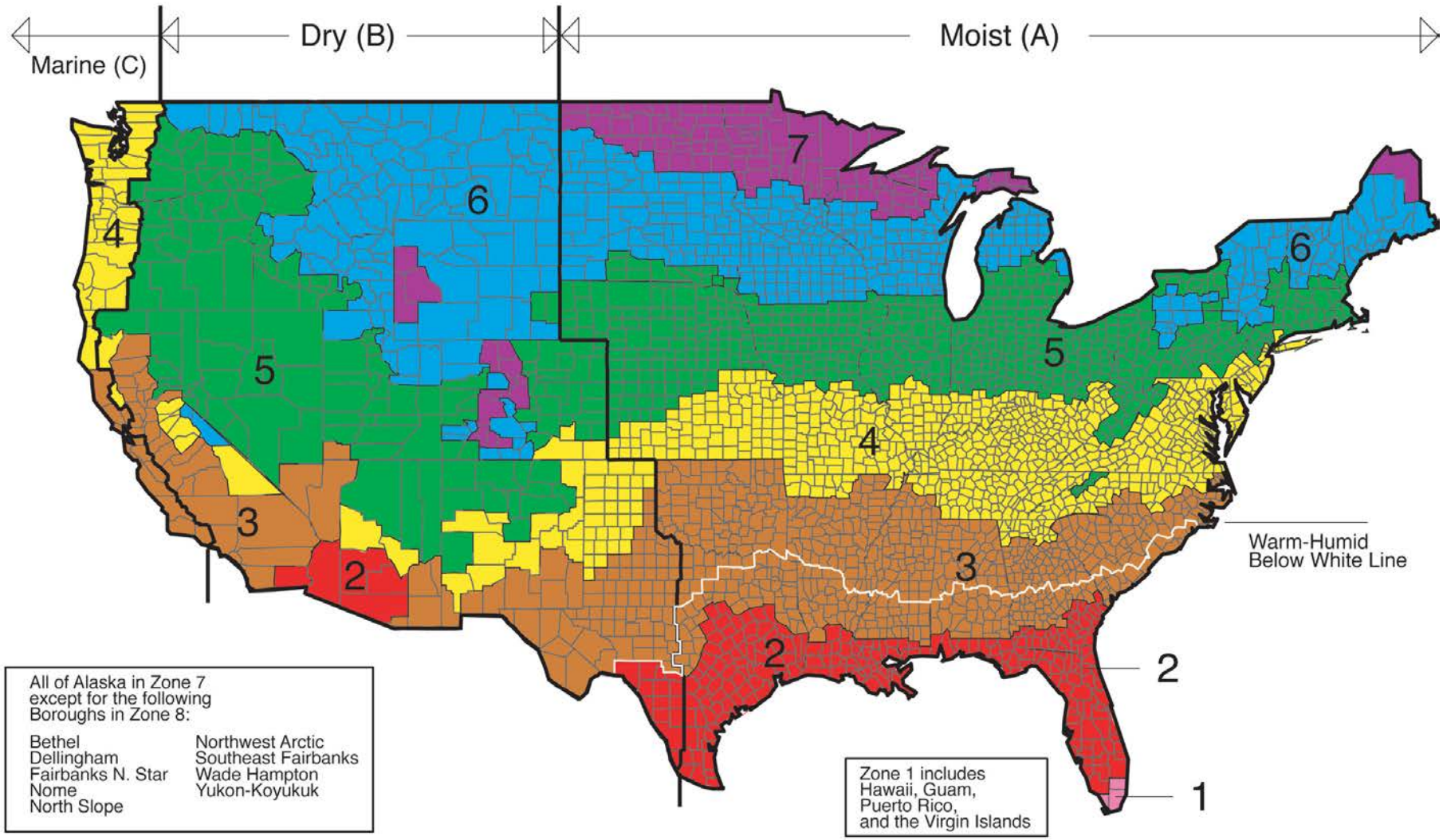

Lansing, MI
100%
75%
50%
25%
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Absolute Humidity (lb/lbdry)
3.2
10.4
17.6
24.8
32.0
39.2
46.4
53.6
60.8
68.0
75.2
82.4
89.6
Drybulb Temperature (°F)


Las Vegas, NV
100%
75%
50%
25%
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Absolute Humidity (lb/lbdry)
17.6
24.8
32.0
39.2
46.4
53.6
60.8
68.0
75.2
82.4
89.6
96.8
104.0
Drybulb Temperature (°F)

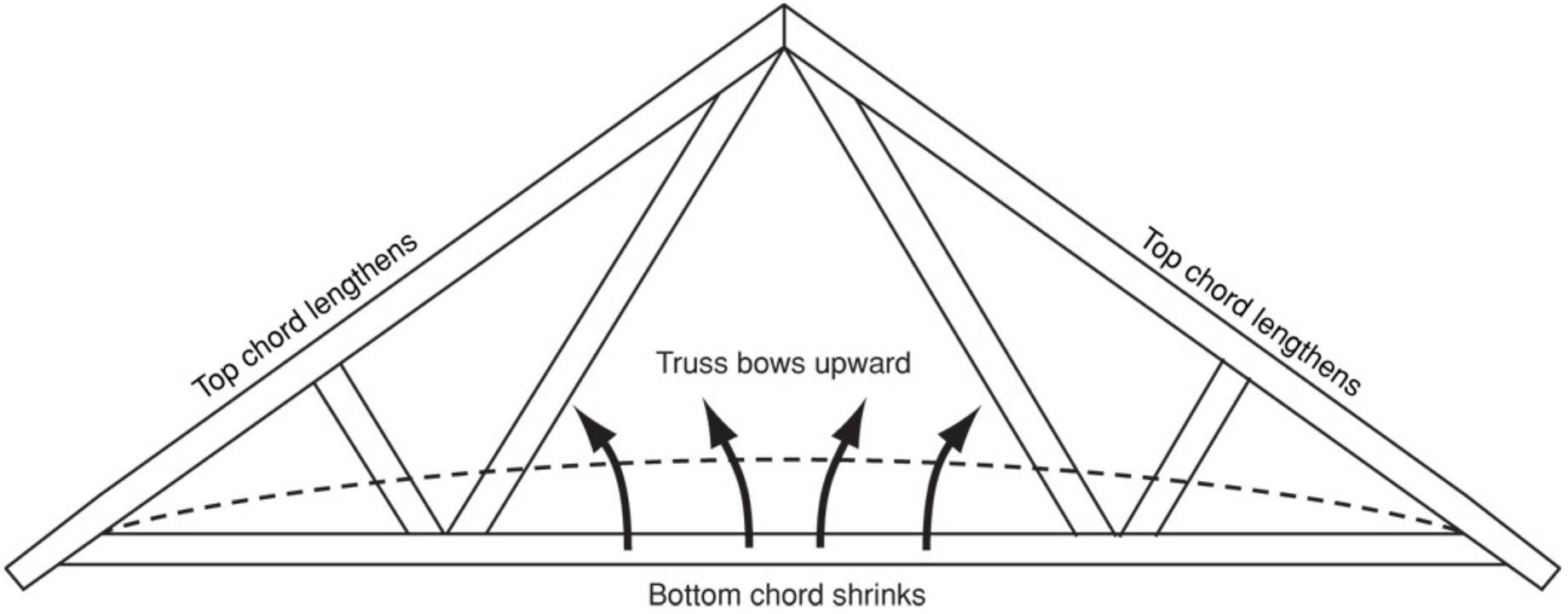

Seattle, WA
100%
75%
50%
25%
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Absolute Humidity (lb/lbdry)
3.2
10.4
17.6
24.8
32.0
39.2
46.4
53.6
60.8
68.0
75.2
82.4
89.6
Drybulb Temperature (°F)

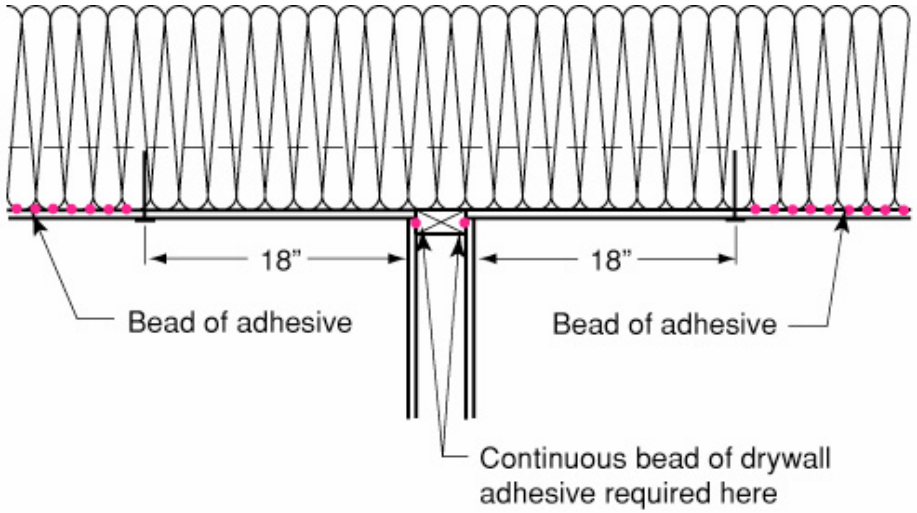
Don’t Do Stupid Things

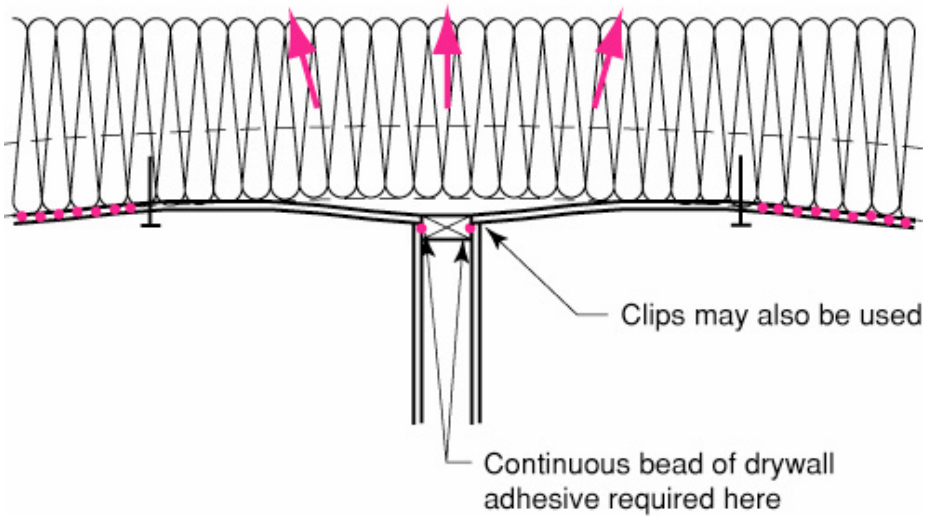

GUARDIAN

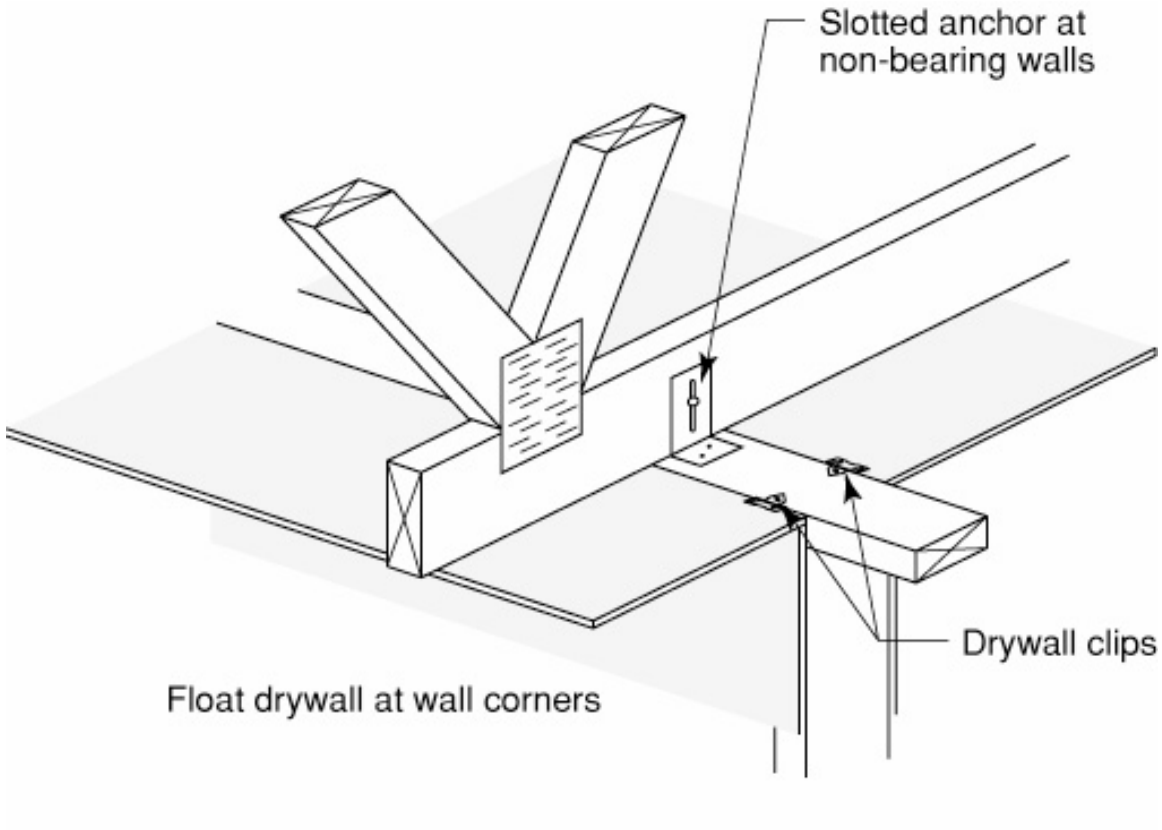

Marine (C)
Dry (B)
Moist (A)
7
6
4
5
3
2
1
Warm-Humid
Below White Line
All of Alaska in Zone 7
except for the following
Boroughs in Zone 8:
Bethel
Dellingham
Fairbanks N. Star
Nome
North Slope
Northwest Arctic
Southeast Fairbanks
Wade Hampton
Yukon-Koyukuk
Zone 1 includes
Hawaii, Guam,
Puerto Rico,
and the Virgin Islands


6537


Top chord lengthens
Truss bows upward
Top chord lengthens
Bottom chord shrinks


18”
18”
Bead of adhesive
Bead of adhesive
Continuous bead of drywall adhesive required here


Clips may also be used
Continuous bead of drywall adhesive required here


Slotted anchor at
non-bearing walls
Drywall clips
Float drywall at wall corners


10-4-8
ermo-ply
STRUCTURAL GRADE
INSULATIVE SHEATING
FOR ADDED ENERGY
PERFORMANCE
ermo
STRUCTURAL GRADE
INSULATIVE SHEAT
FOR ADDED ENE

Exterior Conditions

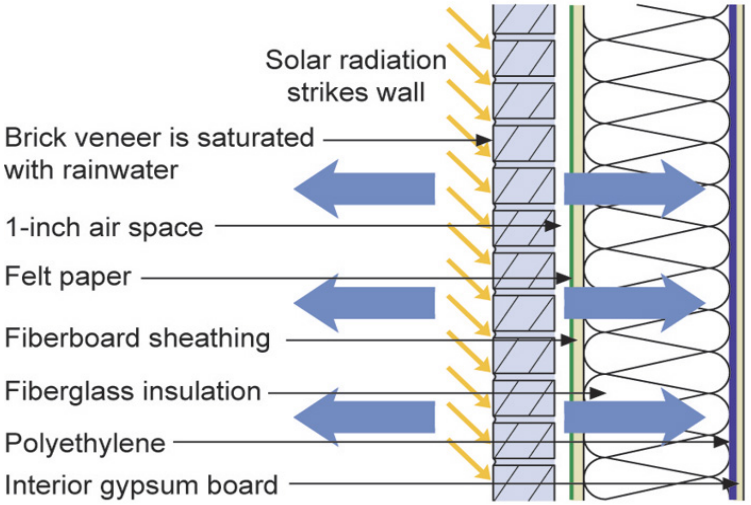
Temperature: 80°F
Relative humidity: 75%
Vapor pressure: 2.49 kPa

Conditions within Cavity:

