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

Building Science

Adventures In Building Science

www.buildingscience.com

Retrofits – Mass Buildings



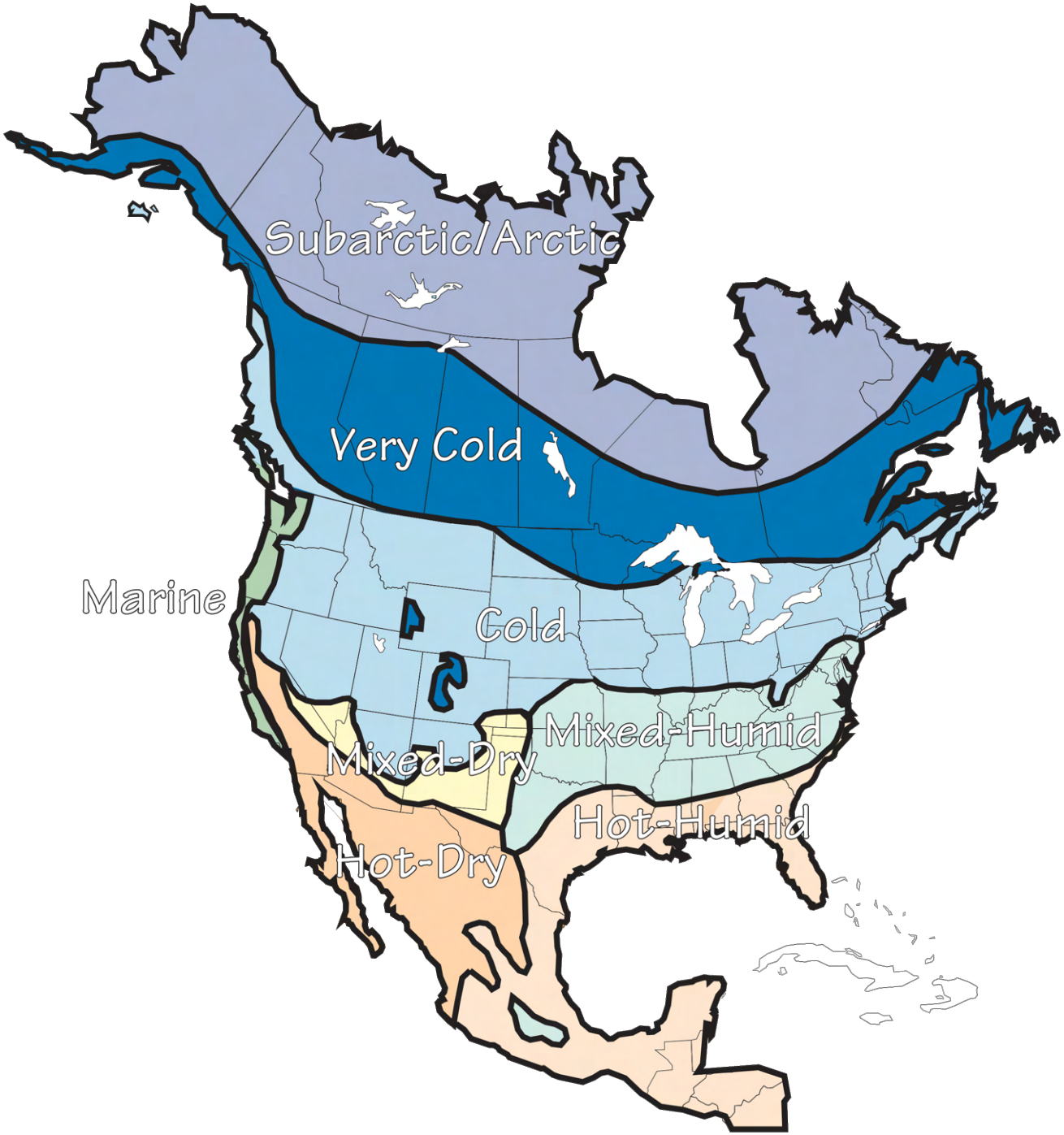
Freeze-Thaw Damage

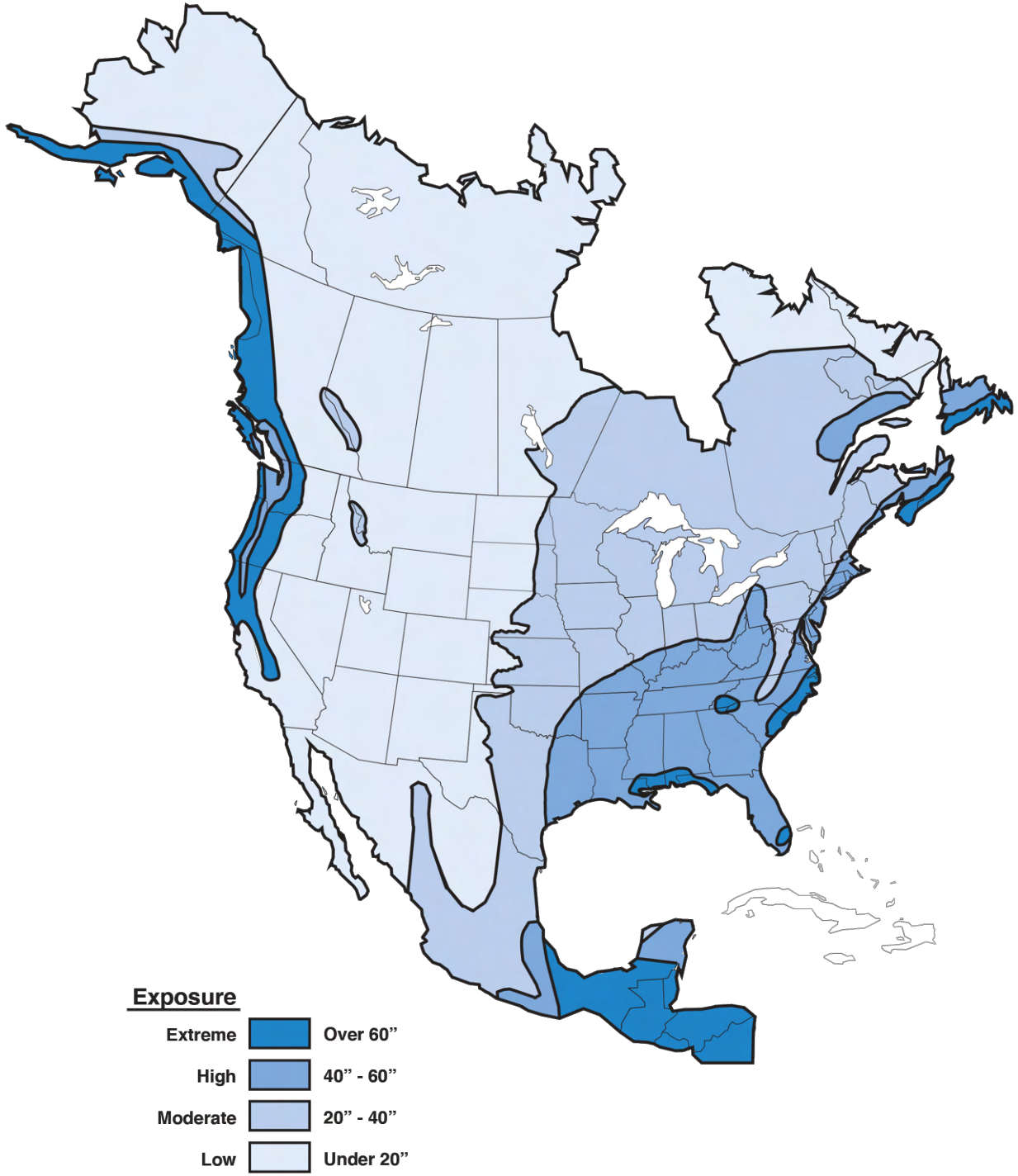
Freeze-Thaw Damage

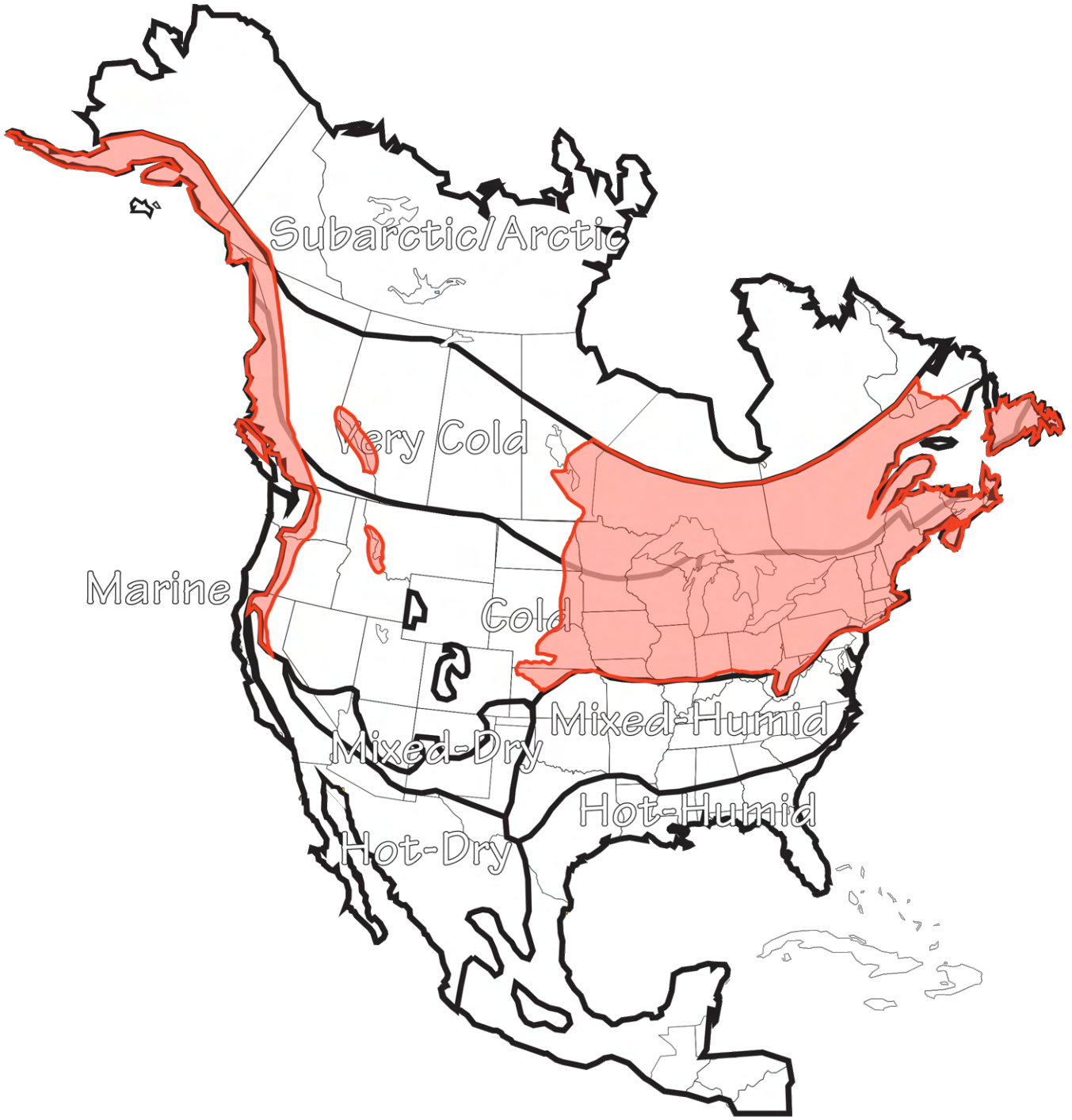
Freezing Temperatures

Water

Susceptible Brick


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

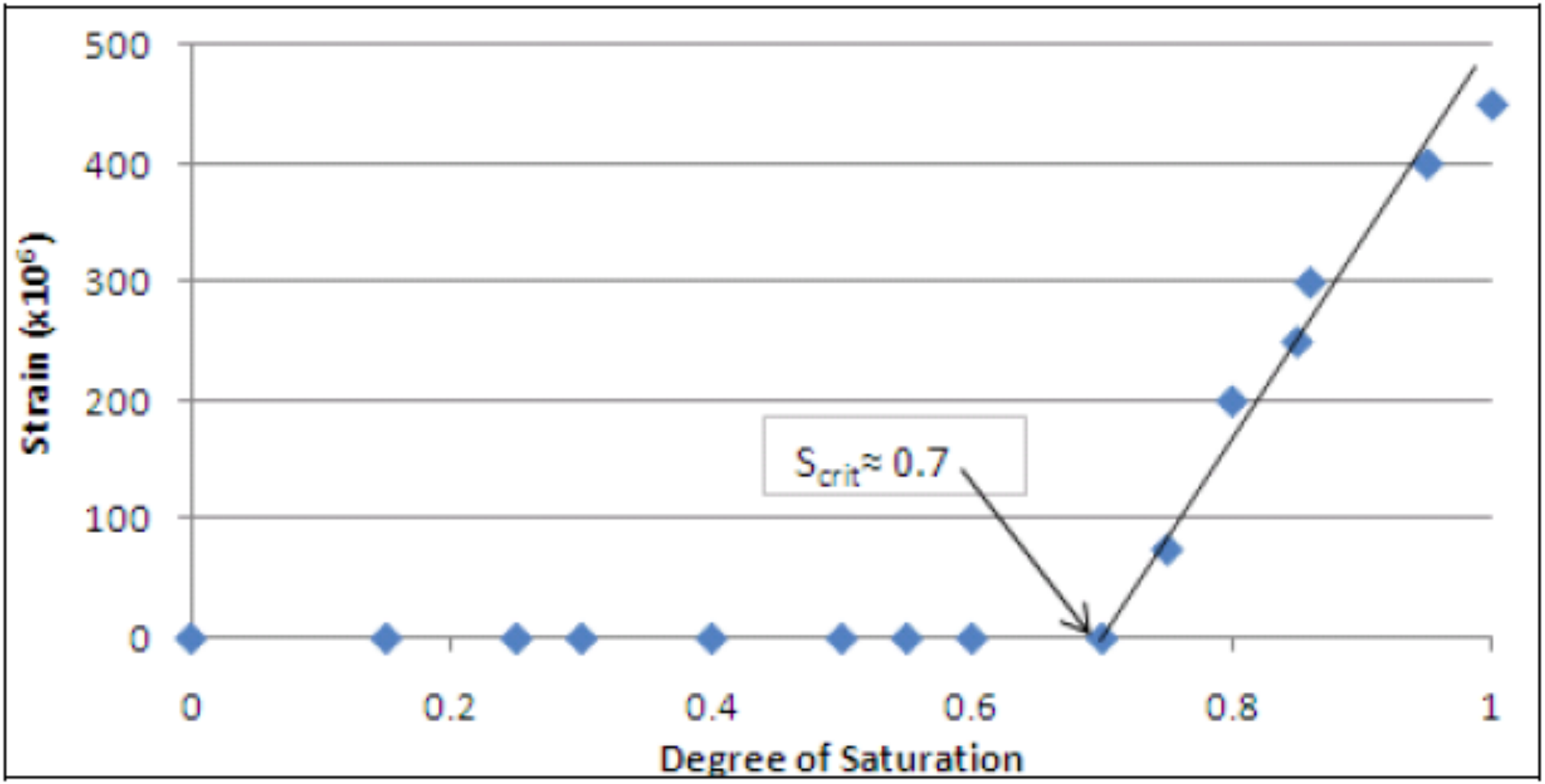

Exposure
Extreme
Over 60”
High
40” - 60”
Moderate
20” - 40”
Low
Under 20”


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

Susceptible Brick

Firing Temperature

Vitrification

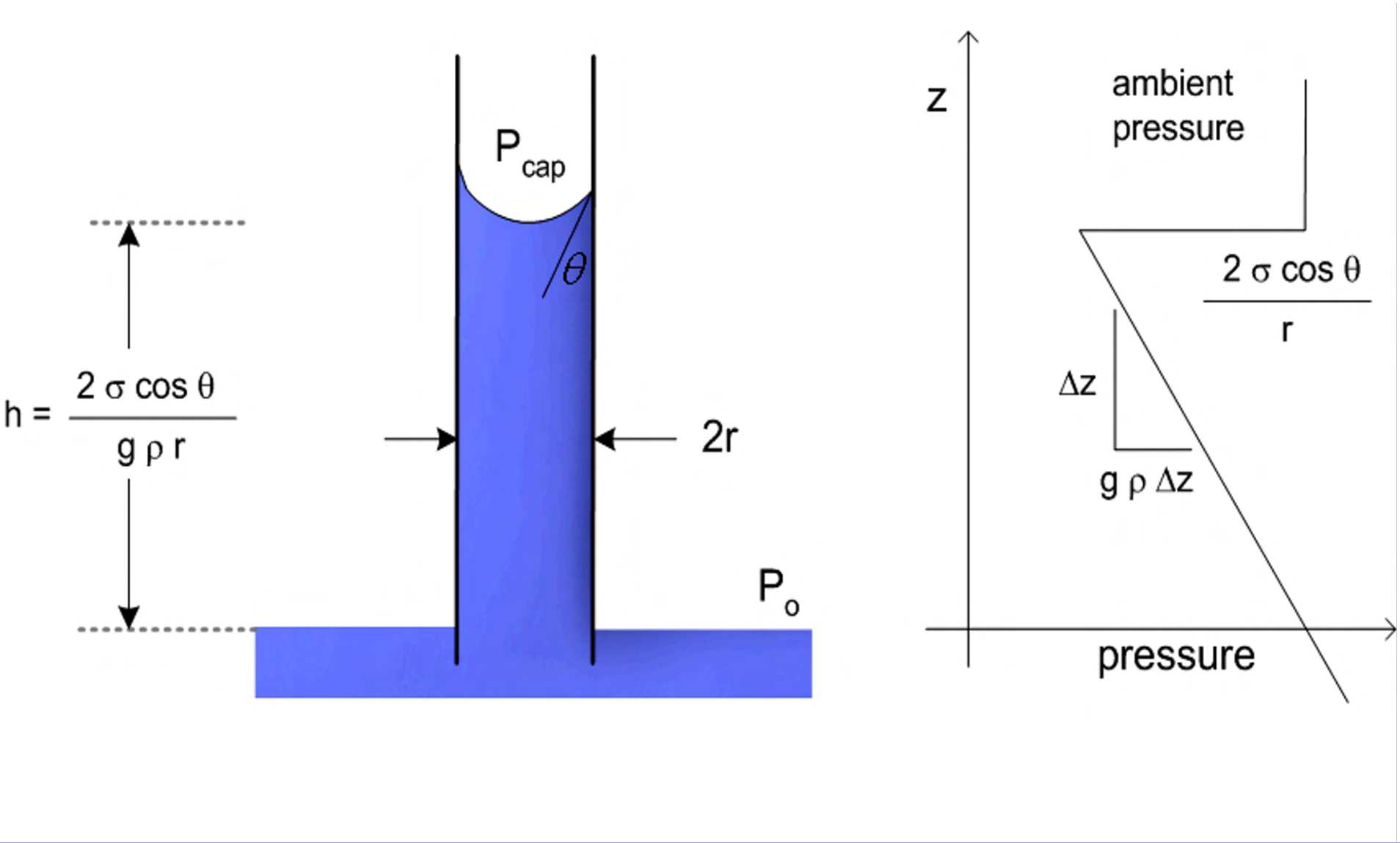

500
400
300
200
100
0
Strain (x10⁶)
$S_{crit} \approx 0.7$
0
0.2
0.4
0.6
0.8
1
Degree of Saturation


ABS
3.804295 in
ABS/INC
mm/inch
SET
ON/OFF
3-4" ASIMETO 0.00005"

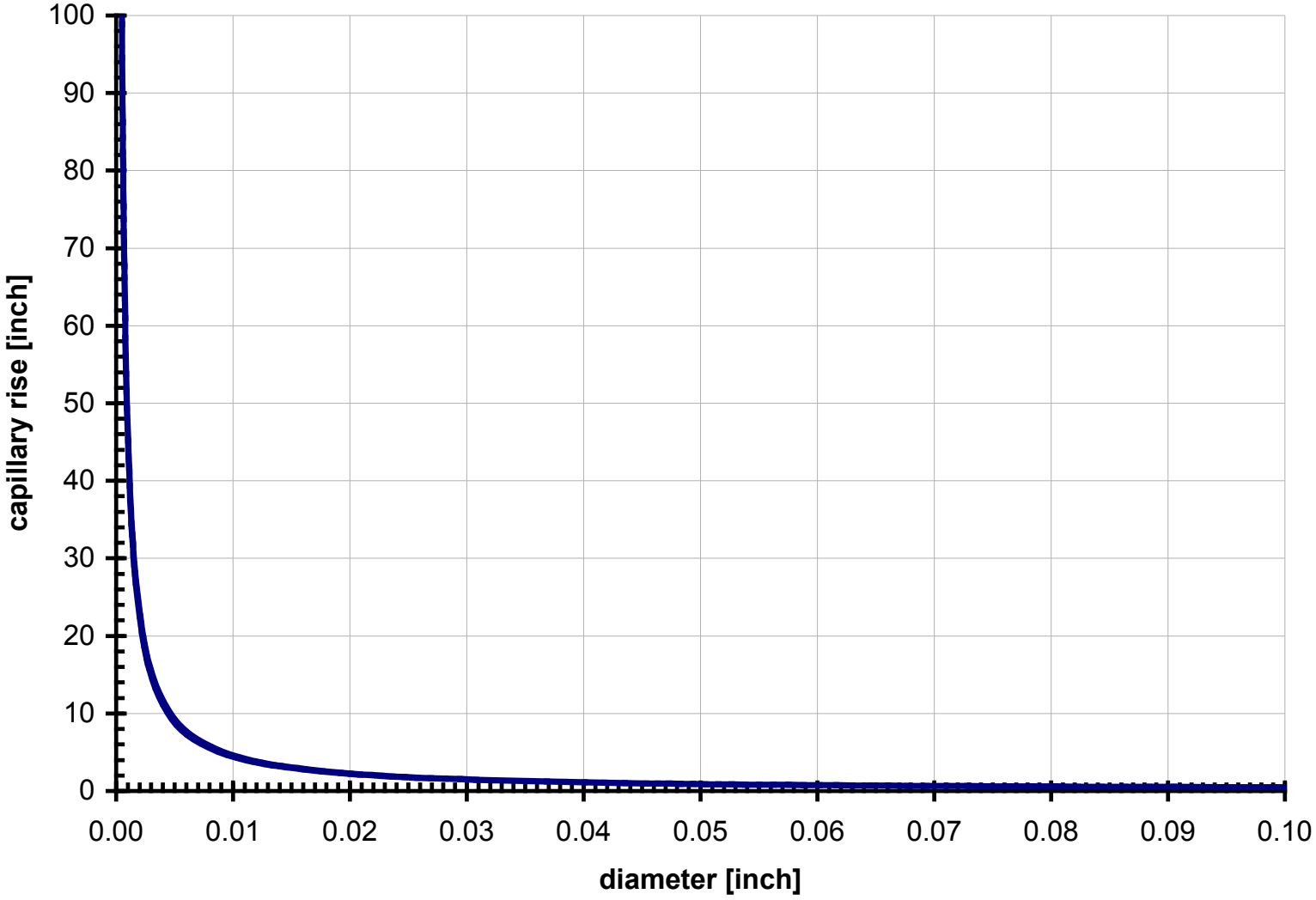
Kelvin Equation

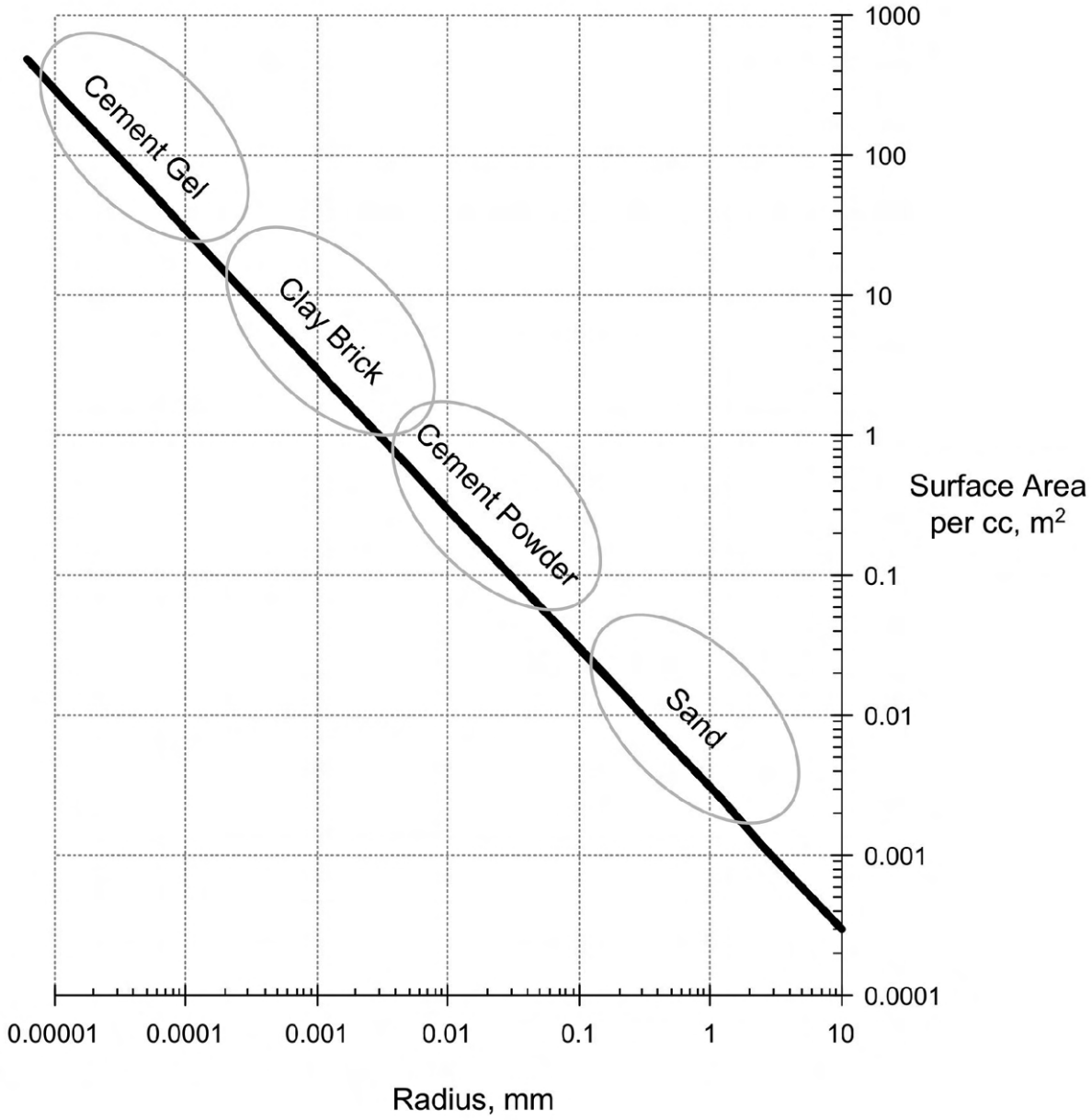
$$\ln \frac{p}{p_0} = \frac{2\gamma V_{\mathrm{m}}}{rRT}$$

