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

Building Science

Adventures In Building Science

www.buildingscience.com

Arrhenius Equation

For Every 10 Degree K Rise

Activation Energy Doubles

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

Damage Functions

Water

Heat

Ultra-violet Radiation

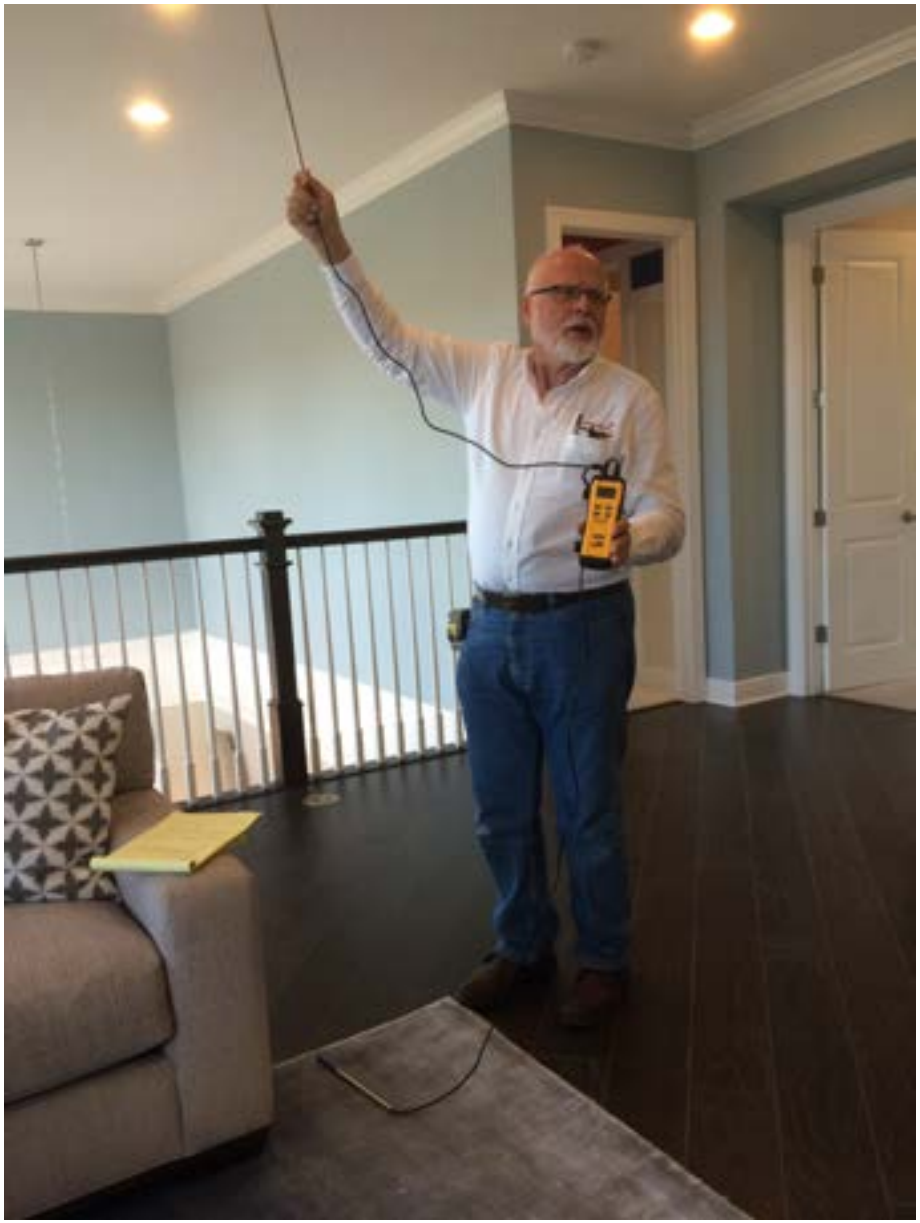
Hygric Buoyancy

Components in Dry Air	Volume Ratio compared to Dry Air	Molecular Mass - *M* *(kg/kmol)*	Molecular Mass in Air
Oxygen	0.2095	32.00	6.704
Nitrogen	0.7809	28.02	21.88
Carbon Dioxide	0.0003	44.01	0.013
Hydrogen	0.0000005	2.02	0
Argon	0.00933	39.94	0.373
Neon	0.000018	20.18	0
Helium	0.000005	4.00	0
Krypton	0.000001	83.8	0
Xenon	$0.09\ 10^{-6}$	131.29	0
Total Molecular Mass of Air			28.97

Components in Dry Air	Volume Ratio compared to Dry Air	Molecular Mass - *M* *(kg/kmol)*	Molecular Mass in Air
Oxygen	0.2095	32.00	6.704
Nitrogen	0.7809	28.02	21.88
Carbon Dioxide	0.0003	44.01	0.013
Hydrogen	0.0000005	2.02	0
Argon	0.00933	39.94	0.373
Neon	0.000018	20.18	0
Helium	0.000005	4.00	0
Krypton	0.000001	83.8	0
Xenon	$0.09\ 10^{-6}$	131.29	0
Total Molecular Mass of Air			28.97