Temperature: 100°F
Relative humidity: 100%
Vapor pressure: 6.45 kPa

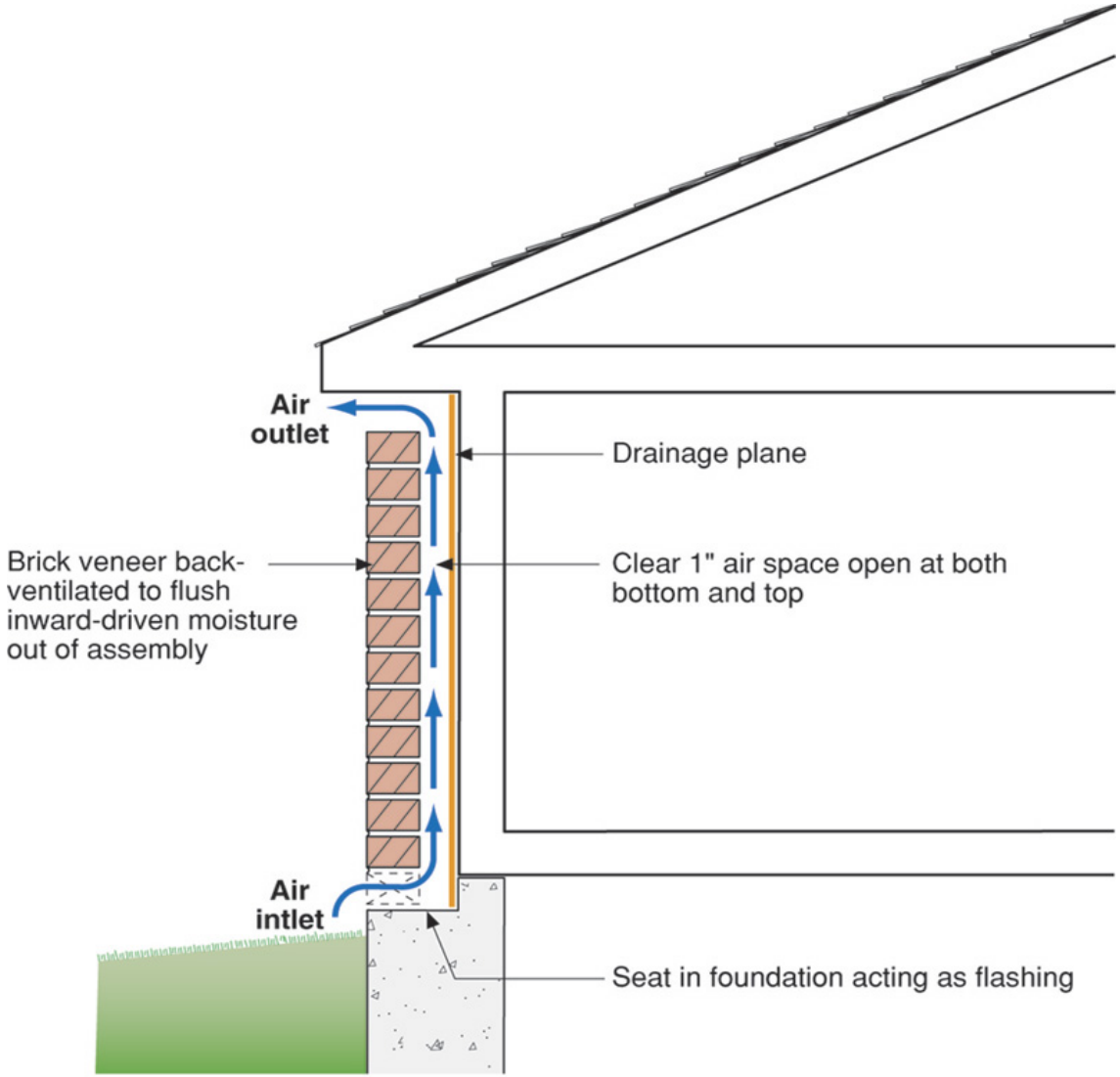
Interior Conditions

Temperature: 75°F
Relative humidity: 60%
Vapor pressure: 1.82 kPa

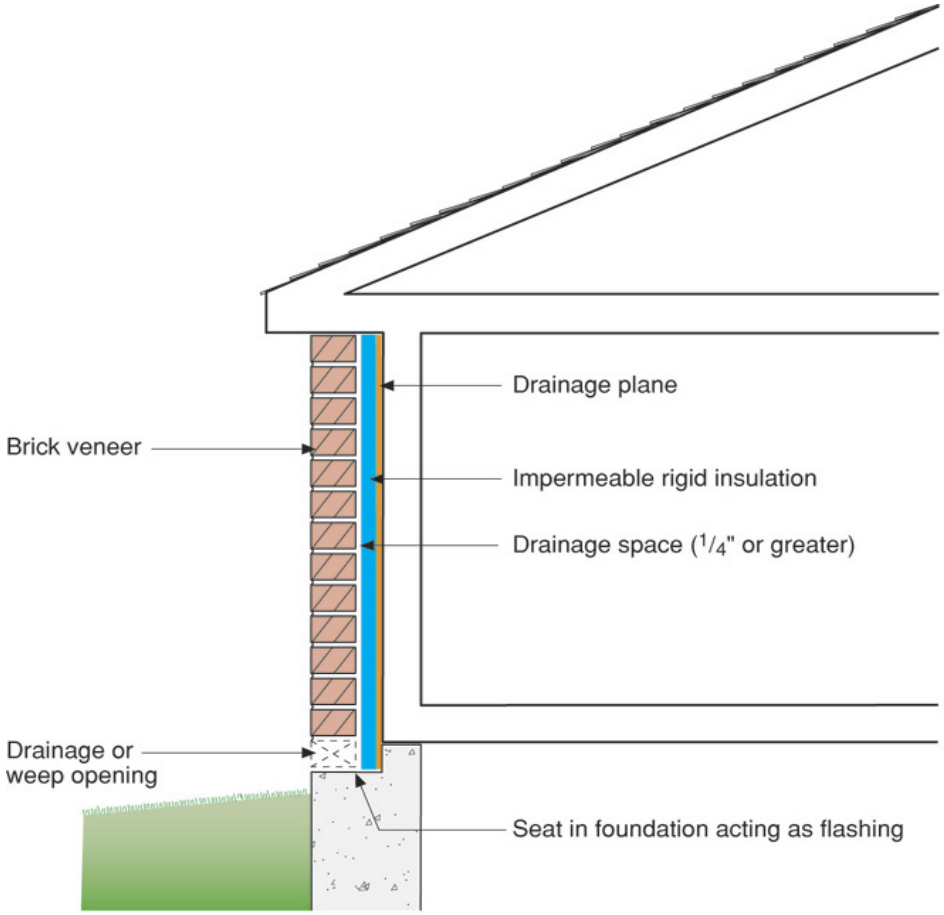


Vapor is driven both inward and outward by a high vapor pressure differential between the brick and the interior and the brick and the exterior.

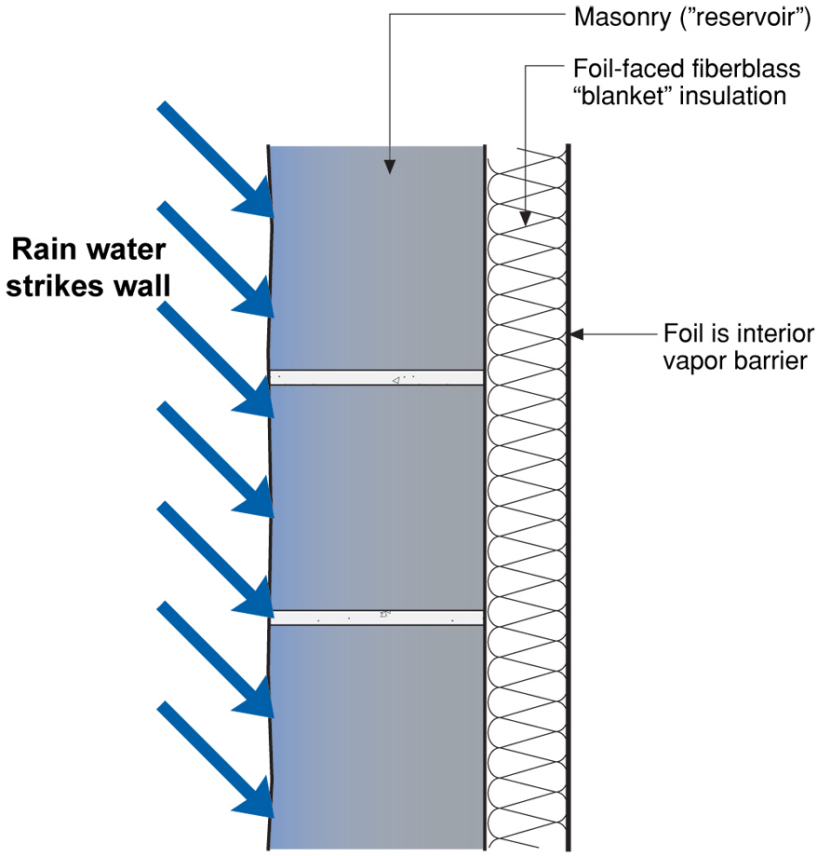
- It is not a good idea to install a vapor barrier (polyethylene) on the inside of an air conditioned assembly. Vinyl wall coverings and foil-backed batt cavity insulation should also be avoided.
- Vapor permeable exterior sheathings, housewraps or building papers should not be used with absorptive claddings such as brick veneers unless a ventilated cavity is provided in conjunction with high inward drying potentials (i.e. no interior polyethylene vapor barriers).
- Failure will occur when brick is installed over a frame wall constructed with felt paper, fiberboard sheathing and an interior polyethylene vapor barrier. Kraft-faced fiberglass batts should be used in place of unfaced batts and a polyethylene vapor barrier. OSB, plywood or foam sheathing should be used in place of the fiberboard sheathing.
- Similar problems occur with stucco.



- To effectively uncouple a brick veneer from a wall system by using back ventilation, a clear cavity must be provided along with both air inlets at the bottom and air outlets at the top

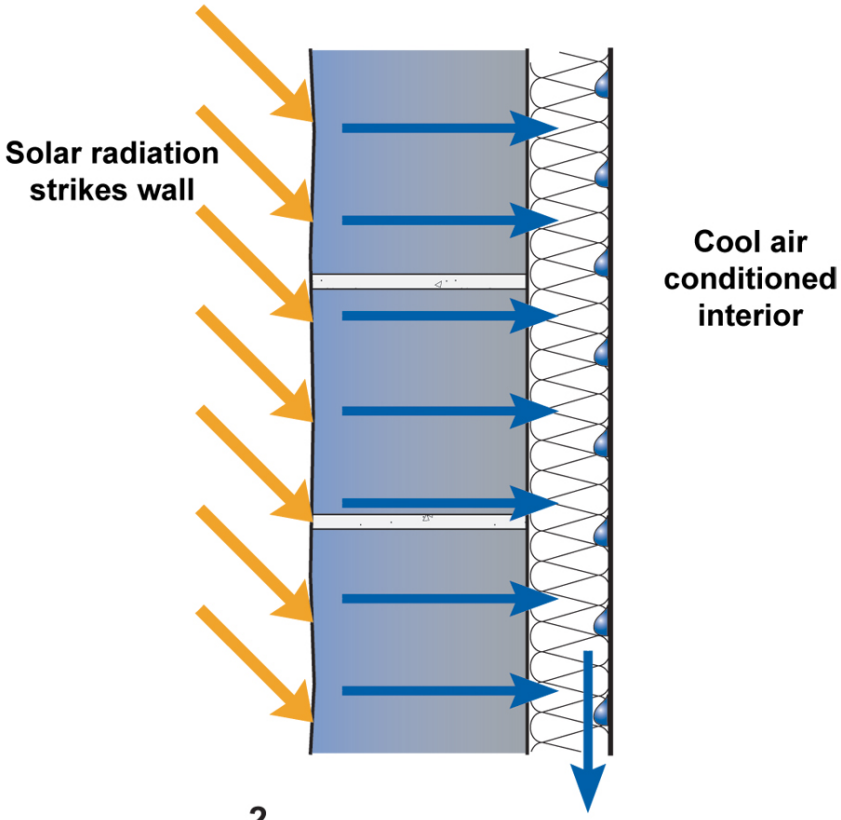


- To effectively uncouple a brick veneer from a wall system by using a condensing surface, the drainage plane must also be a vapor barrier or a vapor impermeable layer (i.e. rigid insulation) must be installed between the drainage plane and the brick veneer. Alternatively, the rigid insulation can be configured to act as both the drainage plane and vapor impermeable layer.
- When a condensing surface is used to uncouple a brick veneer from a wall system, a ventilated air space is no longer necessary — i.e. the presence of mortar droppings is no longer an issue. Additionally, the width of the drainage space is almost irrelevant.



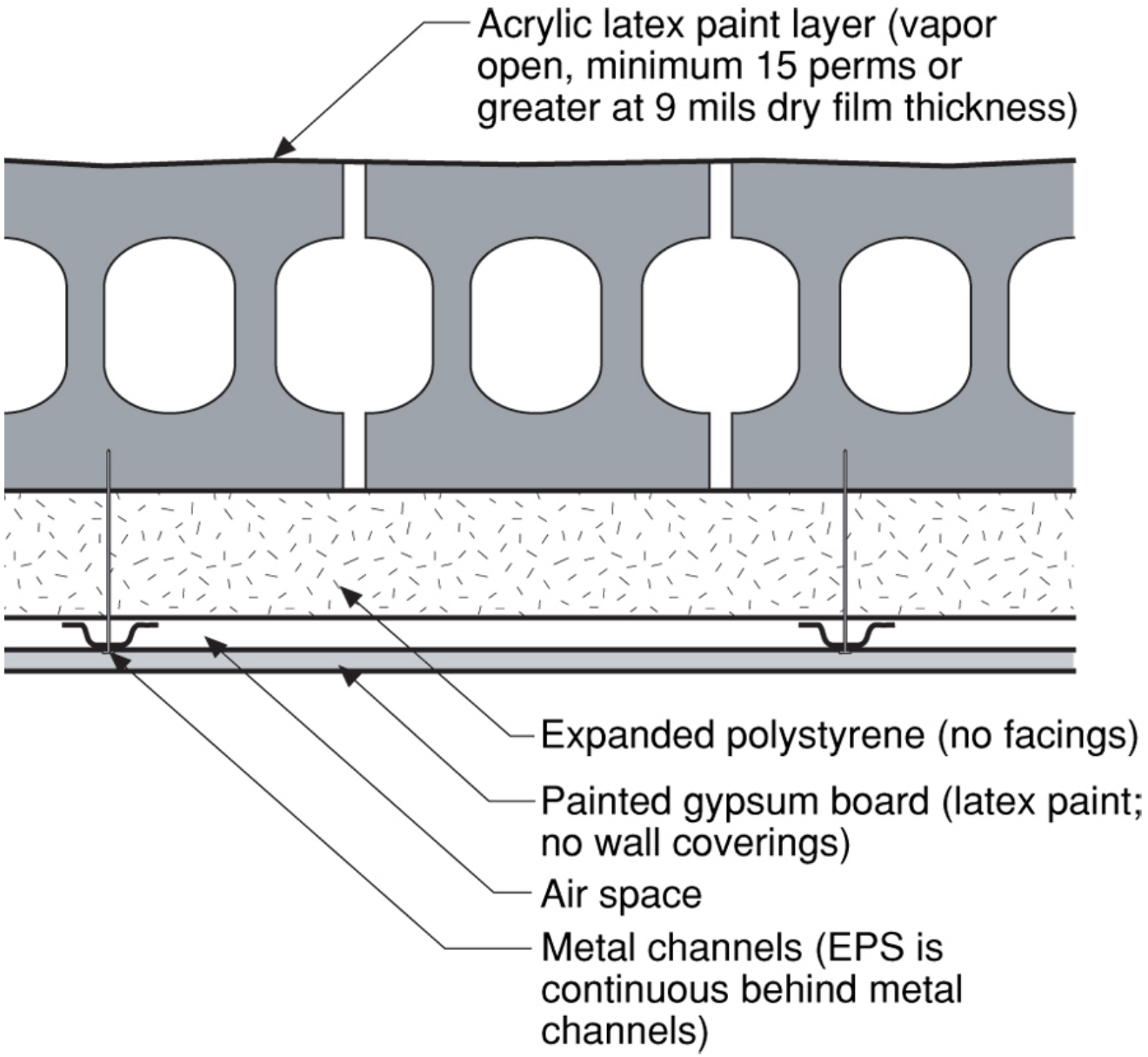
1.

