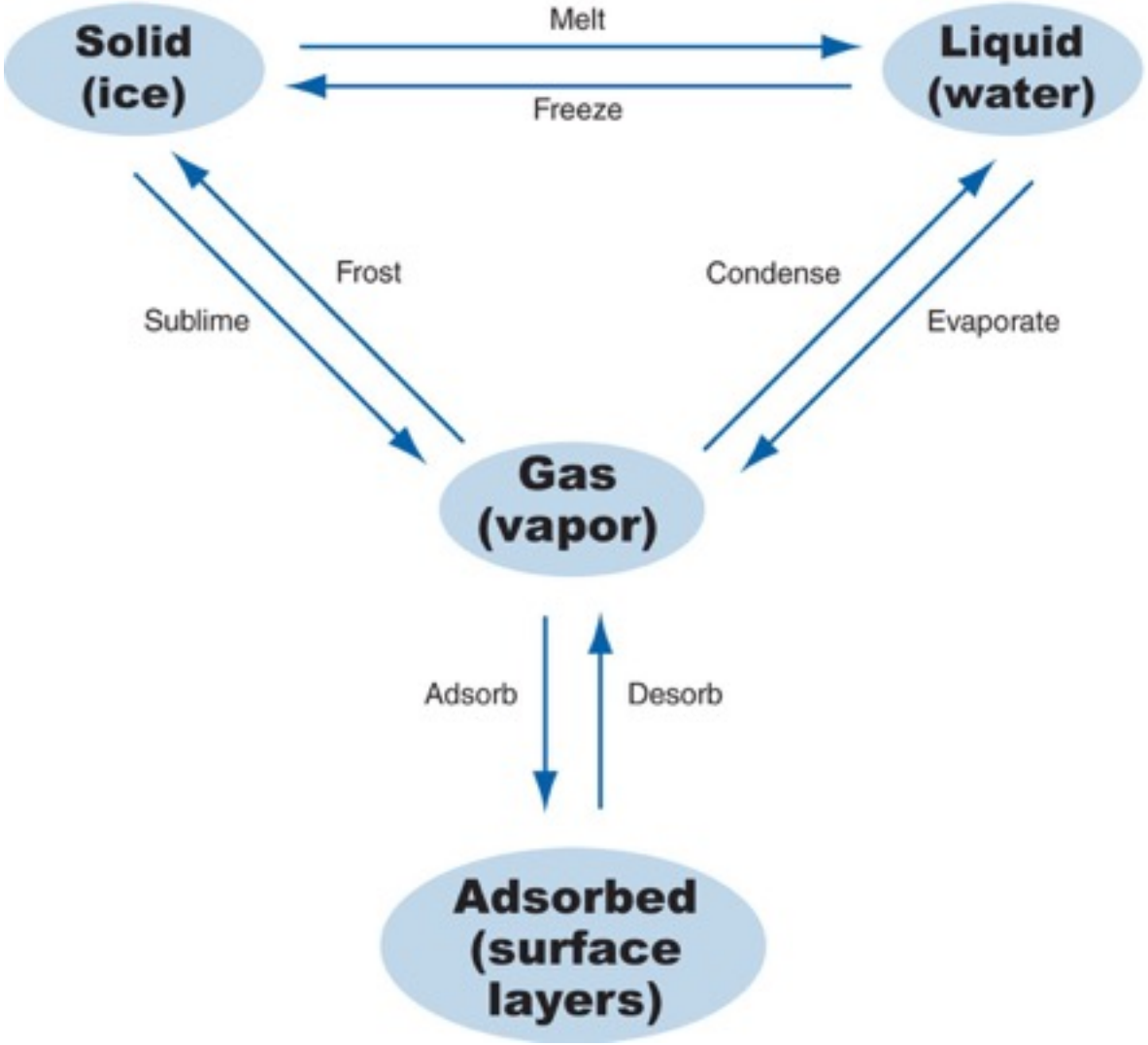
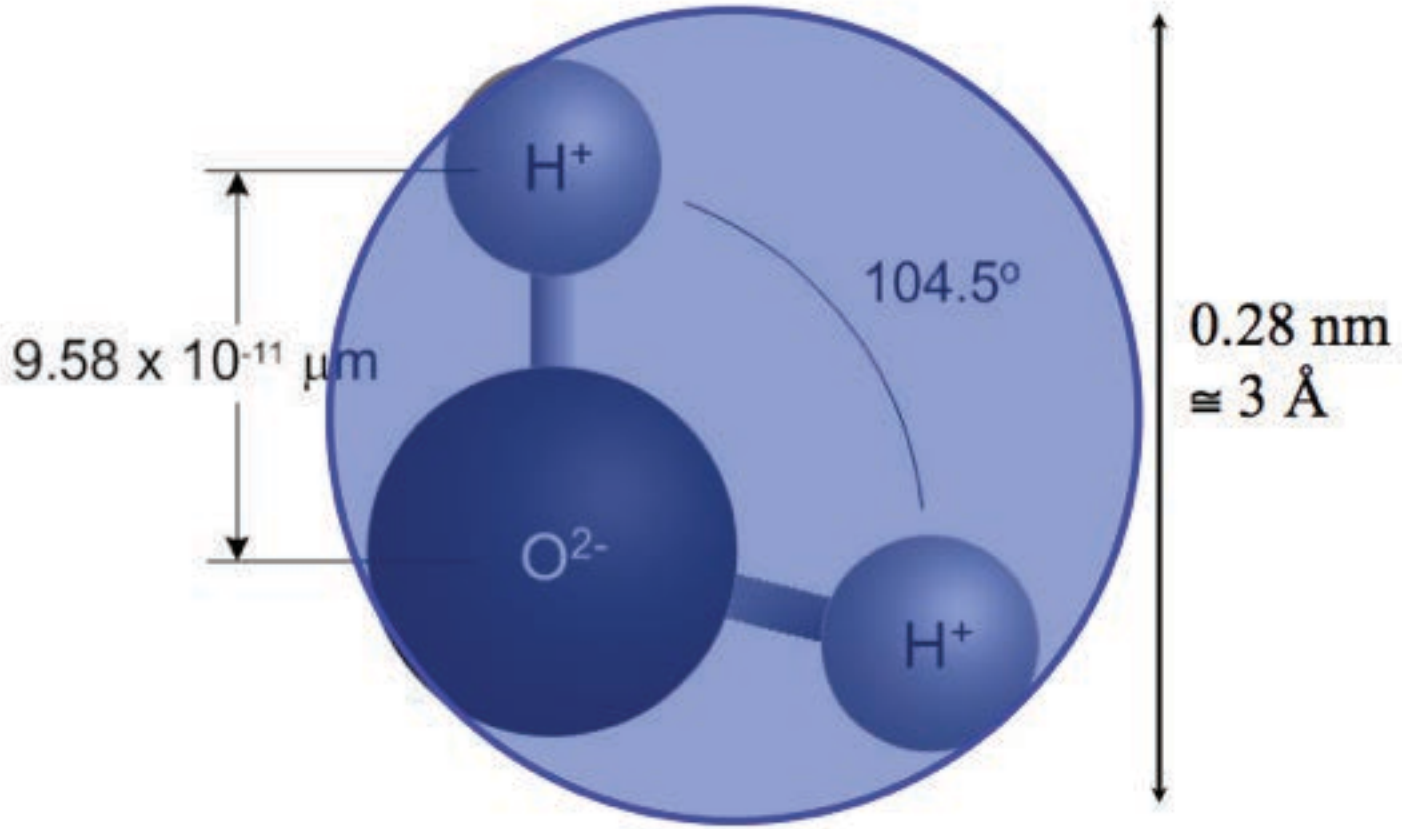
Joseph Lstiburek, Ph.D., P.Eng, ASHRAE Fellow

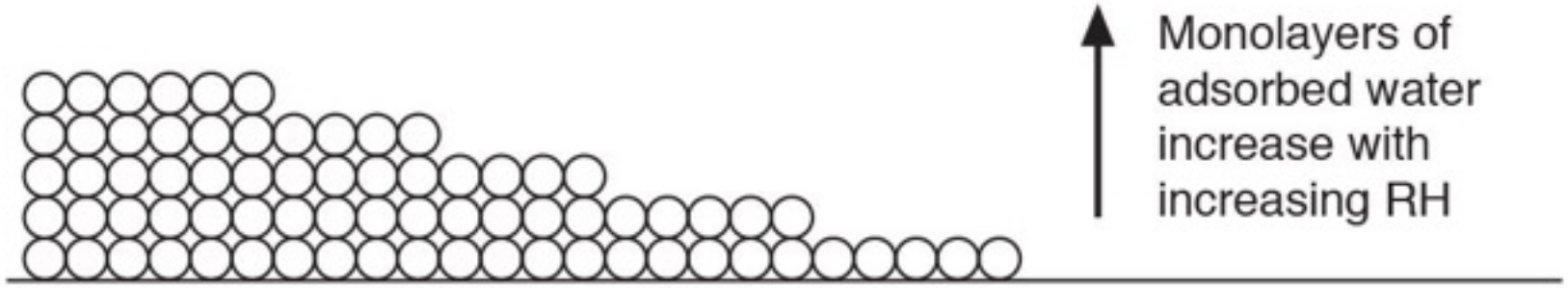
Building Science

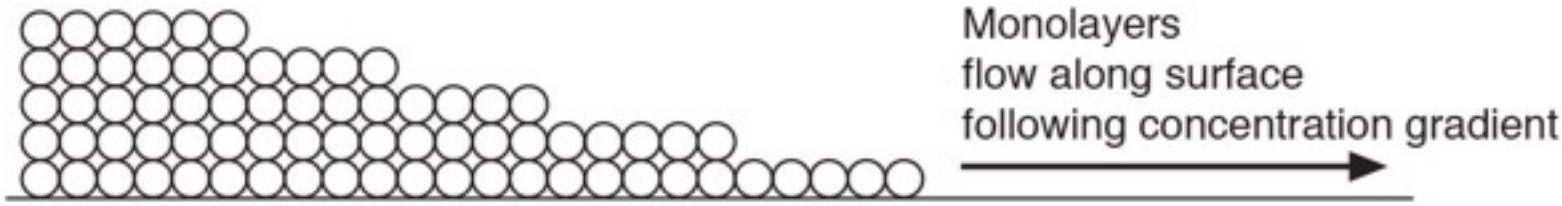
Adventures In Building Science

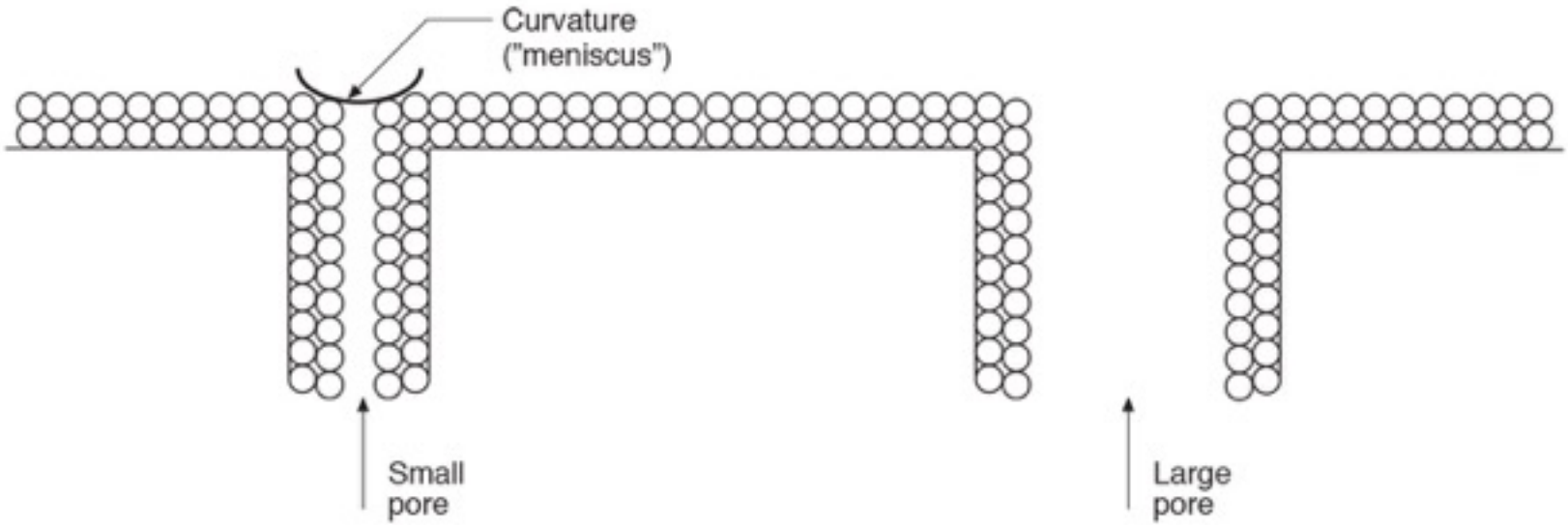
www.buildingscience.com


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


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


Monolayers of
adsorbed water
increase with
increasing RH


Monolayers
flow along surface
following concentration gradient


Curvature
("meniscus")
Small
pore
Large
pore

Kelvin Equation and Capillary Condensation

$$\ln \frac{P_v}{P_{sat}} = -\frac{2H\gamma V_l}{RT}$$

Where...

P_v = equilibrium vapor pressure

P_{sat} = saturation vapor pressure

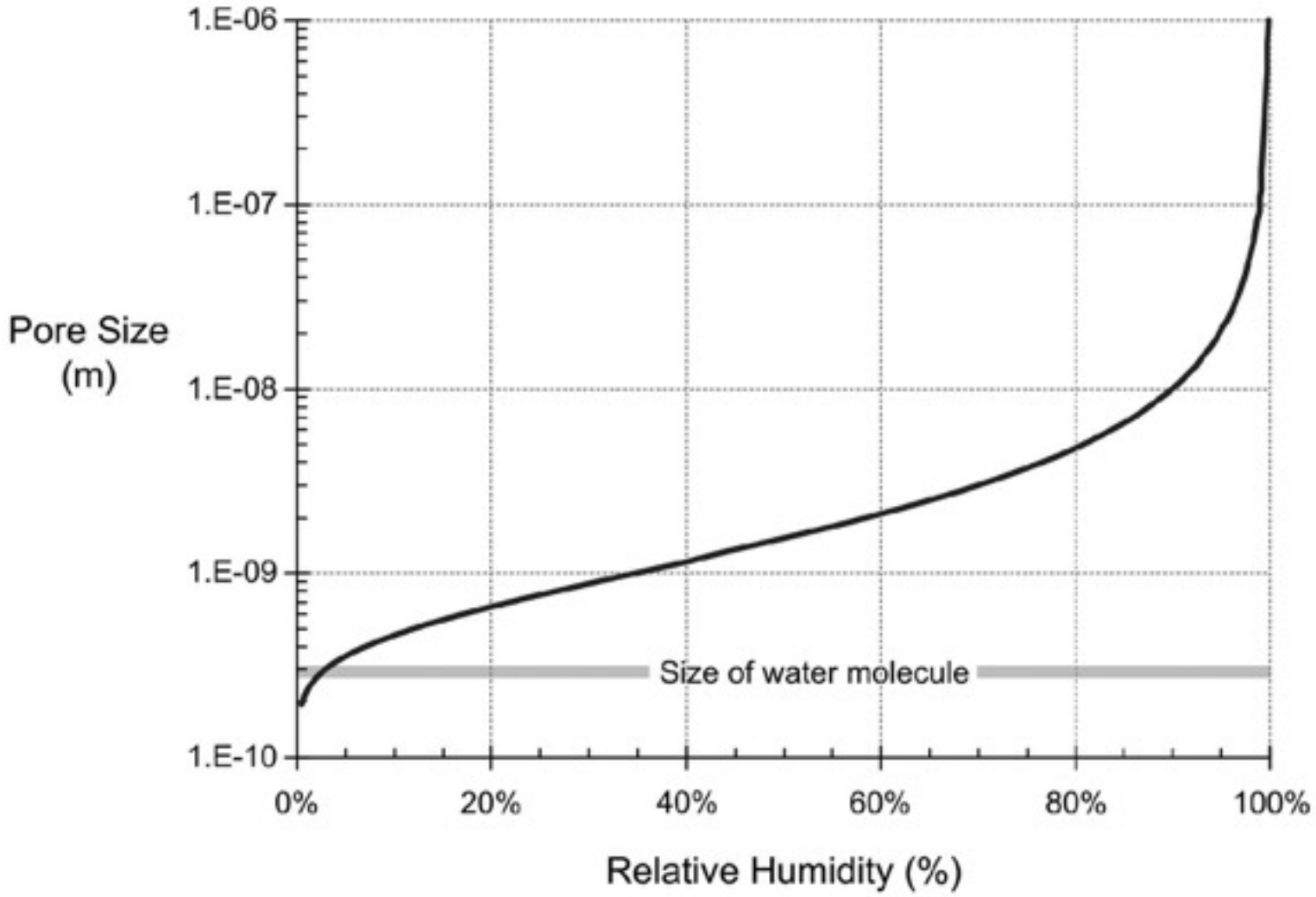
H = mean curvature of meniscus

γ = liquid/vapor surface tension

V_l = liquid molar volume

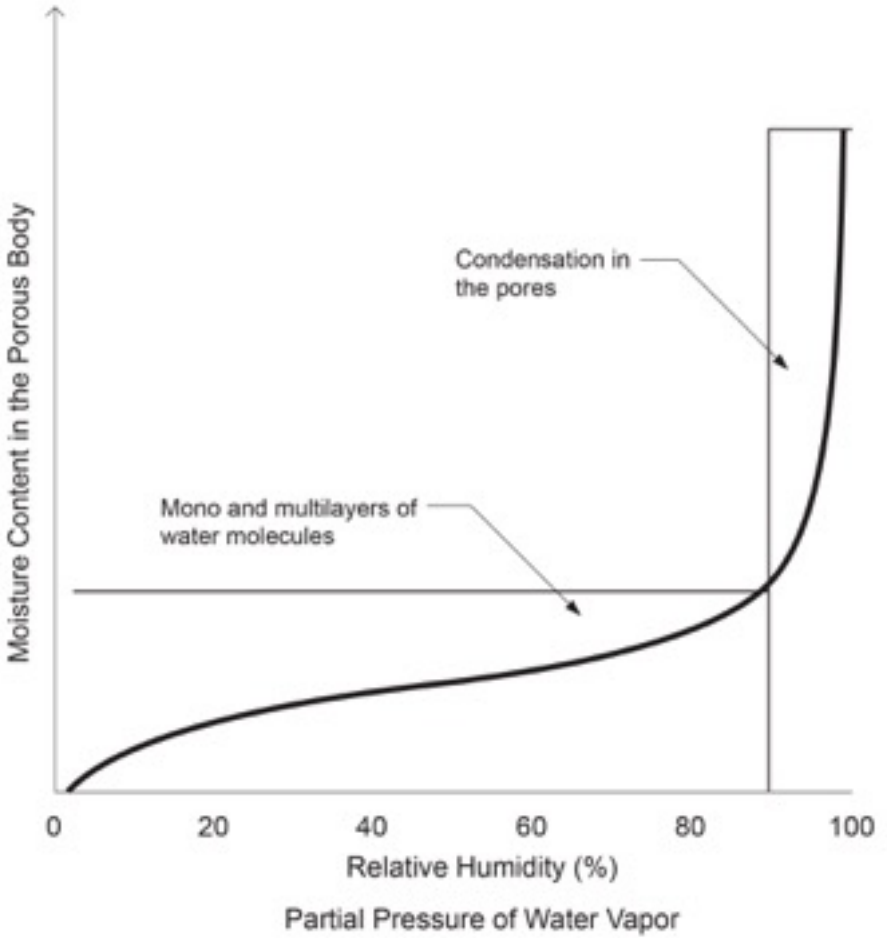
R = ideal gas constant

T = temperature



Ambient relative humidity at which capillary condensation is predicted to occur by the Kelvin equation

From Straube & Burnett, 2005



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

Vented and Unvented Attics

There Is Nothing Wrong With A Vented Attic

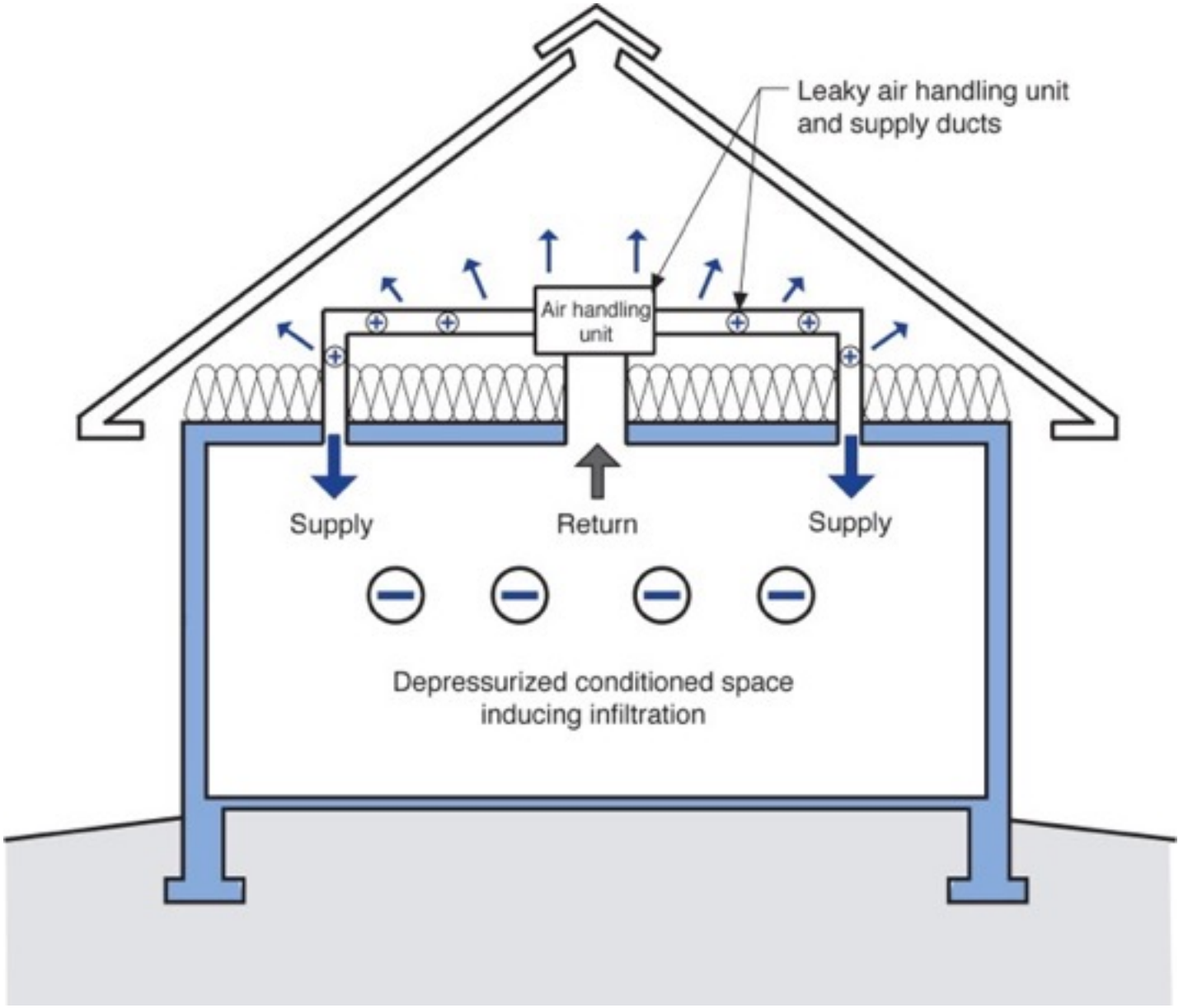
There Is Nothing Wrong With A Vented Attic

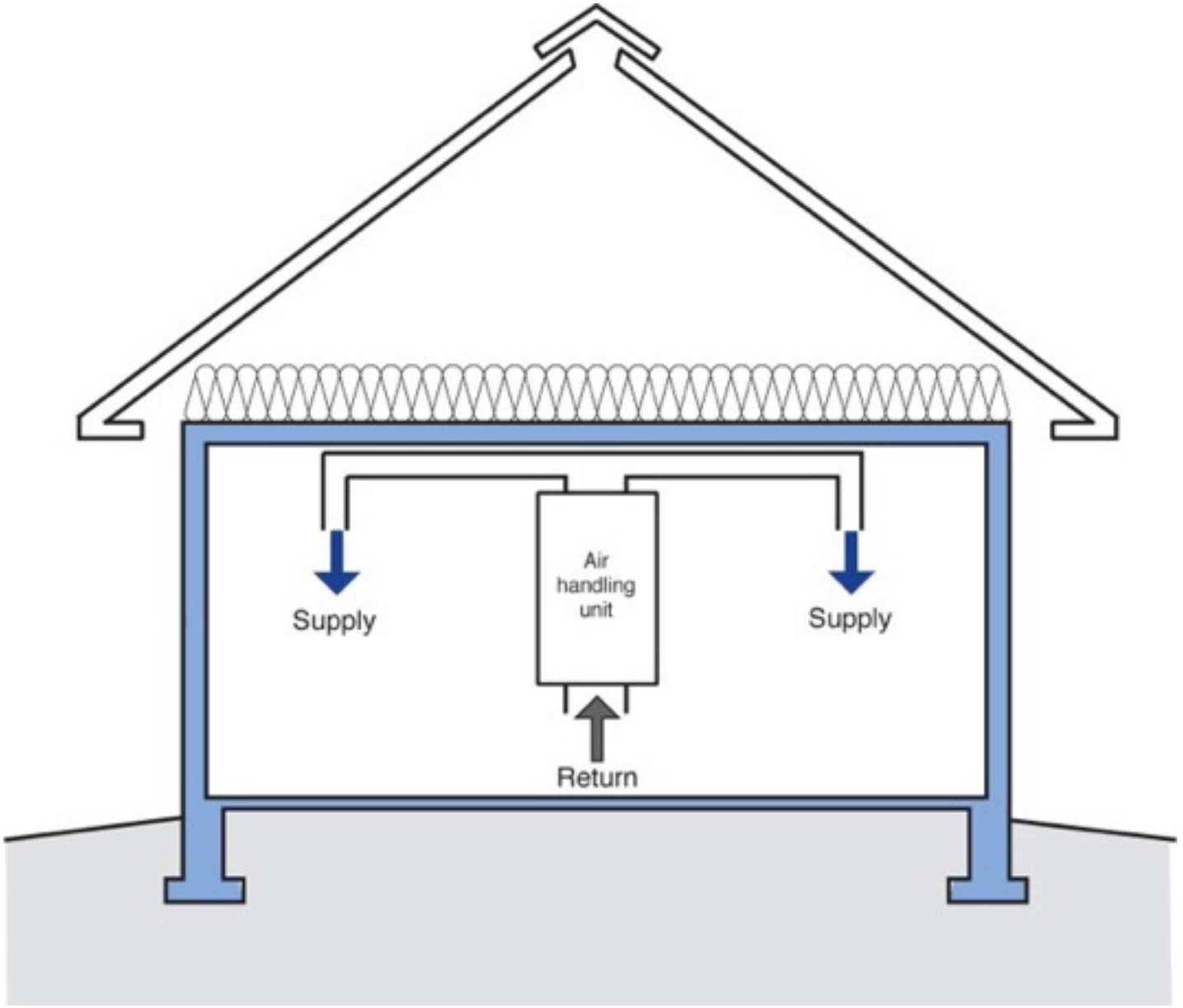
But…..

