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

Building Science

Adventures In Building Science

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Freeze-Thaw Damage

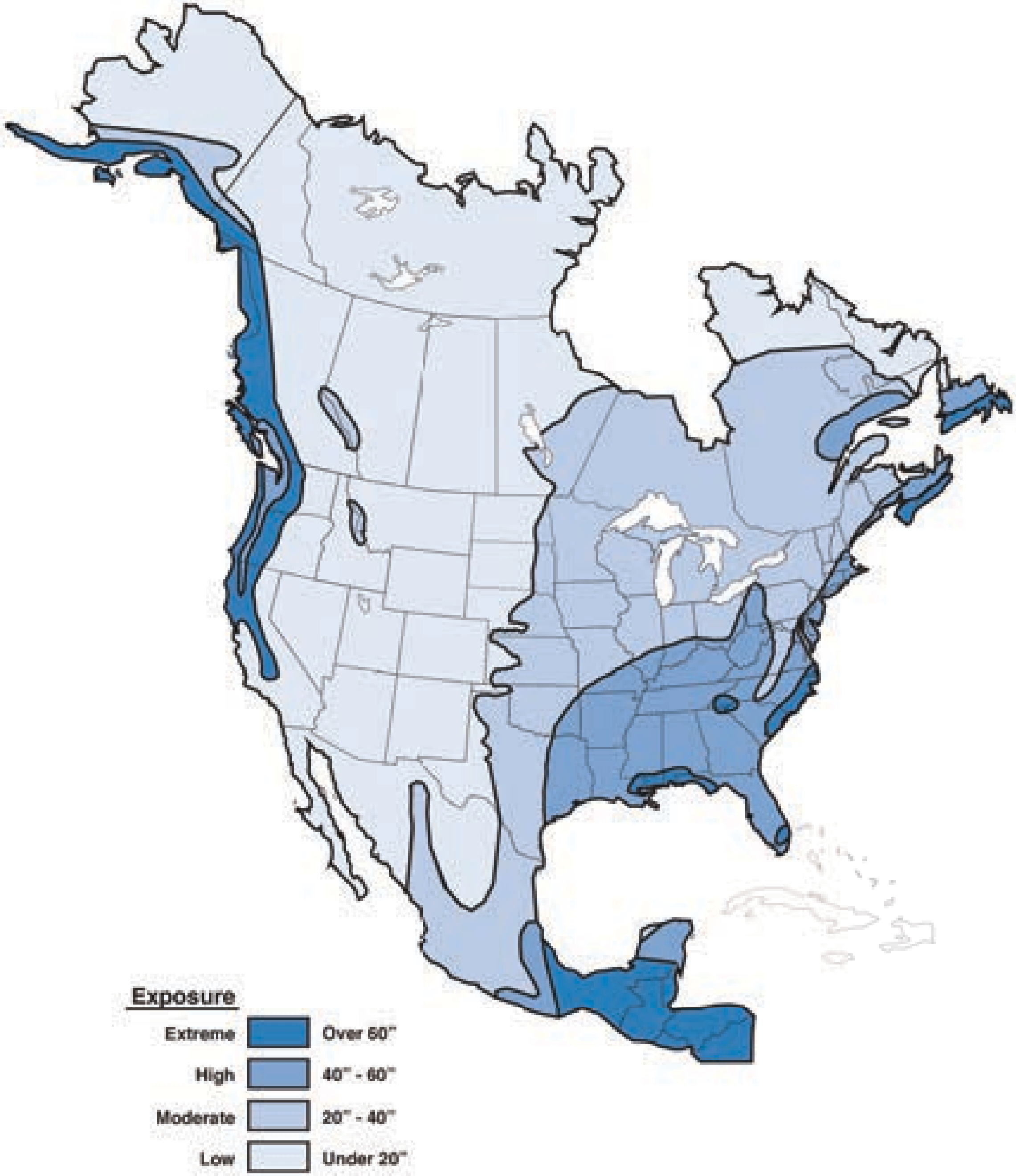
Freeze-Thaw Damage

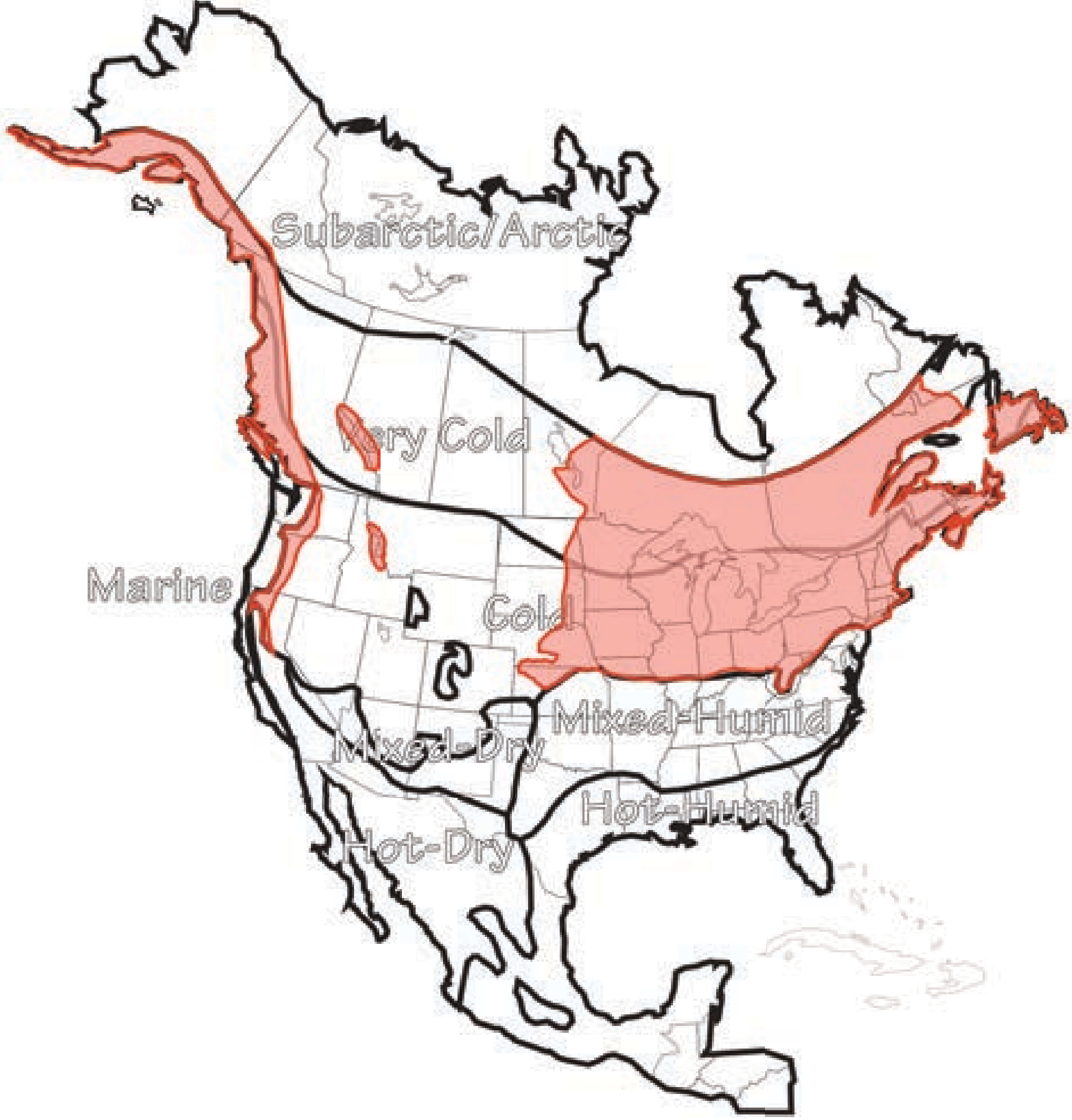
Freezing Temperatures

Water

Susceptible Brick


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

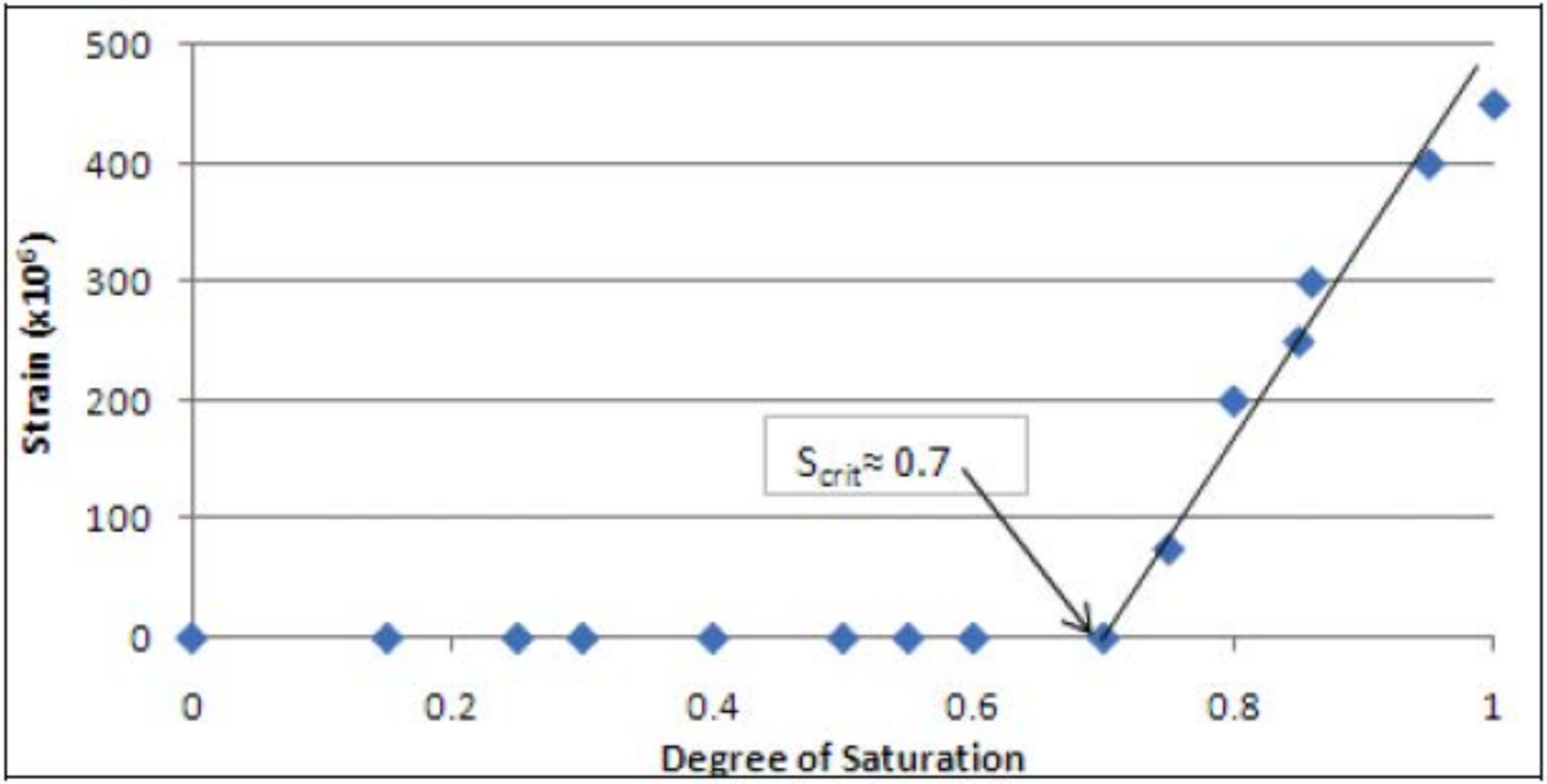

Exposure
Extreme
Over 60"
High
40" - 60"
Moderate
20" - 40"
Low
Under 20"


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

Susceptible Brick

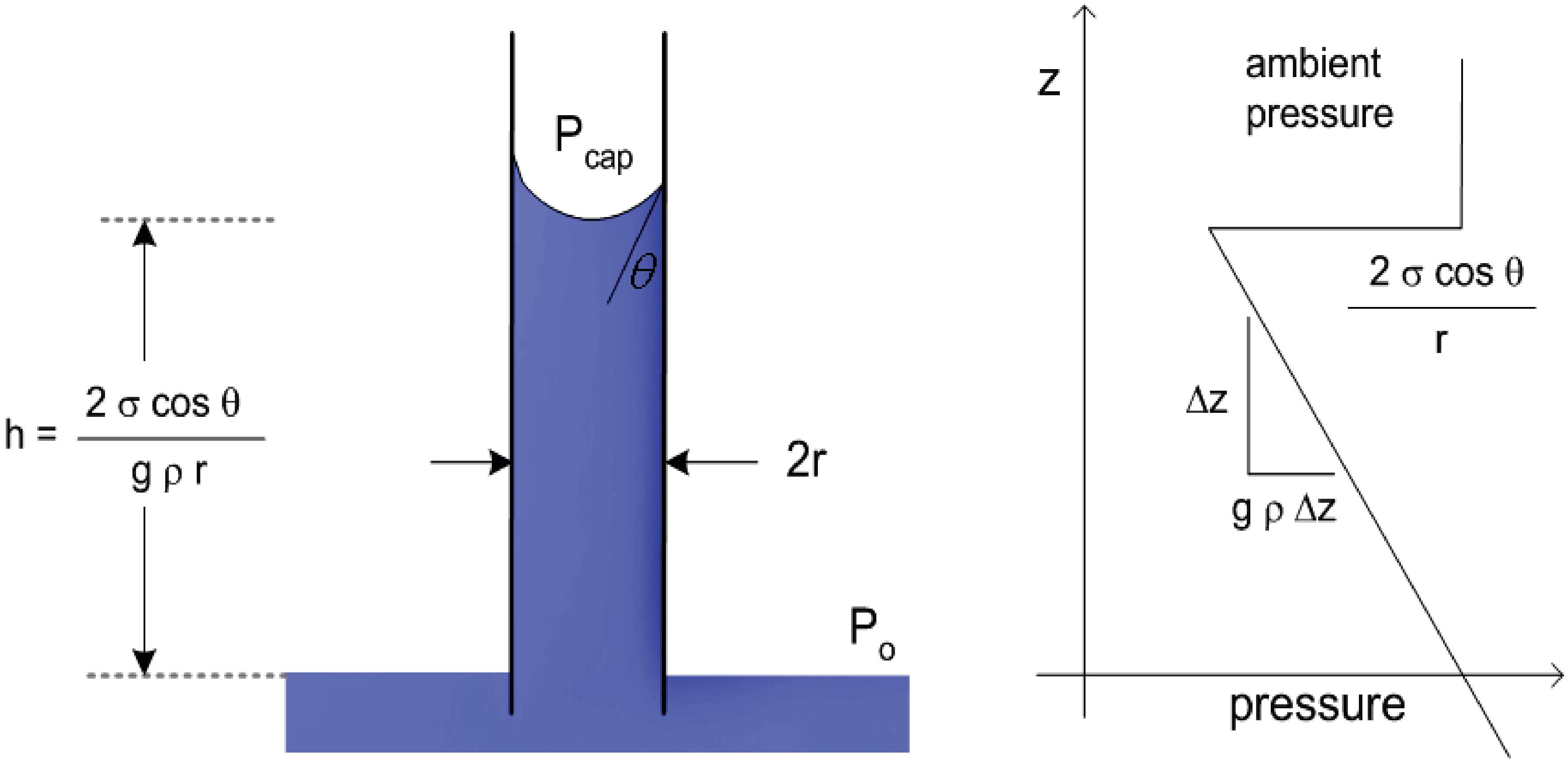
Firing Temperature

Vitrification

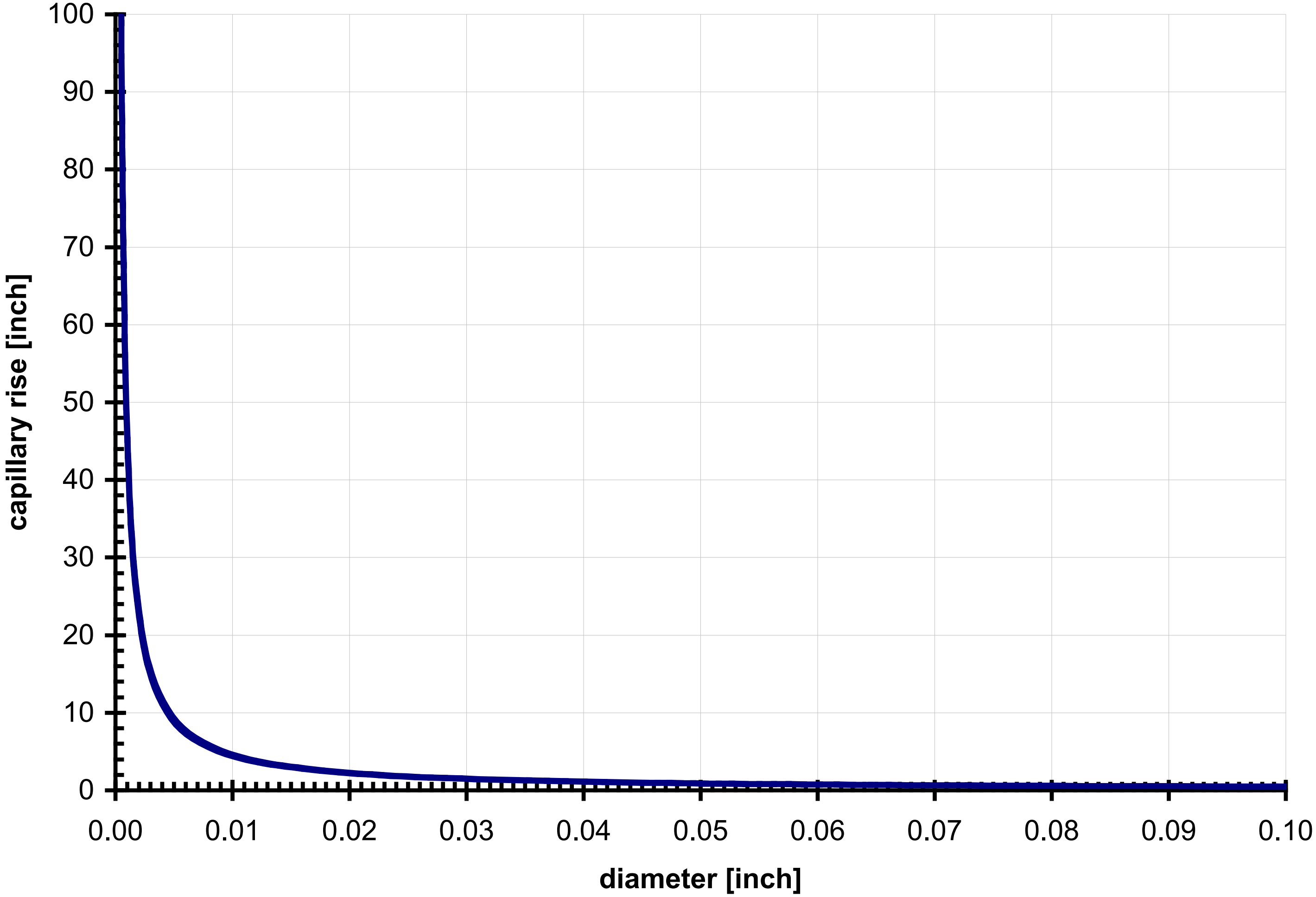

500
400
300
200
100
0
Strain (x10⁶)
0
0.2
0.4
0.6
0.8
1
Degree of Saturation
$S_{crit} \approx 0.7$

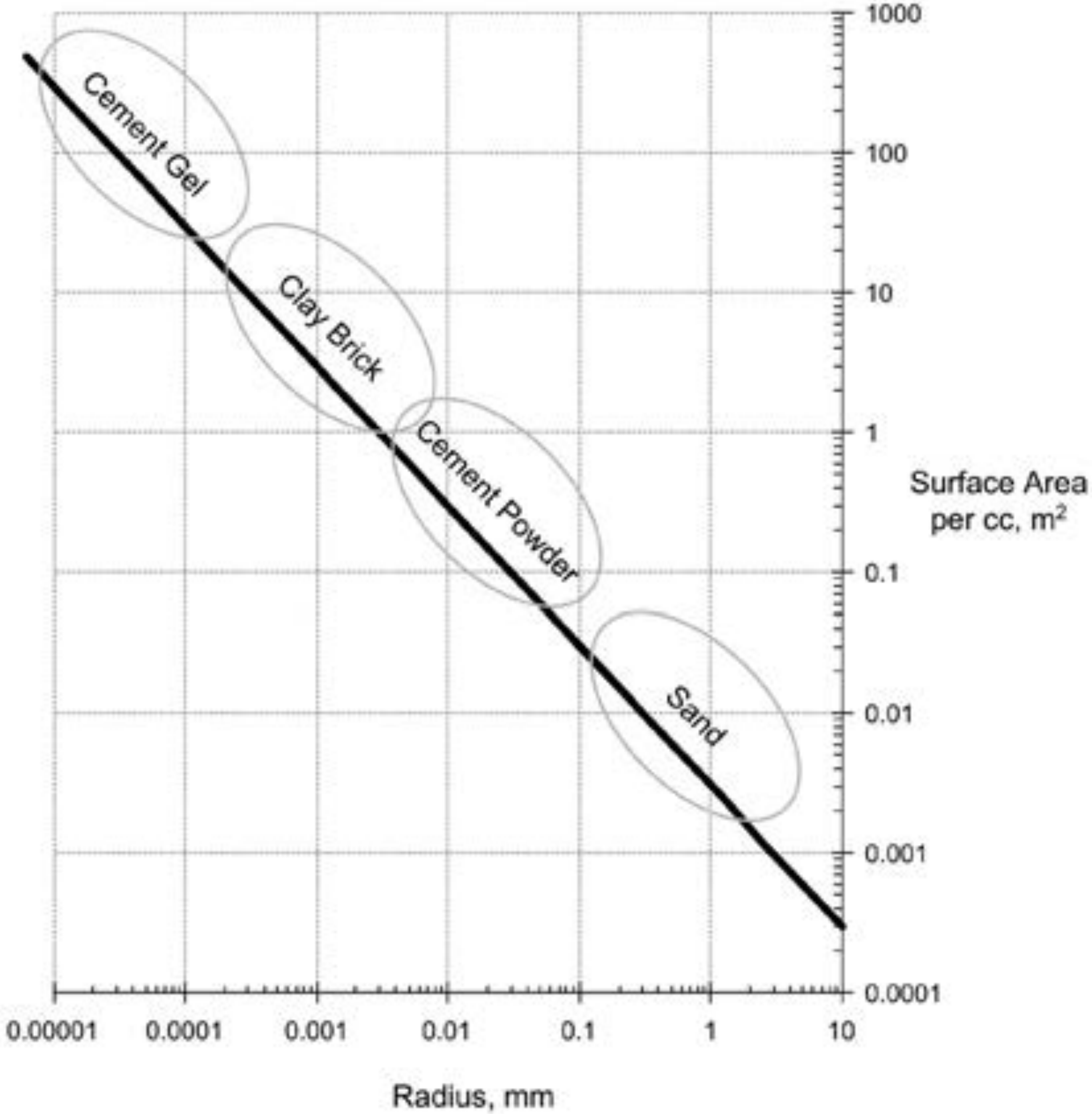

CZ6WC
3.84295
ON/OFF
ABS/INC
mm/inch
SET
3-4" ASIMETO 0.00005"

Calculating capillary rise



Capillary rise versus diameter





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

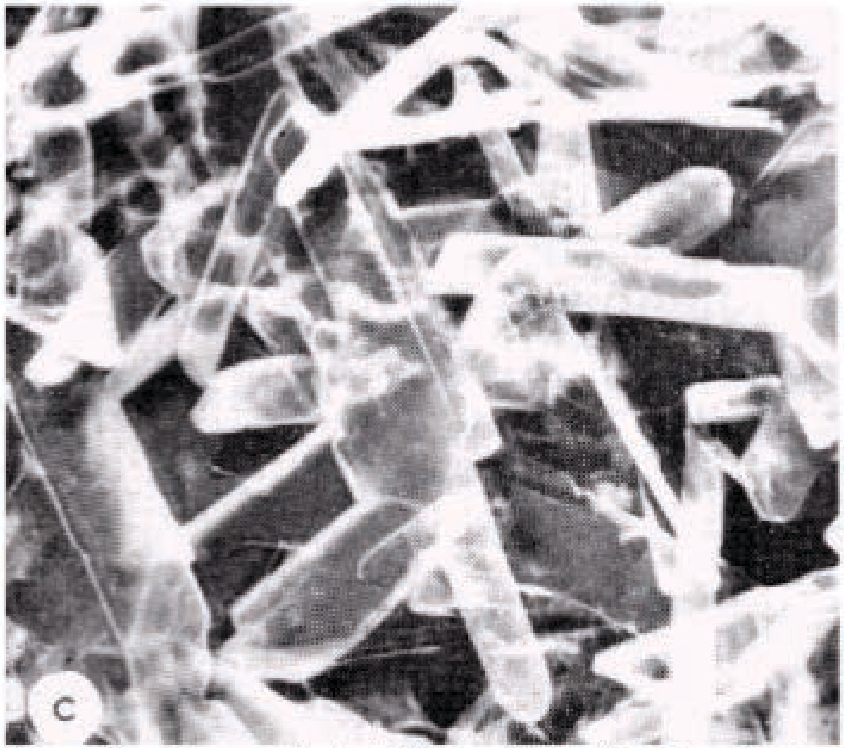


Figure 1c. Gypsum, hydrated from plaster of paris and water, porosity 30 per cent.

