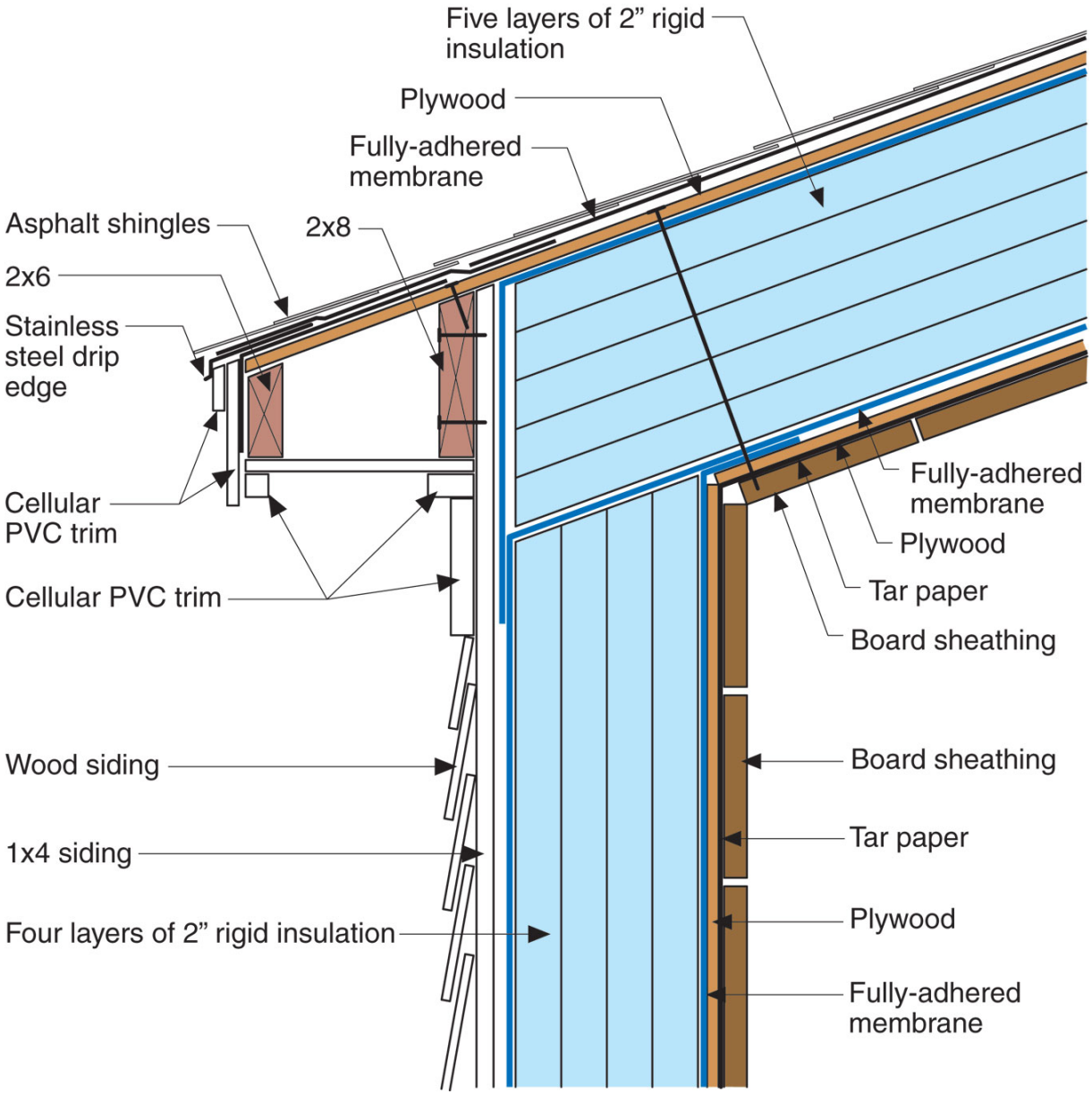
Joseph Lstiburek, Ph.D., P.Eng, ASHRAE Fellow

Building Science

Adventures In Building Science

www.buildingscience.com


Five layers of 2” rigid insulation
Plywood
Fully-adhered membrane
Asphalt shingles
2x8
2x6
Stainless steel drip edge
Cellular PVC trim
Cellular PVC trim
Wood siding
1x4 siding
Four layers of 2” rigid insulation
Fully-adhered membrane
Plywood
Tar paper
Board sheathing
Board sheathing
Tar paper
Plywood
Fully-adhered membrane

GRACE

Super TUFF-R
DOW

DOW
Super TUFF-R
Commercial Insulation

TUFF-R
TUFF-R
TUFF-R

Arrhenius Equation

For Every 10 Degree K Rise

Activation Energy Doubles

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

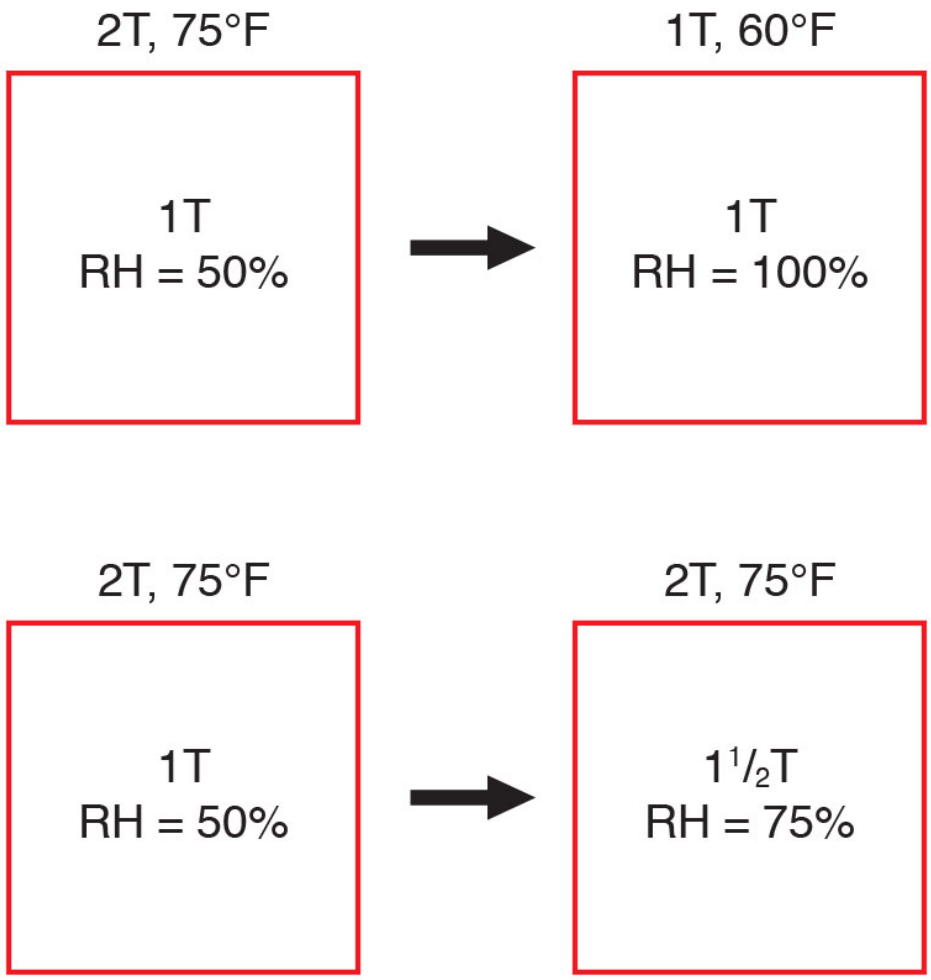
Damage Functions

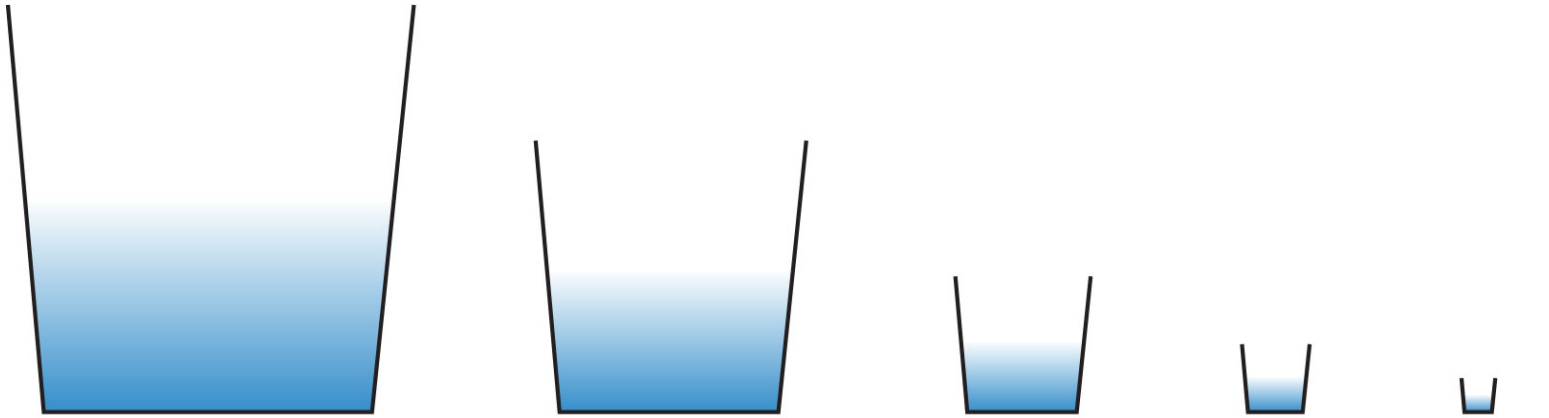
Water

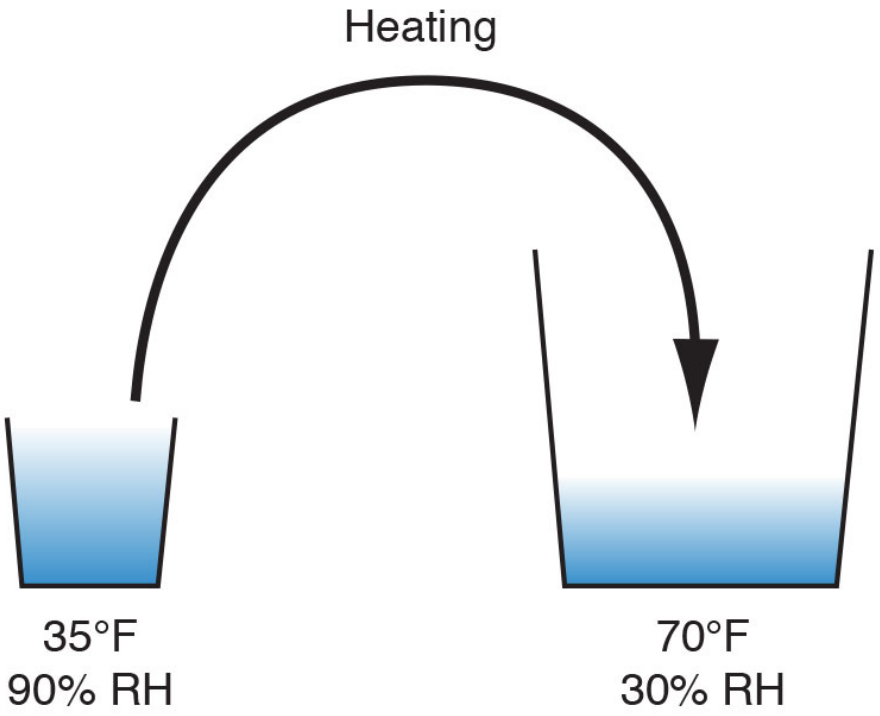
Heat

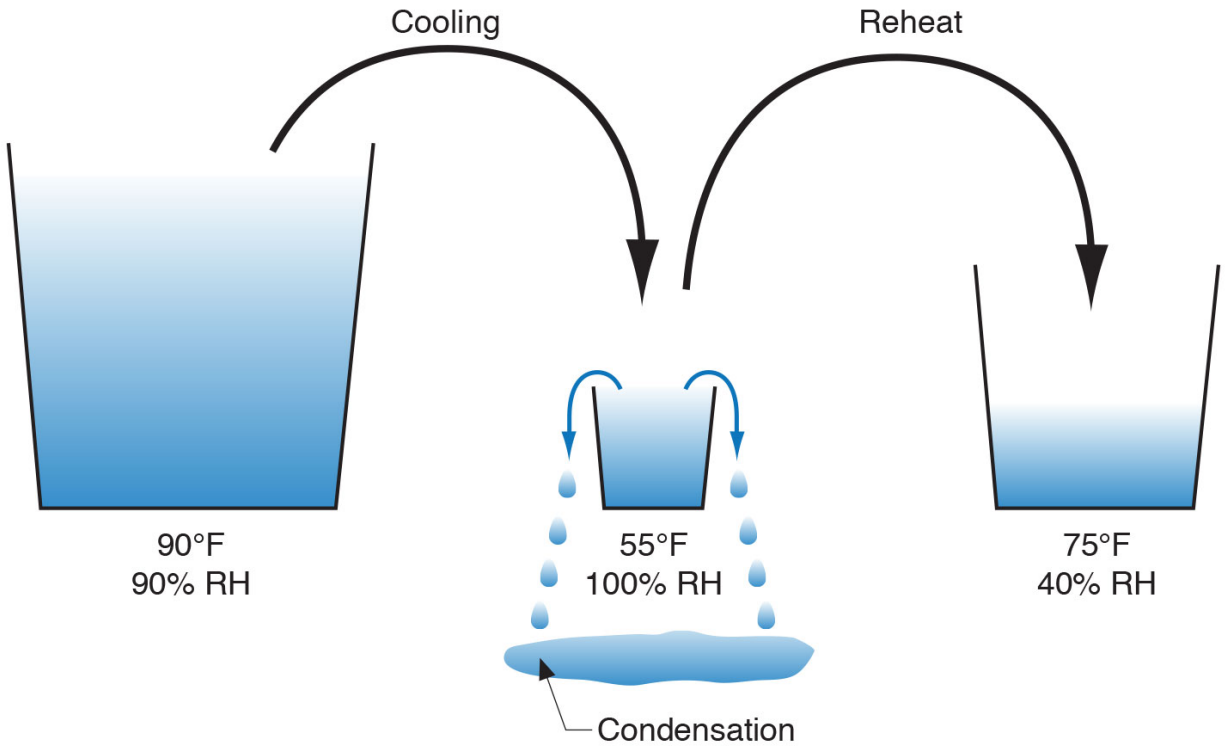
Ultra-violet Radiation

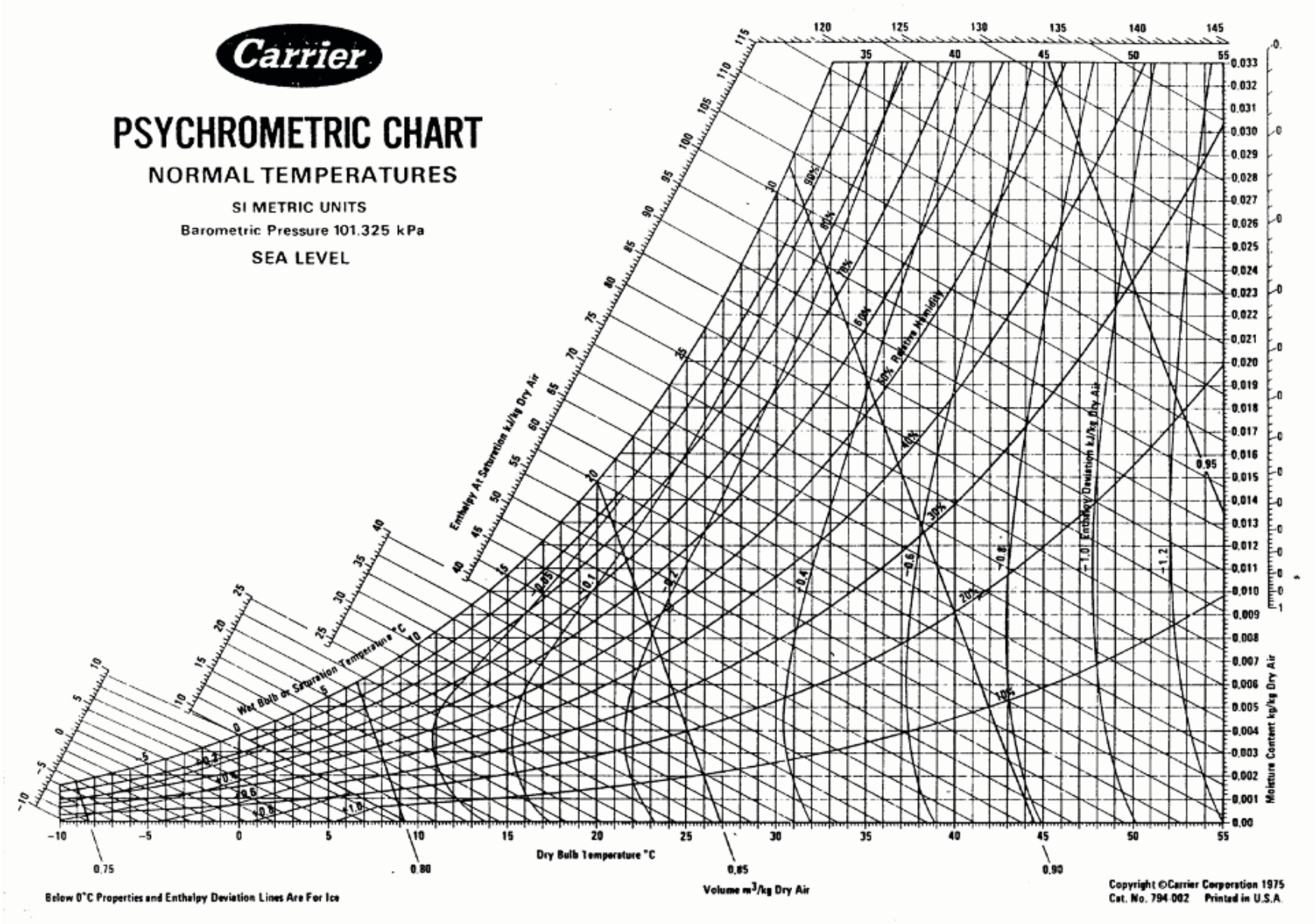
Vapor Pressure and Relative Humidity


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

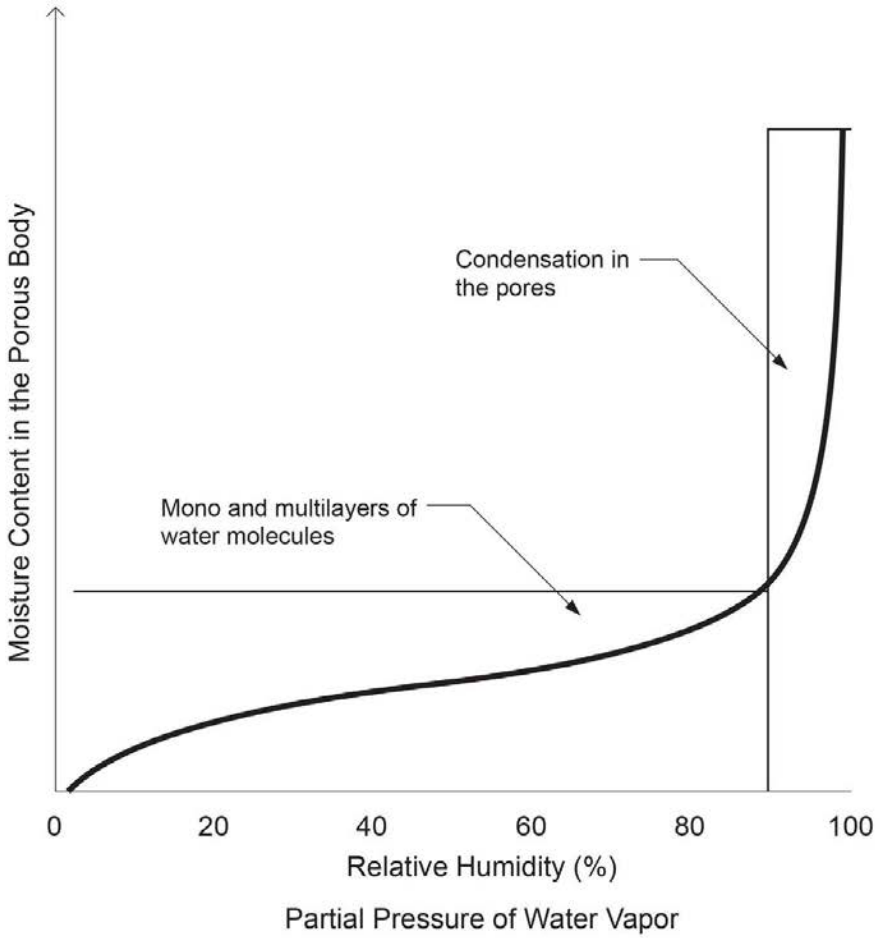

90°F
50% RH
75°F
50% RH
60°F
50% RH
45°F
50% RH
30°F
50% RH


Heating
35°F
90% RH
70°F
30% RH


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


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

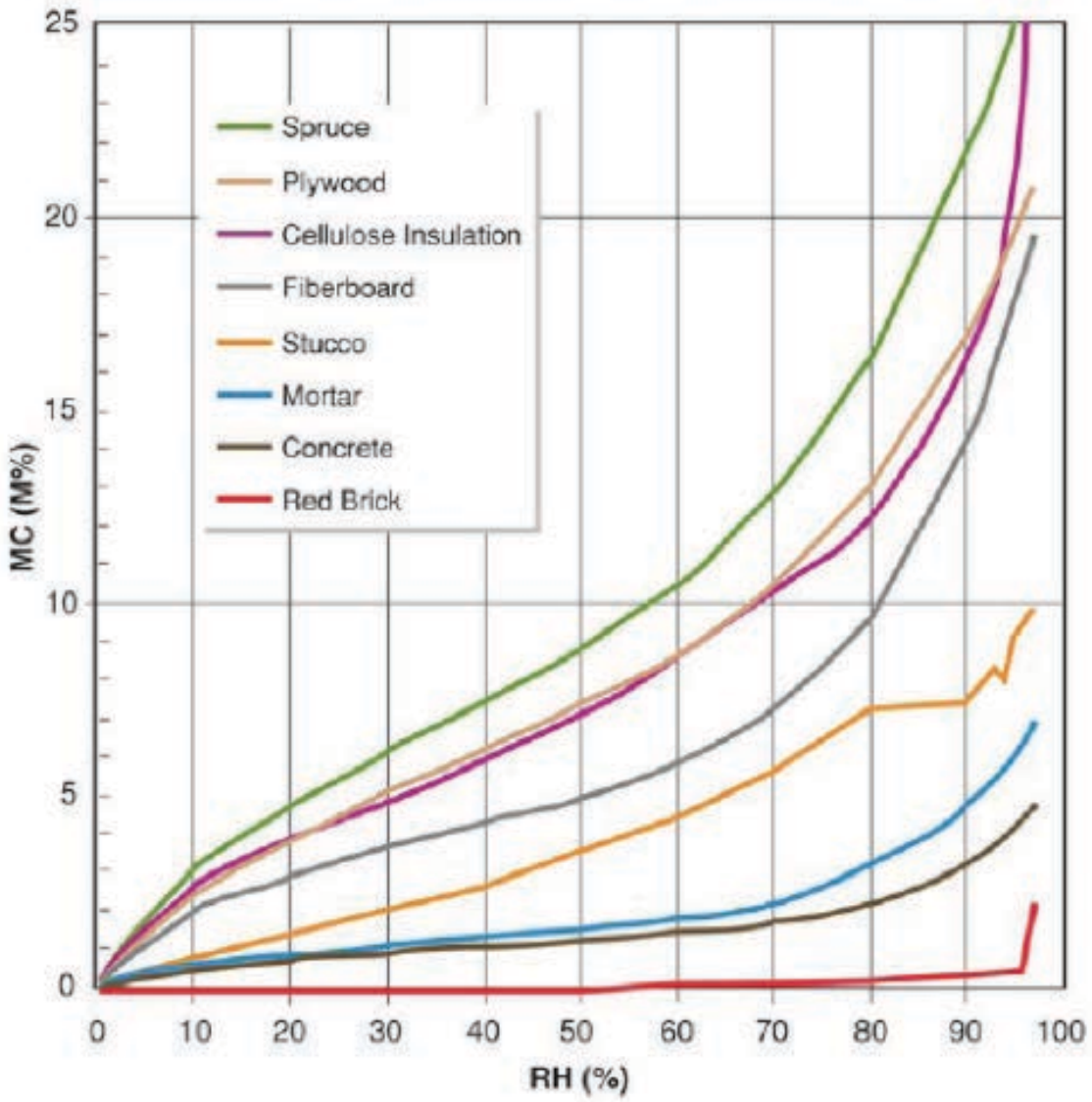
Sorption Isotherms

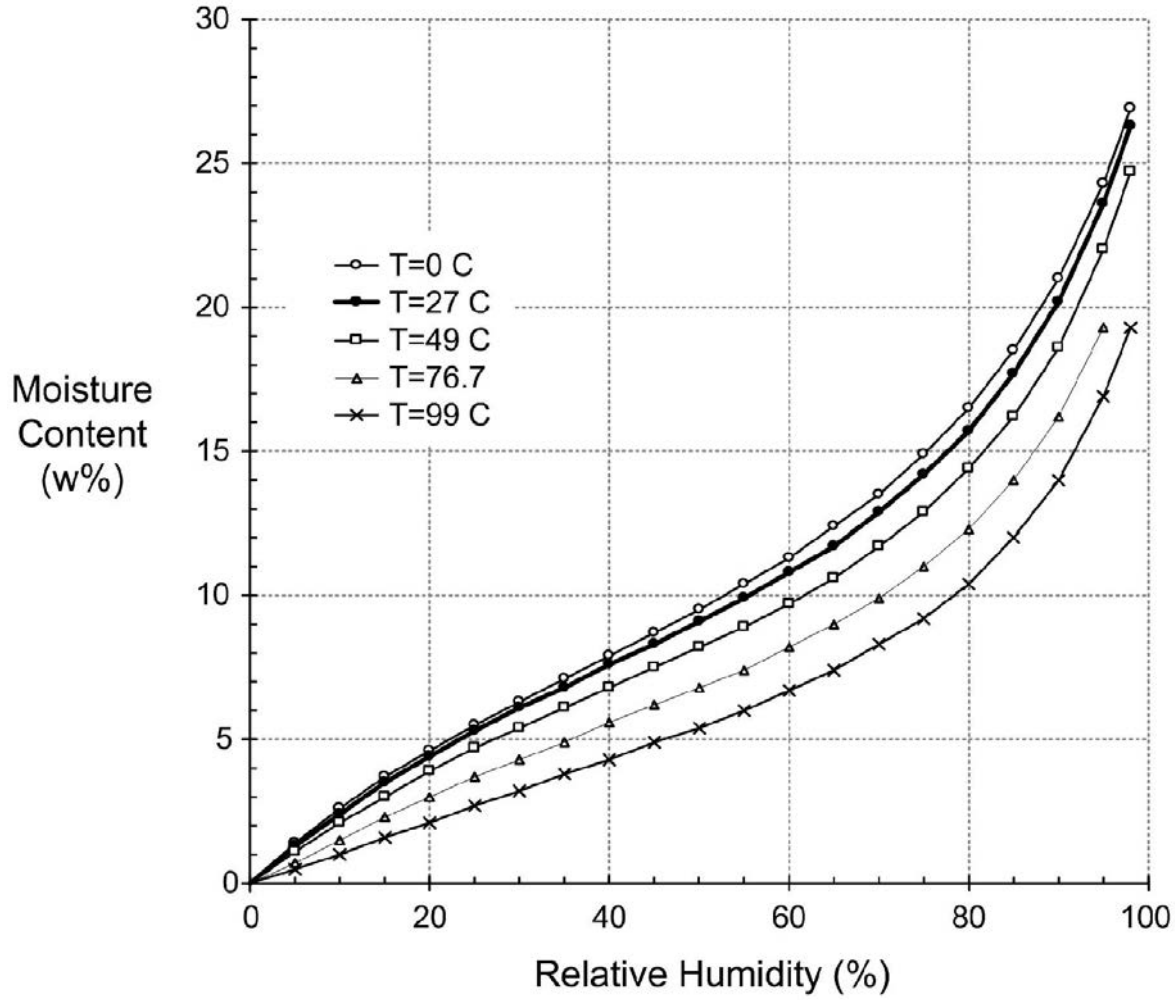


Change in the storage of moisture in a porous building material as the partial pressure of water vapor in the ambient air increases from zero to full saturation value at a given temperature.

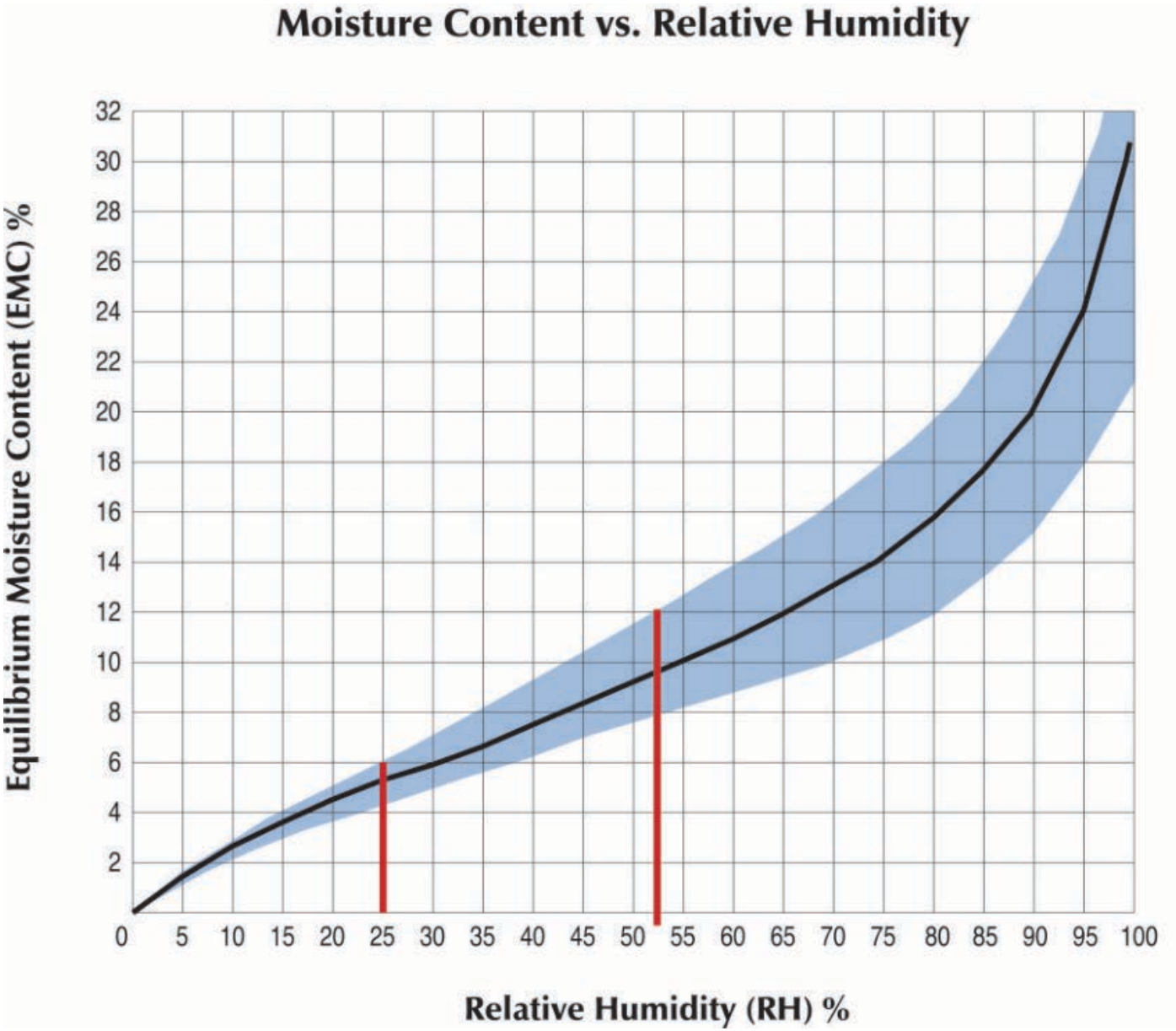
Sorption Curve

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


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



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


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

2nd Law of Thermodynamics

Heat Flow Is From Warm To Cold

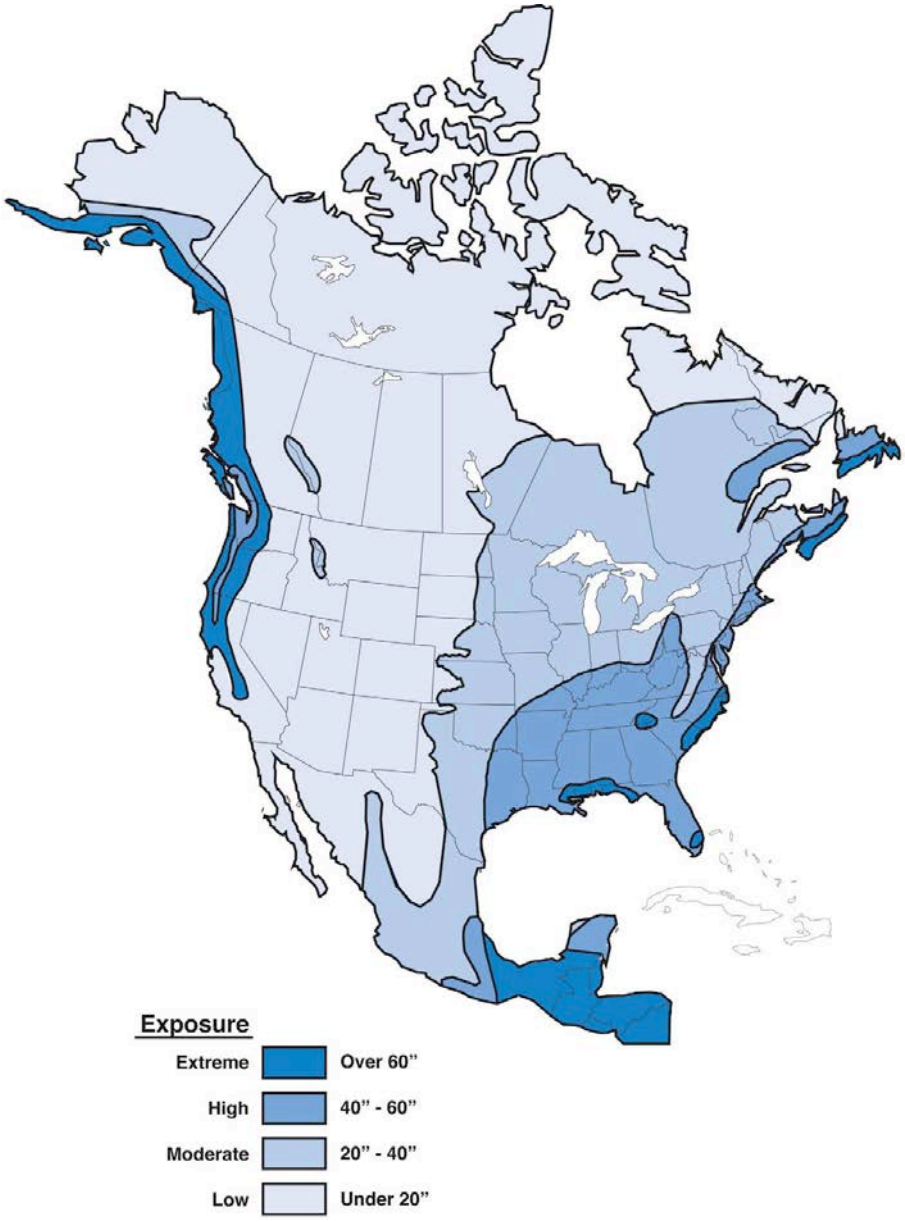
Moisture Flow Is From Warm To Cold

Moisture Flow Is From More To Less

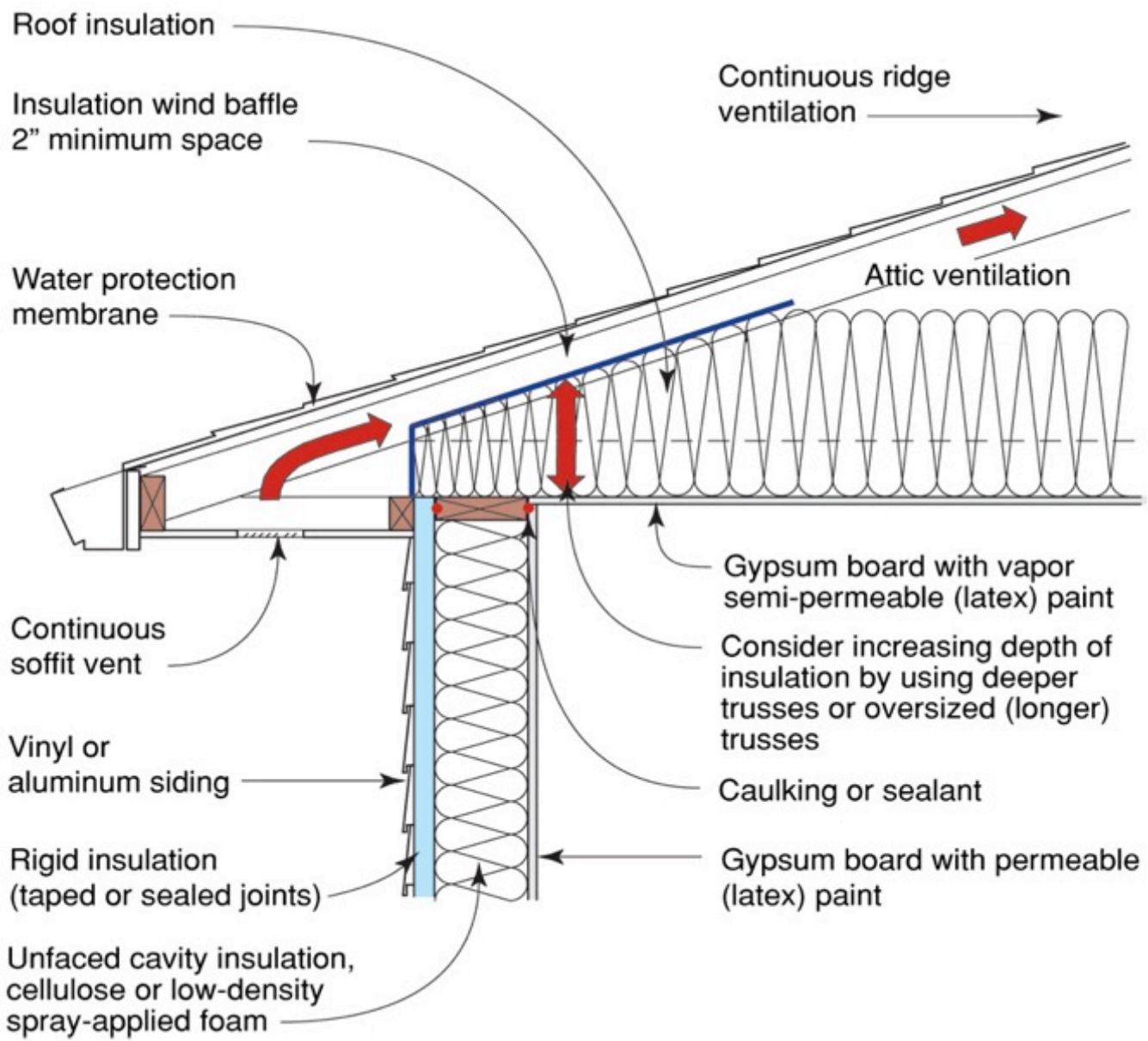
Air Flow Is From A Higher Pressure to a Lower Pressure