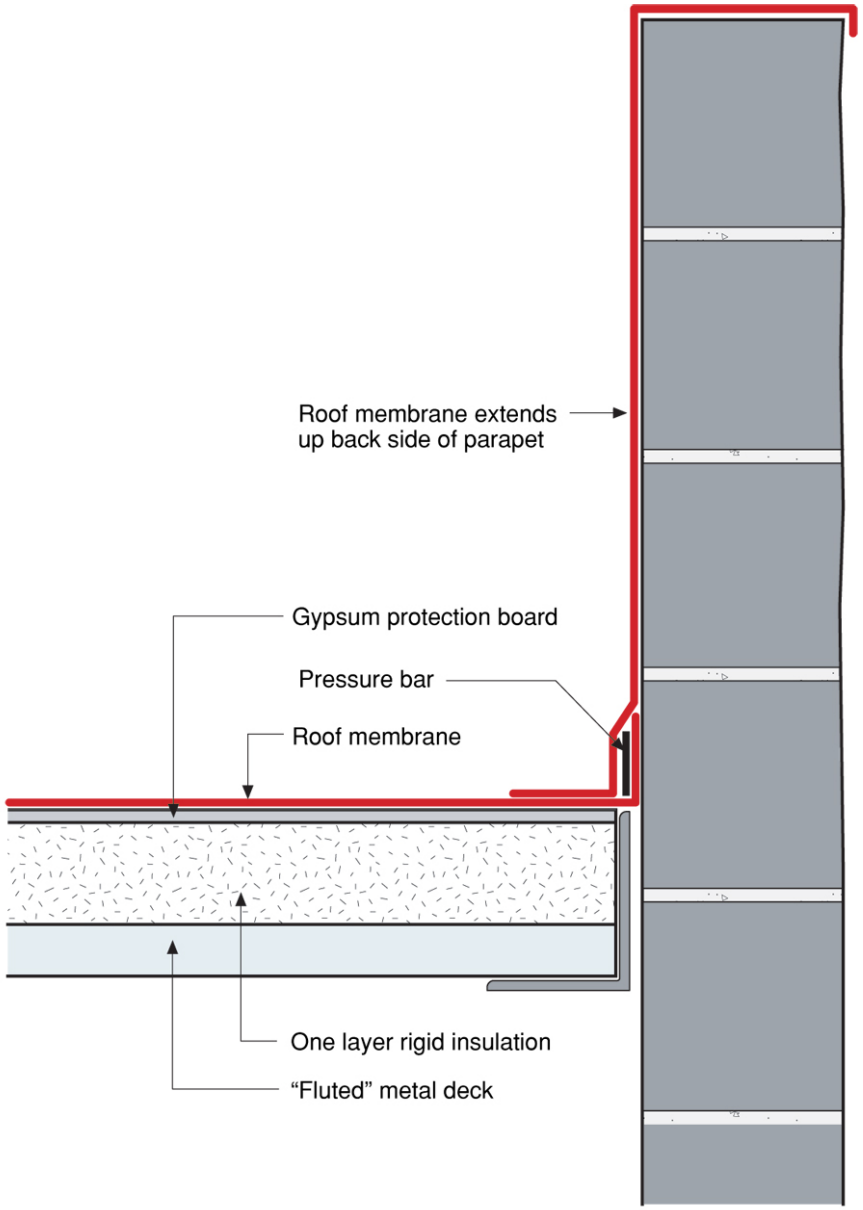
- Rain water is deposited on exterior face of masonry
- Rain water enters masonry through paint layer

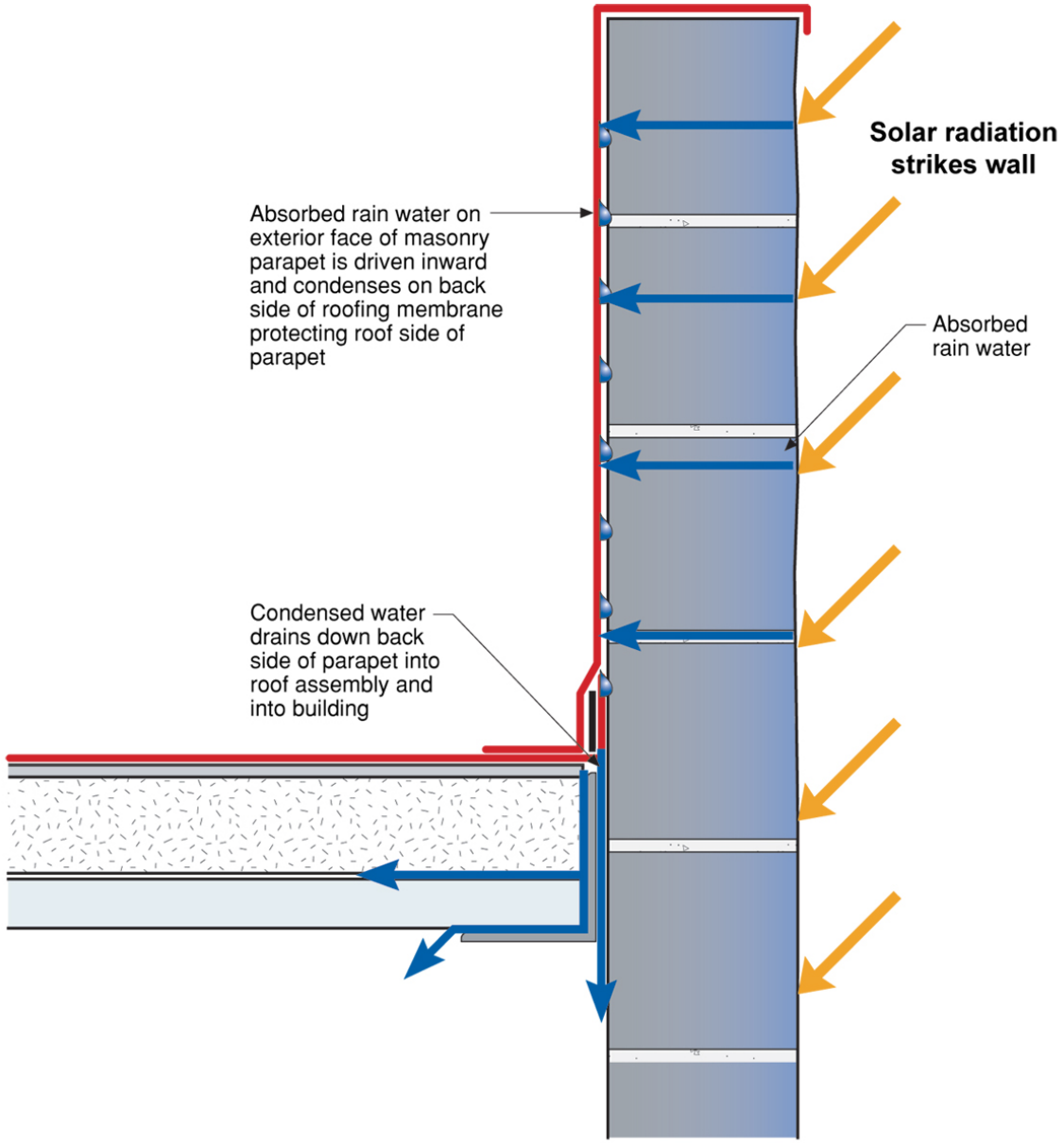


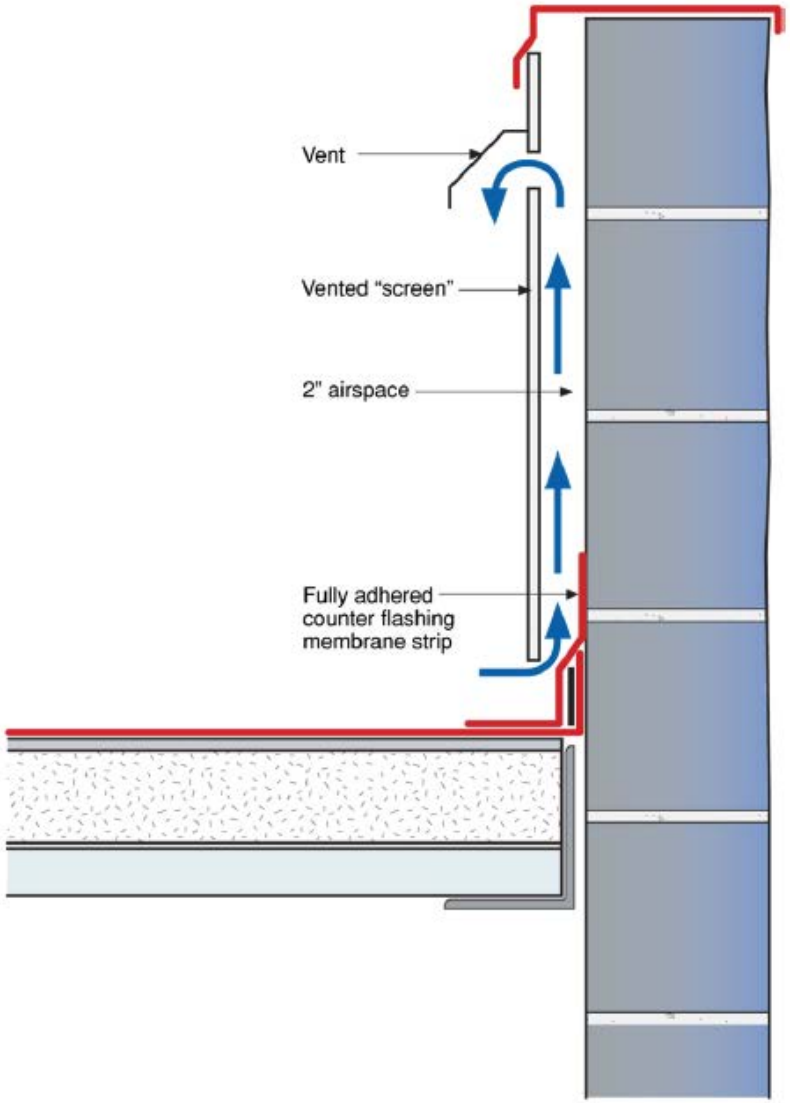
2.

- Solar radiation heats exterior while A/C cools interior
- Moisture is driven inward, condenses on foil vapor barrier and runs down wall

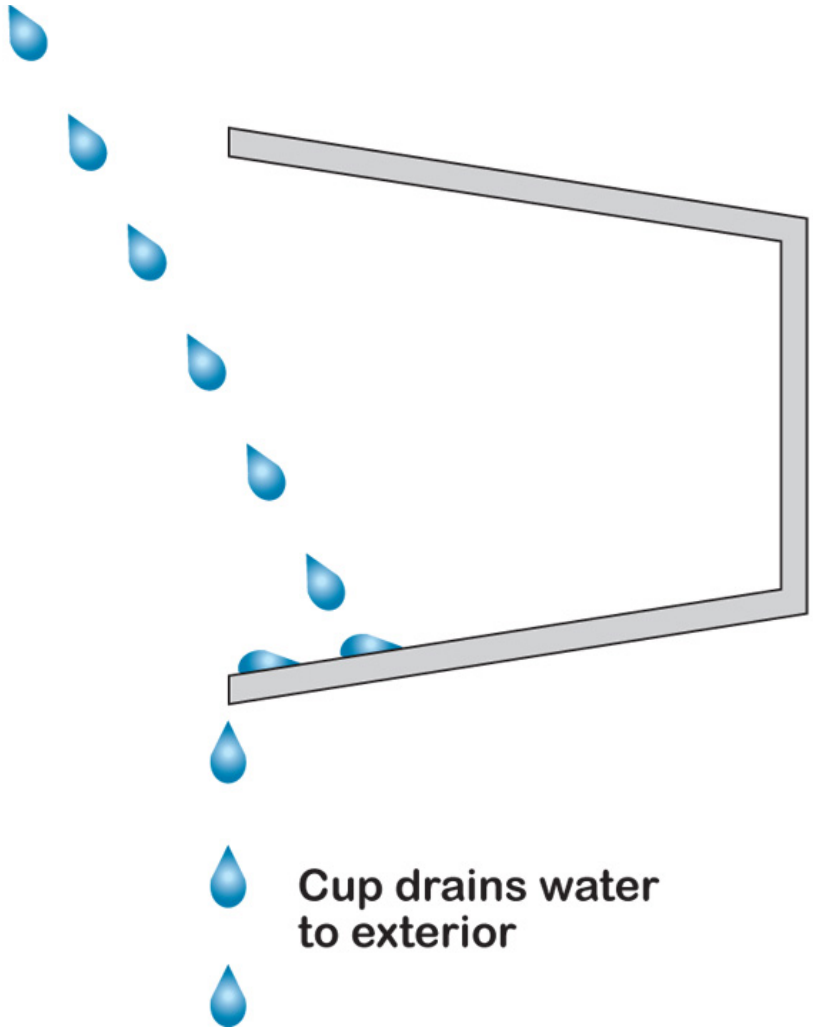

Acrylic latex paint layer (vapor open, minimum 15 perms or greater at 9 mils dry film thickness)
Expanded polystyrene (no facings)
Painted gypsum board (latex paint; no wall coverings)
Air space
Metal channels (EPS is continuous behind metal channels)


Roof membrane extends
up back side of parapet
Gypsum protection board
Pressure bar
Roof membrane
One layer rigid insulation
“Fluted” metal deck

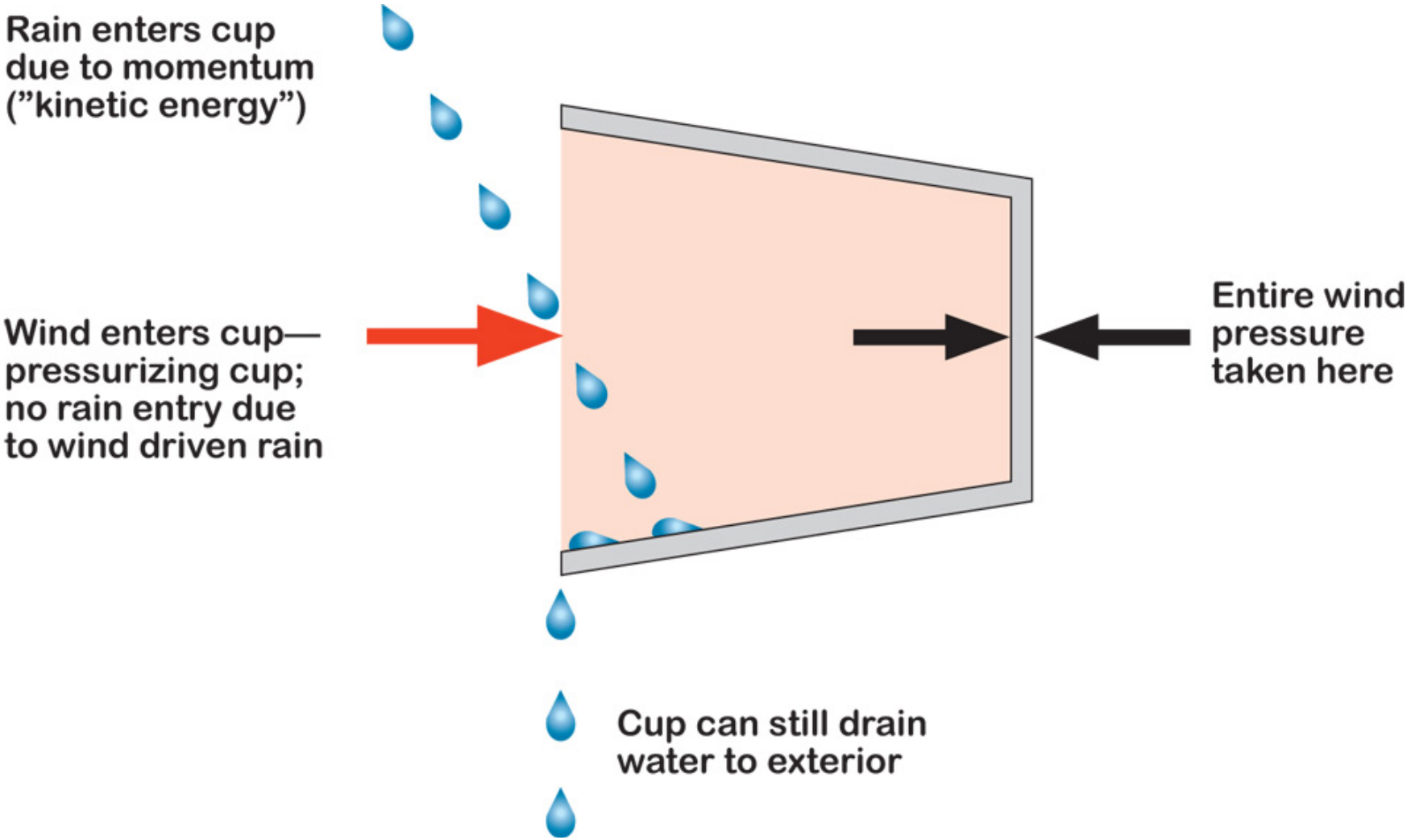

Solar radiation strikes wall
Absorbed rain water on exterior face of masonry parapet is driven inward and condenses on back side of roofing membrane protecting roof side of parapet
Absorbed rain water
Condensed water drains down back side of parapet into roof assembly and into building