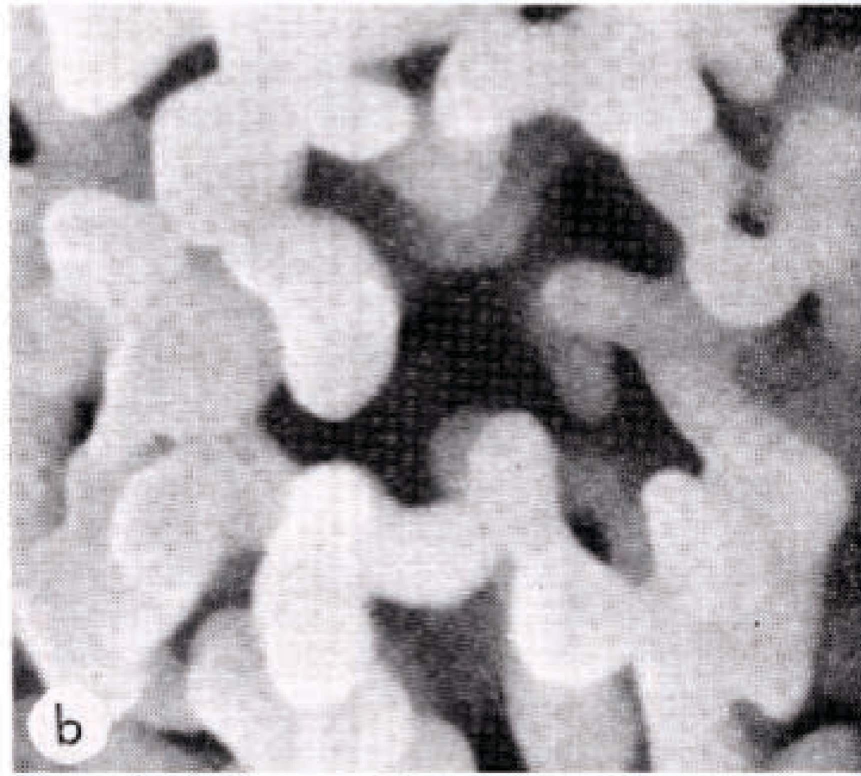
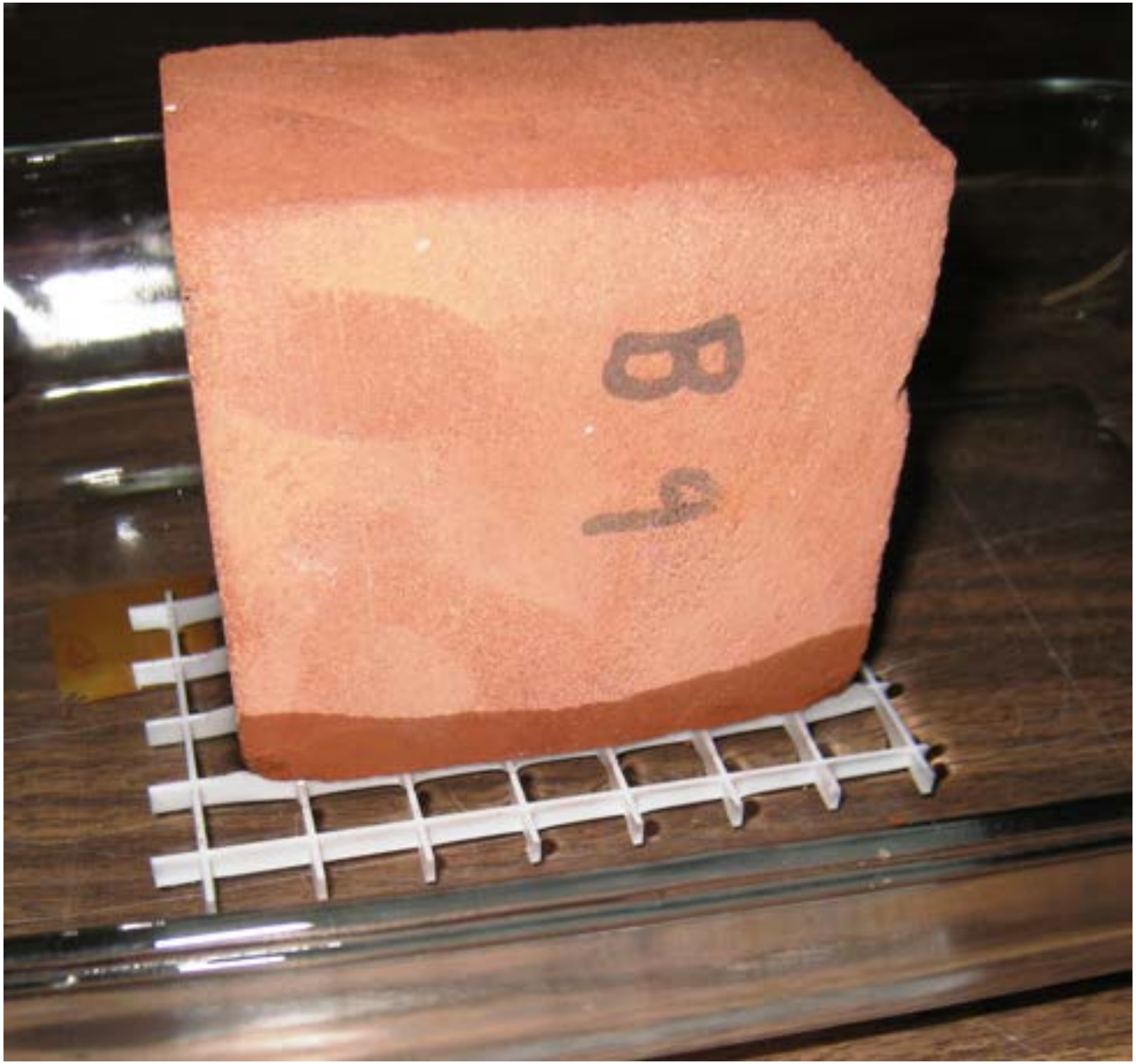
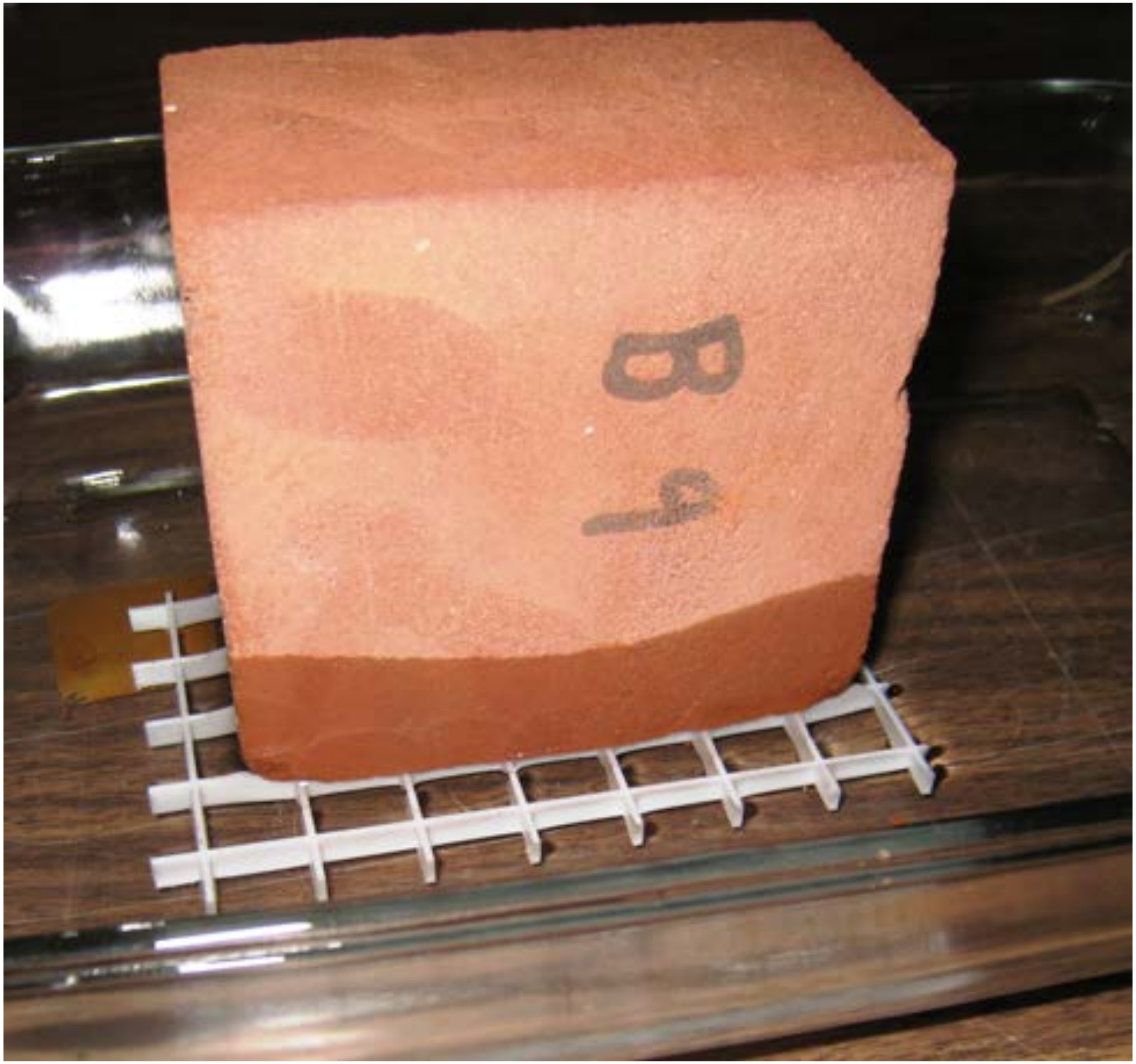
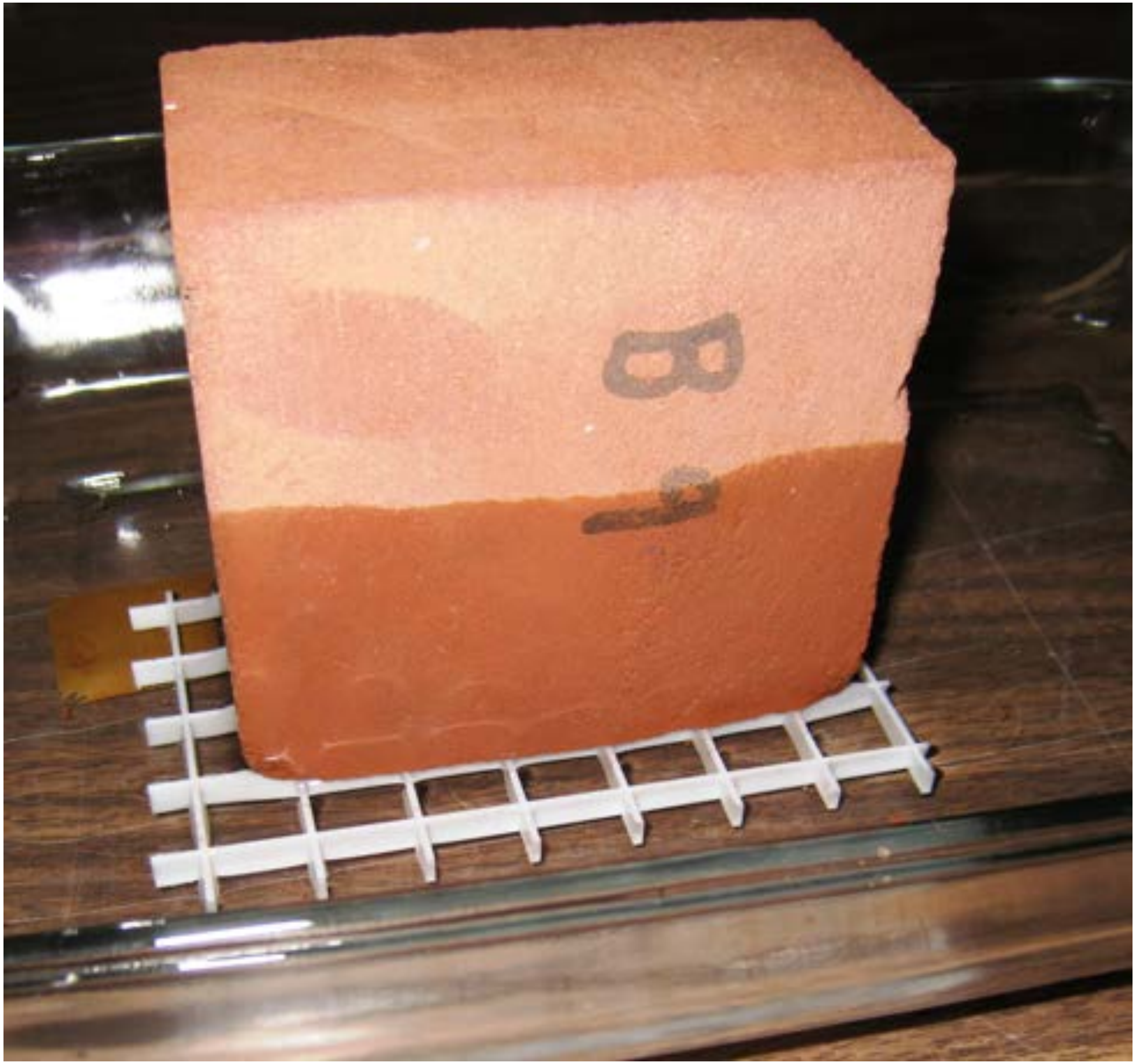
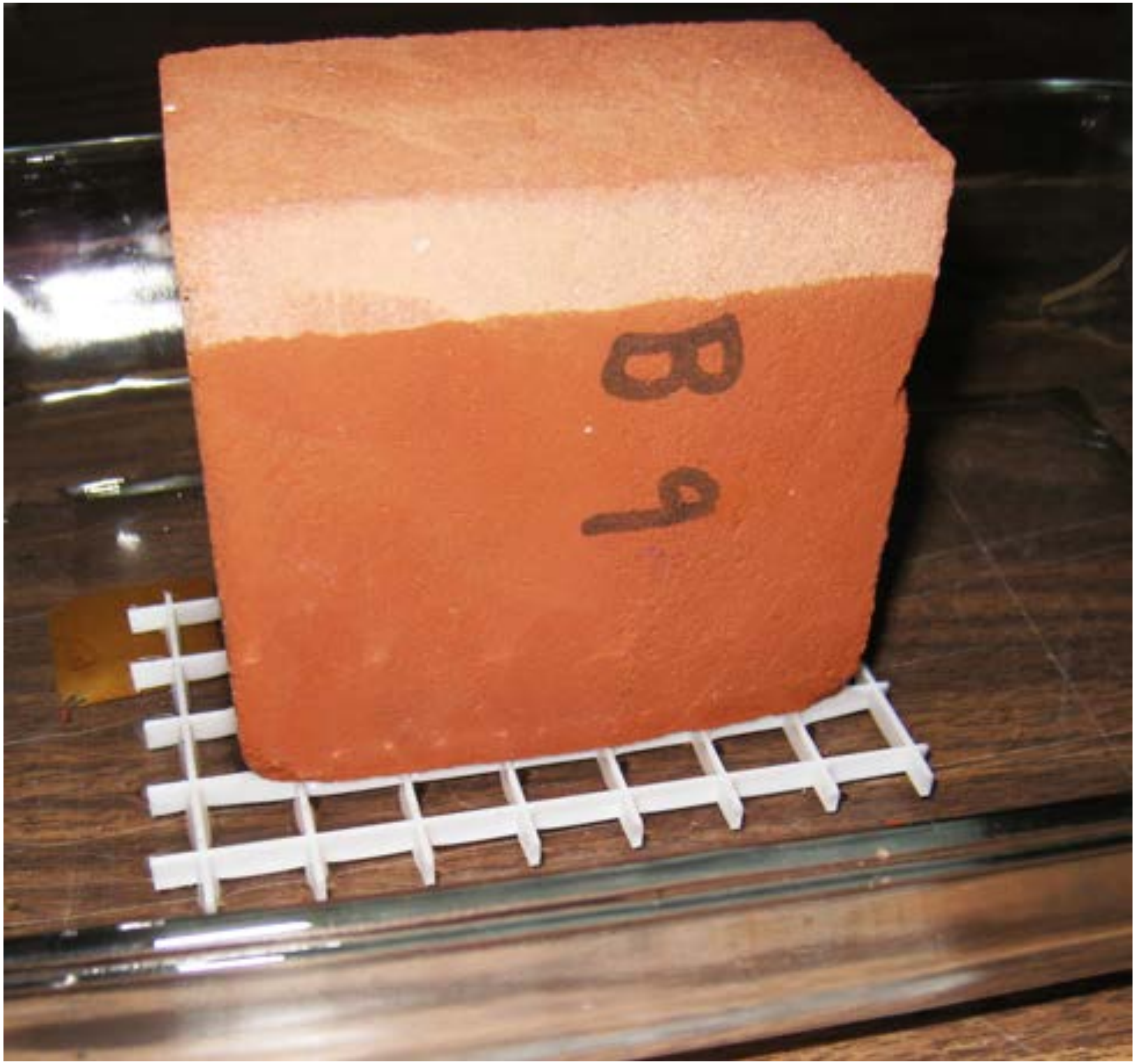


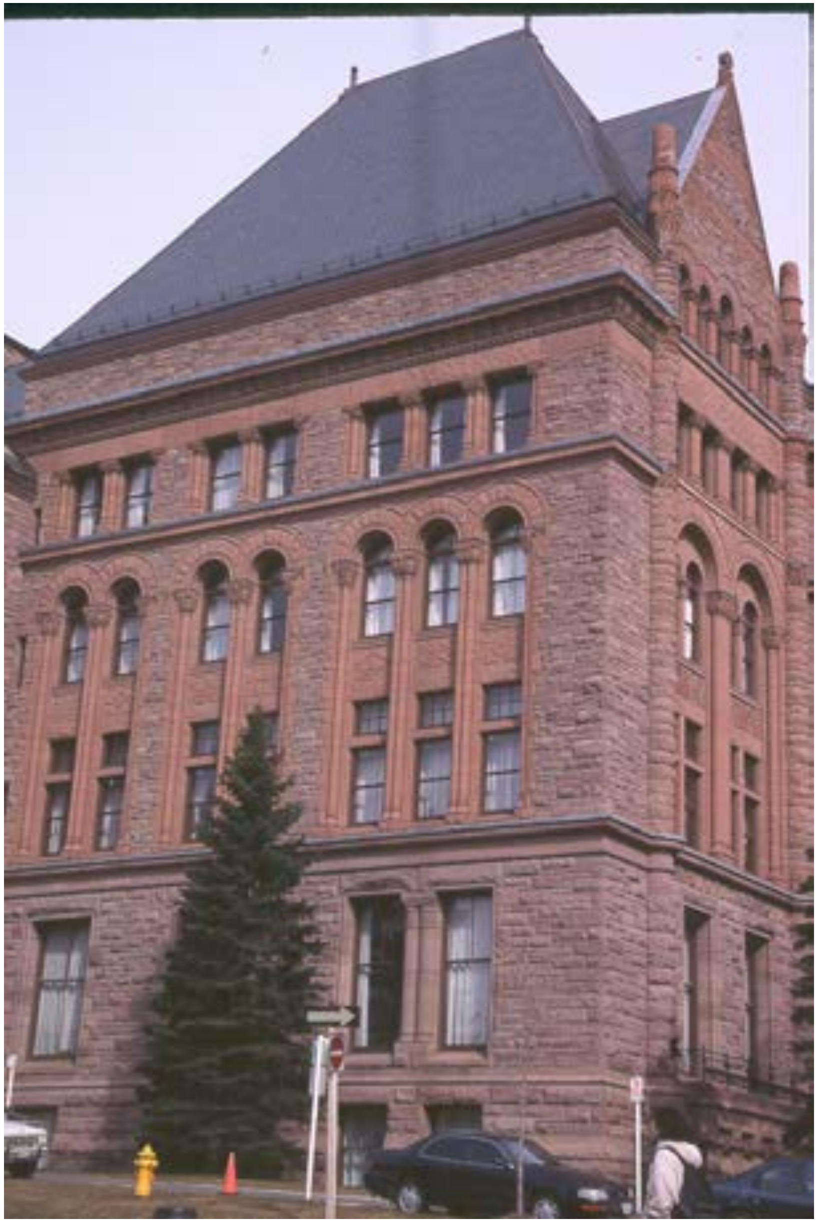
Figure 1b. Brick, sintered clay, porosity 40 per cent.