Note Water Vapor (H_2O) is 18

Dry Air is 29




Dual In-Duct
Psychrometer
Fieldpiece

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

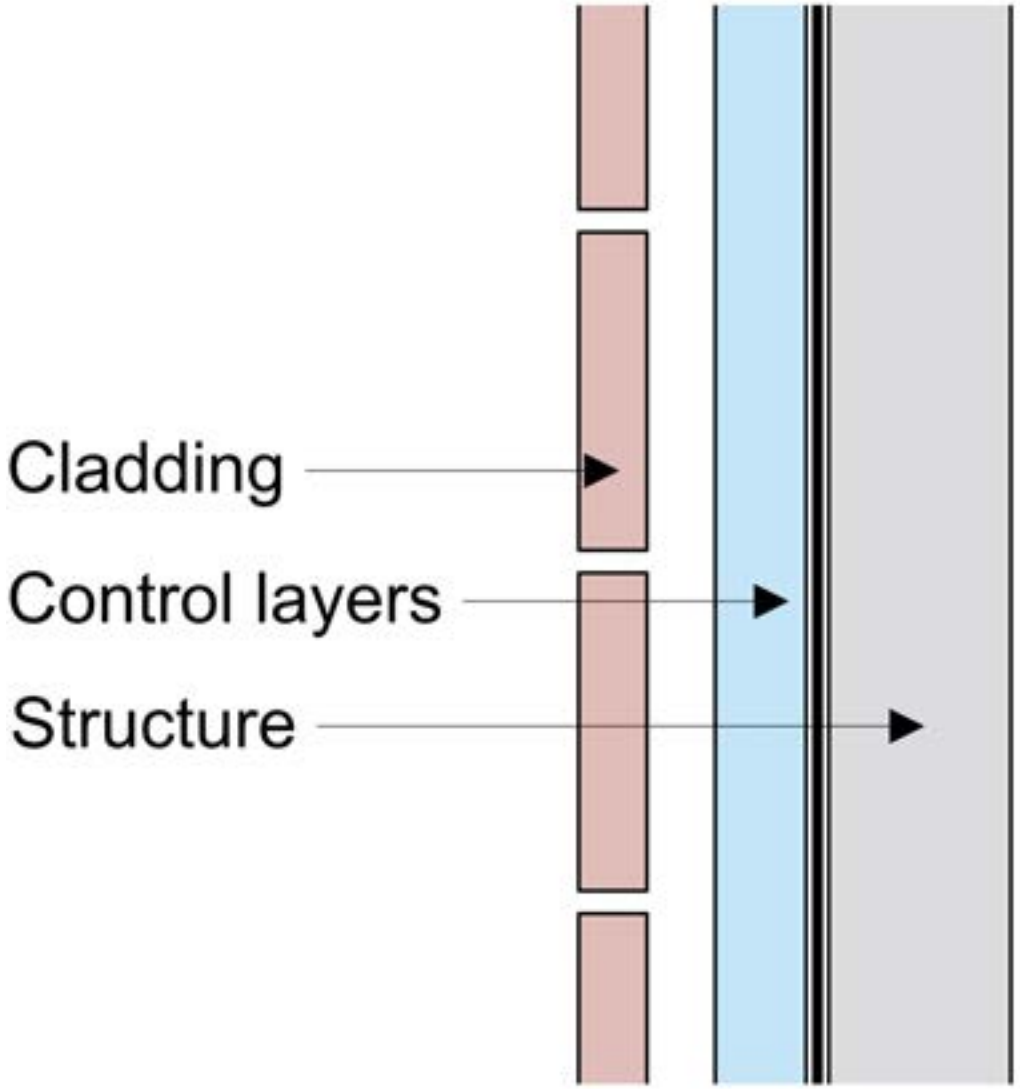
Gravity Acts Down

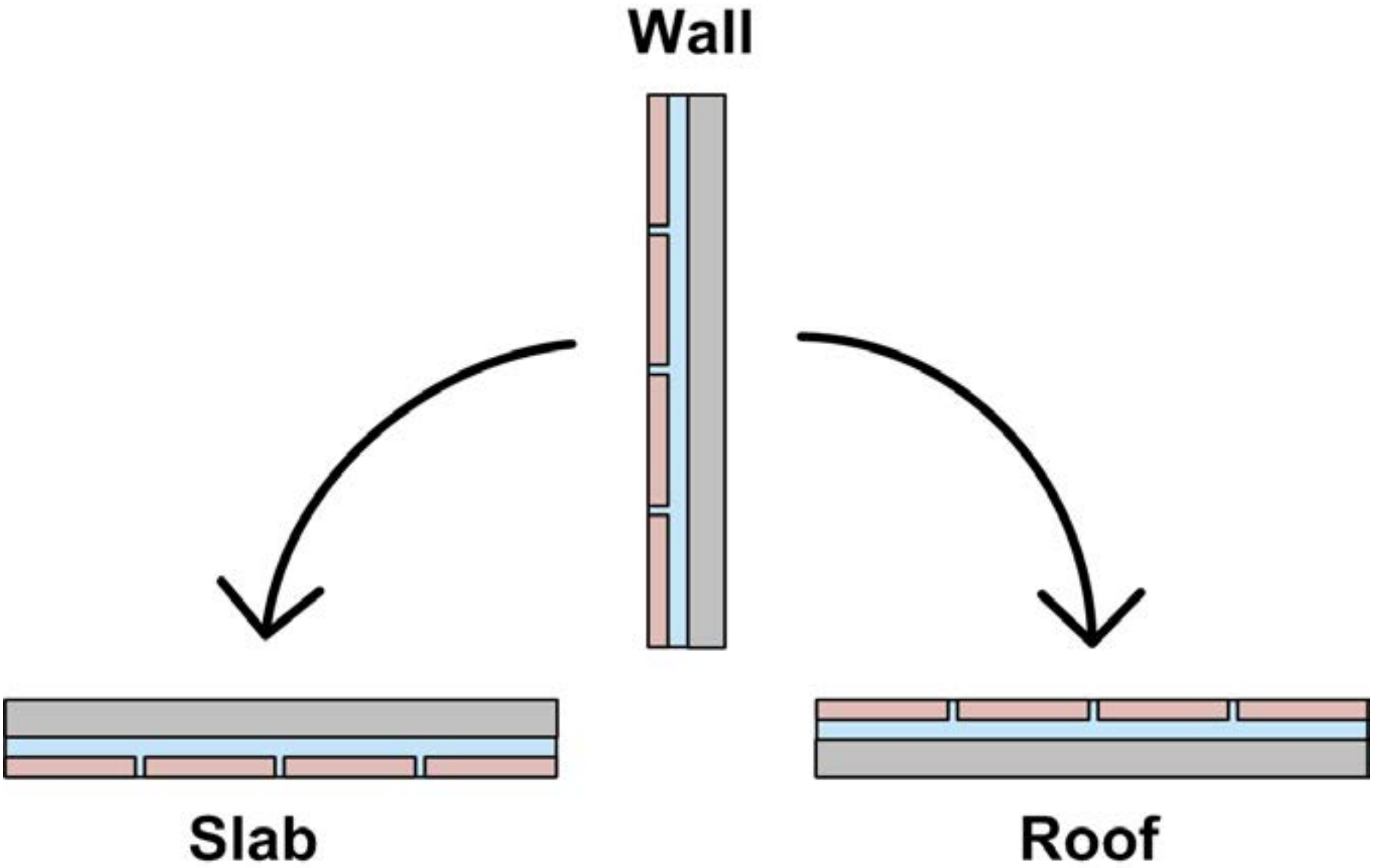
Water Control Layer

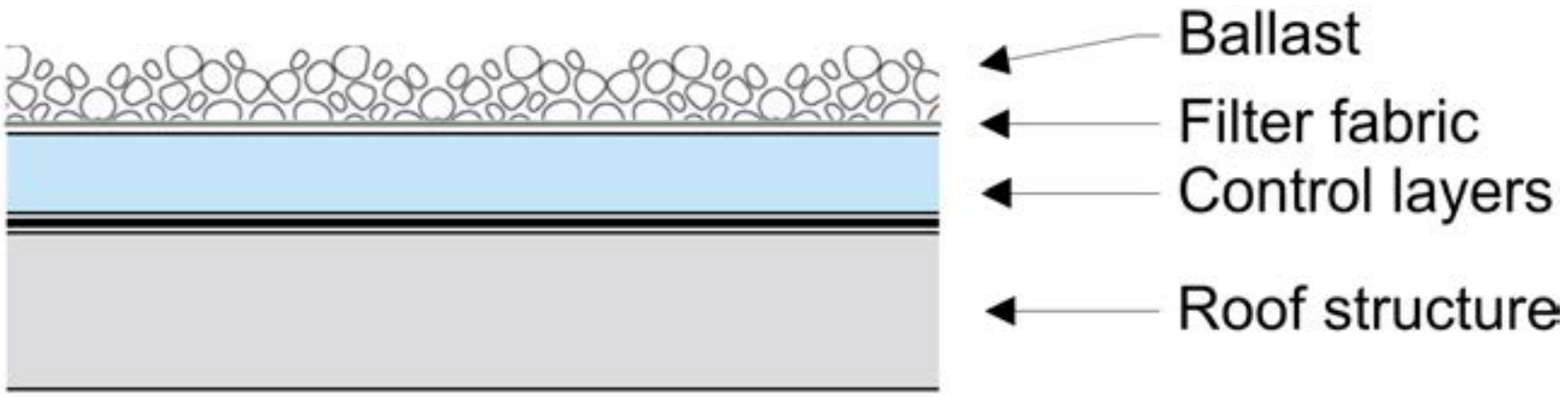
Air Control Layer

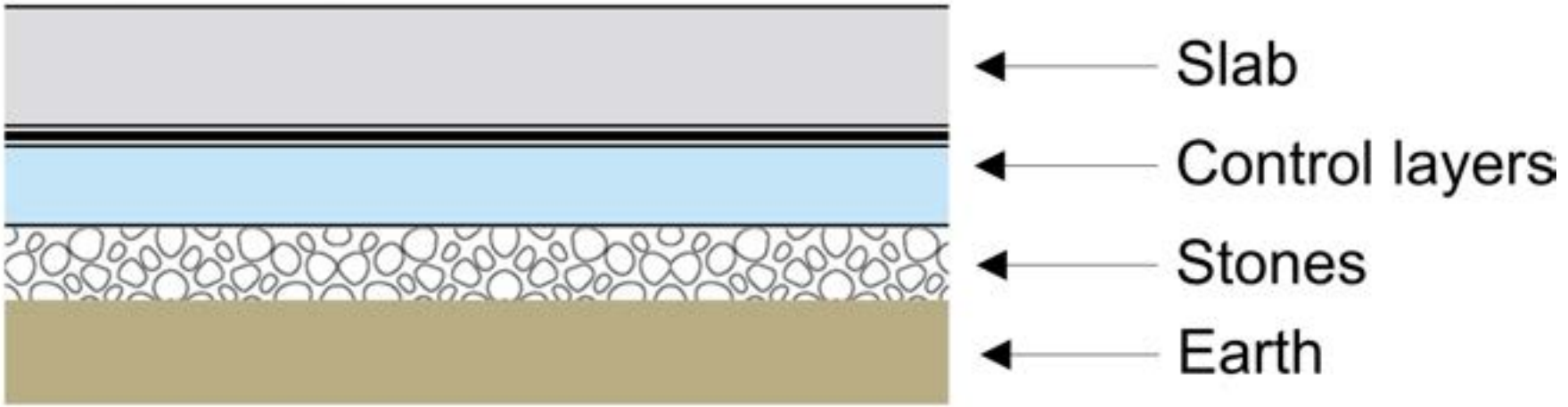
Vapor Control Layer

Thermal Control Layer

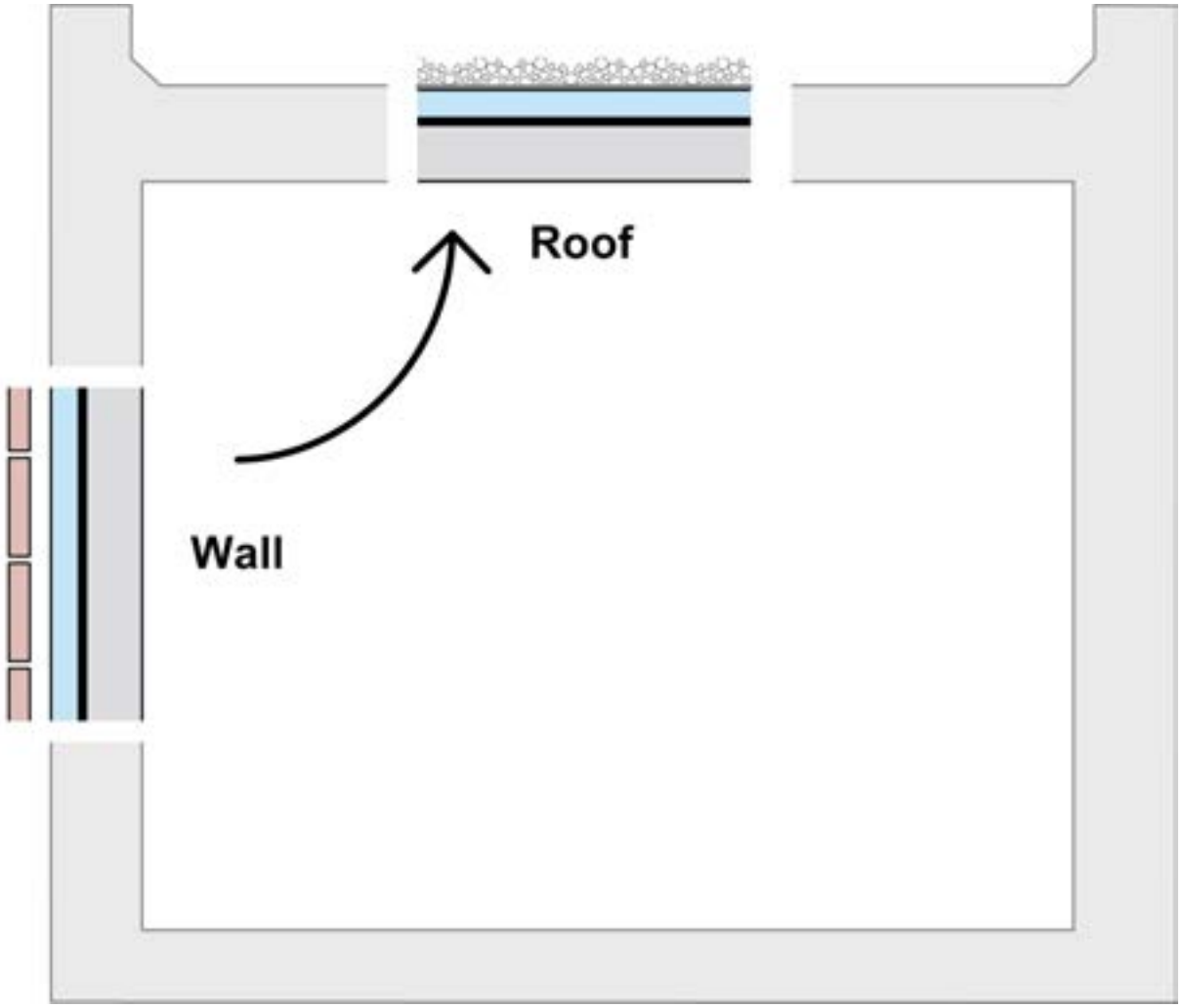

Cladding
Control layers
Structure

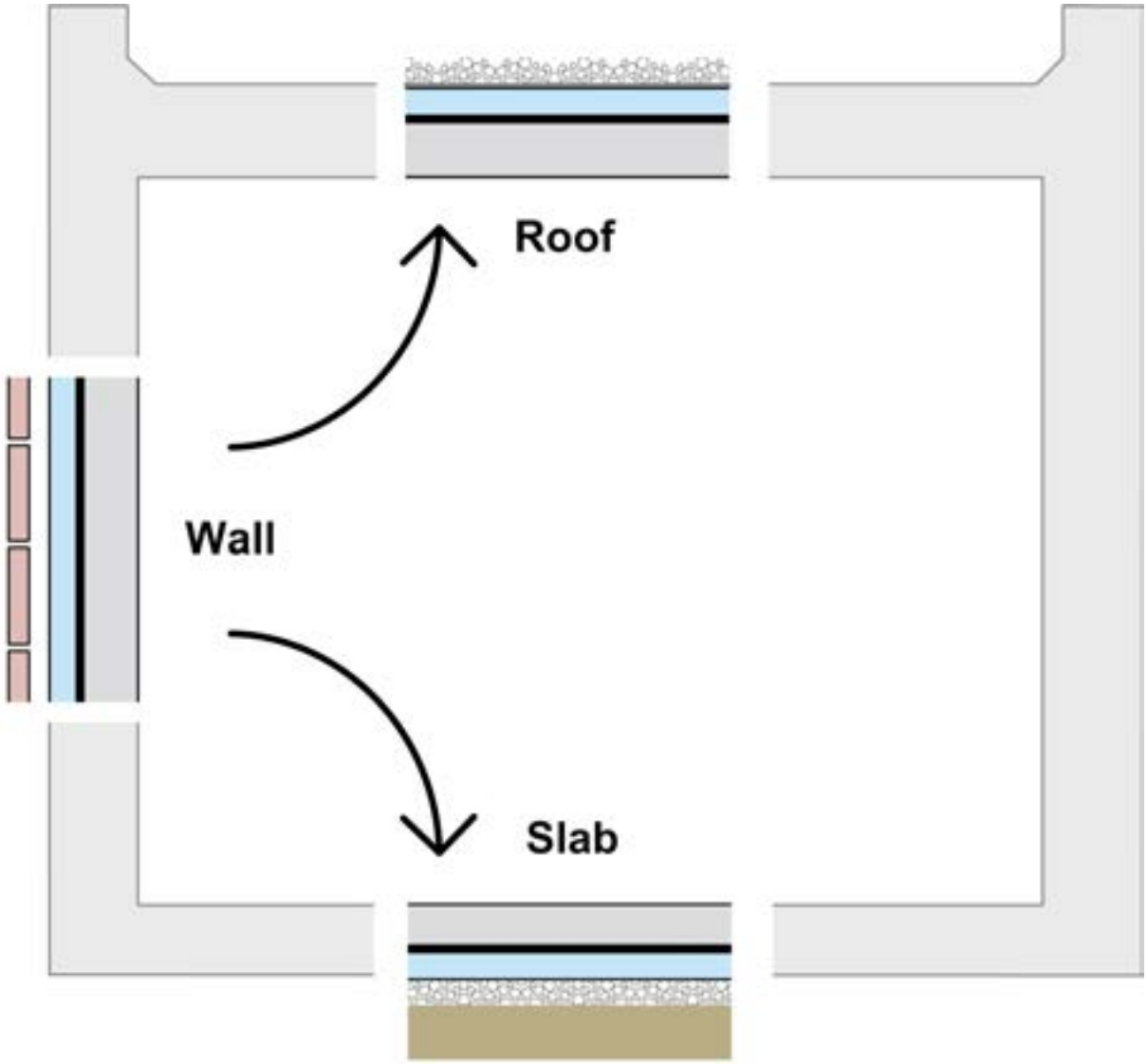

Wall
Slab
Roof

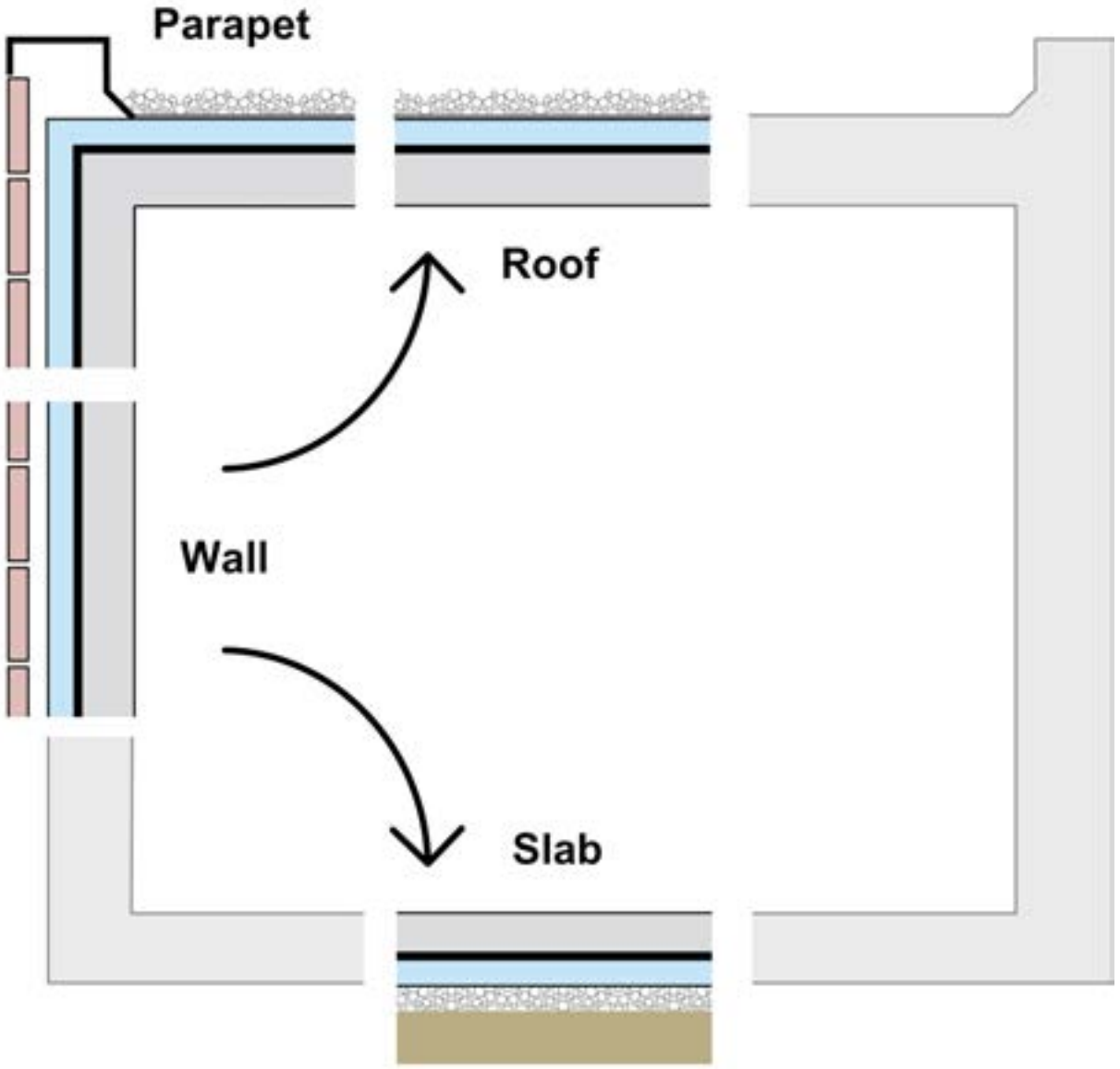

Ballast
Filter fabric
Control layers
Roof structure

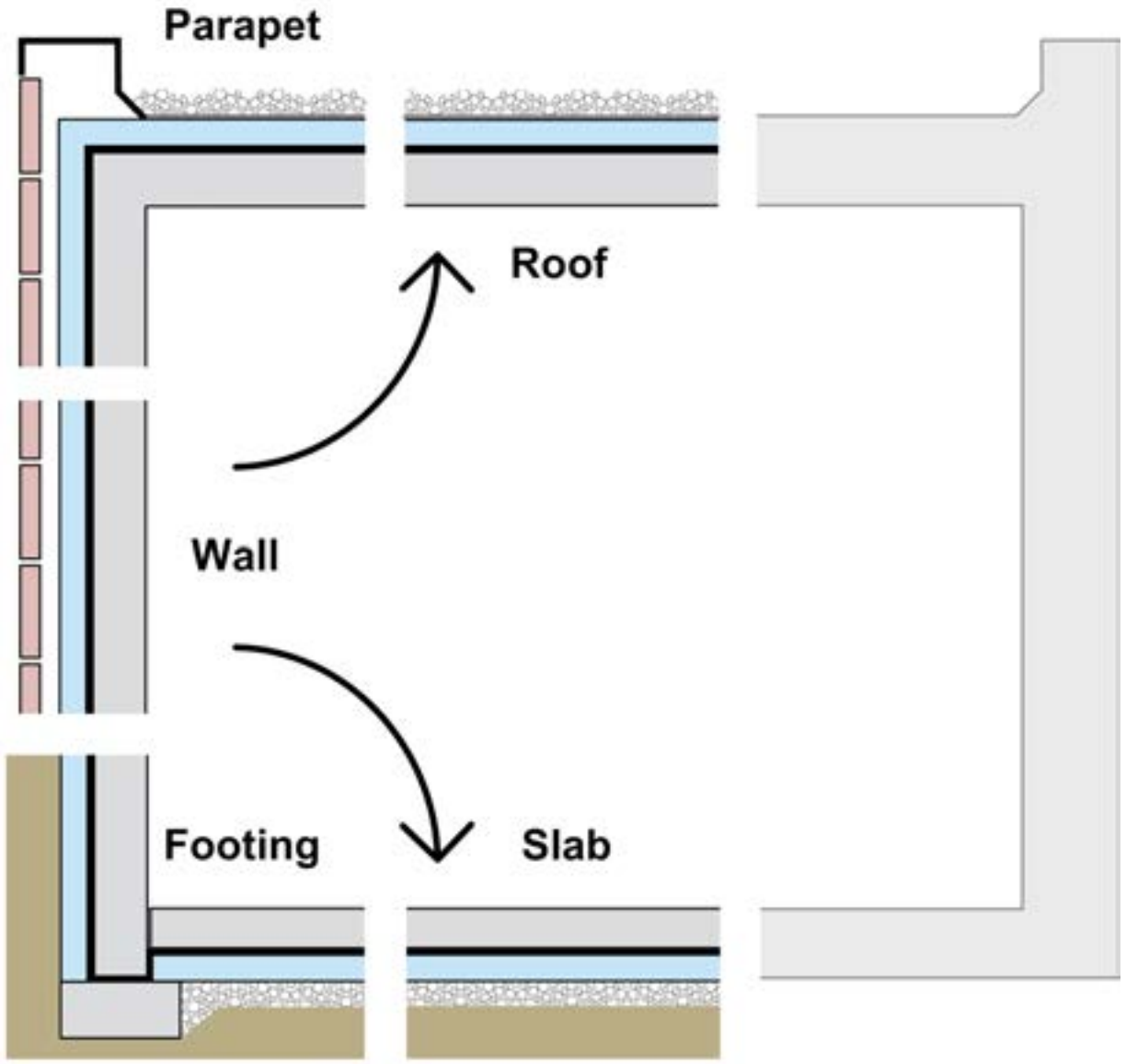

Slab
Control layers
Stones
Earth

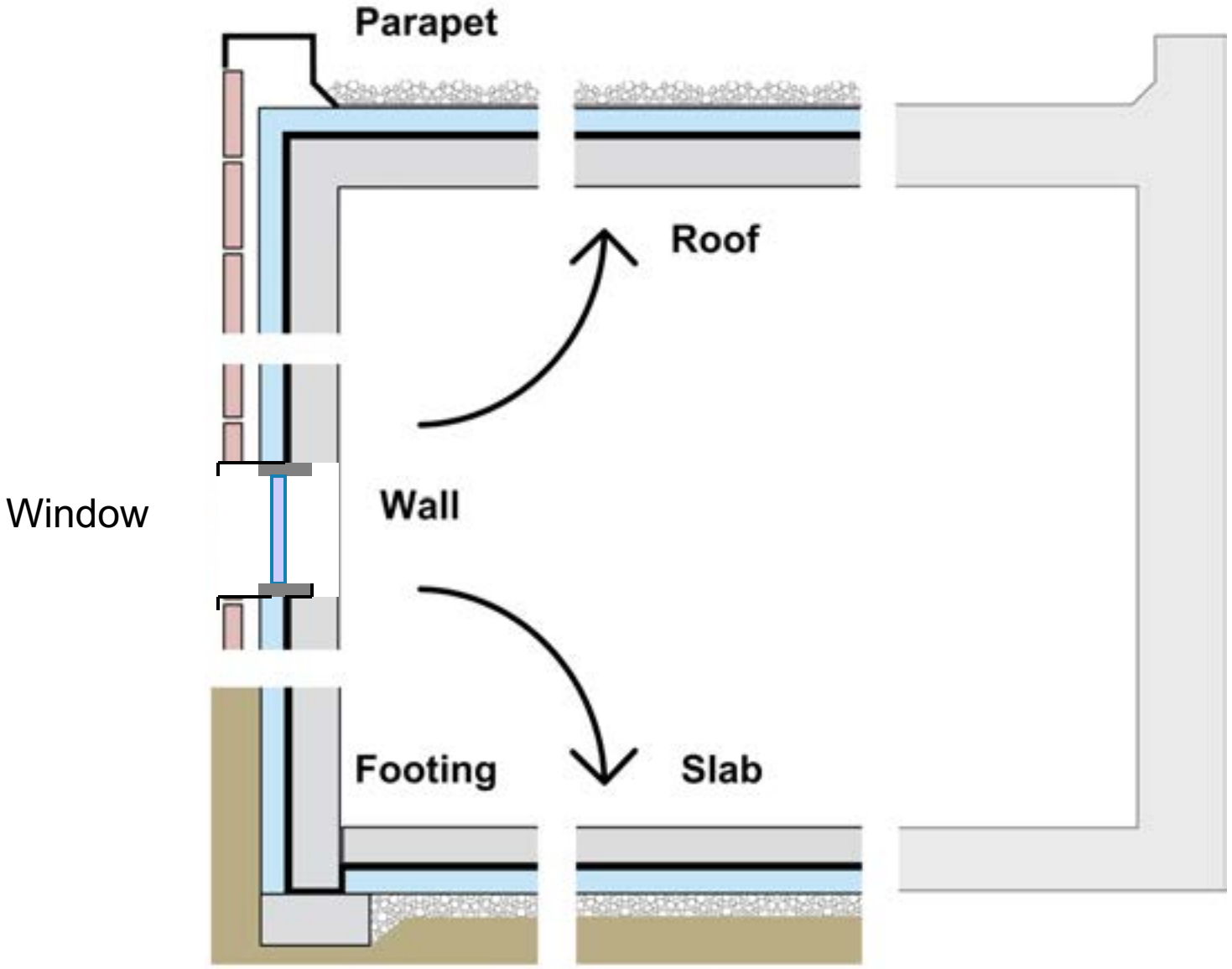

Wall

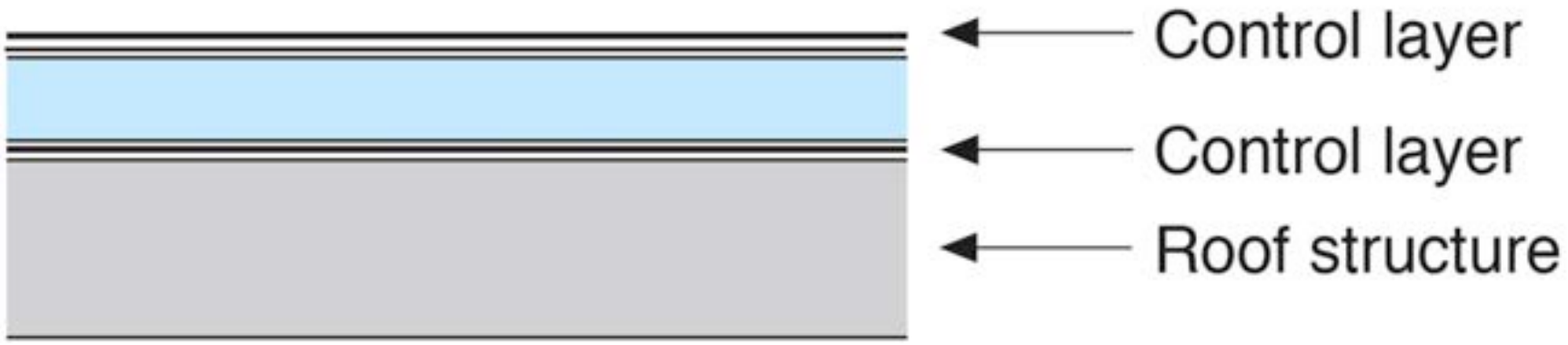

Roof
Wall

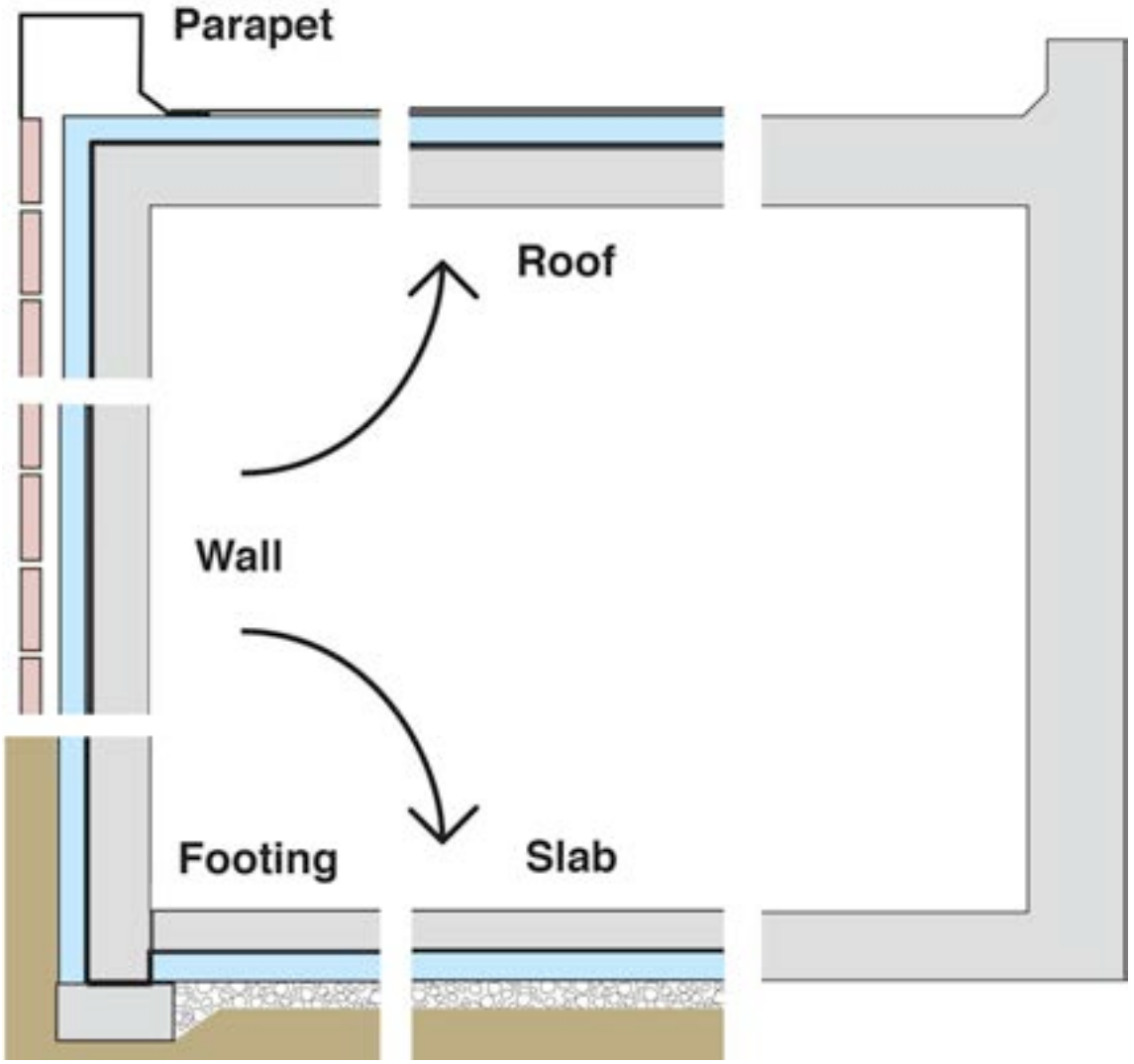

Roof
Wall
Slab

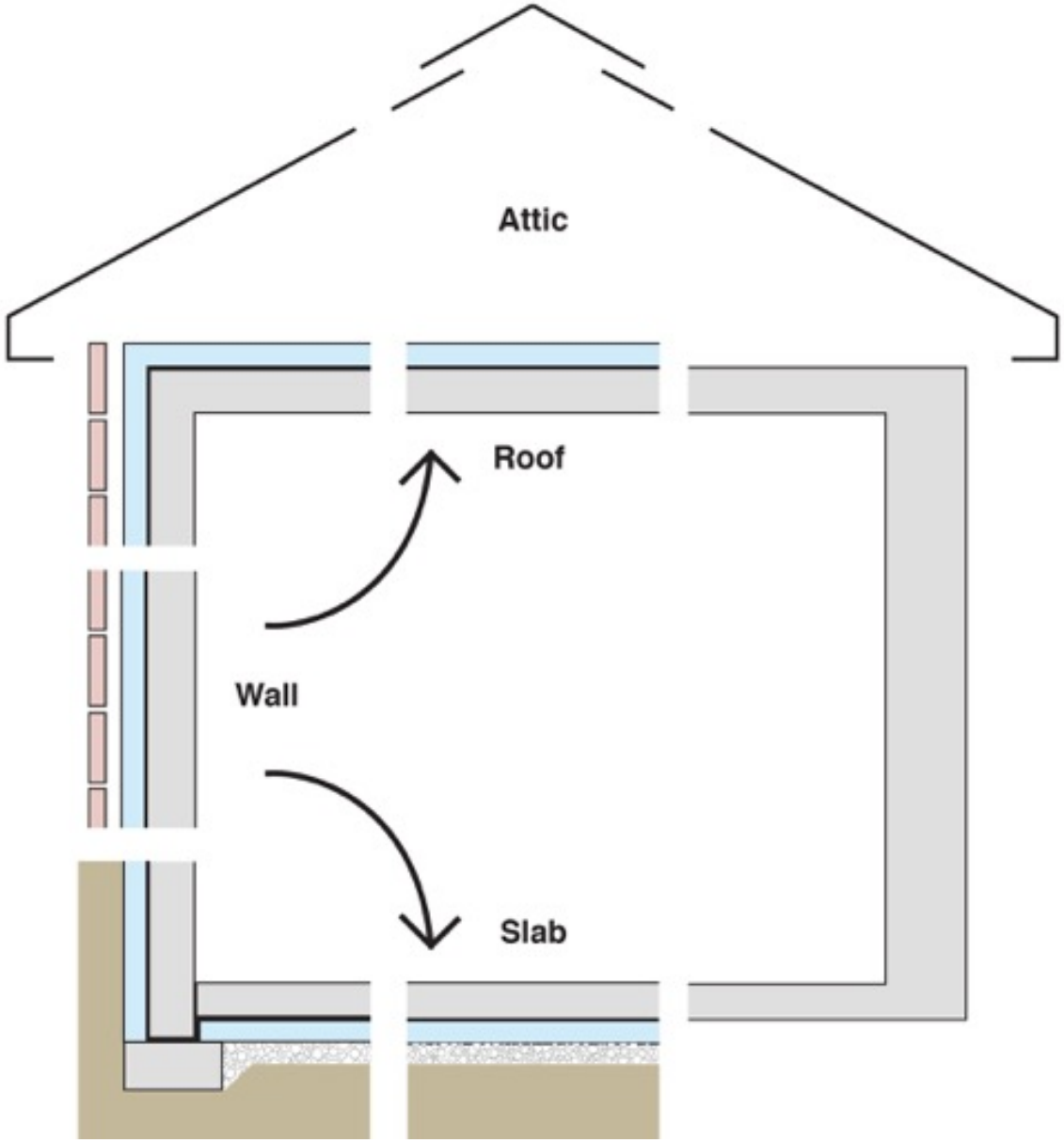

Parapet
Roof
Wall
Slab

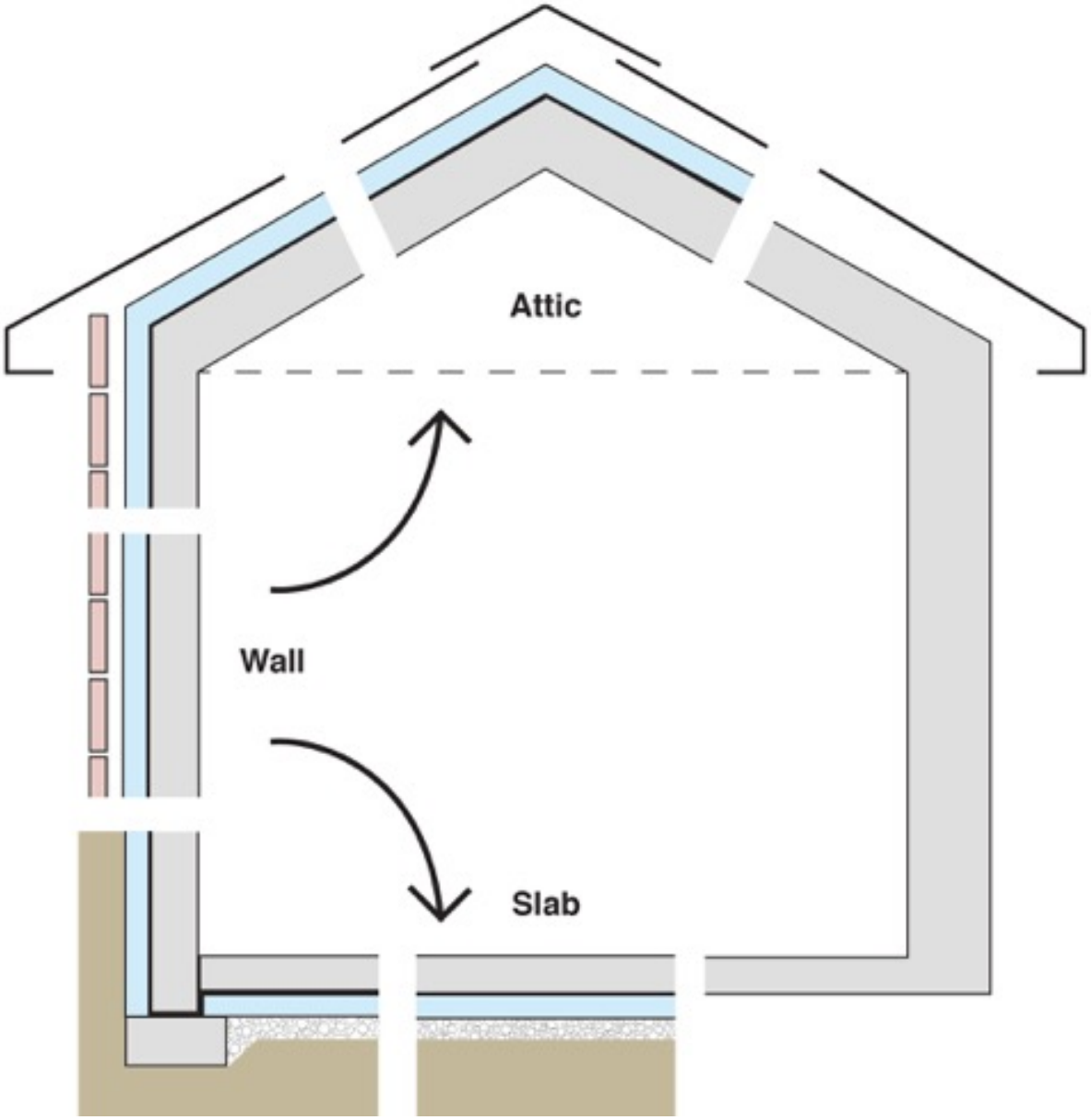

Parapet
Roof
Wall
Footing
Slab

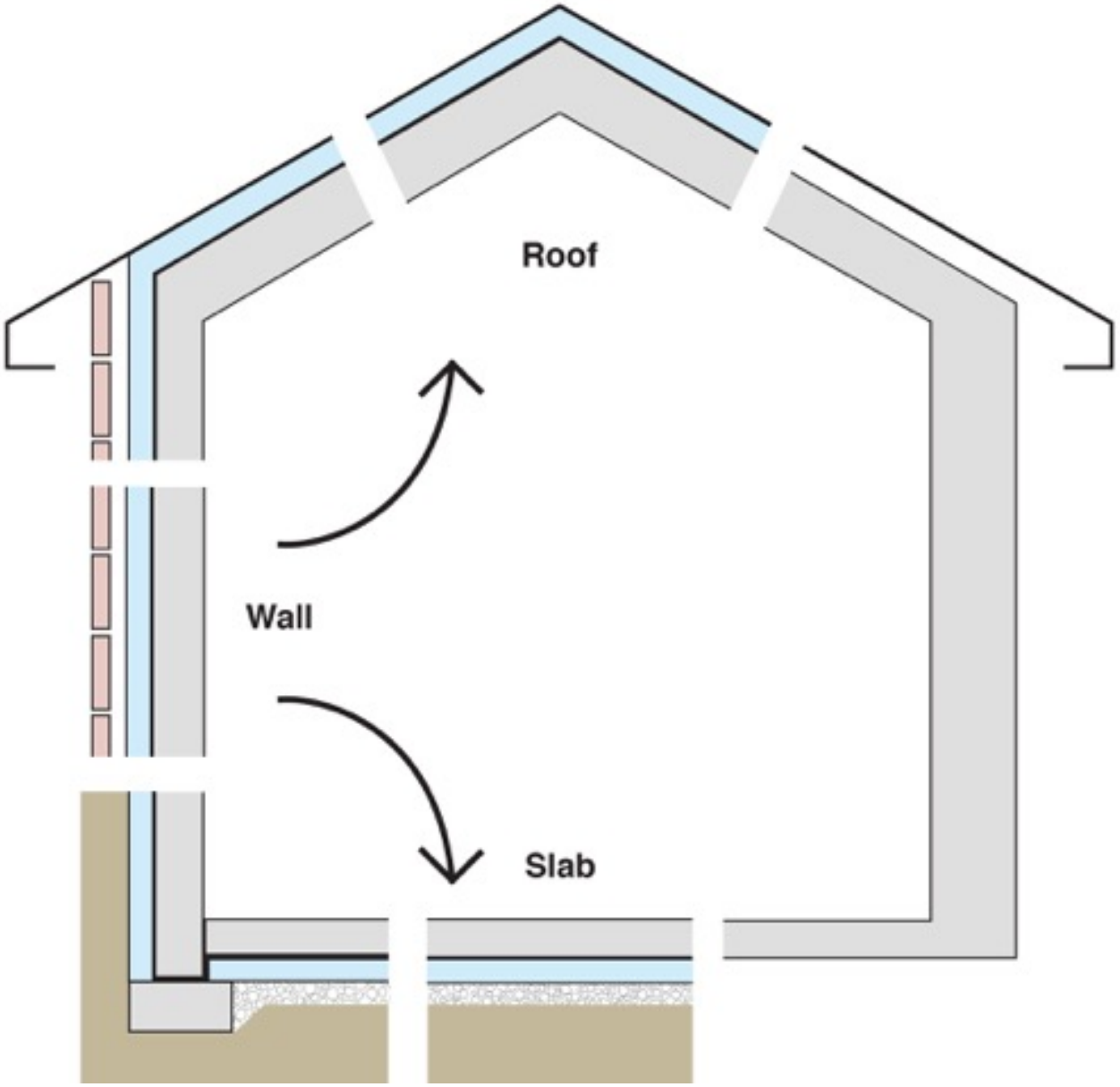

Parapet
Roof
Window
Wall
Footing
Slab

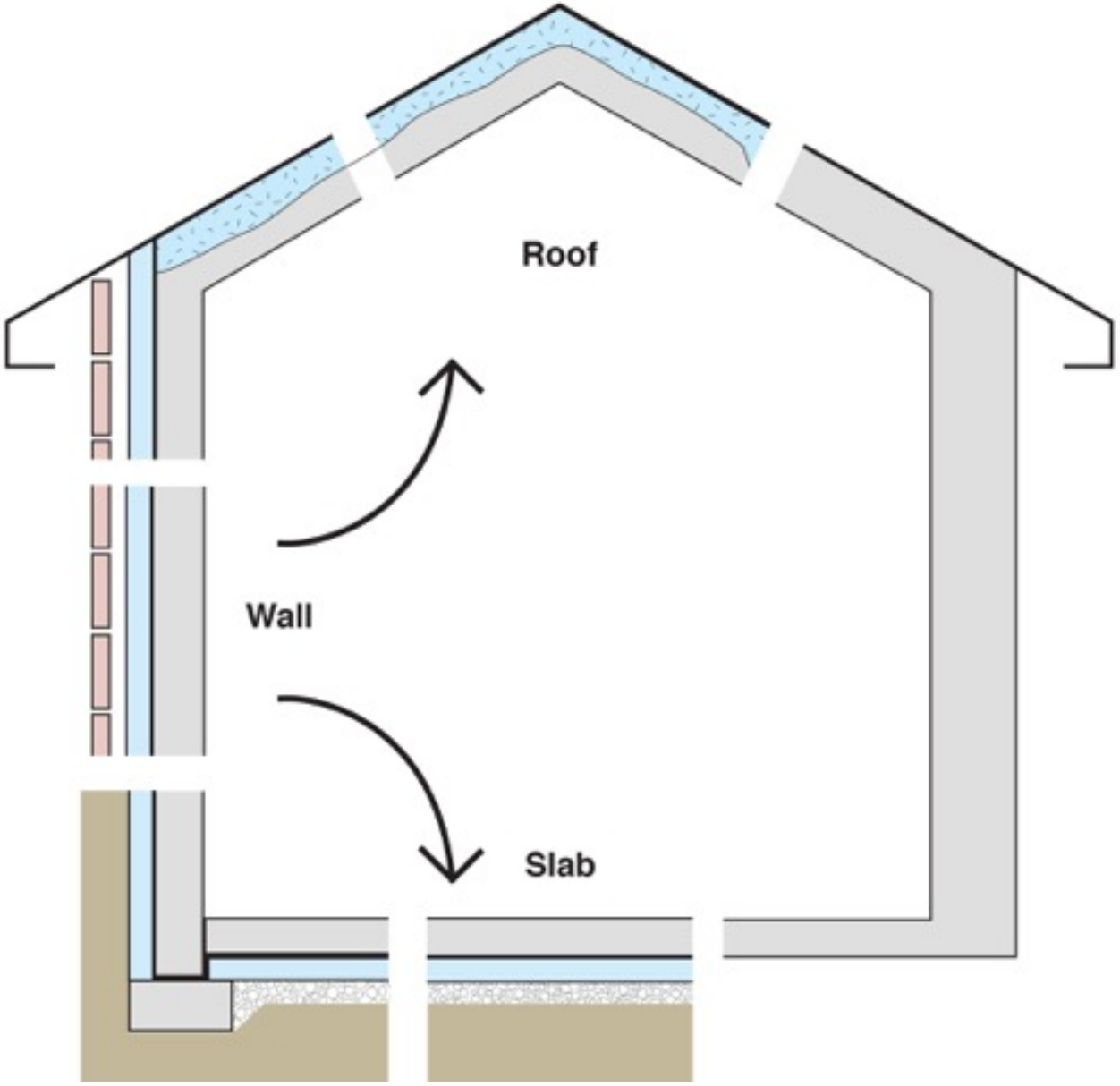

Control layer
Control layer
Roof structure

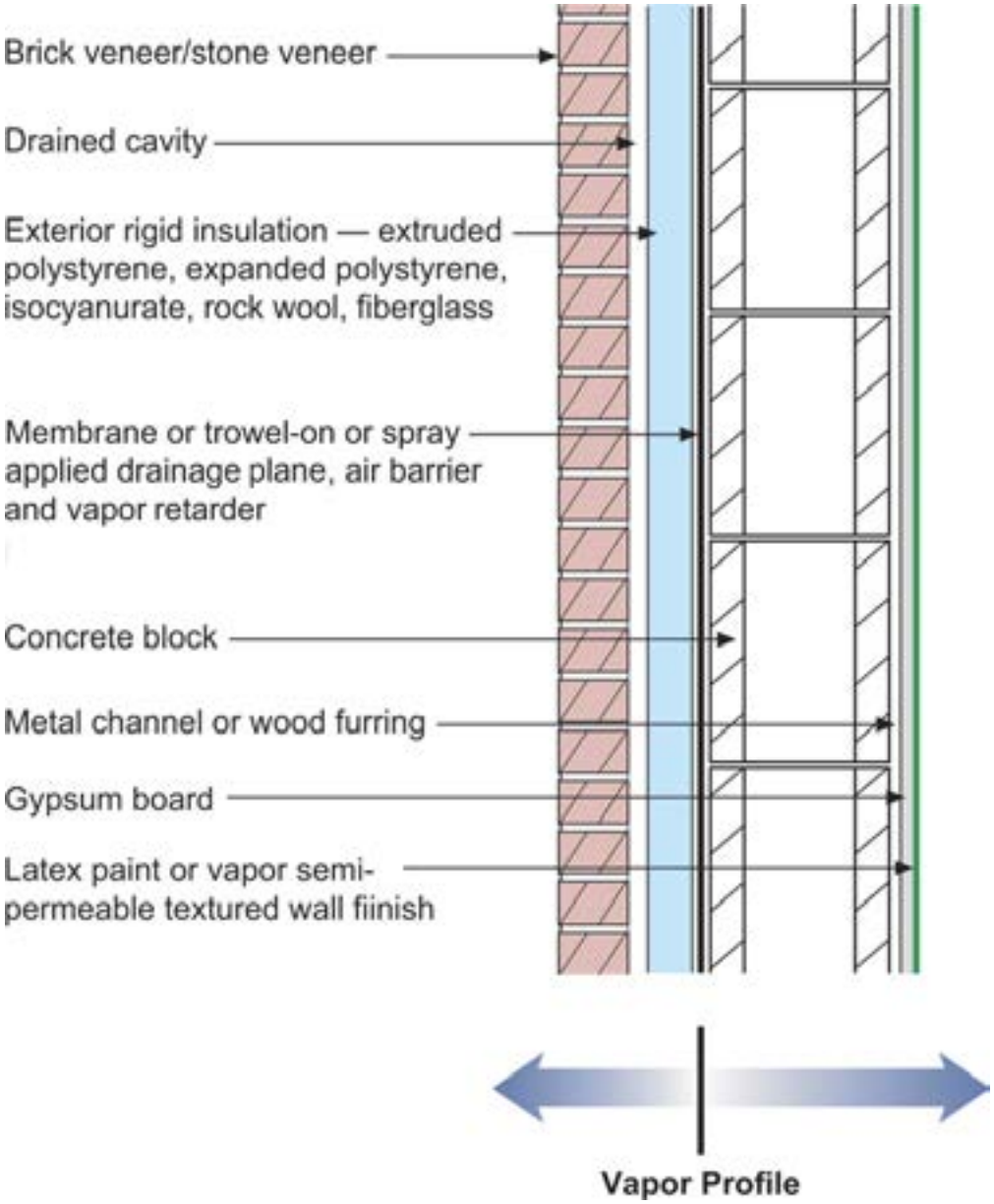

Parapet
Roof
Wall
Footing
Slab

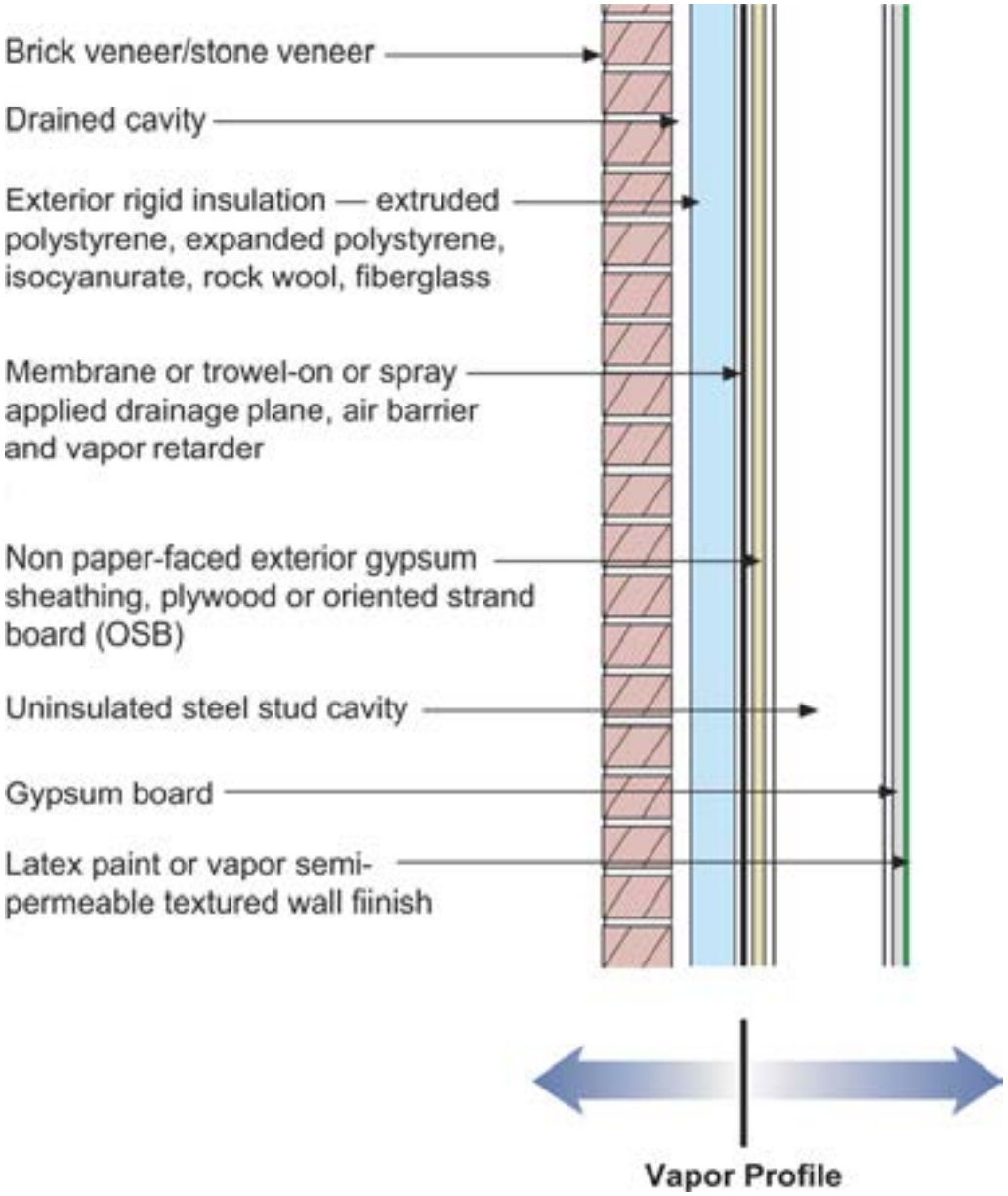

Attic
Roof
Wall
Slab

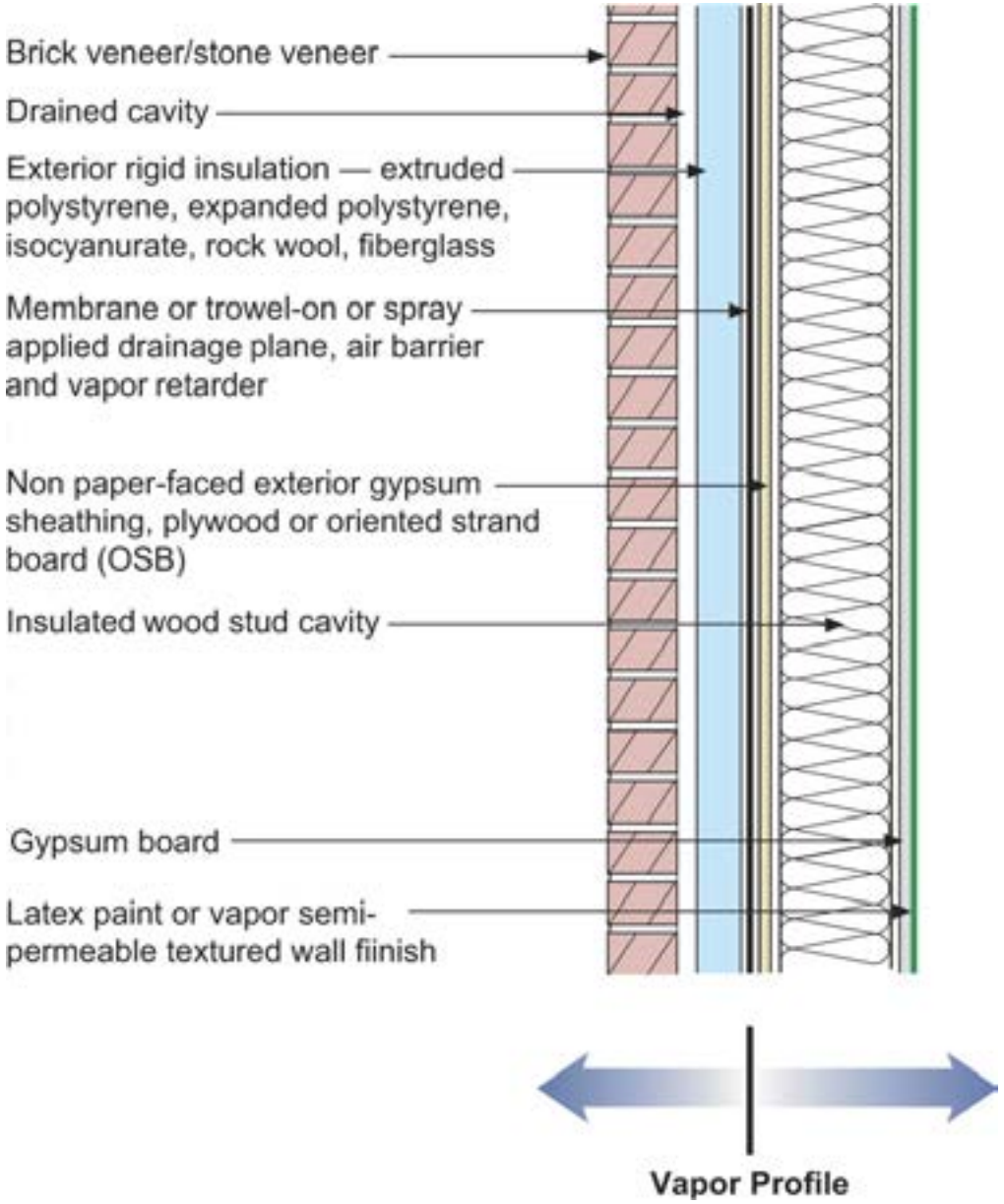

Attic
Wall
Slab

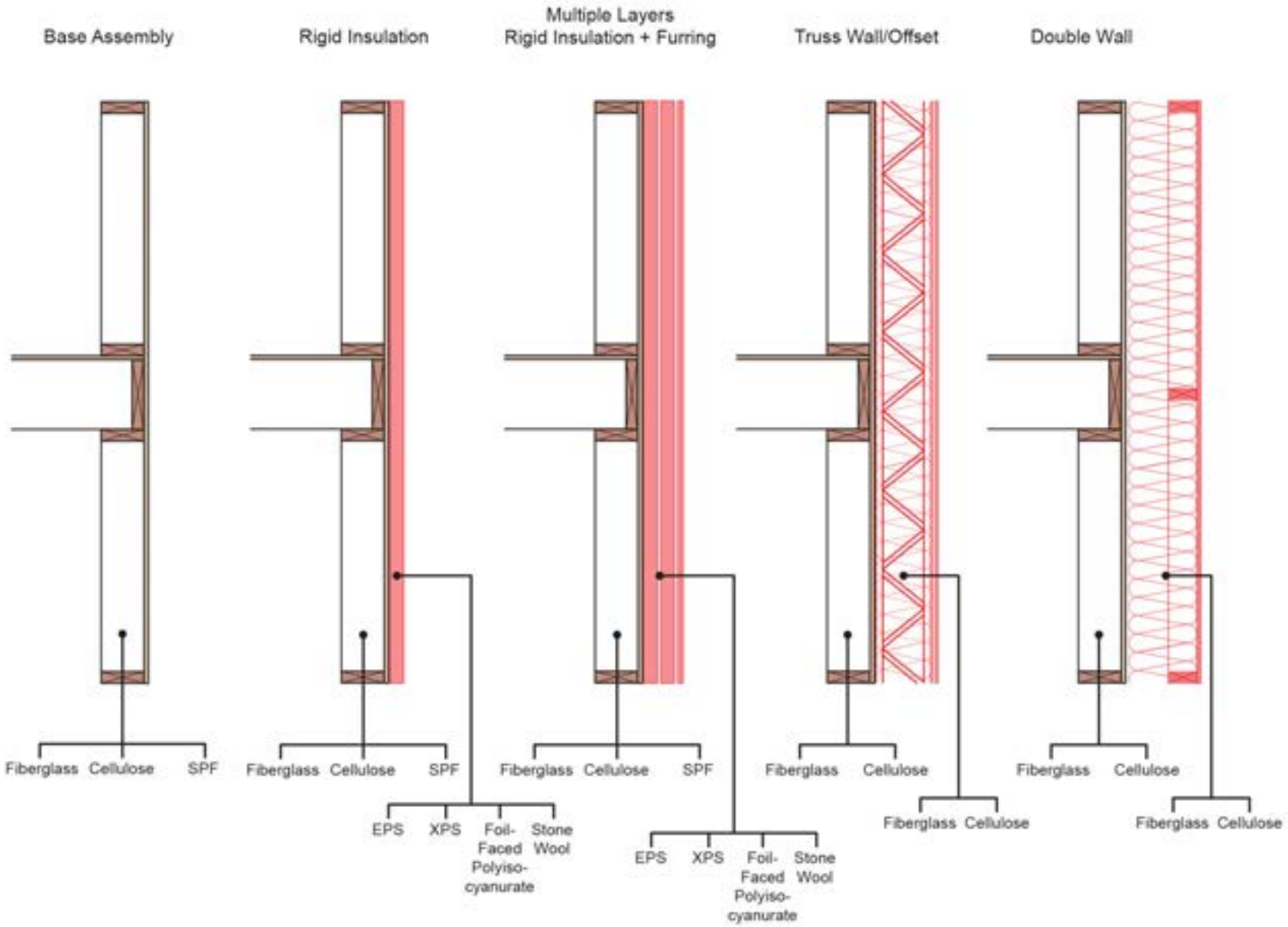

Roof
Wall
Slab

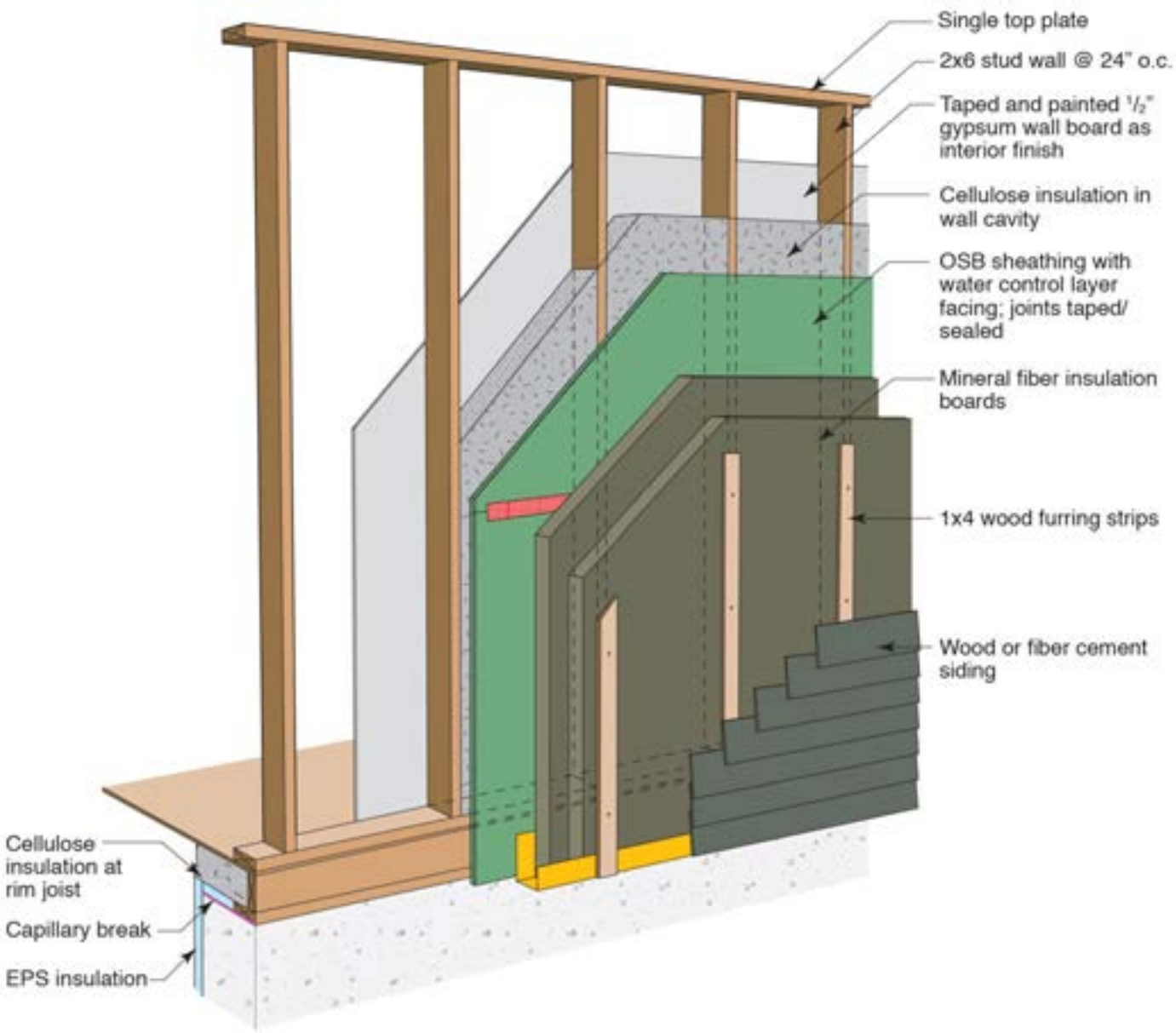

Roof
Wall
Slab

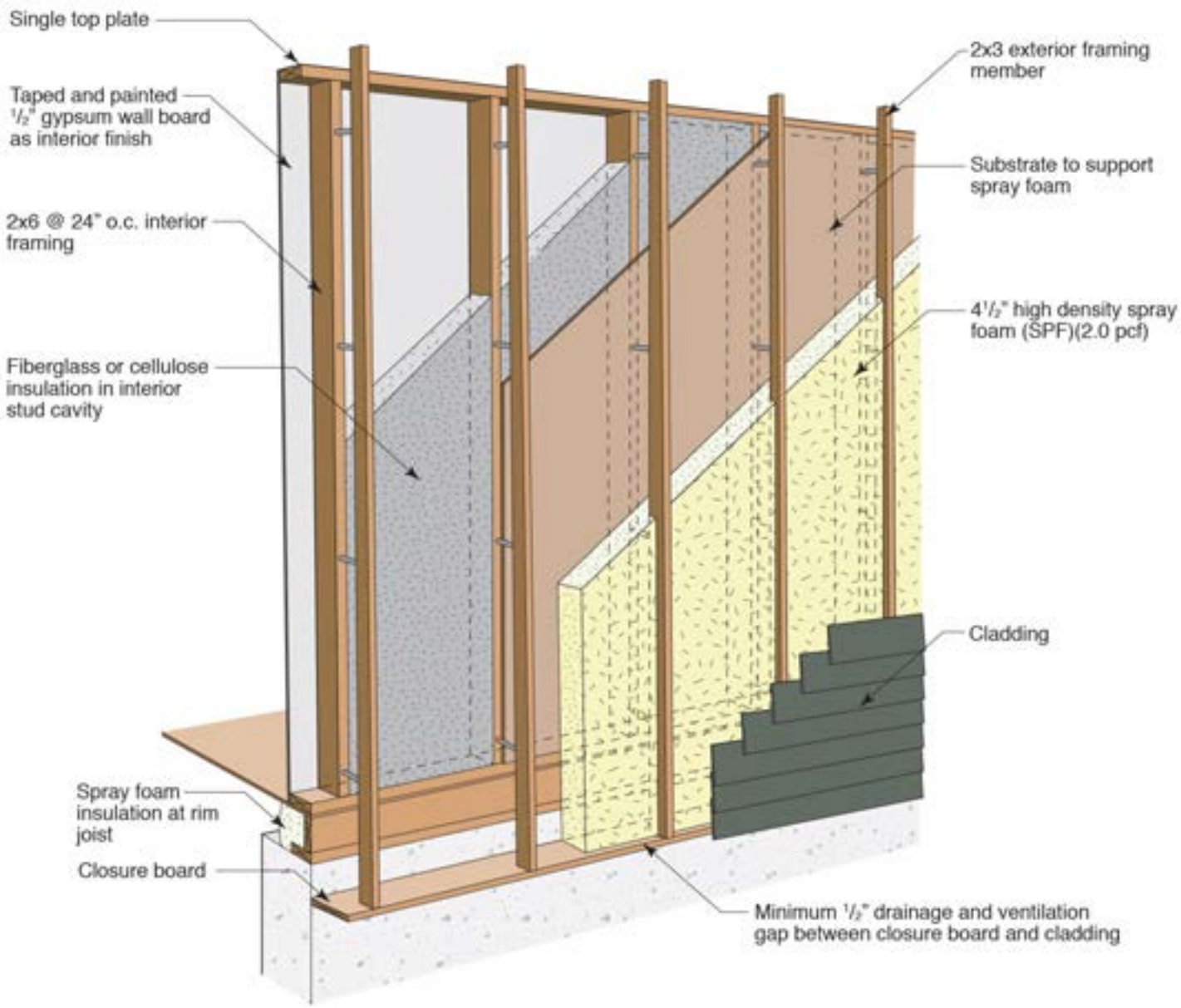

Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied drainage plane, air barrier and vapor retarder
Concrete block
Metal channel or wood furring
Gypsum board
Latex paint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

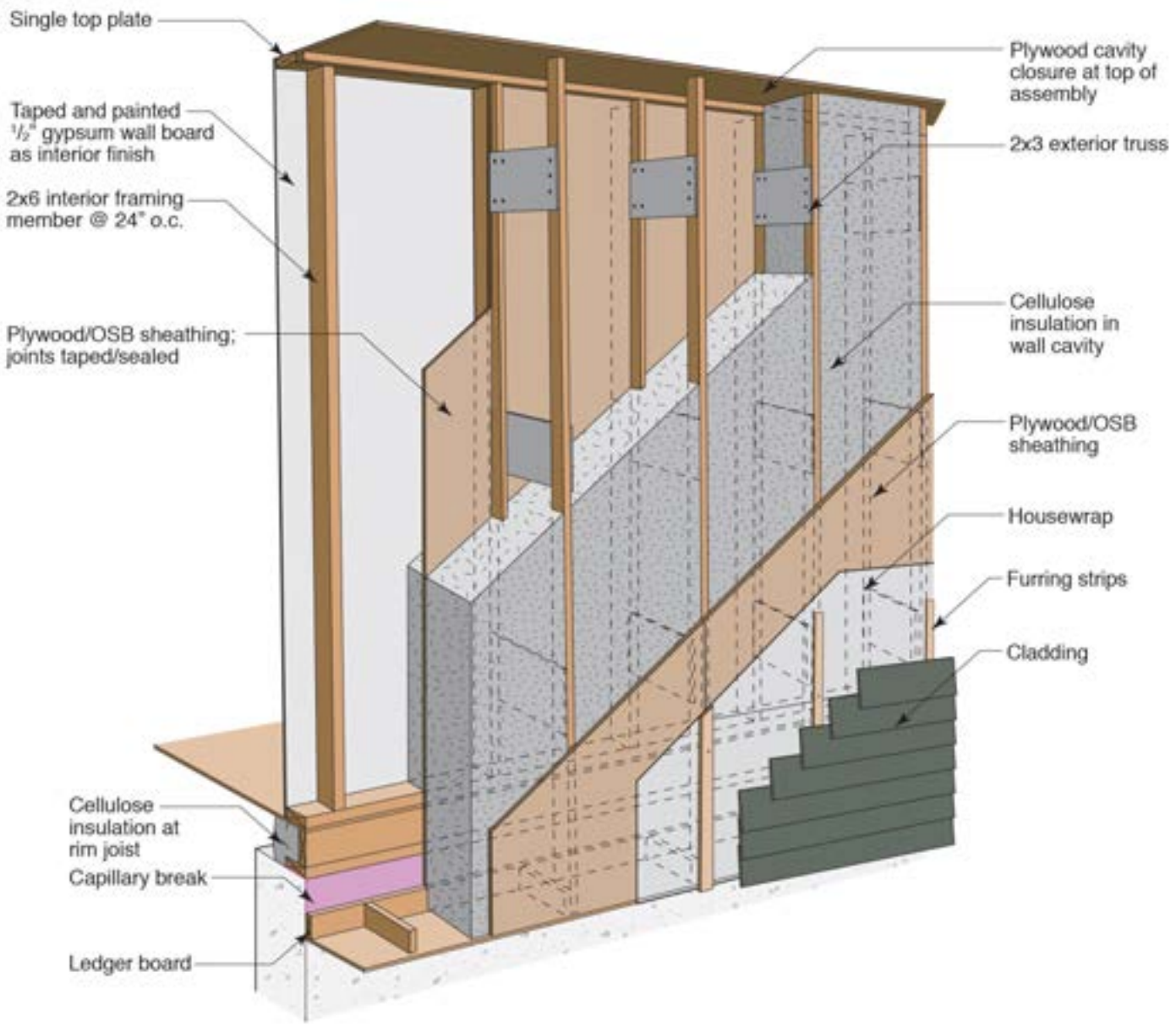

Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied drainage plane, air barrier and vapor retarder
Non paper-faced exterior gypsum sheathing, plywood or oriented strand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

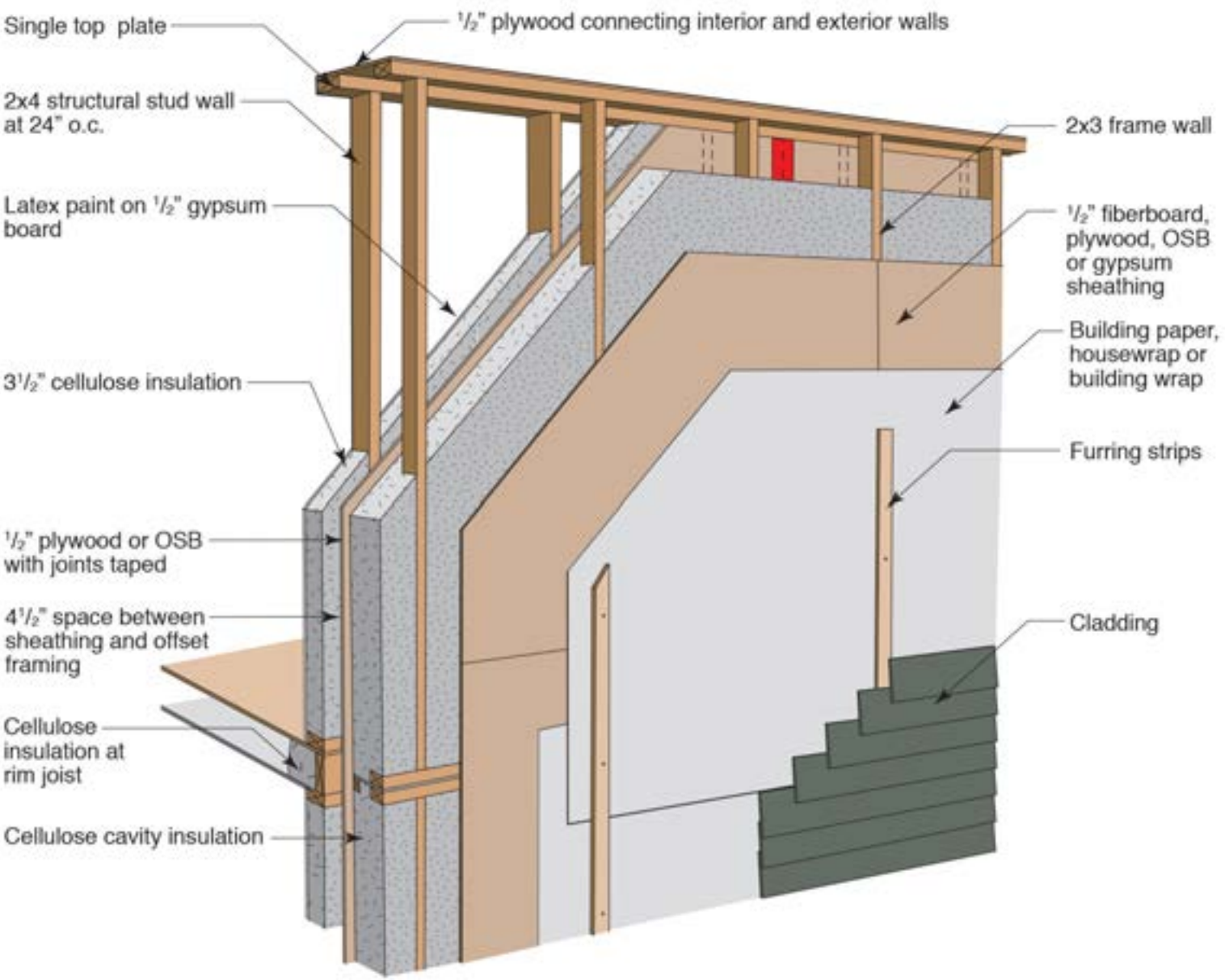

Brick veneer/stone veneer
Drained cavity
Exterior rigid insulation — extruded polystyrene, expanded polystyrene, isocyanurate, rock wool, fiberglass
Membrane or trowel-on or spray applied drainage plane, air barrier and vapor retarder
Non paper-faced exterior gypsum sheathing, plywood or oriented strand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