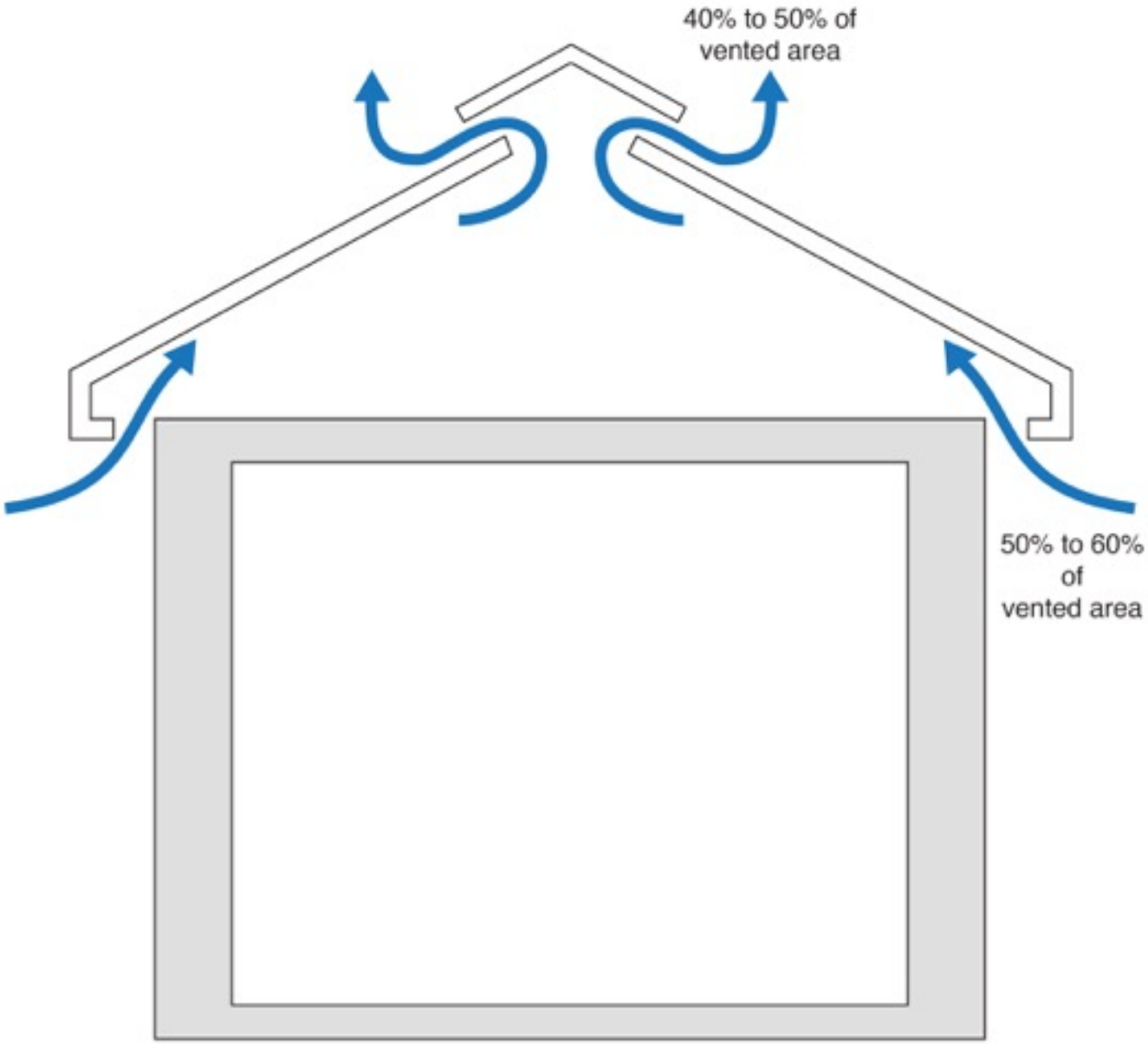
Gravity Acts Down

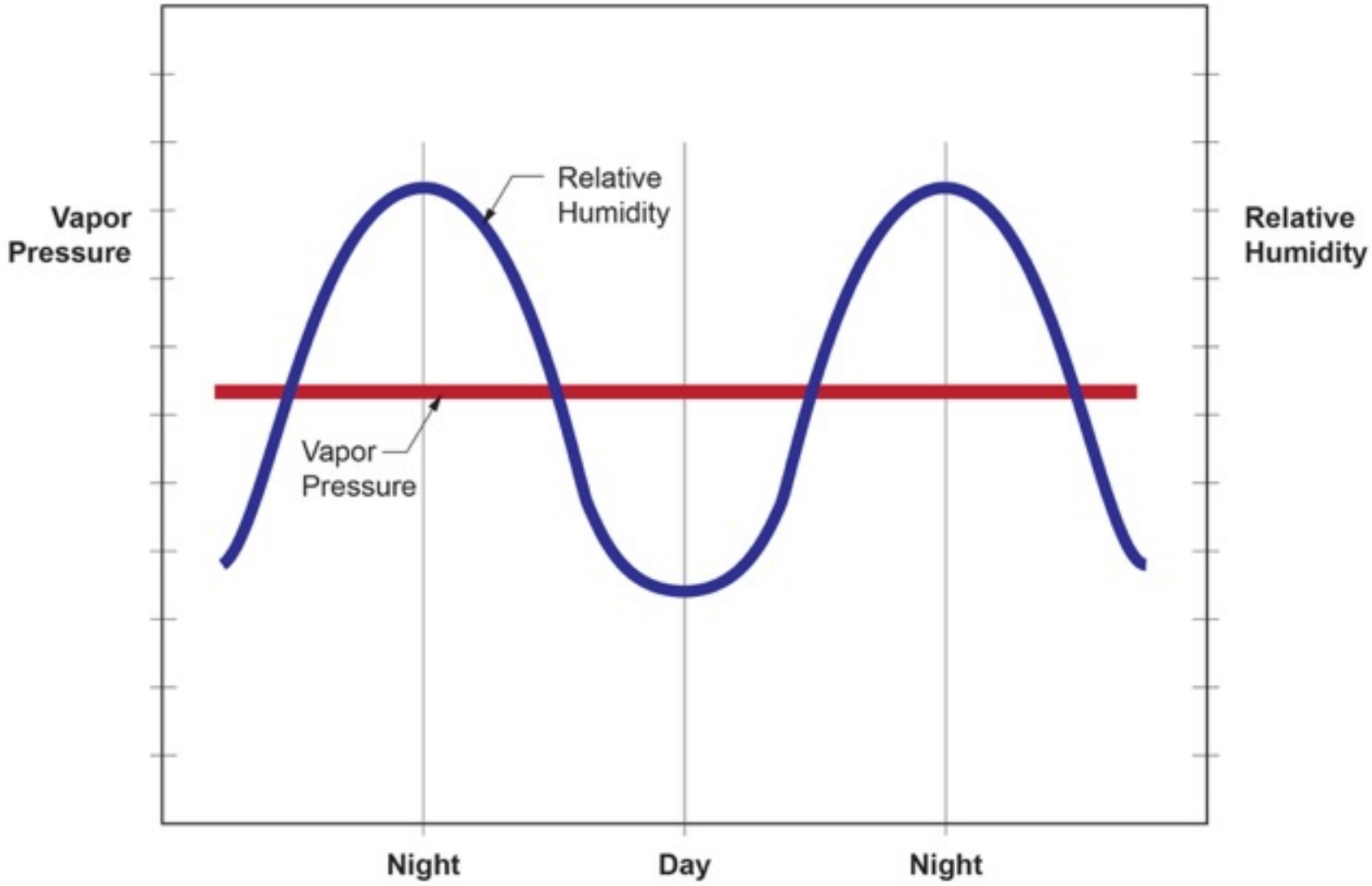
Subarctic/Arctic
Very Cold
Marine
Cold
Mixed-Humid
Mixed-Dry
Hot-Humid
Hot-Dry


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

Vented Attics Are Climate Dependant


Roof insulation
Insulation wind baffle
2" minimum space
Continuous ridge
ventilation
Water protection
membrane
Attic ventilation
Gypsum board with vapor
semi-permeable (latex) paint
Continuous
soffit vent
Consider increasing depth of
insulation by using deeper
trusses or oversized (longer)
trusses
Vinyl or
aluminum siding
Caulking or sealant
Rigid insulation
(taped or sealed joints)
Gypsum board with permeable
(latex) paint
Unfaced cavity insulation,
cellulose or low-density
spray-applied foam


40% to 50% of
vented area
50% to 60%
of
vented area


Vapor Pressure
Relative Humidity
Relative Humidity
Vapor Pressure
Night
Day
Night

