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

Building Science

Adventures In Building Science

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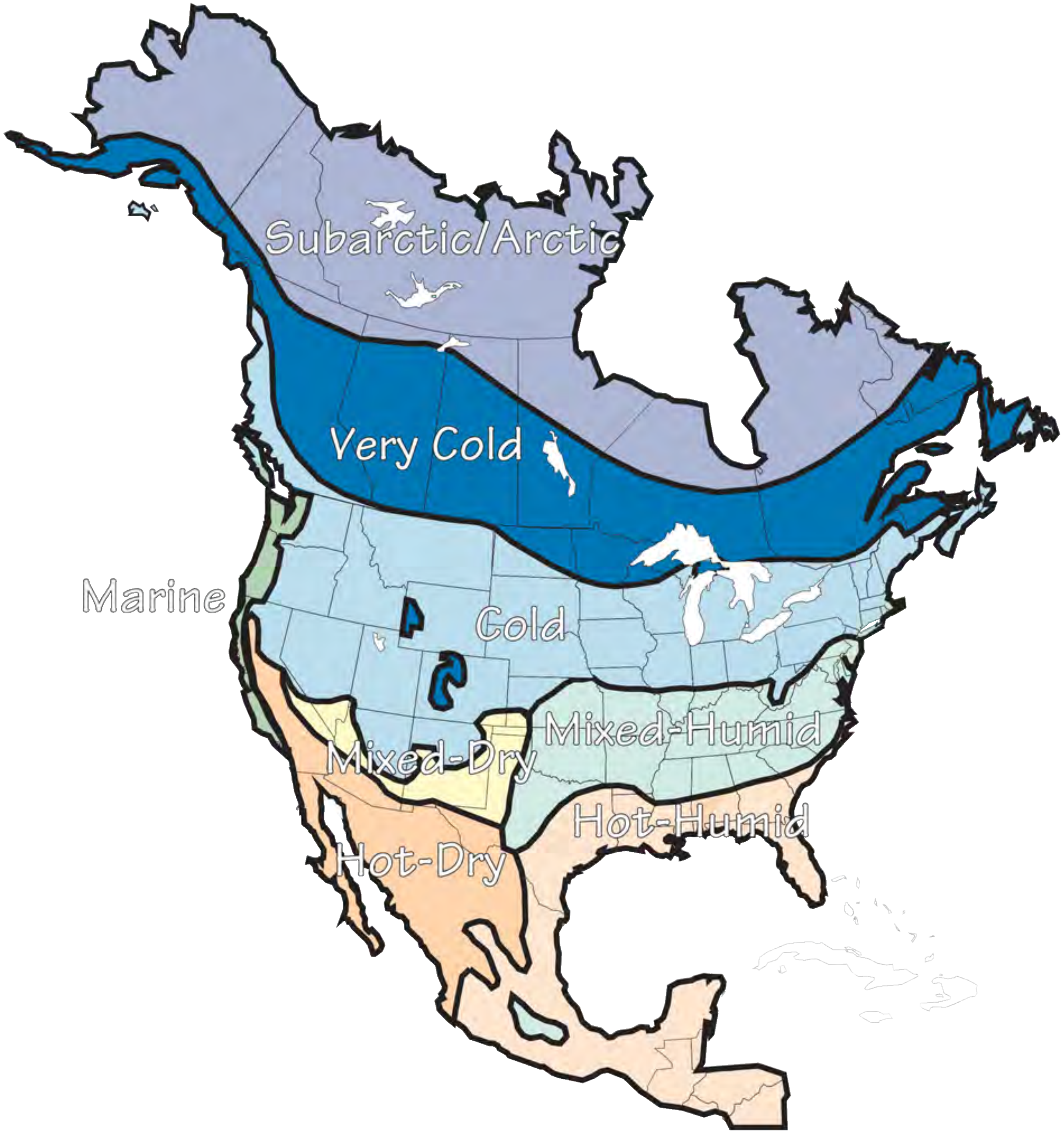
Freeze-Thaw Damage

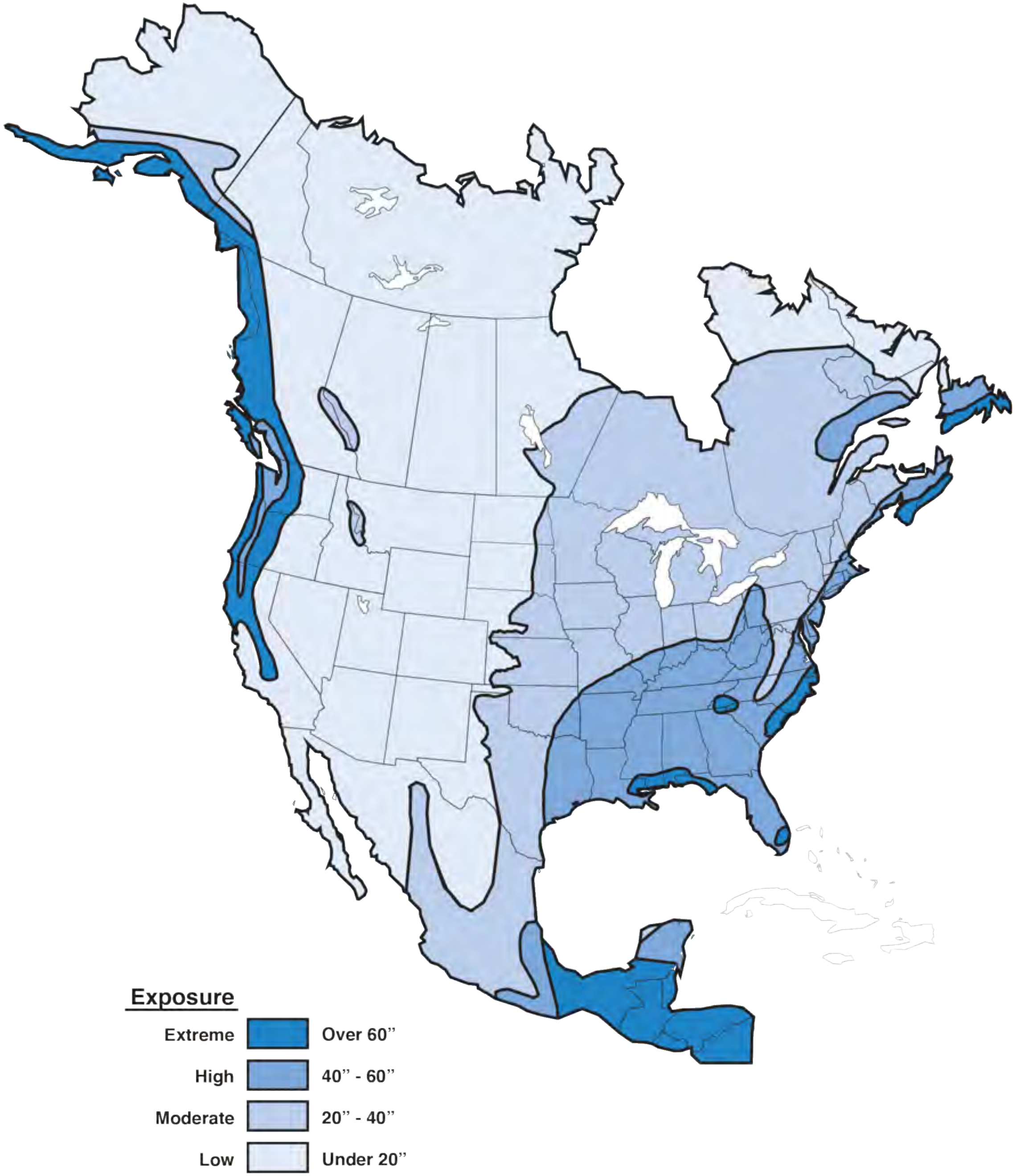
Freeze-Thaw Damage

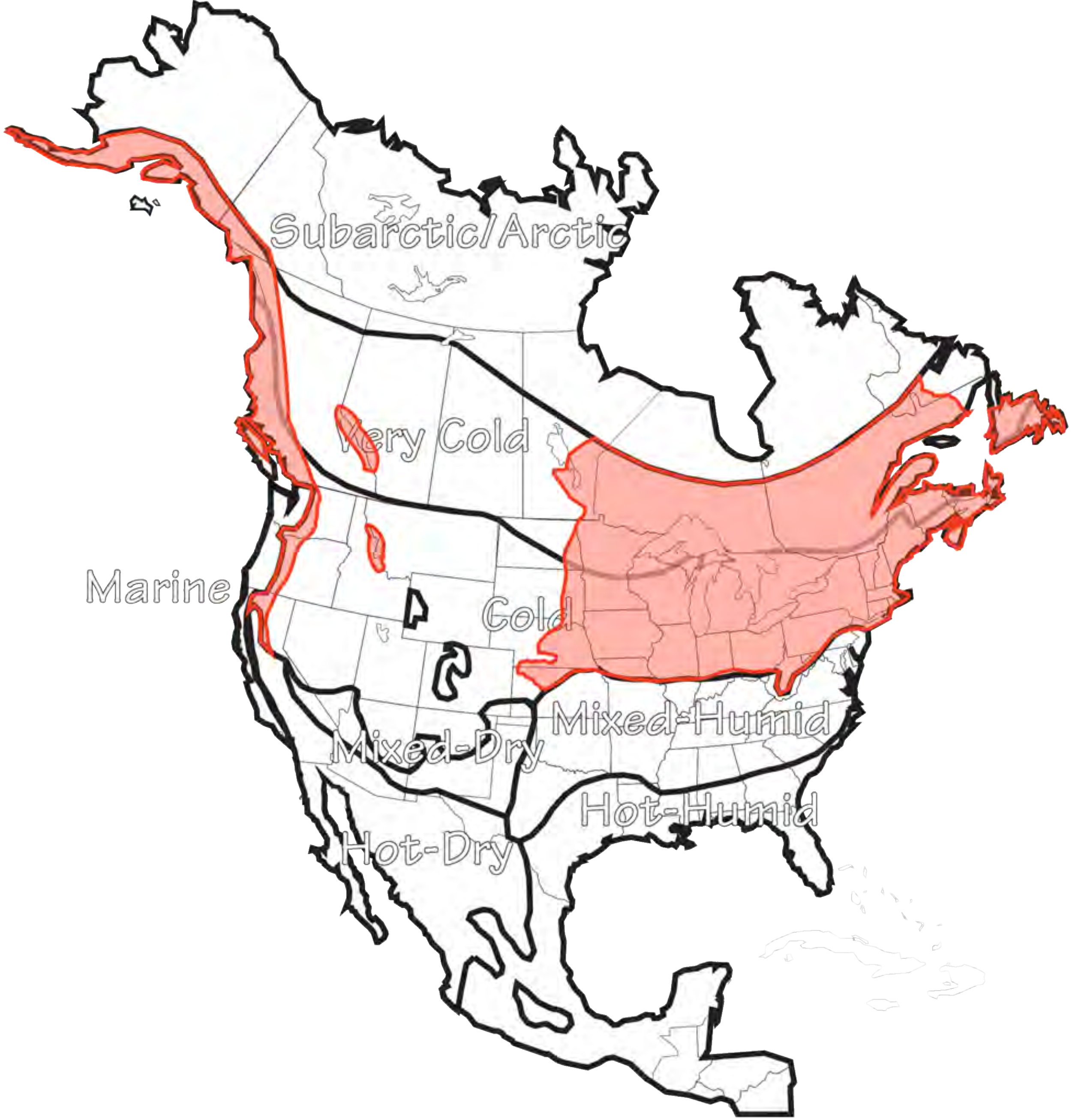
Freezing Temperatures

Water

Susceptible Brick


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”



Subarctic/Arctic
Very Cold
Marine
Cold
Mixed-Humid
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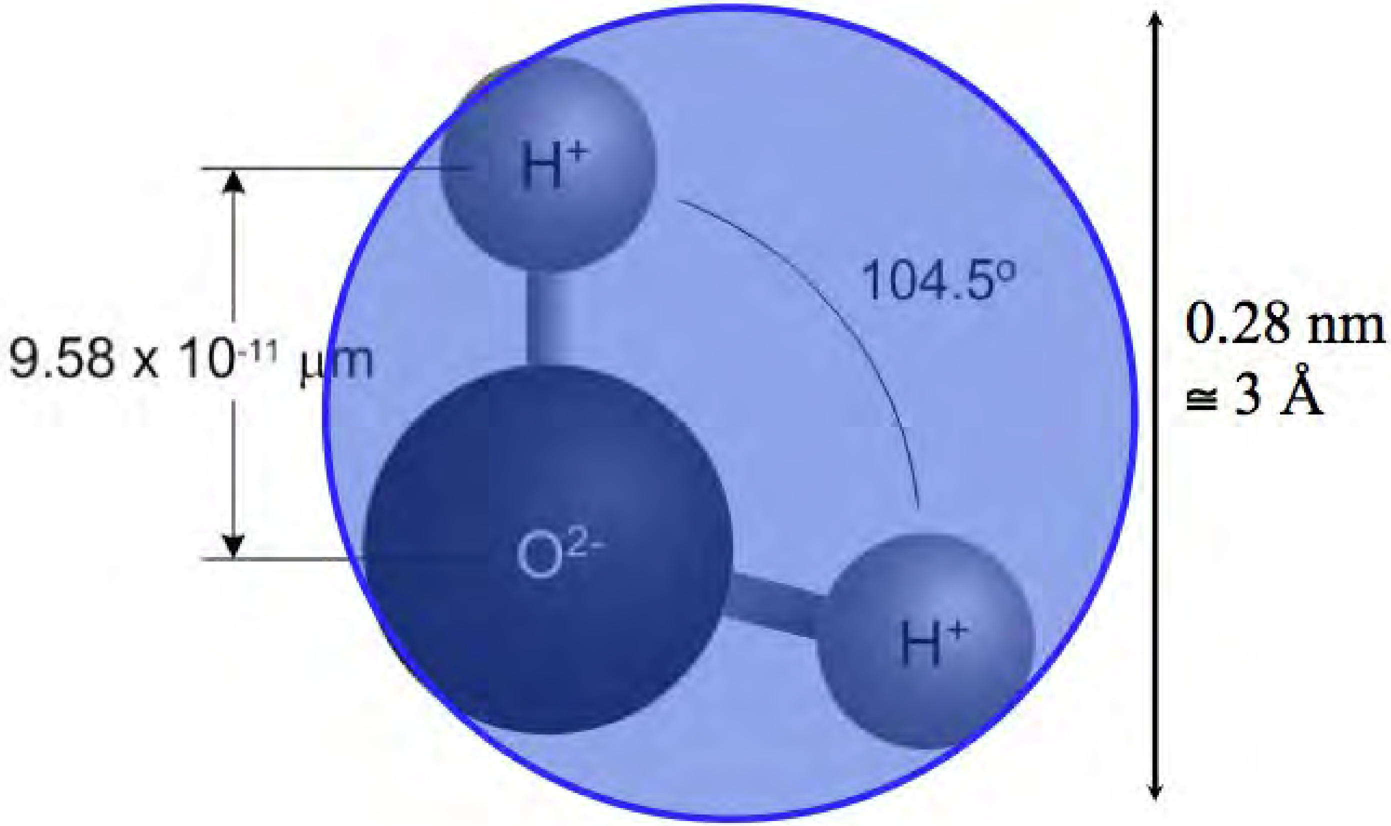
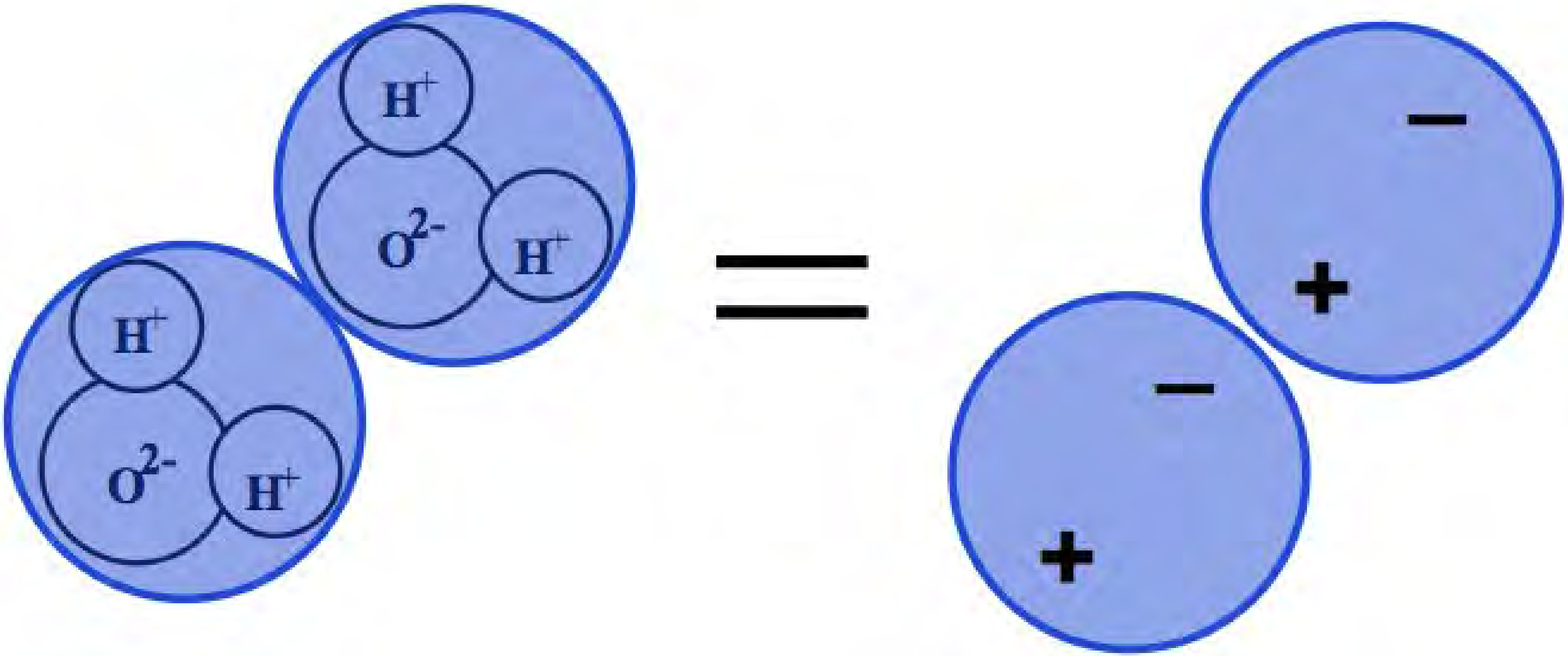
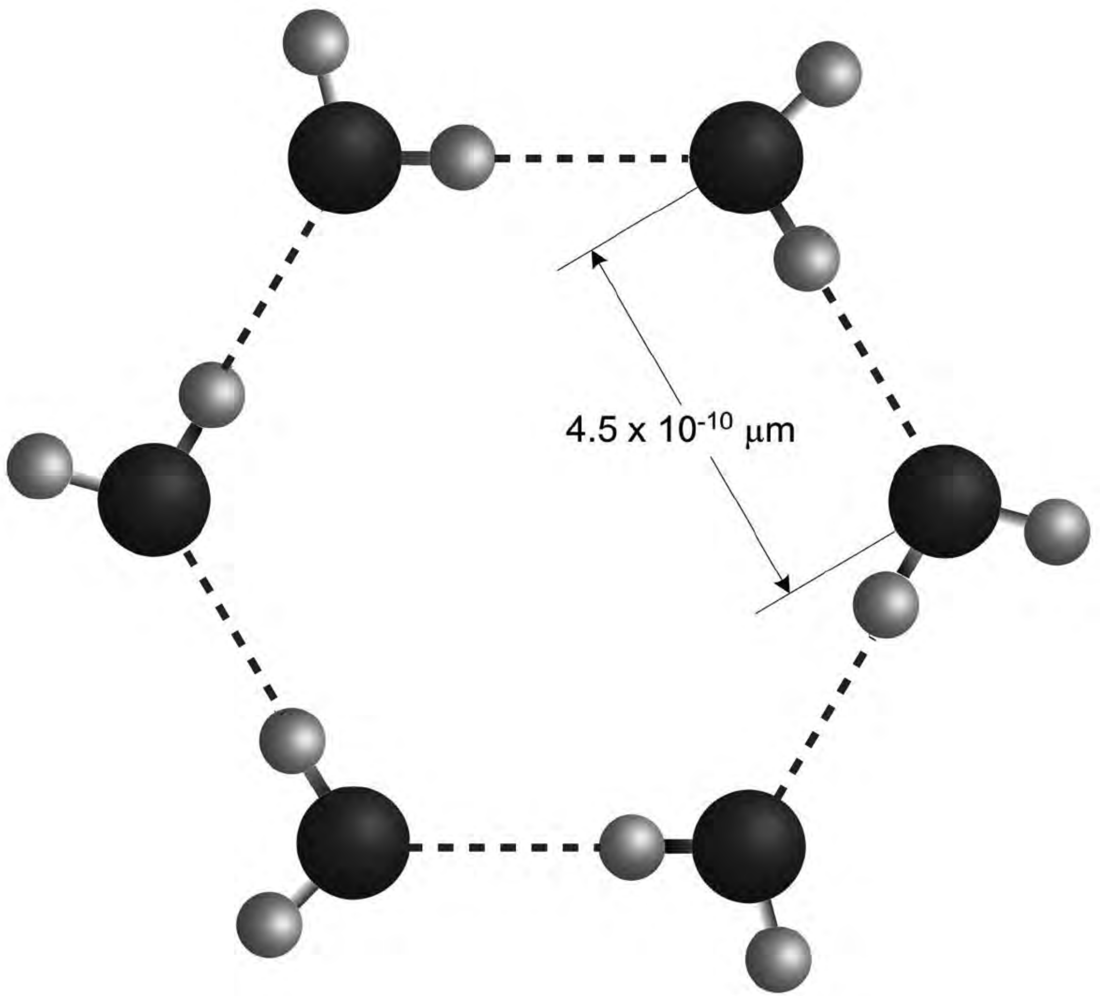

H+
104.5°
9.58 x 10-11 μm
O2-
H+
0.28 nm
≅ 3 Å

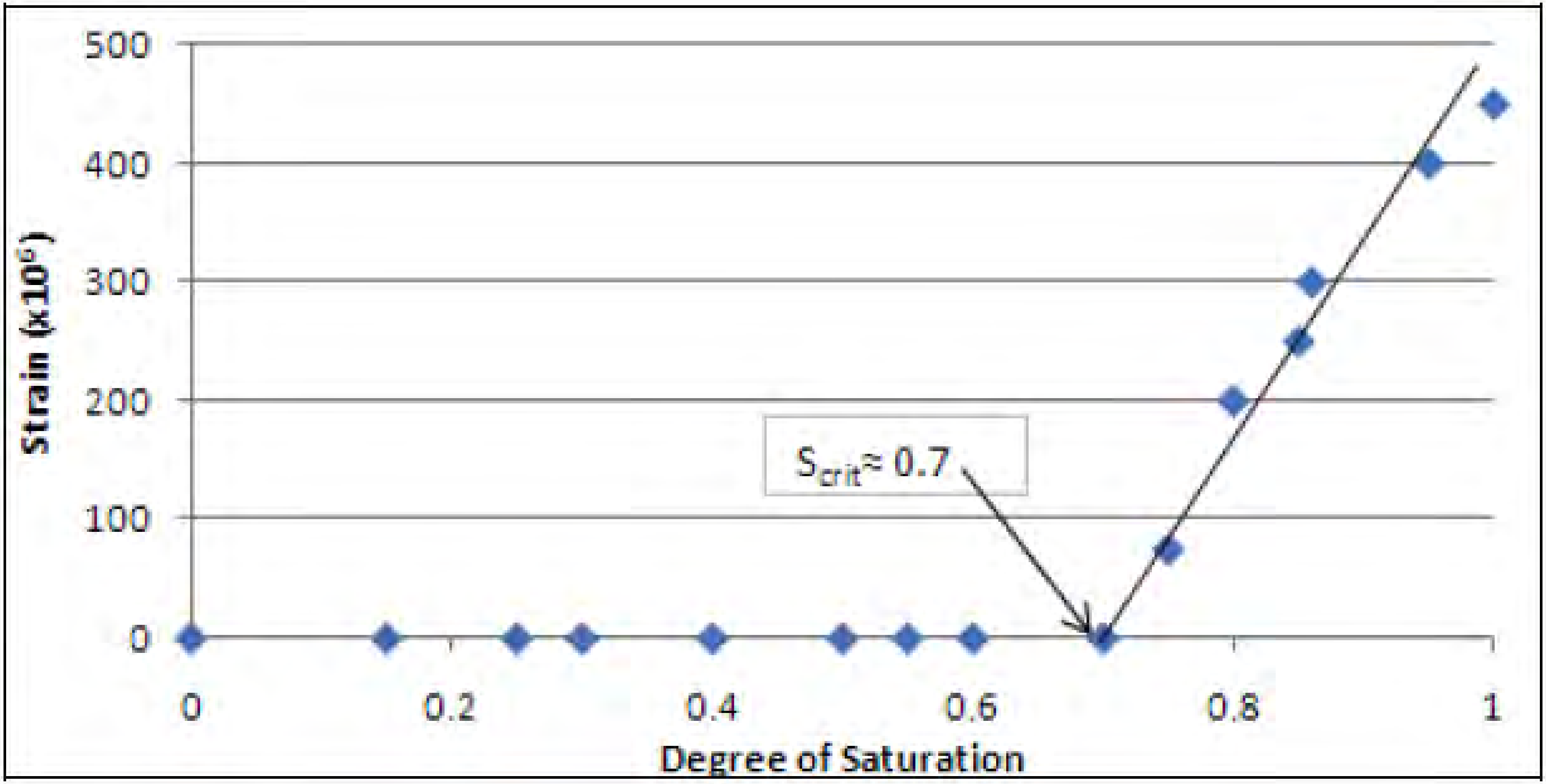

H+
O2-
H+
H+
O2-
H+
=
–
+
–
+


4.5 x 10^{-10} μm

Susceptible Brick

Firing Temperature

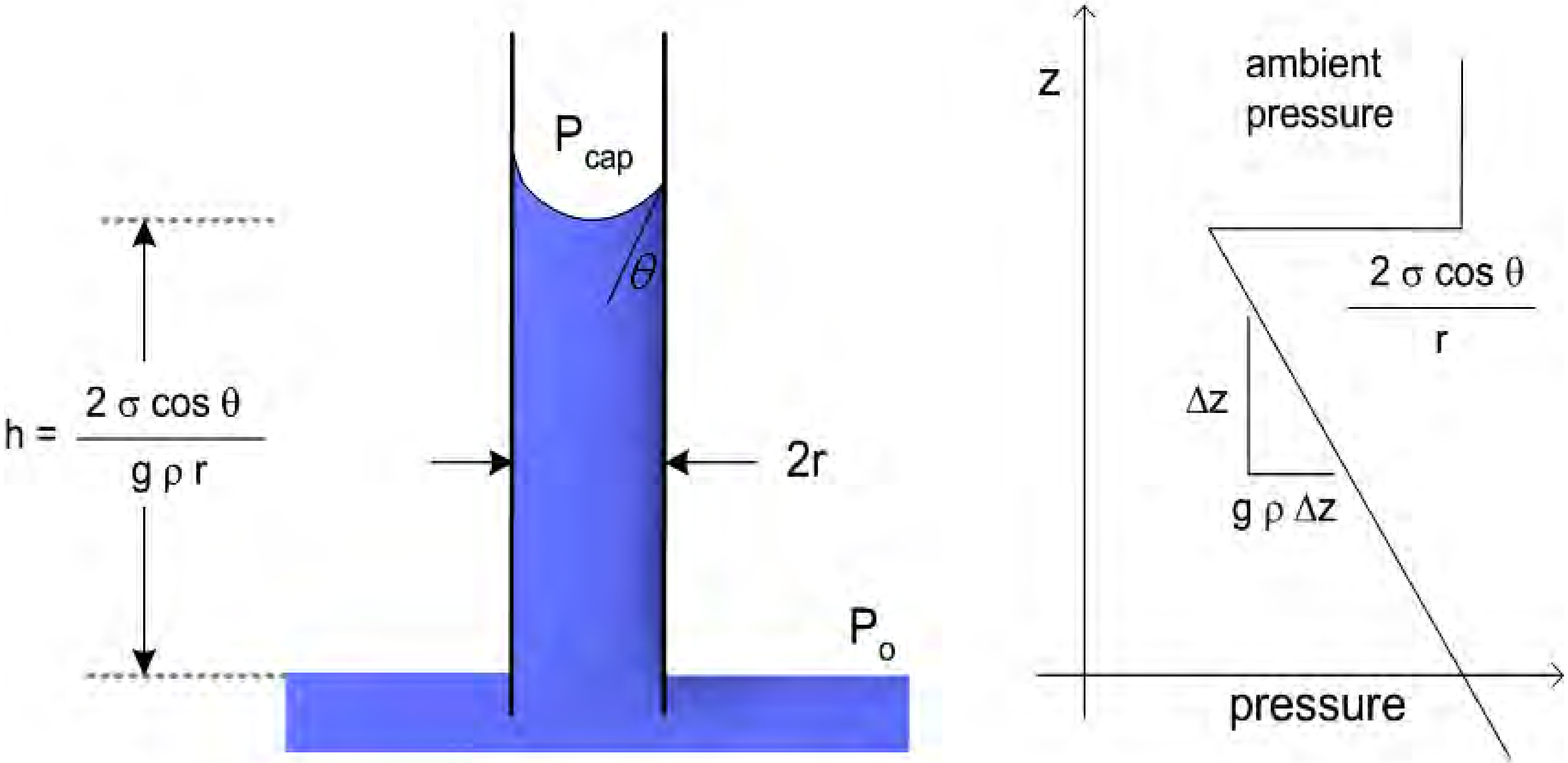
Vitrification



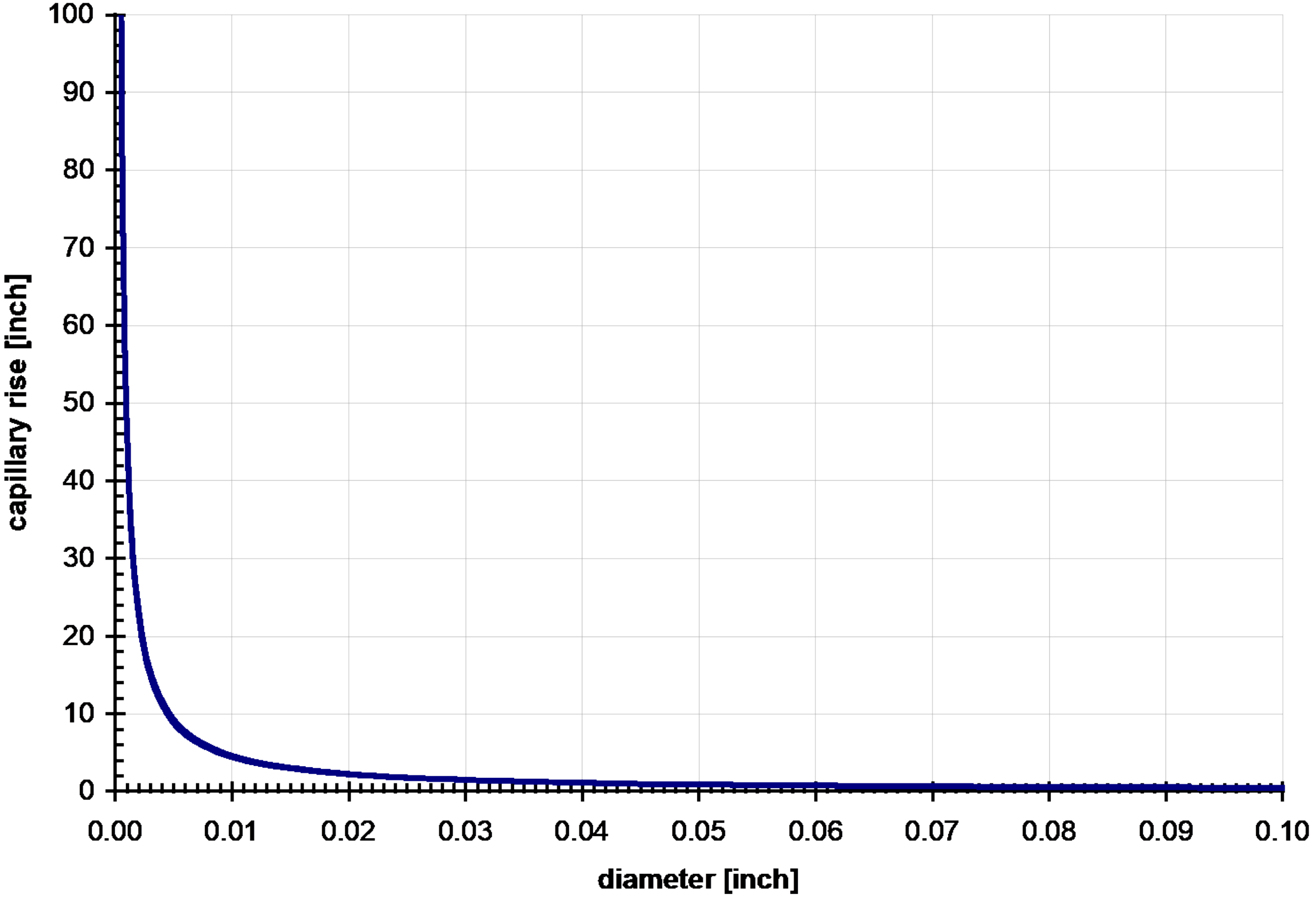
500
400
300
200
100
0
Strain (x10^6)
$S_{crit} \approx 0.7$
0
0.2
0.4
0.6
0.8
1
Degree of Saturation

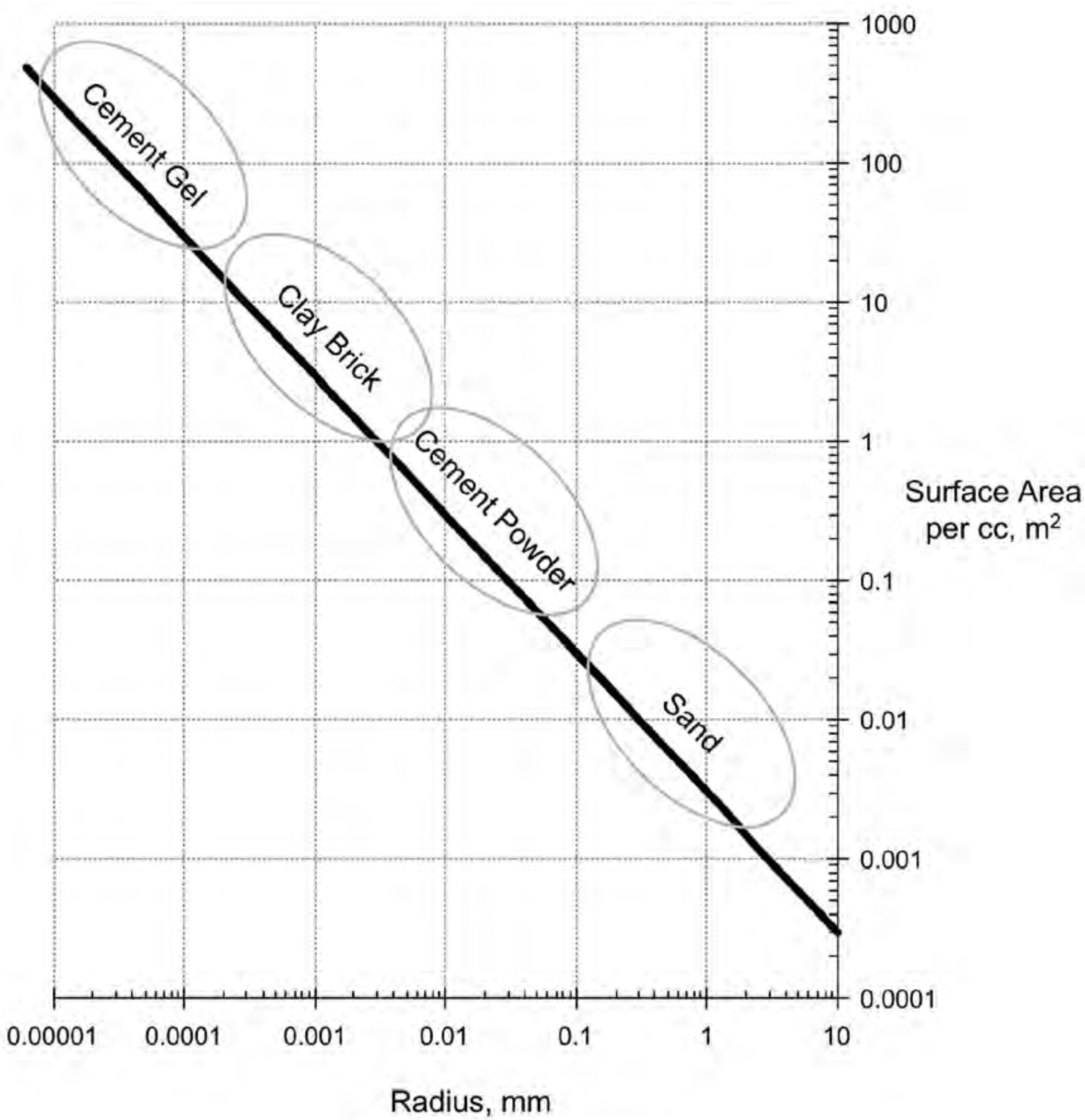

CZ6WC
ABS
3.84295 in
ABS/INC
SET
mm/inch
ON/OFF
3-4" ASIMETO 0.00005"

Calculating capillary rise



Capillary rise versus diameter





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

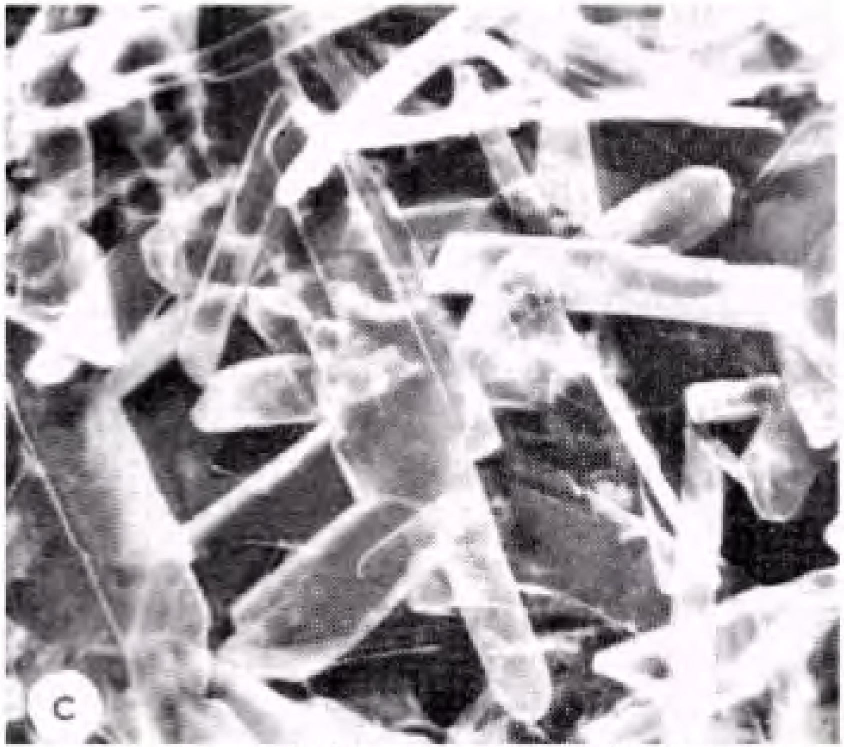


Figure 1c. Gypsum, hydrated from plaster of paris and water, porosity 30 per cent.