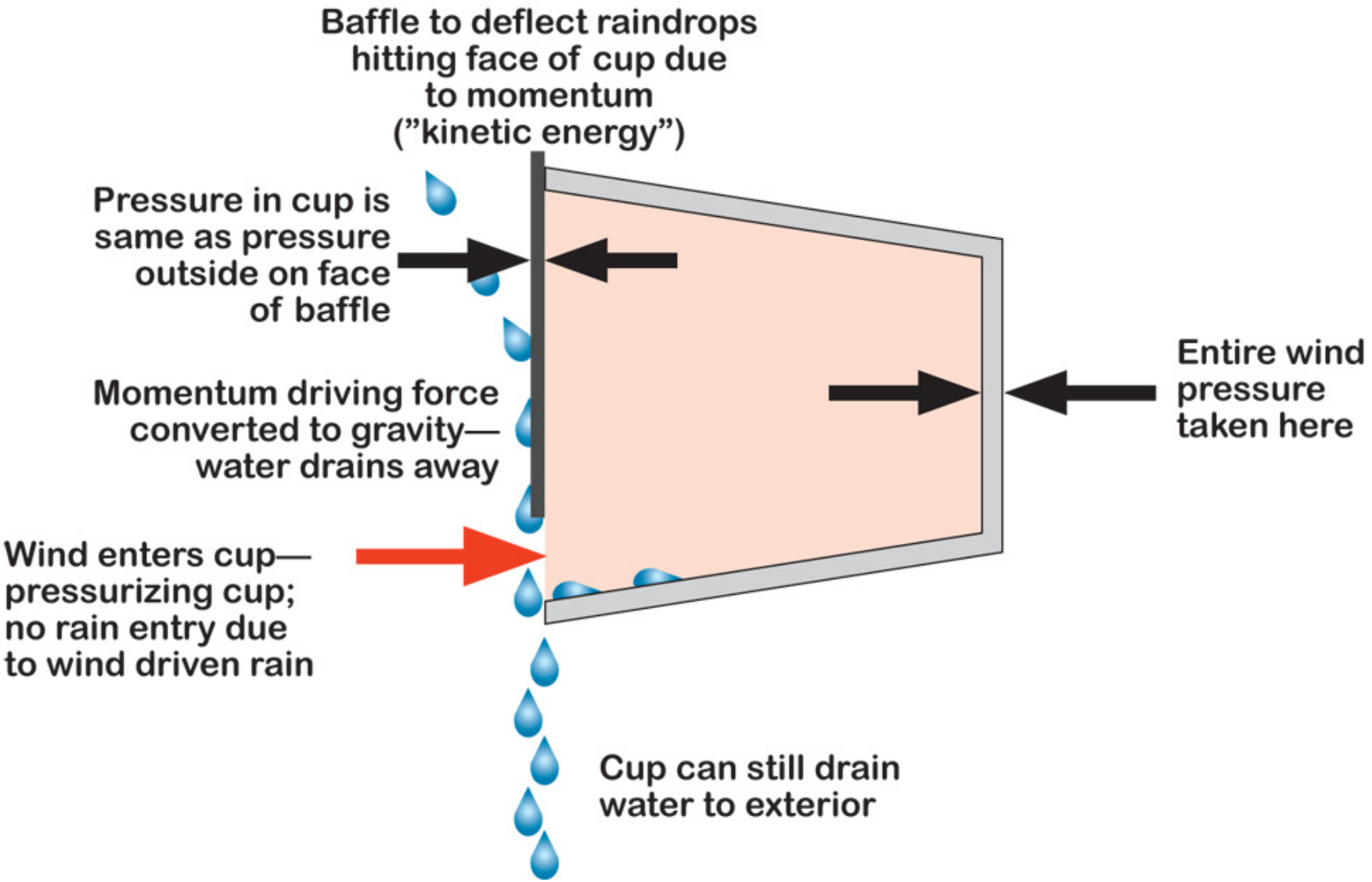

Vent
Vented "screen"
2" airspace
Fully adhered
counter flashing
membrane strip

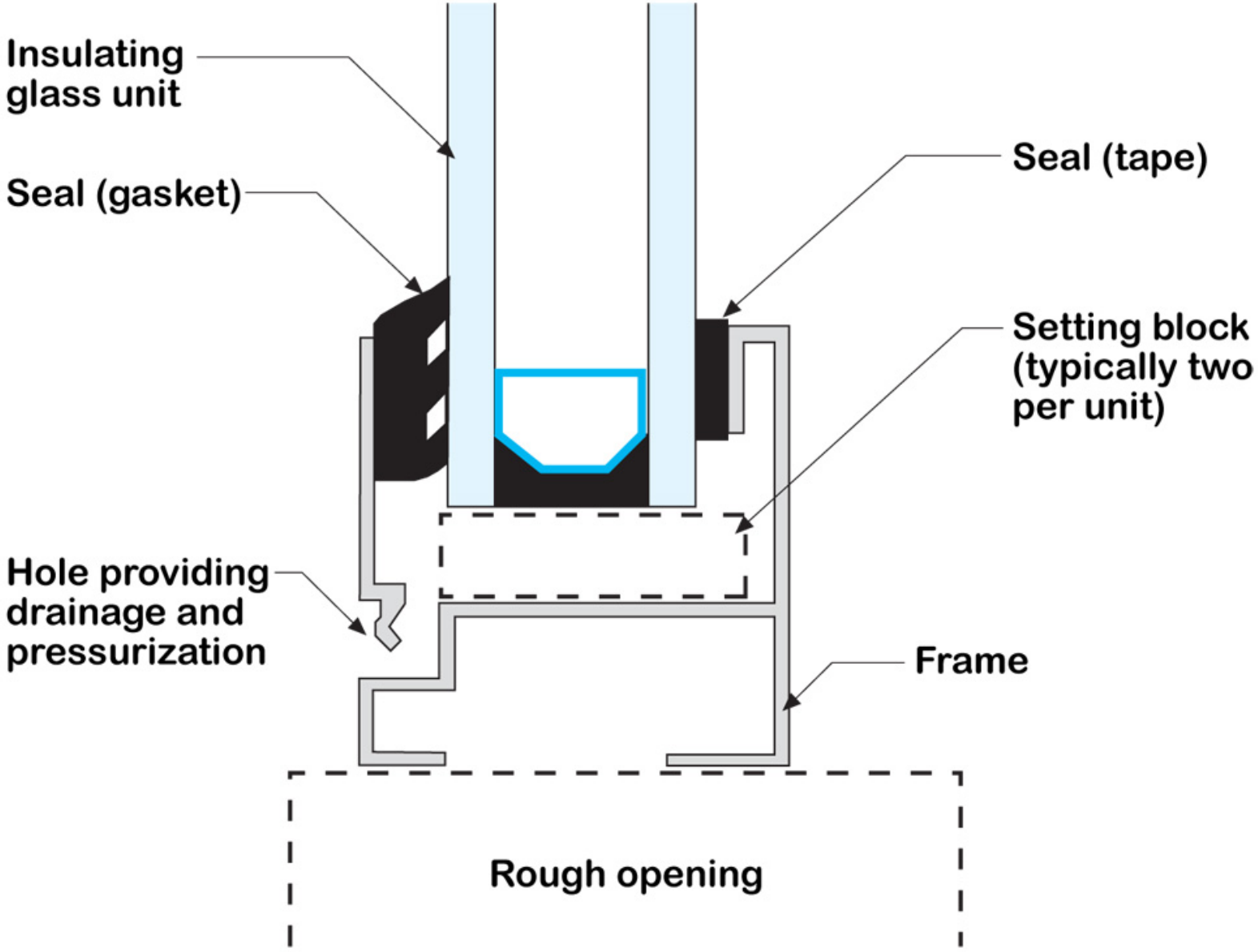
Rain enters cup due to momentum ("kinetic energy")

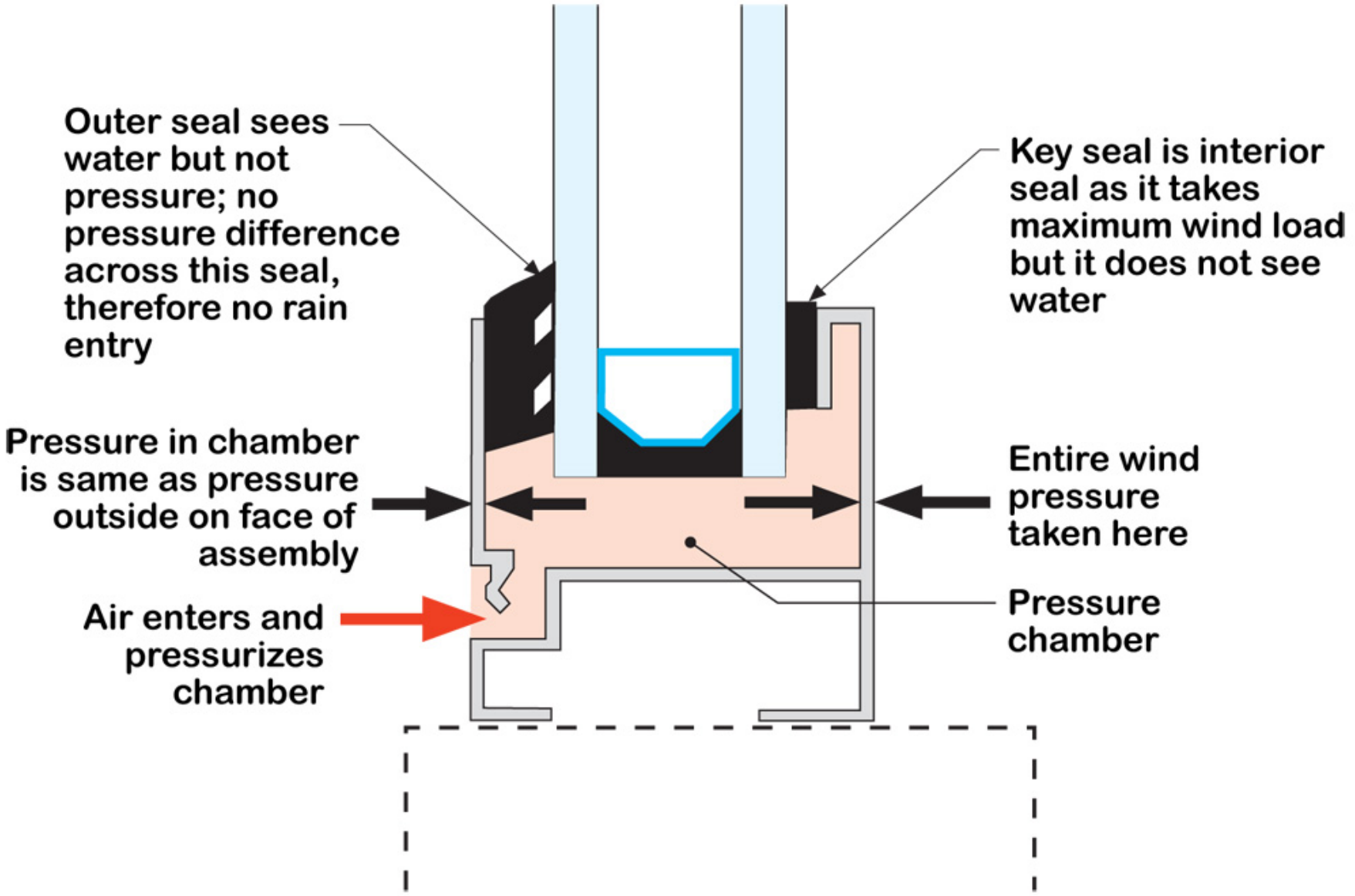


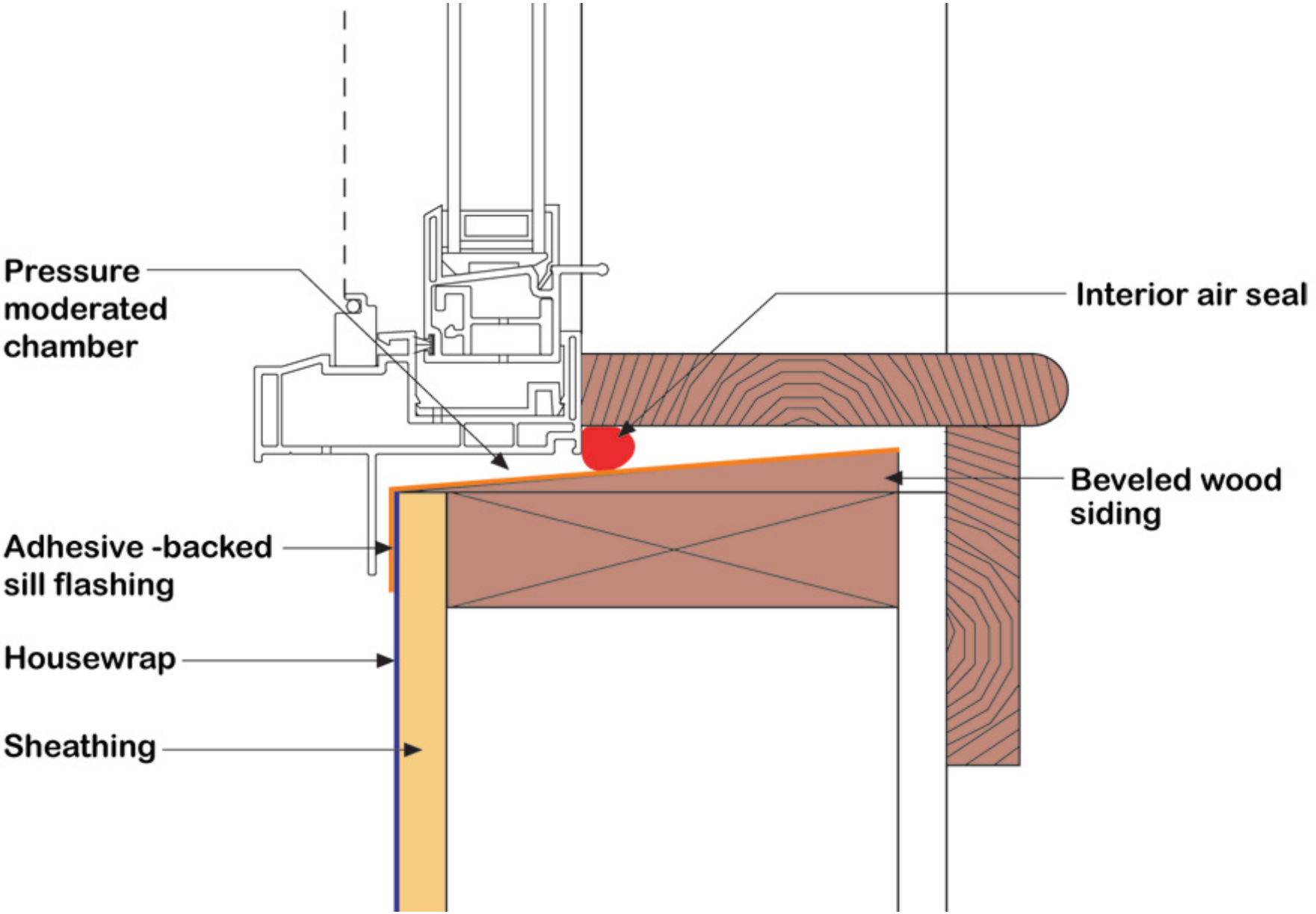
Cup drains water to exterior


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

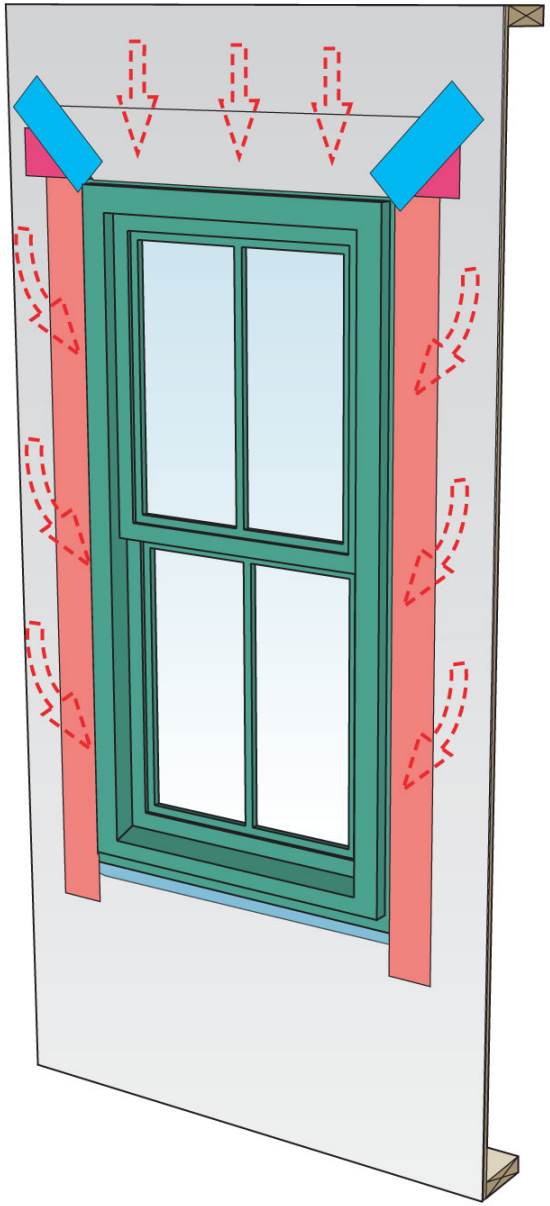

Baffle to deflect raindrops hitting face of cup due to momentum ("kinetic energy")
Pressure in cup is same as pressure outside on face of baffle
Momentum driving force converted to gravity— water drains away
Wind enters cup— pressurizing cup; no rain entry due to wind driven rain
Entire wind pressure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