Calculating capillary rise

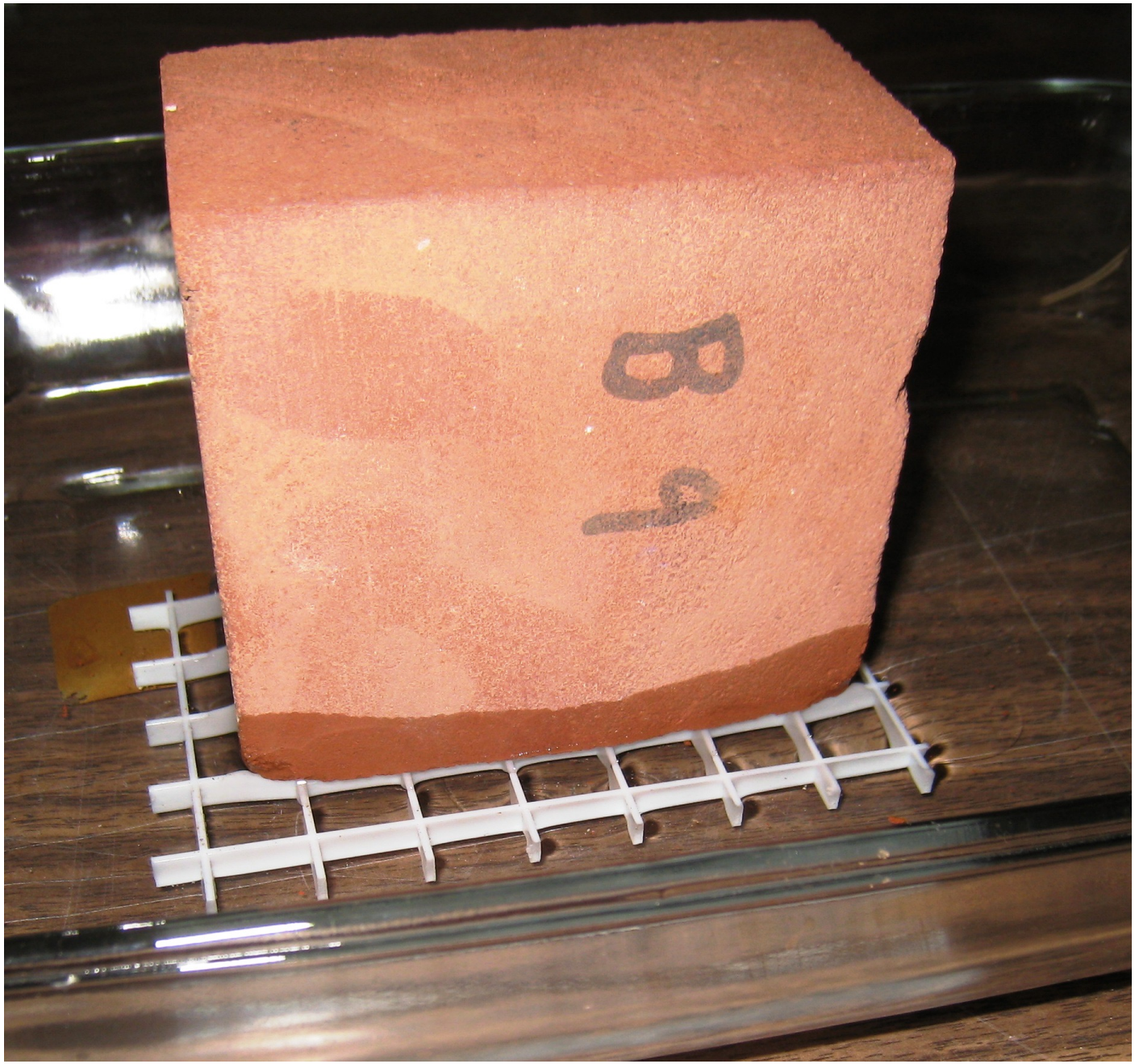


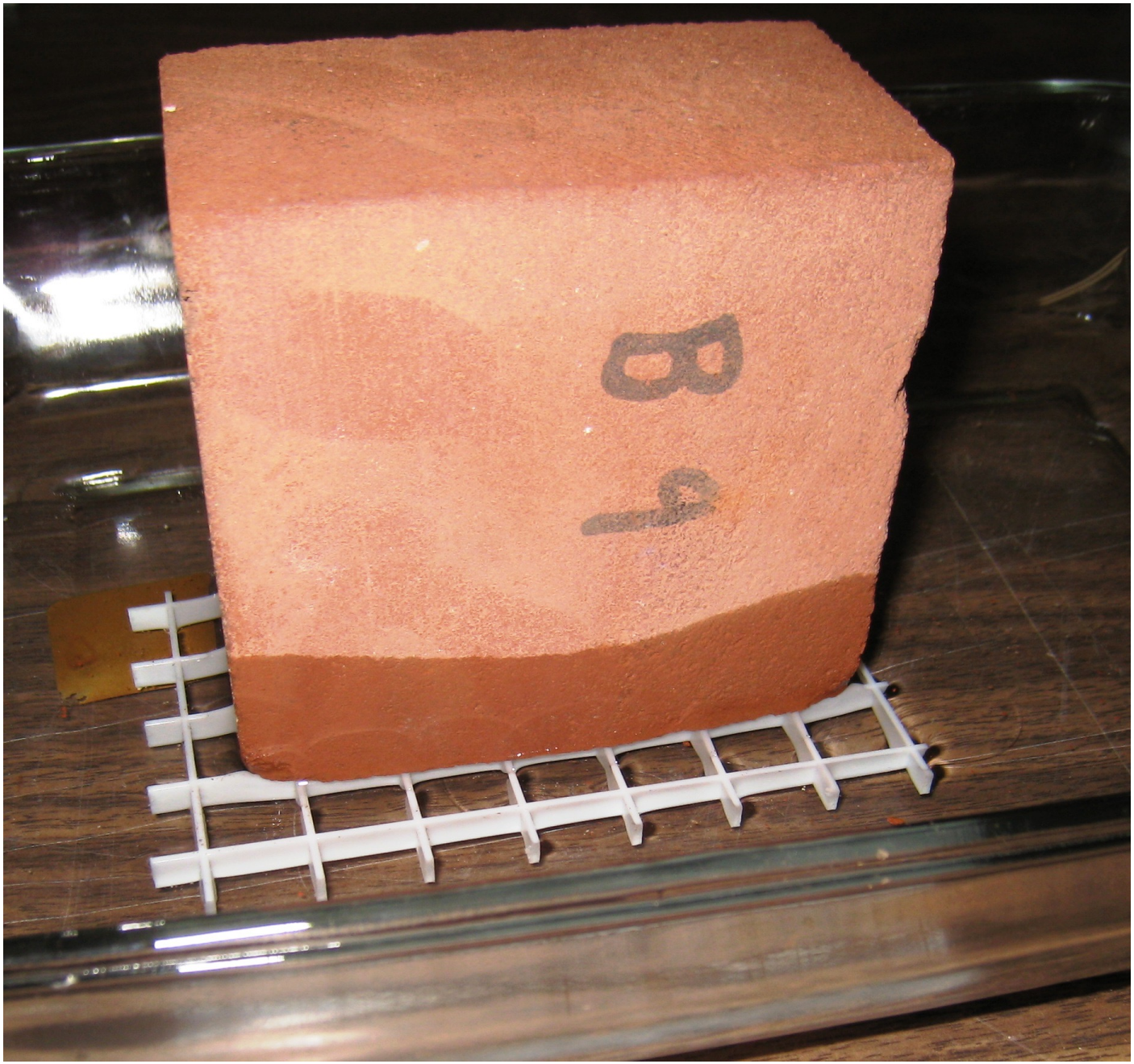
Capillary rise versus diameter

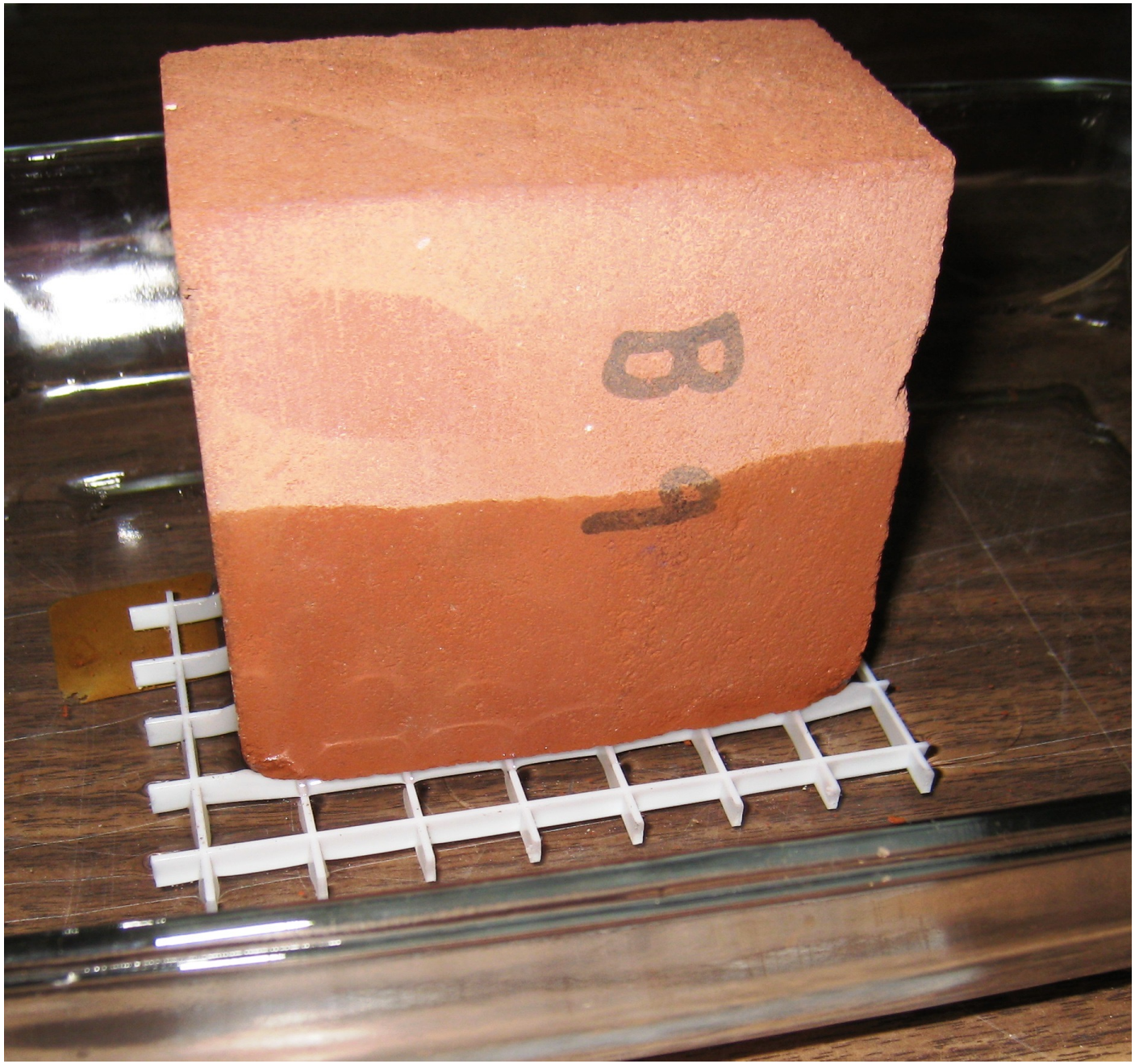


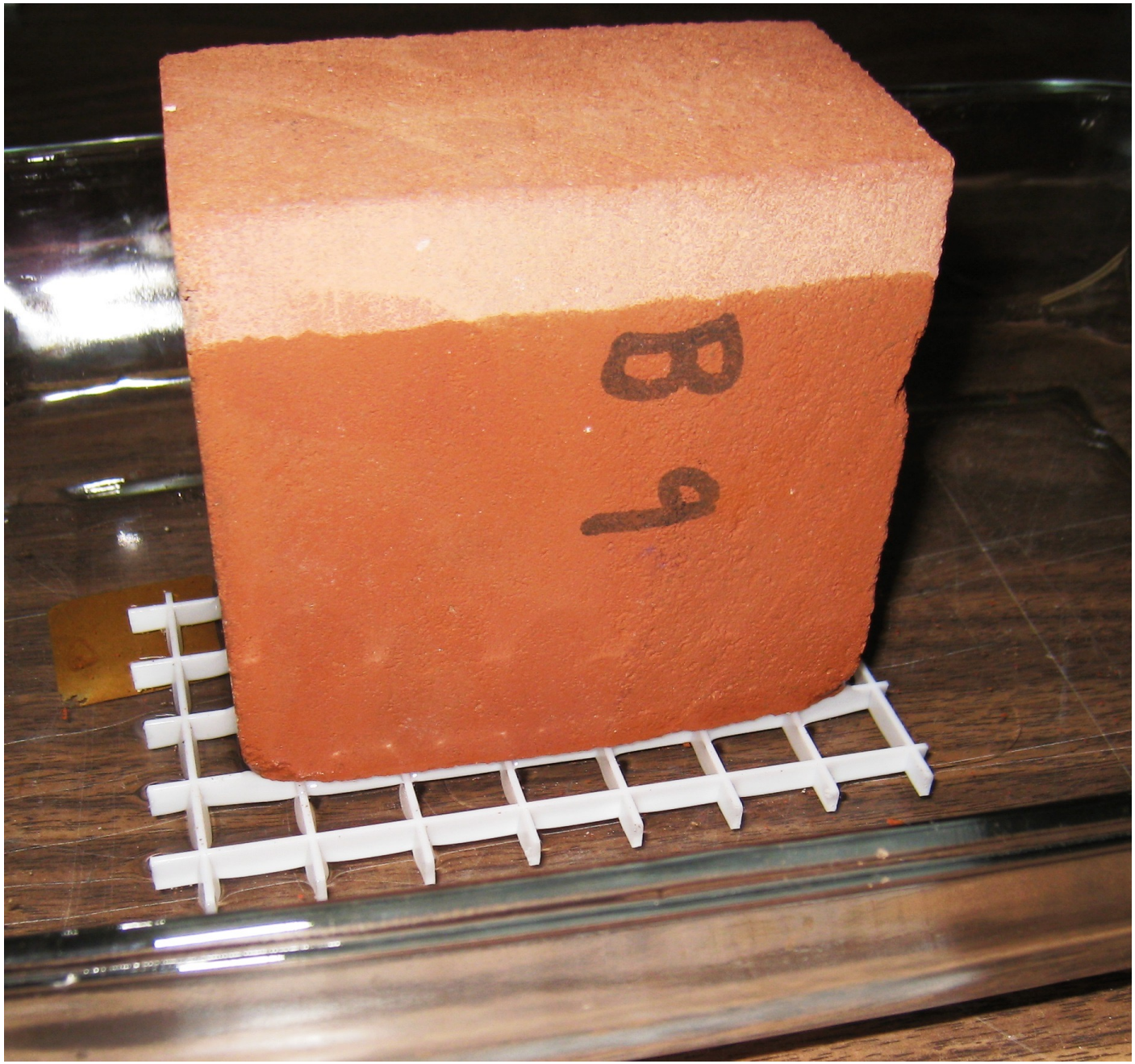


Surface area vs. particle size
From Straube & Burnett, 2005








B
9











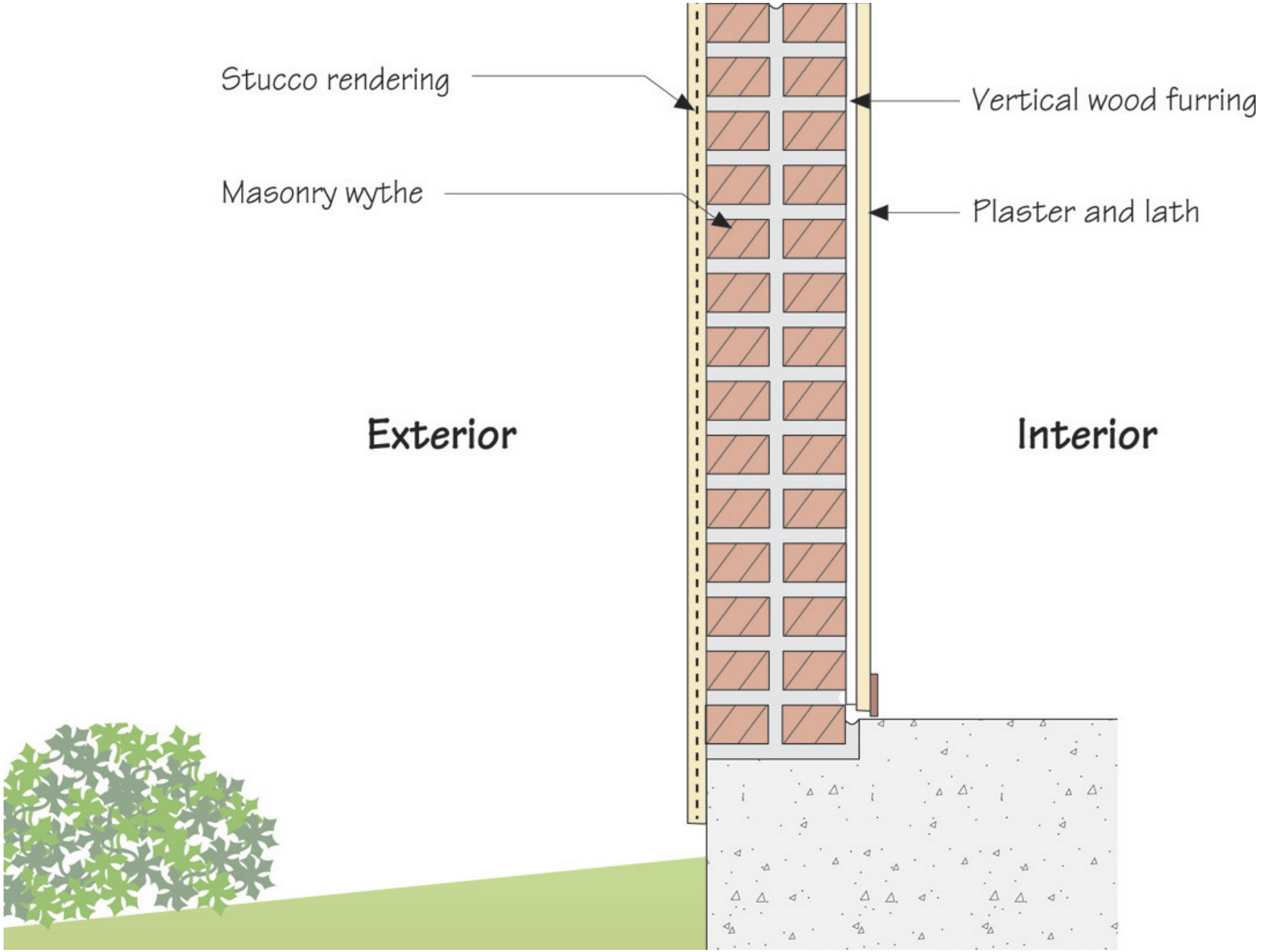











Stucco rendering
Masonry wythe
Vertical wood furring
Plaster and lath
Exterior
Interior