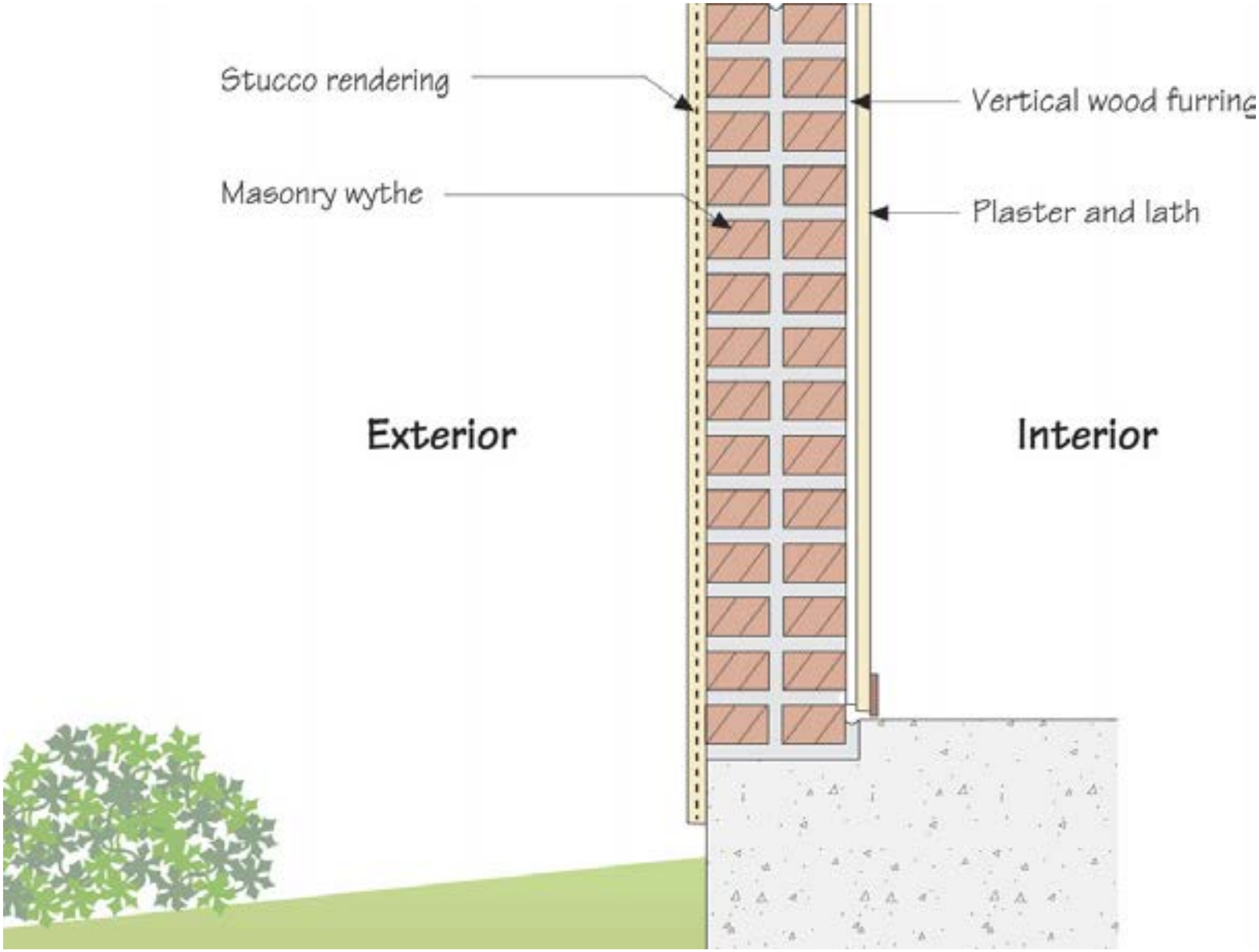

B9

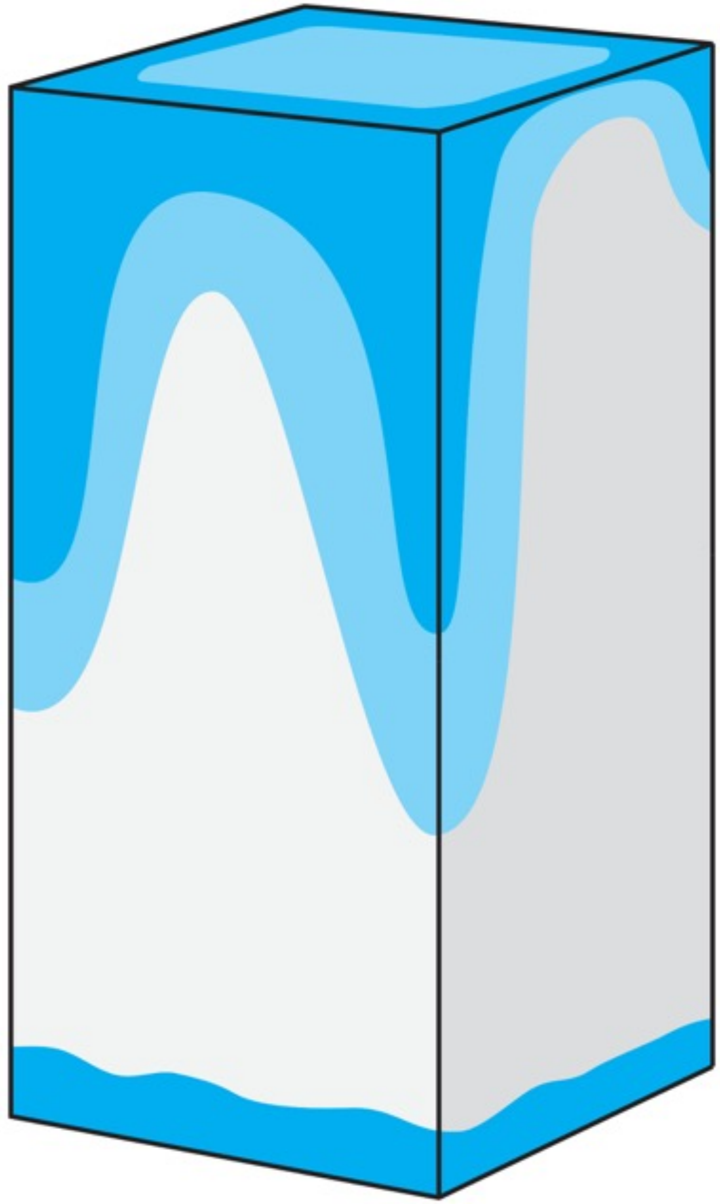

B
9

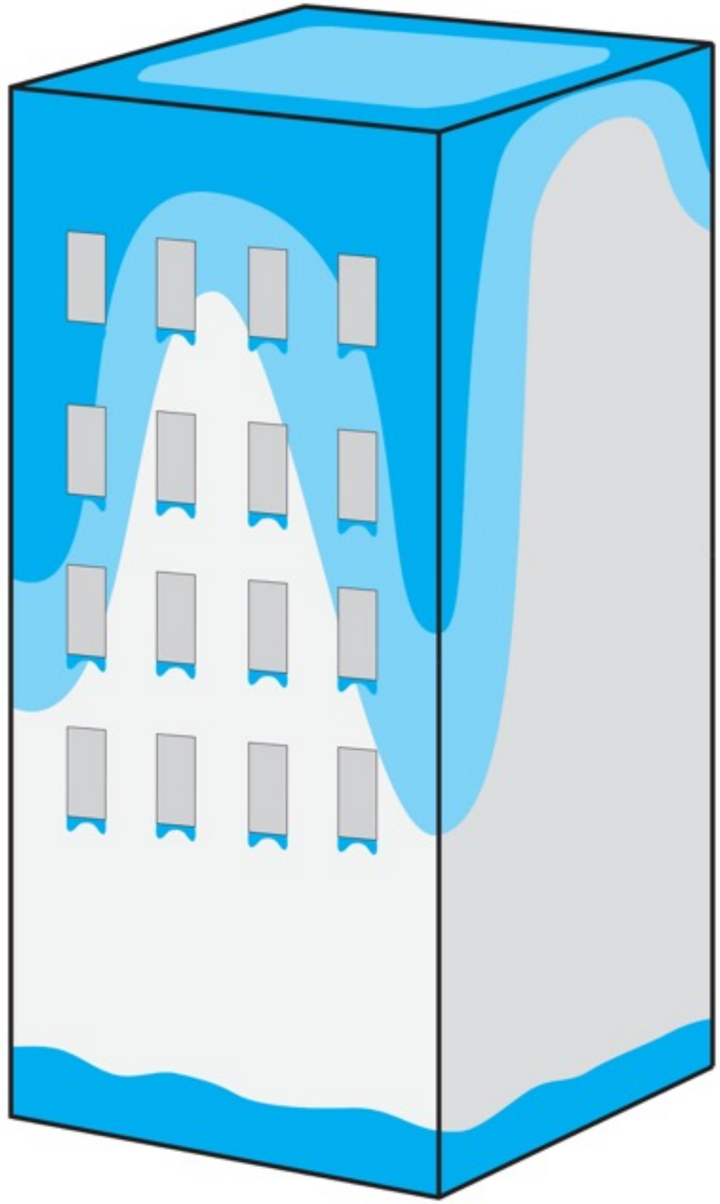

B
9


B 9

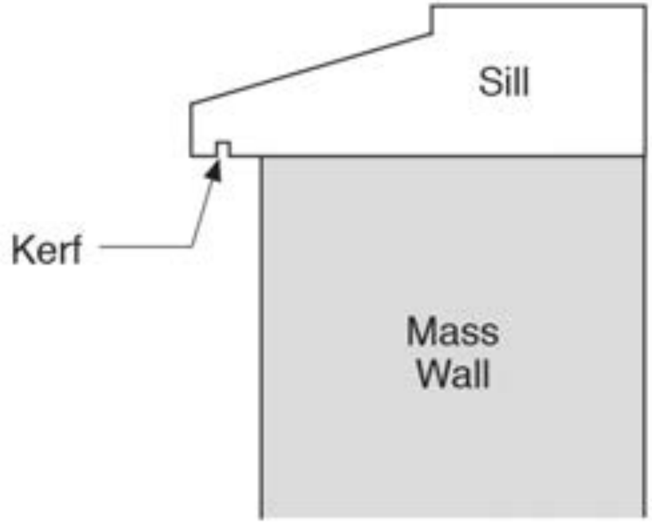


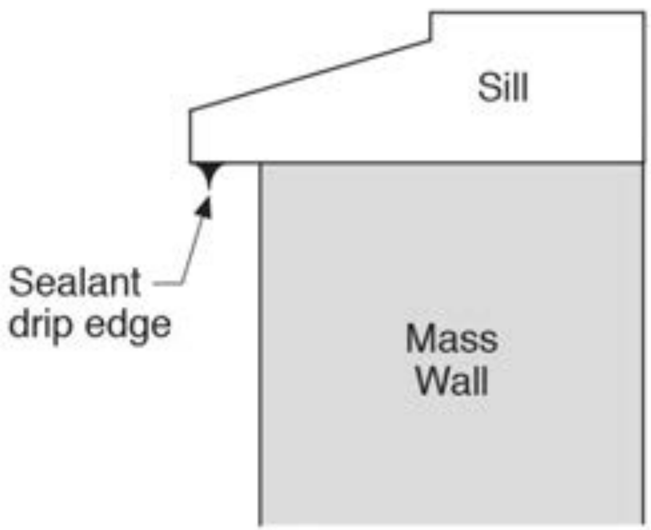

Stucco rendering
Masonry wythe
Vertical wood furring
Plaster and lath
Exterior
Interior

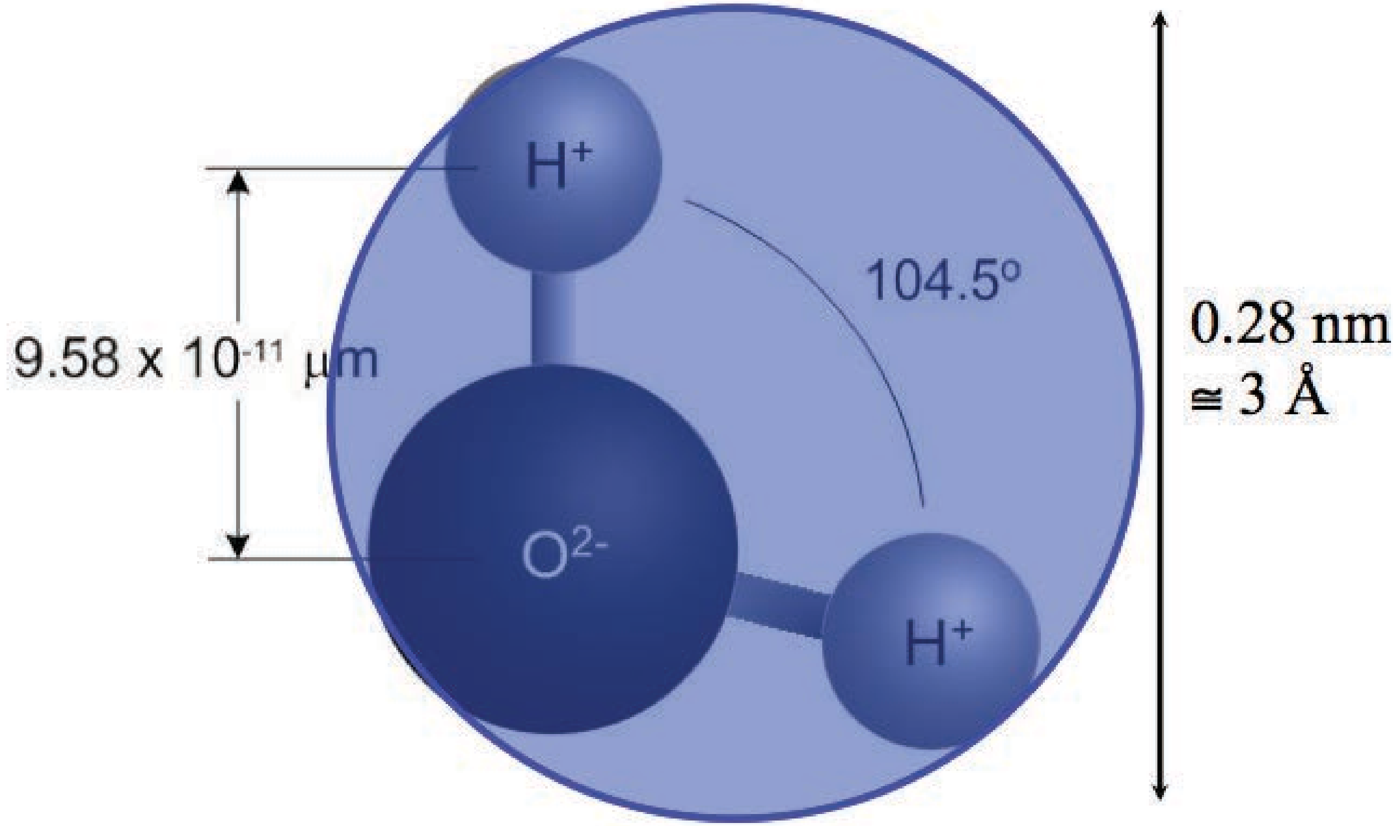


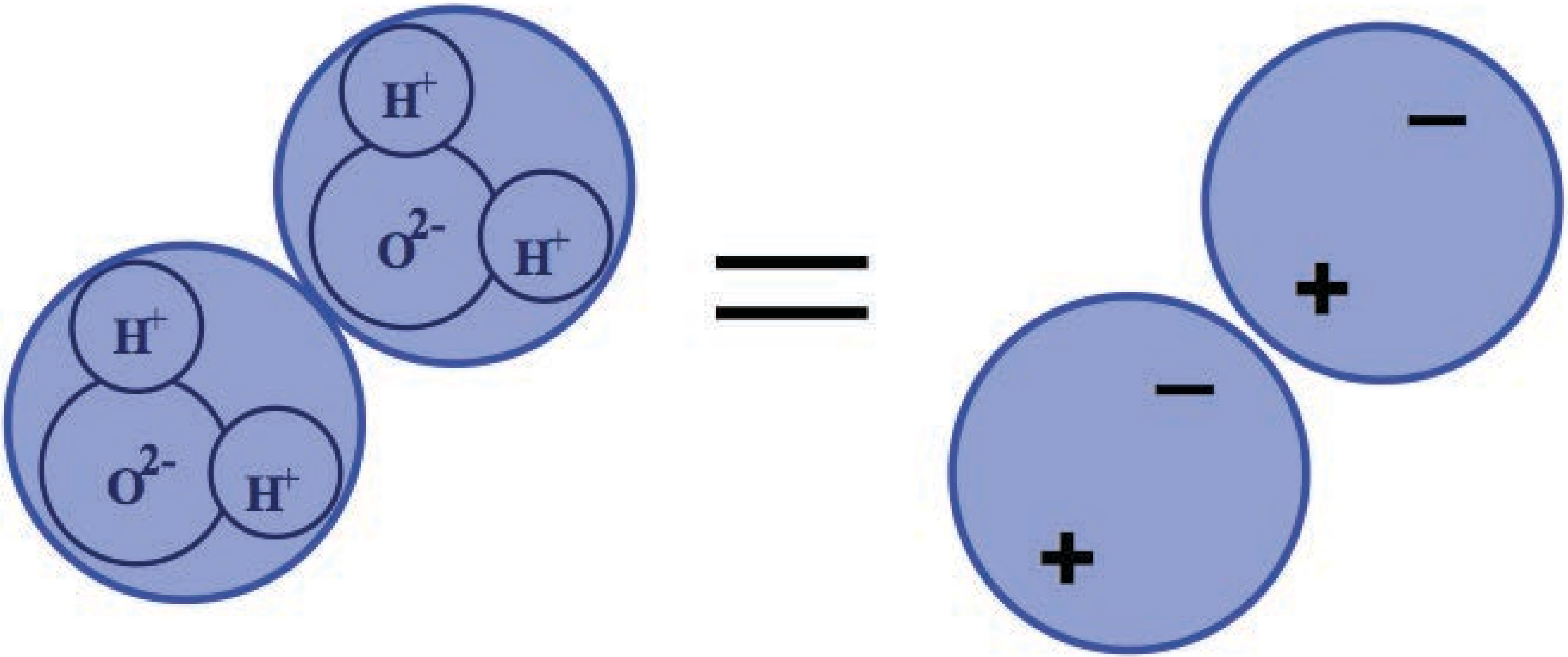


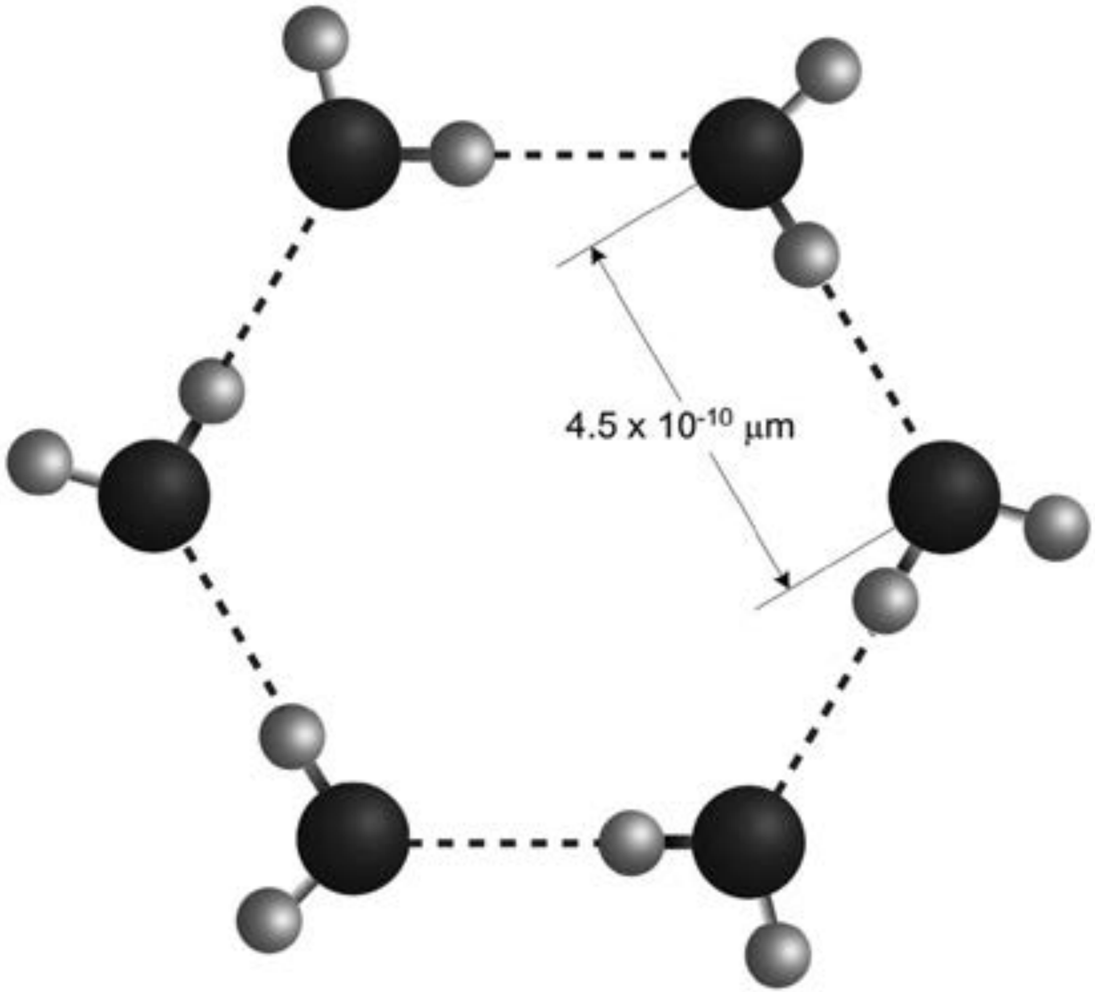

PHOENIX


Sill
Kerf
Mass
Wall


Sill
Sealant
drip edge
Mass
Wall


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


H+
O2-
H+
H+
O2-
H+
=
−
+
−
+


4.5 x 10-10 µm

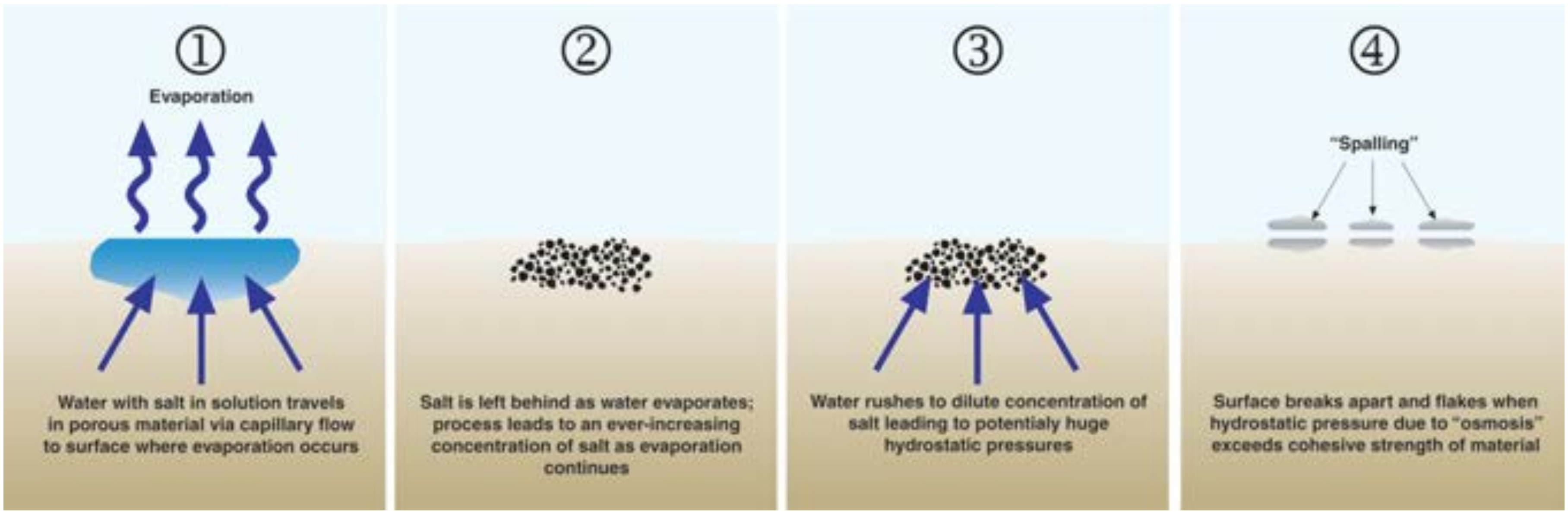
2nd Law of Thermodynamics

Moisture Transport in Porous Media

Phase	Transport Process	Driving Potential
Vapor	Diffusion	Vapor Concentration
Adsorbate	Surface Diffusion	Concentration
Liquid	Capillary Flow	Suction Pressure
	Osmosis	Solute Concentration