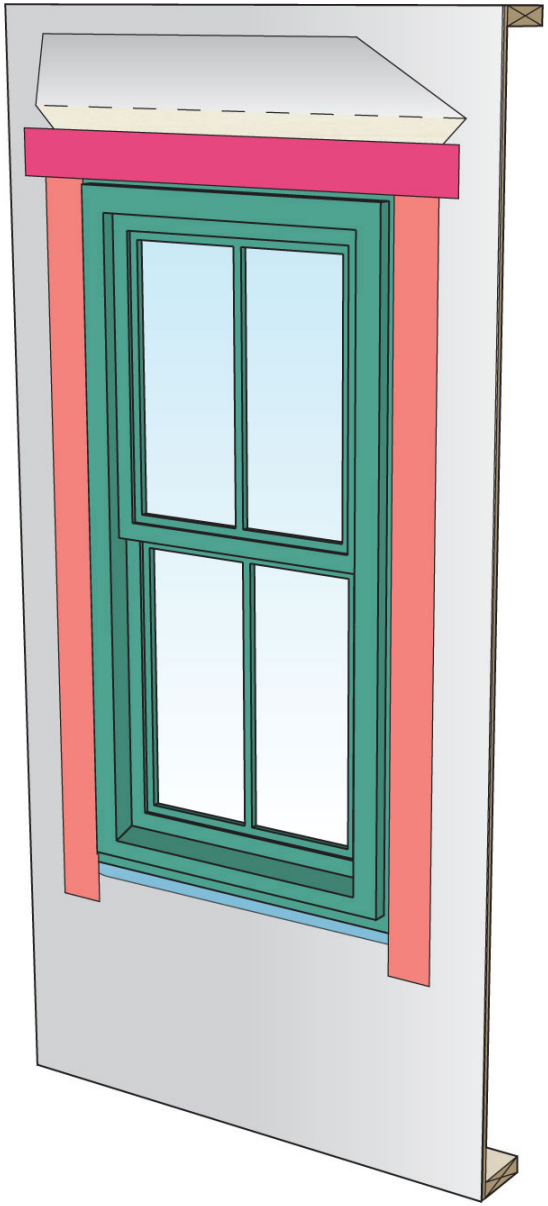

Insulating glass unit
Seal (gasket)
Seal (tape)
Setting block (typically two per unit)
Hole providing drainage and pressurization
Frame
Rough opening

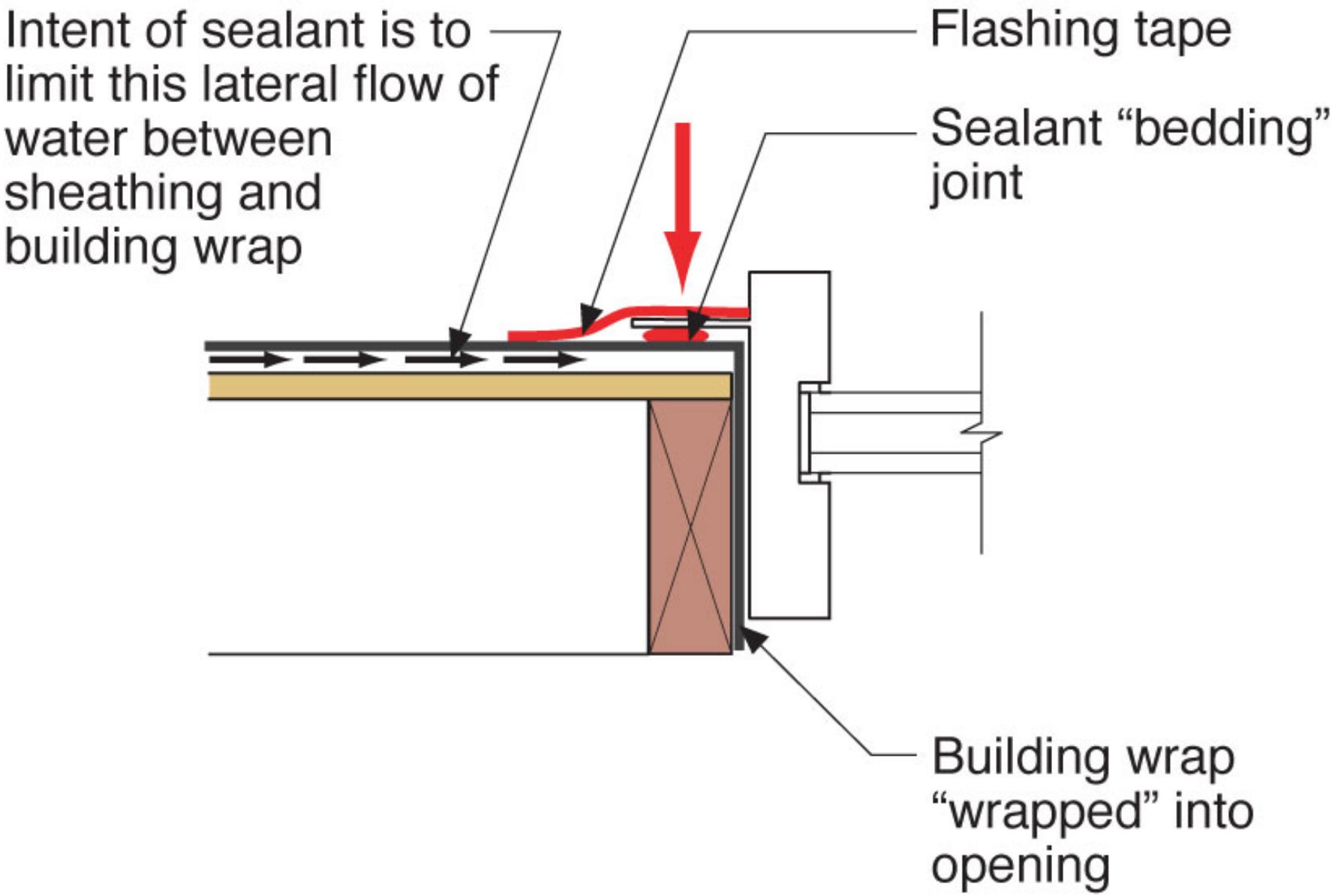

Outer seal sees water but not pressure; no pressure difference across this seal, therefore no rain entry
Key seal is interior seal as it takes maximum wind load but it does not see water
Pressure in chamber is same as pressure outside on face of assembly
Entire wind pressure taken here
Air enters and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

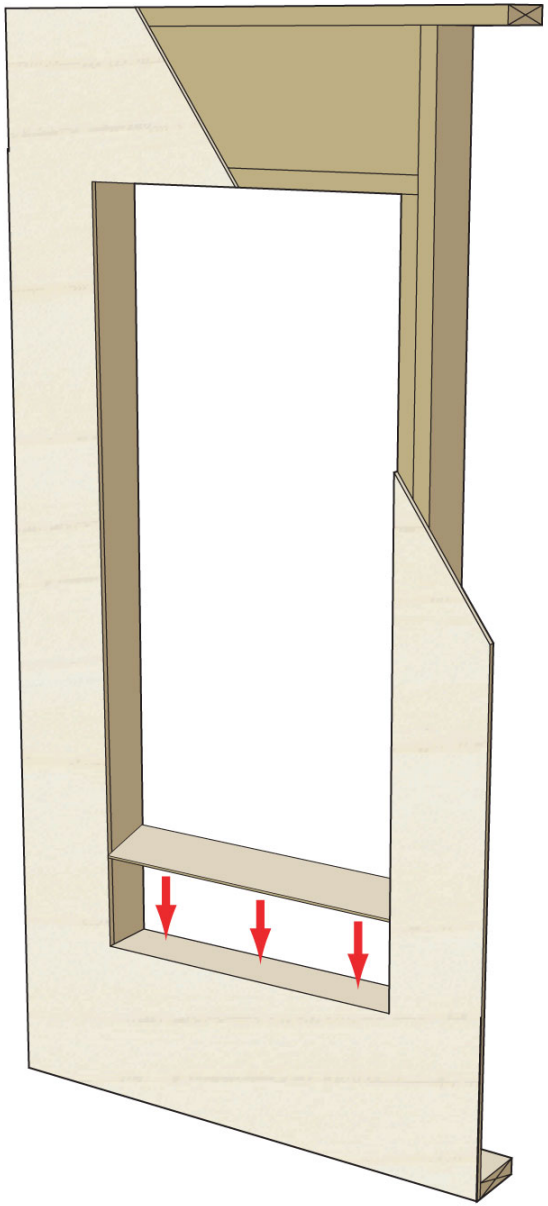

Pressure moderated chamber
Interior air seal
Beveled wood siding
Adhesive -backed sill flashing
Housewrap
Sheathing

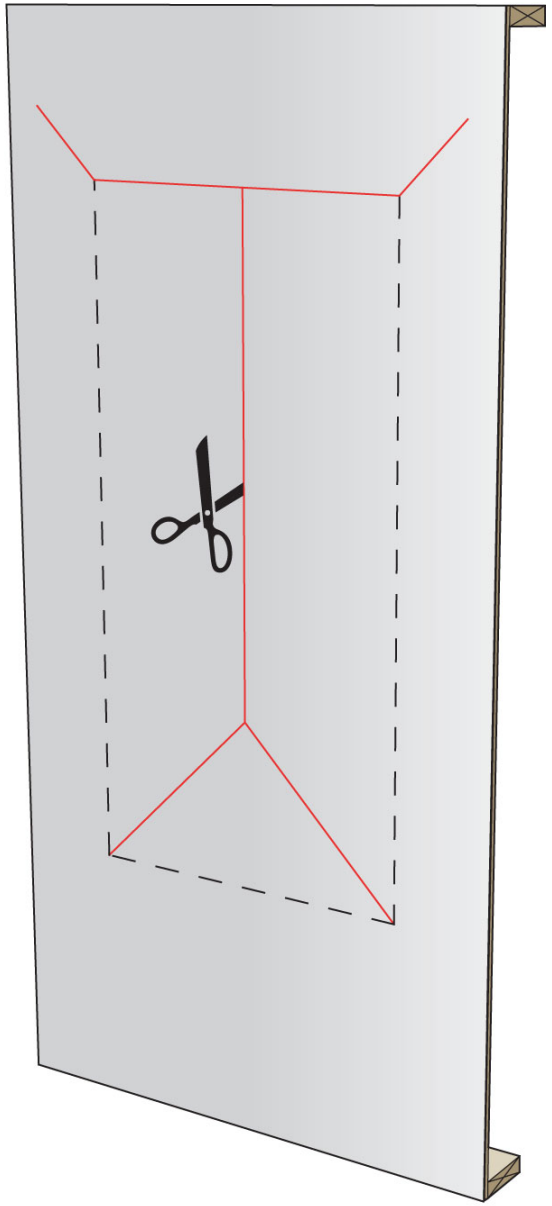

DOW
Styrofoam

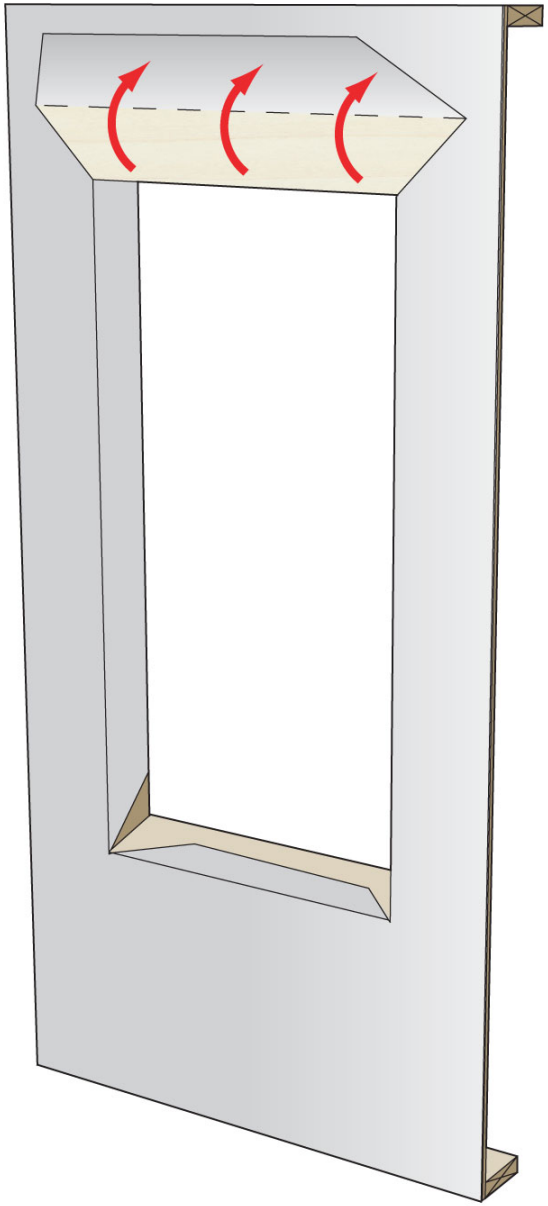


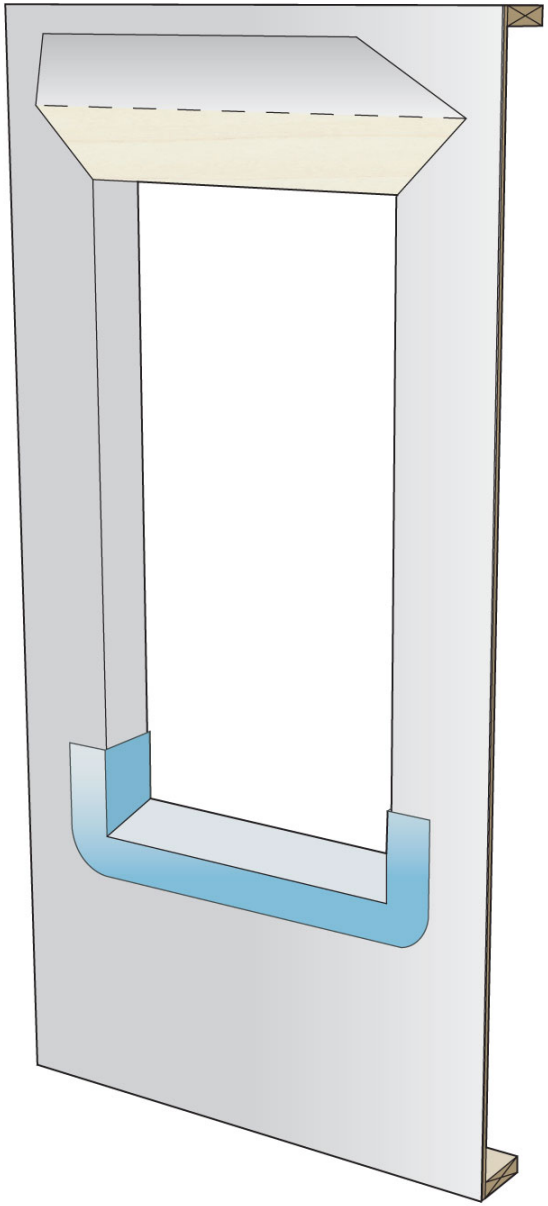


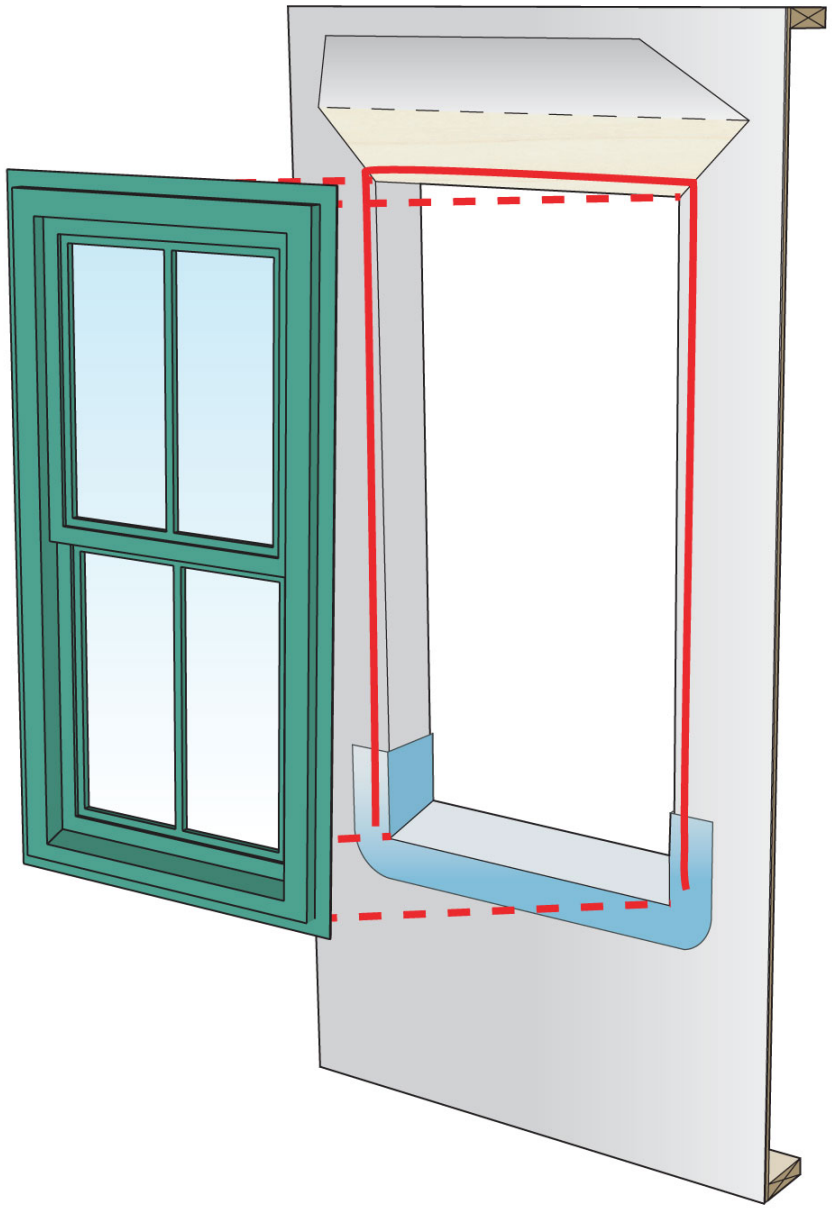

Intent of sealant is to limit this lateral flow of water between sheathing and building wrap
Flashing tape
Sealant “bedding” joint
Building wrap “wrapped” into opening