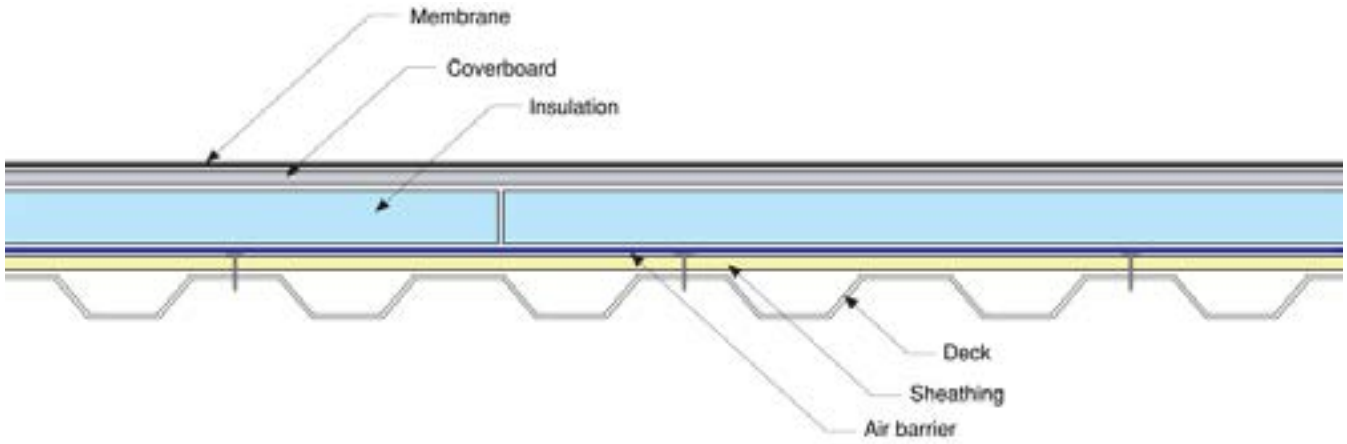

Base Assembly
Rigid Insulation
Multiple Layers
Rigid Insulation + Furring
Truss Wall/Offset
Double Wall
Fiberglass
Cellulose
SPF
EPS
XPS
Foil-Faced Polyiso-cyanurate
Stone Wool

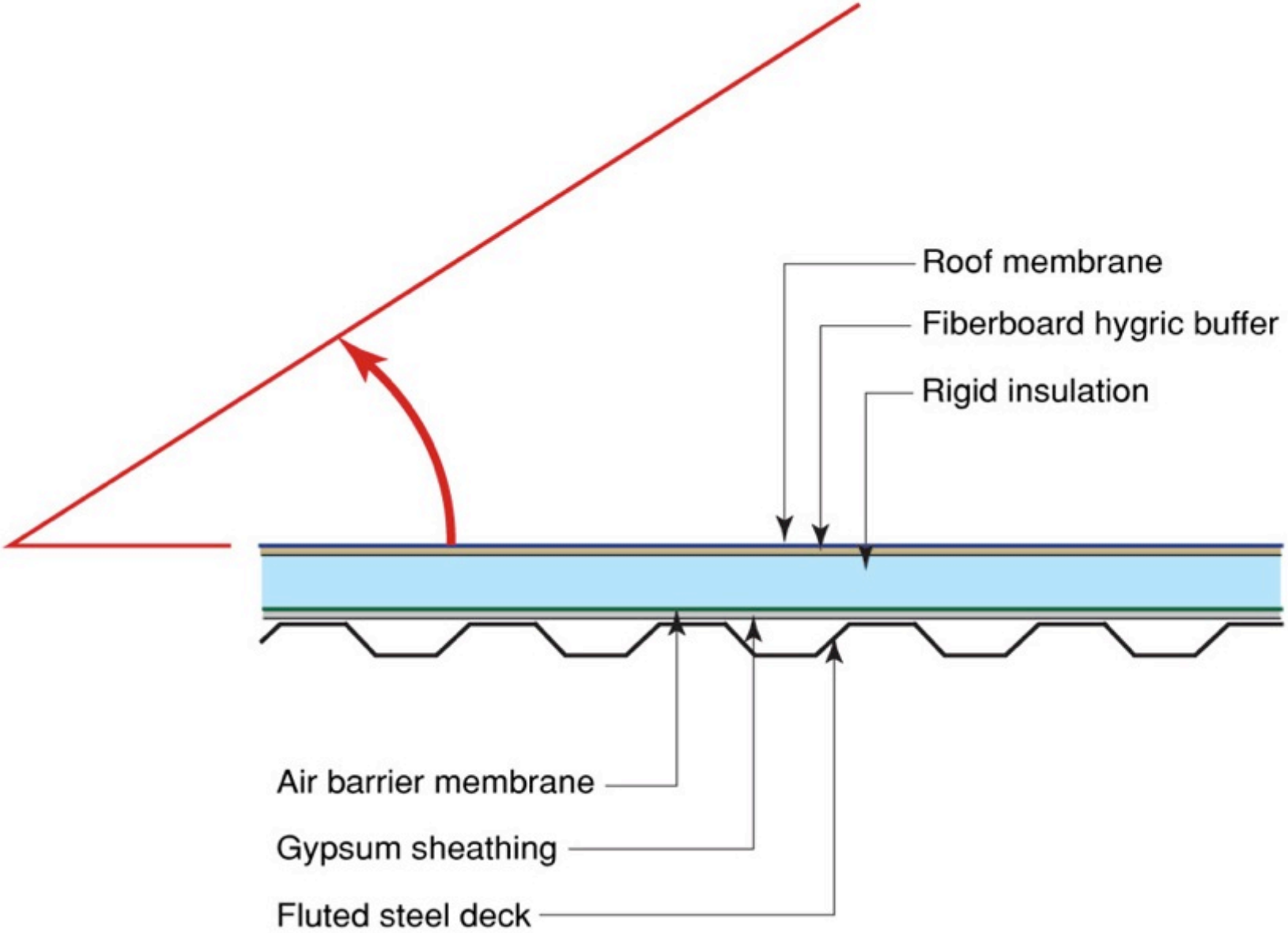

Single top plate
2x6 stud wall @ 24" o.c.
Taped and painted ½" gypsum wall board as interior finish
Cellulose insulation in wall cavity
OSB sheathing with water control layer facing; joints taped/ sealed
Mineral fiber insulation boards
1x4 wood furring strips
Wood or fiber cement siding
Cellulose insulation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

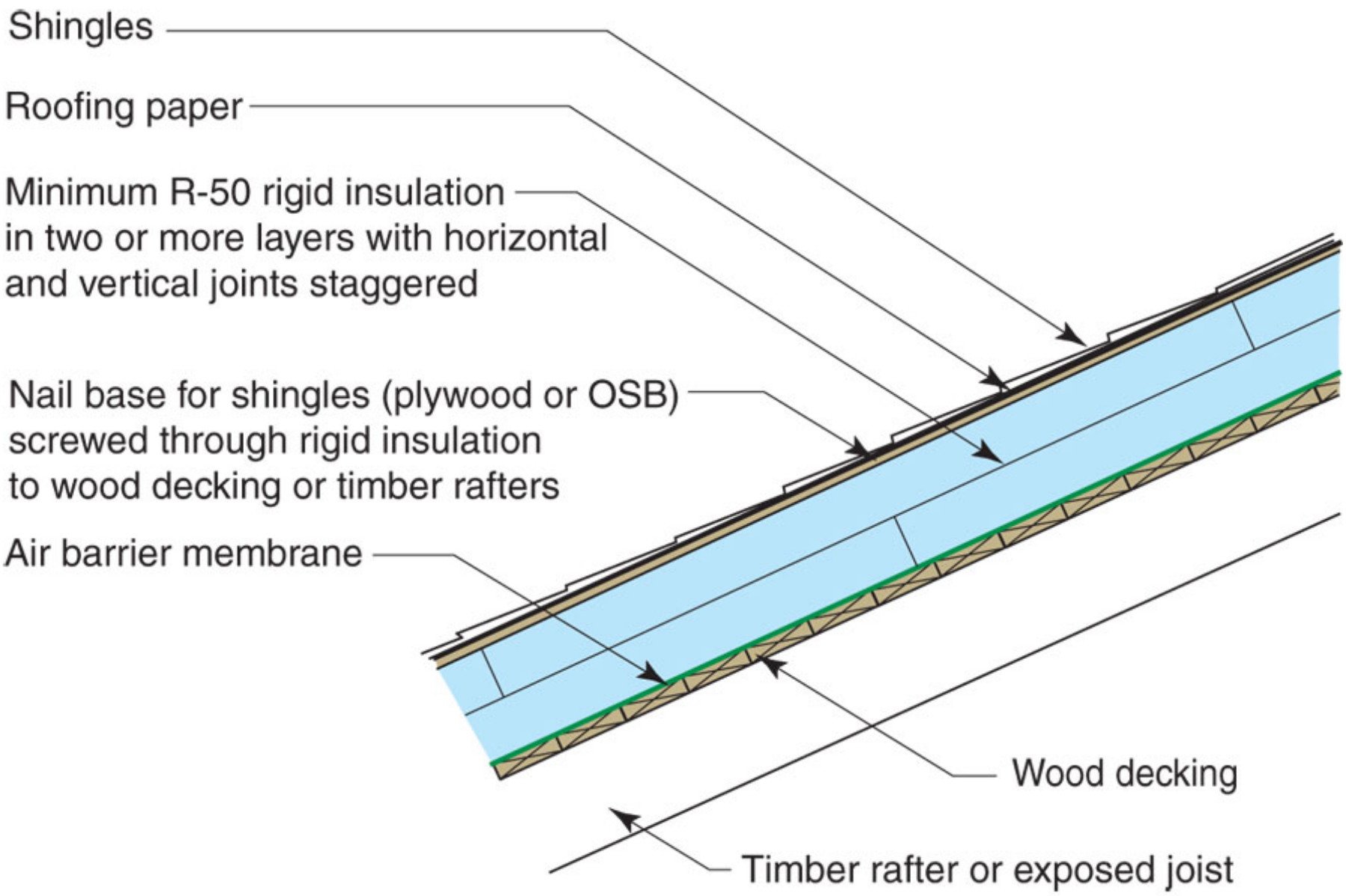

Single top plate
Taped and painted ½" gypsum wall board as interior finish
2x6 @ 24" o.c. interior framing
Fiberglass or cellulose insulation in interior stud cavity
Spray foam insulation at rim joist
Closure board
2x3 exterior framing member
Substrate to support spray foam
4½" high density spray foam (SPF)(2.0 pcf)
Cladding
Minimum ½" drainage and ventilation gap between closure board and cladding

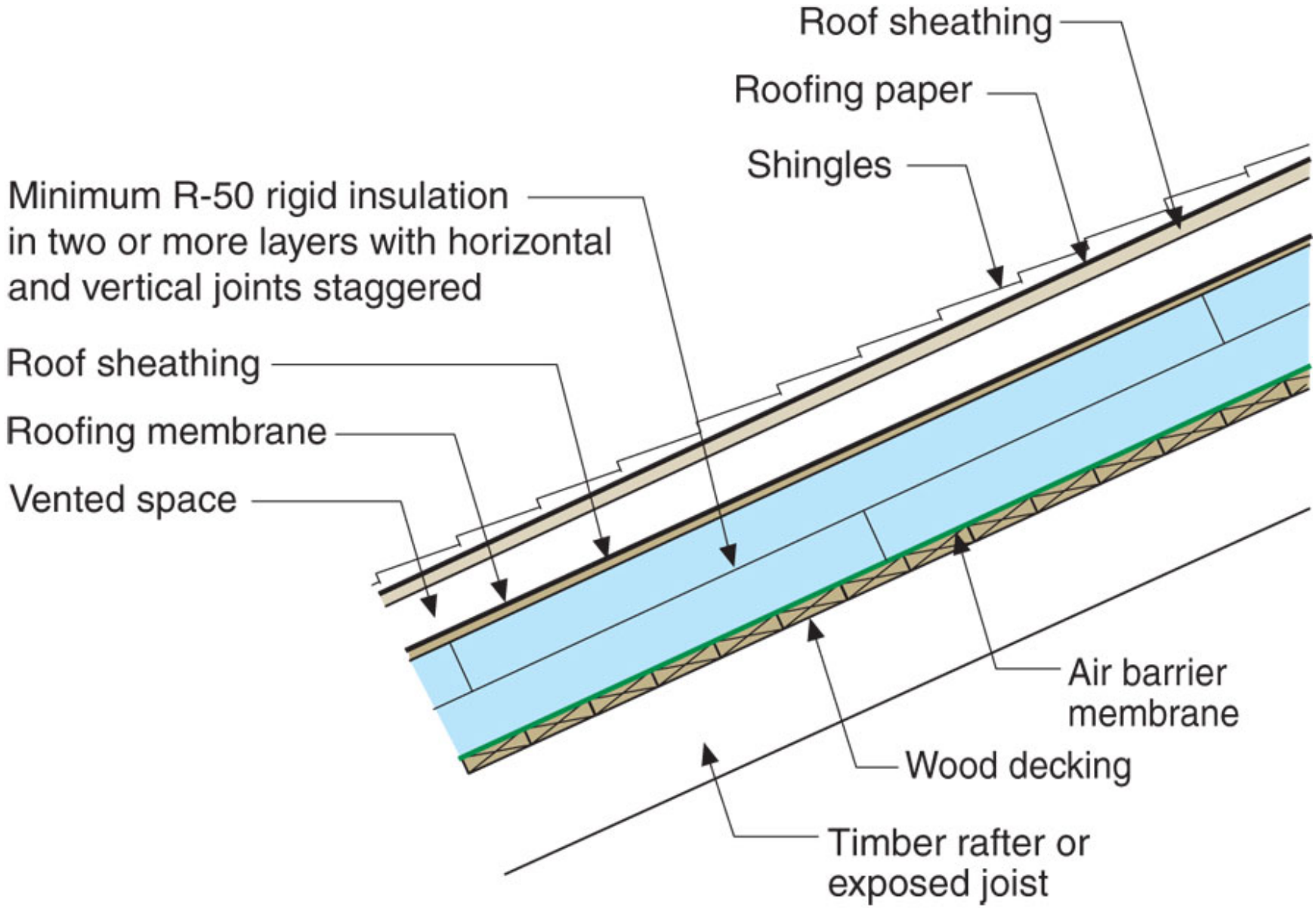

Single top plate
Taped and painted ½" gypsum wall board as interior finish
2x6 interior framing member @ 24" o.c.
Plywood/OSB sheathing; joints taped/sealed
Cellulose insulation at rim joist
Capillary break
Ledger board
Plywood cavity closure at top of assembly
2x3 exterior truss
Cellulose insulation in wall cavity
Plywood/OSB sheathing
Housewrap
Furring strips
Cladding

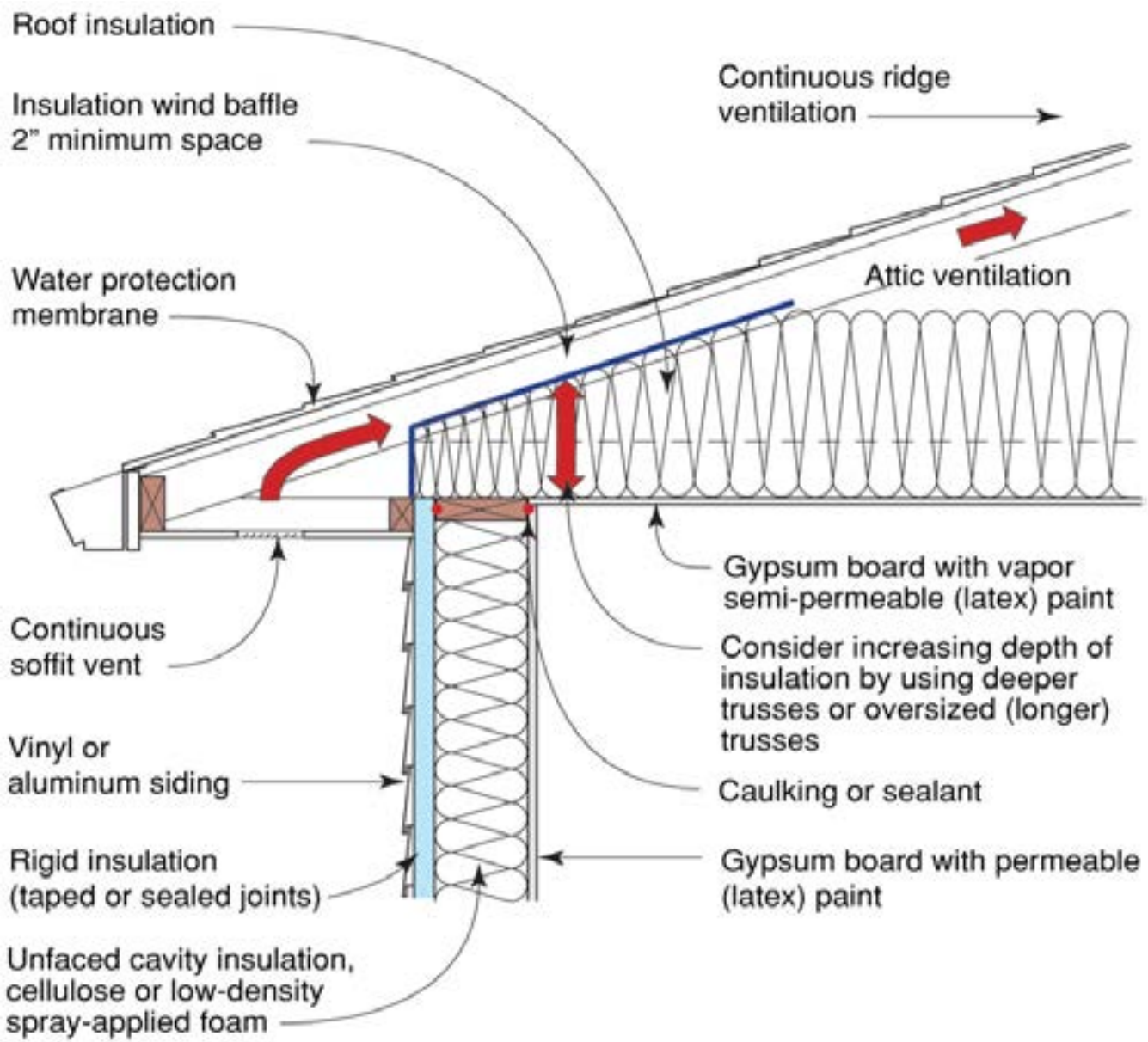

Single top plate
½" plywood connecting interior and exterior walls
2x4 structural stud wall at 24" o.c.
2x3 frame wall
Latex paint on ½" gypsum board
½" fiberboard, plywood, OSB or gypsum sheathing
Building paper, housewrap or building wrap
3½" cellulose insulation
Furring strips
½" plywood or OSB with joints taped
4½" space between sheathing and offset framing
Cladding
Cellulose insulation at rim joist
Cellulose cavity insulation

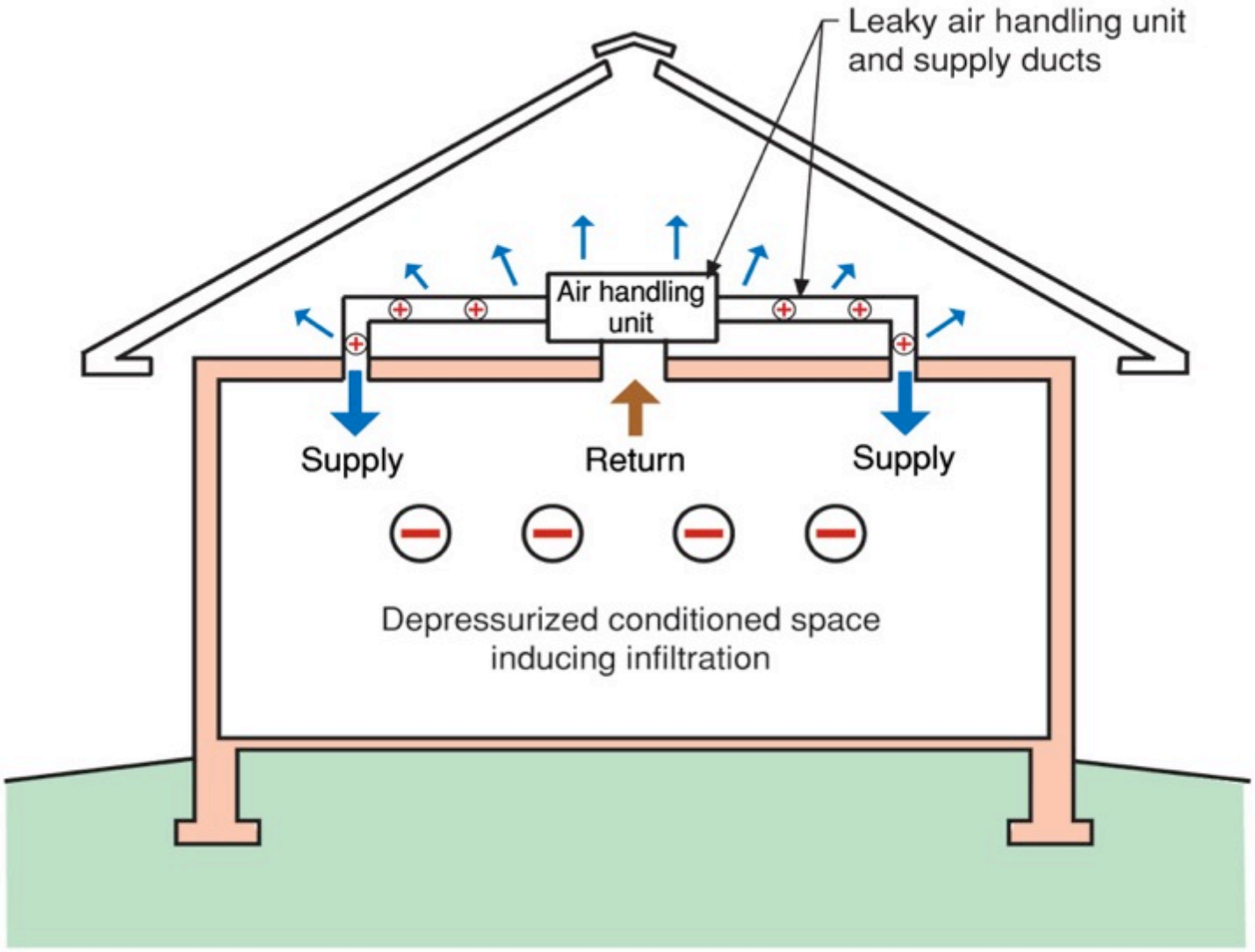

Membrane
Coverboard
Insulation
Deck
Sheathing
Air barrier


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

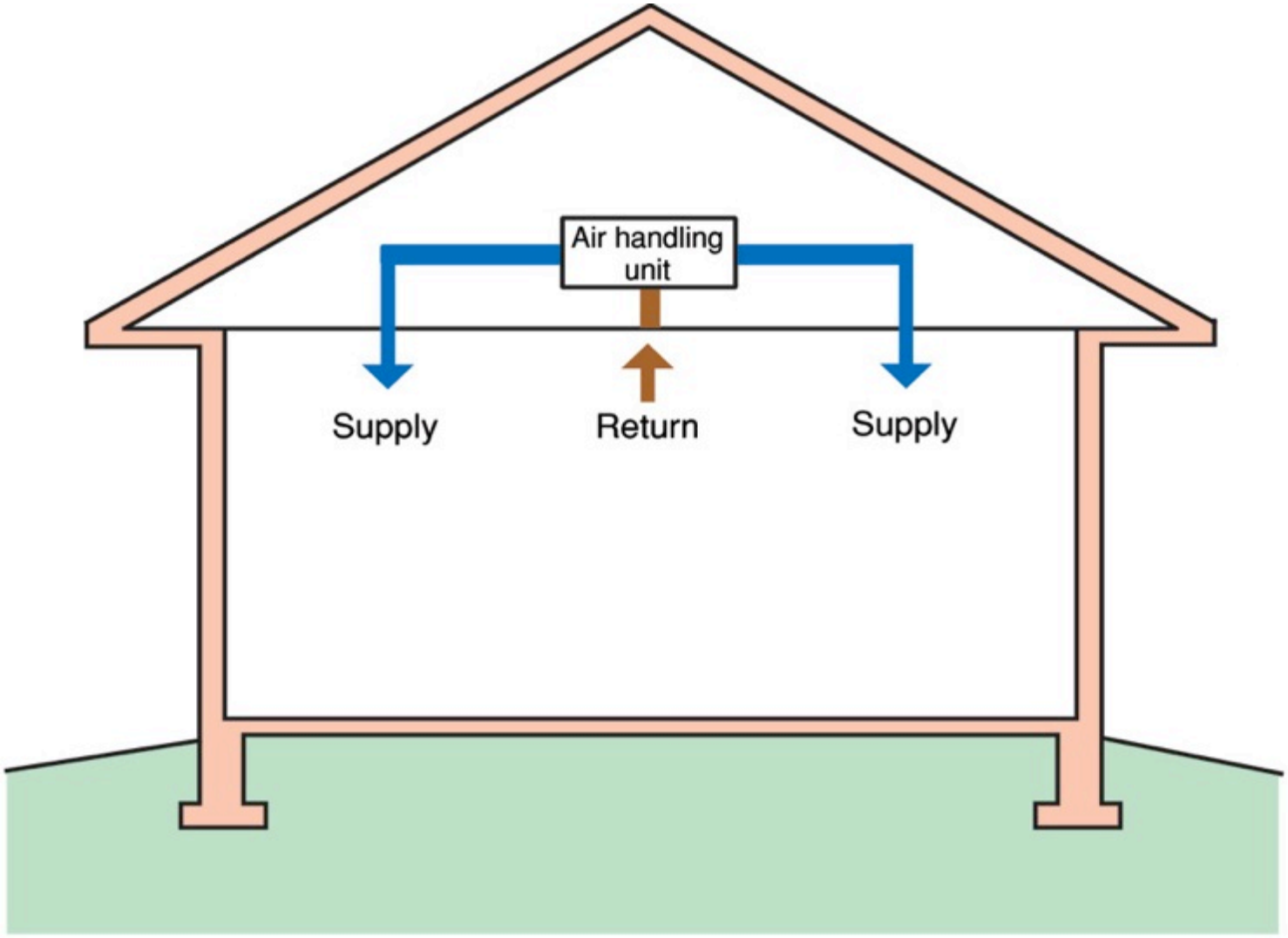

Shingles
Roofing paper
Minimum R-50 rigid insulation
in two or more layers with horizontal
and vertical joints staggered
Nail base for shingles (plywood or OSB)
screwed through rigid insulation
to wood decking or timber rafters
Air barrier membrane
Wood decking
Timber rafter or exposed joist