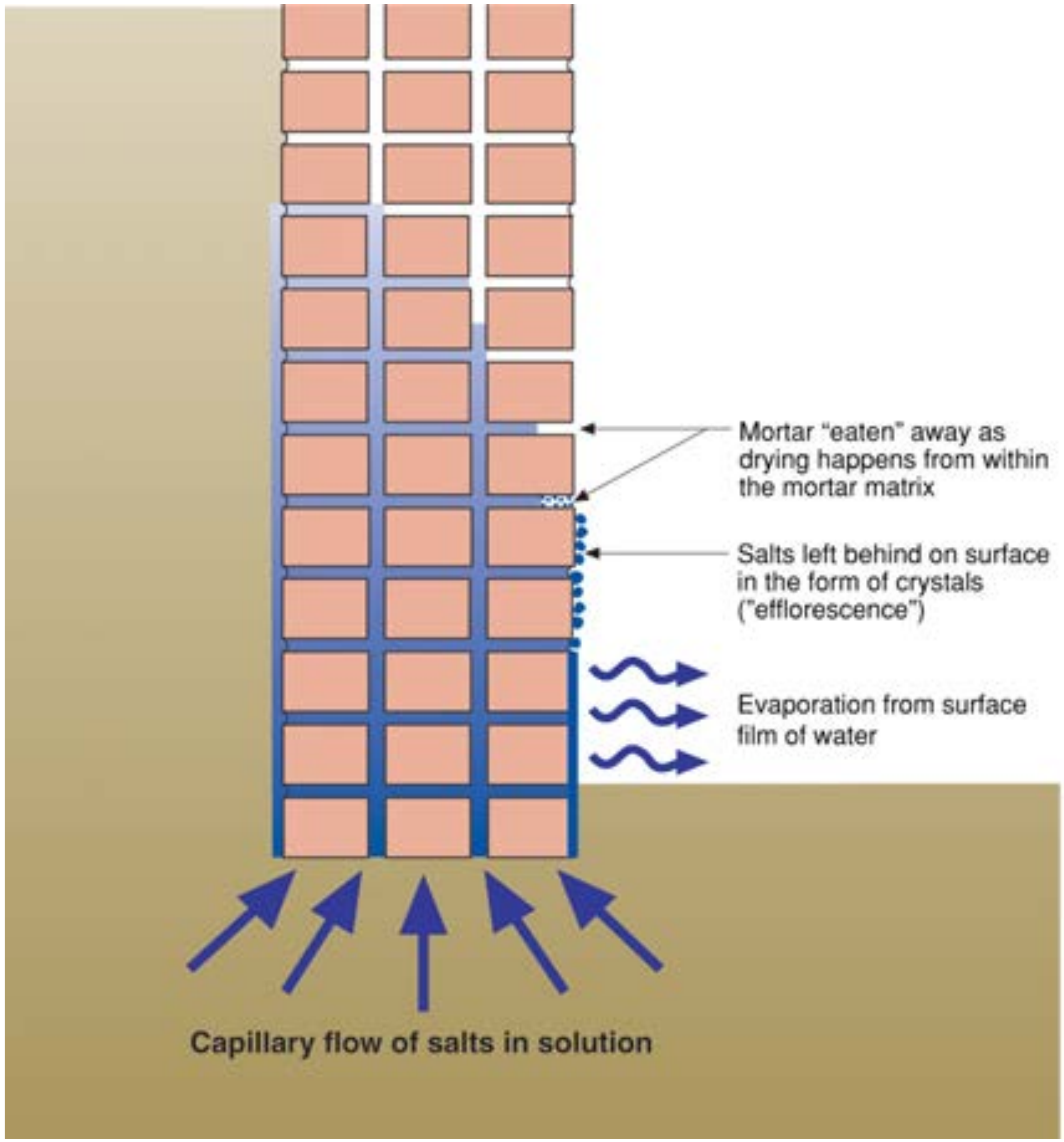
Capillarity + Salt = Osmosis

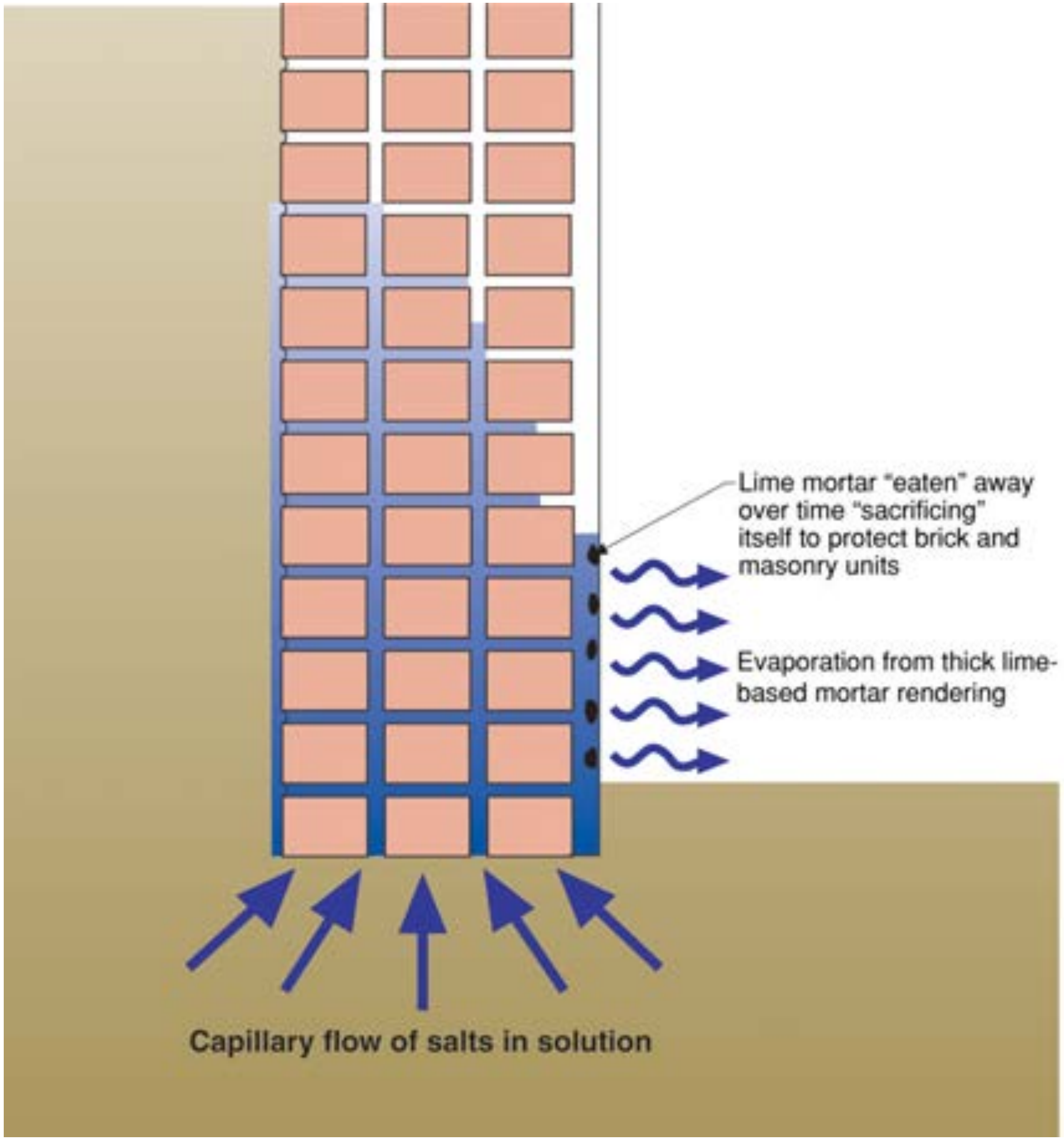
- Mineral salts carried in solution by capillary water
- When water evaporates from a surface the salts left behind form crystals in process called efflorescence
- When water evaporated beneath a surface the salts crystallize within the pore structure of the material in called sub-efflorescence
- The salt crystallization causes expansive forces that can exceed the cohesive strength of the material leading to spalling


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

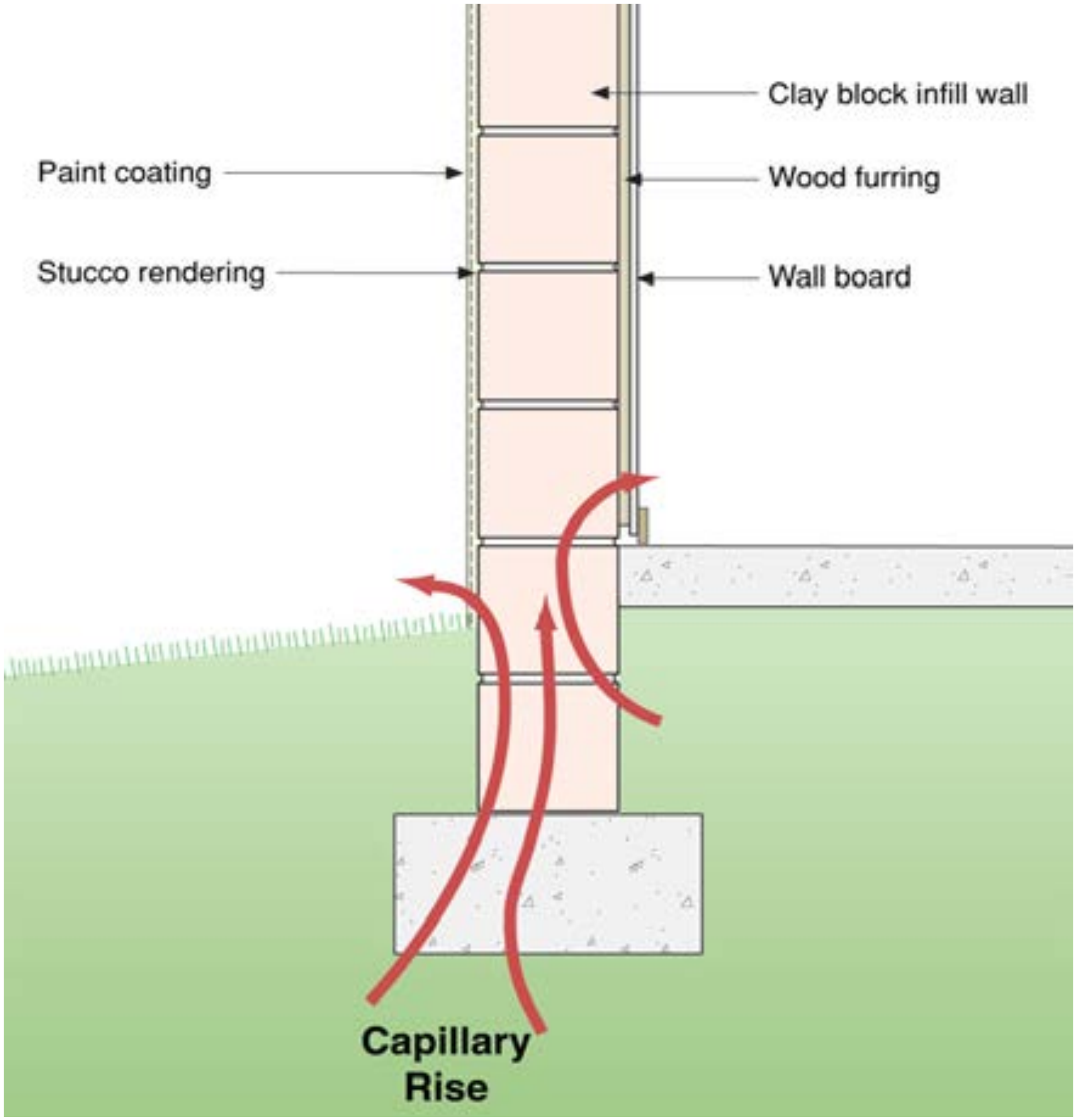
• Diffusion Vapor Pressure	3 to 5 psi
• Capillary Pressure	300 to 500 psi
• Osmosis Pressure	3,000 to 5,000 psi

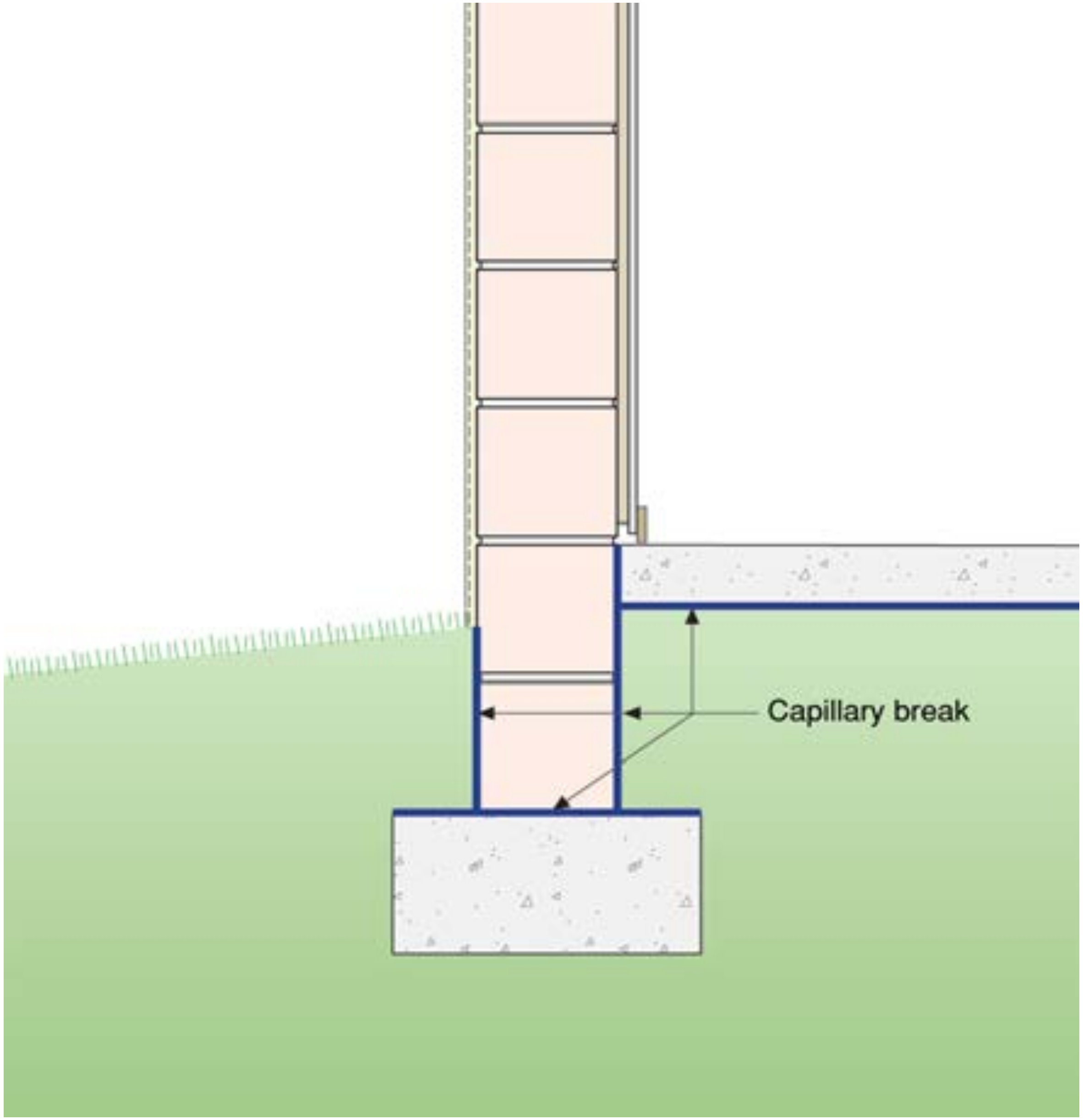

Mortar "eaten" away as drying happens from within the mortar matrix
Salts left behind on surface in the form of crystals ("efflorescence")
Evaporation from surface film of water
Capillary flow of salts in solution

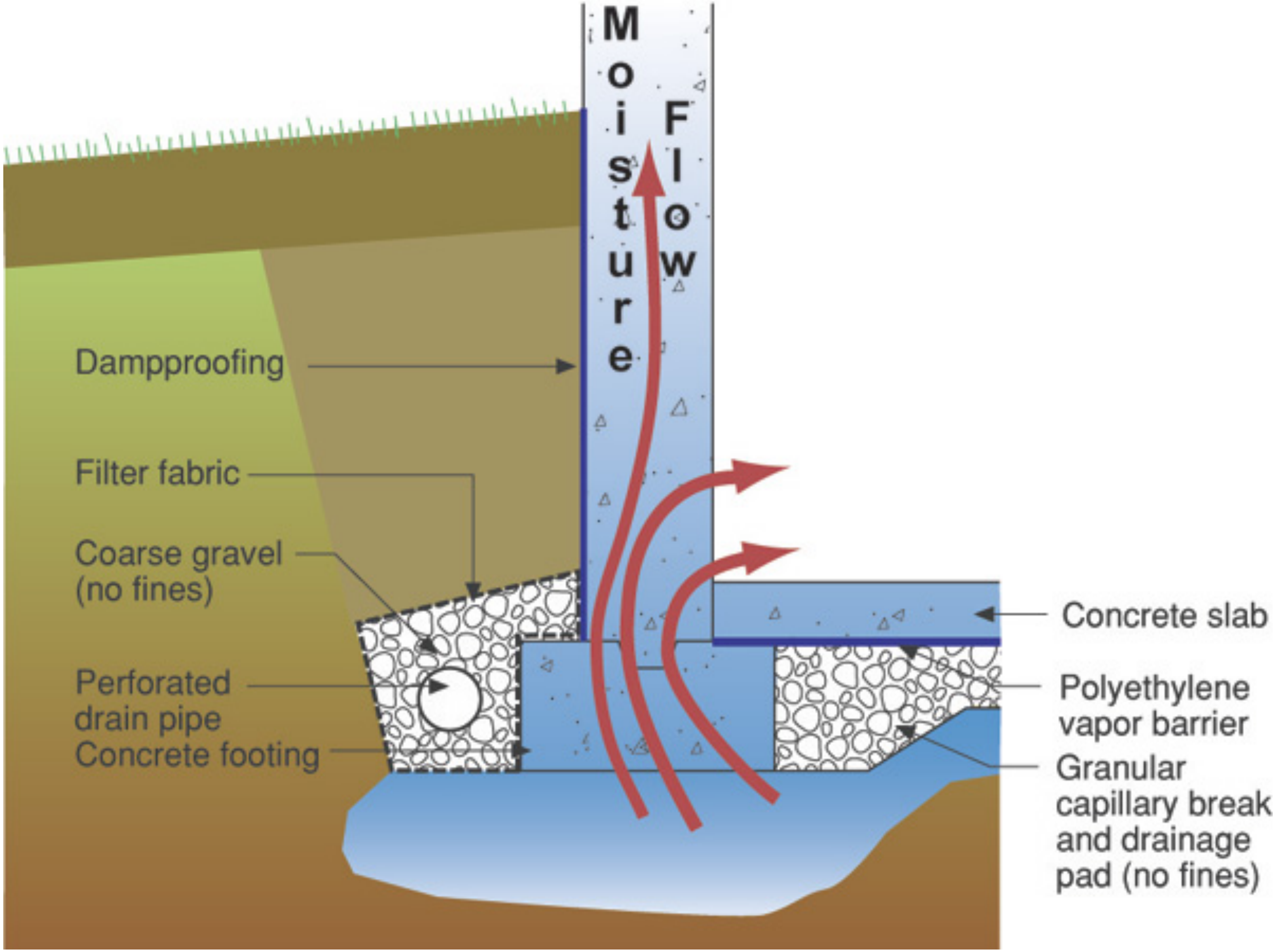

Lime mortar “eaten” away
over time “sacrificing”
itself to protect brick and
masonry units
Evaporation from thick lime-
based mortar rendering
Capillary flow of salts in solution

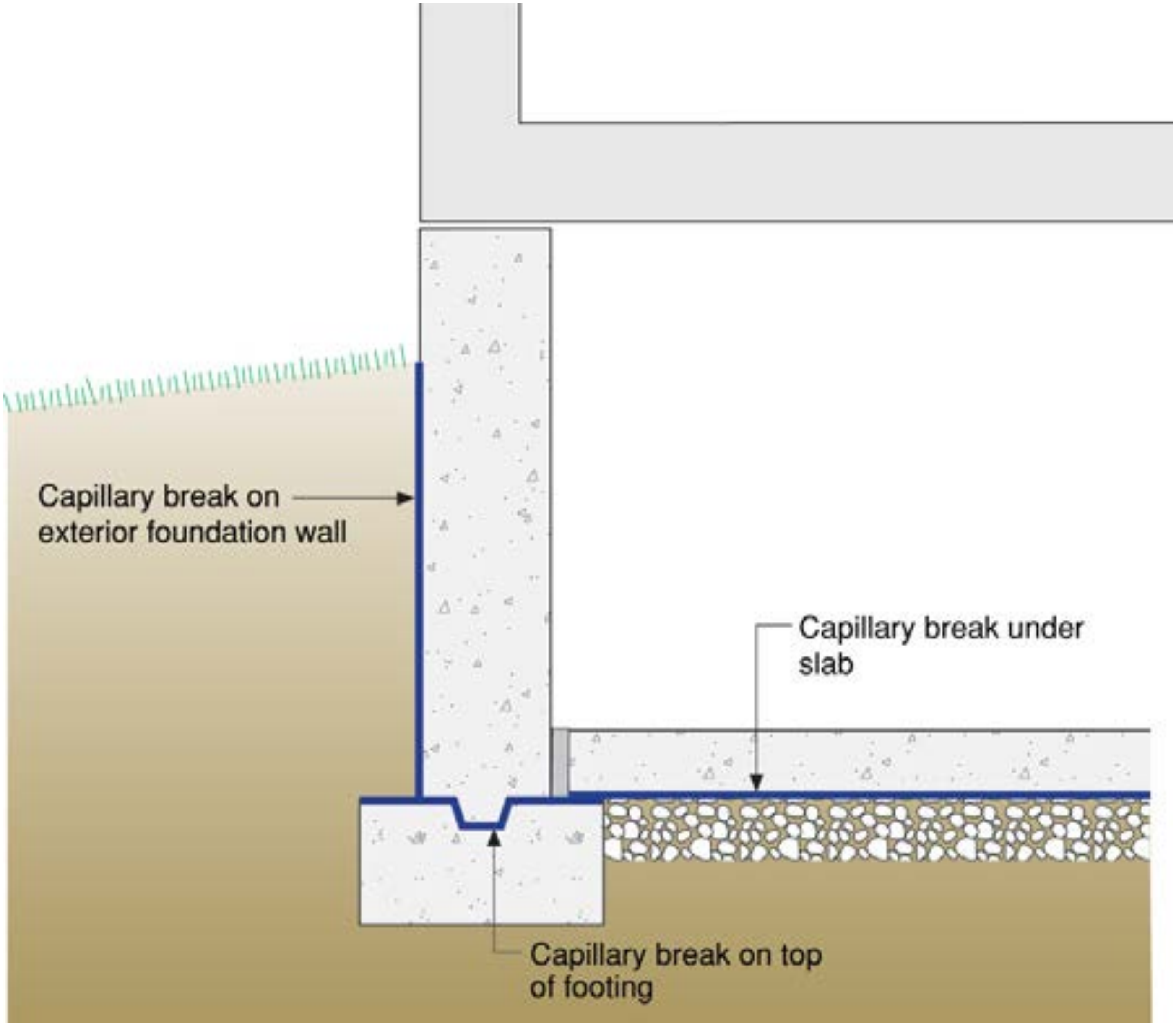

RA 200


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

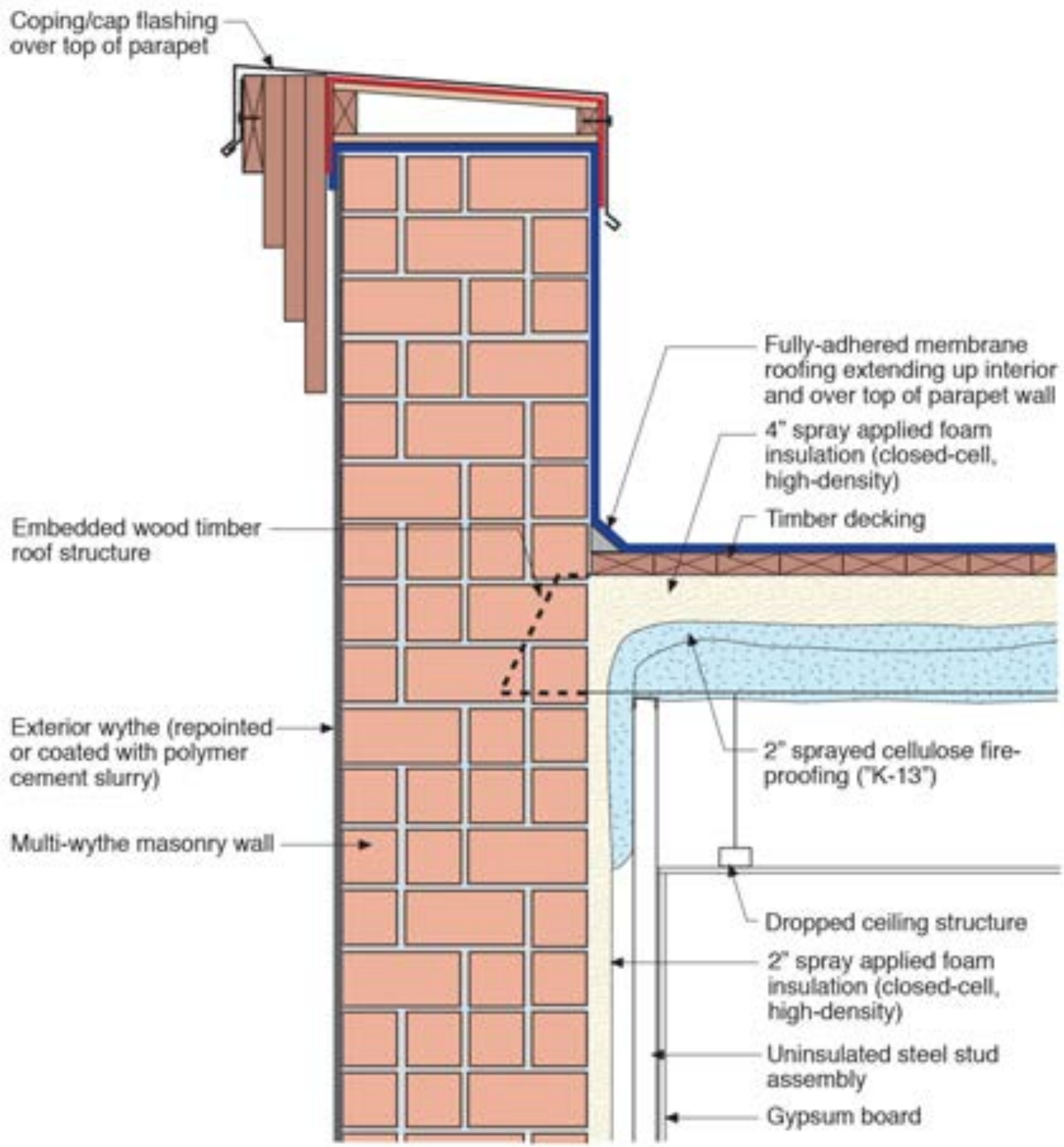

Clay block infill wall
Paint coating
Wood furring
Stucco rendering
Wall board
Capillary Rise