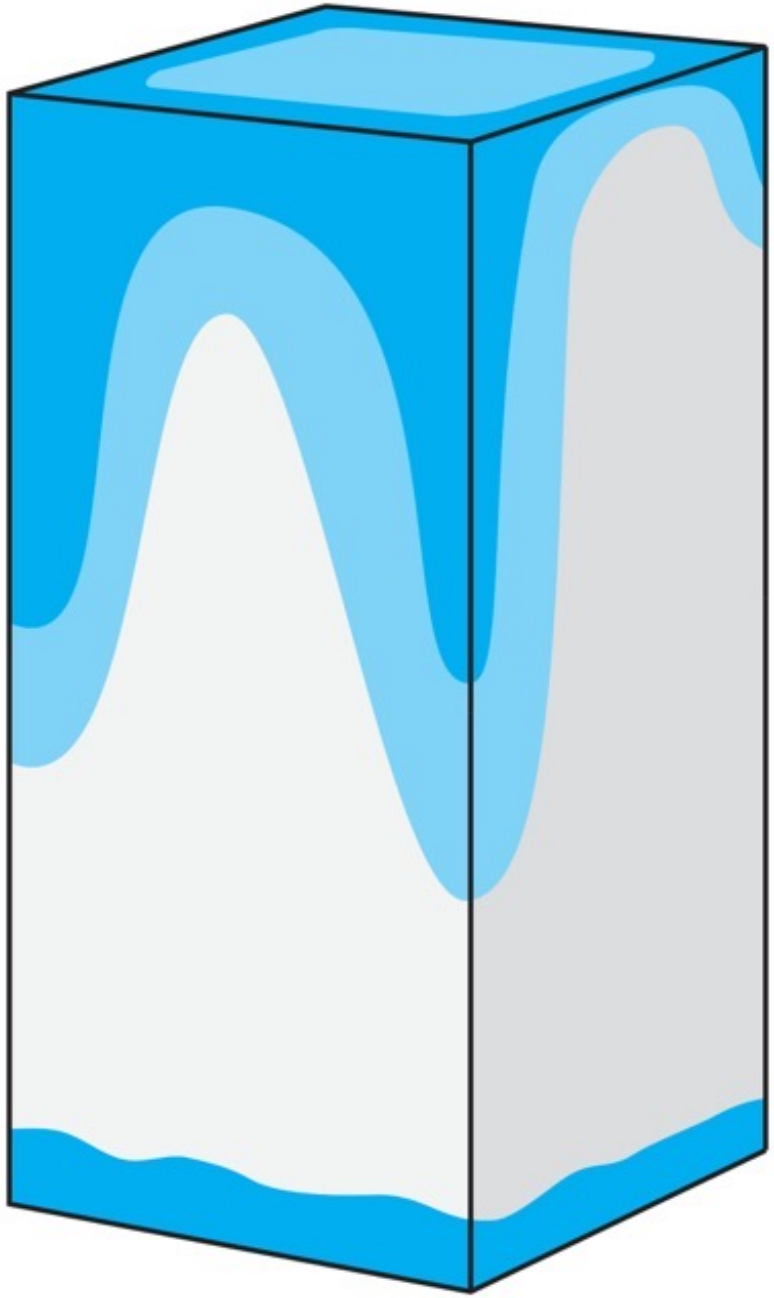


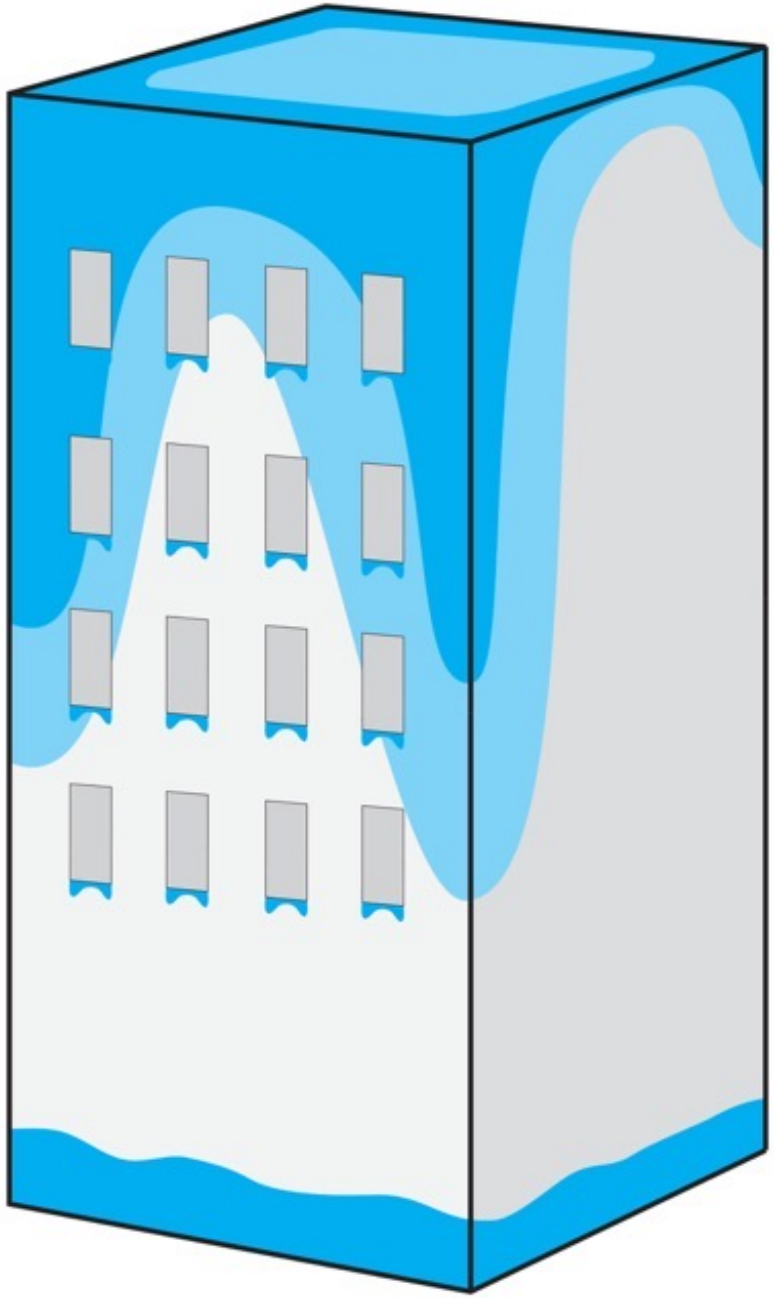
















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Retail
Space

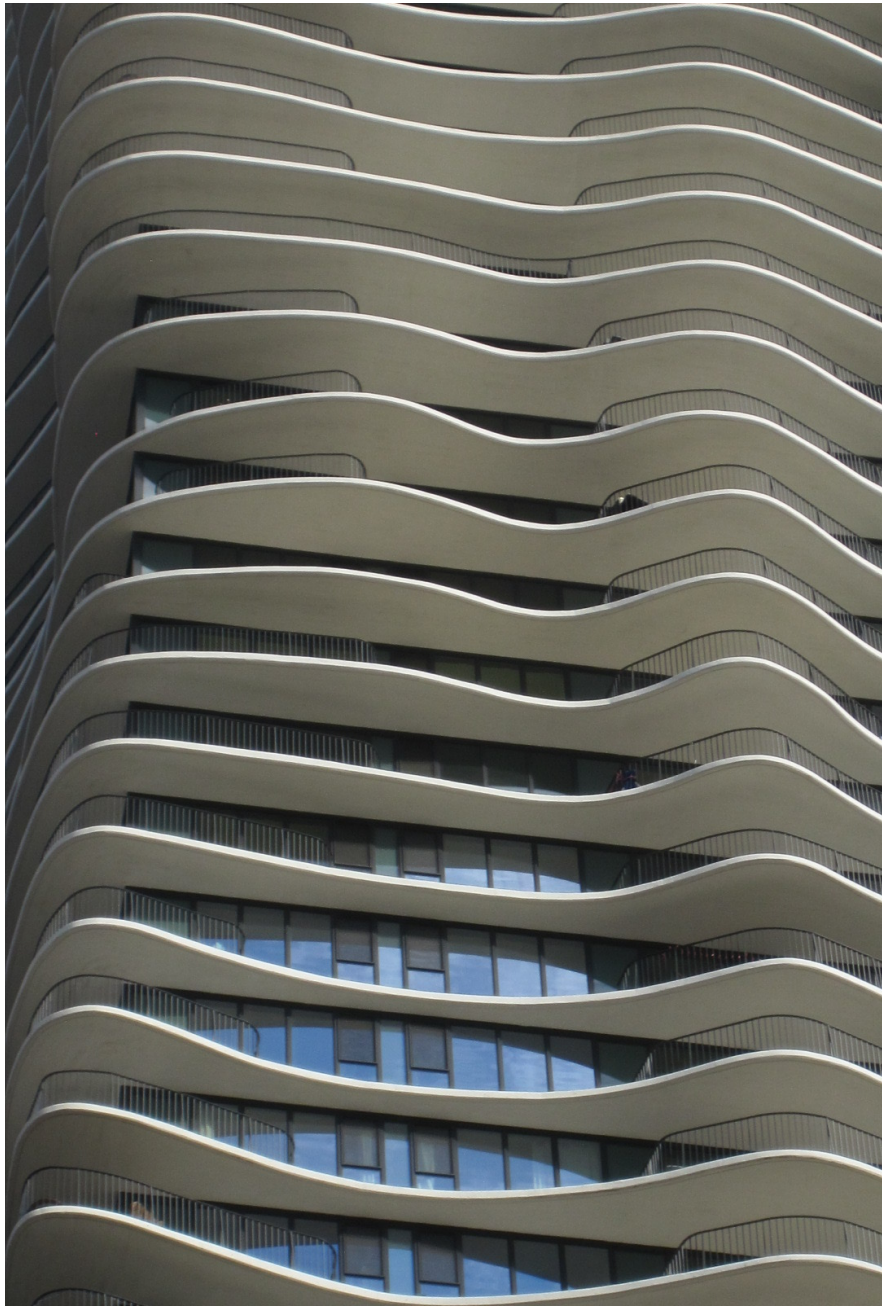




















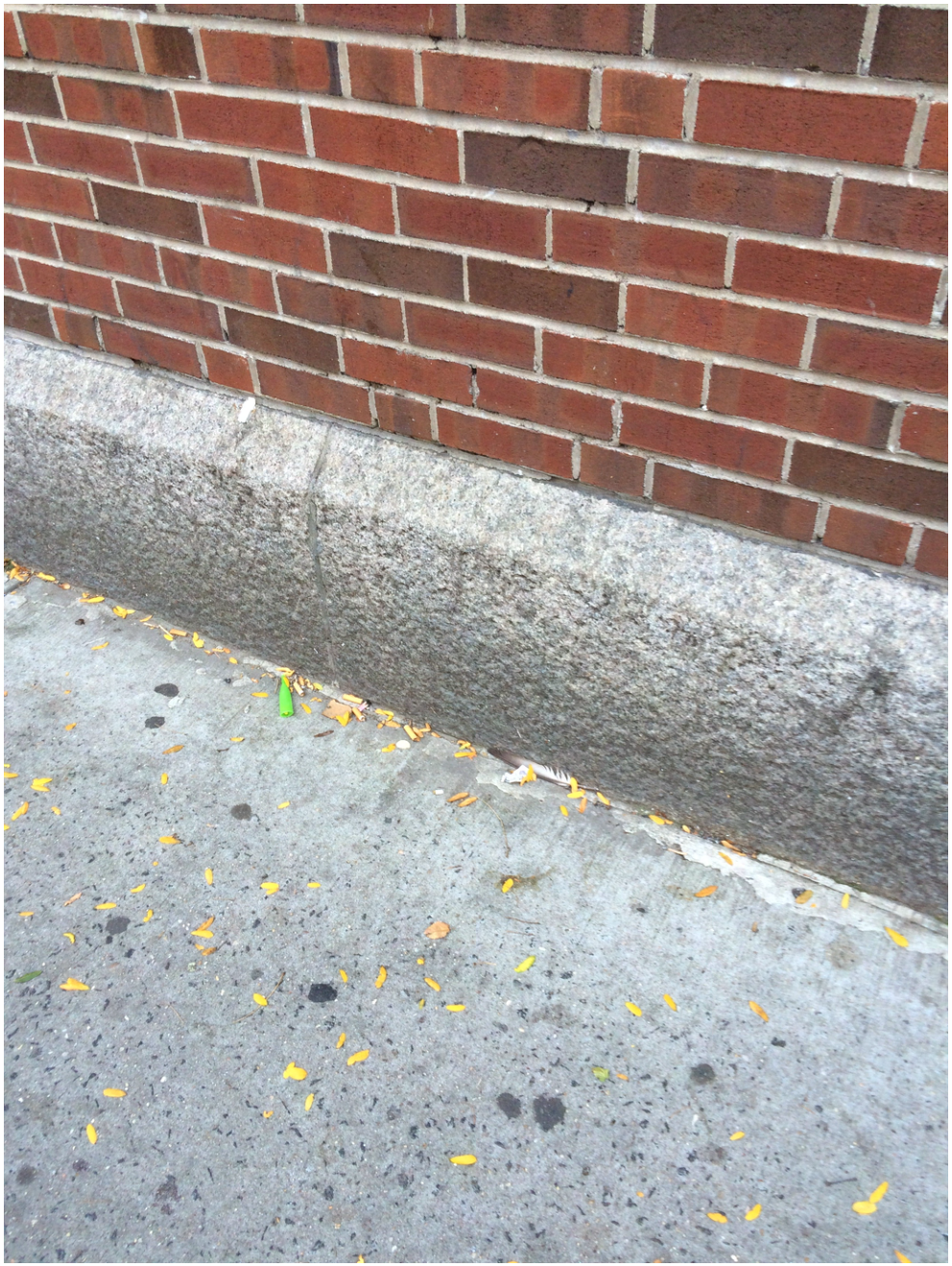
























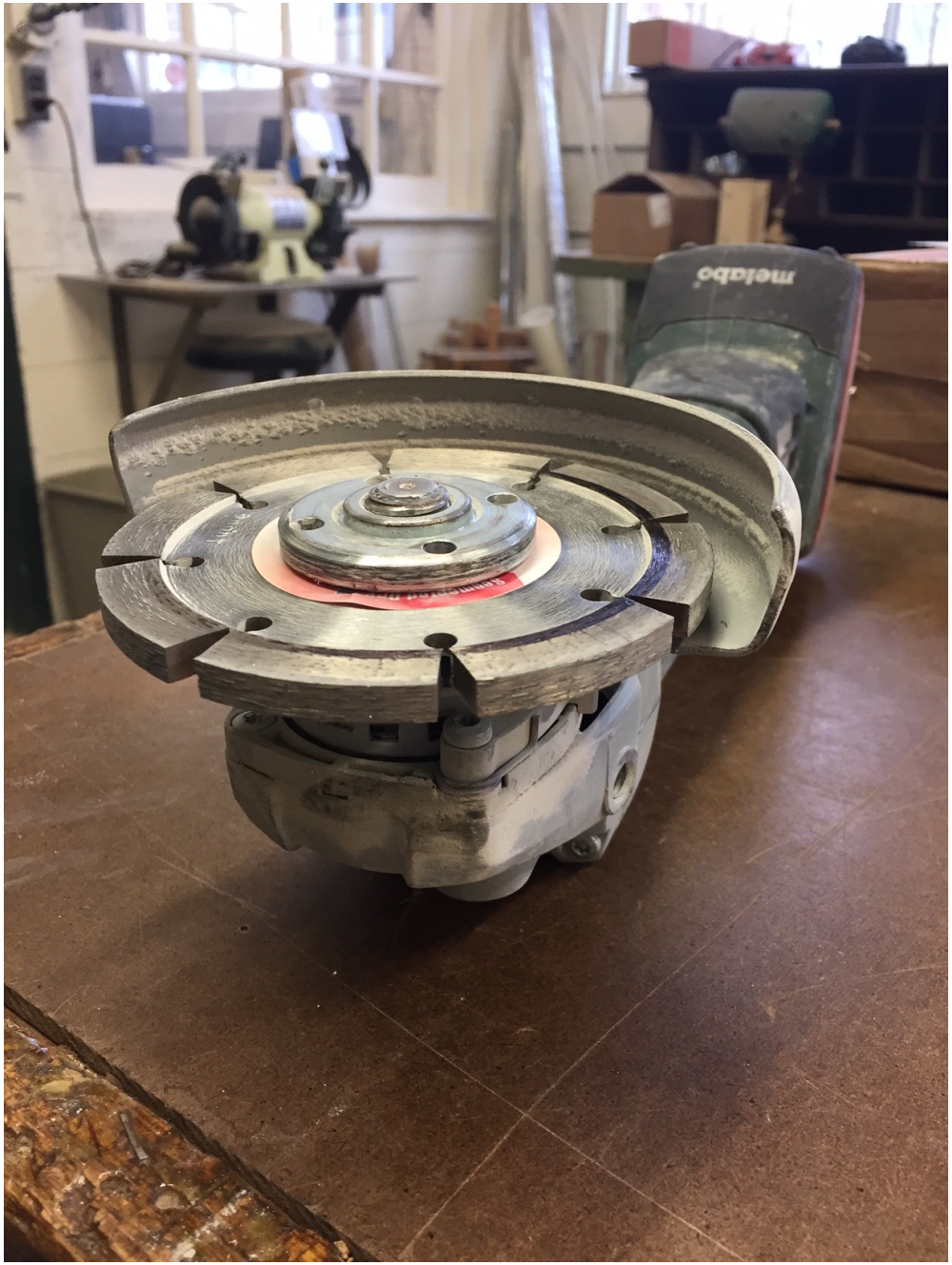


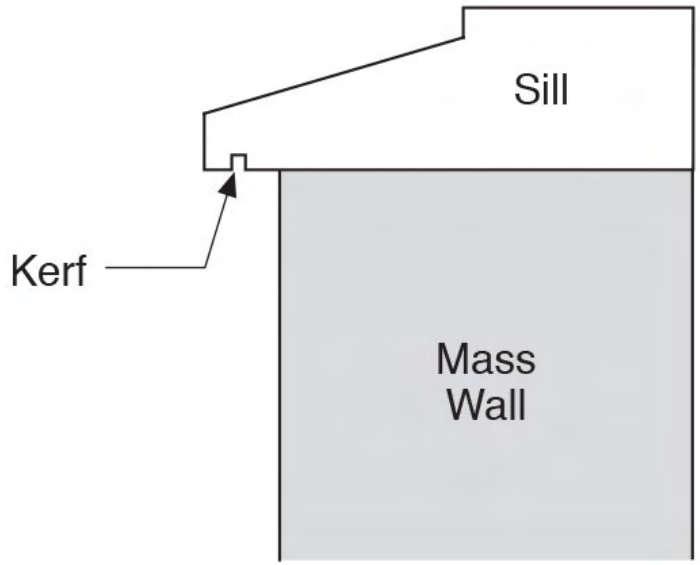


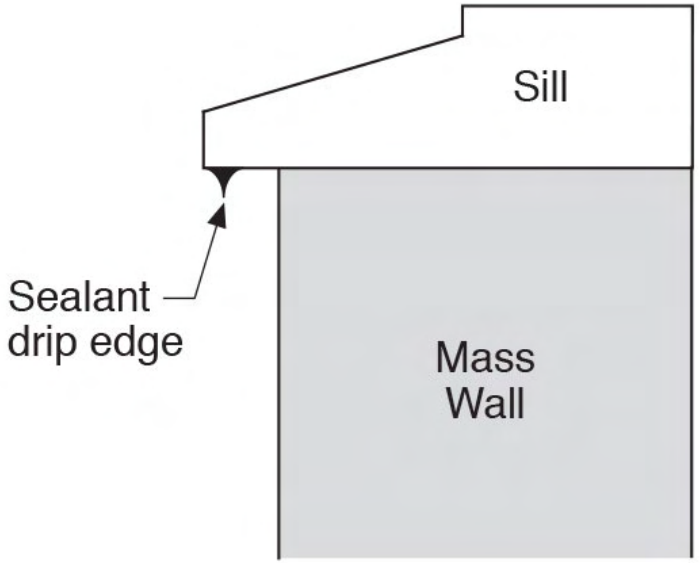




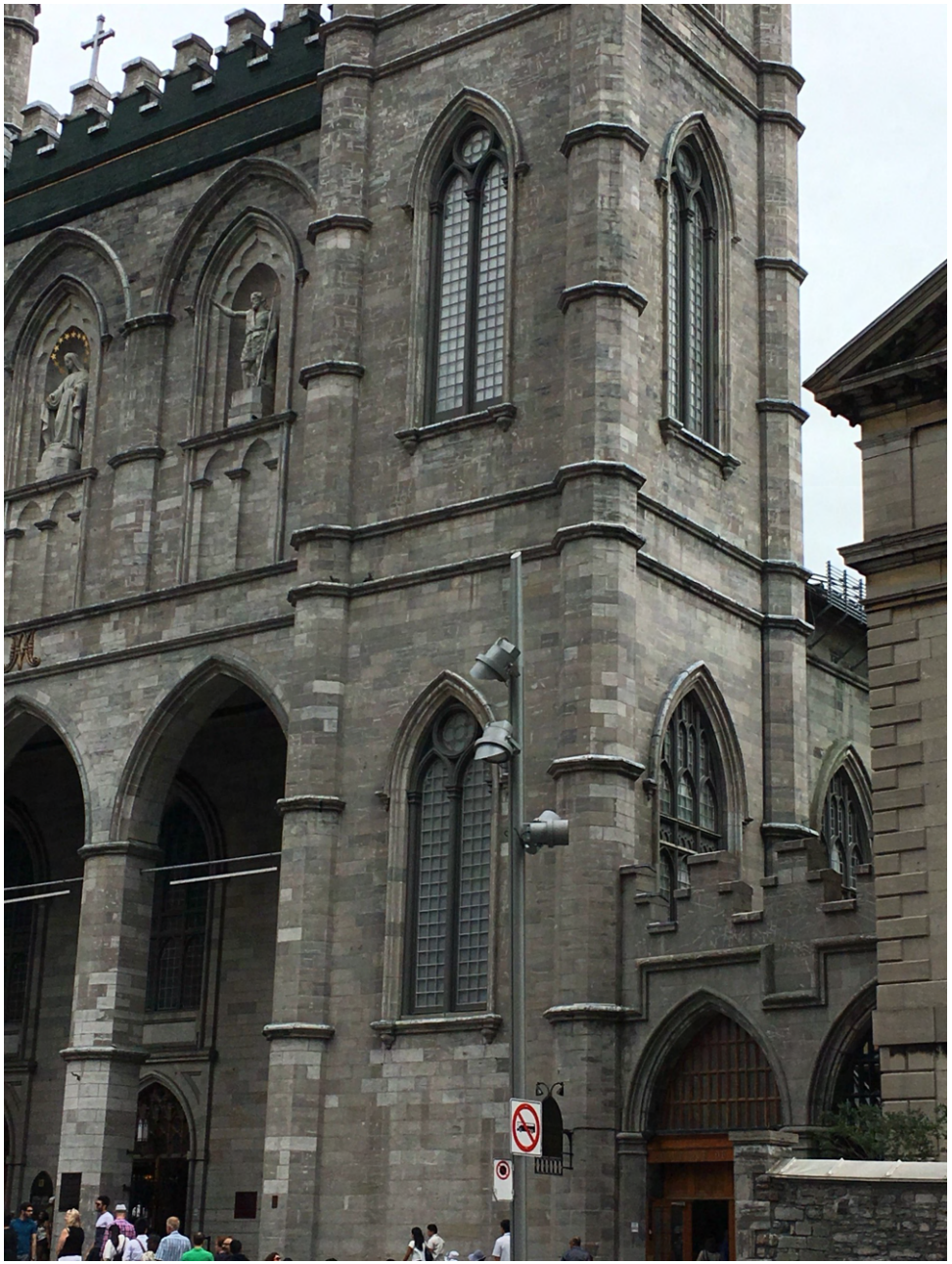



metabo


Sill
Kerf
Mass
Wall


Sill
Sealant
drip edge
Mass
Wall

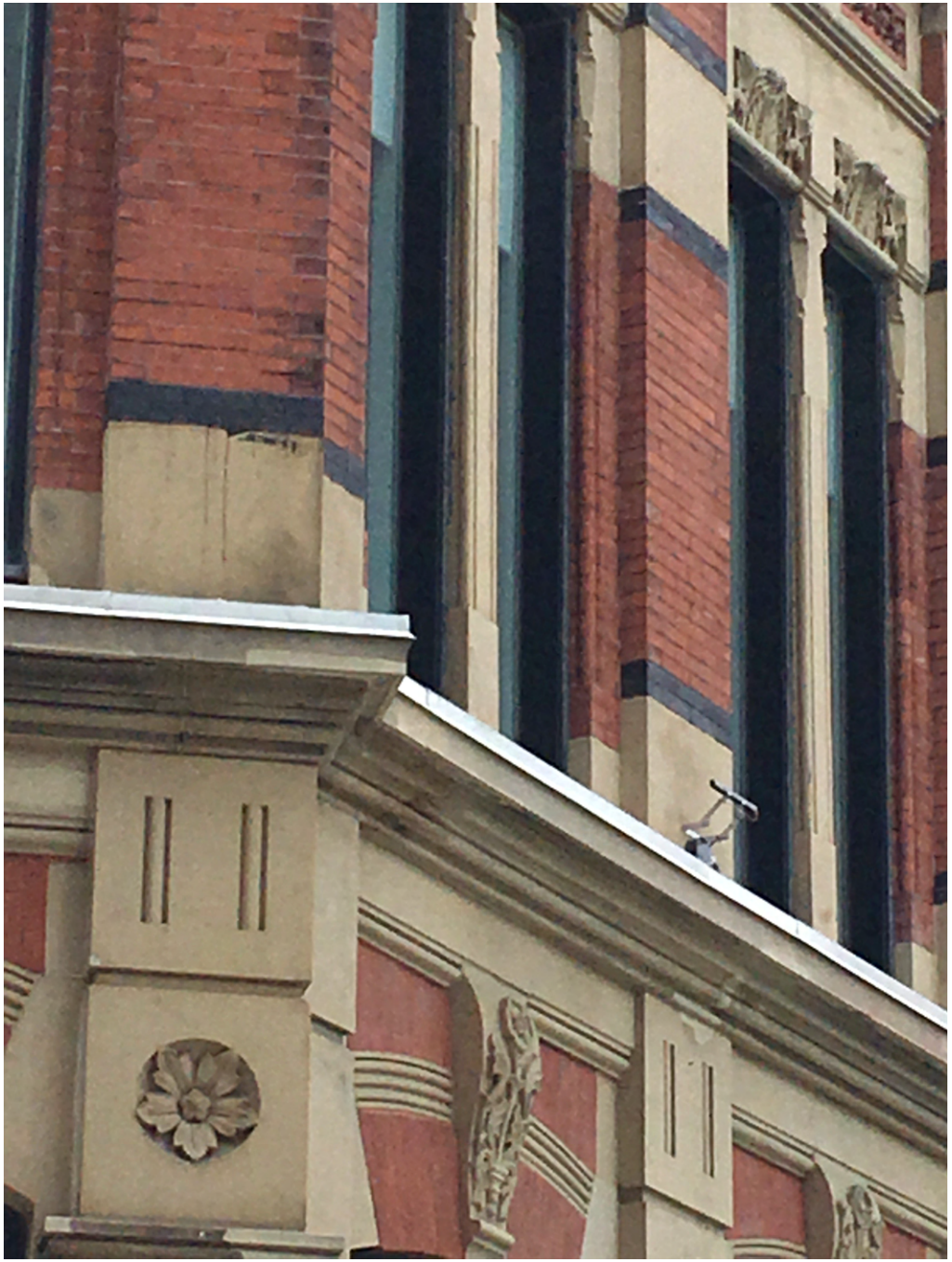









486



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Quatre personnages
Un hôtel... Un désir
418
Crown 44




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Saint-Dizier
6h30-7h30
LUNDI
JEUDI

















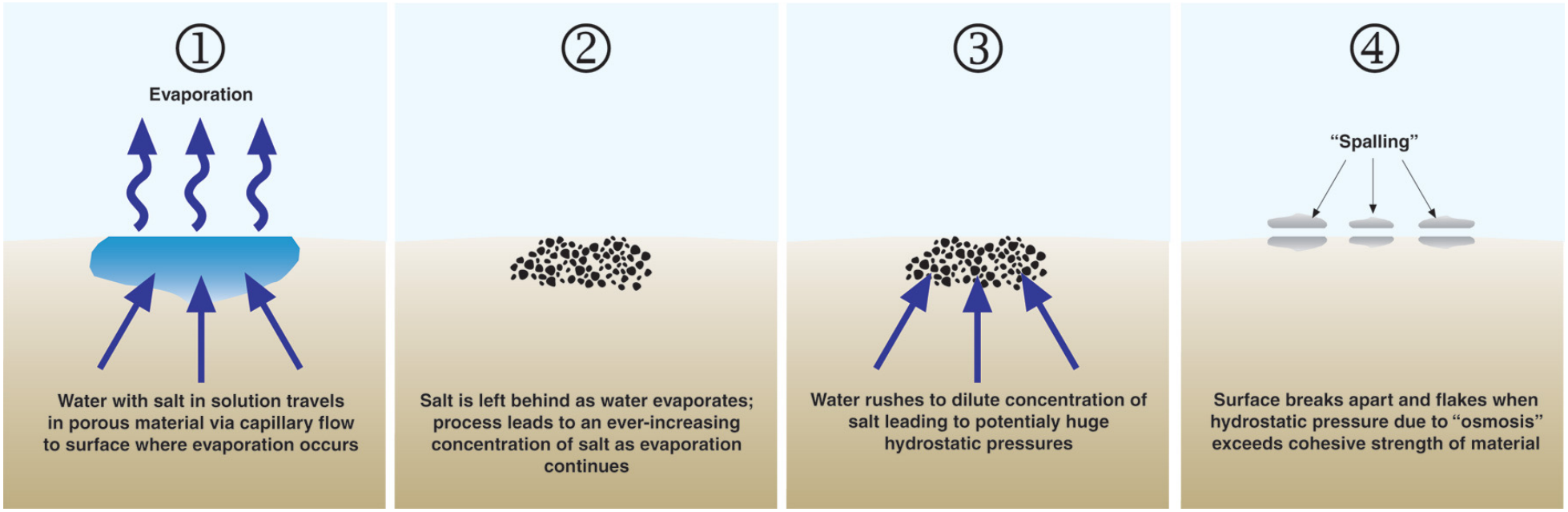










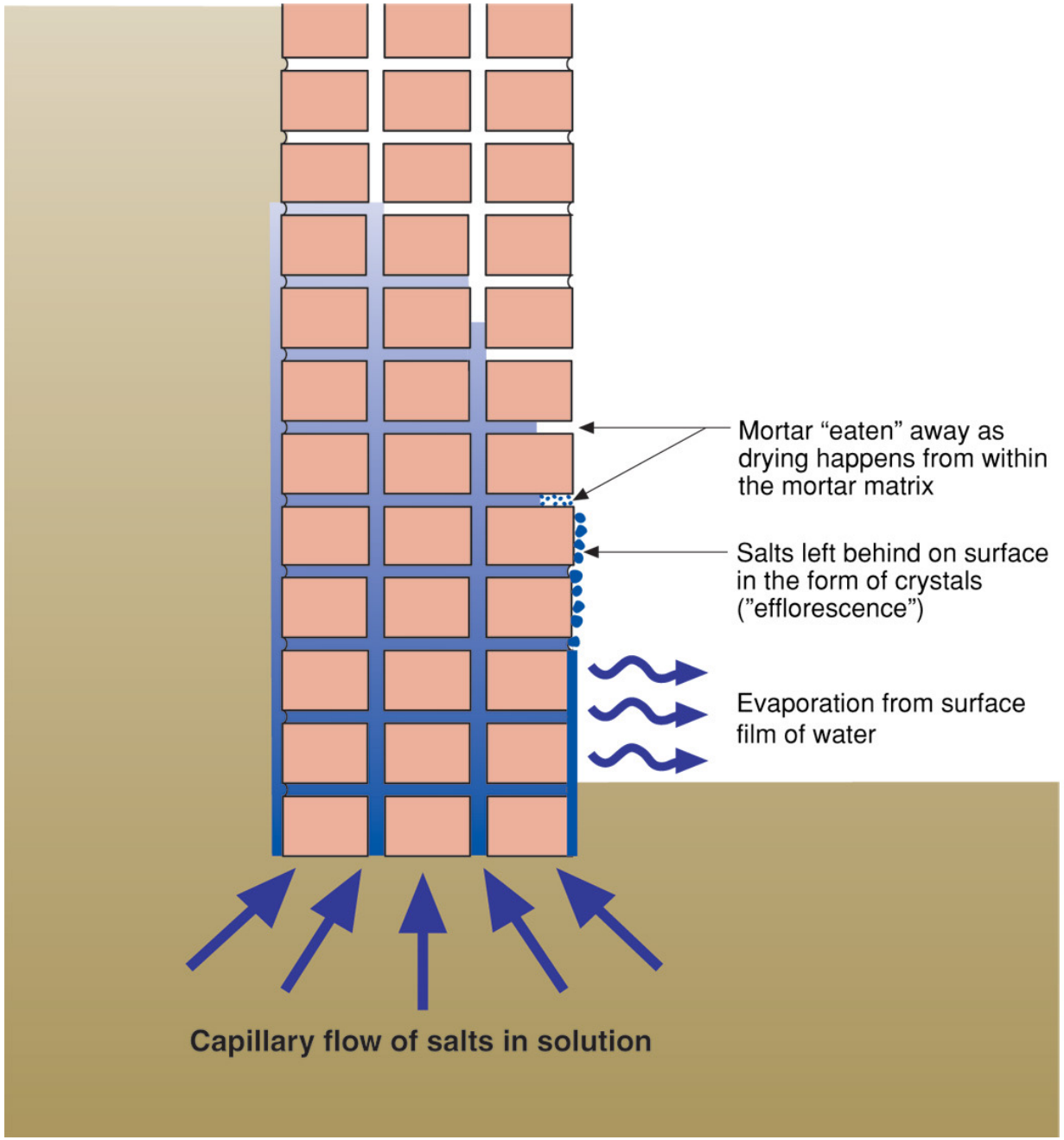

①
Evaporation
Water with salt in solution travels in porous material via capillary flow to surface where evaporation occurs
②
Salt is left behind as water evaporates; process leads to an ever-increasing concentration of salt as evaporation continues
③
Water rushes to dilute concentration of salt leading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

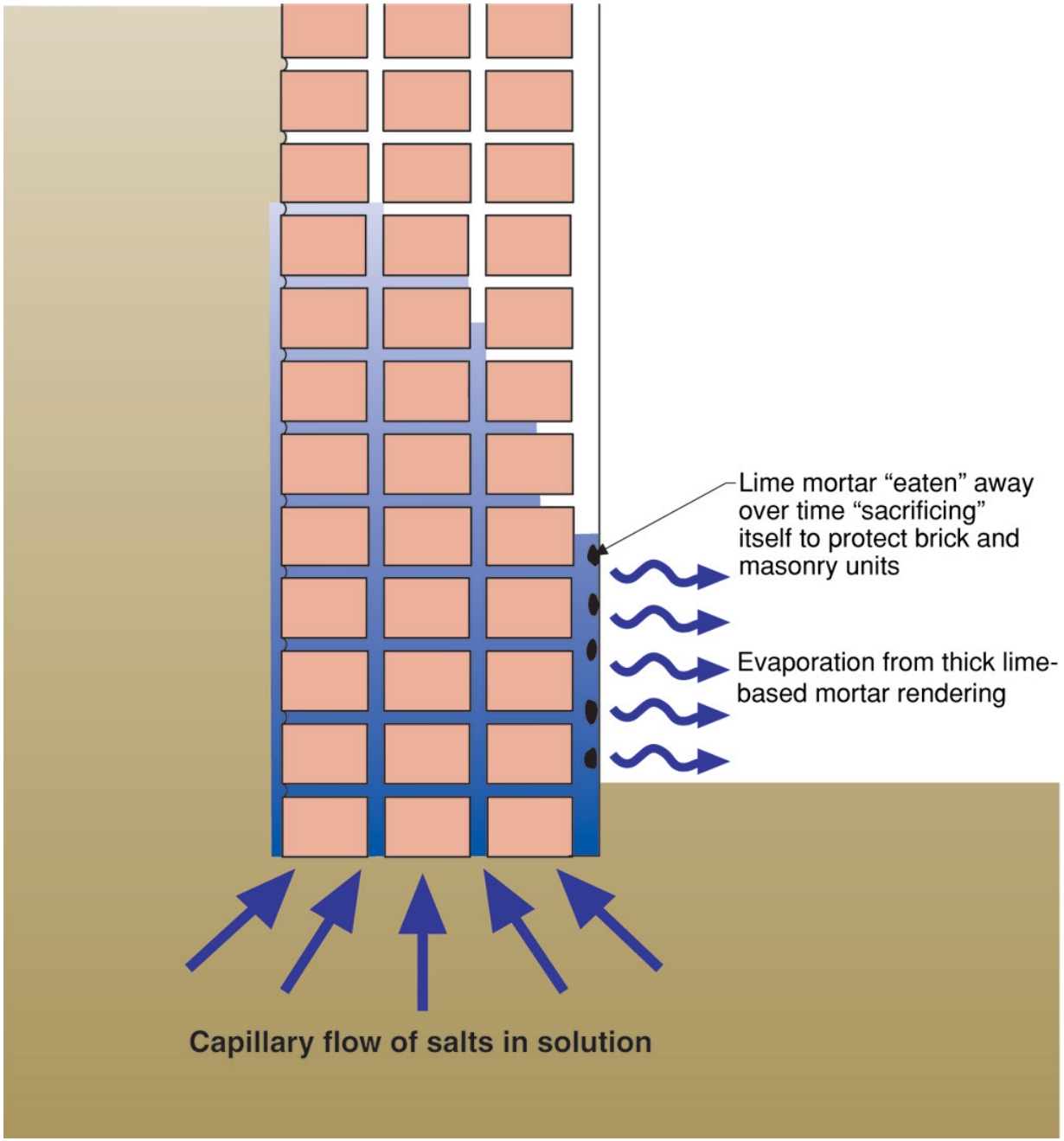
Diffusion + Capillarity + Osmosis = Problem

- 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
RA 200
RA 200

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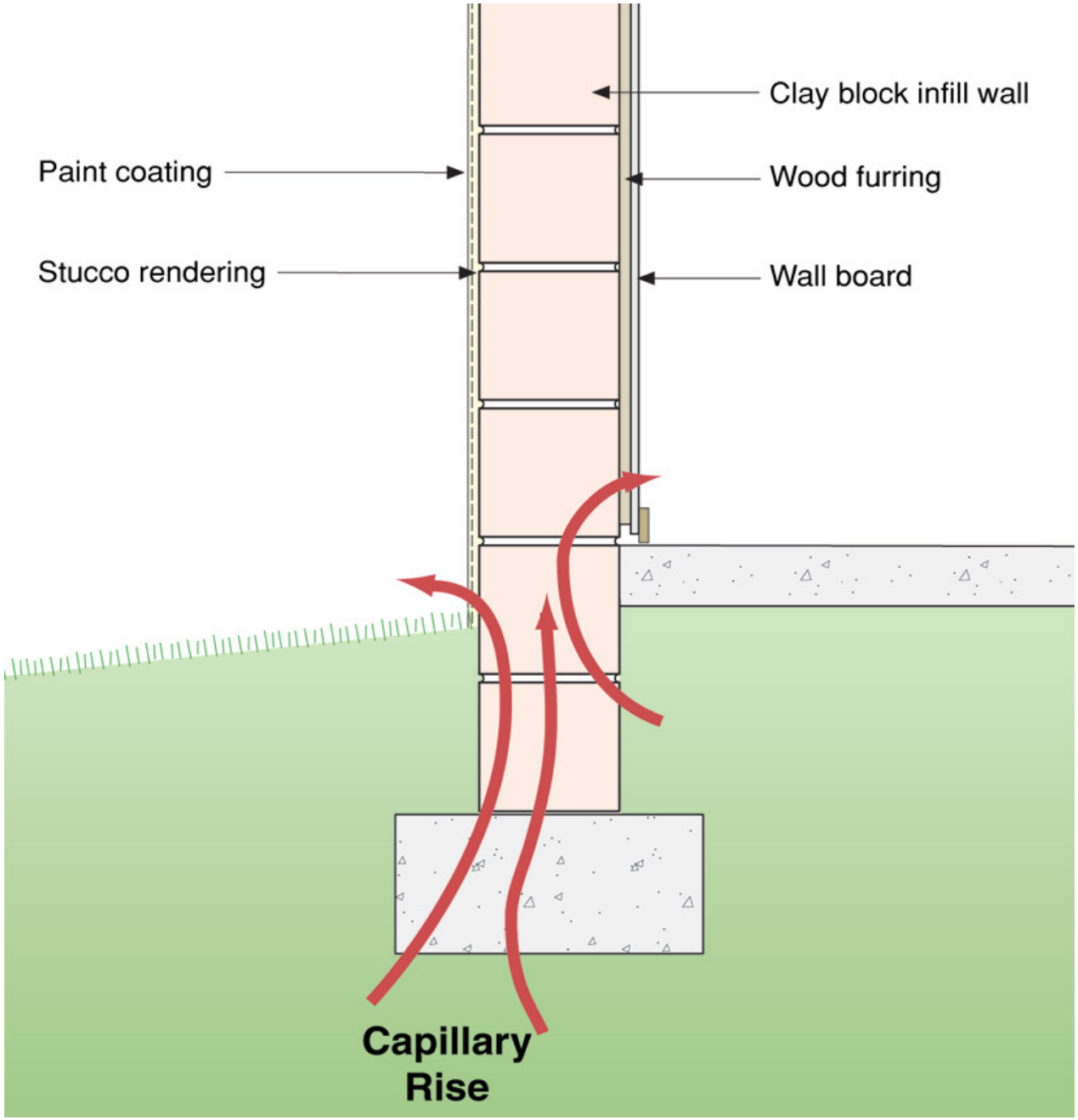
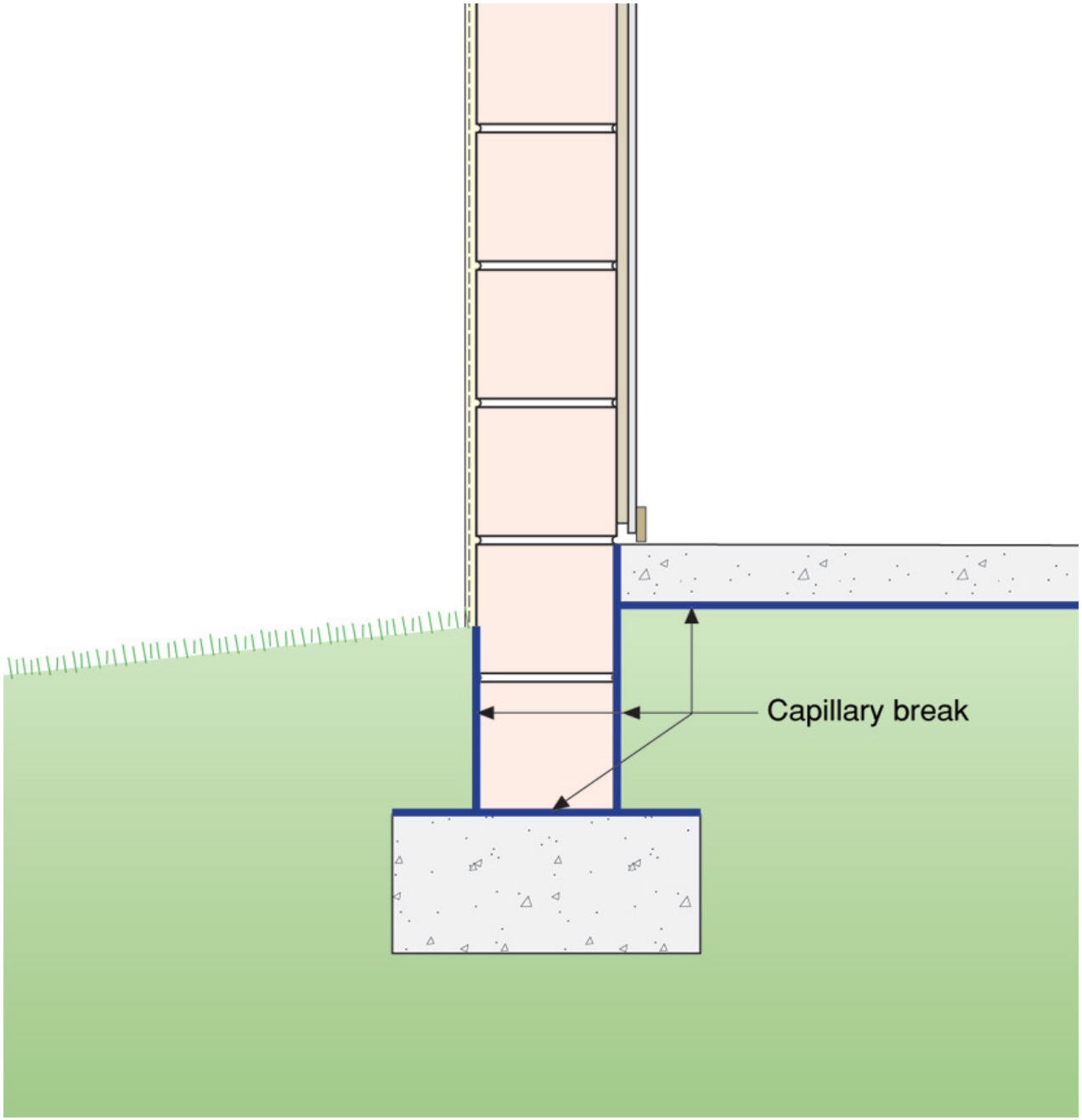
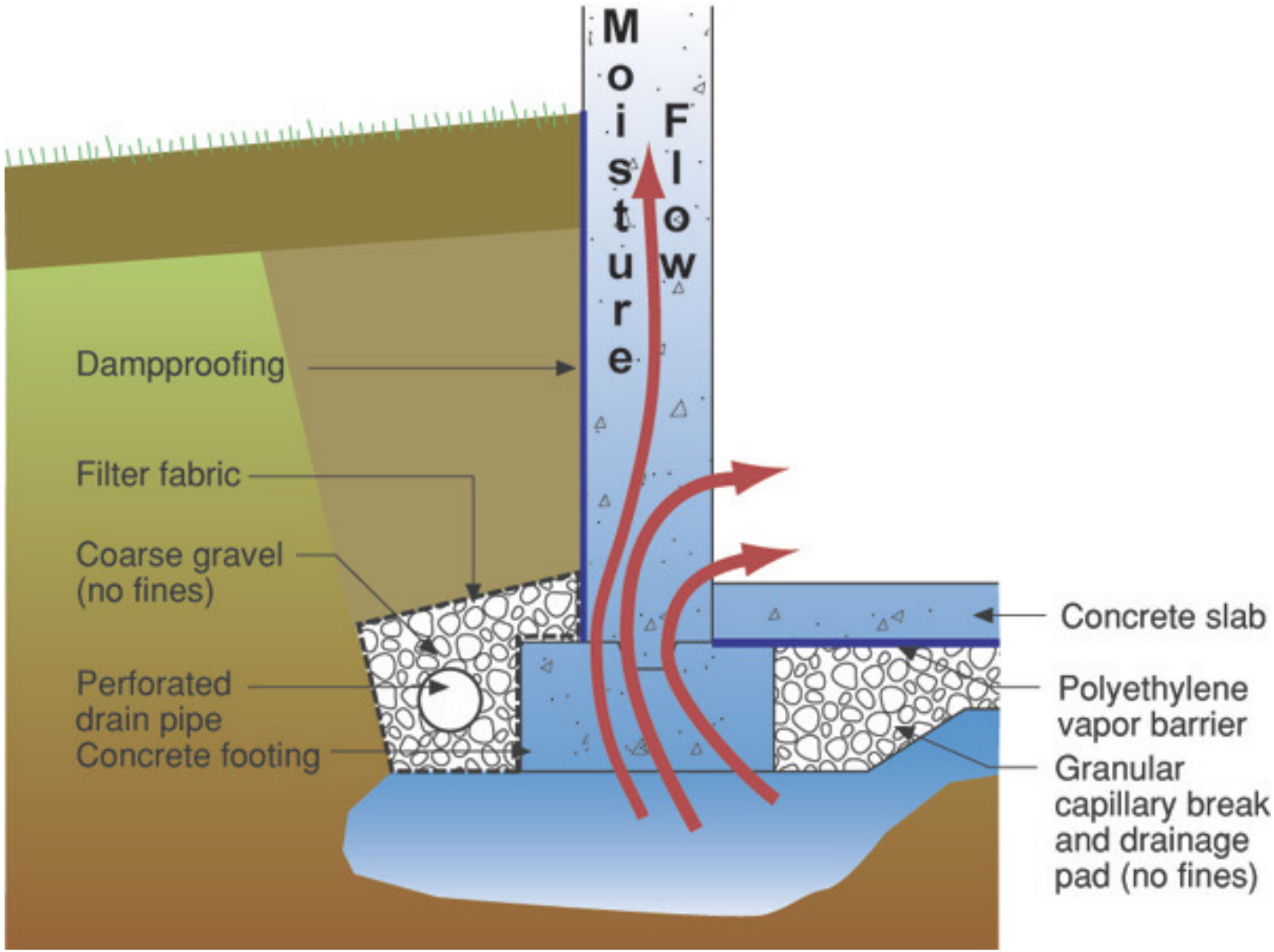
e-mail panekkamen@atlas.cz, www.panek-kamen.cz

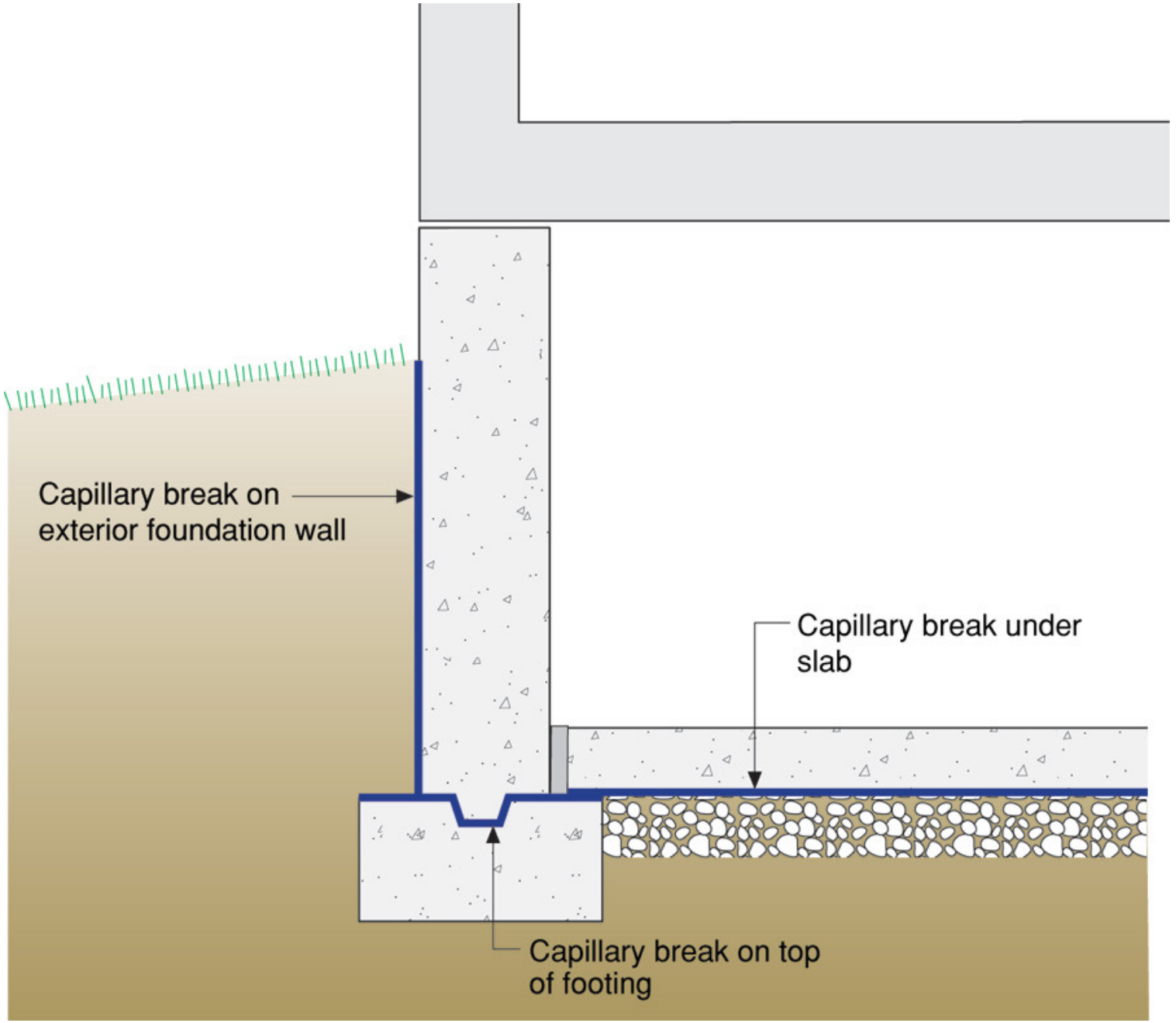



Clay block infill wall
Paint coating
Wood furring
Stucco rendering
Wall board
Capillary
Rise