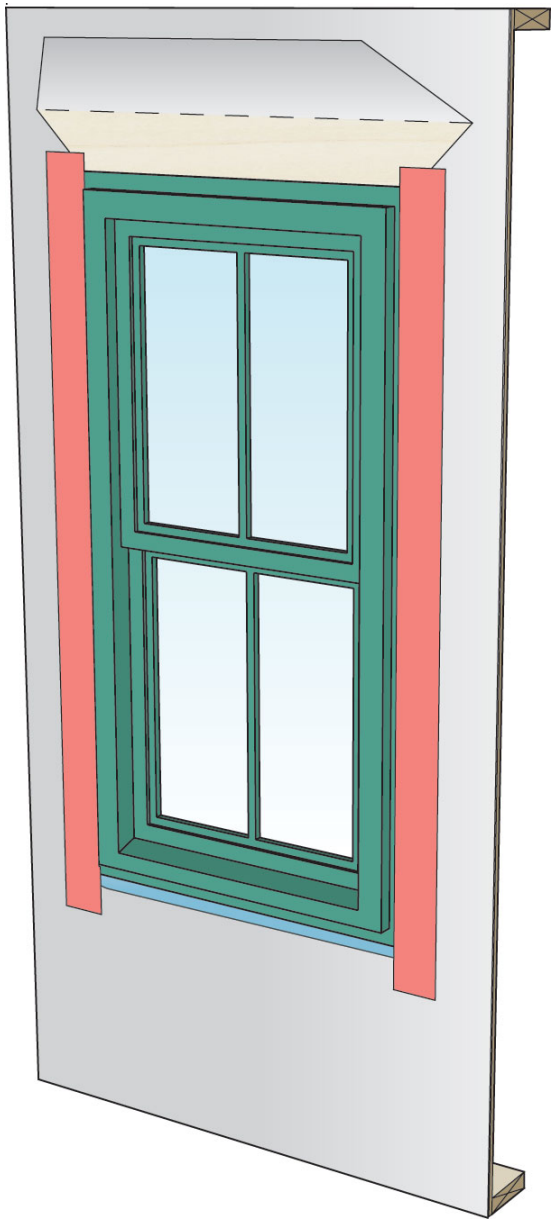


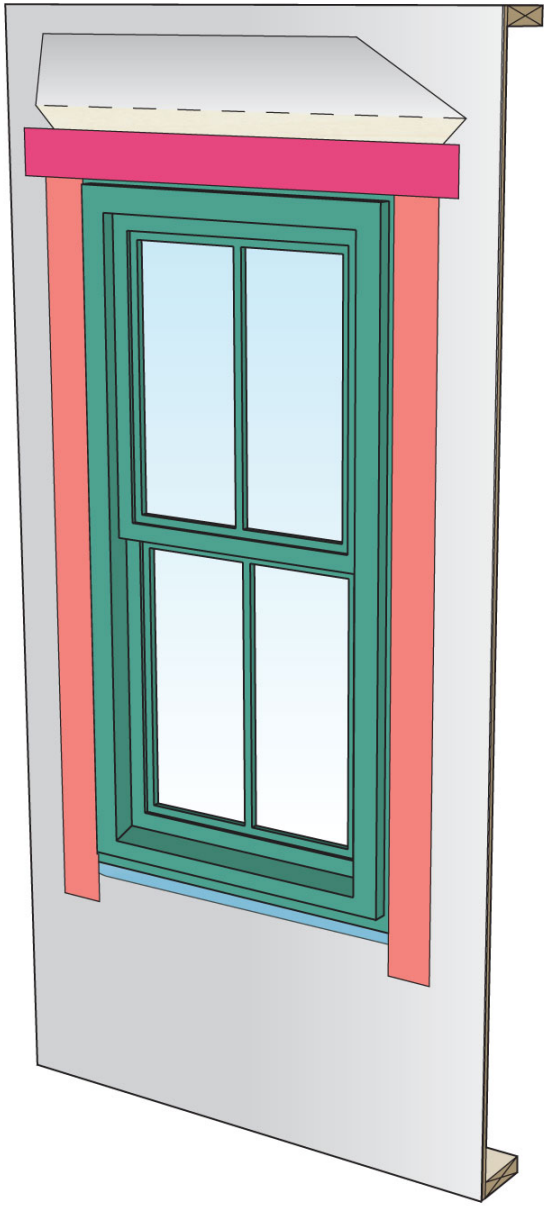


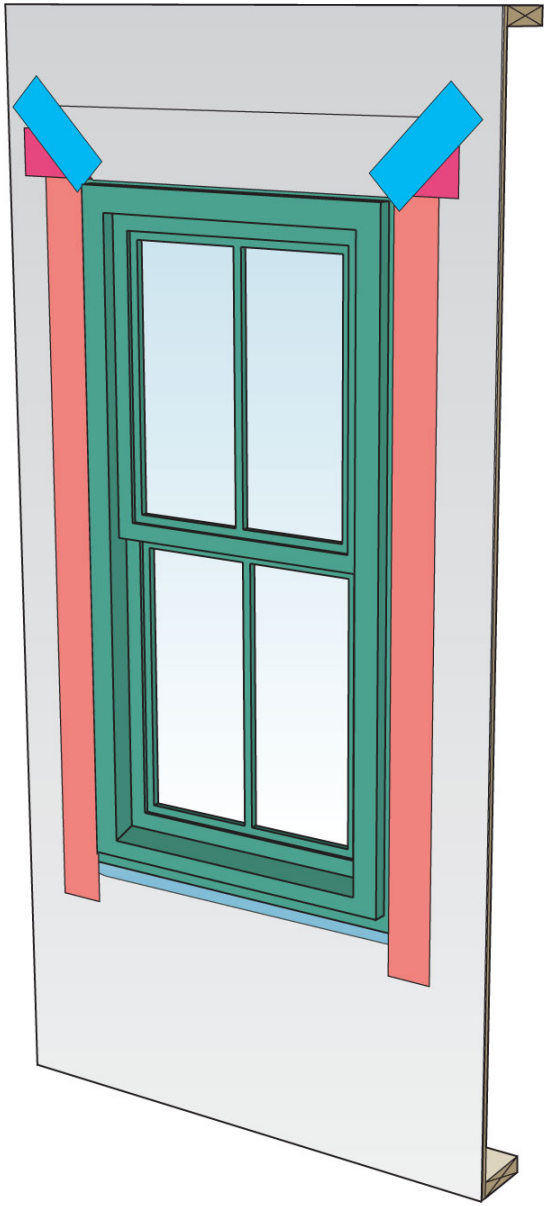


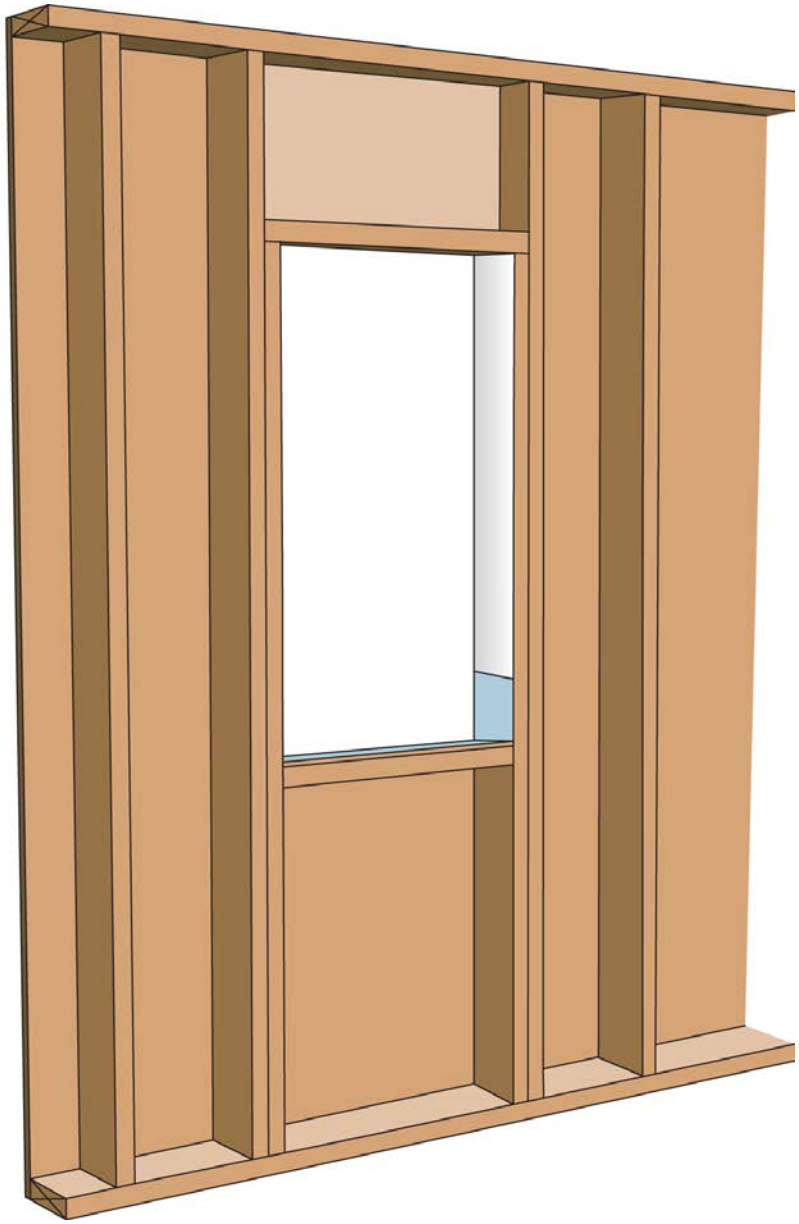




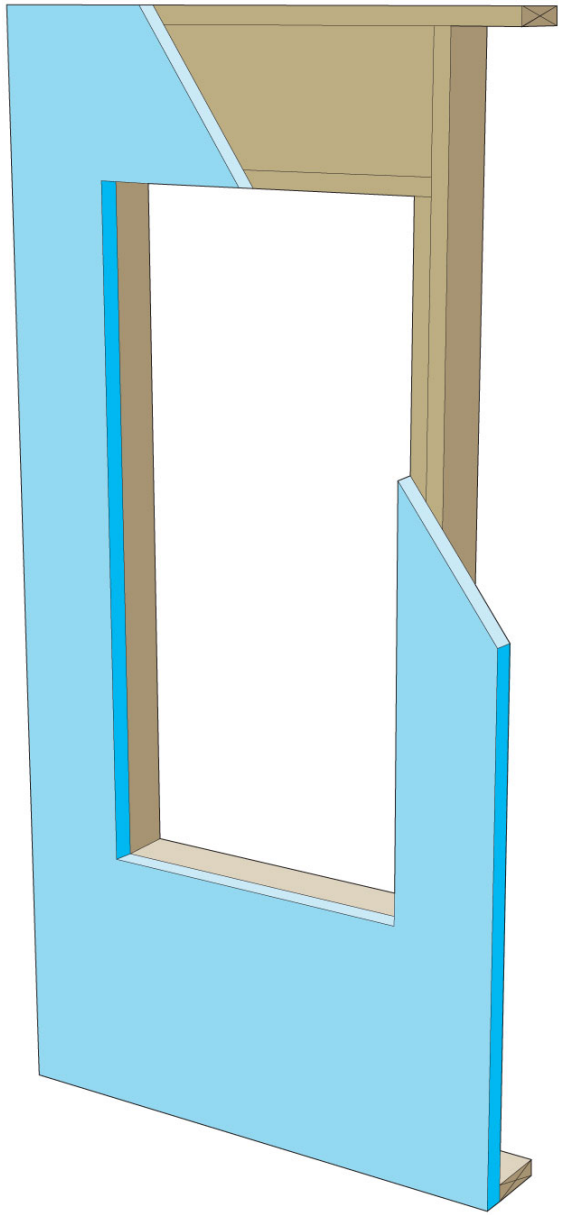


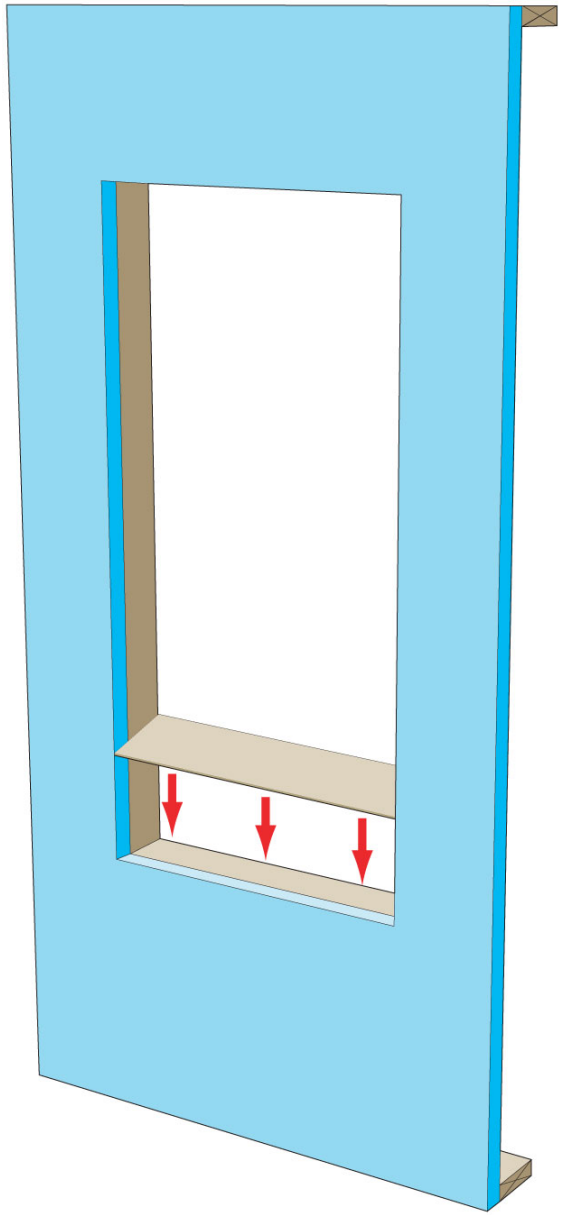


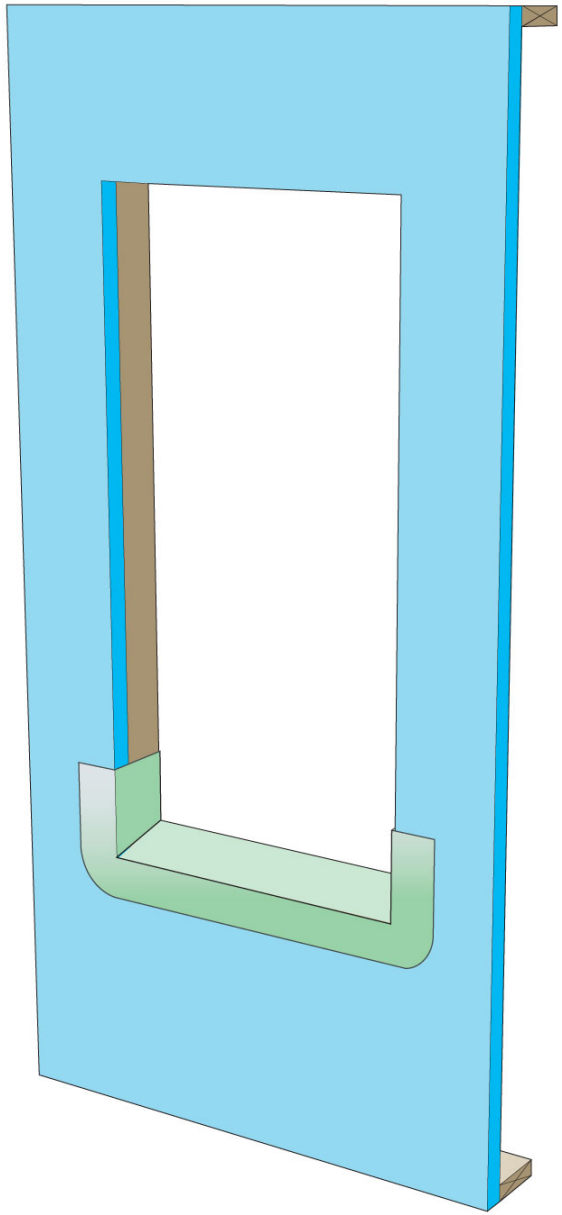


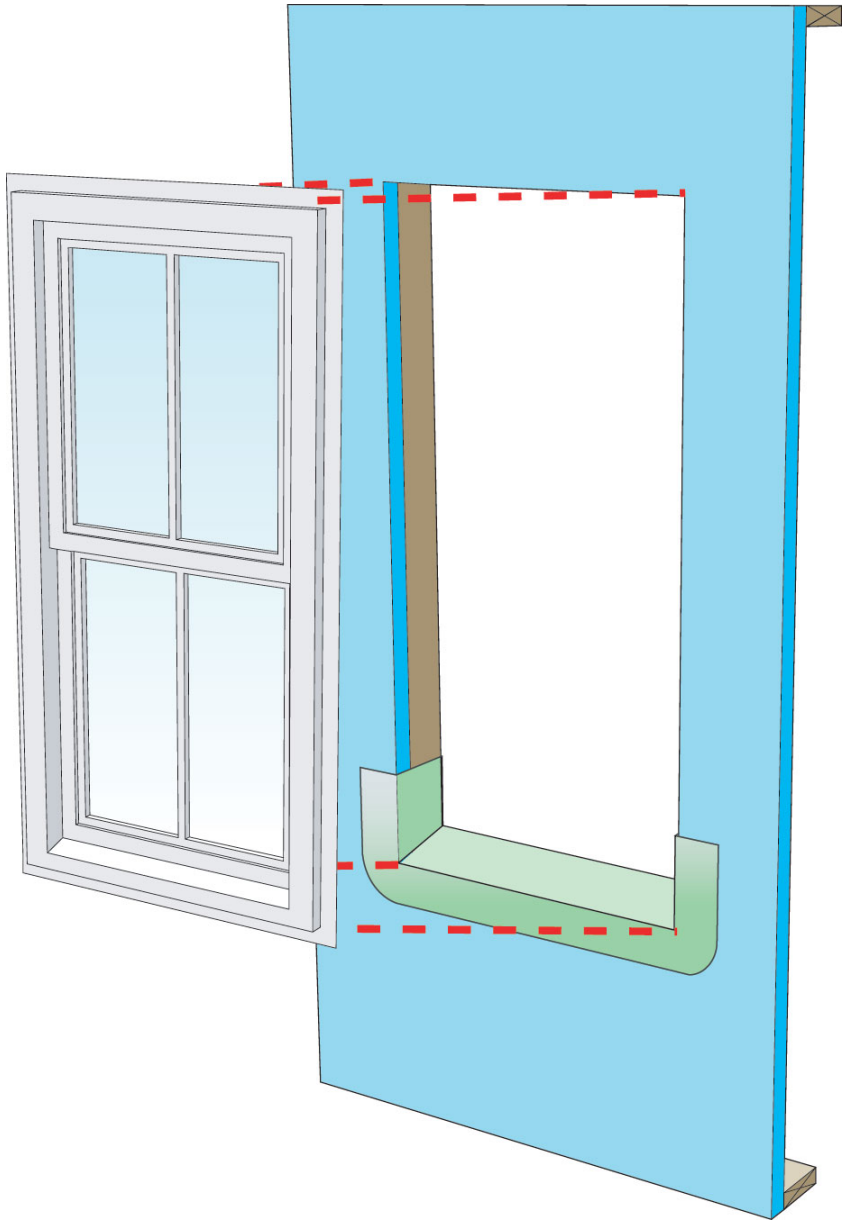


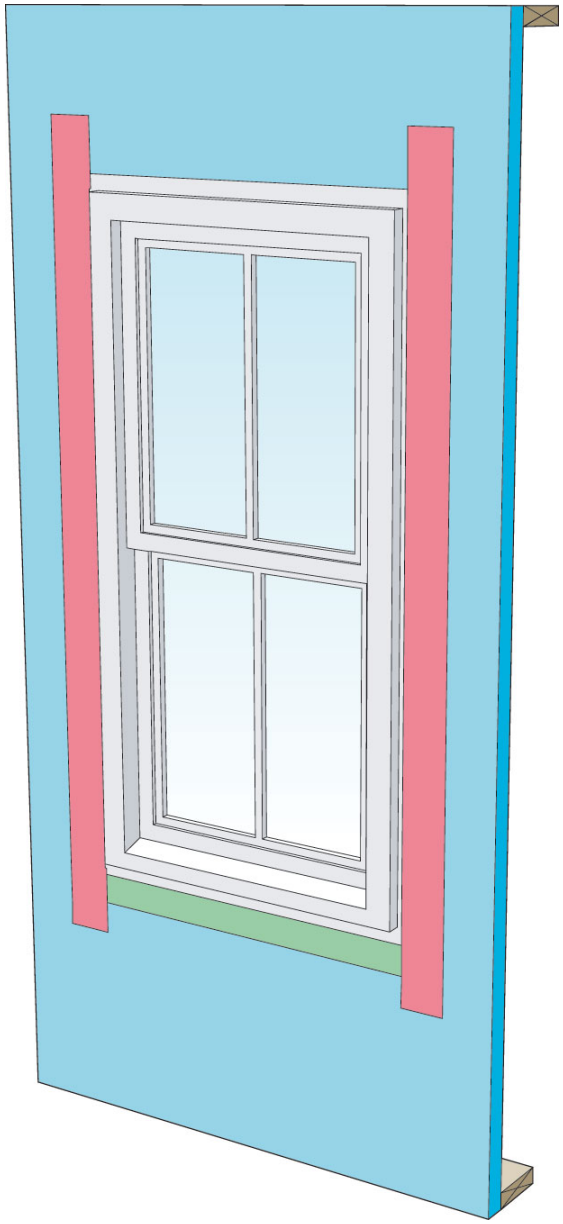

RCI
WARNING: DuPont™ Tyvek®
AVERTISSEMENT: Le matériau
stalled as an air barrier ac