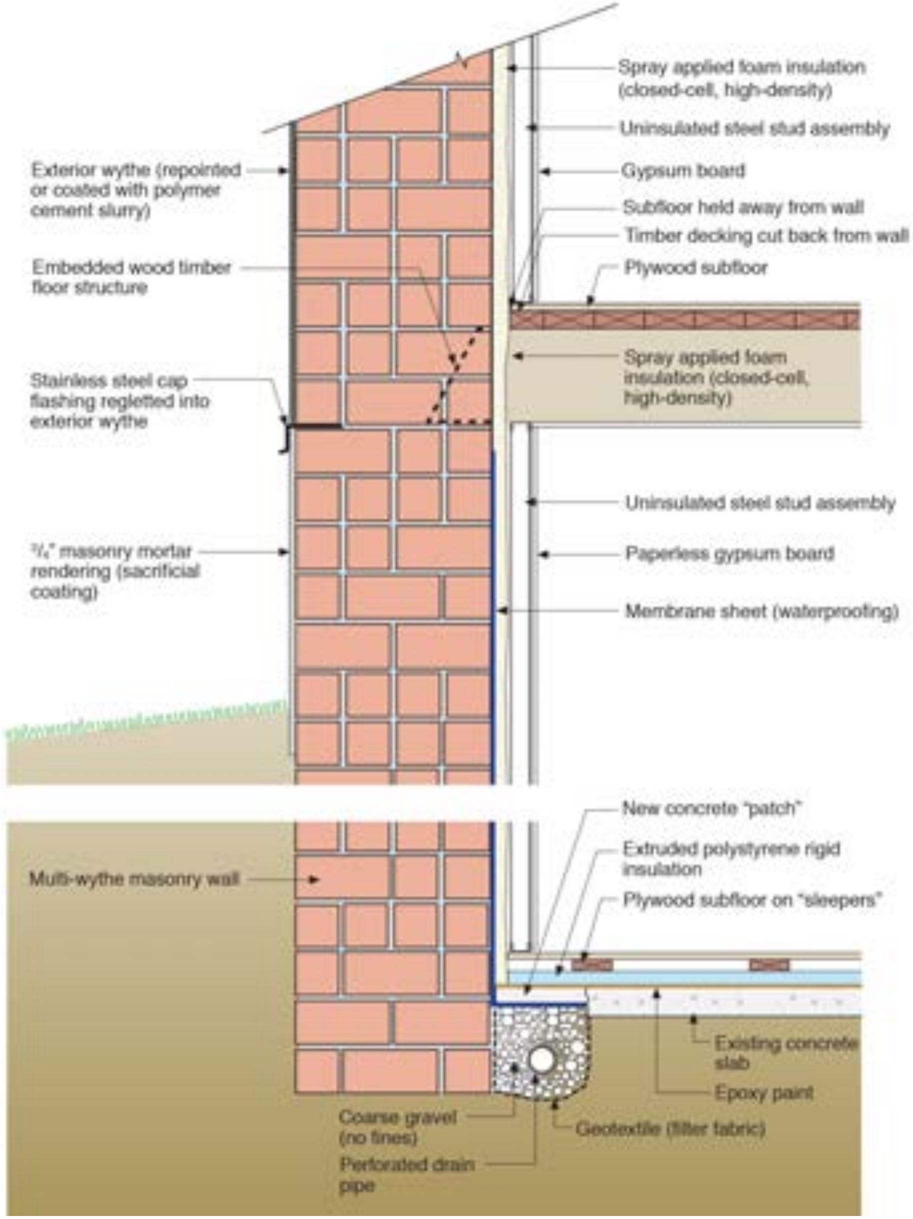

Capillary break

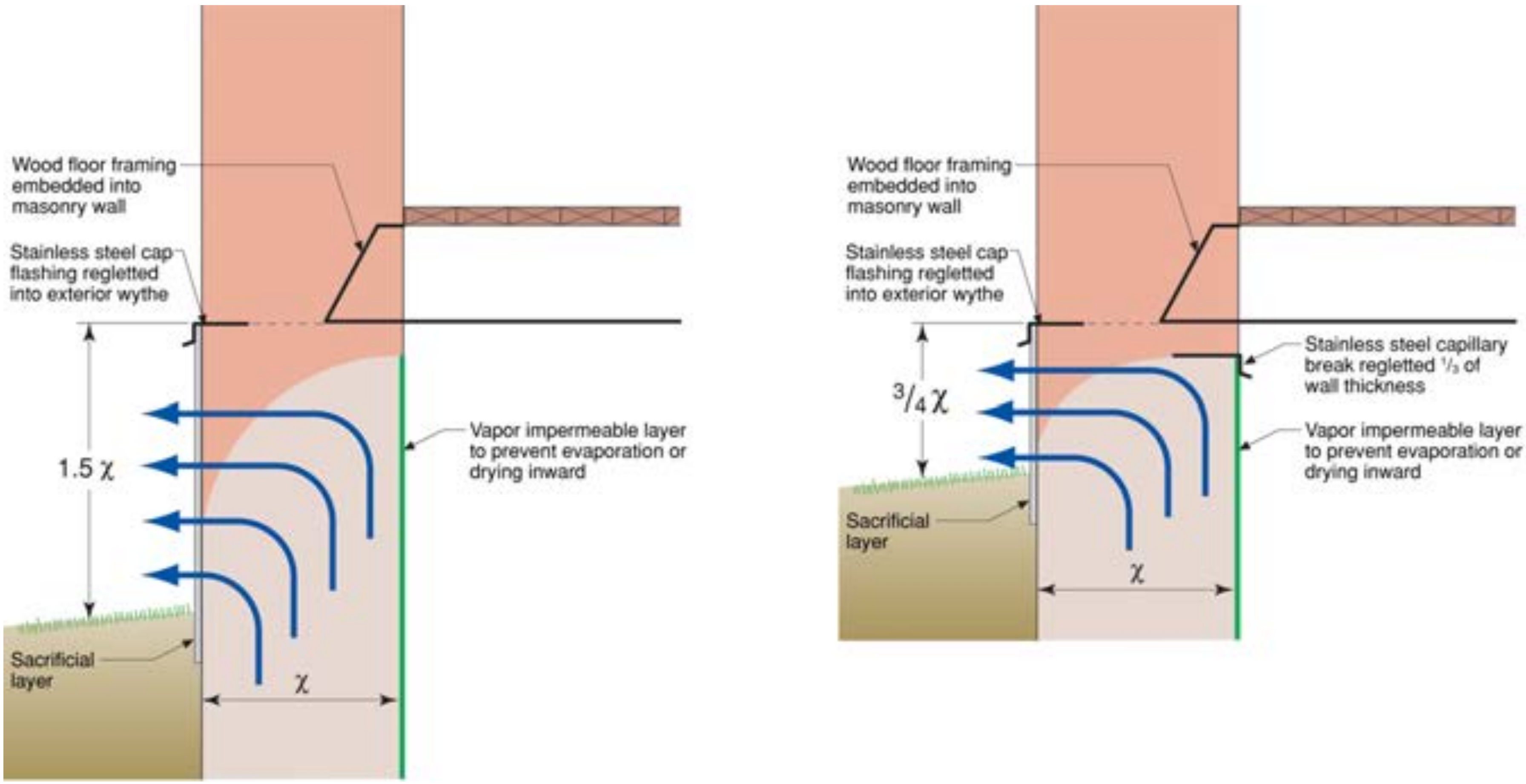

Moisture Flow
Dampproofing
Filter fabric
Coarse gravel
(no fines)
Perforated
drain pipe
Concrete footing
Concrete slab
Polyethylene
vapor barrier
Granular
capillary break
and drainage
pad (no fines)

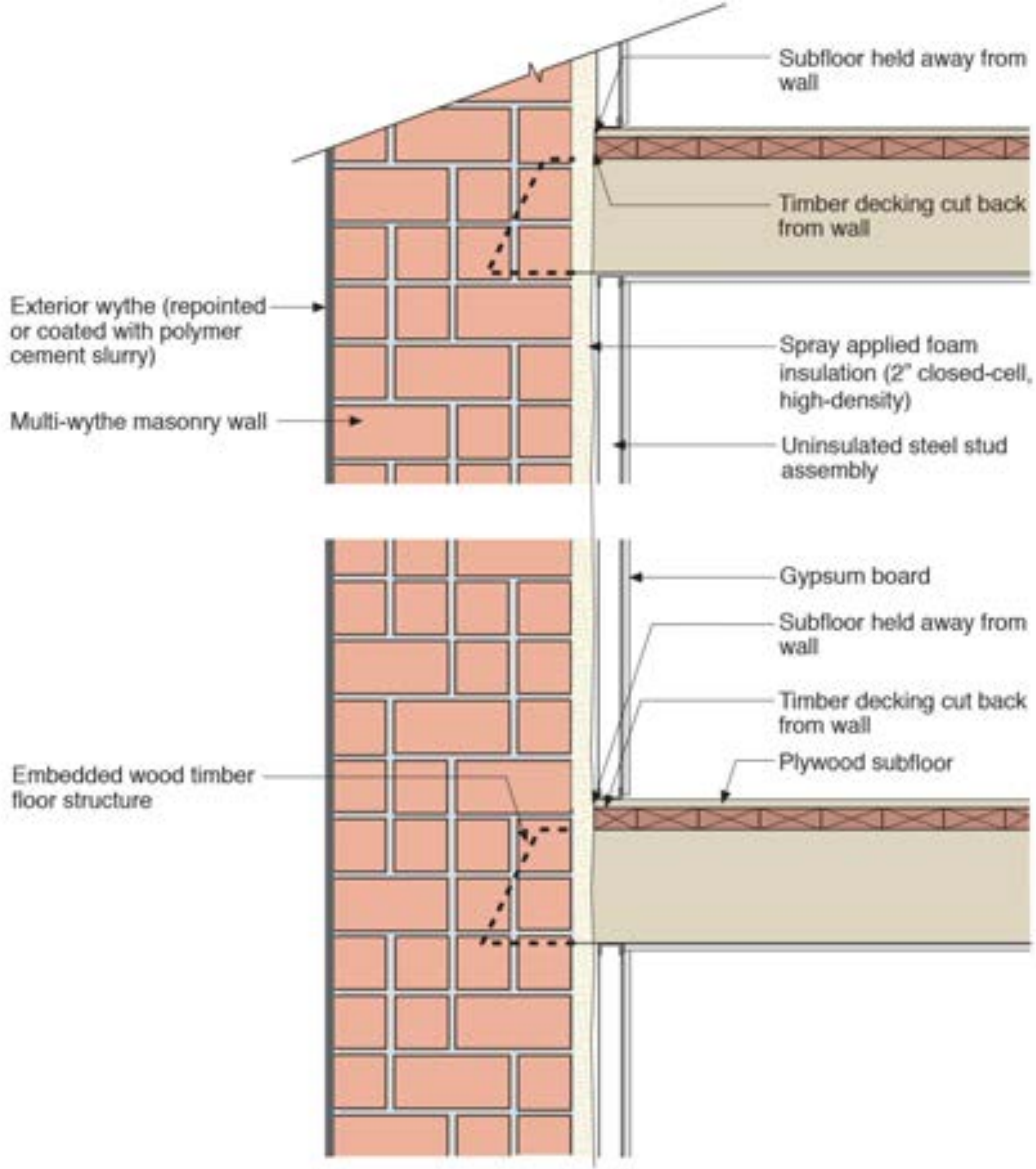

Capillary break on
exterior foundation wall
Capillary break under
slab
Capillary break on top
of footing

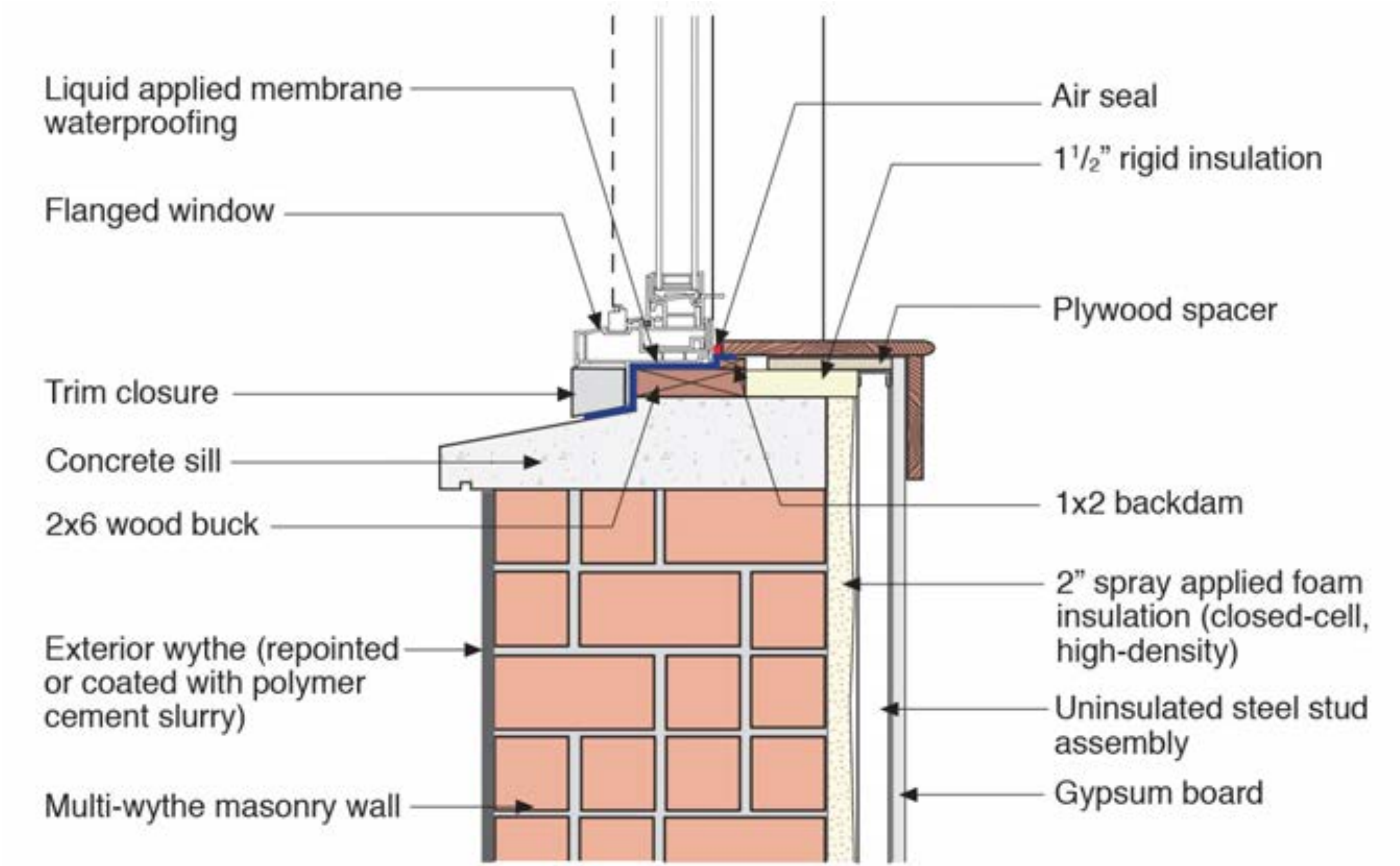

WEST SIDE VILLAGE
113 North 13th Street
An RPM Managed Community

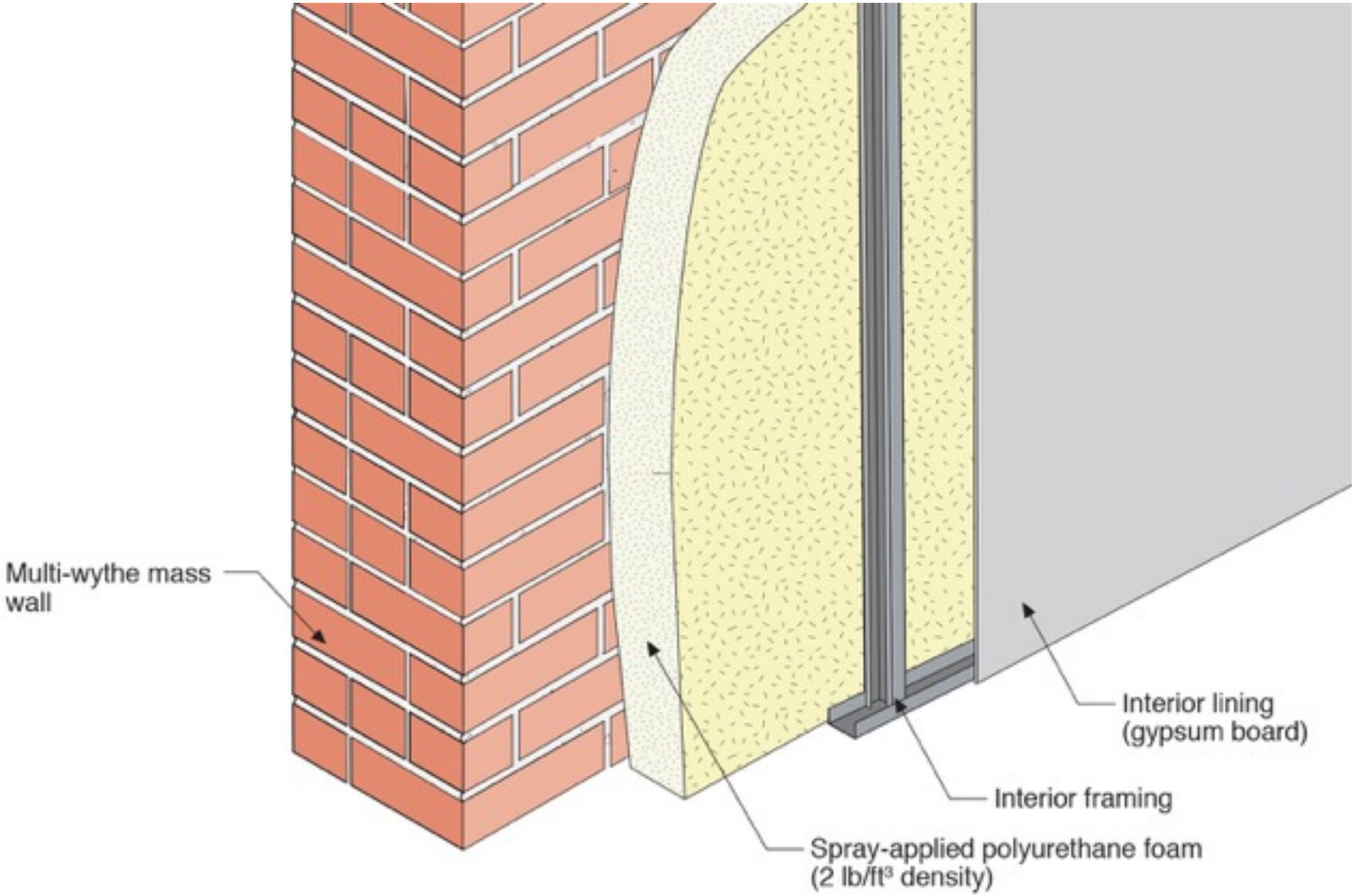

Coping/cap flashing over top of parapet
Fully-adhered membrane roofing extending up interior and over top of parapet wall
4" spray applied foam insulation (closed-cell, high-density)
Timber decking
Embedded wood timber roof structure
Exterior wythe (repointed or coated with polymer cement slurry)
2" 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

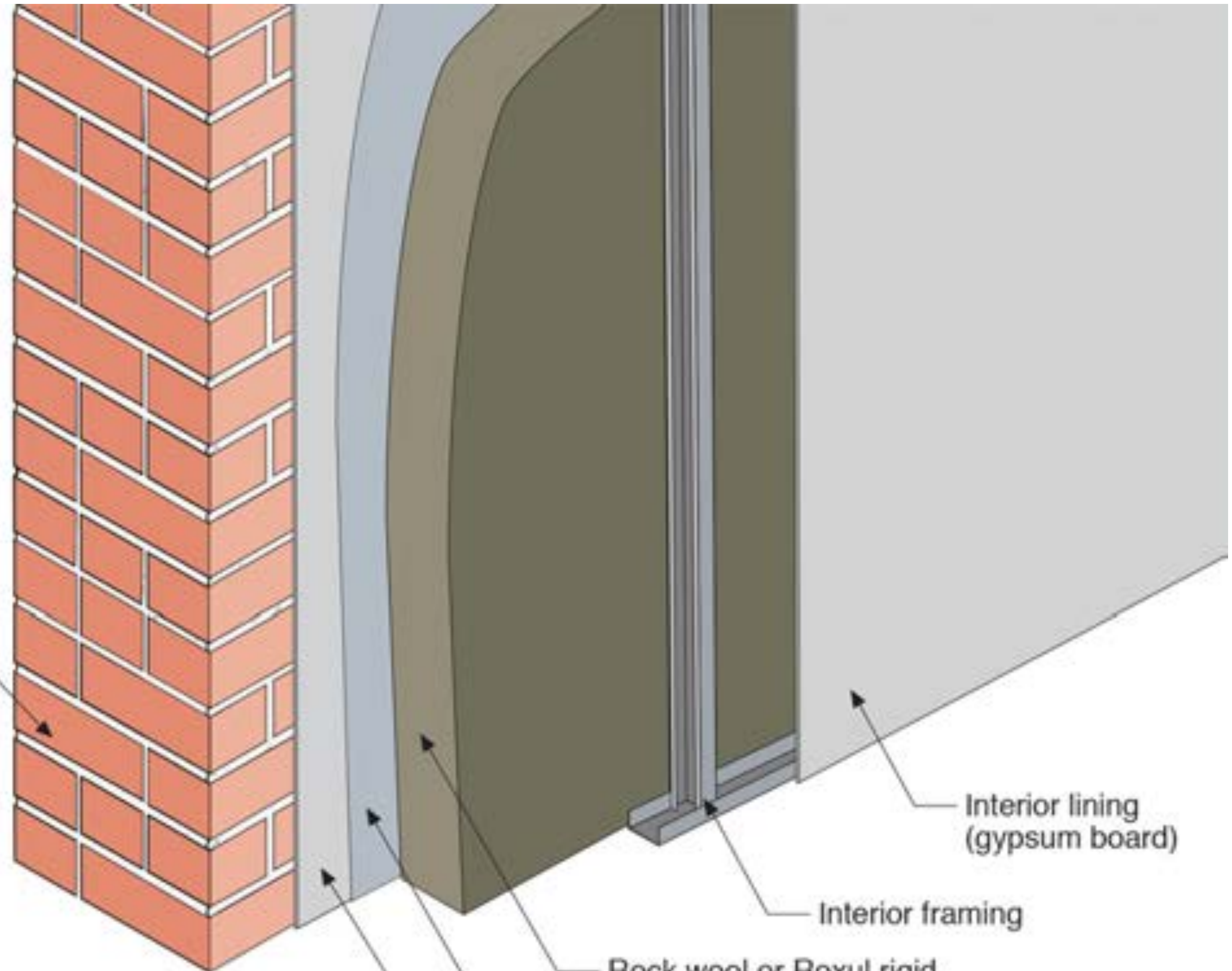

Spray applied foam insulation (closed-cell, high-density)
Uninsulated steel stud assembly
Gypsum board
Subfloor held away from wall
Timber decking cut back from wall
Plywood subfloor
Exterior wythe (repointed or coated with polymer cement slurry)
Embedded wood timber floor structure
Stainless steel cap flashing regletted into exterior wythe
Spray applied foam insulation (closed-cell, high-density)
Uninsulated steel stud assembly
Paperless gypsum board
3/4" masonry mortar rendering (sacrificial coating)
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