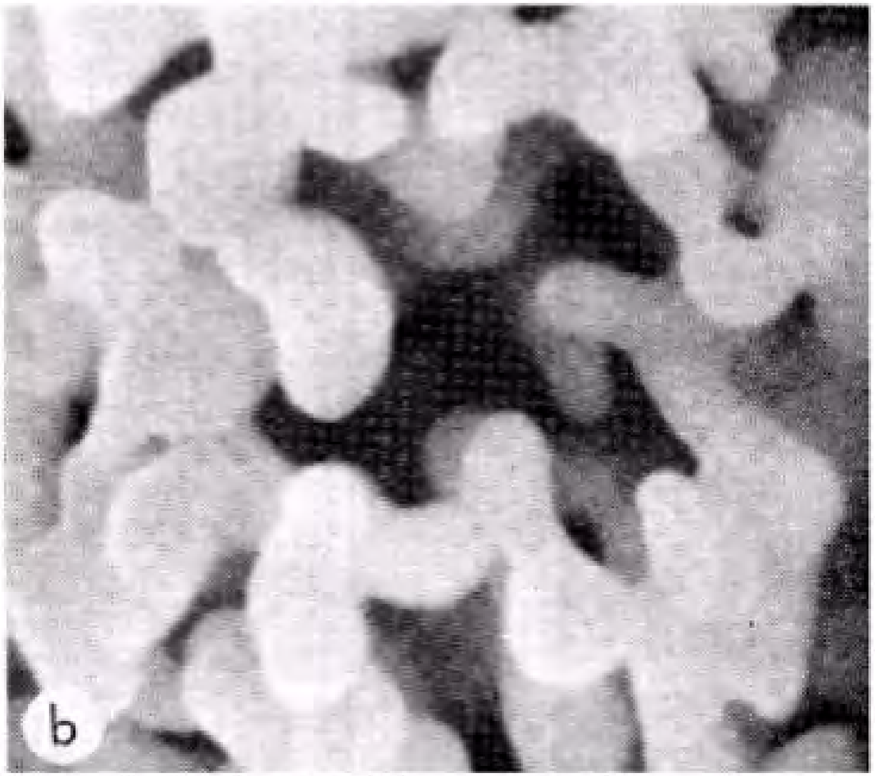
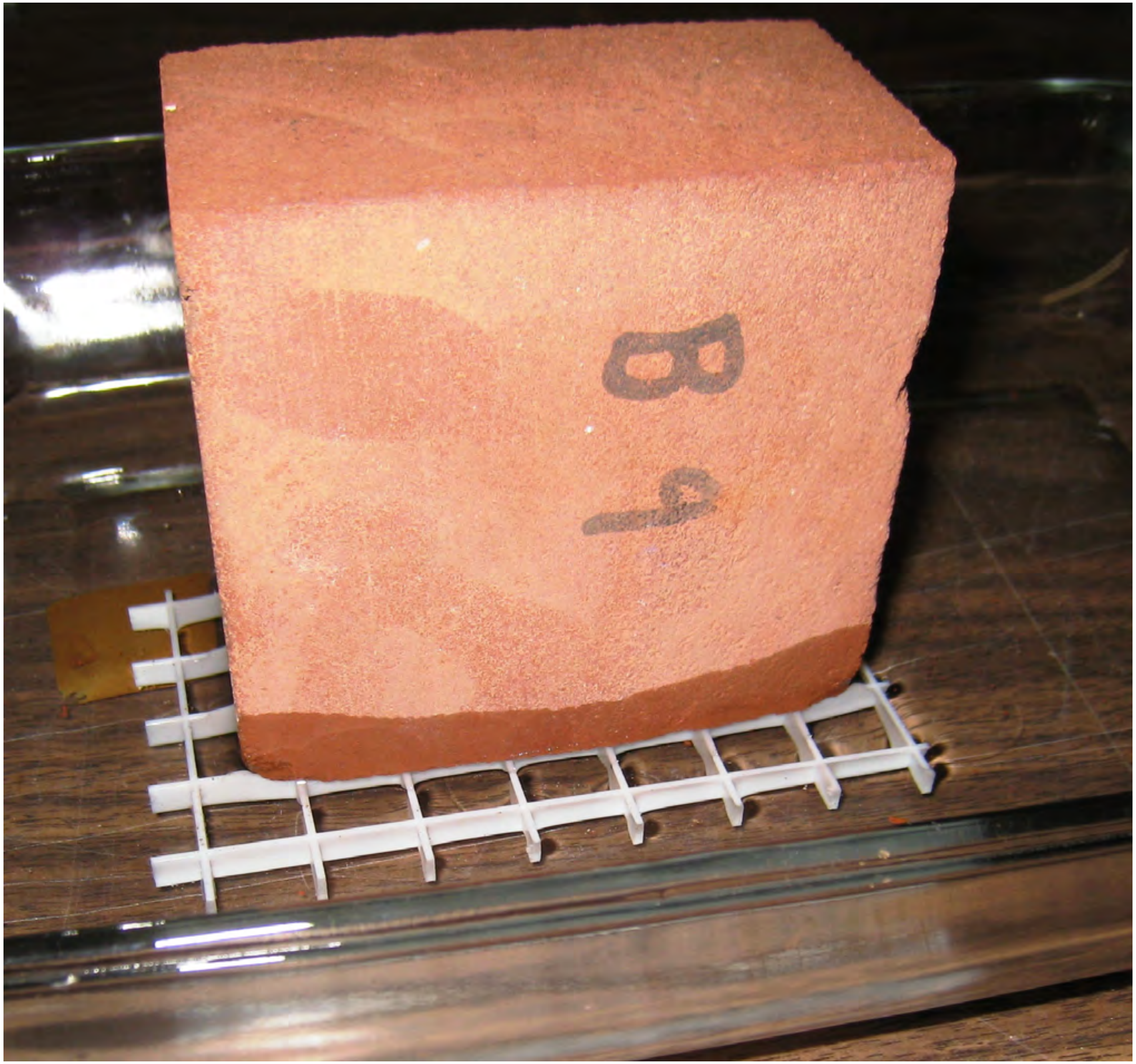
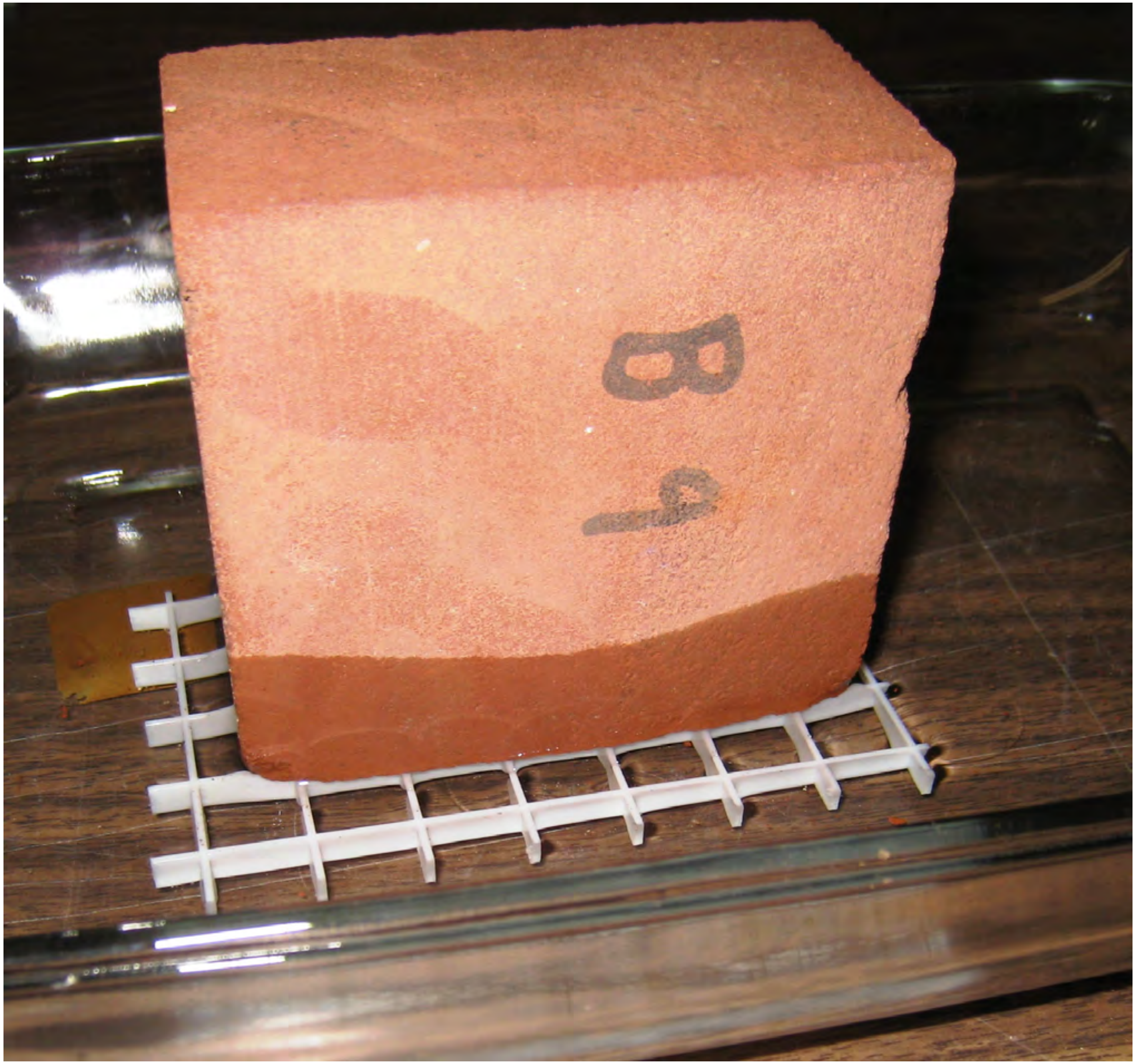
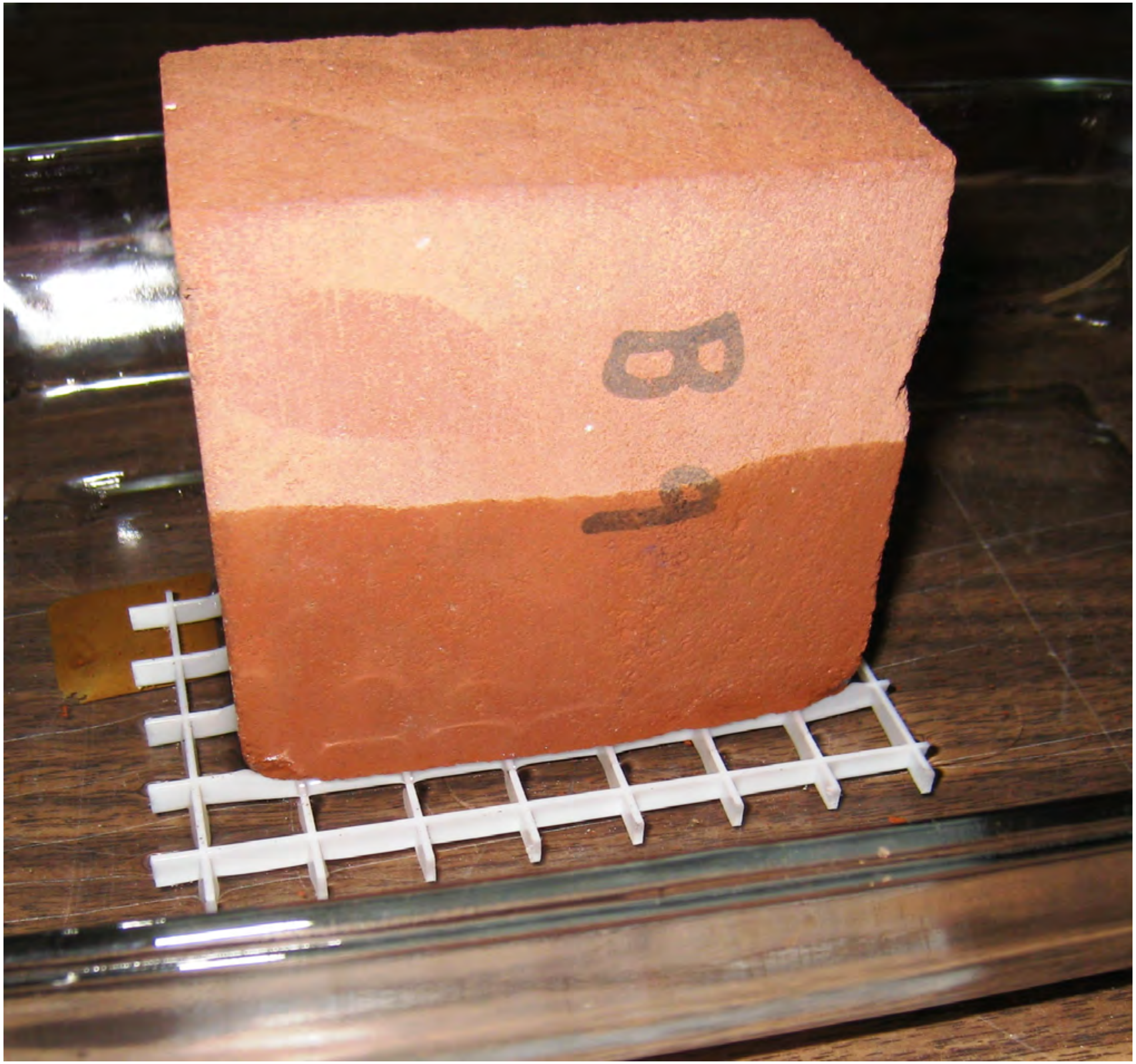
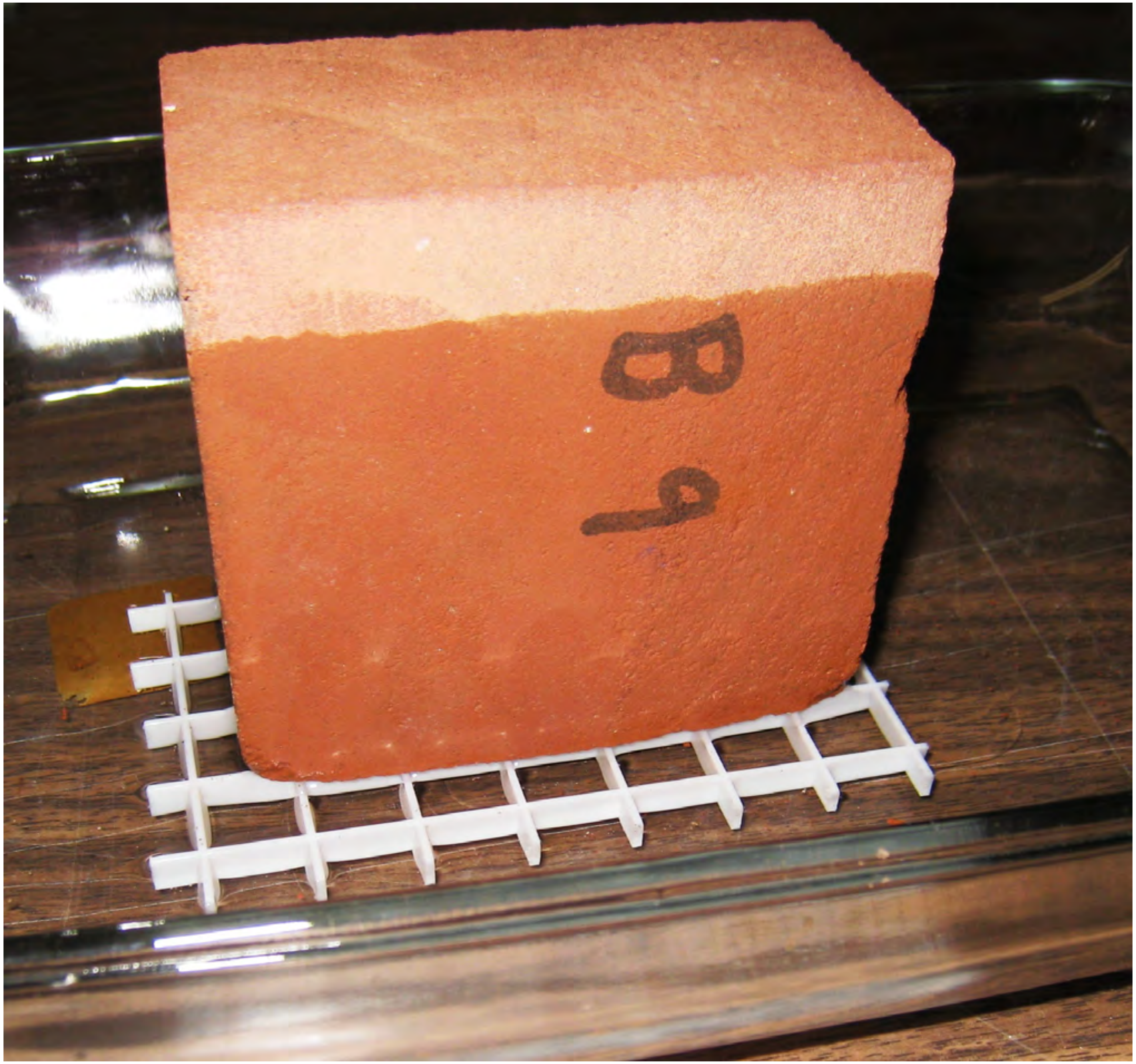


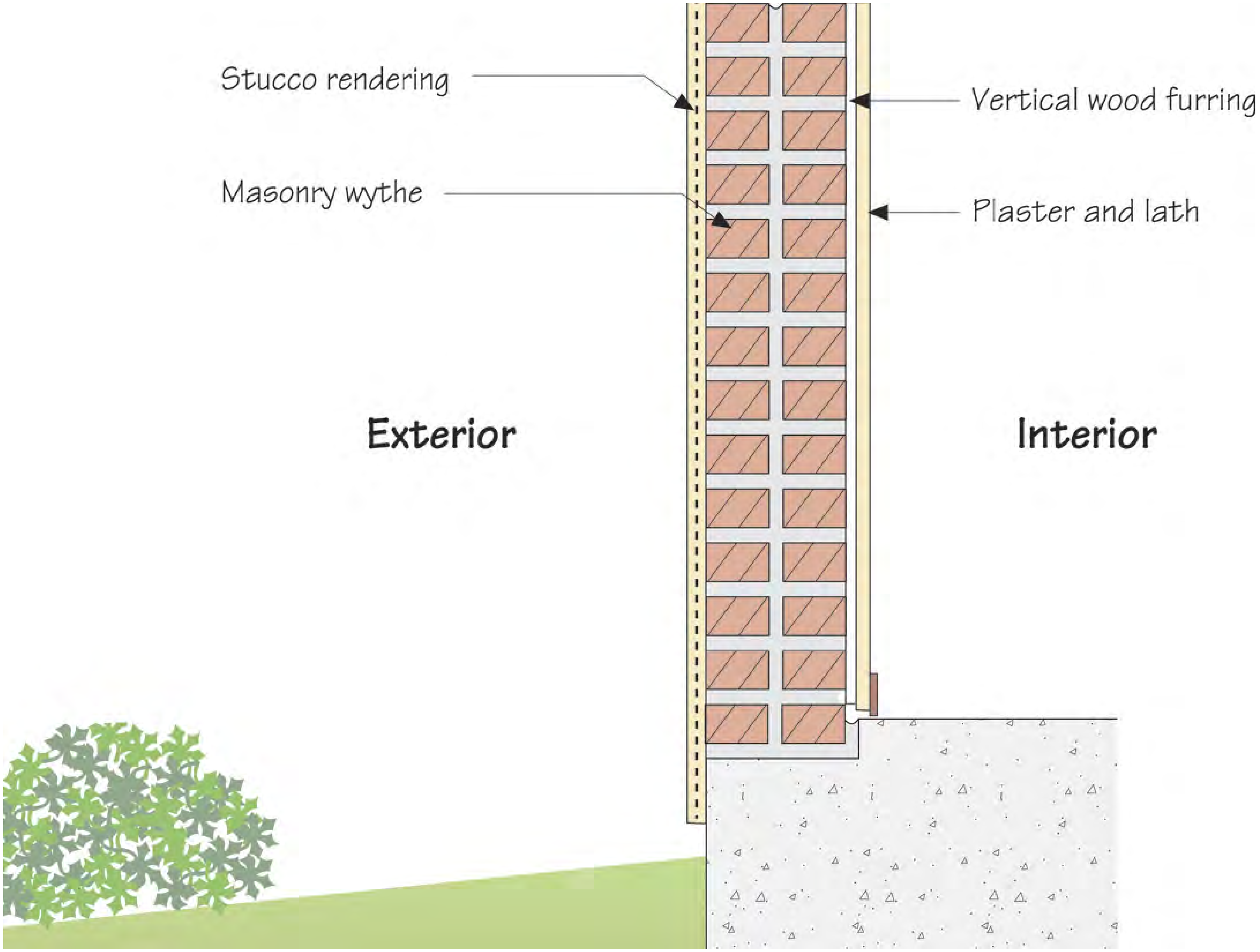
Figure 1b. Brick, sintered clay, porosity 40 per cent.

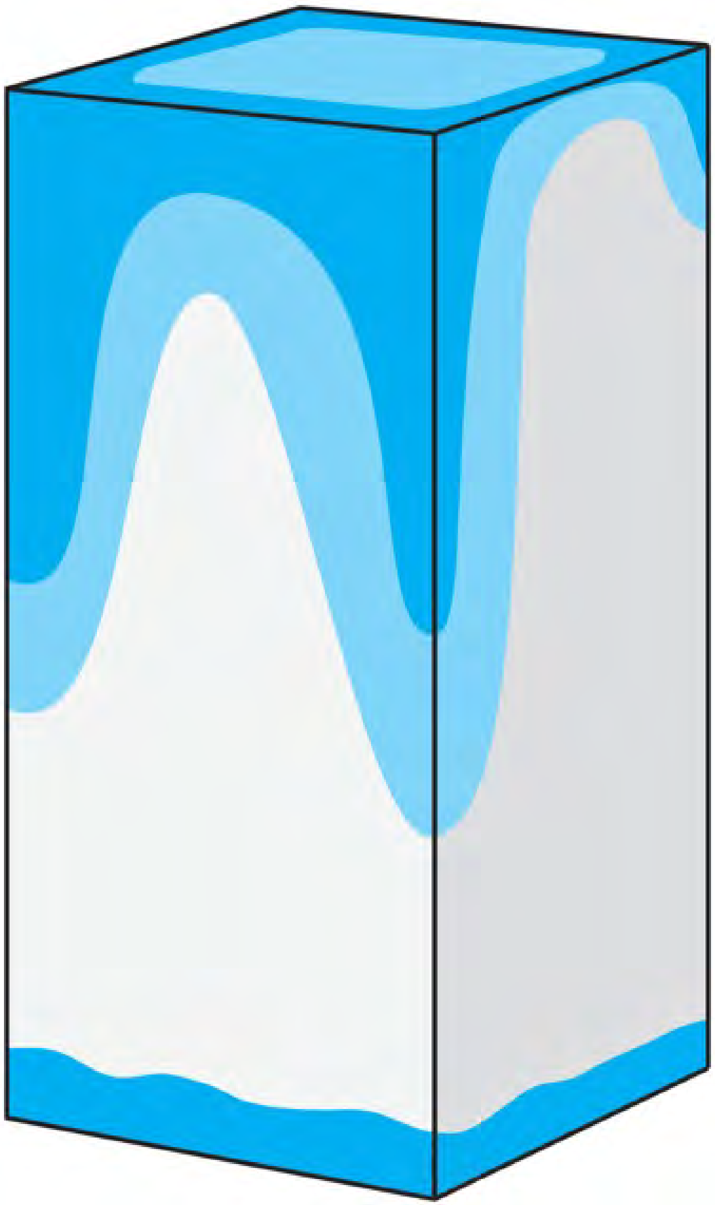

B
9

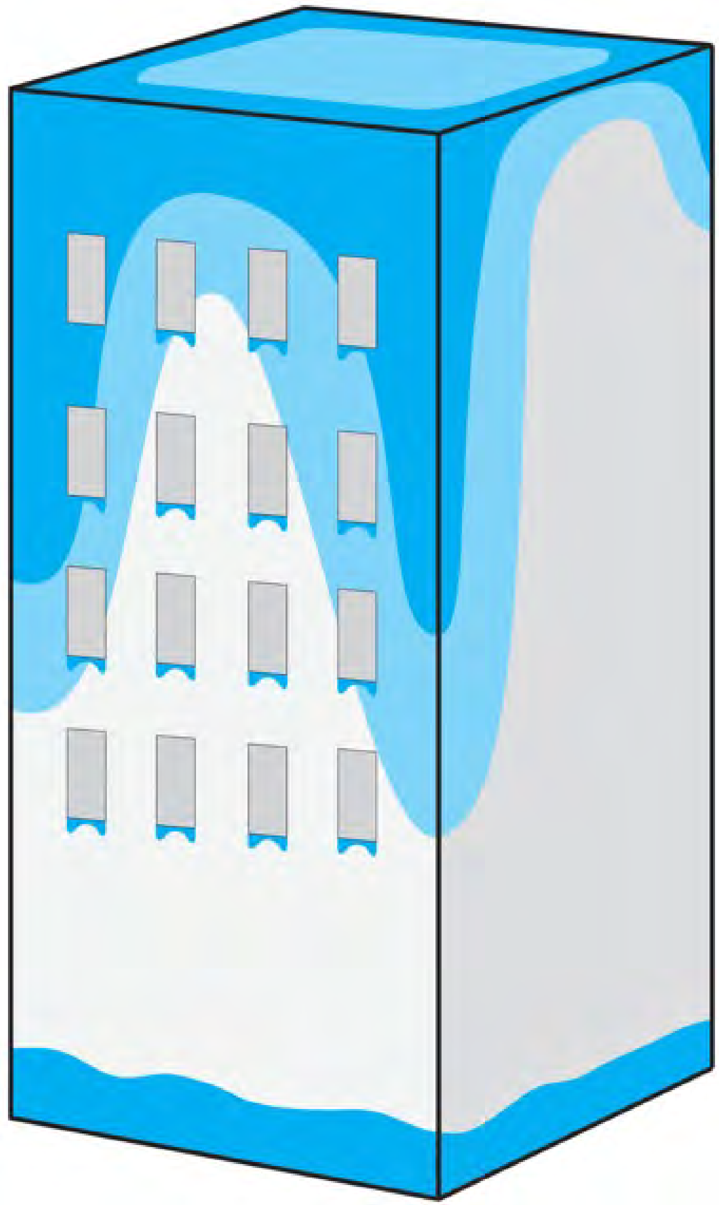

B9


B
9

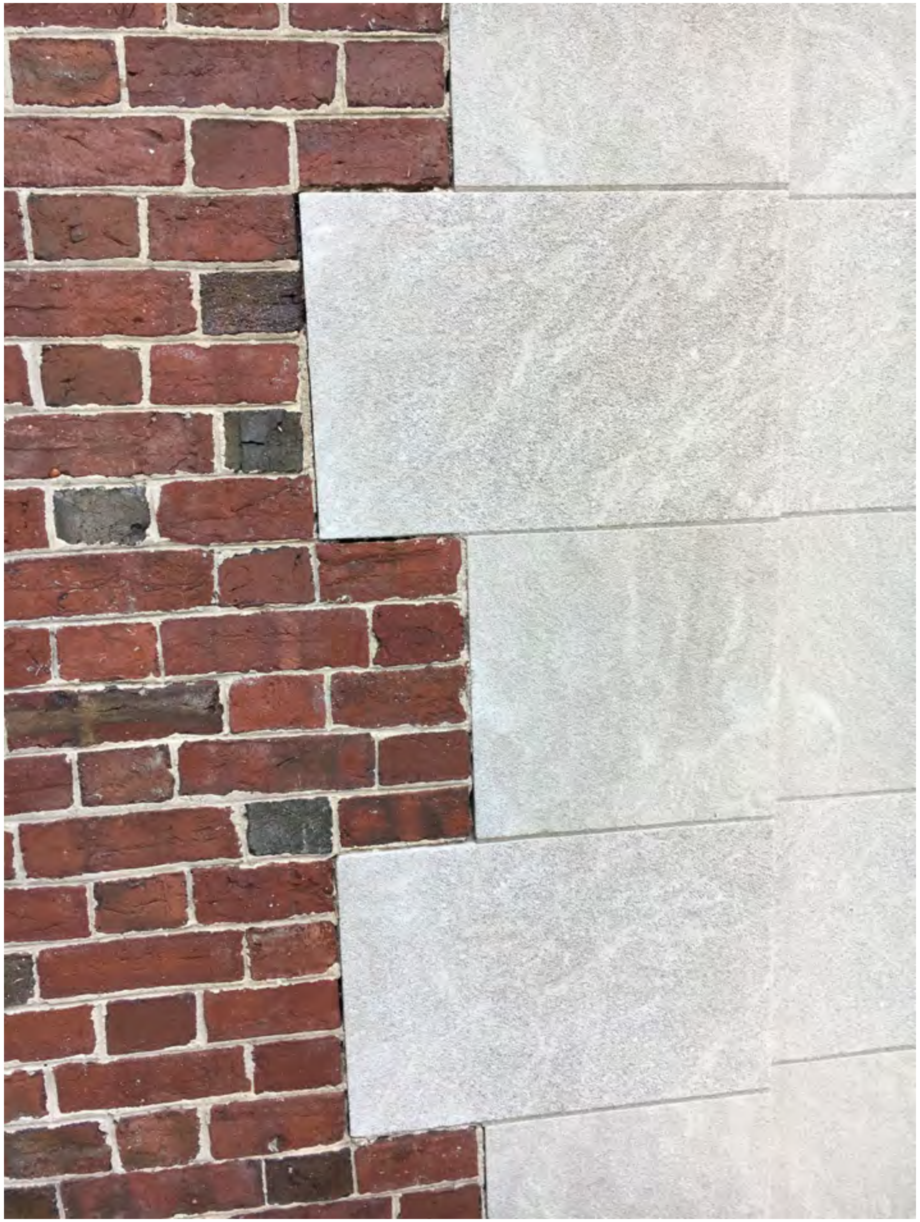

B 9

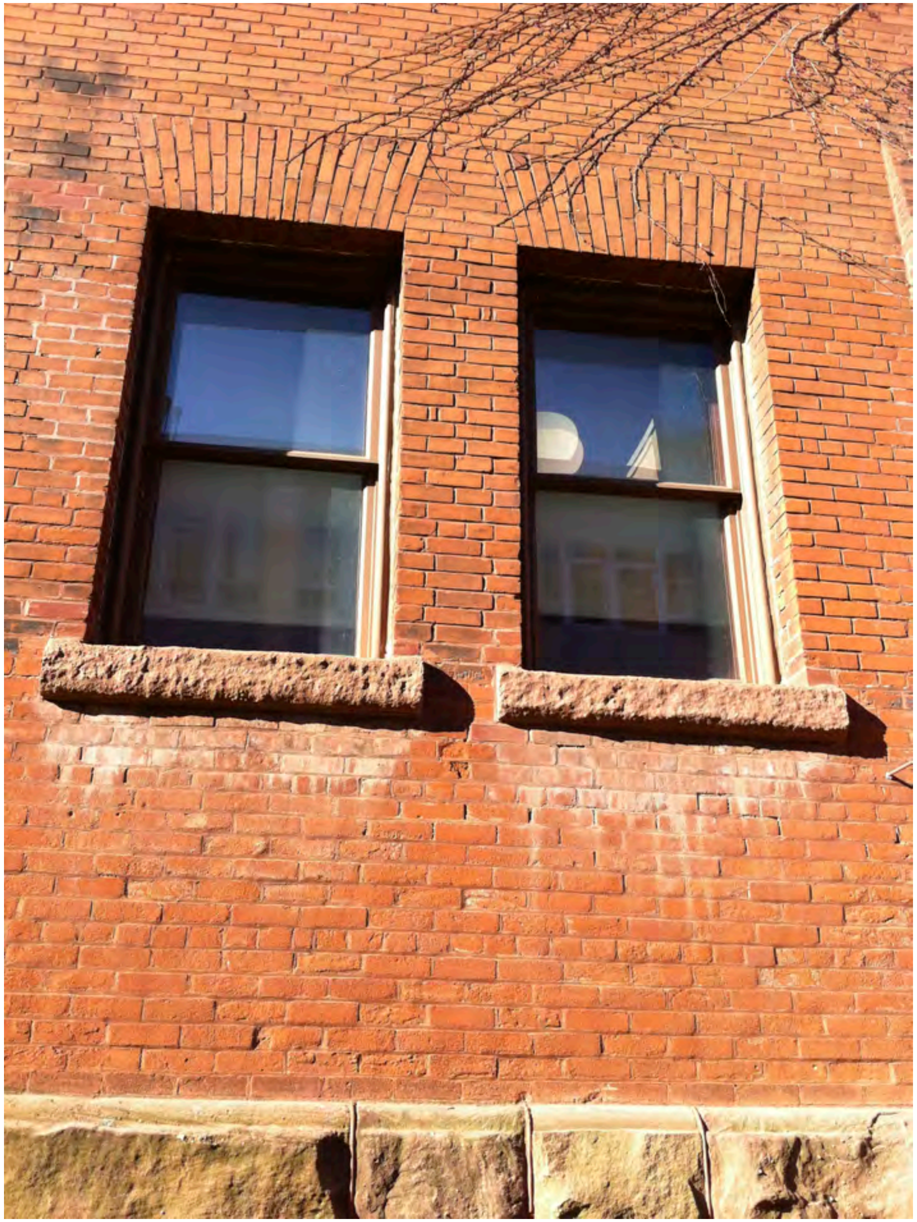

Stucco rendering
Vertical wood furring
Masonry wythe
Plaster and lath
Exterior
Interior