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

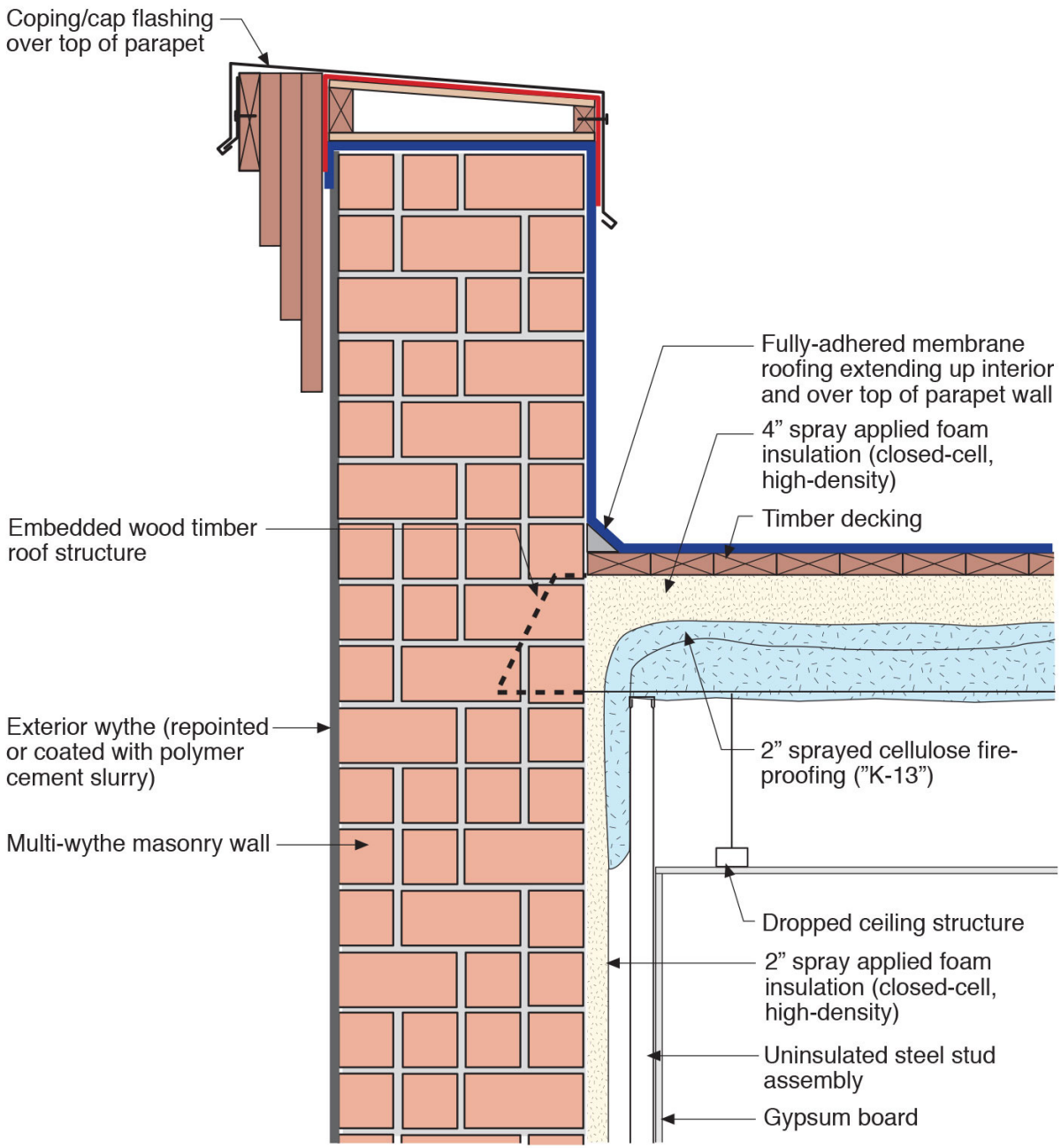






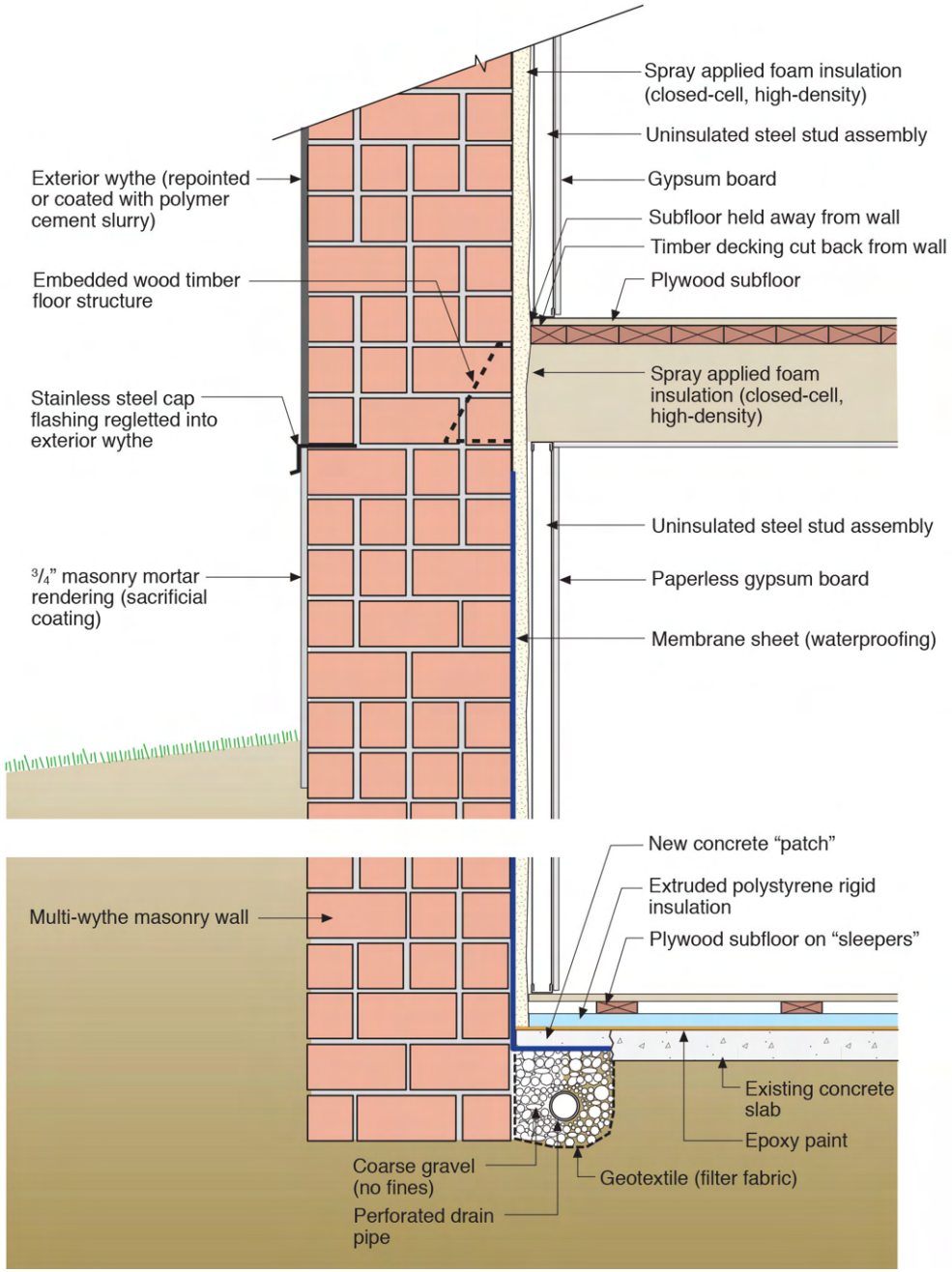


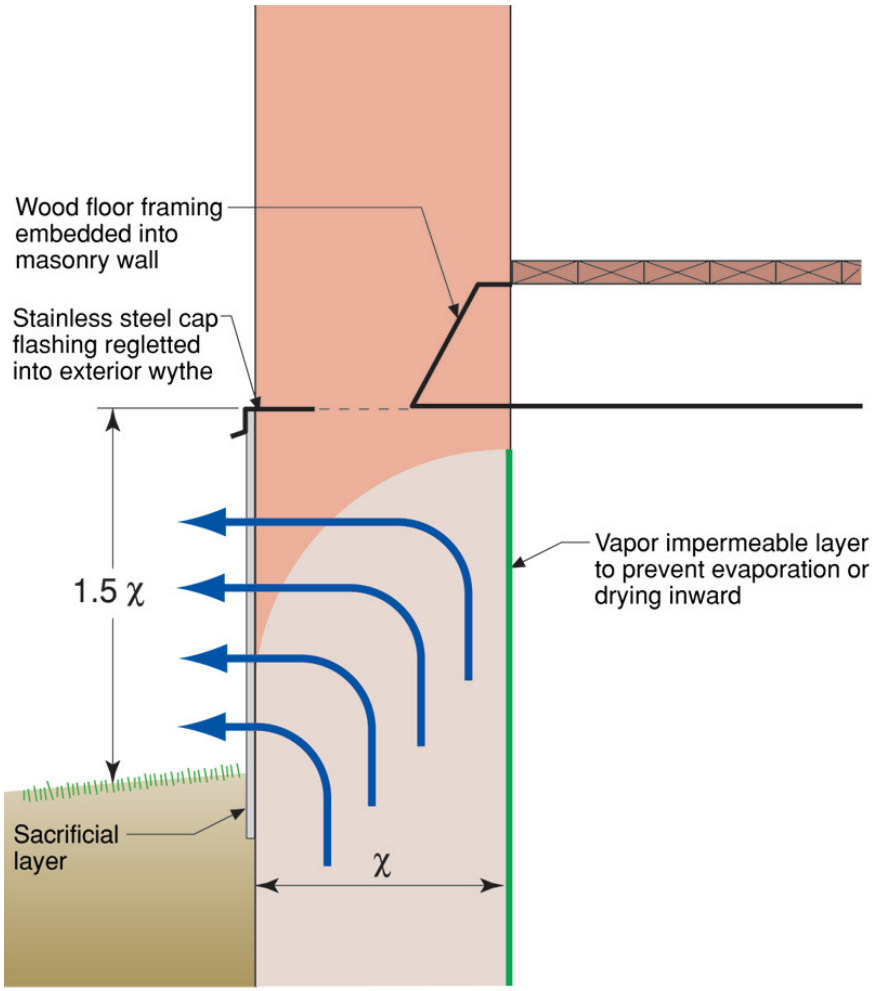

WEST SIDE VILLAGE
113 North 13th Street
An RPM Managed Community
113

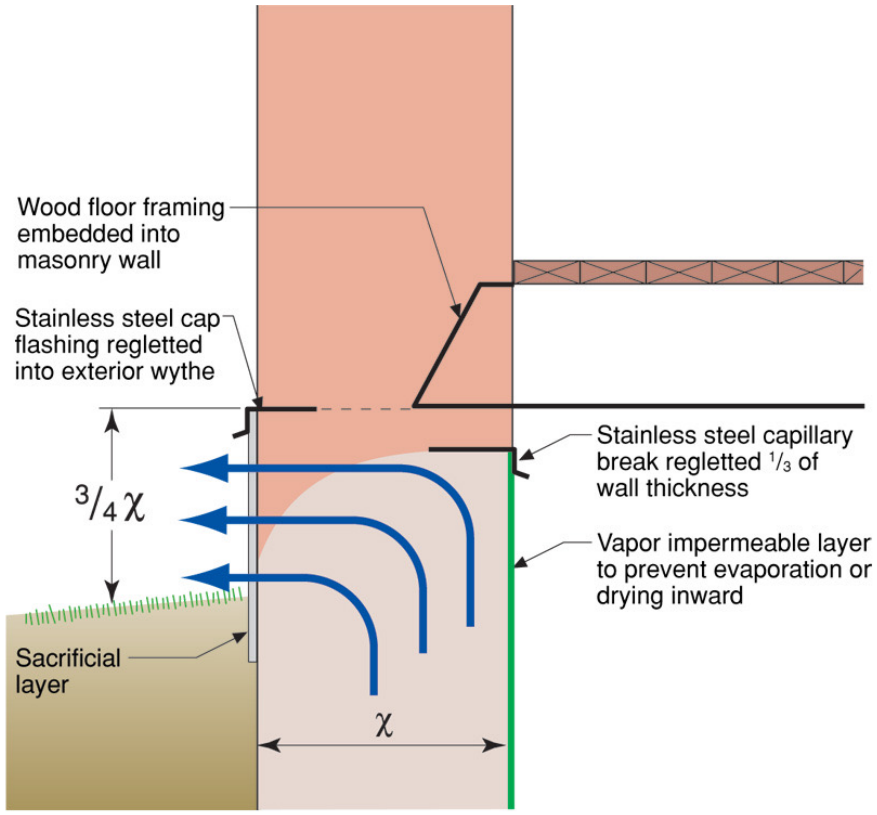

Coping/cap flashing over top of parapet
Fully-adhered membrane roofing extending up interior and over top of parapet wall
4” spray applied foam insulation (closed-cell, high-density)
Timber decking
Embedded wood timber roof structure
Exterior wythe (repointed or coated with polymer cement slurry)
Multi-wythe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

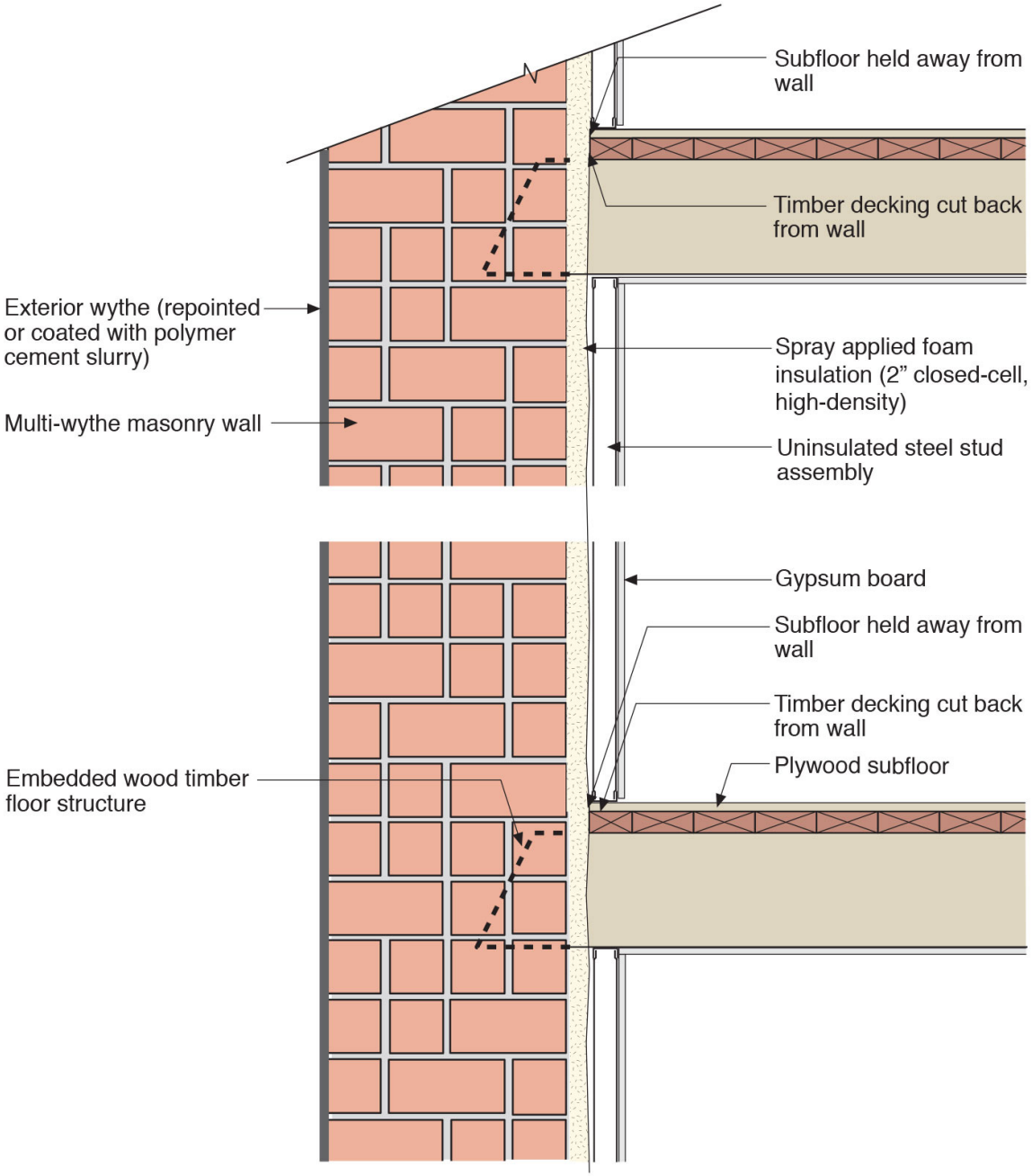


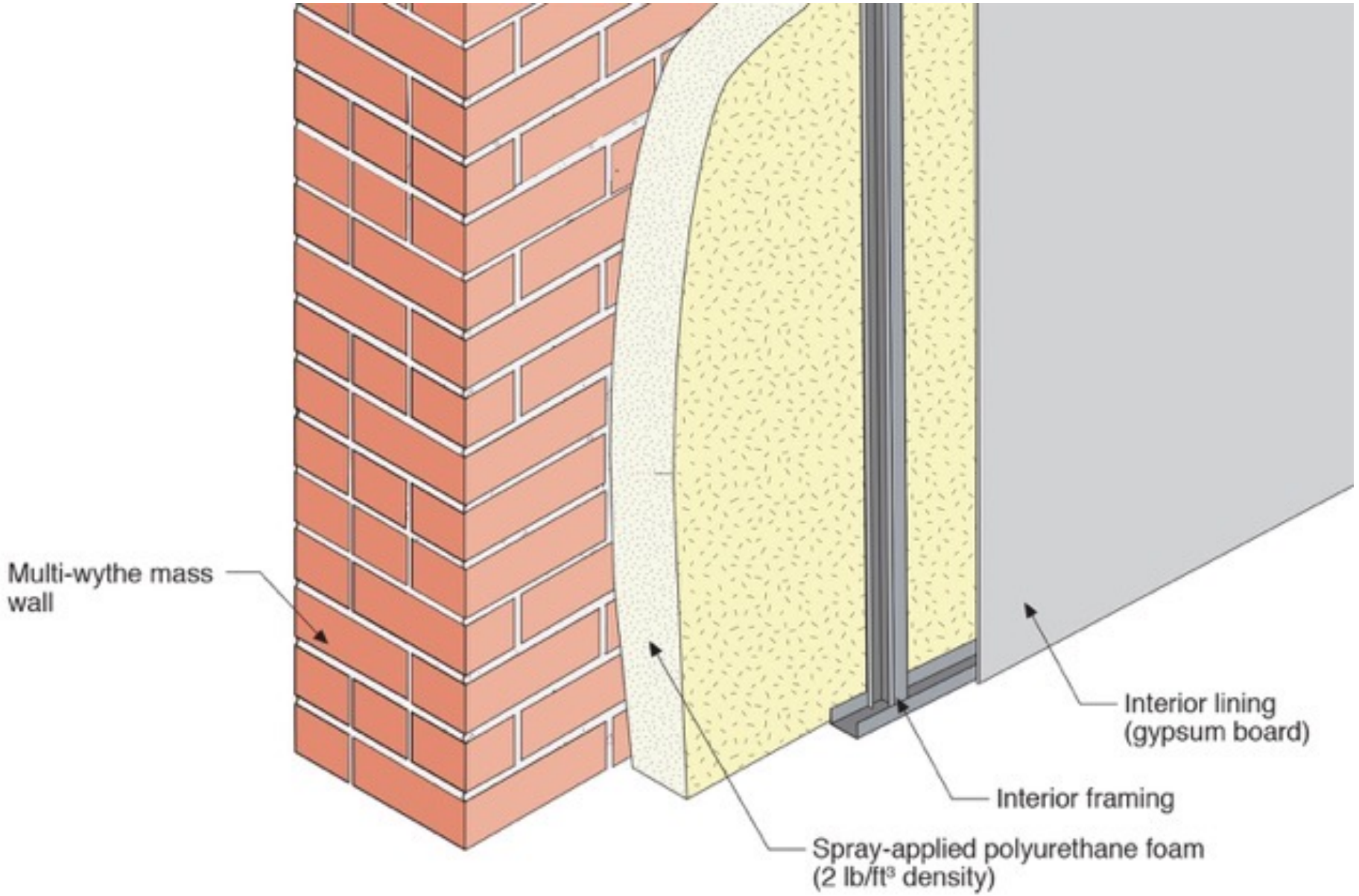


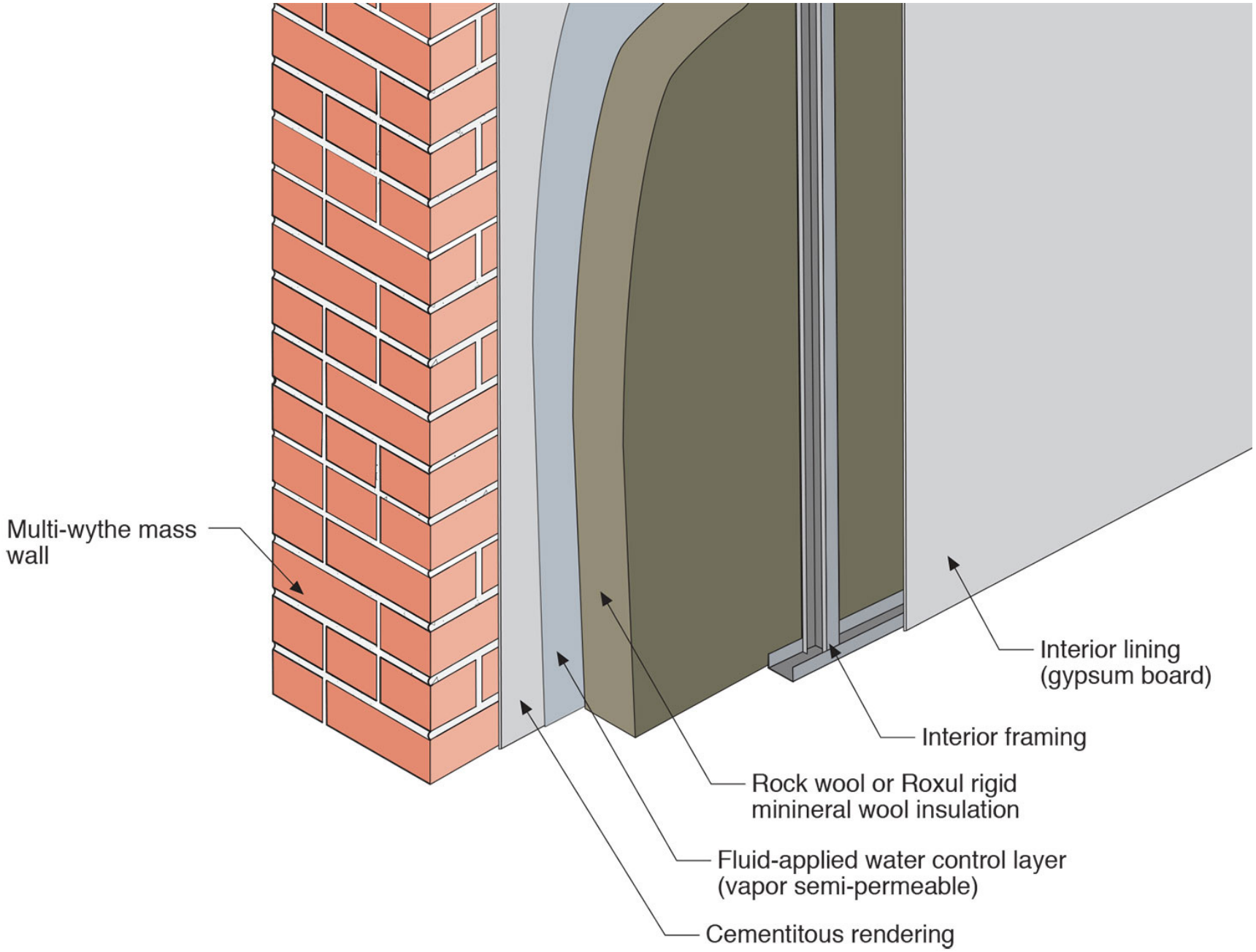

Spray applied foam insulation (closed-cell, high-density)
Uninsulated steel stud assembly
Gypsum board
Subfloor held away from wall
Timber decking cut back from wall
Plywood subfloor
Exterior wythe (repointed or coated with polymer cement slurry)
Embedded wood timber floor structure
Stainless steel cap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

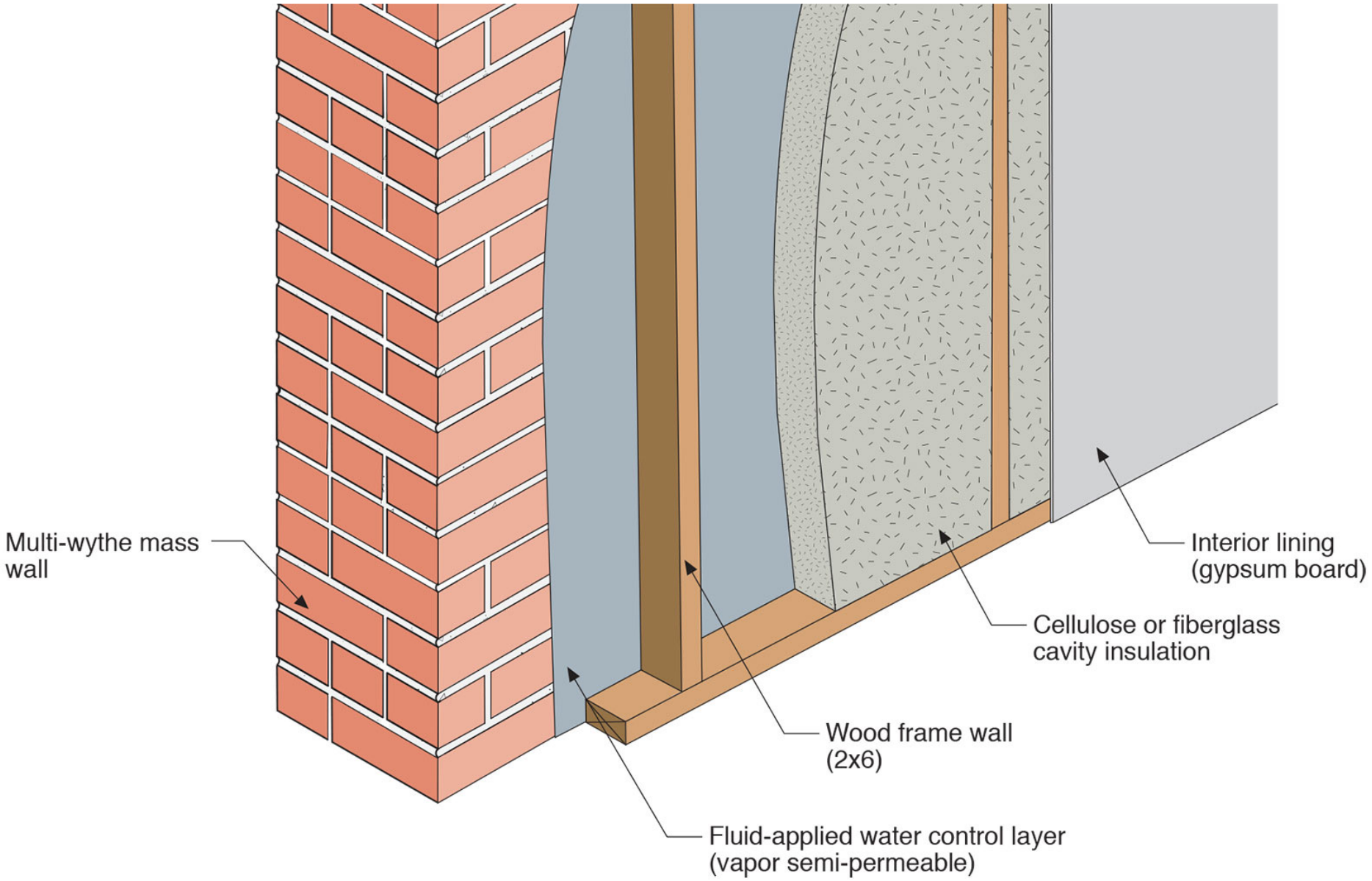

Wood floor framing embedded into masonry wall
Stainless steel cap flashing regletted into exterior wythe
1.5 χ
Vapor impermeable layer to prevent evaporation or drying inward
Sacrificial layer
χ

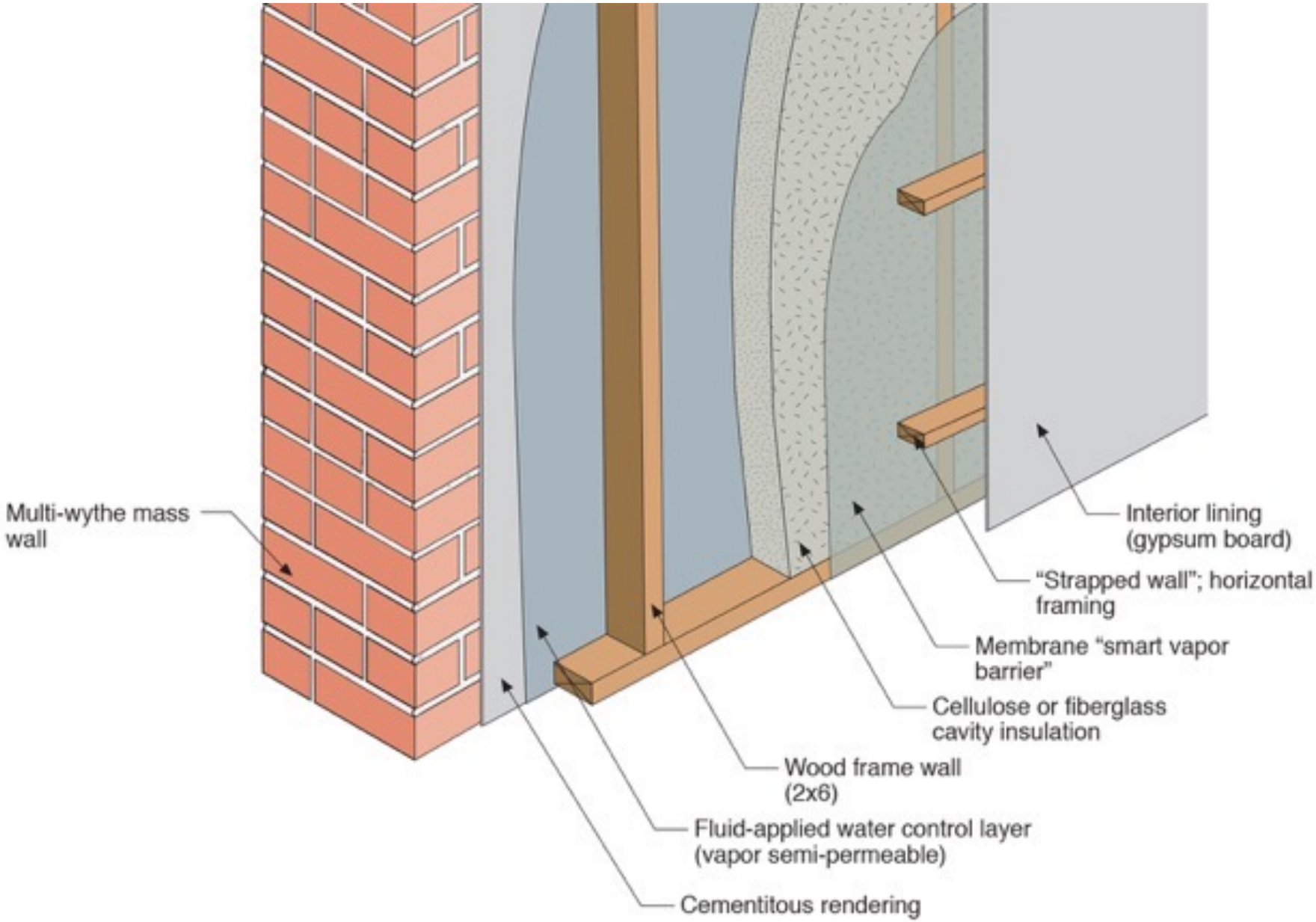

Wood floor framing embedded into masonry wall
Stainless steel cap flashing regletted into exterior wythe
Stainless steel capillary break regletted 1/3 of wall thickness
3/4 χ
Vapor impermeable layer to prevent evaporation or drying inward
Sacrificial layer
χ

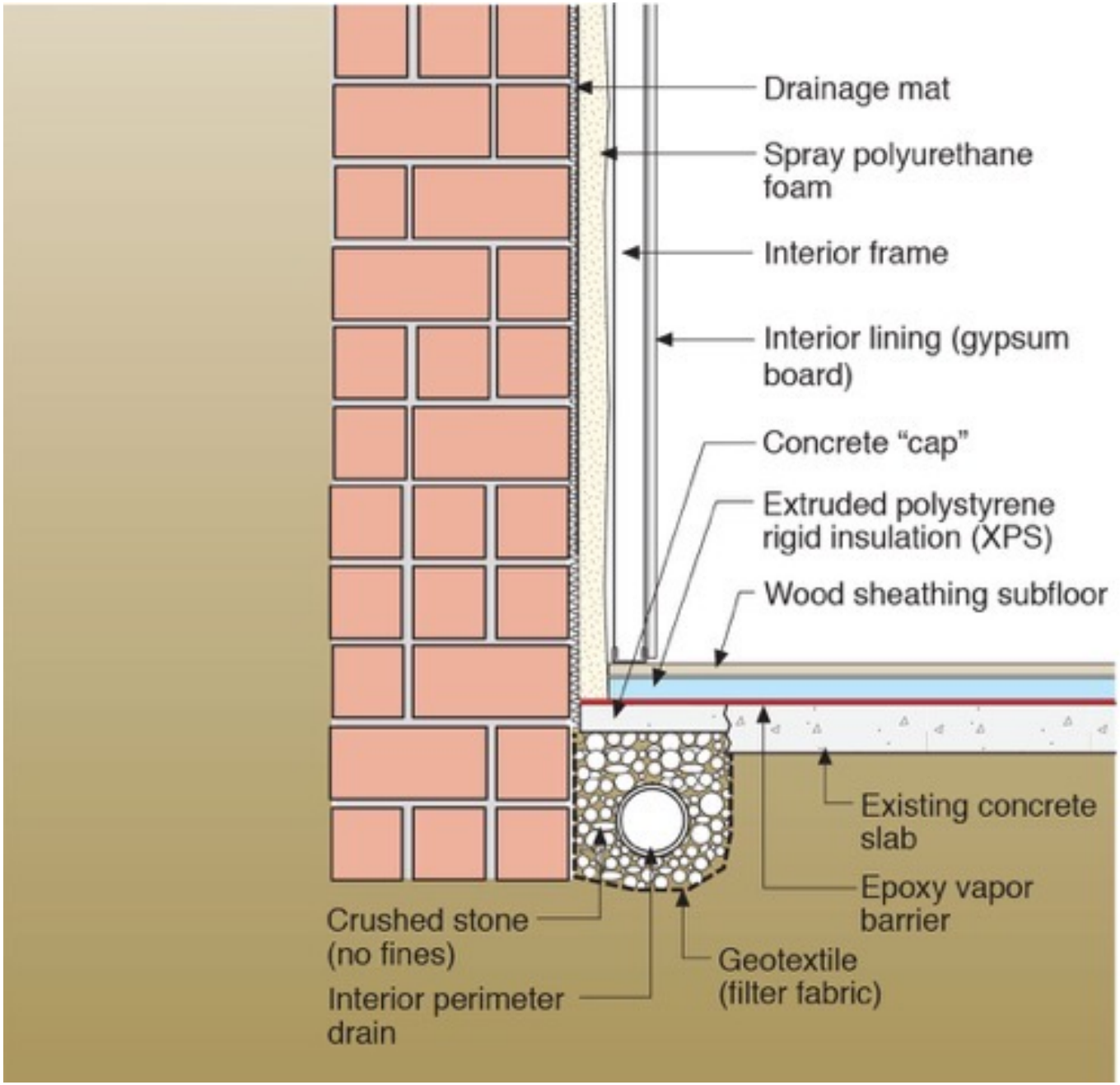

Subfloor held away from wall
Timber decking cut back from wall
Exterior wythe (repointed or coated with polymer cement slurry)
Spray applied foam insulation (2” closed-cell, high-density)
Multi-wythe masonry wall
Uninsulated steel stud assembly
Gypsum board
Subfloor held away from wall
Timber decking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