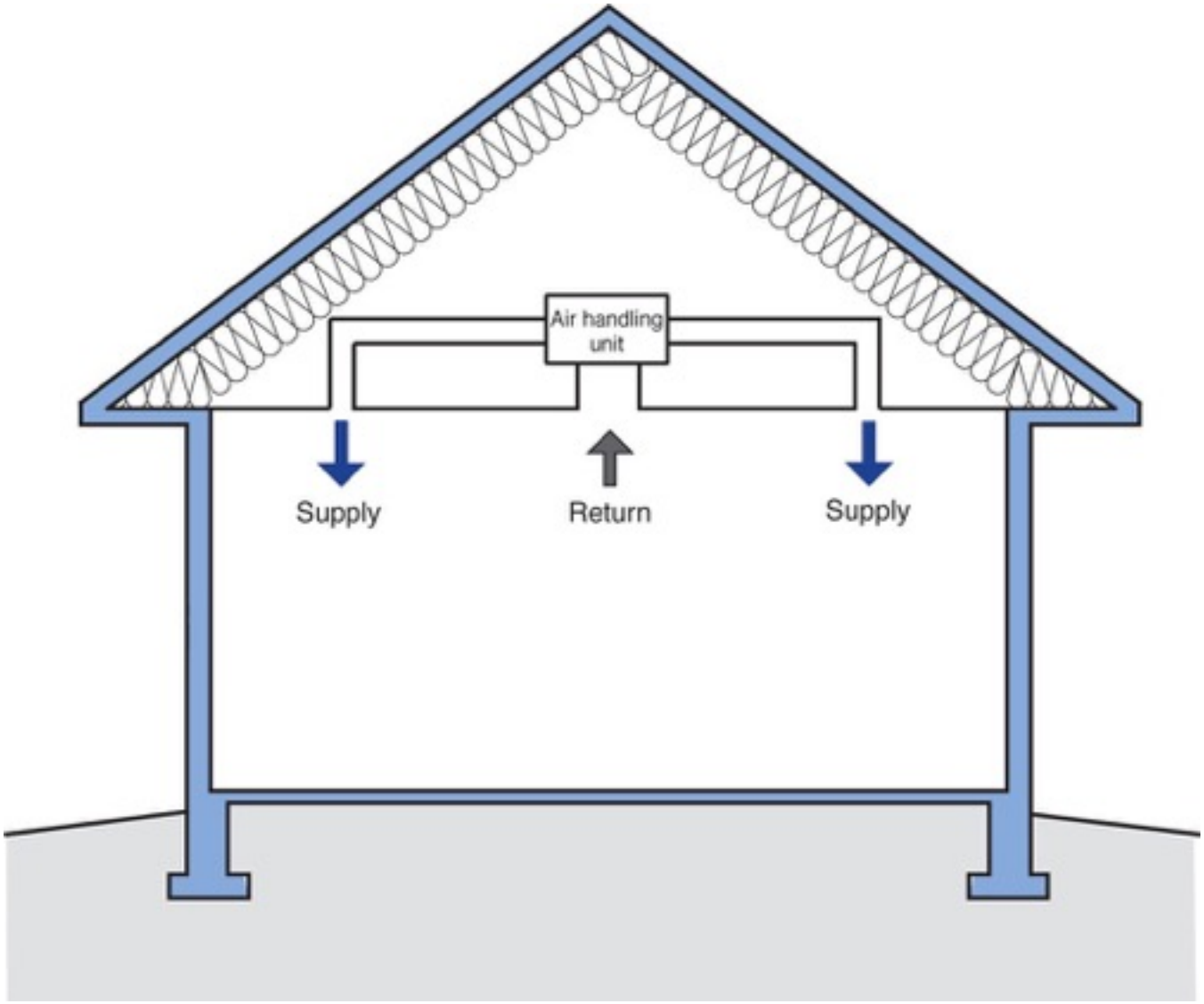
Where It Started…..
And Where It Is Going

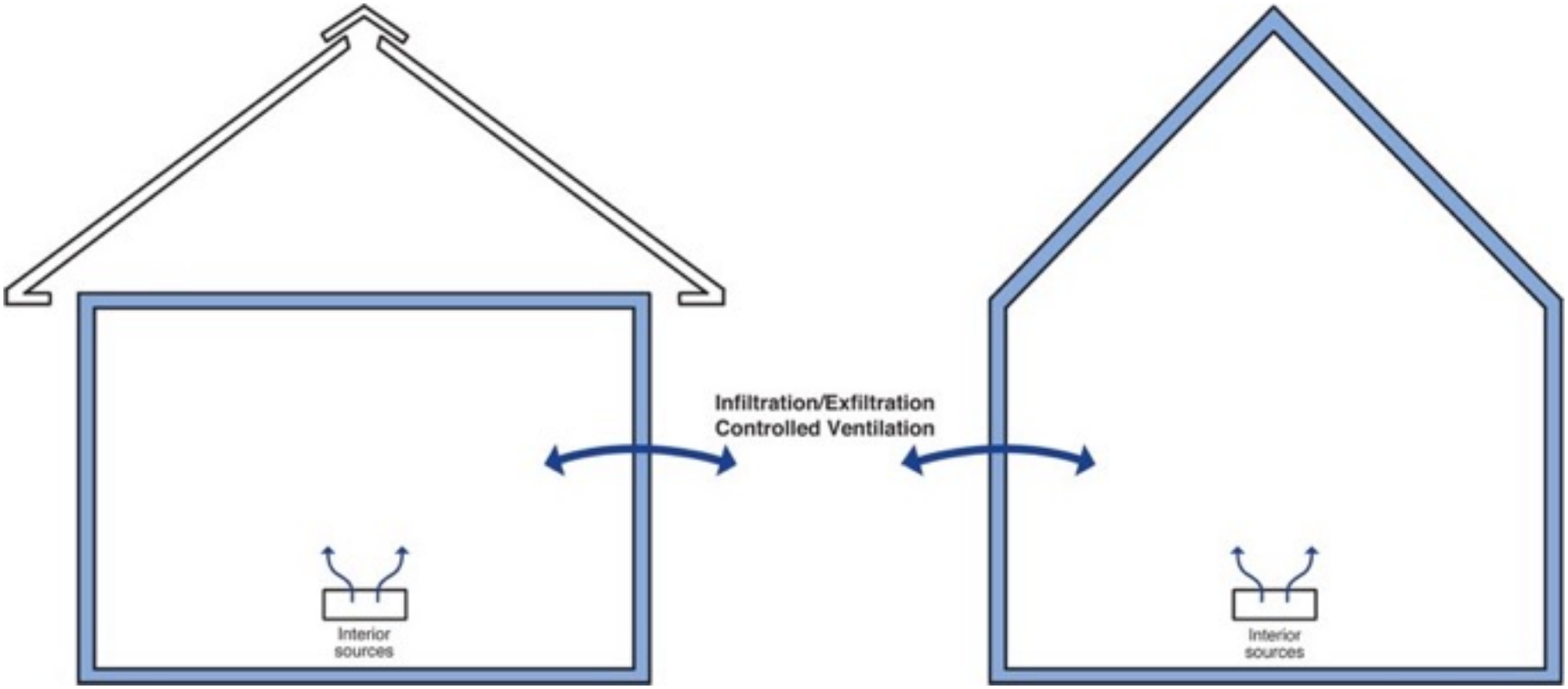
Houses With Vented Attics Suck

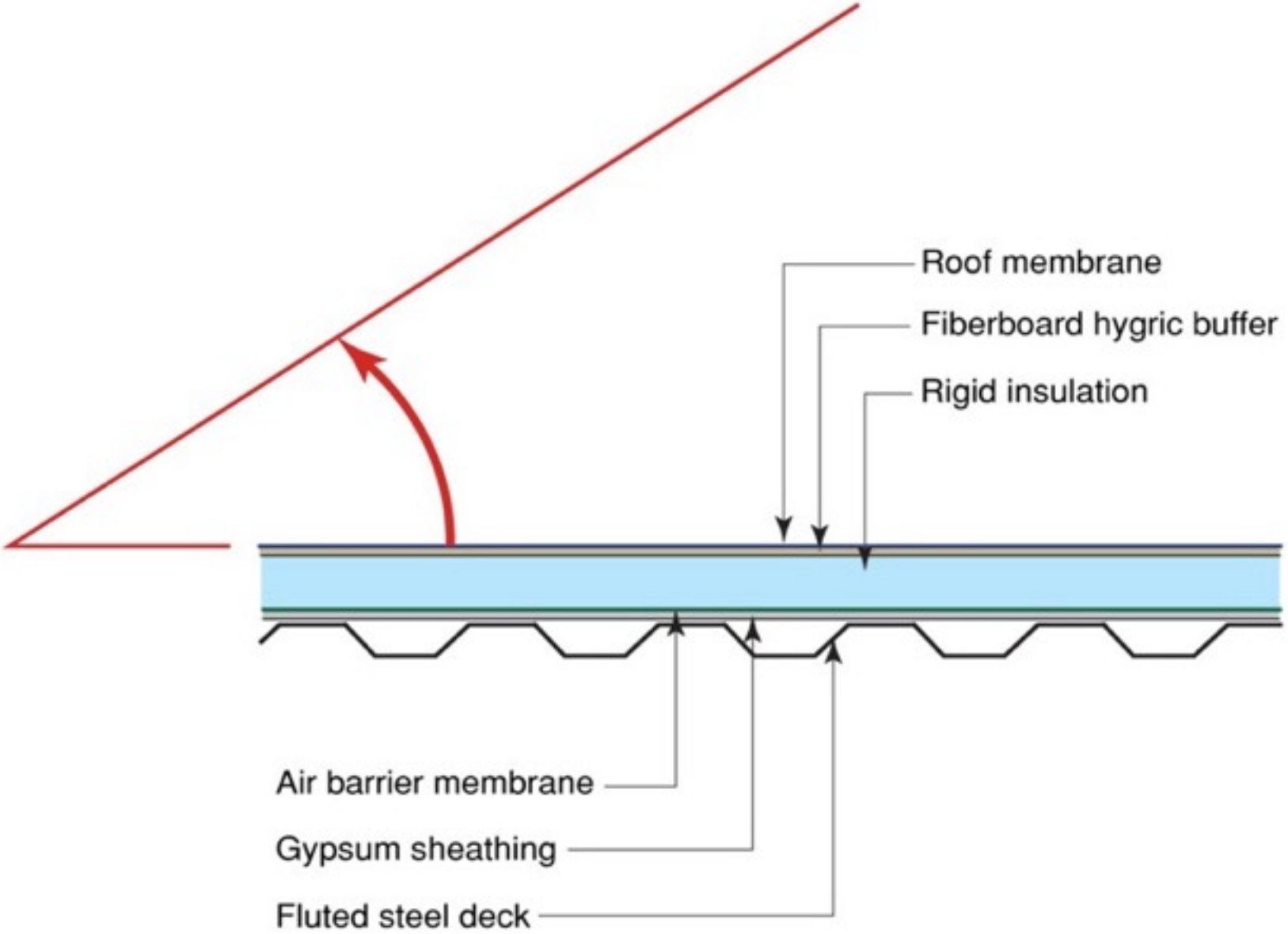
Not all the Time…..but.....

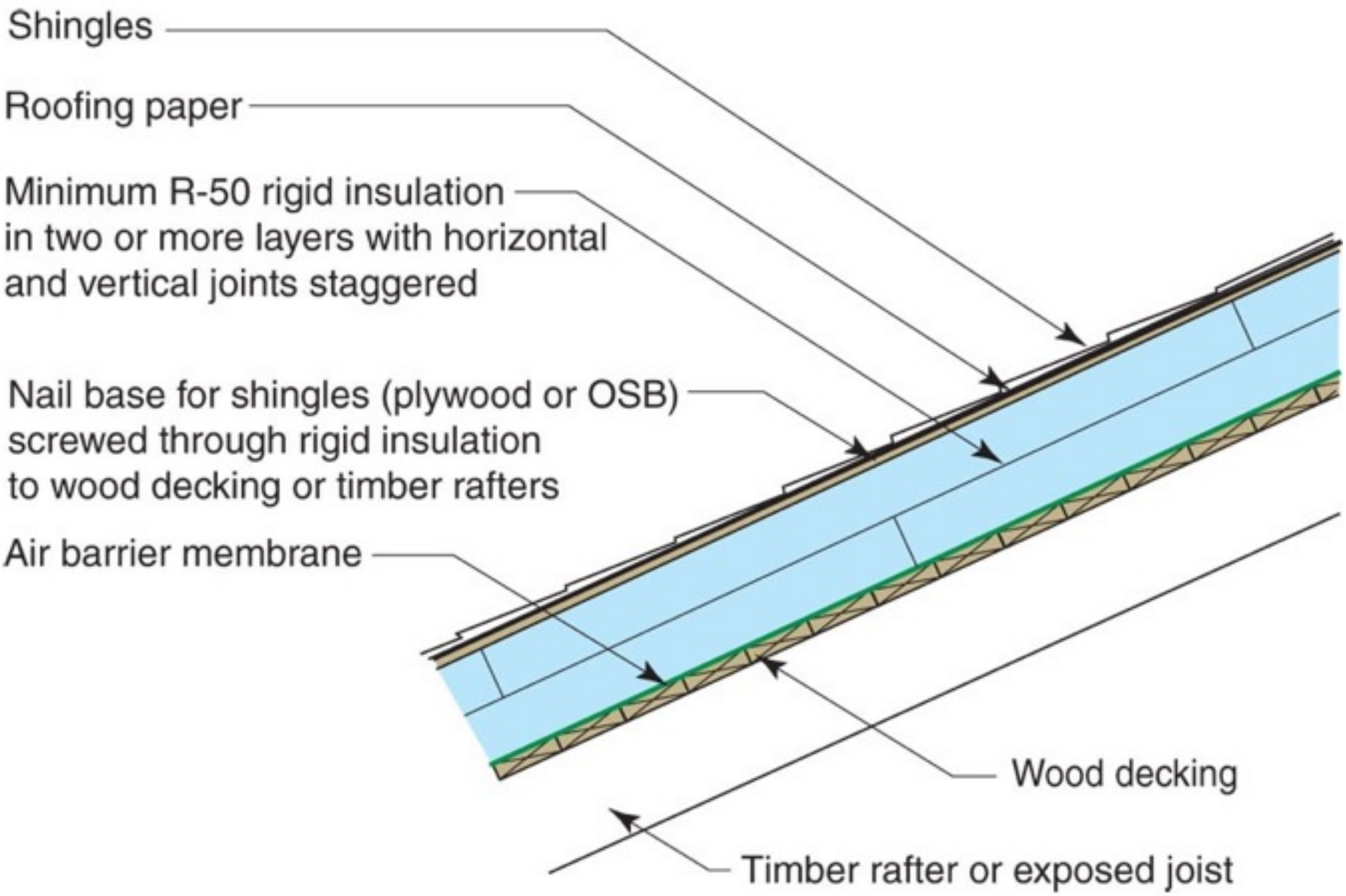

Leaky air handling unit
and supply ducts
Air handling
unit
Supply
Return
Supply
Depressurized conditioned space
inducing infiltration

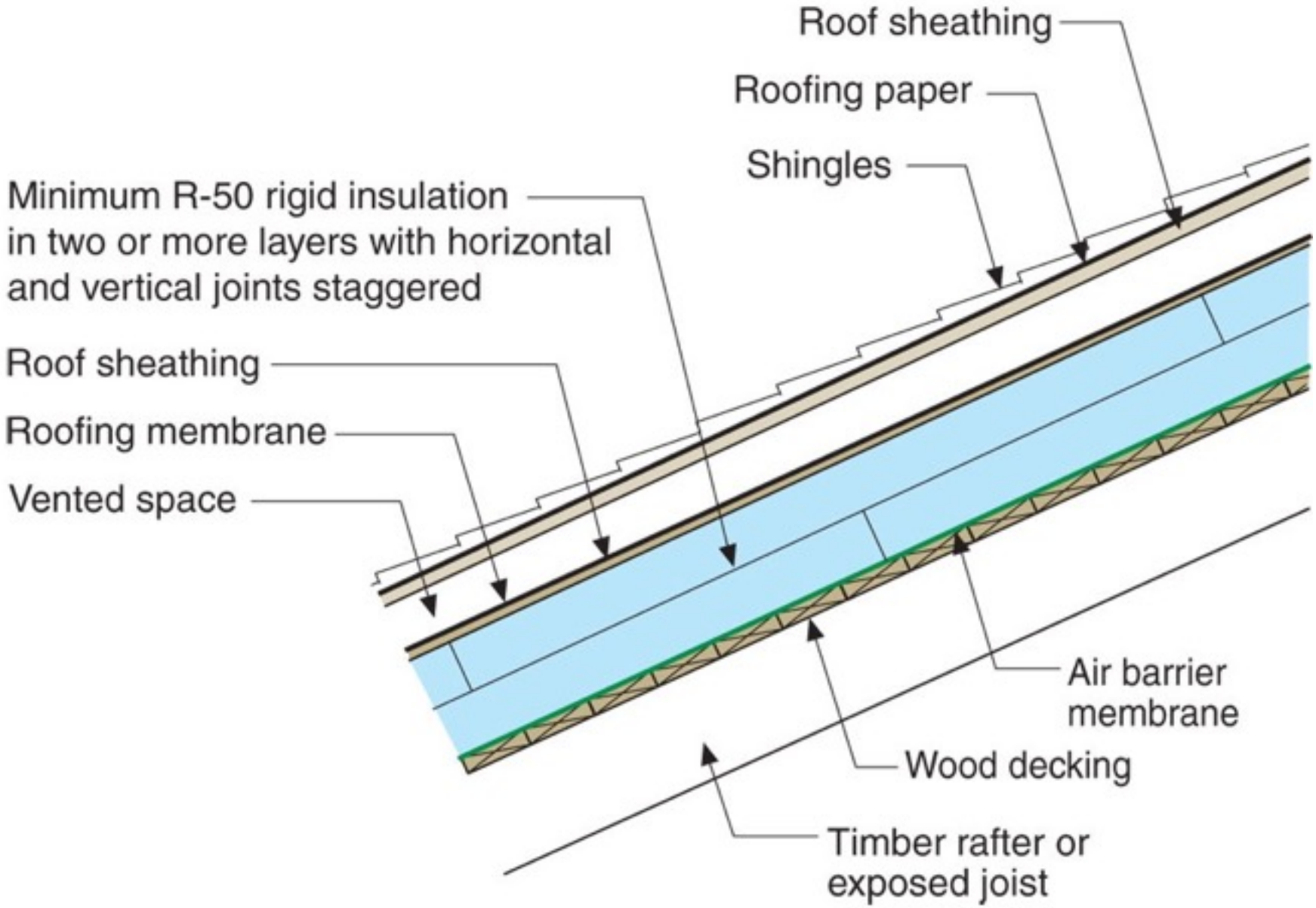

Supply
Air handling unit
Supply
Return

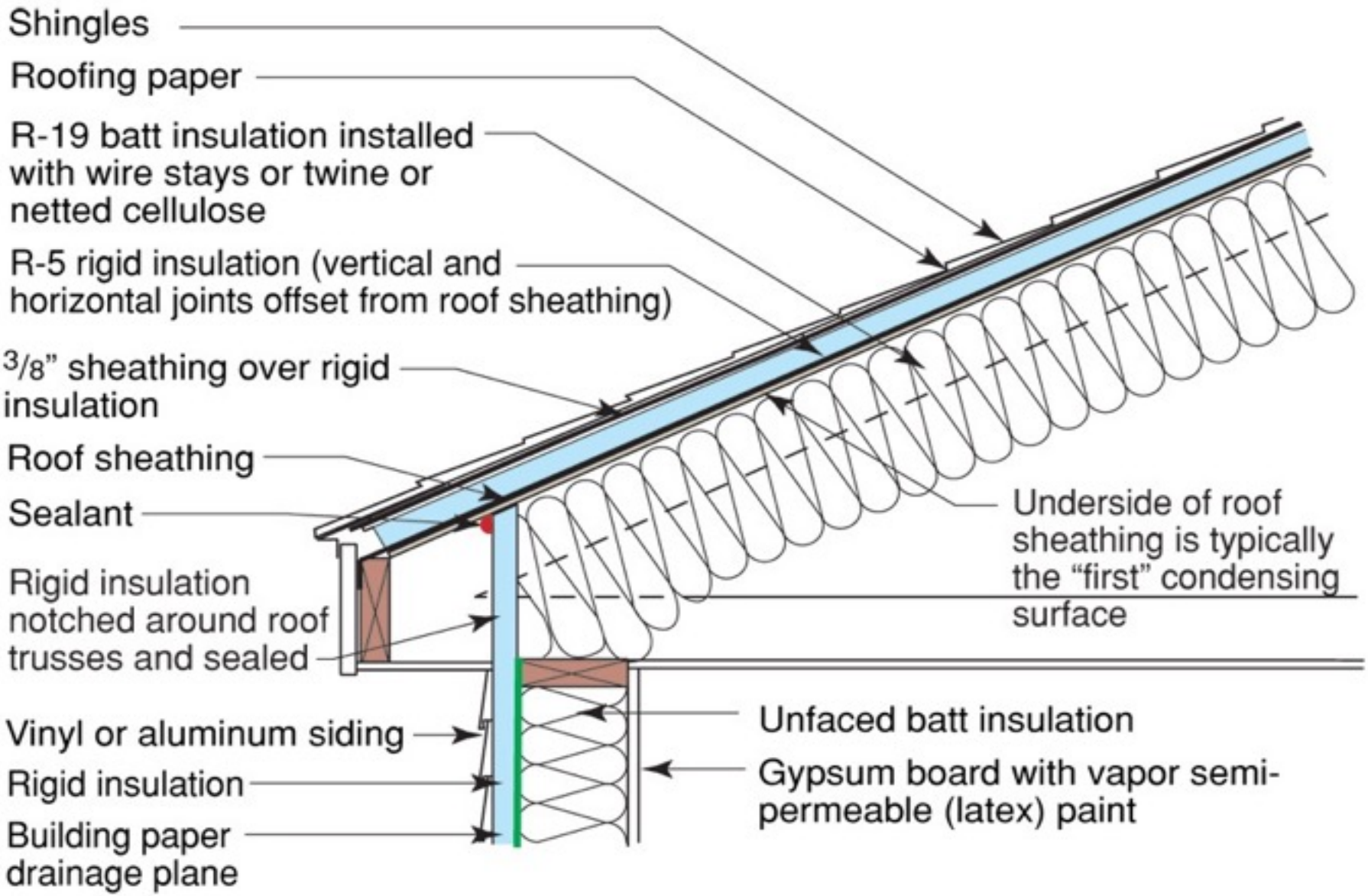

Air handling unit
Supply
Return
Supply

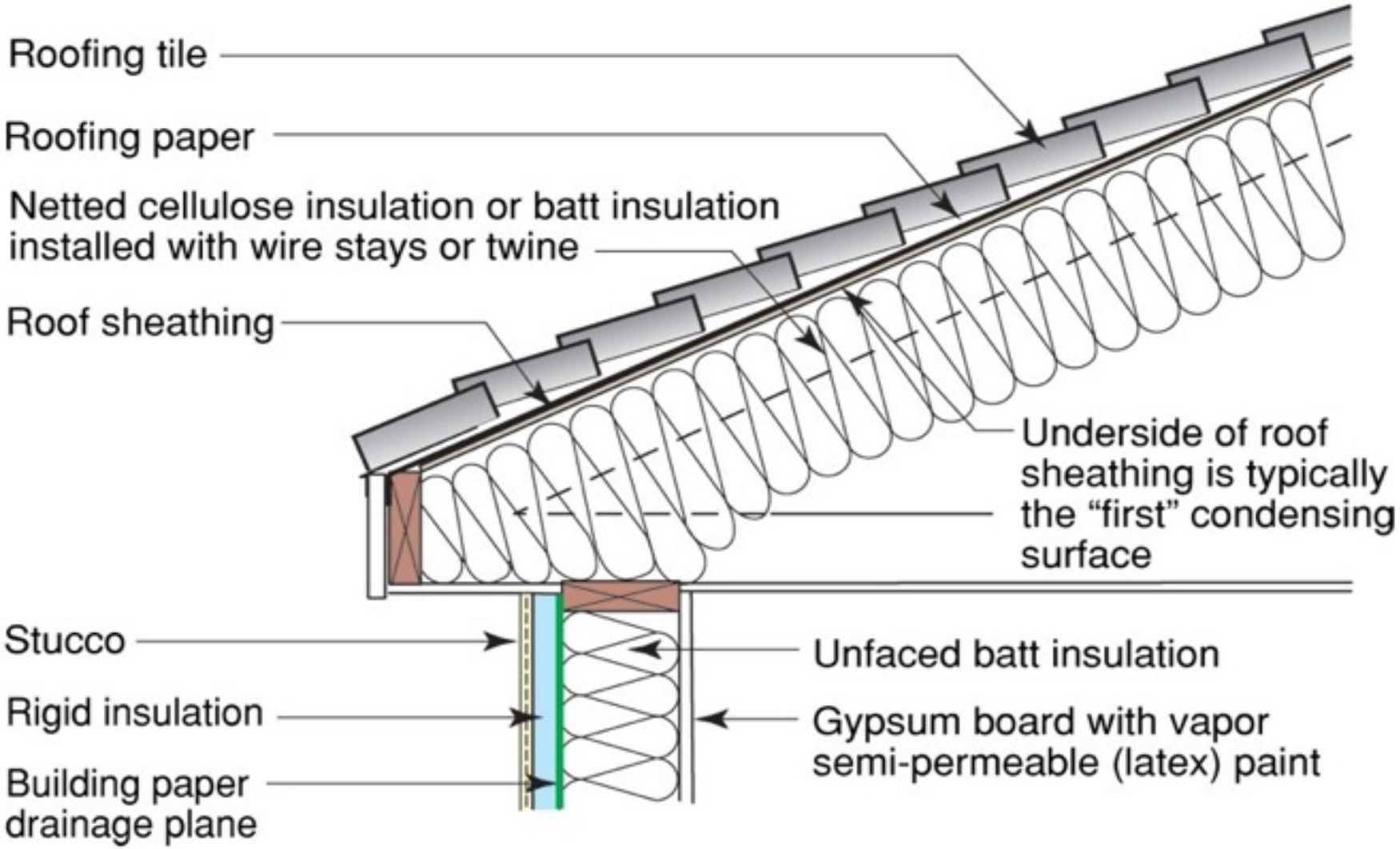

Infiltration/Exfiltration
Controlled Ventilation
Interior sources
Interior sources

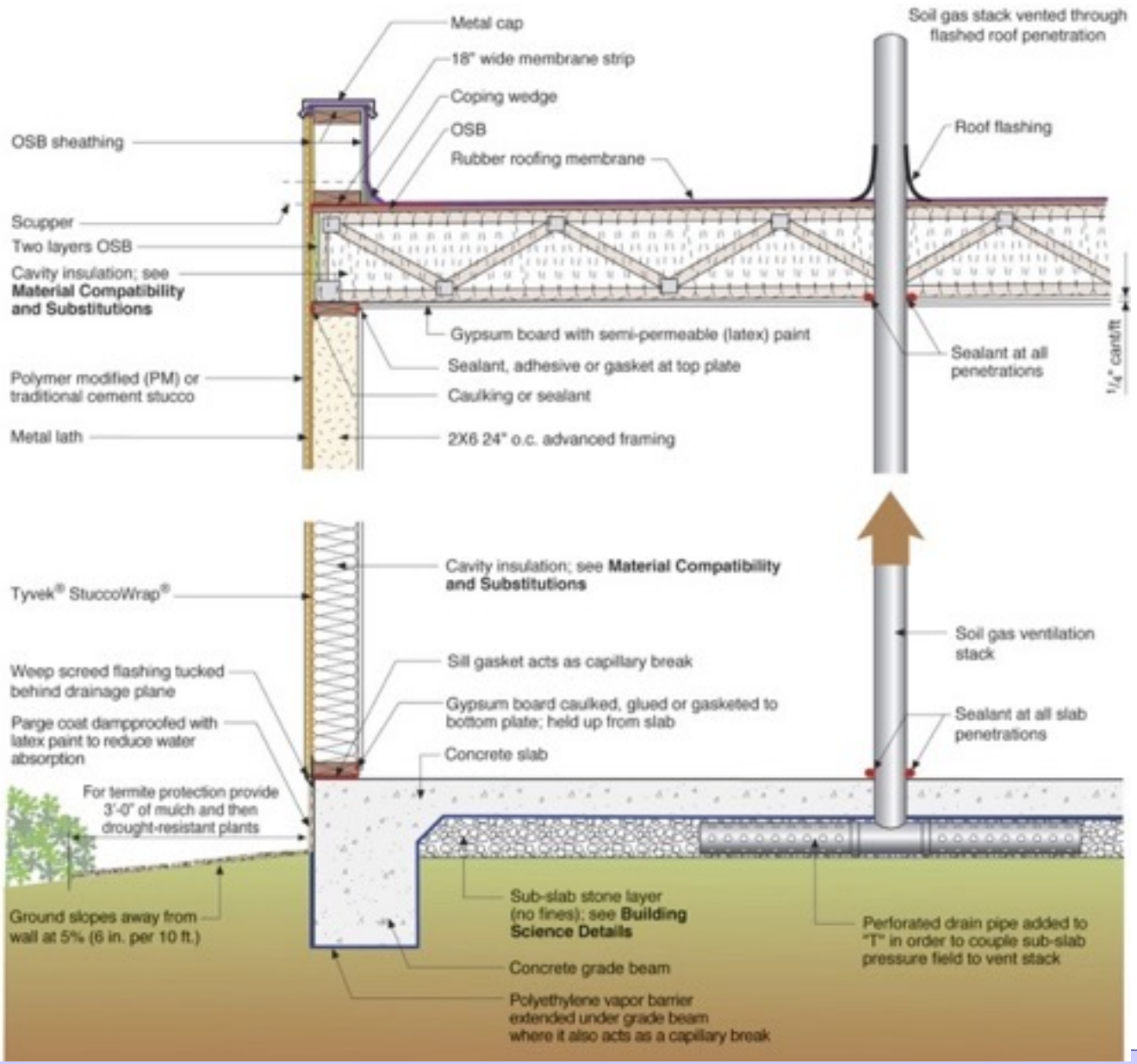

Roof membrane
Fiberboard hygric buffer
Rigid insulation
Air barrier membrane
Gypsum sheathing
Fluted steel deck

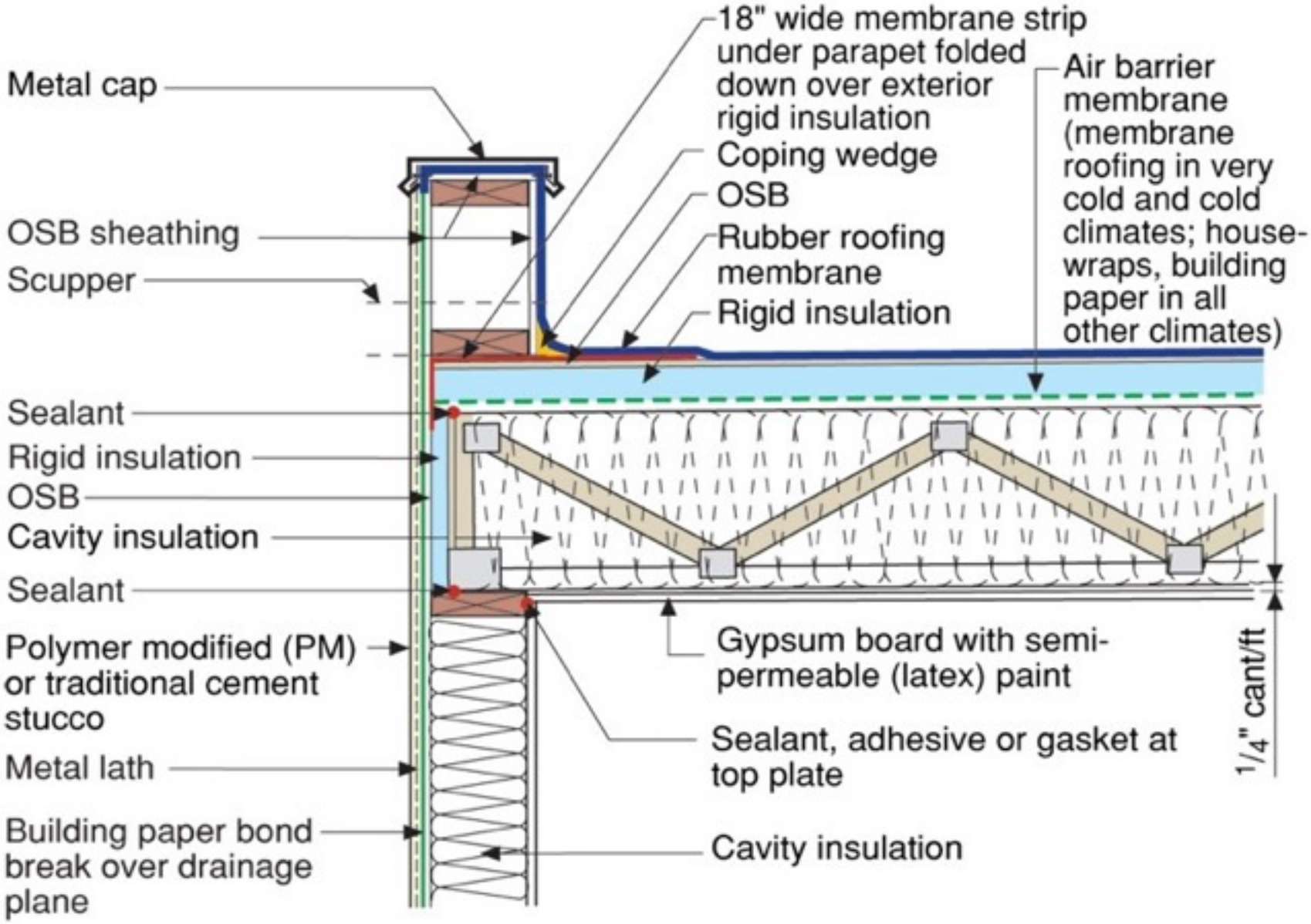

Shingles
Roofing paper
Minimum R-50 rigid insulation
in two or more layers with horizontal
and vertical joints staggered
Nail base for shingles (plywood or OSB)
screwed through rigid insulation
to wood decking or timber rafters
Air barrier membrane
Wood decking
Timber rafter or exposed joist