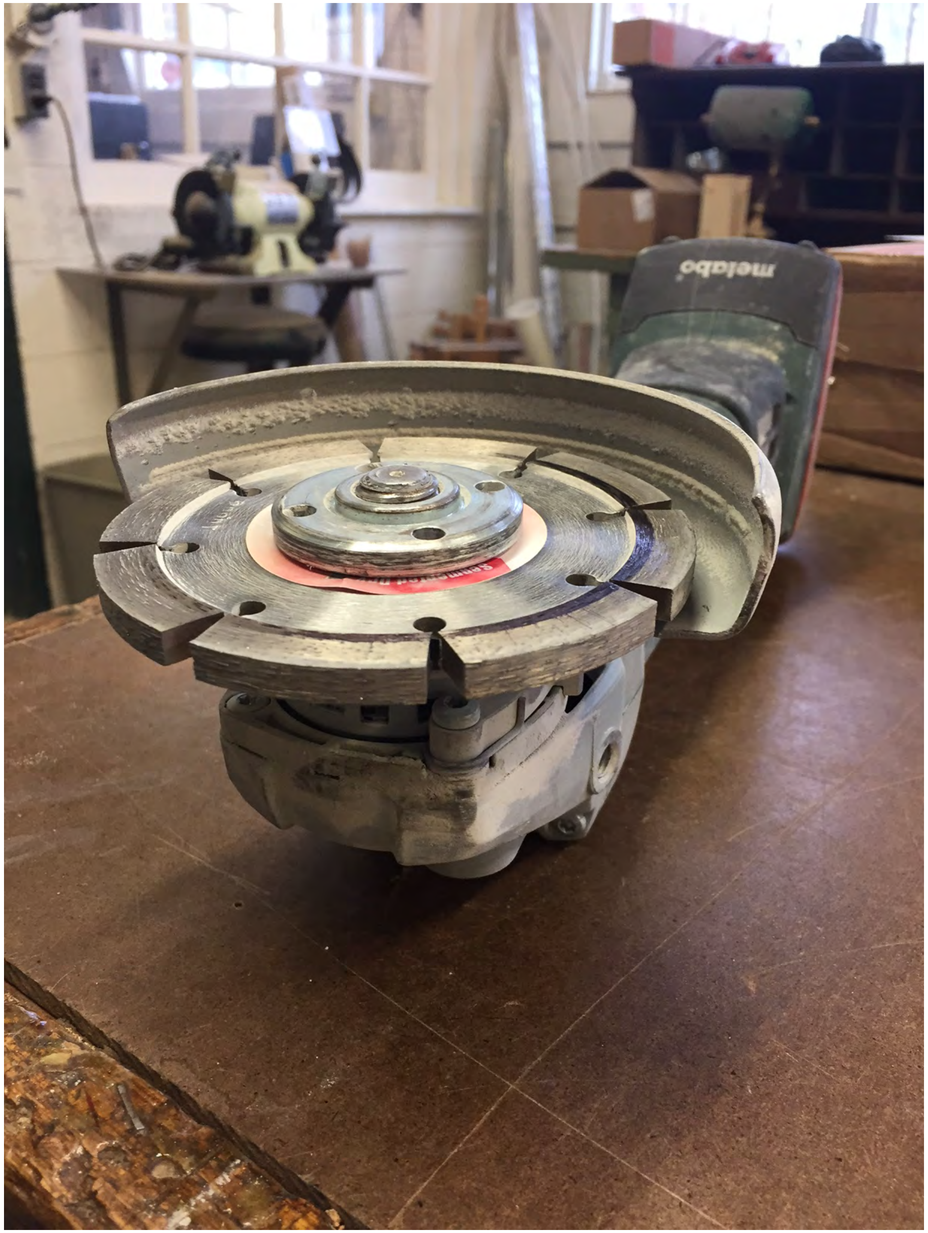


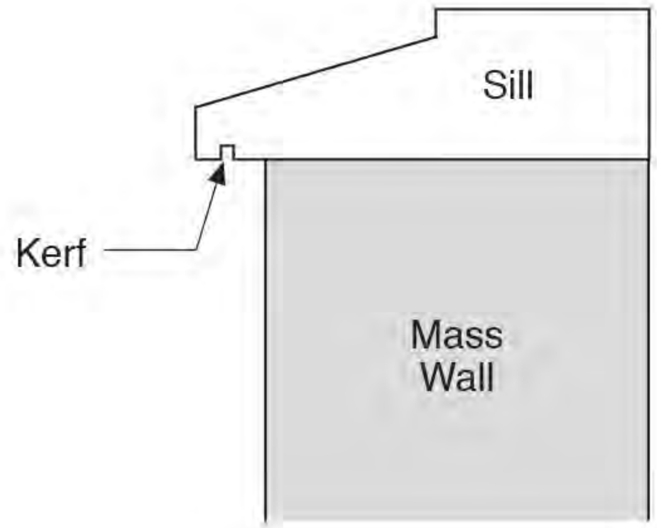


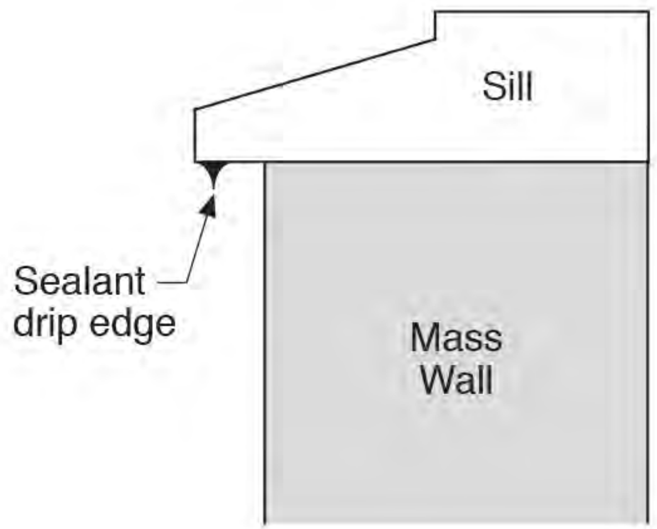

Lafayette
PHOENIX
(718) 963-9304
380 Lafayette Street
380 Holdings LLC
Lafayette





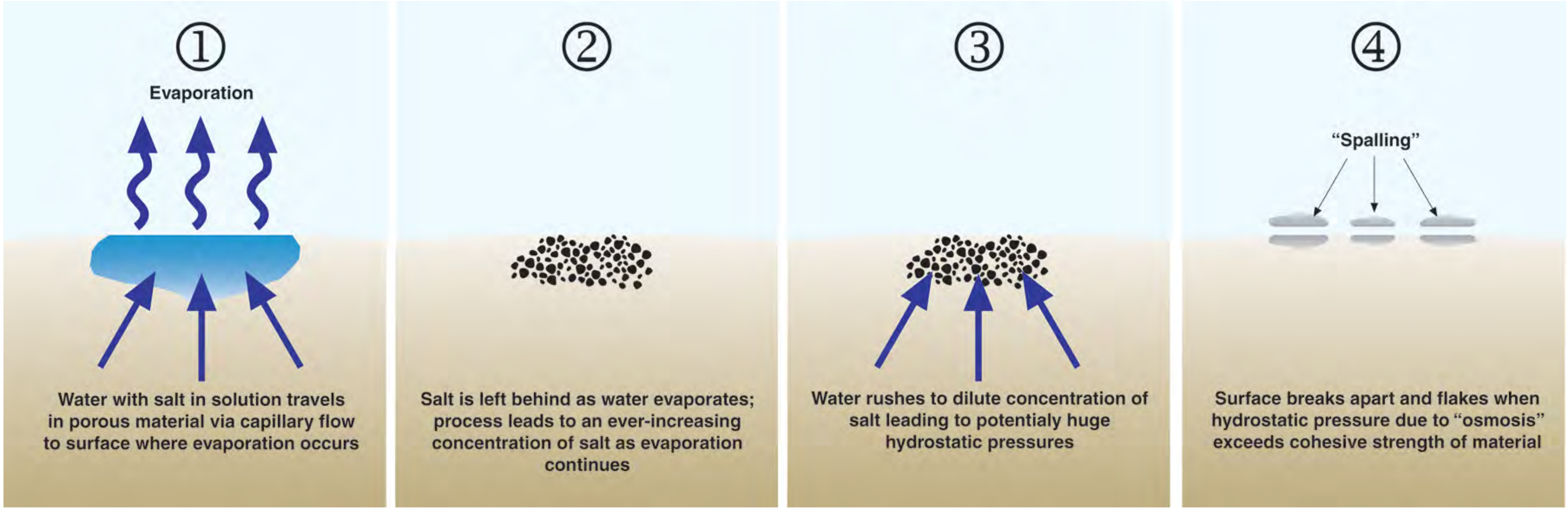

metabo


Sill
Kerf
Mass
Wall


Sill
Sealant
drip edge
Mass
Wall

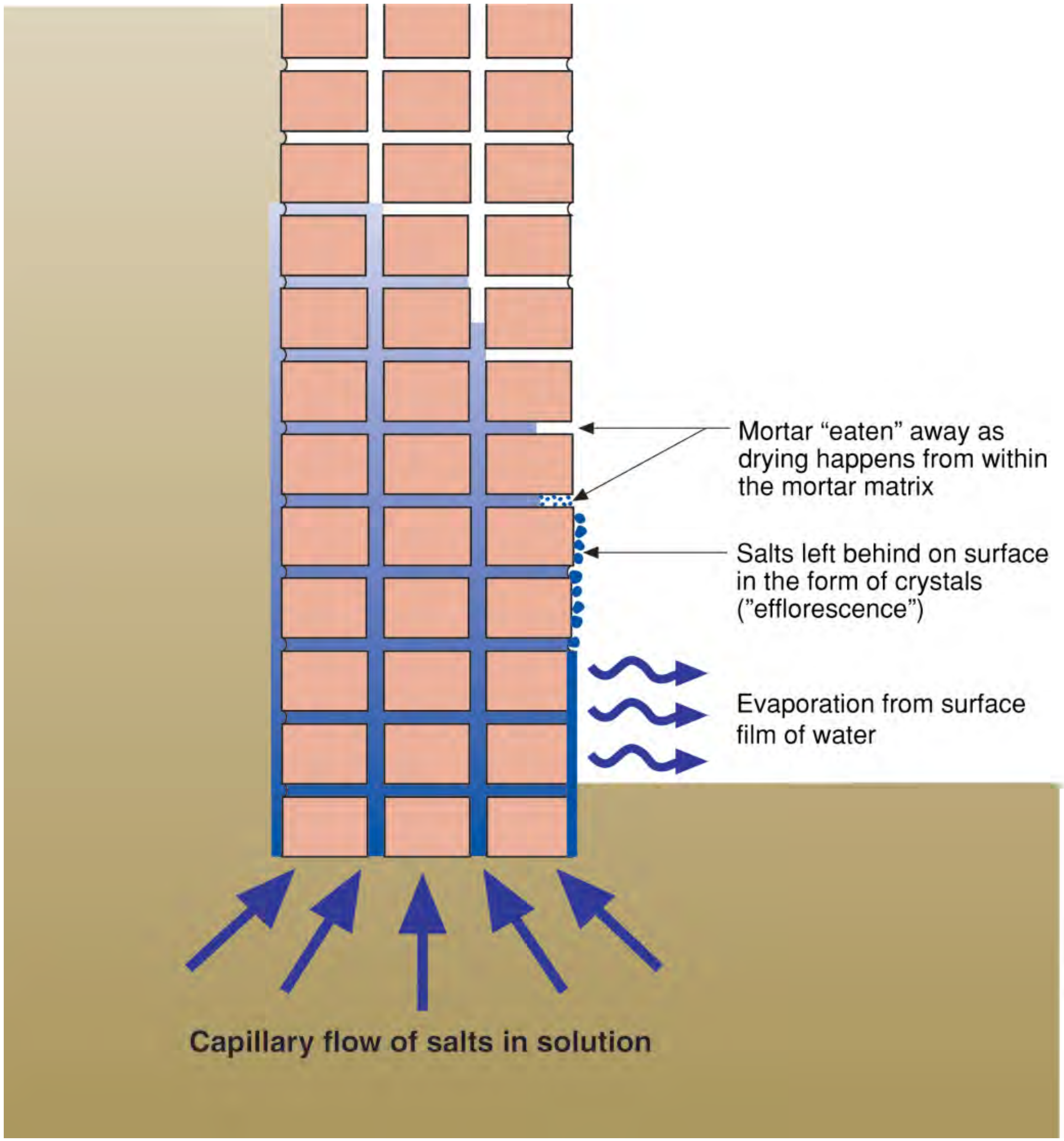

486

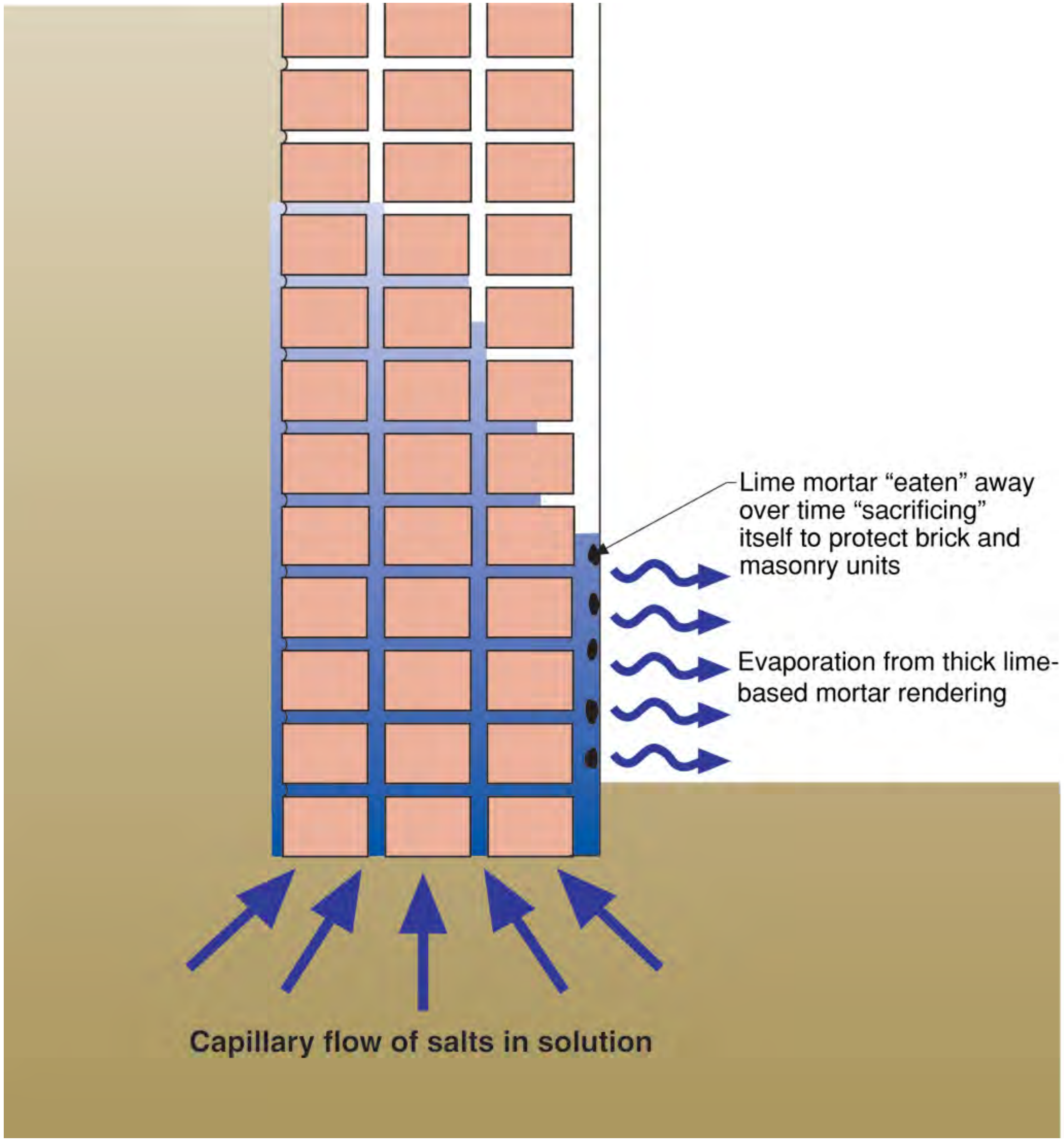

418
Crown 44


①
Evaporation
Water with salt in solution travels in porous material via capillary flow to surface where evaporation occurs
②
Salt is left behind as water evaporates; process leads to an ever-increasing concentration of salt as evaporation continues
③
Water rushes to dilute concentration of salt leading to potentialy huge hydrostatic pressures
④
"Spalling"
Surface breaks apart and flakes when hydrostatic pressure due to "osmosis" exceeds cohesive strength of material

Diffusion + Capillarity + Osmosis = Problem

• Diffusion Vapor Pressure	3 to 5 psi
• Capillary Pressure	300 to 500 psi
• Osmosis Pressure	3,000 to 5,000 psi

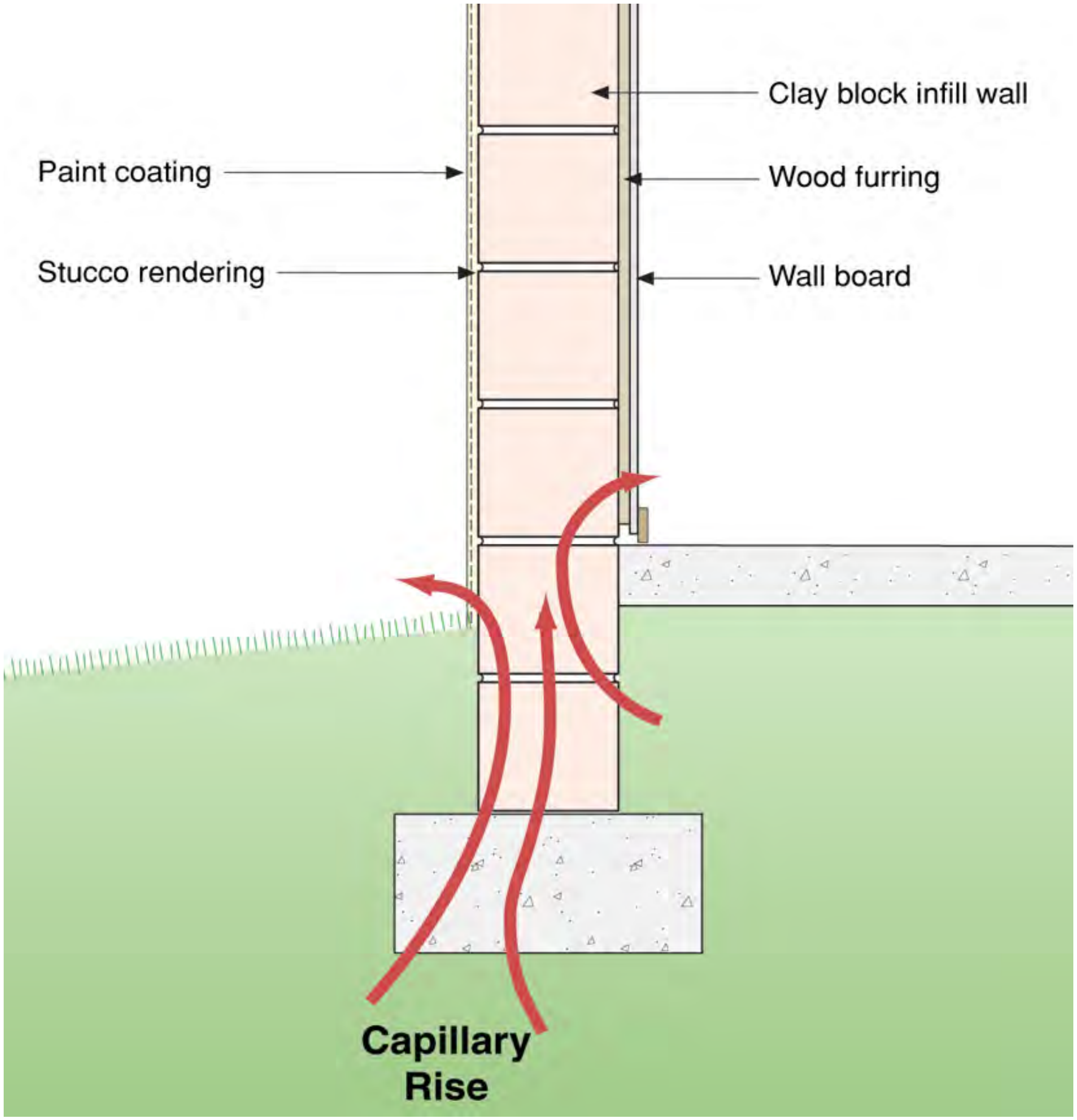

Mortar "eaten" away as drying happens from within the mortar matrix
Salts left behind on surface in the form of crystals ("efflorescence")
Evaporation from surface film of water
Capillary flow of salts in solution

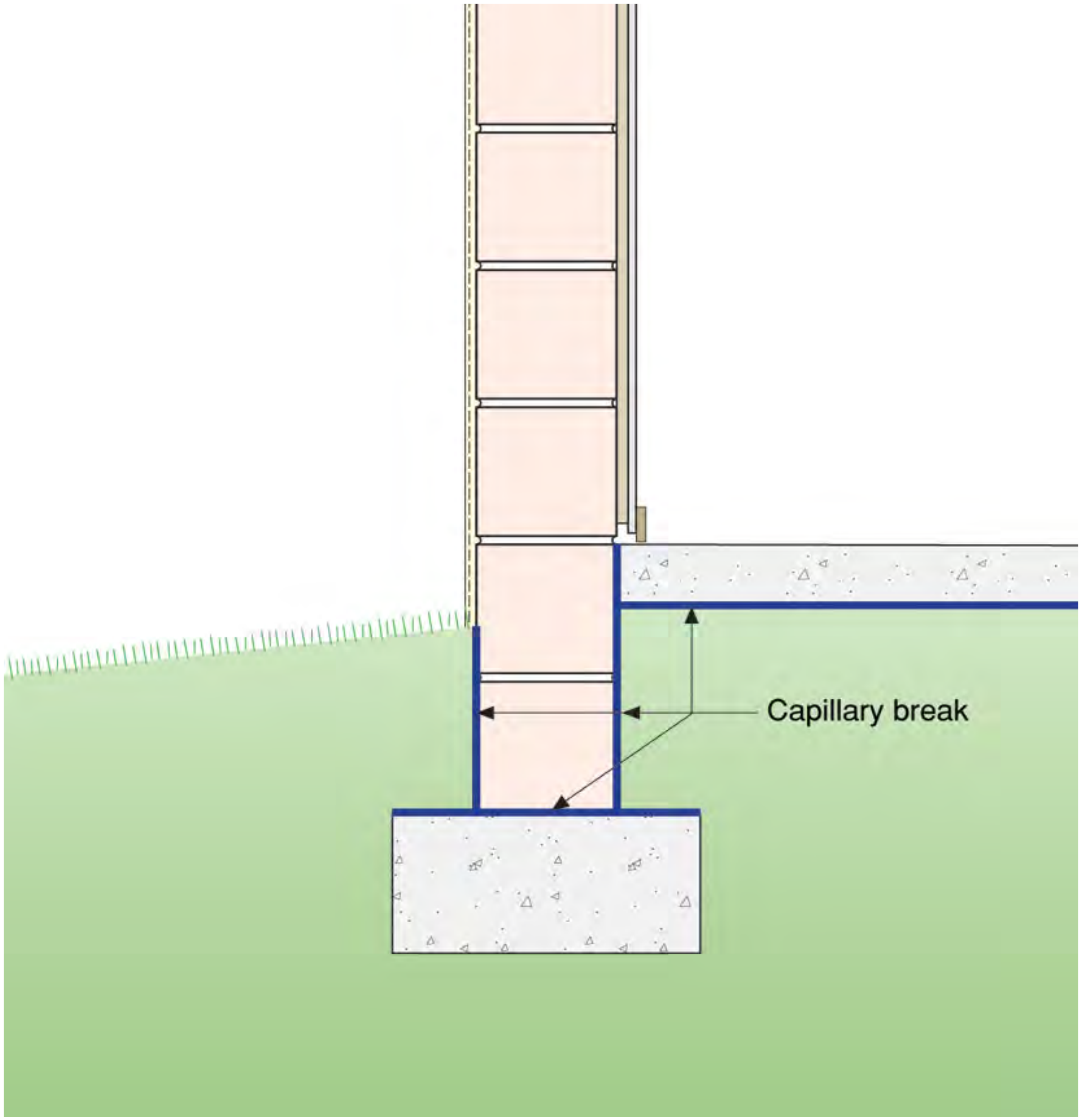

Lime mortar "eaten" away over time "sacrificing" itself to protect brick and masonry units
Evaporation from thick lime-based mortar rendering
Capillary flow of salts in solution

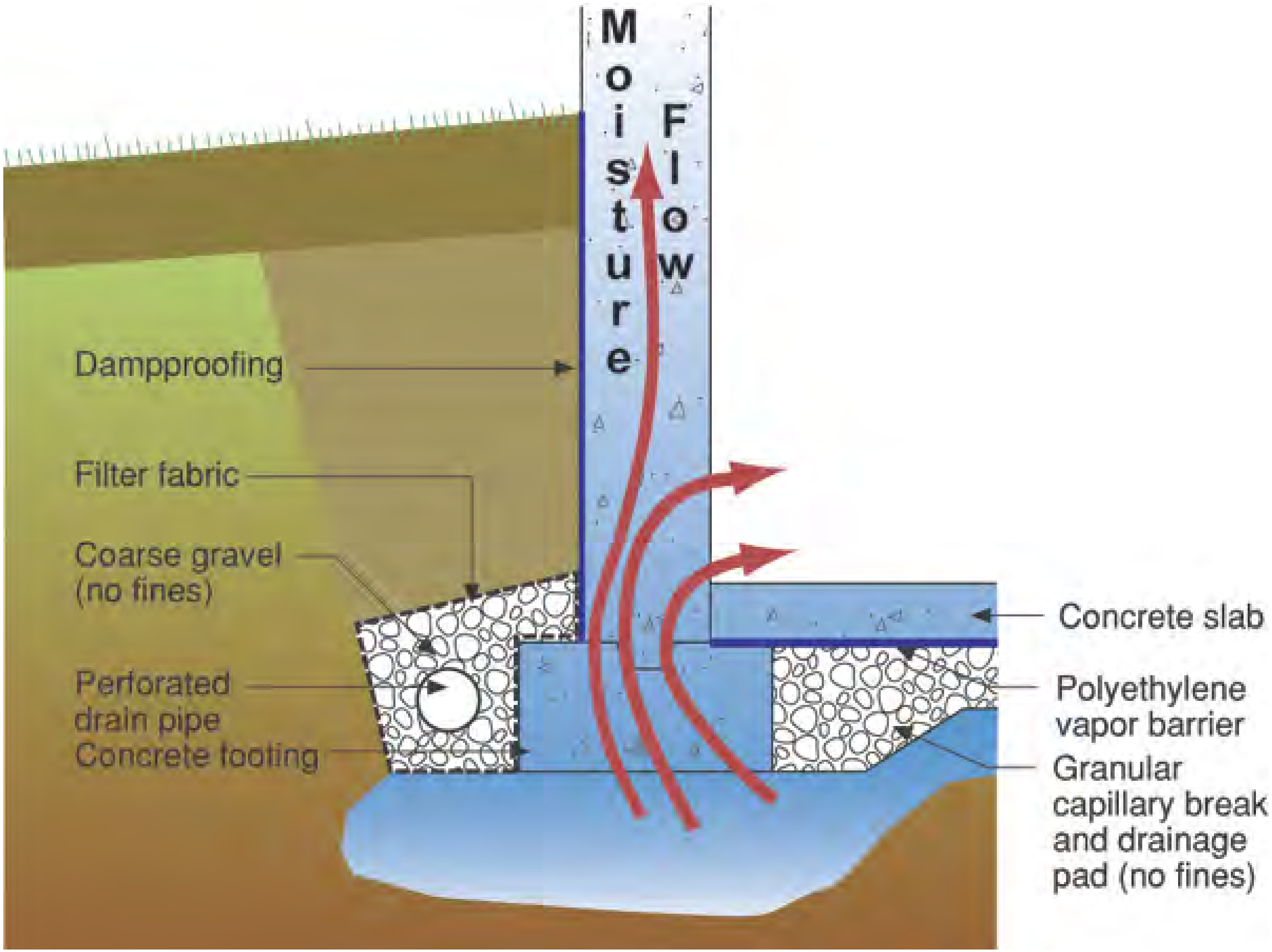

35

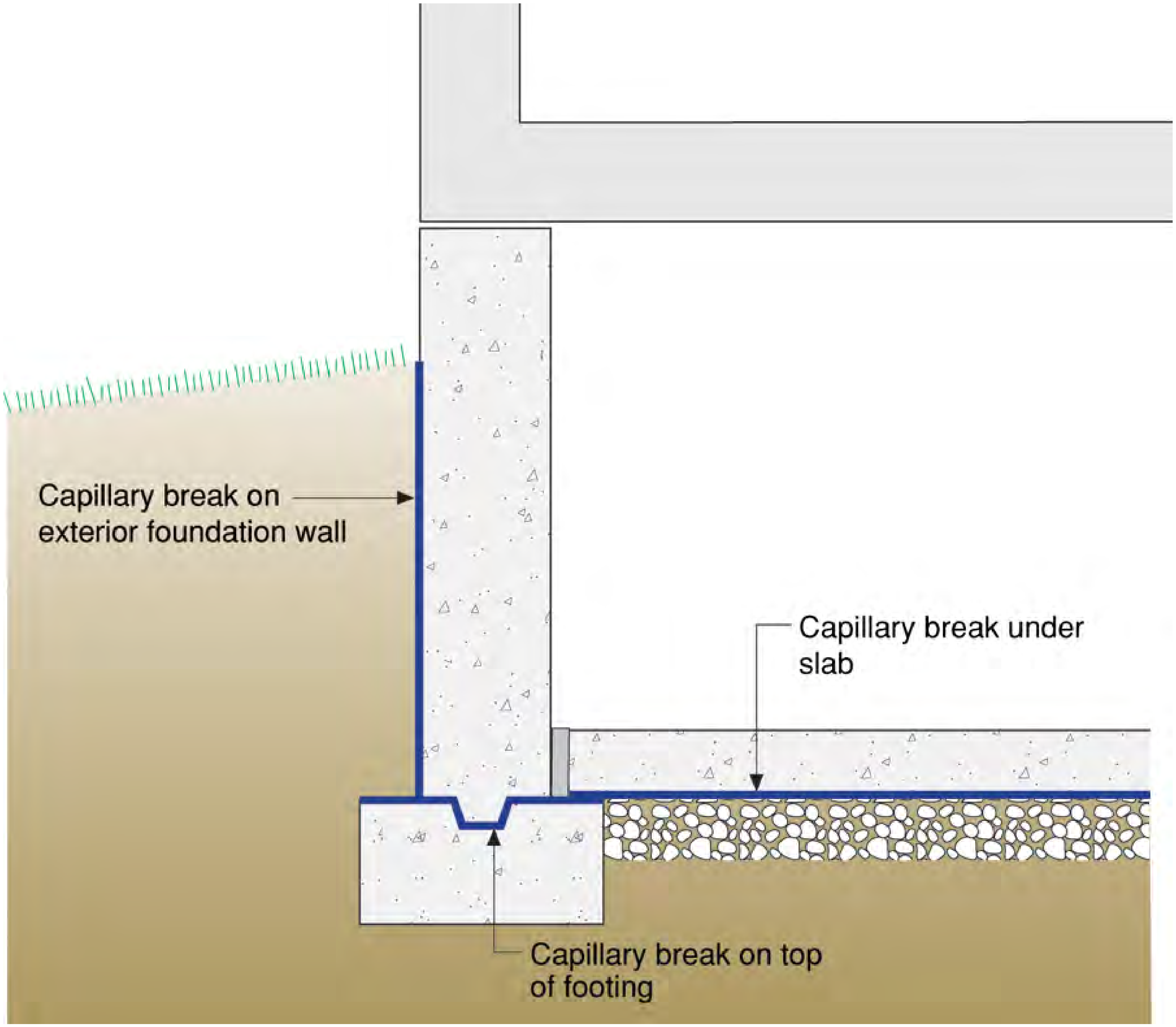

RA 200
RA 200
RA 200


KAMENOSOCHAŘSTVÍ - RESTAURÁTORSTVÍ
BOHUMIL PÁNEK
Ř Í Č A N Y
firma s historickou tradicí od roku 1673
tel. 602 341 965, tel./fax 323 602 942
e-mail panekkamen@atlas.cz, www.panek-kamen.cz

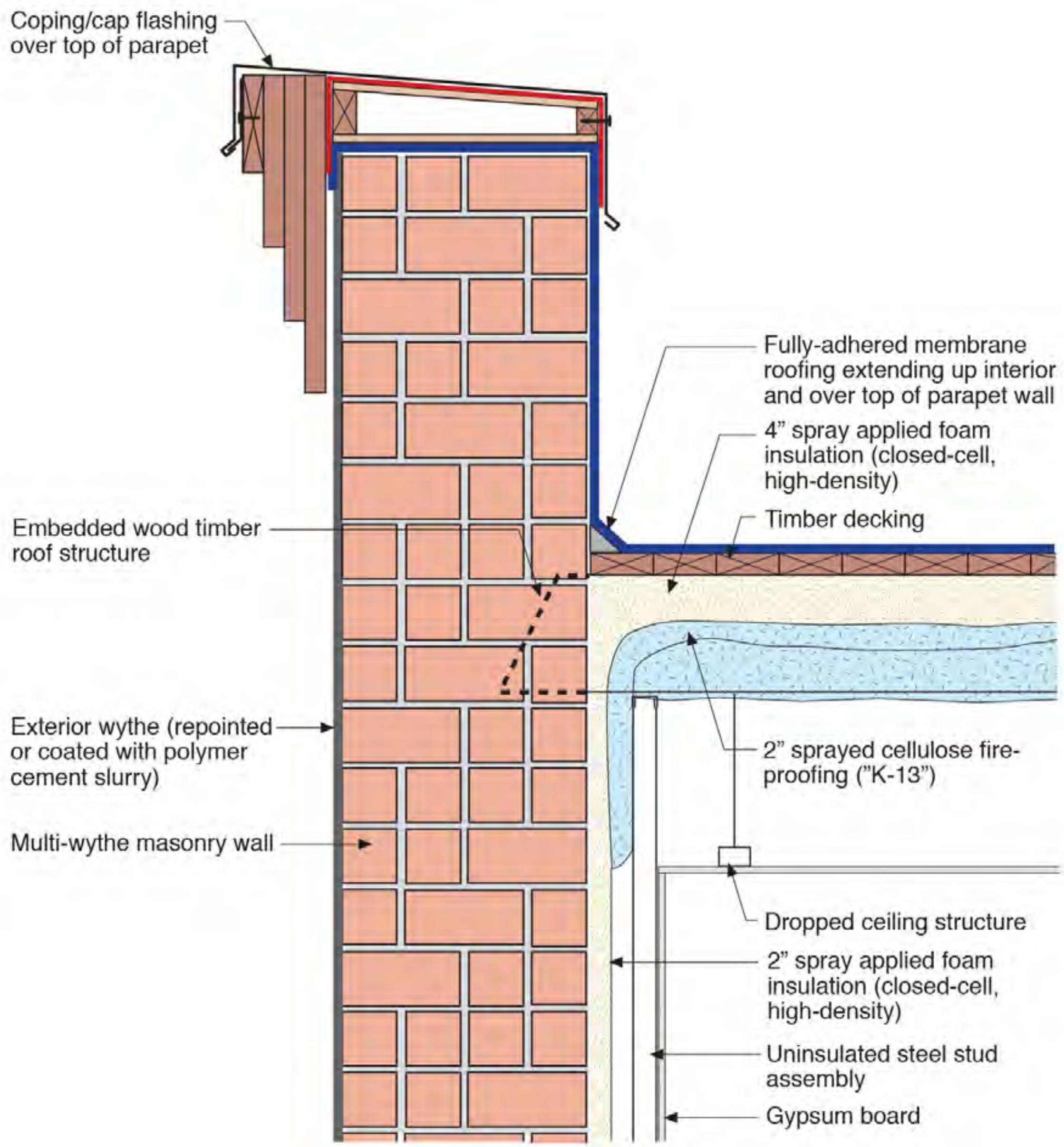

Clay block infill wall
Paint coating
Wood furring
Stucco rendering
Wall board
Capillary
Rise