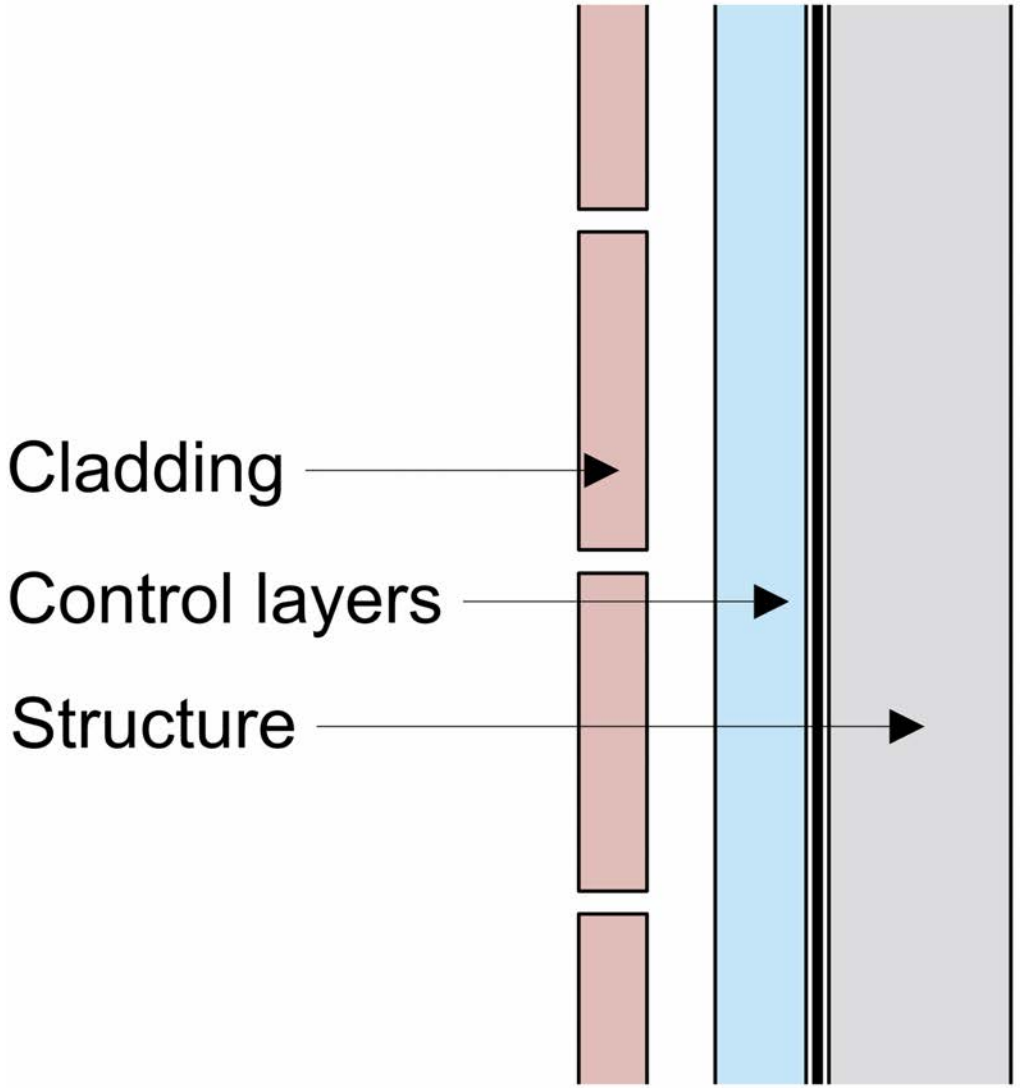
Enclosures

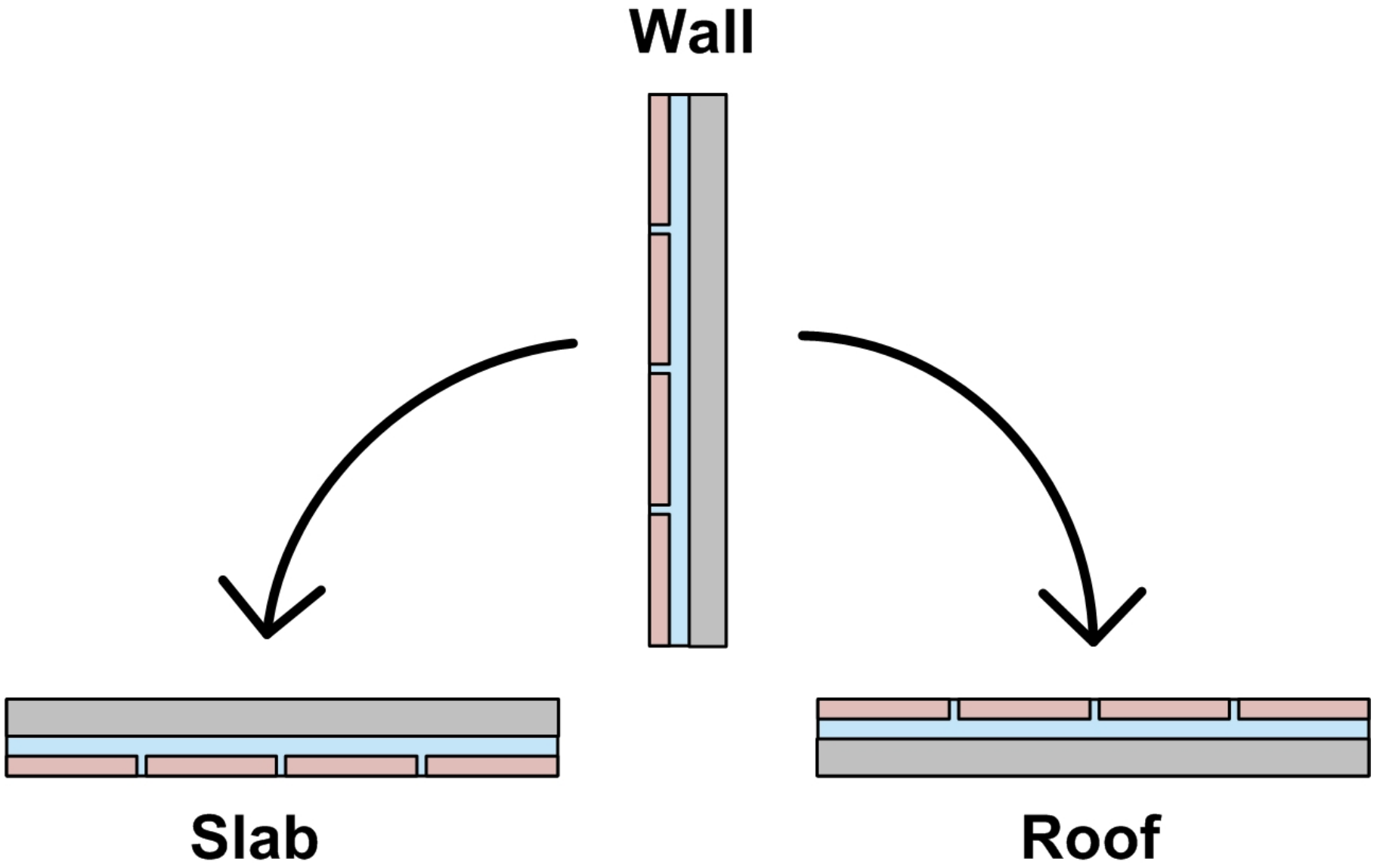
Water Control Layer

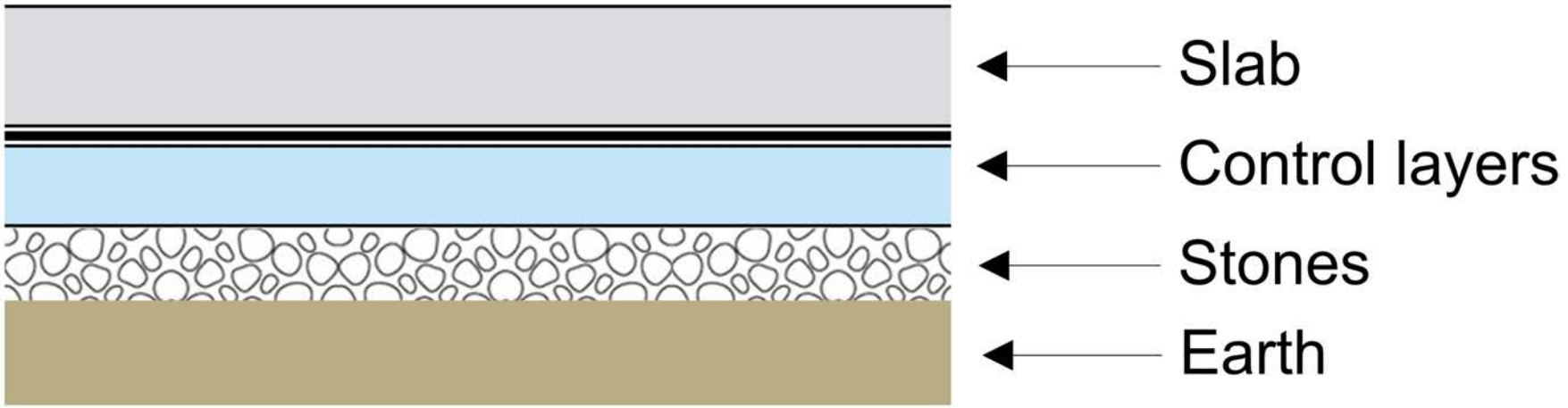
Air Control Layer

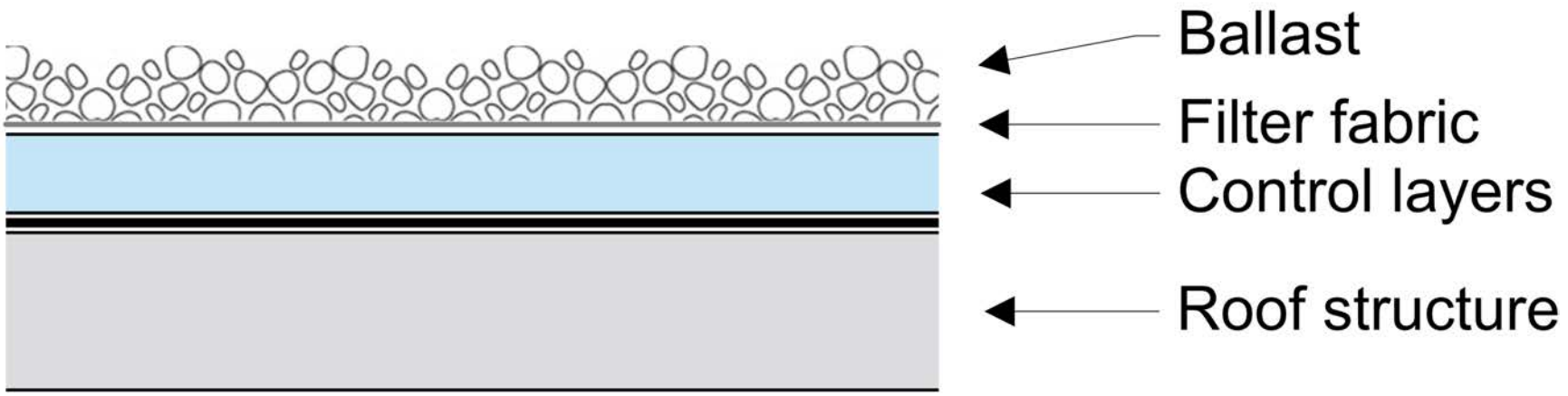
Vapor Control Layer

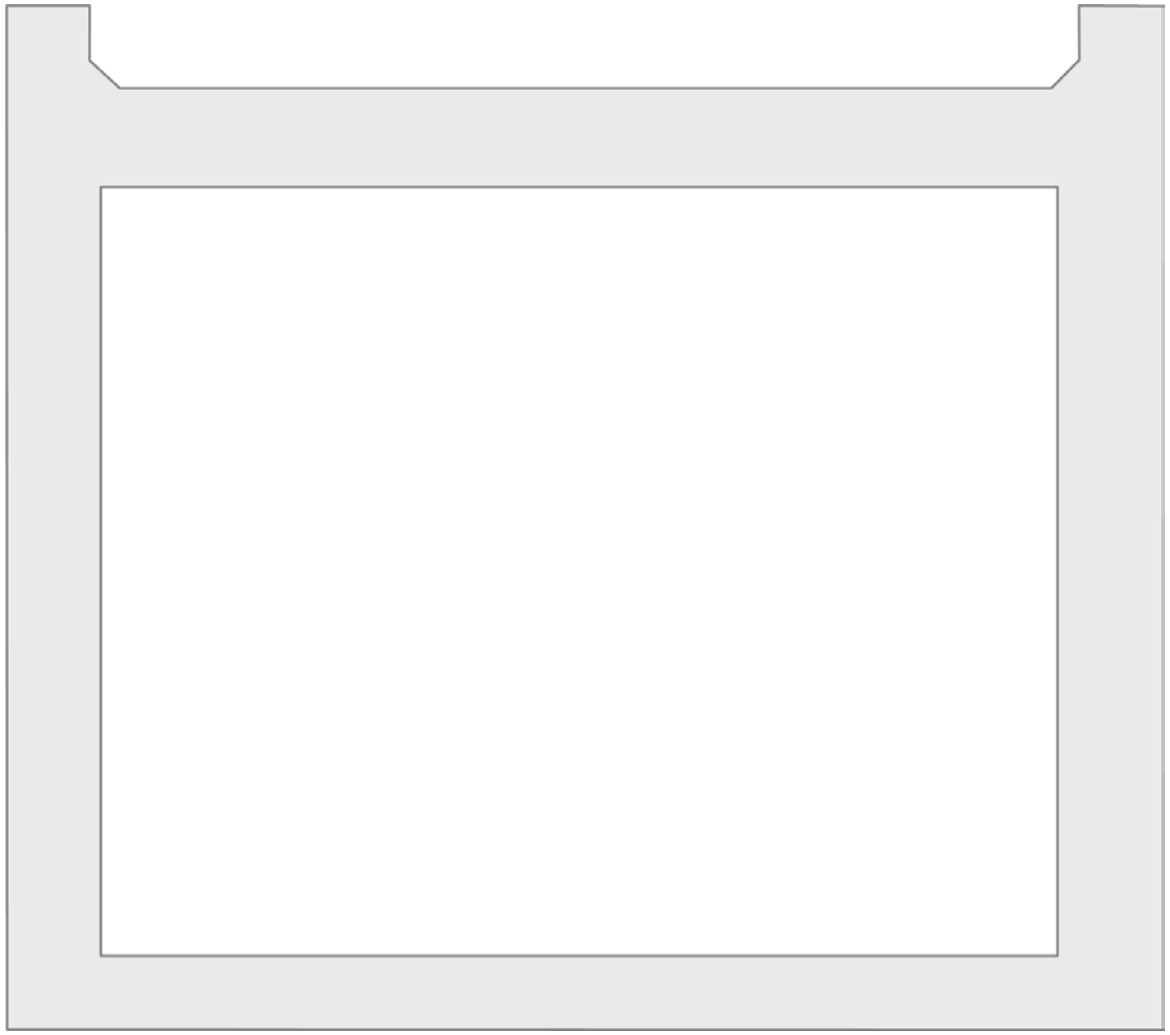
Thermal Control Layer

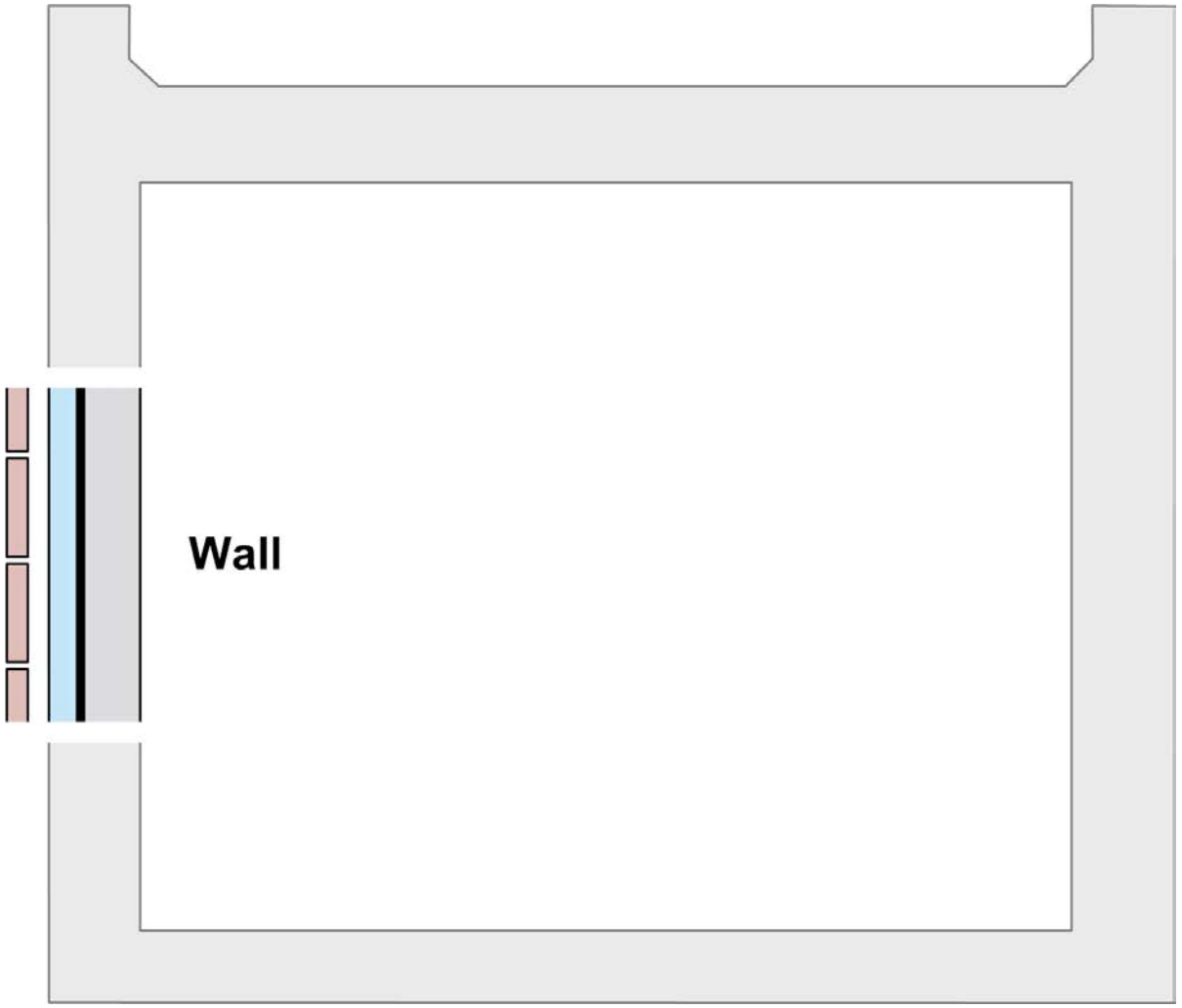

Cladding
Control layers
Structure

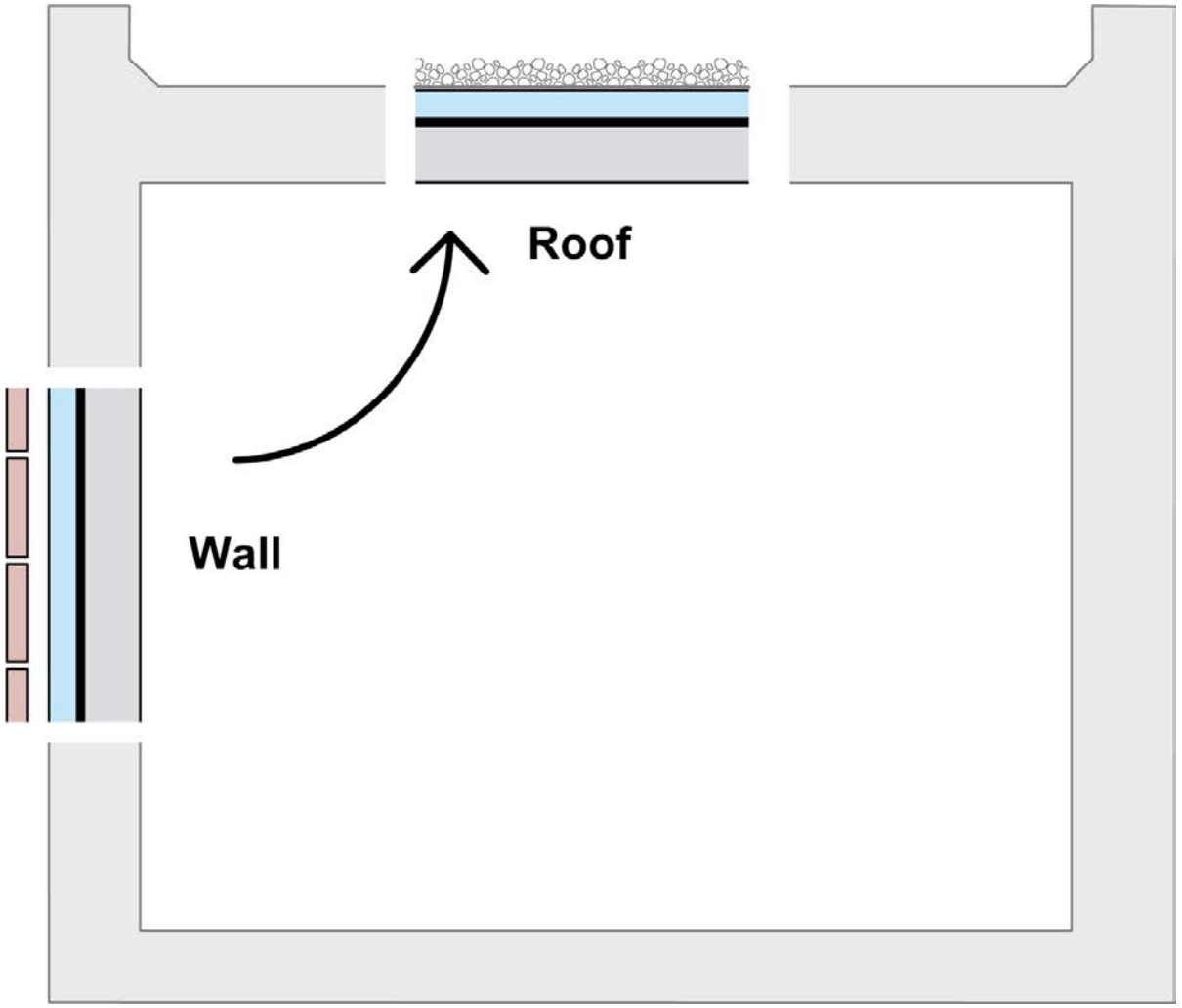

Wall
Slab
Roof

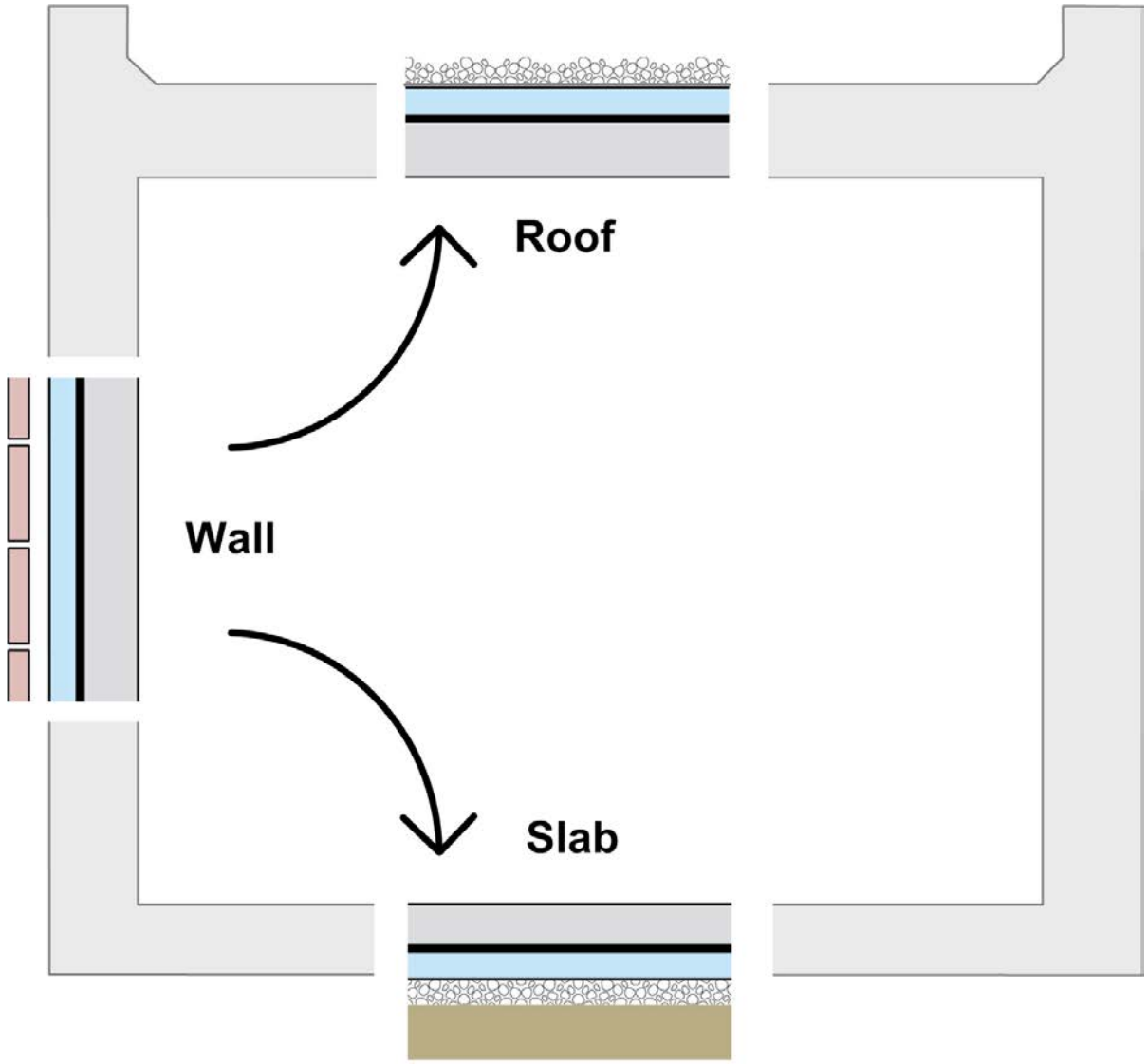

Slab
Control layers
Stones
Earth

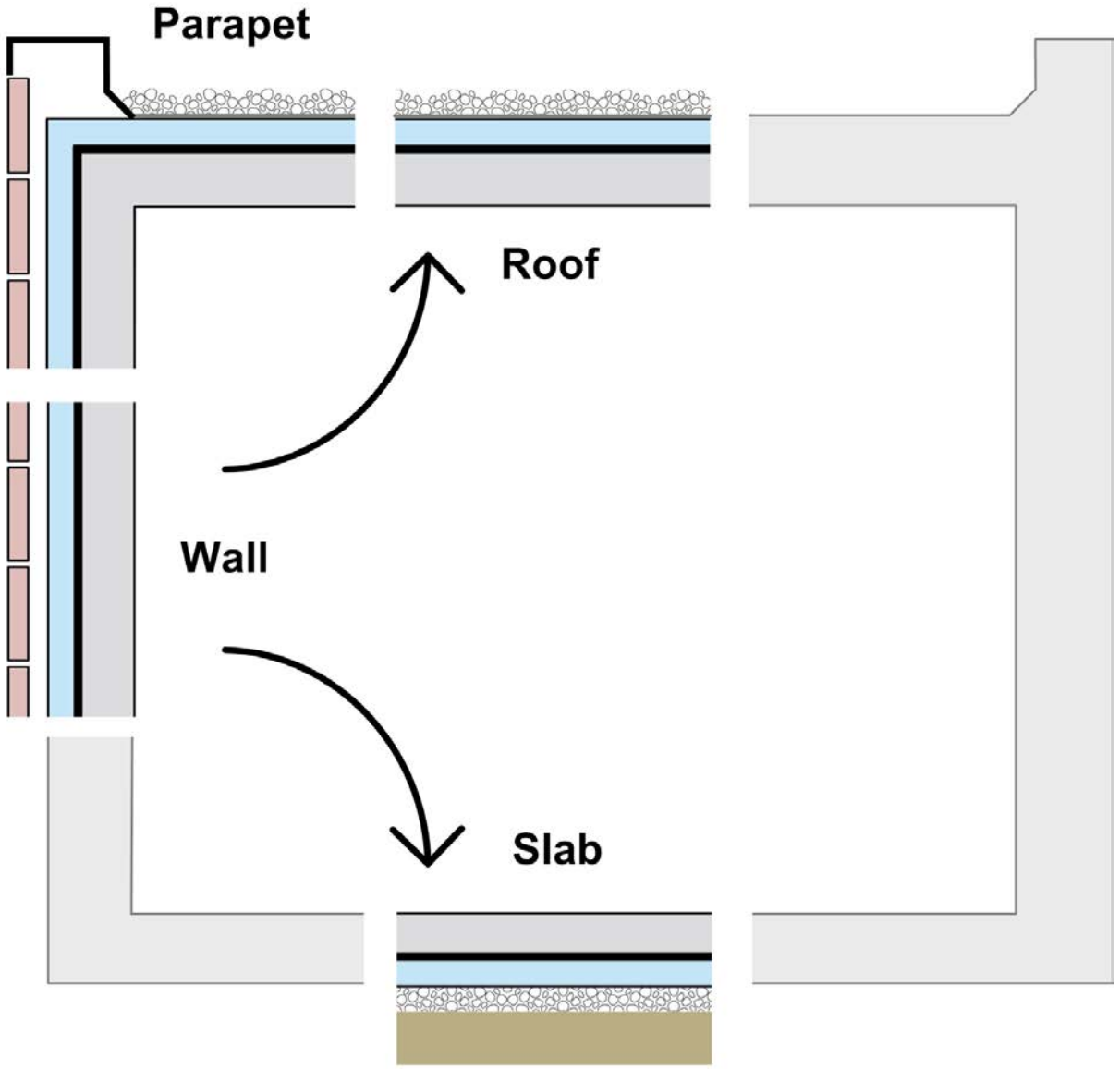

Ballast
Filter fabric
Control layers
Roof structure

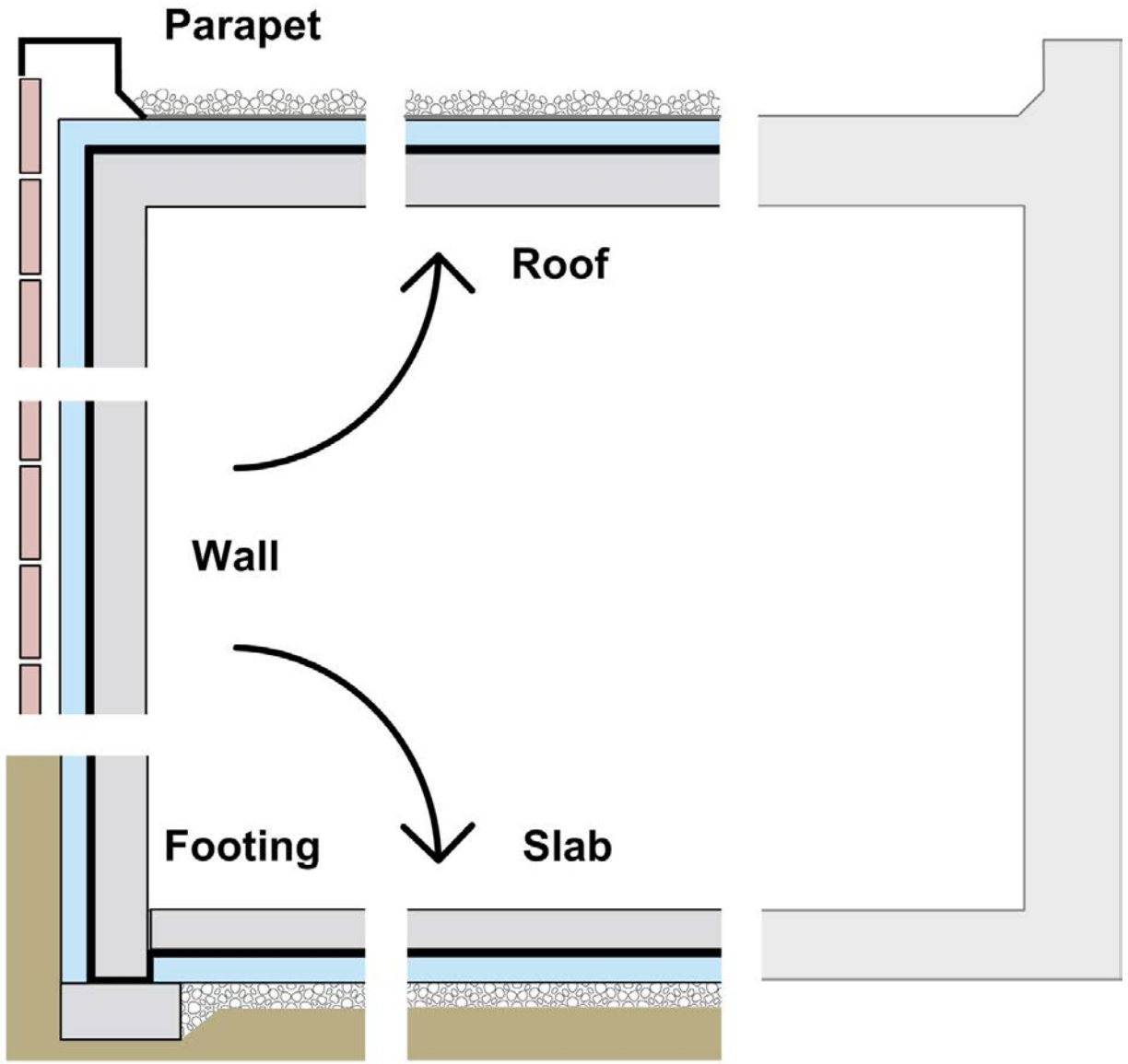


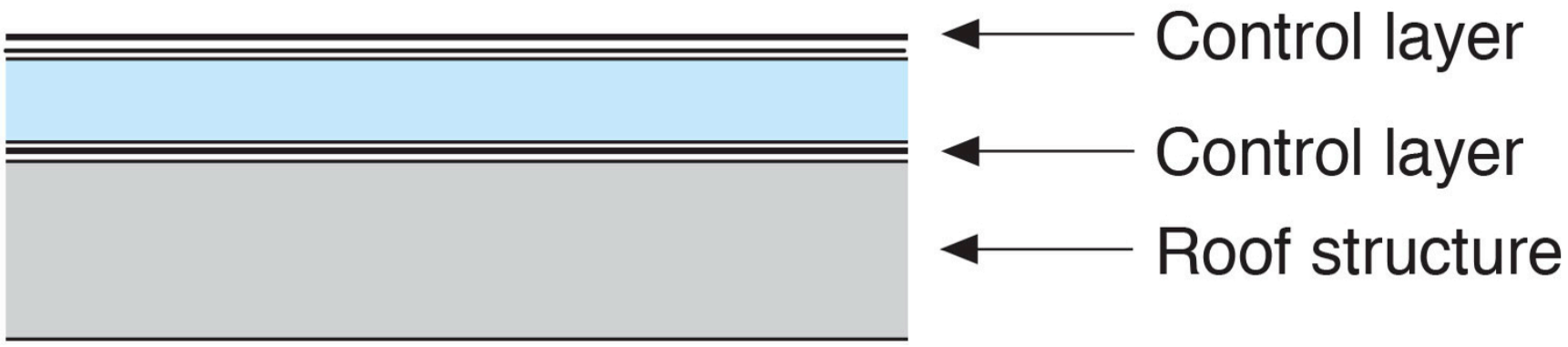

Wall

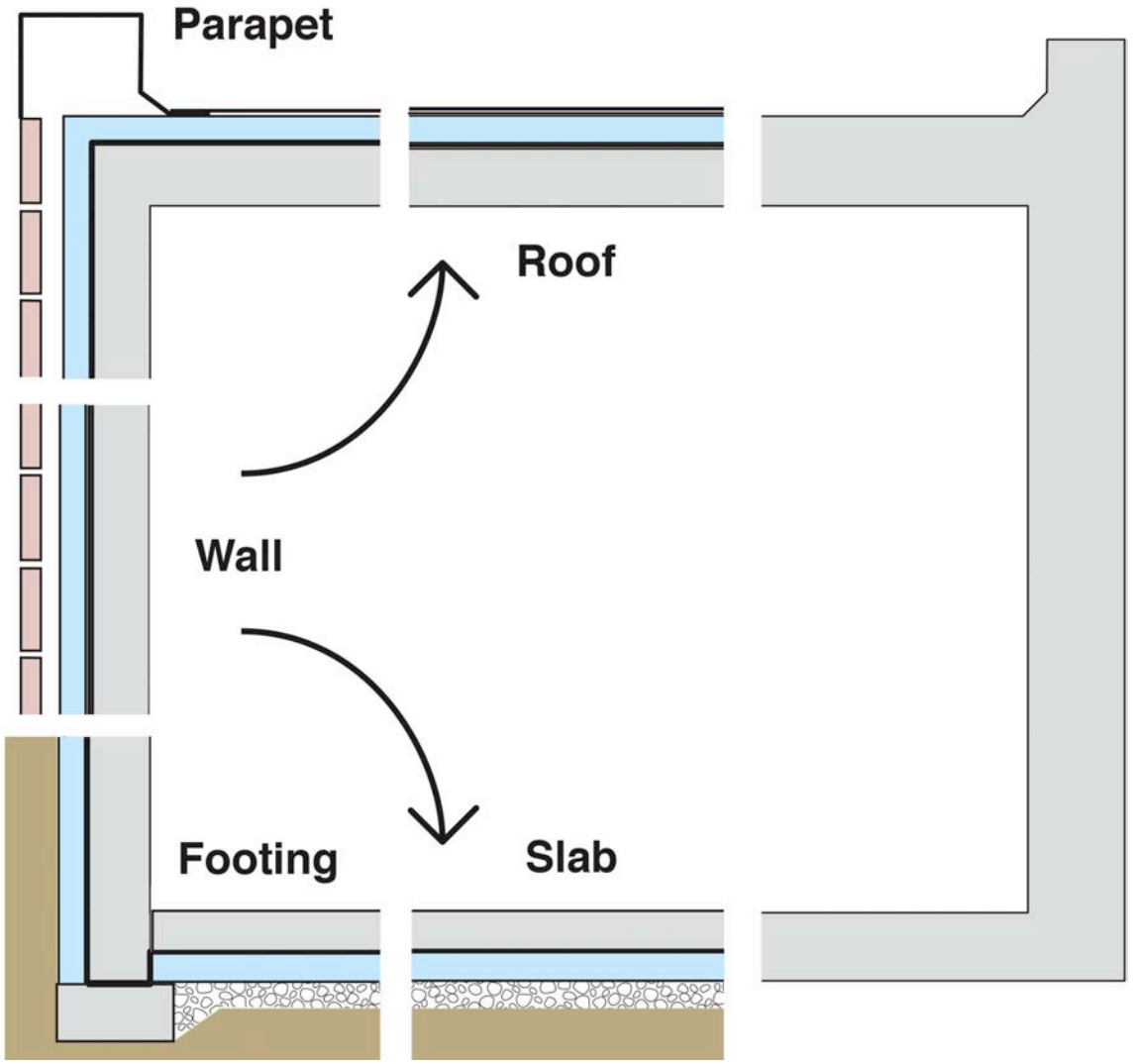

Roof
Wall

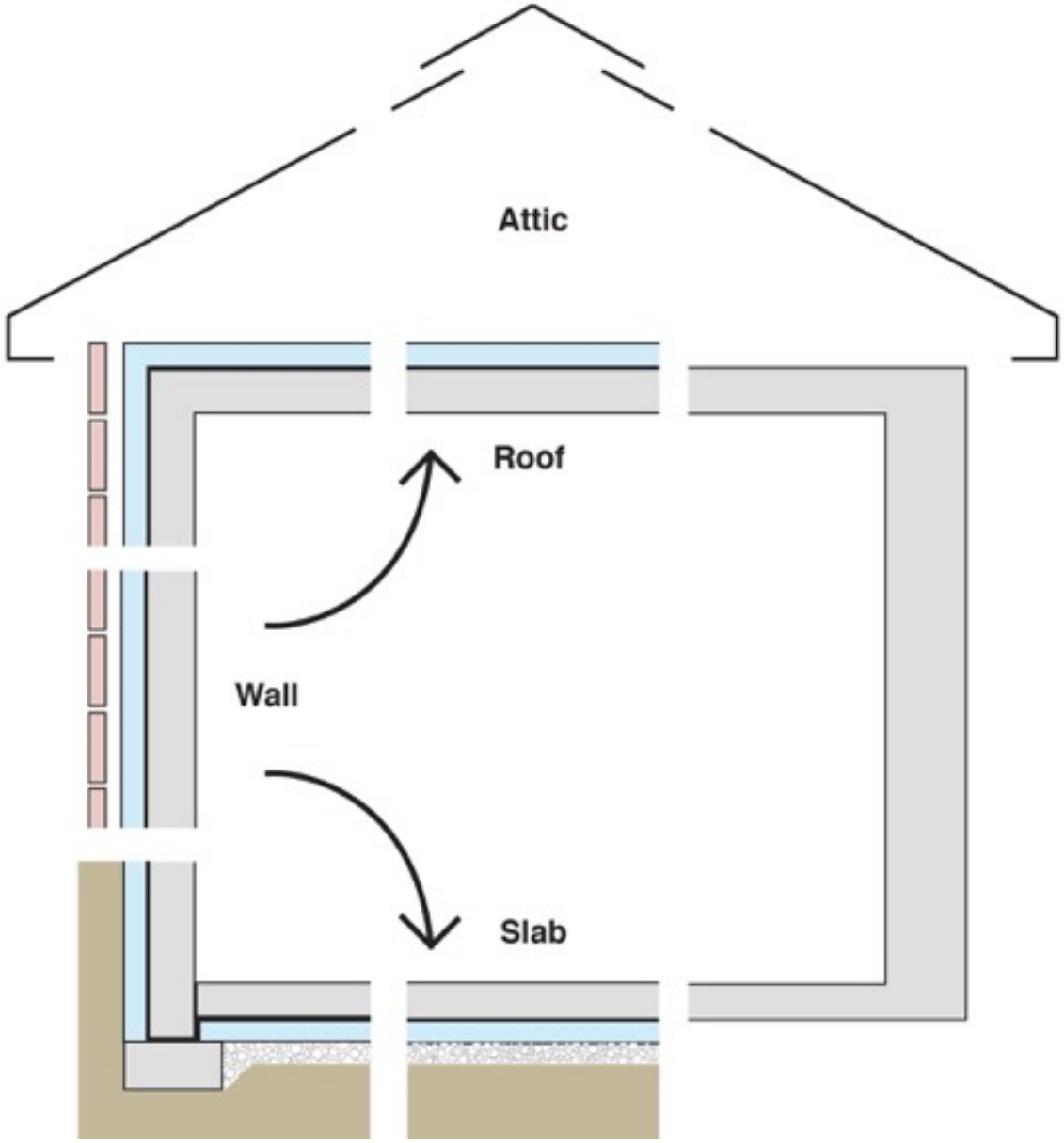

Roof
Wall
Slab

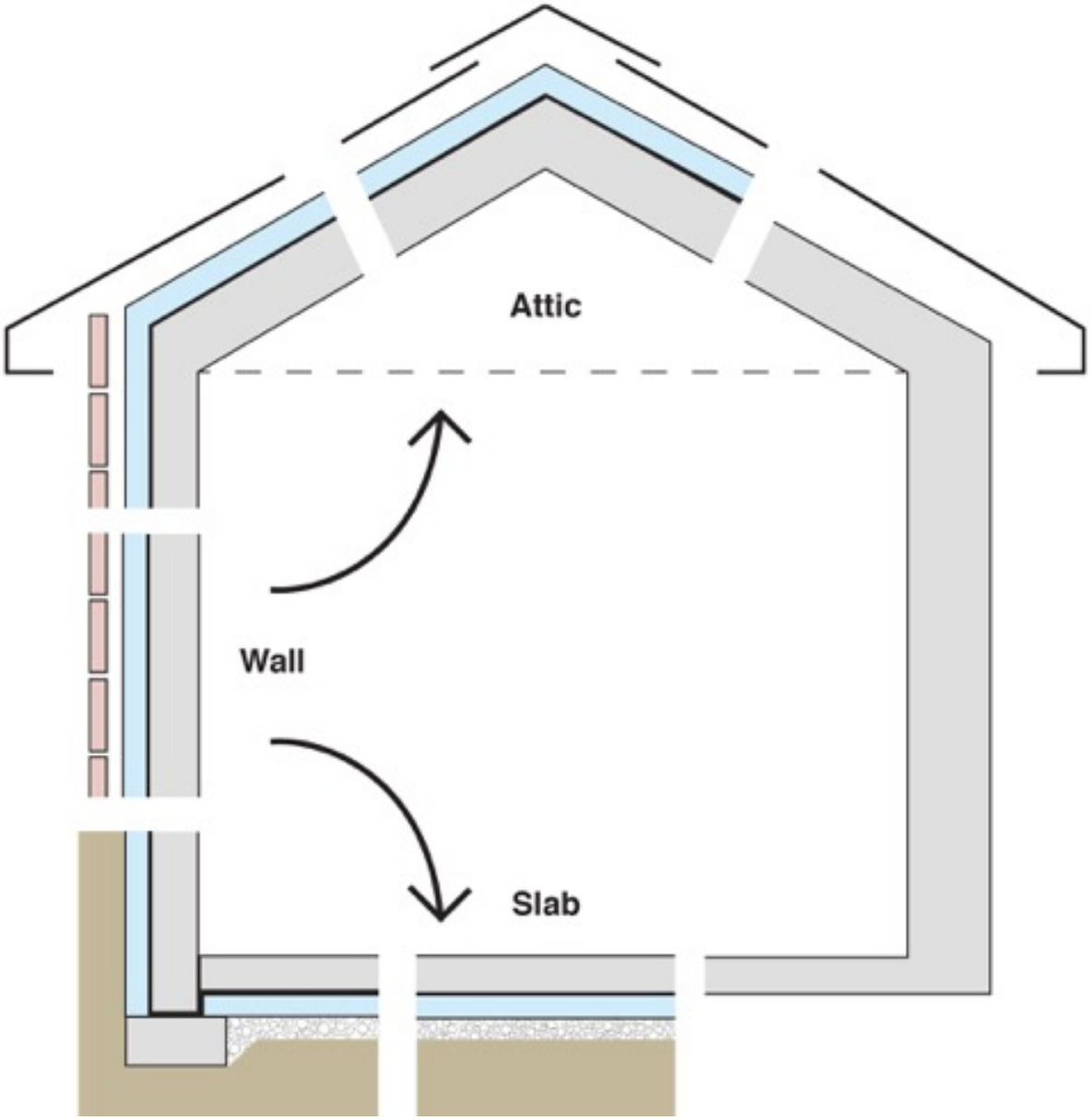

Parapet
Roof
Wall
Slab

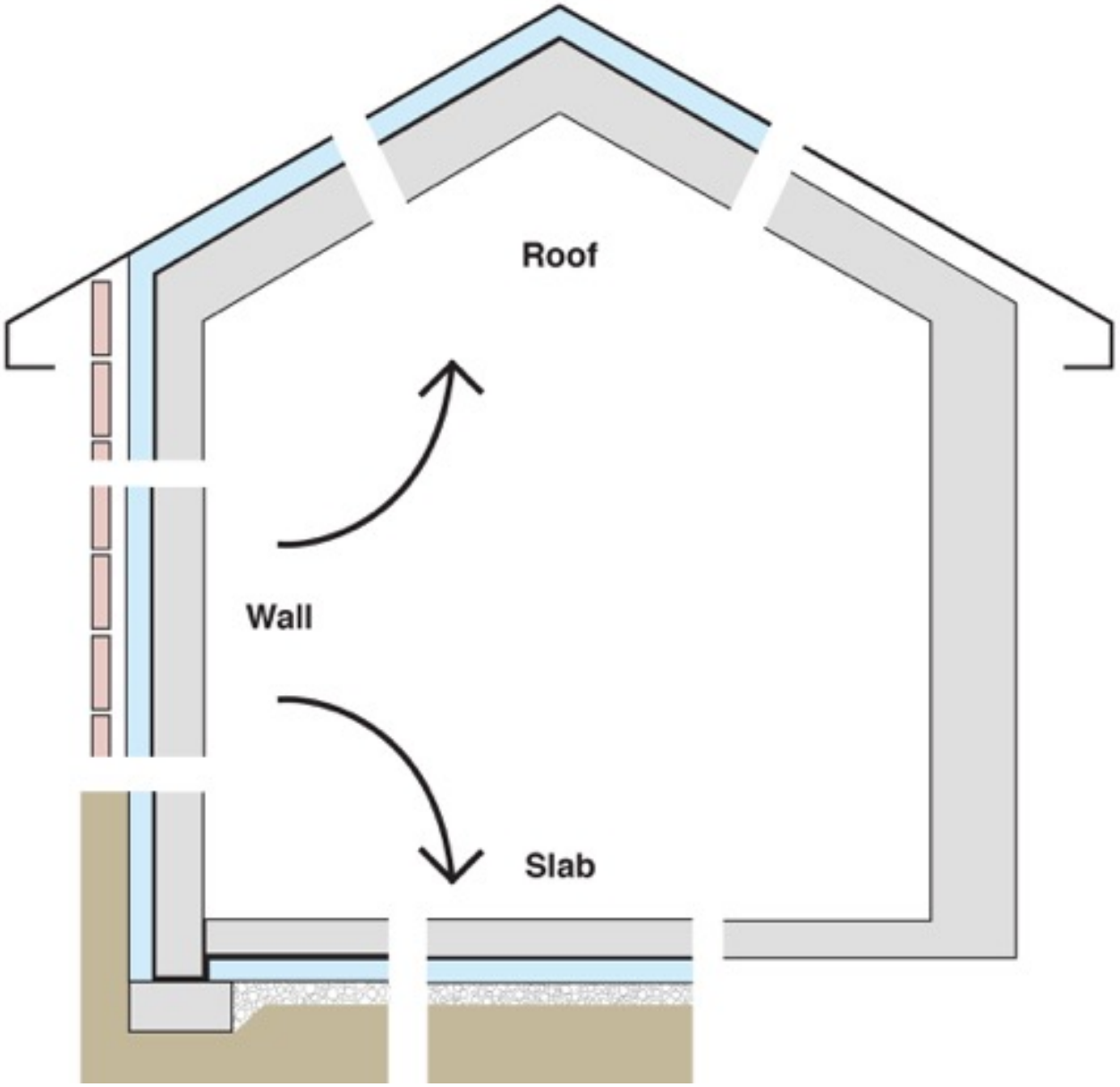

Parapet
Roof
Wall
Footing
Slab

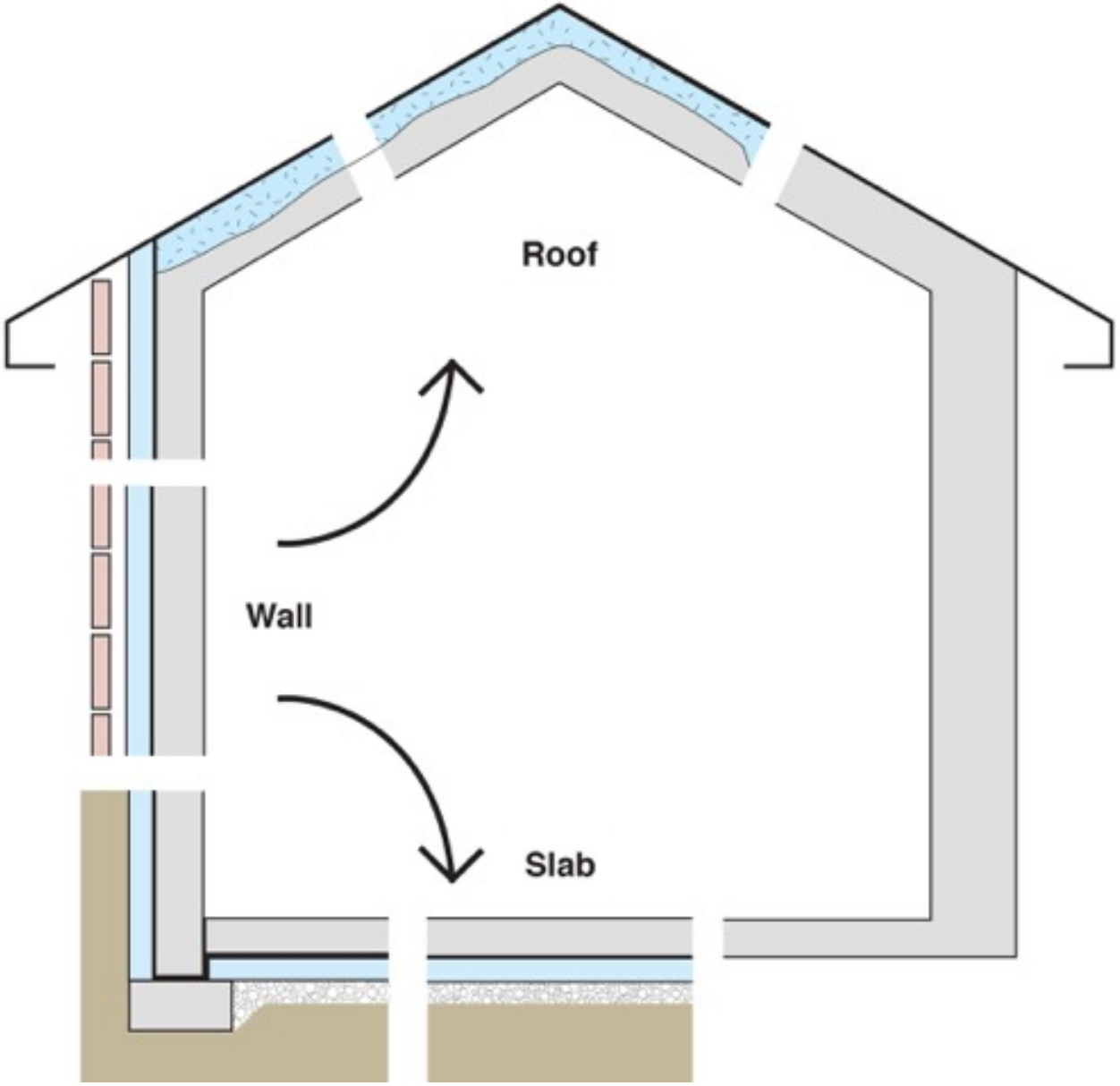

Control layer
Control layer
Roof structure


Parapet
Roof
Wall
Footing
Slab


Attic
Roof
Wall
Slab


Attic
Wall
Slab

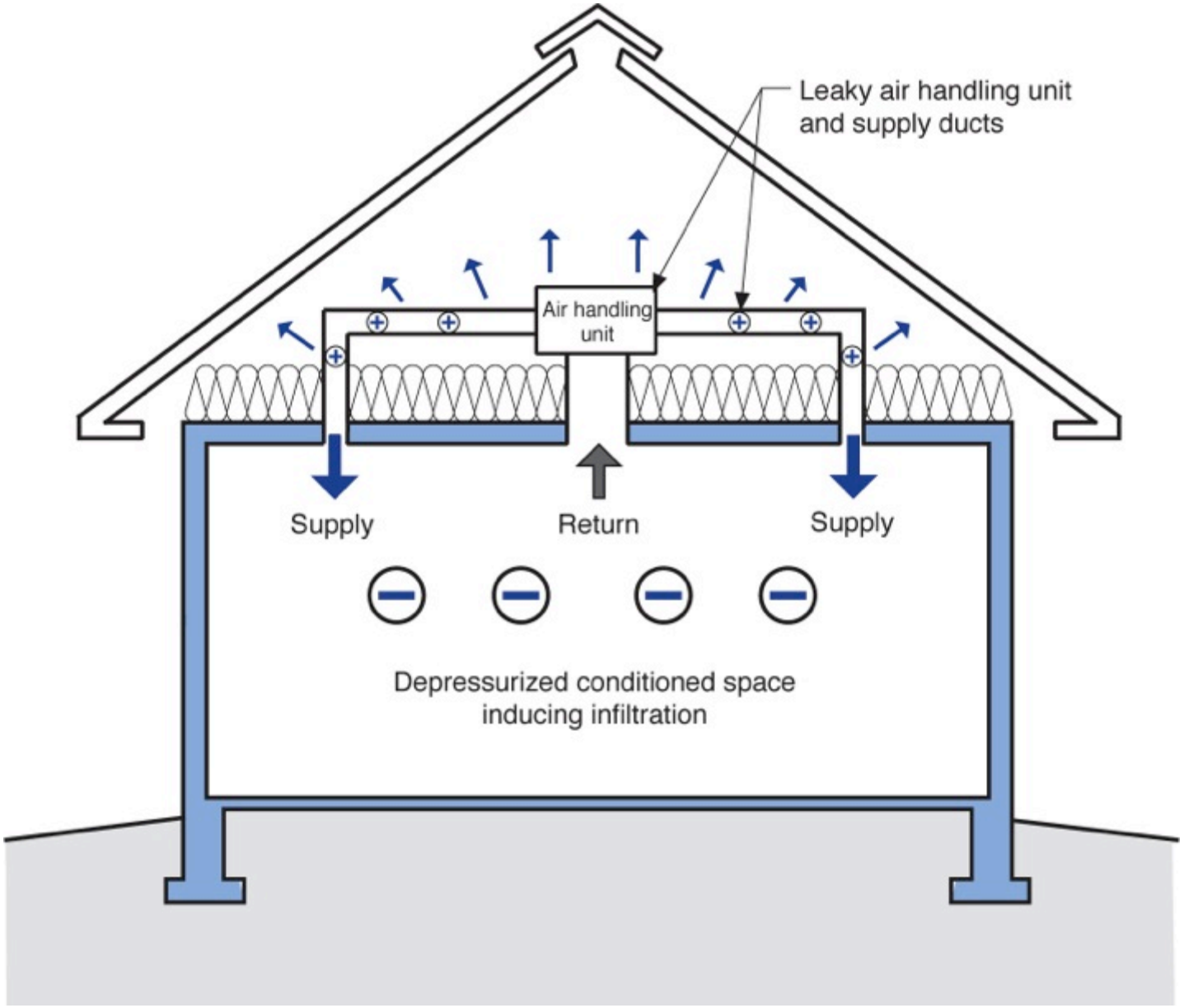

Roof
Wall
Slab

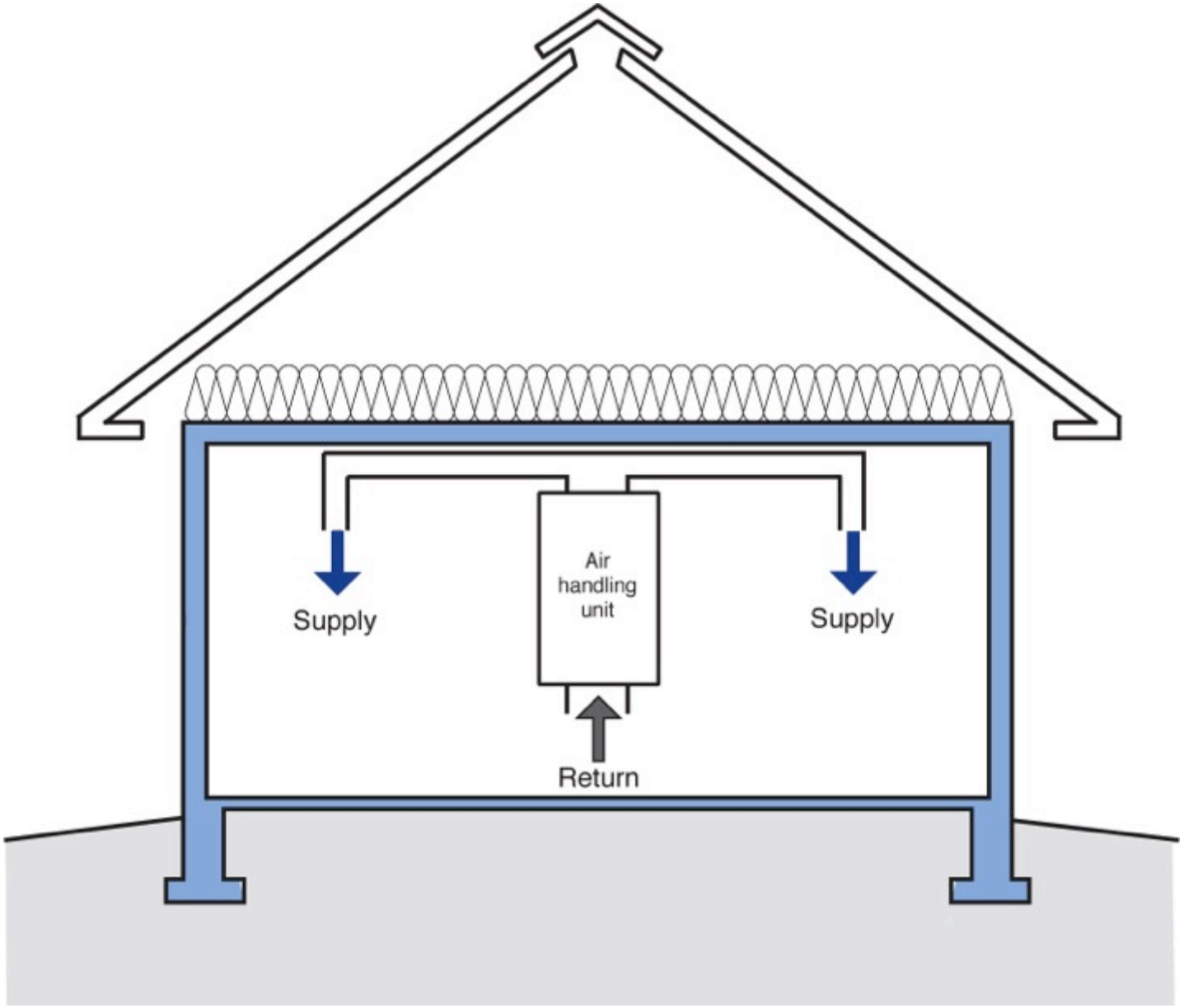

Roof
Wall
Slab

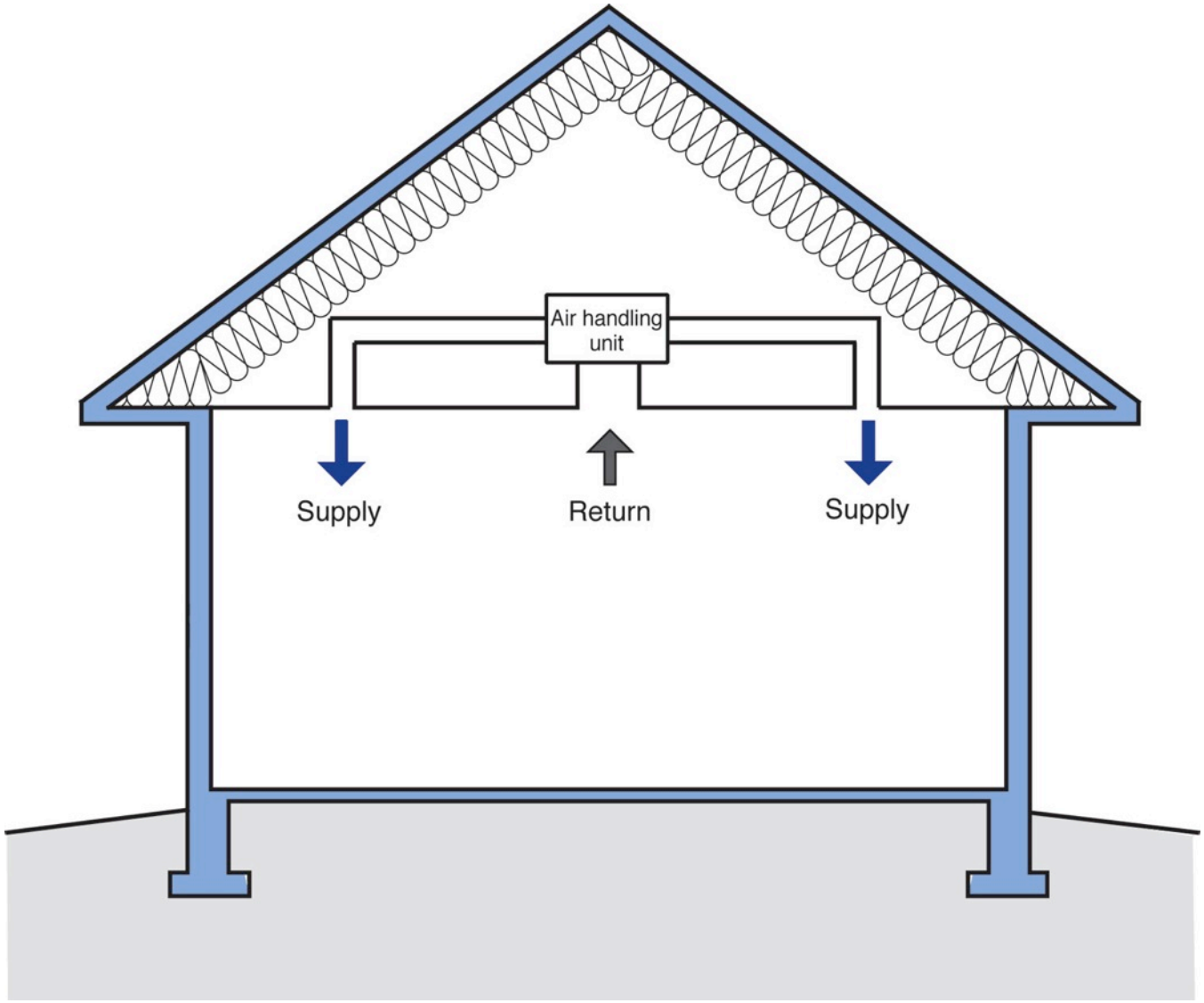
Houses With Vented Attics Suck

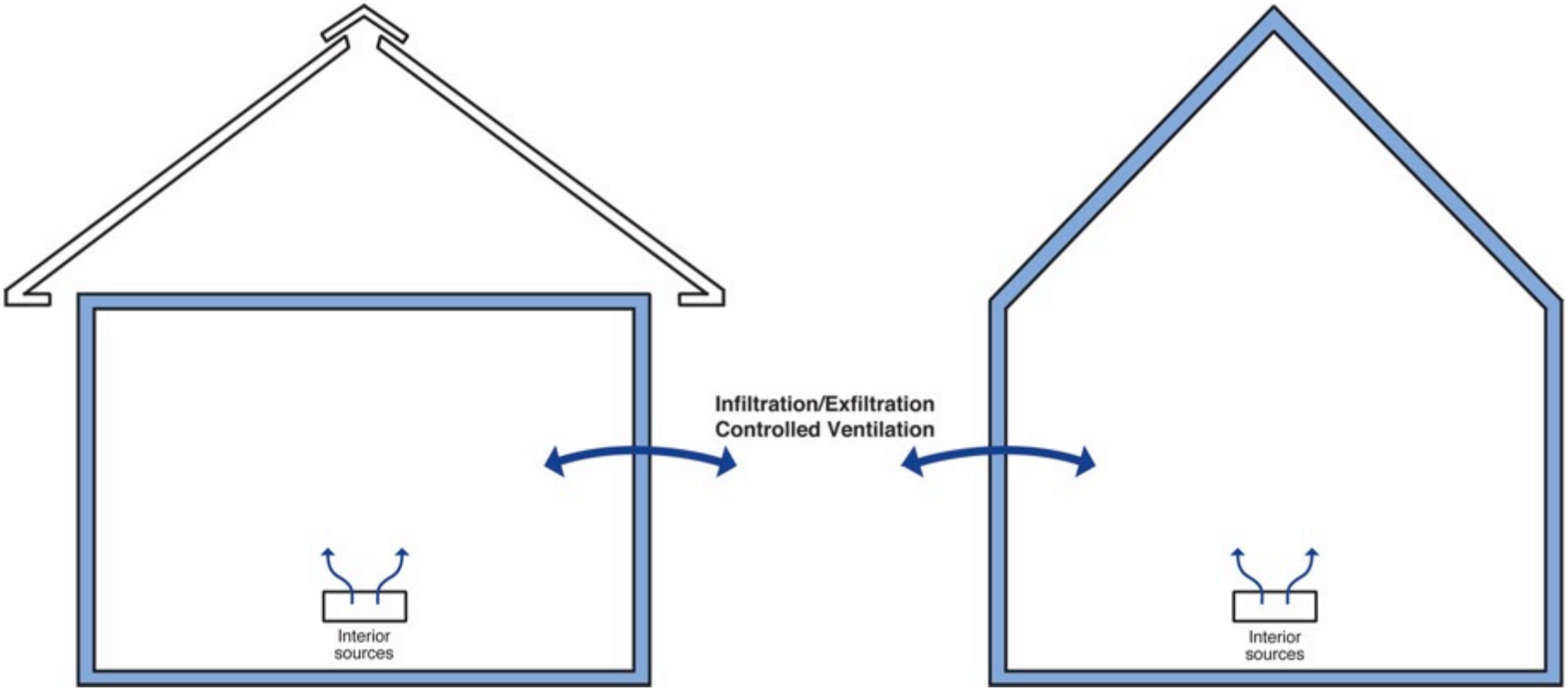
Houses With Vented Attics Suck

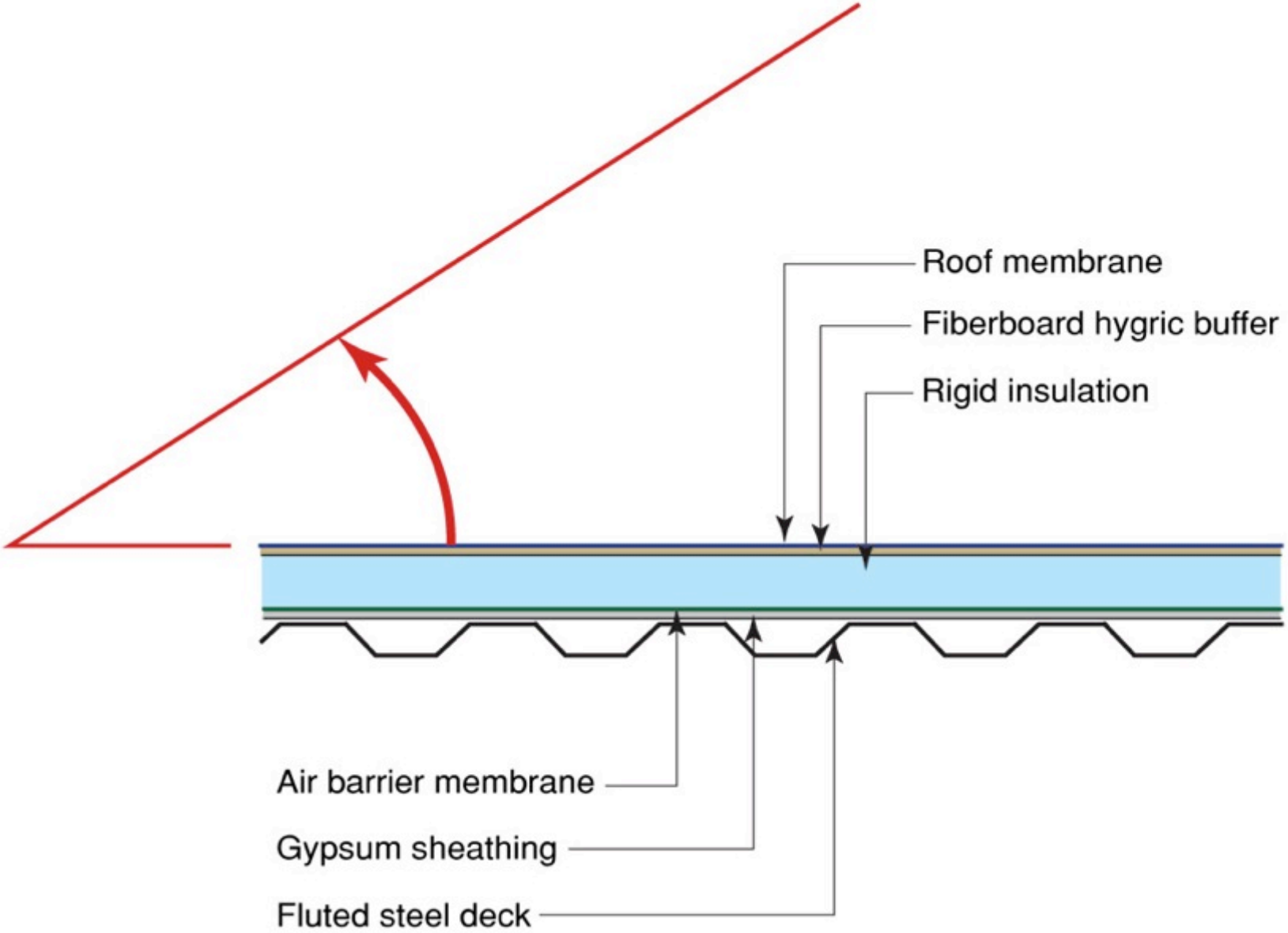
Not all the Time…..but.....