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


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

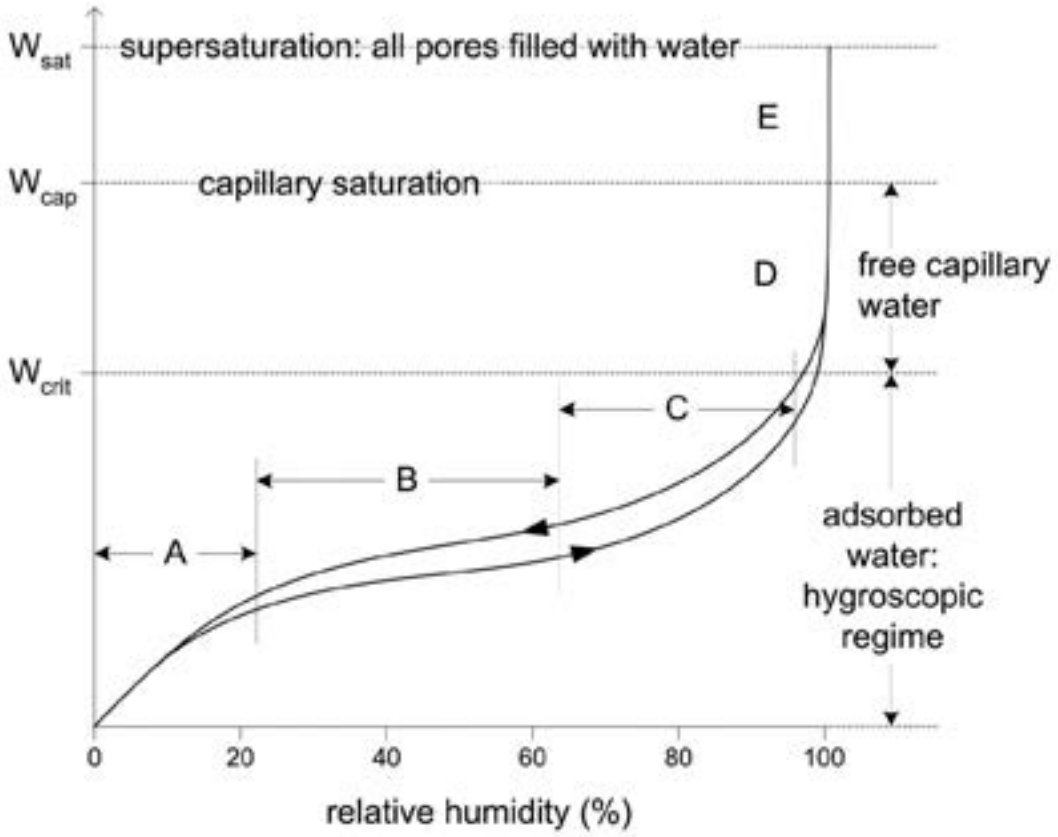


Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.



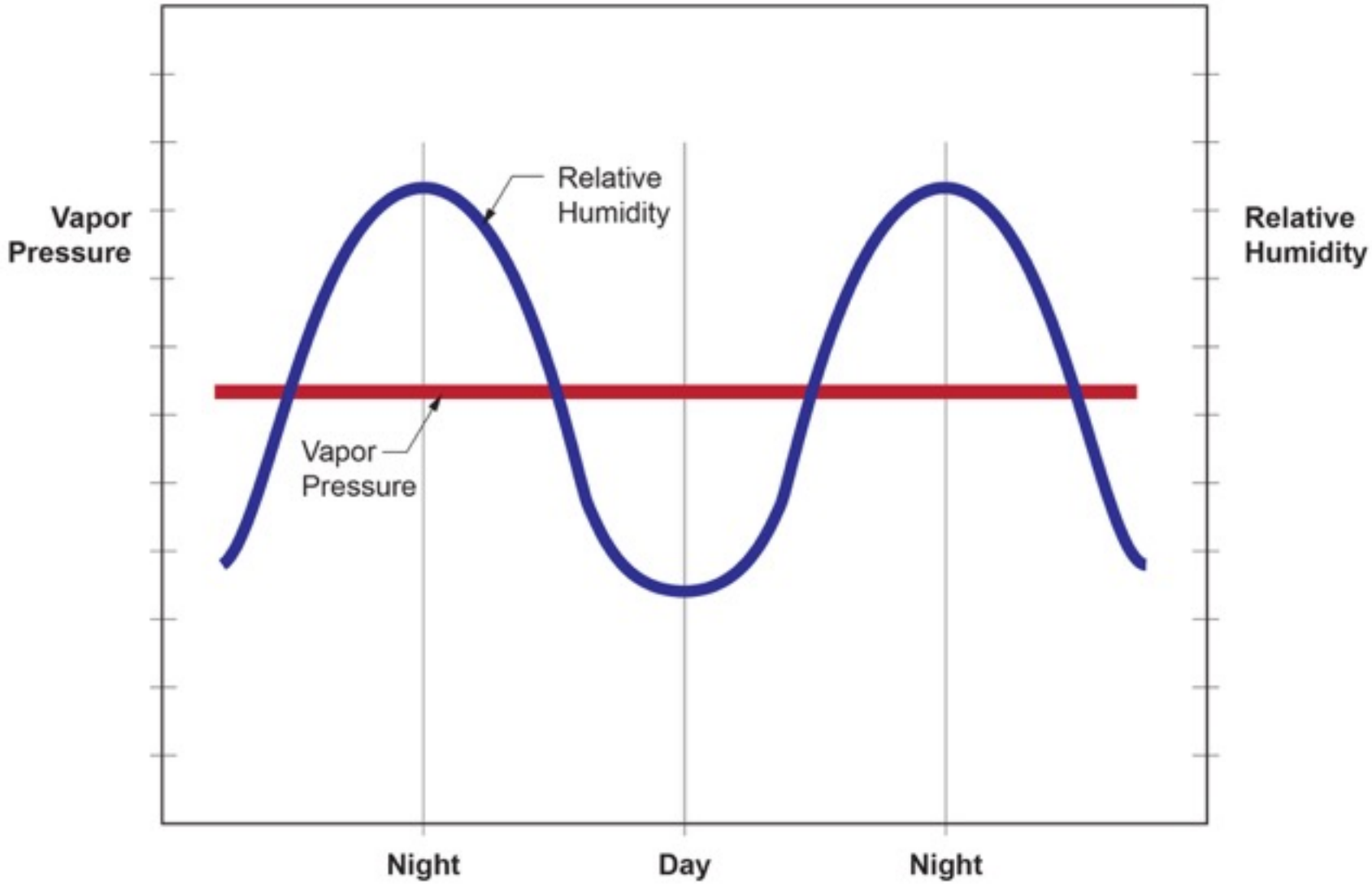
Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

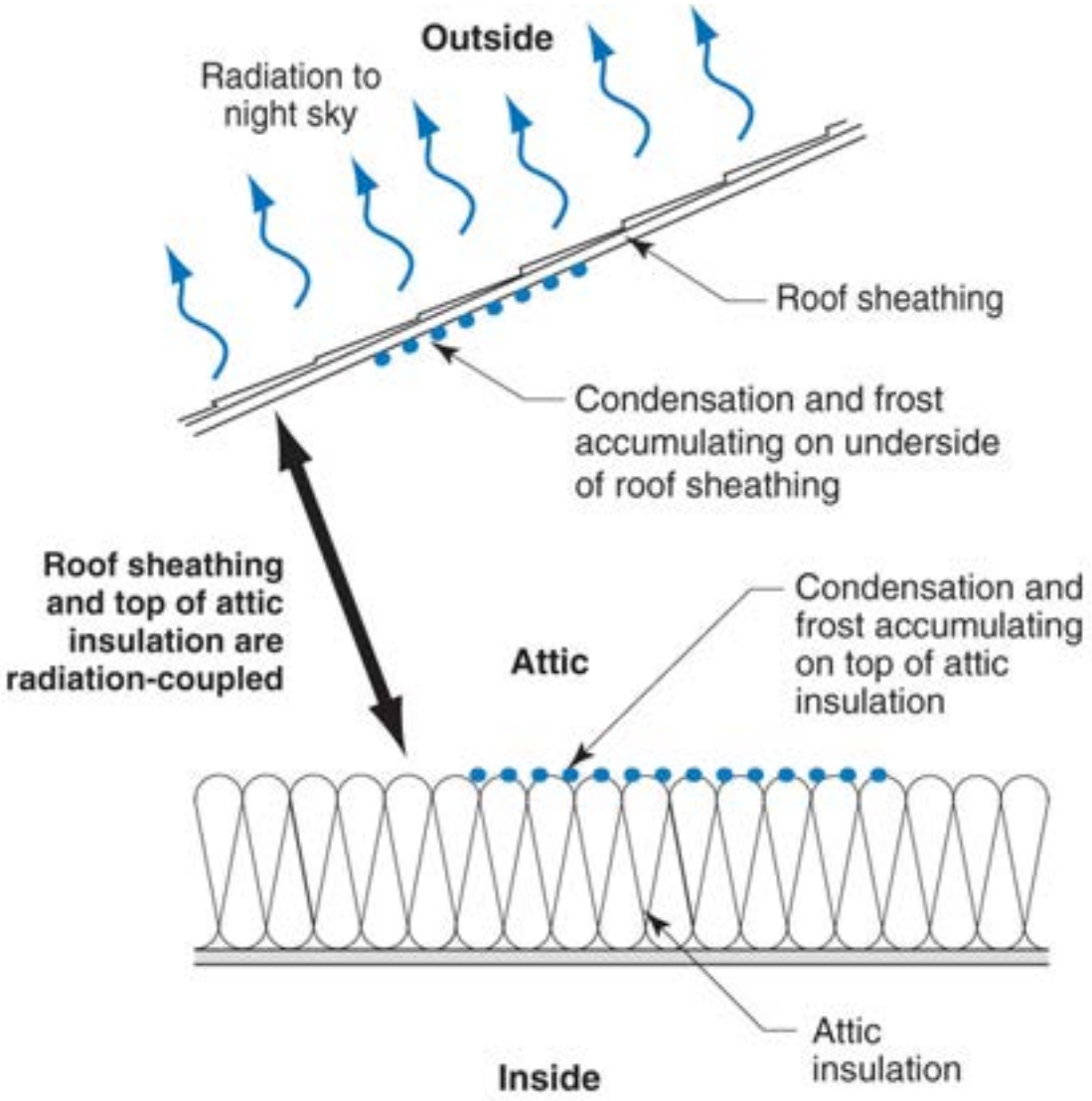
Vancouver Mold

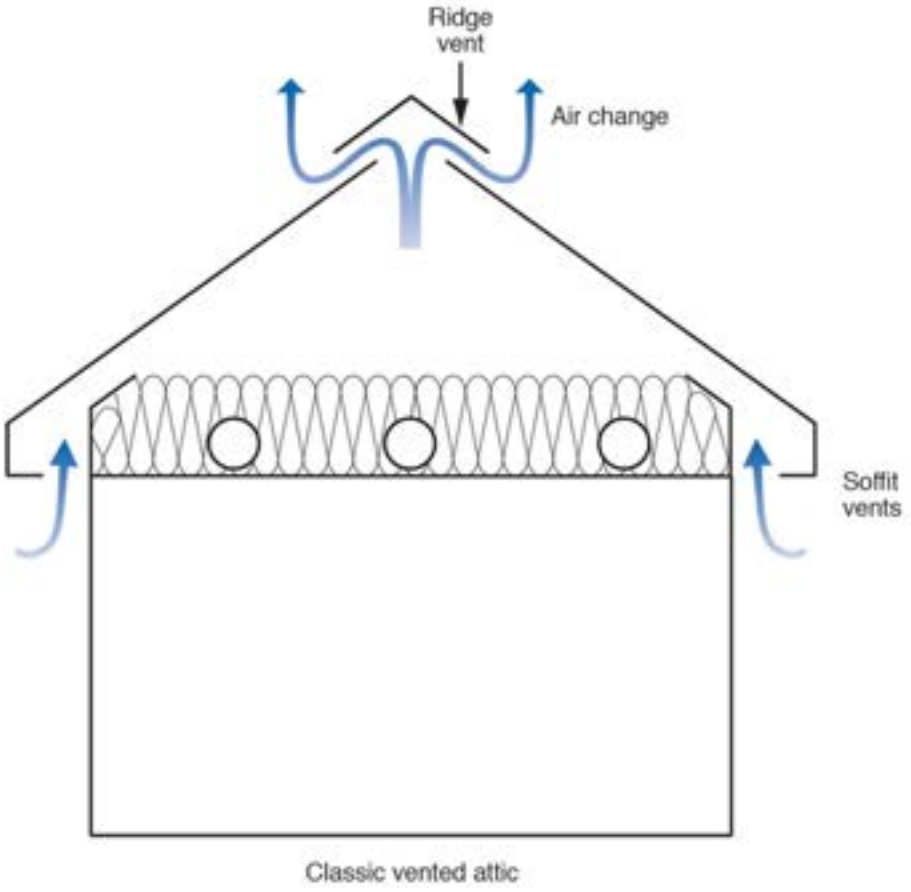


A: Single-layer of adsorbed molecules
B: Multiple layers of adsorbed molecules
C: Interconnected layers (internal capillary condensation
D: Free water in Pores, capillary suction
E: Supersaturated Regime

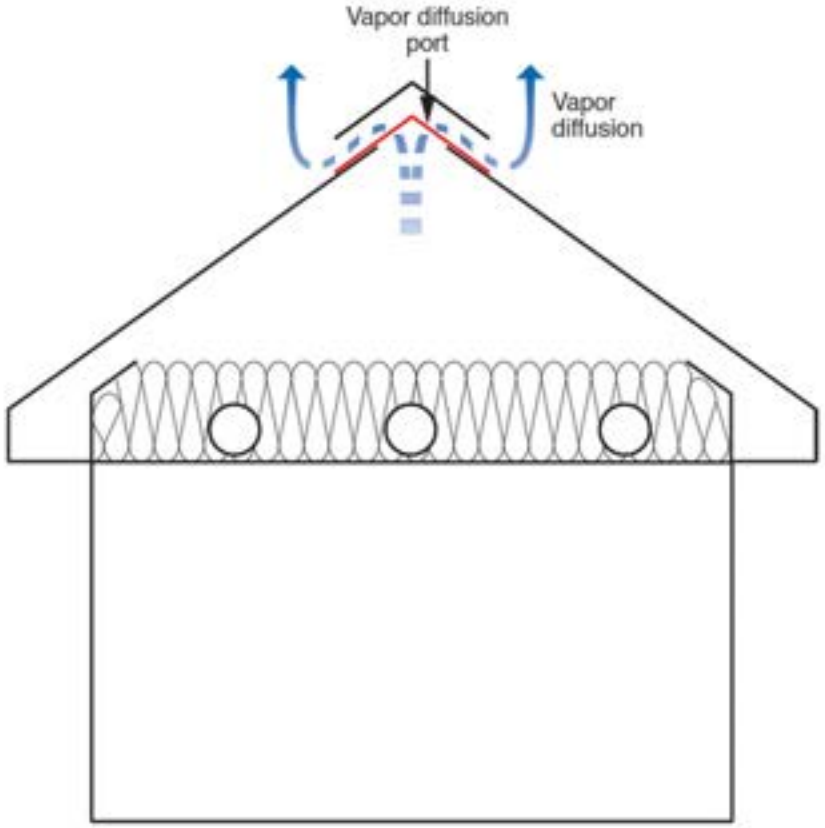
Regimes of moisture storage in a hygroscopic porous material
From Straube & Burnett, 2005


Vapor Pressure
Relative Humidity
Relative Humidity
Vapor Pressure
Night
Day
Night

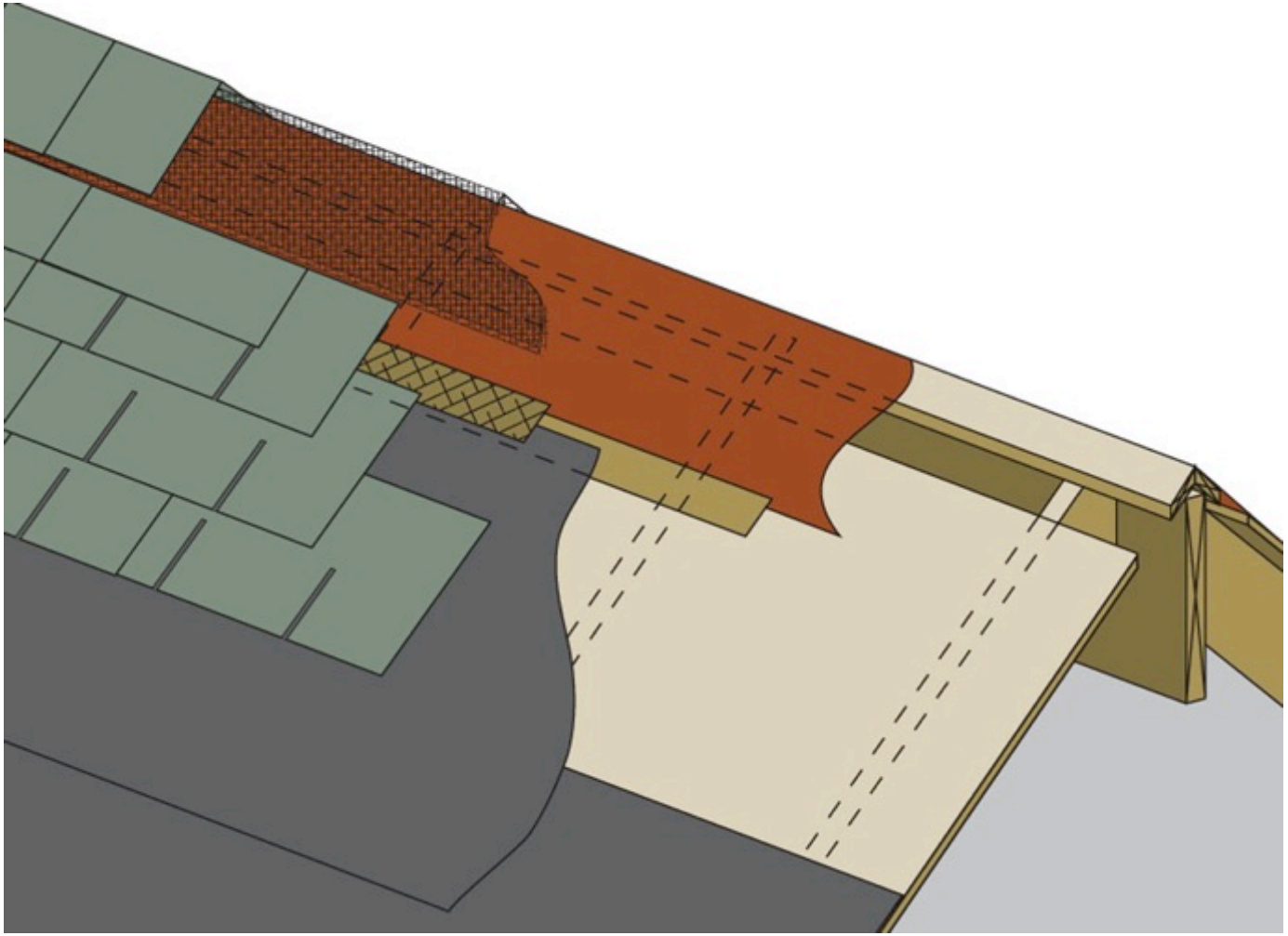

Outside
Radiation to night sky
Roof sheathing
Condensation and frost accumulating on underside of roof sheathing
Roof sheathing and top of attic insulation are radiation-coupled
Attic
Condensation and frost accumulating on top of attic insulation
Attic insulation
Inside

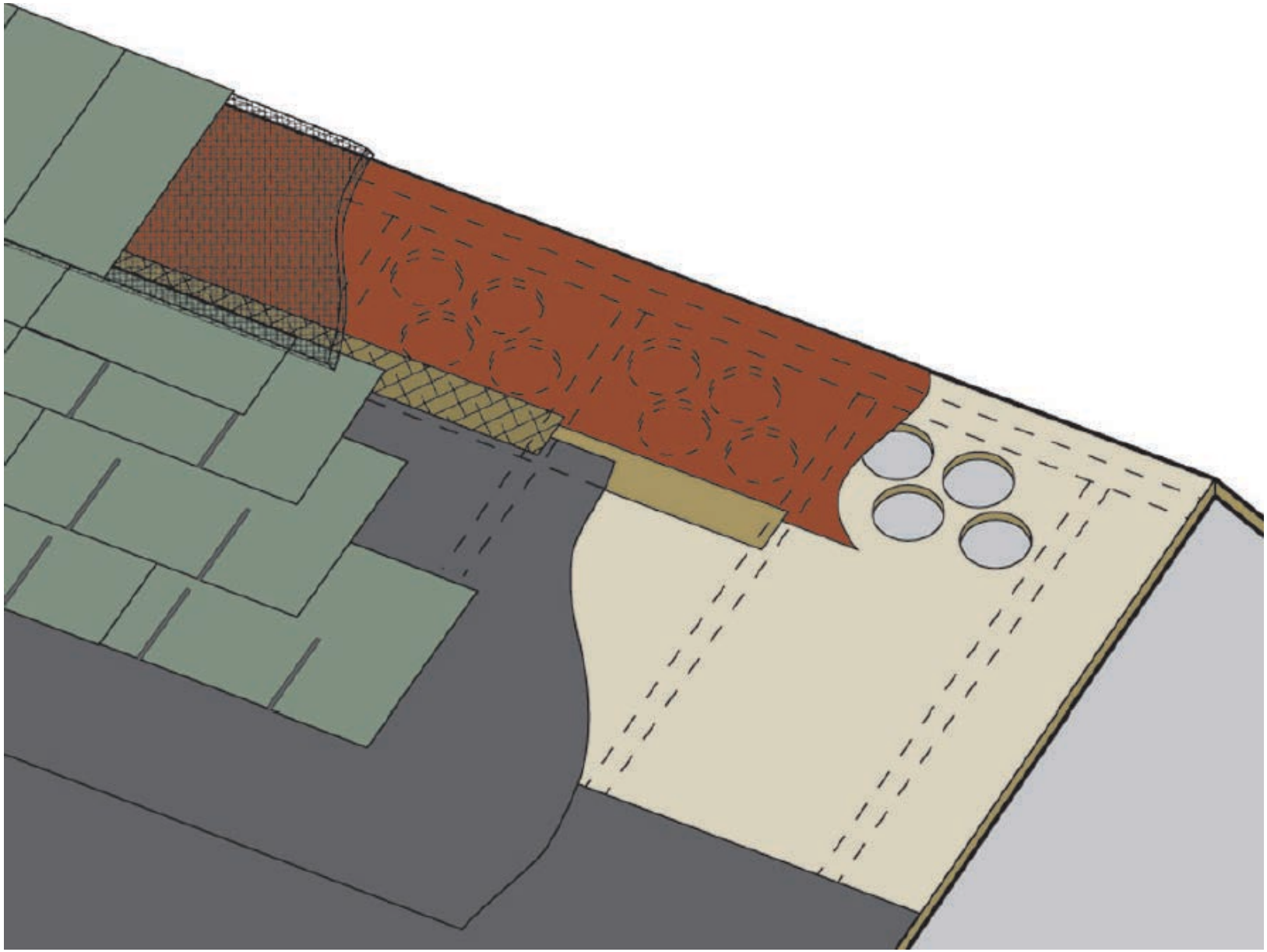


Classic vented attic



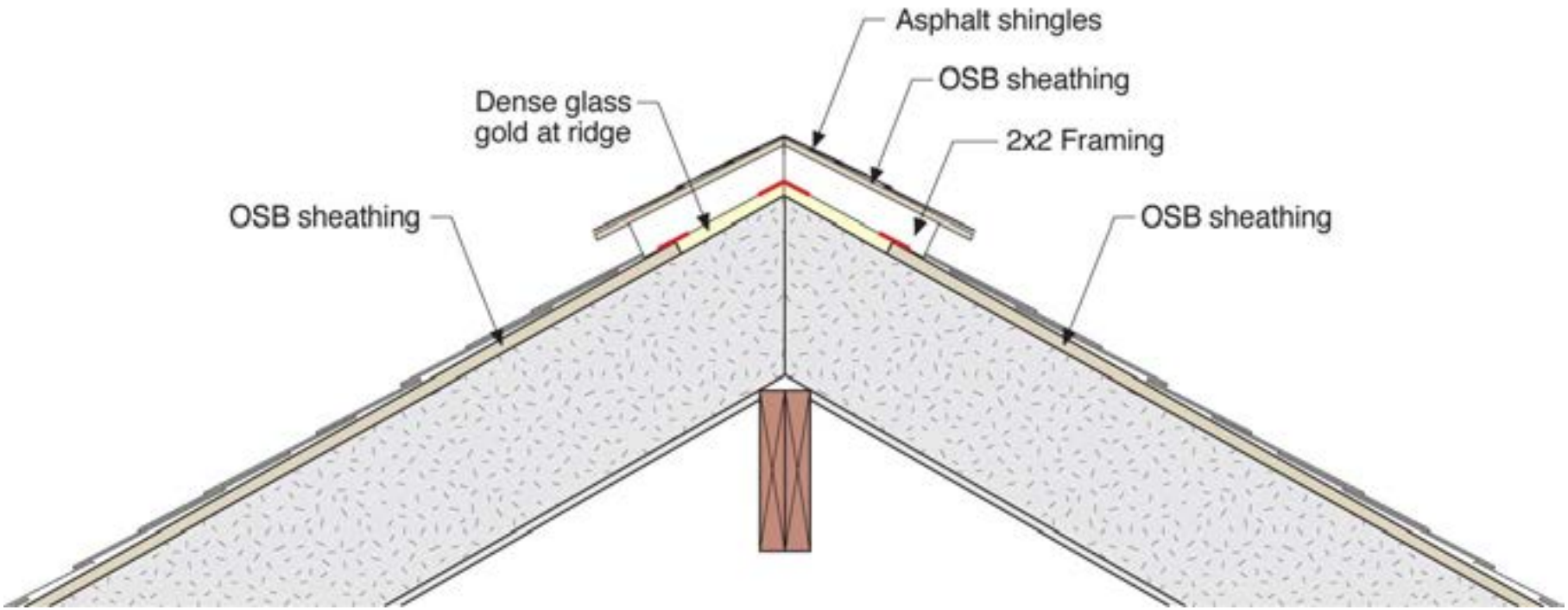
Unvented attic with vapor diffusion port