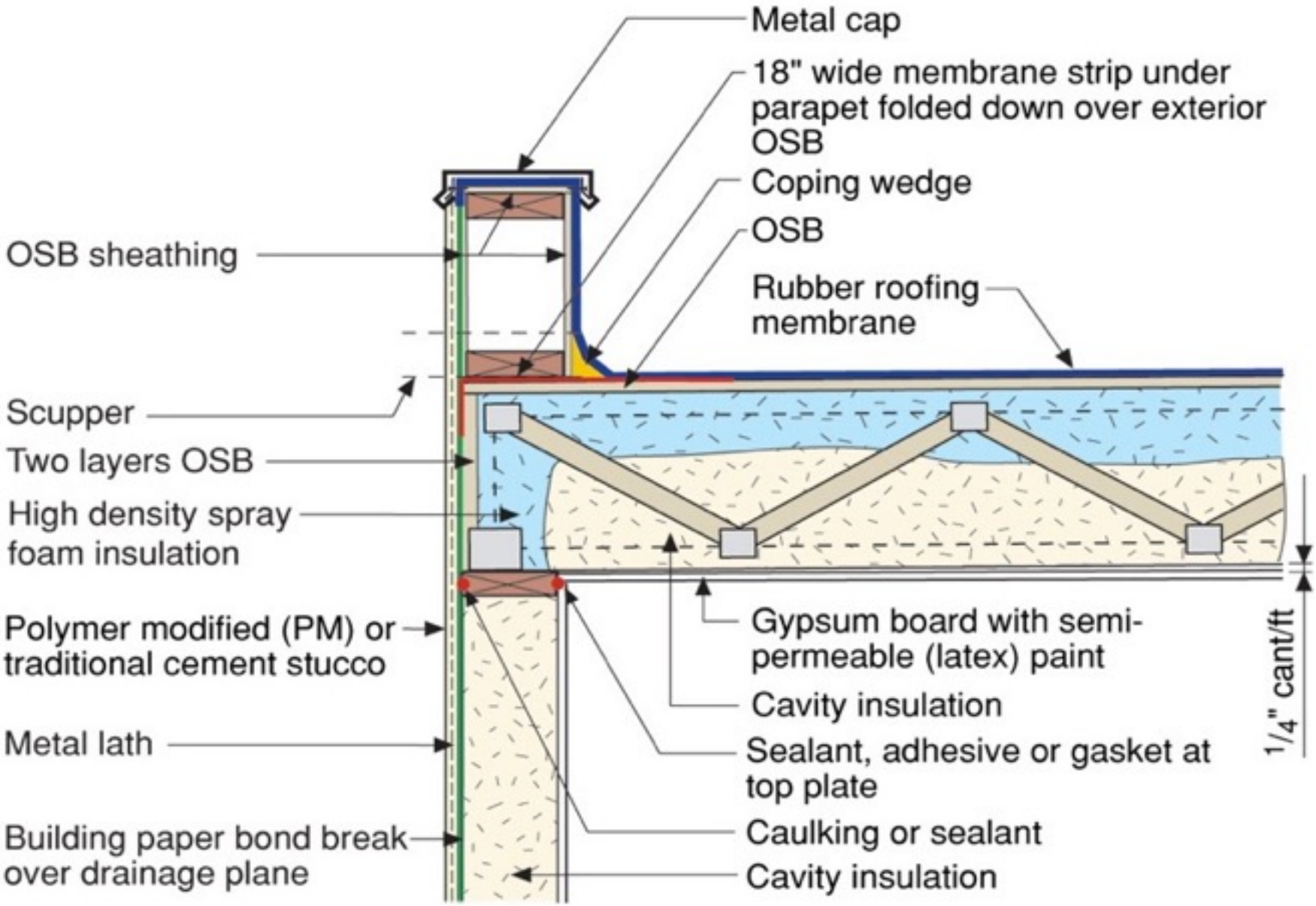

Roof sheathing
Roofing paper
Shingles
Minimum R-50 rigid insulation
in two or more layers with horizontal
and vertical joints staggered
Roof sheathing
Roofing membrane
Vented space
Air barrier
membrane
Wood decking
Timber rafter or
exposed joist

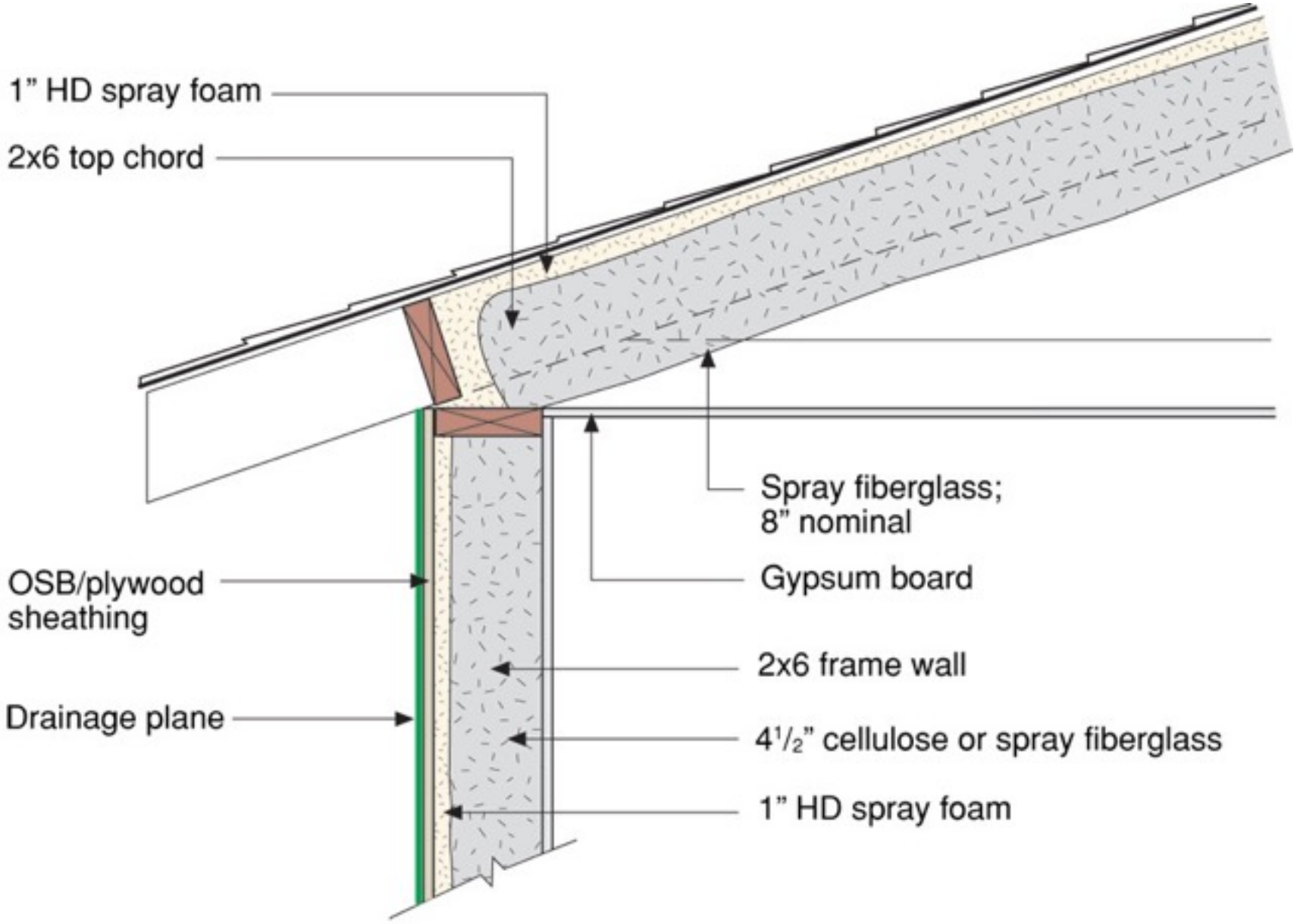

Shingles
Roofing paper
R-19 batt insulation installed with wire stays or twine or netted cellulose
R-5 rigid insulation (vertical and horizontal joints offset from roof sheathing)
3/8" sheathing over rigid insulation
Roof sheathing
Sealant
Rigid insulation notched around roof trusses and sealed
Vinyl 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

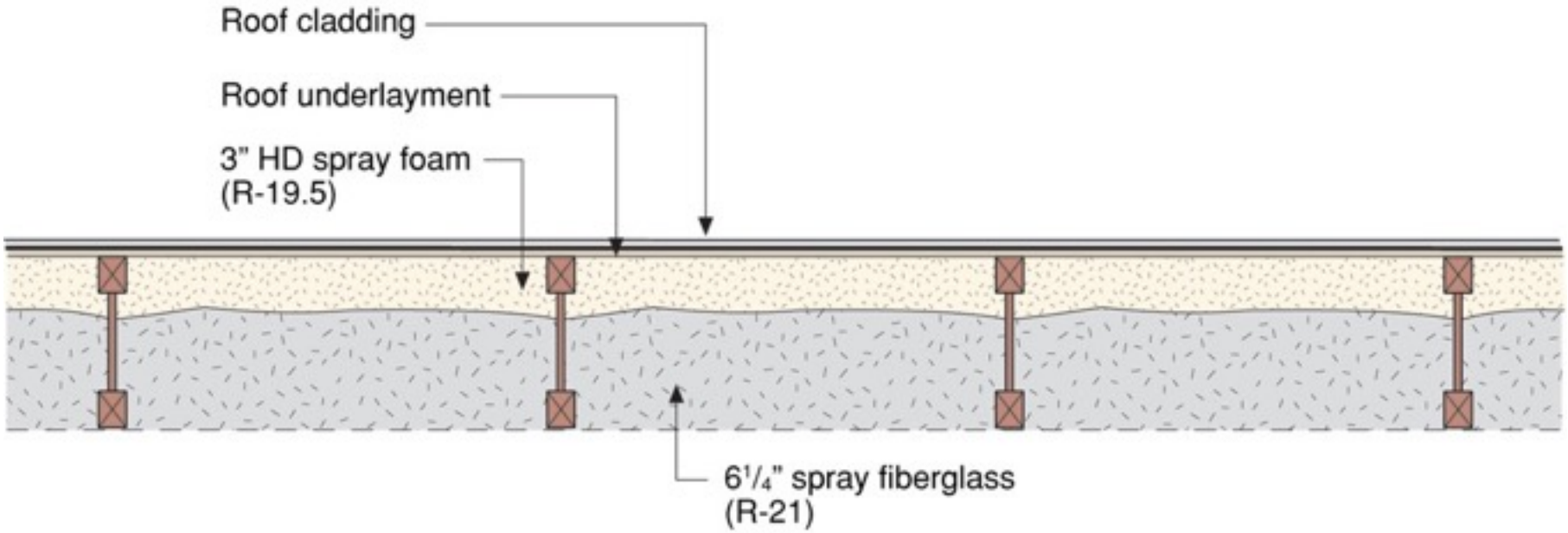

Roofing tile
Roofing paper
Netted cellulose insulation or batt insulation installed with wire stays or twine
Roof sheathing
Underside of roof sheathing is typically the "first" condensing surface
Stucco
Rigid insulation
Building paper drainage plane
Unfaced batt insulation
Gypsum board with vapor semi-permeable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

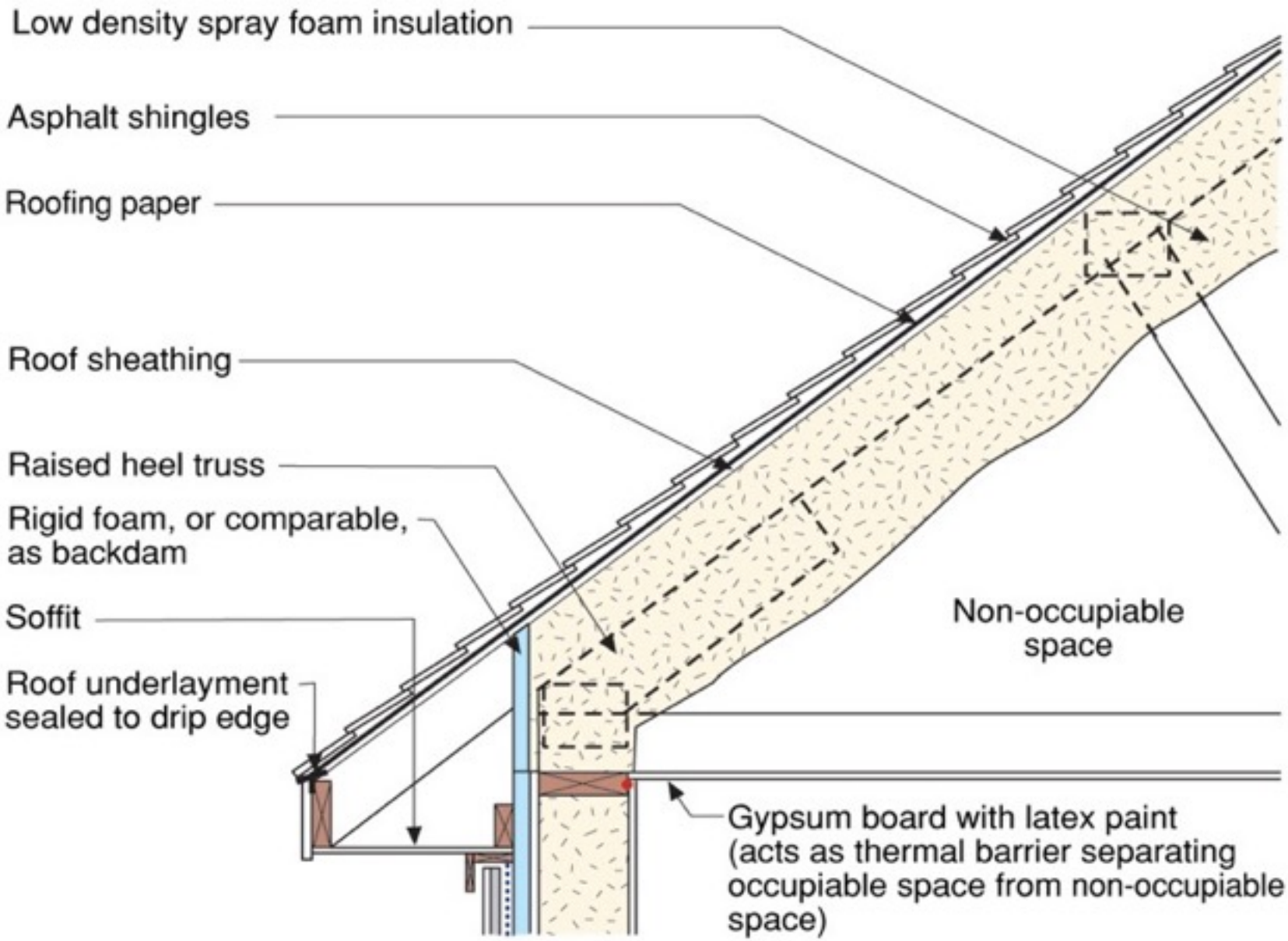

Metal cap
18" wide membrane strip
Coping wedge
OSB
Rubber roofing membrane
Soil gas stack vented through flashed roof penetration
Roof flashing
OSB sheathing
Scupper
Two layers OSB
Cavity insulation; see Material Compatibility and Substitutions
Gypsum board with semi-permeable (latex) paint
Sealant, adhesive or gasket at top plate
Caulking or sealant
Sealant at all penetrations
1/4" cant/ft
Polymer modified (PM) or traditional cement stucco
Metal lath
2X6 24" o.c. advanced framing
Cavity insulation; see Material Compatibility and Substitutions
Tyvek® StuccoWrap®
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
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
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Concrete grade beam
Polyethylene vapor barrier extended under grade beam where it also acts as a capillary break

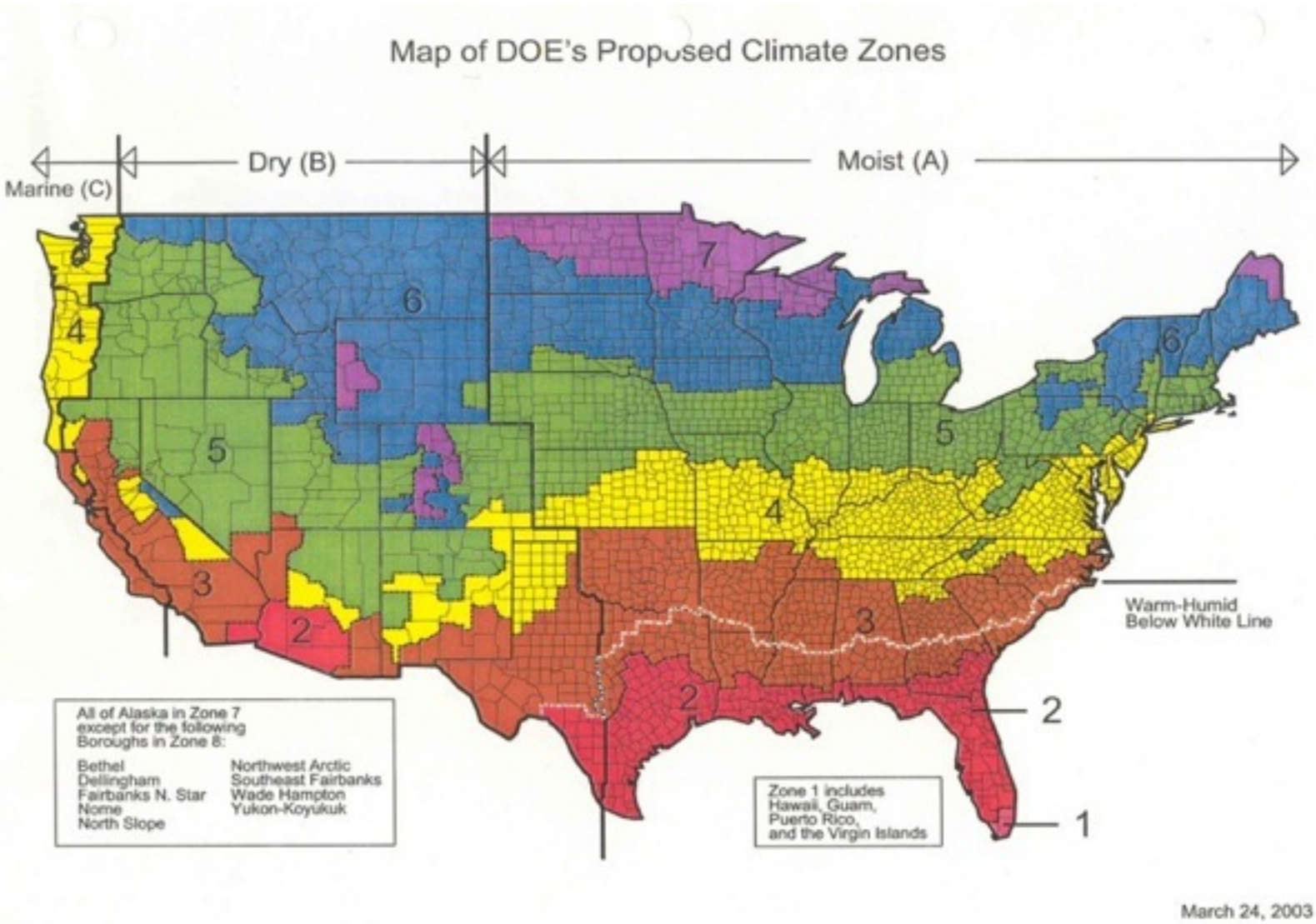

Metal cap
OSB sheathing
Scupper
Sealant
Rigid insulation
OSB
Cavity insulation
Sealant
Polymer modified (PM) or traditional cement stucco
Metal lath
Building paper bond break over drainage plane
18" wide membrane strip under parapet folded down over exterior rigid insulation
Coping wedge
OSB
Rubber roofing 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

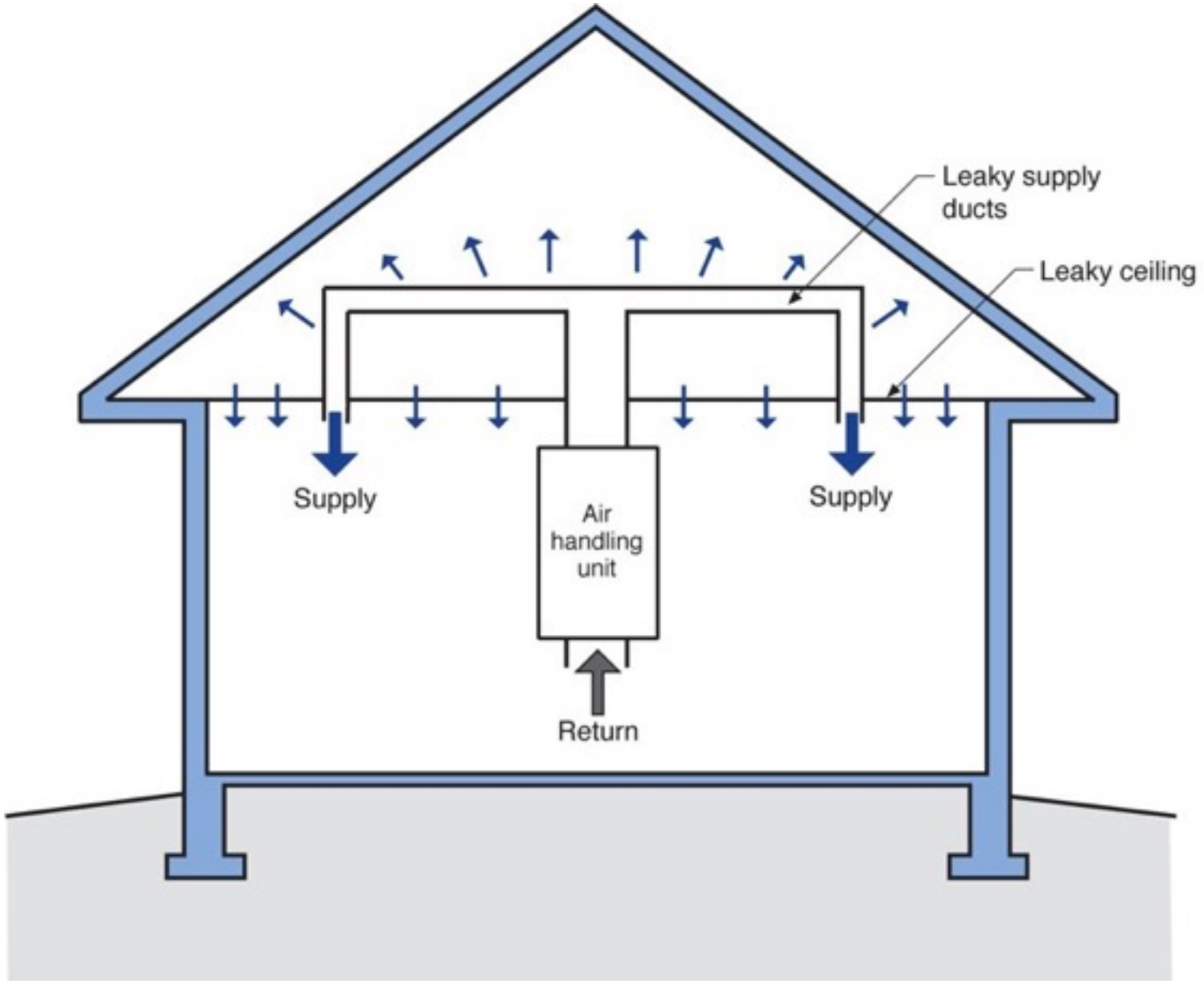

1" HD spray foam
2x6 top chord
Spray fiberglass;
8" nominal
Gypsum board
OSB/plywood
sheathing
2x6 frame wall
Drainage plane
4½" cellulose or spray fiberglass
1" HD spray foam


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)


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

Conditioned Attics Not Unvented Attics


Leaky supply ducts
Leaky ceiling
Supply
Supply
Air handling unit
Return

Conditioned Attics Not Unvented Attics Need Supply Air

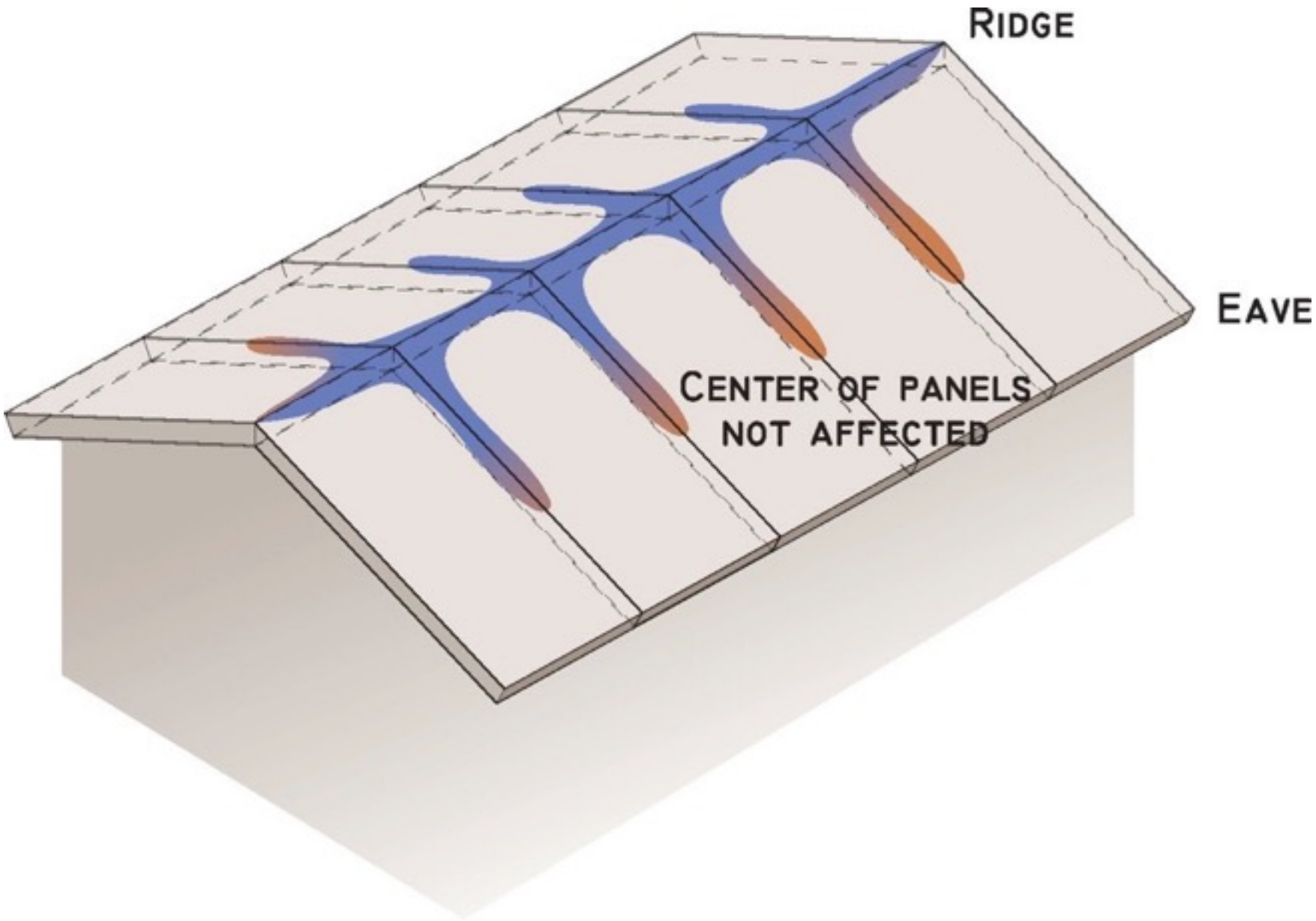
Conditioned Attics Not Unvented Attics

Need Supply Air

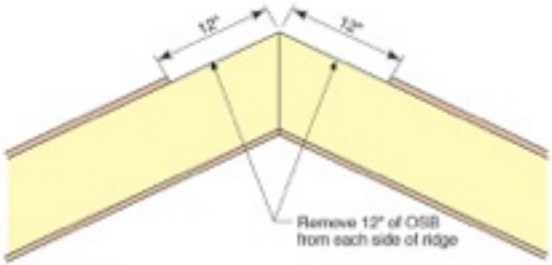
50 cfm/1000 ft2 of Attic

SIP Failures

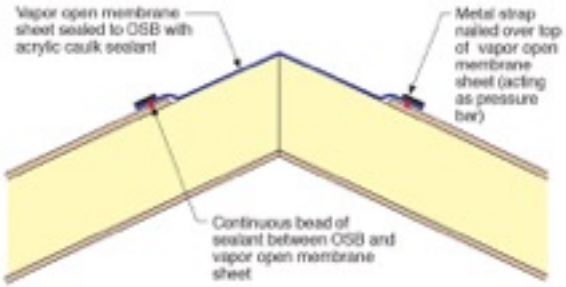

8/22/01 09:32


RIDGE
EAVE
CENTER OF PANELS
NOT AFFECTED

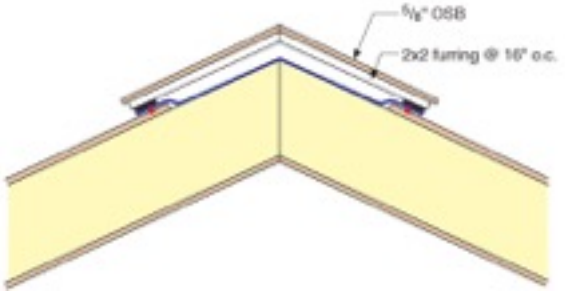
Step 1
- Remove strip of OSB from each side of ridge