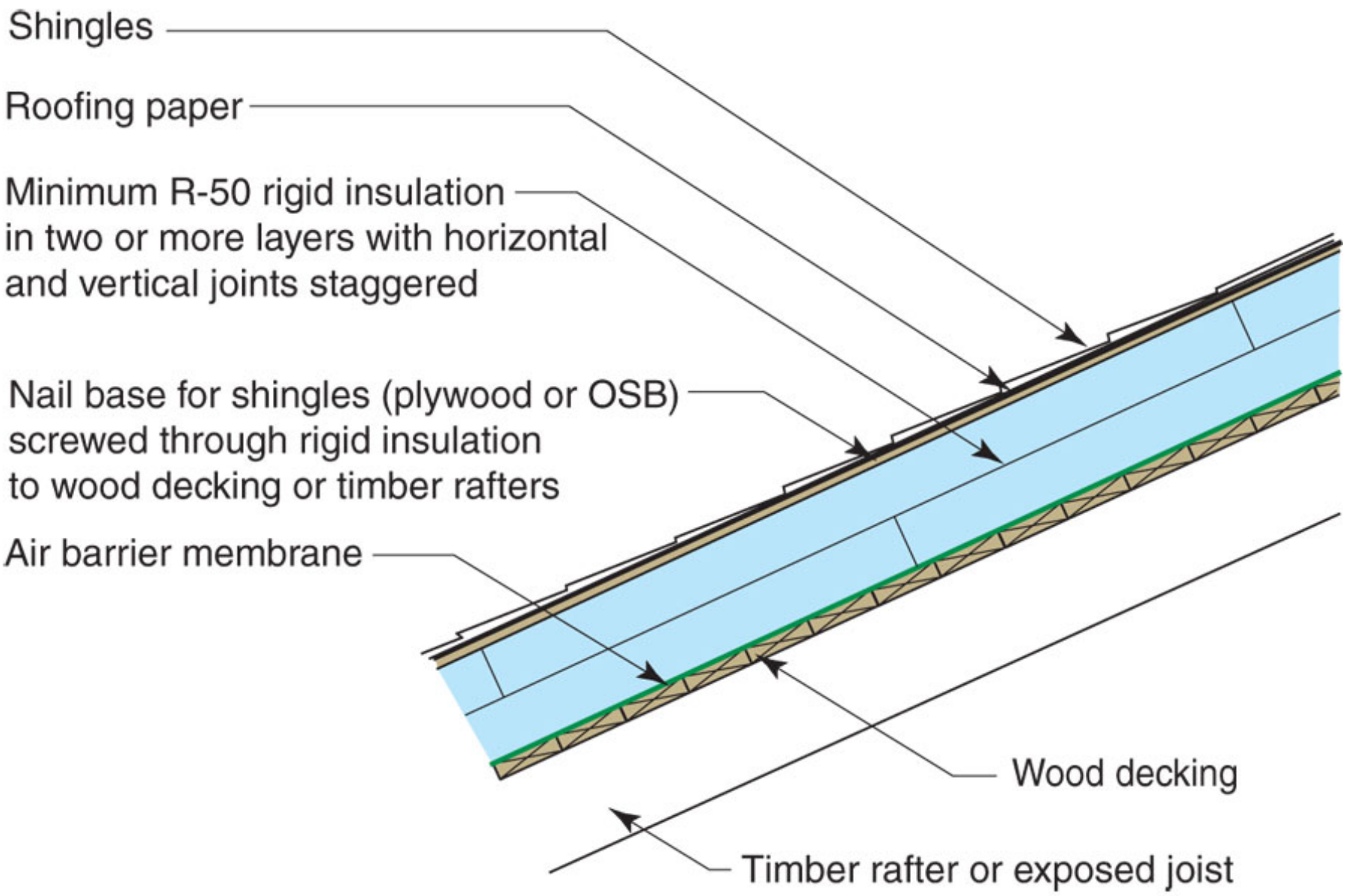

Leaky air handling unit
and supply ducts
Air handling
unit
Supply
Return
Supply
Depressurized conditioned space
inducing infiltration

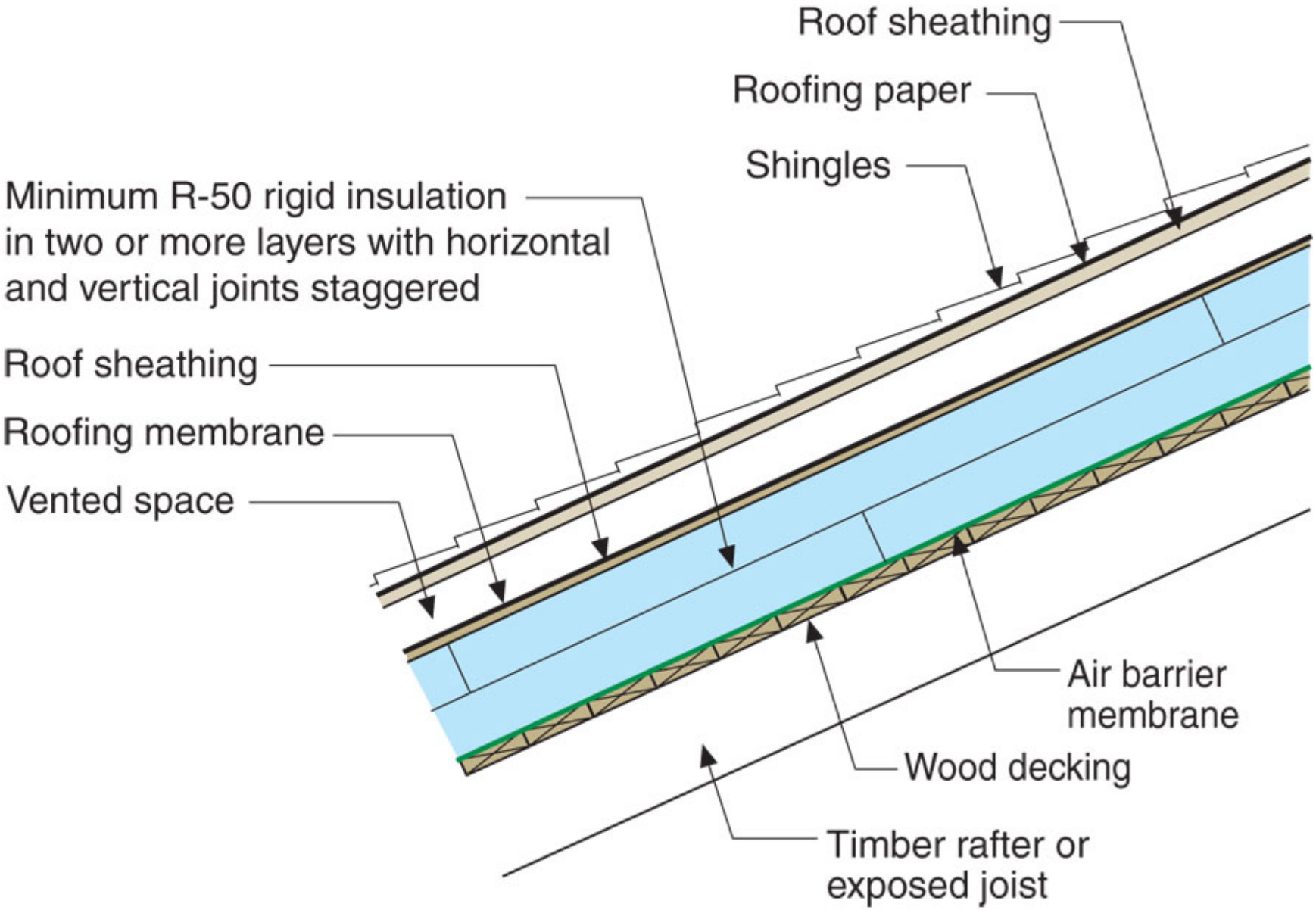

Supply
Air handling unit
Supply
Return

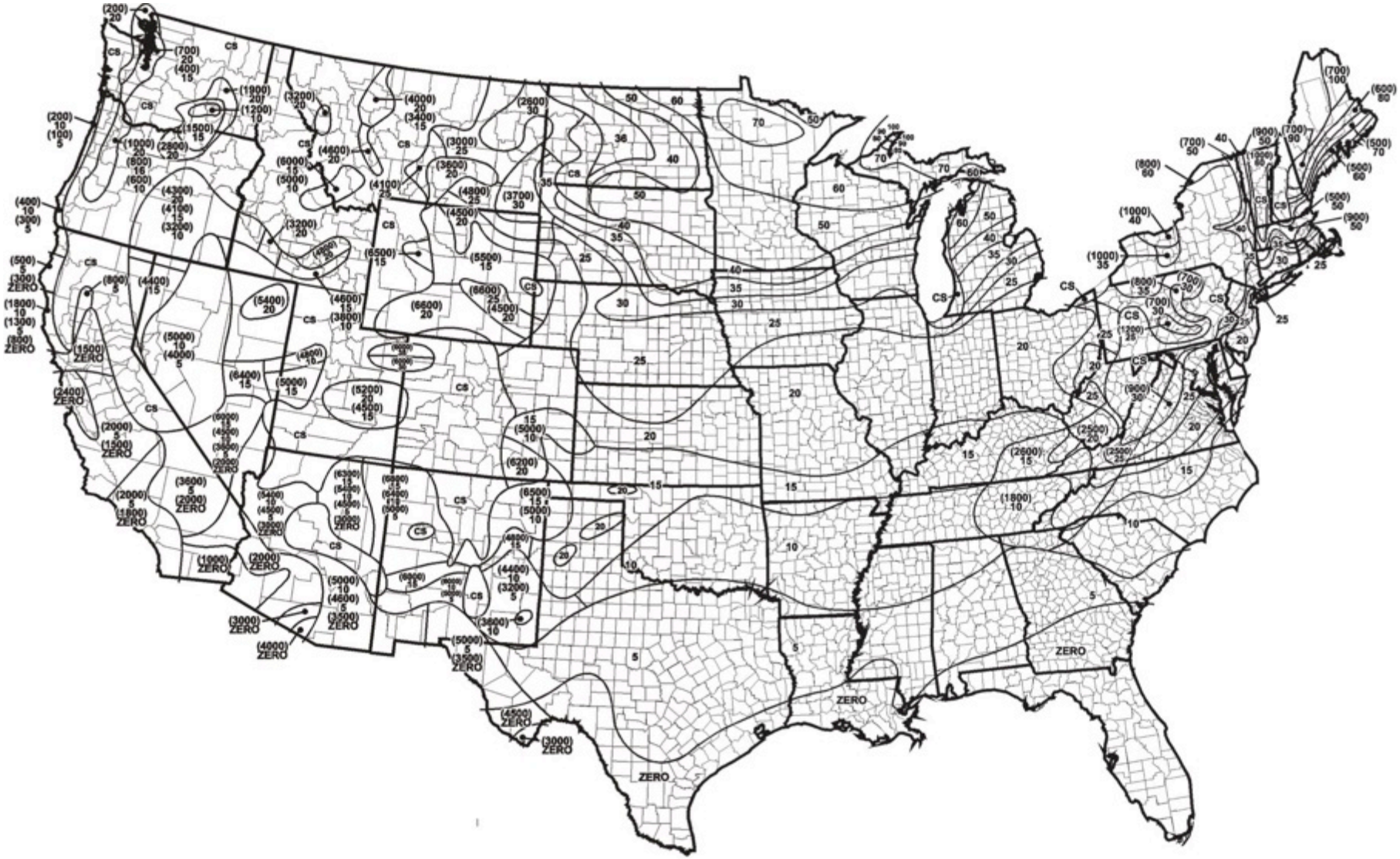

Air handling unit
Supply
Return
Supply

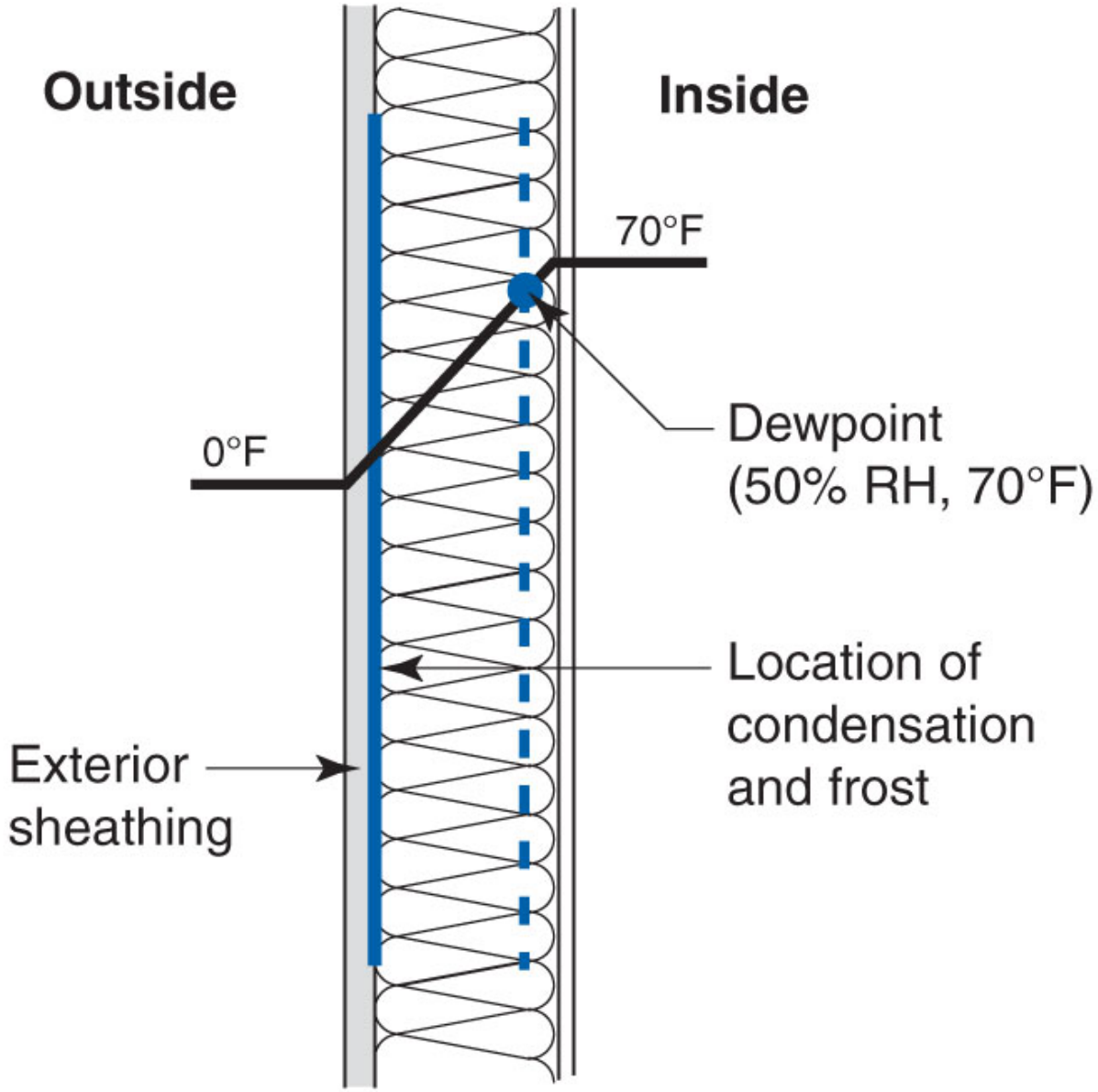

Infiltration/Exfiltration
Controlled Ventilation
Interior sources
Interior sources

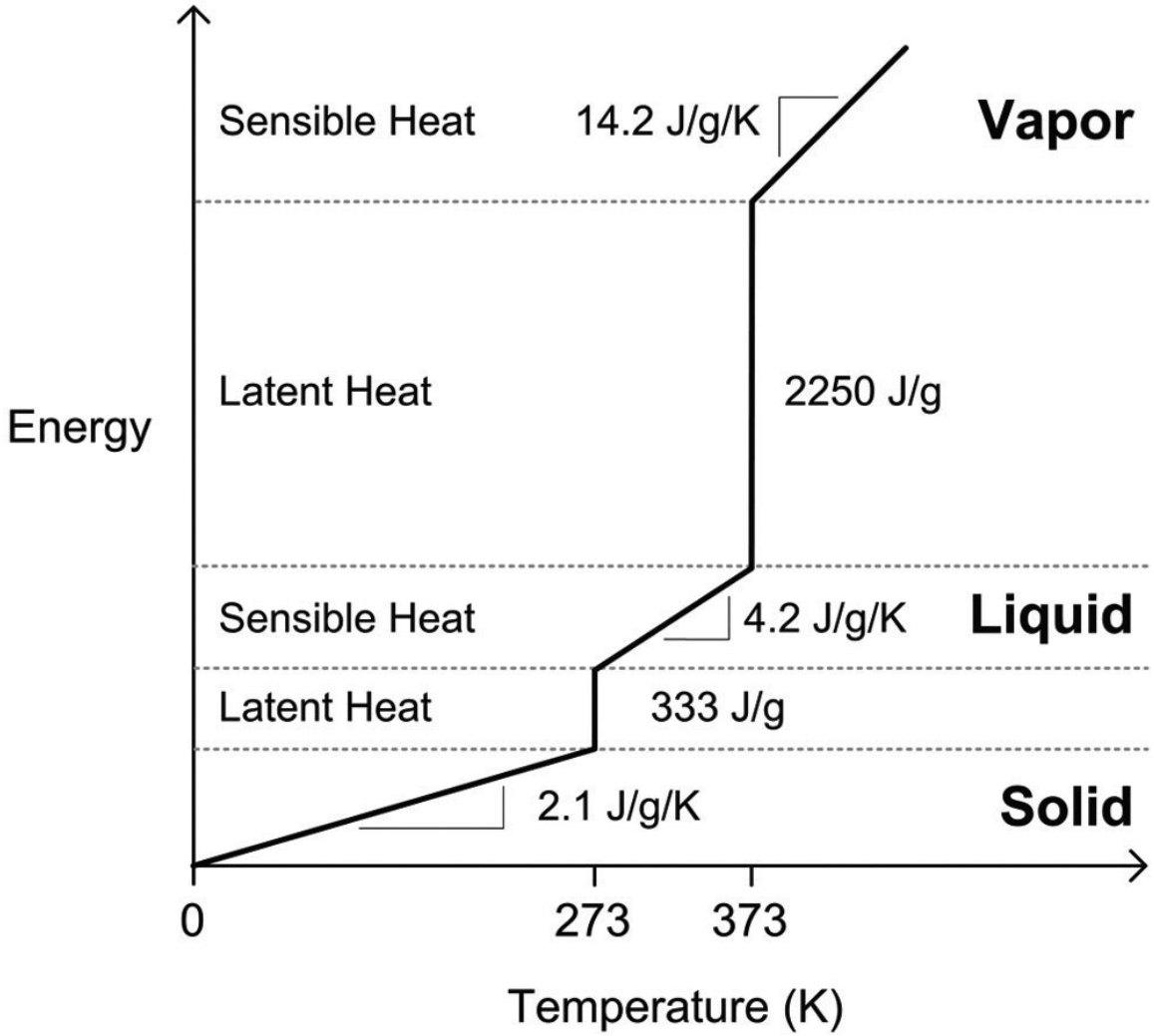

Roof membrane
Fiberboard hygric buffer
Rigid insulation
Air barrier membrane
Gypsum sheathing
Fluted steel deck


Shingles
Roofing paper
Minimum R-50 rigid insulation
in two or more layers with horizontal
and vertical joints staggered
Nail base for shingles (plywood or OSB)
screwed through rigid insulation
to wood decking or timber rafters
Air barrier membrane
Wood decking
Timber rafter or exposed joist

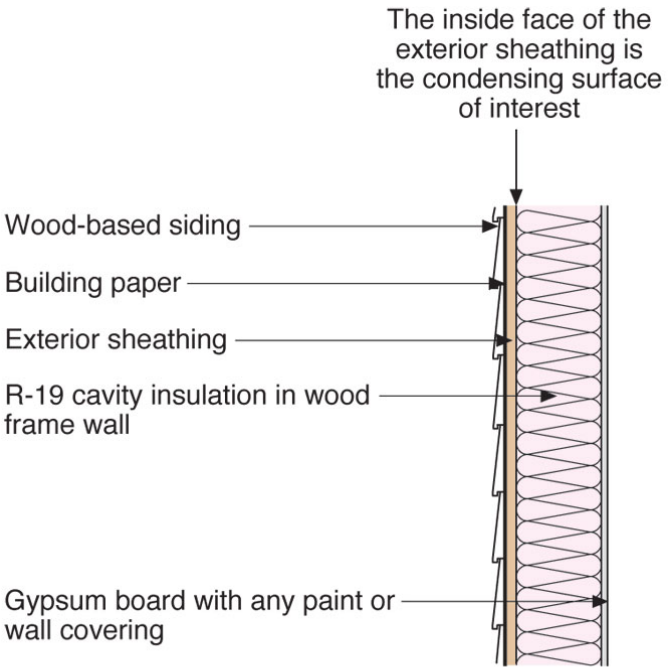

Roof sheathing
Roofing paper
Shingles
Minimum R-50 rigid insulation
in two or more layers with horizontal
and vertical joints staggered
Roof sheathing
Roofing membrane
Vented space
Air barrier
membrane
Wood decking
Timber rafter or
exposed joist

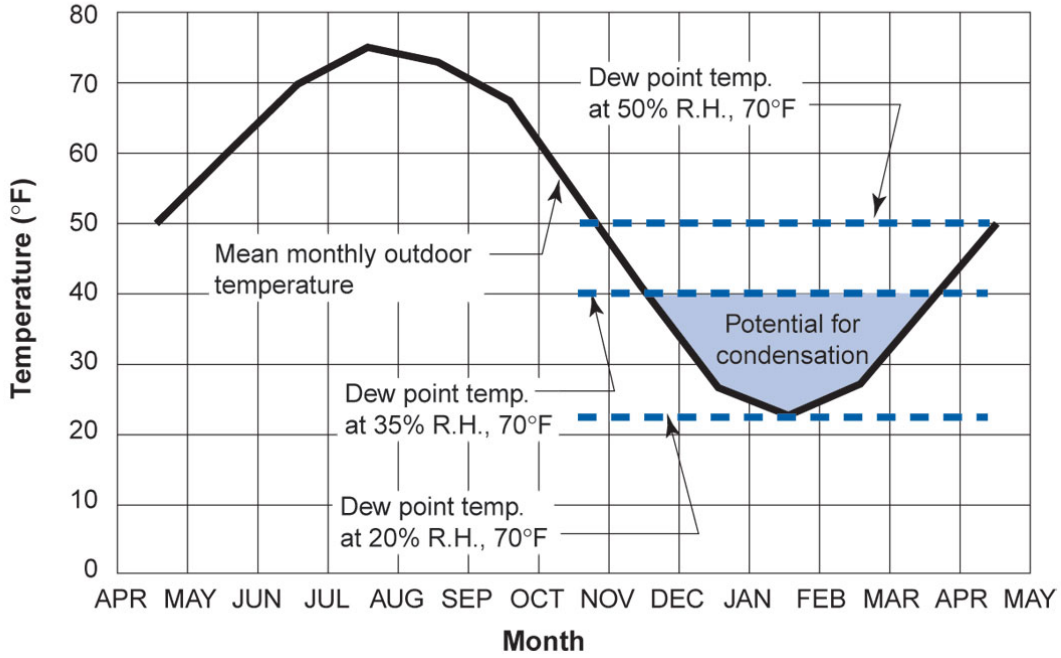


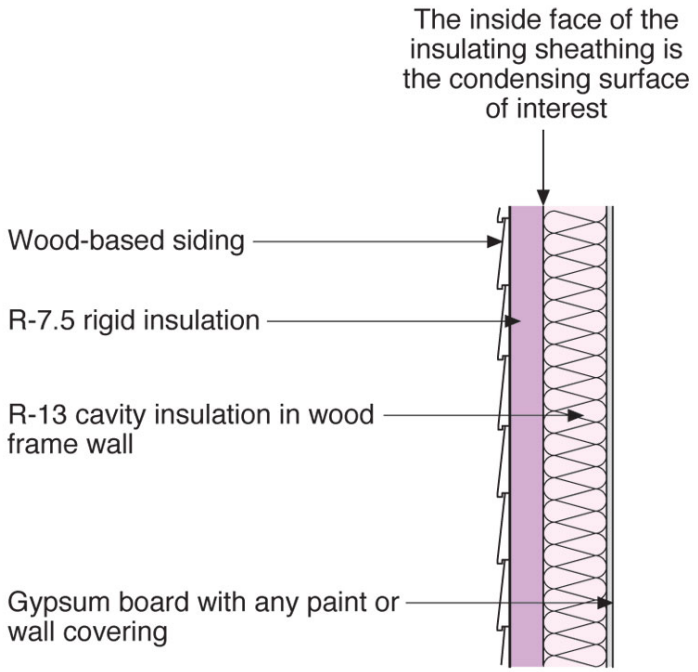

Outside
Inside
70°F
0°F
Dewpoint
(50% RH, 70°F)
Location of
condensation
and frost
Exterior
sheathing

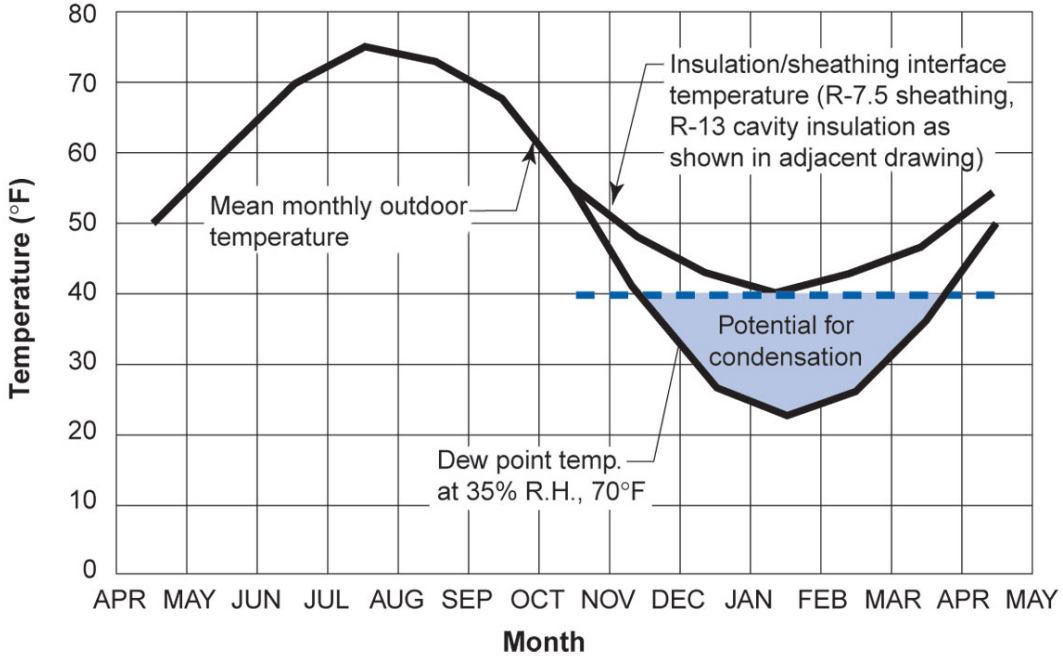


Simple linearized energy-temperature relation for water
From Straube & Burnett, 2005


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

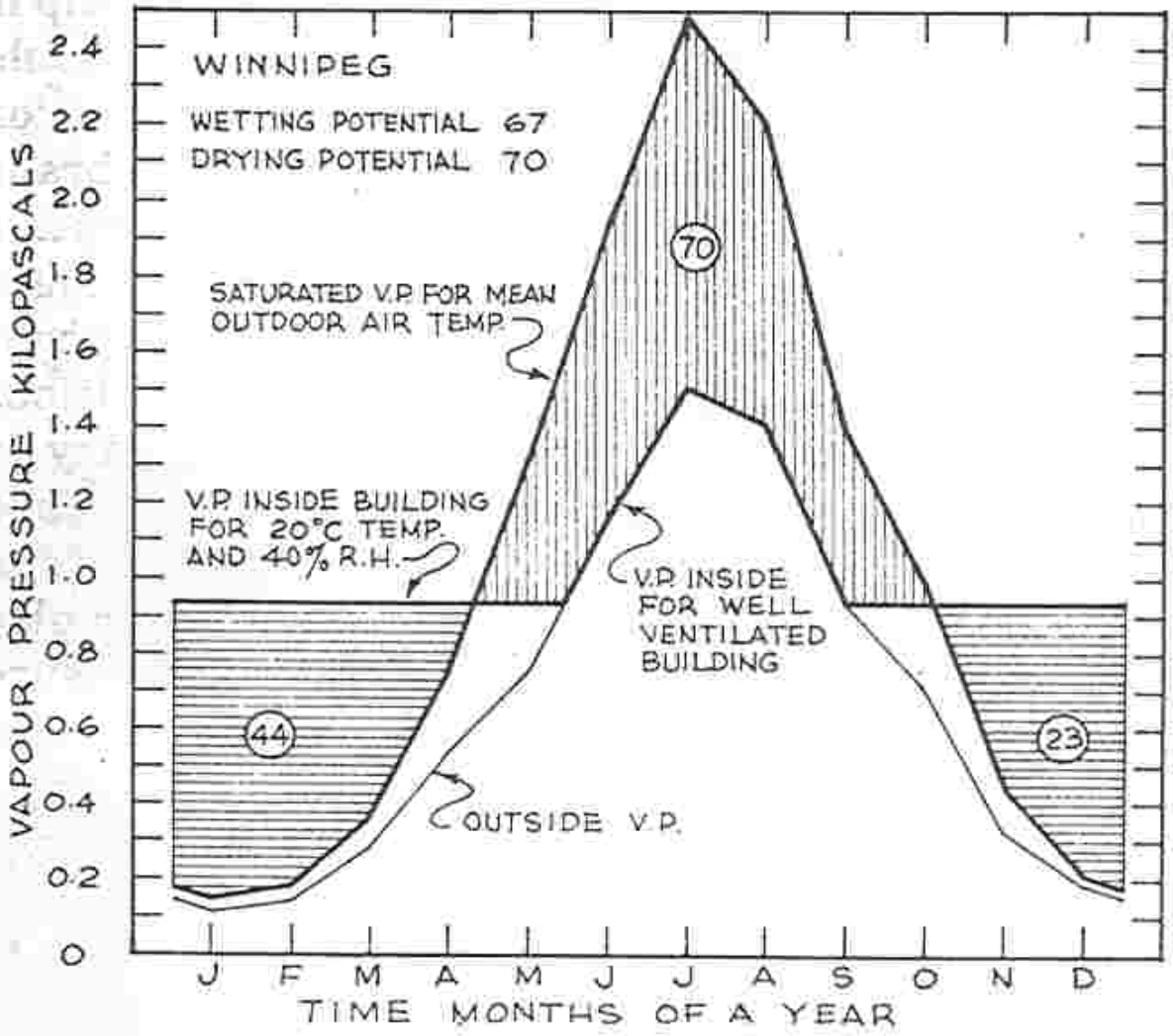
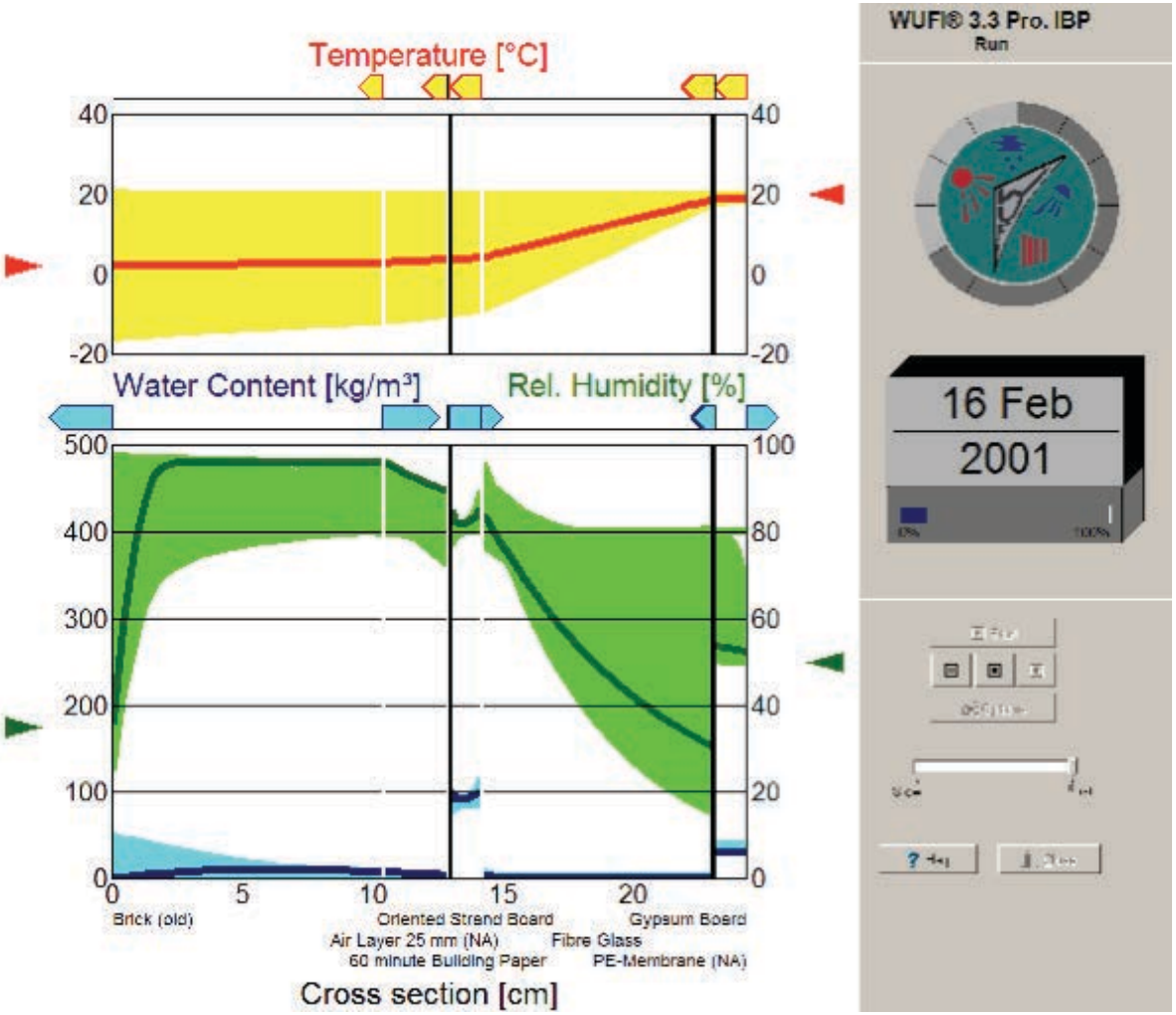
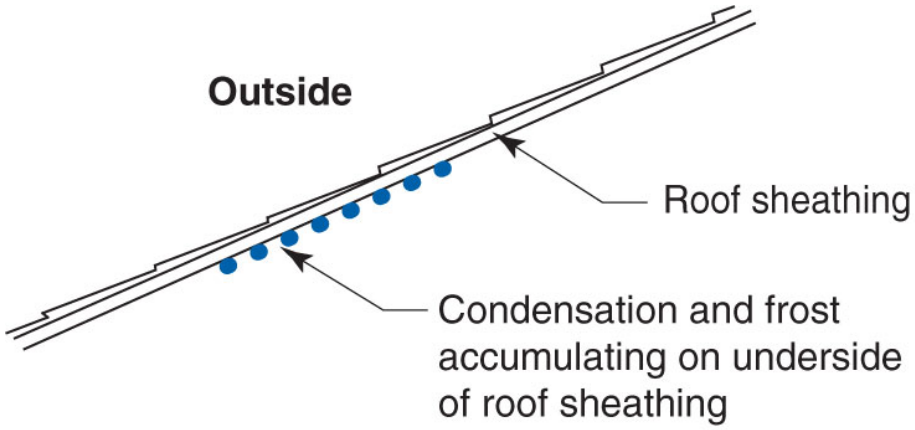
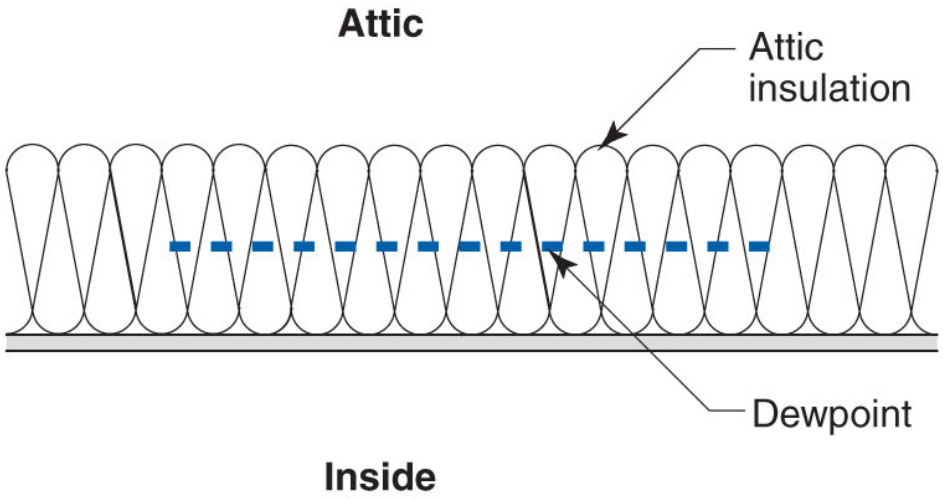
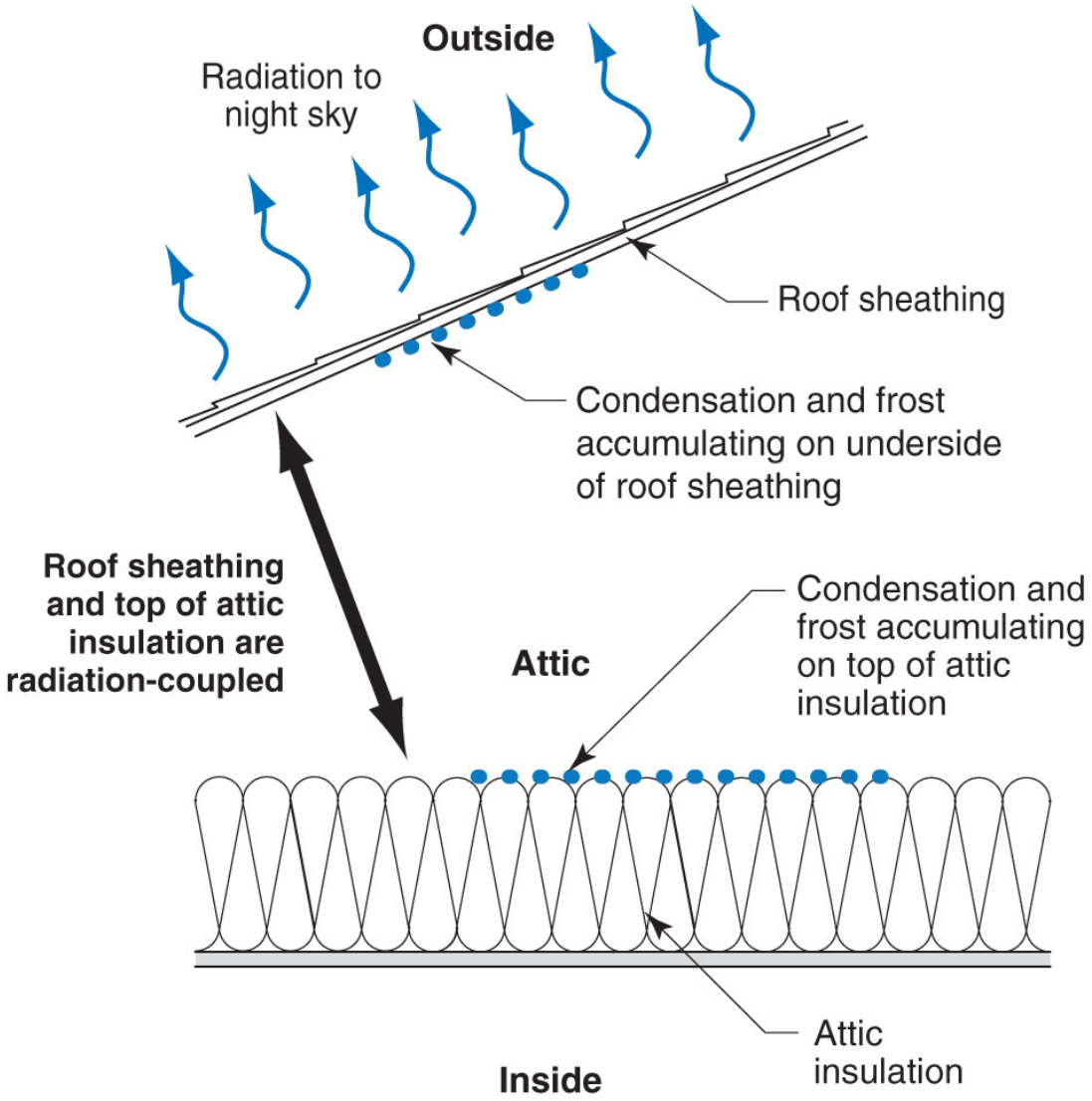