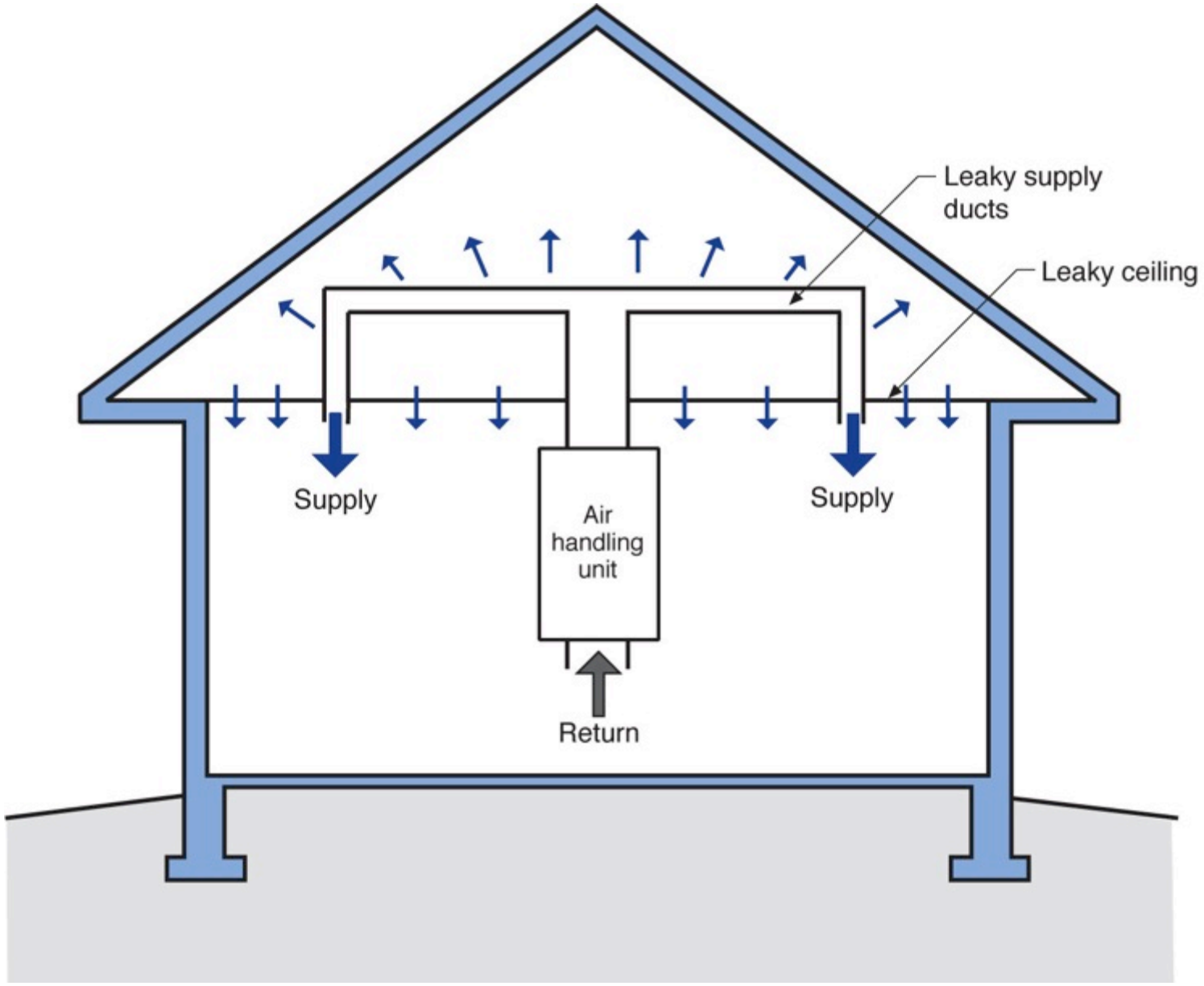



DELTA
DELTA
DELTA


3M


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

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

Conditioned Attics Not Unvented Attics

Need Supply Air

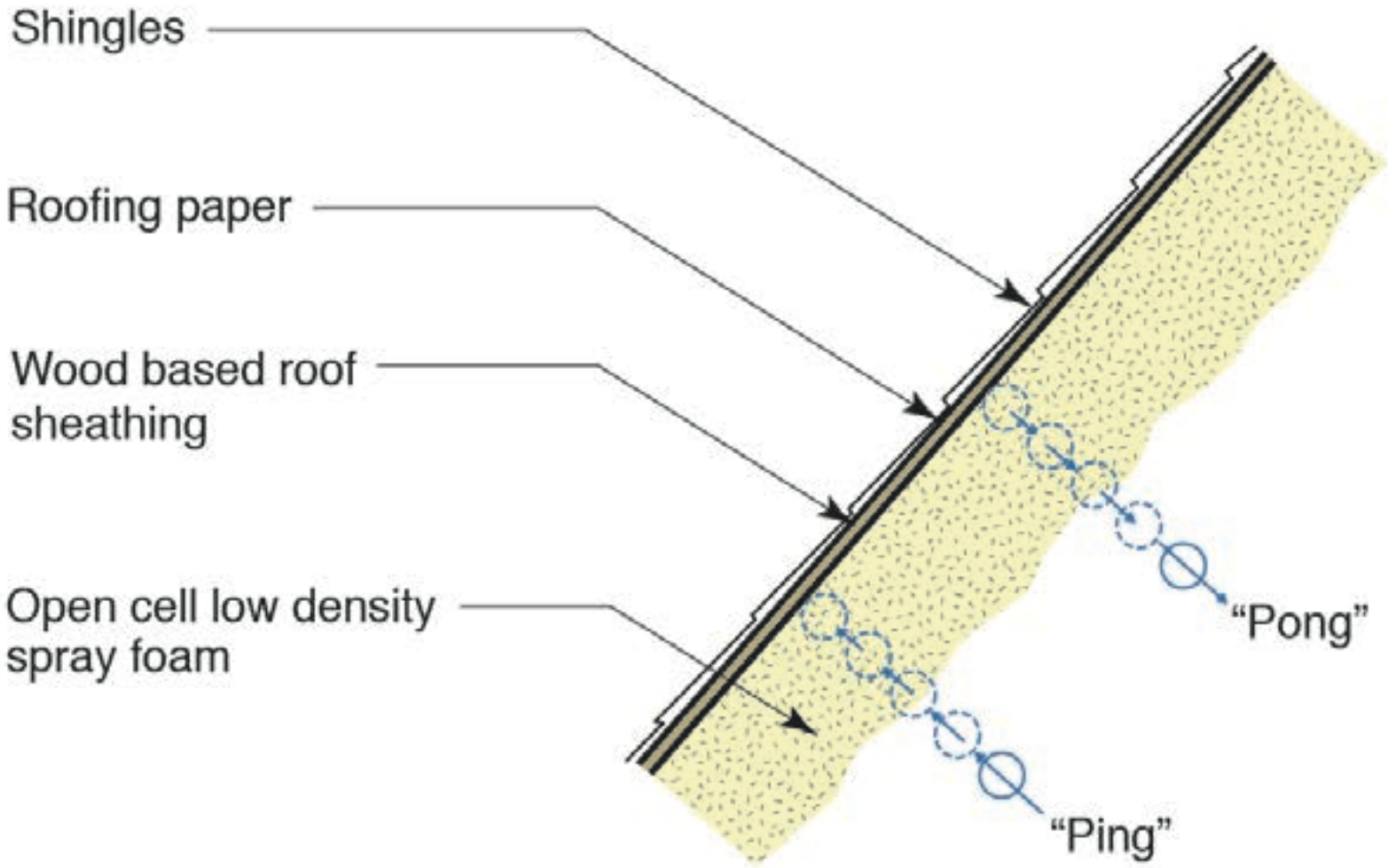
50 cfm/1000 ft2 of Attic

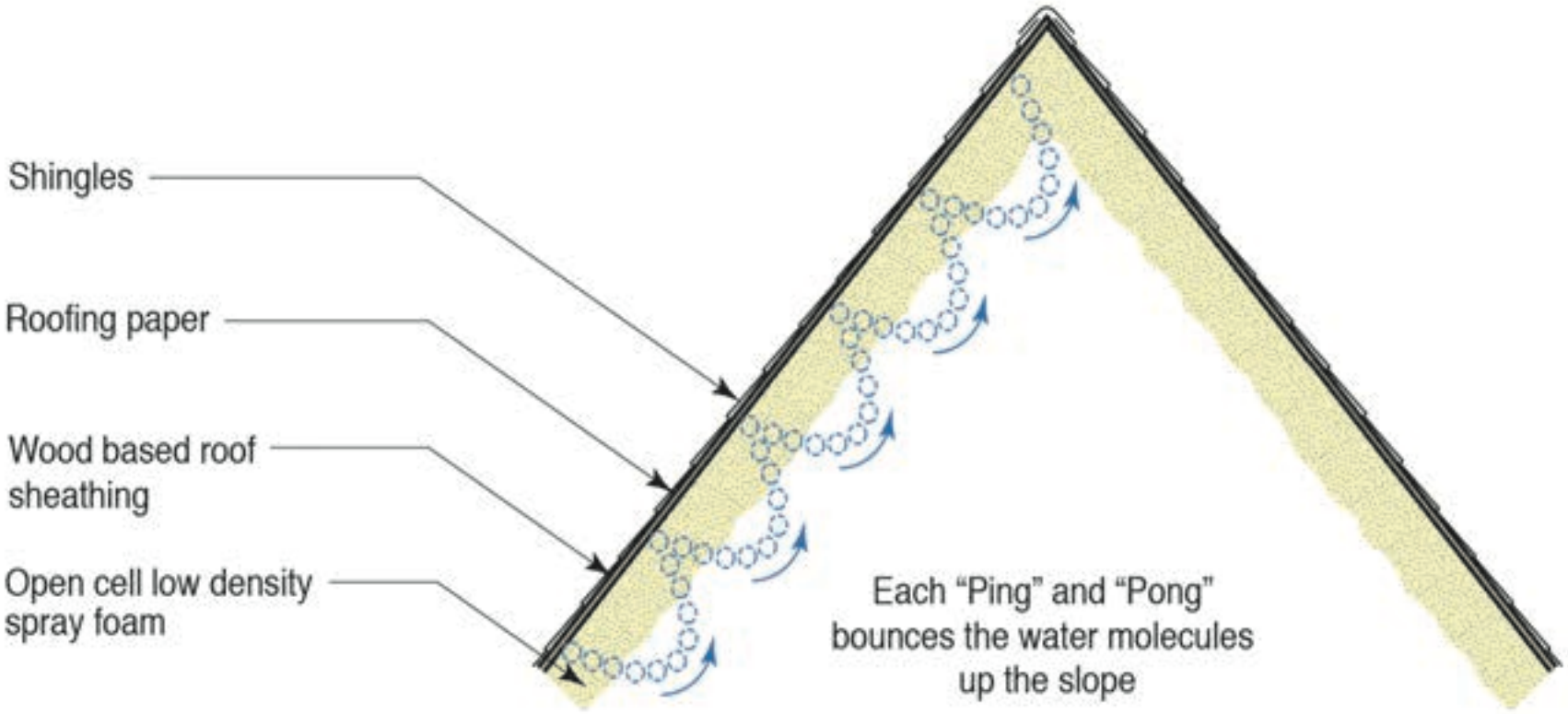
Or

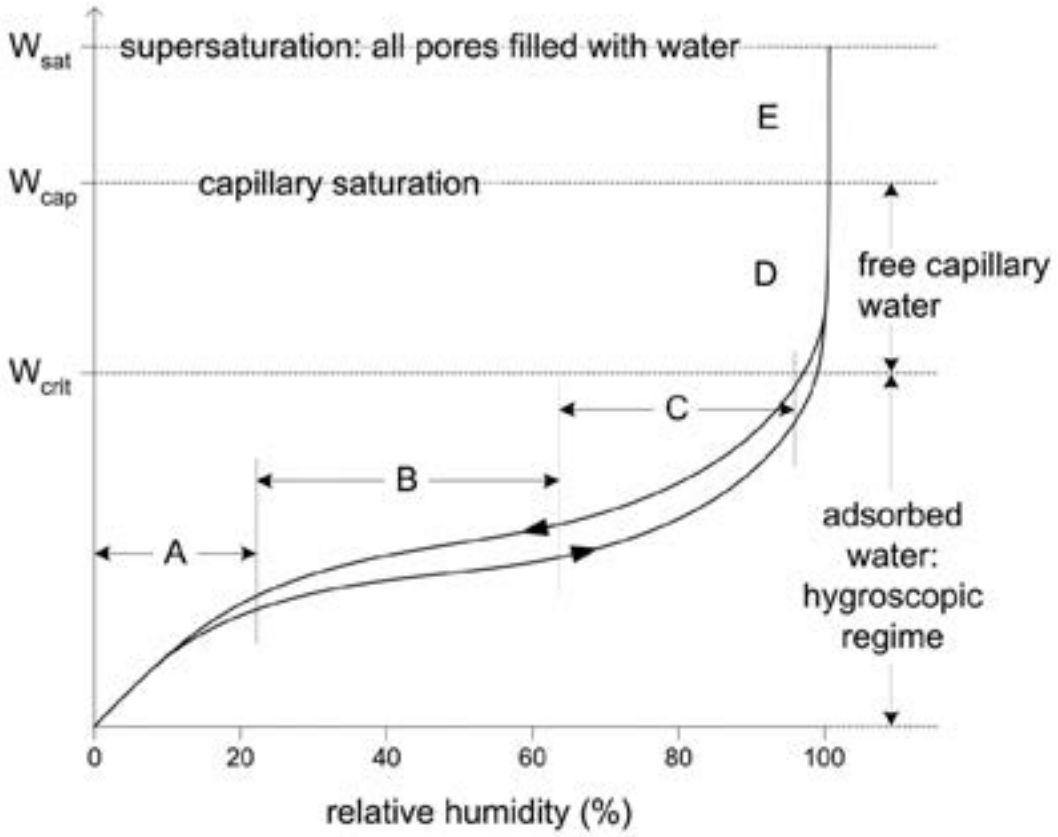
Dehumidification

Low-Density Open-Cell Foam Is The Problem

Ping Pong Water

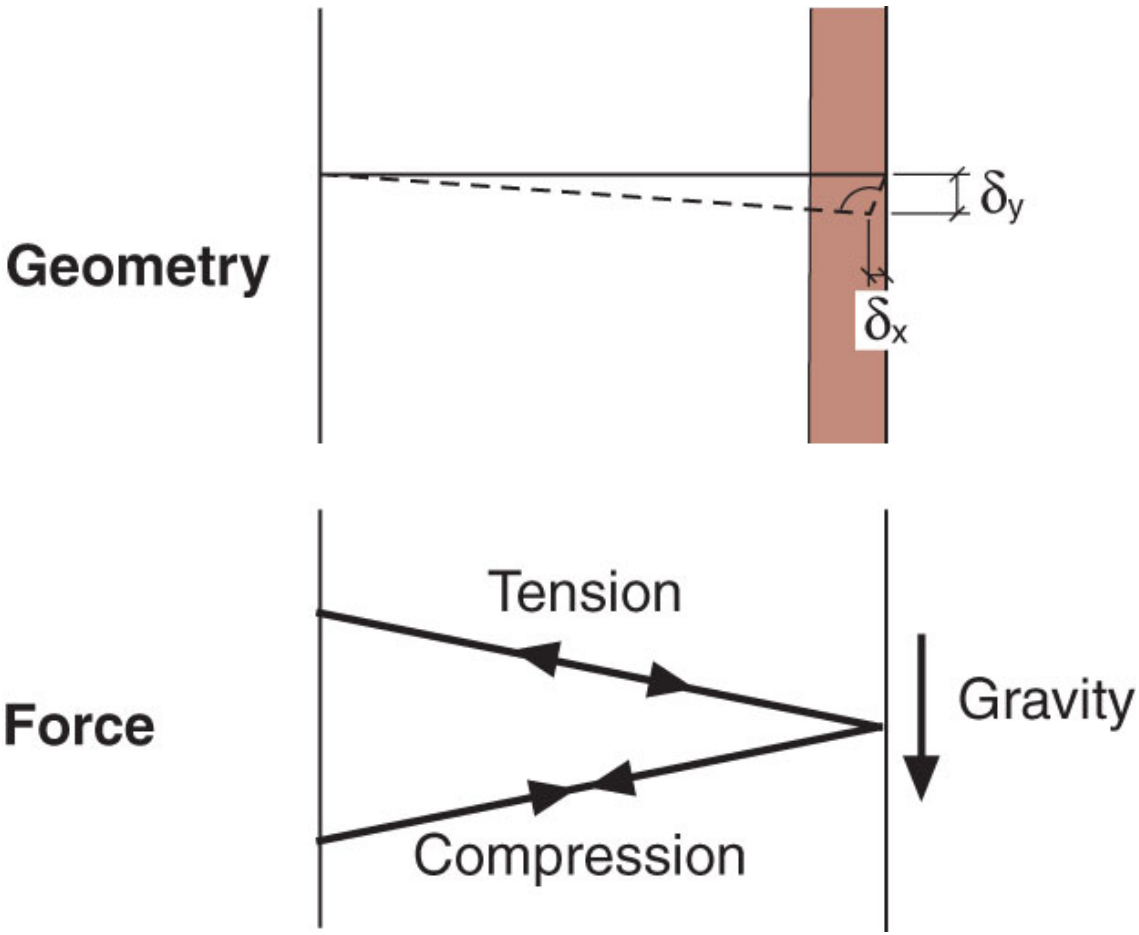

Shingles
Roofing paper
Wood based roof sheathing
Open cell low density spray foam
"Pong"
"Ping"


Shingles
Roofing paper
Wood based roof sheathing
Open cell low density spray foam
Each "Ping" and "Pong" bounces the water molecules up the slope



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

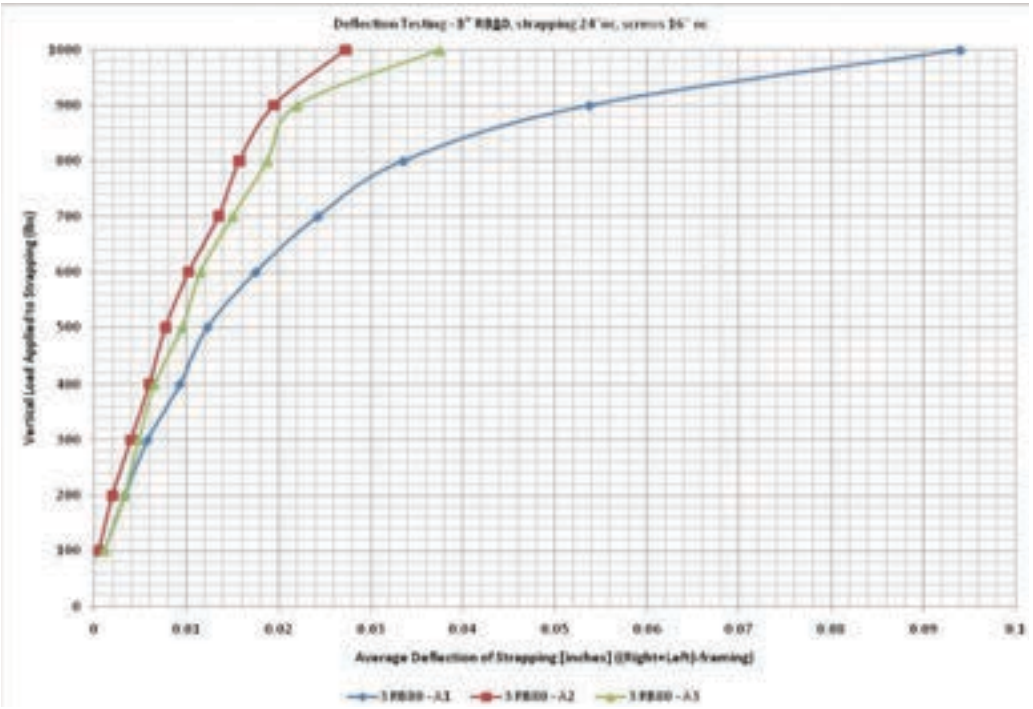
Regimes of moisture storage in a hygroscopic porous material
From Straube & Burnett, 2005

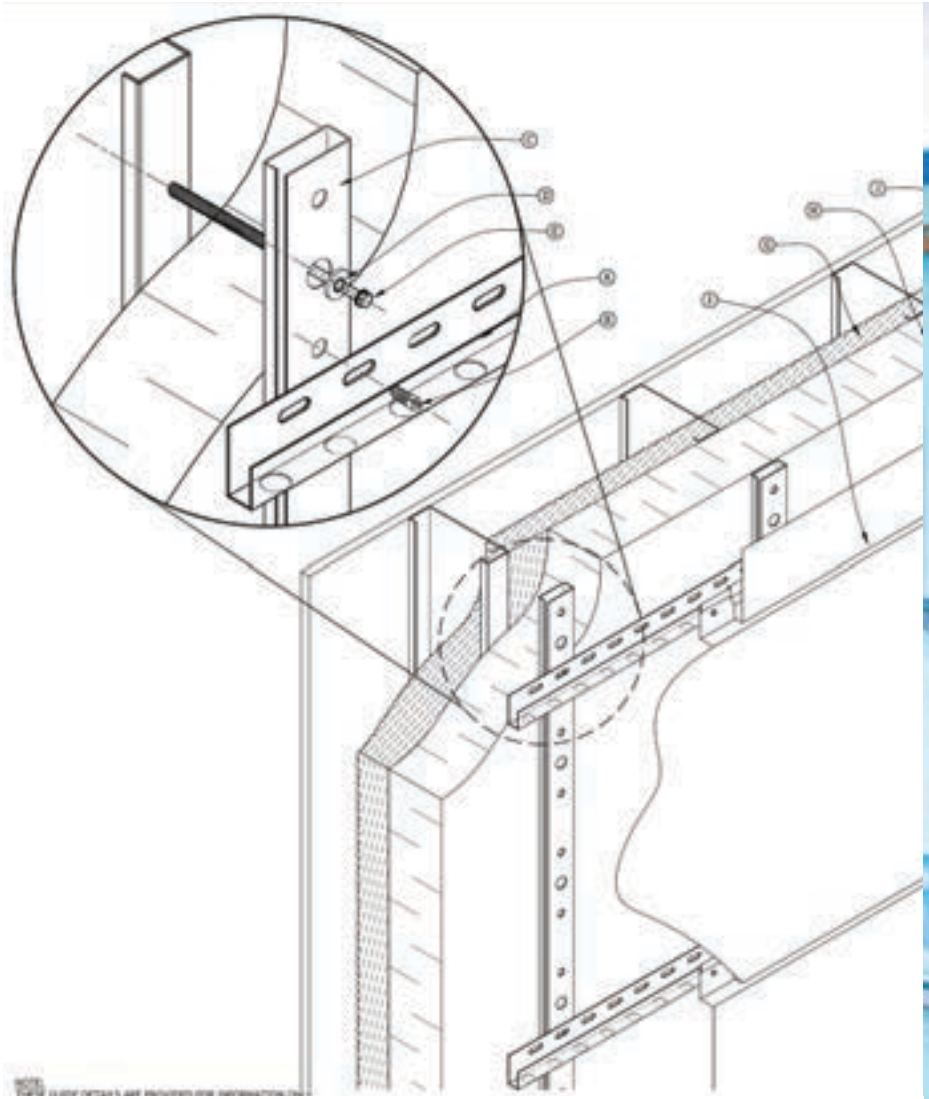

Geometry
δy
δx
Force
Tension
Gravity
Compression


PlastiSpan HD
R8
PlastiSpan HD
R8
PlastiSpan HD
PlastiSpan HD

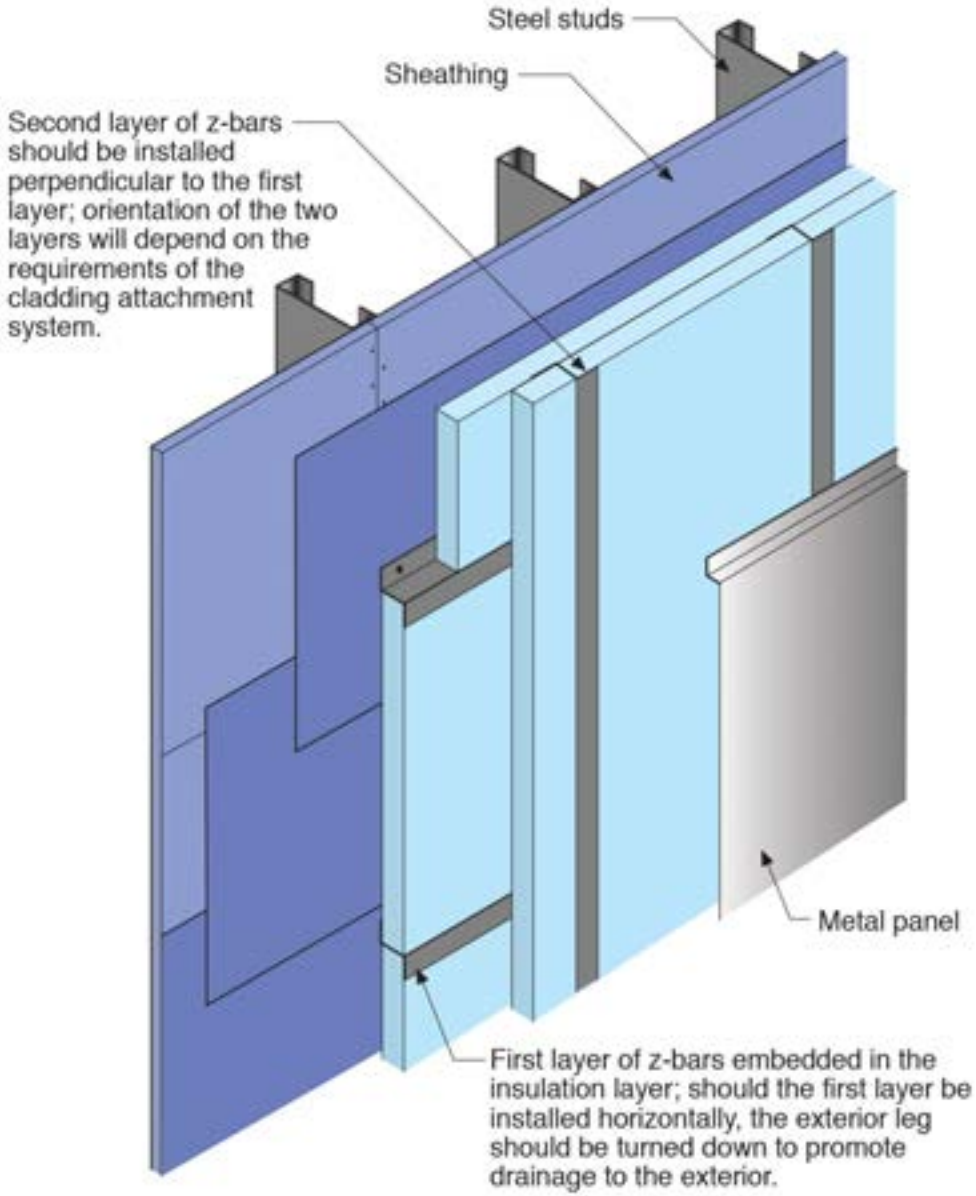
Rockwool

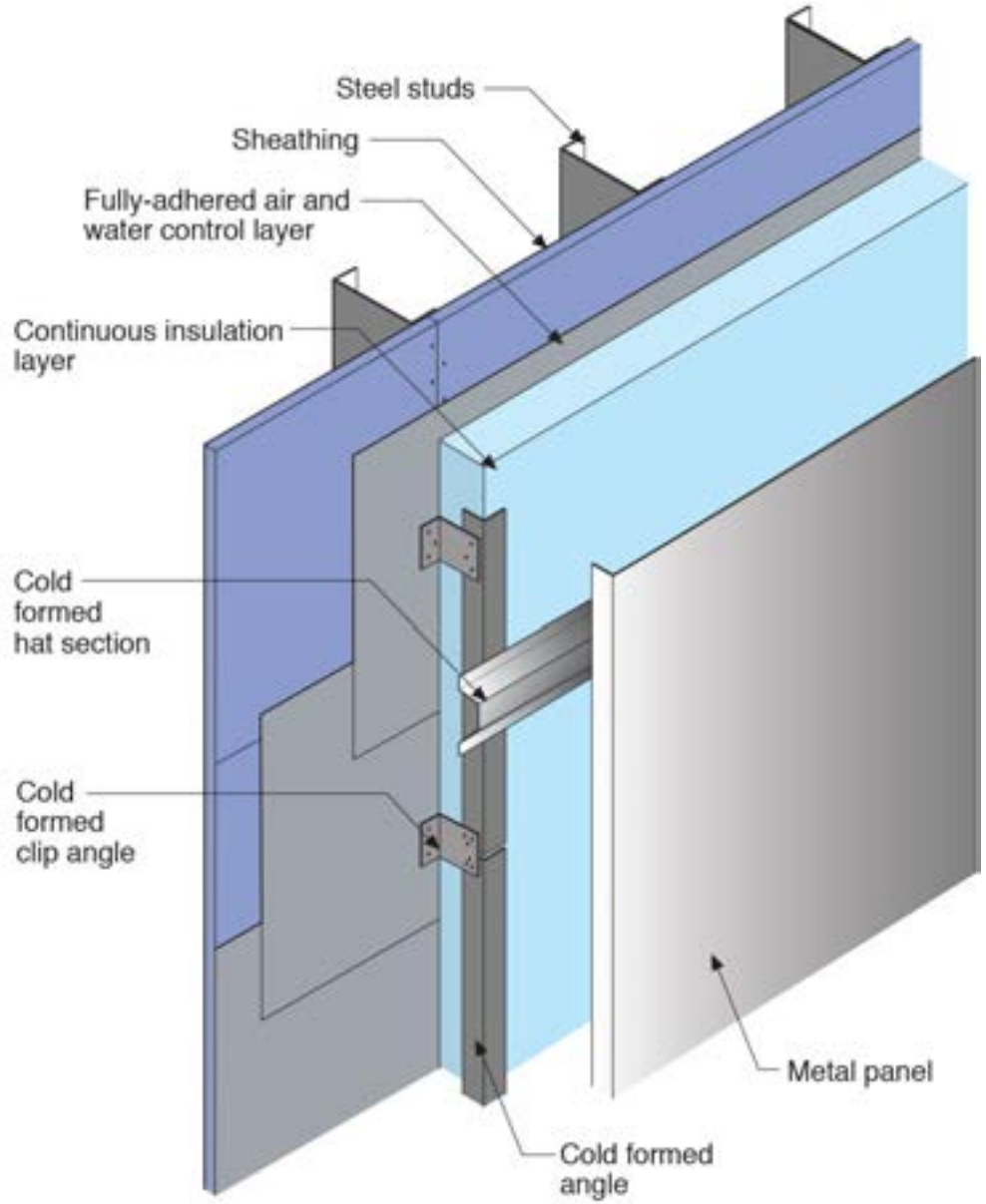
1x3 furring @ 24” o.c.
#10 screws @ 16” o.c. vertically
Result: 20 psf cladding weight
with < 2/100” deflection

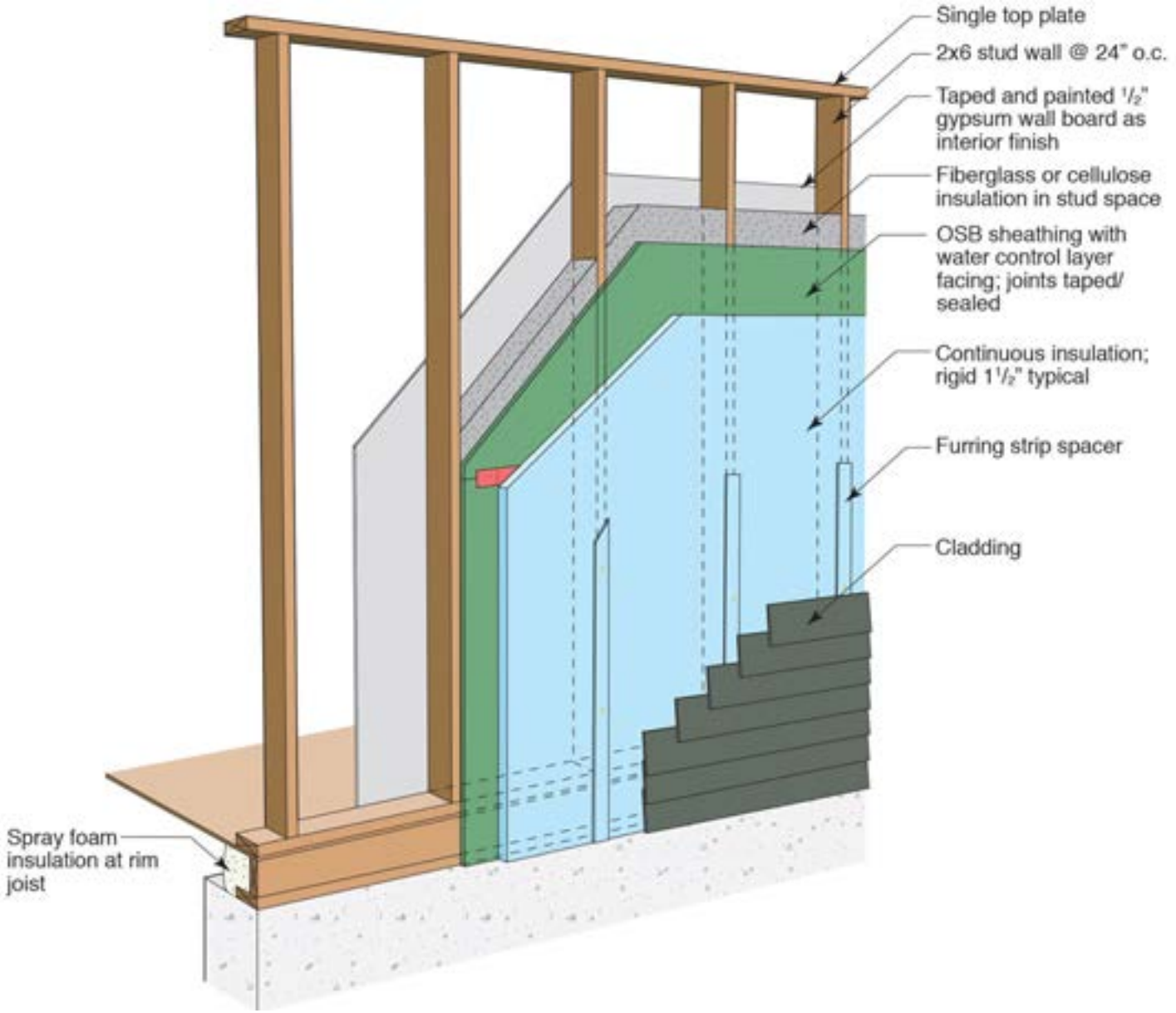


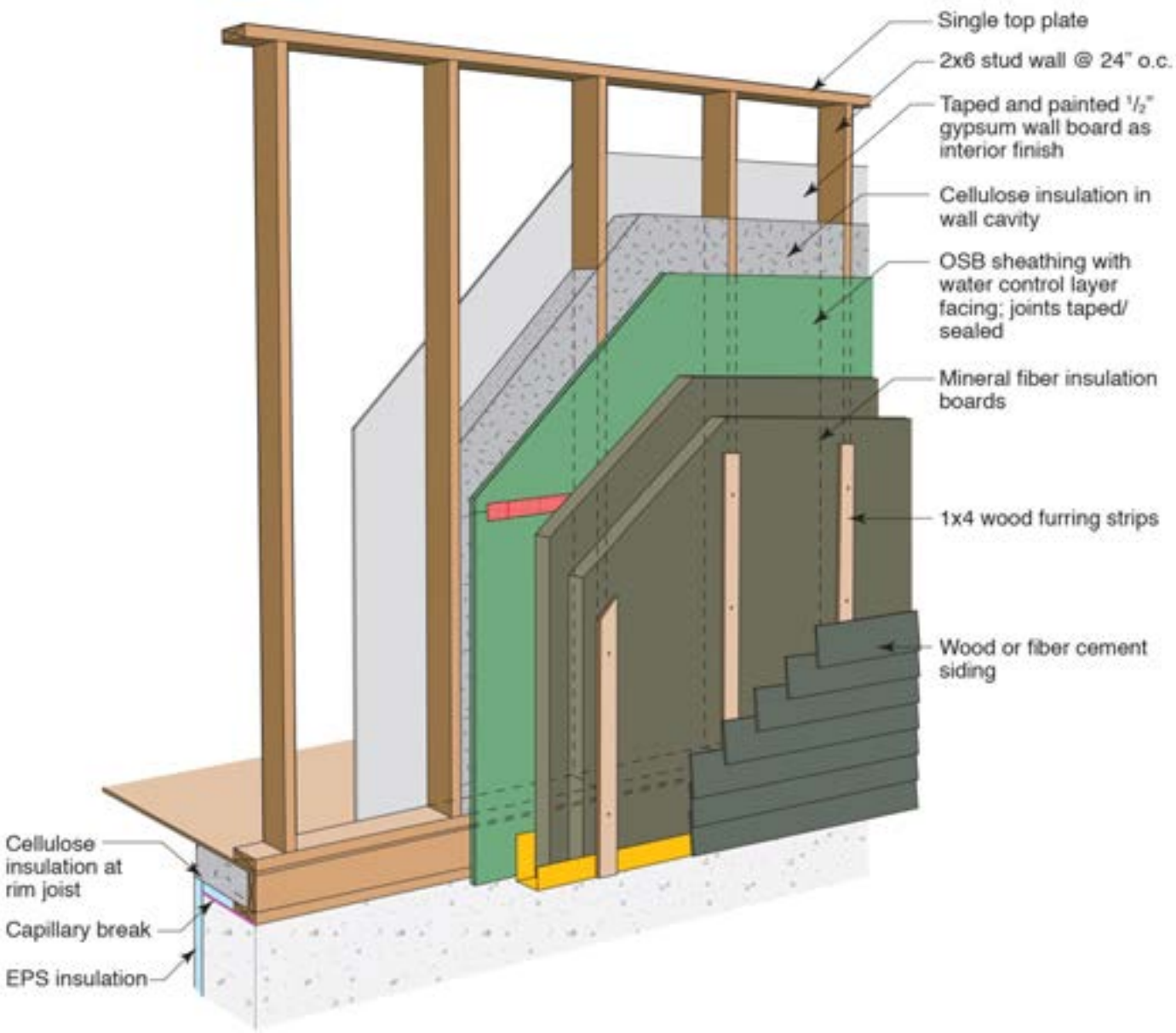



DOW
Thermax ci
Exterior Insulation


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


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


Single top plate
2x6 stud wall @ 24" o.c.
Taped and painted ½" gypsum wall board as interior finish
Fiberglass or cellulose insulation in stud space
OSB sheathing with water control layer facing; joints taped/ sealed
Continuous insulation; rigid 1½" typical
Furring strip spacer
Cladding
Spray foam insulation at rim joist


Single top plate
2x6 stud wall @ 24" o.c.
Taped and painted ½" gypsum wall board as interior finish
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

Where Is The Water Control Layer?

Where Is The Water Control Layer?

Behind The Continuous Insulation?

Or The Face of The Continuous Insulation?

Where Is The Water Control Layer?

Behind The Continuous Insulation?

Or The Face of The Continuous Insulation?

Where Is The Window?

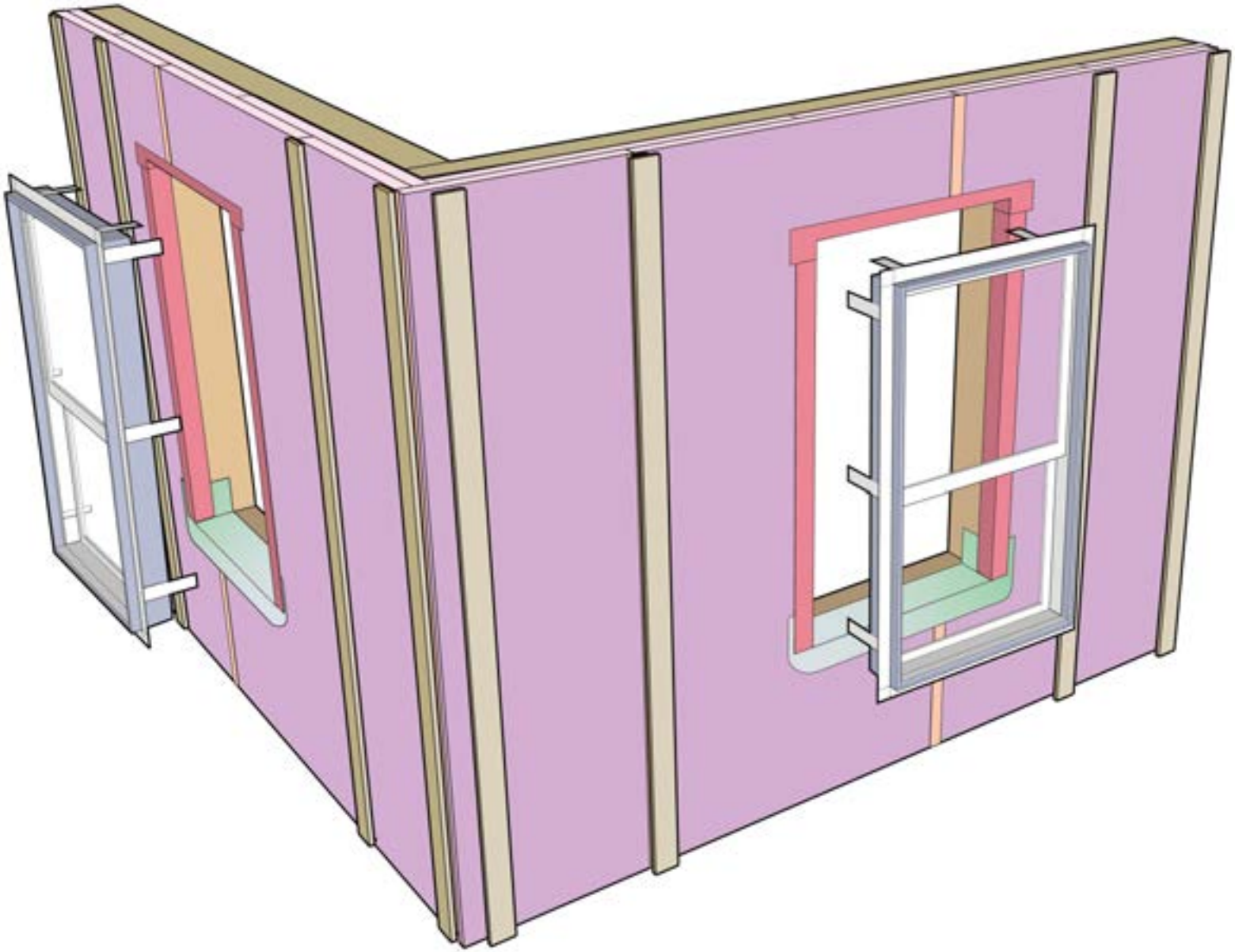
Where Is The Water Control Layer?