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
DuPont


Tyvek


GAF
VEK


GRACE
Ice & Water Shield®


JUL 9 2006

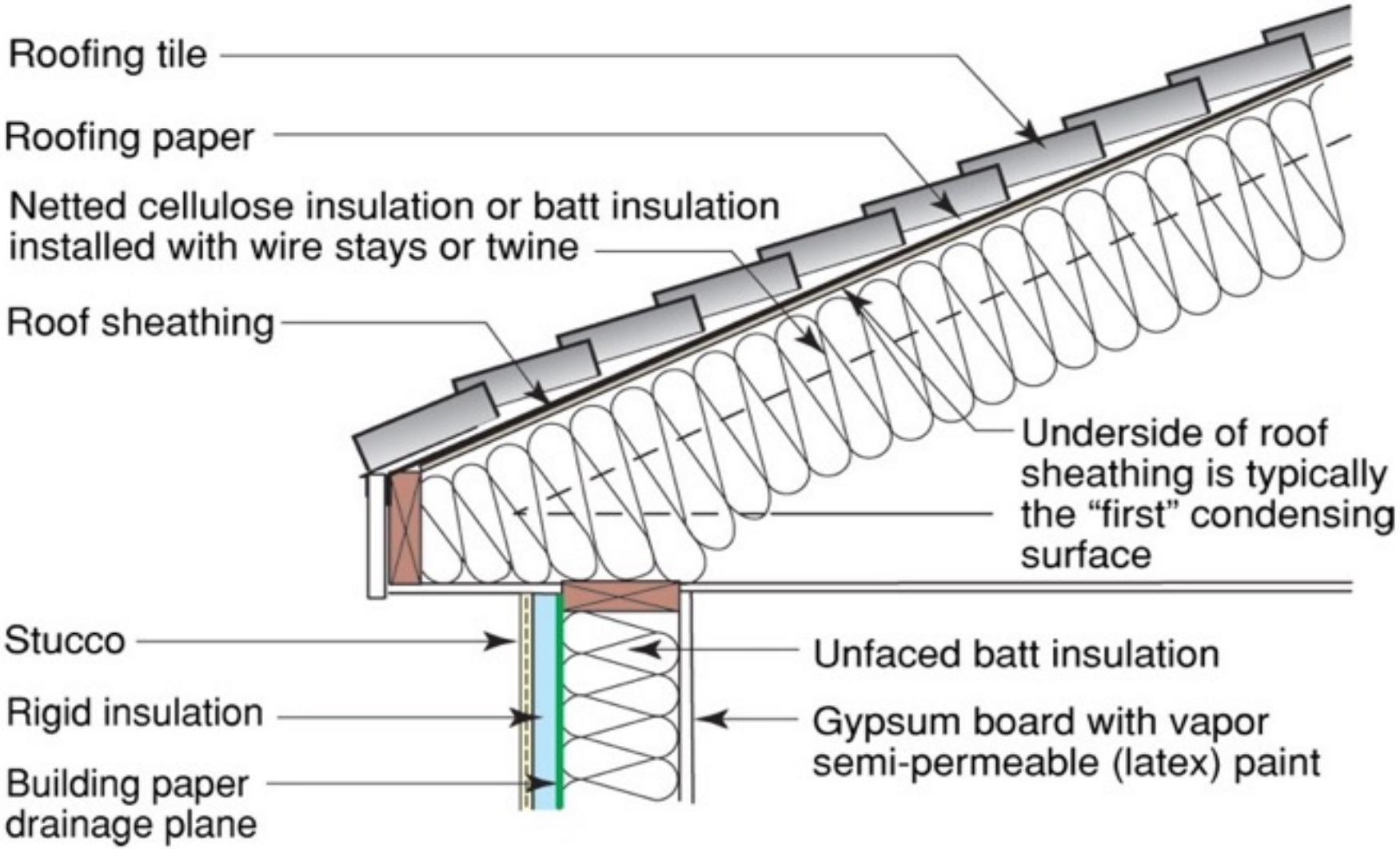
Unvented Cellulose

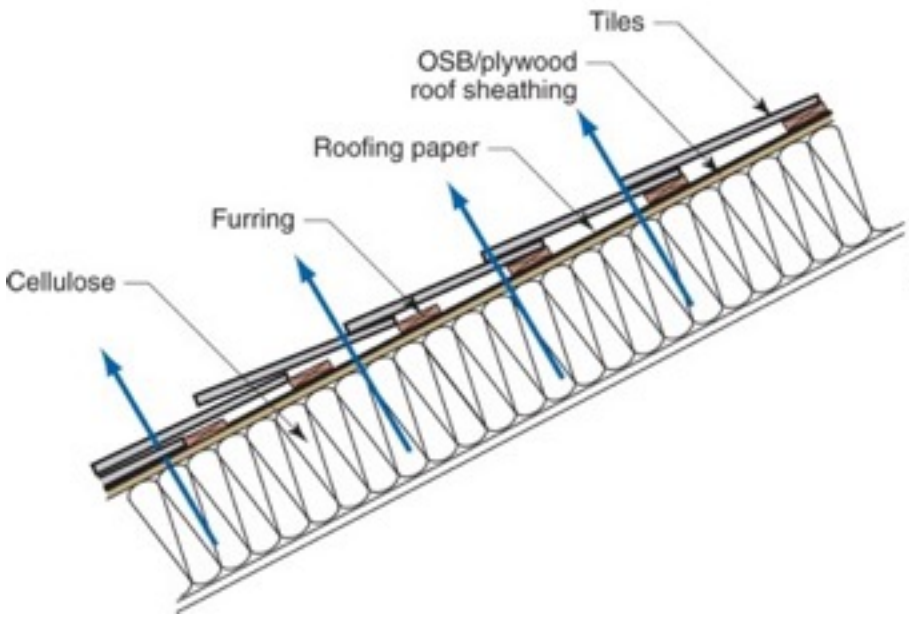
Inward Vapor Drive

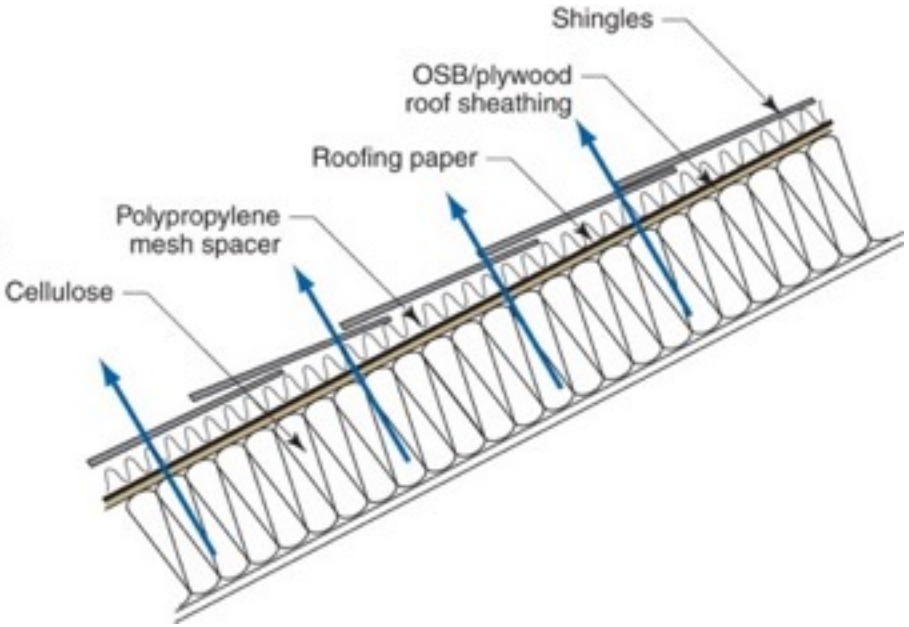

APR 20 2004


APR 20 2004

Chicago

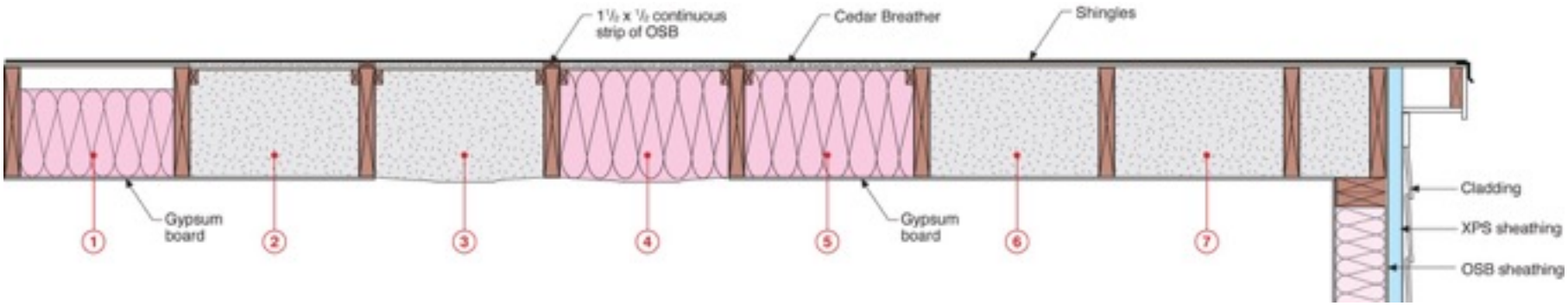

Roofing tile
Roofing paper
Netted cellulose insulation or batt insulation installed with wire stays or twine
Roof sheathing
Underside of roof sheathing is typically the "first" condensing surface
Stucco
Rigid insulation
Building paper drainage plane
Unfaced batt insulation
Gypsum board with vapor semi-permeable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

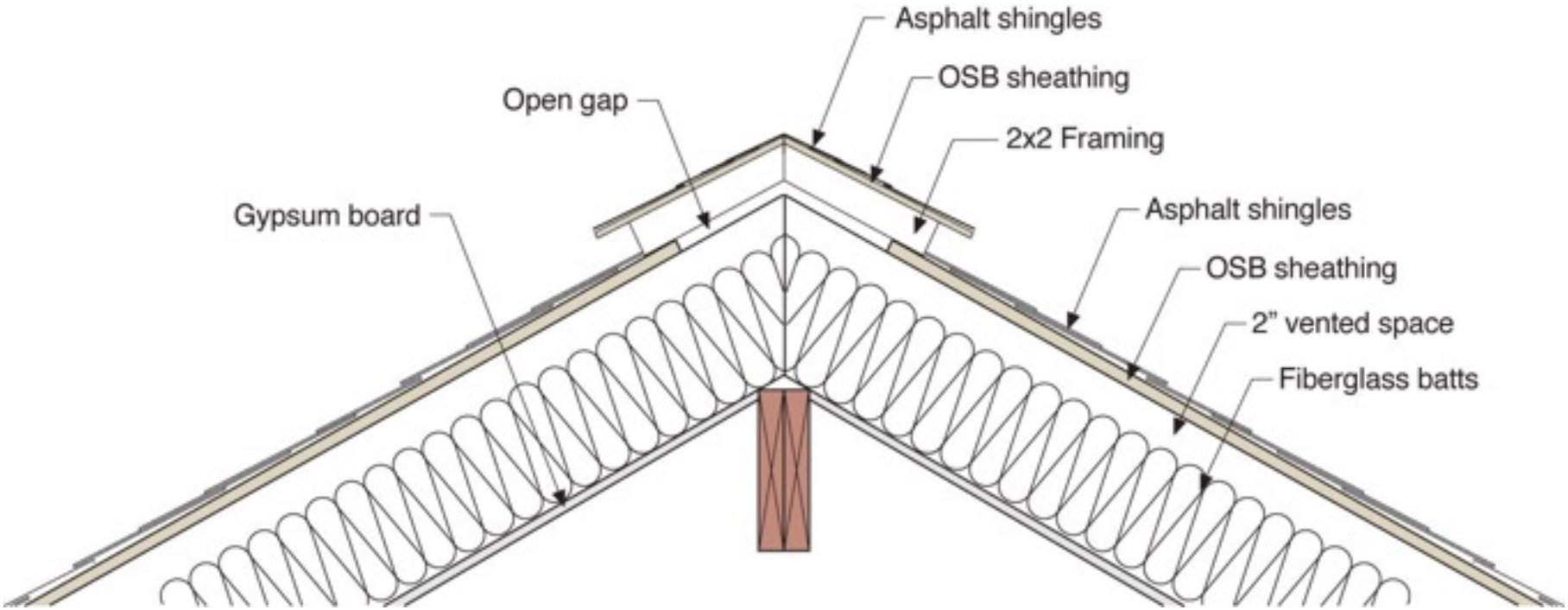

Tiles
OSB/plywood
roof sheathing
Roofing paper
Furring
Cellulose

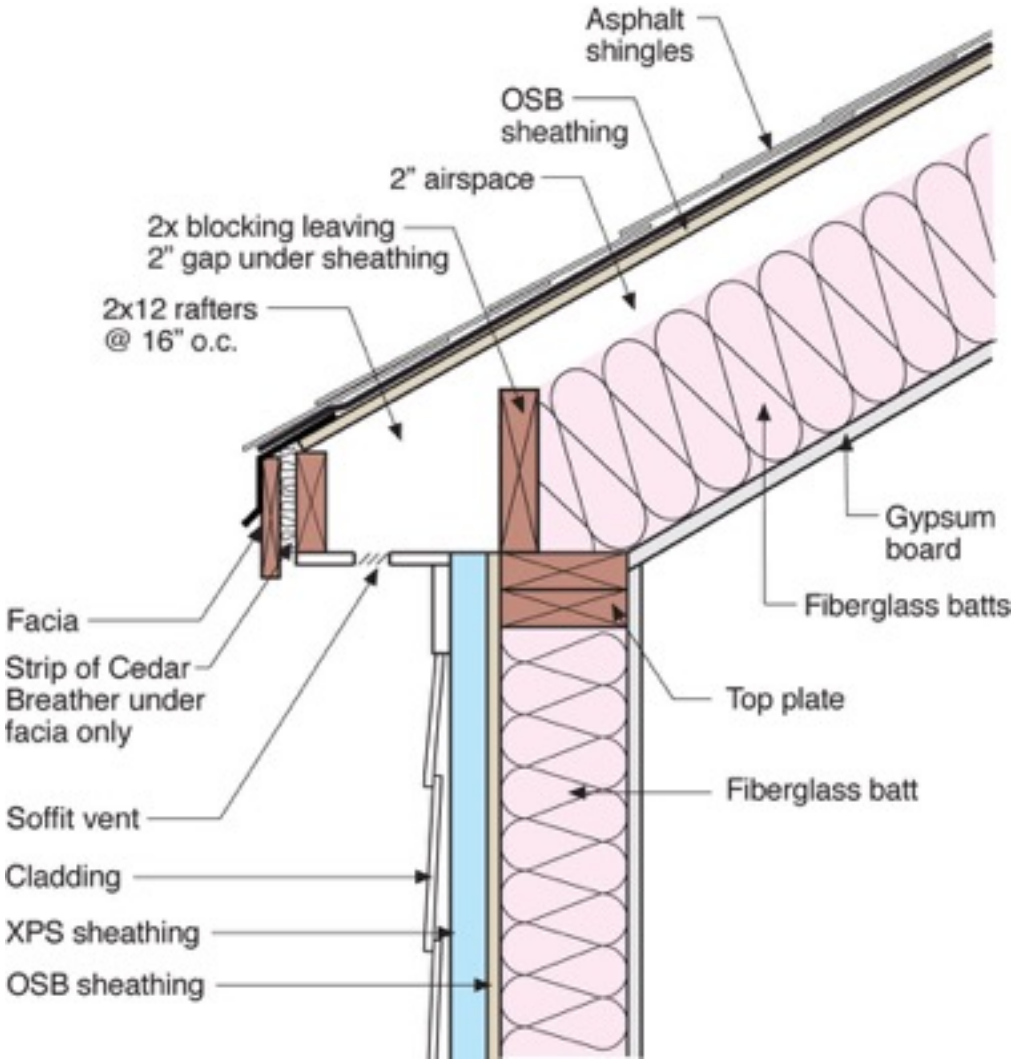

Shingles
OSB/plywood
roof sheathing
Roofing paper
Polypropylene
mesh spacer
Cellulose

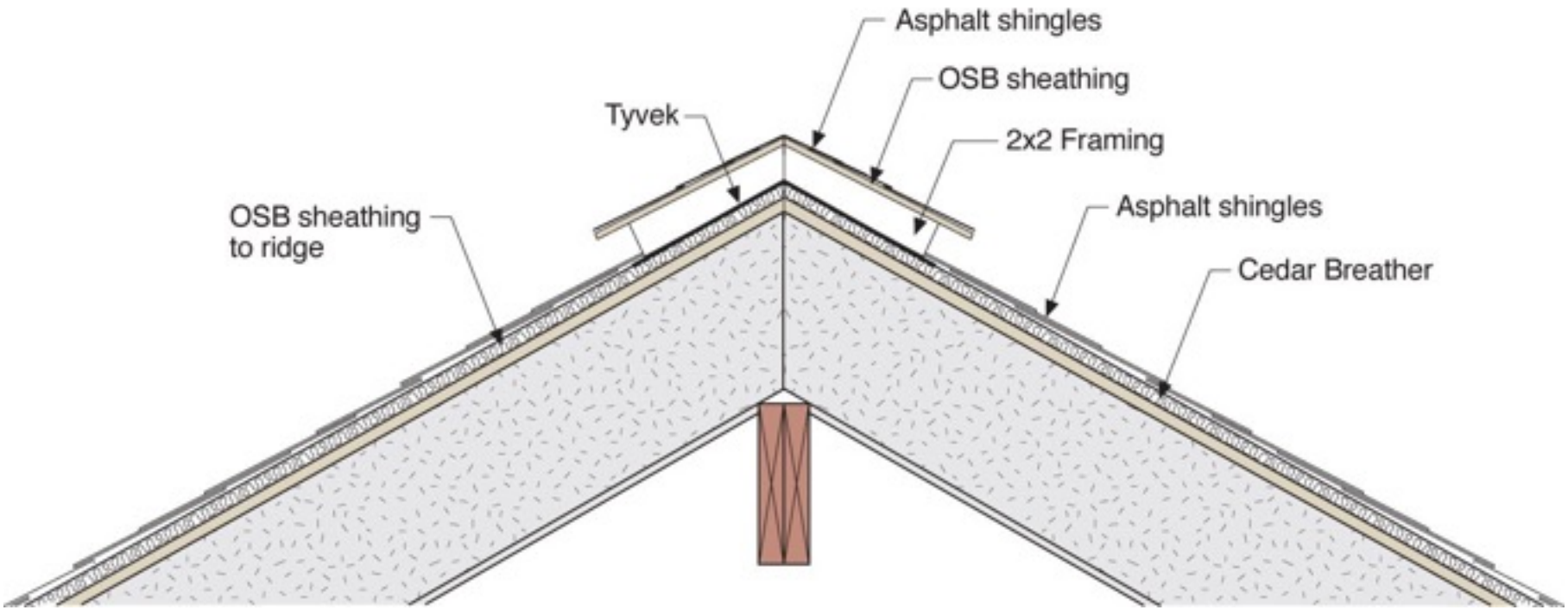

AVAILABLE

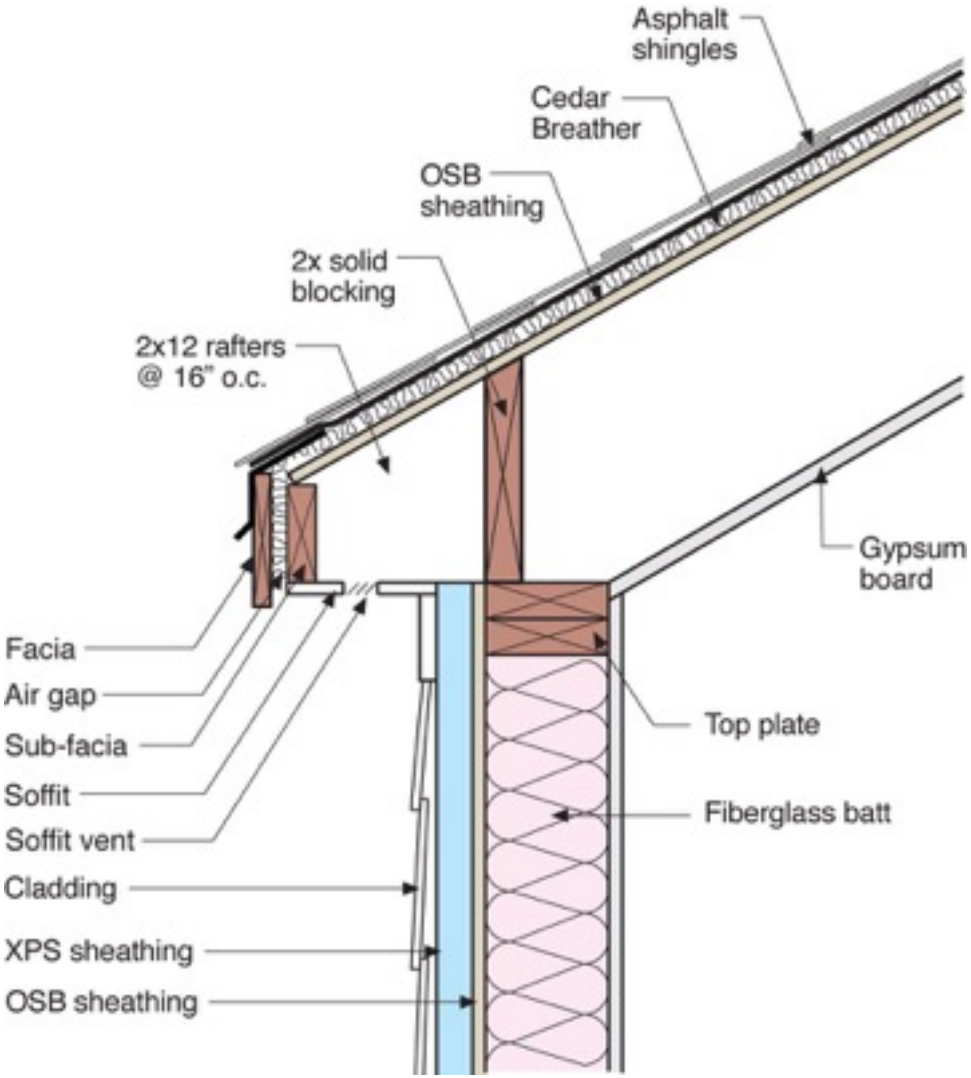

Styrofoam
Tongue and Groove Insulation
DOW
Styrofoam
Tongue and Groove Insulation
DOW
Styrofoam

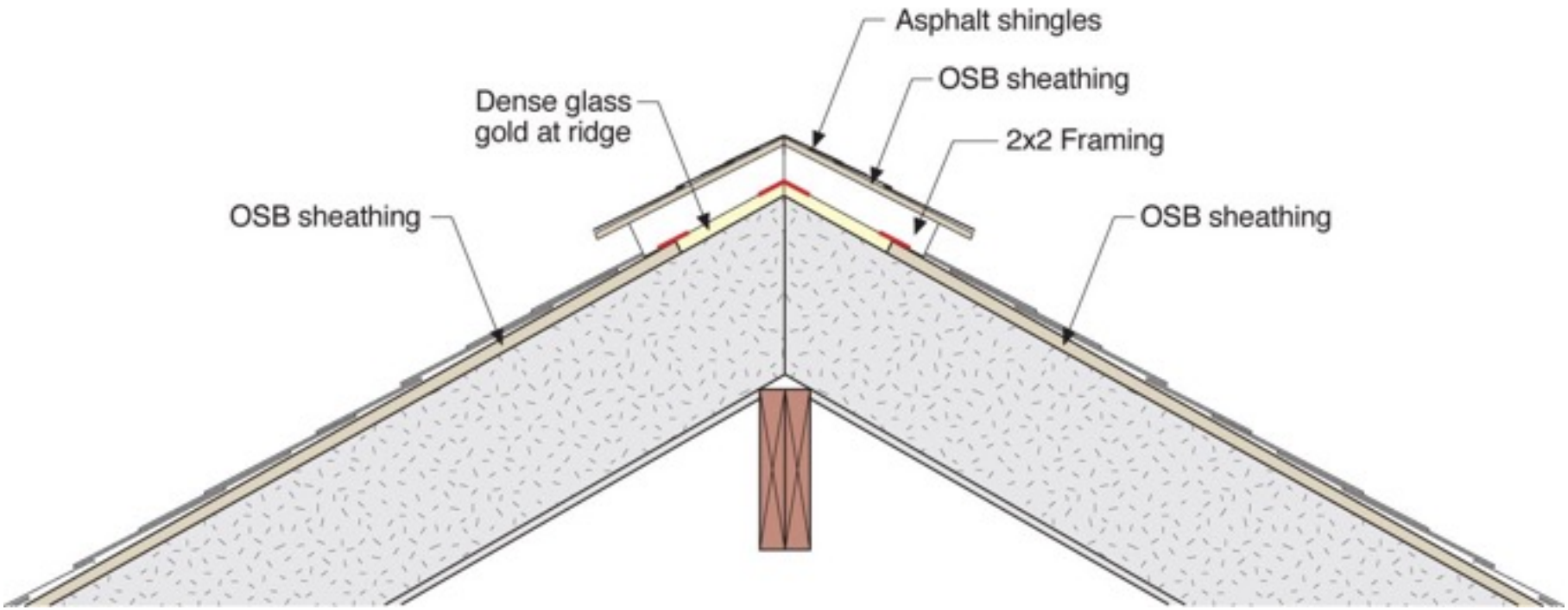

1½ x ⅛ continuous strip of OSB
Cedar Breather
Shingles
Gypsum board
Gypsum board
Cladding
XPS sheathing
OSB sheathing
1
2
3
4
5
6
7

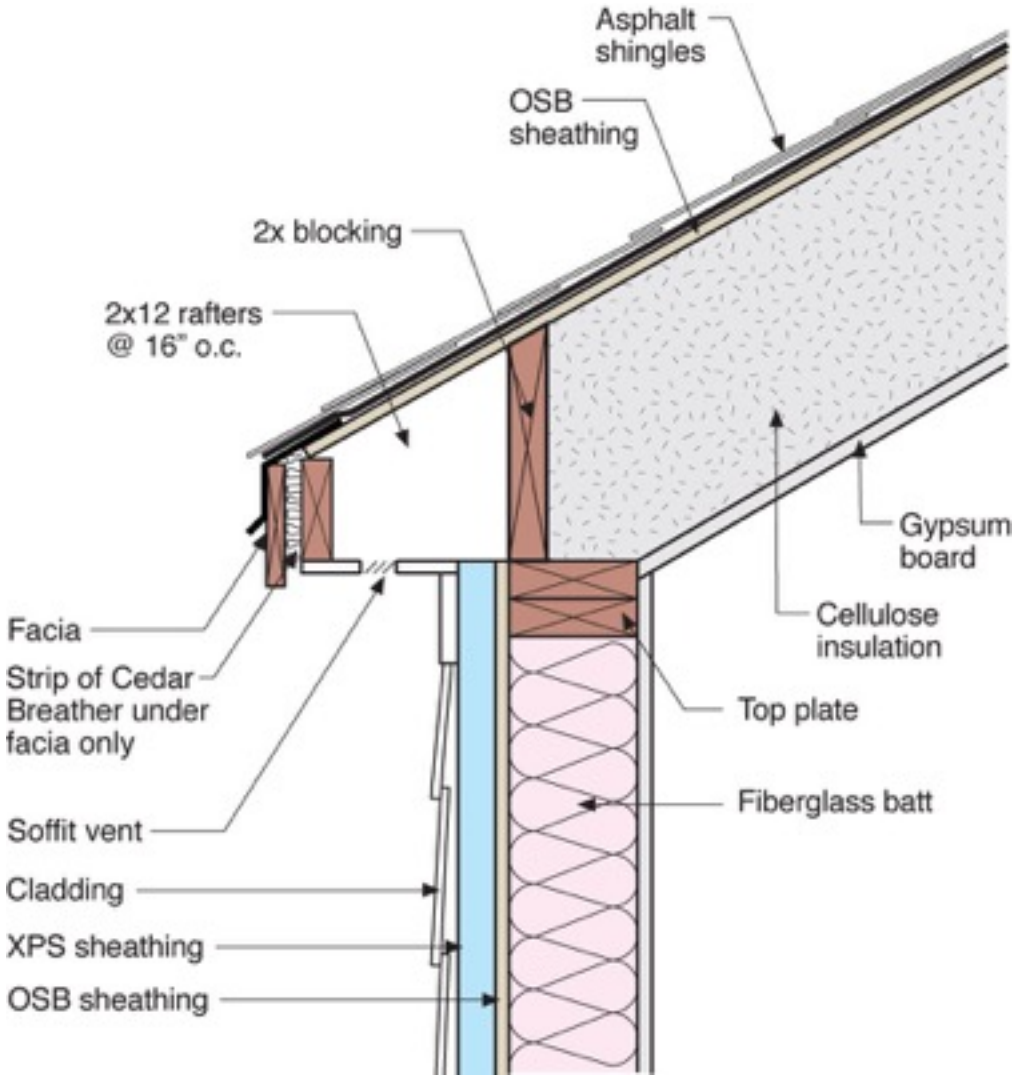

Asphalt shingles
OSB sheathing
Open gap
2x2 Framing
Gypsum board
Asphalt shingles
OSB sheathing
2" vented space
Fiberglass batts


Asphalt shingles
OSB sheathing
2" airspace
2x blocking leaving 2" gap under sheathing
2x12 rafters @ 16" o.c.
Gypsum board
Fiberglass batts
Facia
Strip of Cedar Breather under facia only
Top plate
Fiberglass batt
Soffit vent
Cladding
XPS sheathing
OSB sheathing


Asphalt shingles
OSB sheathing
Tyvek
2x2 Framing
OSB sheathing
to ridge
Asphalt shingles
Cedar Breather


Asphalt shingles
Cedar Breather
OSB sheathing
2x solid blocking
2x12 rafters @ 16" o.c.
Gypsum board
Facia
Air gap
Sub-facia
Soffit
Soffit vent
Cladding
XPS sheathing
OSB sheathing
Top plate
Fiberglass batt


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


Asphalt shingles
OSB sheathing
2x blocking
2x12 rafters @ 16" o.c.
Gypsum board
Cellulose insulation
Facia
Strip of Cedar Breather under facia only
Top plate
Fiberglass batt
Soffit vent
Cladding
XPS sheathing
OSB sheathing