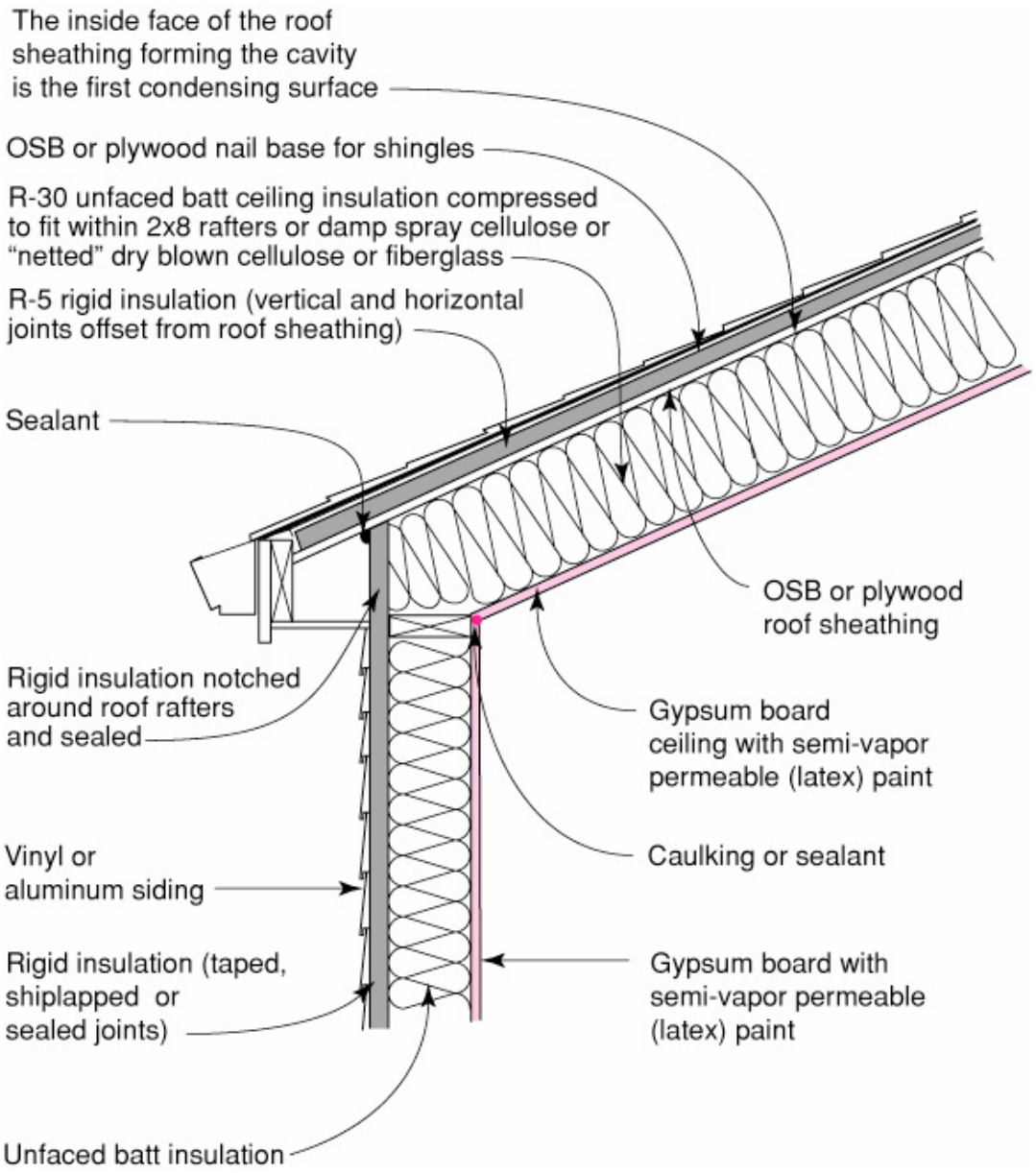
Figure 8-7. Outside vapour pressure, saturated vapour pressure and inside vapour pressure for Winnipeg.

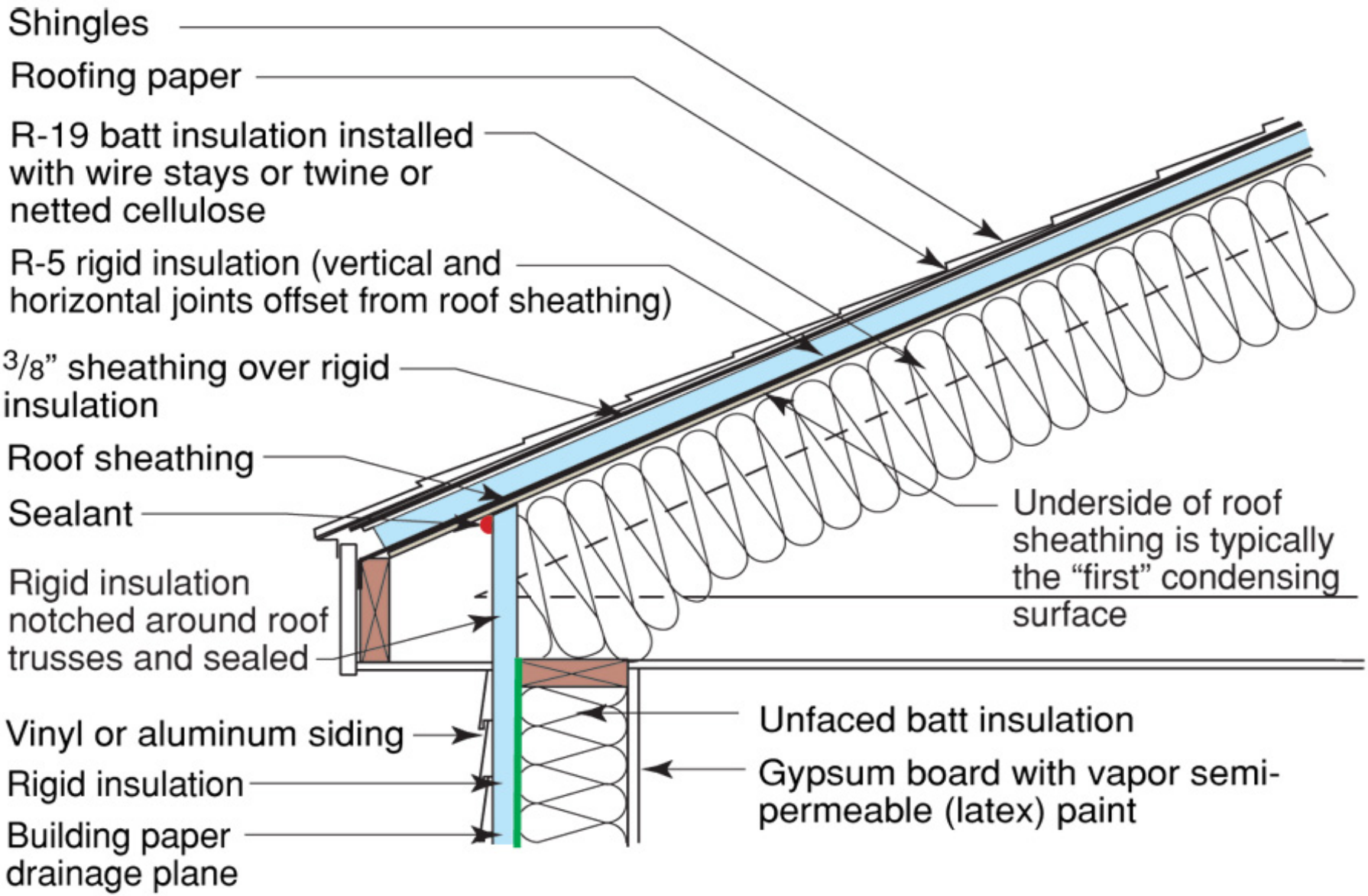

Temperature [°C]
40
20
0
-20
Water Content [kg/m³]
Rel. Humidity [%]
500
400
300
200
100
0
100
80
60
40
20
0
0
5
10
15
20
Brick (old)
Air Layer 25 mm (NA)
60 minute Building Paper
Oriented Strand Board
Fibre Glass
PE-Membrane (NA)
Gypsum Board
Cross section [cm]
WUFI® 3.3 Pro. IBP
Run
16 Feb
2001

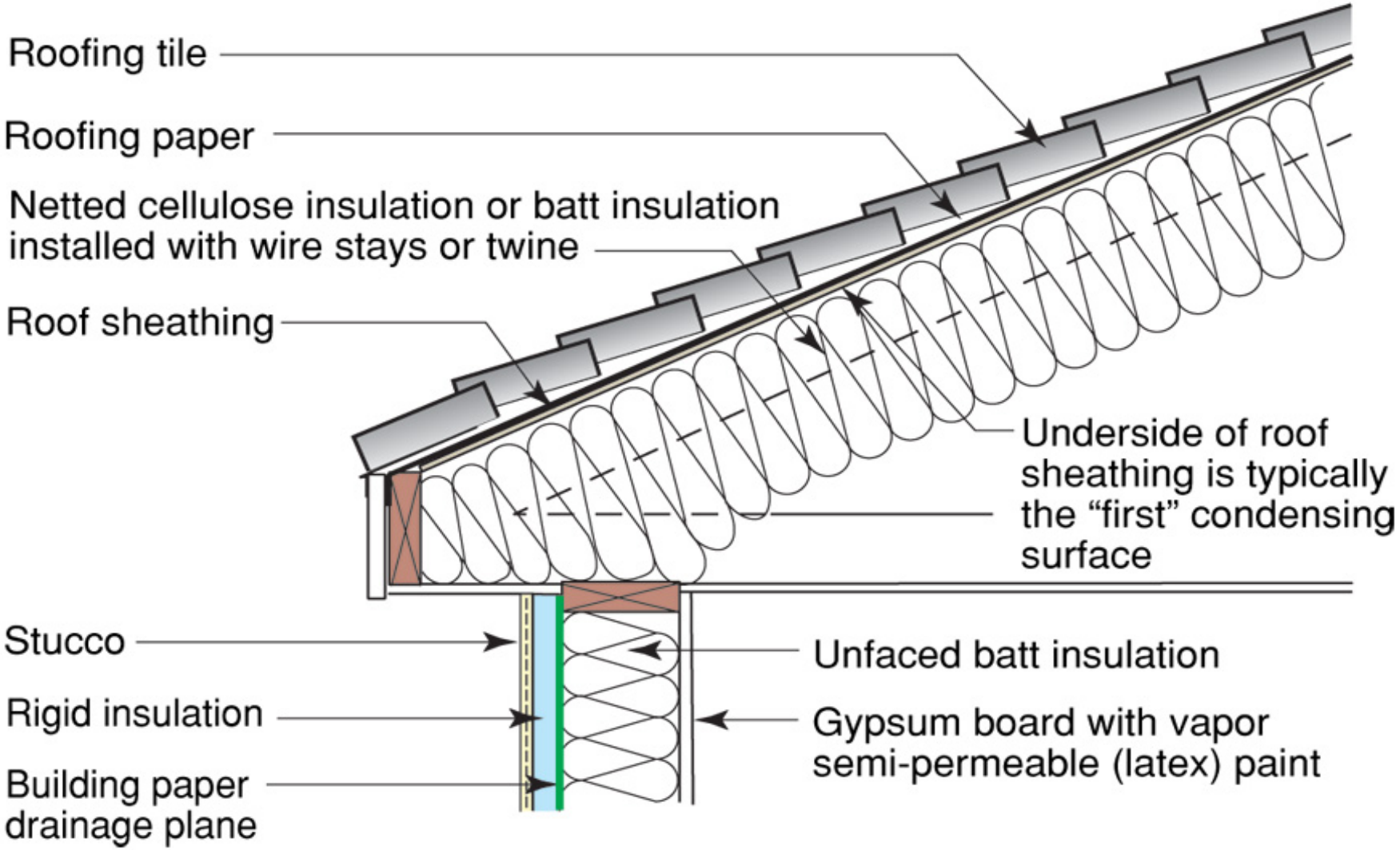

Outside
Roof sheathing
Condensation and frost
accumulating on underside
of roof sheathing

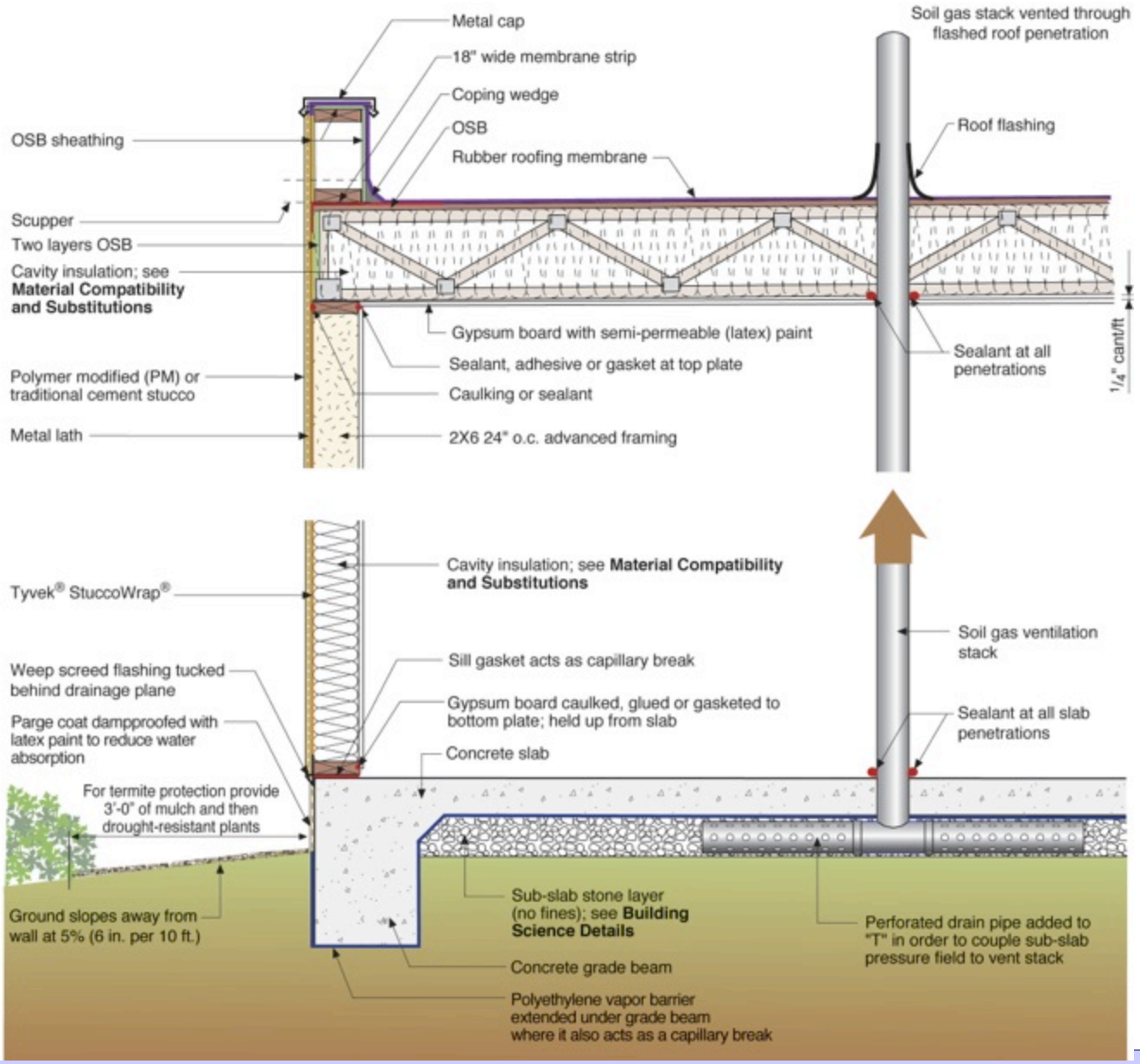

Attic
Attic
insulation
Dewpoint
Inside


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


The inside face of the roof sheathing forming the cavity is the first condensing surface
OSB or plywood nail base for shingles
R-30 unfaced batt ceiling insulation compressed to fit within 2x8 rafters or damp spray cellulose or "netted" dry blown cellulose or fiberglass
R-5 rigid insulation (vertical and horizontal joints offset from roof sheathing)
Sealant
OSB or plywood roof sheathing
Rigid insulation notched around roof rafters and sealed
Gypsum board ceiling with semi-vapor permeable (latex) paint
Caulking or sealant
Vinyl or aluminum siding
Rigid insulation (taped, shiplapped or sealed joints)
Gypsum board with semi-vapor permeable (latex) paint
Unfaced batt insulation

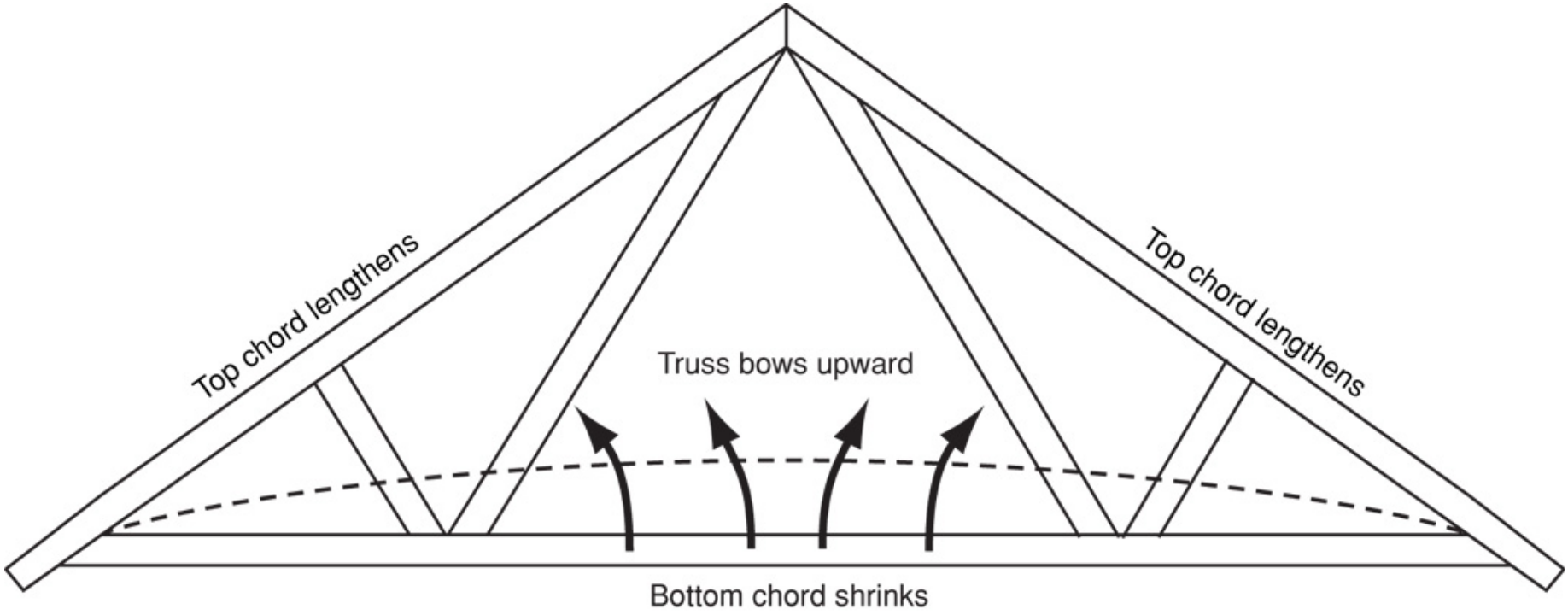

Shingles
Roofing paper
R-19 batt insulation installed with wire stays or twine or netted cellulose
R-5 rigid insulation (vertical and horizontal joints offset from roof sheathing)
3/8" sheathing over rigid insulation
Roof sheathing
Sealant
Rigid insulation notched around roof trusses and sealed
Vinyl or aluminum siding
Rigid insulation
Building paper drainage plane
Underside of roof sheathing is typically the "first" condensing surface
Unfaced batt insulation
Gypsum board with vapor semi-permeable (latex) paint

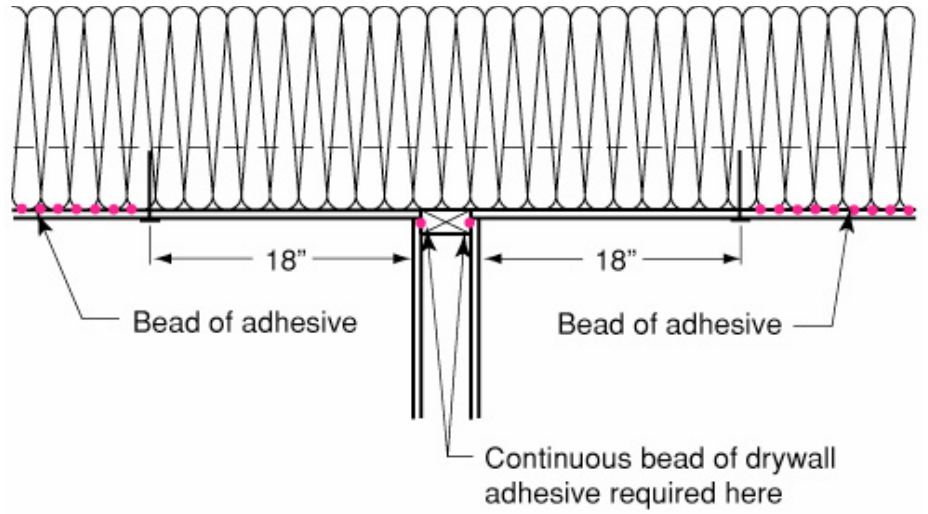

Roofing tile
Roofing paper
Netted cellulose insulation or batt insulation installed with wire stays or twine
Roof sheathing
Underside of roof sheathing is typically the “first” condensing surface
Stucco
Rigid insulation
Building paper drainage plane
Unfaced batt insulation
Gypsum board with vapor semi-permeable (latex) paint

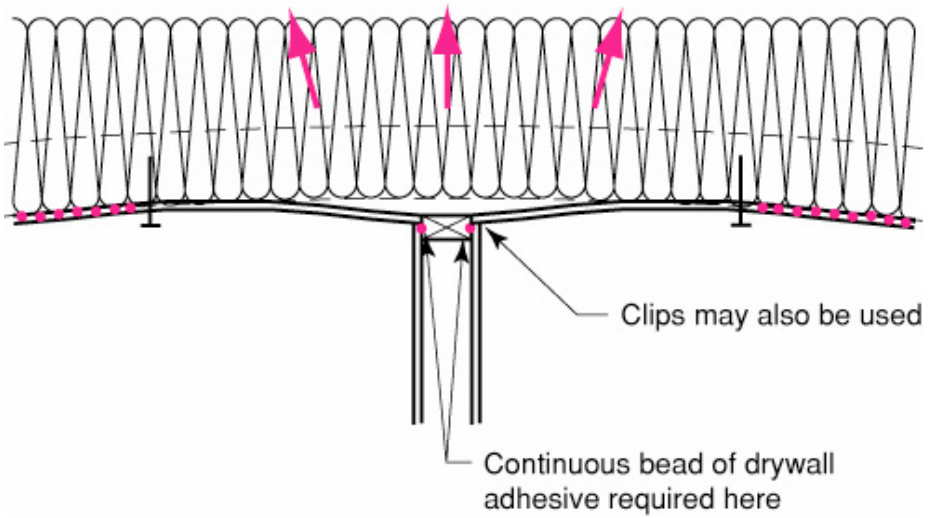

Metal cap
18" wide membrane strip
Coping wedge
OSB
Rubber roofing membrane
Soil gas stack vented through flashed roof penetration
Roof flashing
OSB sheathing
Scupper
Two layers OSB
Cavity insulation; see Material Compatibility and Substitutions
Gypsum board with semi-permeable (latex) paint
Sealant, adhesive or gasket at top plate
Caulking or sealant
2X6 24" o.c. advanced framing
Sealant at all penetrations
1/4" cant/ft
Polymer modified (PM) or traditional cement stucco
Metal lath
Tyvek® StuccoWrap®
Cavity insulation; see Material Compatibility and Substitutions
Soil gas ventilation stack
Weep screed flashing tucked behind drainage plane
Sill gasket acts as capillary break
Gypsum board caulked, glued or gasketed to bottom plate; held up from slab
Sealant at all slab penetrations
Parge coat dampproofed with latex paint to reduce water absorption
Concrete slab
For termite protection provide 3'-0" of mulch and then drought-resistant plants
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Sub-slab stone layer (no fines); see Building Science Details
Perforated drain pipe added to "T" in order to couple sub-slab pressure field to vent stack
Concrete grade beam
Polyethylene vapor barrier extended under grade beam where it also acts as a capillary break

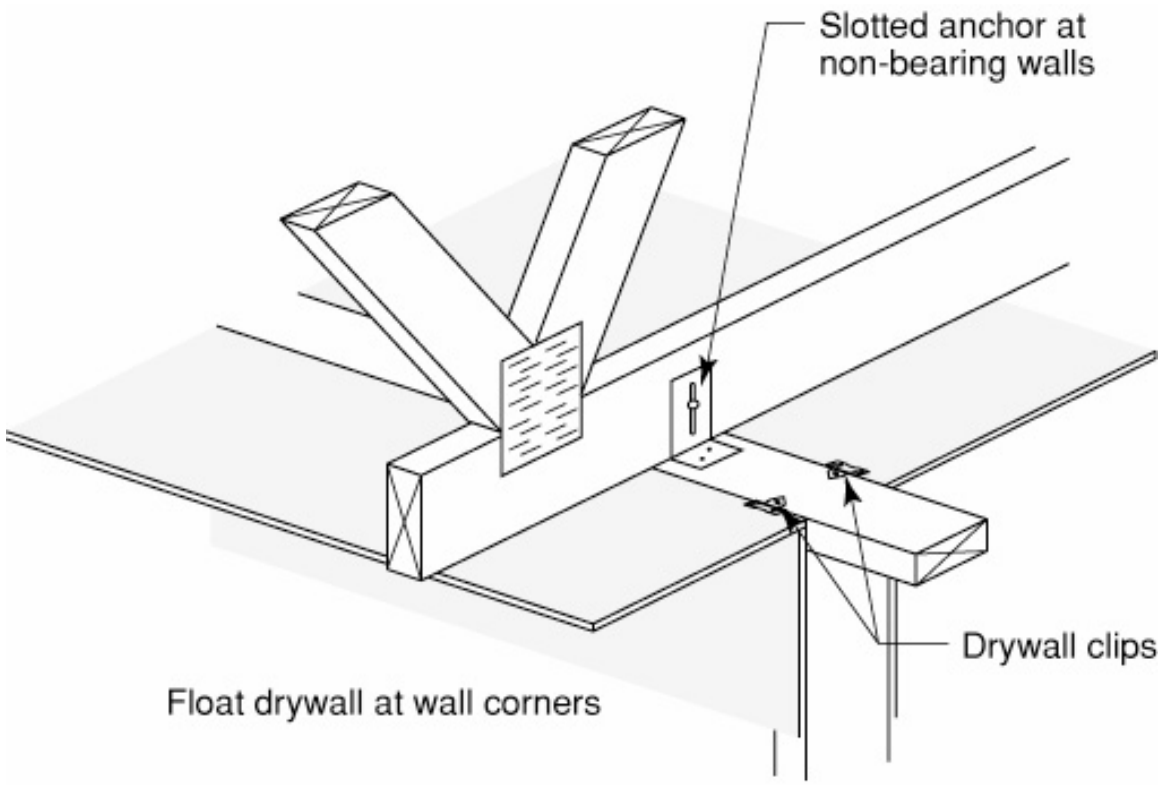
Truss Uplift

6537

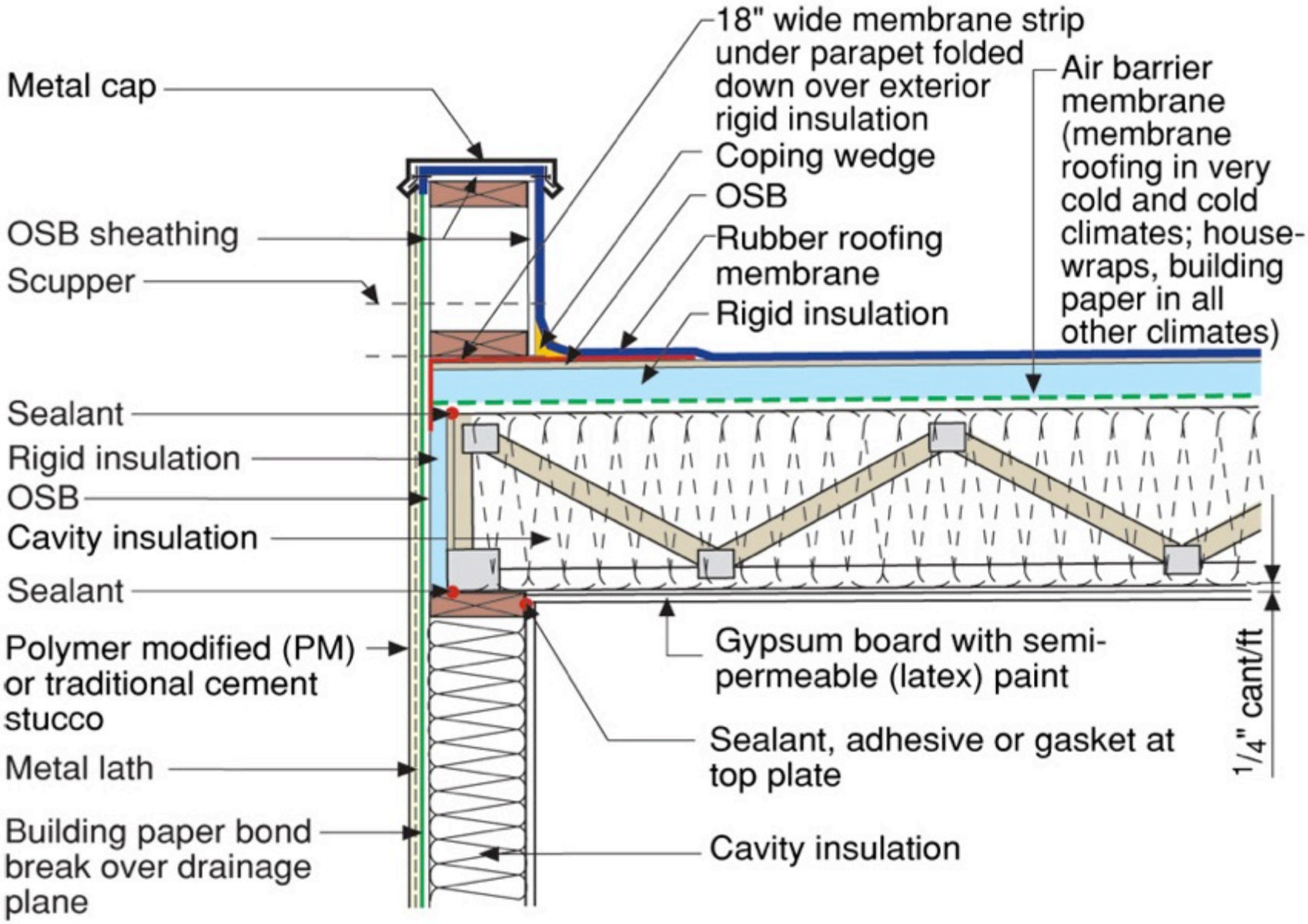

Top chord lengthens
Truss bows upward
Top chord lengthens
Bottom chord shrinks

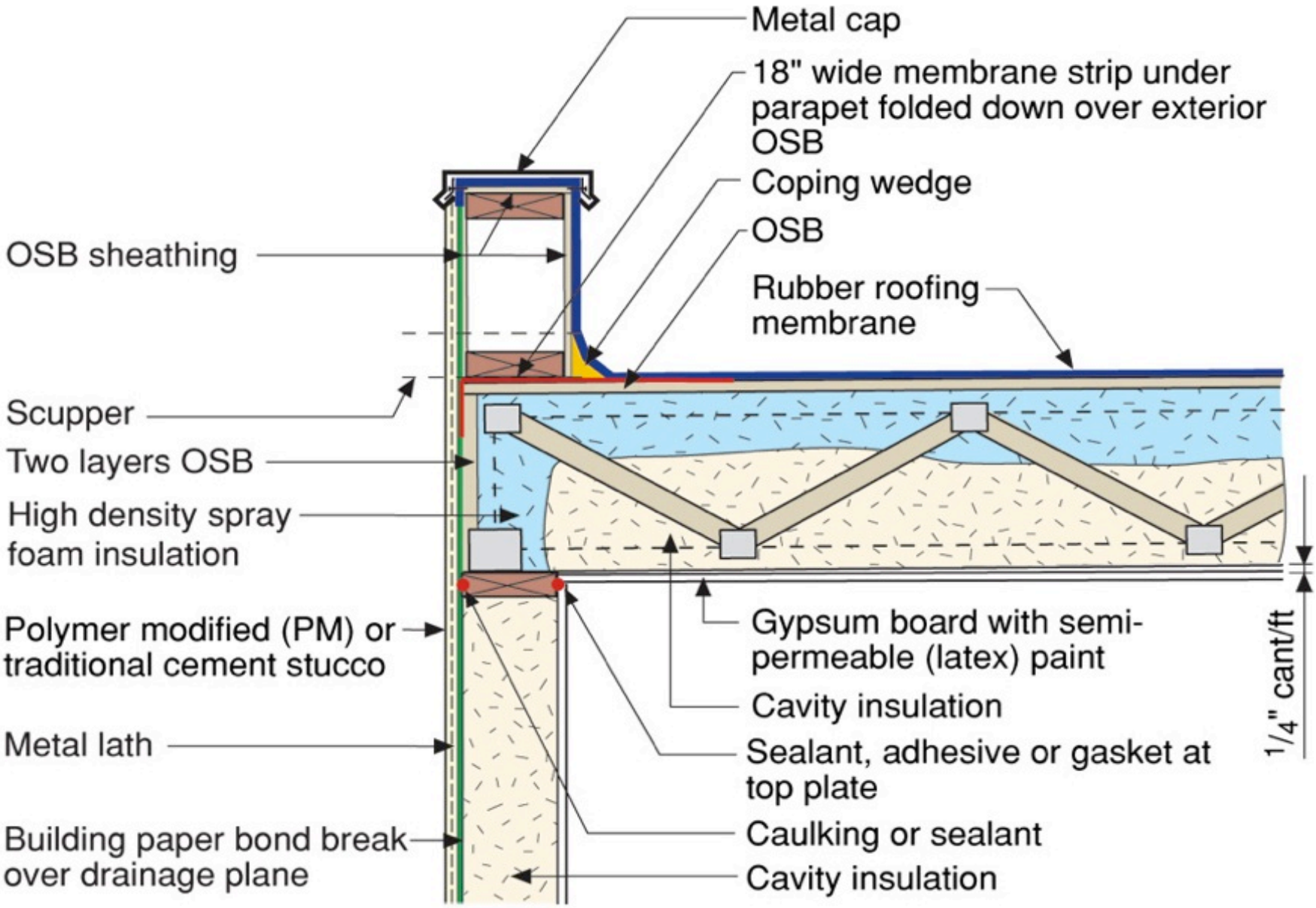

18”
18”
Bead of adhesive
Bead of adhesive
Continuous bead of drywall adhesive required here