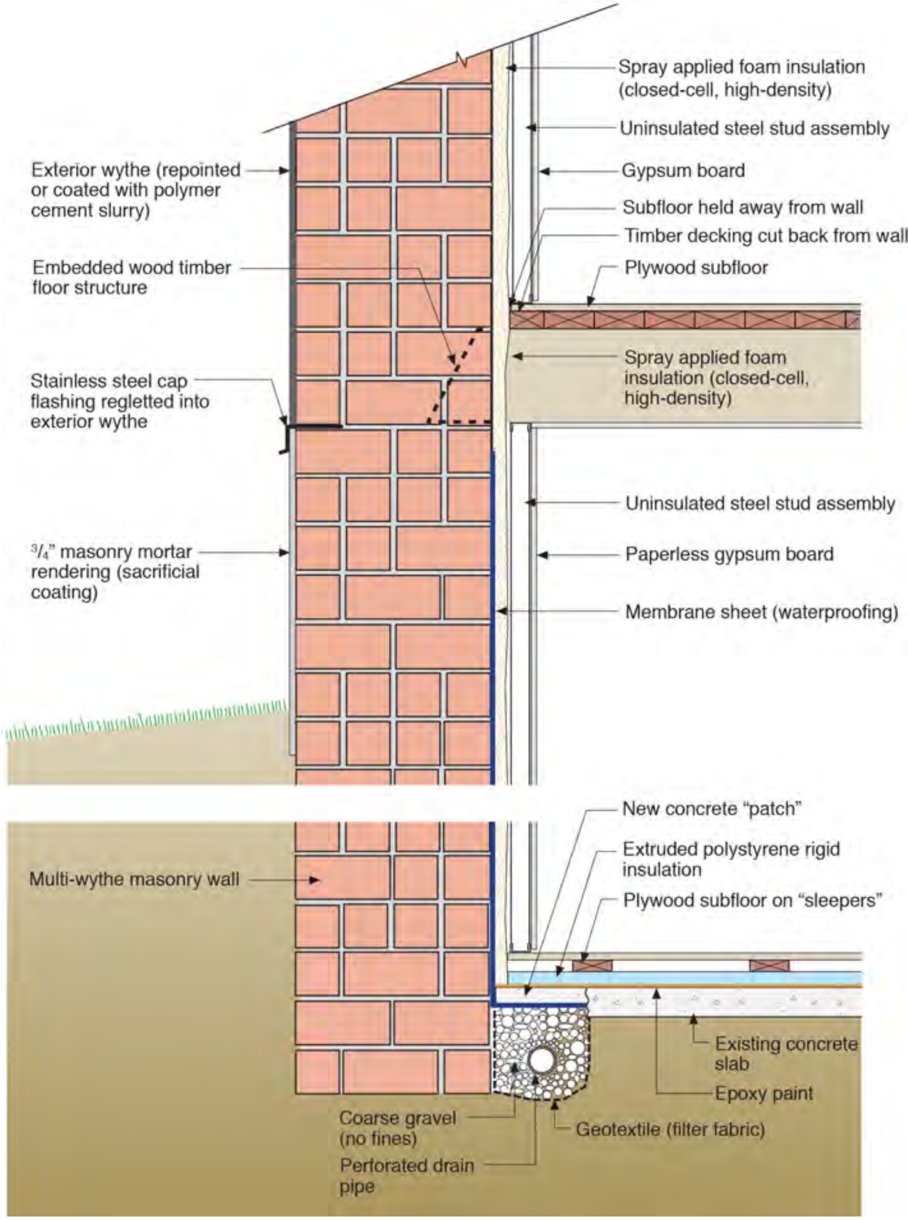

Capillary break

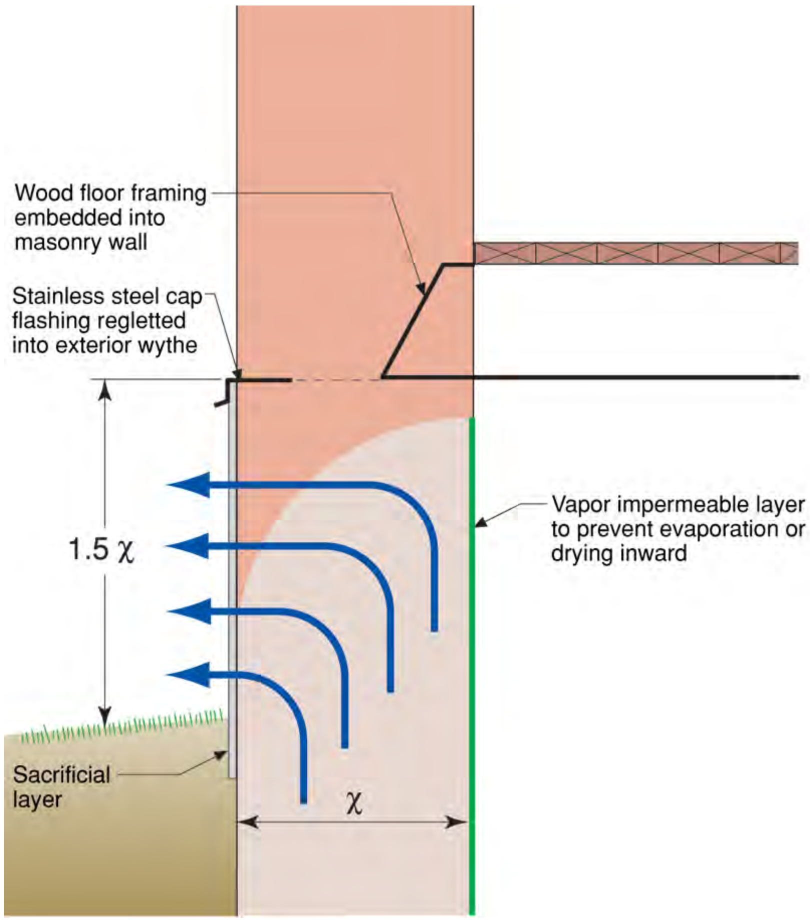

Moisture Flow
Dampproofing
Filter fabric
Coarse gravel (no fines)
Perforated drain pipe
Concrete footing
Concrete slab
Polyethylene vapor barrier
Granular capillary break and drainage pad (no fines)

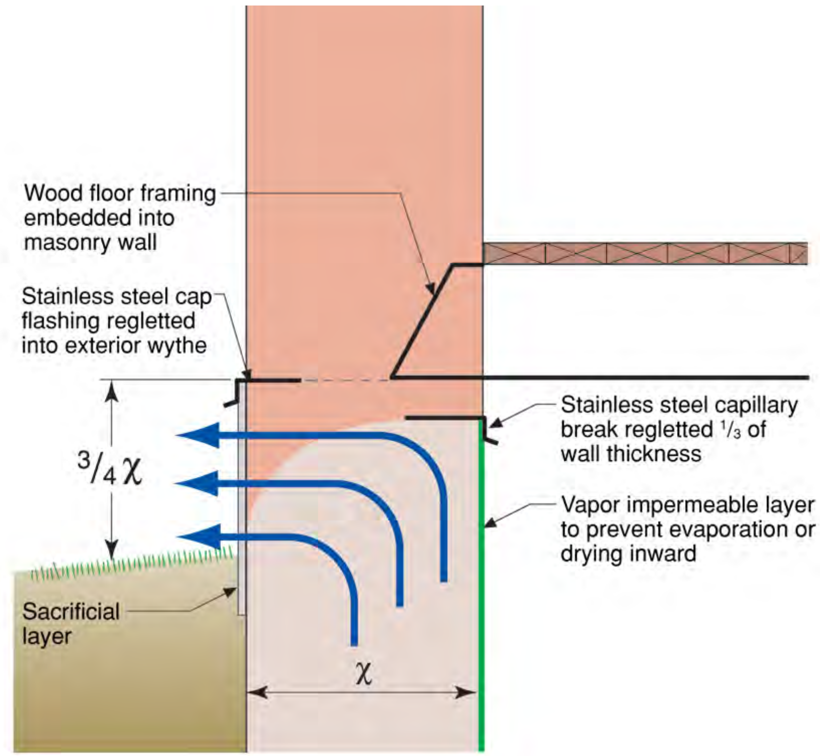

Capillary break on exterior foundation wall
Capillary break under slab
Capillary break on top of footing

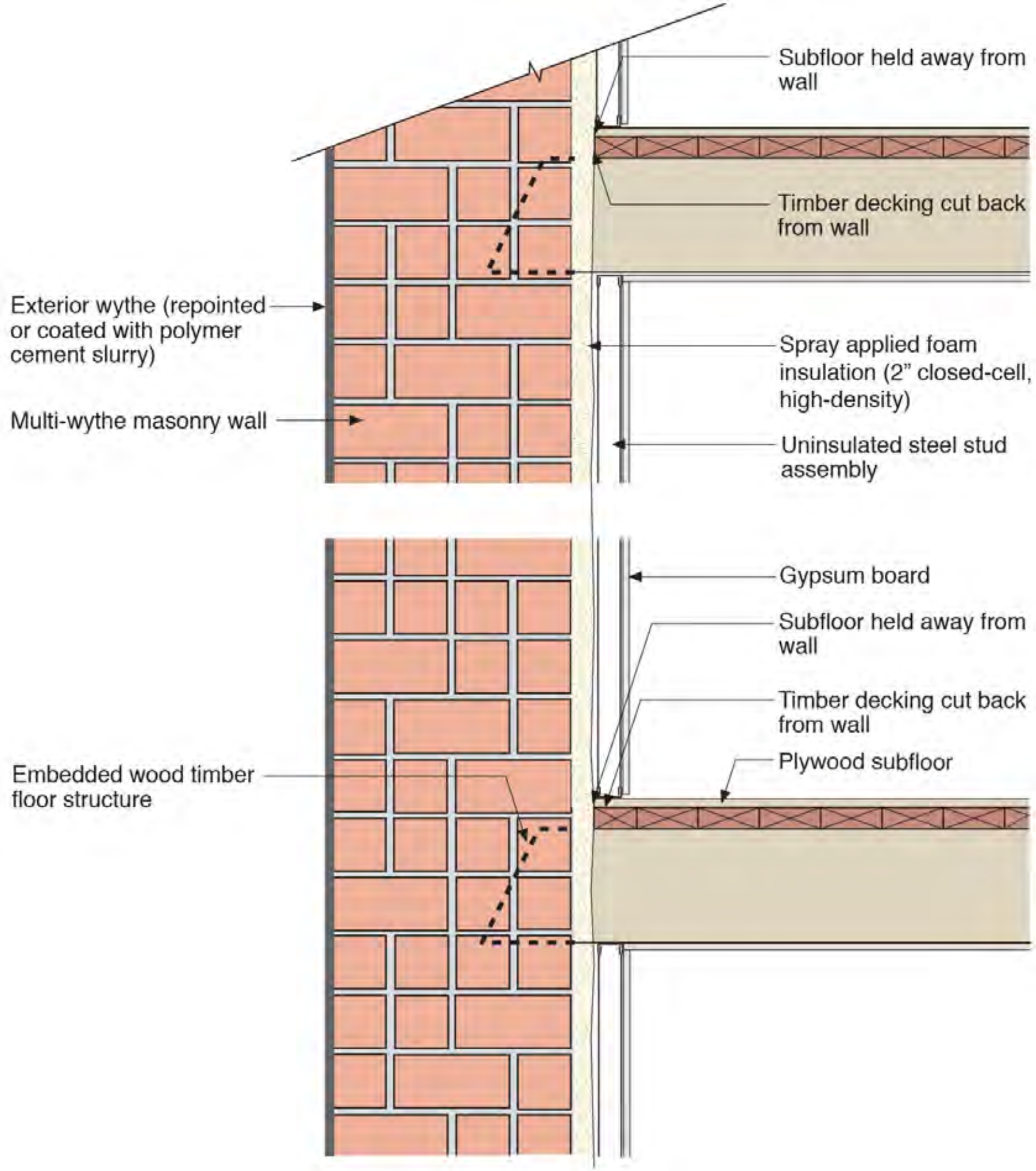

WEST SIDE VILLAGE
113 North 13th Street
An RPM Managed Community
113

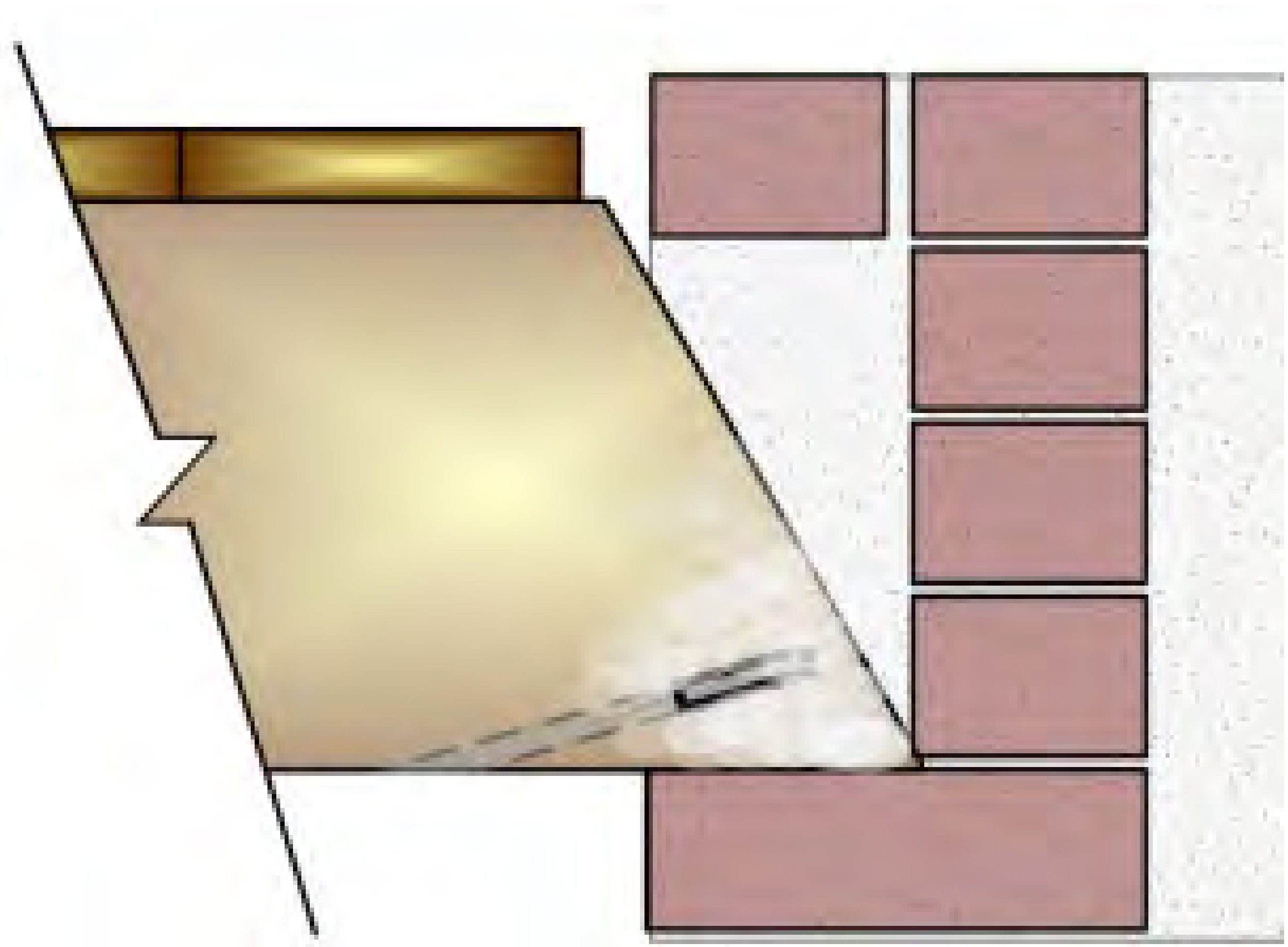

Coping/cap flashing over top of parapet
Fully-adhered membrane roofing extending up interior and over top of parapet wall
4” spray applied foam insulation (closed-cell, high-density)
Timber decking
Embedded wood timber roof structure
Exterior wythe (repointed or coated with polymer cement slurry)
2” sprayed cellulose fire-proofing (”K-13”)
Multi-wythe masonry wall
Dropped ceiling structure
2” spray applied foam insulation (closed-cell, high-density)
Uninsulated steel stud assembly
Gypsum board

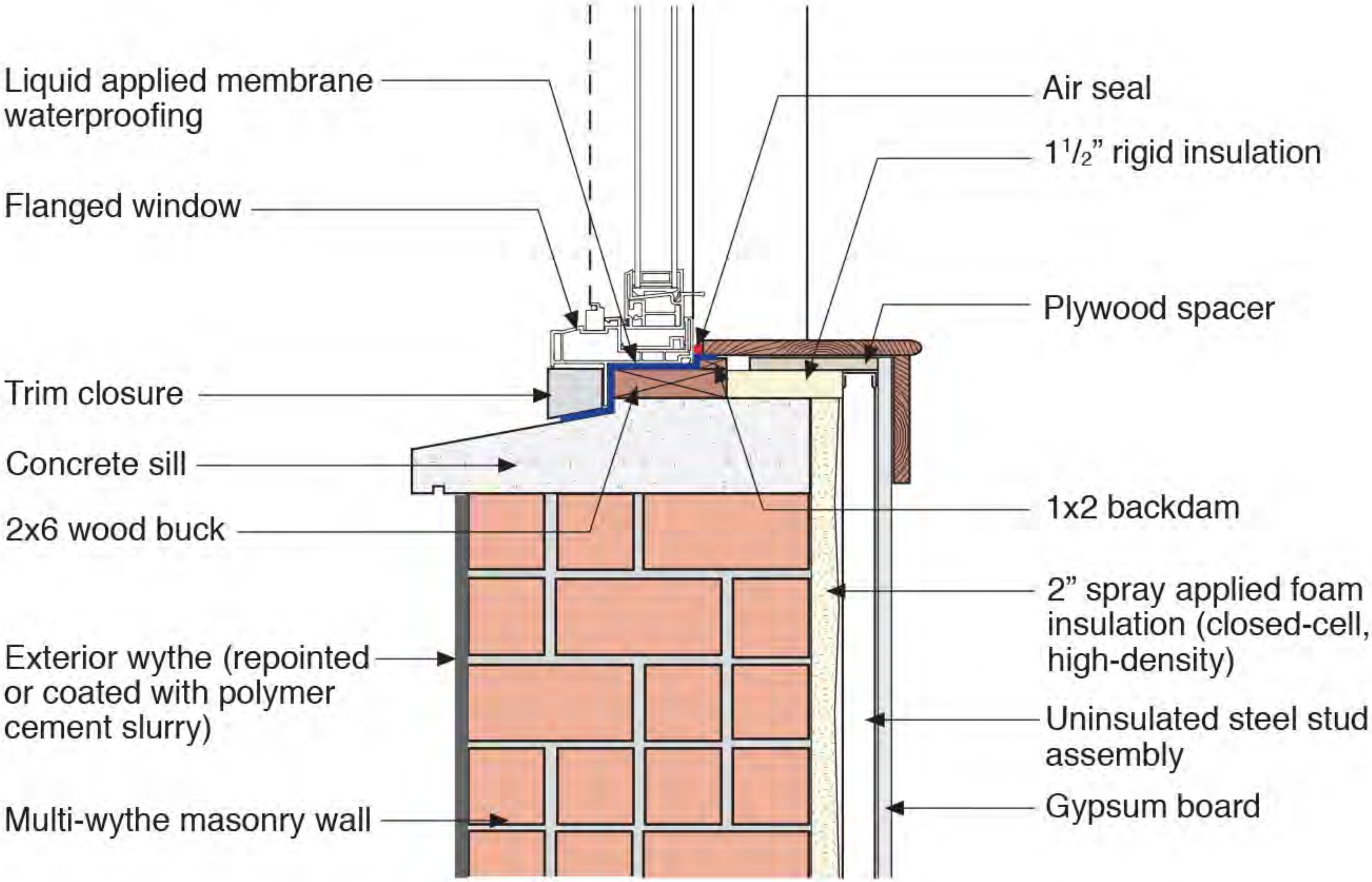

Spray applied foam insulation (closed-cell, high-density)
Uninsulated steel stud assembly
Gypsum board
Subfloor held away from wall
Timber decking cut back from wall
Plywood subfloor
Exterior wythe (repointed or coated with polymer cement slurry)
Embedded wood timber floor structure
Stainless steel cap flashing regletted into exterior wythe
Spray applied foam insulation (closed-cell, high-density)
Uninsulated steel stud assembly
3/4" masonry mortar rendering (sacrificial coating)
Paperless gypsum board
Membrane sheet (waterproofing)
New concrete "patch"
Extruded polystyrene rigid insulation
Plywood subfloor on "sleepers"
Multi-wythe masonry wall
Existing concrete slab
Epoxy paint
Coarse gravel (no fines)
Geotextile (filter fabric)
Perforated drain pipe

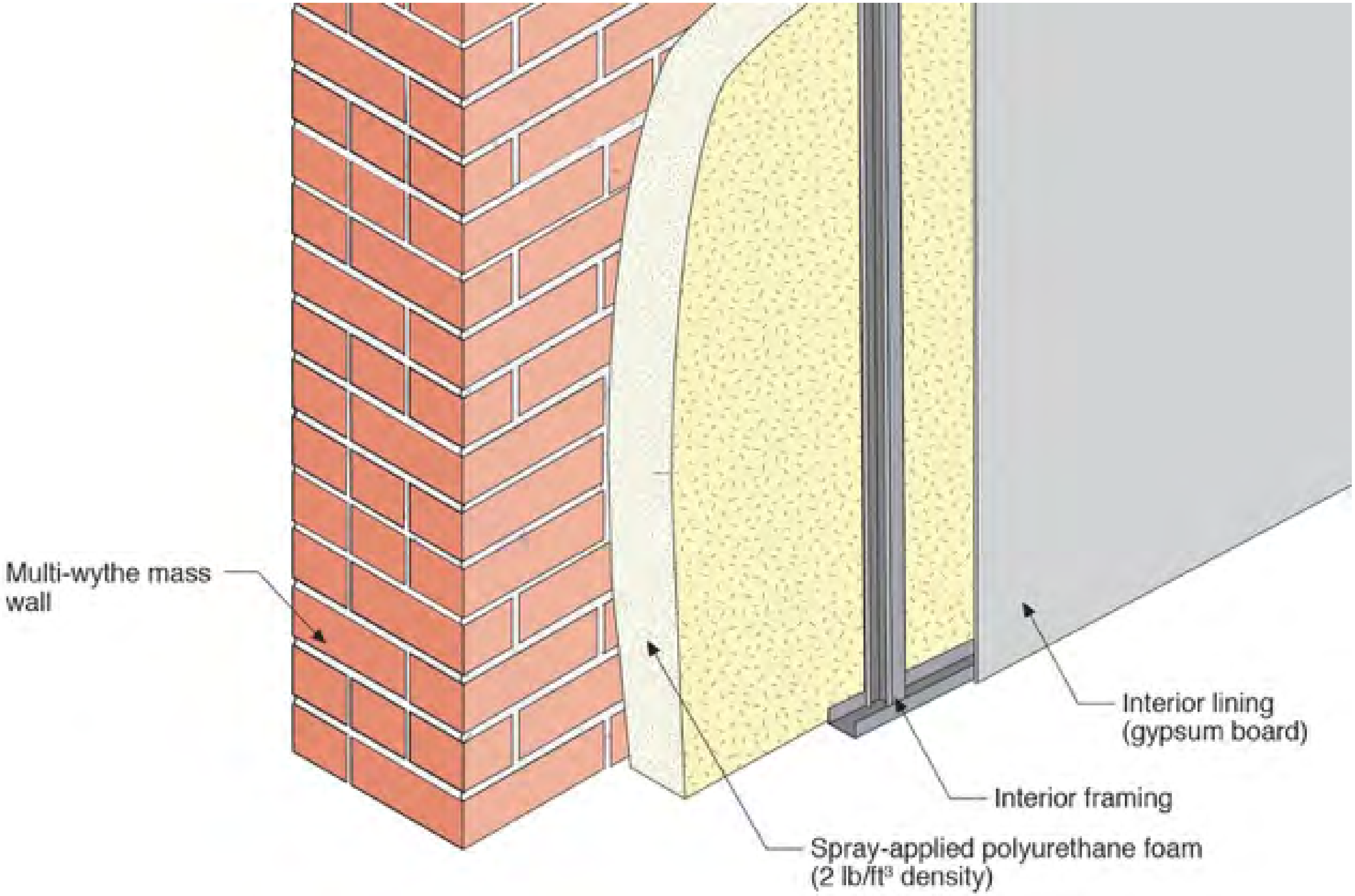

Wood floor framing embedded into masonry wall
Stainless steel cap flashing regletted into exterior wythe
1.5 χ
Vapor impermeable layer to prevent evaporation or drying inward
Sacrificial layer
χ

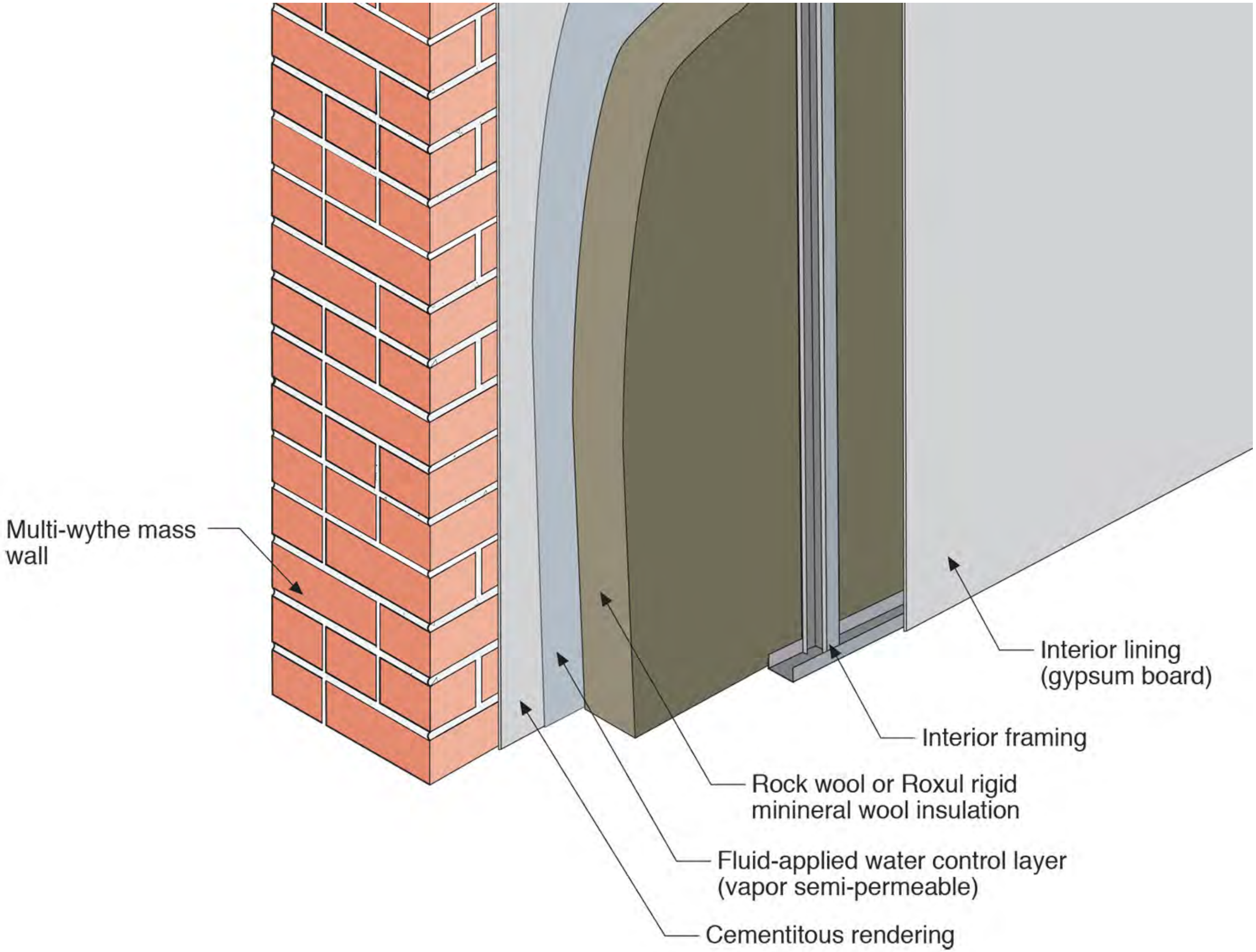

Wood floor framing embedded into masonry wall
Stainless steel cap flashing regletted into exterior wythe
Stainless steel capillary break regletted 1/3 of wall thickness
3/4 χ
Vapor impermeable layer to prevent evaporation or drying inward
Sacrificial layer
χ

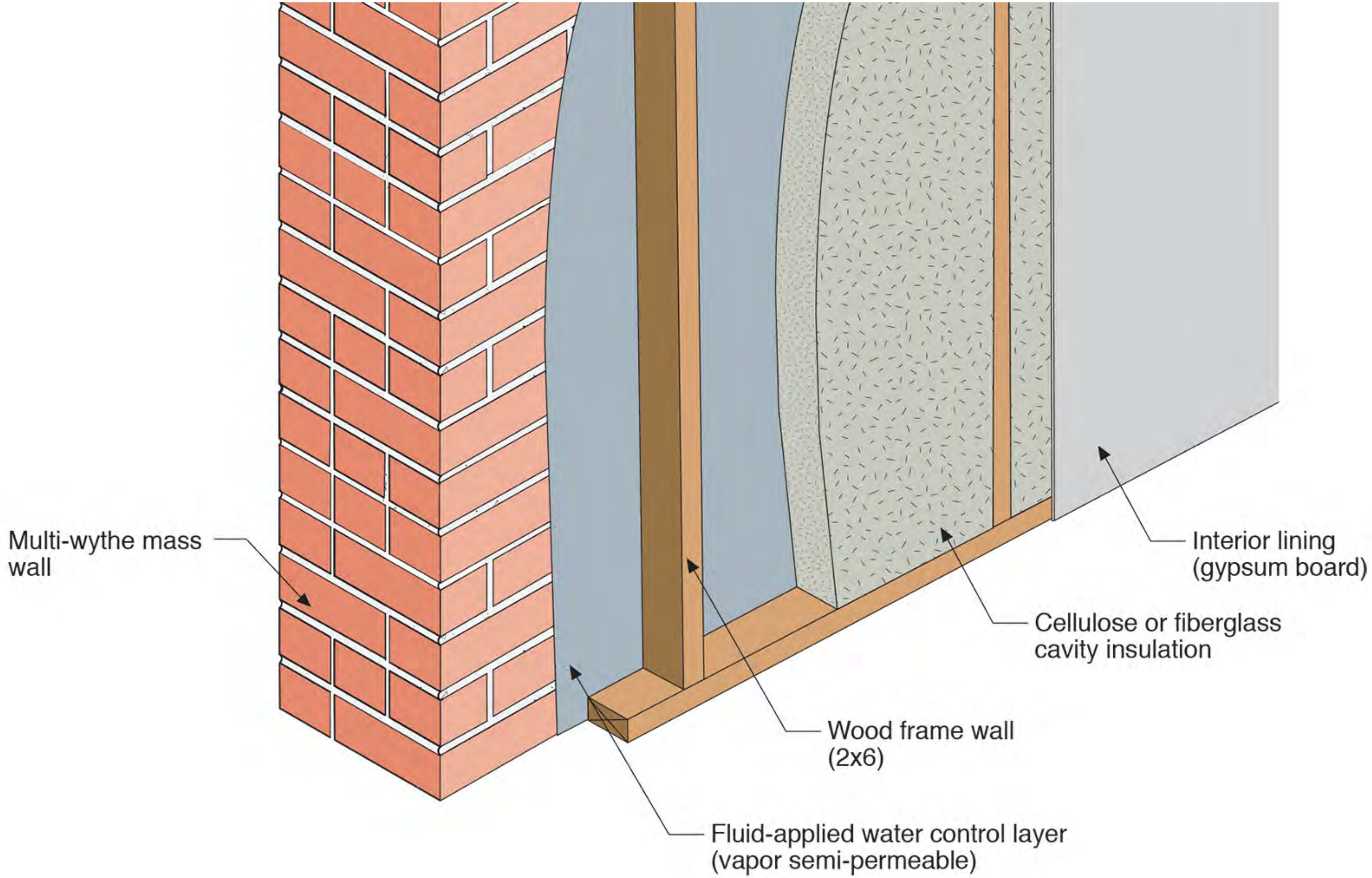

Subfloor held away from wall
Timber decking cut back from wall
Exterior wythe (repointed or coated with polymer cement slurry)
Spray applied foam insulation (2” closed-cell, high-density)
Multi-wythe masonry wall
Uninsulated steel stud assembly
Gypsum board
Subfloor held away from wall
Timber decking cut back from wall
Plywood subfloor
Embedded wood timber floor structure

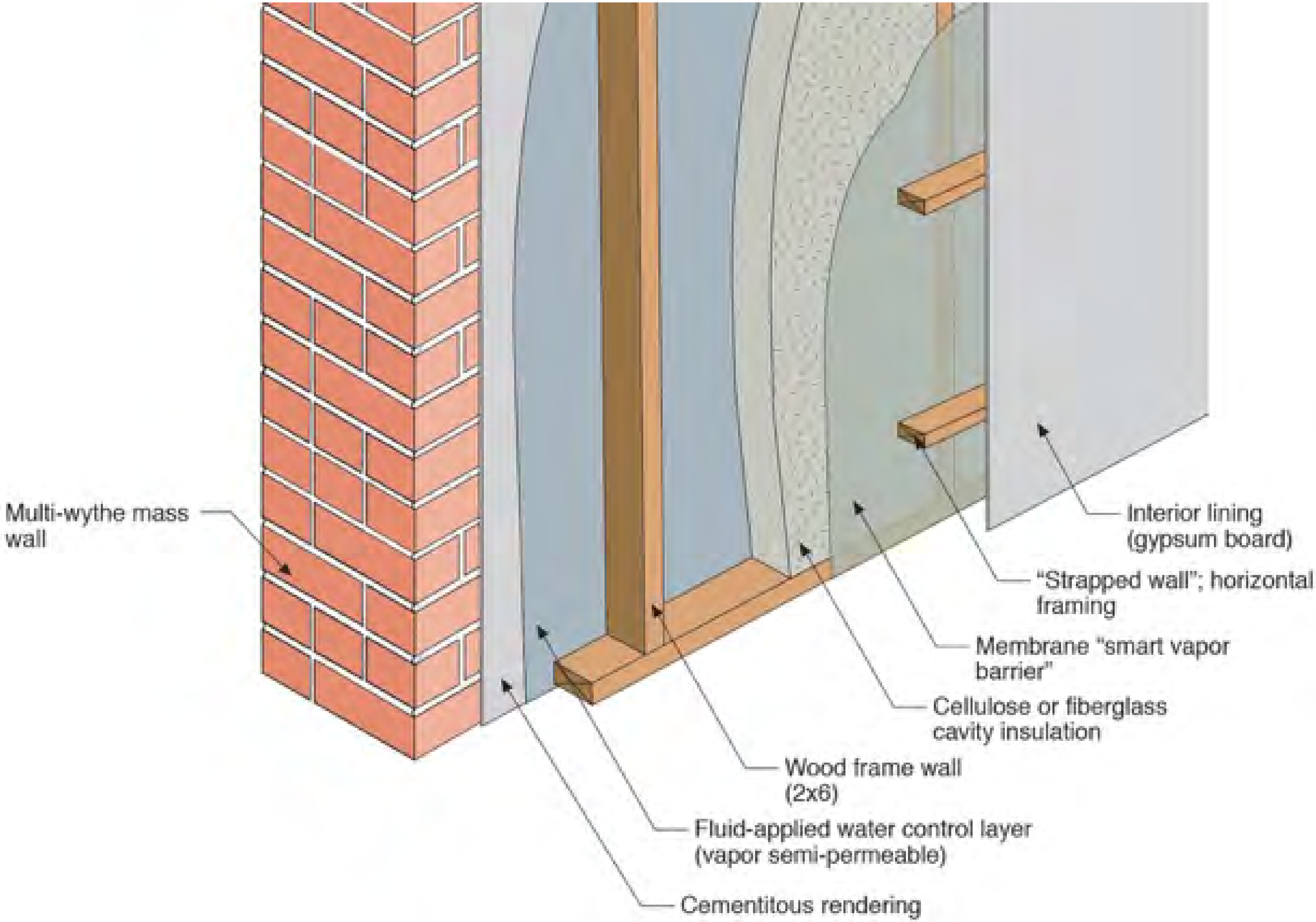



Liquid applied membrane waterproofing
Flanged window
Trim closure
Concrete sill
2x6 wood buck
Exterior wythe (repointed or coated with polymer cement slurry)
Multi-wythe masonry wall
Air seal
1 1/2” rigid insulation
Plywood spacer
1x2 backdam
2” spray applied foam insulation (closed-cell, high-density)
Uninsulated steel stud assembly
Gypsum board