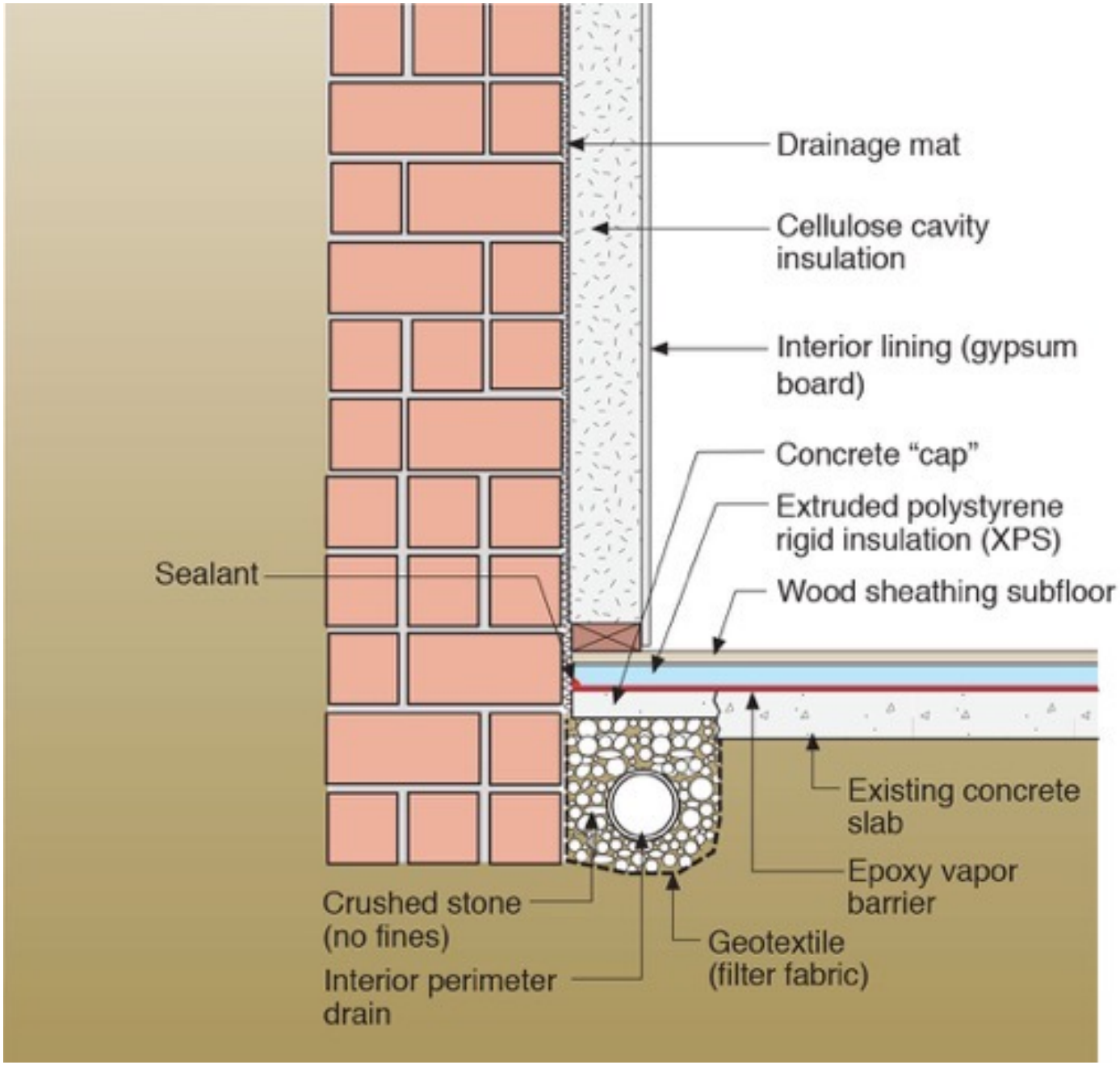

Multi-wythe mass wall
Interior lining (gypsum board)
Interior framing
Spray-applied polyurethane foam (2 lb/ft³ density)

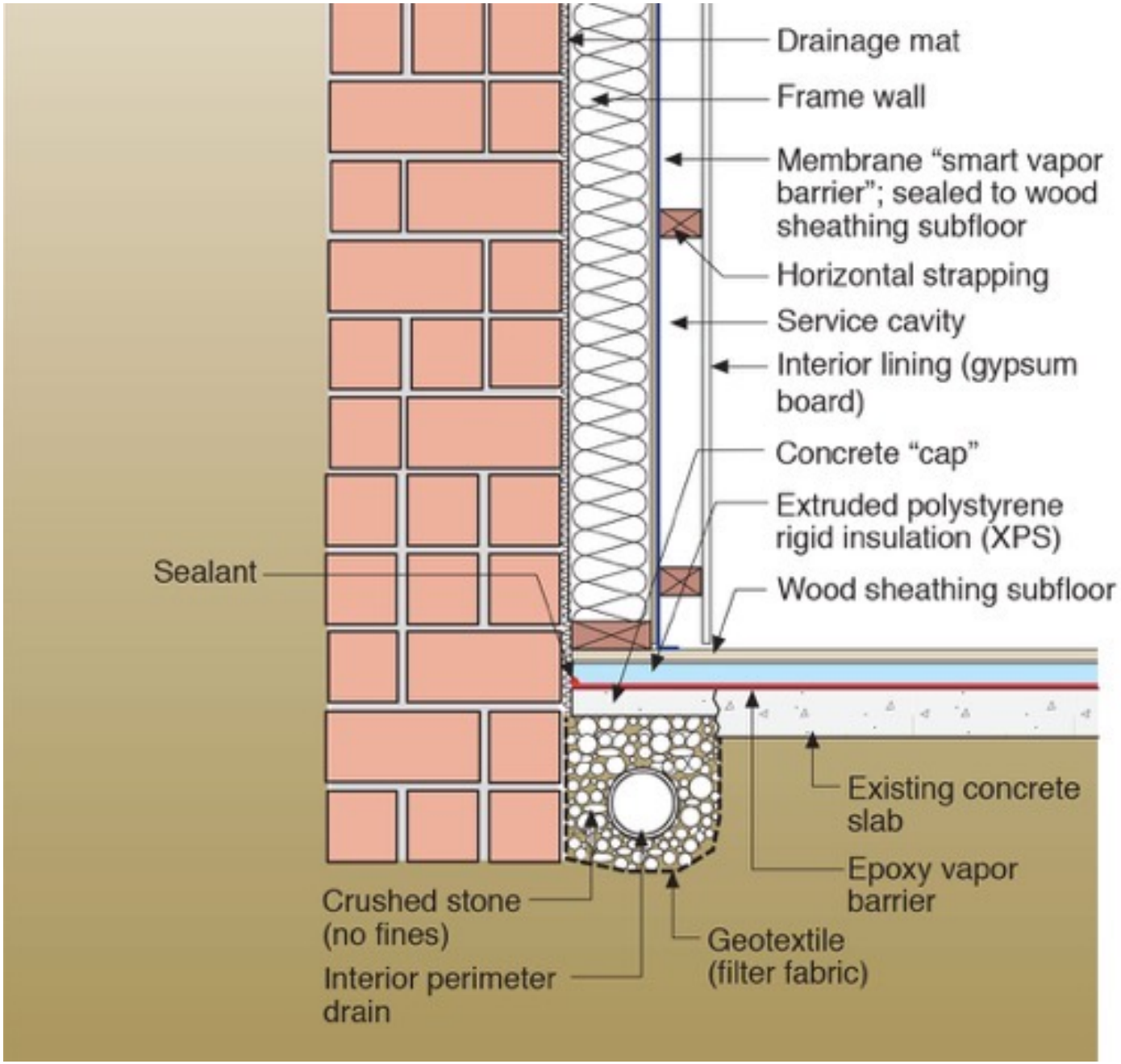

Multi-wythe mass wall
Interior lining (gypsum board)
Interior framing
Rock wool or Roxul rigid minineral wool insulation
Fluid-applied water control layer (vapor semi-permeable)
Cementitous rendering


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)

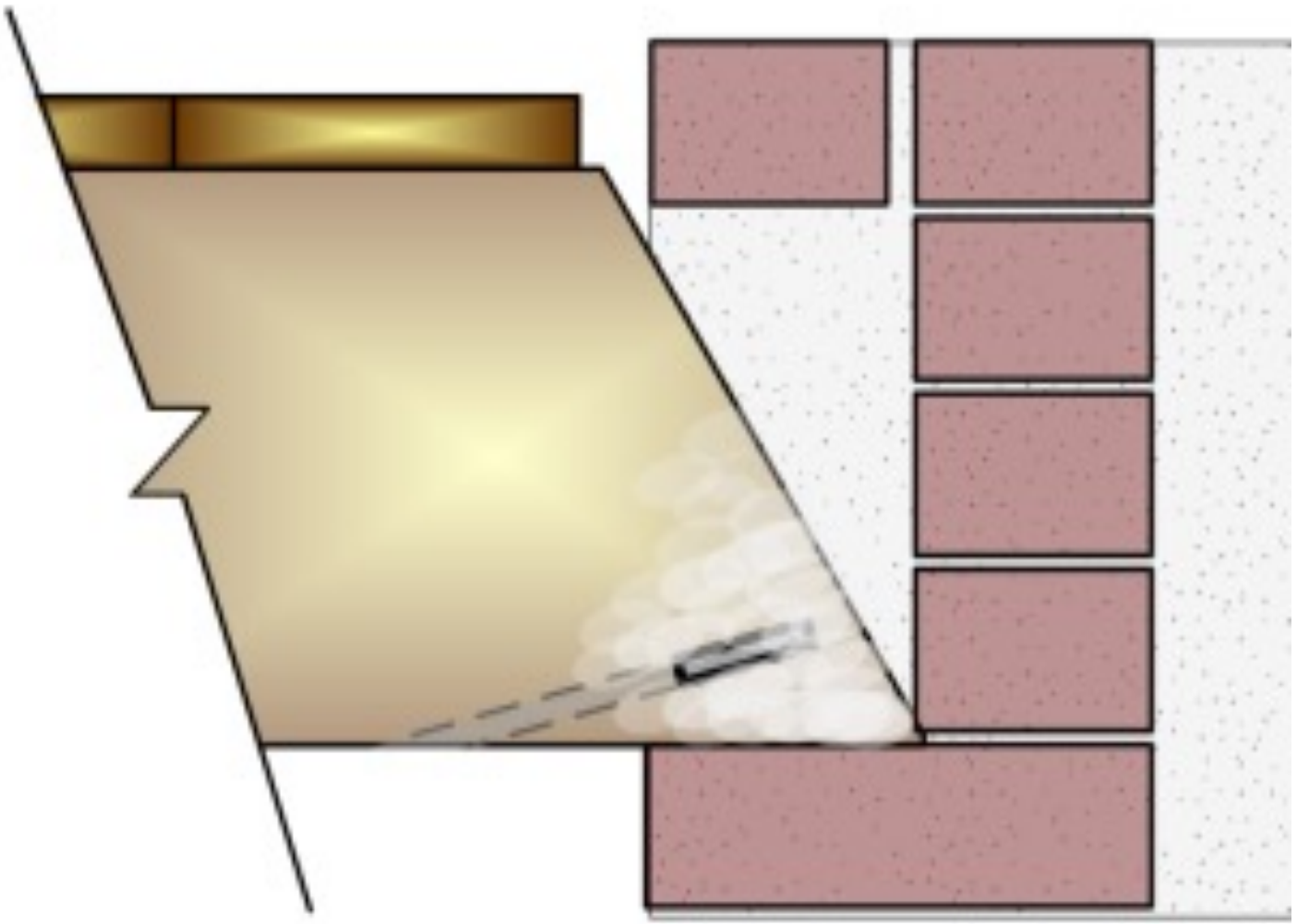

Multi-wythe mass wall
Interior lining (gypsum board)
"Strapped wall"; horizontal framing
Membrane "smart vapor barrier"
Cellulose or fiberglass cavity insulation
Wood frame wall (2x6)
Fluid-applied water control layer (vapor semi-permeable)
Cementitous rendering


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
Geotextile (filter fabric)
Crushed stone (no fines)
Interior perimeter drain


Drainage mat
Cellulose cavity insulation
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)
Interior perimeter drain
Geotextile (filter fabric)

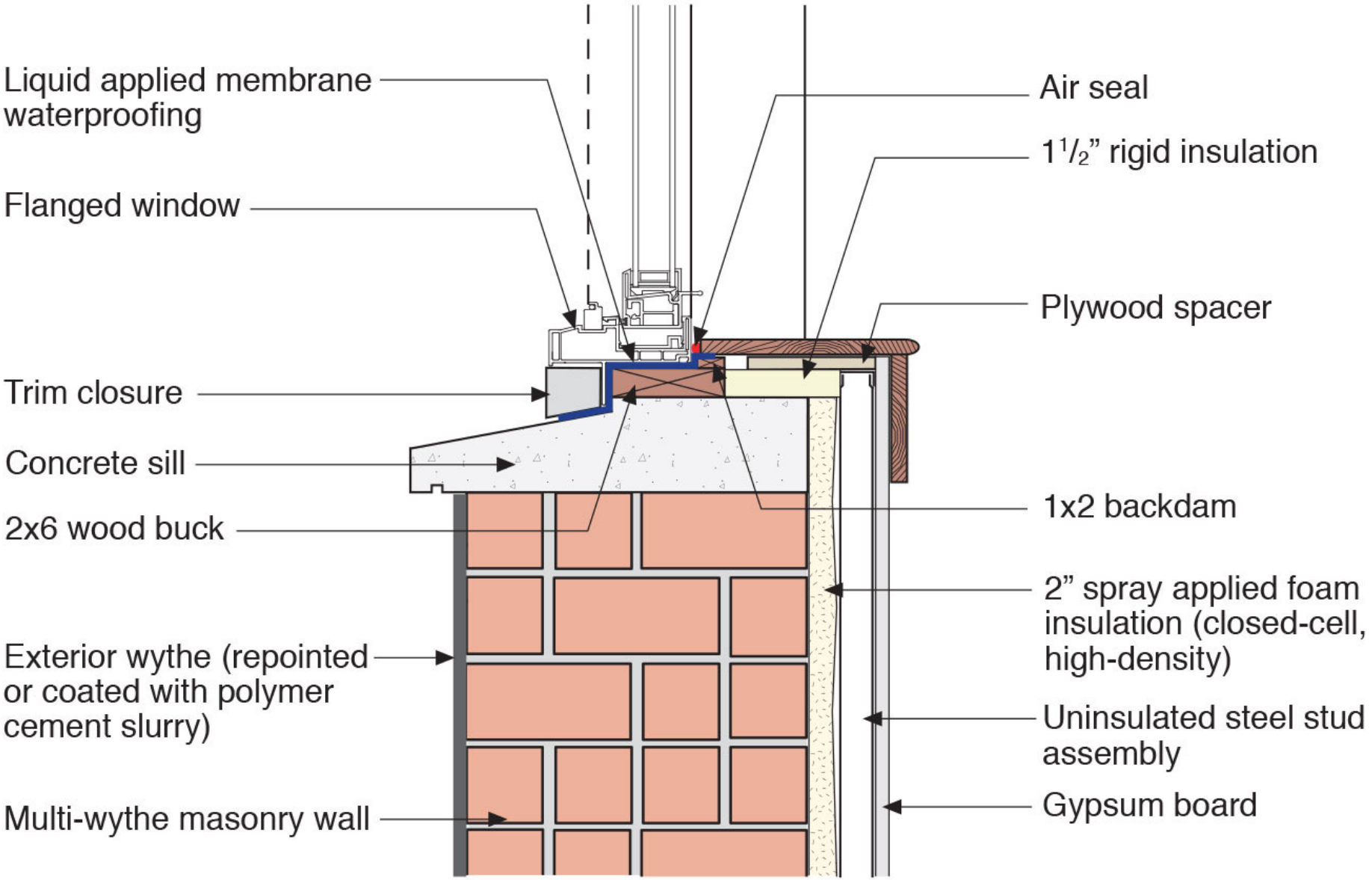

Drainage mat
Frame wall
Membrane “smart vapor barrier”; sealed to wood sheathing subfloor
Horizontal strapping
Service cavity
Interior lining (gypsum board)
Concrete “cap”
Extruded polystyrene rigid insulation (XPS)
Wood sheathing subfloor
Sealant
Existing concrete slab
Epoxy vapor barrier
Crushed stone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










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
1½" rigid insulation
Plywood spacer
1x2 backdam
2" spray applied foam insulation (closed-cell, high-density)
Uninsulated steel stud assembly
Gypsum board

























Stucco

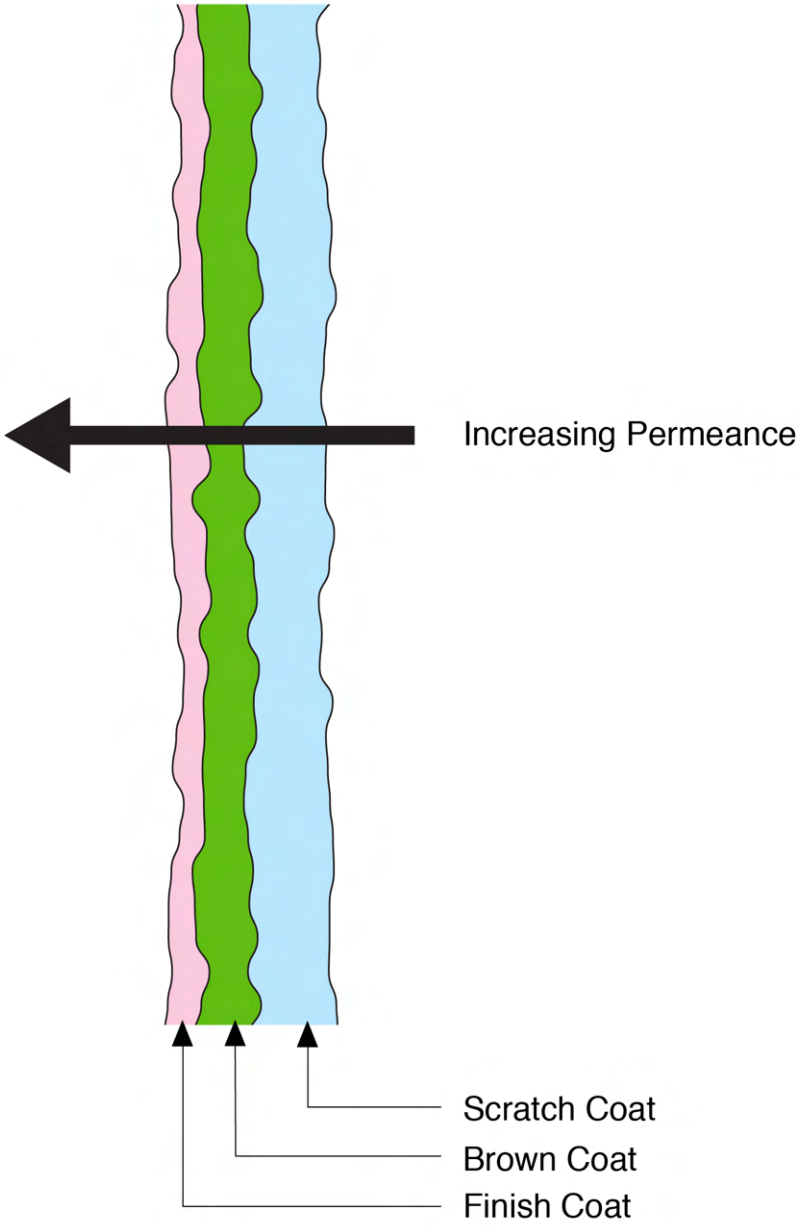


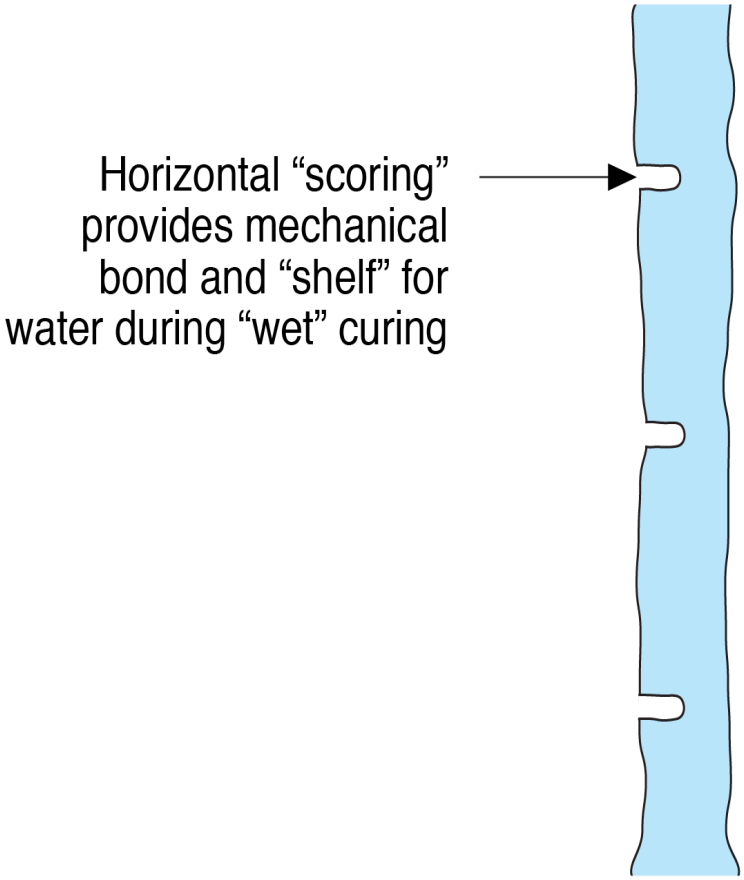






Traditional Lime Stucco	Greater than 20 perms
Lime/Portland Cement Stucco	5 to 10 perms
Portland Cement Stucco	1 to 5 perms
Polymer Modification	Less than 1


Increasing Permeance
Scratch Coat
Brown Coat
Finish Coat


Horizontal “scoring” provides mechanical bond and “shelf” for water during “wet” curing

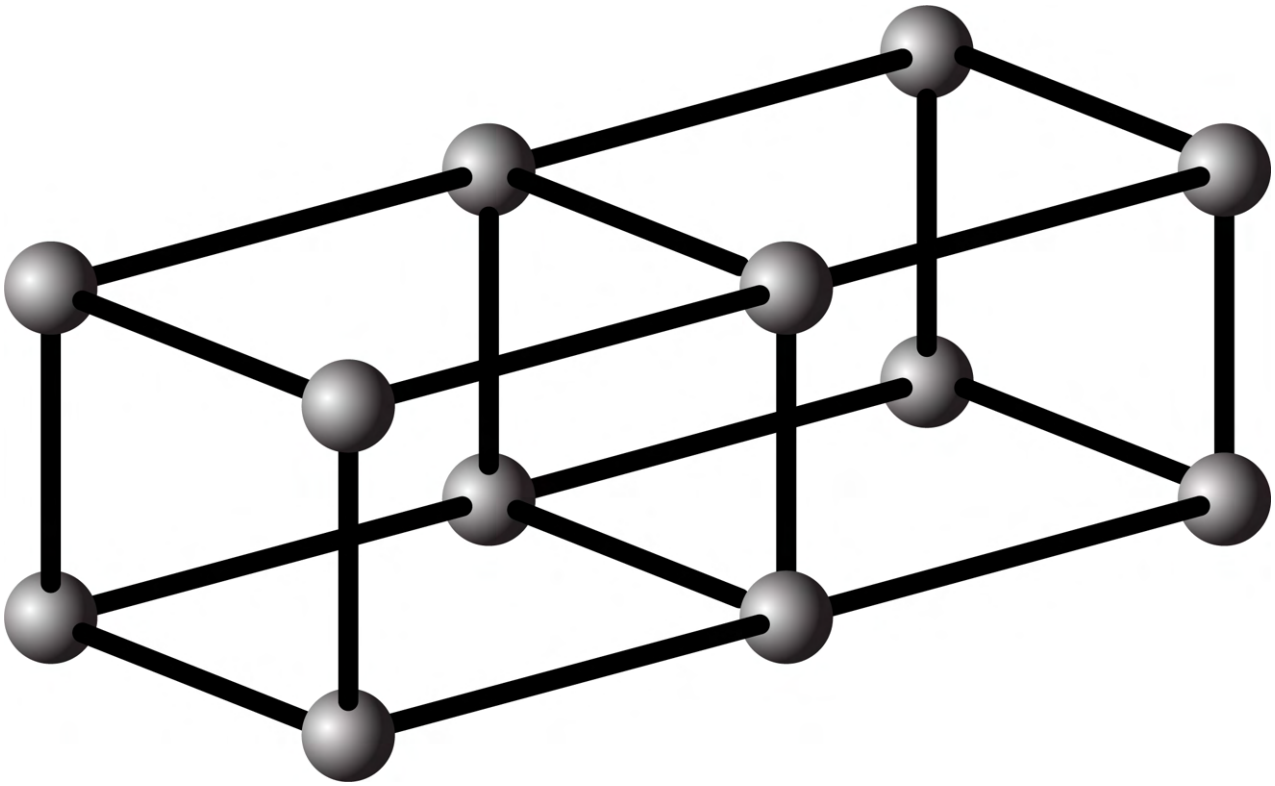




Figure 1c. Gypsum, hydrated from plaster of paris and water, porosity 30 per cent.

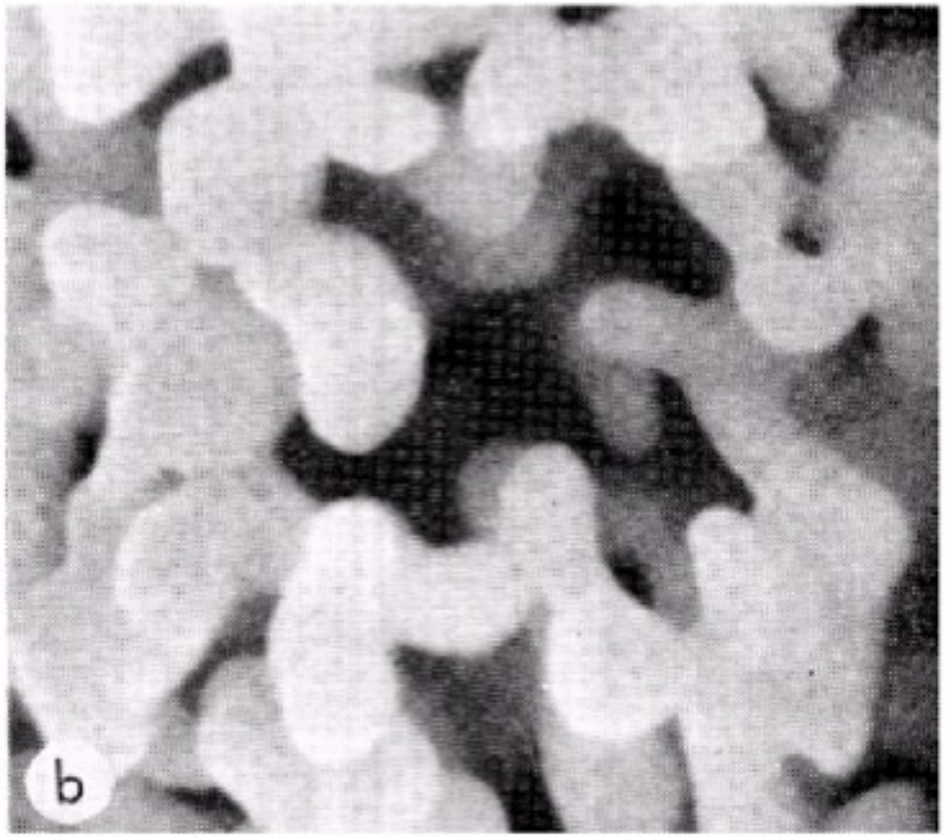
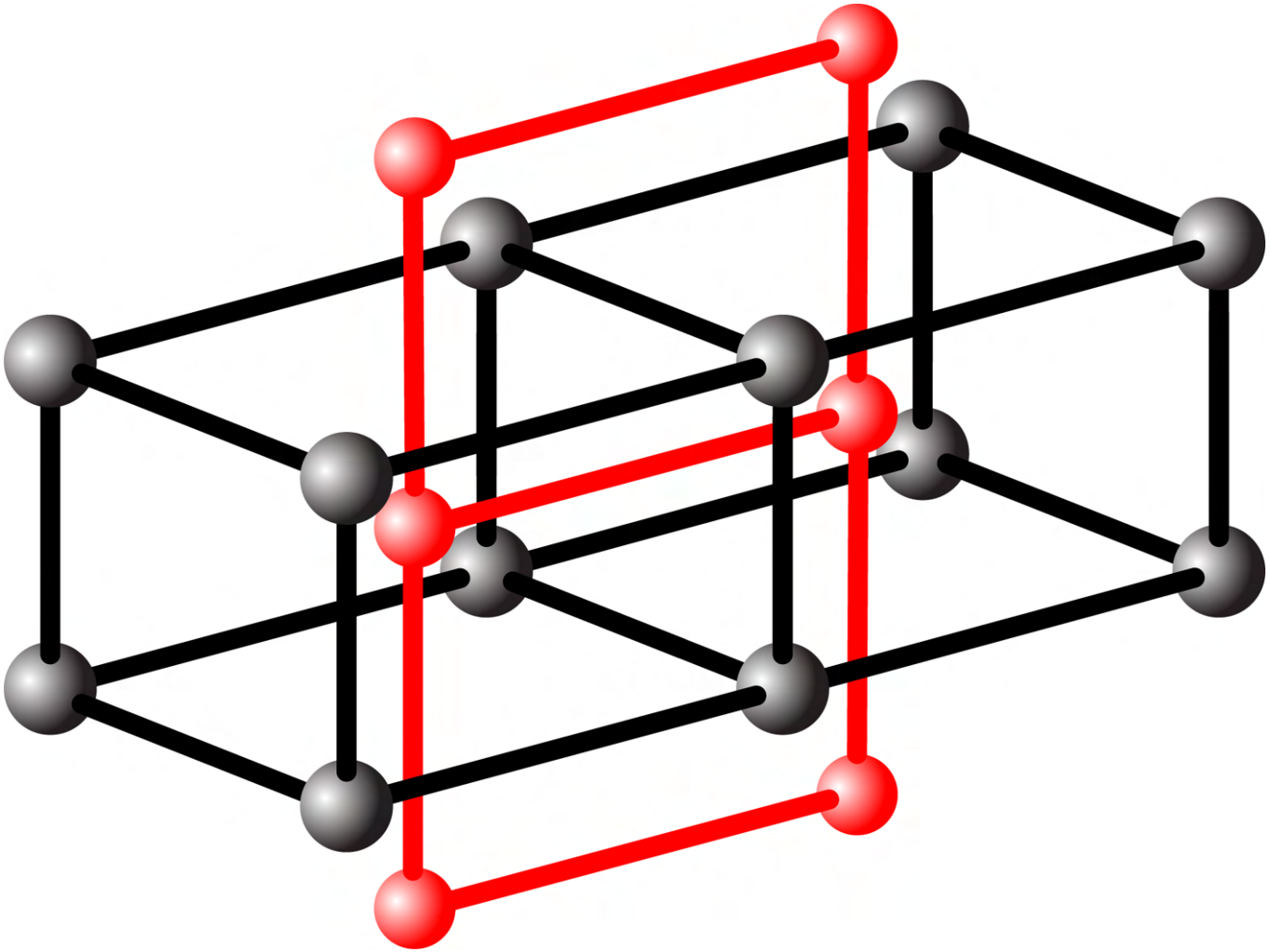


Figure 1b. Brick, sintered clay, porosity 40 per cent.