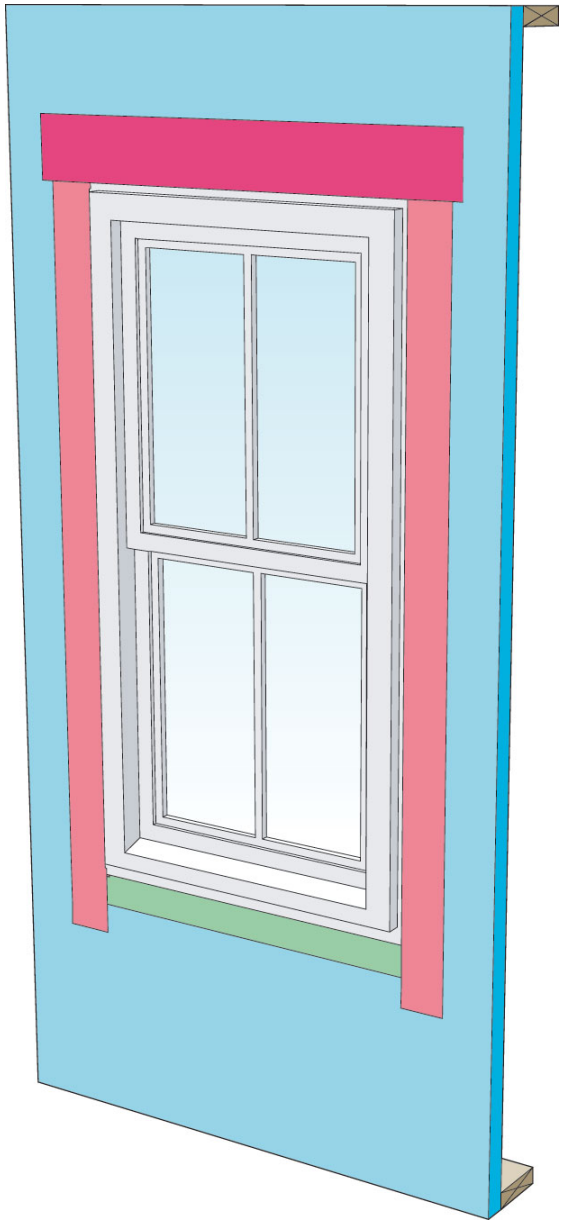


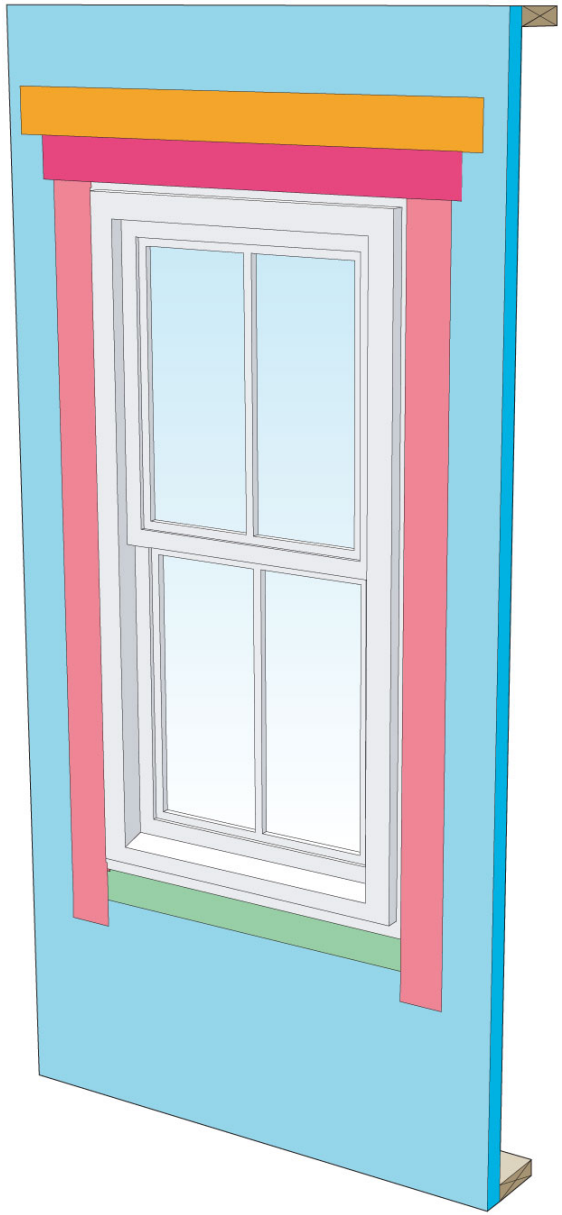


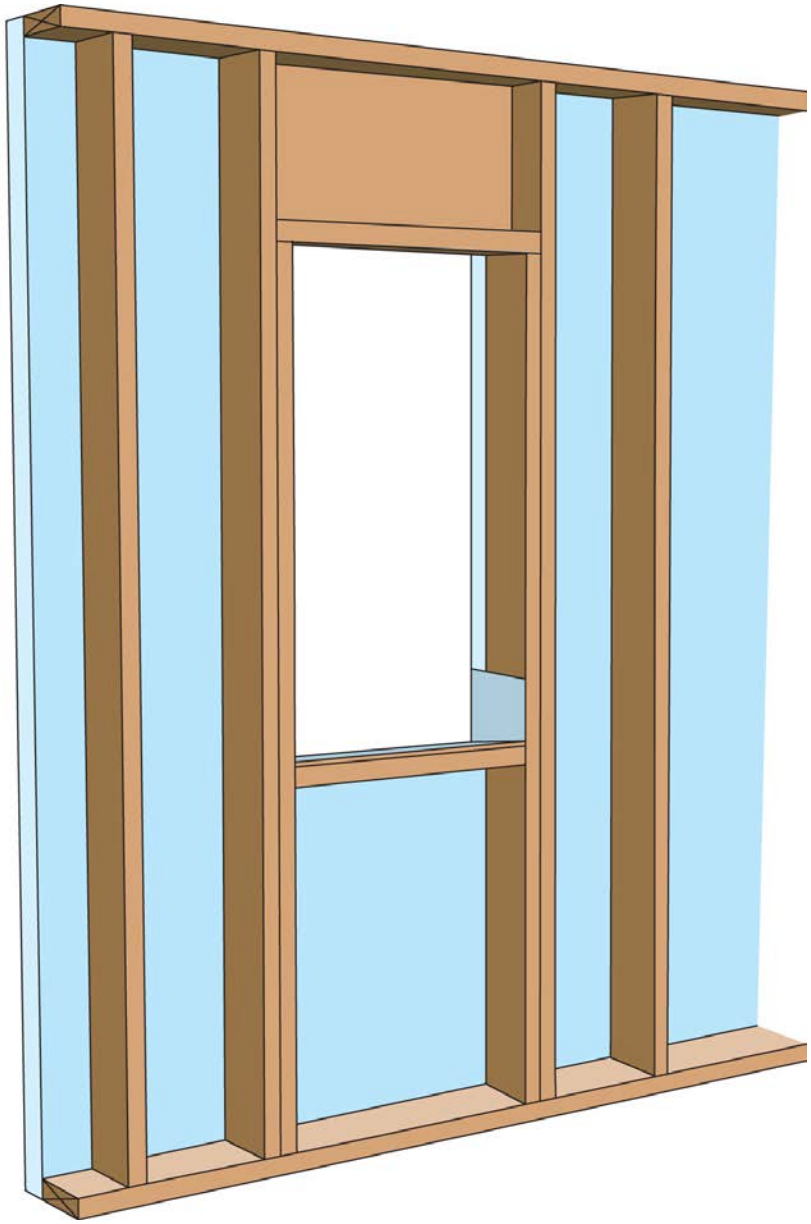


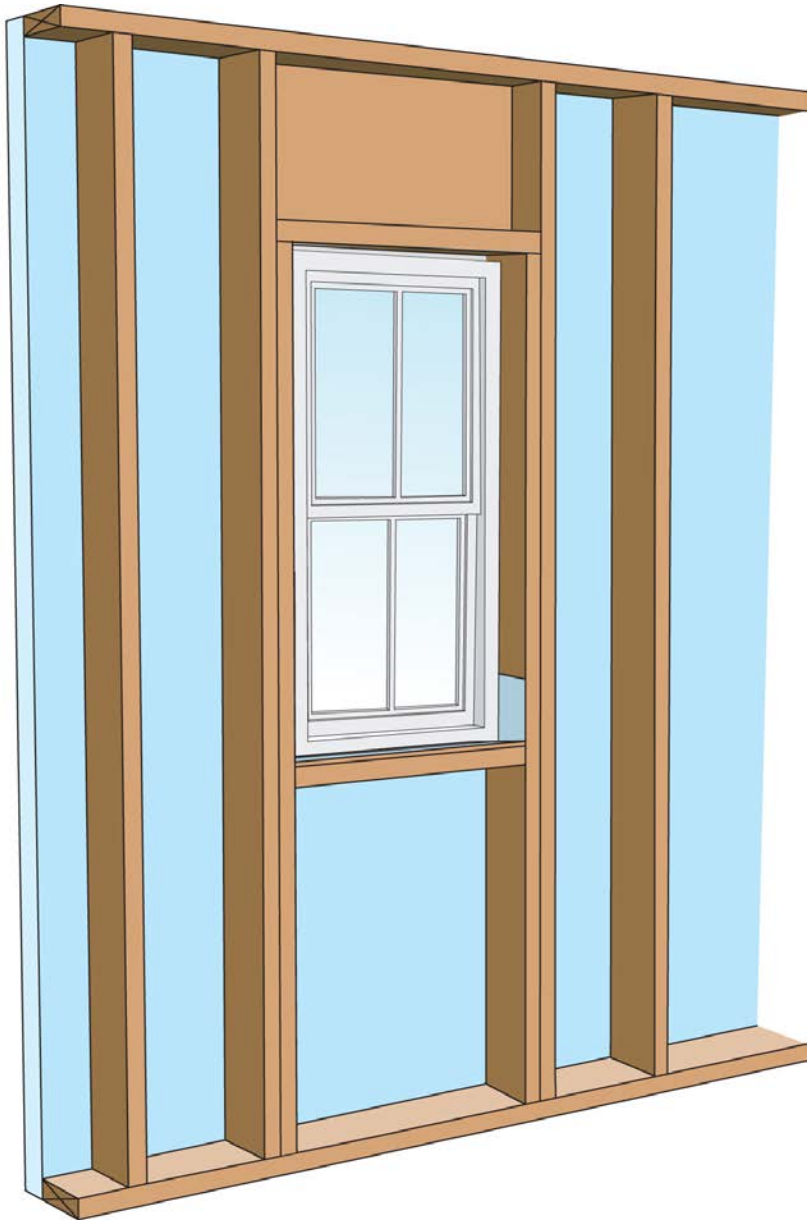


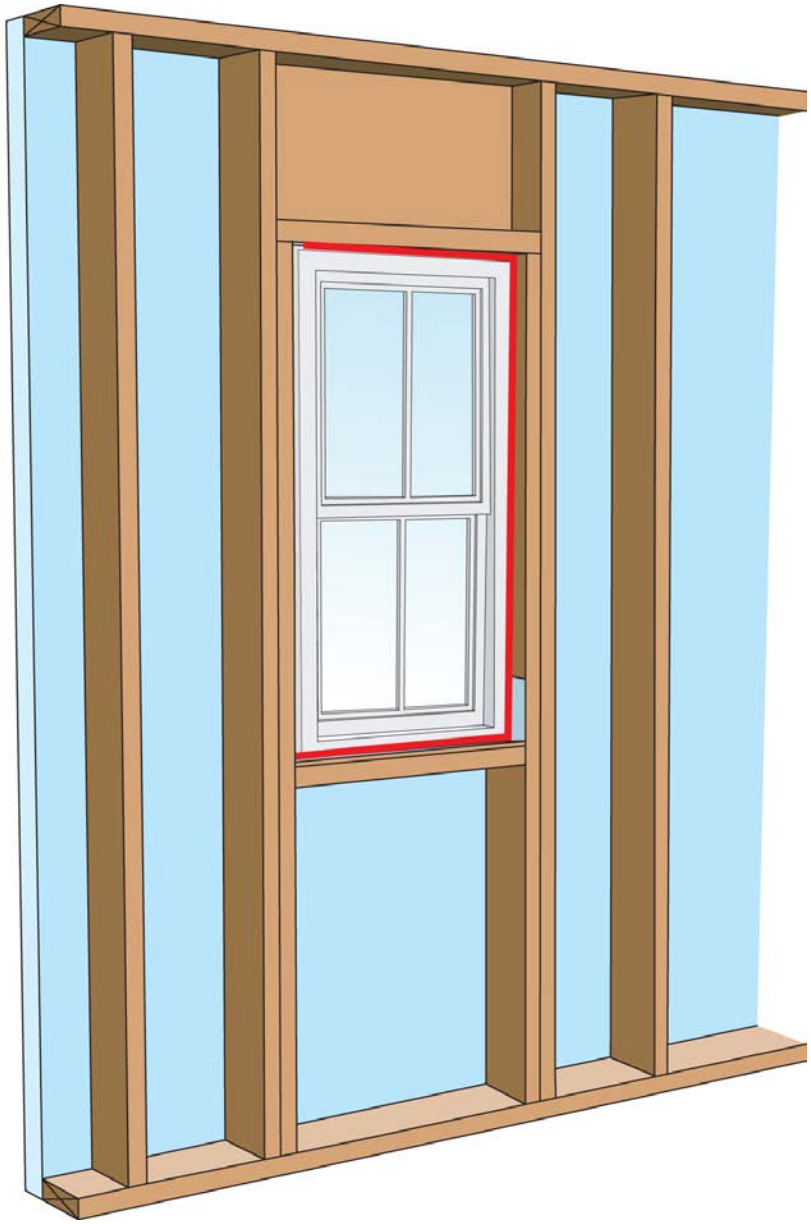










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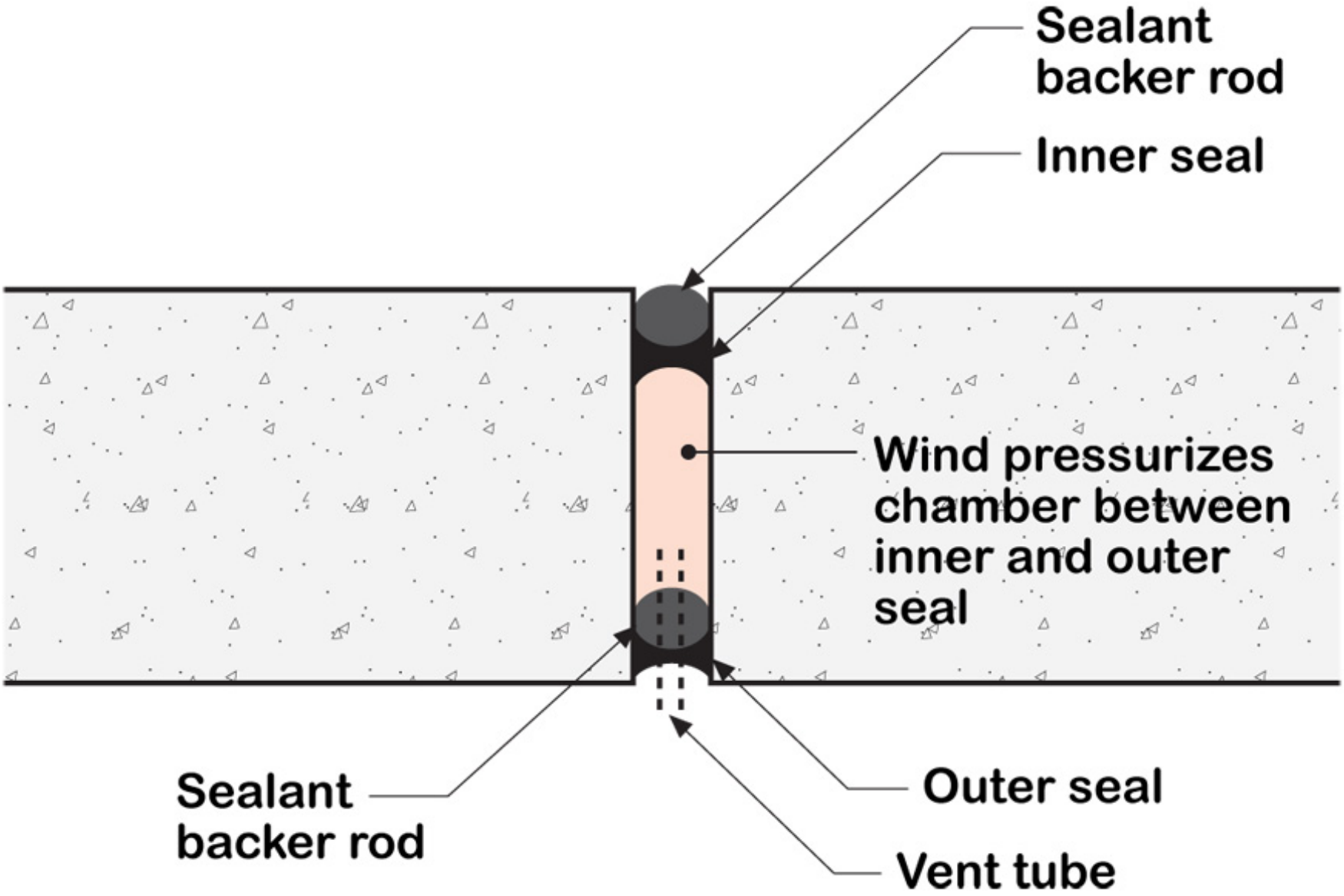
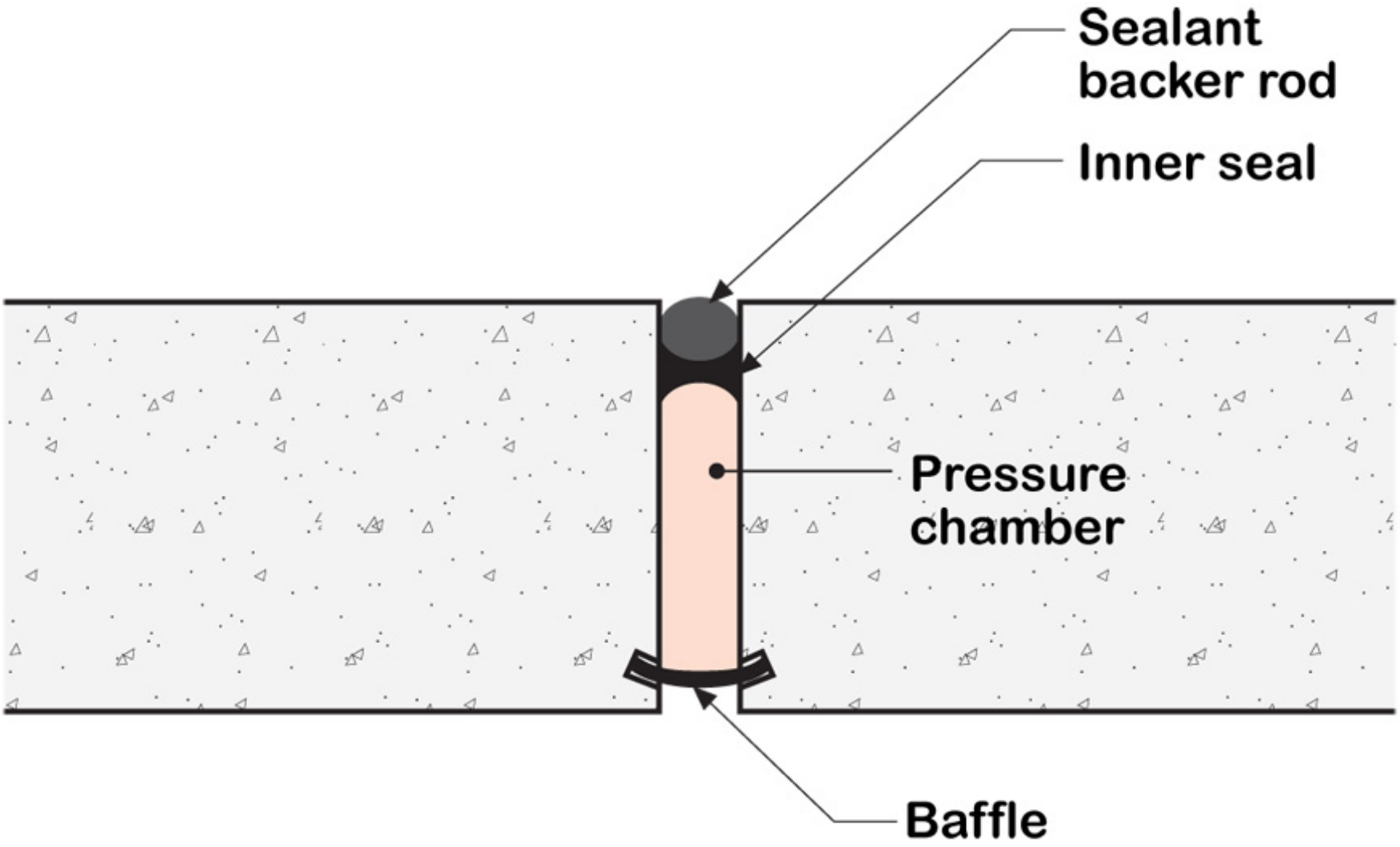
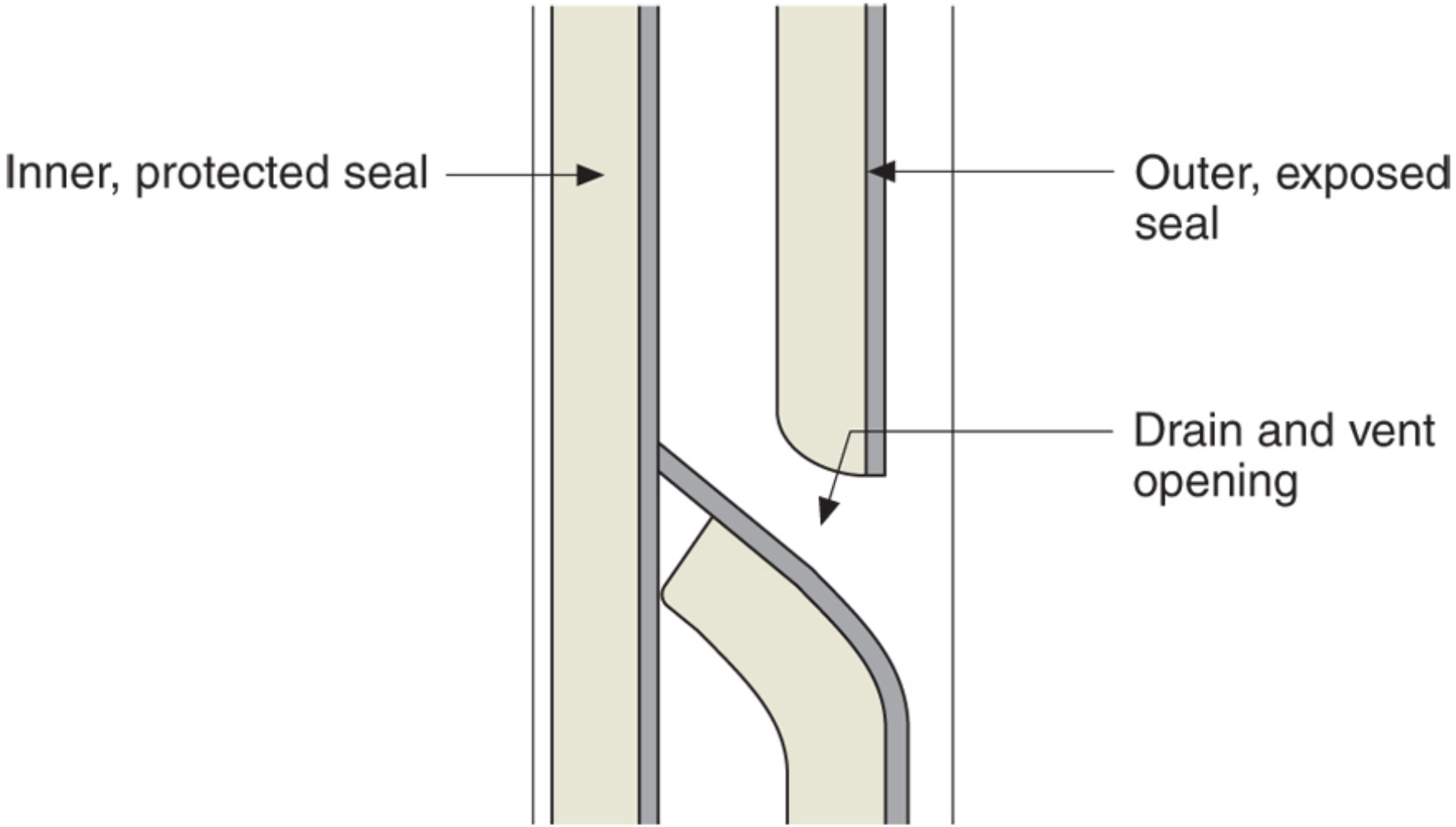