FlexWrap

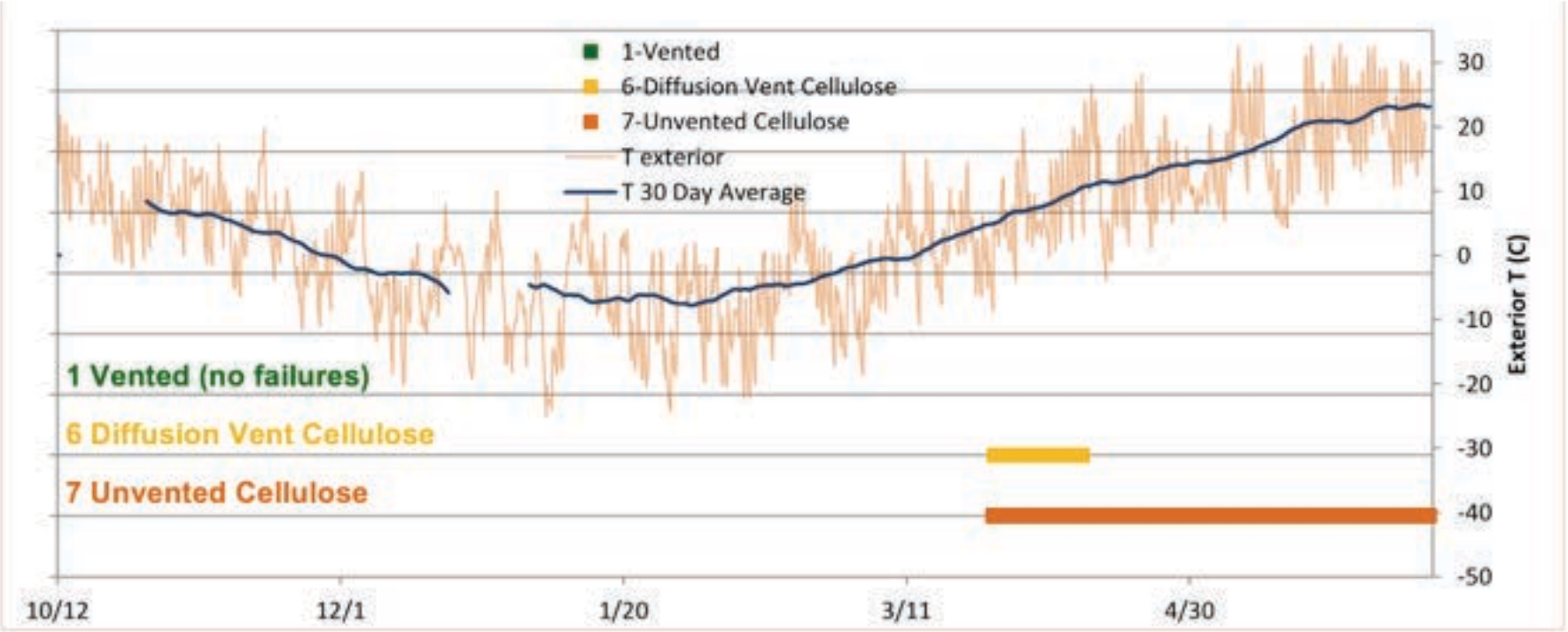
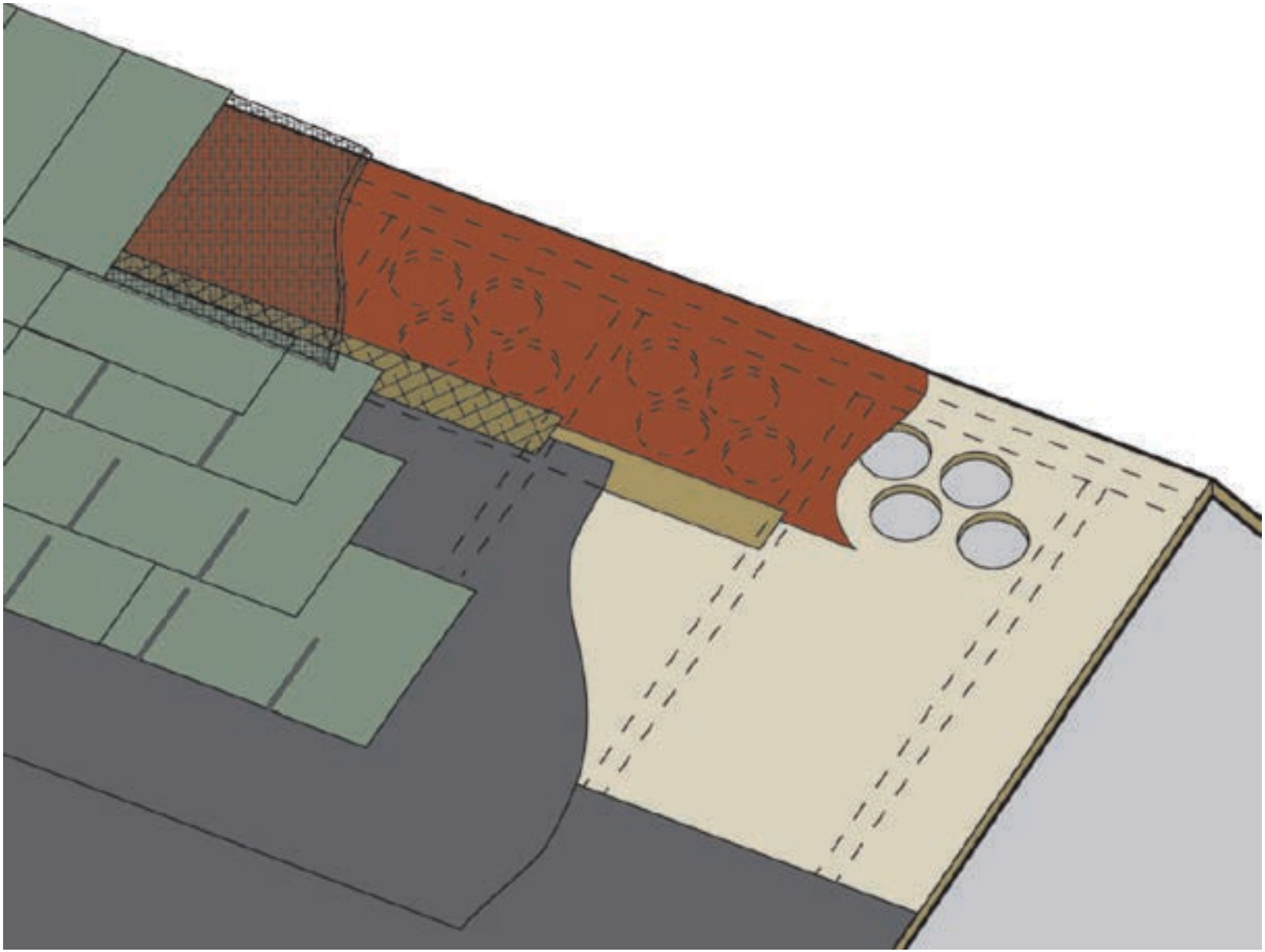


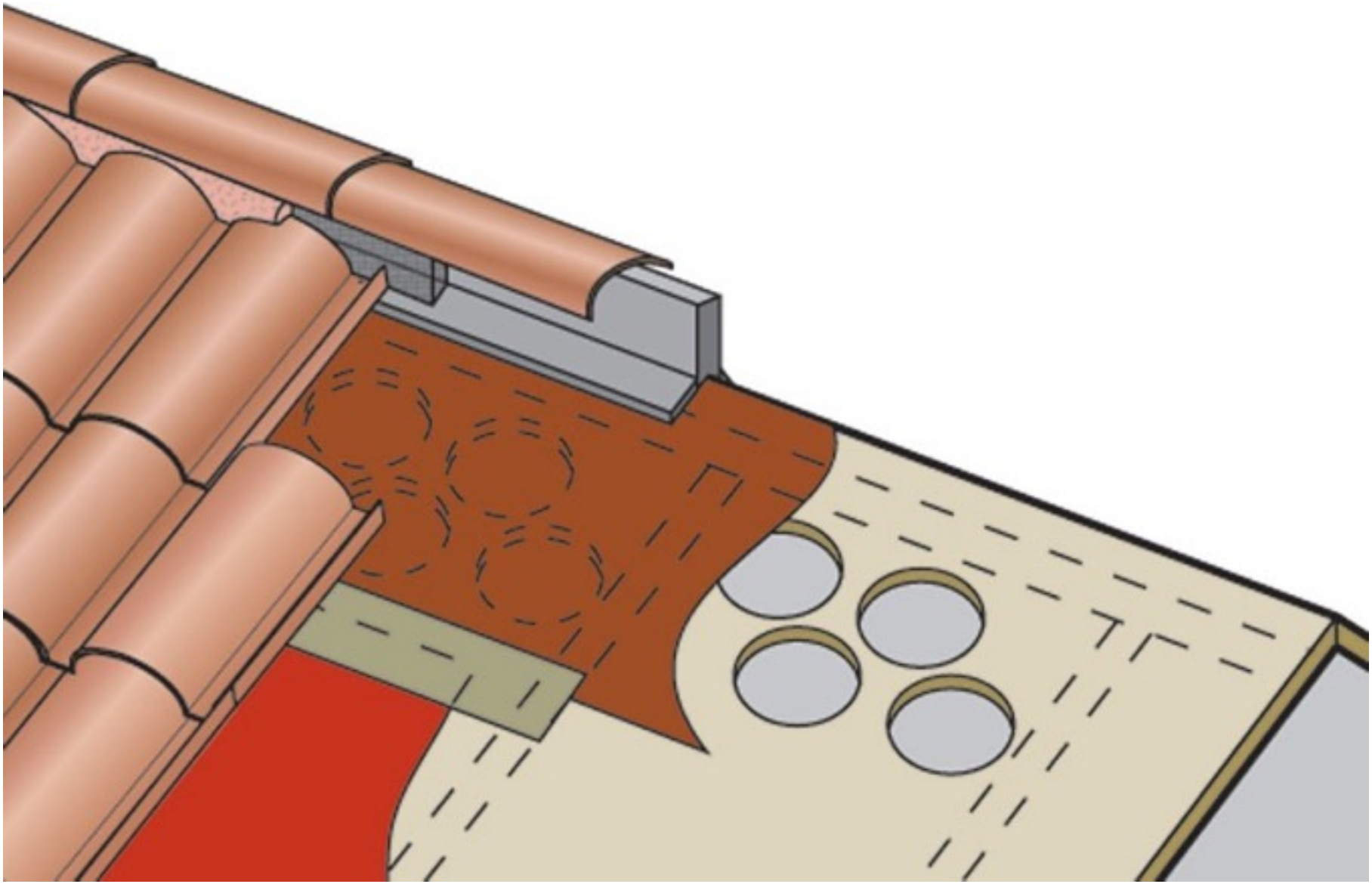
Figure 84: ASHRAE 160 failures, vented (1), diffusion vent (6), and unvented (7)

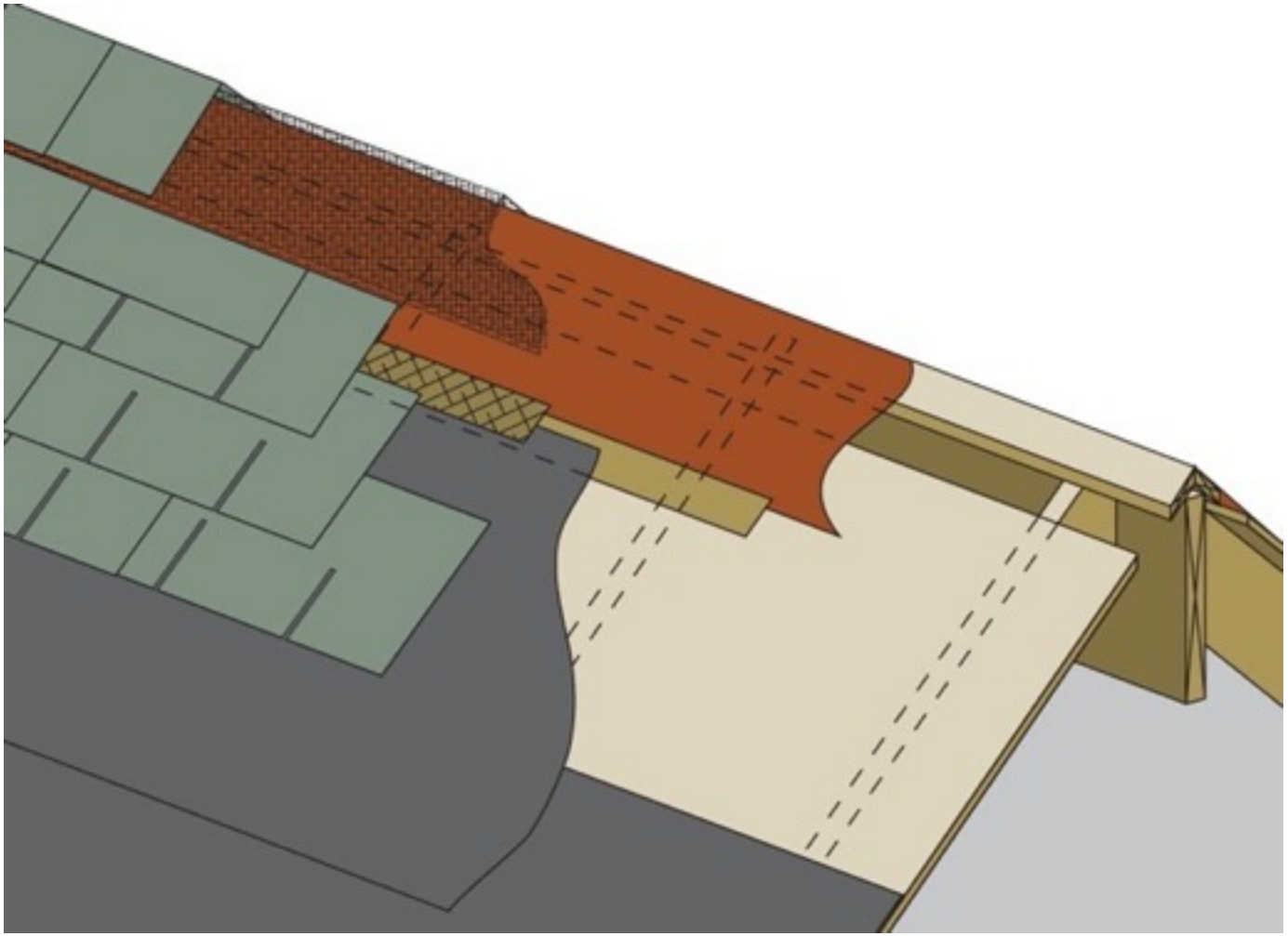

6
DIFFUSION
VENT

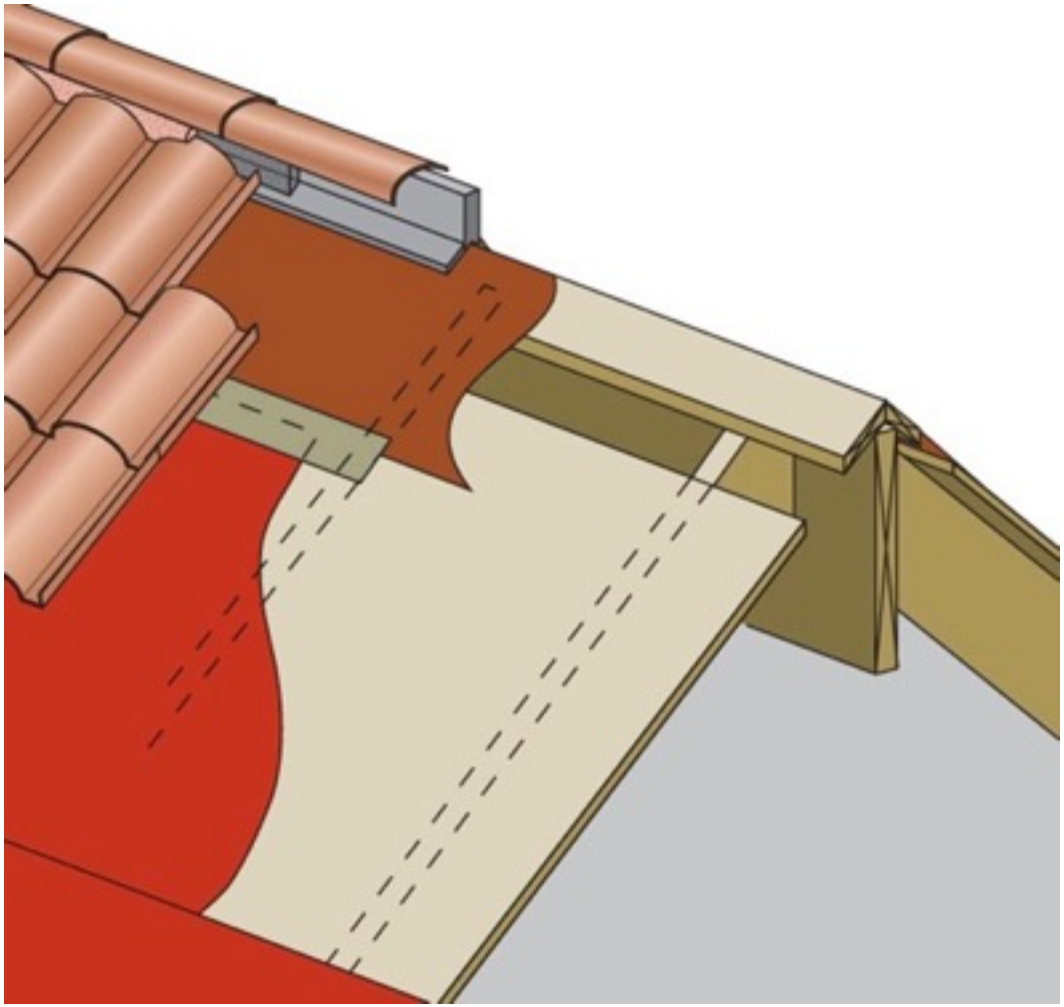

7
UNVENTED

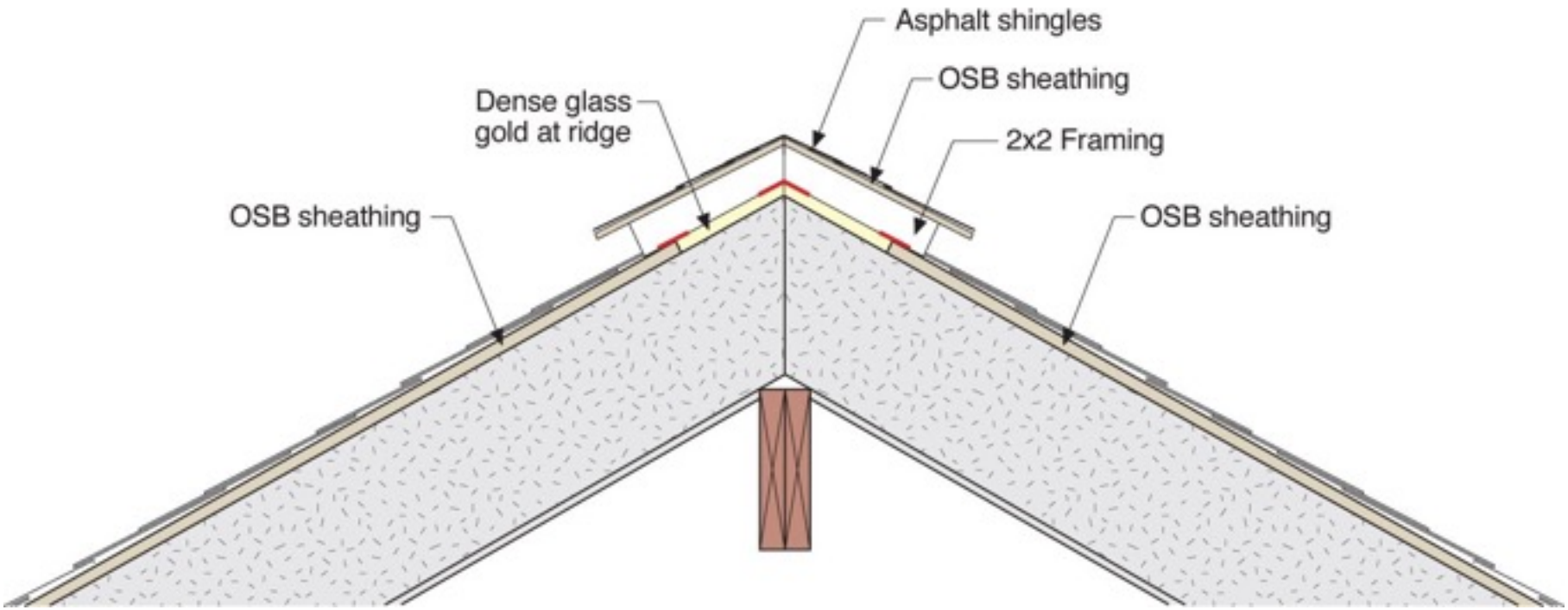
Houston and Orlando









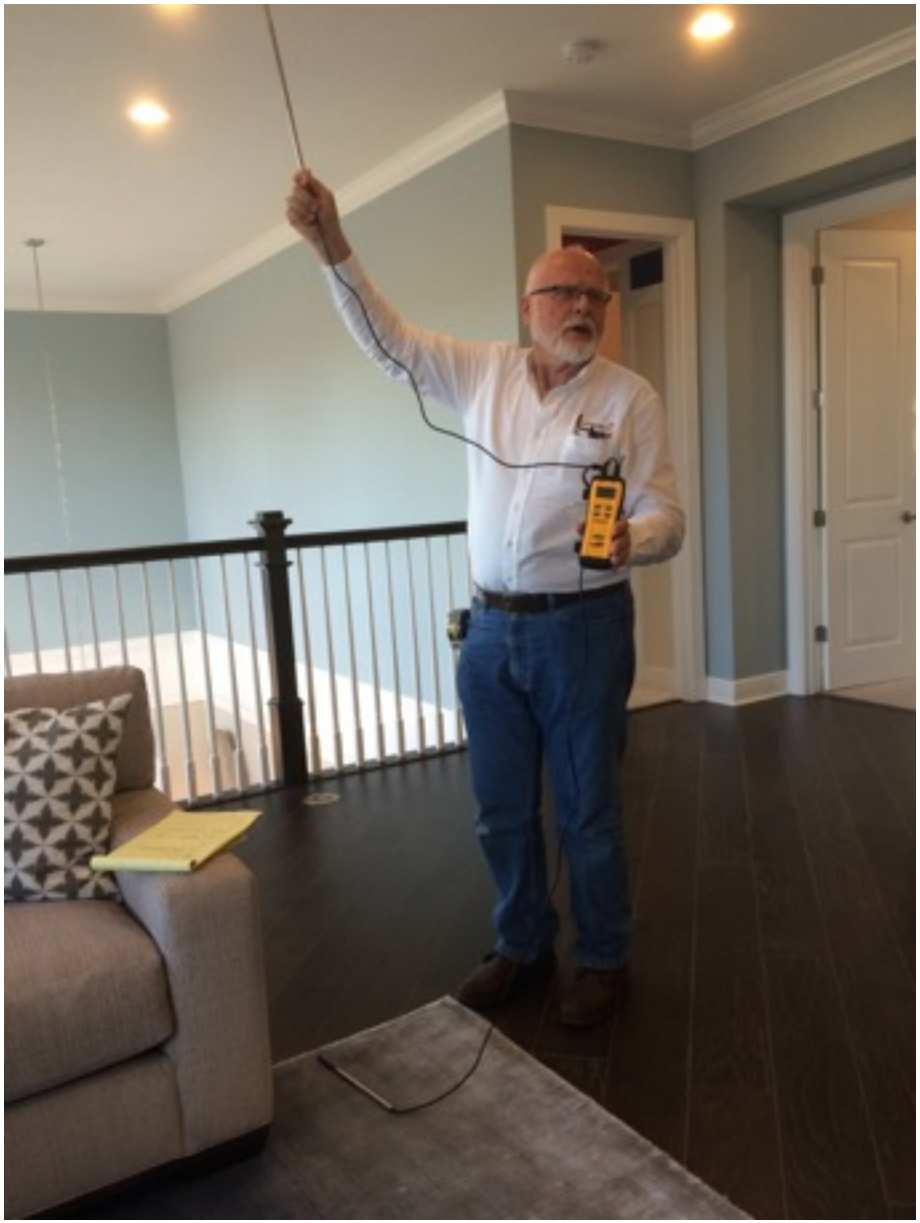

Asphalt shingles
OSB sheathing
Dense glass
gold at ridge
2x2 Framing
OSB sheathing
OSB sheathing


DELTA
DELTA
DELTA


3M

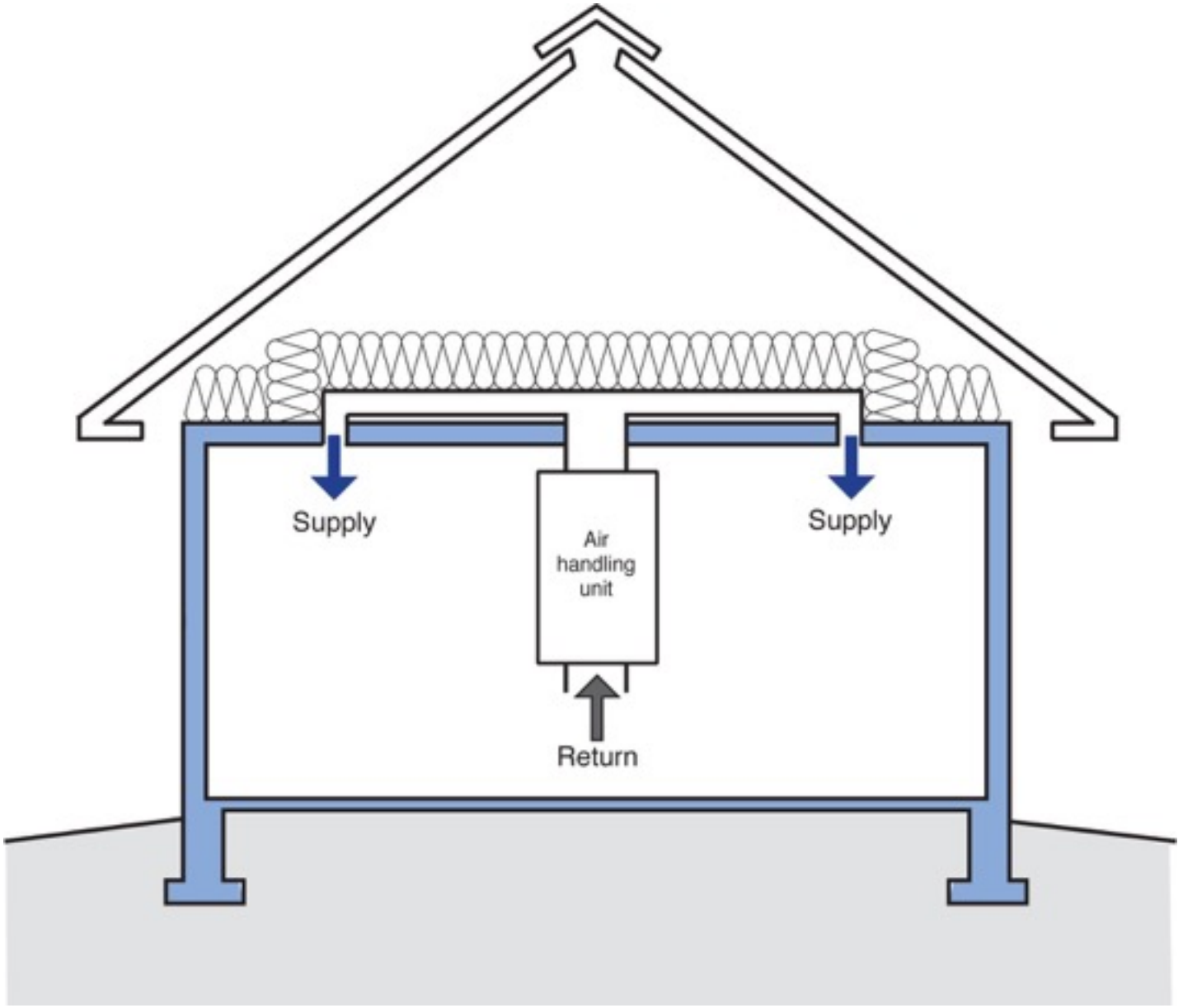

R-30
PROPINK
High Performance
Attic System
OWENS CORNING
R-30
PROPINK
High Performance
Attic System