Ancient Modification Additives

Cow Dung

Egg Whites

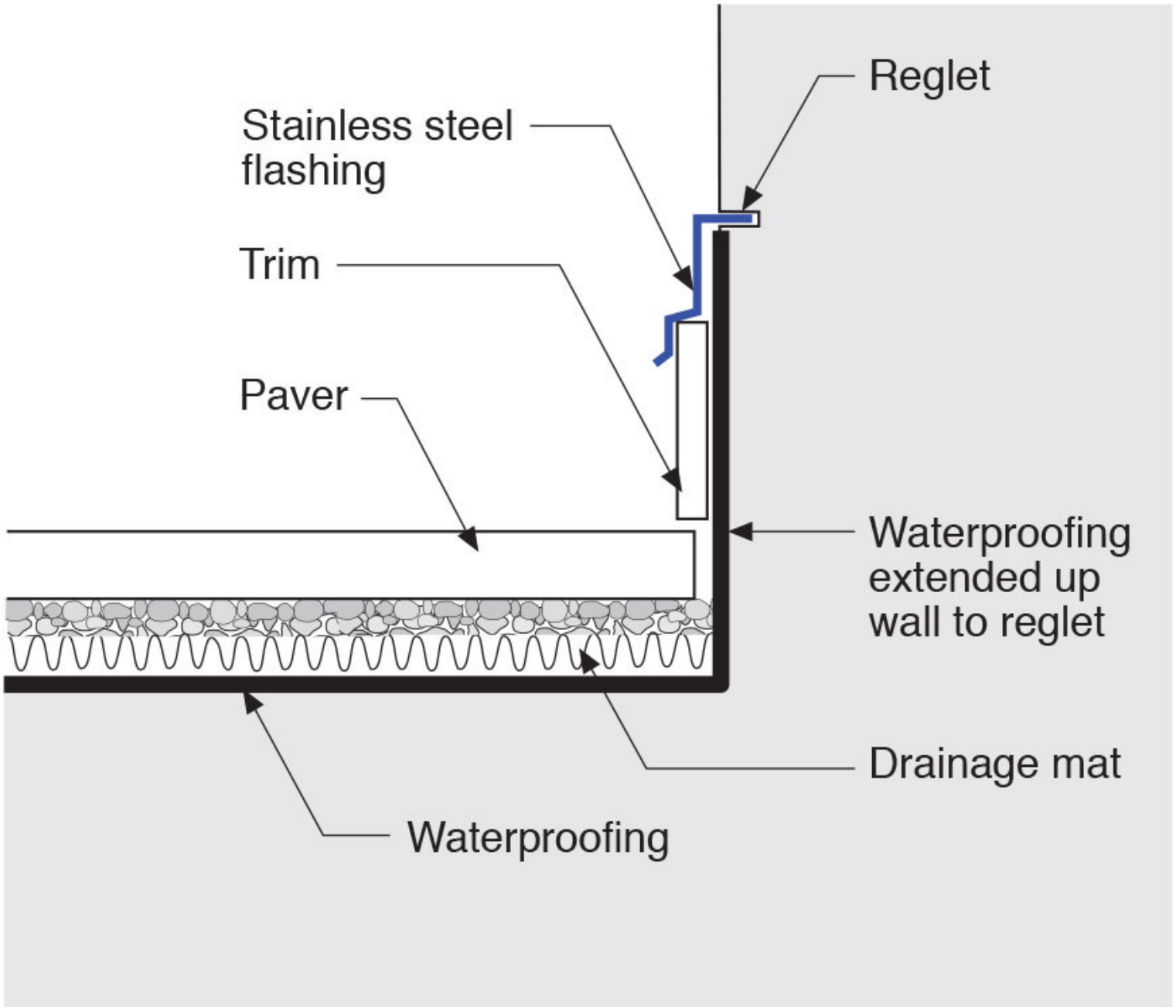
Pig Blood


DISTRICT OF COLUMBIA COURT OF APPEALS


EXIT
EXIT

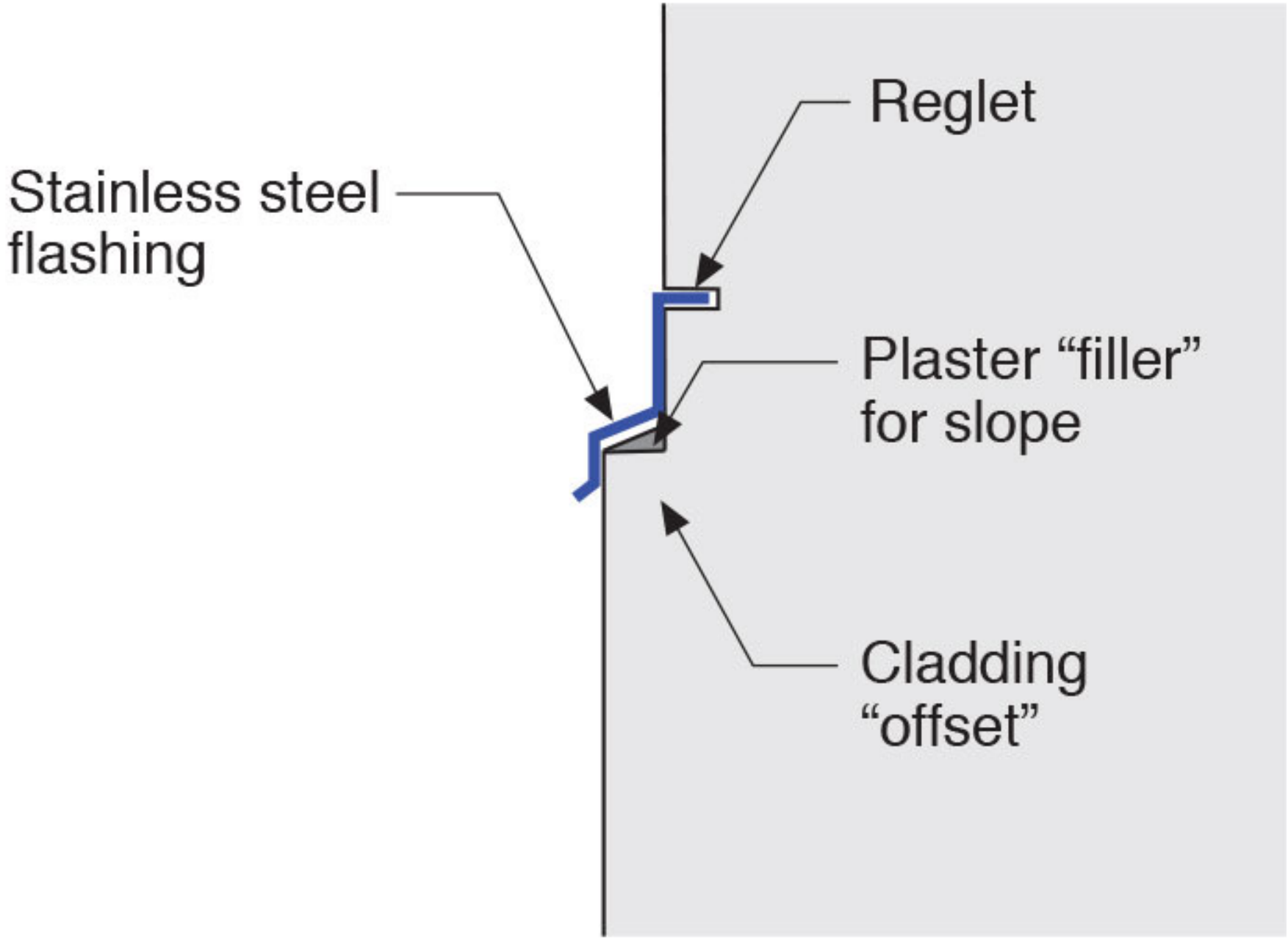




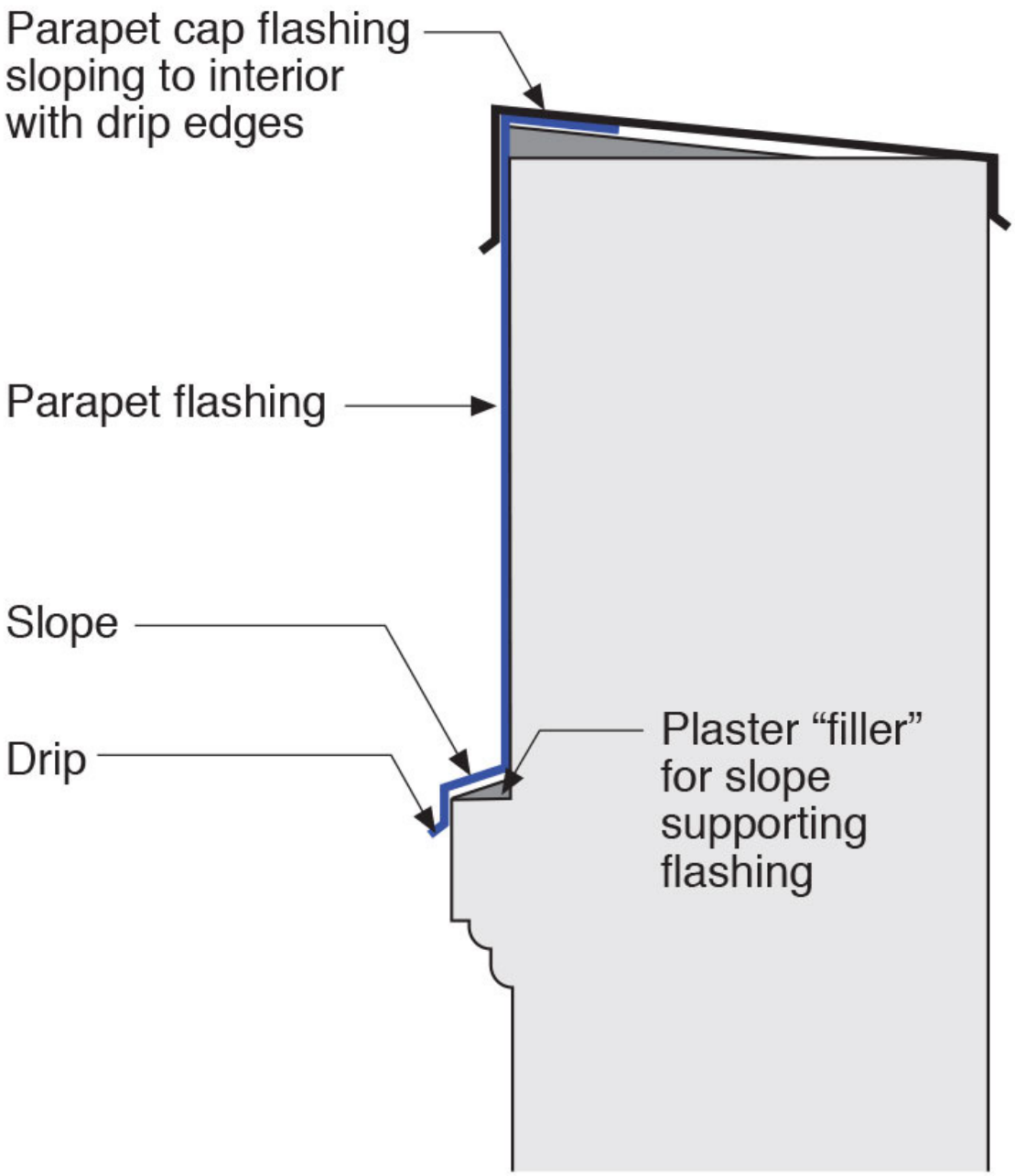

Reglet
Stainless steel flashing
Trim
Paver
Waterproofing extended up wall to reglet
Drainage mat
Waterproofing






Stainless steel
flashing
Reglet
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

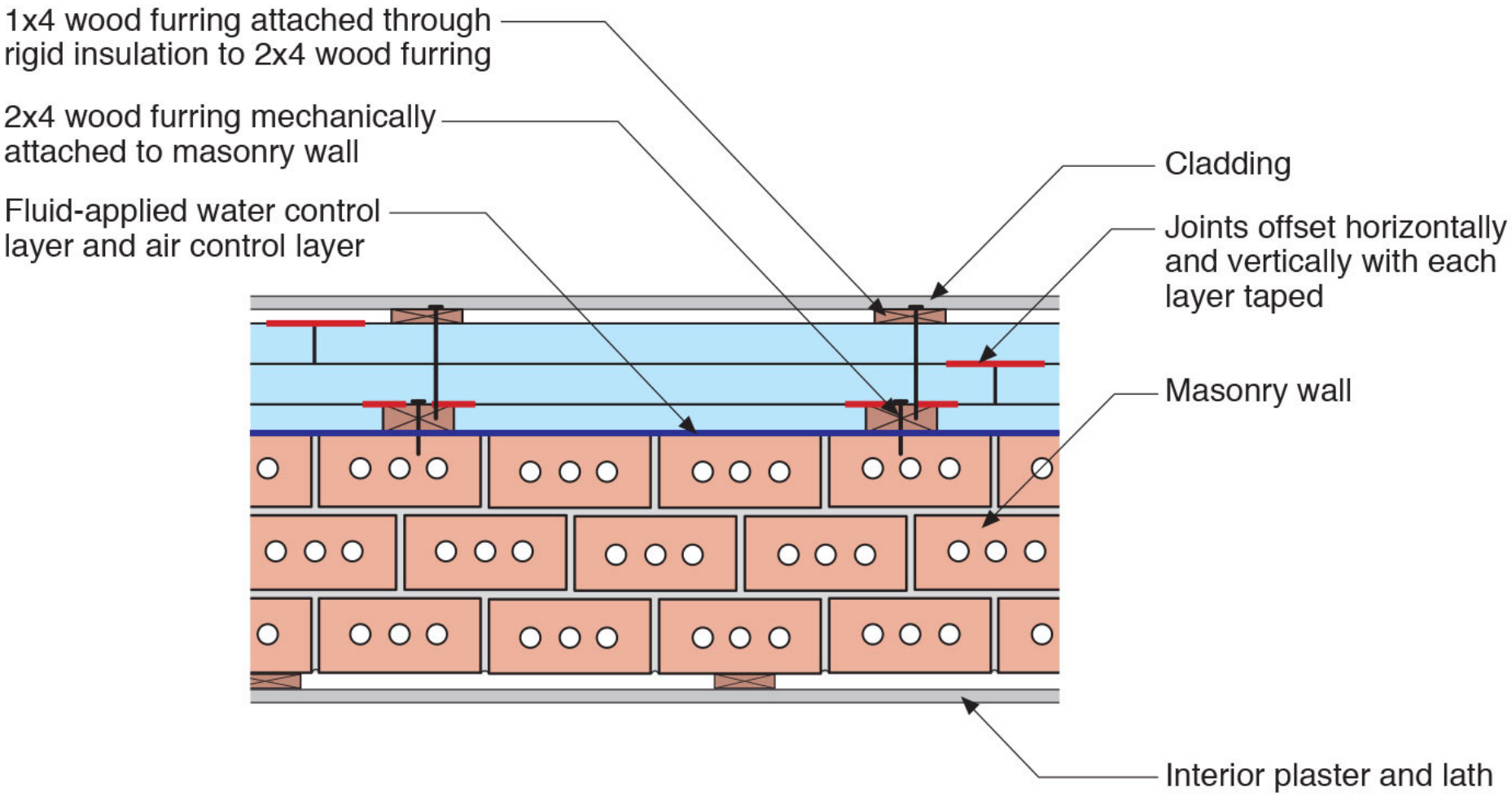




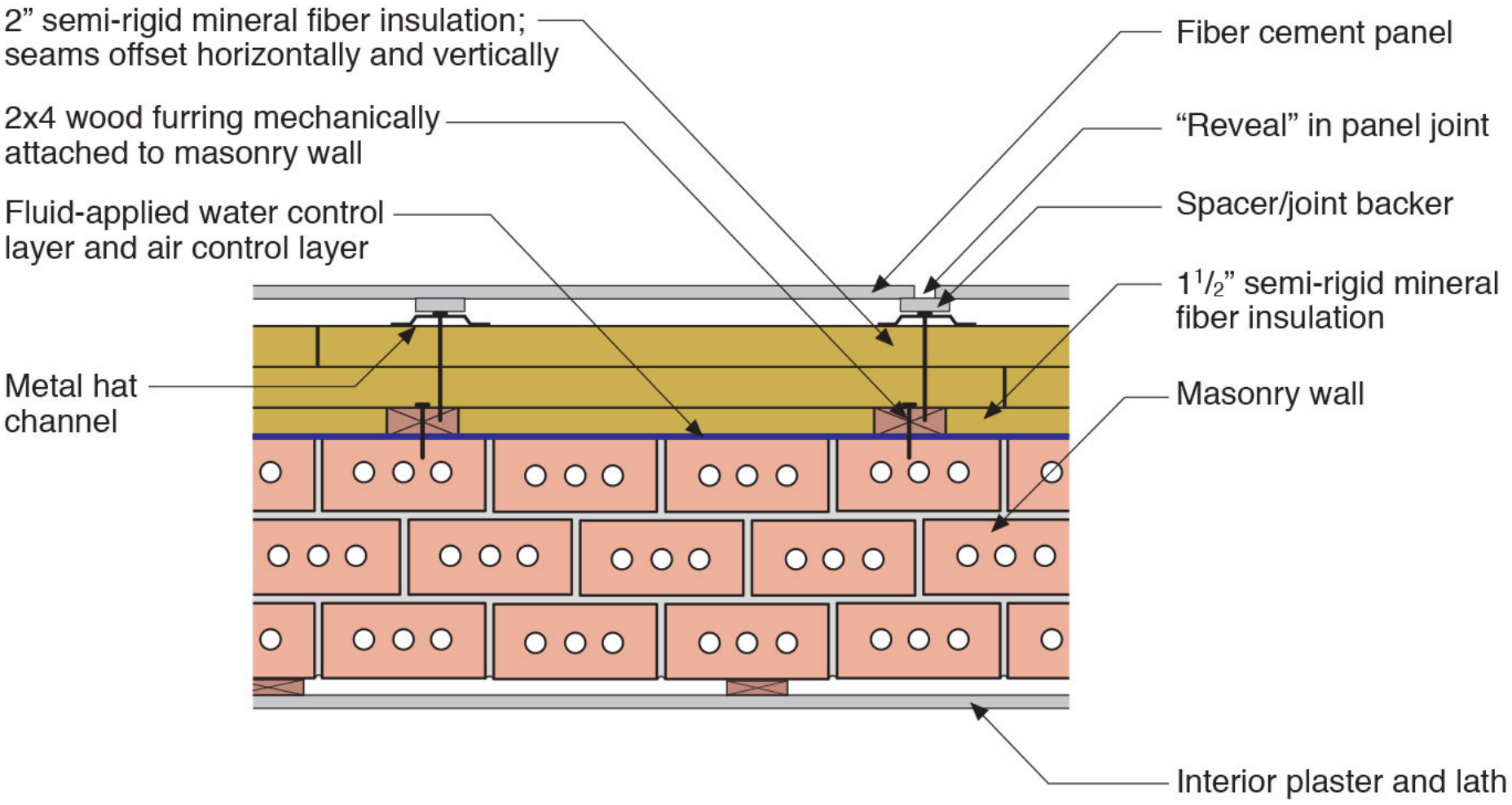



852

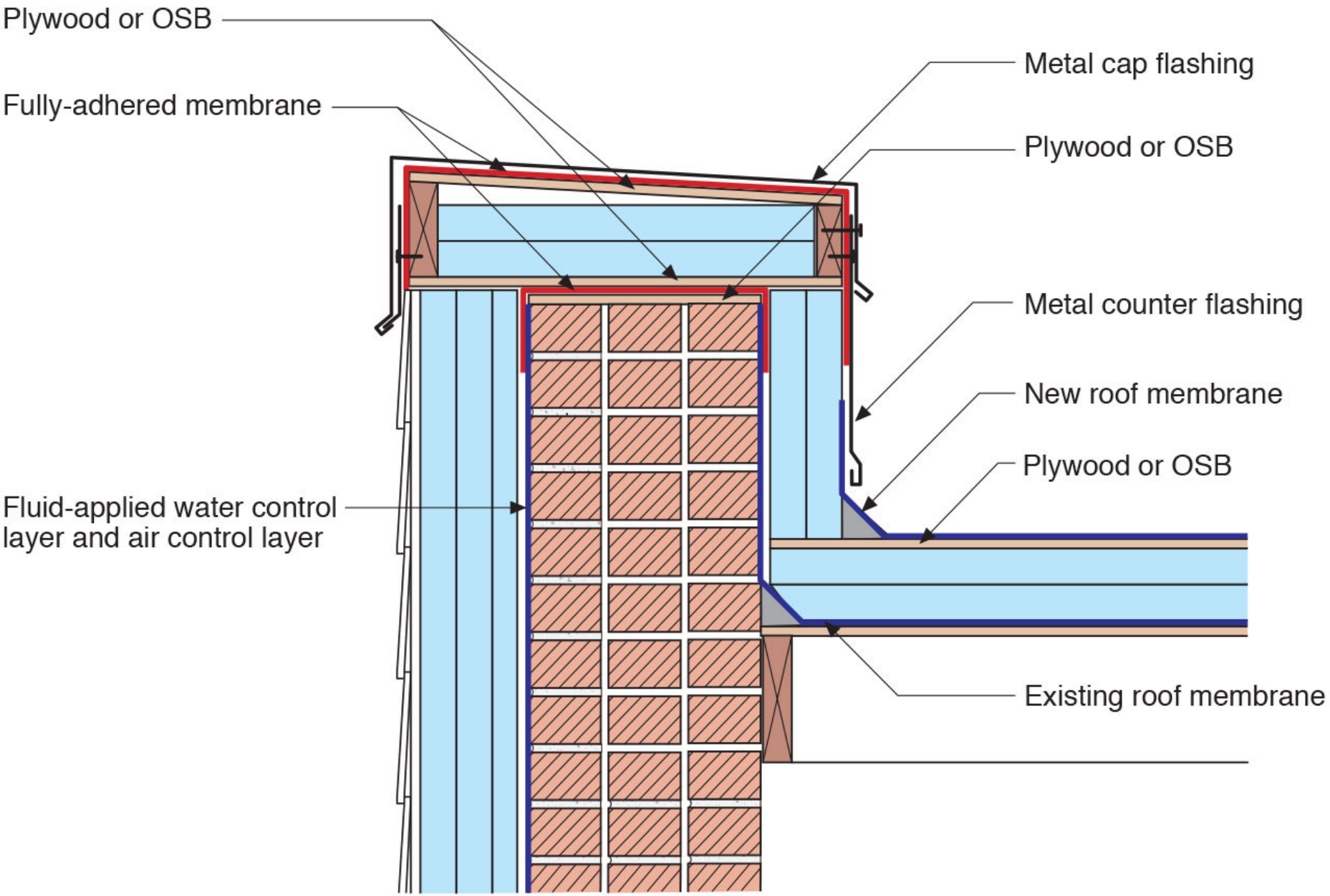



1x4 wood furring attached through rigid insulation to 2x4 wood furring
2x4 wood furring mechanically attached to masonry wall
Fluid-applied water control layer and air control layer
Cladding
Joints offset horizontally and vertically with each layer taped
Masonry wall
Interior plaster and lath


With ENERGY STAR
R-10
2 inch Thickness
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
Fluid-applied water control layer and air control layer
Metal cap flashing
Plywood or OSB
Metal counter flashing
New roof membrane
Plywood or OSB
Existing roof membrane