Multi-wythe mass wall
Interior lining (gypsum board)
Interior framing
Spray-applied polyurethane foam (2 lb/ft³ density)

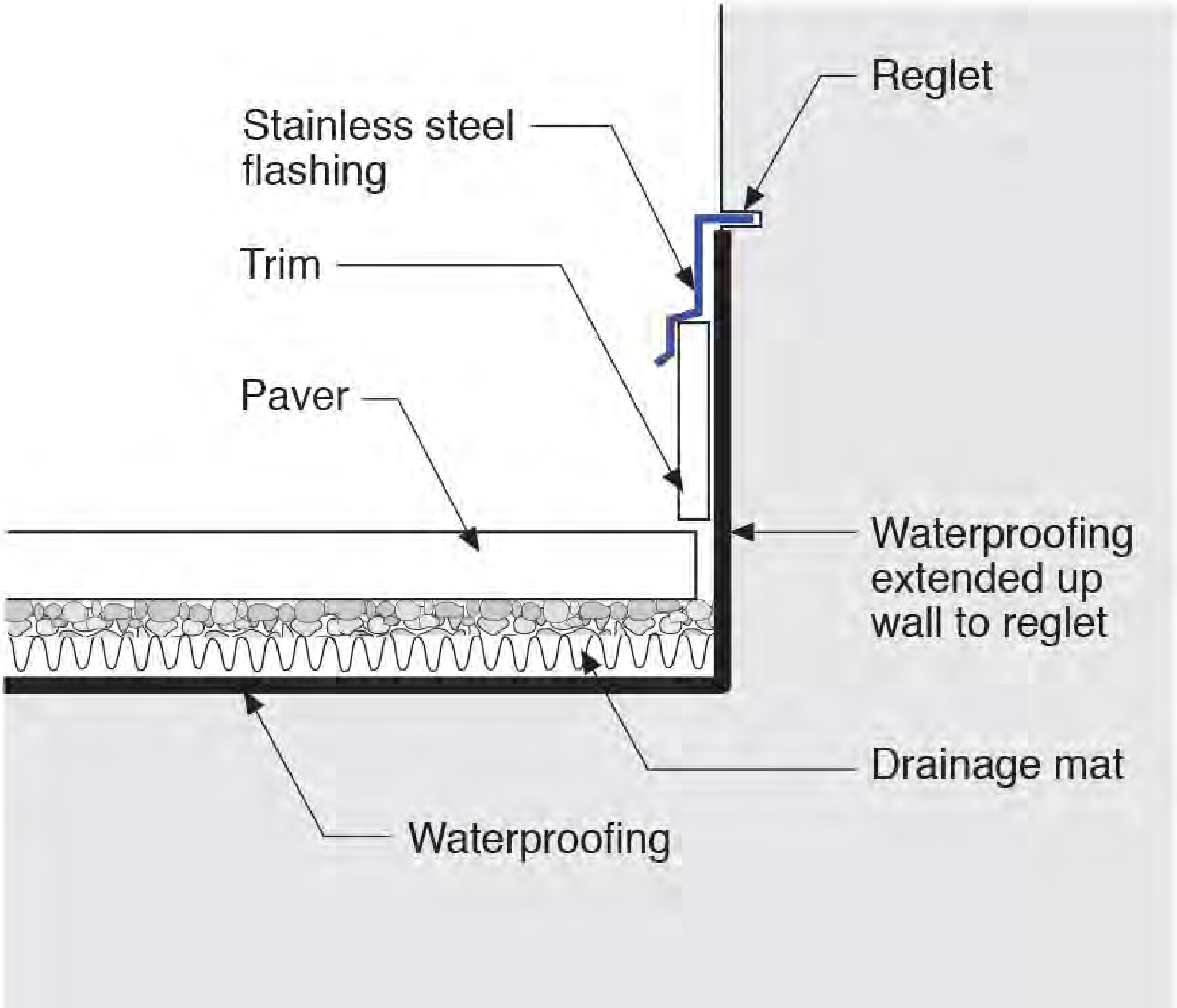

Multi-wythe mass wall
Interior lining (gypsum board)
Interior framing
Rock wool or Roxul rigid minineral wool insulation
Fluid-applied water control layer (vapor semi-permeable)
Cementitous rendering

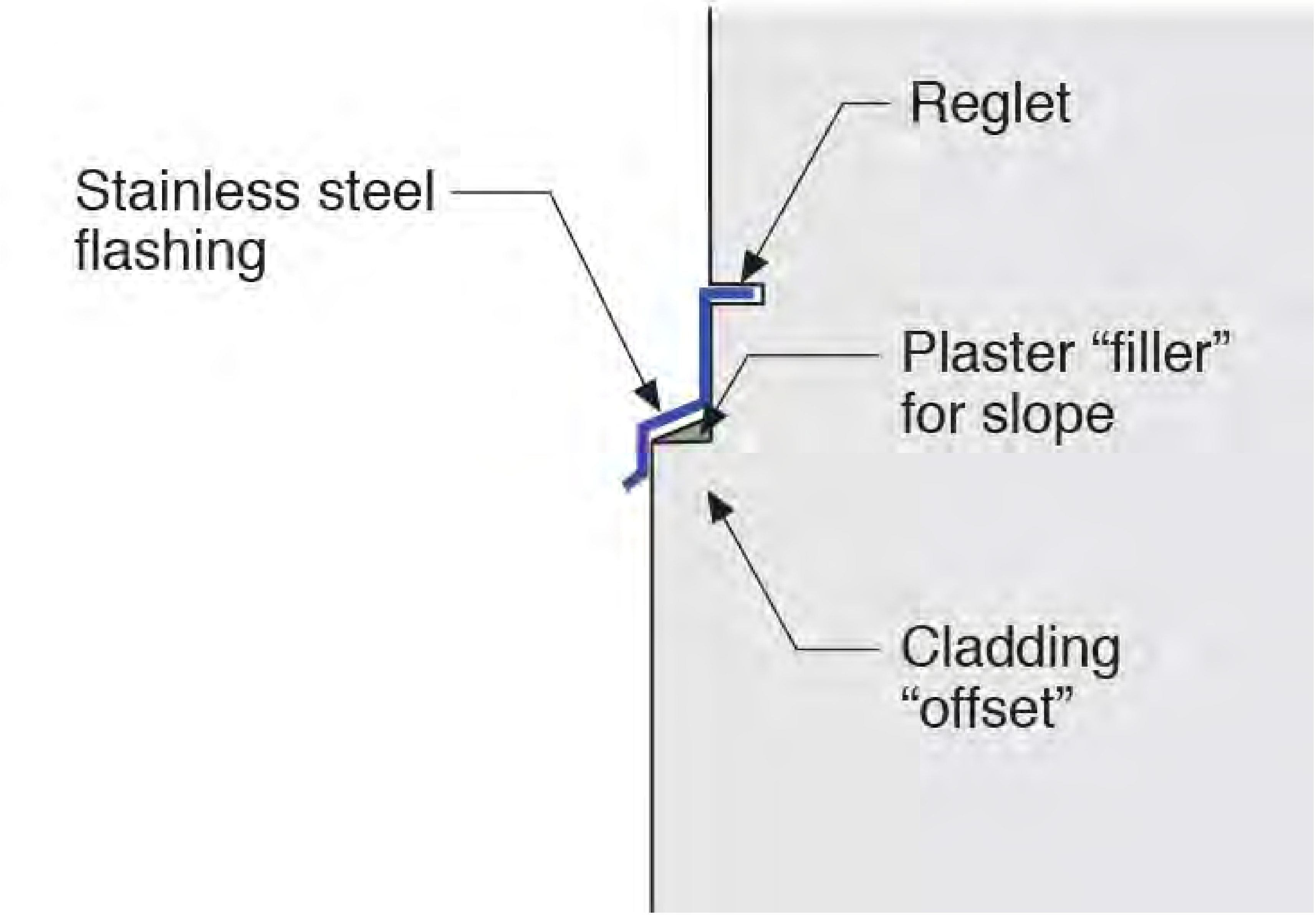

Multi-wythe mass wall
Interior lining (gypsum board)
Cellulose or fiberglass cavity insulation
Wood frame wall (2x6)
Fluid-applied water control layer (vapor semi-permeable)

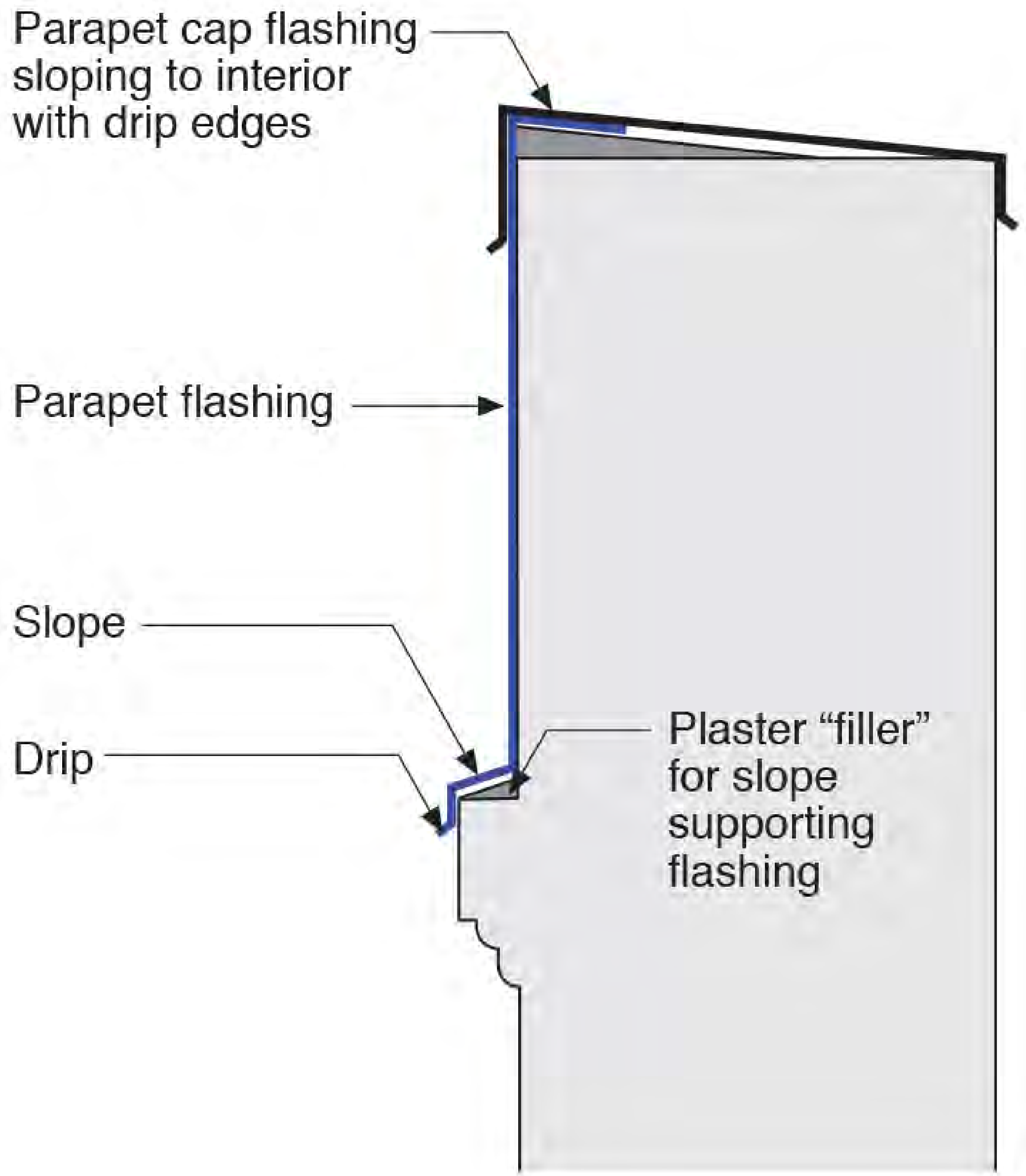

Multi-wythe mass wall
Interior lining (gypsum board)
"Strapped wall"; horizontal framing
Membrane "smart vapor barrier"
Cellulose or fiberglass cavity insulation
Wood frame wall (2x6)
Fluid-applied water control layer (vapor semi-permeable)
Cementitous rendering


DISTRICT OF COLUMBIA COURT OF APPEALS

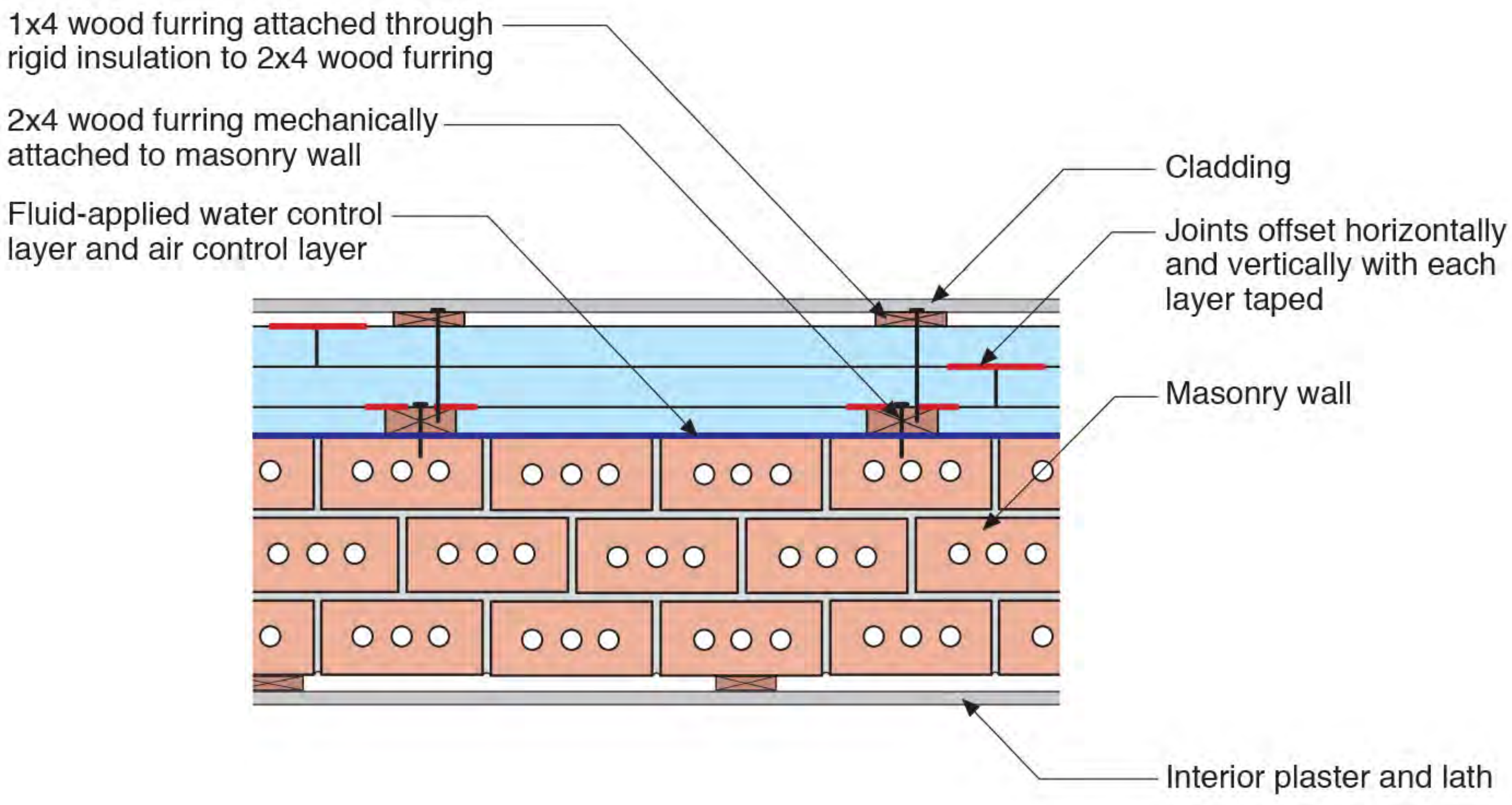

EXIT
EXIT


Reglet
Stainless steel flashing
Trim
Paver
Waterproofing extended up wall to reglet
Drainage mat
Waterproofing

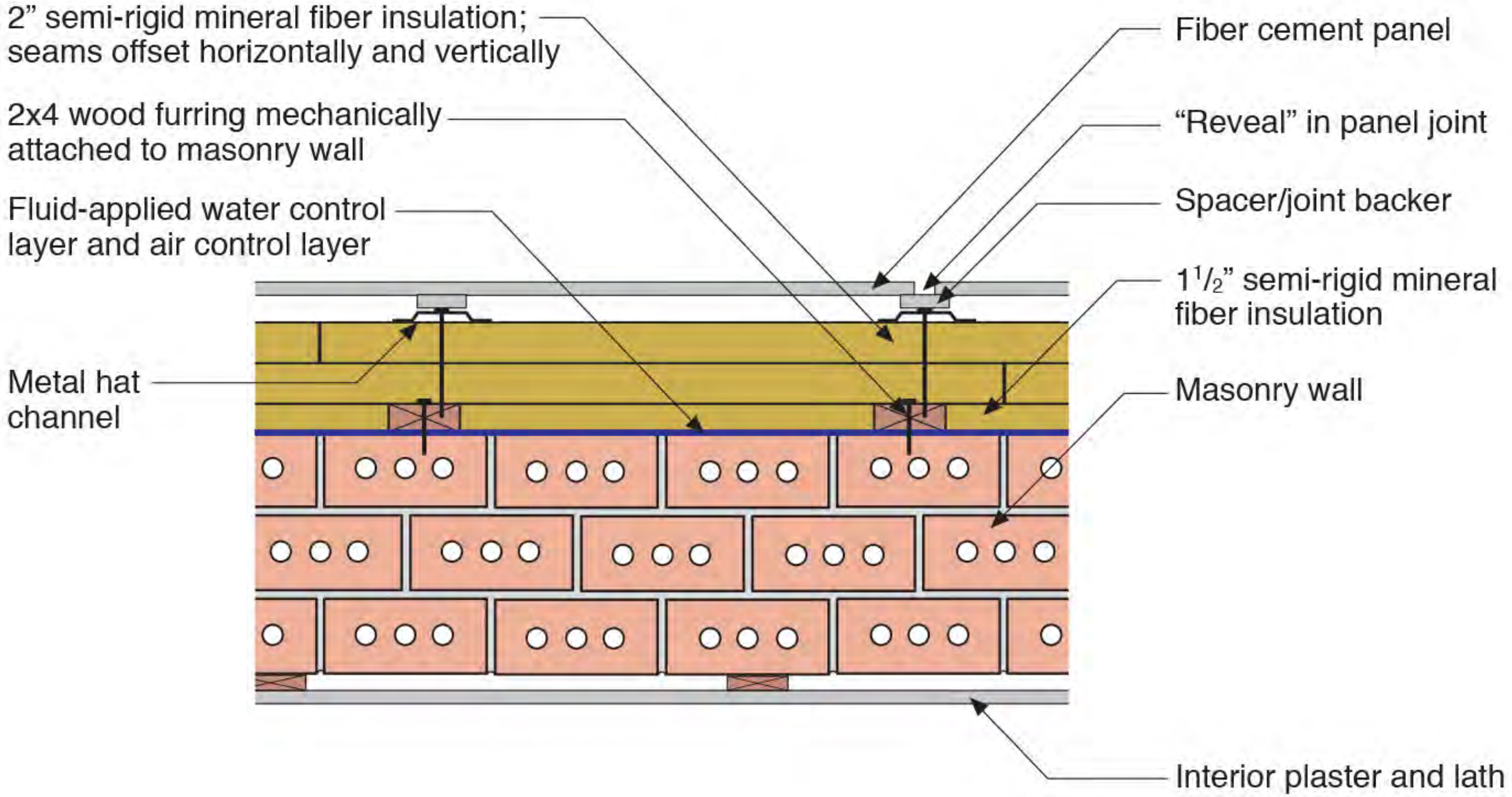

Reglet
Stainless steel flashing
Plaster “filler” for slope
Cladding “offset”


Parapet cap flashing
sloping to interior
with drip edges
Parapet flashing
Slope
Drip
Plaster “filler”
for slope
supporting
flashing

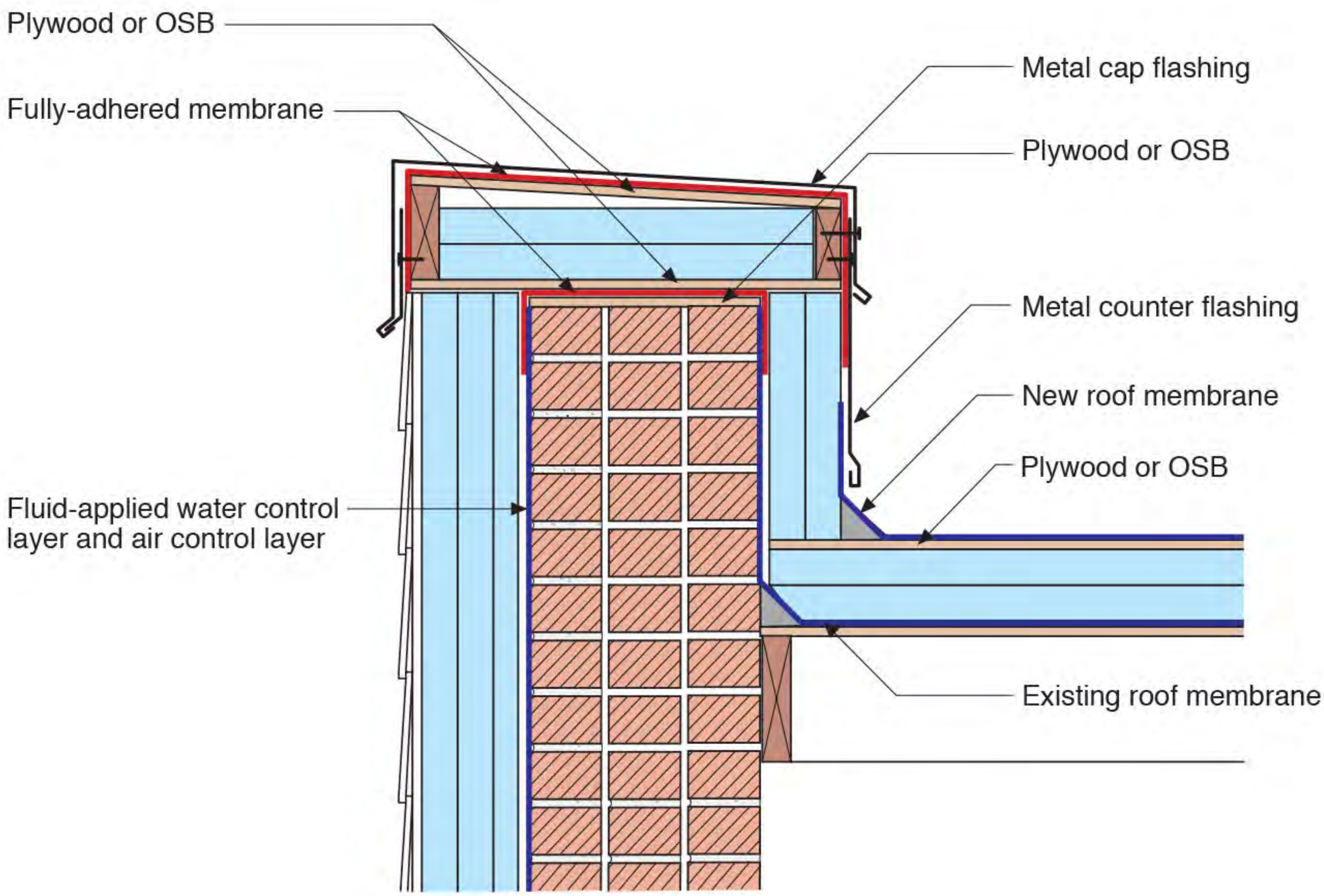

852


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


with ENERGY STAR
R-10
Seal and insulate
with ENERGY STAR



2” semi-rigid mineral fiber insulation; seams offset horizontally and vertically
2x4 wood furring mechanically attached to masonry wall
Fluid-applied water control layer and air control layer
Metal hat channel
Fiber cement panel
“Reveal” in panel joint
Spacer/joint backer
1 1/2” semi-rigid mineral fiber insulation
Masonry wall
Interior plaster and lath

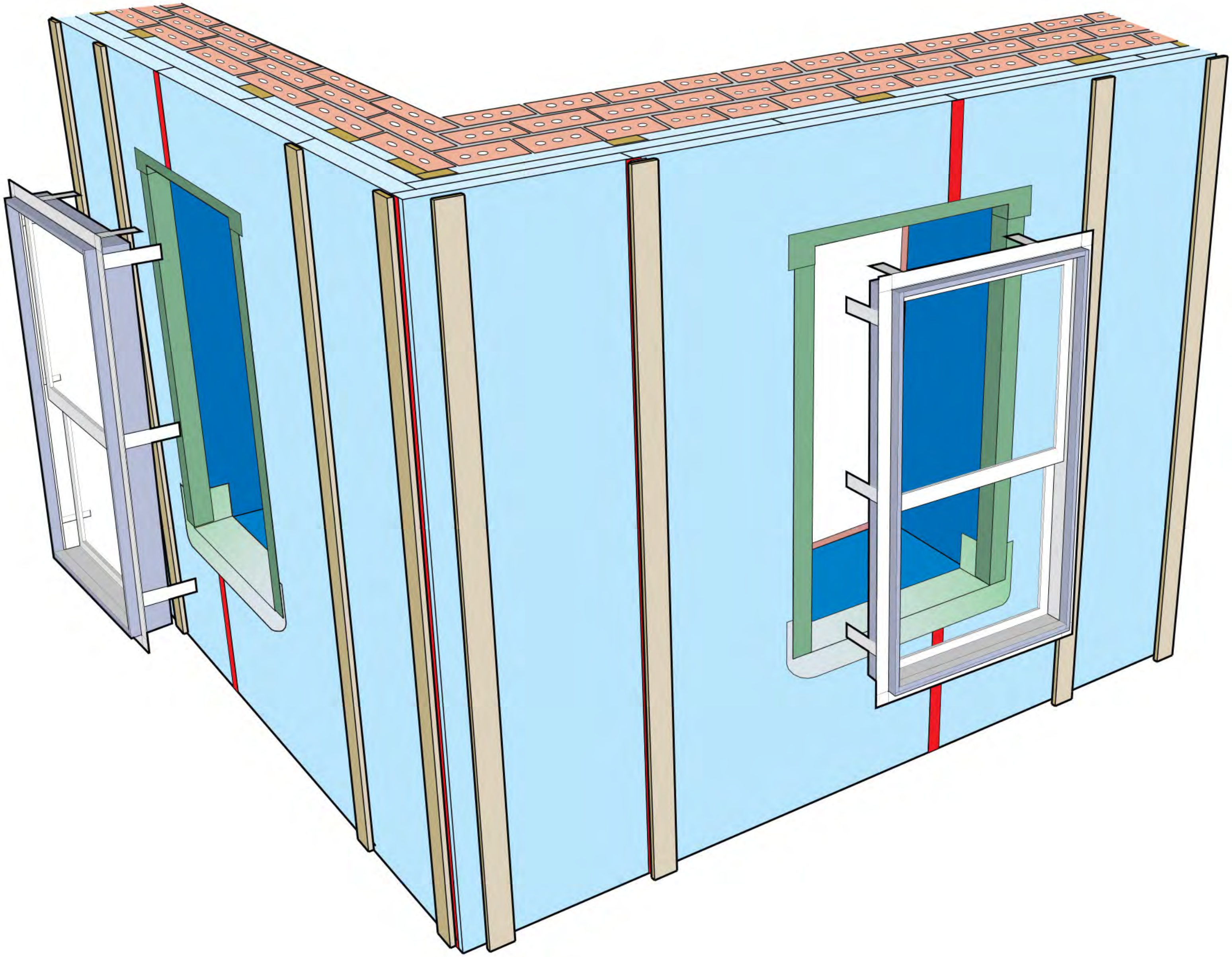

Plywood or OSB
Fully-adhered membrane
Metal cap flashing
Plywood or OSB
Metal counter flashing
New roof membrane
Plywood or OSB
Fluid-applied water control layer and air control layer
Existing roof membrane