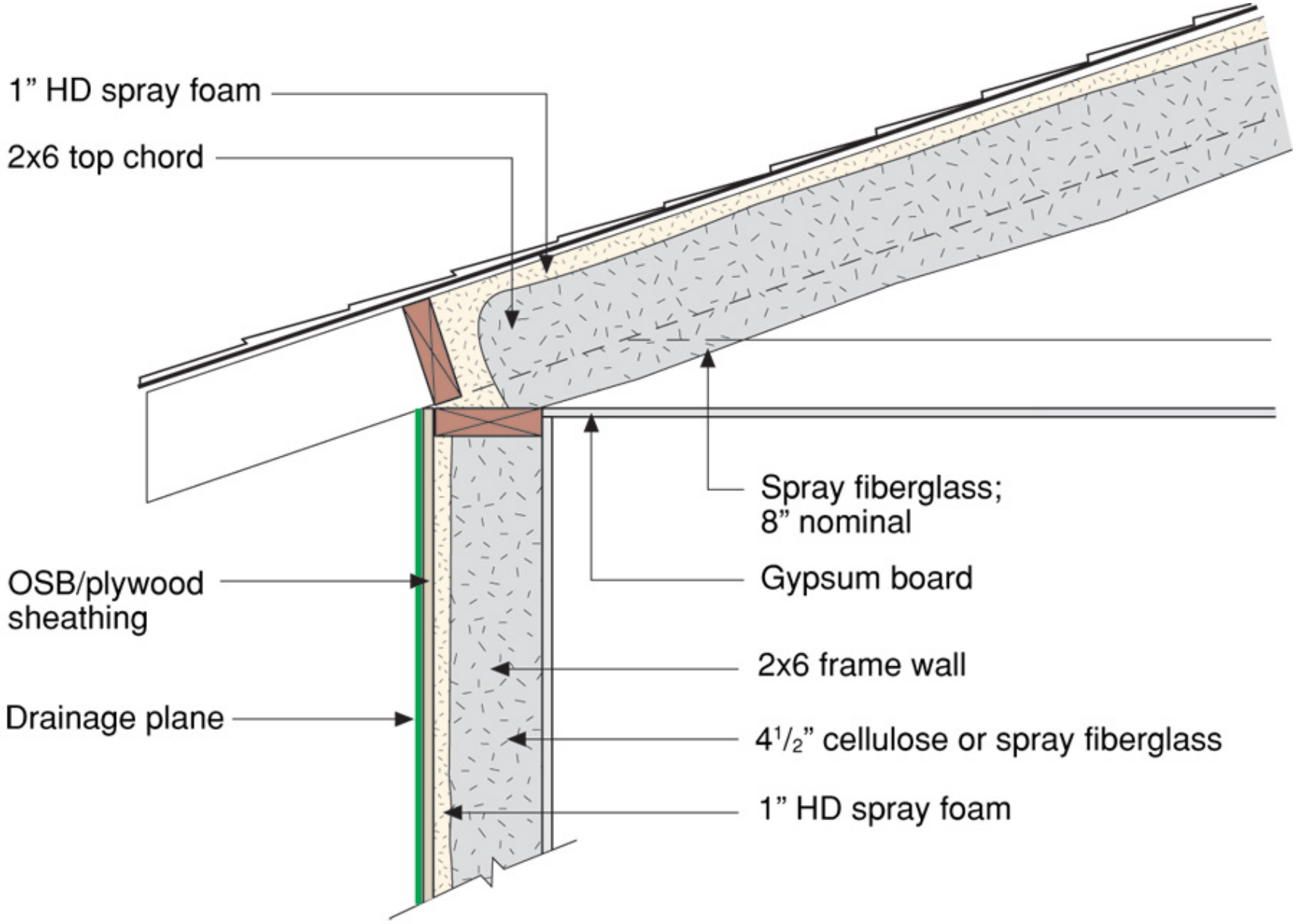

Clips may also be used
Continuous bead of drywall adhesive required here

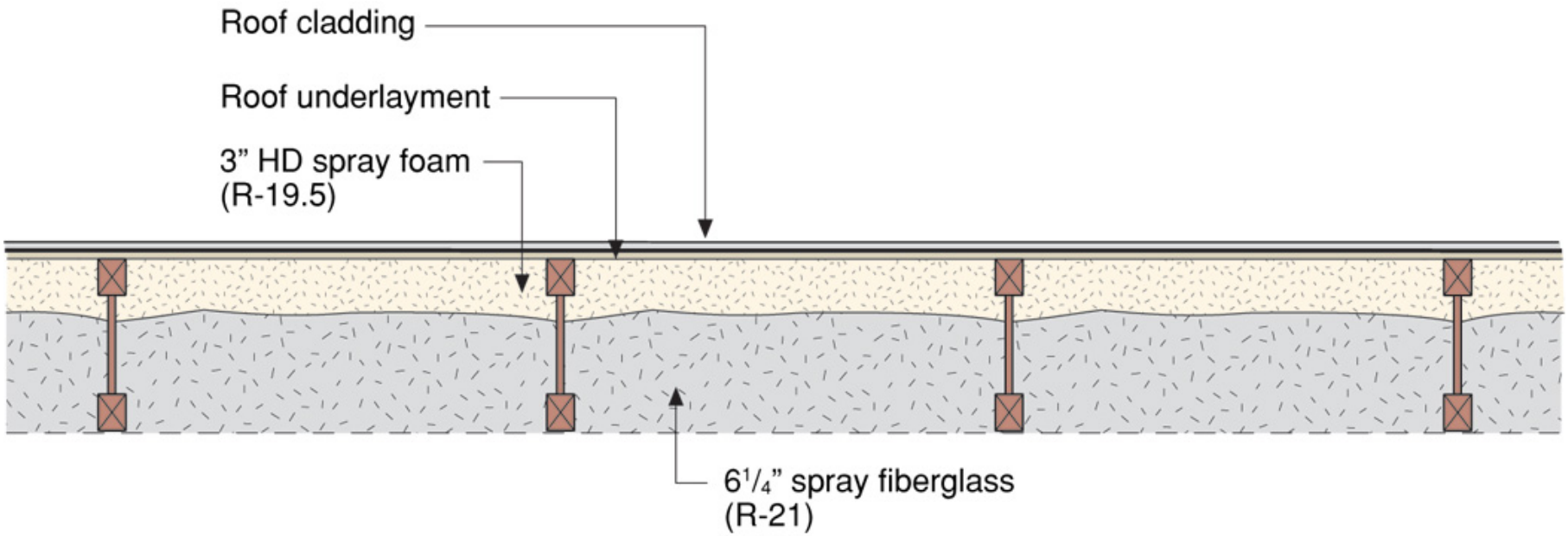

Slotted anchor at
non-bearing walls
Drywall clips
Float drywall at wall corners

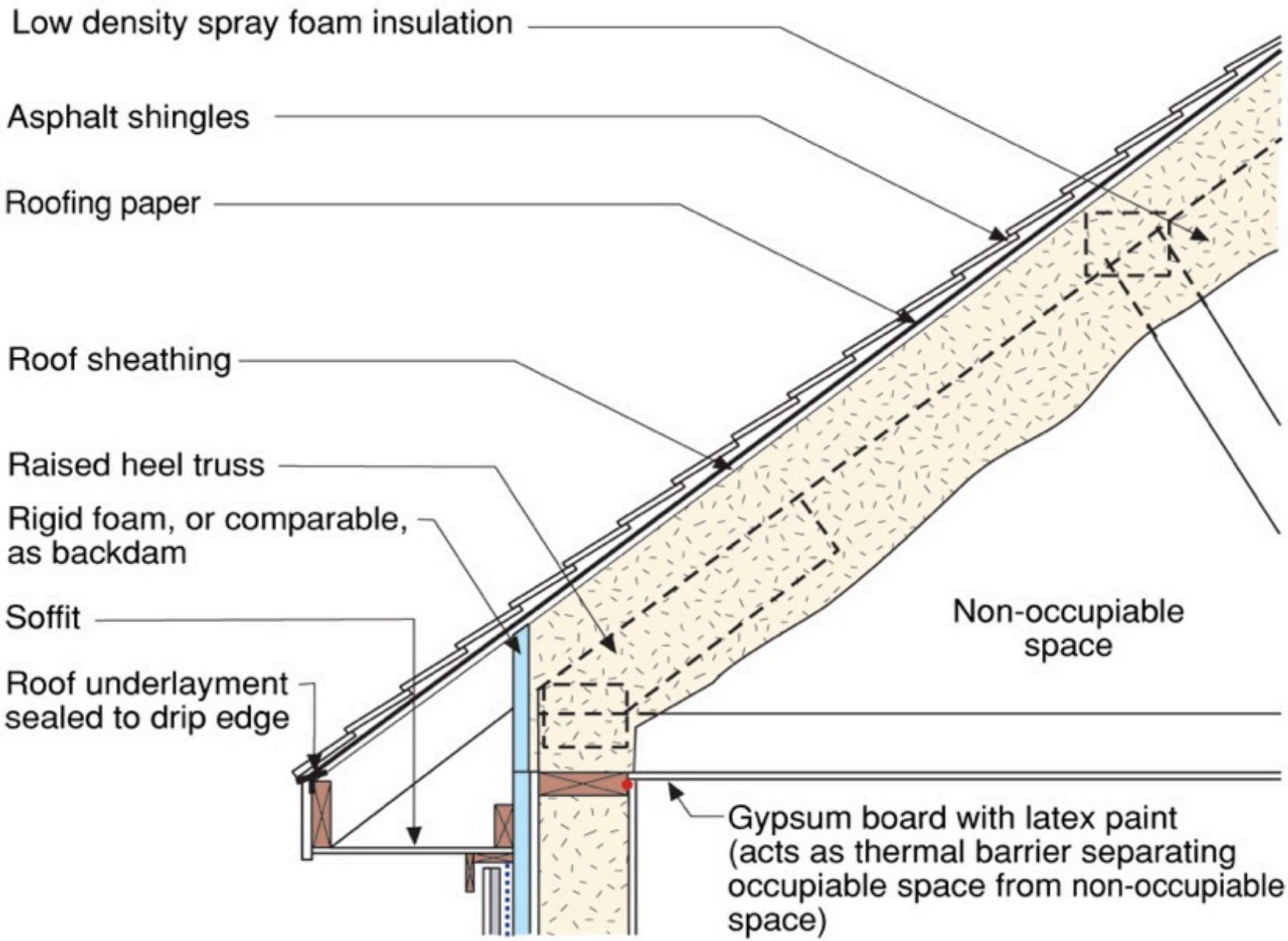
10-4-8
STRUCTURAL GRADE
INSULATIVE SHEATHING
FOR ADDED ENERGY
PERFORMANCE
STRUCTURAL GRADE
INSULATIVE SHEAT
FOR ADDED ENE


Metal cap
OSB sheathing
Scupper
Sealant
Rigid insulation
OSB
Cavity insulation
Sealant
Polymer modified (PM) or traditional cement stucco
Metal lath
Building paper bond break over drainage plane
18" wide membrane strip under parapet folded down over exterior rigid insulation
Coping wedge
OSB
Rubber roofing membrane
Rigid insulation
Air barrier membrane (membrane roofing in very cold and cold climates; house-wraps, building paper in all other climates)
Gypsum board with semi-permeable (latex) paint
Sealant, adhesive or gasket at top plate
Cavity insulation
1/4" cant/ft

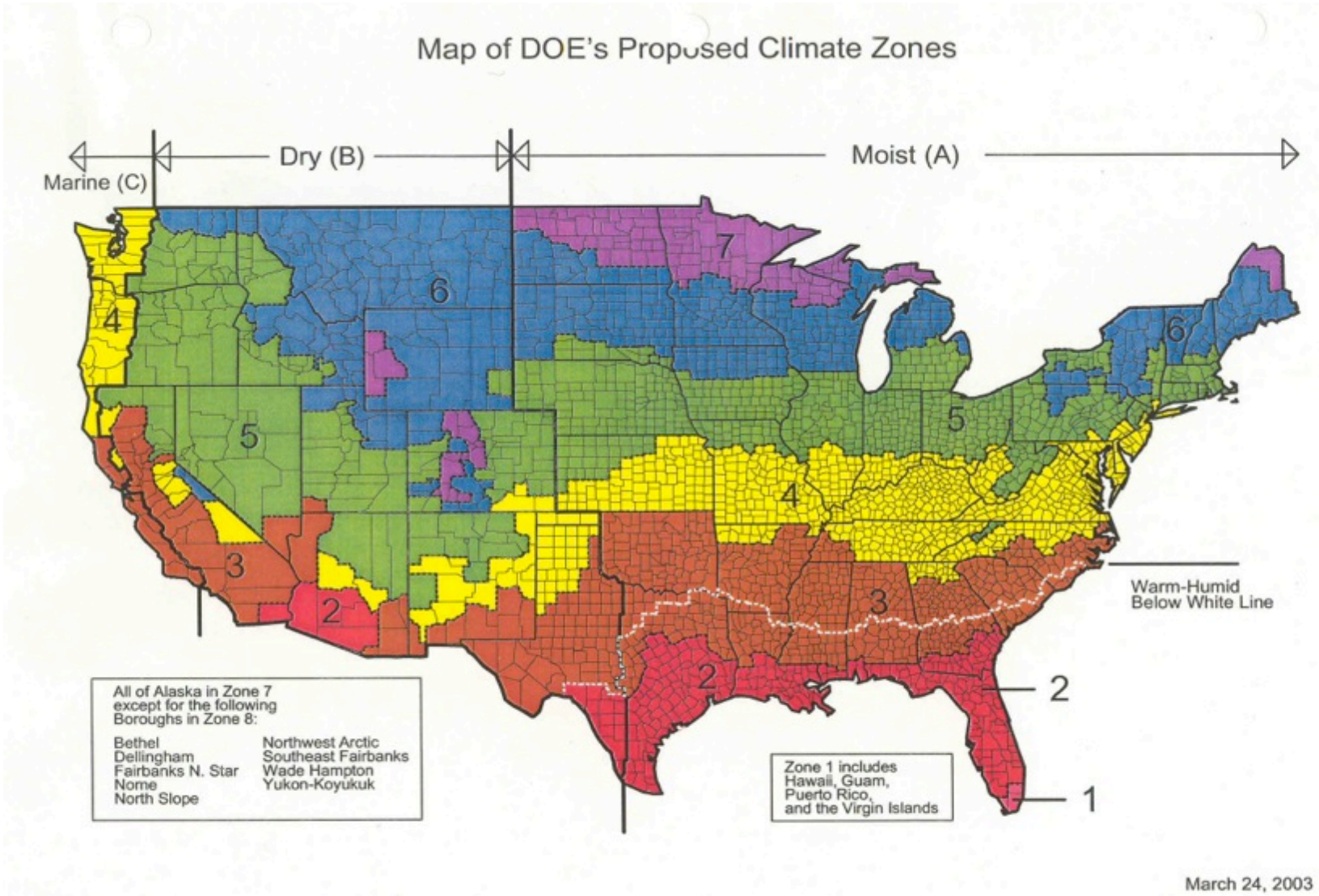

Metal cap
18" wide membrane strip under parapet folded down over exterior OSB
Coping wedge
OSB
OSB sheathing
Rubber roofing membrane
Scupper
Two layers OSB
High density spray foam insulation
Polymer modified (PM) or traditional cement stucco
Metal lath
Building paper bond break over drainage plane
Gypsum board with semi-permeable (latex) paint
Cavity insulation
Sealant, adhesive or gasket at top plate
Caulking or sealant
Cavity insulation
1/4" cant/ft


1” HD spray foam
2x6 top chord
Spray fiberglass;
8” nominal
Gypsum board
OSB/plywood
sheathing
2x6 frame wall
Drainage plane
4½” cellulose or spray fiberglass
1” HD spray foam


Roof cladding
Roof underlayment
3” HD spray foam
(R-19.5)
6¼” spray fiberglass
(R-21)


Low density spray foam insulation
Asphalt shingles
Roofing paper
Roof sheathing
Raised heel truss
Rigid foam, or comparable, as backdam
Soffit
Roof underlayment sealed to drip edge
Non-occupiable space
Gypsum board with latex paint (acts as thermal barrier separating occupiable space from non-occupiable space)

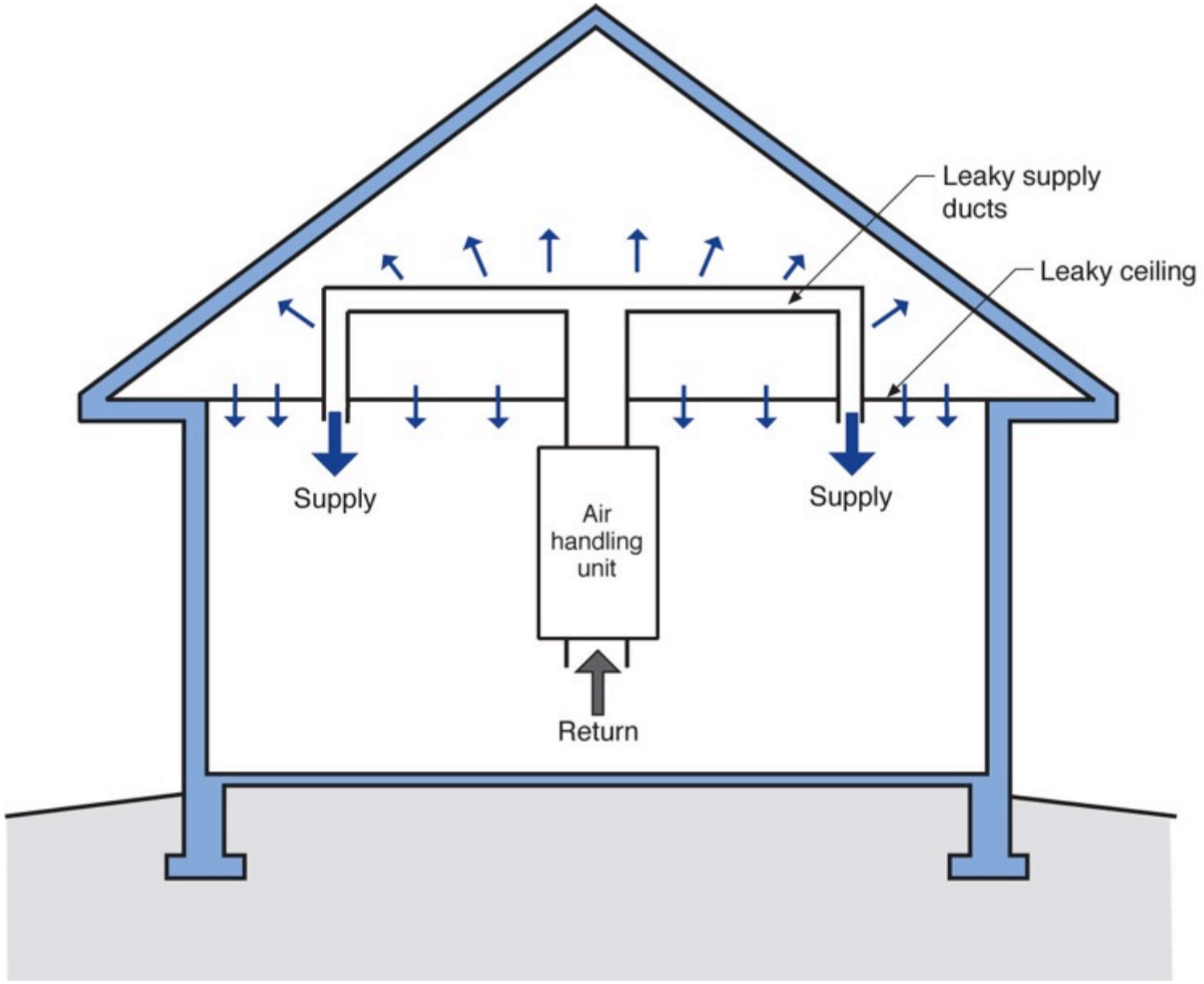
FOAMULAR
OWENS CORNING


Map of DOE's Proposed Climate Zones
Marine (C)
Dry (B)
Moist (A)
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
March 24, 2003

GRACE
Ice & Water Shield
TRI-FLEX 30
APR 20 2004

APR 20 2004

Conditioned Attics Not Unvented Attics


Leaky supply ducts
Leaky ceiling
Supply
Supply
Air handling unit
Return

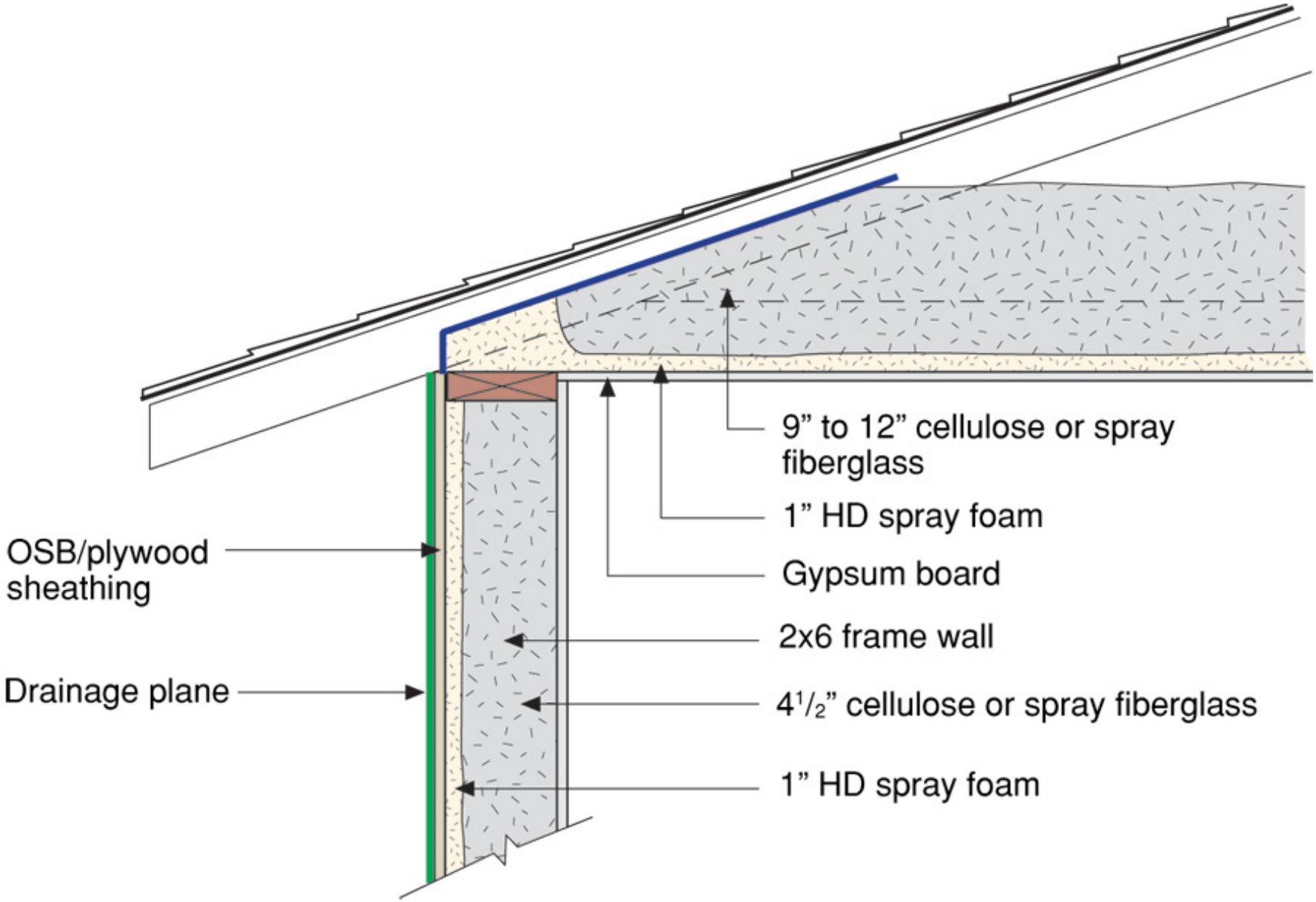
Conditioned Attics Not Unvented Attics

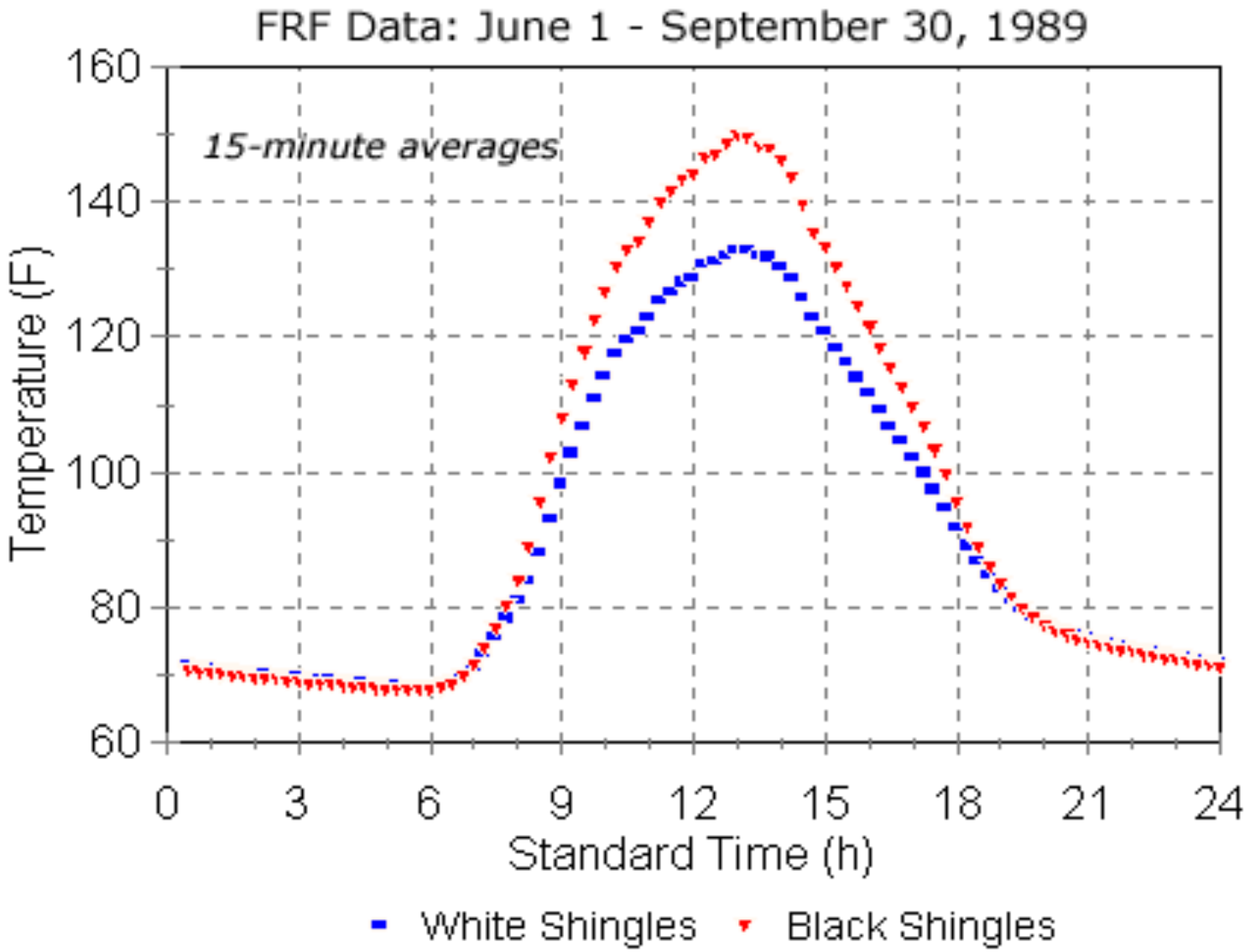
Need Supply Air

Conditioned Attics Not Unvented Attics

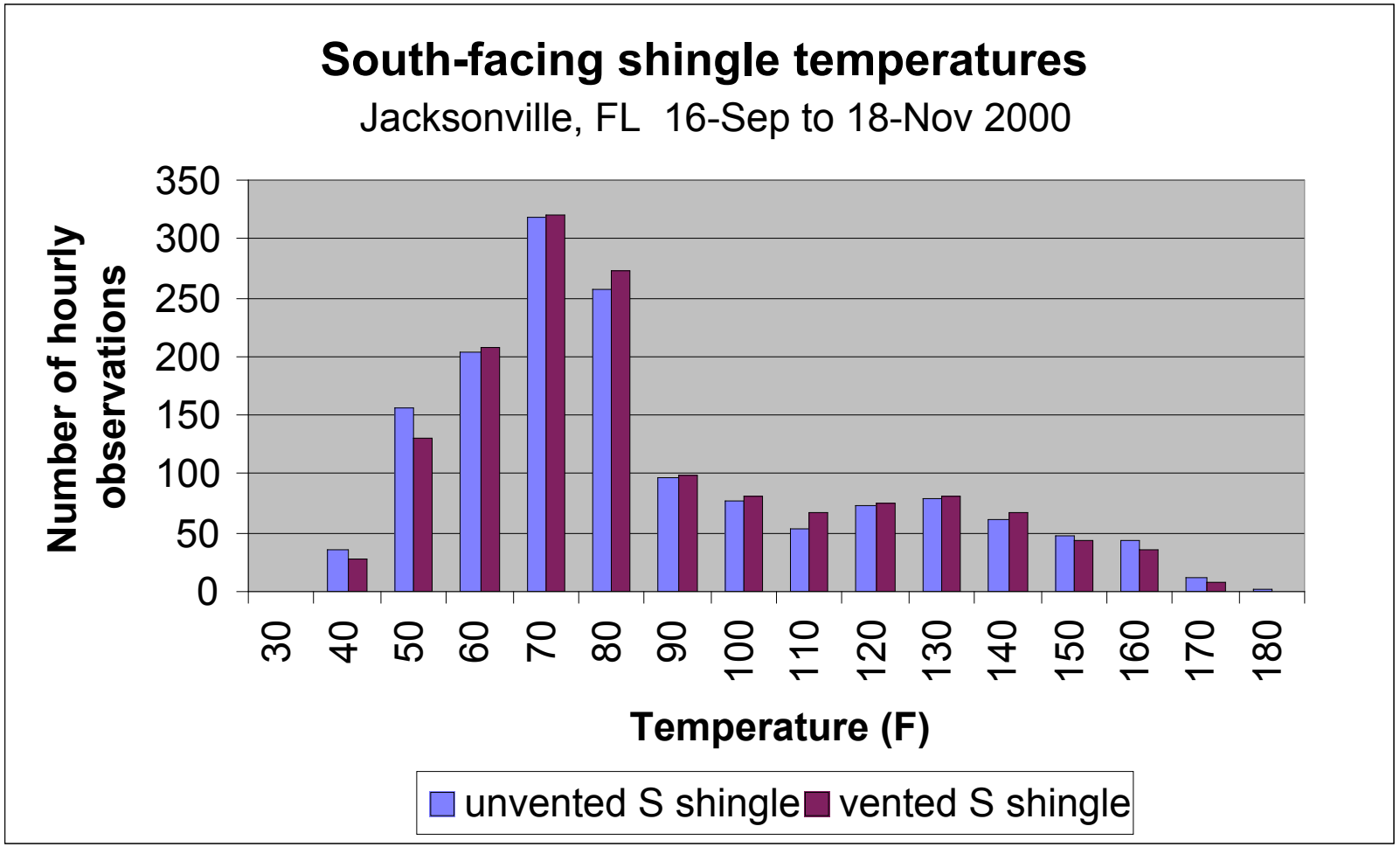
Need Supply Air

50 cfm/1000 ft2 of Attic

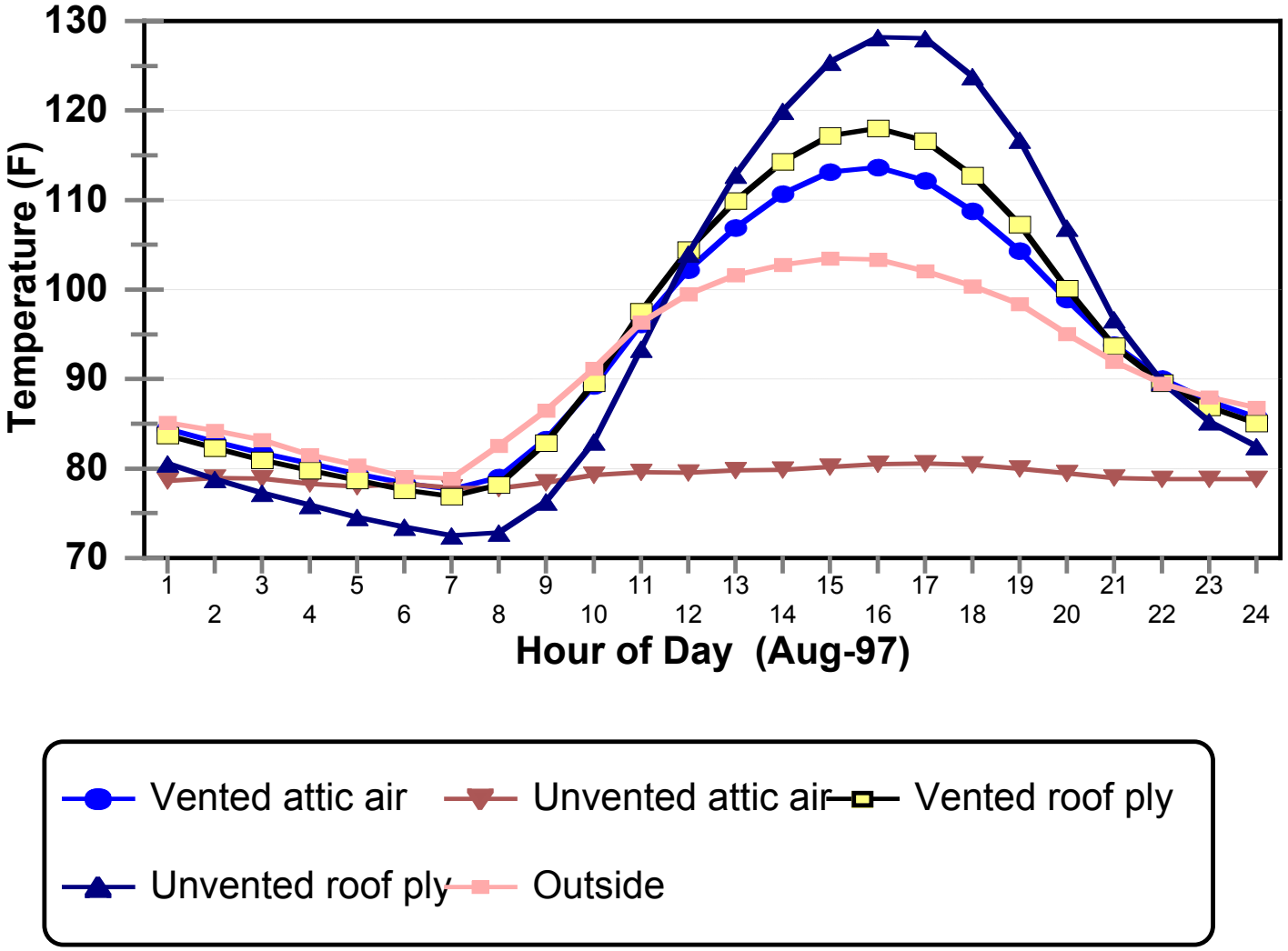

9” to 12” cellulose or spray fiberglass
1” HD spray foam
Gypsum board
2x6 frame wall
4 1/2” cellulose or spray fiberglass
1” HD spray foam
OSB/plywood sheathing
Drainage plane

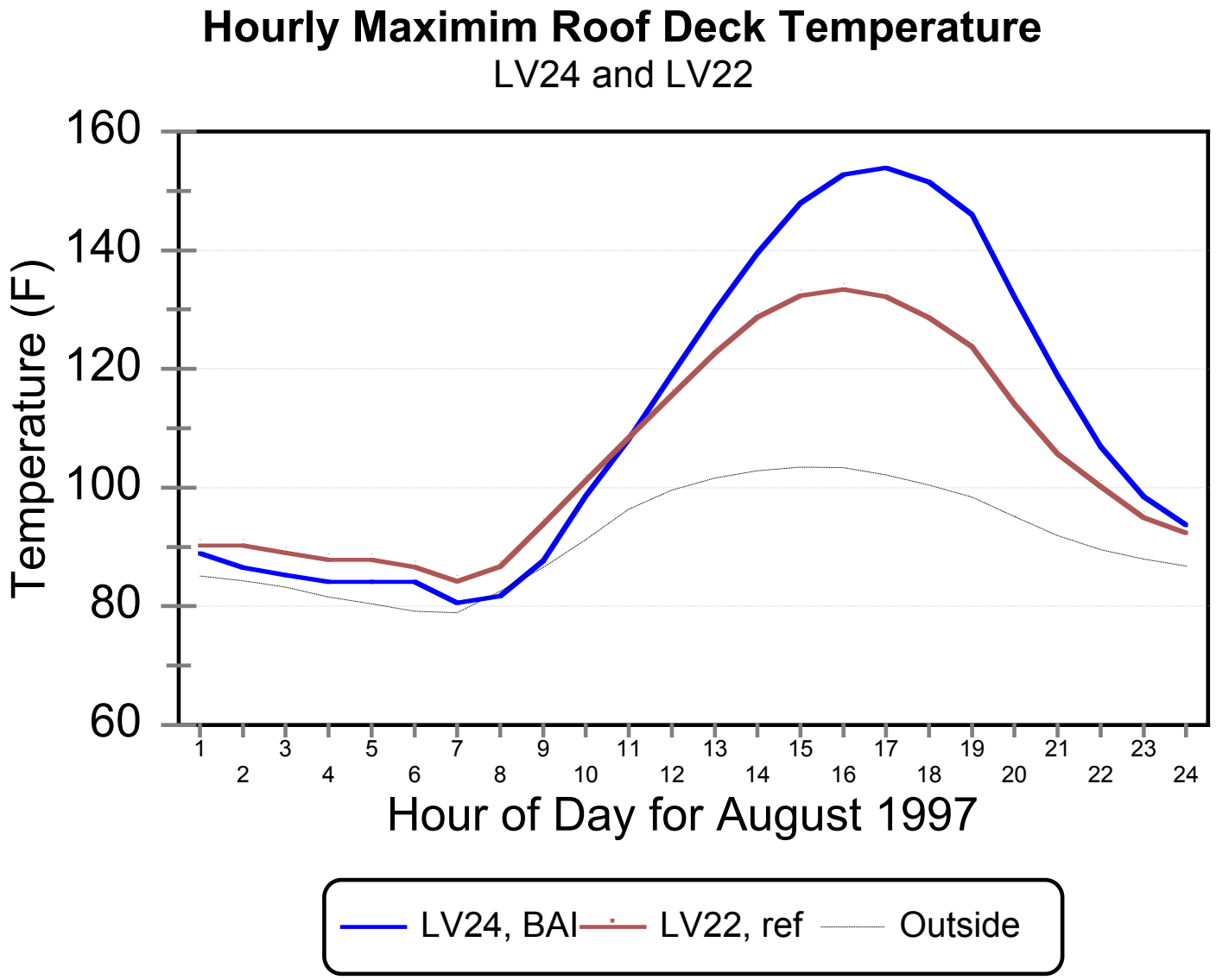

FRF Data: June 1 - September 30, 1989
15-minute averages
Temperature (F)
160
140
120
100
80
60
0
3
6
9
12
15
18
21
24
Standard Time (h)
White Shingles
Black Shingles