RACE
RIPCORD


SPEED
HUMP

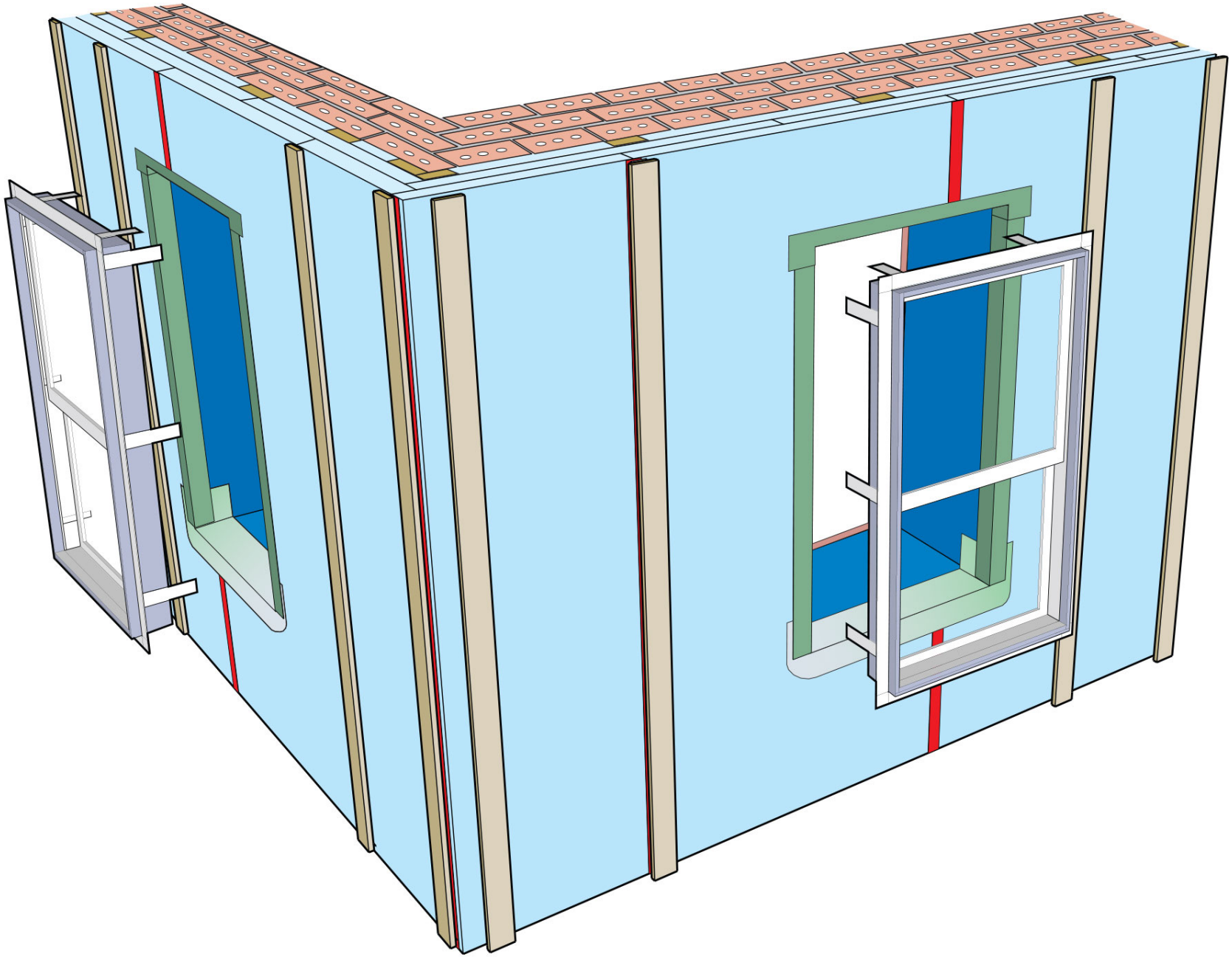



SPEED
HUMP



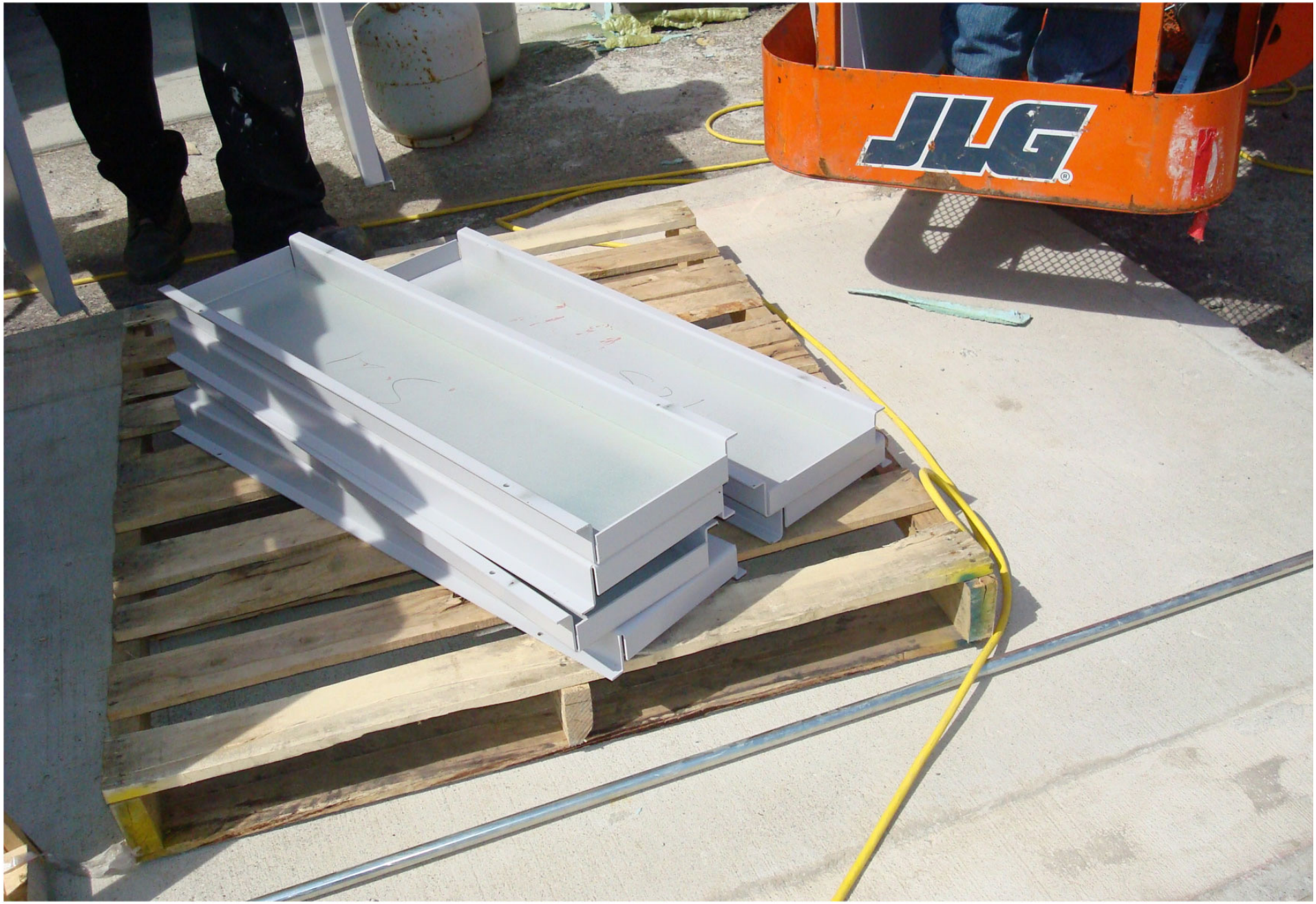



OWENS CORNING
FOAMULAR 150
OZONE DEPLETION
LOWE'S



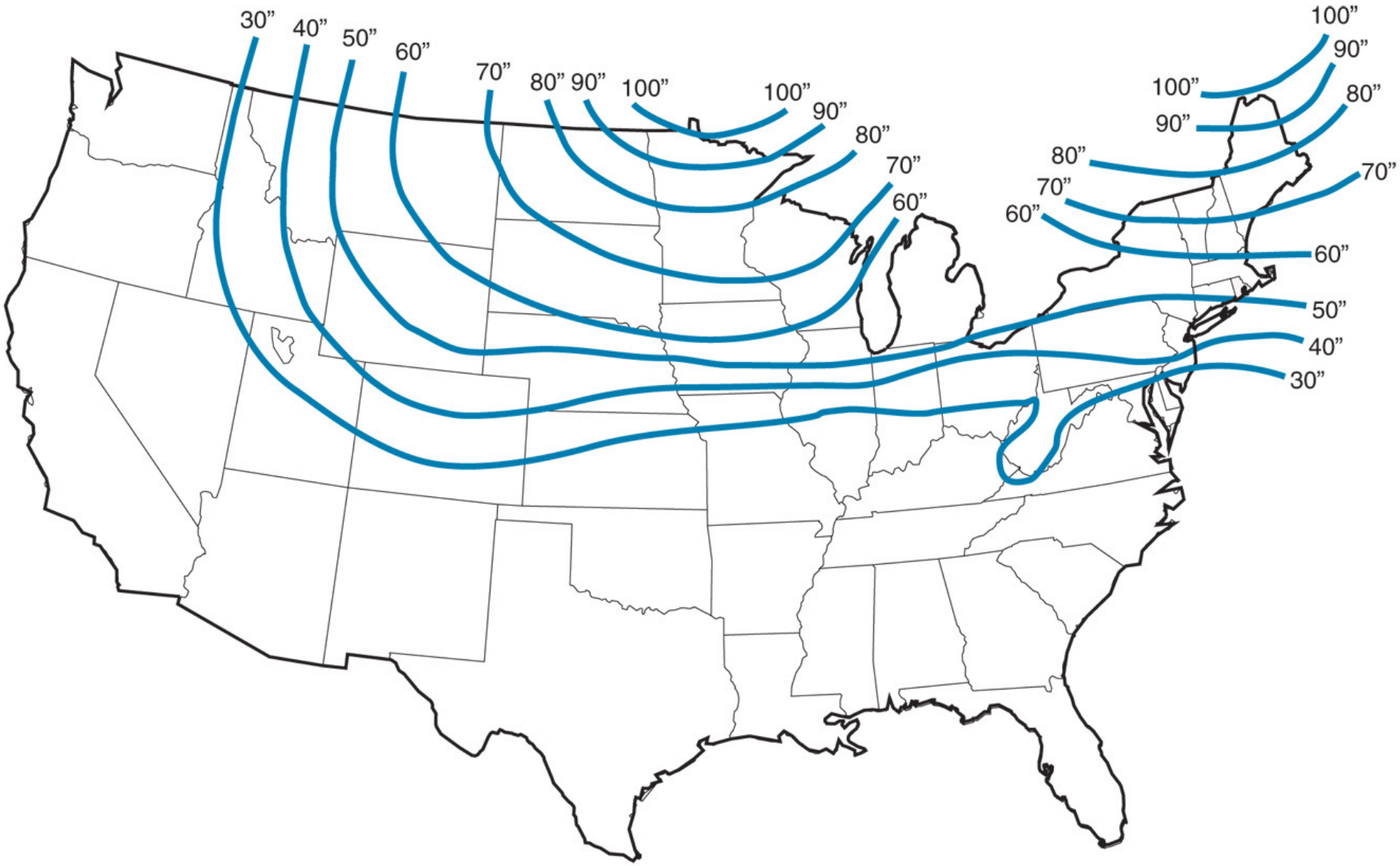




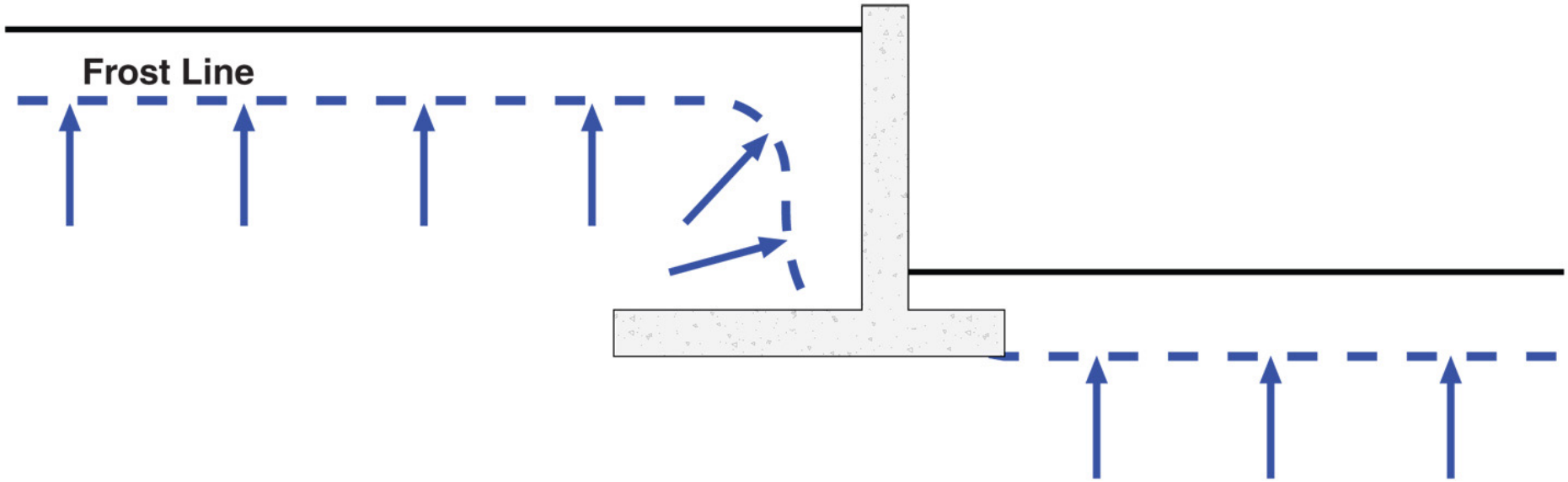

JLG

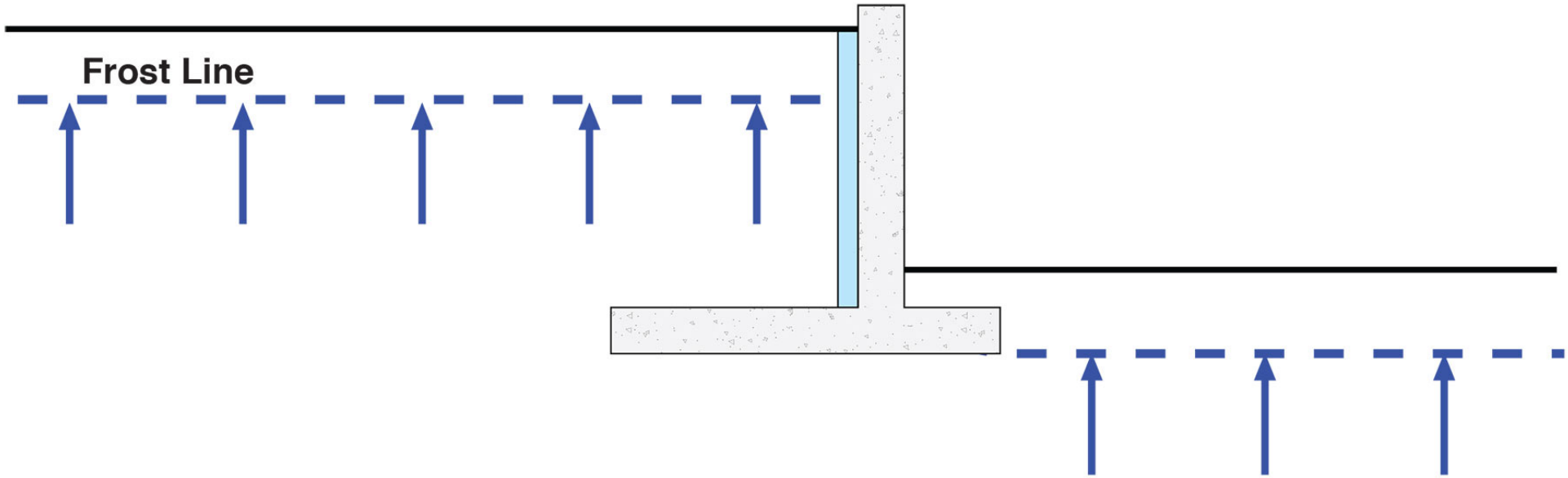



SKYTEC

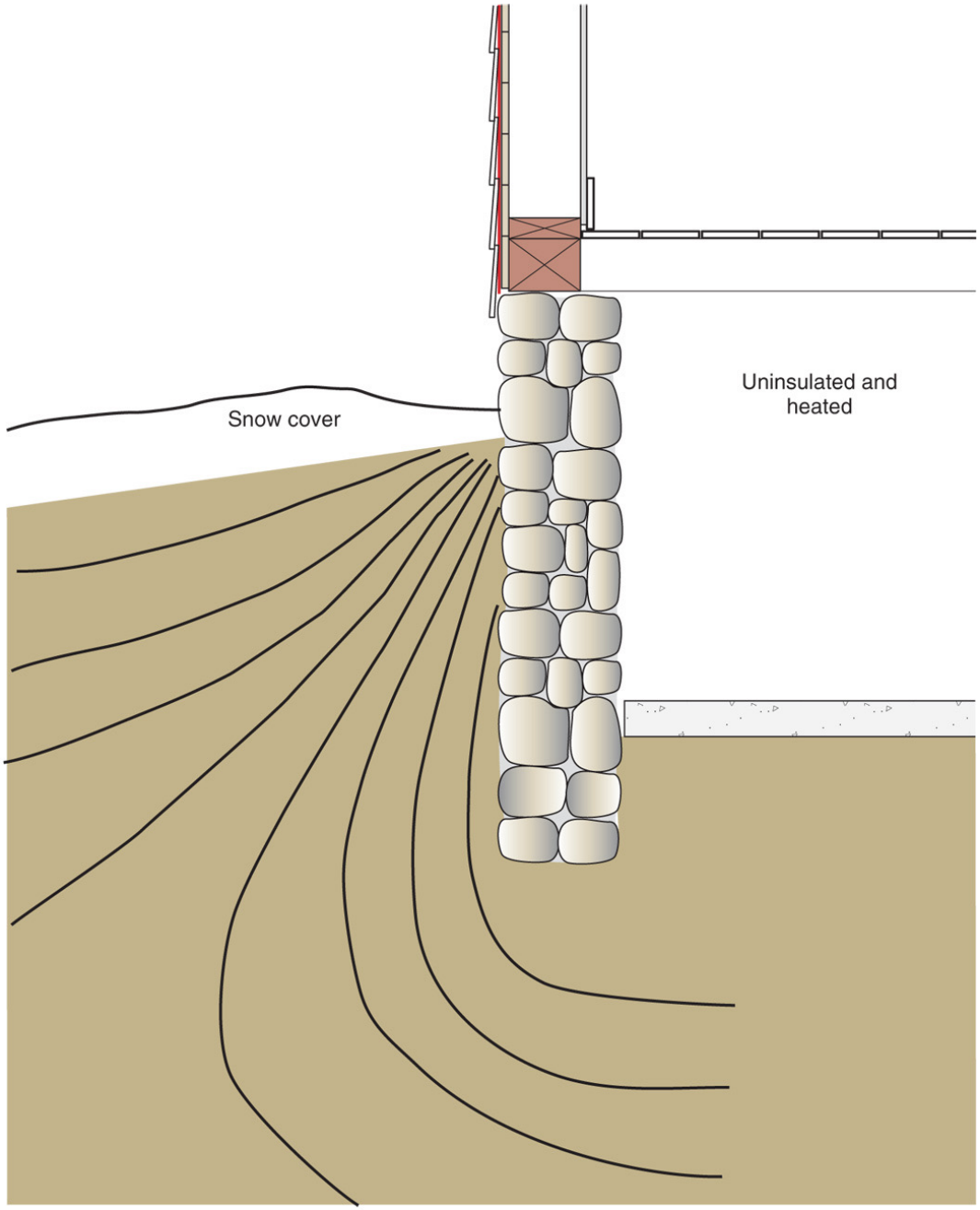


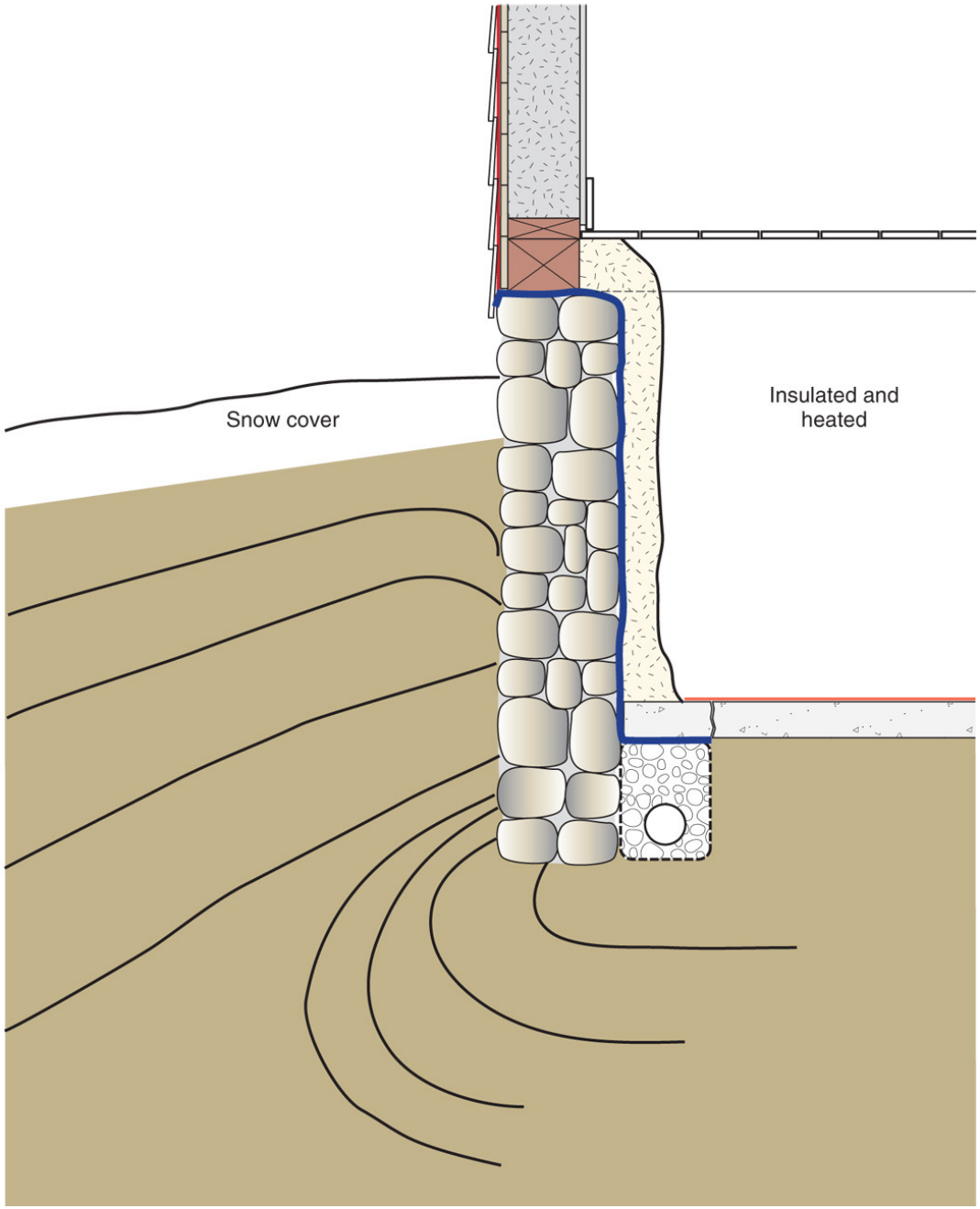
From the US Army Corps Engineers Extreme Frost Penetration
(in inches) based on state averages.

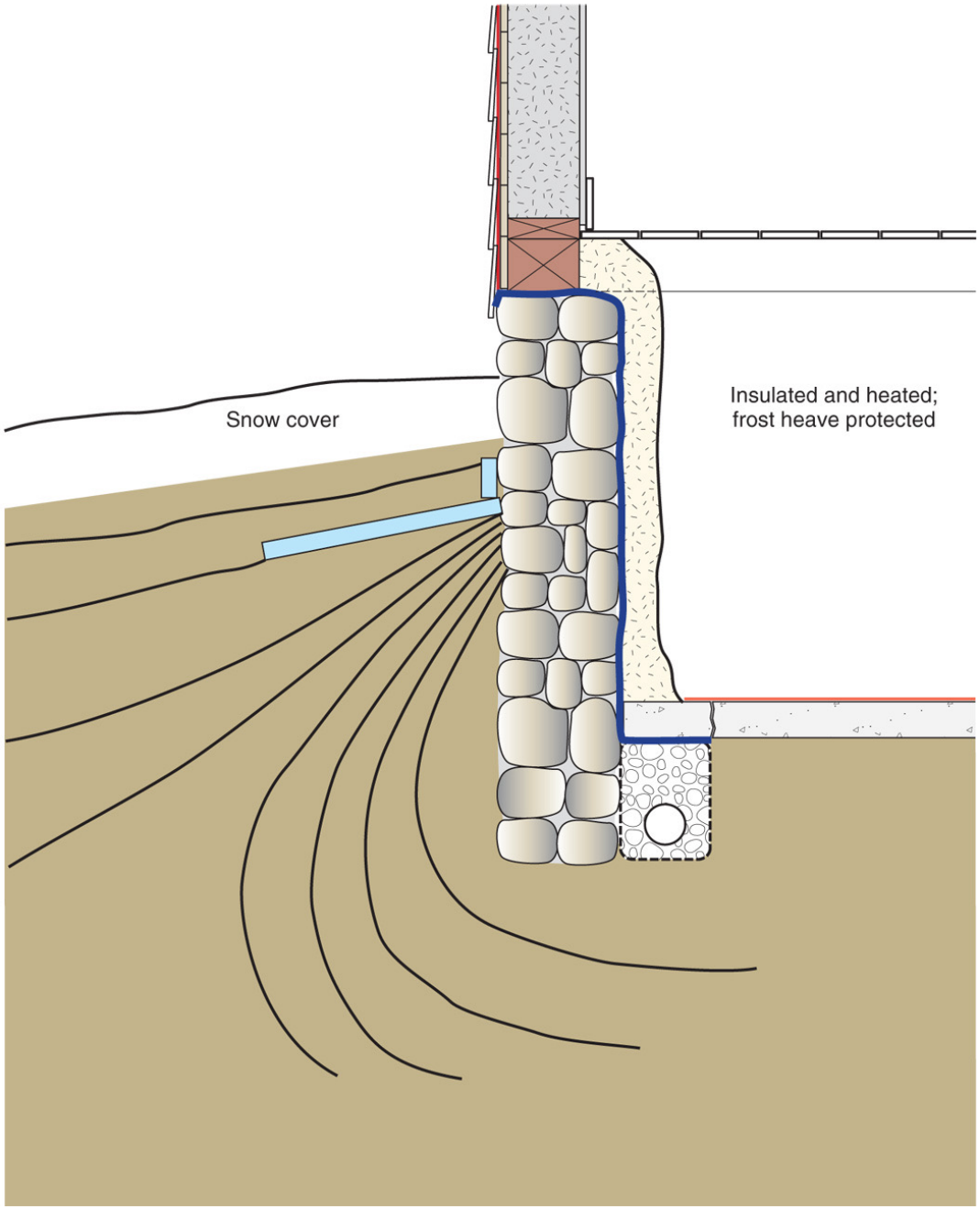

Frost Line

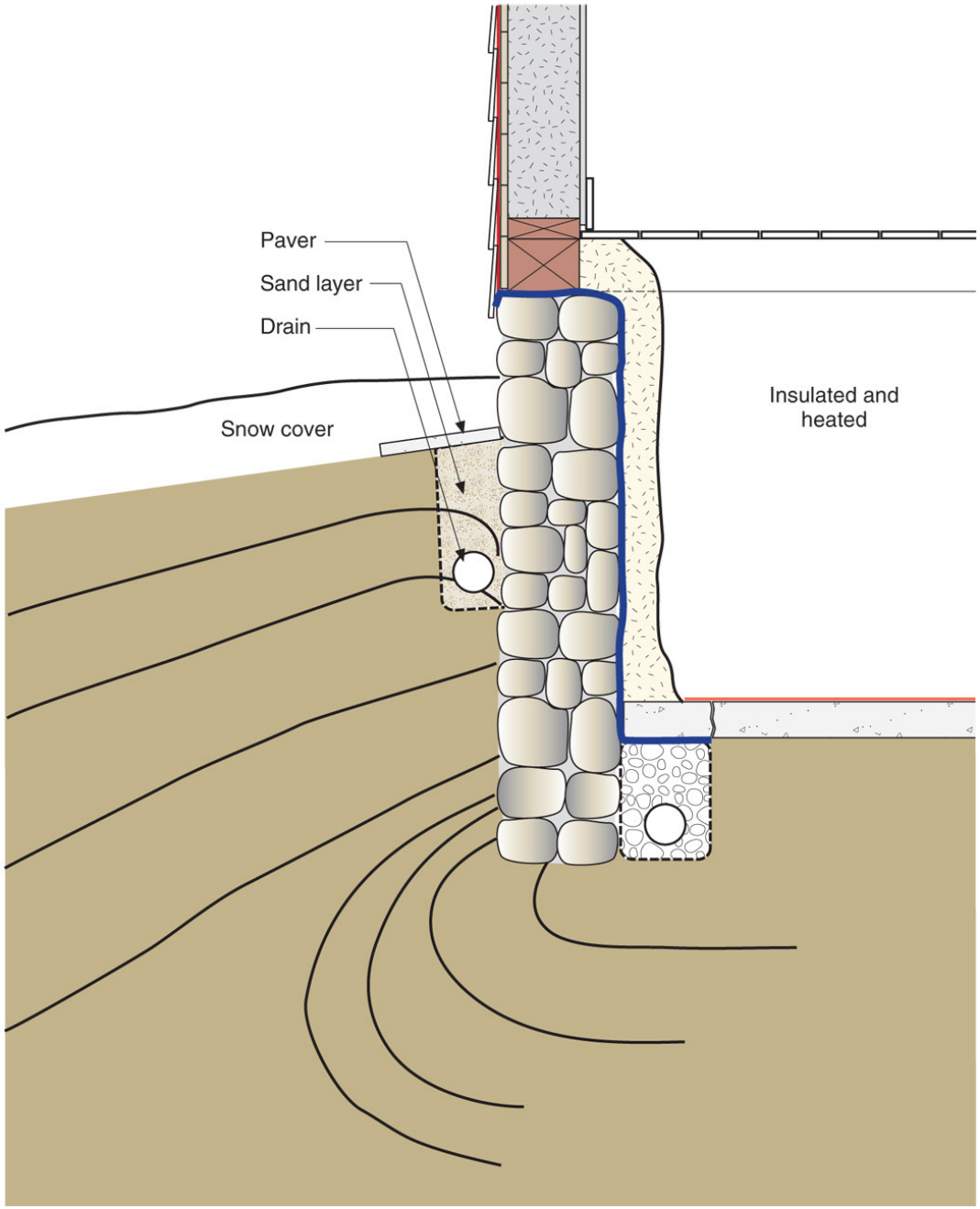

Frost Line

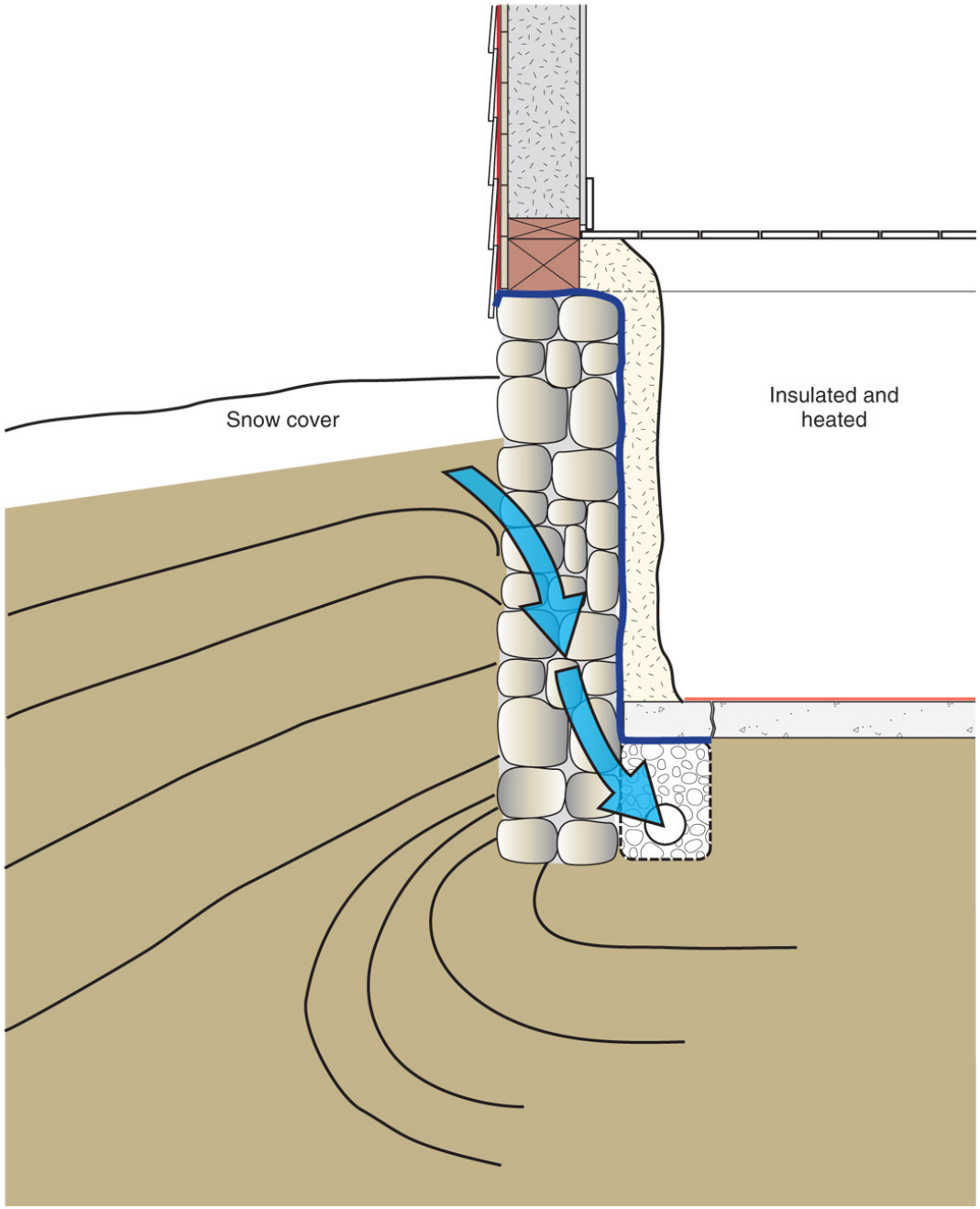



Snow cover
Uninsulated and
heated


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

Retrofits – Frame Buildings







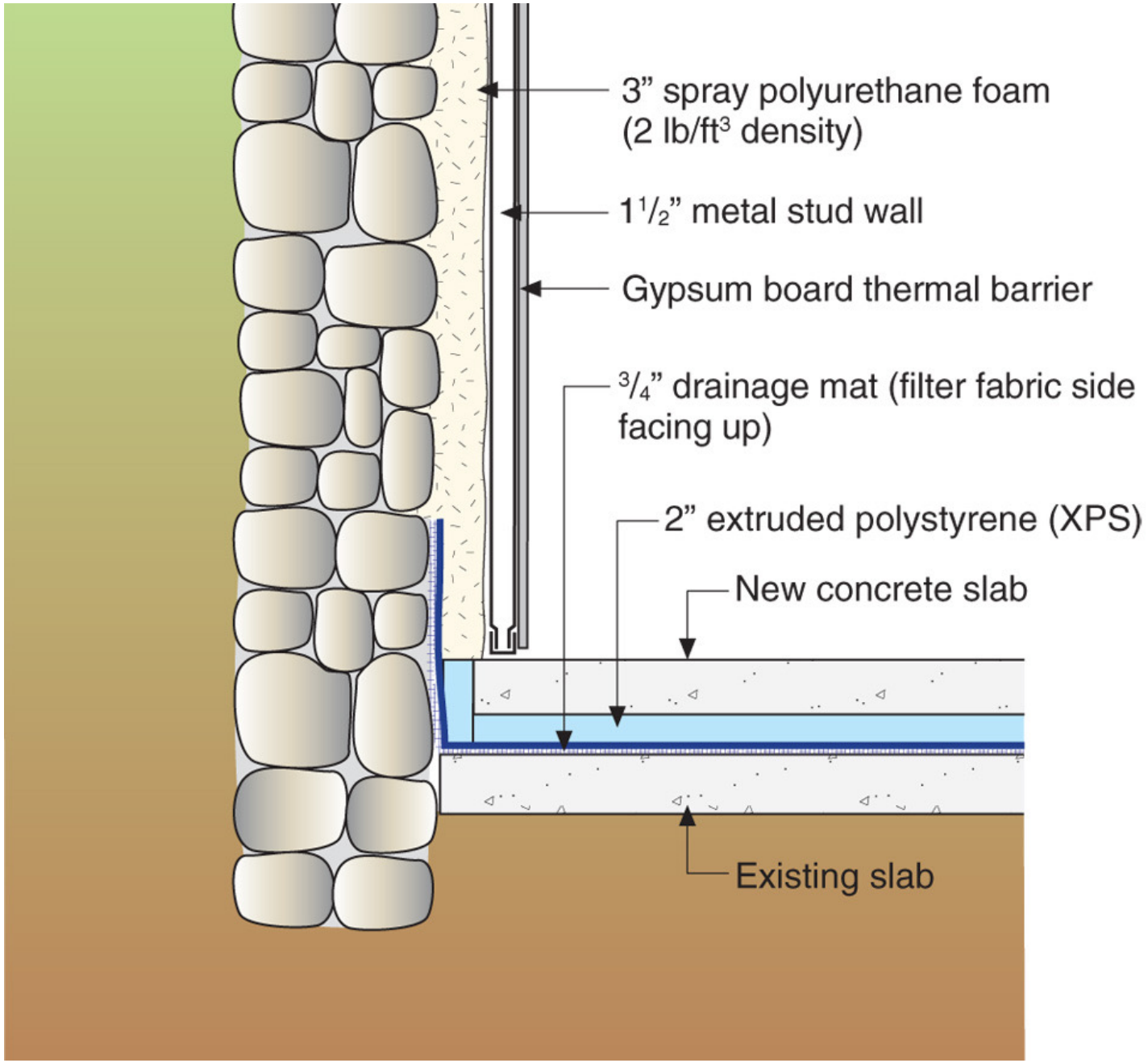


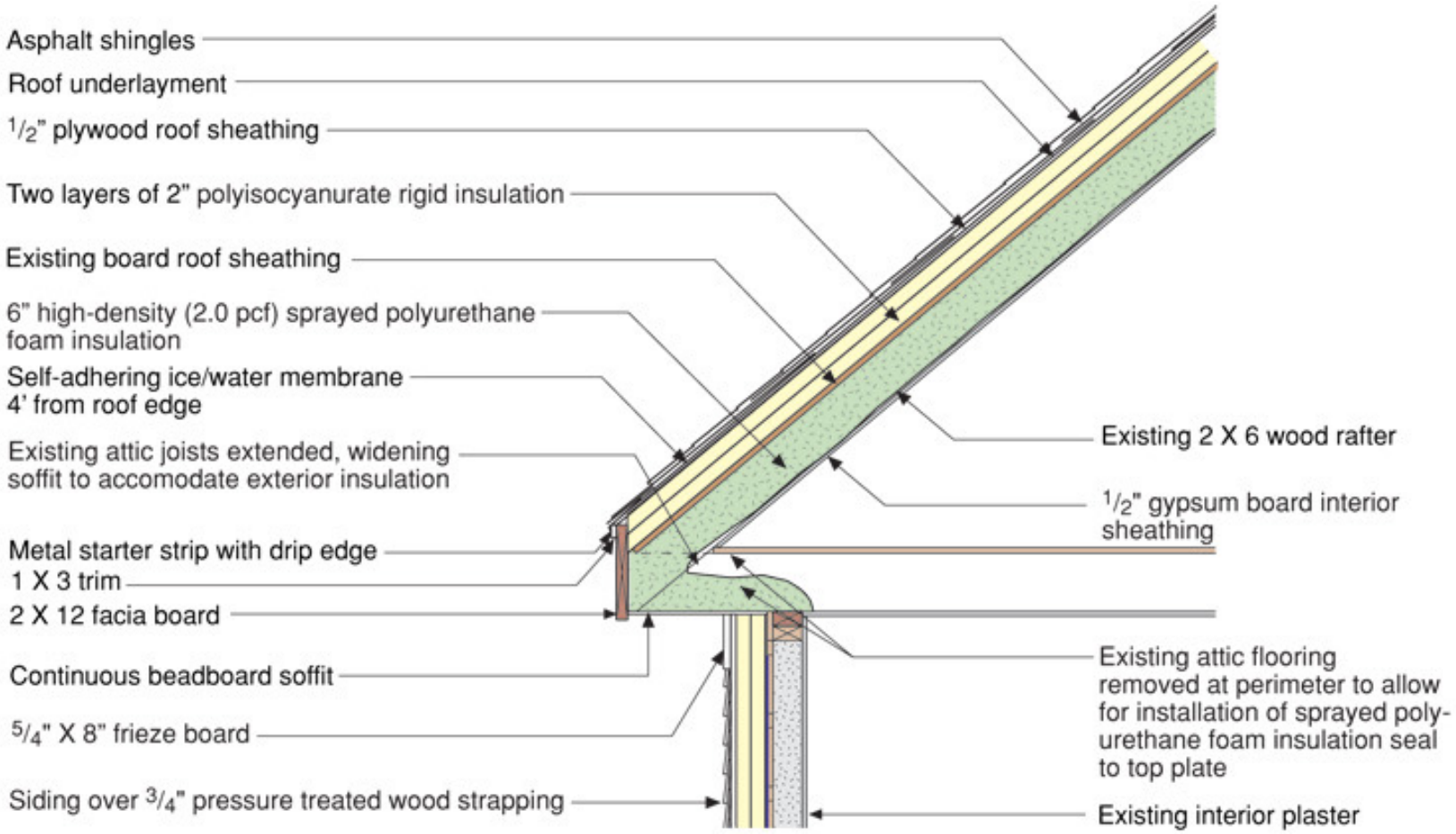

Styrofoam
Styrofoam
Styrofoam








3” spray polyurethane foam
(2 lb/ft3 density)
1 1/2” metal stud wall
Gypsum board thermal barrier
3/4” drainage mat (filter fabric side
facing up)
2” extruded polystyrene (XPS)
New concrete slab
Existing slab


Asphalt shingles
Roof underlayment
1/2" plywood roof sheathing
Two layers of 2" polyisocyanurate rigid insulation
Existing board roof sheathing
6" high-density (2.0 pcf) sprayed polyurethane foam insulation
Self-adhering ice/water membrane 4' from roof edge
Existing attic joists extended, widening soffit to accomodate exterior insulation
Metal starter strip with drip edge
1 X 3 trim
2 X 12 facia board
Continuous beadboard soffit
5/4" X 8" frieze board
Siding over 3/4" pressure treated wood strapping
Existing 2 X 6 wood rafter
1/2" gypsum board interior sheathing
Existing attic flooring removed at perimeter to allow for installation of sprayed poly-urethane foam insulation seal to top plate
Existing interior plaster














GRACE












STAY BACK
100 FEET


GRACE VYCOR® PLUS
GRACE VYCOR® PLUS


ENERGY PERFORMANCE RATINGS
U-Factor (U.S./I-P
0.32
Solar Heat Gain Coefficient
0.33
ADDITIONAL PERFORMANCE RATINGS
Visible Transmittance
0.54
DESIGN PRESSURE (PSF)
DP25
WDMA
CERTIFIED
100-00283160-010
0283160-010
123.19
785158