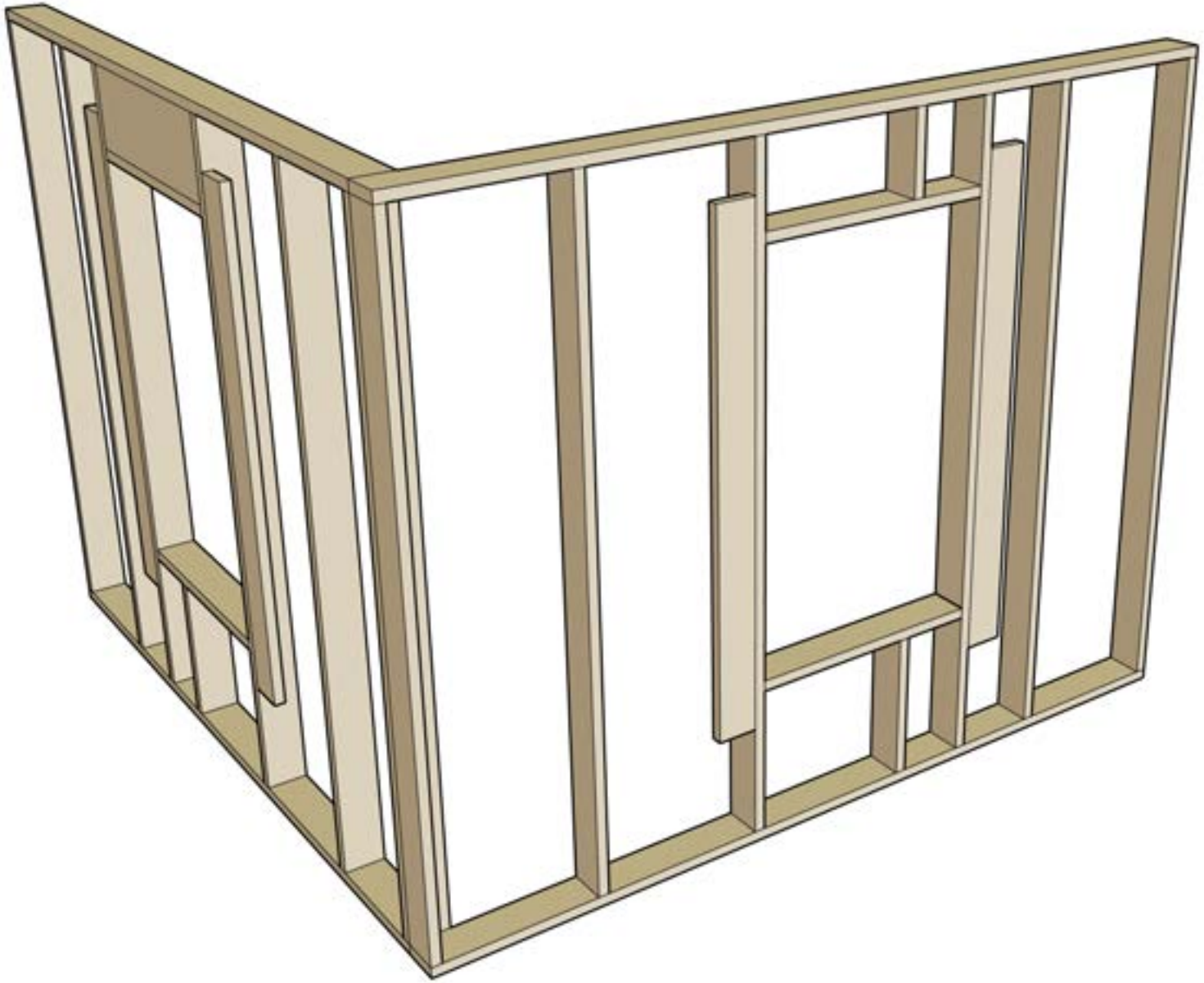
Behind The Continuous Insulation?

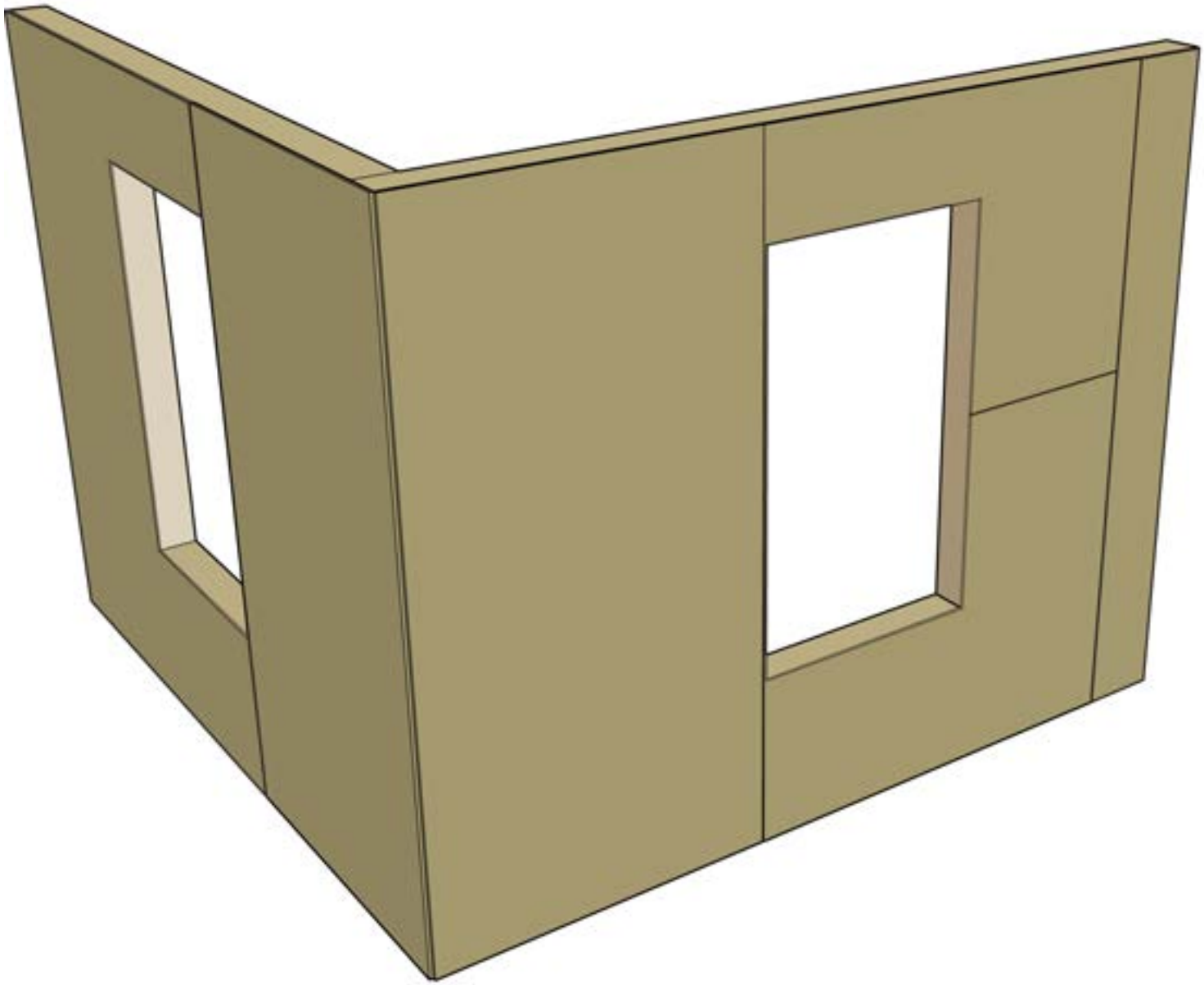
Or The Face of The Continuous Insulation?

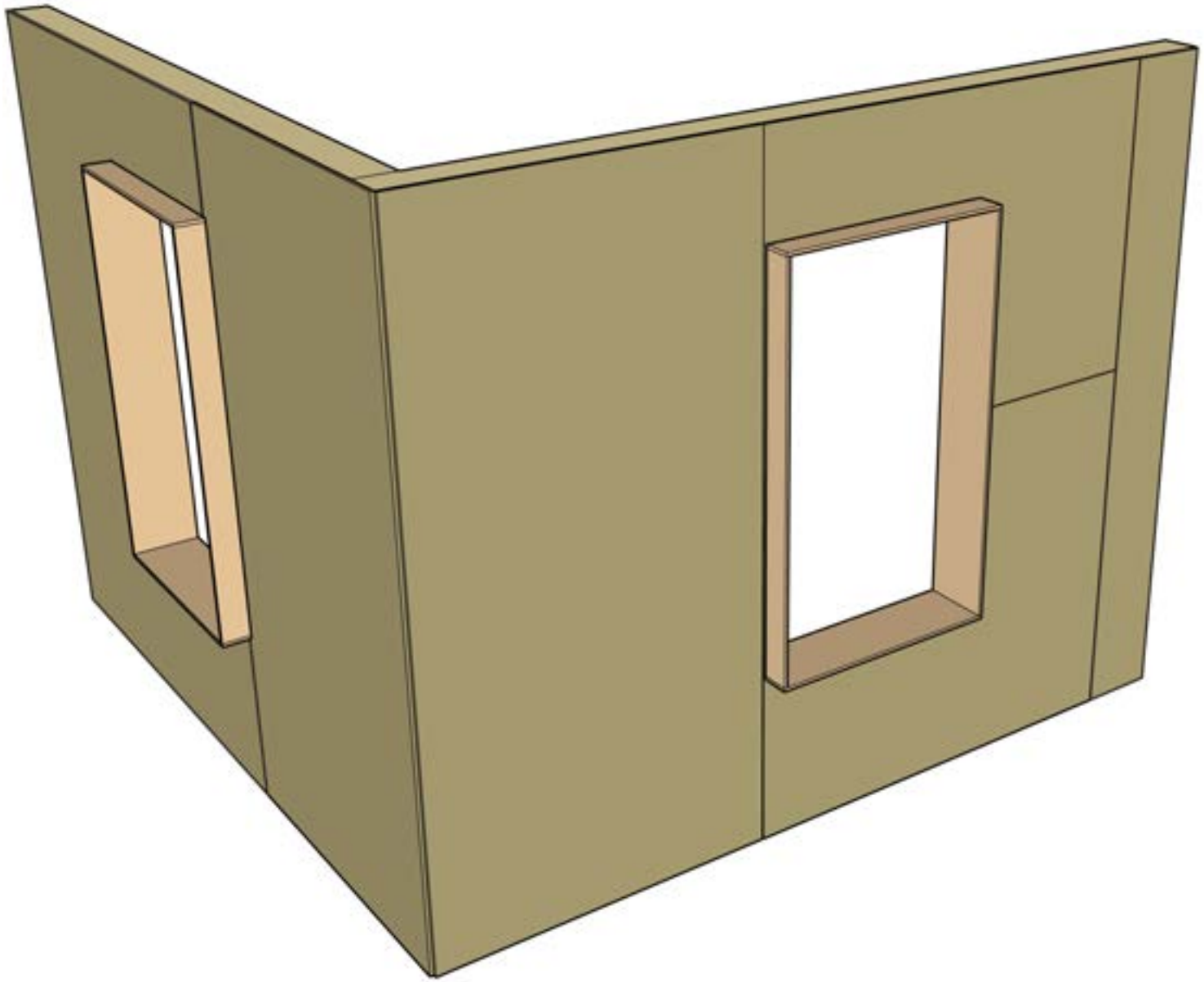
Where Is The Window?

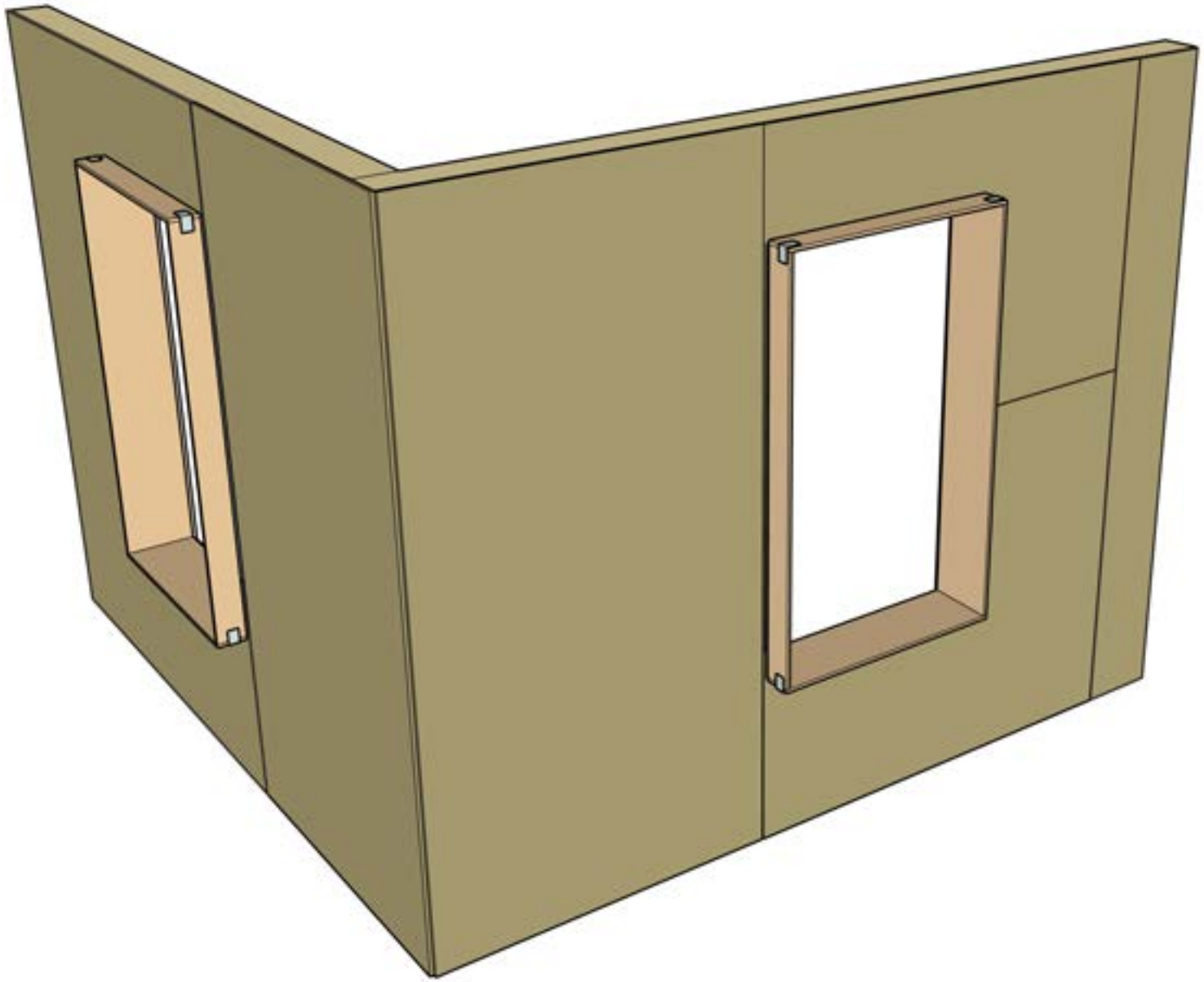
Is It An Innie Or Outie Or Tweeny?