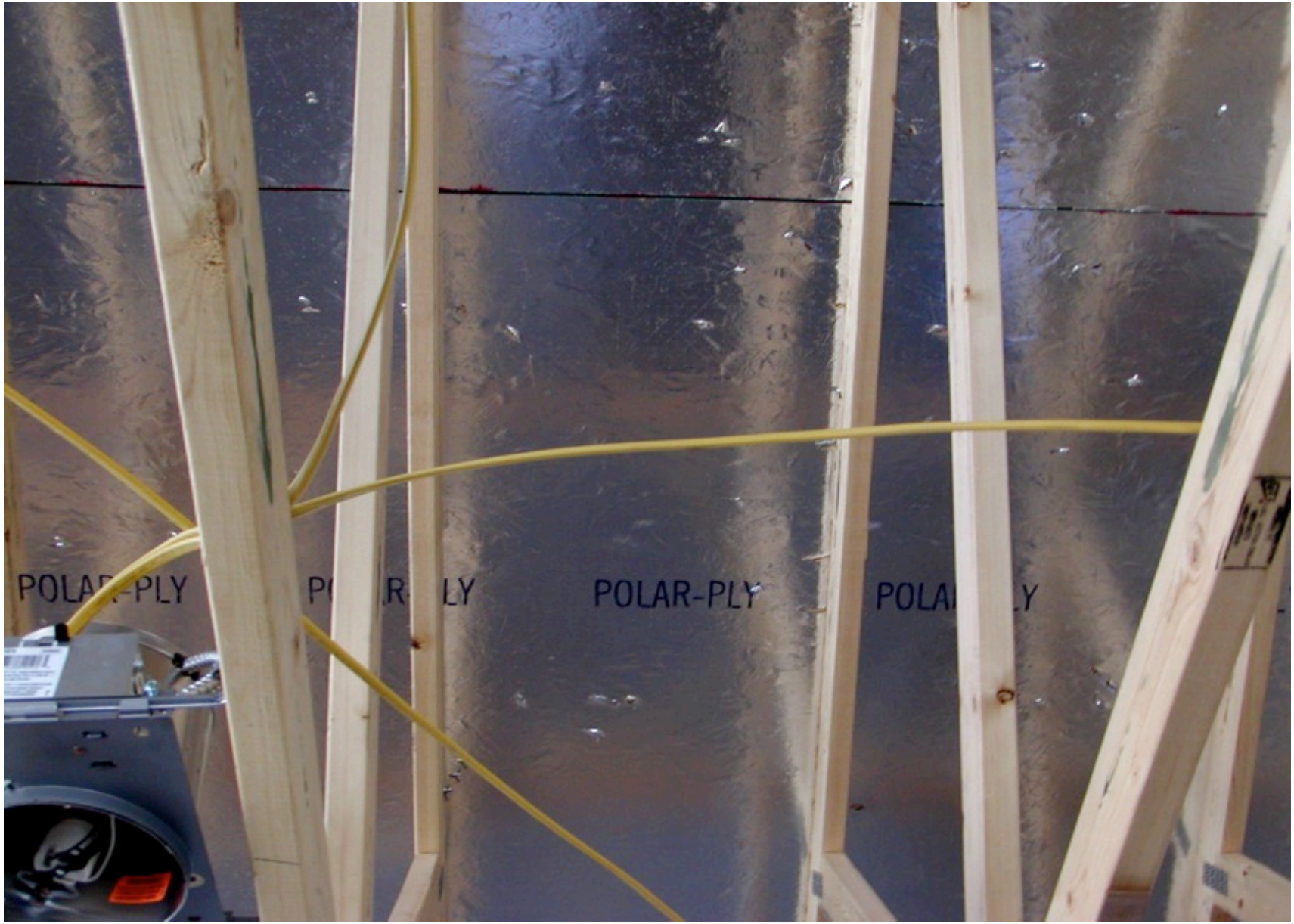
Vented vs. unvented shingle temperatures



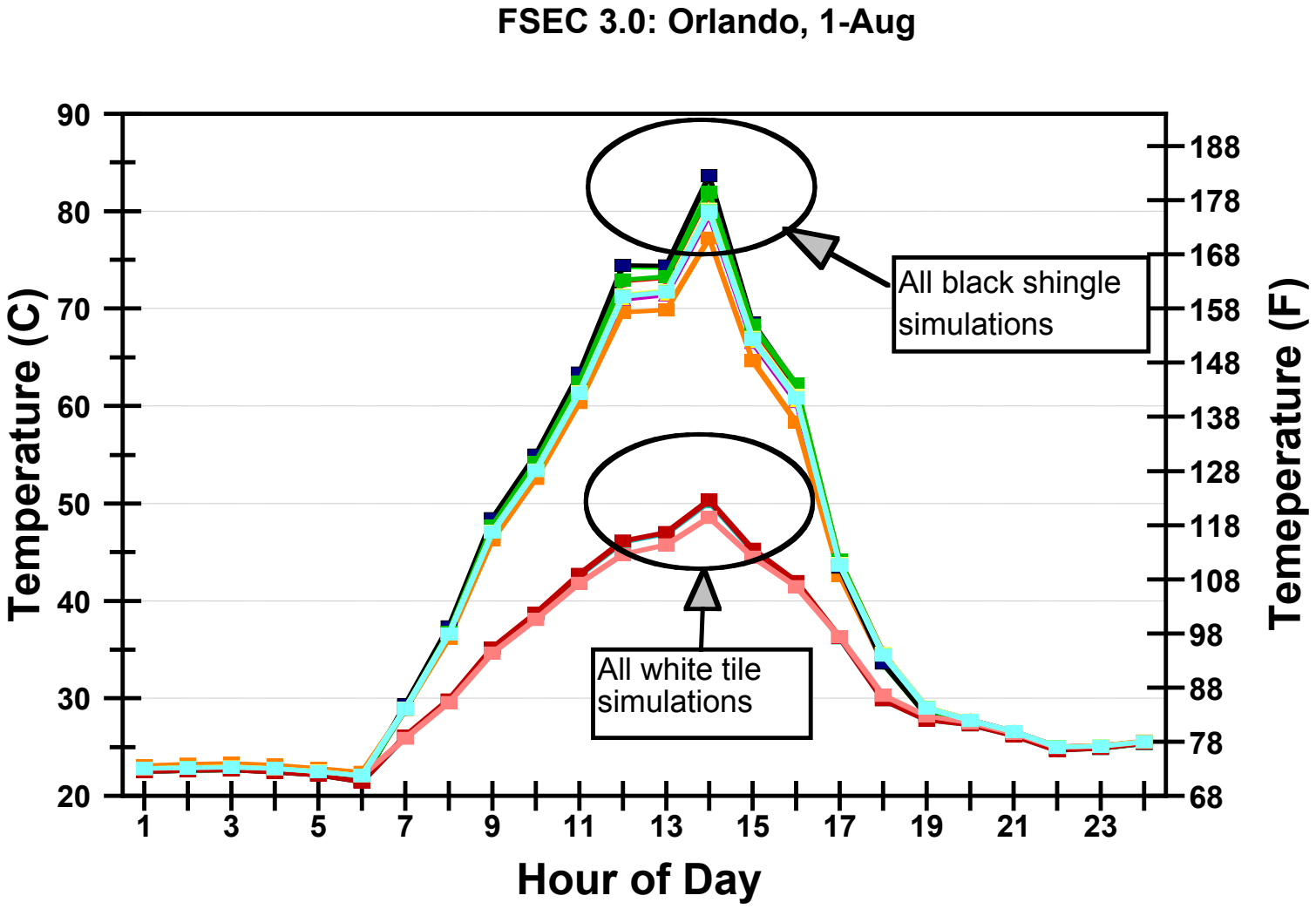
Average Temperatures
Vented and Unvented Attics, Aug-97



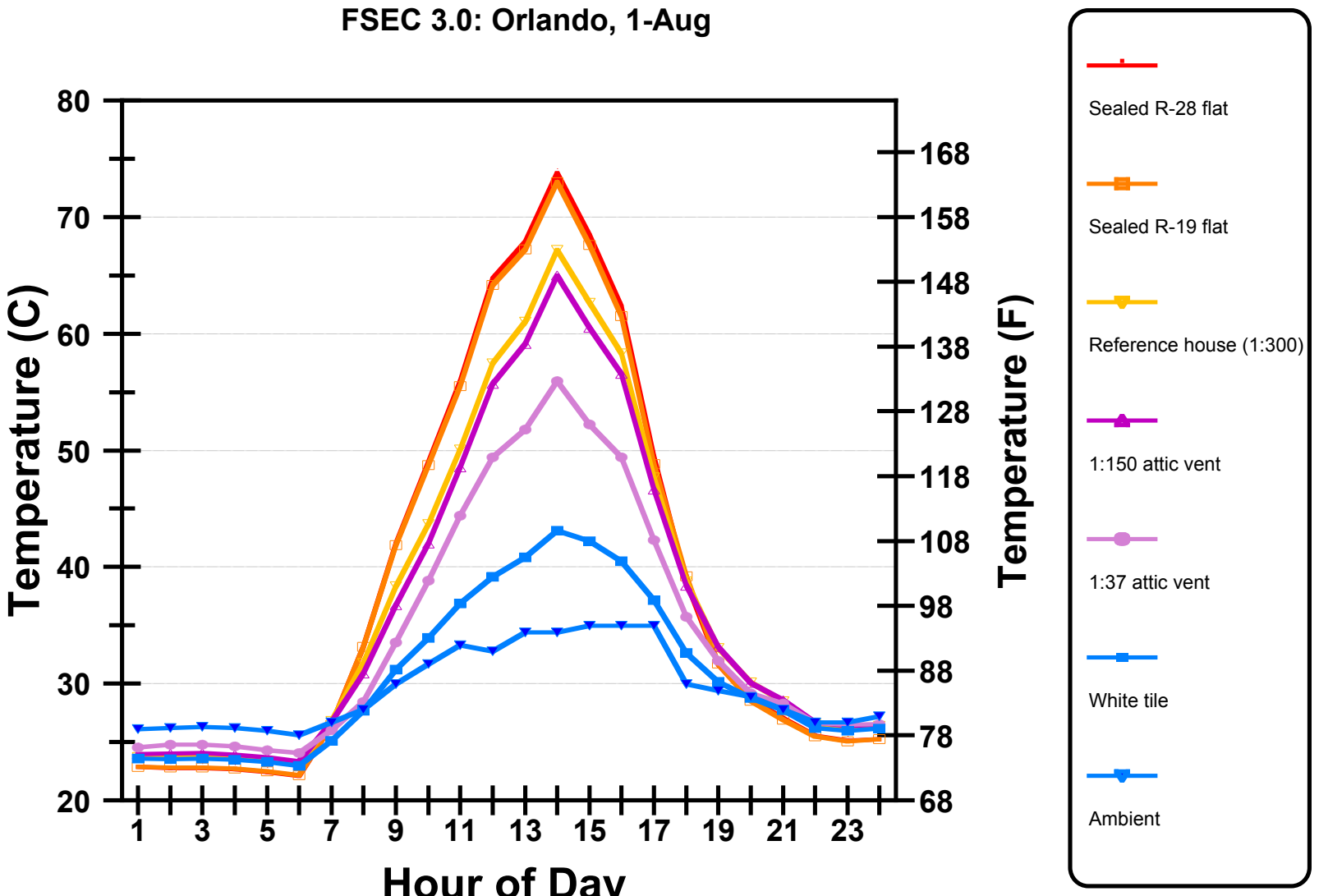

Hourly Maximim Roof Deck Temperature
LV24 and LV22
160
140
120
100
80
60
Temperature (F)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Hour of Day for August 1997
LV24, BAI
LV22, ref
Outside

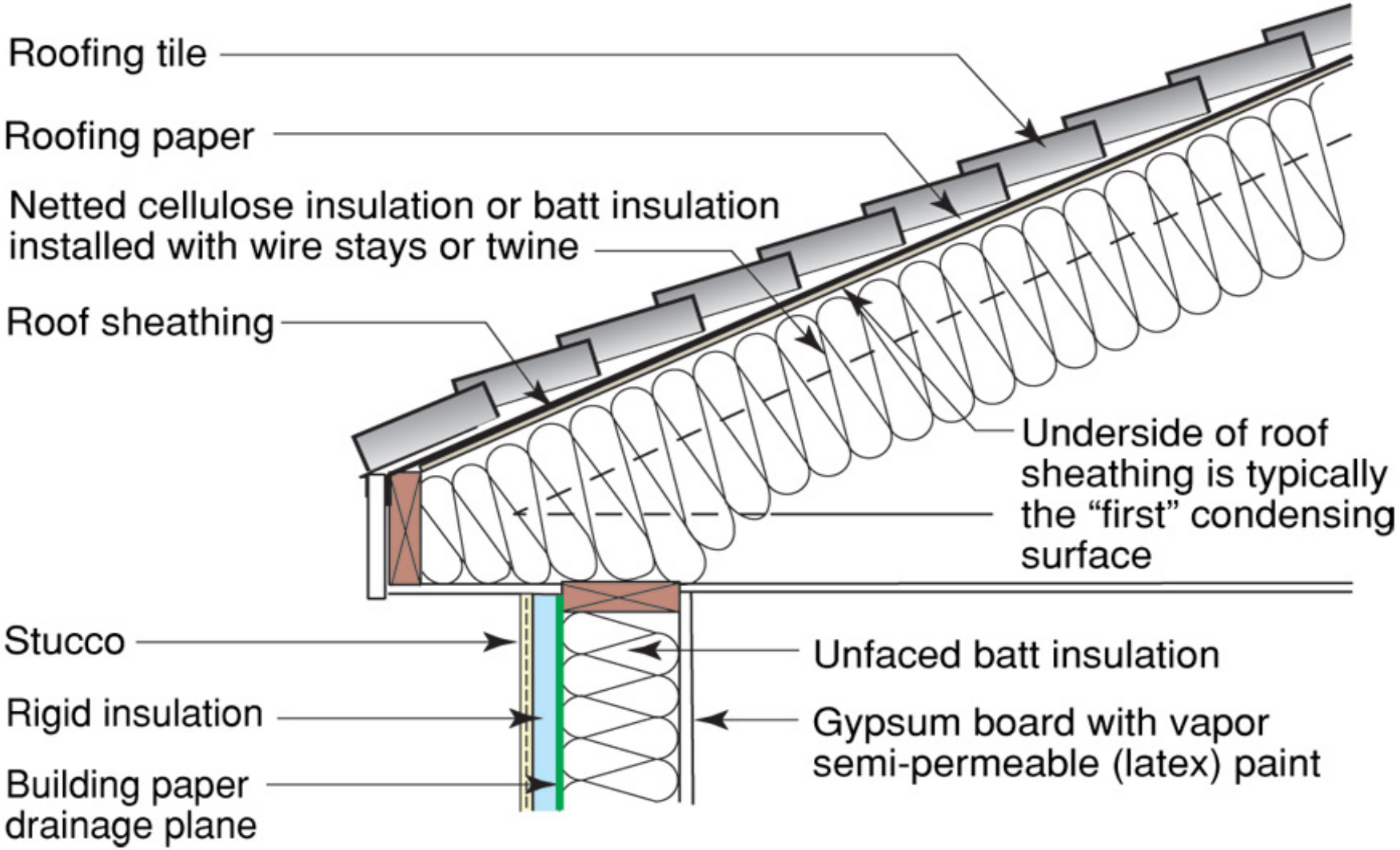

POLAR-PLY
POLAR-PLY

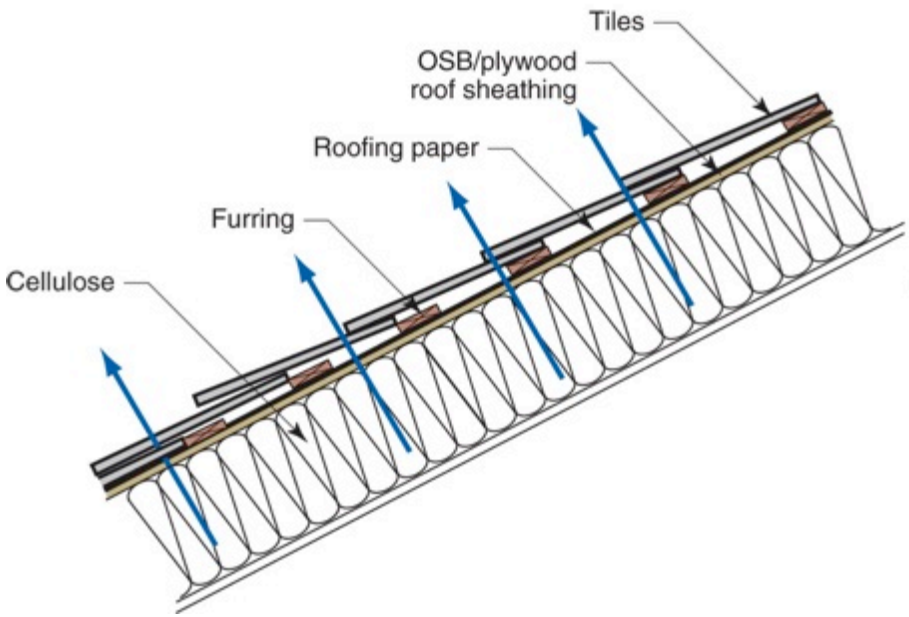
Roof Shingle Temperature

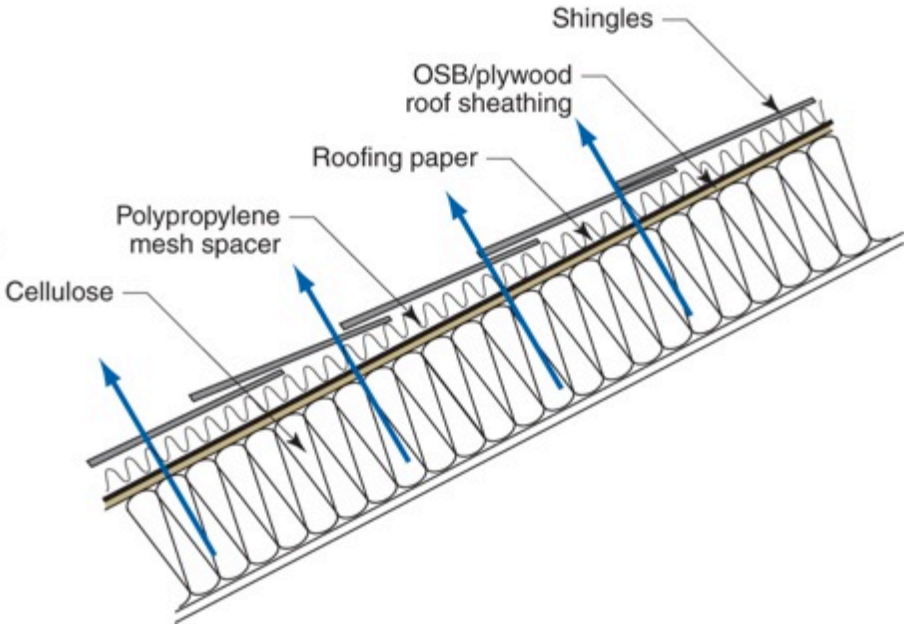


Bottom of Roof Plywood Temperature

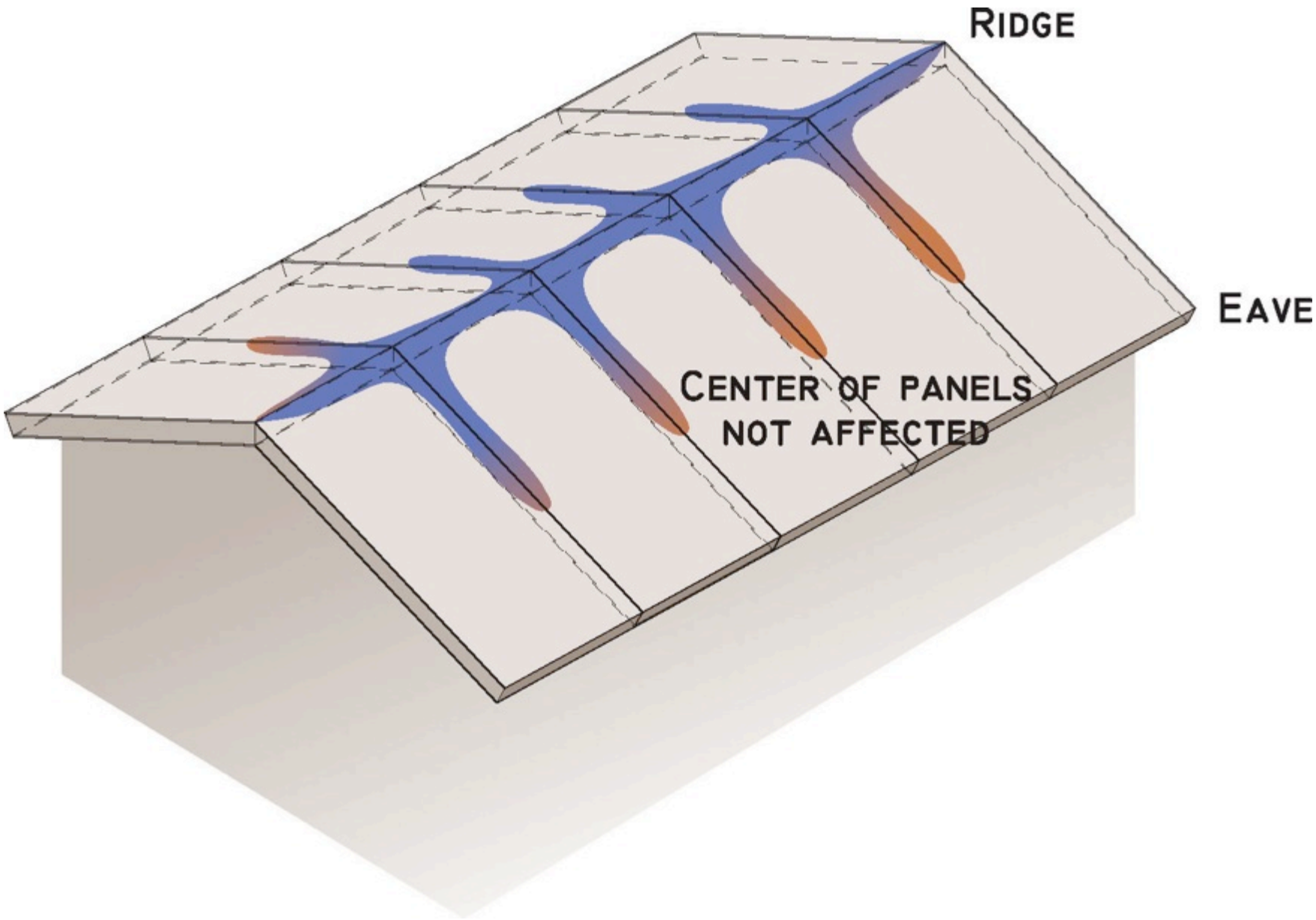



Roofing tile
Roofing paper
Netted cellulose insulation or batt insulation installed with wire stays or twine
Roof sheathing
Underside of roof sheathing is typically the “first” condensing surface
Stucco
Rigid insulation
Building paper drainage plane
Unfaced batt insulation
Gypsum board with vapor semi-permeable (latex) paint

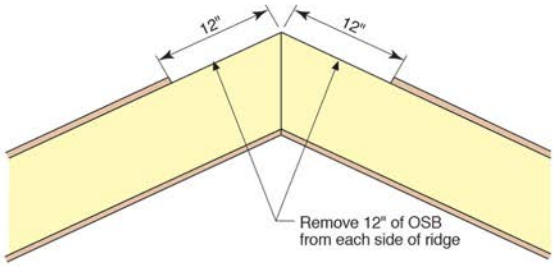

Tiles
OSB/plywood
roof sheathing
Roofing paper
Furring
Cellulose


Shingles
OSB/plywood
roof sheathing
Roofing paper
Polypropylene
mesh spacer
Cellulose

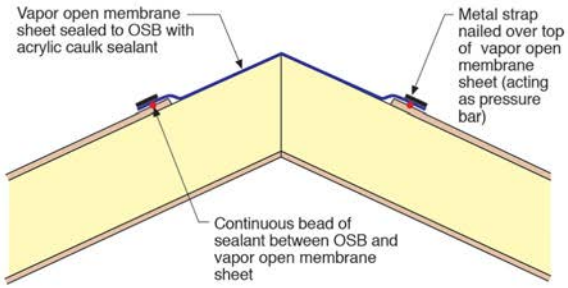
8/22/01 09:32


RIDGE
EAVE
CENTER OF PANELS
NOT AFFECTED

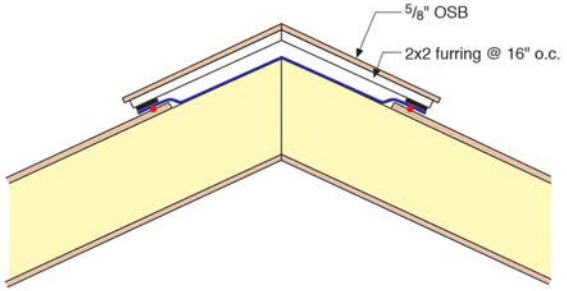
Step 1
- Remove strip of OSB from each side of ridge



Step 2
- Create air seal with strip of vapor open membrane (tape seams)
- Vapor open membrane sheet sealed to OSB with acrylic caulk sealant
- Hold vapor open membrane sheet in place with metal strapping



Step 3
- Construct wood ridge vent with 2x2 furring

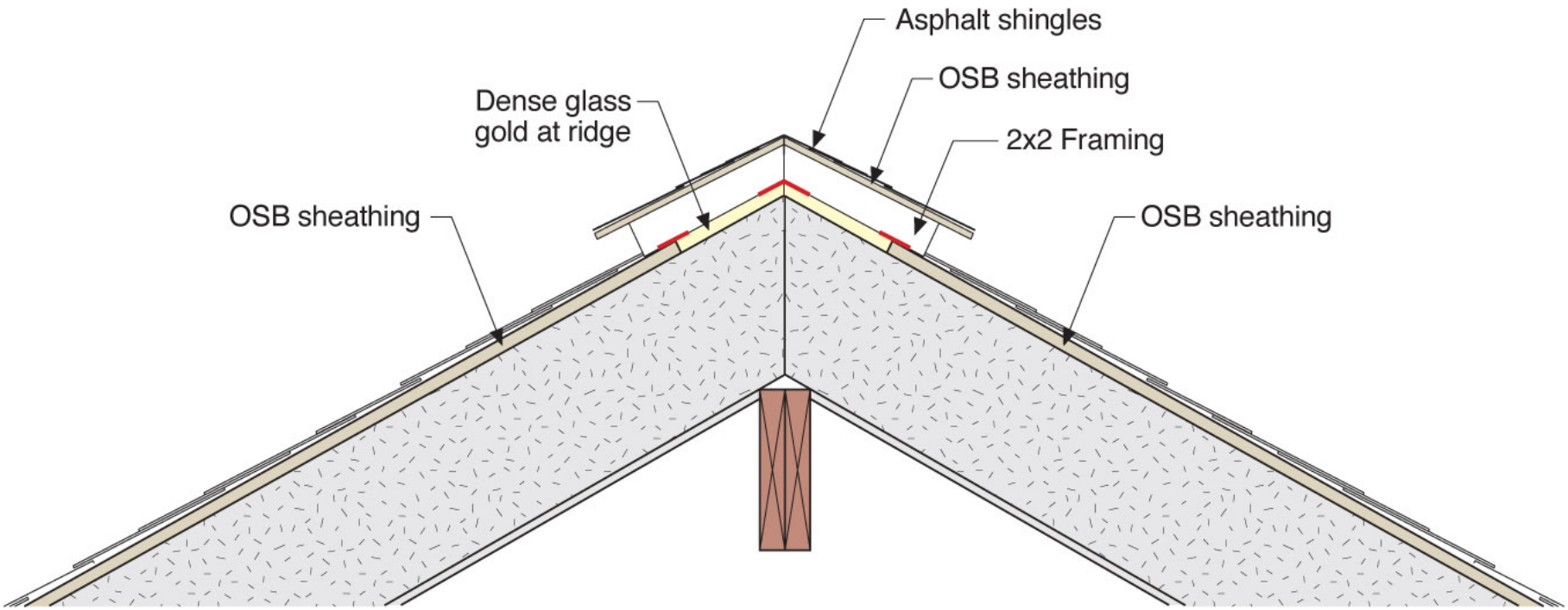


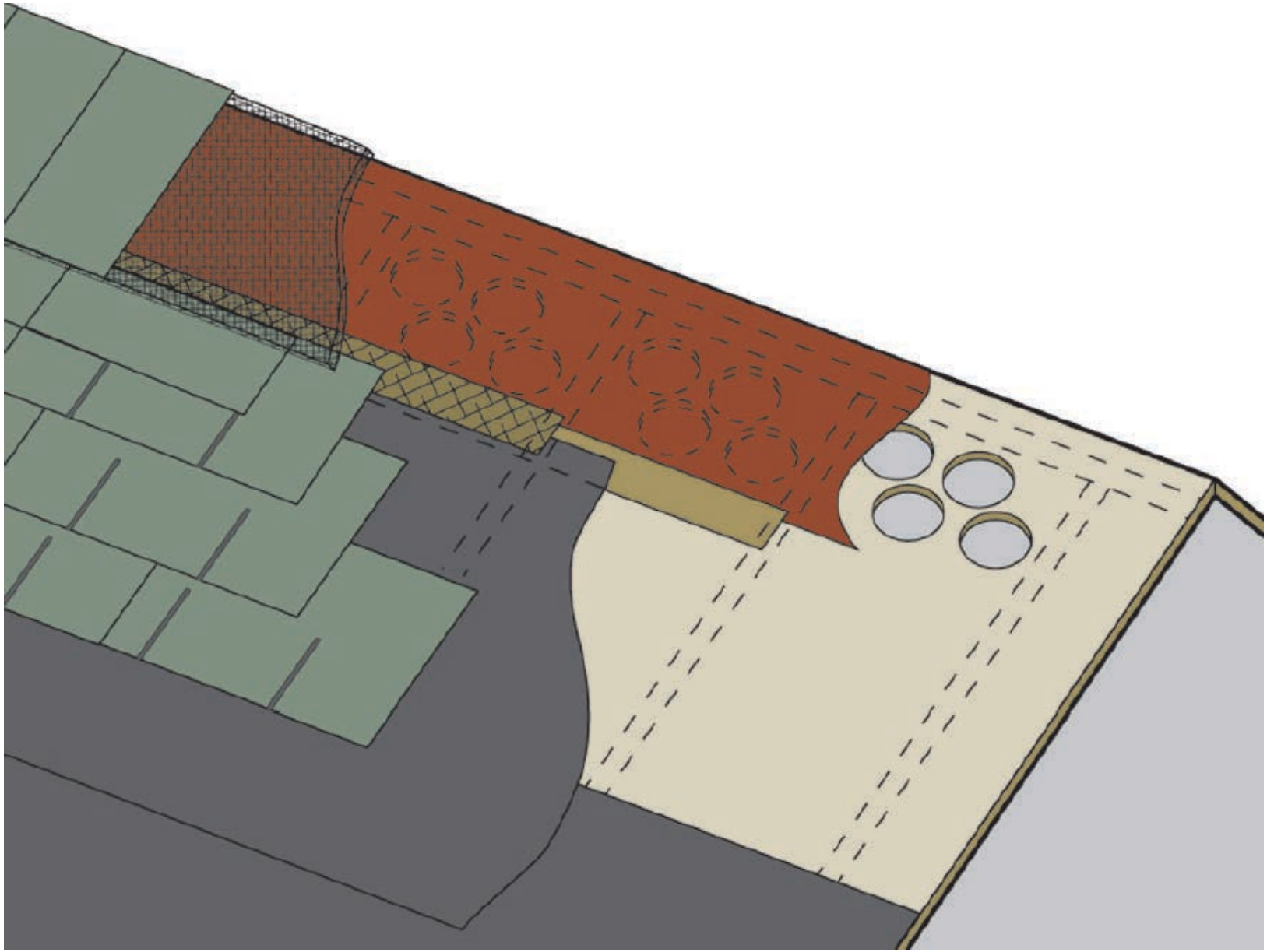
GRACE
Ice & Water Shield
Tyvek
Attic Wrap
DUPONT

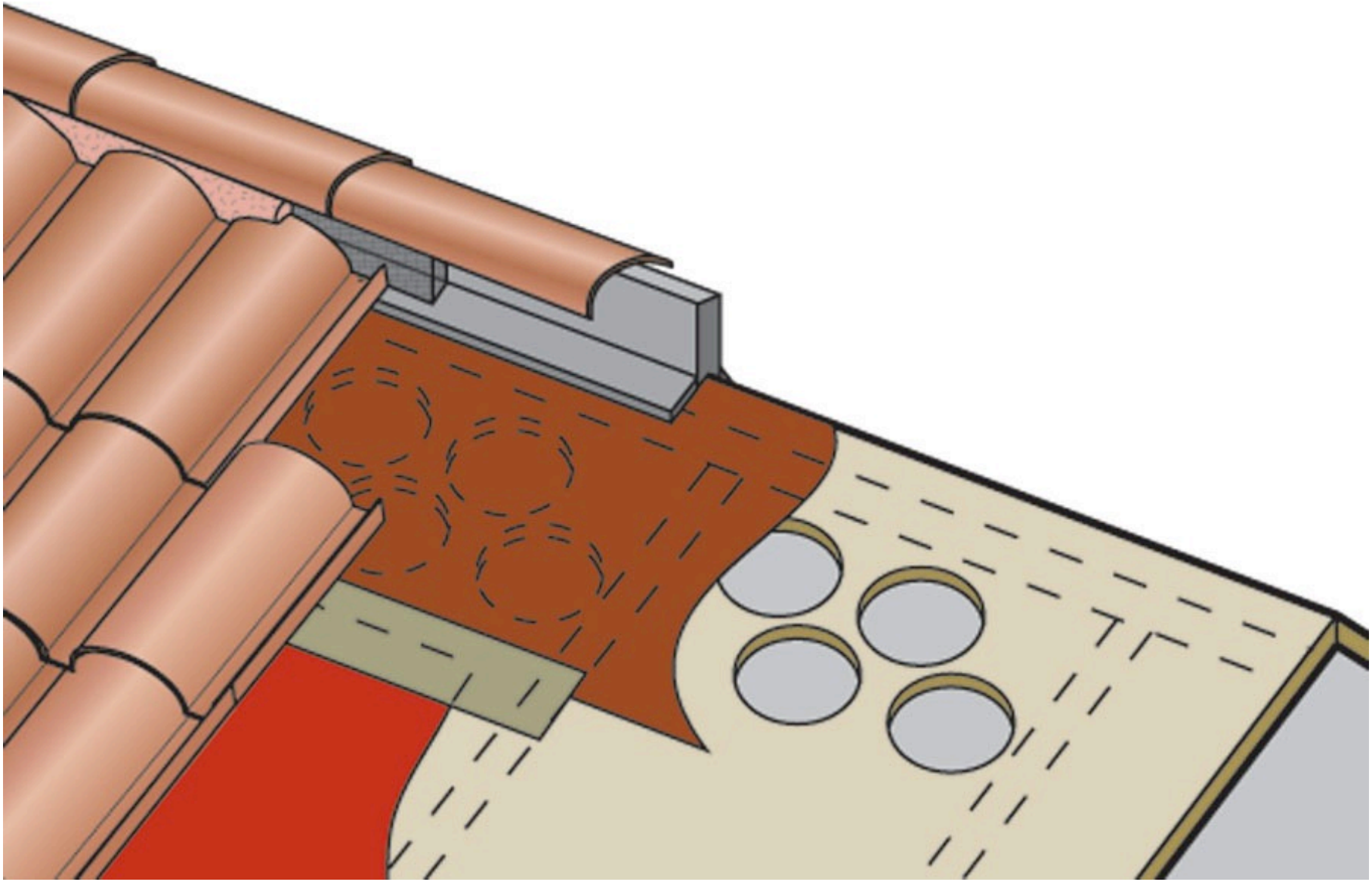
Tyvek
AtticWrap

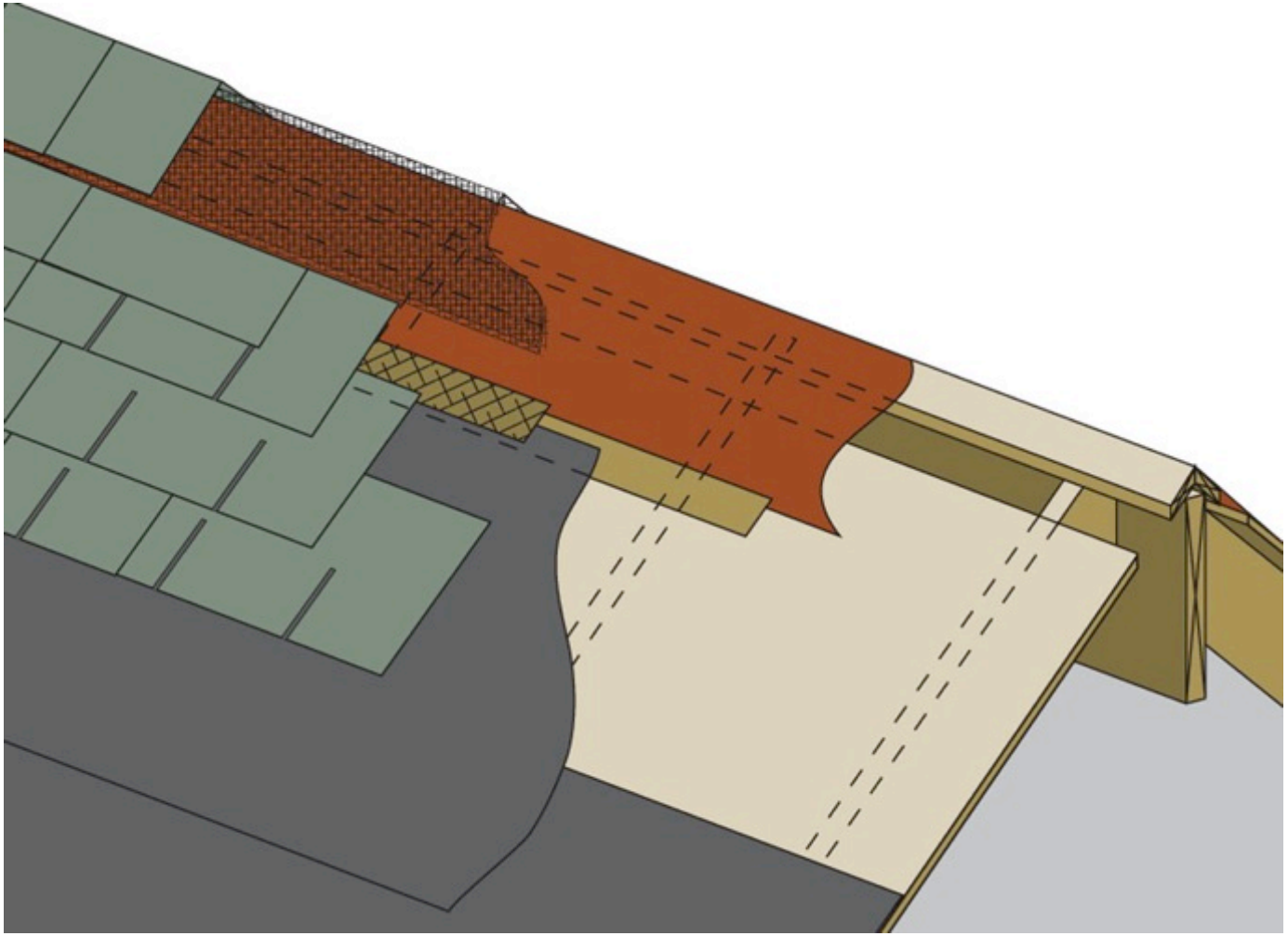
GRACE
Ice & Water Shield®

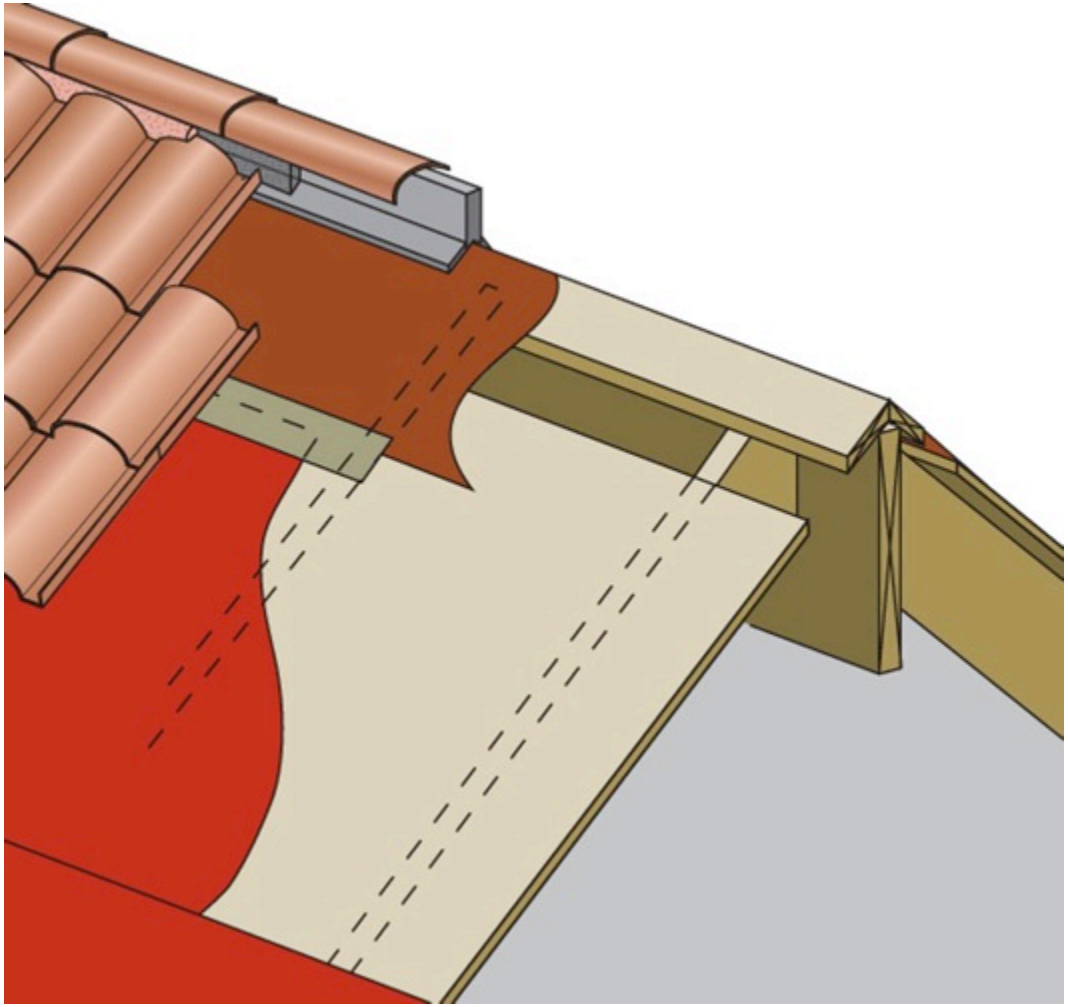
JUL 9 2006


Asphalt shingles
OSB sheathing
Dense glass
gold at ridge
2x2 Framing
OSB sheathing
OSB sheathing