GRACE WCOP® PLUS








DUPONT
DrainWra






293


Tyvek
Tyvek








MUNCHKIN



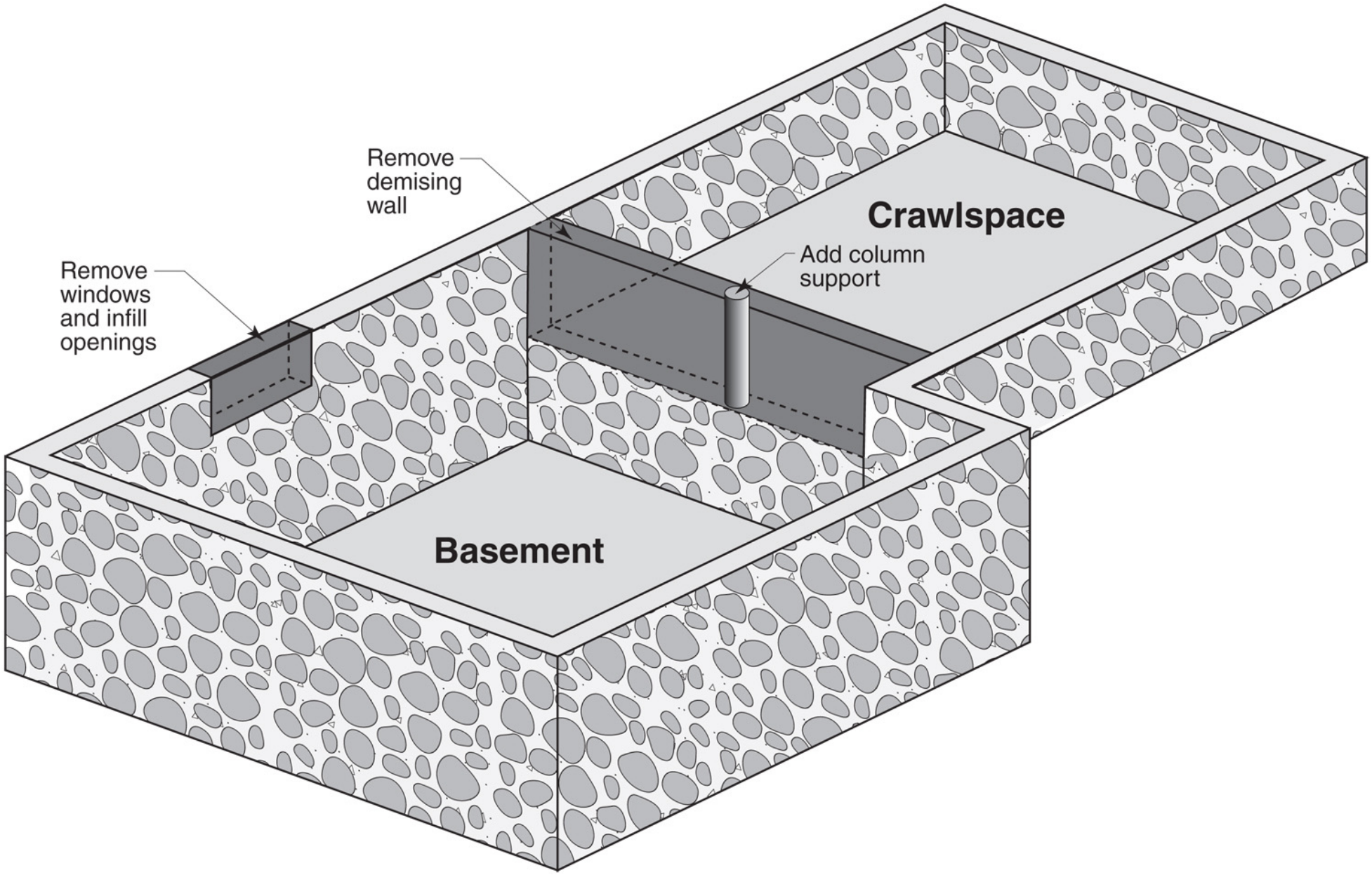




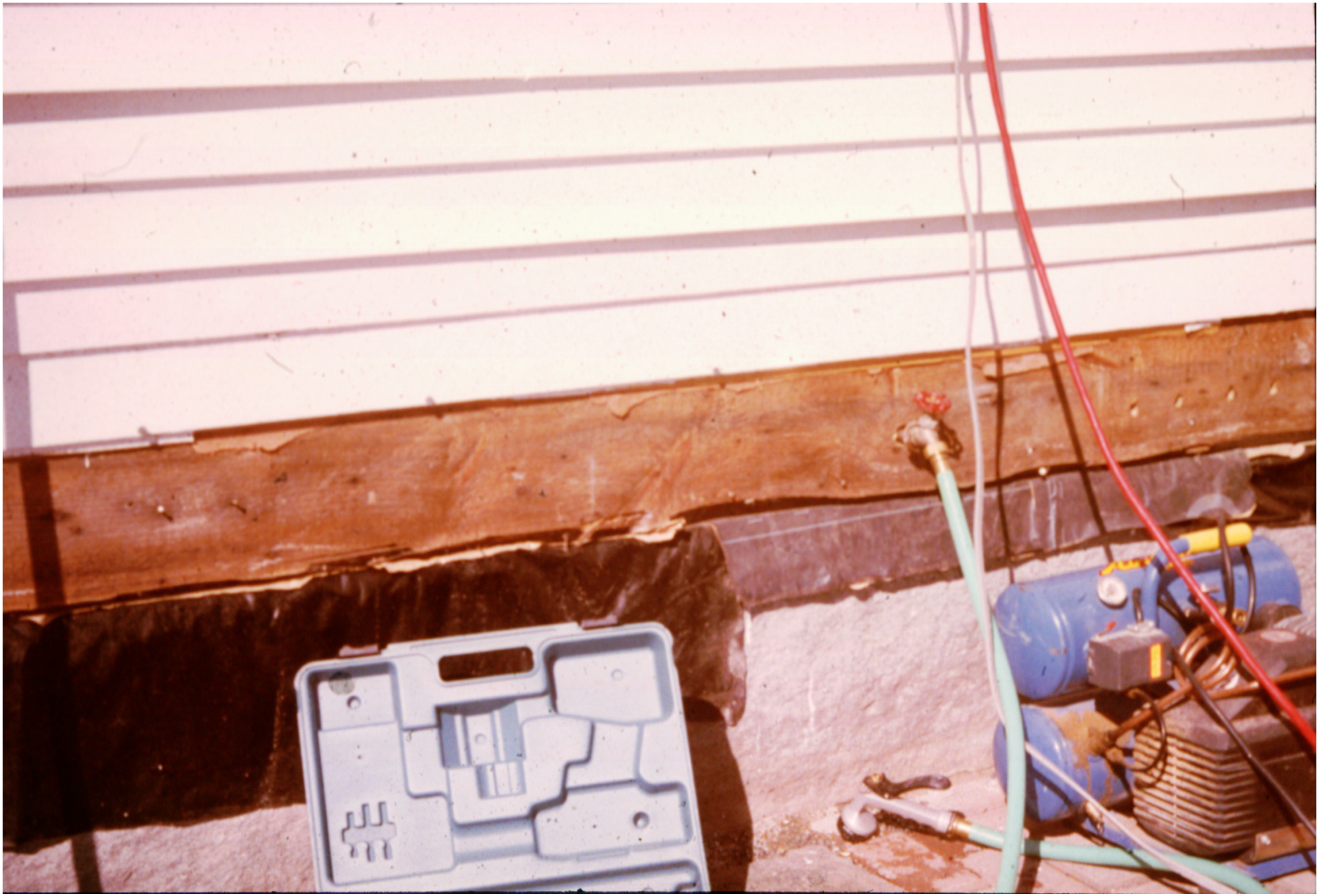







Remove
demising
wall
Crawlspace
Add column
support
Remove
windows
and infill
openings
Basement










GRACE
Ice & Water Shield








Tyvek
DUPONT
Tyve
HomeWr
DUPONT
Tyve
HomeWr

























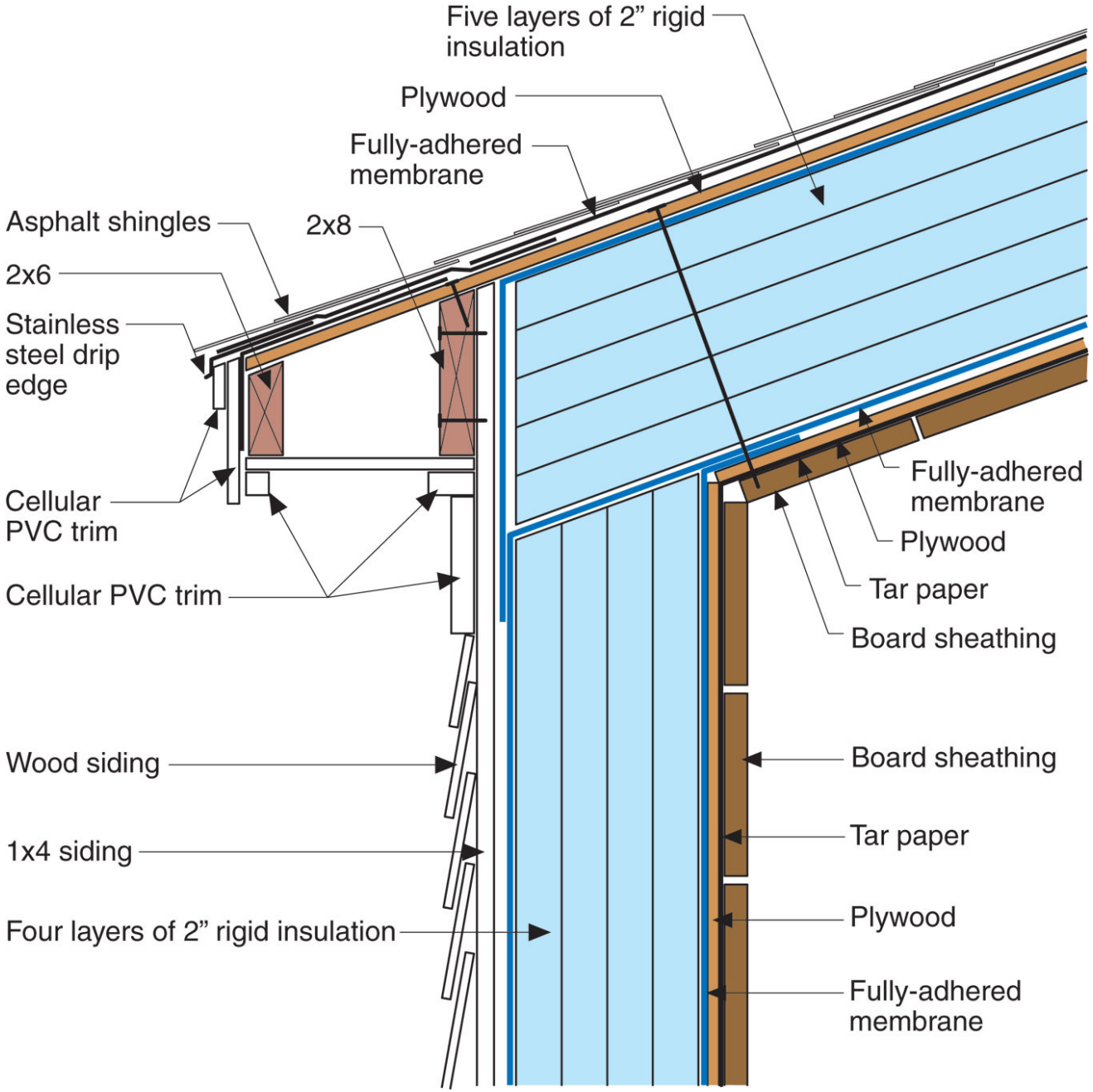

Tyvek

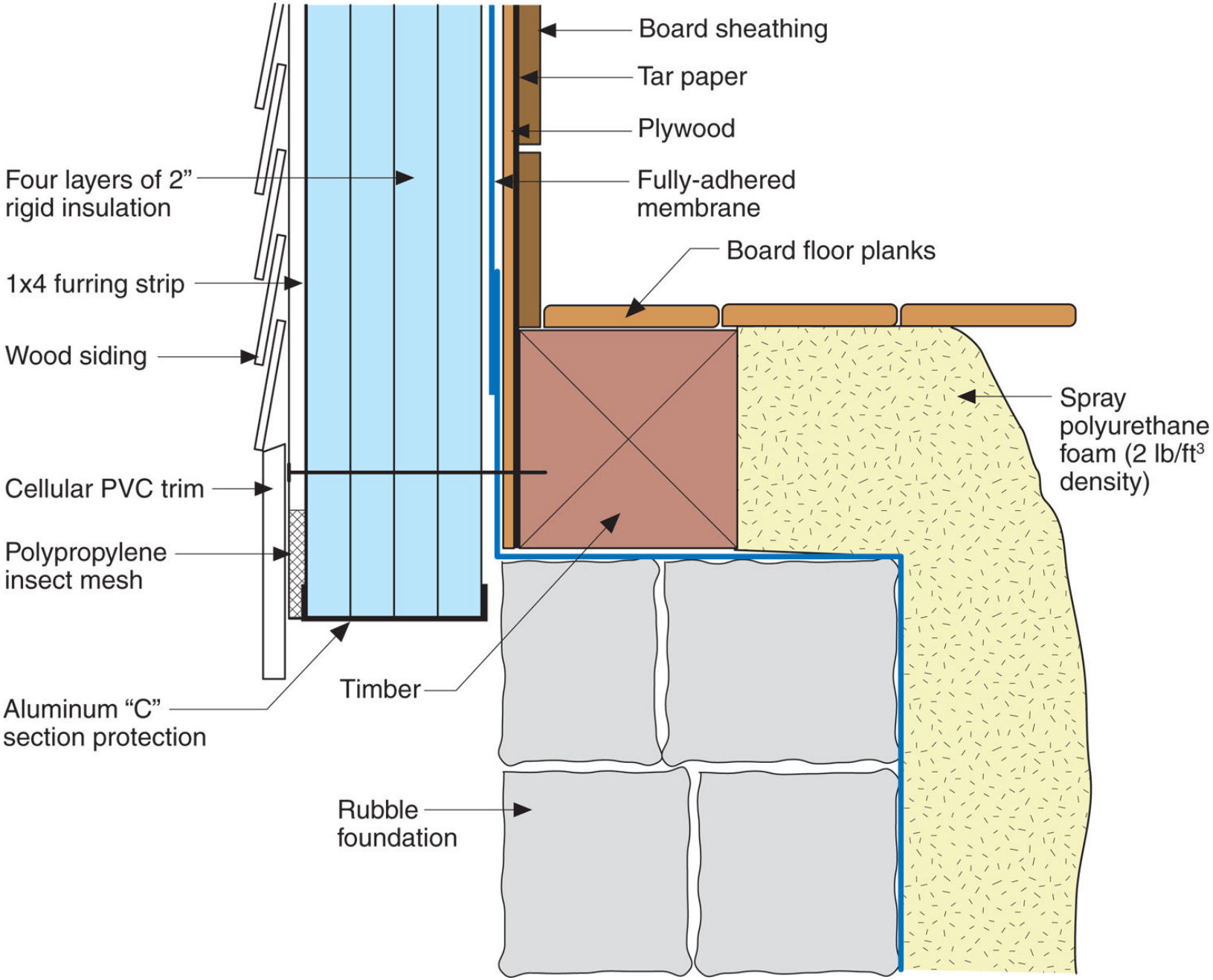


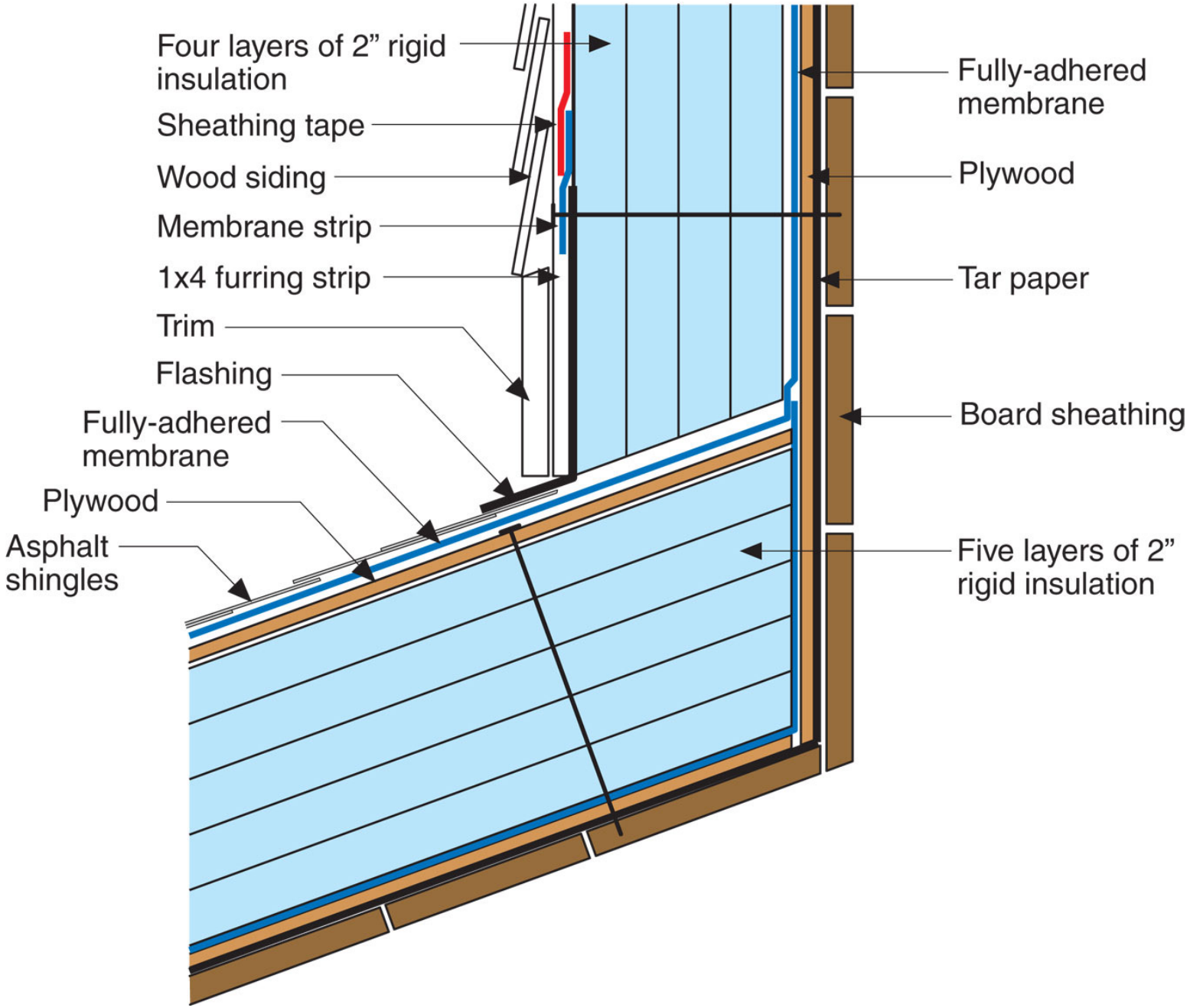

DIABLO


DOW
Styrofoam
BRAND
TONGUE &
GROOVE
EXTRUDED
POLYSTYRENE
COMBUSTIBLE. Protect from flame and other high heat sources. Fo
more information, consult MSDS and/or call Dow (1-800-441-4369).
Surface Burning Characteristics for STYROFOAM Brand Insulation
Flame Spread 5 (1) Smoke Developed 165 (1)
(1) These numerical flame spread and smoke ratings are not
intended to reflect hazards presented by this material under actual
fire conditions.
Thickness (inches) 3/4 1 1-1/2 2 3
R-value at 75°F mean 3.8 5.0 7.5 10 15
R means resistance to heat flow. The higher the R-value, the greater
the insulating power. Ask for insulation manufacturer's fact sheet.
To get the marked R-value, it is essential that this insulation be
installed properly. If you do it yourself, follow the instructions
carefully. Obtain instructions from your supplier or The Dow
Chemical Company, Midland, MI 48674. Instructions do not come
with this package.
MEETS CAL. QUAL. STAND. REG. # CA-T064, UND. LAB. INC.®
ICBO, SBCCI, ASTM C578 Type IV, HUD UMB-71,
NYC BSA 912-52-SM
24X96
LI240105
DOW
TONGUE &
GROOVE
EXTRUDED
POLYSTYRENE
Tyvek


778
L.KENNEDY
ALIQUIPPA
PA.
776


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


Board sheathing
Tar paper
Plywood
Four layers of 2" rigid insulation
Fully-adhered membrane
Board floor planks
1x4 furring strip
Wood siding
Spray polyurethane foam (2 lb/ft³ density)
Cellular PVC trim
Polypropylene insect mesh
Timber
Aluminum "C" section protection
Rubble foundation


Four layers of 2” rigid insulation
Sheathing tape
Wood siding
Membrane strip
1x4 furring strip
Trim
Flashing
Fully-adhered membrane
Plywood
Asphalt shingles
Fully-adhered membrane
Plywood
Tar paper
Board sheathing
Five layers of 2” rigid insulation





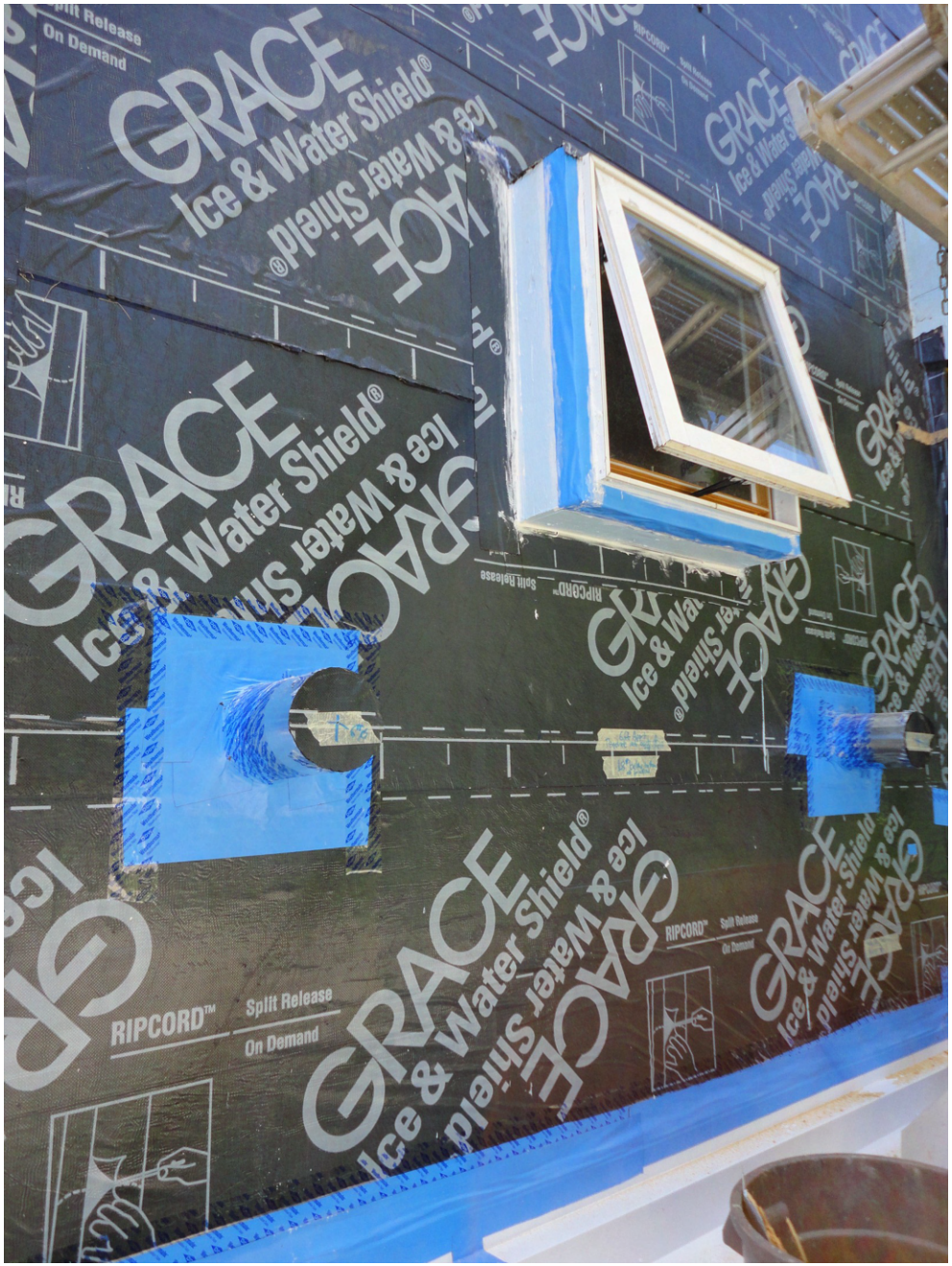



DOW
TUFF-R
DOW
TUFF-R
DOW
TUFF-R
Sup
Comm


IMPORTANT
WARNING




GRACE
Ice & Water Shield


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


Super TUFF-R
Commercial Insulation
DOW


DOW
Super TUFF-R
Commercial Insulation
Super TUFF-R
Commercial Insulation
DOW
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ercial Insulati
UFF-R
Insulation




TUFF-R
TUFF-R
TUFF-R
TUFF-R





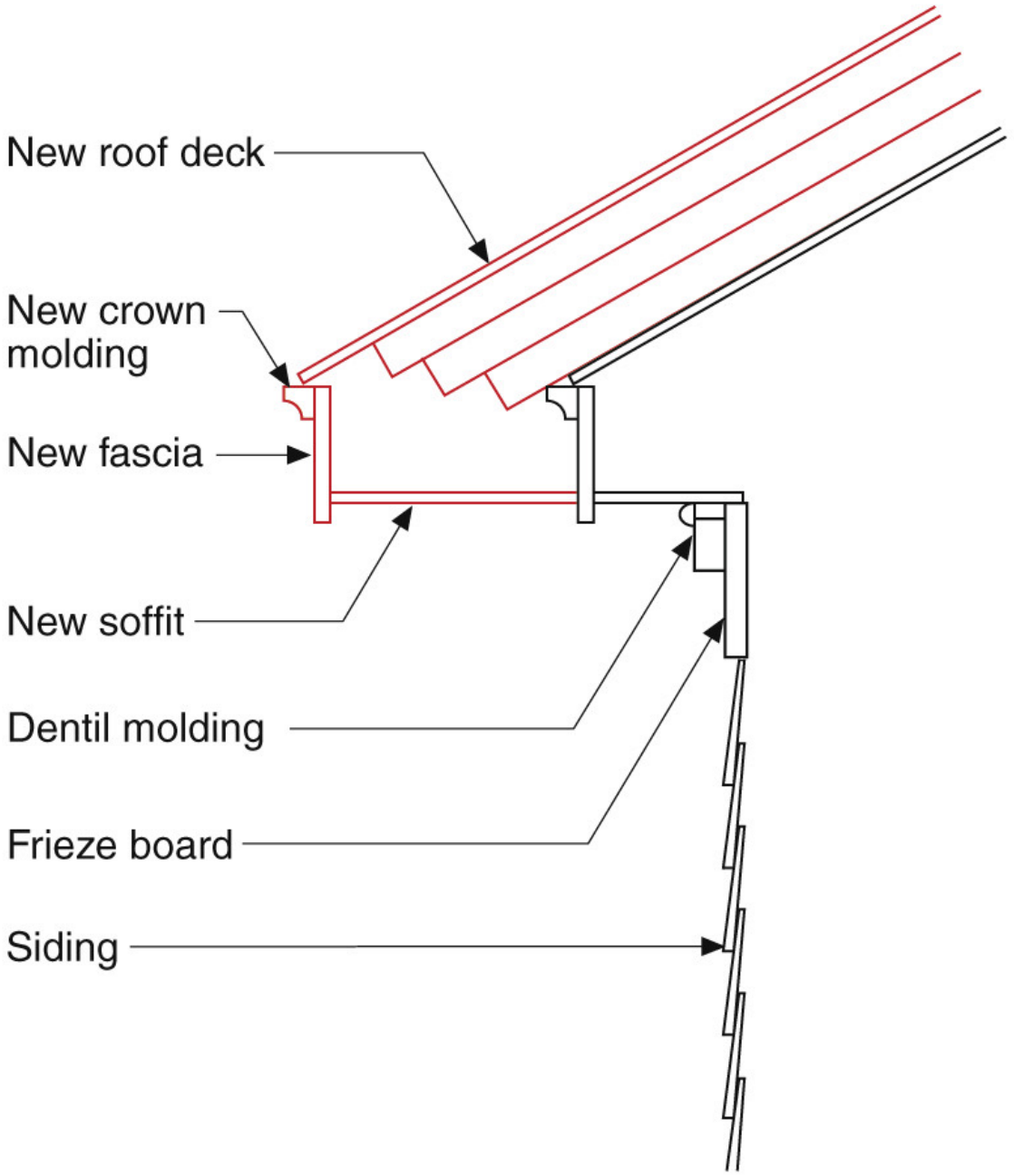


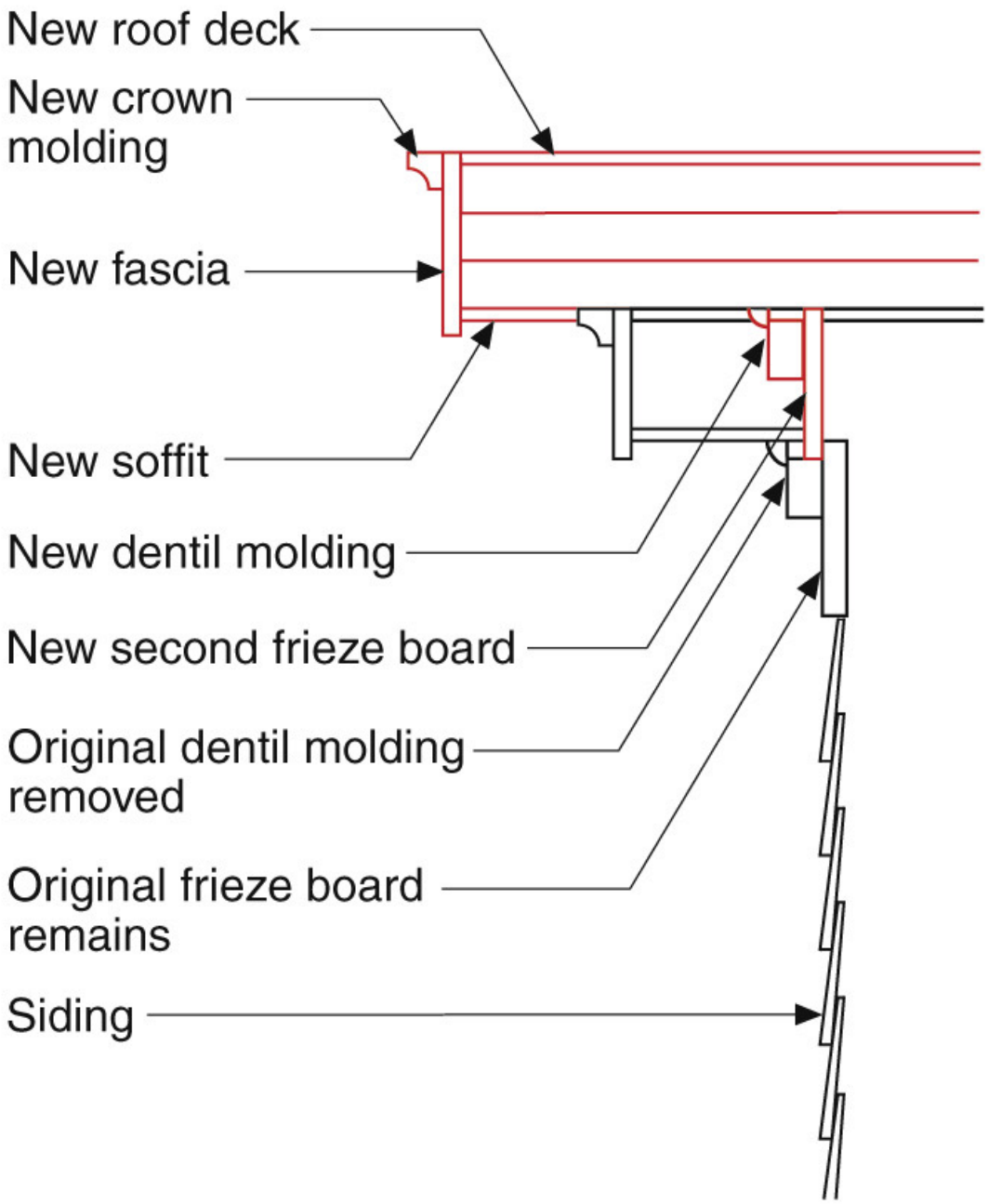









New roof deck
New crown molding
New fascia
New soffit
Dentil molding
Frieze board
Siding


New roof deck
New crown molding
New fascia
New soffit
New dentil molding
New second frieze board
Original dentil molding removed
Original frieze board remains
Siding
















DOW
BRAND





R-70 roof

R-30 wall

R-20 Basement

R-10 Slab

2 ach @ 50 Pa

- 80 percent efficient power vented sealed combustion gas boiler for heating and domestic hot water
- Radiant hot water baseboard heating
- 15 SEER a/c
- ERV (no dehumidifier, no humidifier)
- Direct vented bathrooms/vented range hood

Wood burning fireplace