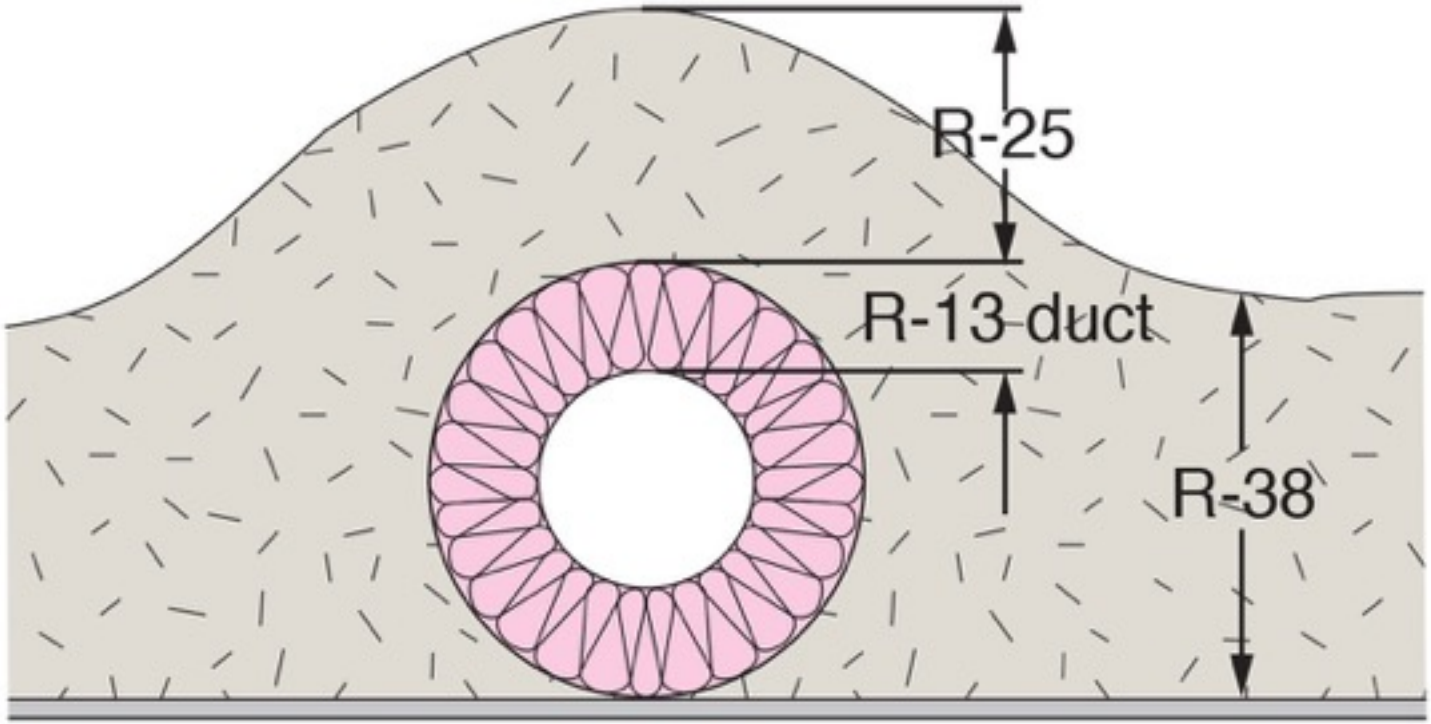
Hygric Buoyancy

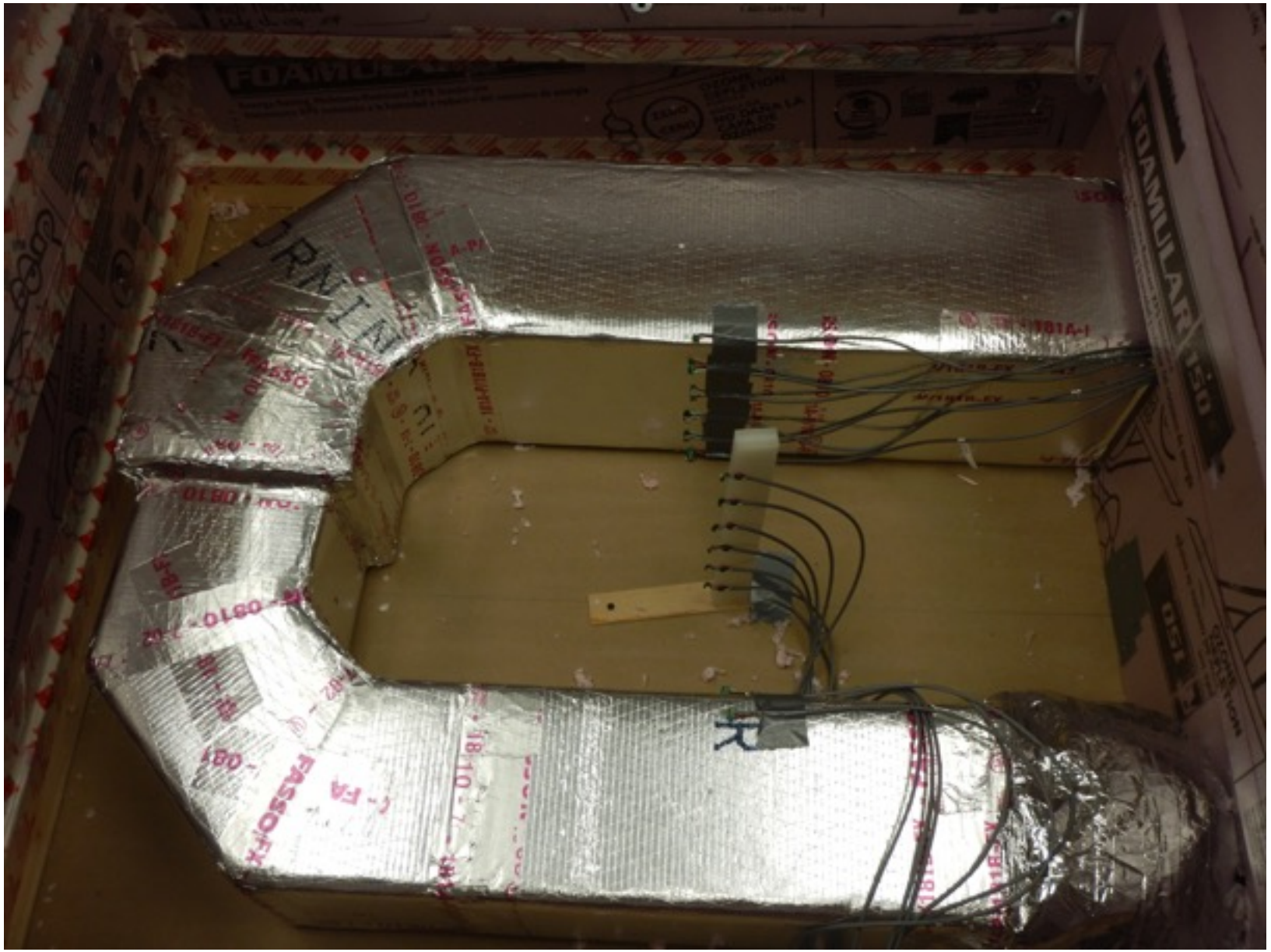



Dual In-Duct
Psychrometer
Fieldpiece
SDP2

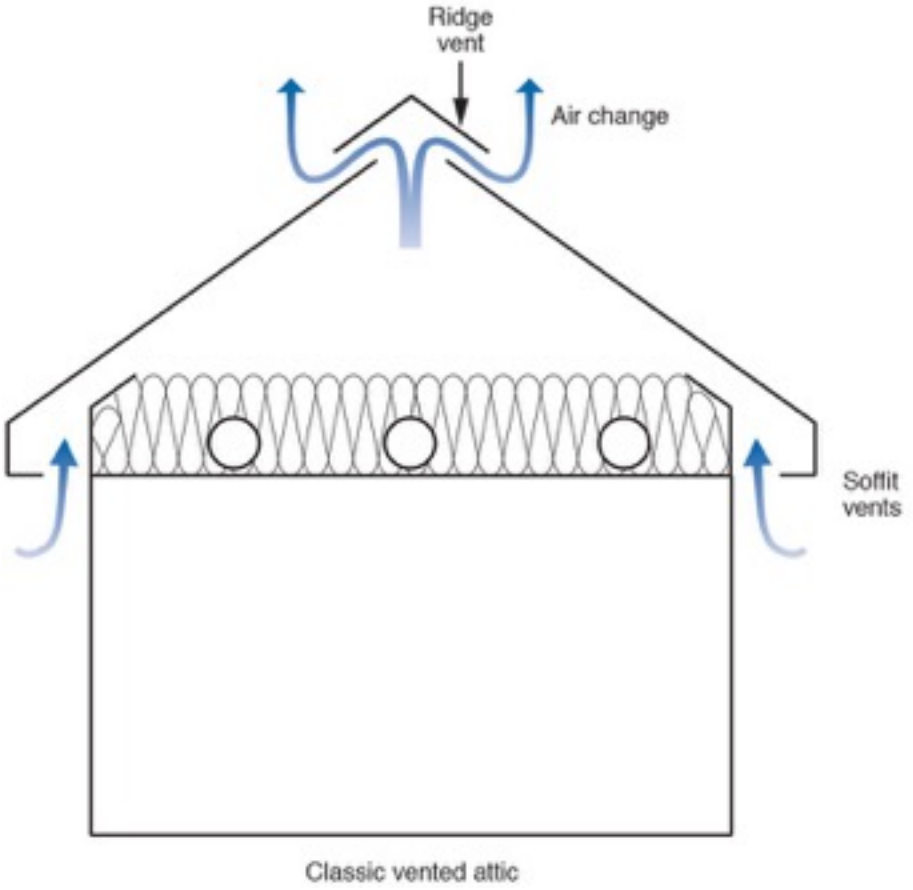
Burying Ducts


Supply
Air handling unit
Supply
Return

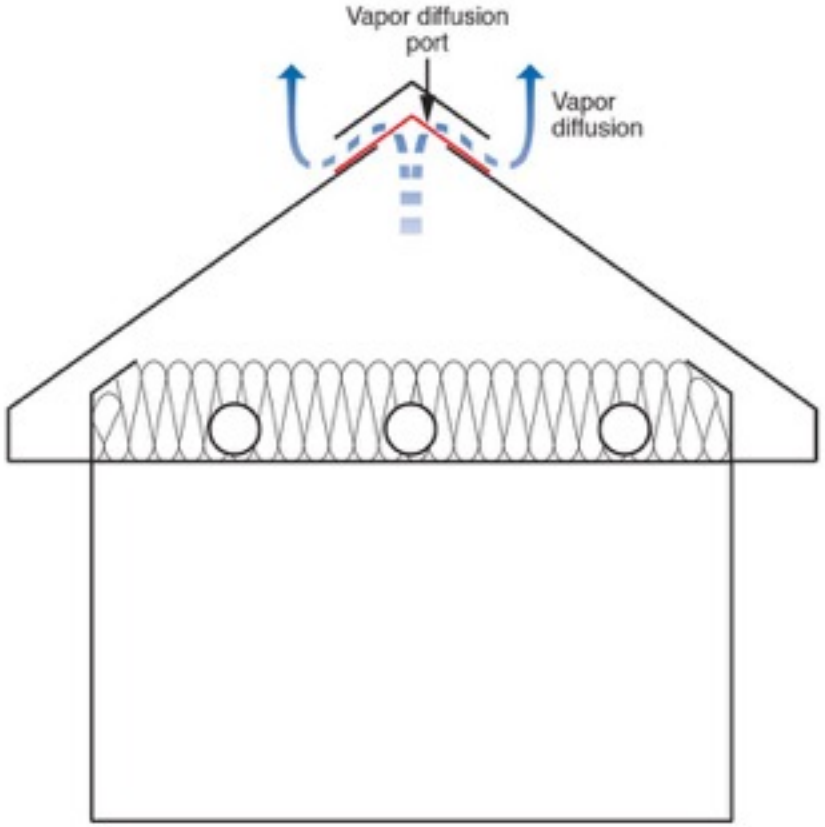

R-25
R-13 duct
R-38


FOAMULAR


R-5.0
FOAMULAR 150

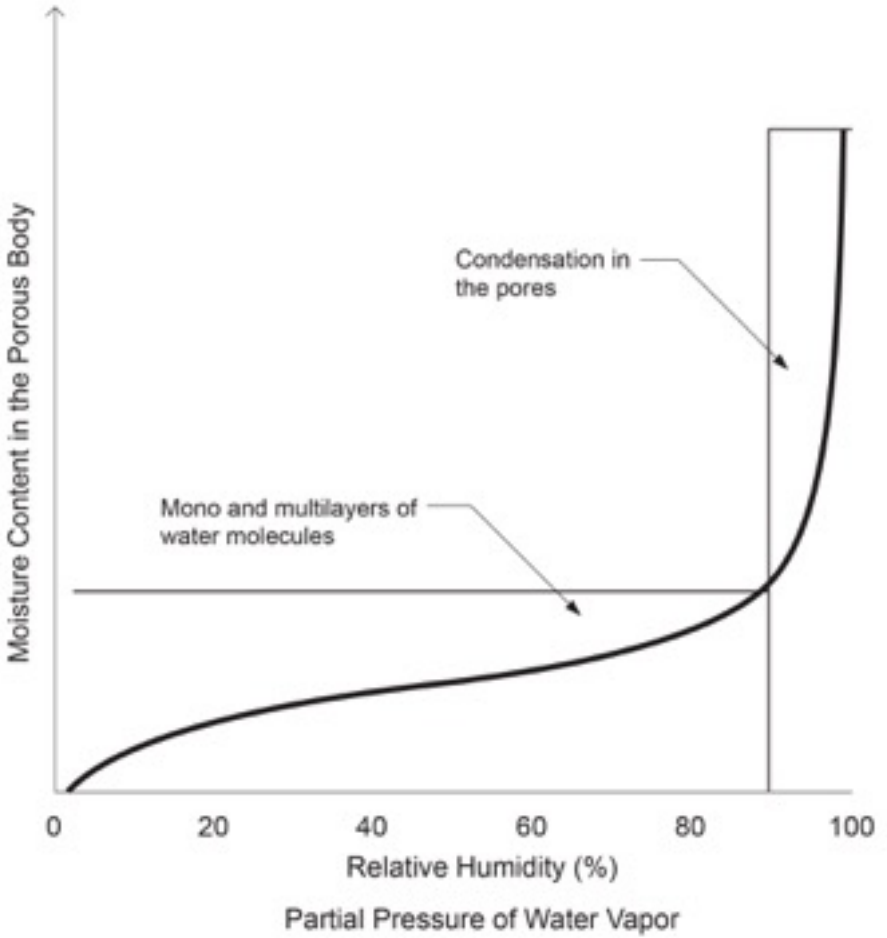


Classic vented attic



Unvented attic with vapor diffusion port

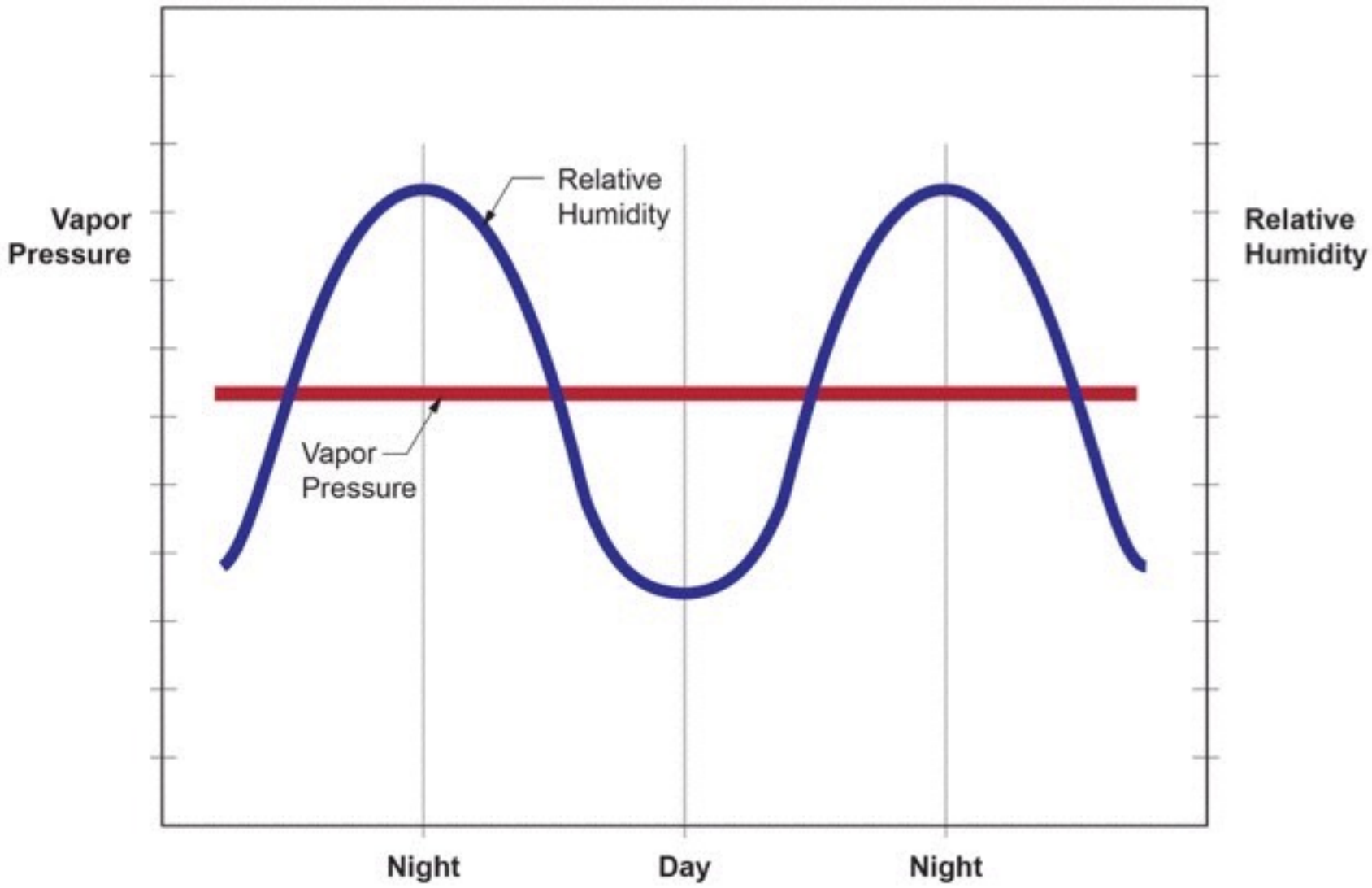
Vancouver Mold

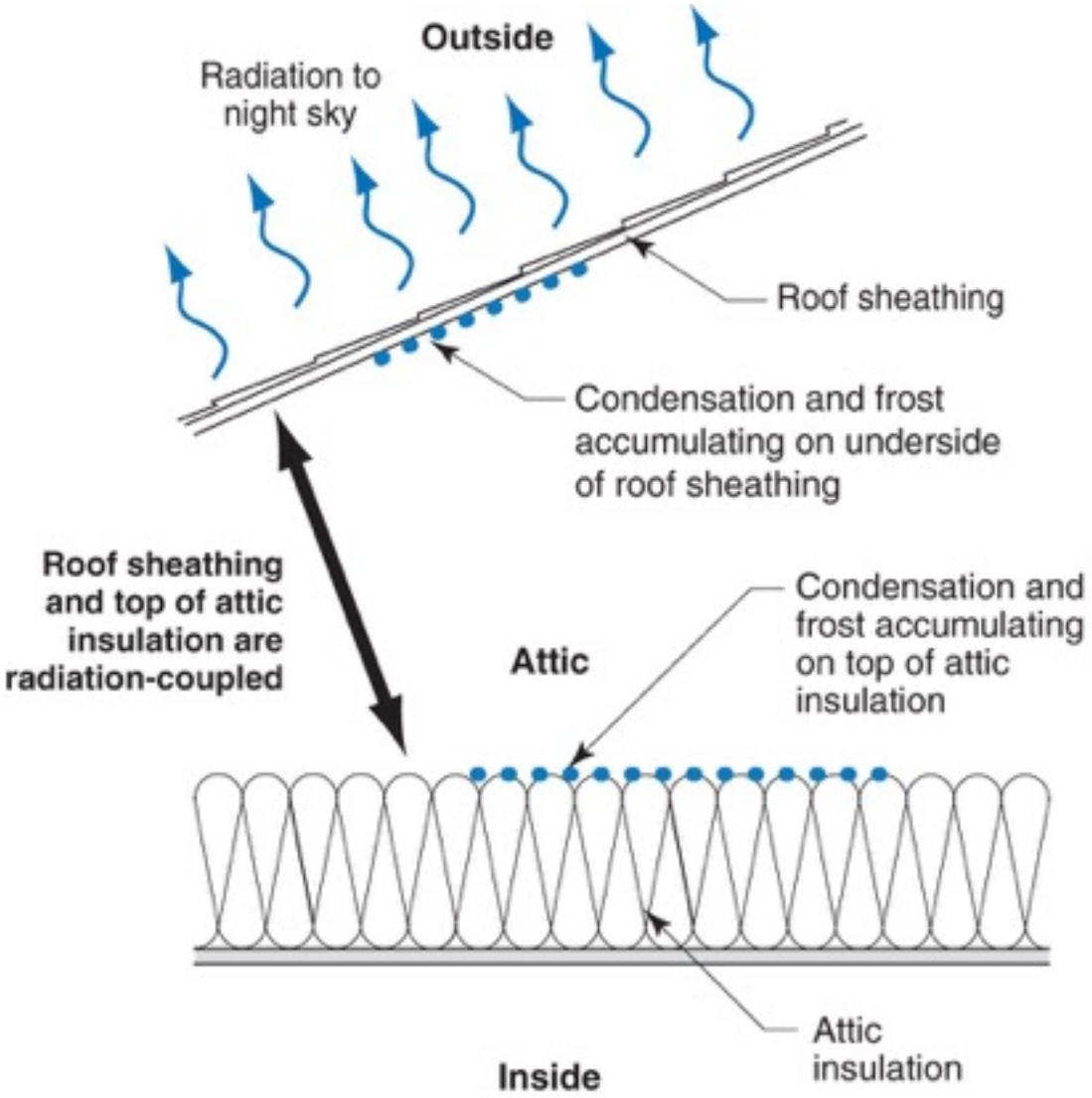


Change in the storage of moisture in a porous building material as the partial pressure of water vapor in the ambient air increases from zero to full saturation value at a given temperature.

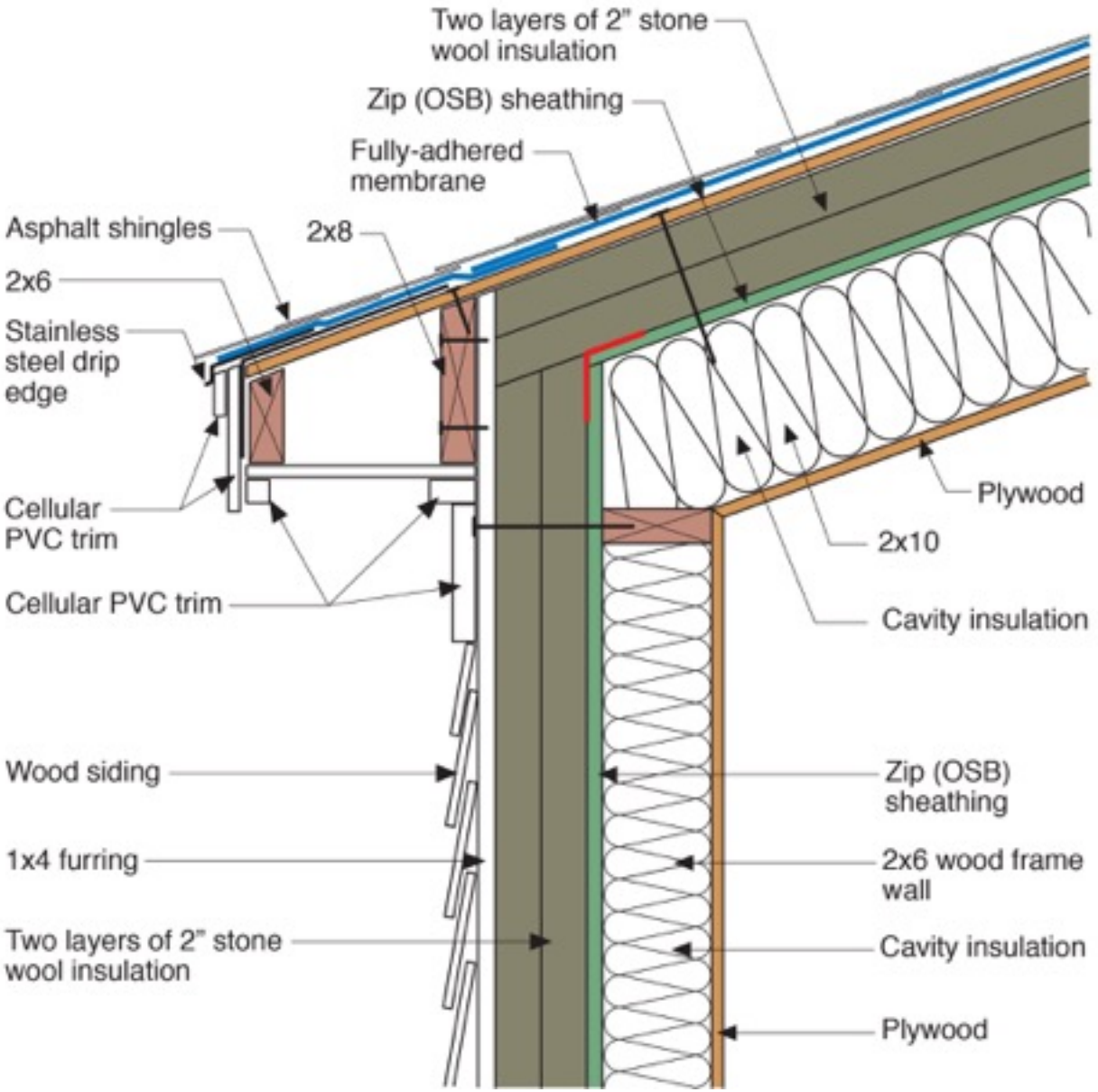
Sorption Curve

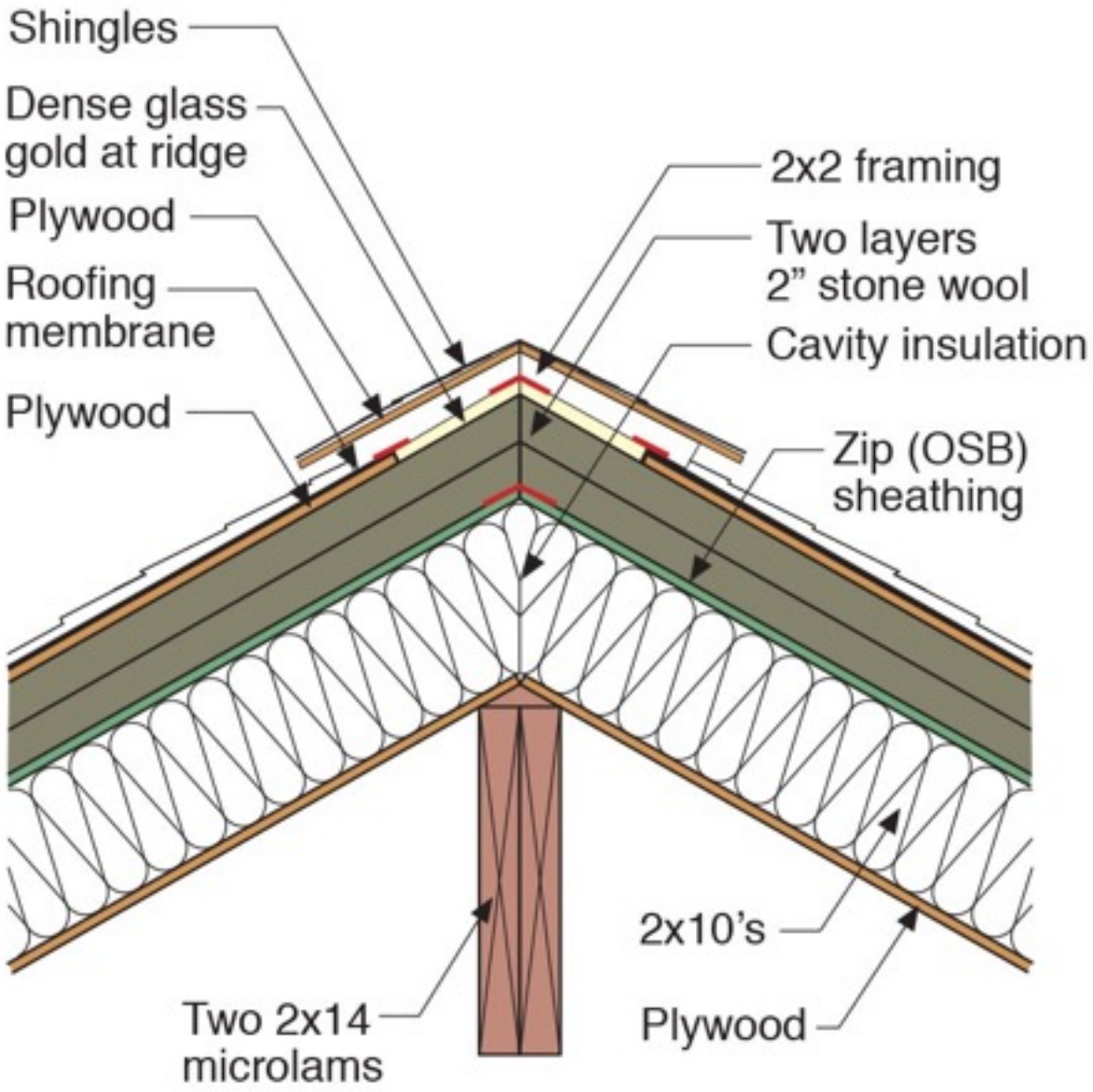
From M.K. Kumaran, ASTM MNL 18-2nd Edition, Moisture Control in Buildings, 2009

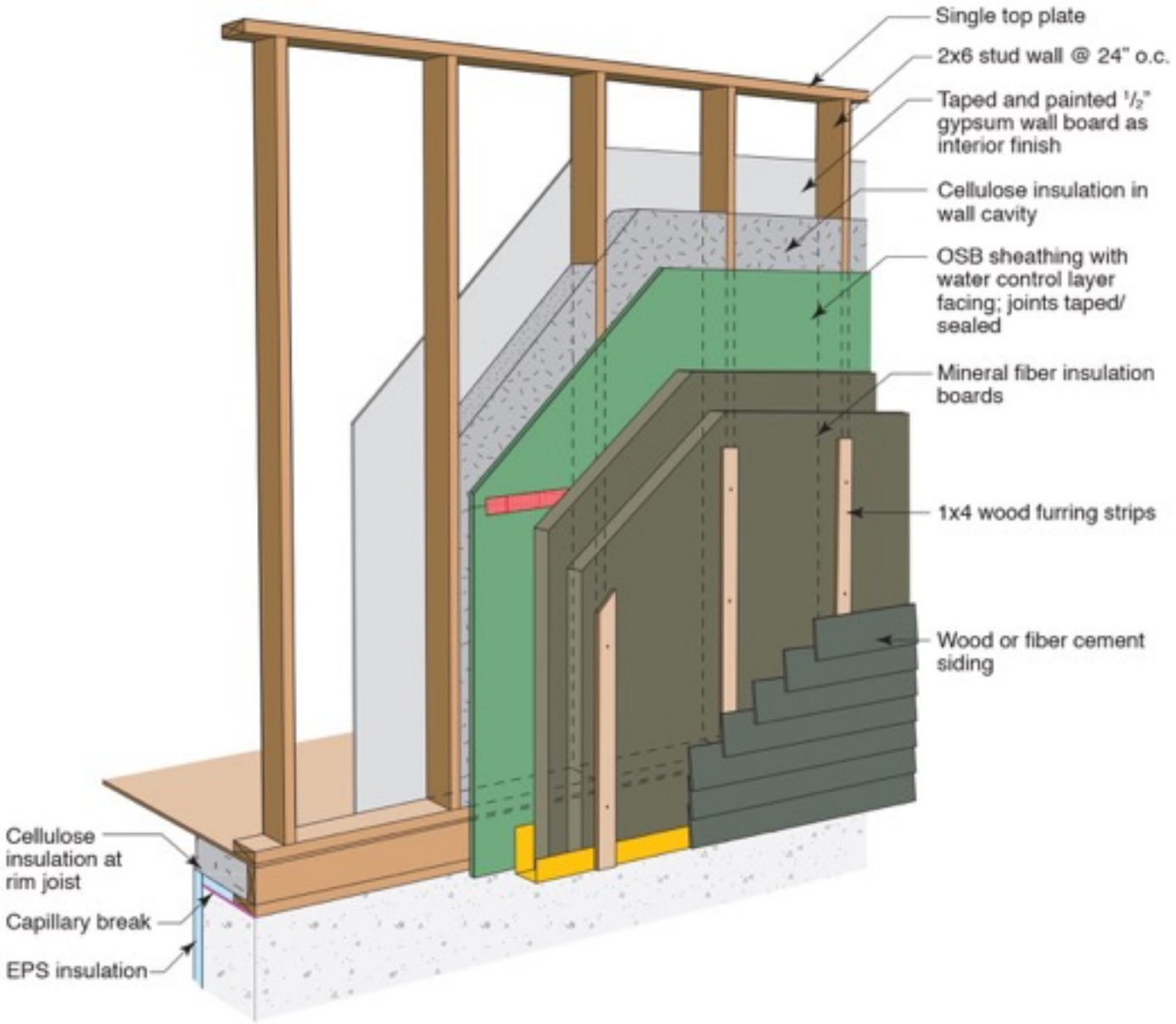

Vapor Pressure
Relative Humidity
Relative Humidity
Vapor Pressure
Night
Day
Night