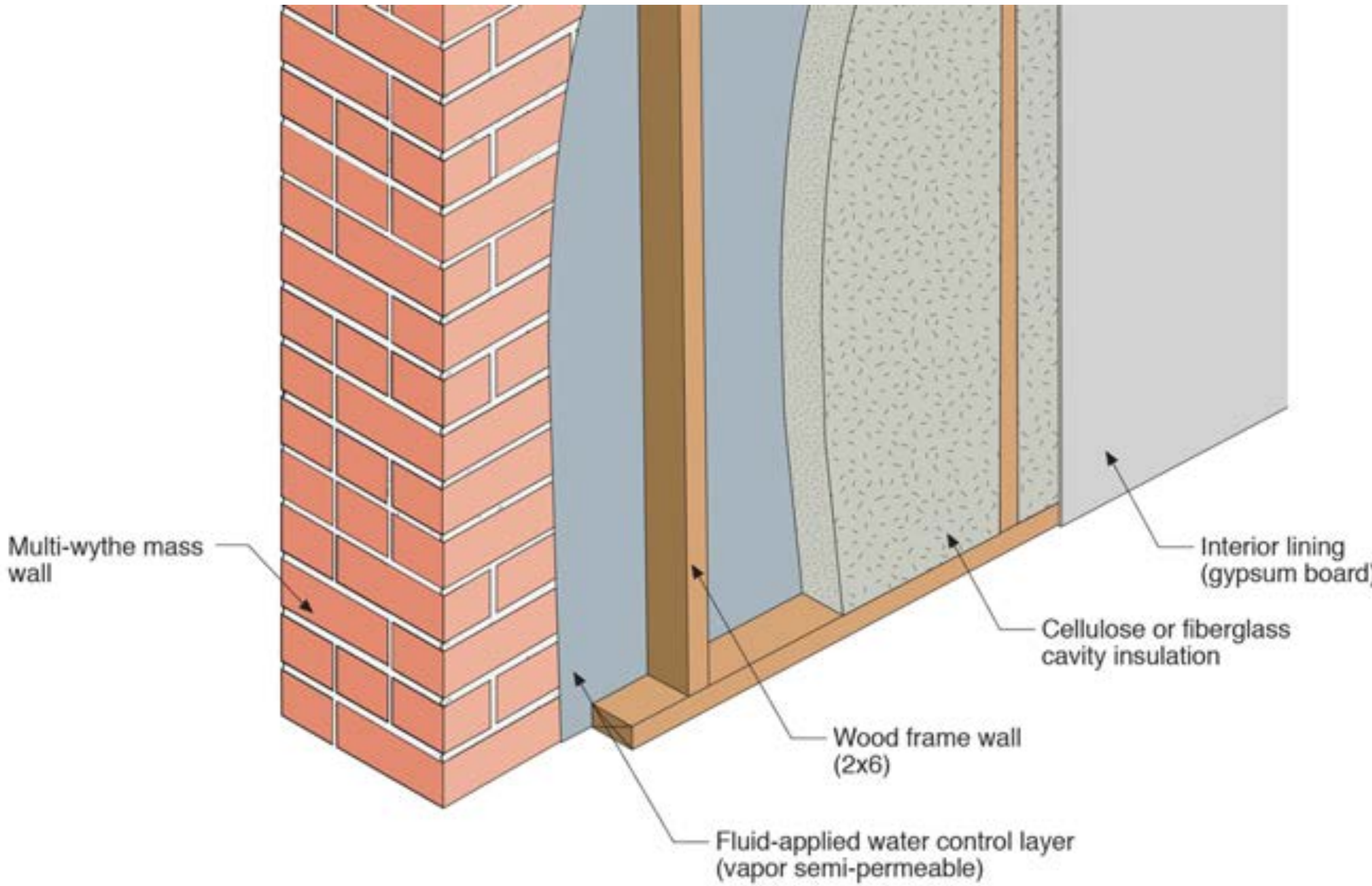

Wood floor framing embedded into masonry wall
Stainless steel cap flashing regletted into exterior wythe
1.5 χ
Vapor impermeable layer to prevent evaporation or drying inward
Sacrificial layer
χ
Wood floor framing embedded into masonry wall
Stainless steel cap flashing regletted into exterior wythe
Stainless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

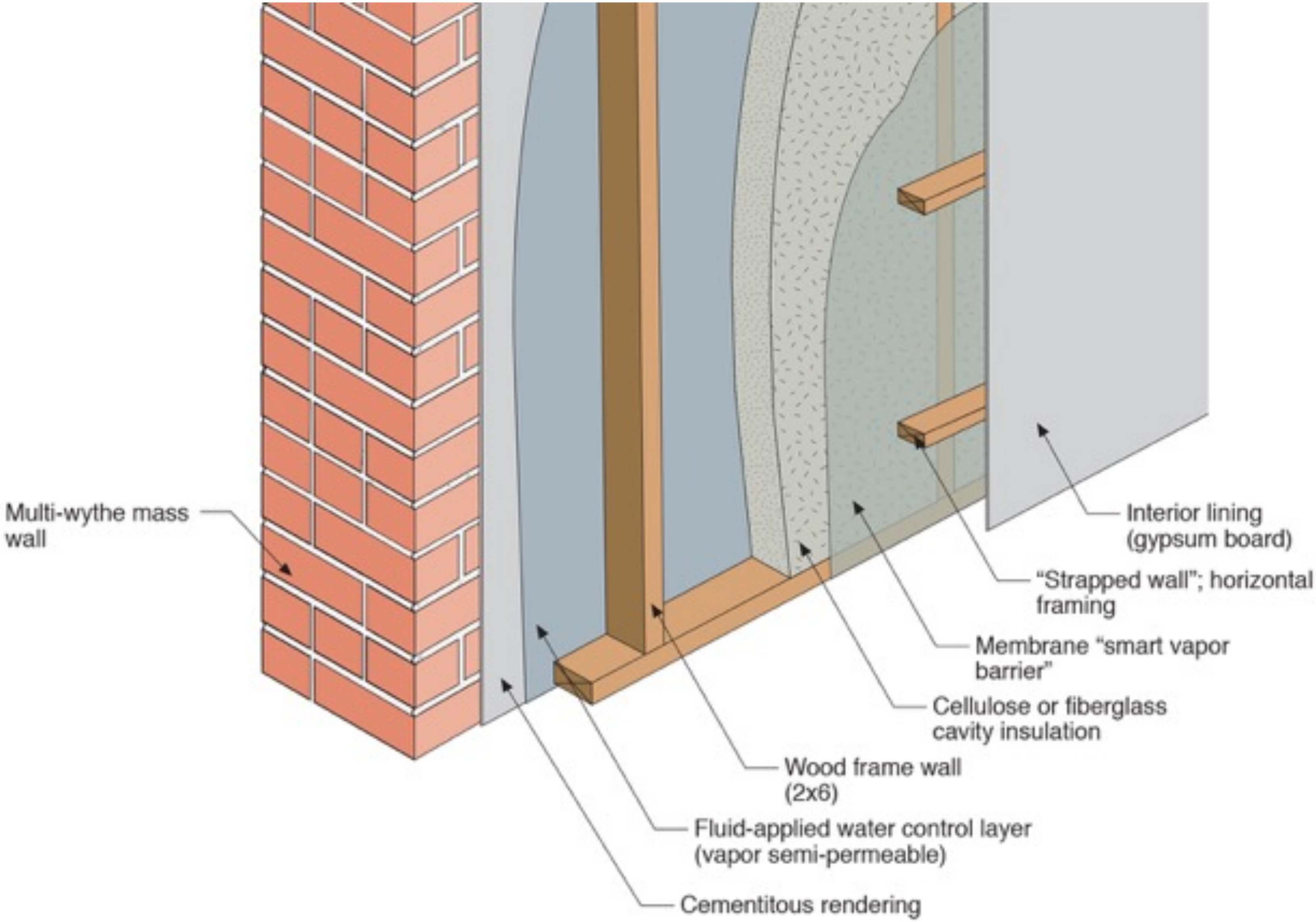

Subfloor held away from wall
Timber decking cut back from wall
Exterior wythe (repointed or coated with polymer cement slurry)
Multi-wythe masonry wall
Spray applied foam insulation (2" closed-cell, high-density)
Uninsulated steel stud assembly
Gypsum board
Subfloor held away from wall
Timber decking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

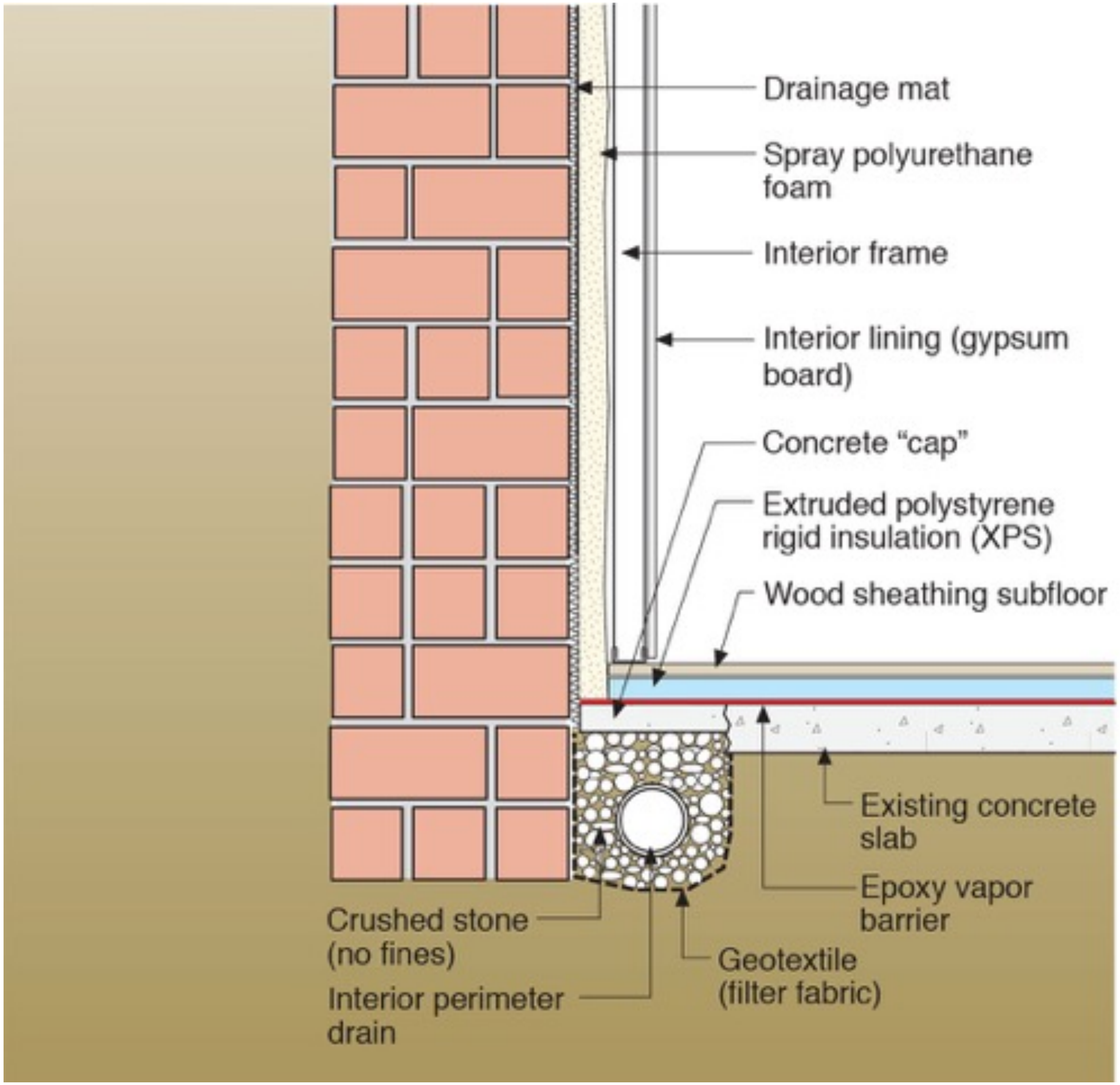

Liquid applied membrane waterproofing
Flanged window
Trim closure
Concrete sill
2x6 wood buck
Exterior wythe (repointed or coated with polymer cement slurry)
Multi-wythe masonry wall
Air seal
1 1/2" rigid insulation
Plywood spacer
1x2 backdam
2" spray applied foam insulation (closed-cell, high-density)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

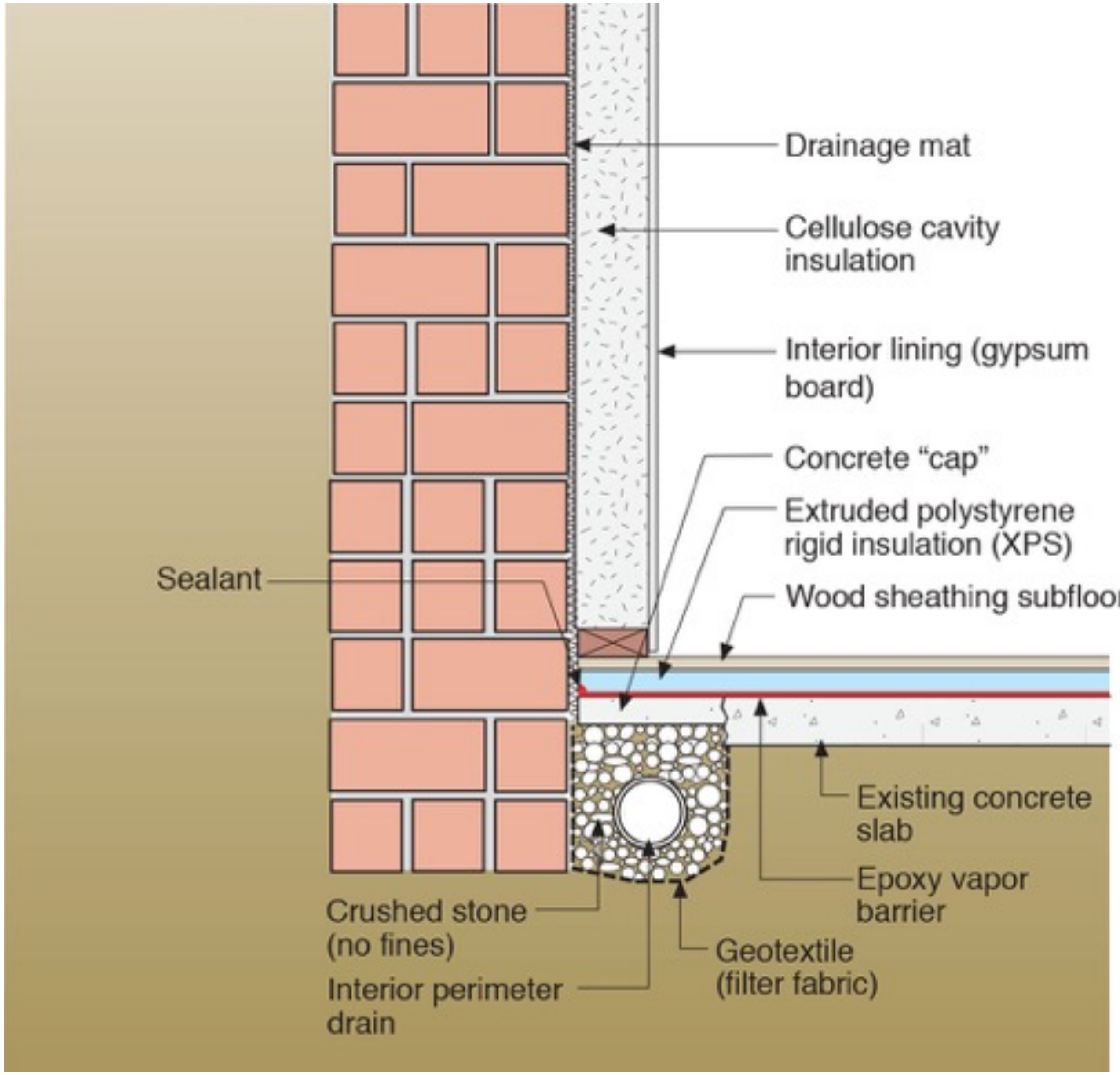

Multi-wythe mass wall
Interior lining (gypsum board)
Interior framing
Spray-applied polyurethane foam (2 lb/ft³ density)

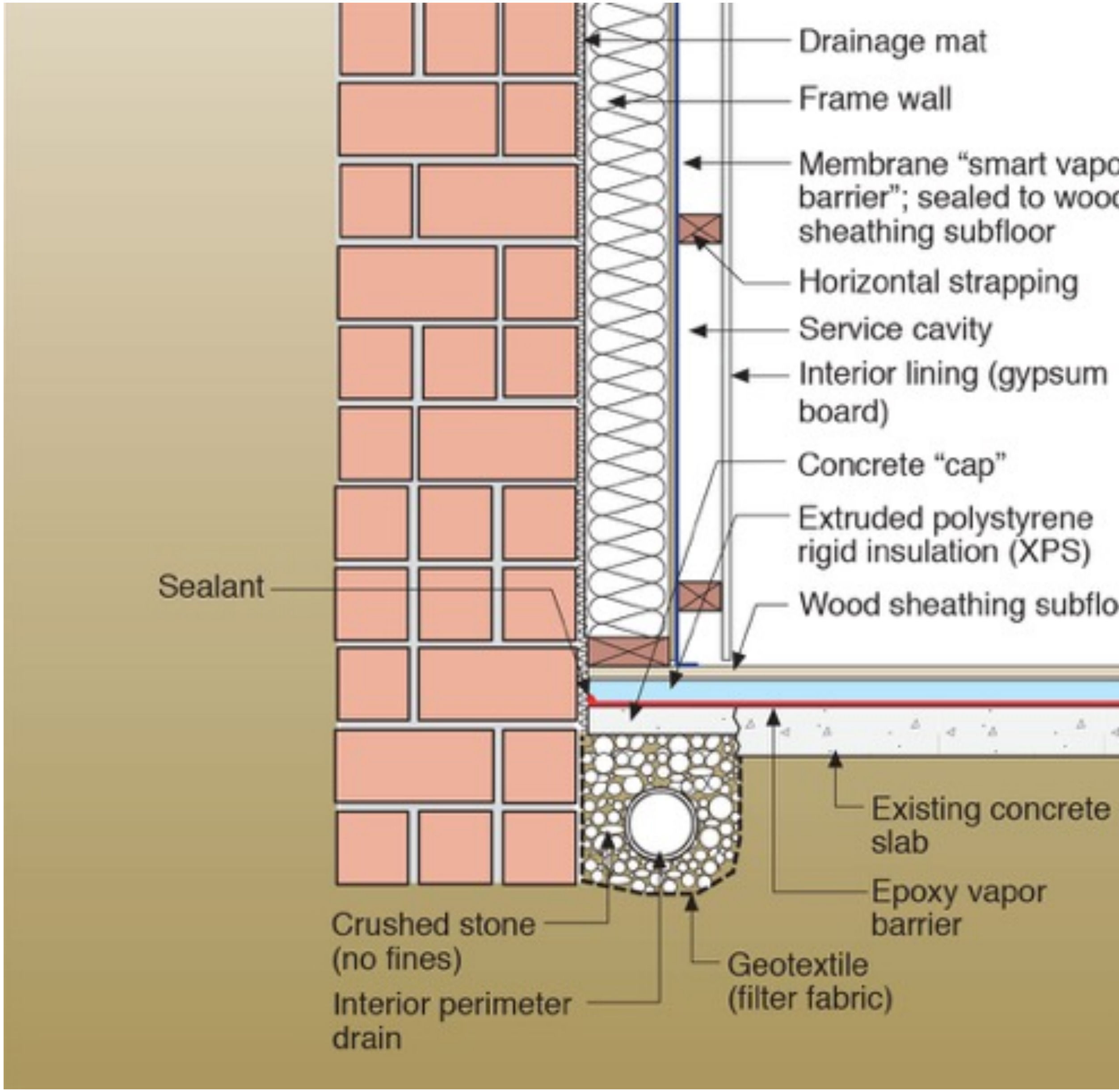

Multi-wythe mass
wall
Interior lining
(gypsum board)
Interior framing
Rock wool or Roxul rigid
minineral wool insulation
Fluid-applied water control layer
(vapor semi-permeable)
Cementitous rendering


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

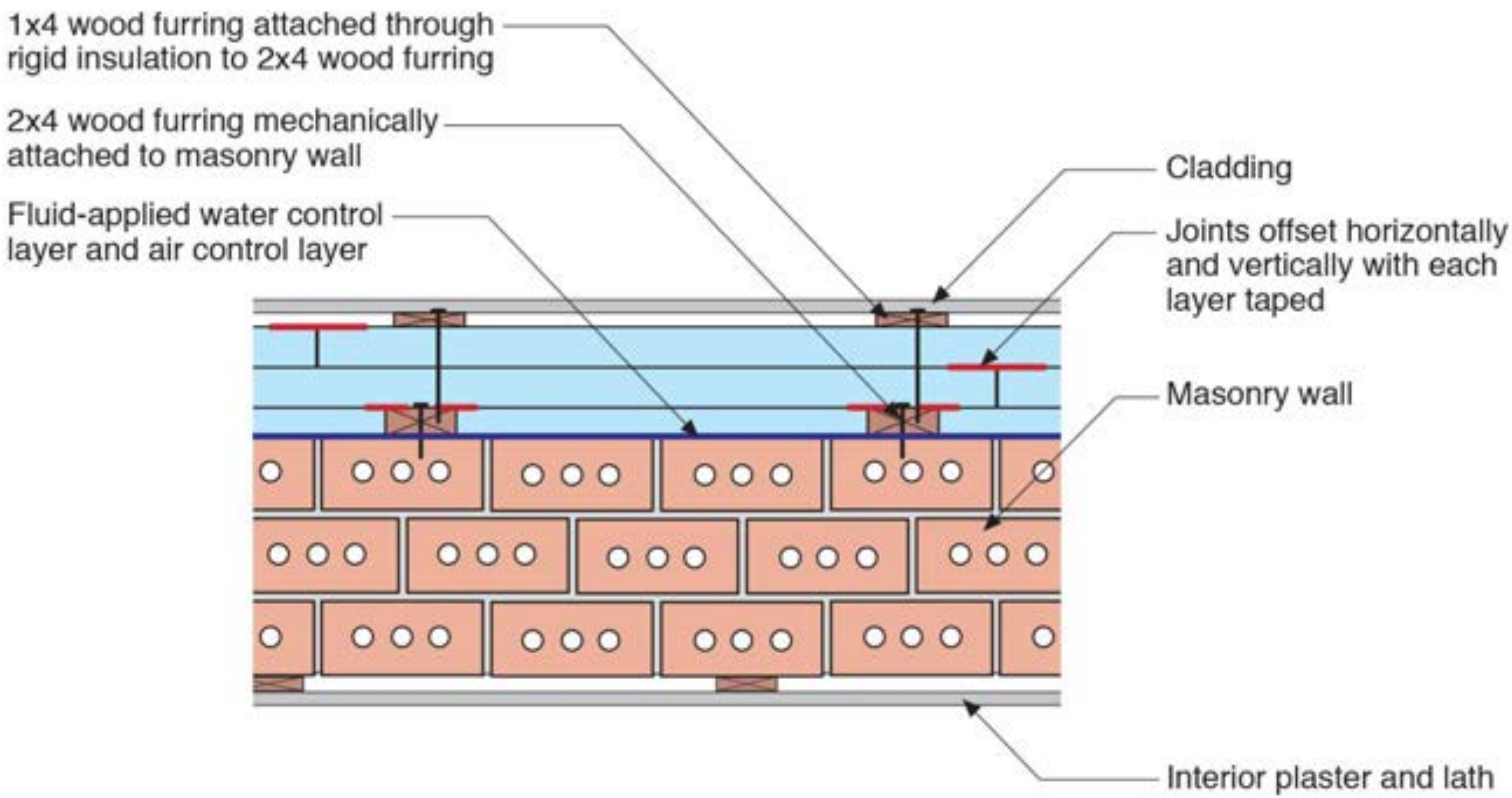

Drainage mat
Spray polyurethane foam
Interior frame
Interior lining (gypsum board)
Concrete "cap"
Extruded polystyrene rigid insulation (XPS)
Wood sheathing subfloor
Existing concrete slab
Epoxy vapor barrier
Geotextile (filter fabric)
Crushed stone (no fines)
Interior perimeter drain