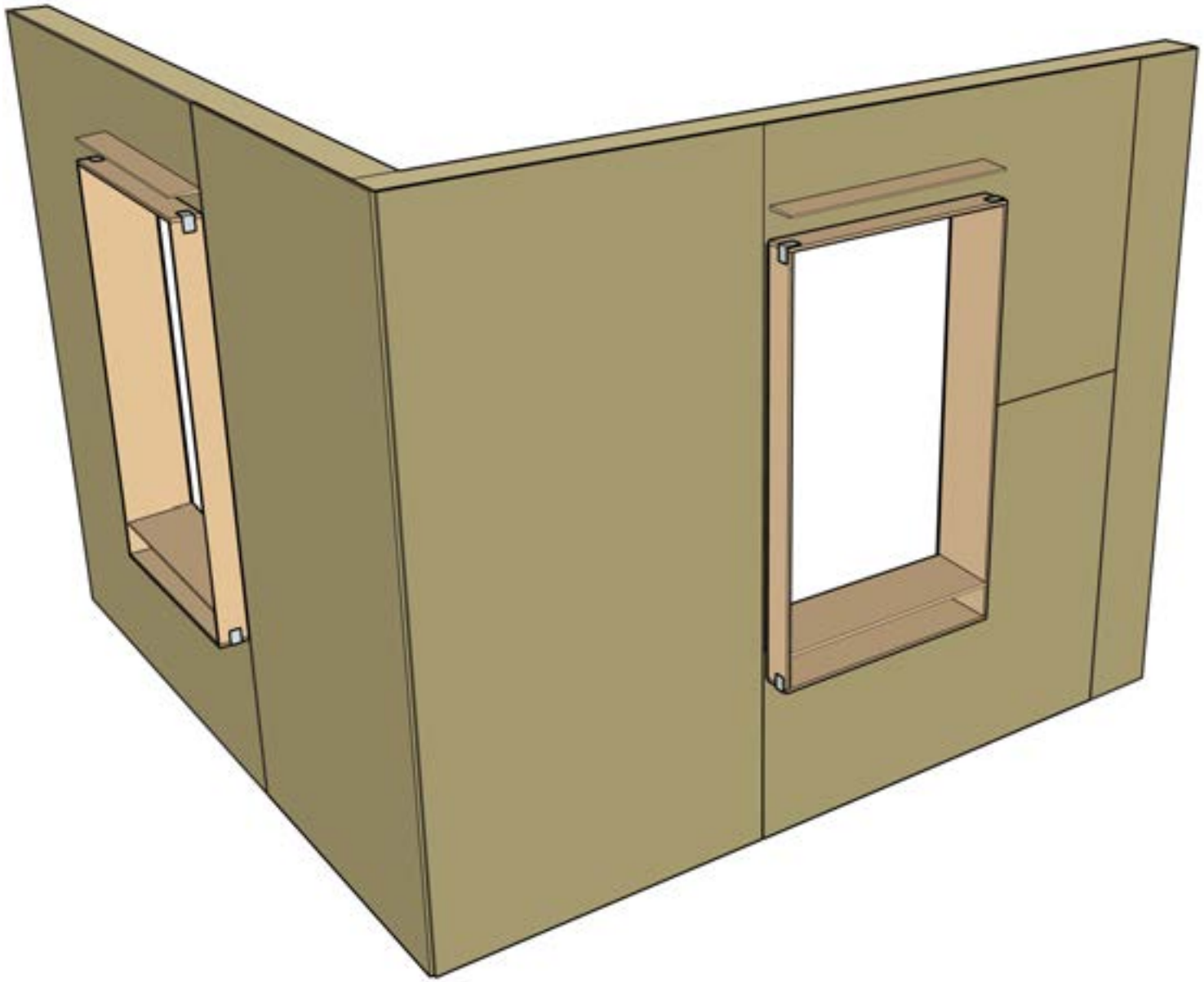


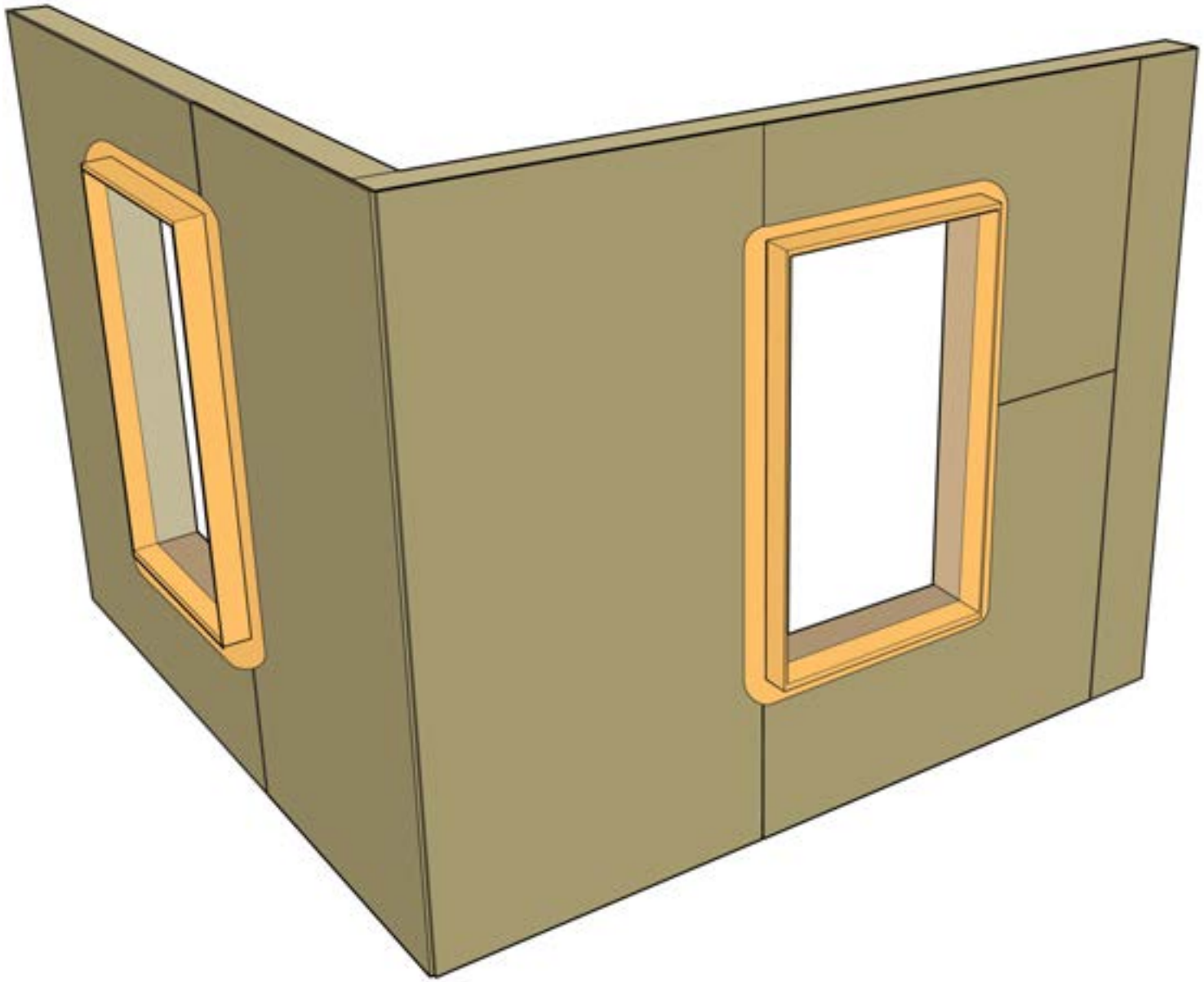


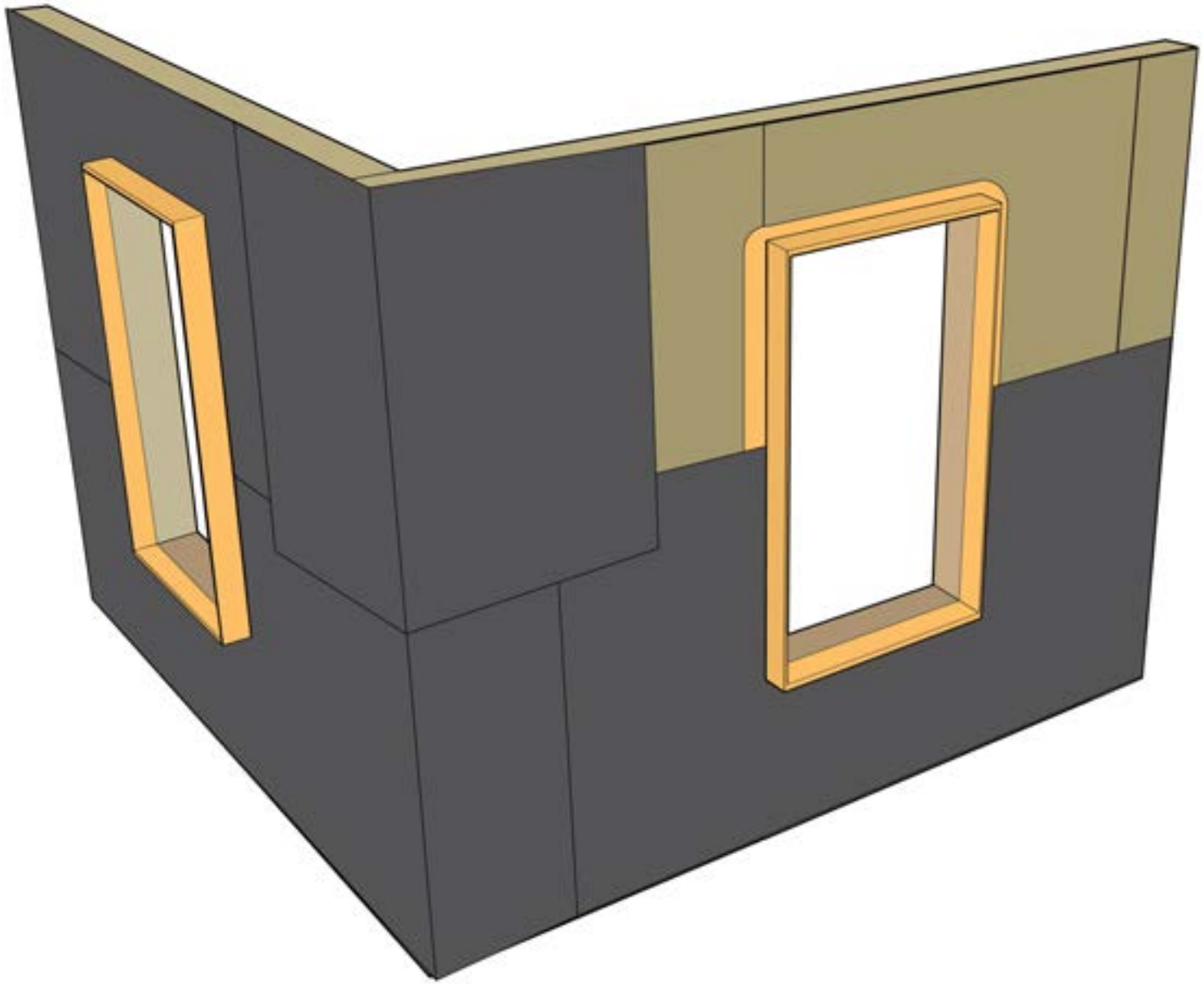


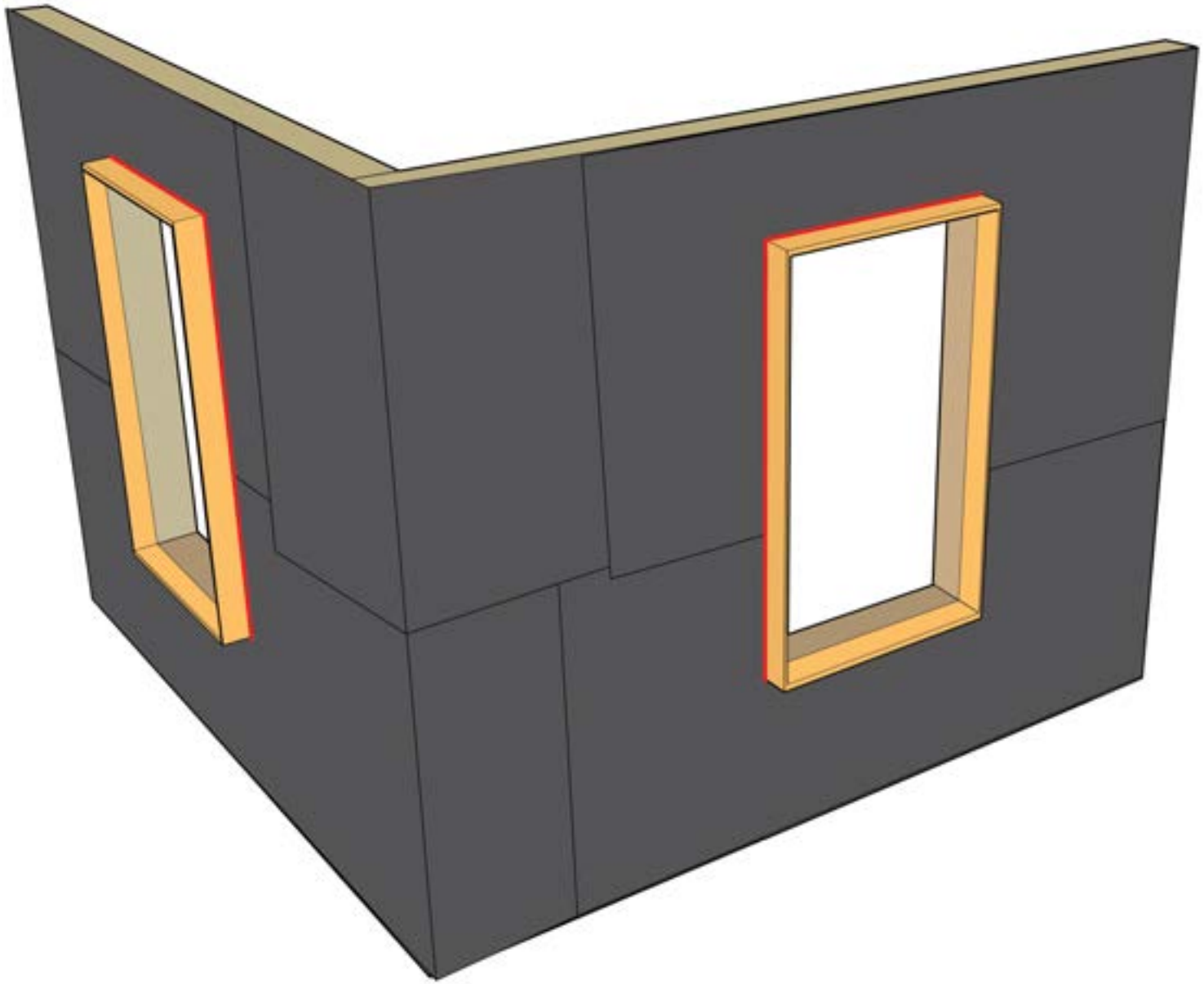


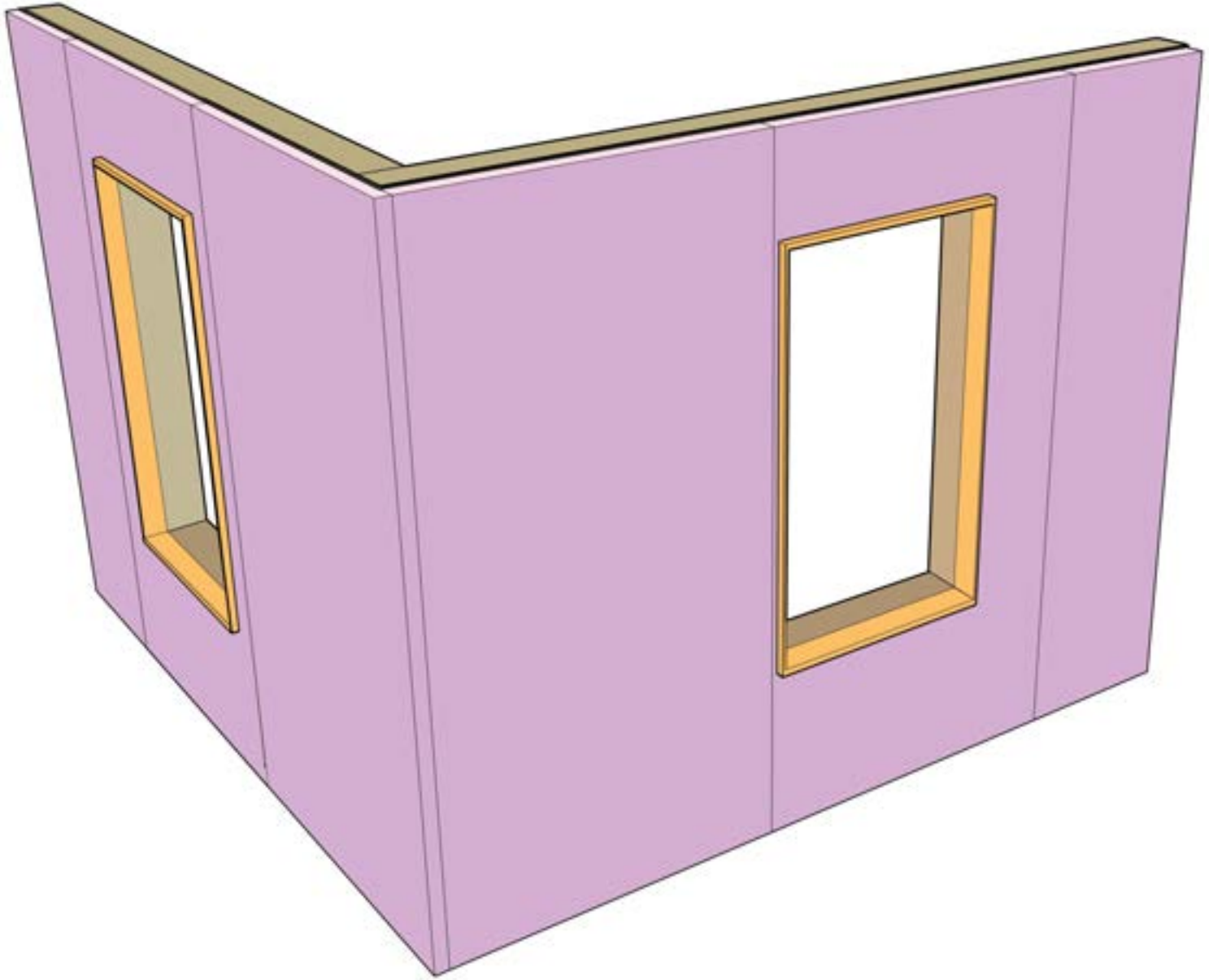


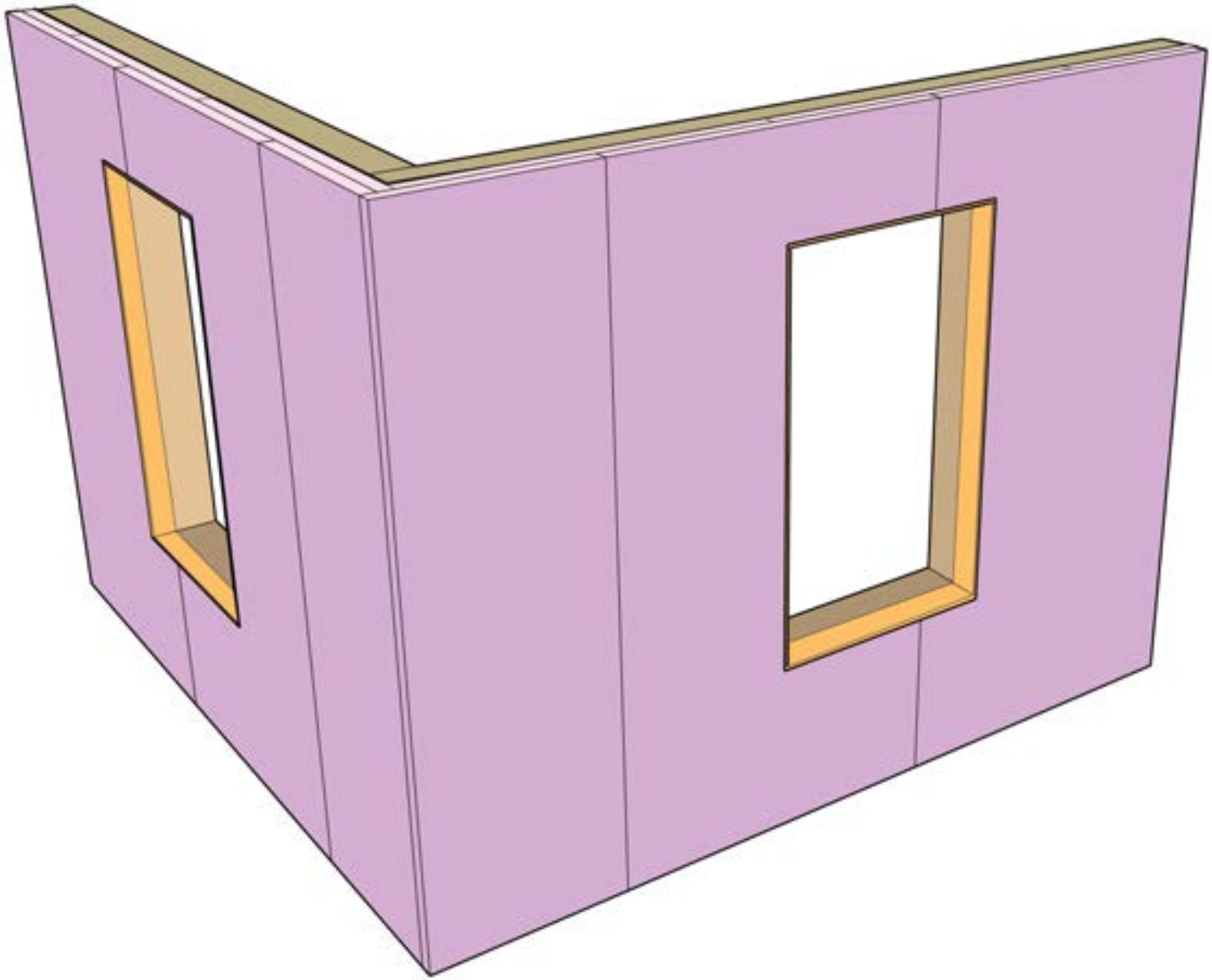


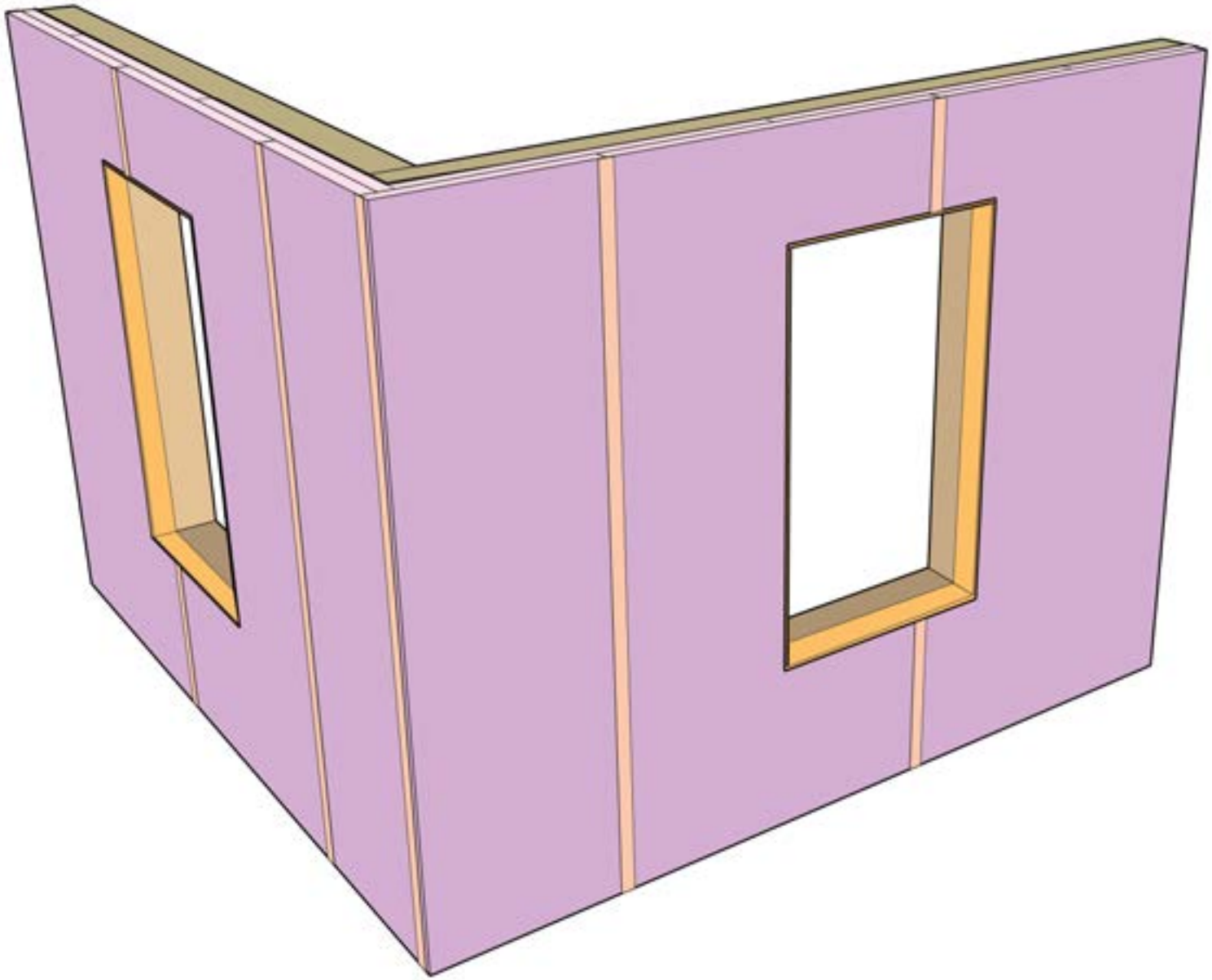


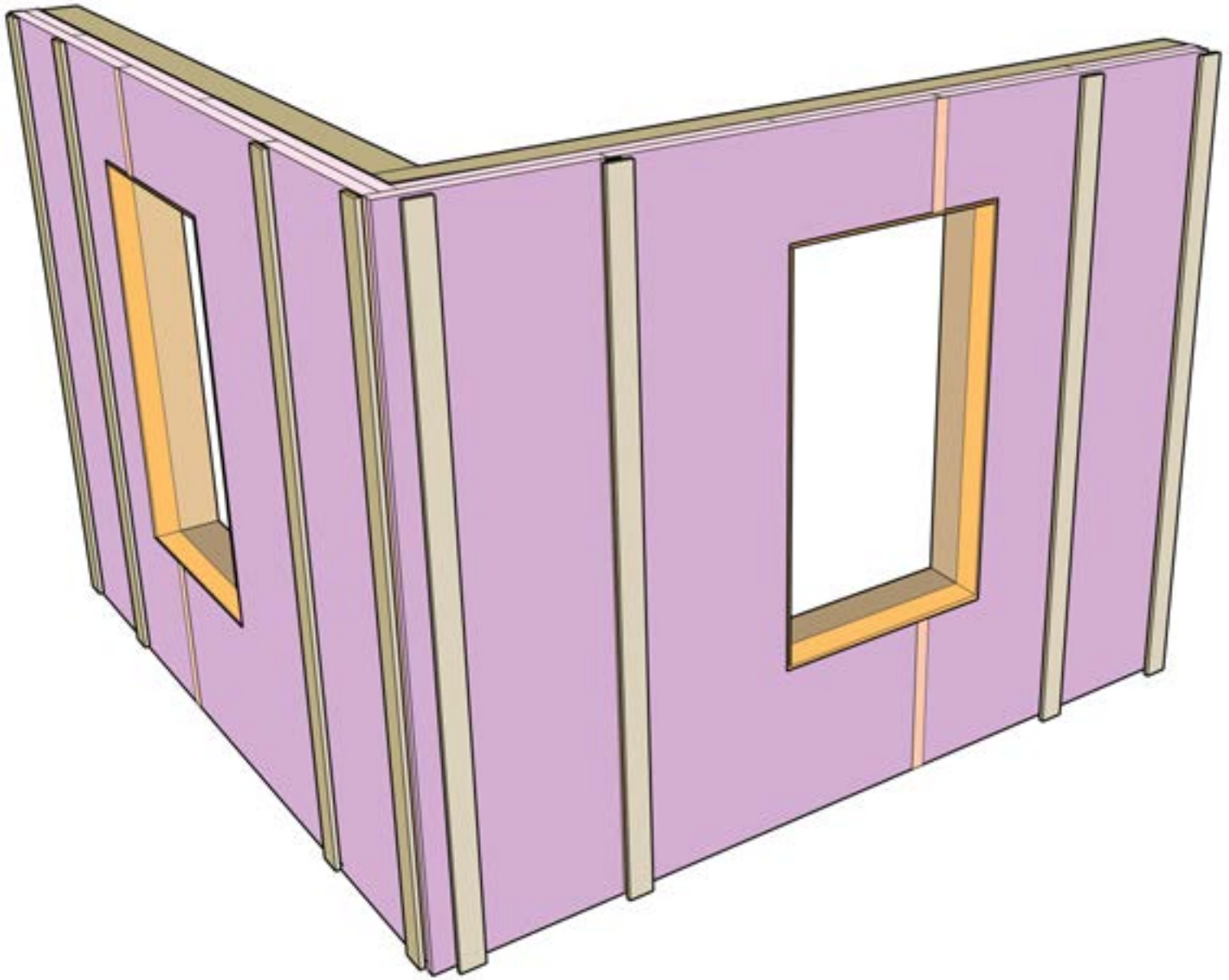


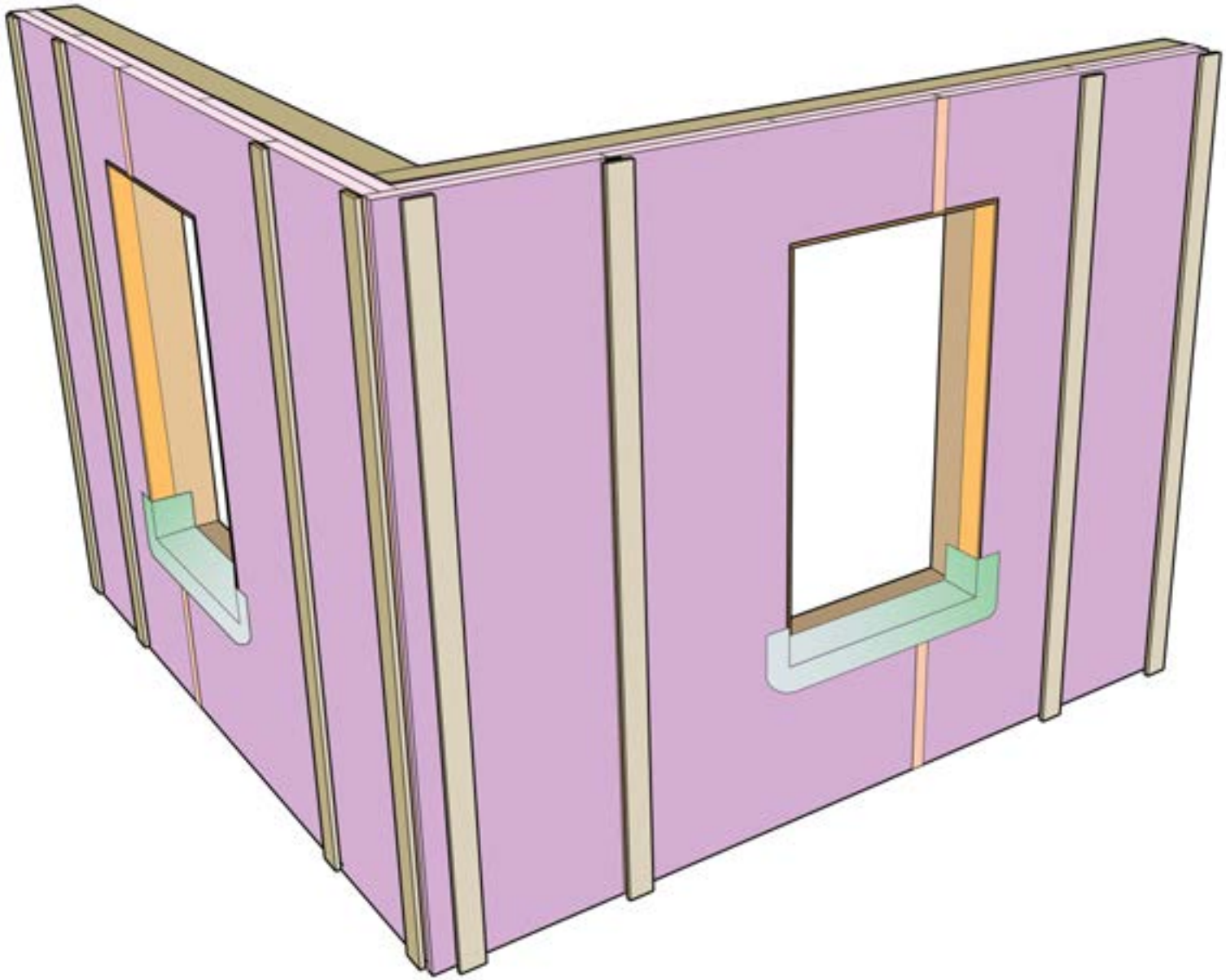


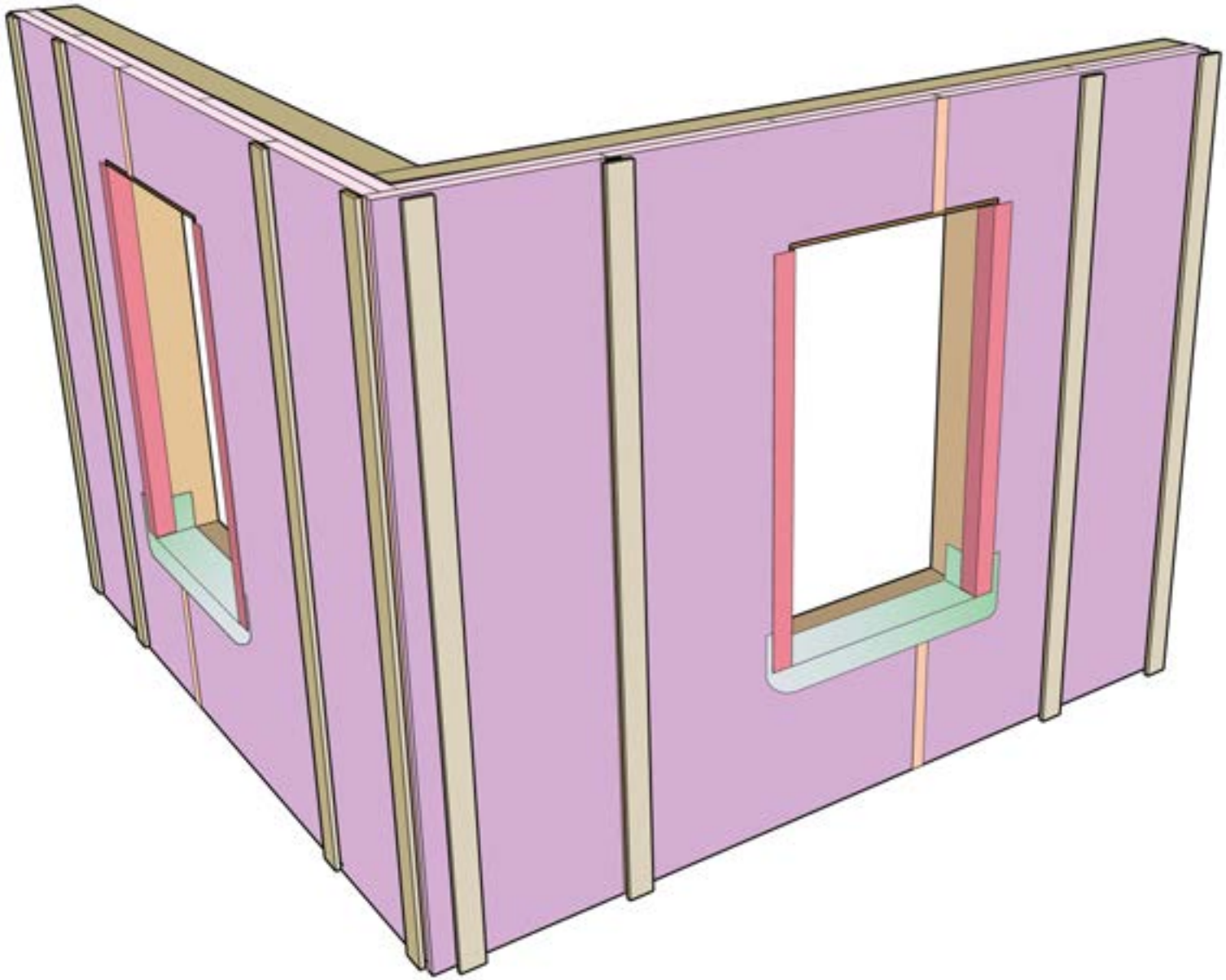


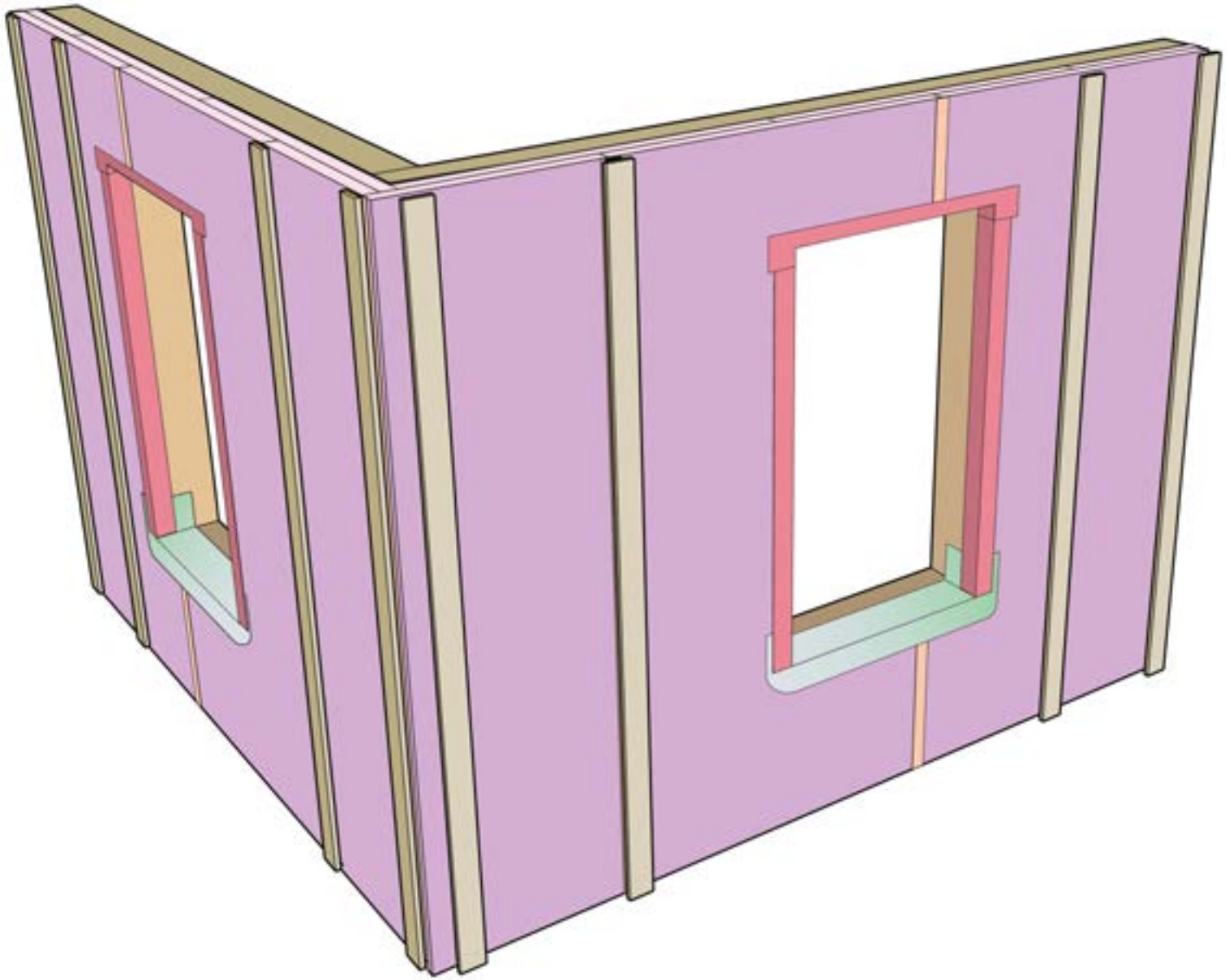


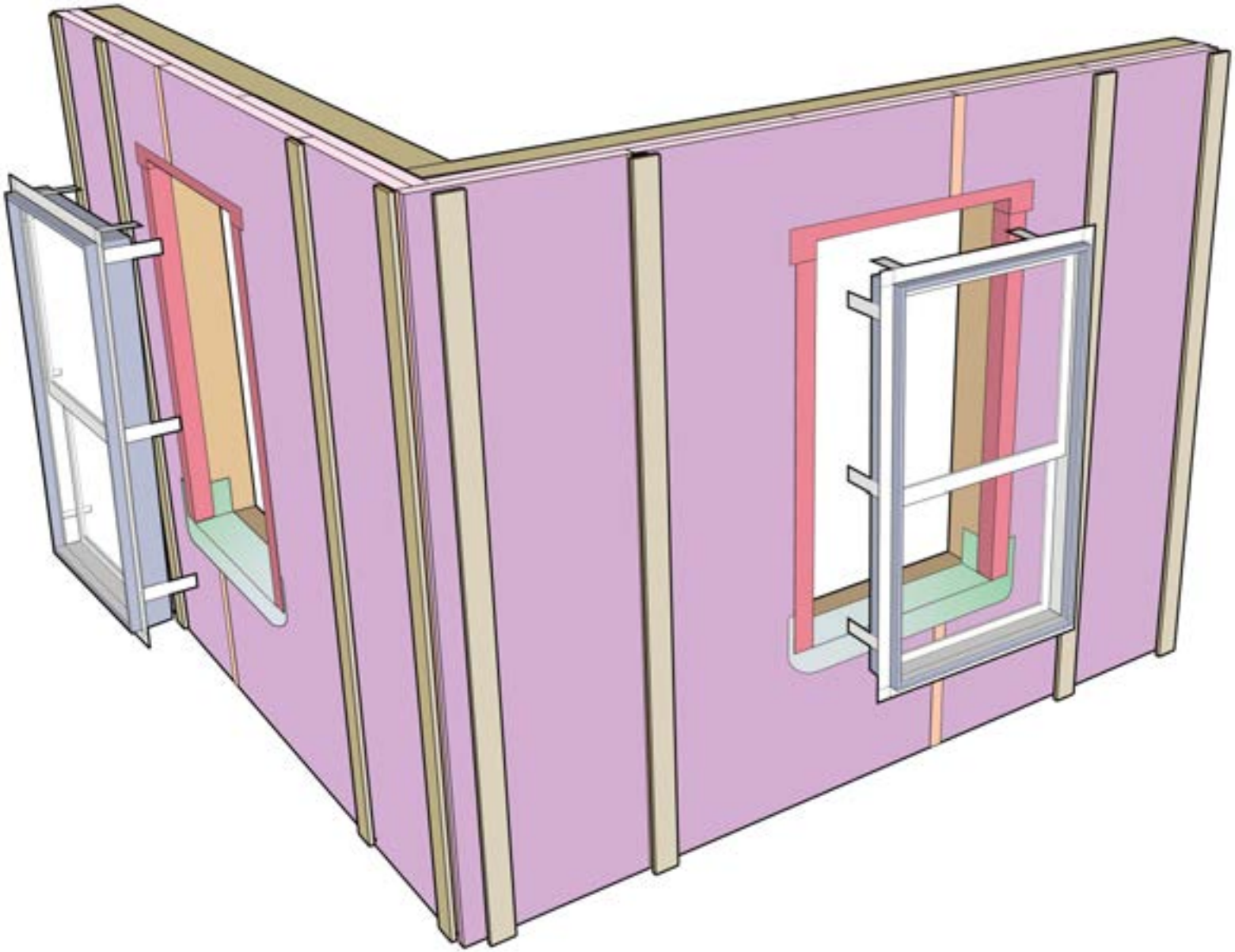


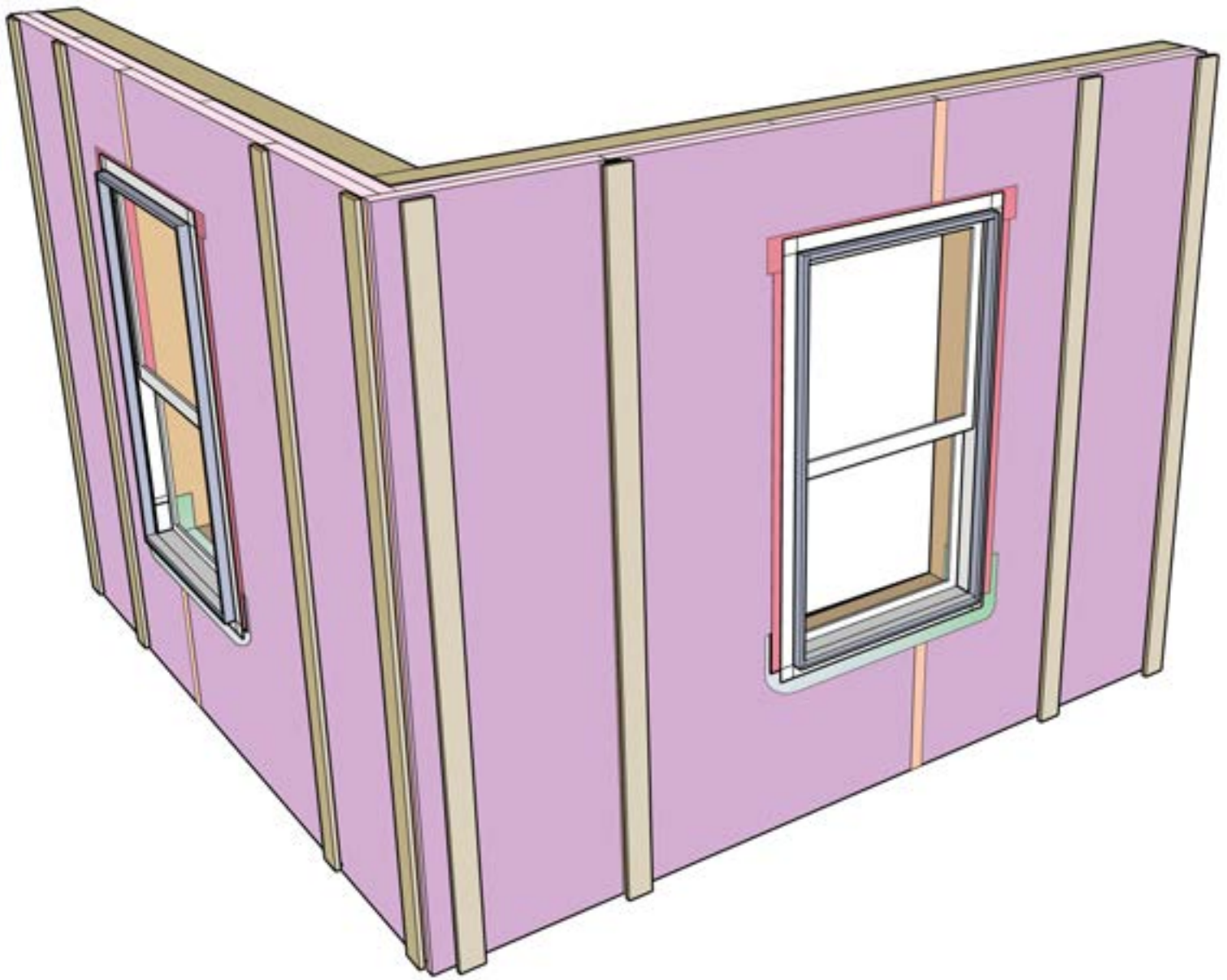


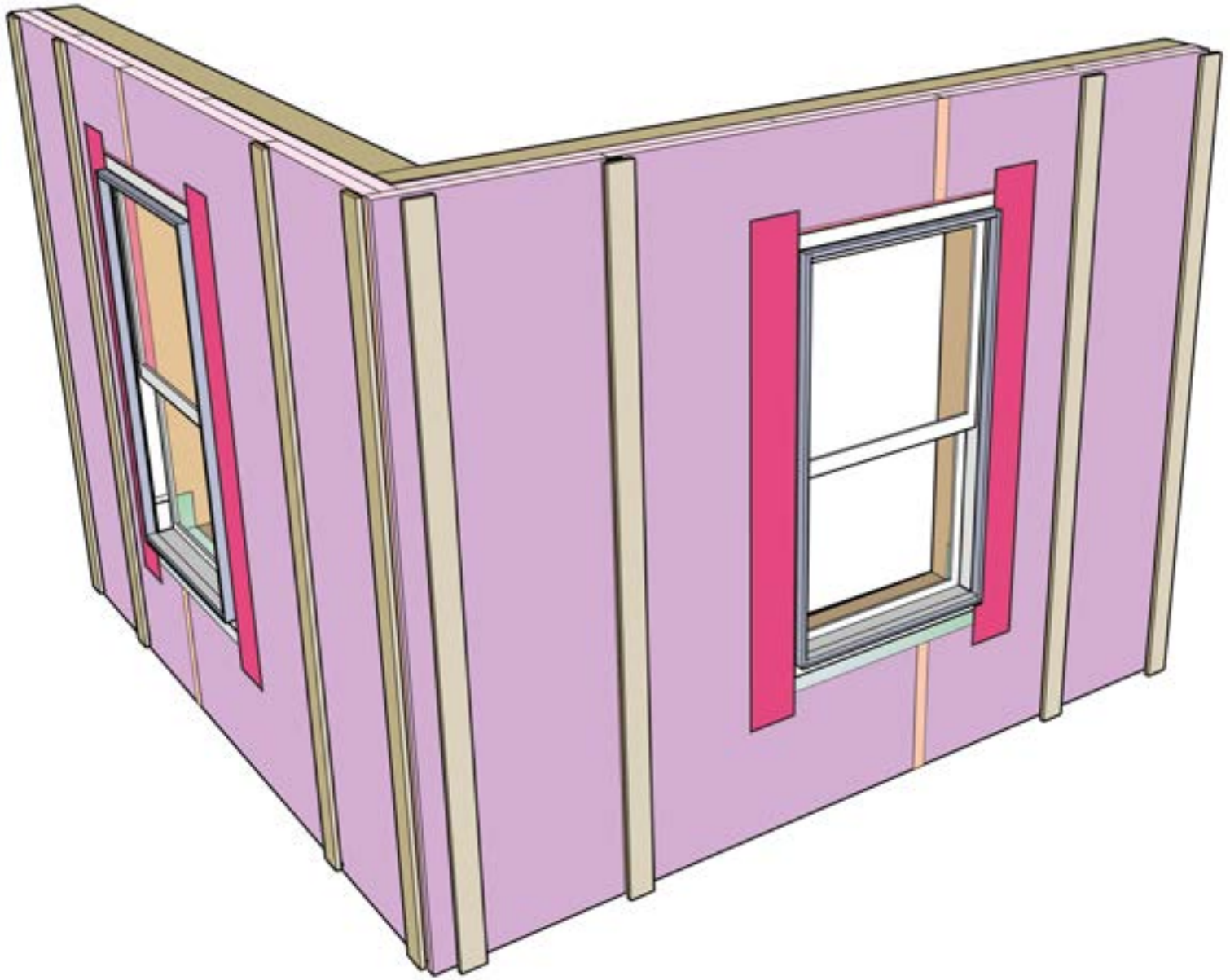


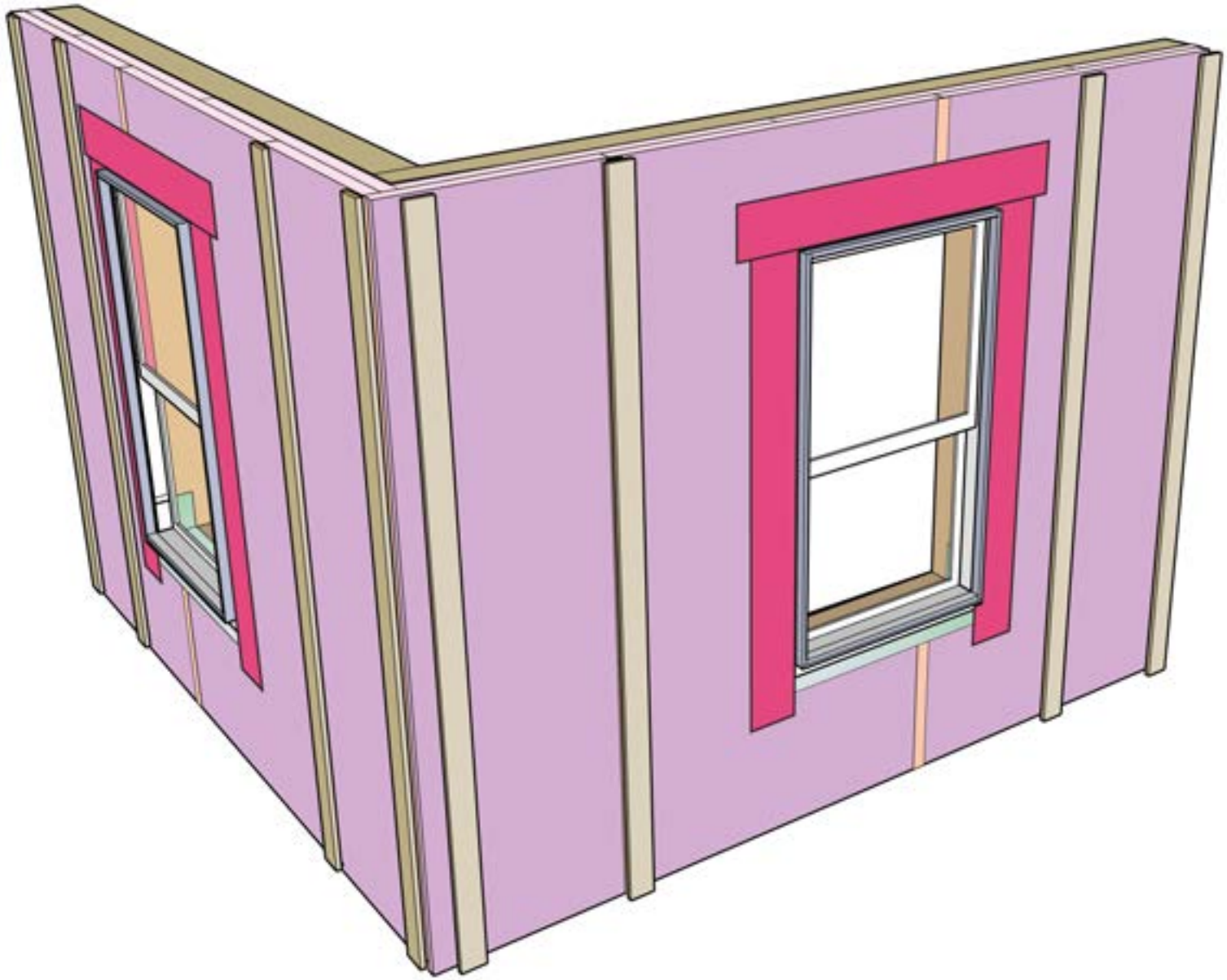


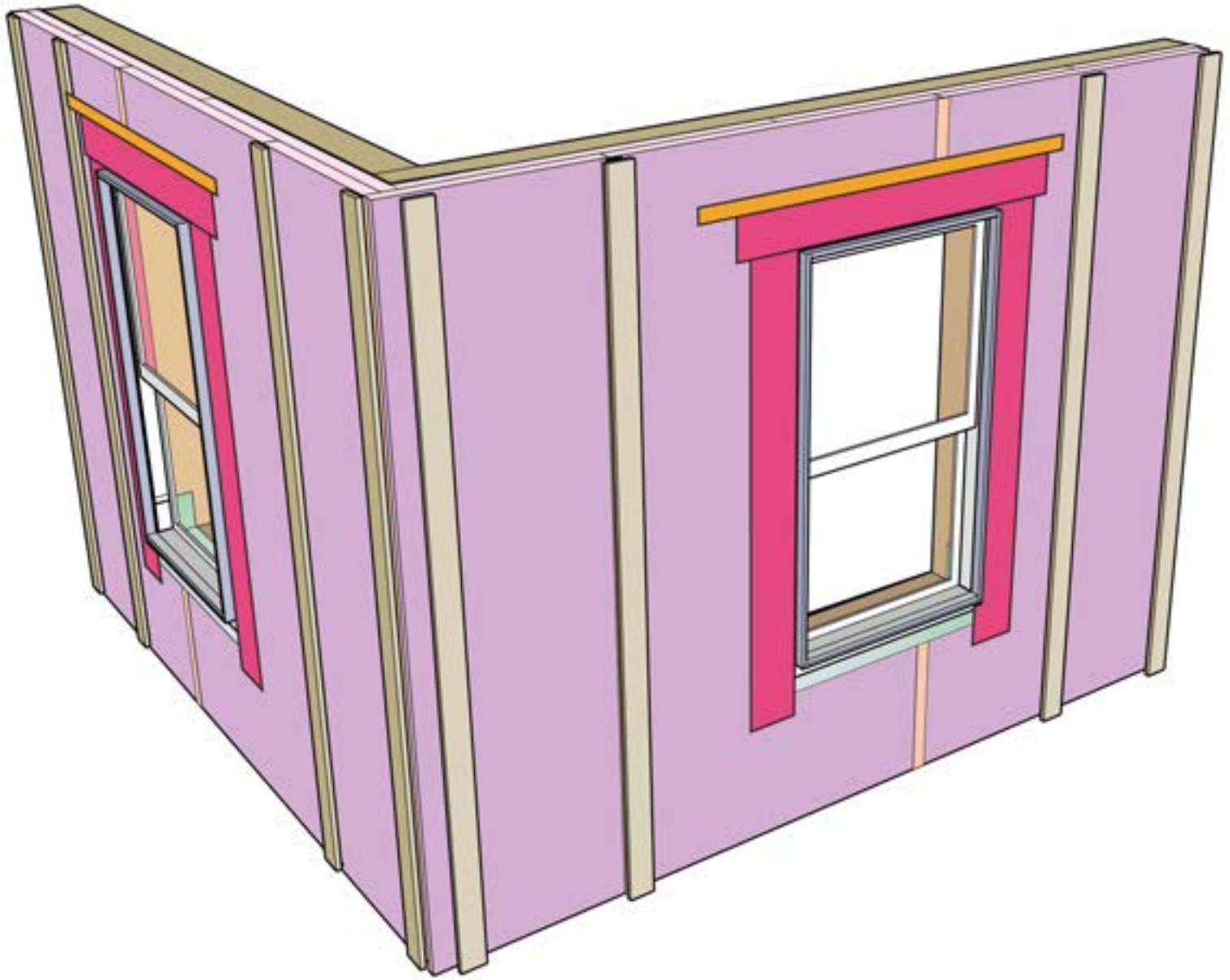


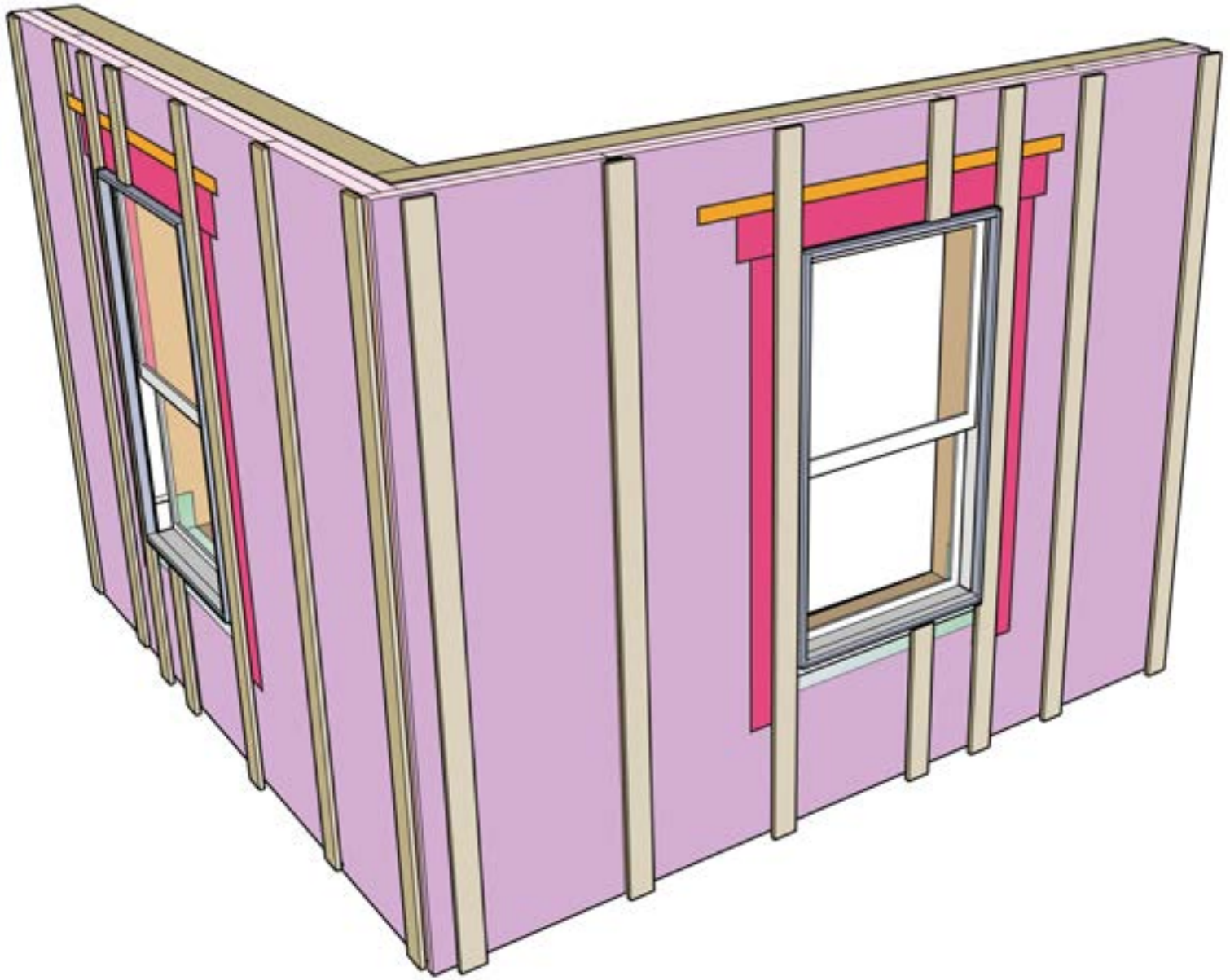


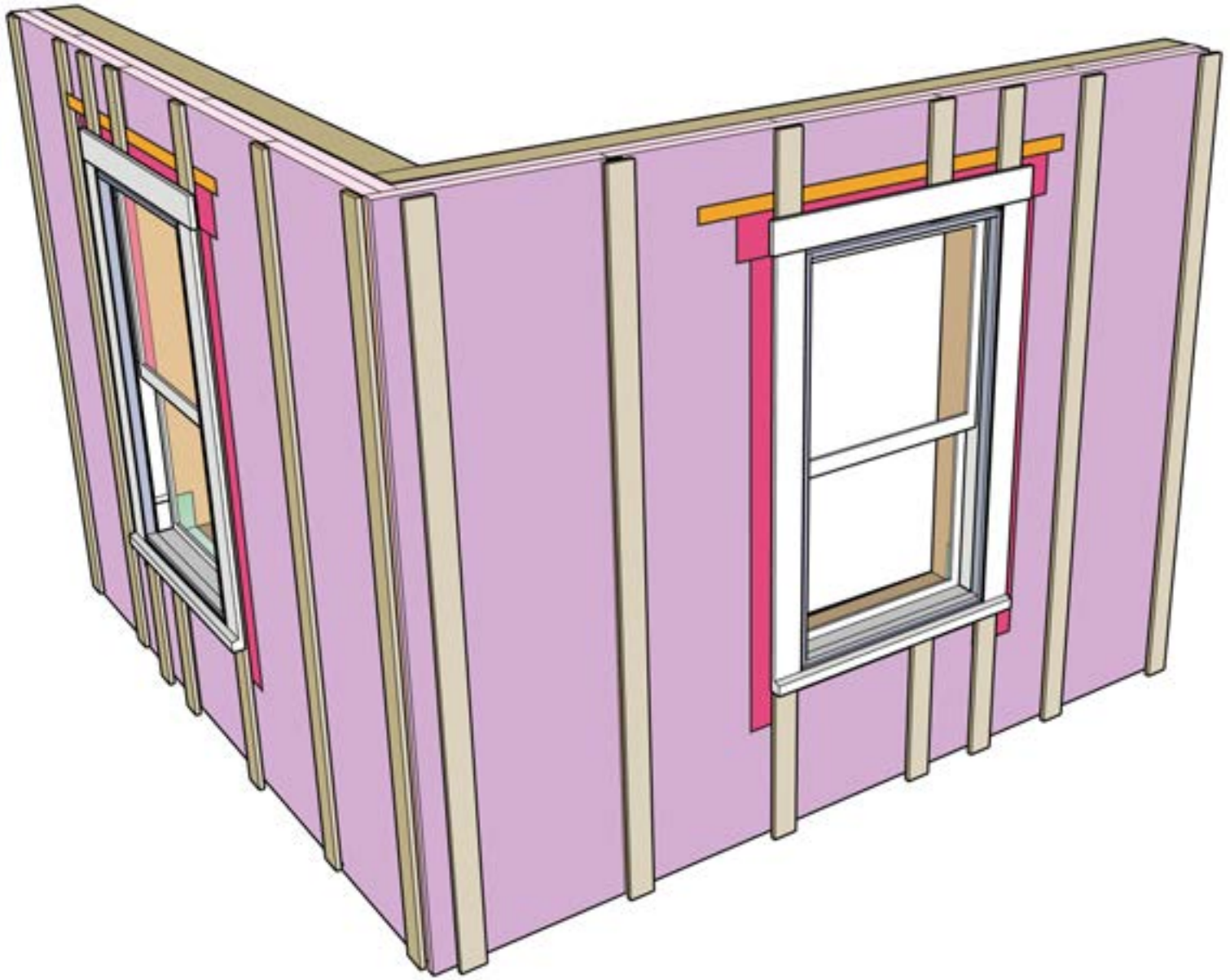


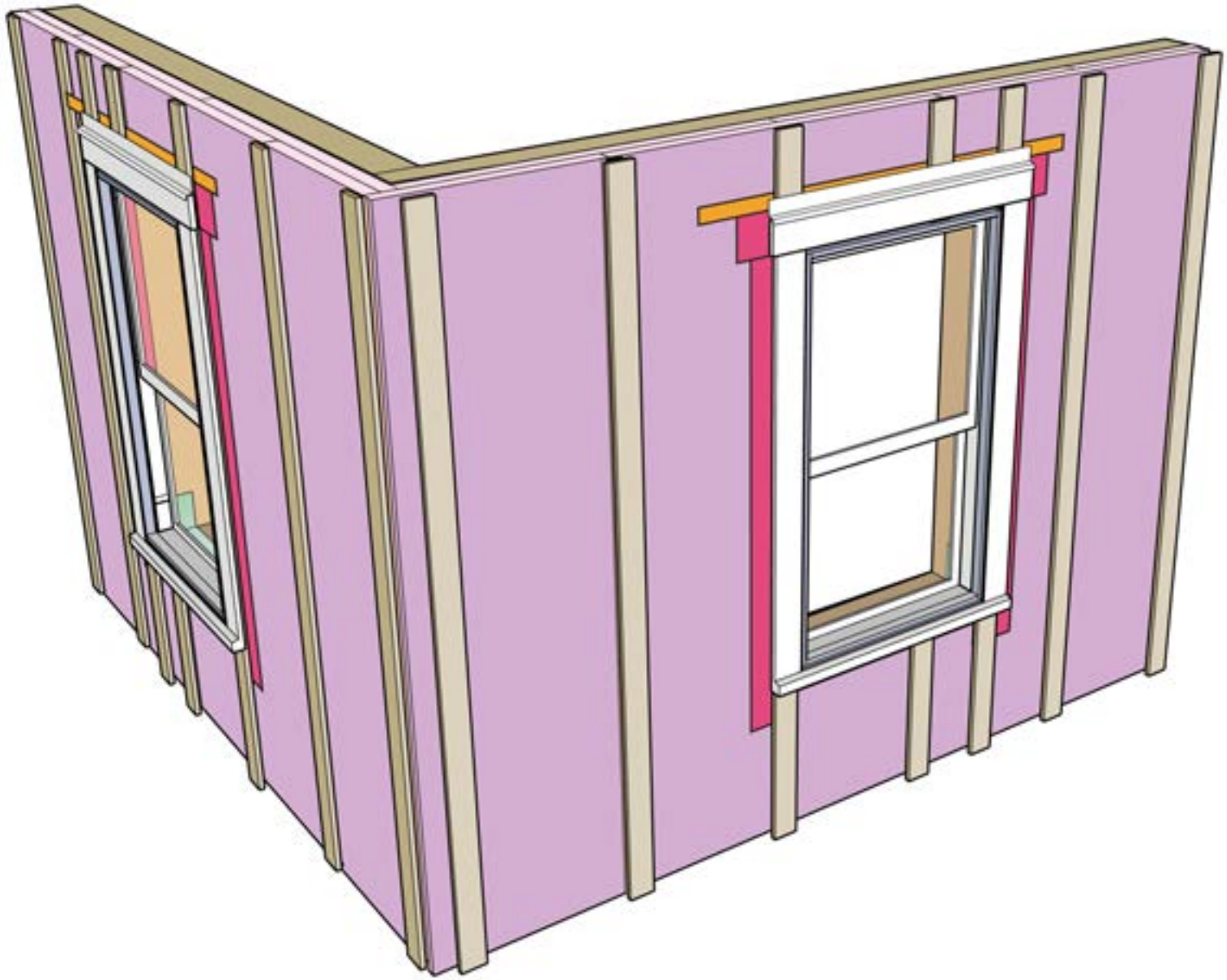


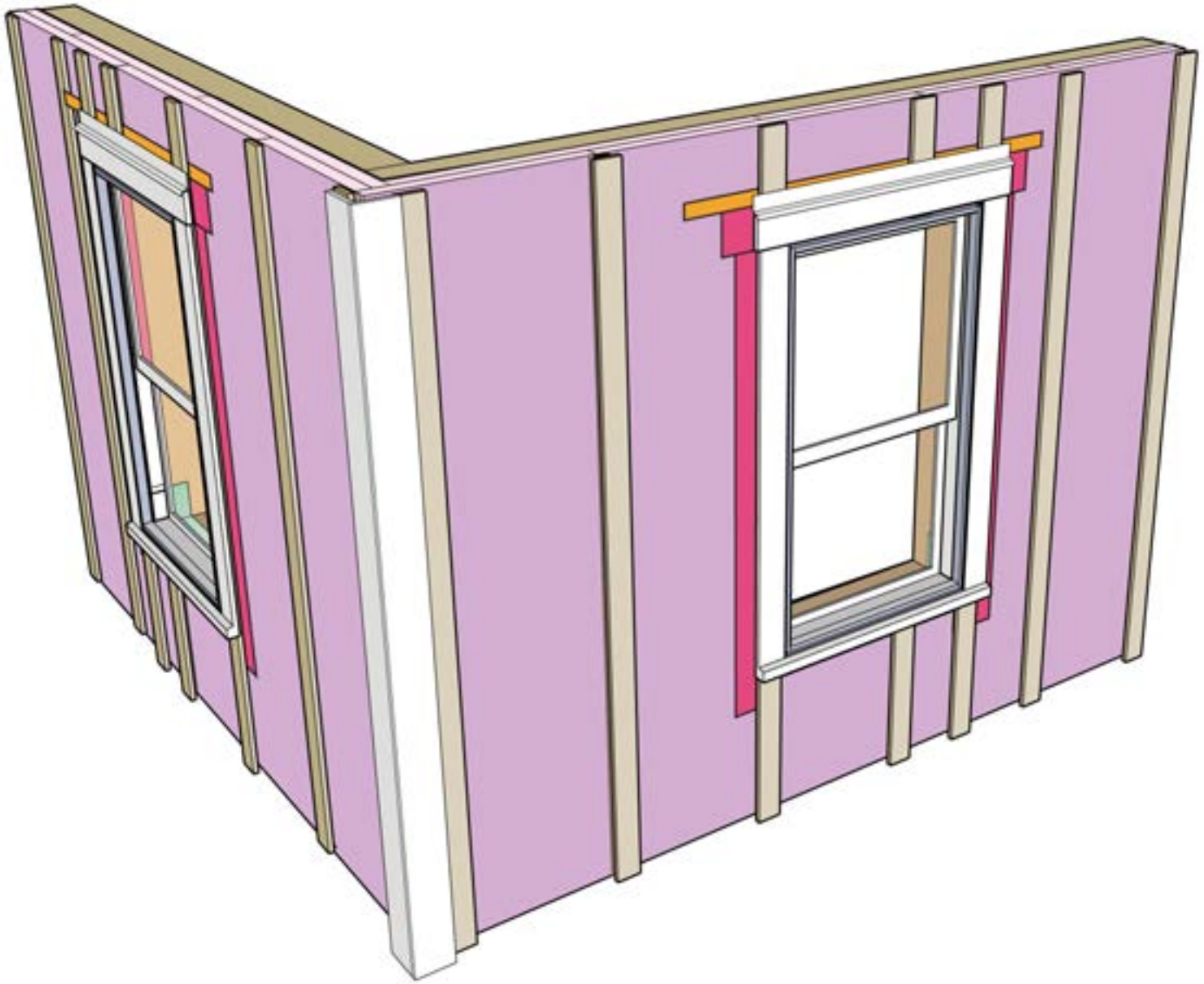










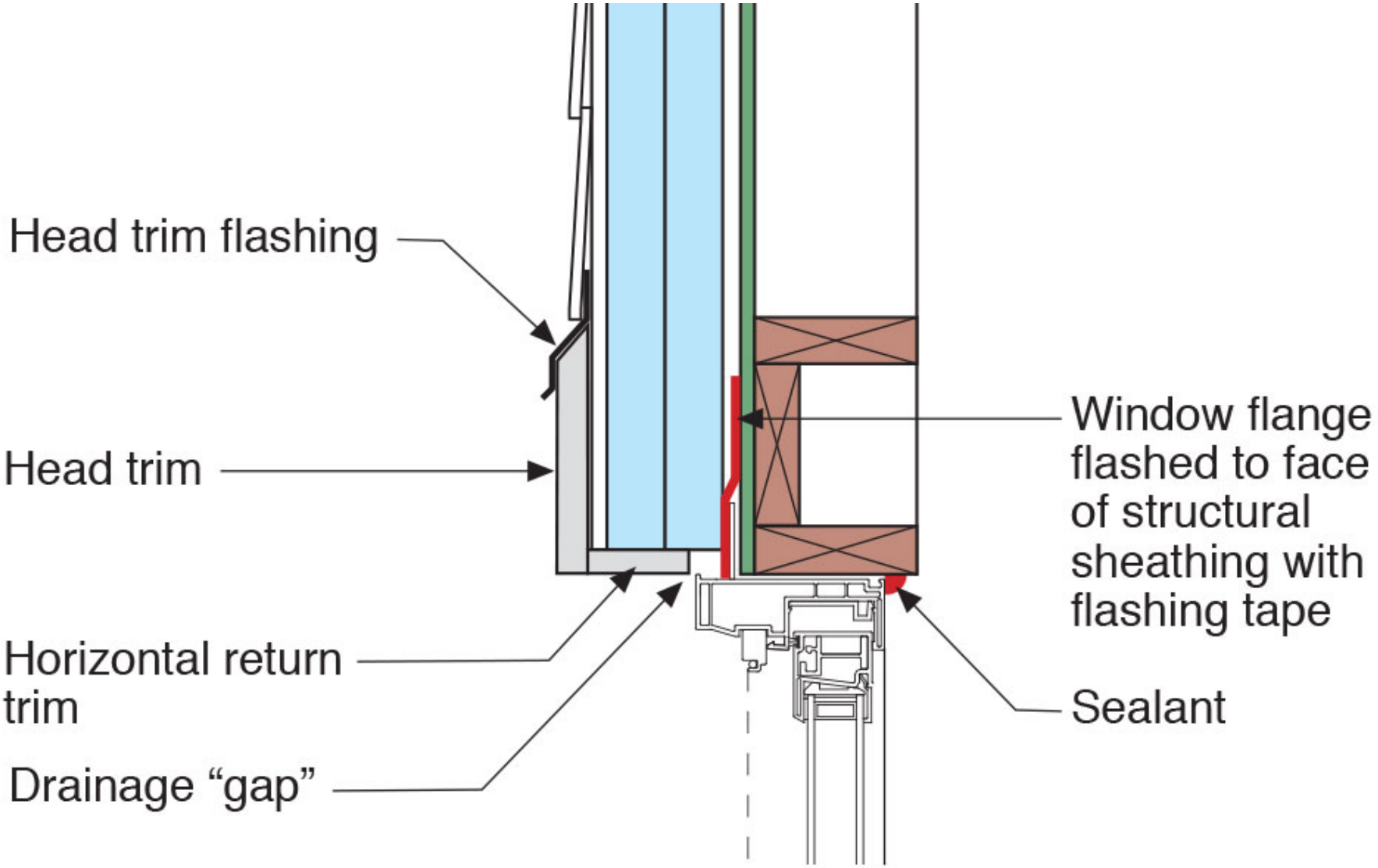



GRACE
Perm-A


ALS UNLIMITED INC.

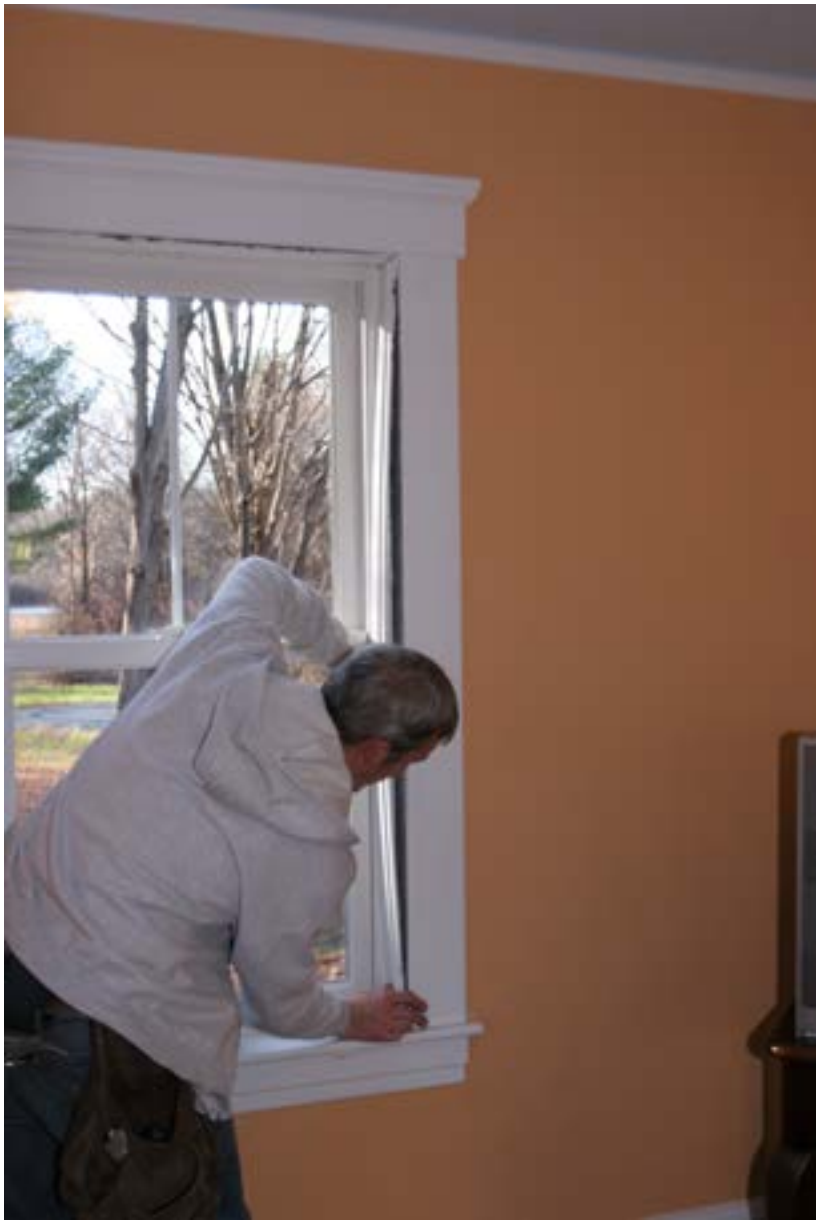

DOW


Anders

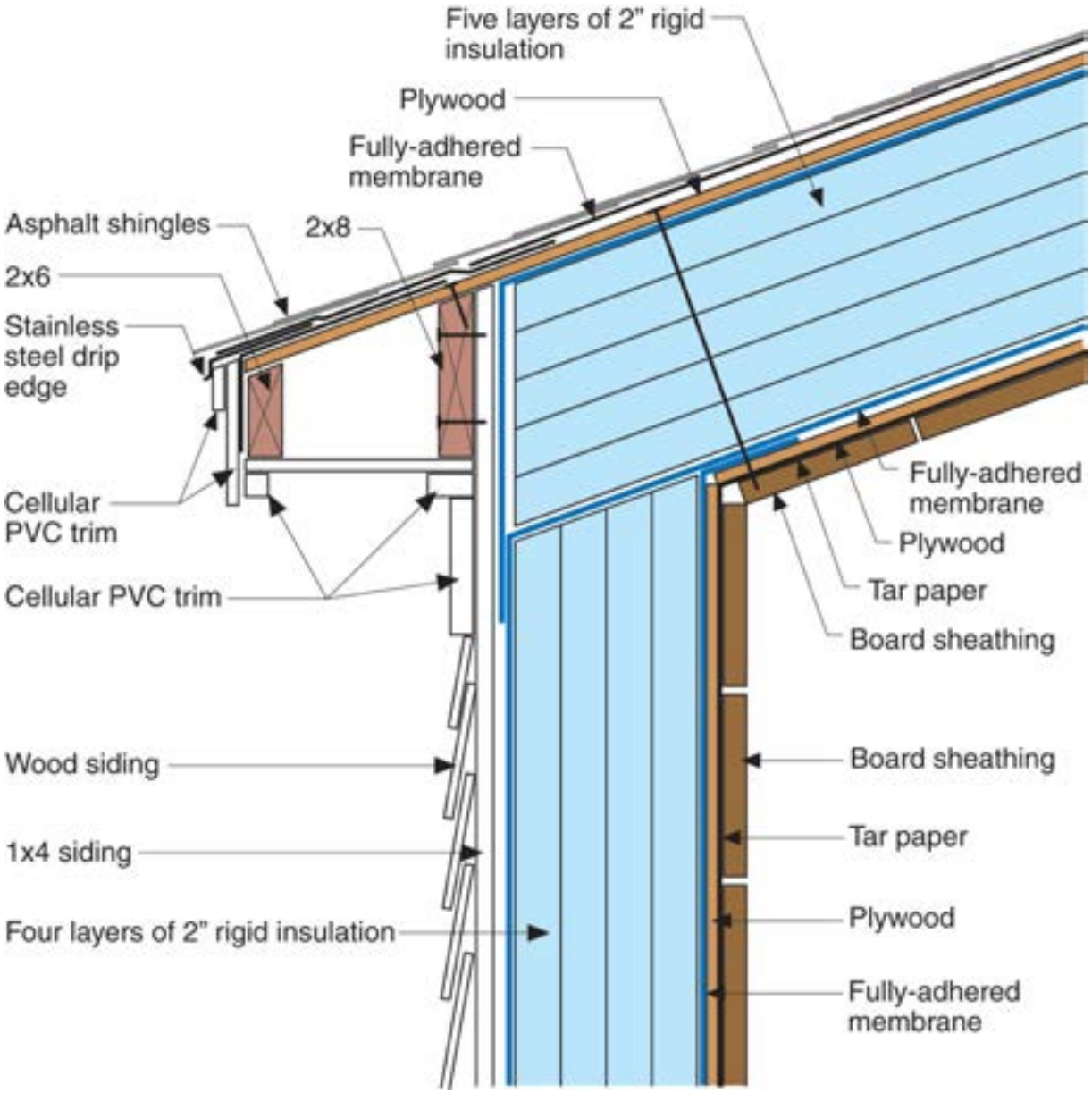

Head trim flashing
Head trim
Horizontal return trim
Drainage “gap”
Window flange flashed to face of structural sheathing with flashing tape
Sealant


GRACE VYCOR® PLUS
GRACE VYCOR® PLUS


0.32
0.33
0.54
DP25



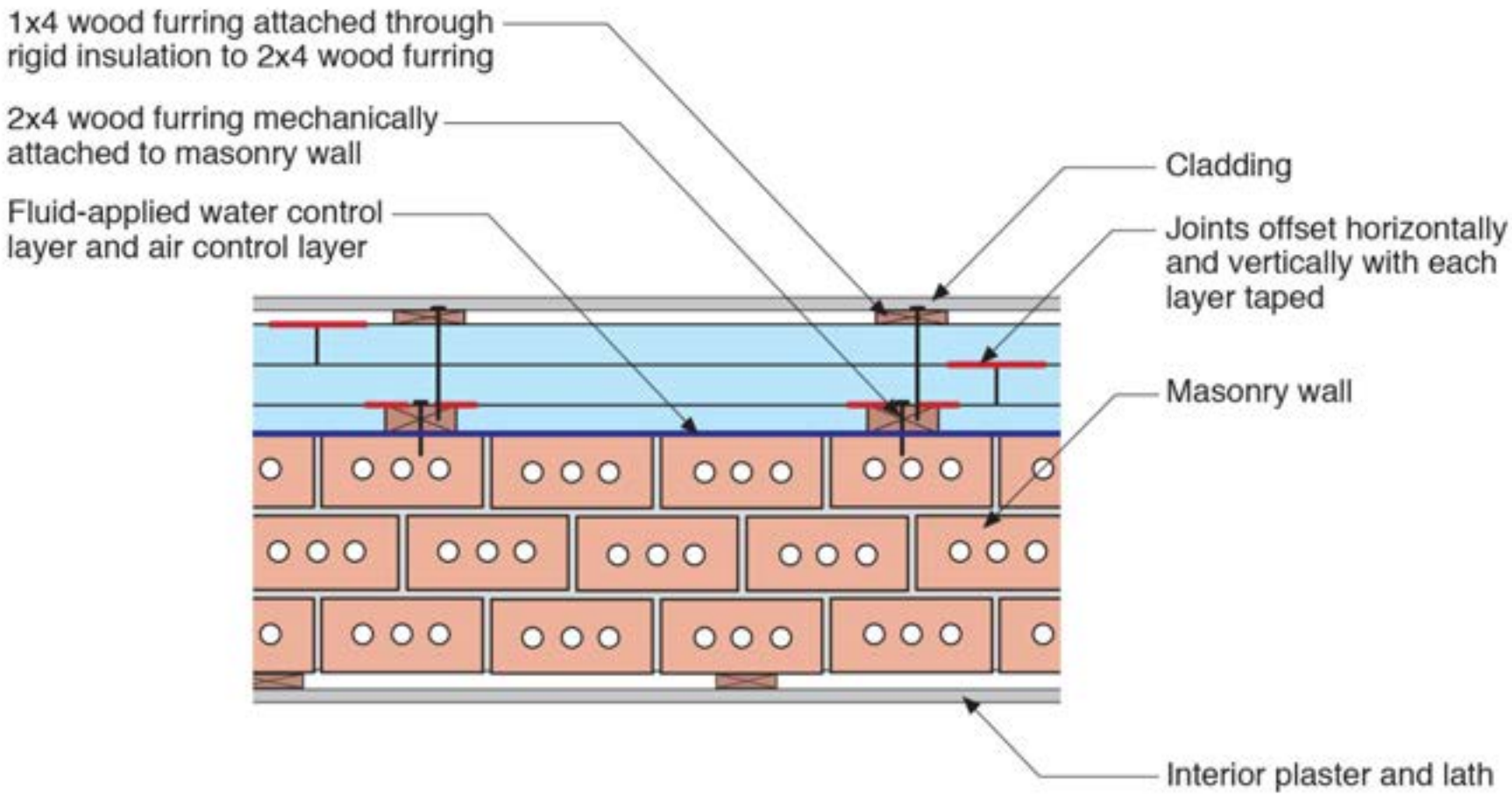

DU PONT
Tyve
DrainWra

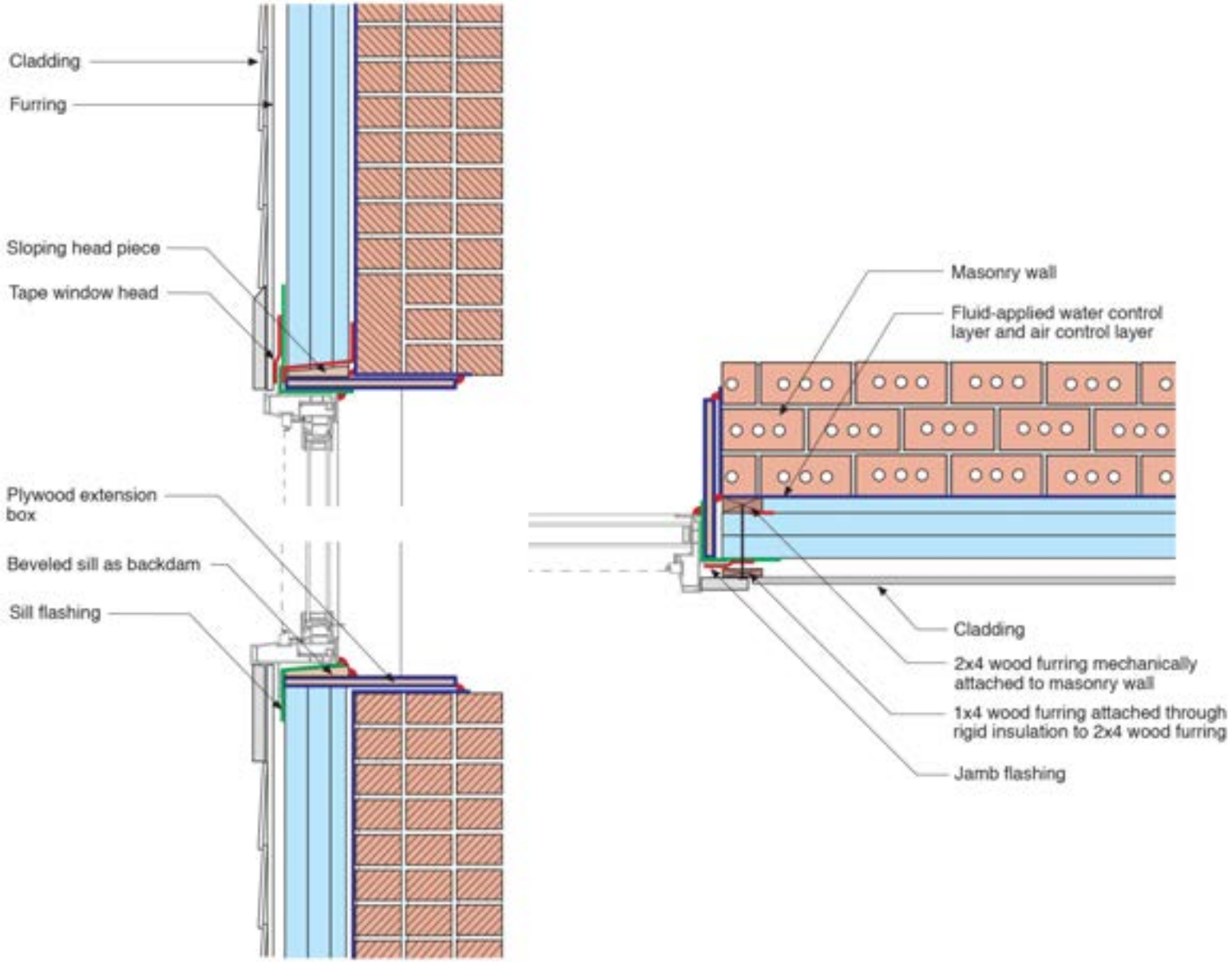