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

Pushing the Envelope


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

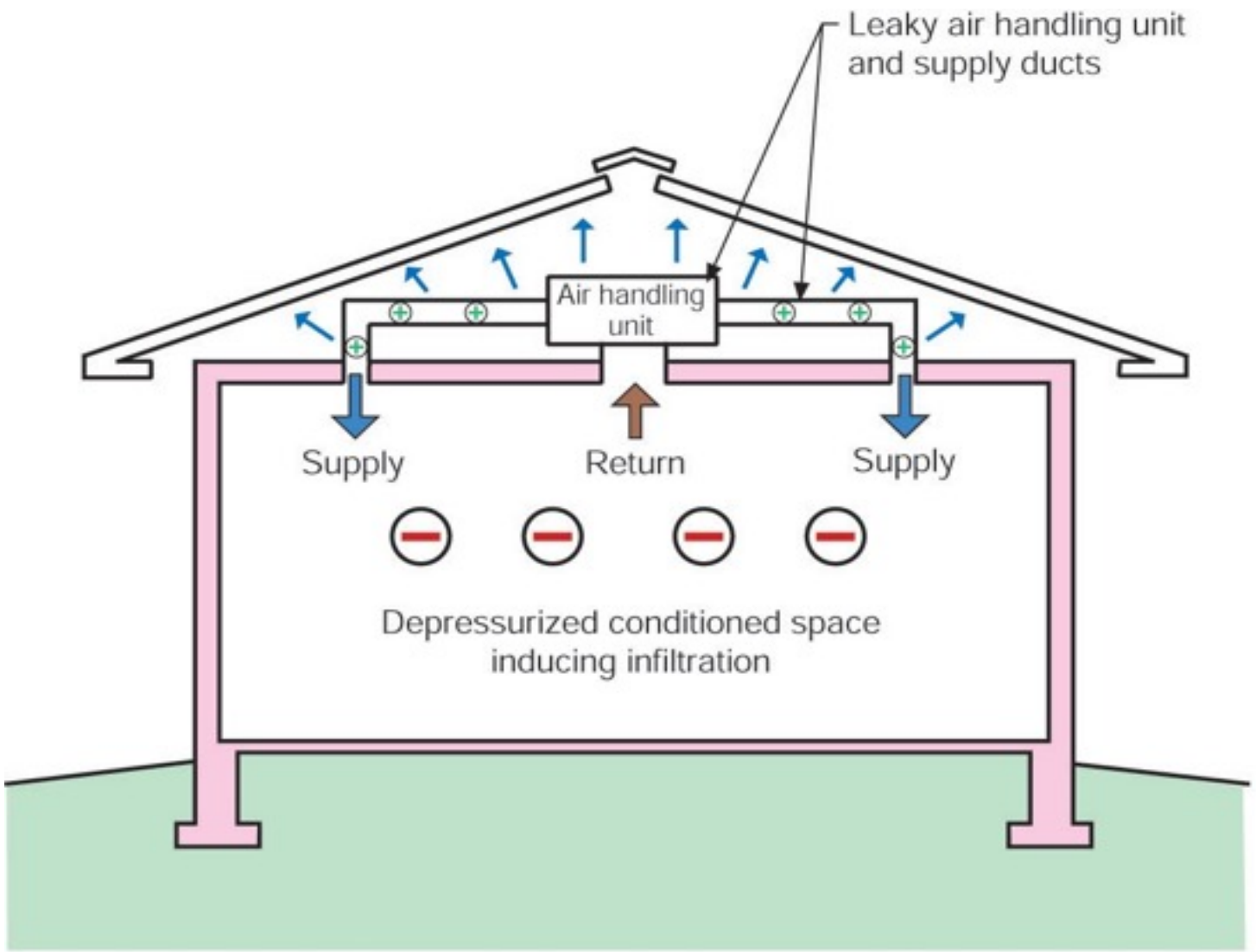

Single top plate
2x6 stud wall @ 24" o.c.
Taped and painted ½" gypsum wall board as interior finish
Cellulose insulation in wall cavity
OSB sheathing with water control layer facing; joints taped/ sealed
Mineral fiber insulation boards
1x4 wood furring strips
Wood or fiber cement siding
Cellulose insulation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


ZIP system

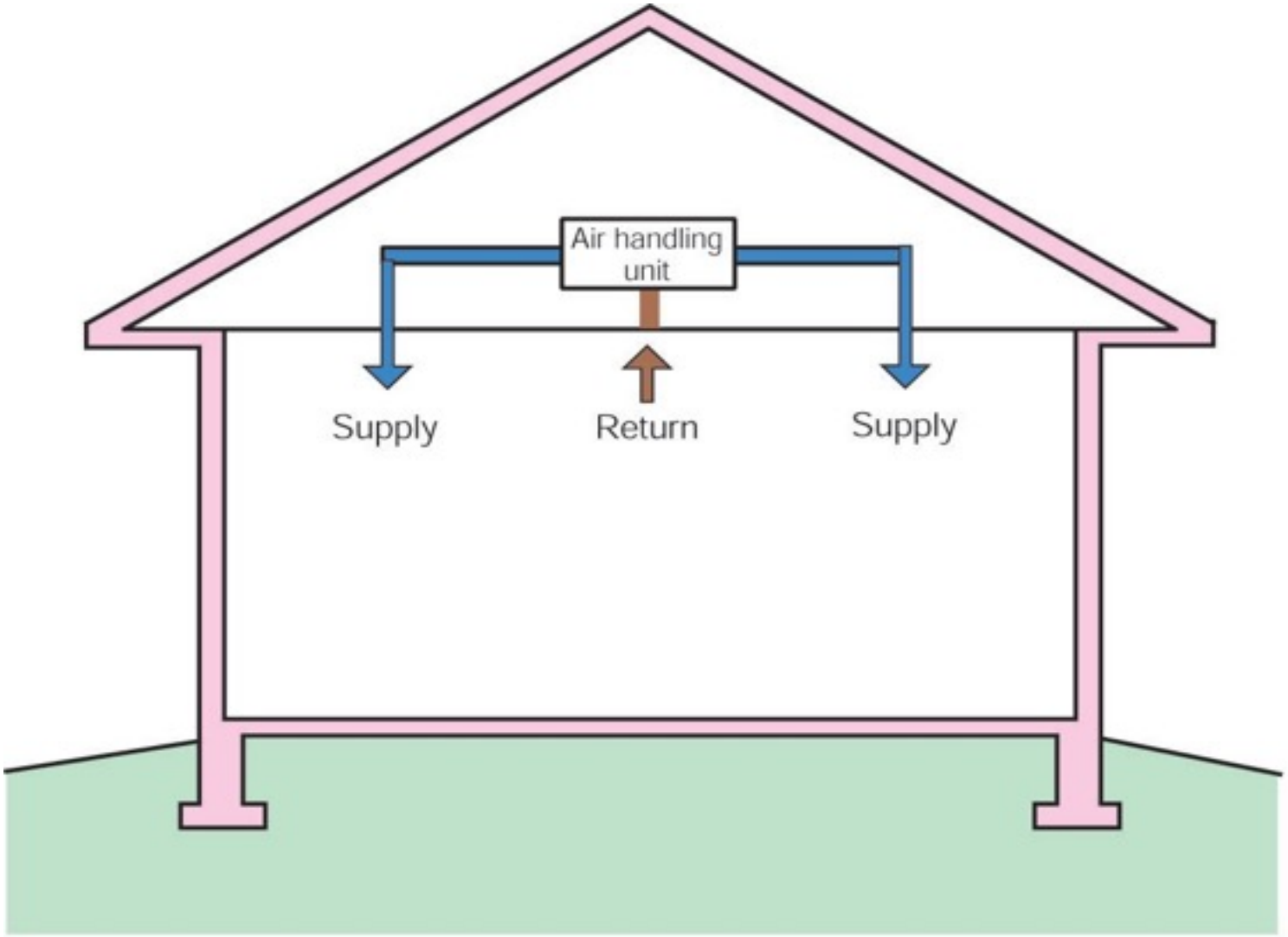

GRACE
Ice & Water Shield®
Ice & Water Shield®
Ice & Water Shield®

Where It Started…..


GUEST

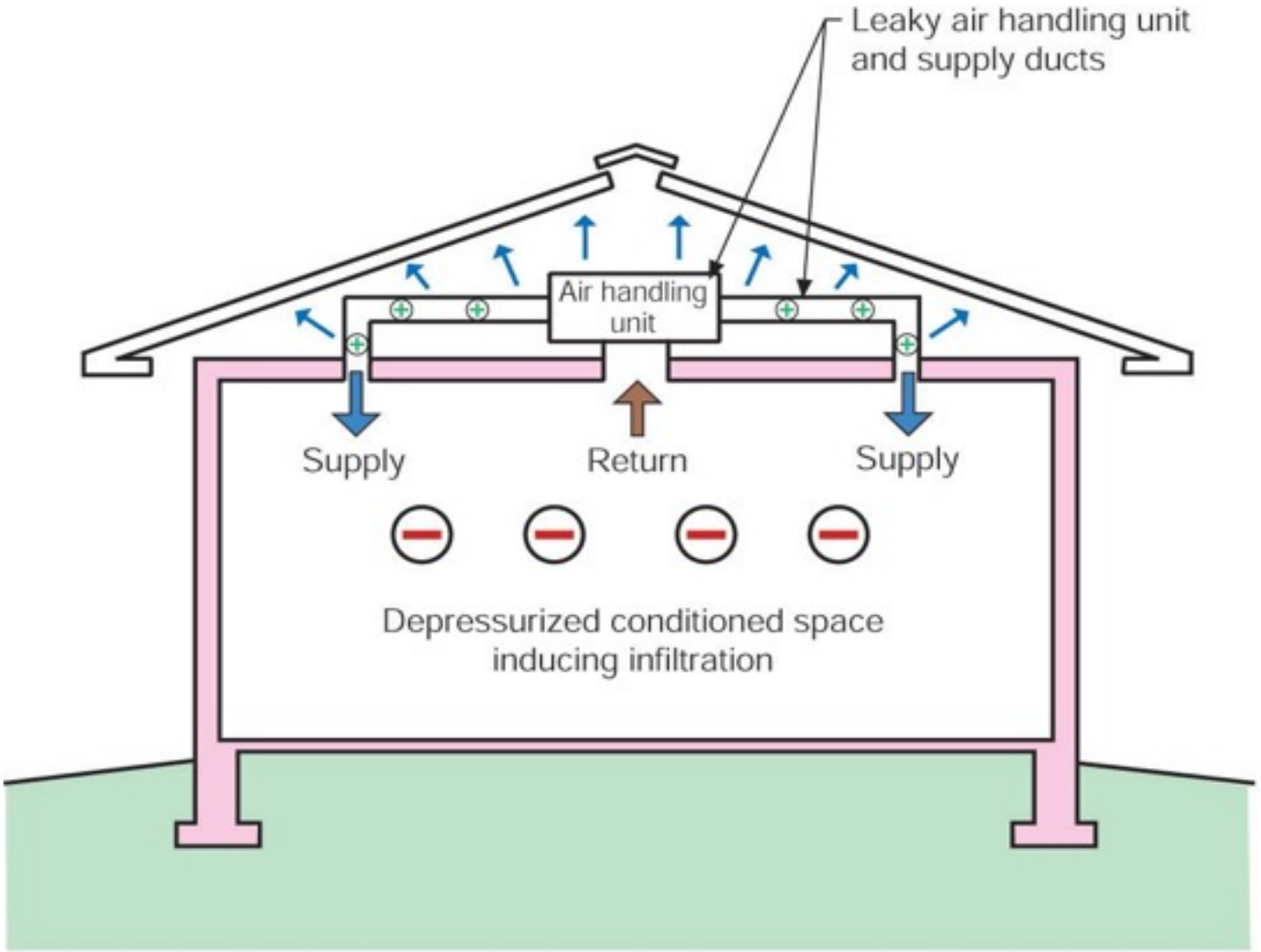


Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.



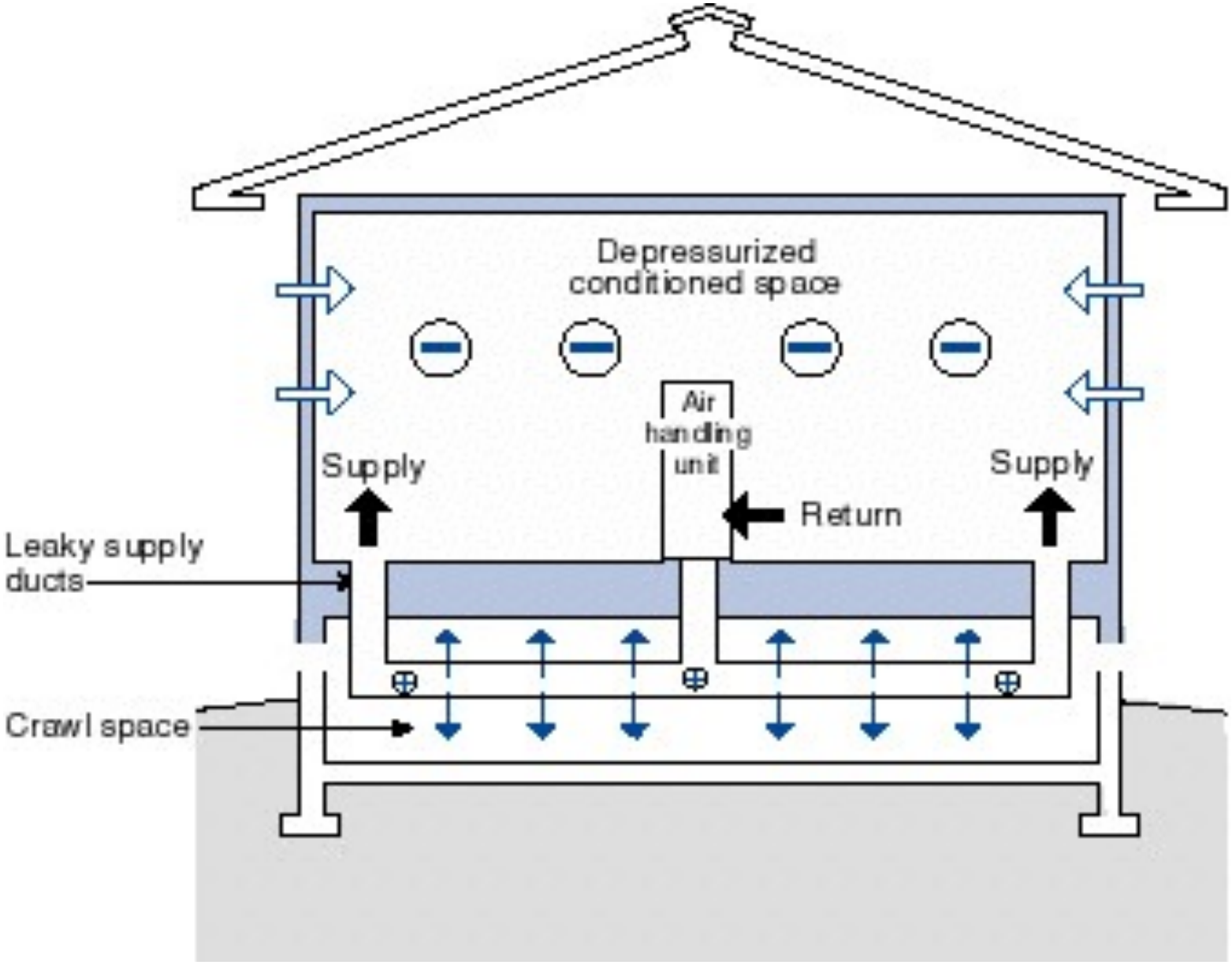
Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

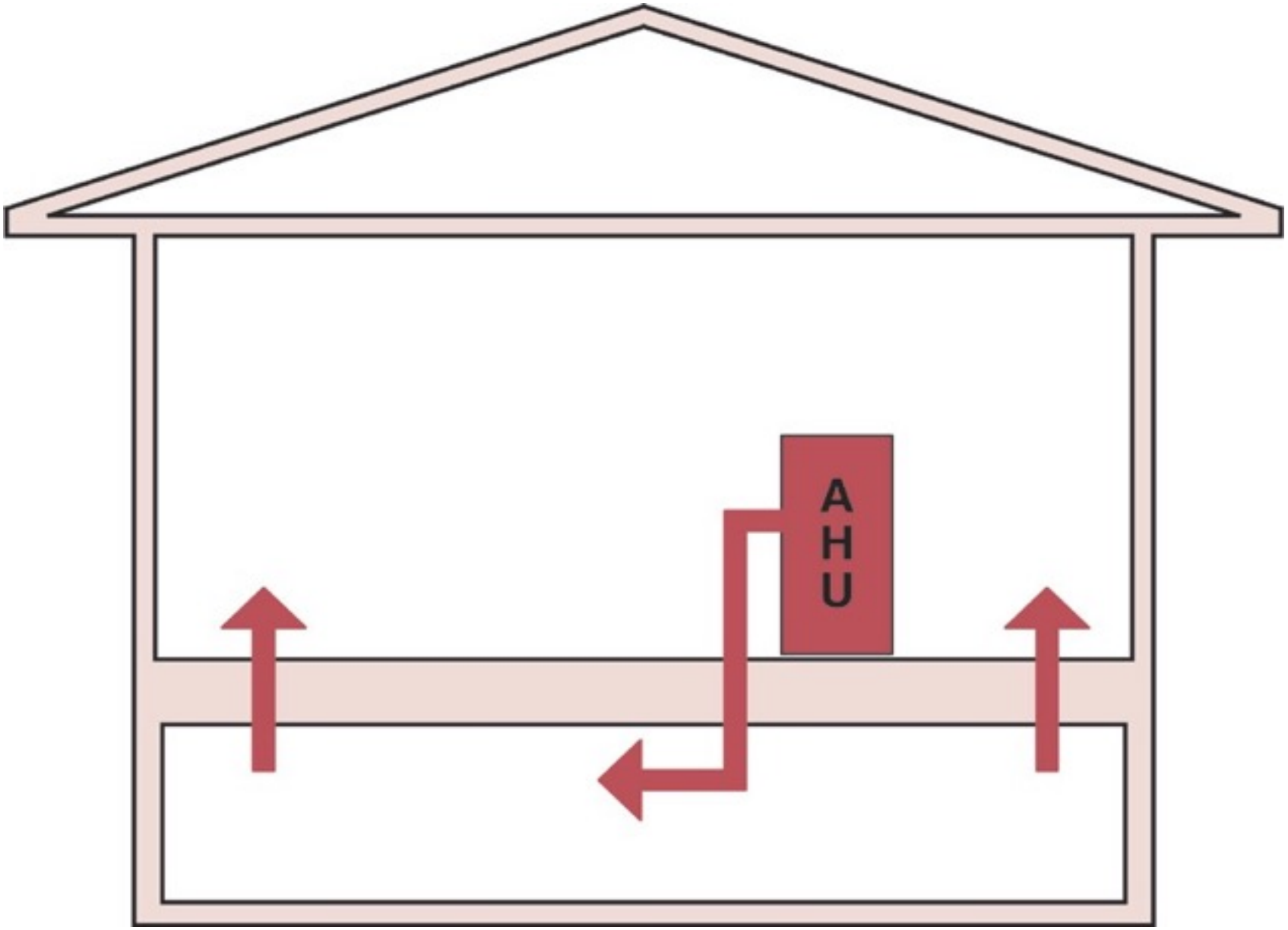
Crawl Spaces

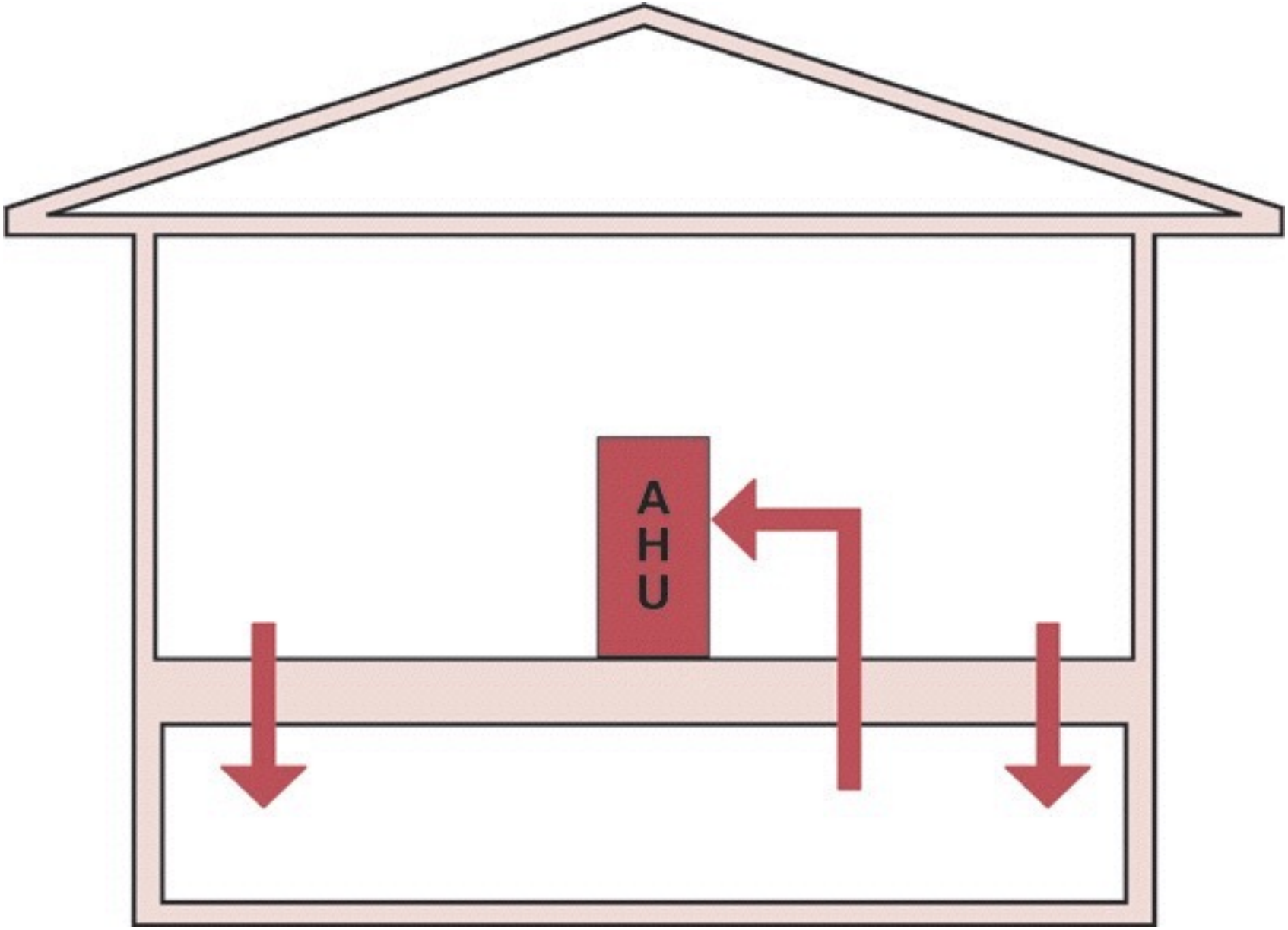


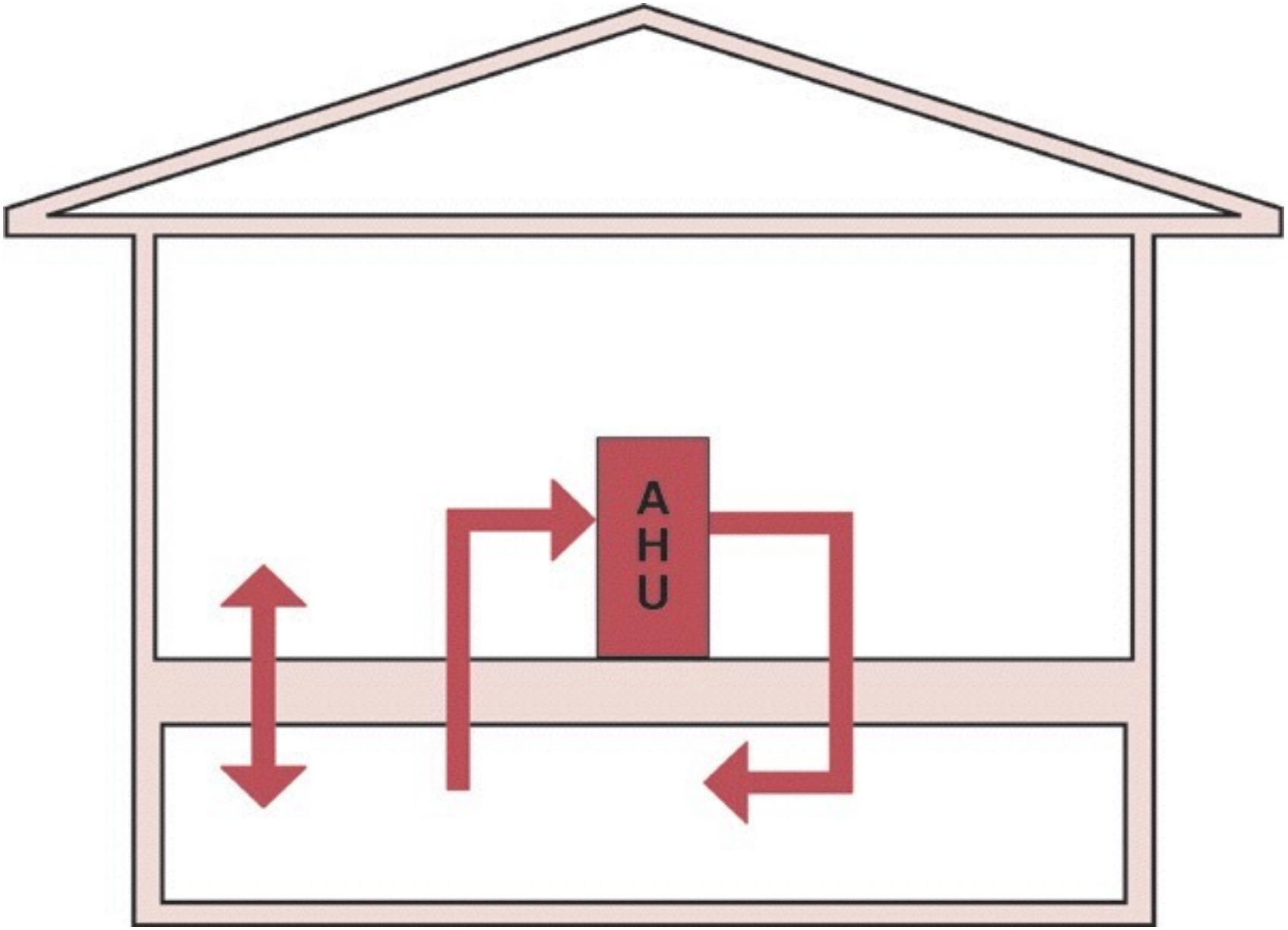
Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

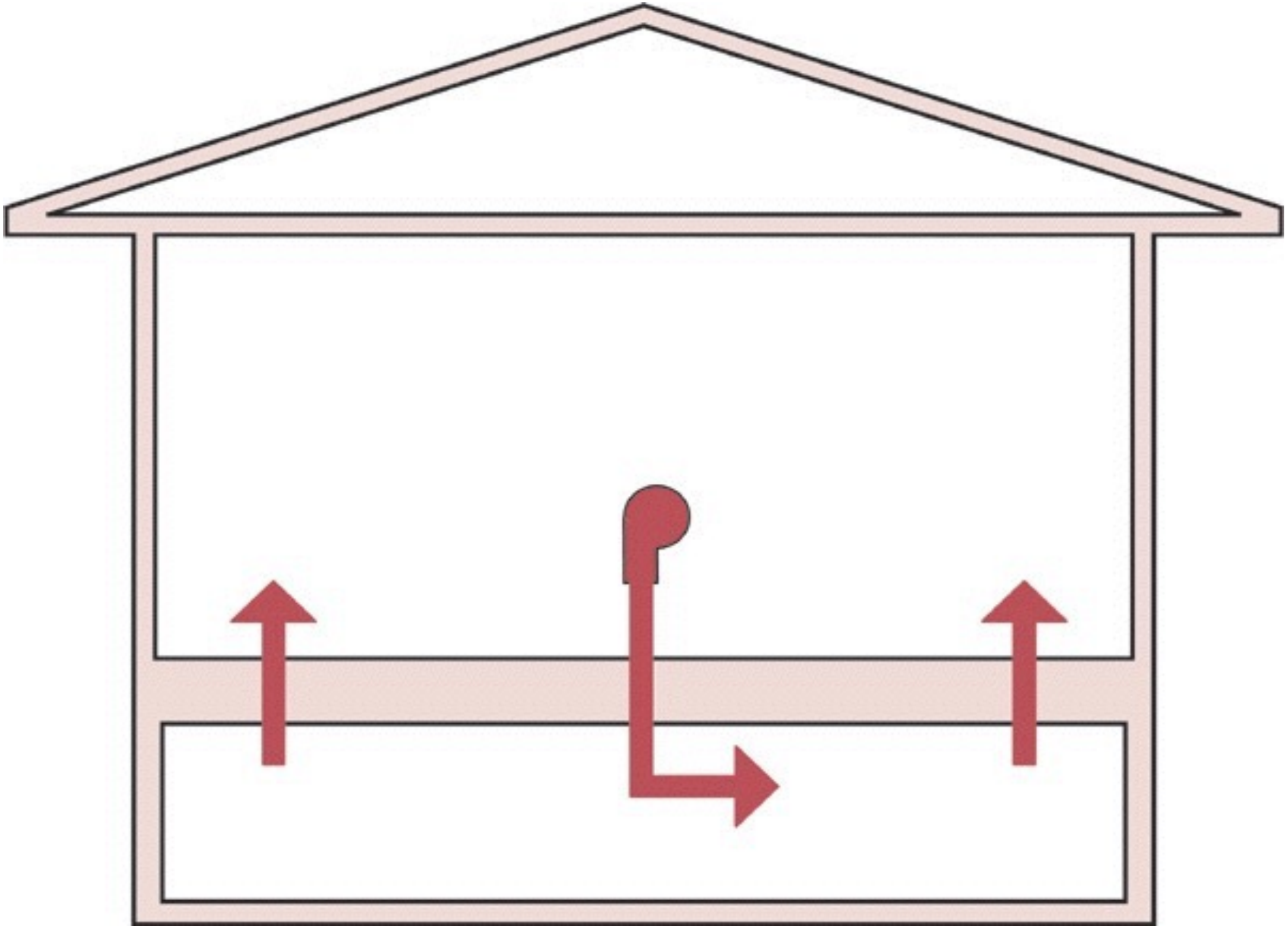
Depressurized conditioned space
inducing infiltration
Supply
Return
Supply
Air handling
unit
Leaky air handling unit
and supply ducts