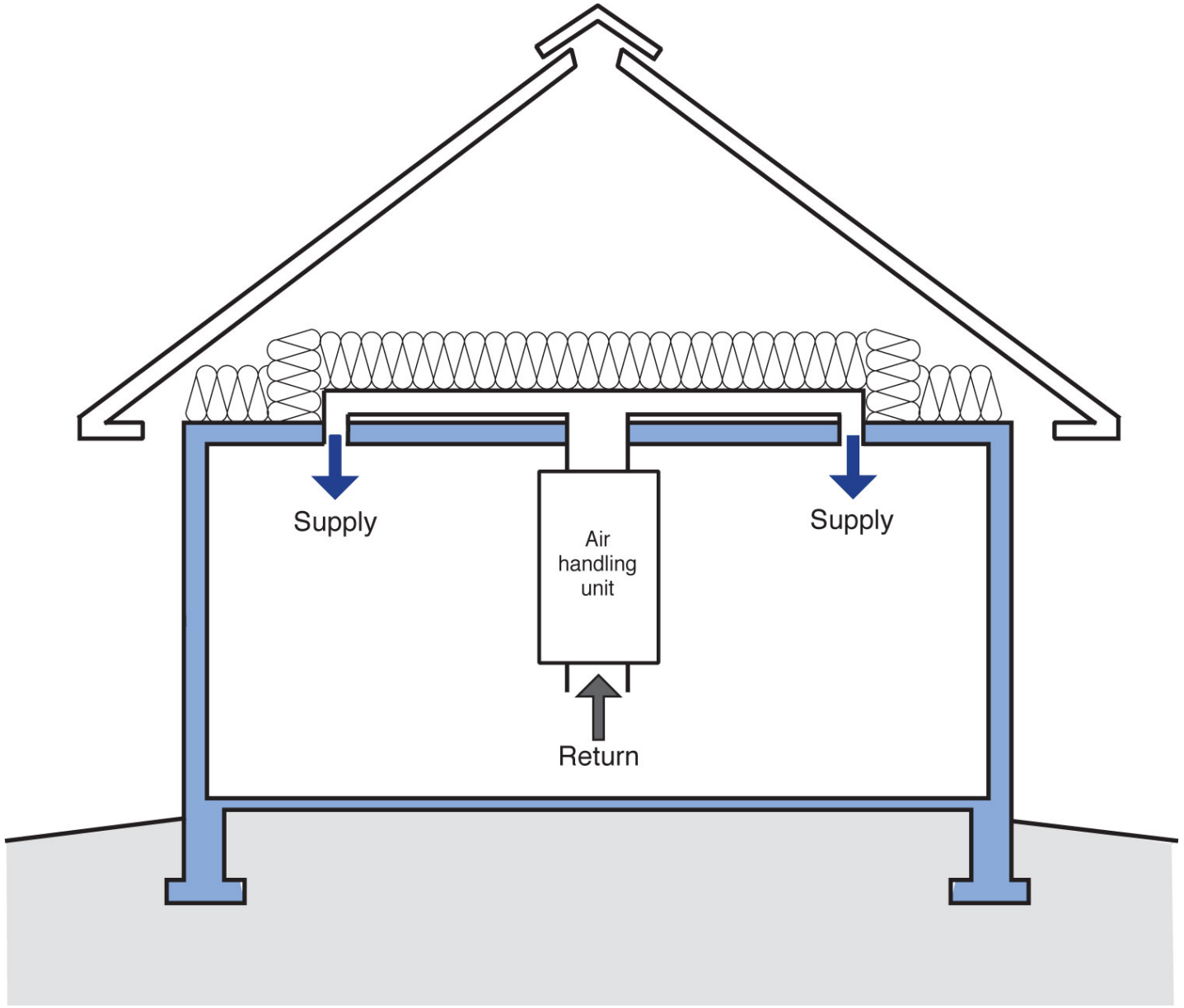


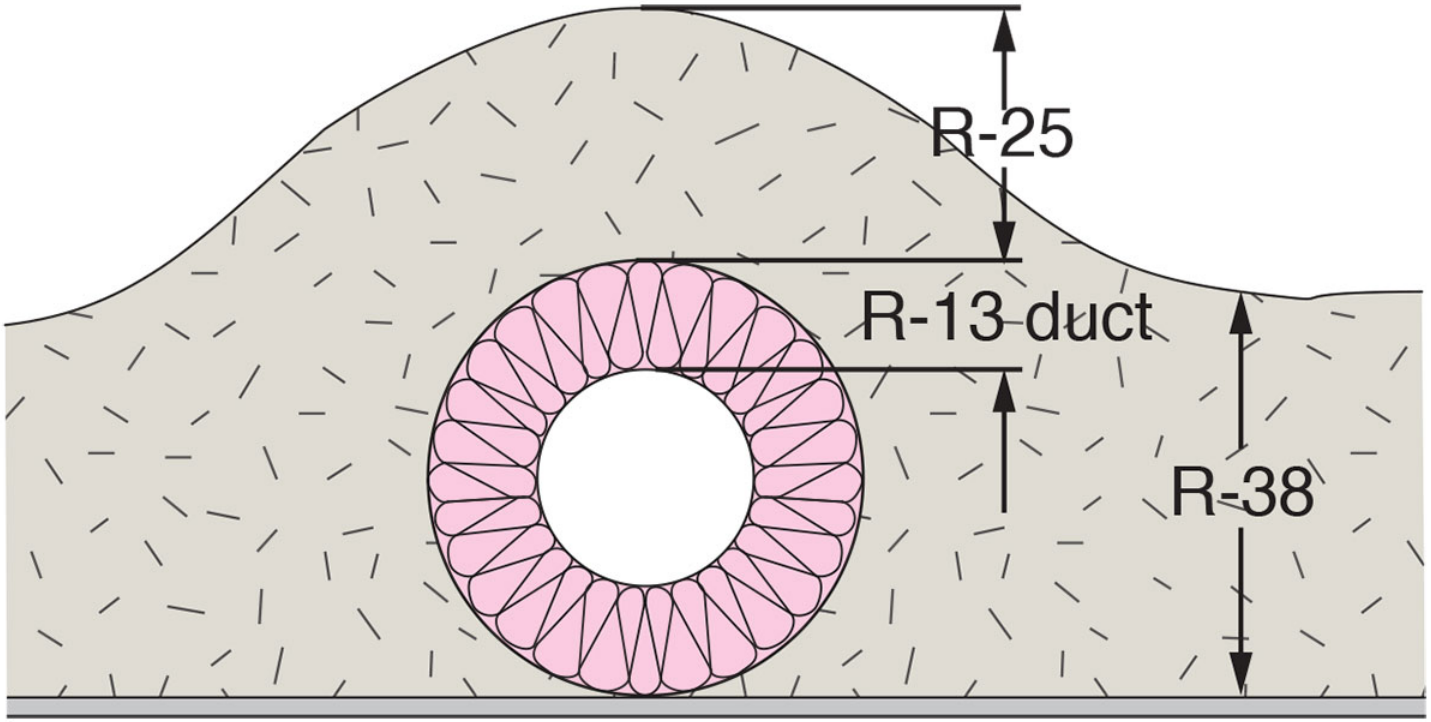
3M
All Weather
Flashing Tape 8067

DELTA
DELTA
DELTA
Made by Dörken GmbH & Co. KG, D-58311 Herdecke

PROPINK
High Performance
Attic System
OWENS CORNING
R-30
PROPINK
High Performance
Attic System
OWENS CORNING
R-30
PROPINK
High Performance
Attic System

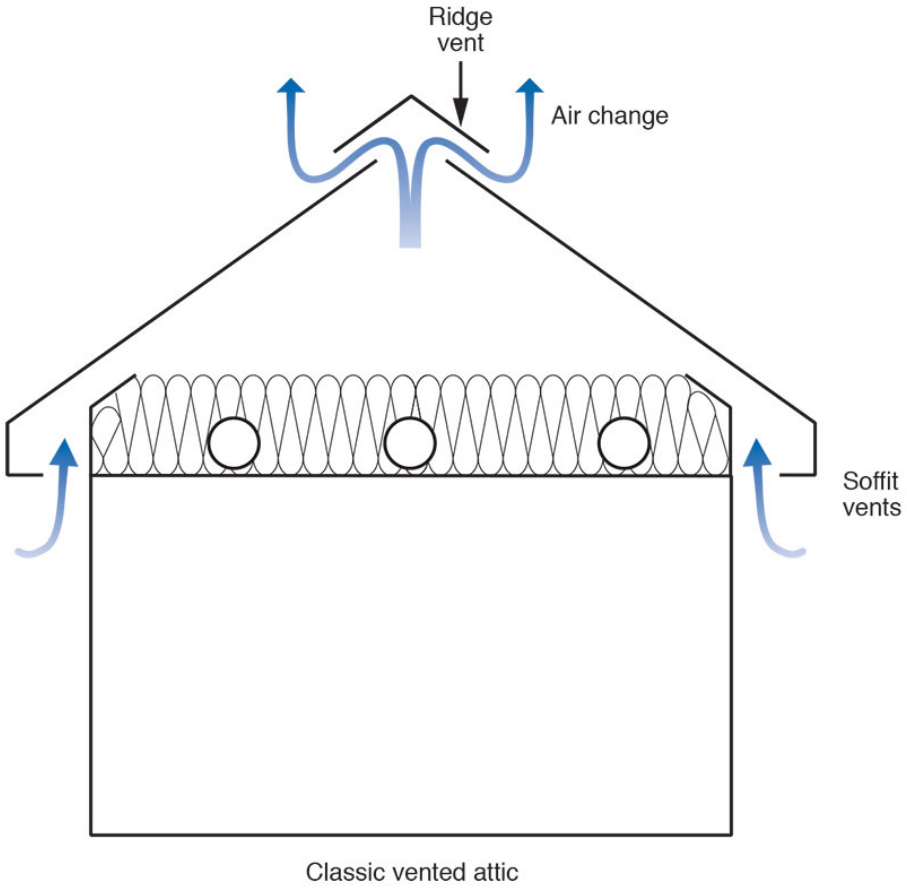
Burying Ducts


Supply
Air handling unit
Supply
Return

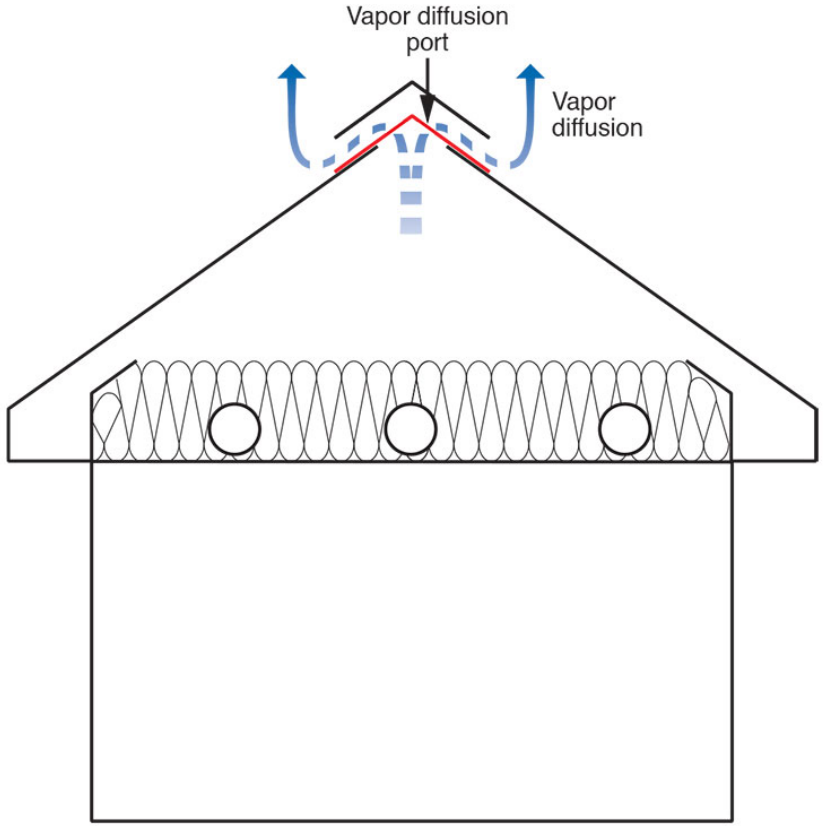

R-25
R-13 duct
R-38

FOAMULAR
FASSOFIX

R-5.0
1 inch thick
CERO
CAPA DE OZONO
OWENS CORNING
FOAMULAR 150



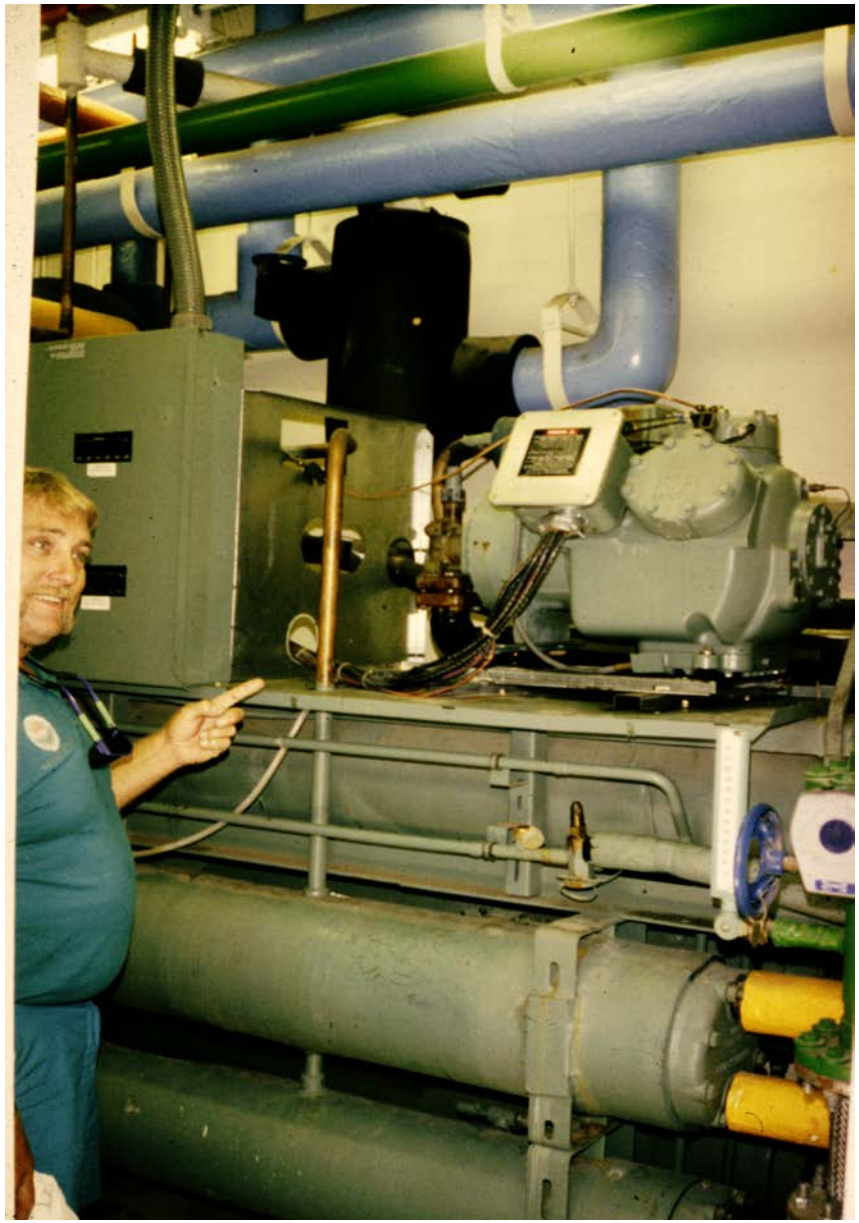
Classic vented attic

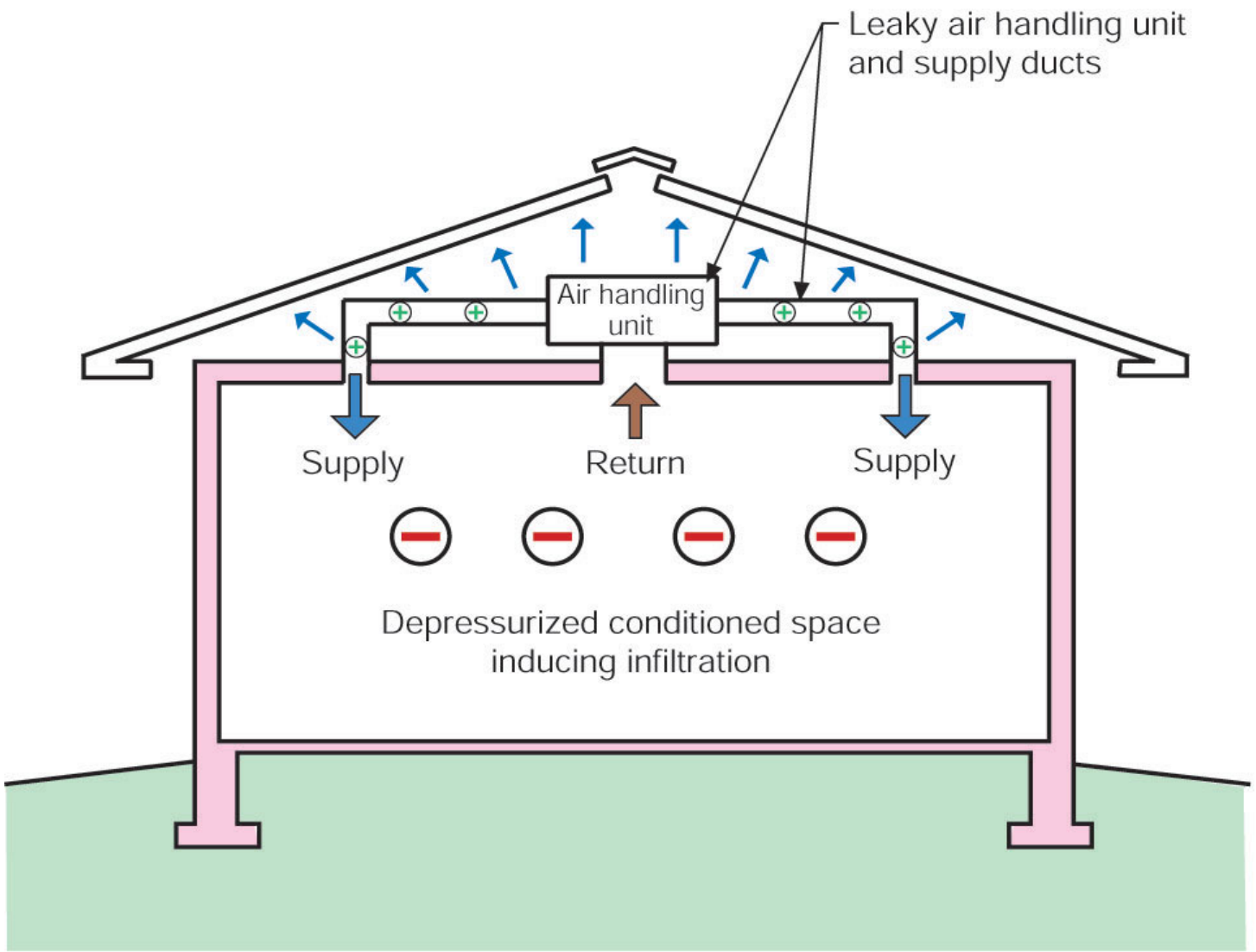


Unvented attic with vapor diffusion port

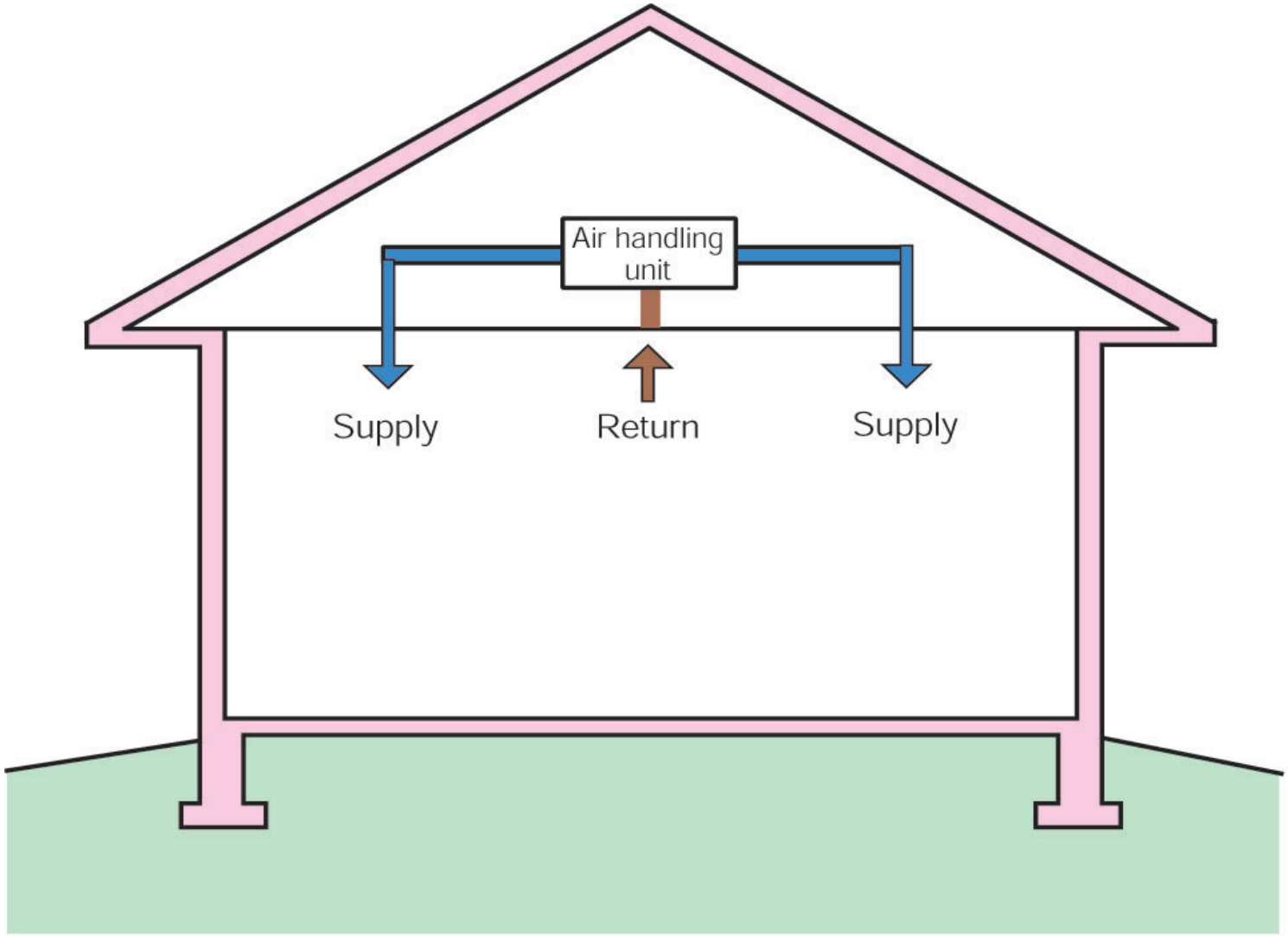
Where It Started

GUEST

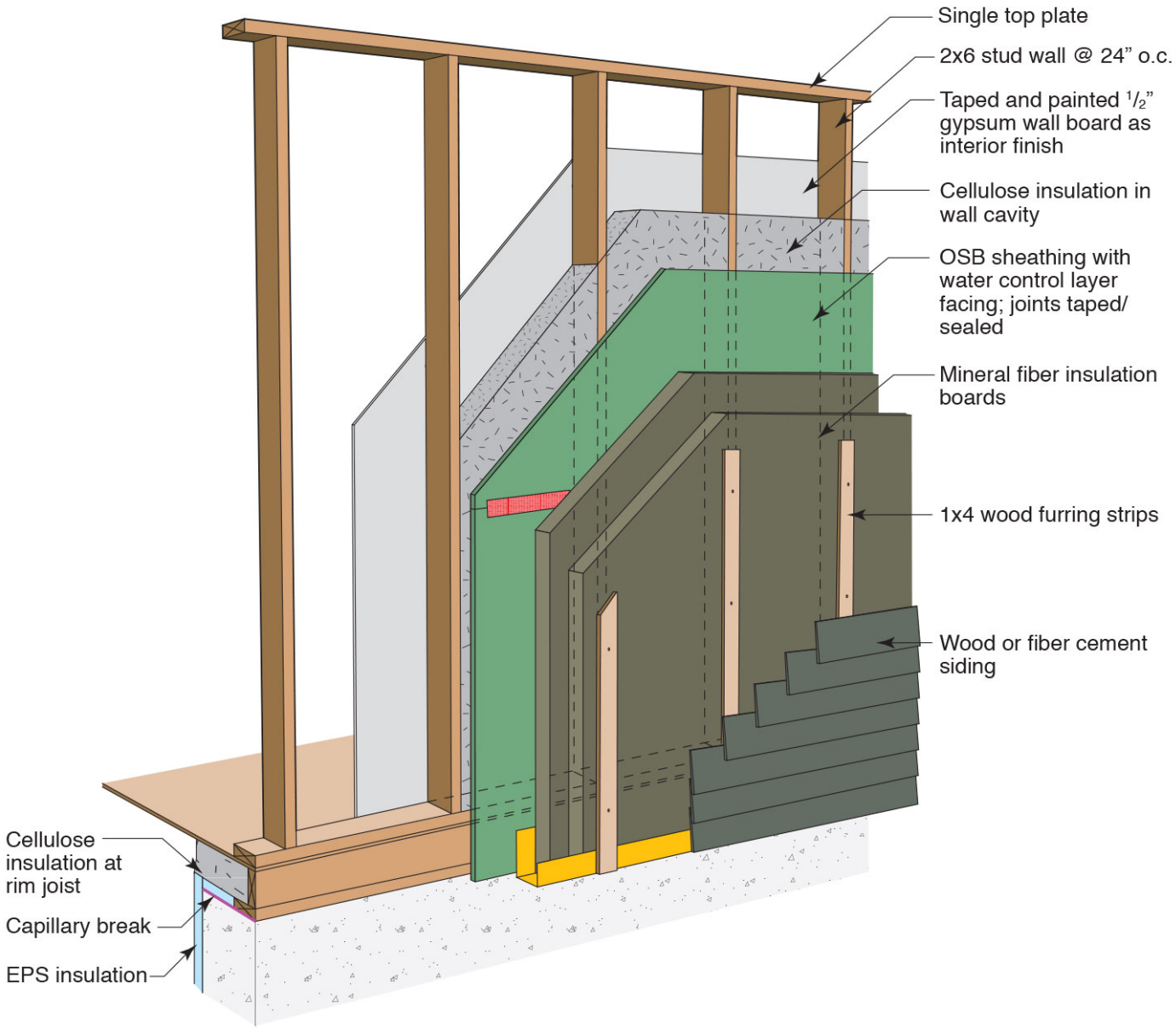


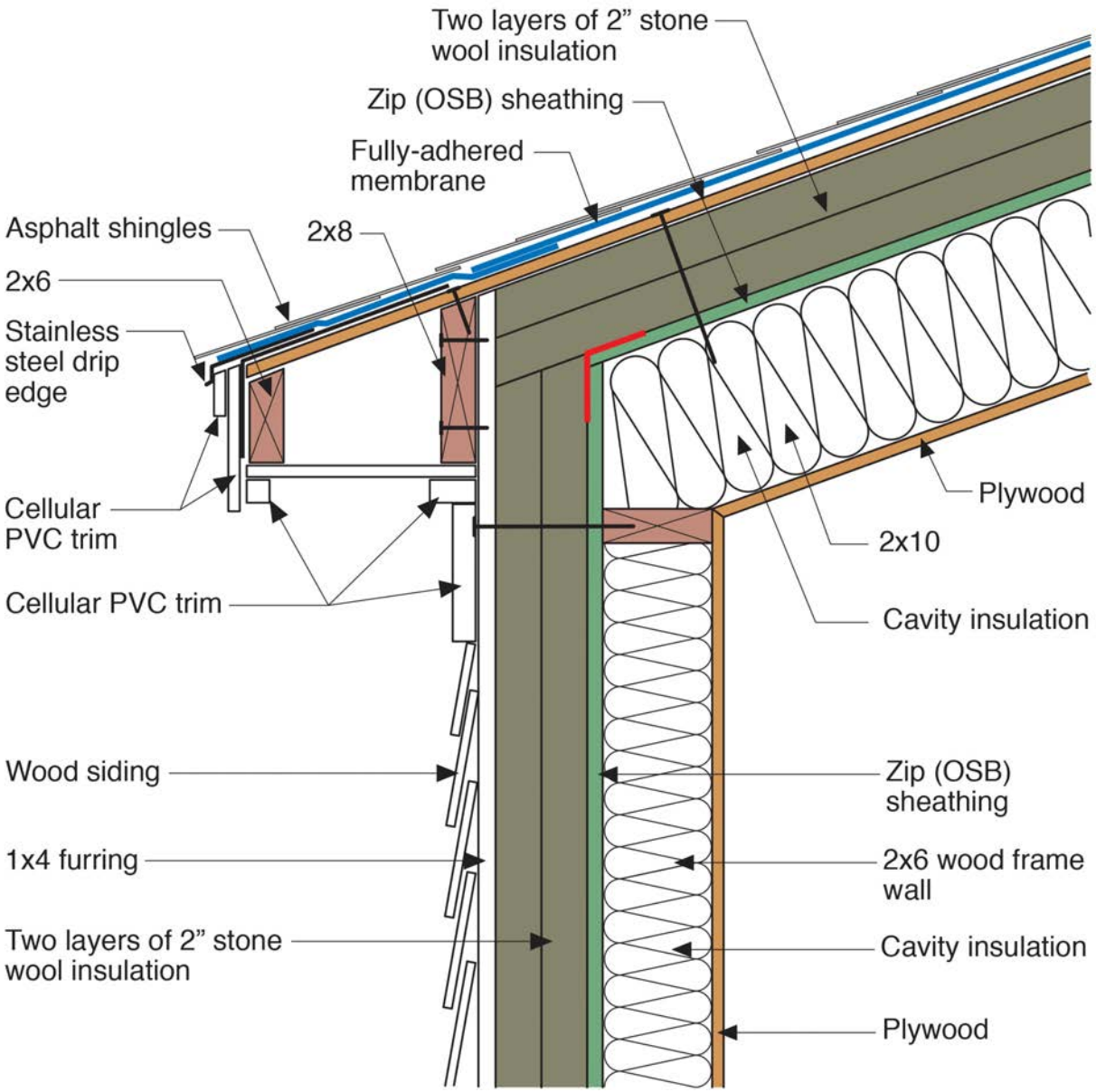


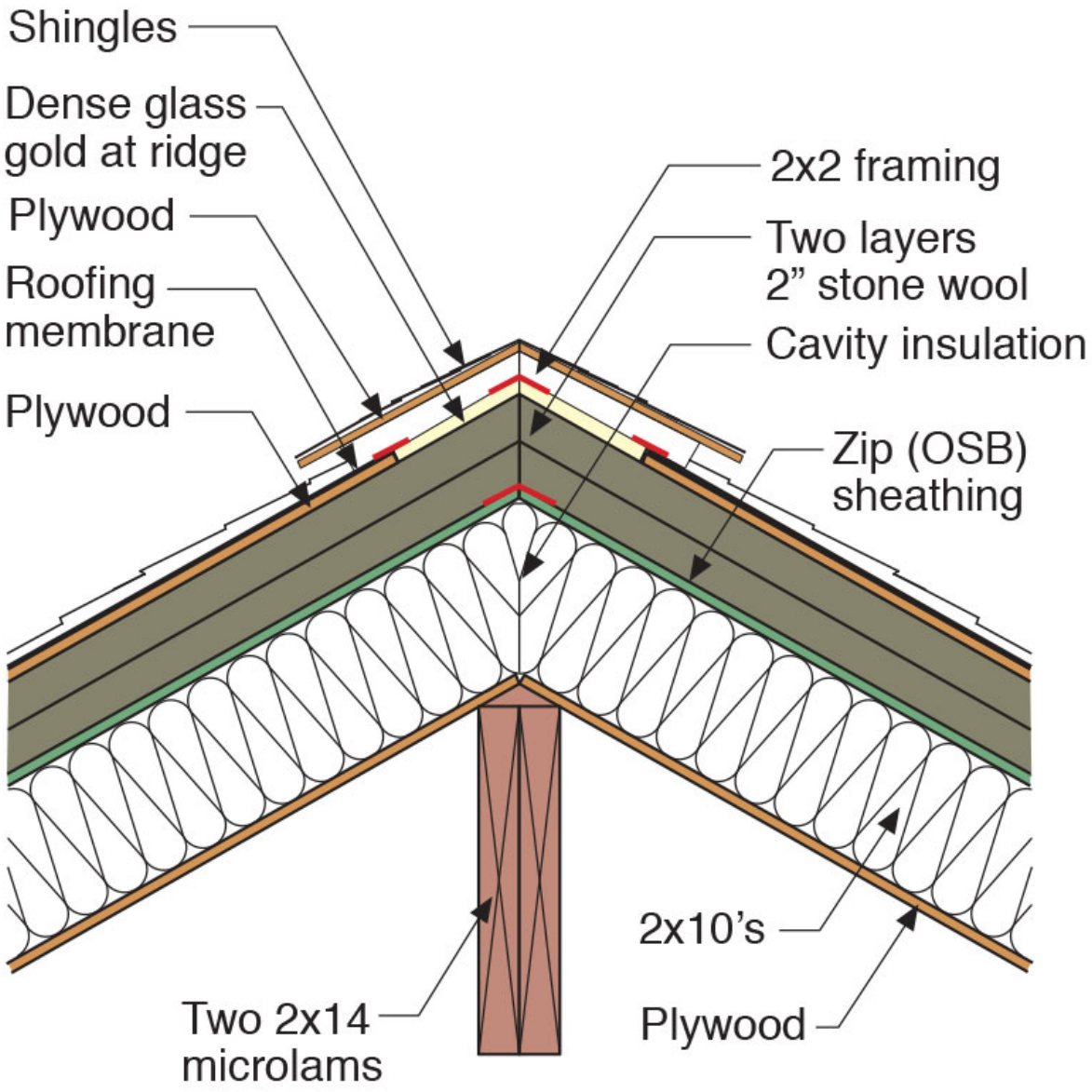
Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.



Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.


Single top plate
2x6 stud wall @ 24" o.c.
Taped and painted 1/2" 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


Two layers of 2” stone wool insulation
Zip (OSB) sheathing
Fully-adhered membrane
Asphalt shingles
2x8
2x6
Stainless steel drip edge
Cellular PVC trim
Cellular PVC trim
Plywood
2x10
Cavity insulation
Wood siding
1x4 furring
Two layers of 2” stone wool insulation
Zip (OSB) sheathing
2x6 wood frame wall
Cavity insulation
Plywood


Shingles
Dense glass gold at ridge
Plywood
Roofing membrane
Plywood
2x2 framing
Two layers 2” stone wool
Cavity insulation
Zip (OSB) sheathing
2x10’s
Plywood
Two 2x14 microlams