Five layers of 2" rigid insulation
Plywood
Fully-adhered membrane
Asphalt shingles
2x8
2x6
Stainless steel drip edge
Cellular PVC trim
Cellular PVC trim
Wood siding
1x4 siding
Four layers of 2" rigid insulation
Fully-adhered membrane
Plywood
Tar paper
Board sheathing
Board sheathing
Tar paper
Plywood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


DOW
DOW
DOW
Sup
Comm


Super TUFF-R


DOW
Super TUFF-R
Commercial Insulation


1x4 wood furring attached through rigid insulation to 2x4 wood furring
2x4 wood furring mechanically attached to masonry wall
Fluid-applied water control layer and air control layer
Cladding
Joints offset horizontally and vertically with each layer taped
Masonry wall
Interior plaster and lath


Cladding
Furring
Sloping head piece
Tape window head
Plywood extension box
Beveled sill as backdam
Sill flashing
Masonry wall
Fluid-applied water control layer and air control layer
Cladding
2x4 wood furring mechanically attached to masonry wall
1x4 wood furring attached through rigid insulation to 2x4 wood furring
Jamb flashing


with ENERGY STAR
R-10
2
Seal and Insulate
with ENERGY STAR


SPEED
HUMP


SPEED
HUMP


TallWall
TallWall
TallWall
TallWall


GP
DensGlass
Sheathing


GRACE
Ice & Water Shield®
RIPCORD™
Split Release
On Demand


Super TUFF-R


DOW
Super TUFF-R
Commercial Insulation