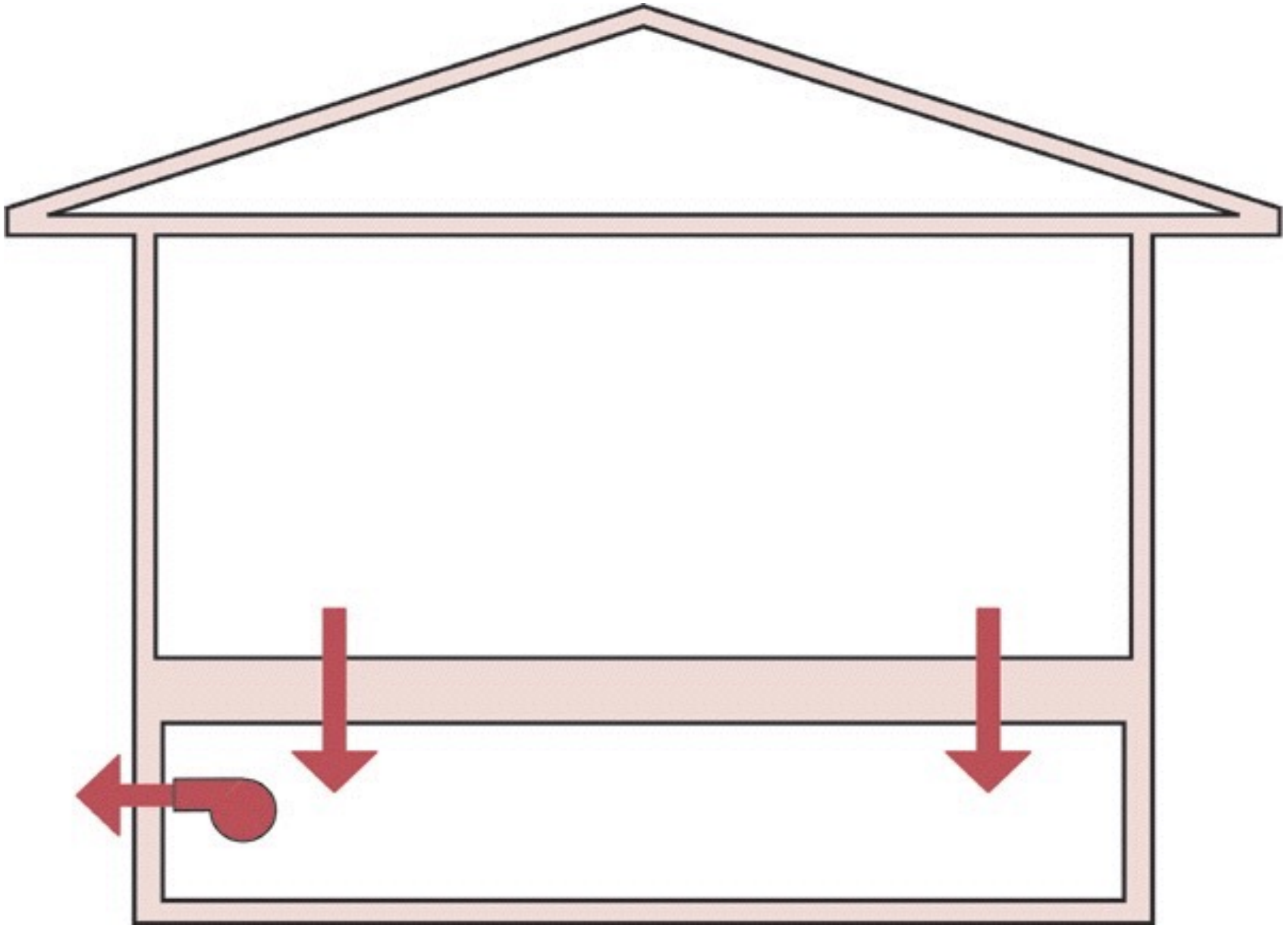

Depressurized
conditioned space
Air
handling
unit
Supply
Supply
Return
Leaky supply
ducts
Crawl space

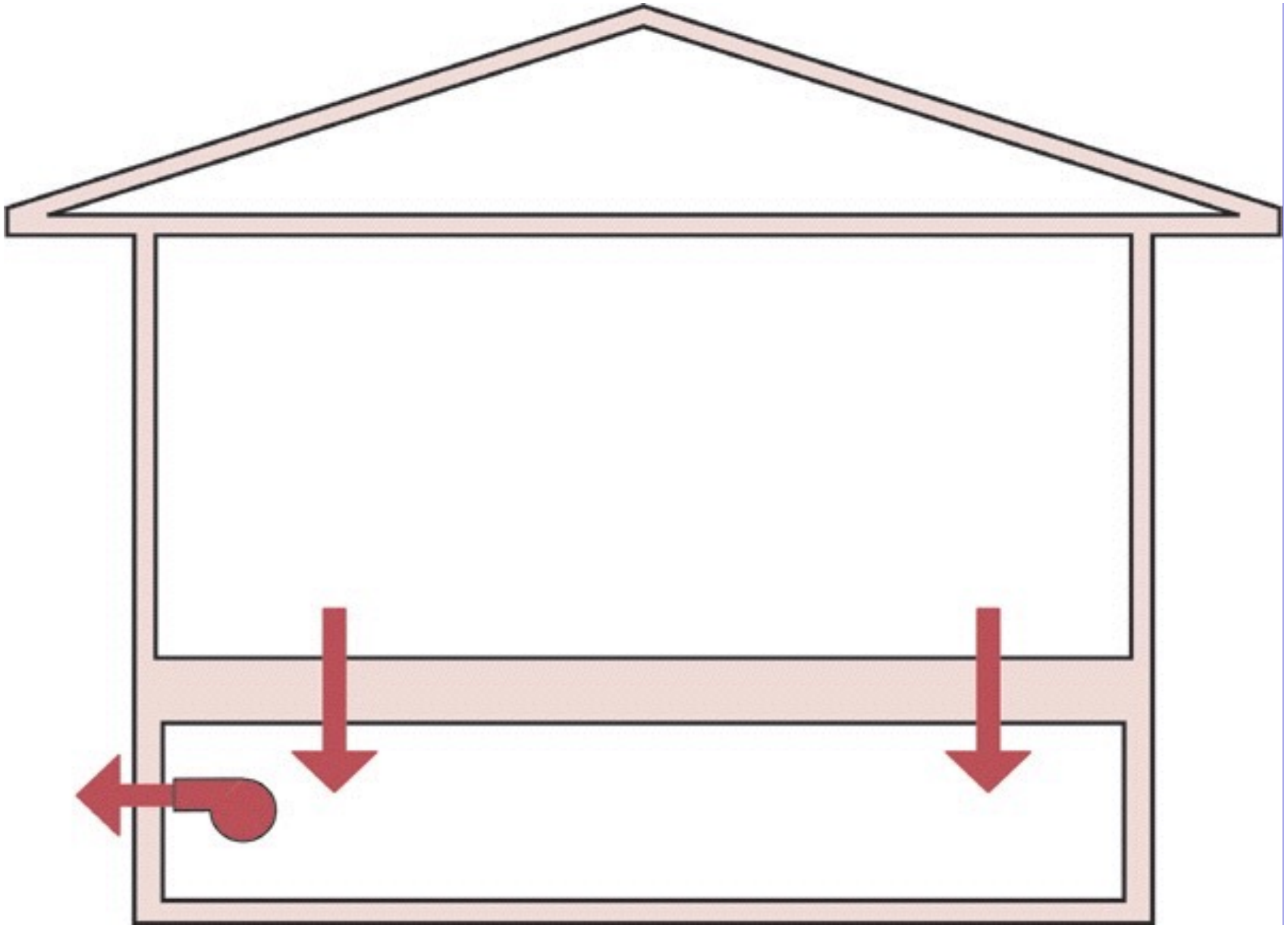

AHU

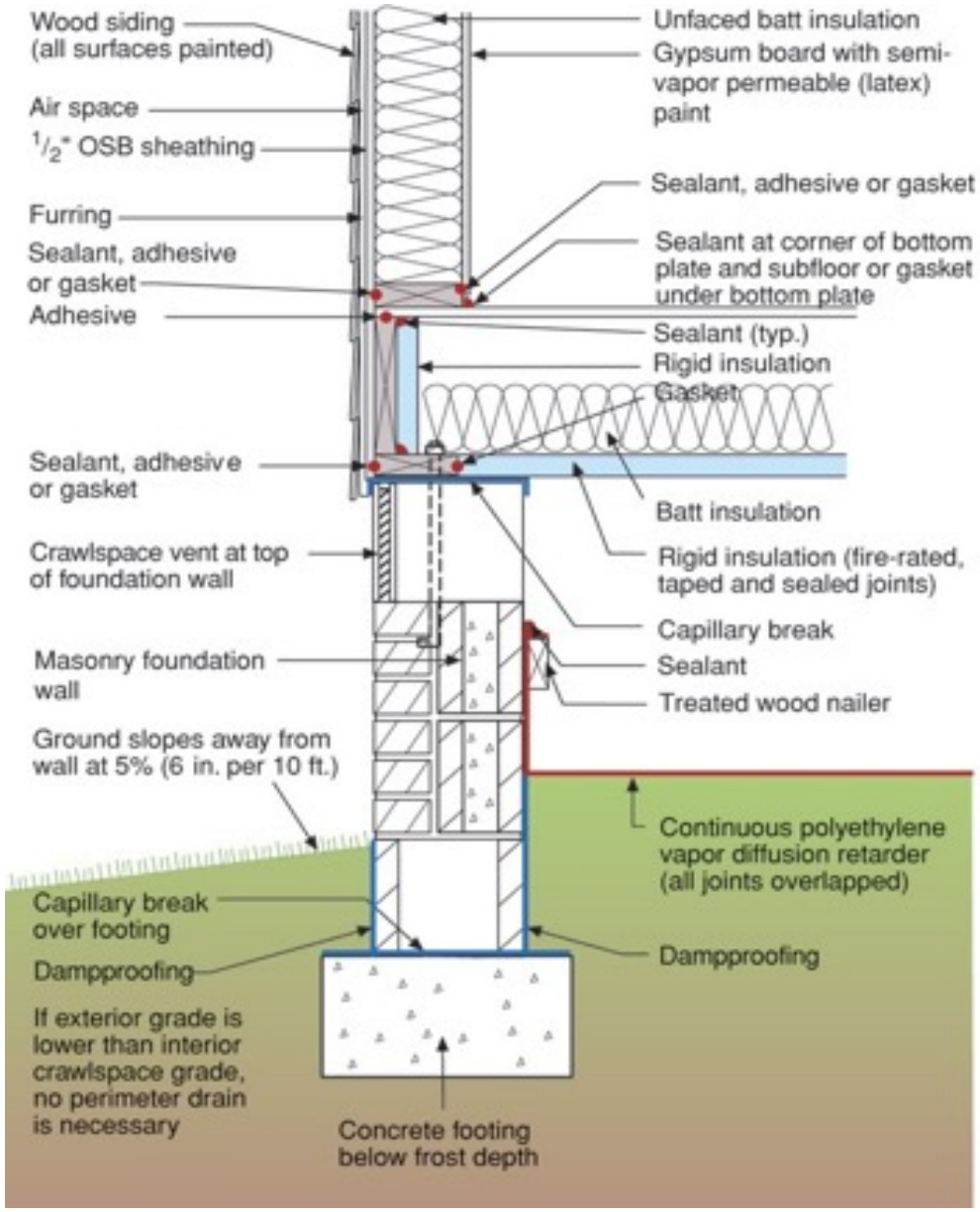

AHU

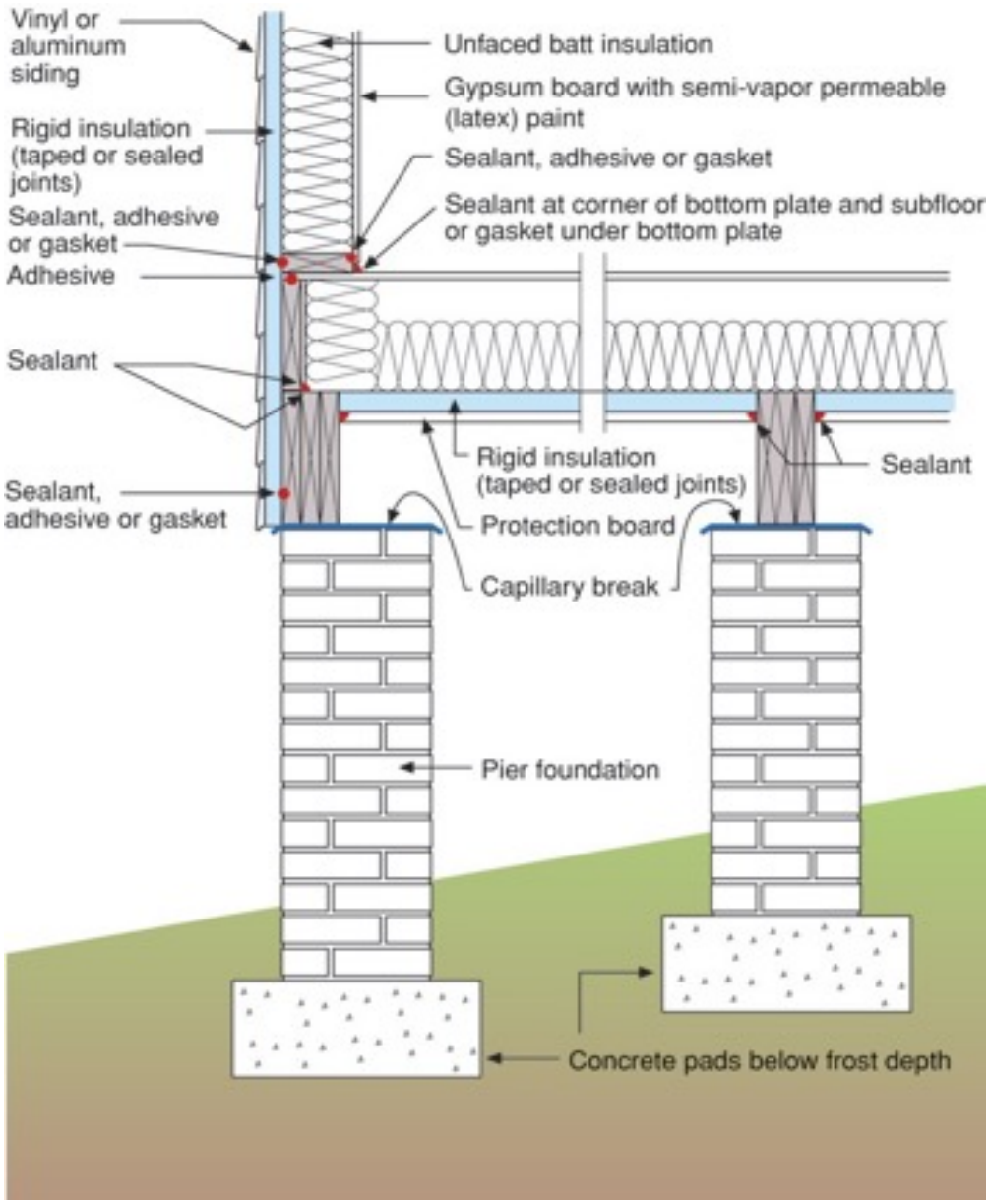

AHU

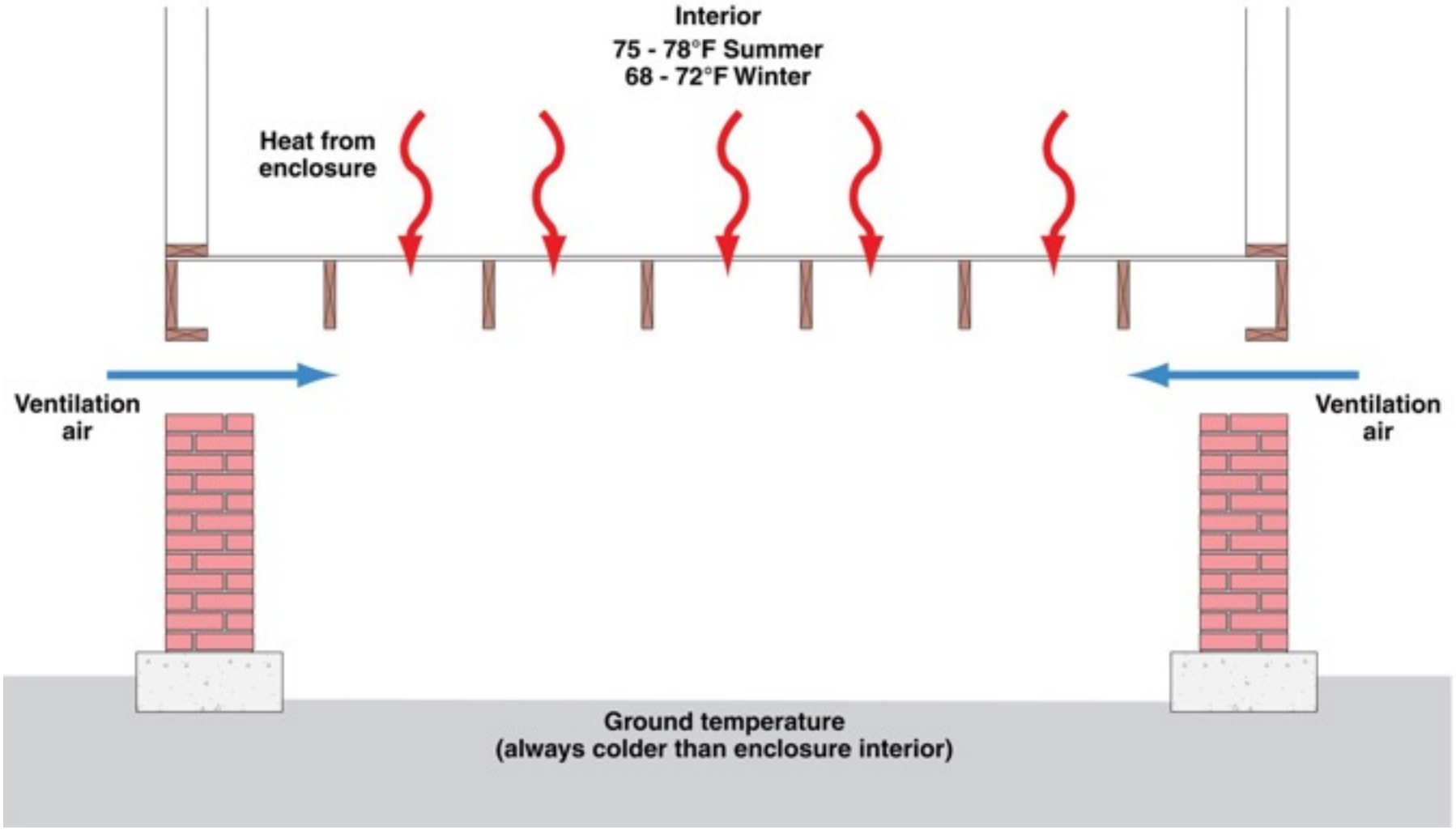


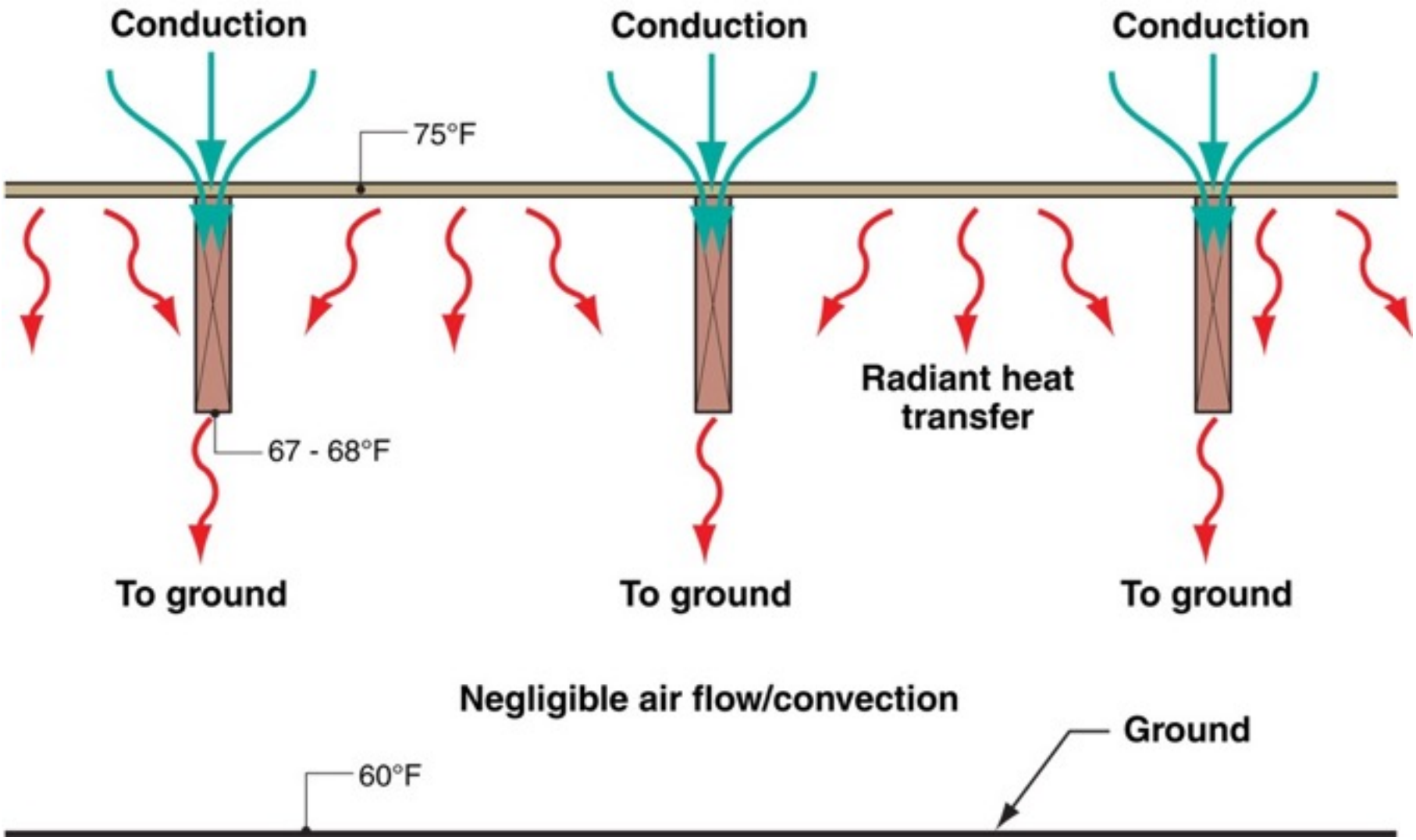


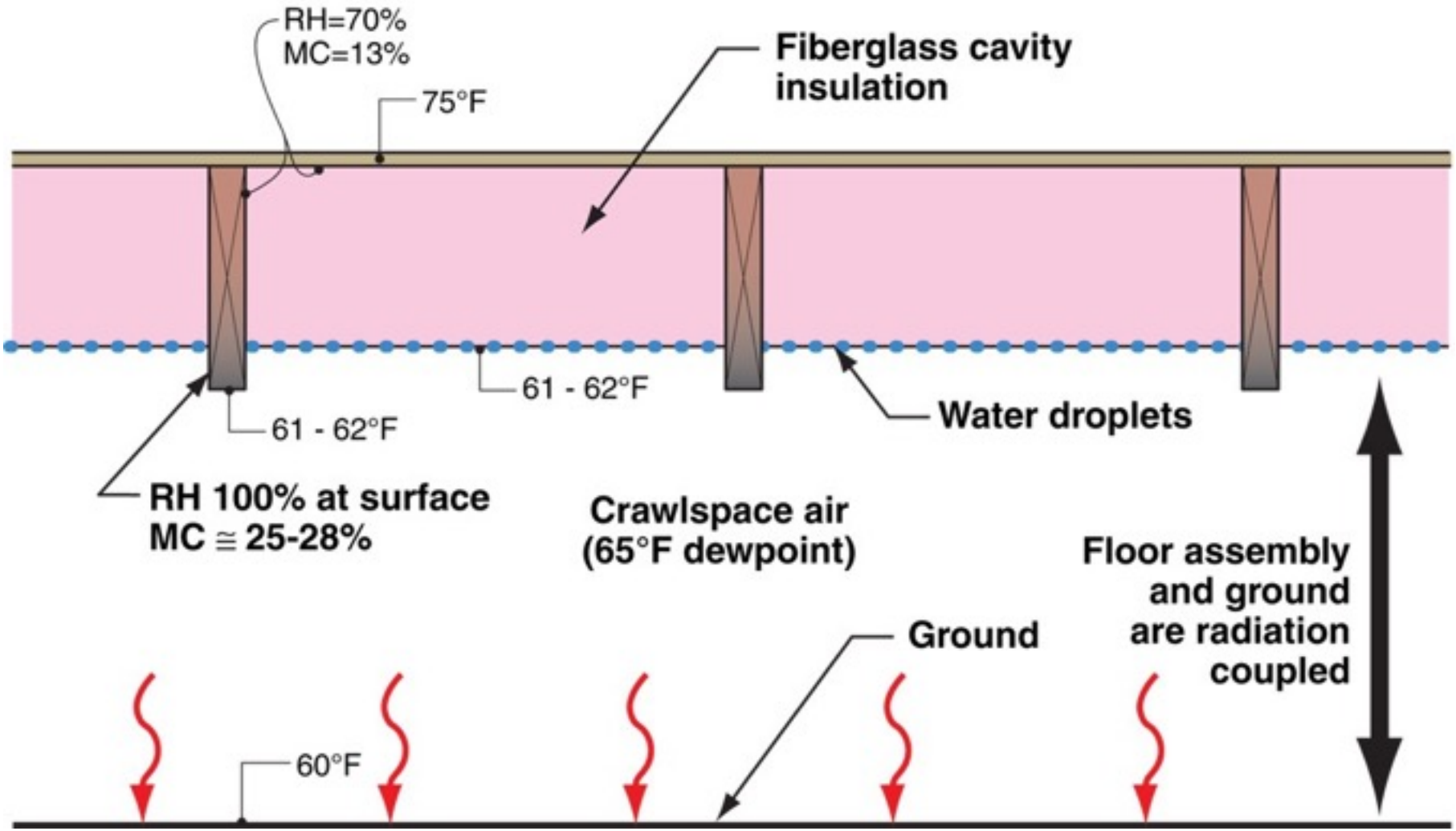


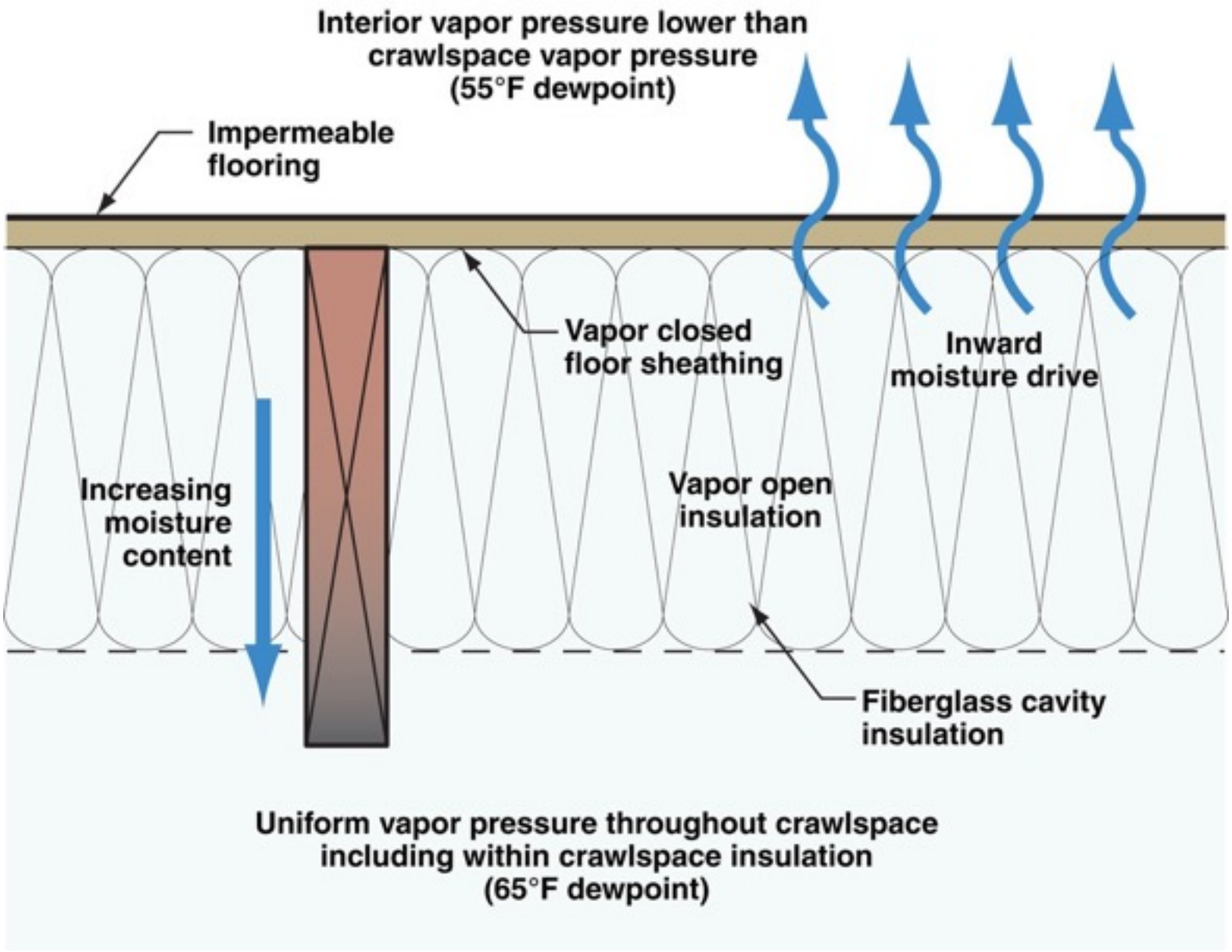

Wood siding
(all surfaces painted)
Air space
1/2" OSB sheathing
Furring
Sealant, adhesive
or gasket
Adhesive
Sealant, adhesive
or gasket
Crawlspace vent at top
of foundation wall
Masonry foundation
wall
Ground slopes away from
wall at 5% (6 in. per 10 ft.)
Capillary break
over footing
Dampproofing
If 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


Interior
75 - 78°F Summer
68 - 72°F Winter
Heat from enclosure
Ventilation air
Ventilation air
Ground temperature
(always colder than enclosure interior)


Conduction
Conduction
Conduction
75°F
Radiant heat transfer
67 - 68°F
To ground
To ground
To ground
Negligible air flow/convection
Ground
60°F


RH=70%
MC=13%
75°F
Fiberglass cavity insulation
61 - 62°F
61 - 62°F
Water droplets
RH 100% at surface
MC ≅ 25-28%
Crawlspace air
(65°F dewpoint)
Floor assembly and ground are radiation coupled
Ground
60°F


Interior vapor pressure lower than
crawlspace vapor pressure
(55°F dewpoint)
Impermeable
flooring
Vapor closed
floor sheathing
Inward
moisture drive
Increasing
moisture
content
Vapor open
insulation
Fiberglass cavity
insulation
Uniform vapor pressure throughout crawlspace
including within crawlspace insulation
(65°F dewpoint)