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

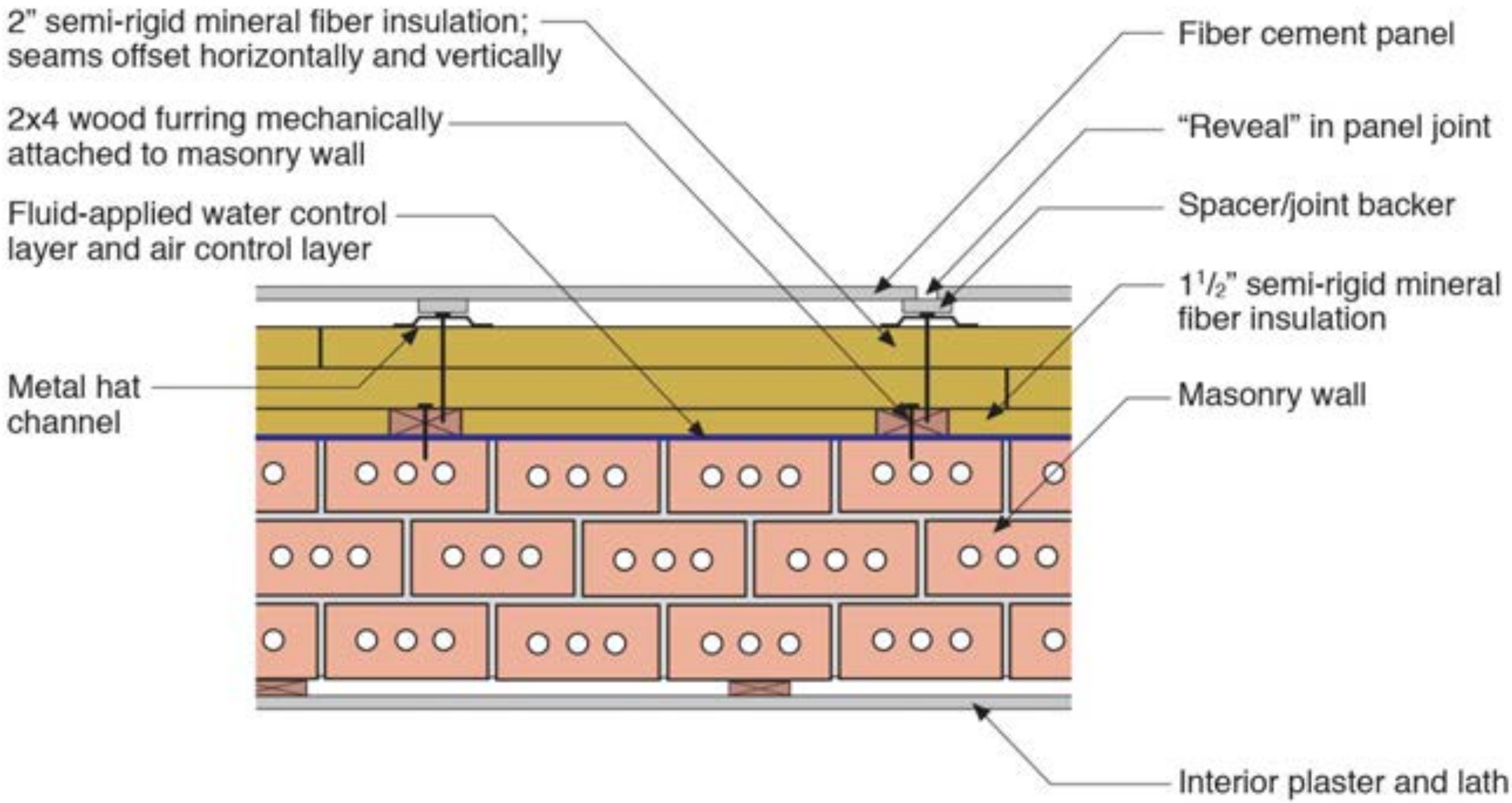


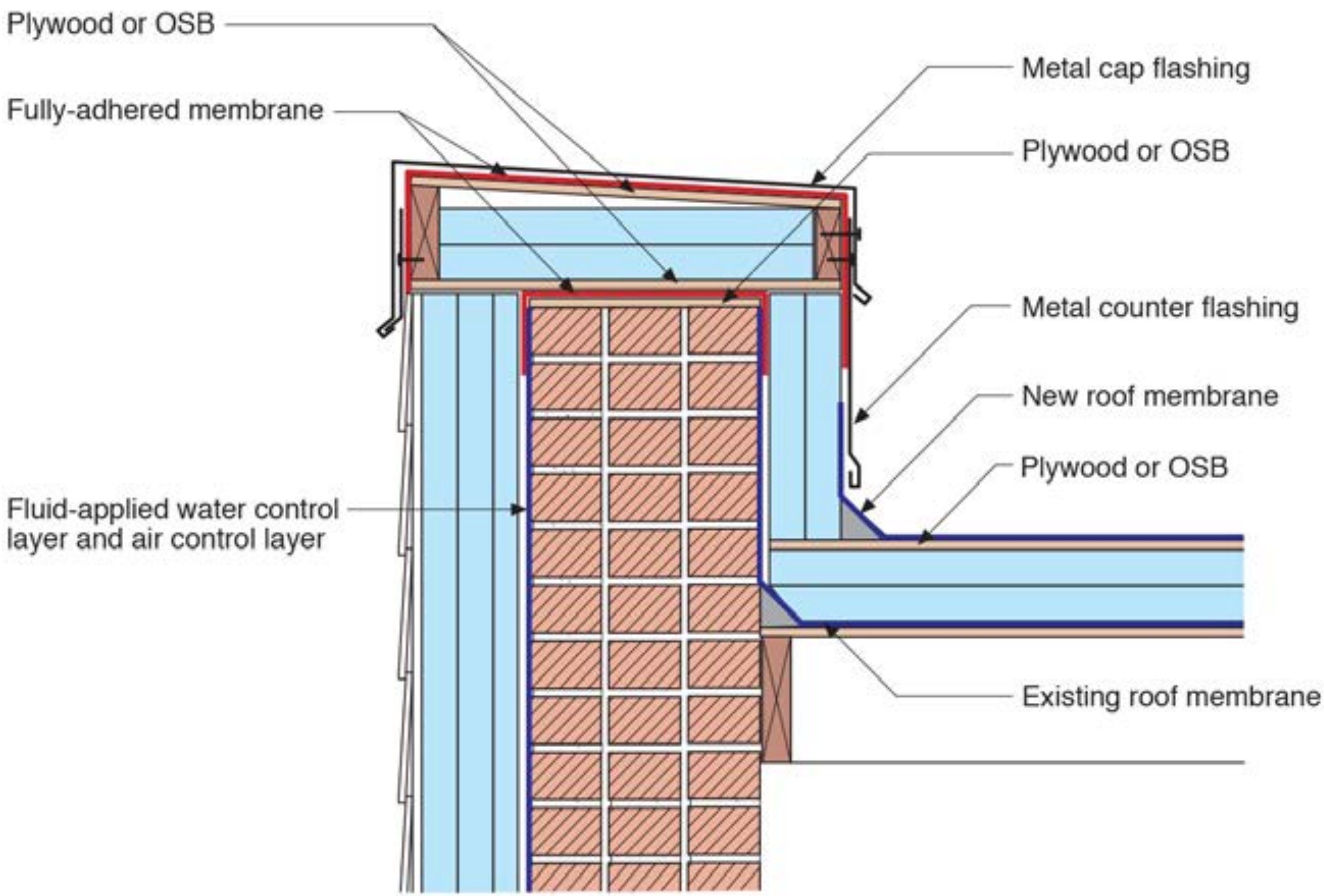
Drainage mat
Frame wall
Membrane “smart vapor barrier”; sealed to wood sheathing subfloor
Horizontal strapping
Service cavity
Interior lining (gypsum board)
Concrete “cap”
Extruded polystyrene rigid insulation (XPS)
Sealant
Wood sheathing subfloor
Existing concrete slab
Epoxy vapor barrier
Crushed stone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


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
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

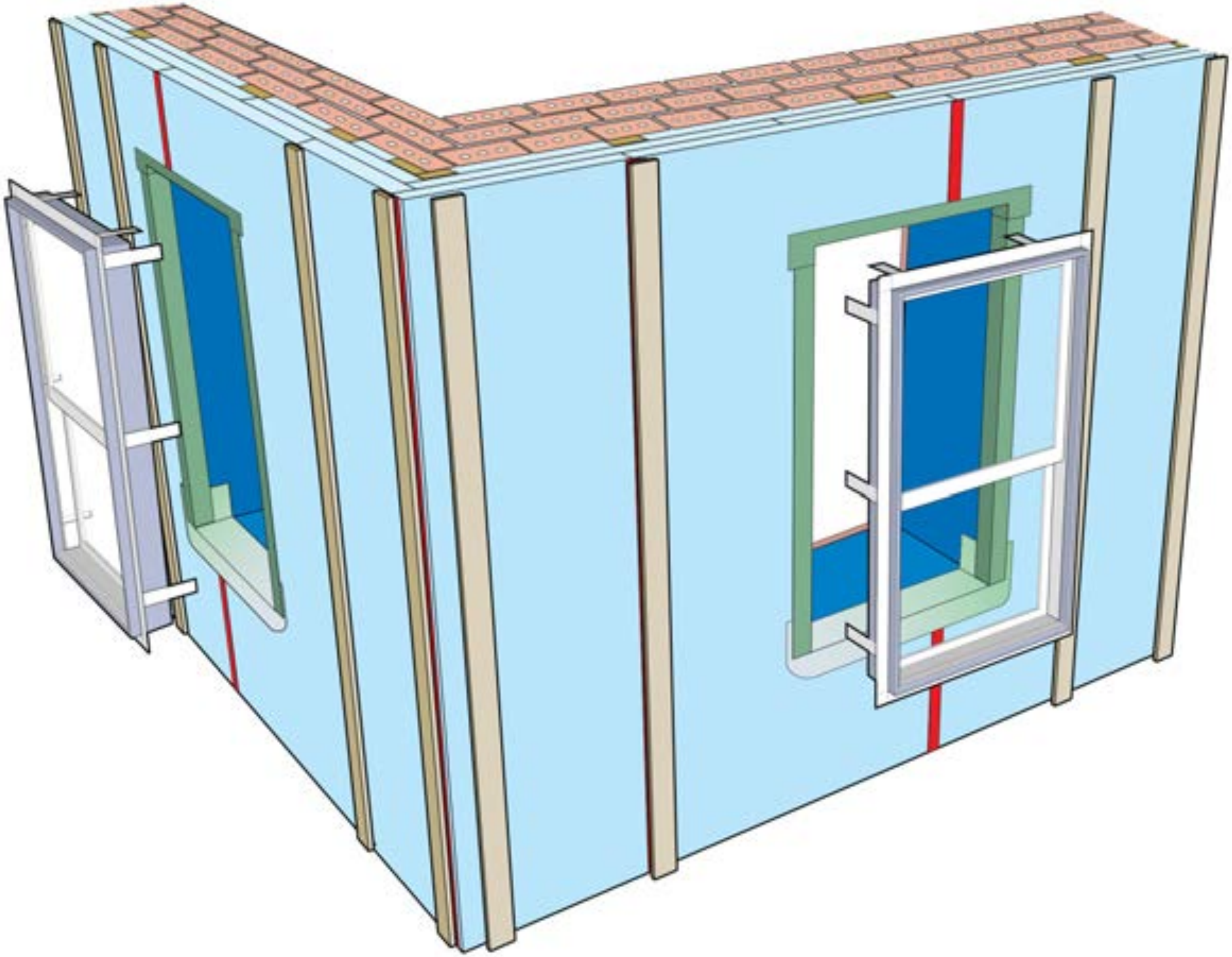

Plywood or OSB
Fully-adhered membrane
Metal cap flashing
Plywood or OSB
Metal counter flashing
New roof membrane
Plywood or OSB
Fluid-applied water control
layer and air control layer
Existing roof membrane


GRACE
Ice & Water Shield


SPEED
HUMP

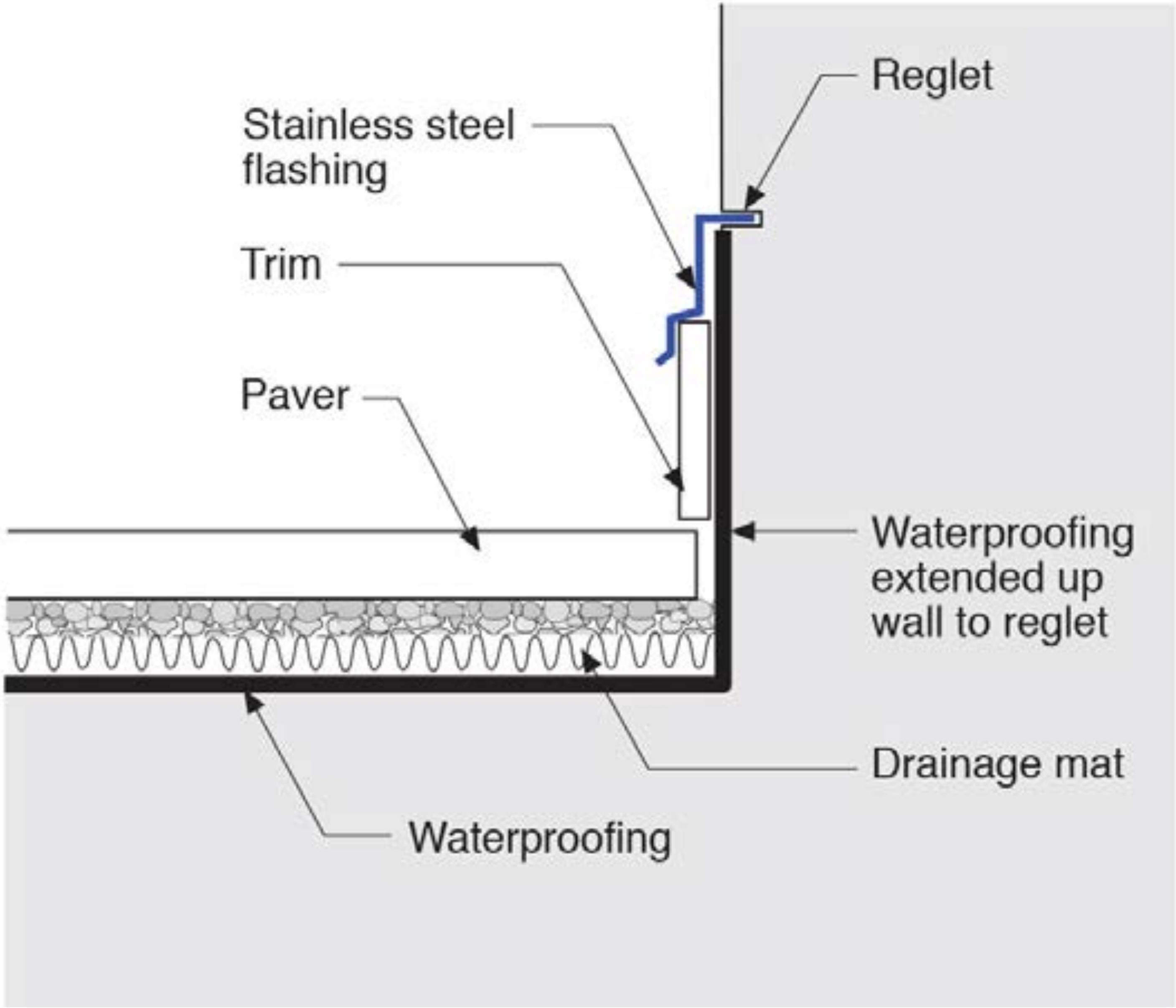

SPEED
HUMP

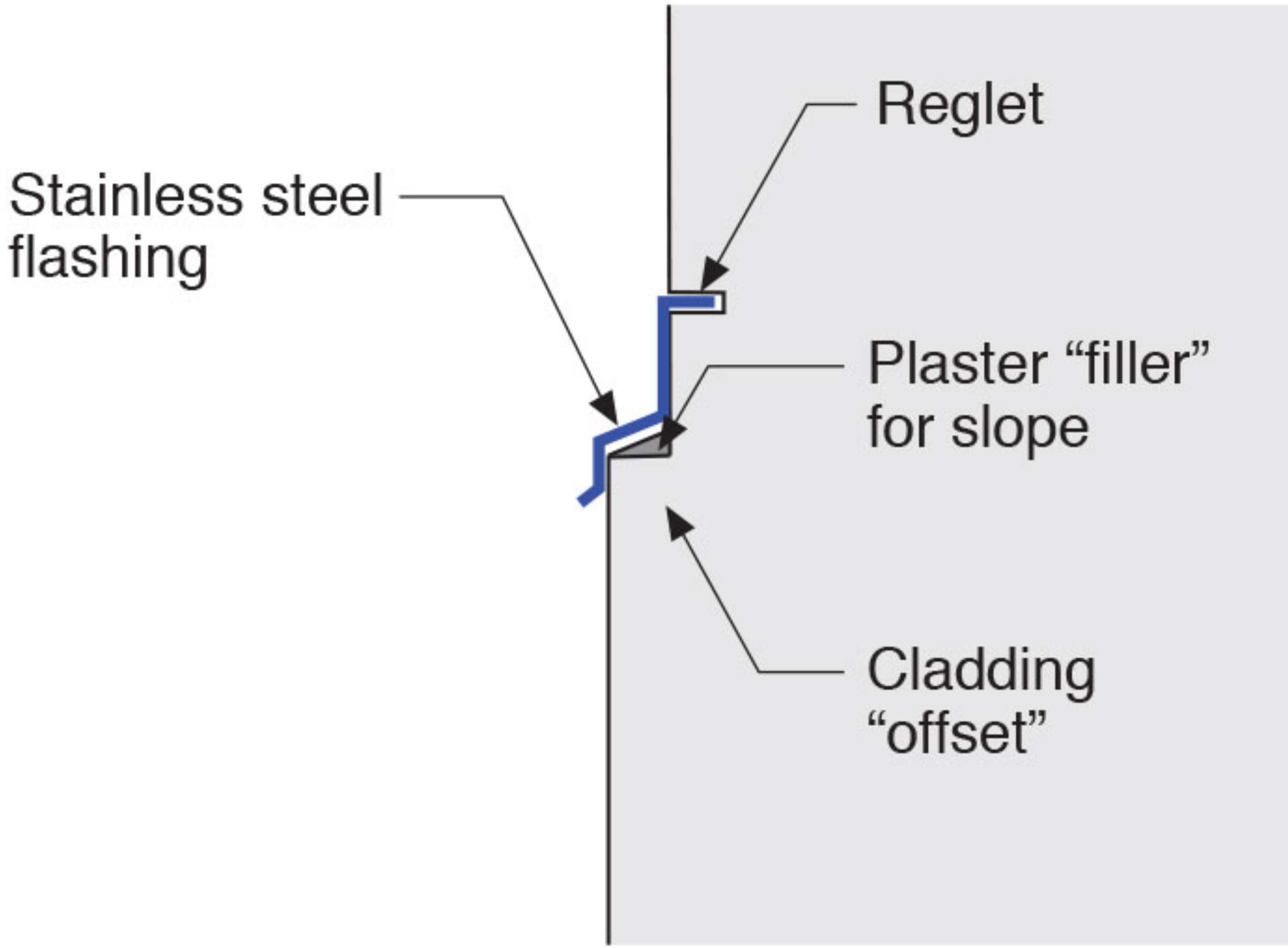

FOAMULAR

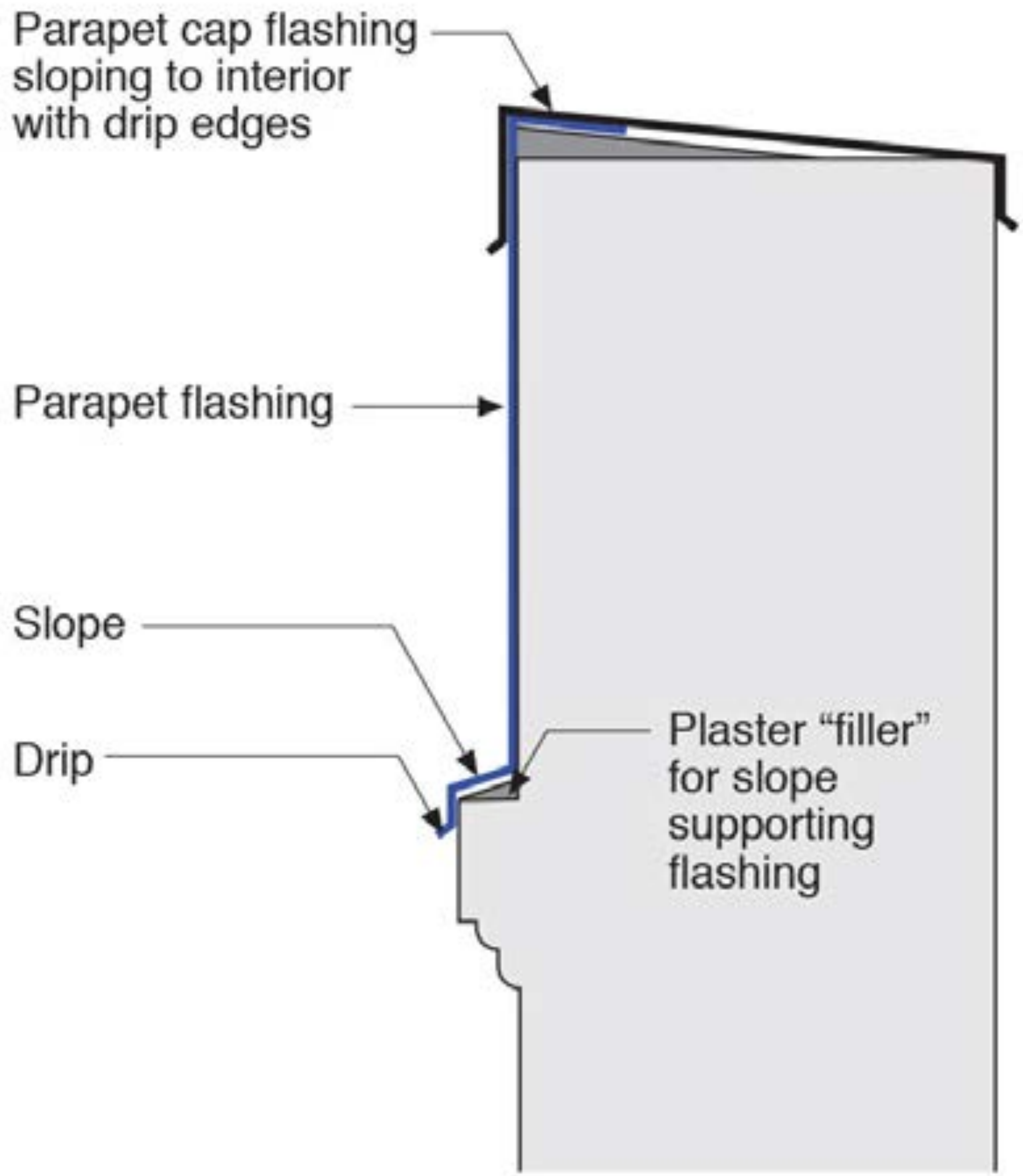


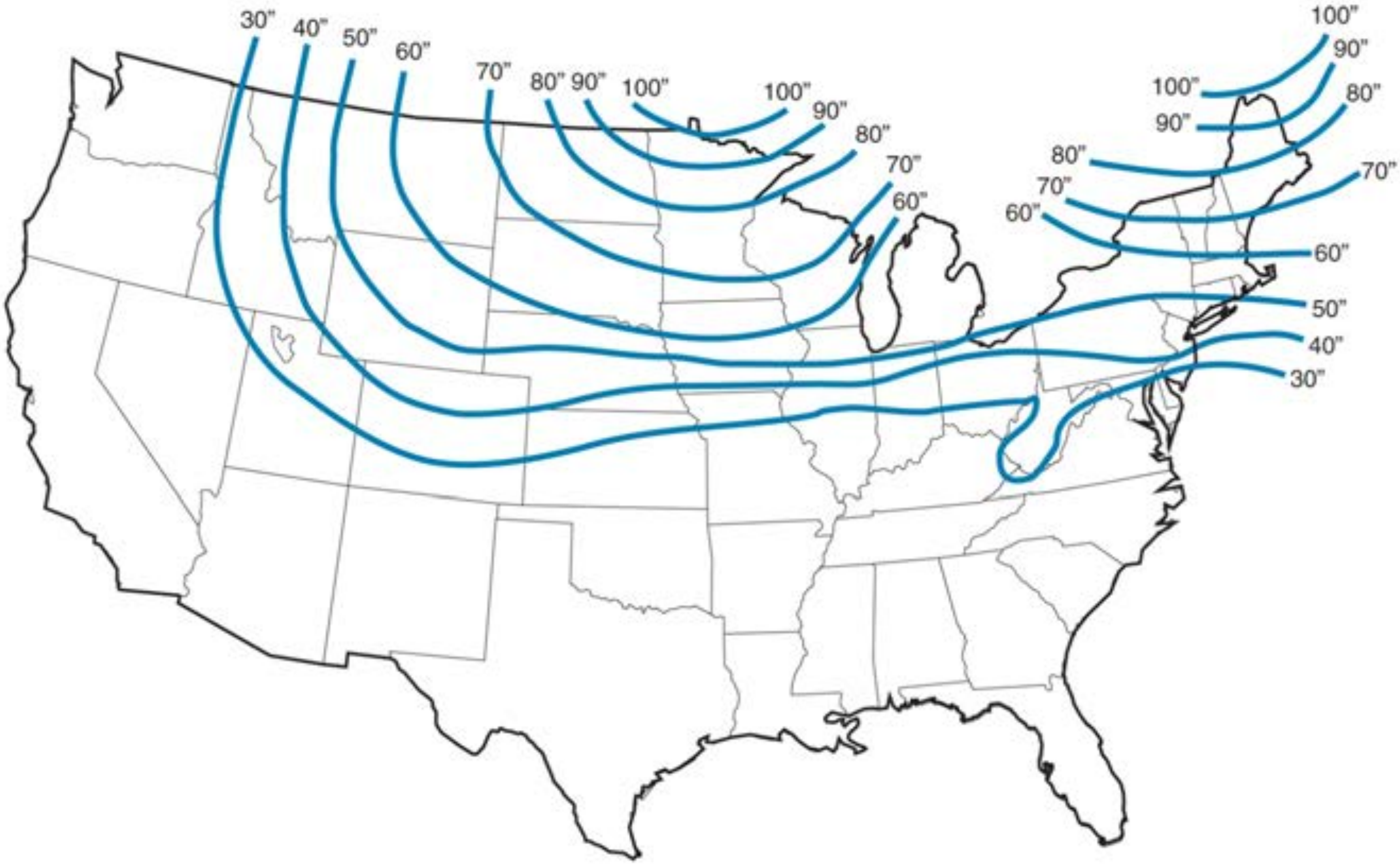

DISTRICT OF COLUMBIA COURT OF APPEALS


EXIT

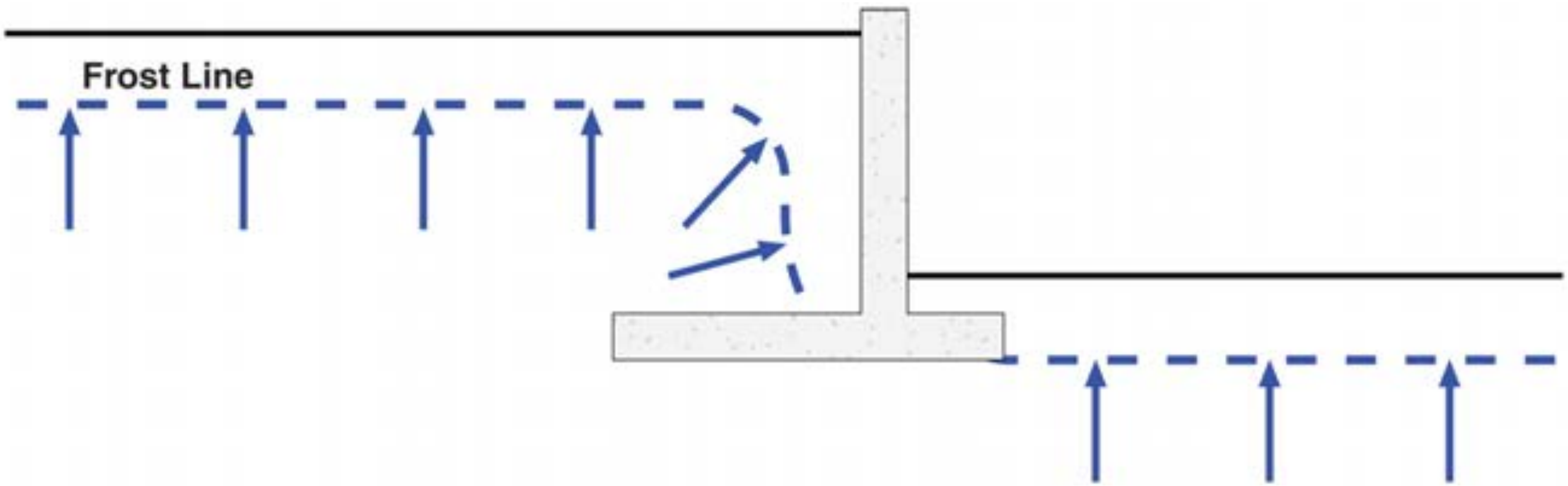

Reglet
Stainless steel
flashing
Trim
Paver
Waterproofing
extended up
wall to reglet
Drainage mat
Waterproofing