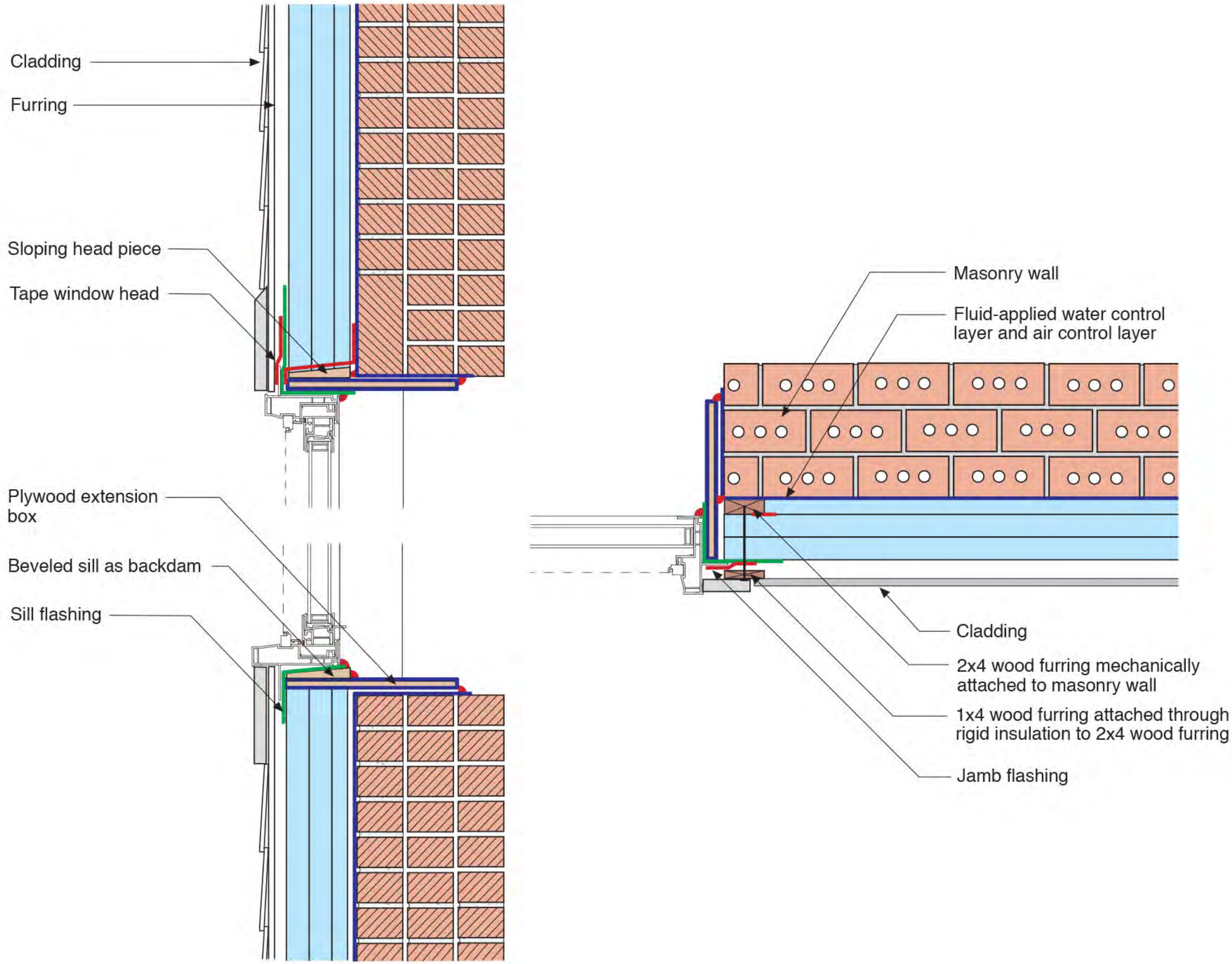

RIPCORD

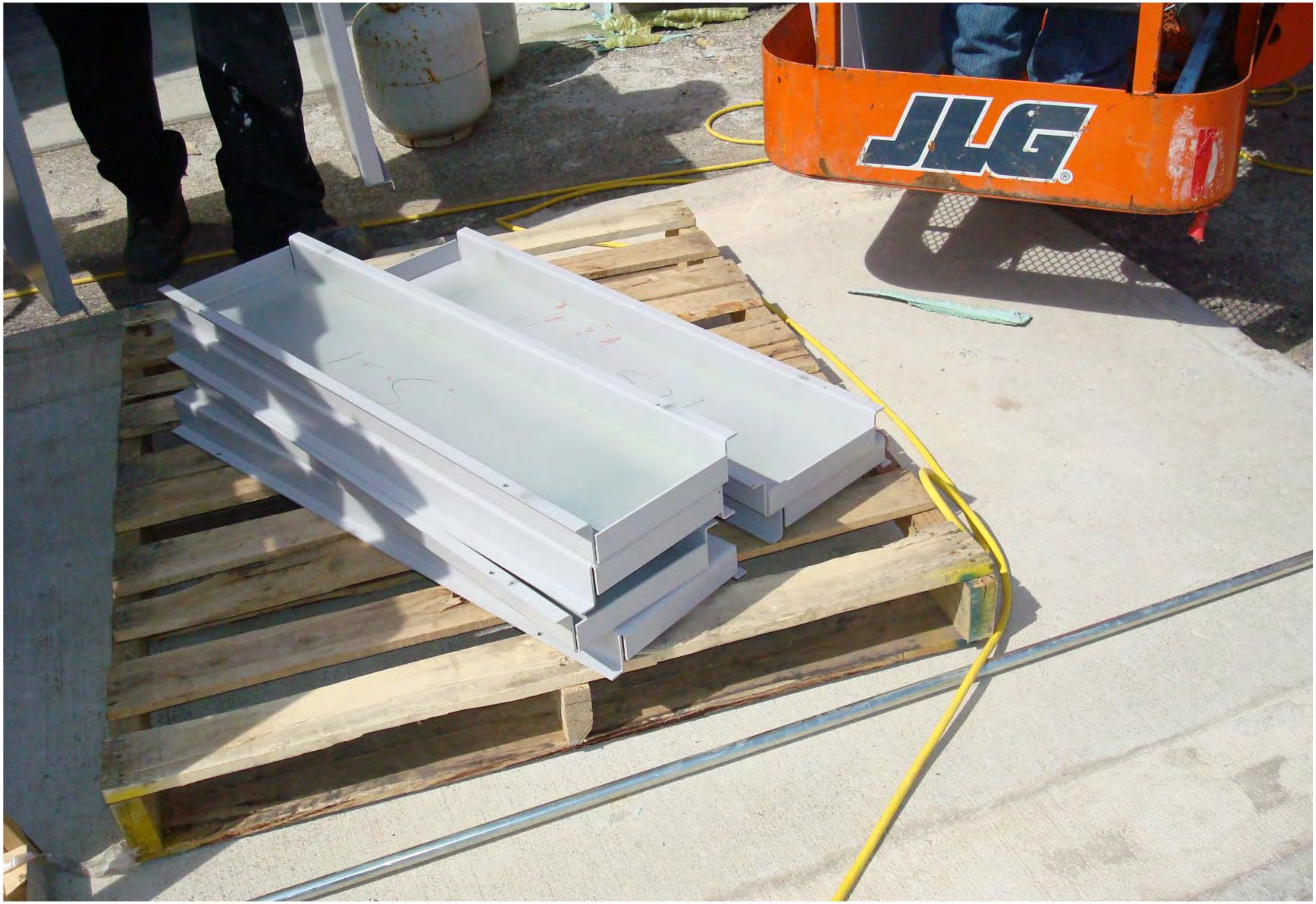

SPEED
HUMP

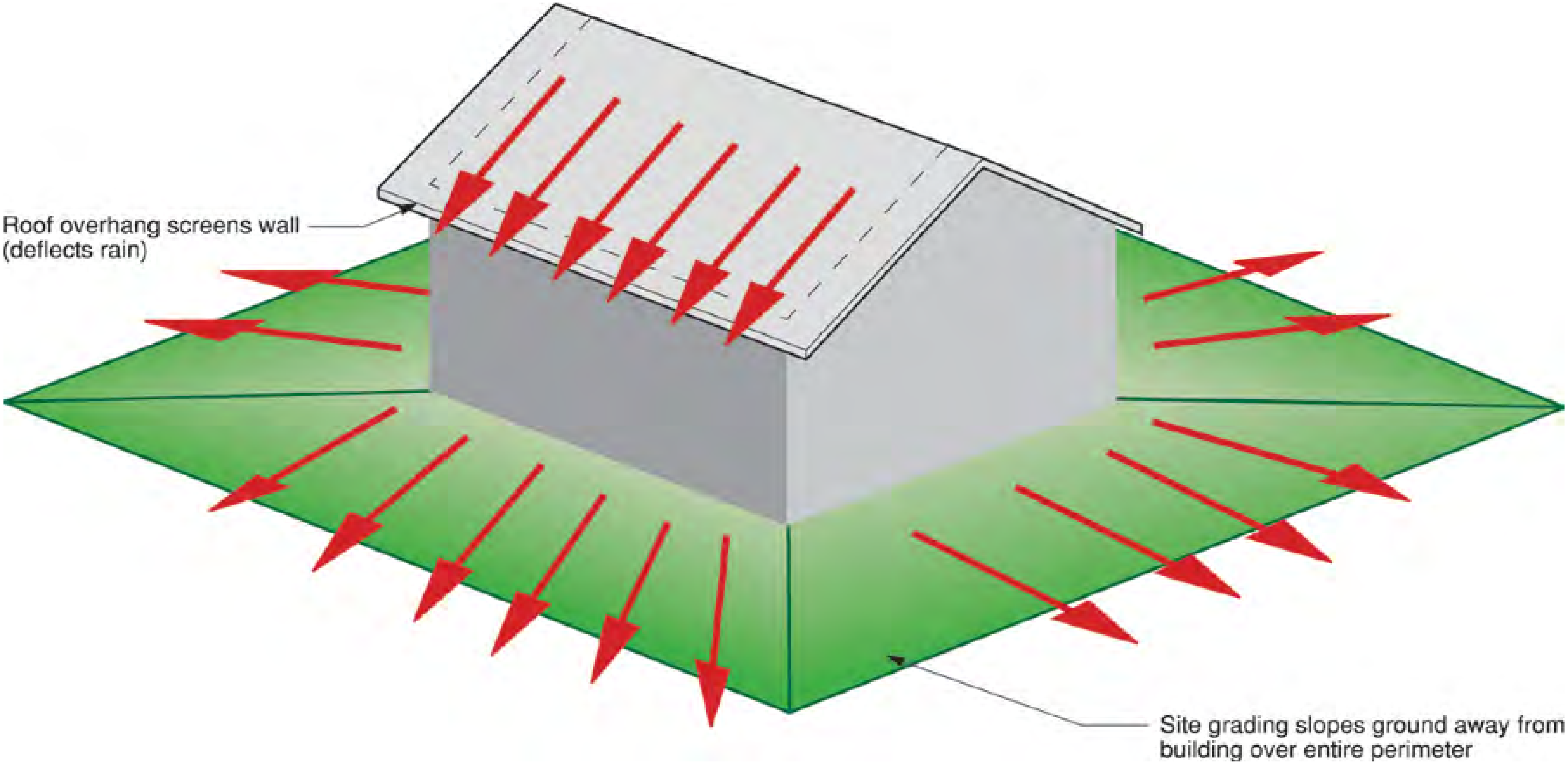

SPEED
HUMP

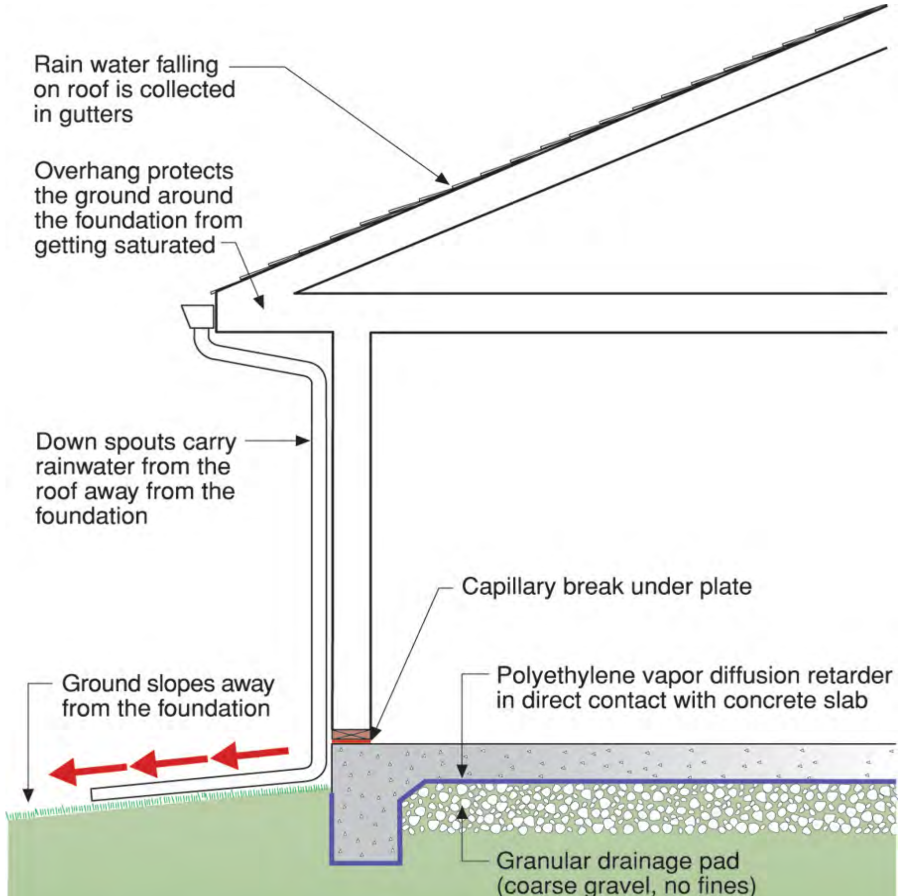

OWENS CORNING
FOAMULAR 150
OZONE DEPLETION
GREENGUARD



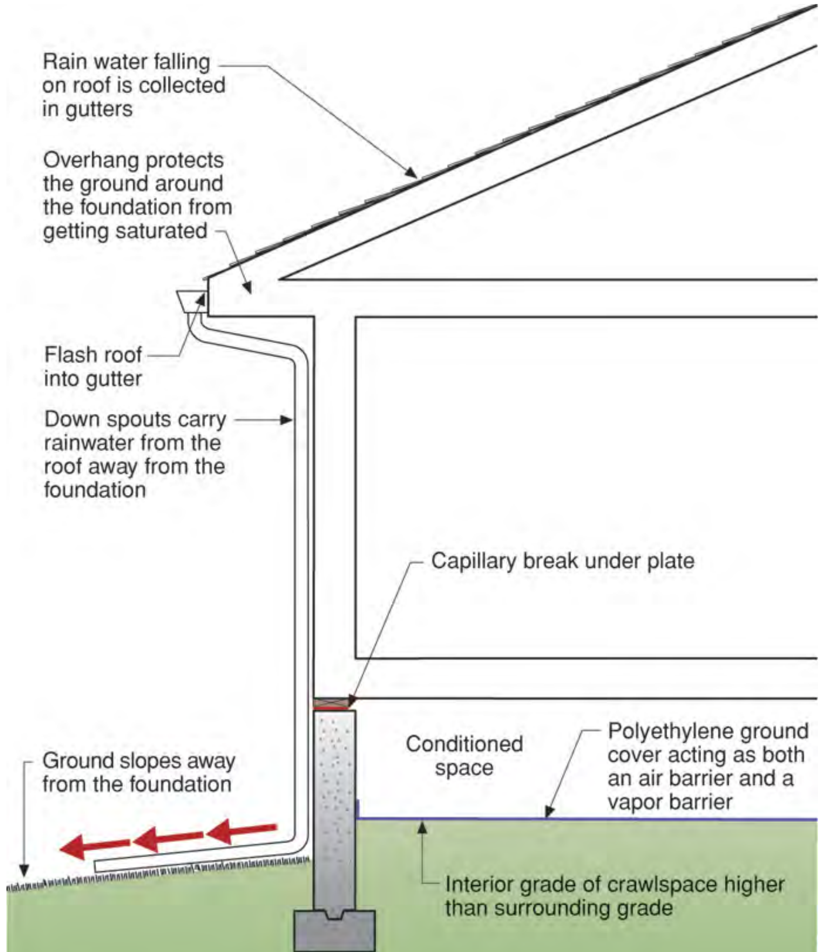

Cladding
Furring
Sloping head piece
Tape window head
Plywood extension box
Beveled sill as backdam
Sill flashing
Masonry wall
Fluid-applied water control layer and air control layer
Cladding
2x4 wood furring mechanically attached to masonry wall
1x4 wood furring attached through rigid insulation to 2x4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


JLG

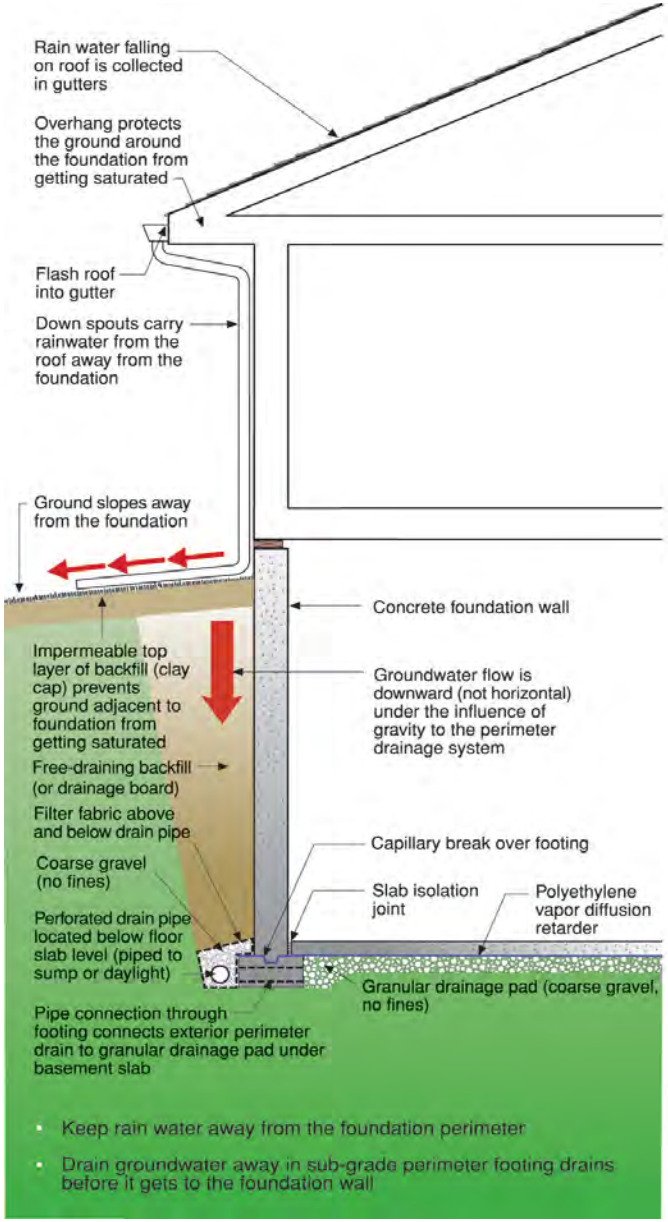

Roof overhang screens wall
(deflects rain)
Site grading slopes ground away from
building over entire perimeter



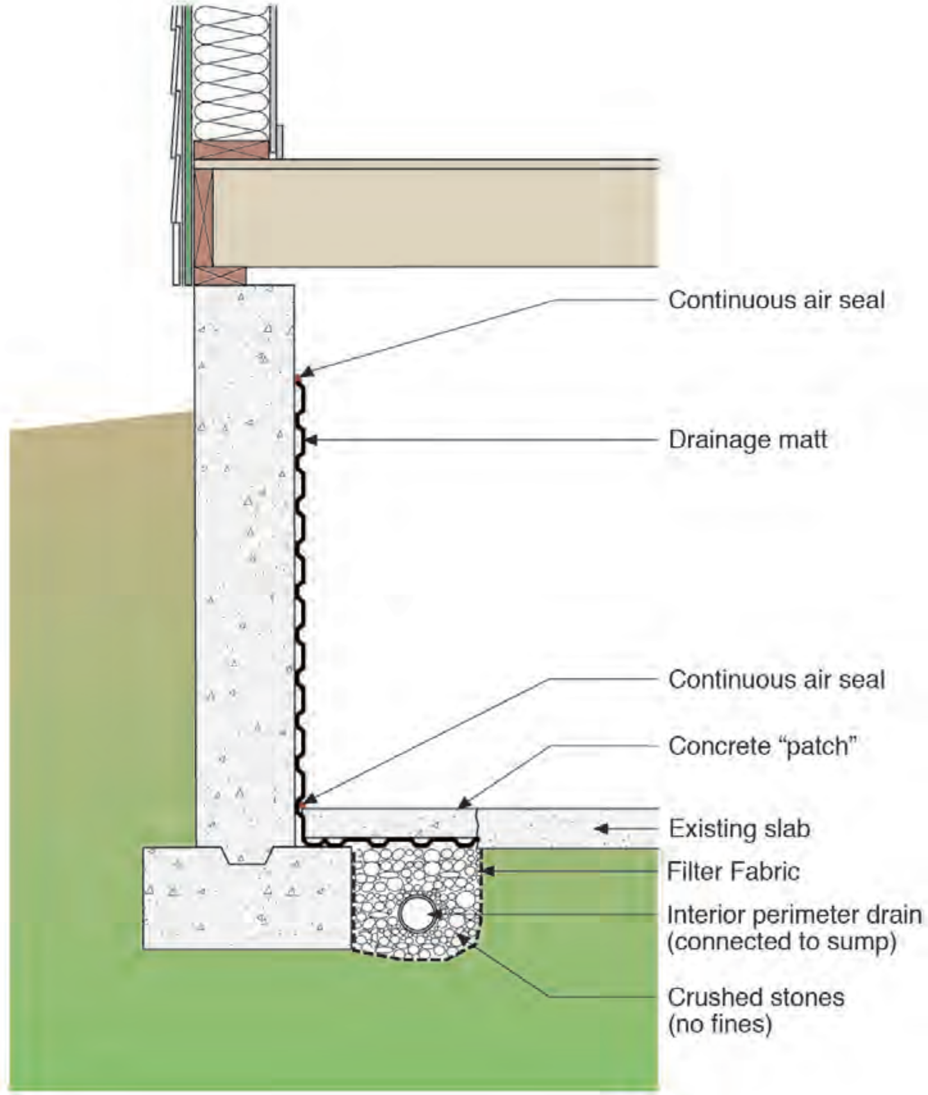
- Keep rain water away from the foundation perimeter
- Do not place sand layer over polyethylene vapor diffusion retarder under concrete slab
- Where vinyl flooring is installed over slabs, a low water-to-cement (w/c) ratio (≅ 0.45 or less is recommended) to reduce water content in the concrete; alternatively, the slab should be allowed to dry (less than 0.3 grams/24 hrs/ft^2) prior to flooring installation



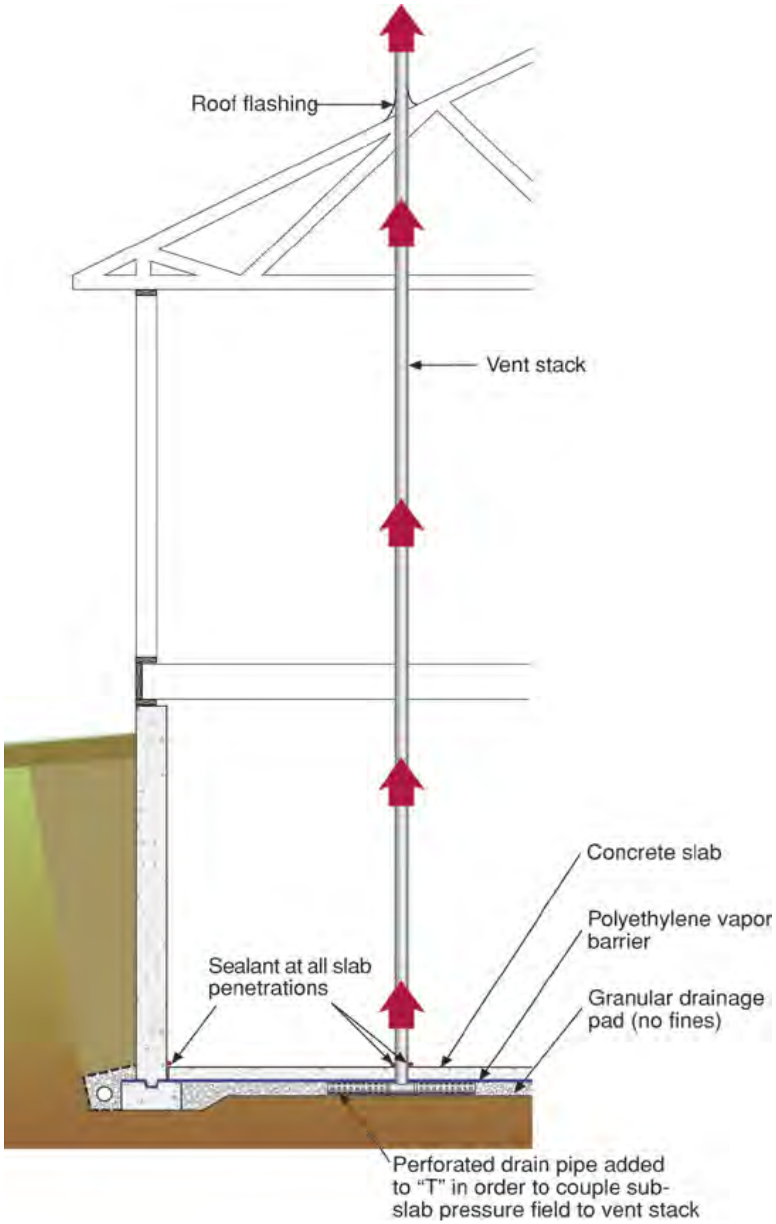
- Keep rain water away from the foundation perimeter
- If the interior crawlspace is lower than the exterior grade, a sub-grade perimeter footing drain is necessary as in a basement foundation
- The crawlspace is conditioned space; it is part of the "interior" of the building and should be heated, cooled and ventilated as part of the building's heating, cooling and ventilating strategy

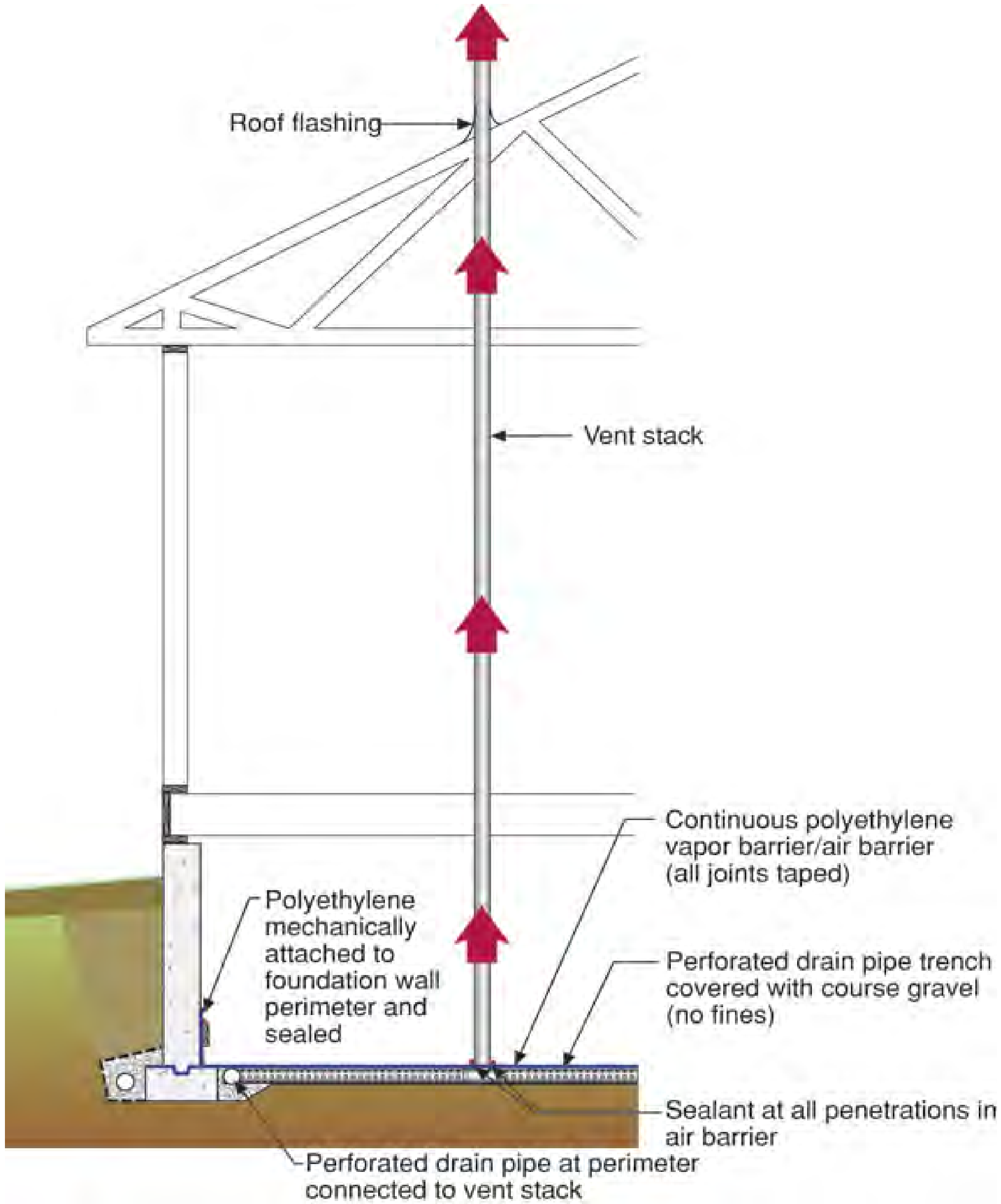

Rain water falling on roof is collected in gutters
Overhang protects the ground around the foundation from getting saturated
Flash roof into gutter
Down spouts carry rainwater from the roof away from the foundation
Ground slopes away from the foundation
Concrete foundation wall
Impermeable top layer of backfill (clay cap) prevents ground adjacent to foundation from getting saturated
Groundwater flow is downward (not horizontal) under the influence of gravity to the perimeter drainage system
Free-draining backfill (or drainage board)
Filter fabric above and below drain pipe
Capillary break over footing
Coarse gravel (no fines)
Slab isolation joint
Polyethylene vapor diffusion retarder
Perforated drain pipe located below floor slab level (piped to sump or daylight)
Granular drainage pad (coarse gravel, no fines)
Pipe connection through footing connects exterior perimeter drain to granular drainage pad under basement slab
Keep rain water away from the foundation perimeter
Drain groundwater away in sub-grade perimeter footing drains before it gets to the foundation wall


DELTA-MS
DELTA-MS

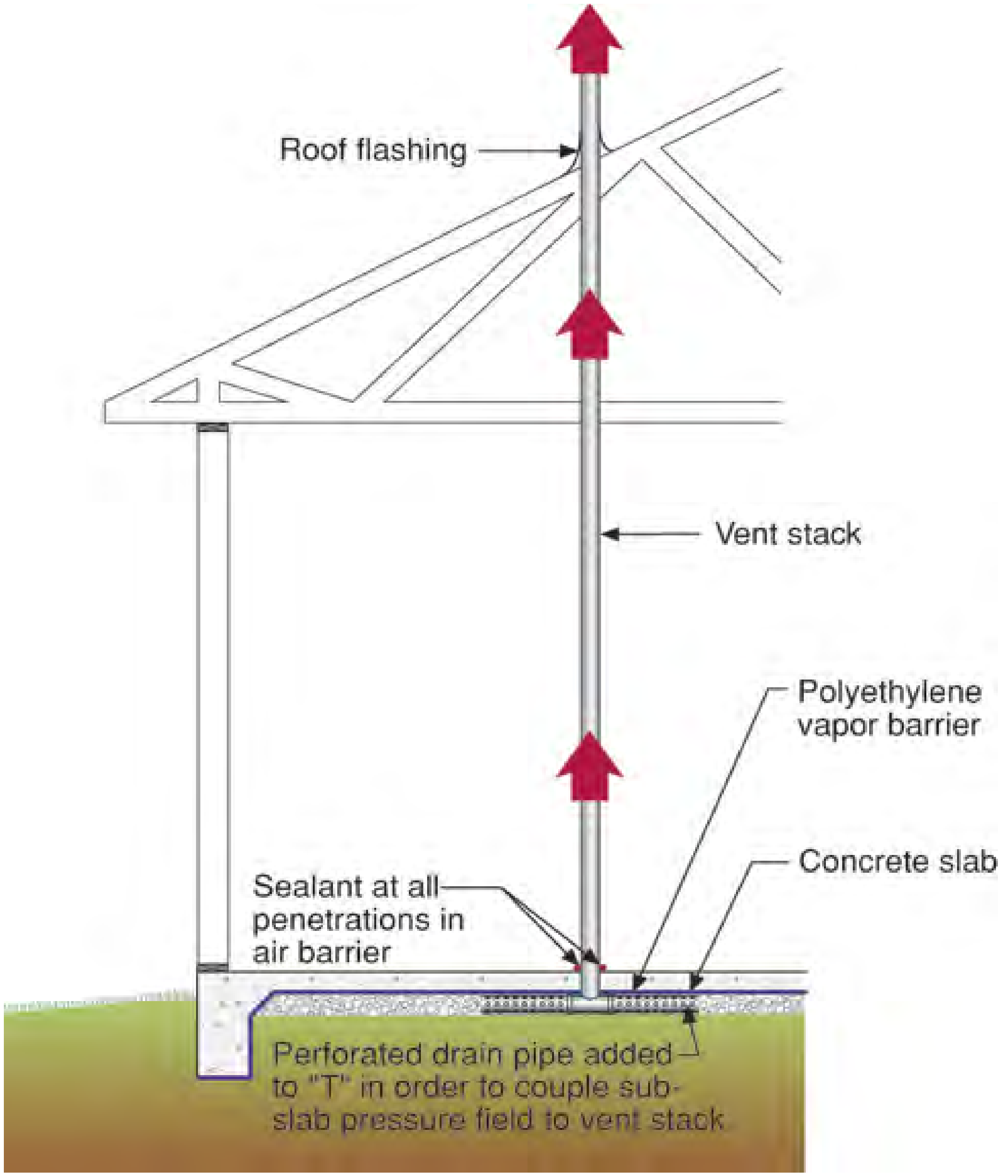

Continuous air seal
Drainage matt
Continuous air seal
Concrete “patch”
Existing slab
Filter Fabric
Interior perimeter drain
(connected to sump)
Crushed stones
(no fines)

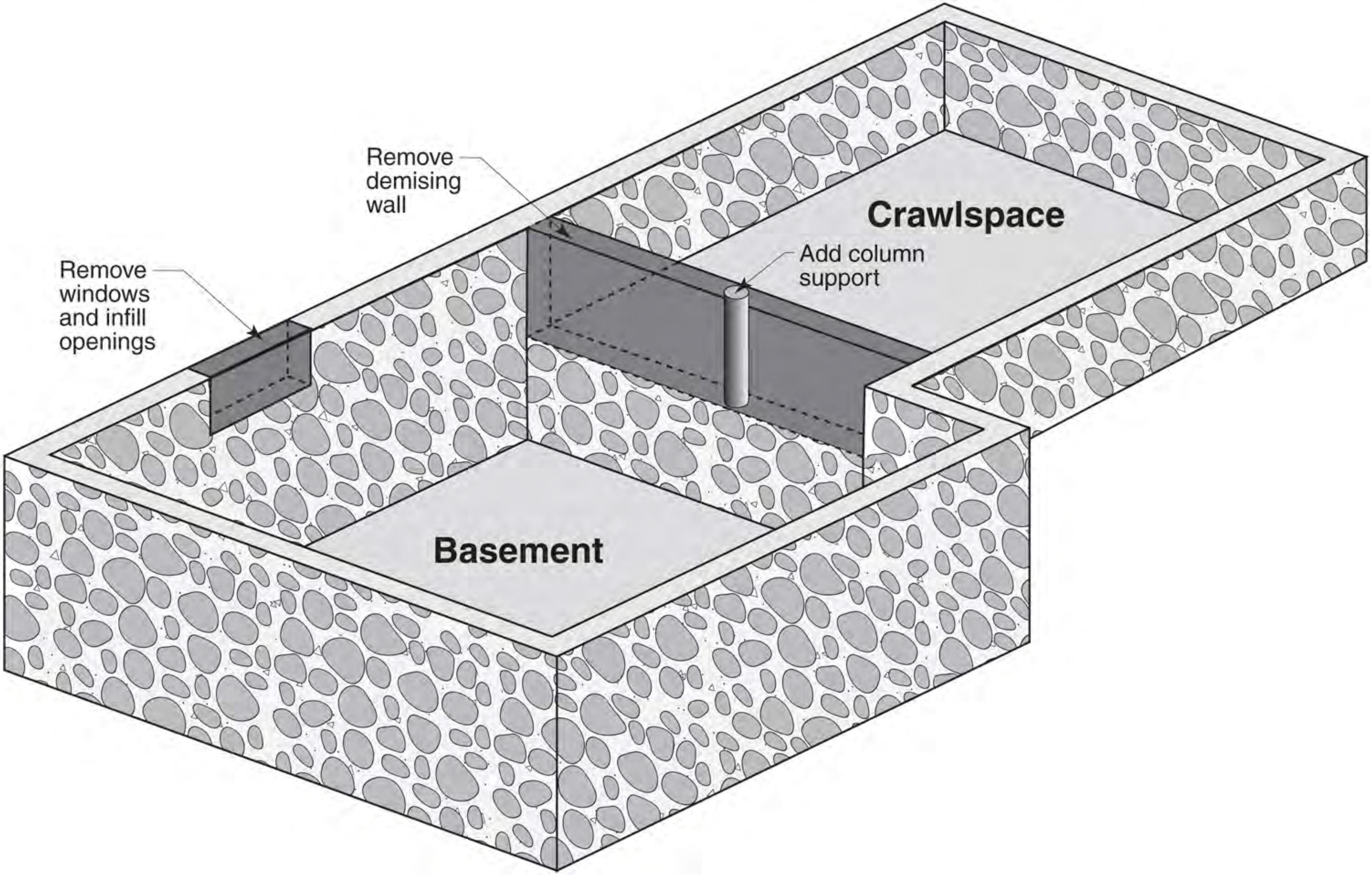

EURO
TUNNEL

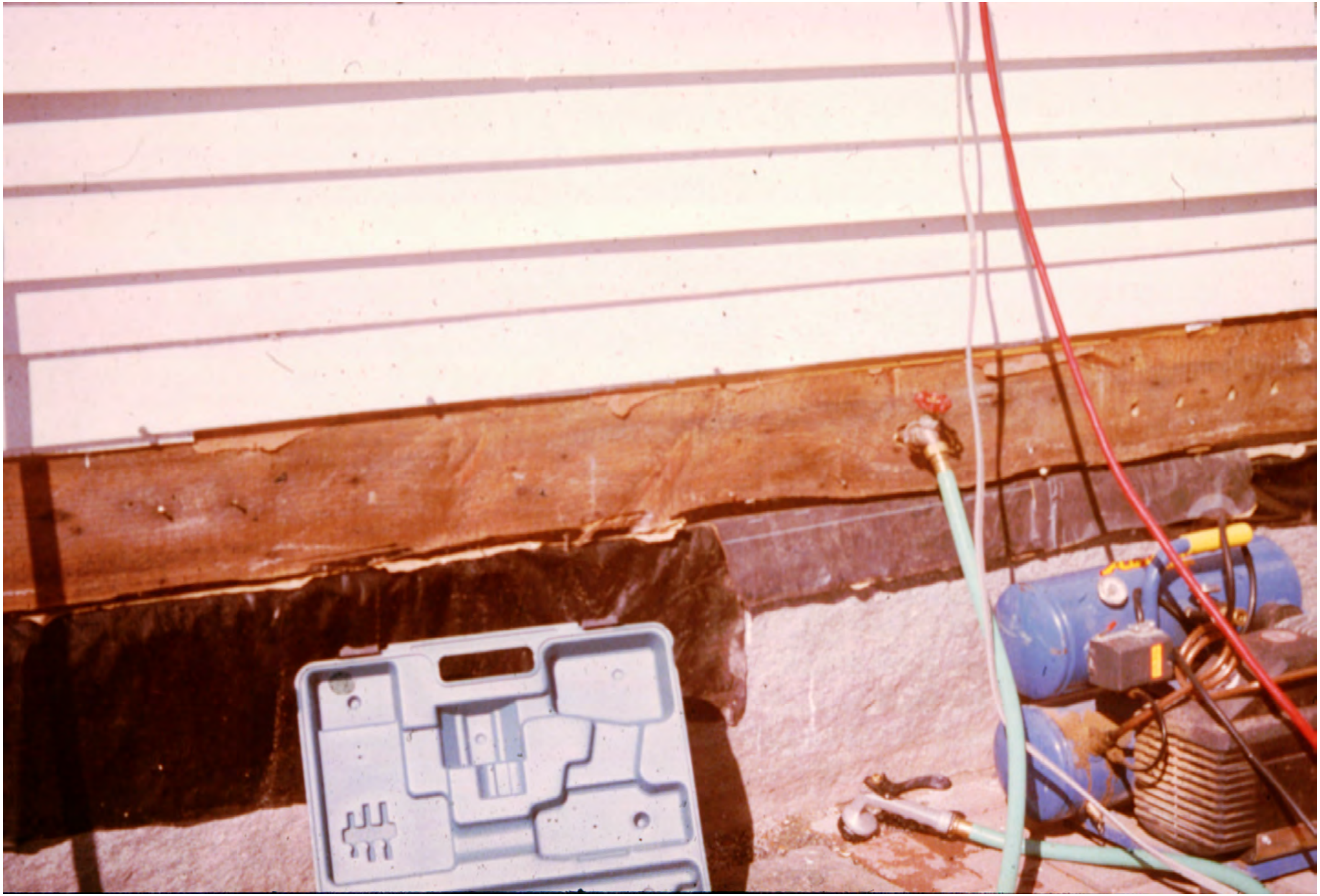

Roof flashing
Vent stack
Concrete slab
Polyethylene vapor barrier
Granular drainage pad (no fines)
Sealant at all slab penetrations
Perforated drain pipe added to "T" in order to couple sub-slab pressure field to vent stack

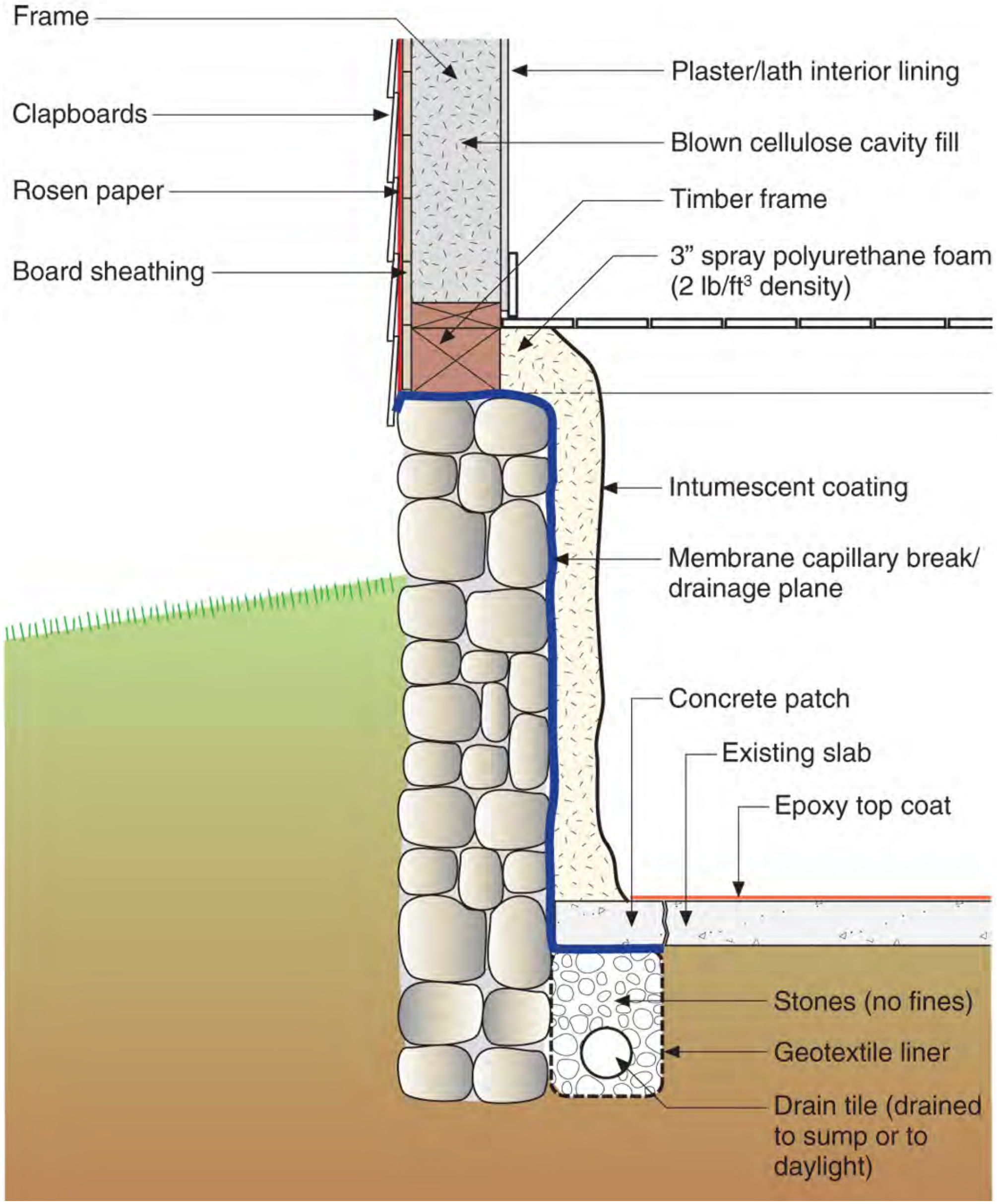


Roof flashing
Vent stack
Continuous polyethylene vapor barrier/air barrier (all joints taped)
Polyethylene mechanically attached to foundation wall perimeter and sealed
Perforated drain pipe trench covered with course gravel (no fines)
Sealant at all penetrations in air barrier
Perforated drain pipe at perimeter connected to vent stack