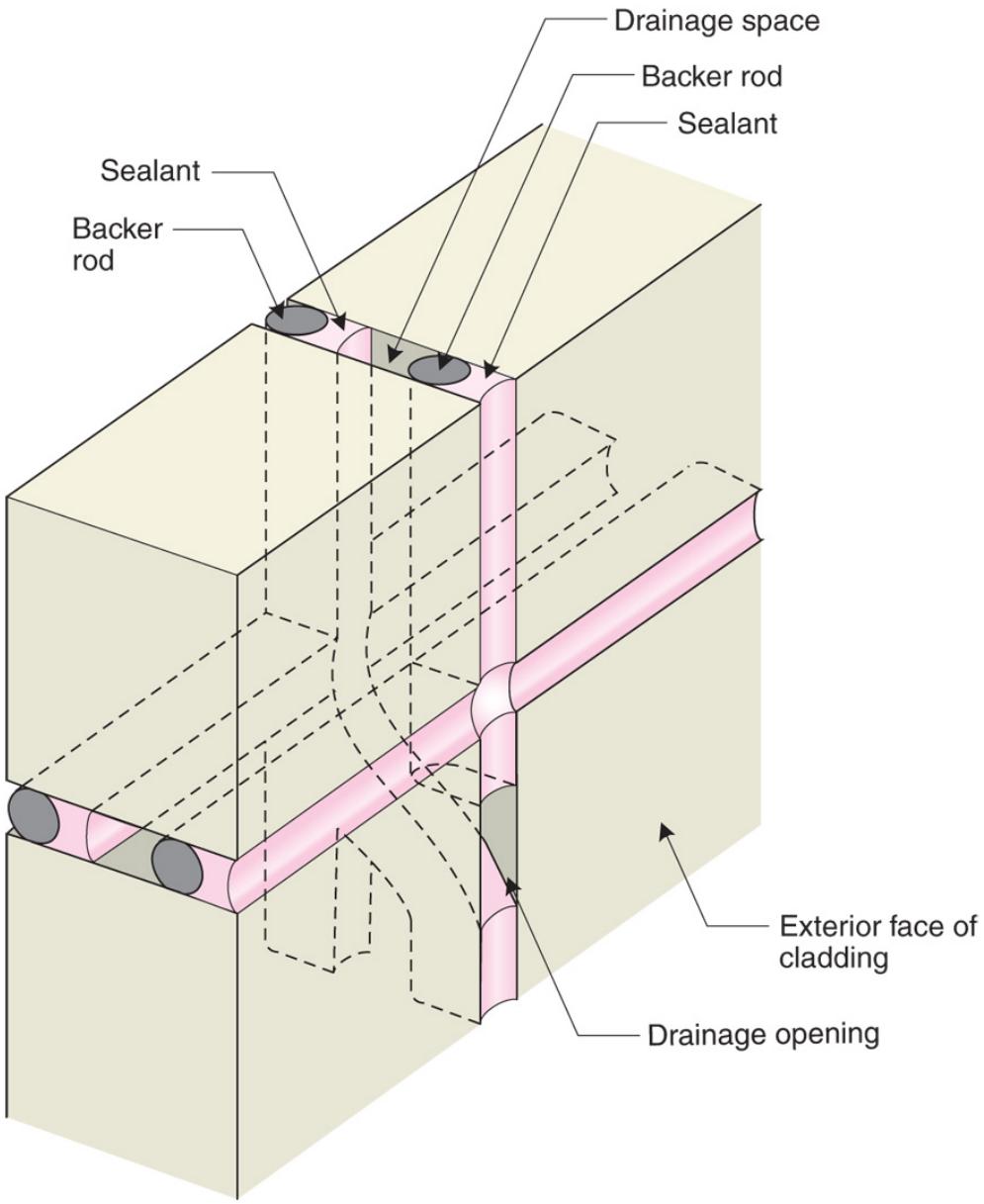

Sealant backer rod
Inner seal
Wind pressurizes chamber between inner and outer seal
Sealant backer rod
Outer seal
Vent tube


Sealant
backer rod
Inner seal
Pressure
chamber
Baffle


Inner, protected seal
Outer, exposed seal
Drain and vent opening


Drainage space
Backer rod
Sealant
Sealant
Backer rod
Exterior face of cladding
Drainage opening