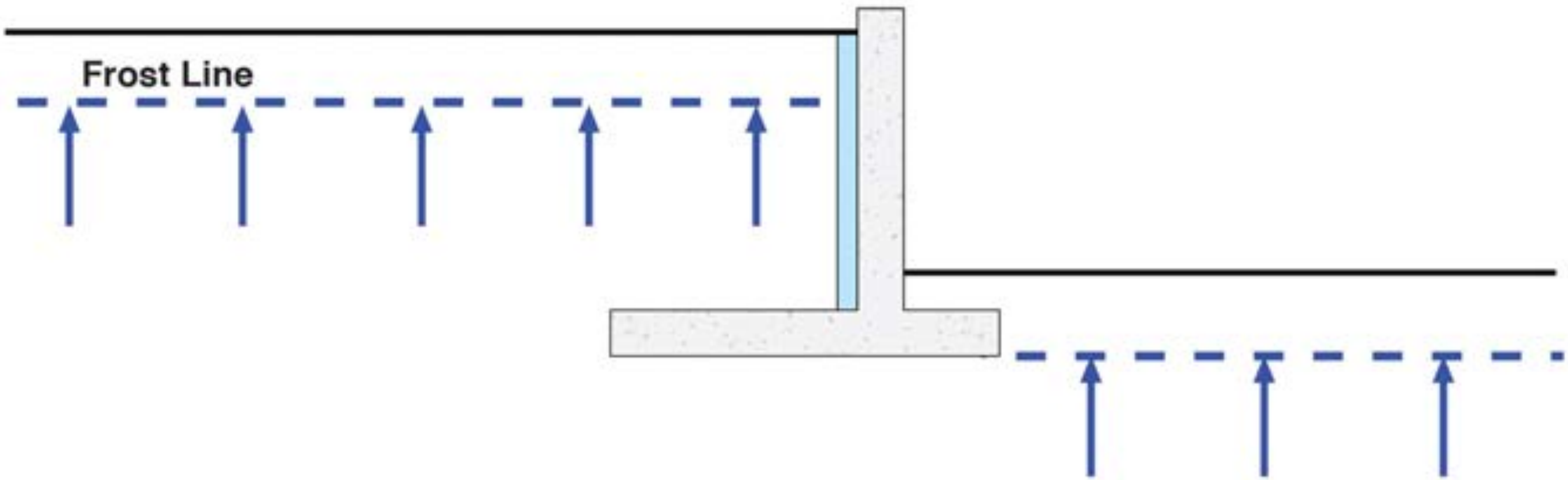

Reglet
Stainless steel flashing
Plaster "filler" for slope
Cladding "offset"

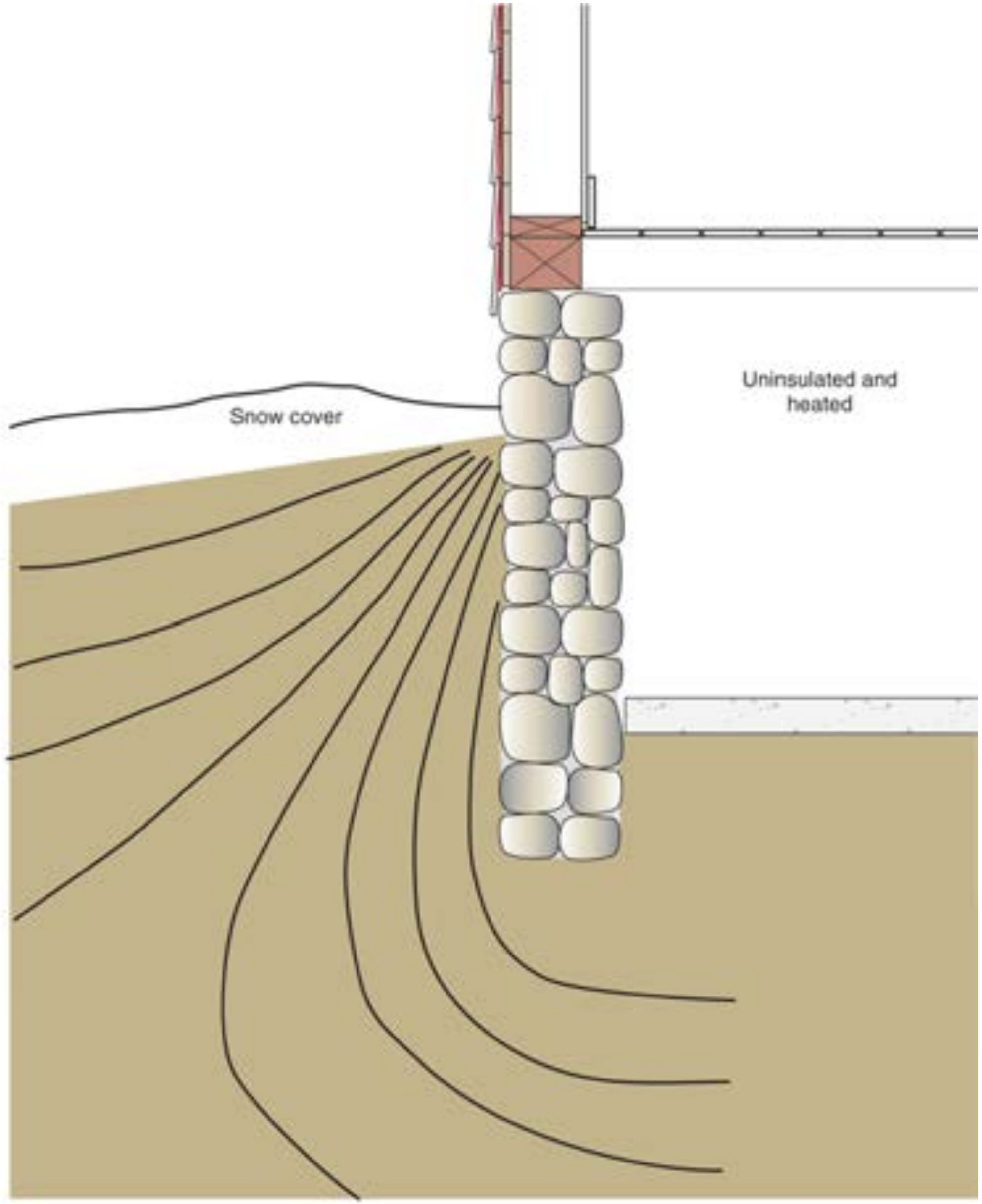

Parapet cap flashing sloping to interior with drip edges
Parapet flashing
Slope
Drip
Plaster "filler" for slope supporting flashing

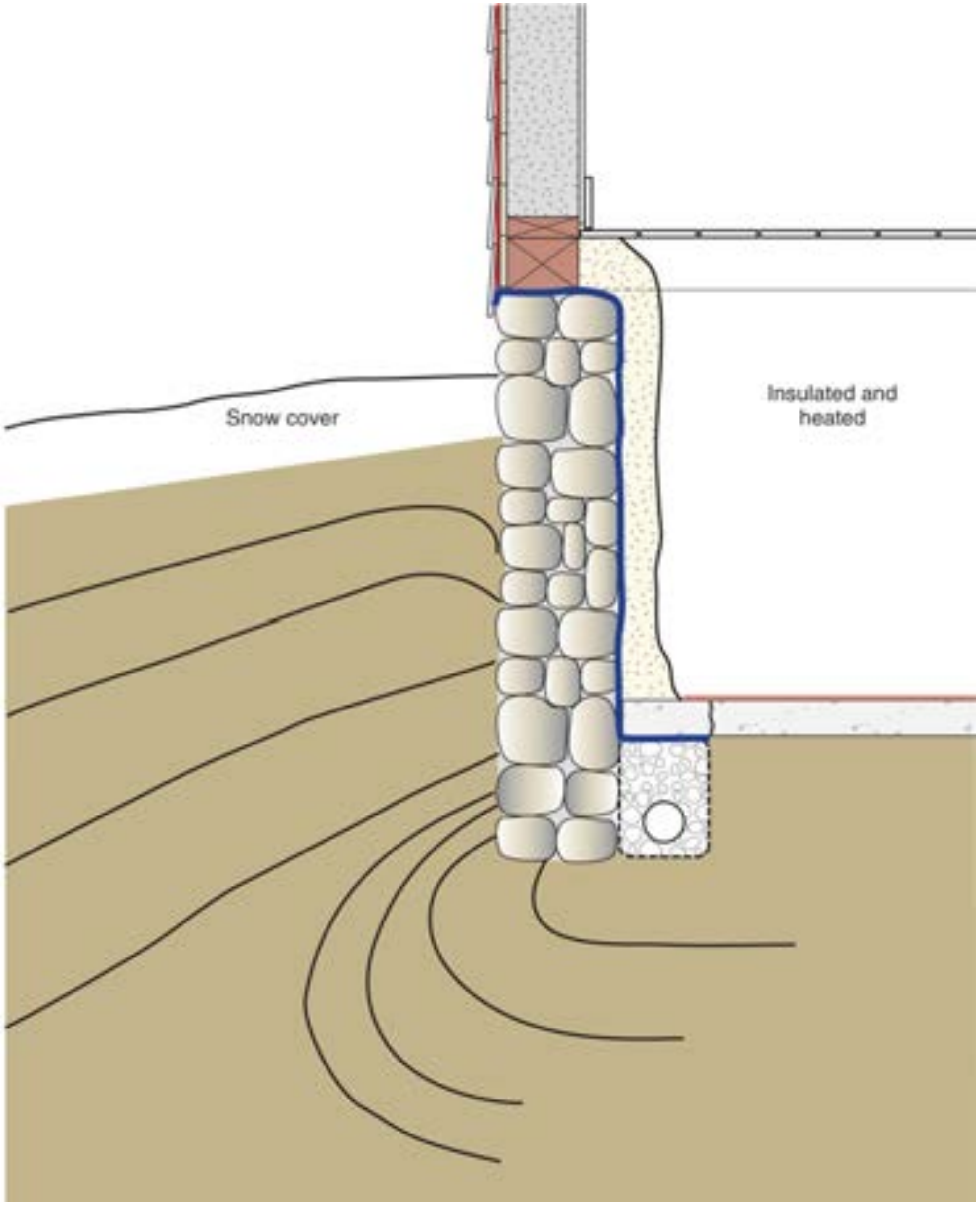


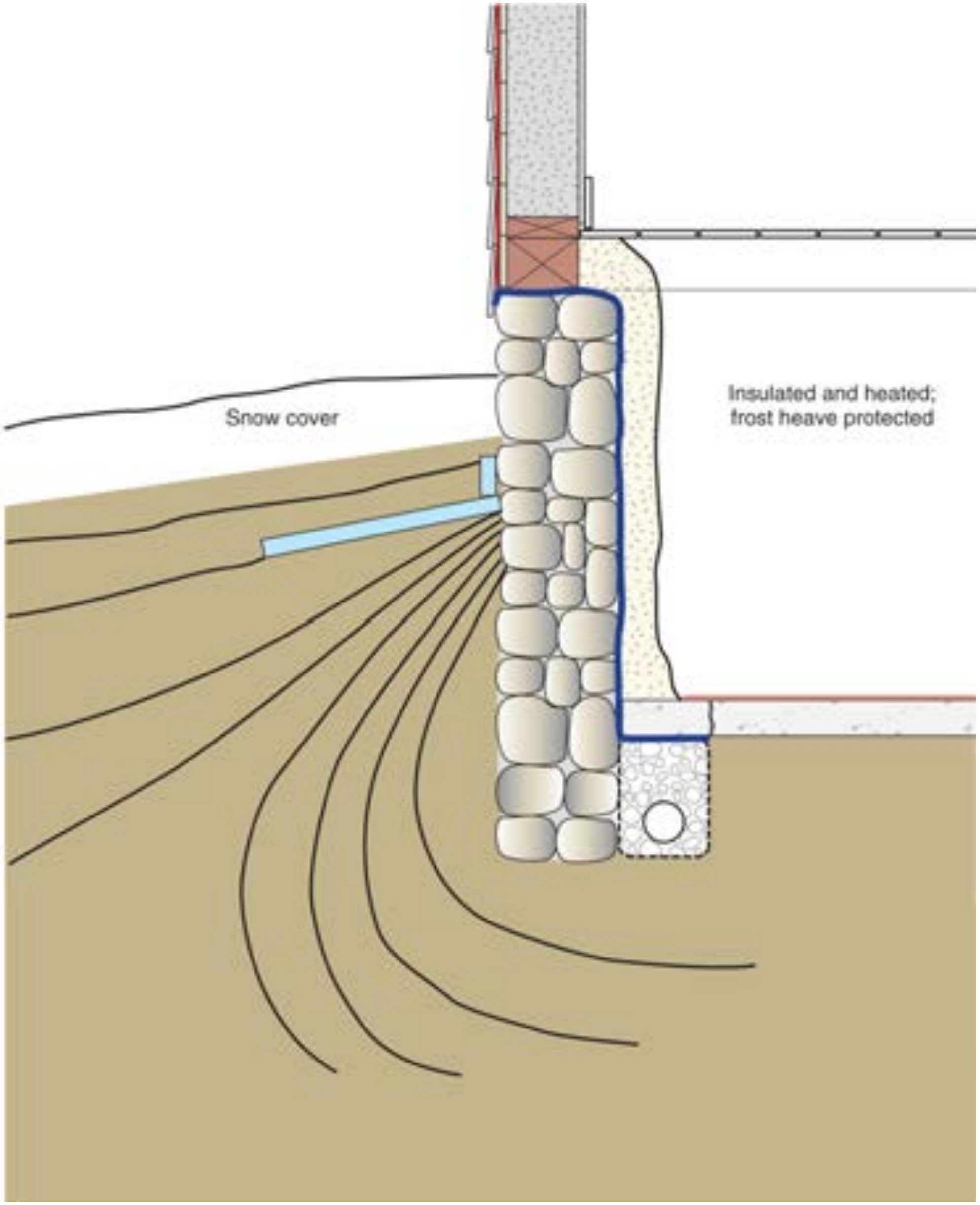
From the US Army Corps Engineers Extreme Frost Penetration
(in inches) based on state averages.

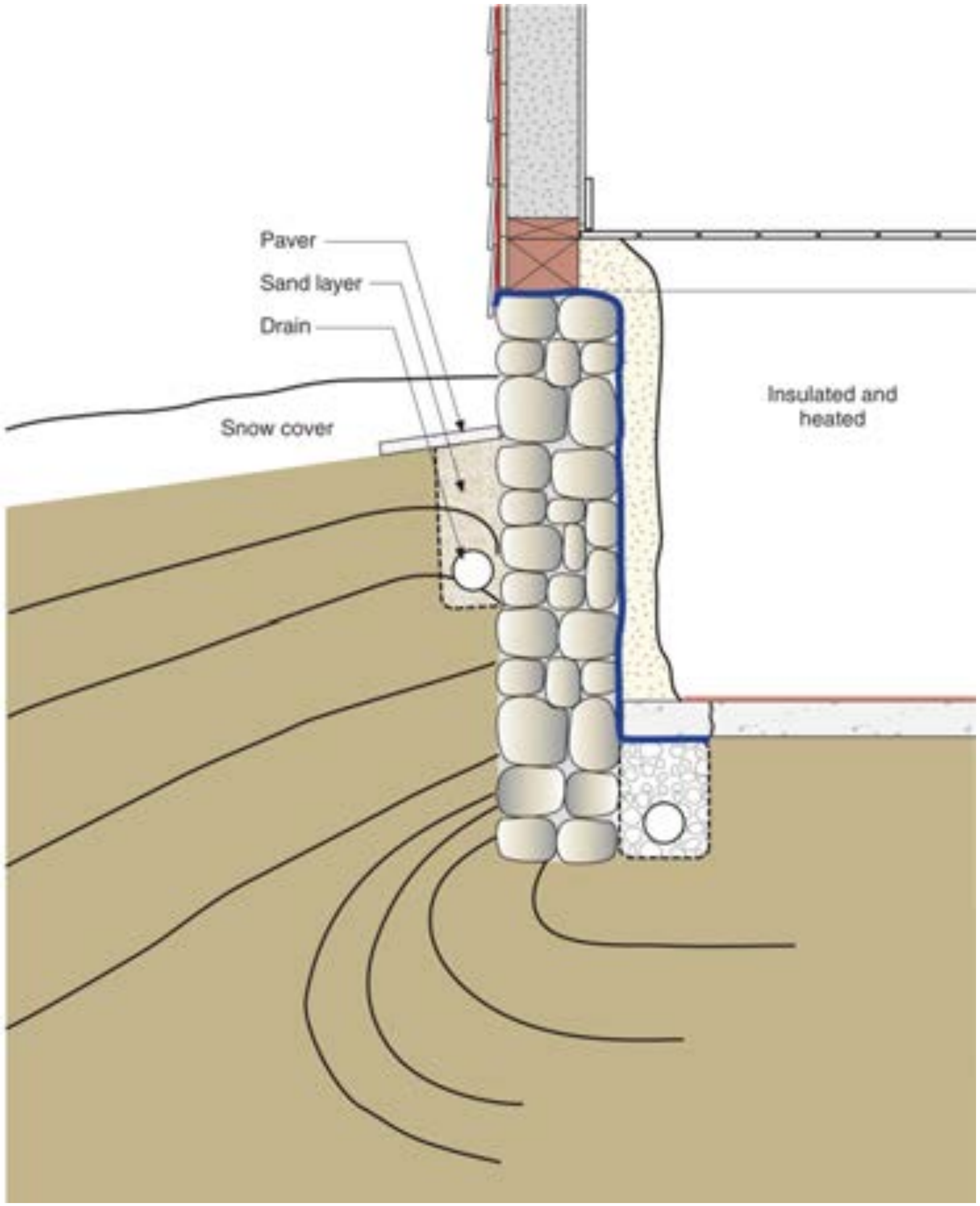

Frost Line

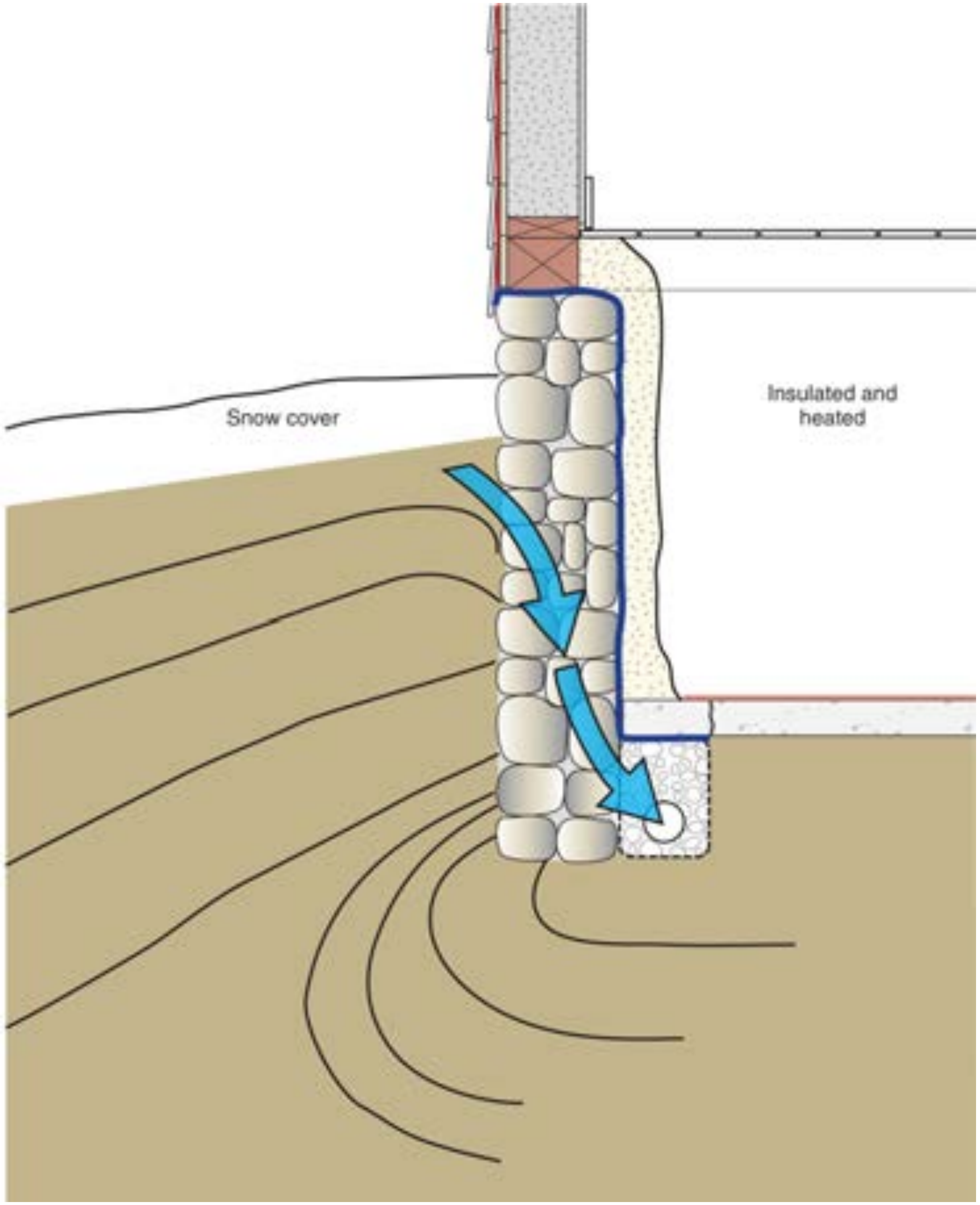

Frost Line


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


JLG