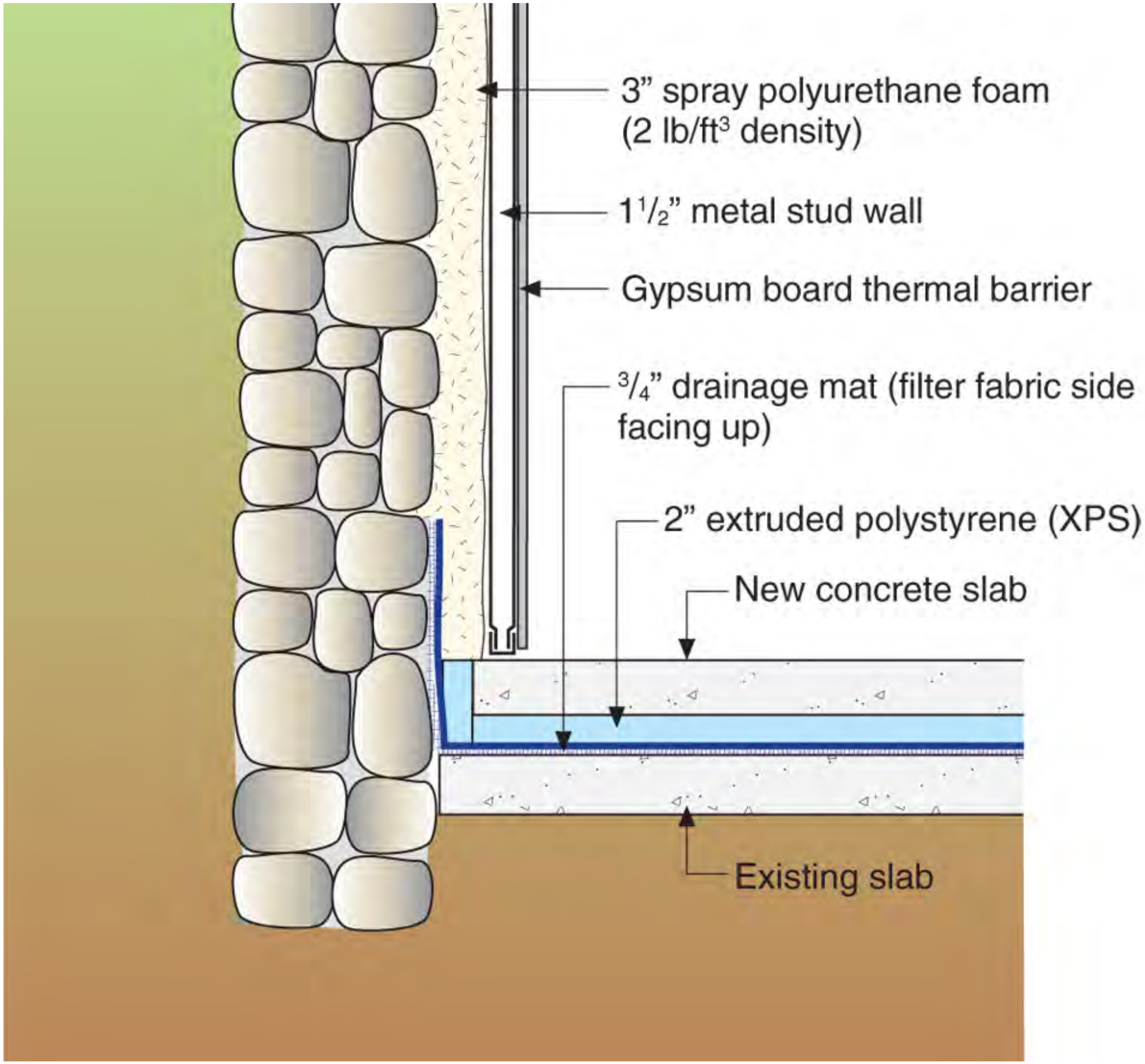

Roof flashing
Vent stack
Polyethylene vapor barrier
Concrete slab
Sealant at all penetrations in air barrier
Perforated drain pipe added to "T" in order to couple sub-slab pressure field to vent stack


Remove
demising
wall
Remove
windows
and infill
openings
Crawlspace
Add column
support
Basement




Frame
Clapboards
Rosen paper
Board sheathing
Plaster/lath interior lining
Blown cellulose cavity fill
Timber frame
3” spray polyurethane foam (2 lb/ft³ density)
Intumescent coating
Membrane capillary break/ drainage plane
Concrete patch
Existing slab
Epoxy top coat
Stones (no fines)
Geotextile liner
Drain tile (drained to sump or to daylight)

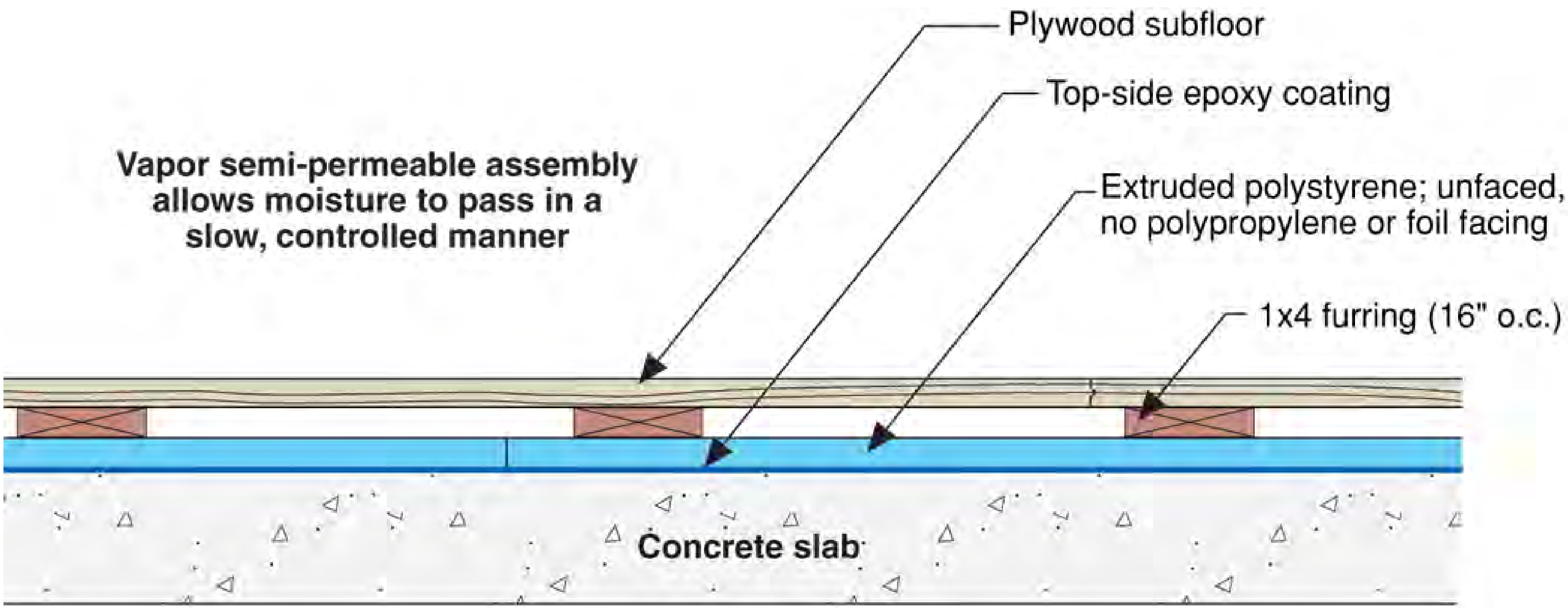

GRACE
Ice & Water
Shield



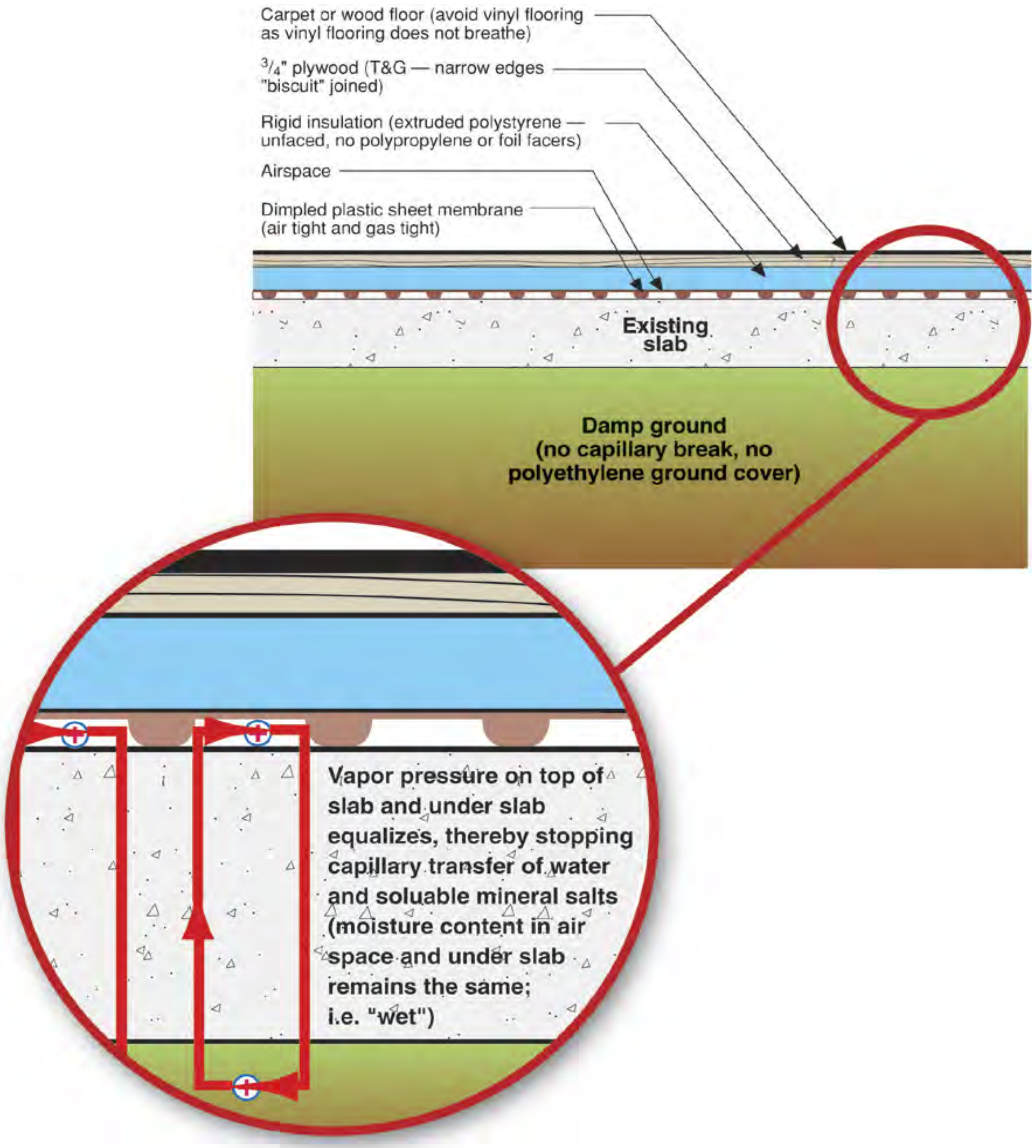
3" spray polyurethane foam
(2 lb/ft³ density)
1½" metal stud wall
Gypsum board thermal barrier
¾" drainage mat (filter fabric side
facing up)
2" extruded polystyrene (XPS)
New concrete slab
Existing slab


On Demand

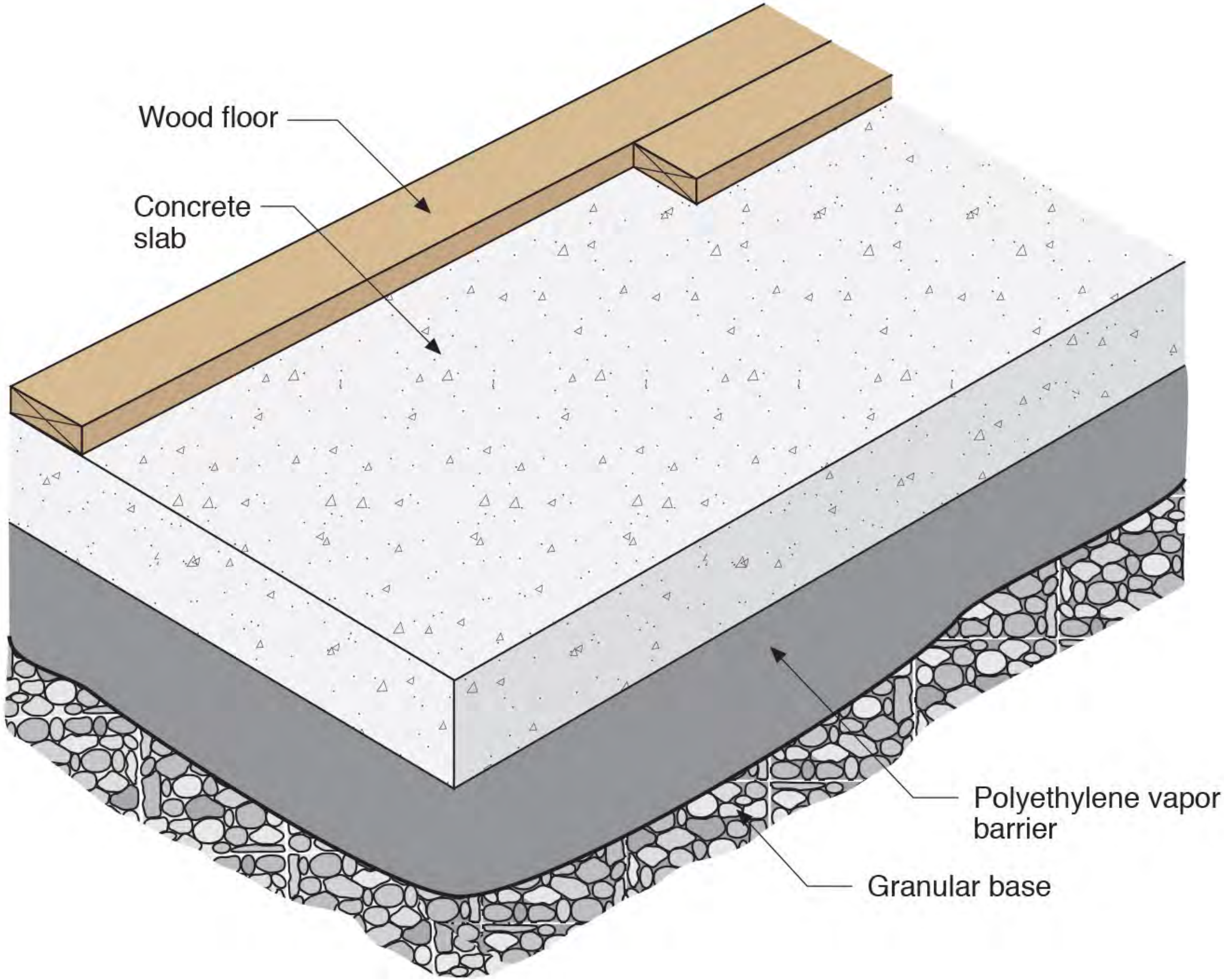

Styrofoam
UTILITYFIT EPS
DOW

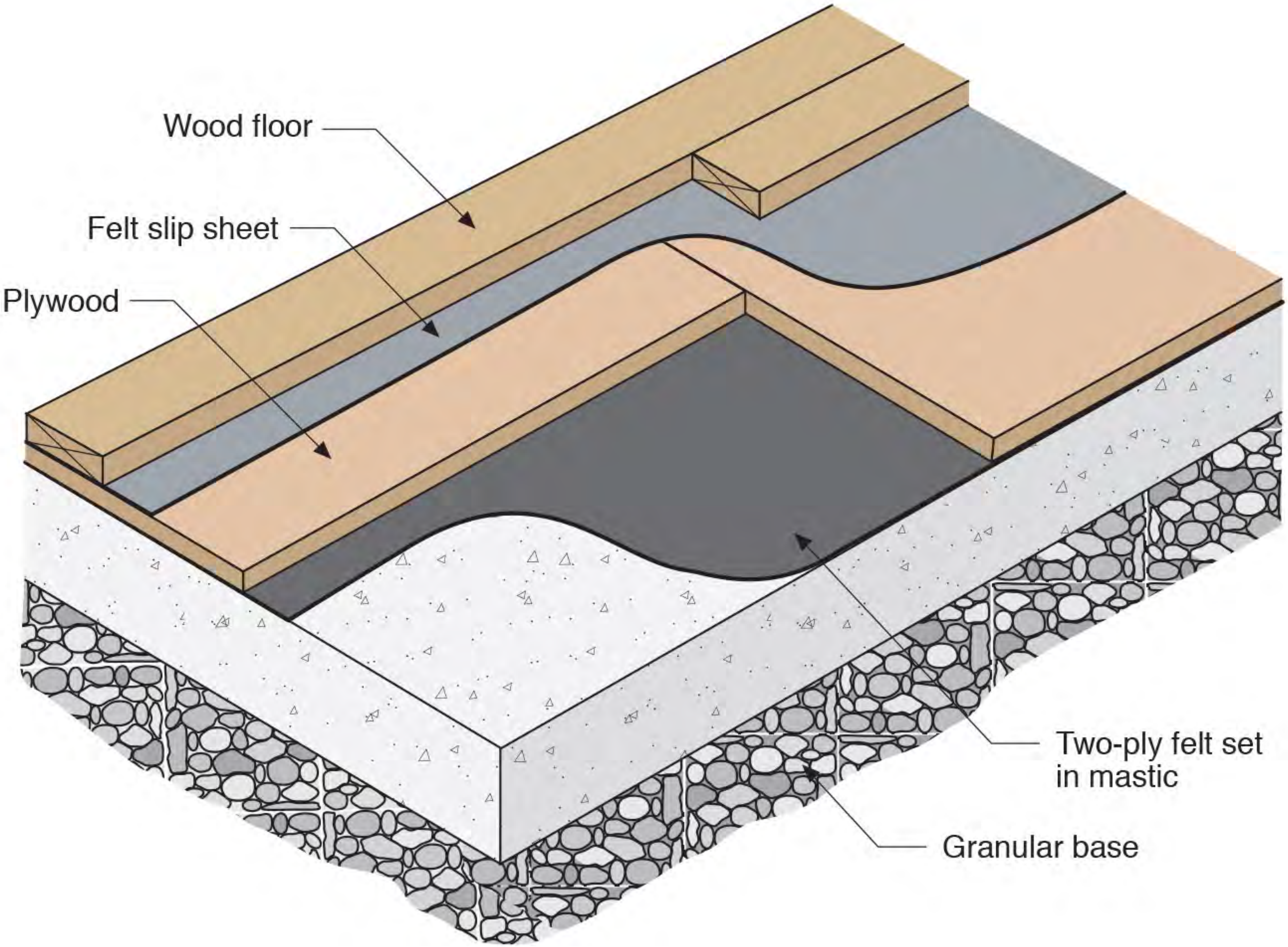

Plywood subfloor
Top-side epoxy coating
Vapor semi-permeable assembly allows moisture to pass in a slow, controlled manner
Extruded polystyrene; unfaced, no polypropylene or foil facing
1x4 furring (16" o.c.)
Concrete slab


shop-vac
10
CONTRACTOR


Carpet or wood floor (avoid vinyl flooring as vinyl flooring does not breathe)
3/4" plywood (T&G — narrow edges "biscuit" joined)
Rigid insulation (extruded polystyrene — unfaced, no polypropylene or foil facers)
Airspace
Dimpled plastic sheet membrane (air tight and gas tight)
Existing slab
Damp ground (no capillary break, no polyethylene ground cover)
Vapor pressure on top of slab and under slab equalizes, thereby stopping capillary transfer of water and soluable mineral salts (moisture content in air space and under slab remains the same; i.e. "wet")

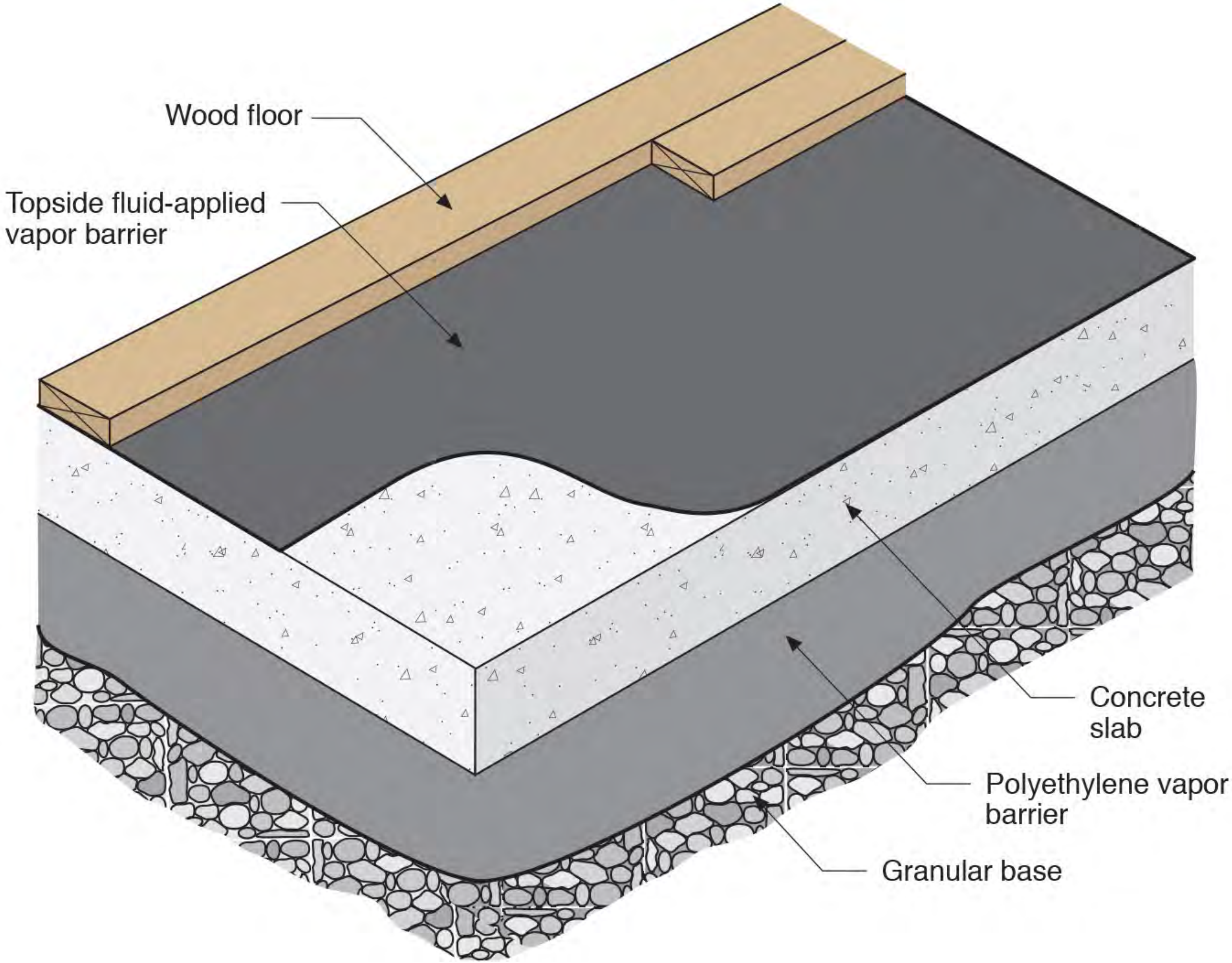

DELTA-FL


Wood floor
Concrete slab
Polyethylene vapor barrier
Granular base

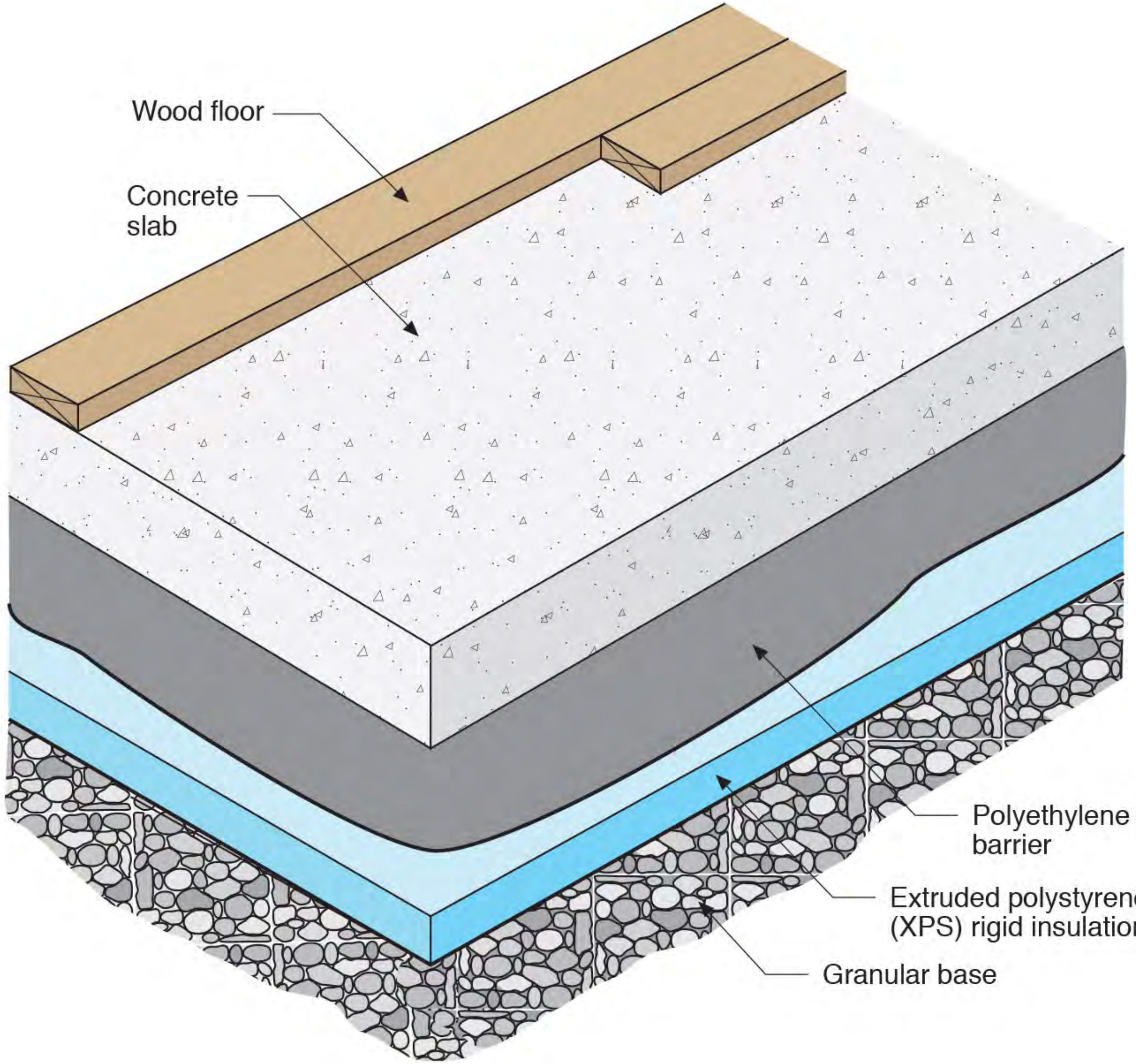


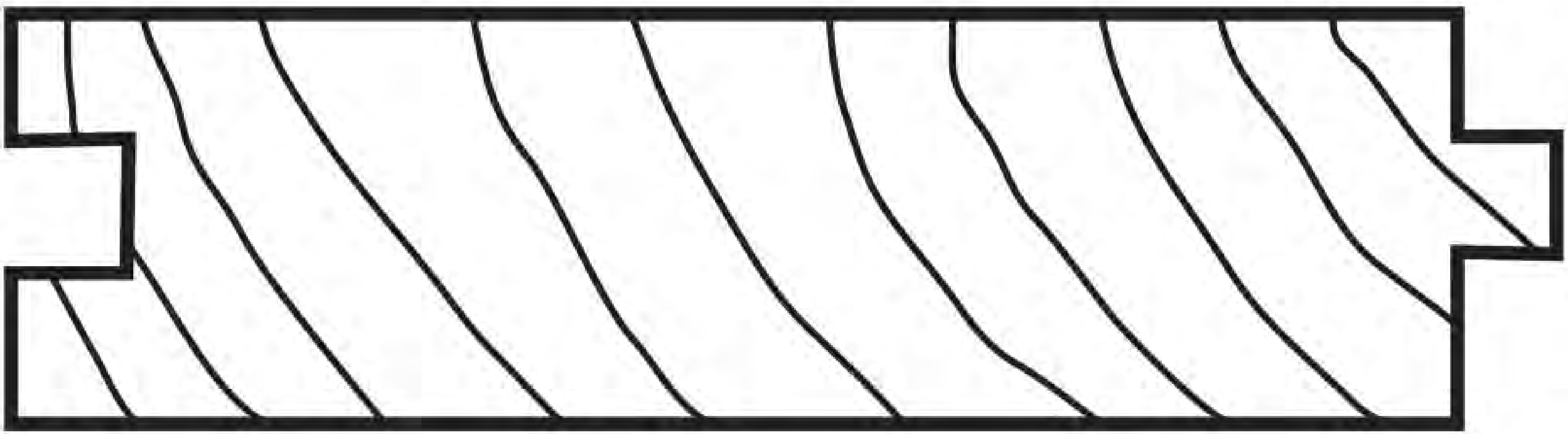
Wood floor
Felt slip sheet
Plywood
Two-ply felt set in mastic
Granular base


shop-vac

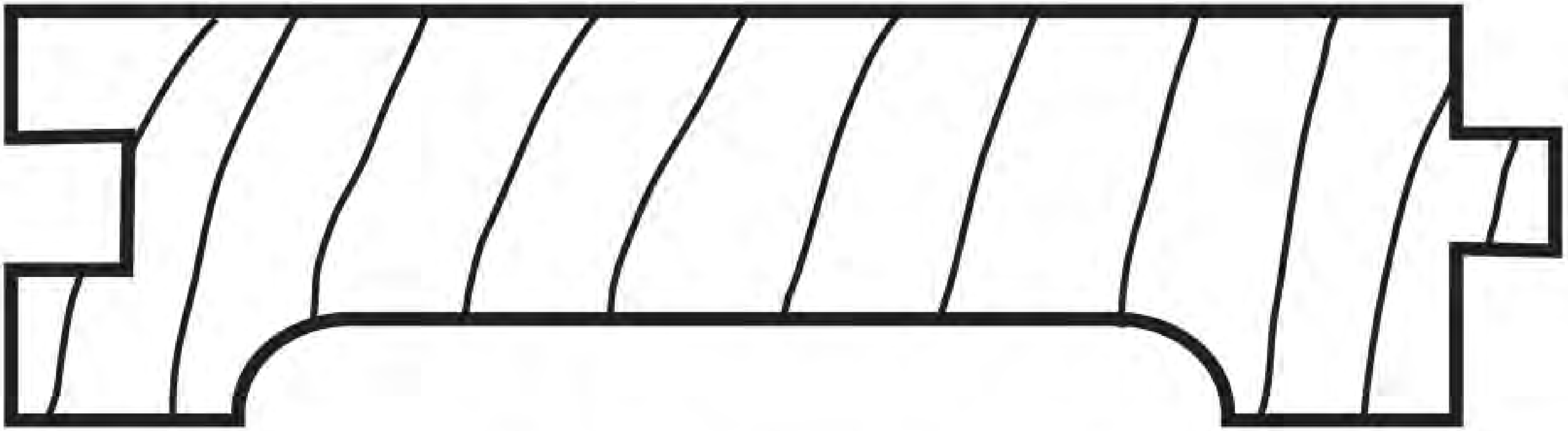

Wood floor
Topside fluid-applied vapor barrier
Concrete slab
Polyethylene vapor barrier
Granular base


COLA

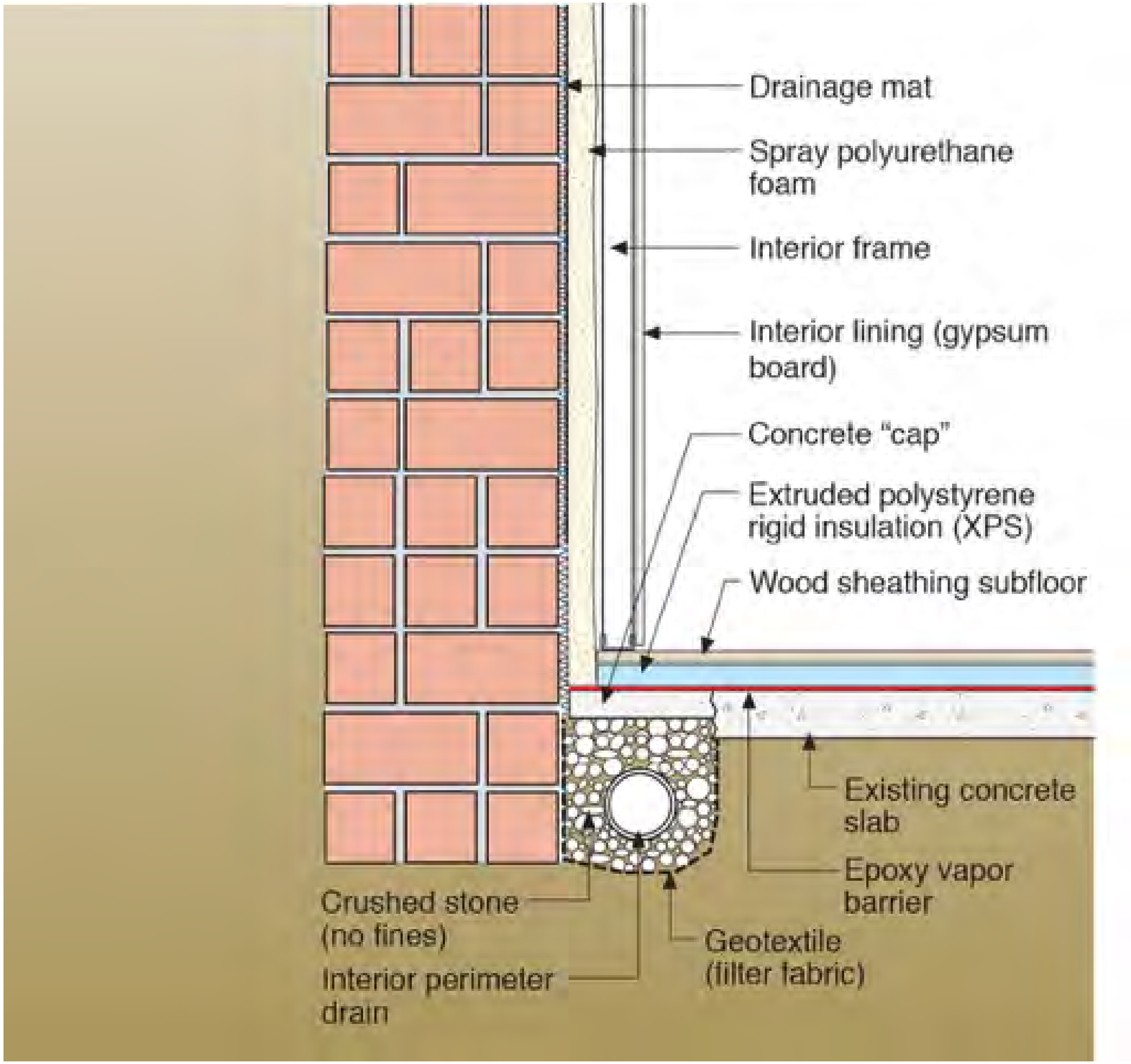

Wood floor
Concrete slab
Polyethylene vapor barrier
Extruded polystyrene (XPS) rigid insulation
Granular base

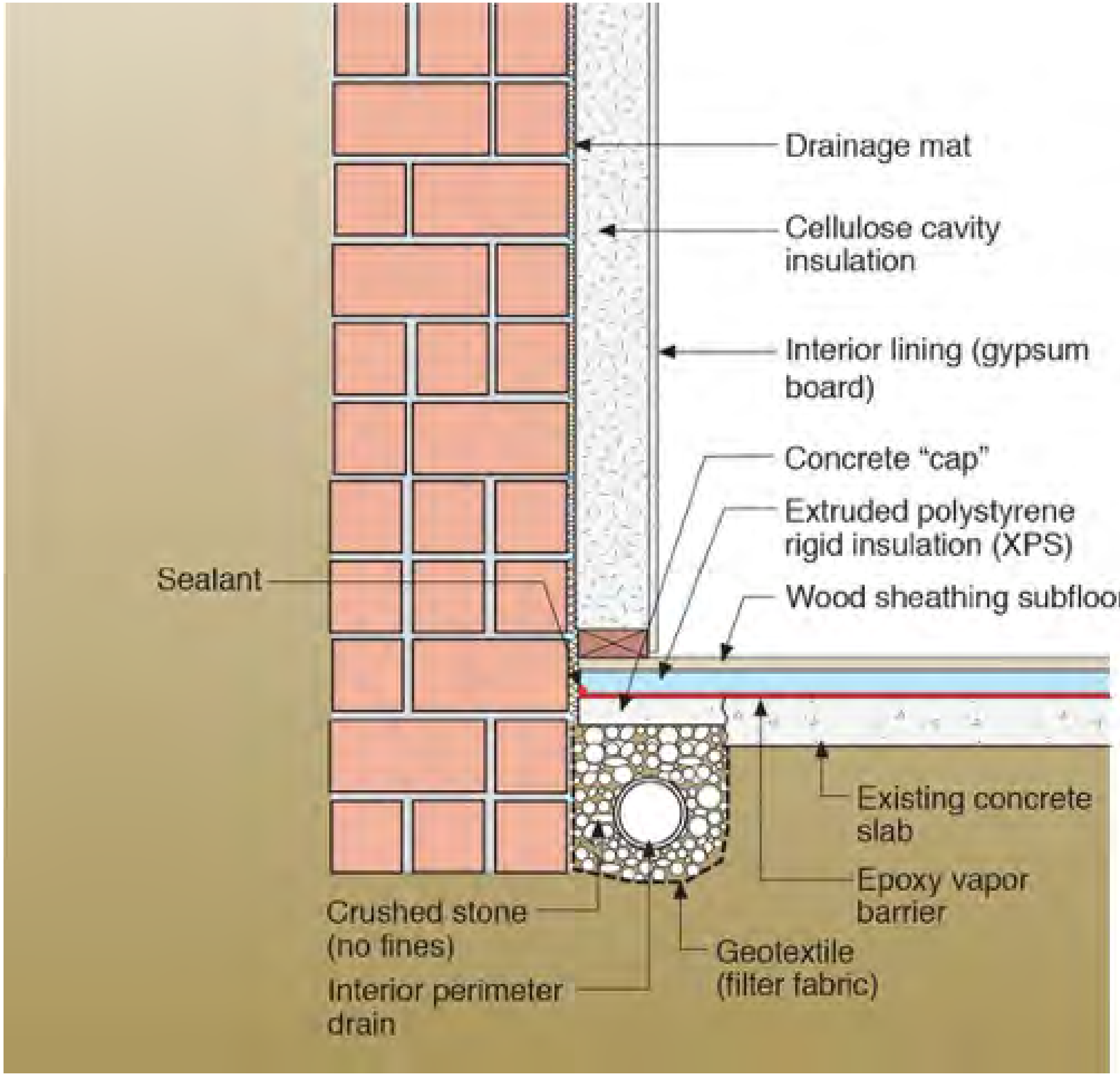


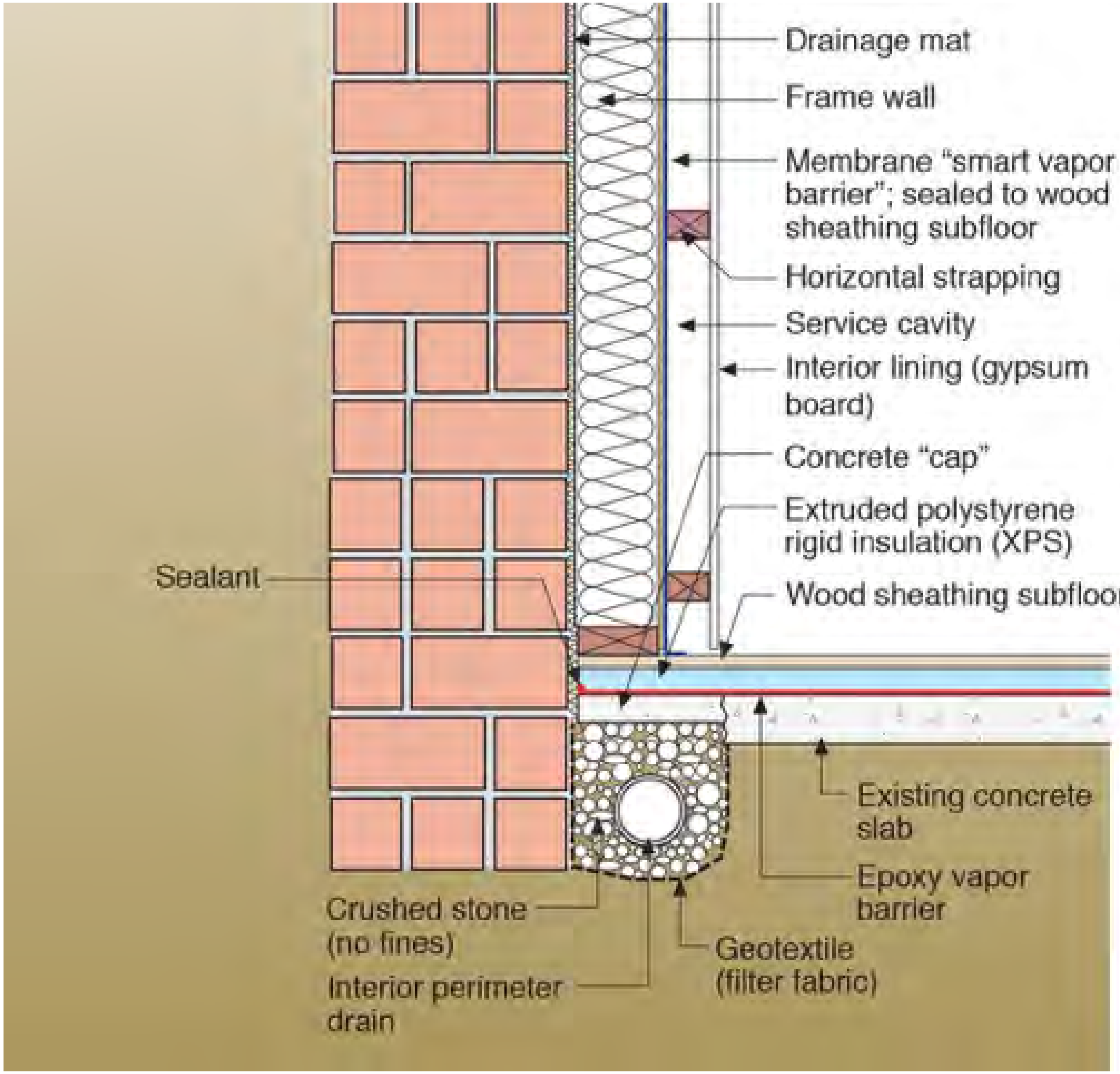
Plain



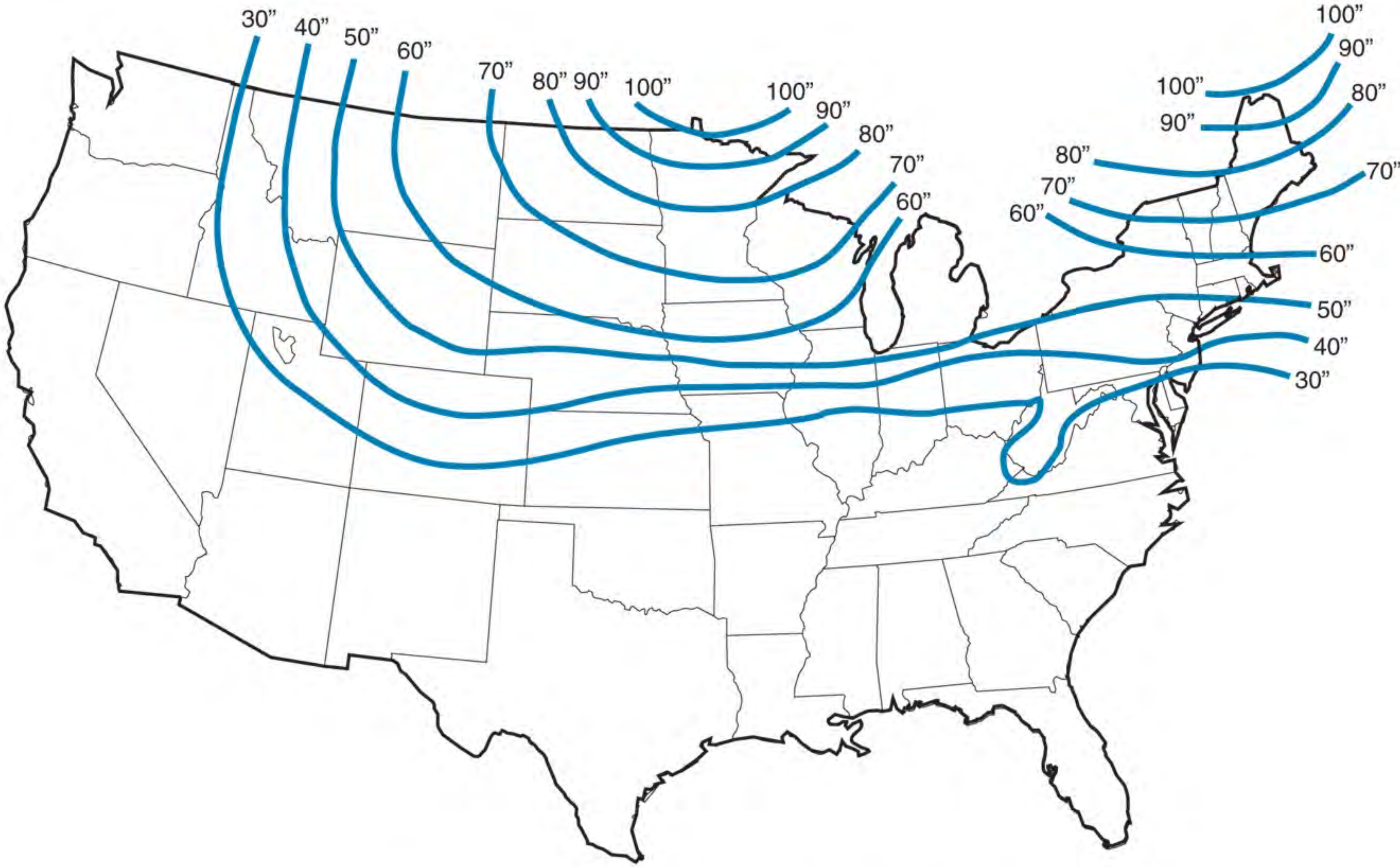
Hollow Back


Drainage mat
Spray polyurethane foam
Interior frame
Interior lining (gypsum board)
Concrete "cap"
Extruded polystyrene rigid insulation (XPS)
Wood sheathing subfloor
Existing concrete slab
Epoxy vapor barrier
Crushed stone (no fines)
Interior perimeter drain
Geotextile (filter fabric)

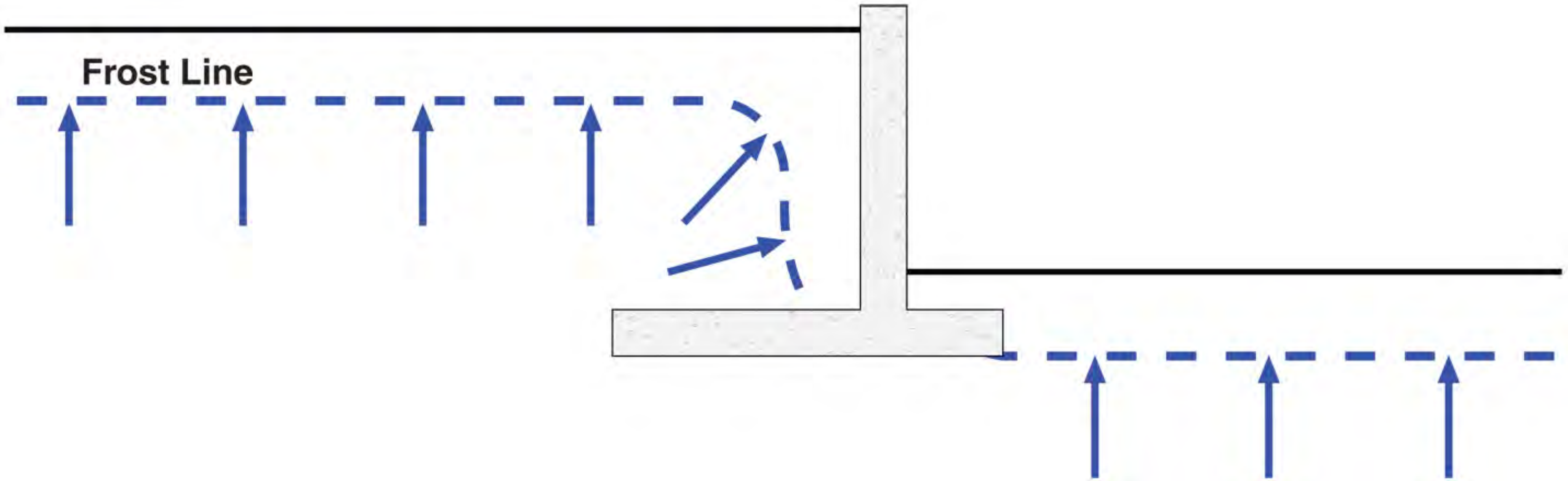

Drainage mat
Cellulose cavity insulation
Interior lining (gypsum board)
Concrete “cap”
Extruded polystyrene rigid insulation (XPS)
Wood sheathing subfloor
Sealant
Existing concrete slab
Epoxy vapor barrier
Geotextile (filter fabric)
Crushed stone (no fines)
Interior perimeter drain

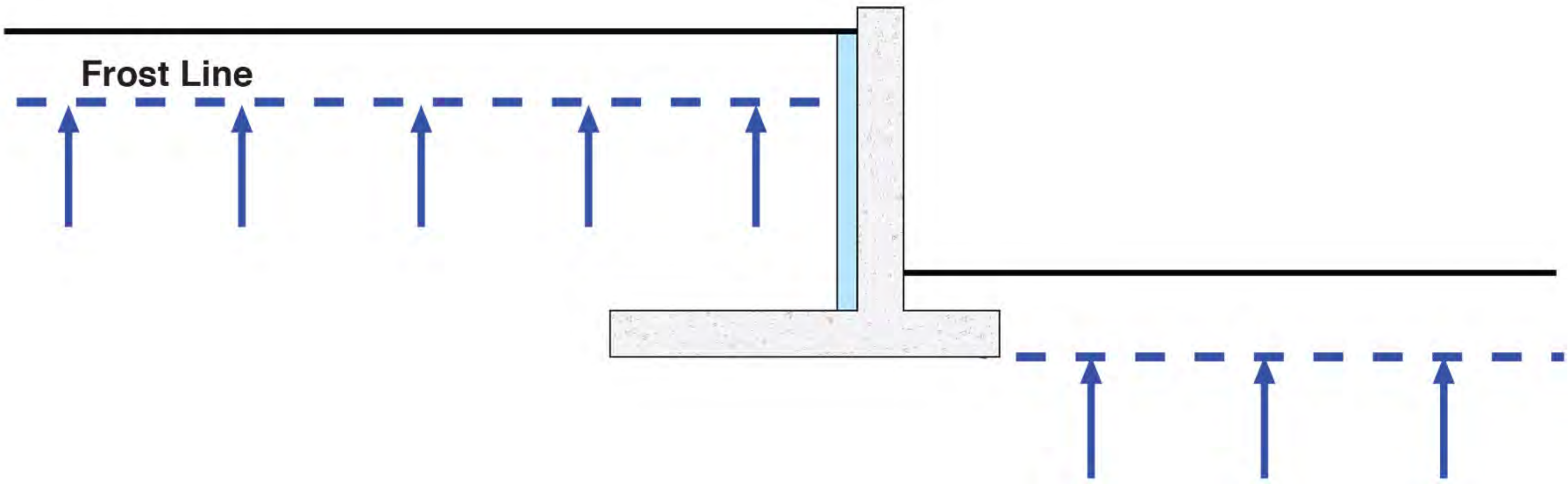


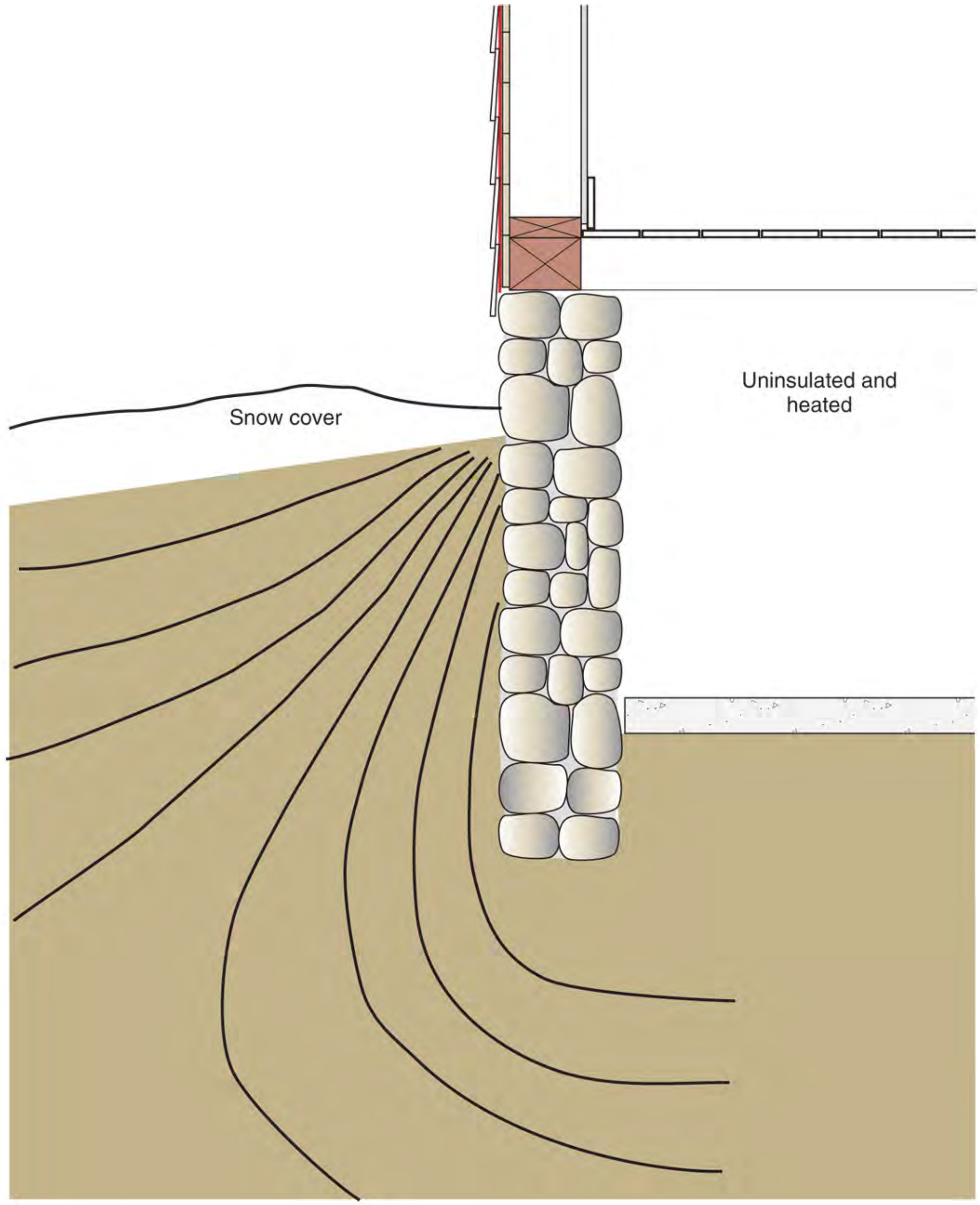
Drainage mat
Frame wall
Membrane "smart vapor barrier"; sealed to wood sheathing subfloor
Horizontal strapping
Service cavity
Interior lining (gypsum board)
Concrete "cap"
Extruded polystyrene rigid insulation (XPS)
Sealant
Wood sheathing subfloor
Existing concrete slab
Epoxy vapor barrier
Crushed stone (no fines)
Geotextile (filter fabric)
Interior perimeter drain

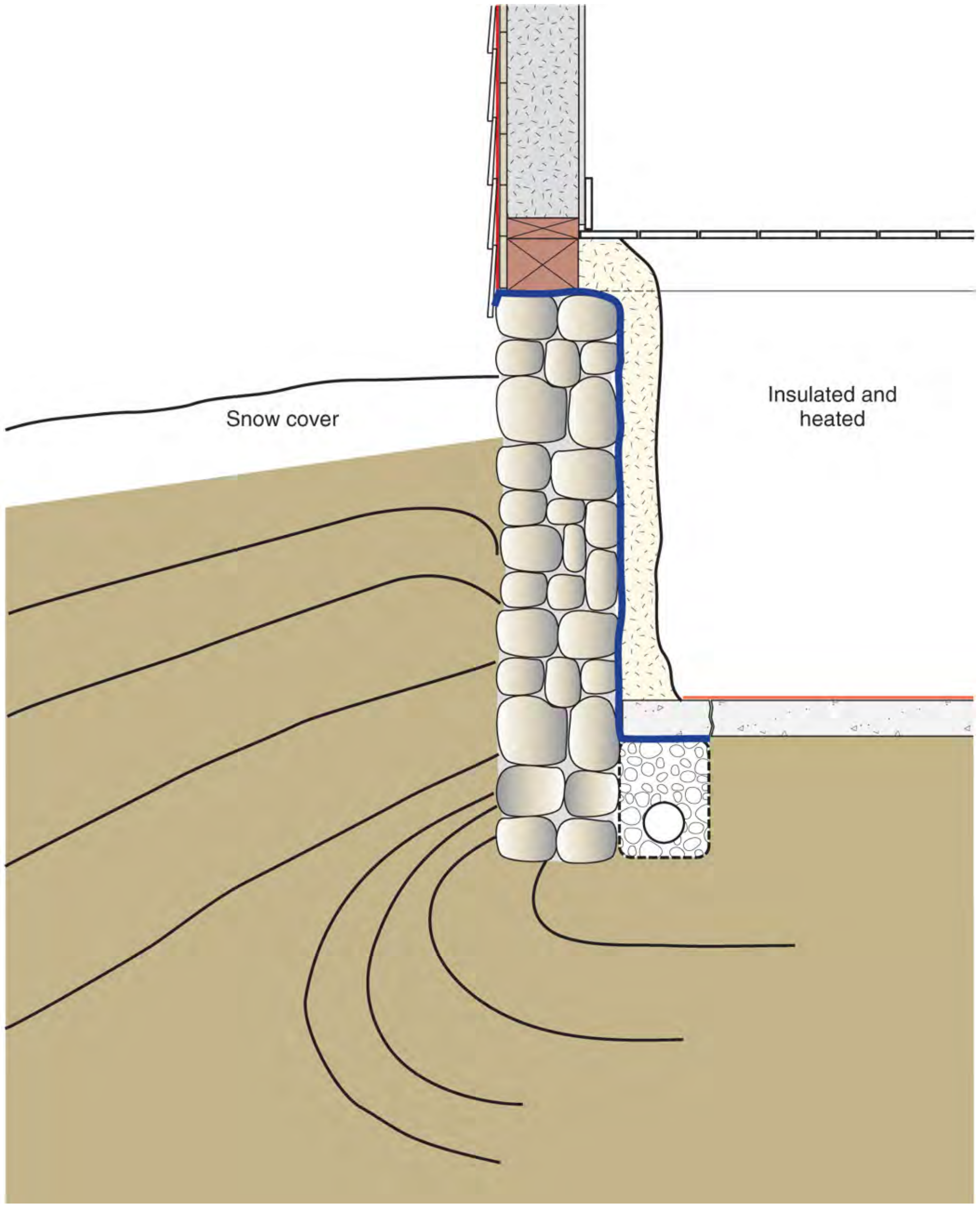


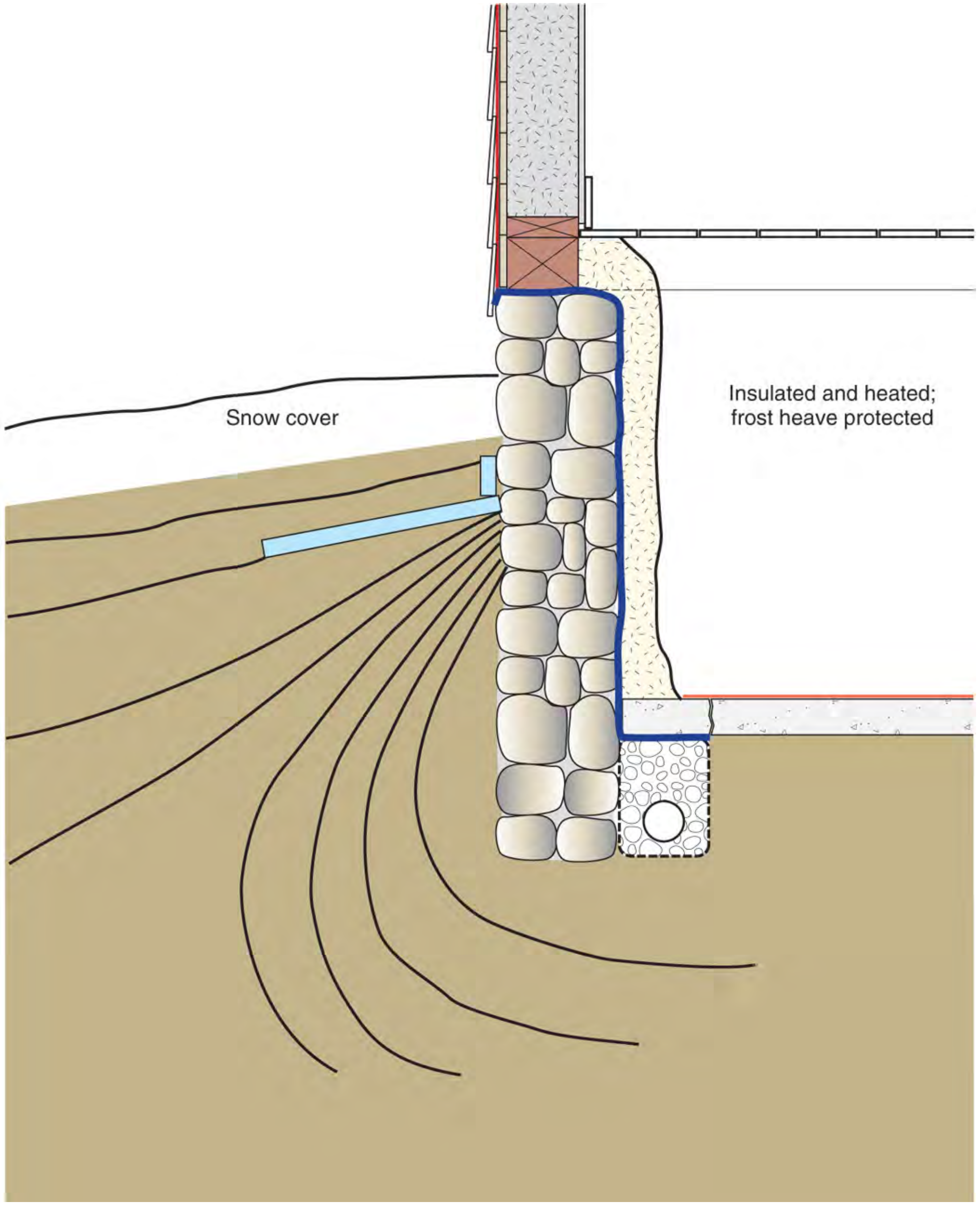
From the US Army Corps Engineers Extreme Frost Penetration
(in inches) based on state averages.

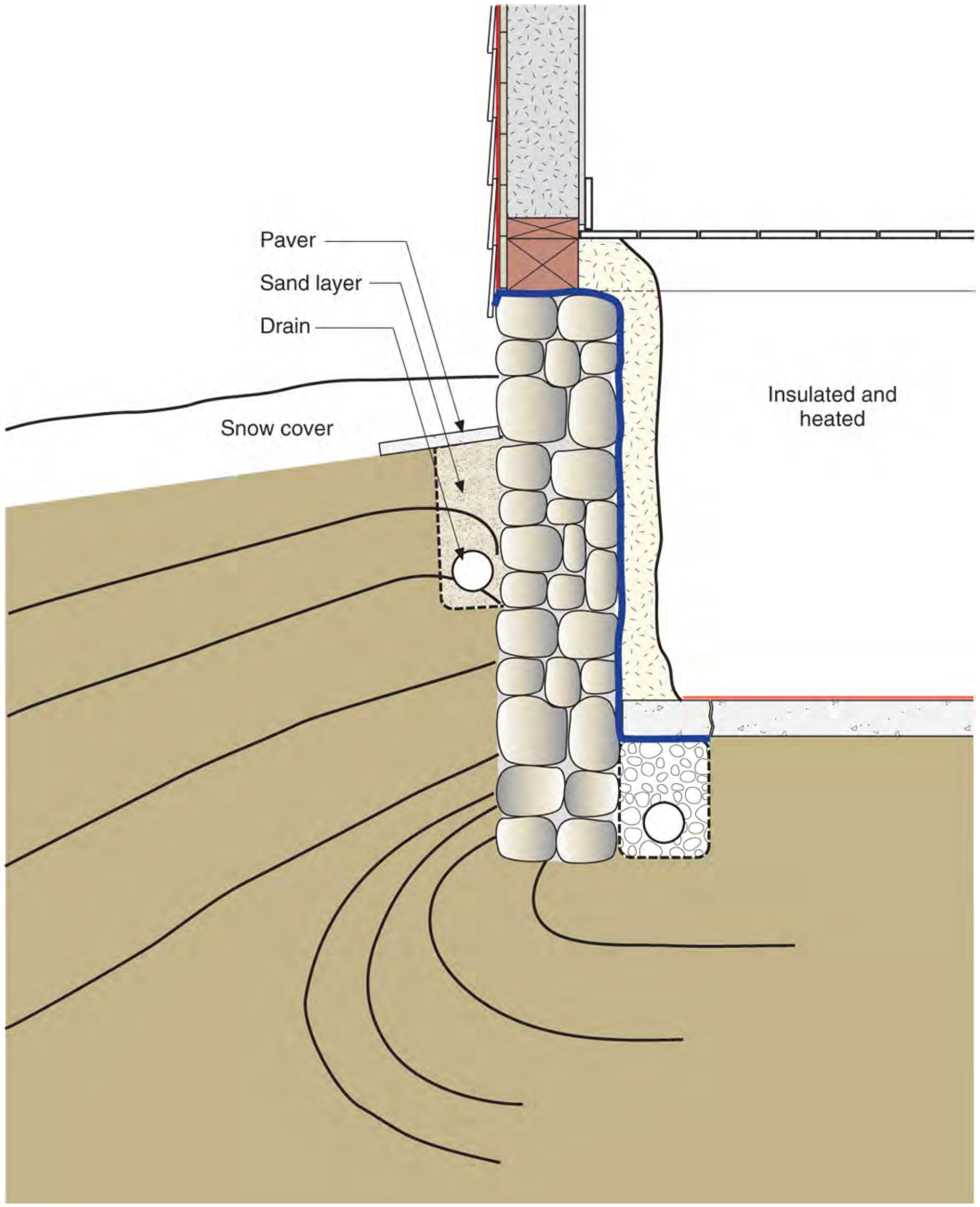

Frost Line

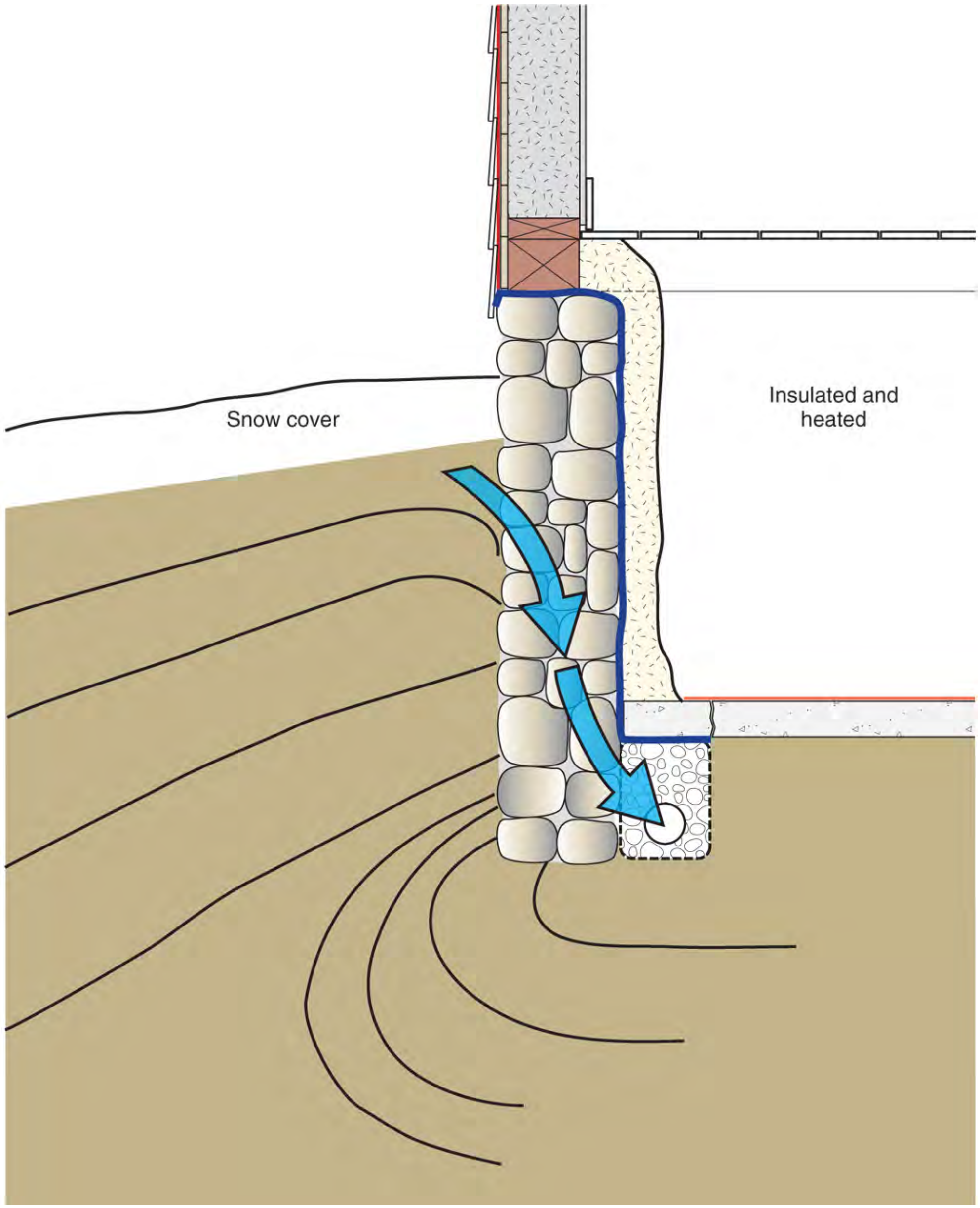

Frost Line


Uninsulated and heated
Snow cover


Snow cover
Insulated and heated


Snow cover
Insulated and heated;
frost heave protected


Paver
Sand layer
Drain
Snow cover
Insulated and heated


Snow cover
Insulated and heated