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

Building Science

Adventures In Building Science

presented by www.buildingscience.com

What is a Building?

A Building is an Environmental Separator

- Control heat flow
- Control airflow
- Control water vapor flow
- Control rain
- Control ground water
- Control light and solar radiation
- Control noise and vibrations
- Control contaminants, environmental hazards and odors
- Control insects, rodents and vermin
- Control fire
- Provide strength and rigidity
- Be durable
- Be aesthetically pleasing
- Be economical

Arrhenius Equation

For Every 10 Degree K Rise

Activation Energy Doubles

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

Damage Functions

Water

Heat

Ultra-violet Radiation

2nd Law of Thermodynamics

In an isolated system, a process can occur only if it increases the total entropy of the system

Rudolf Clausius

Heat Flow Is From Warm To Cold

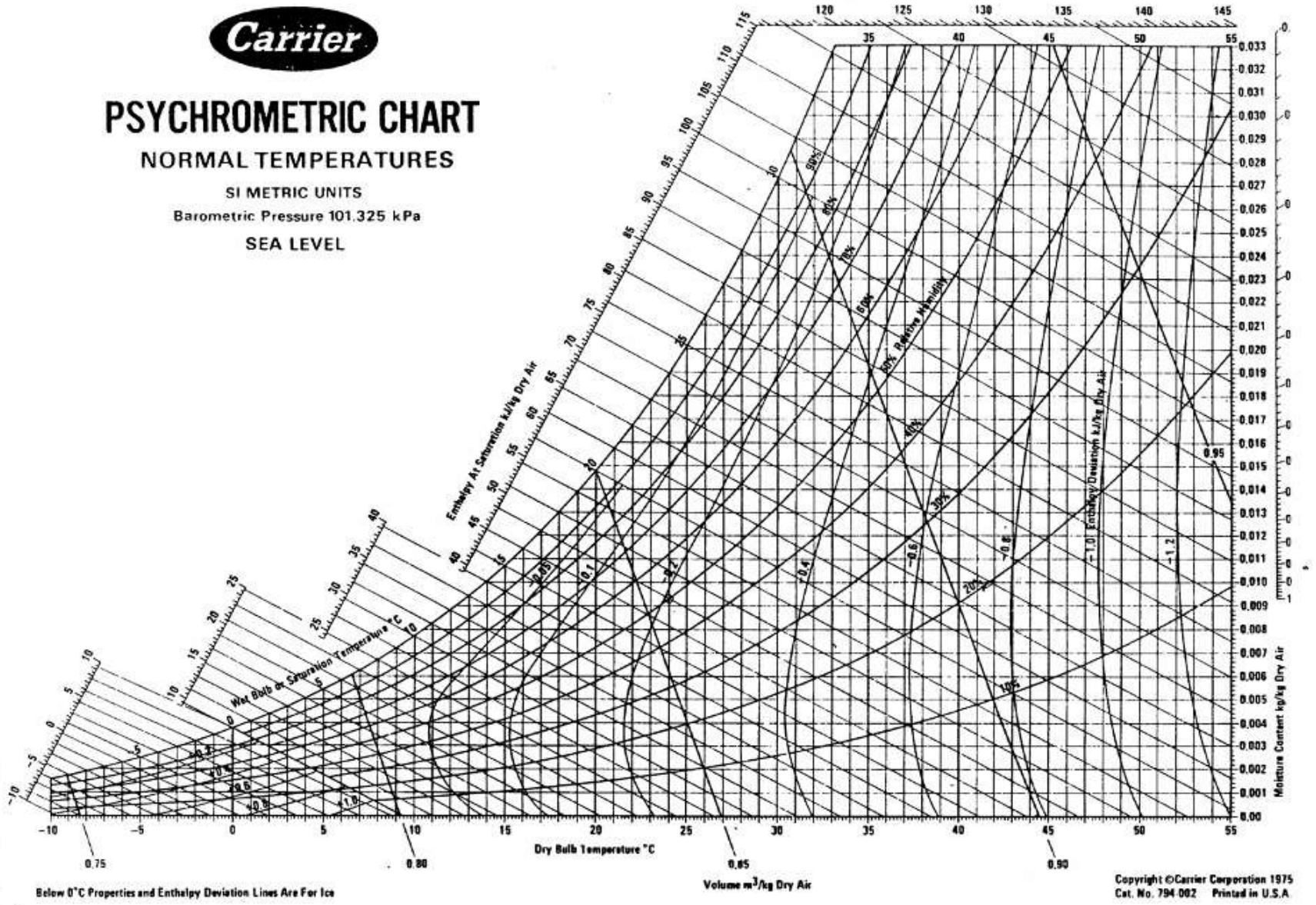
Moisture Flow Is From Warm To Cold

Moisture Flow Is From More To Less

Air Flow Is From A Higher Pressure to a Lower Pressure

Gravity Acts Down

Thermodynamic Potential


Carrier
PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101.325 kPa
SEA LEVEL
Dry Bulb Temperature °C
Wet Bulb or Saturation Temperature °C
Enthalpy At Saturation kJ/kg Dry Air
Moisture Content kg/kg Dry Air
Volume m³/kg Dry Air
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice
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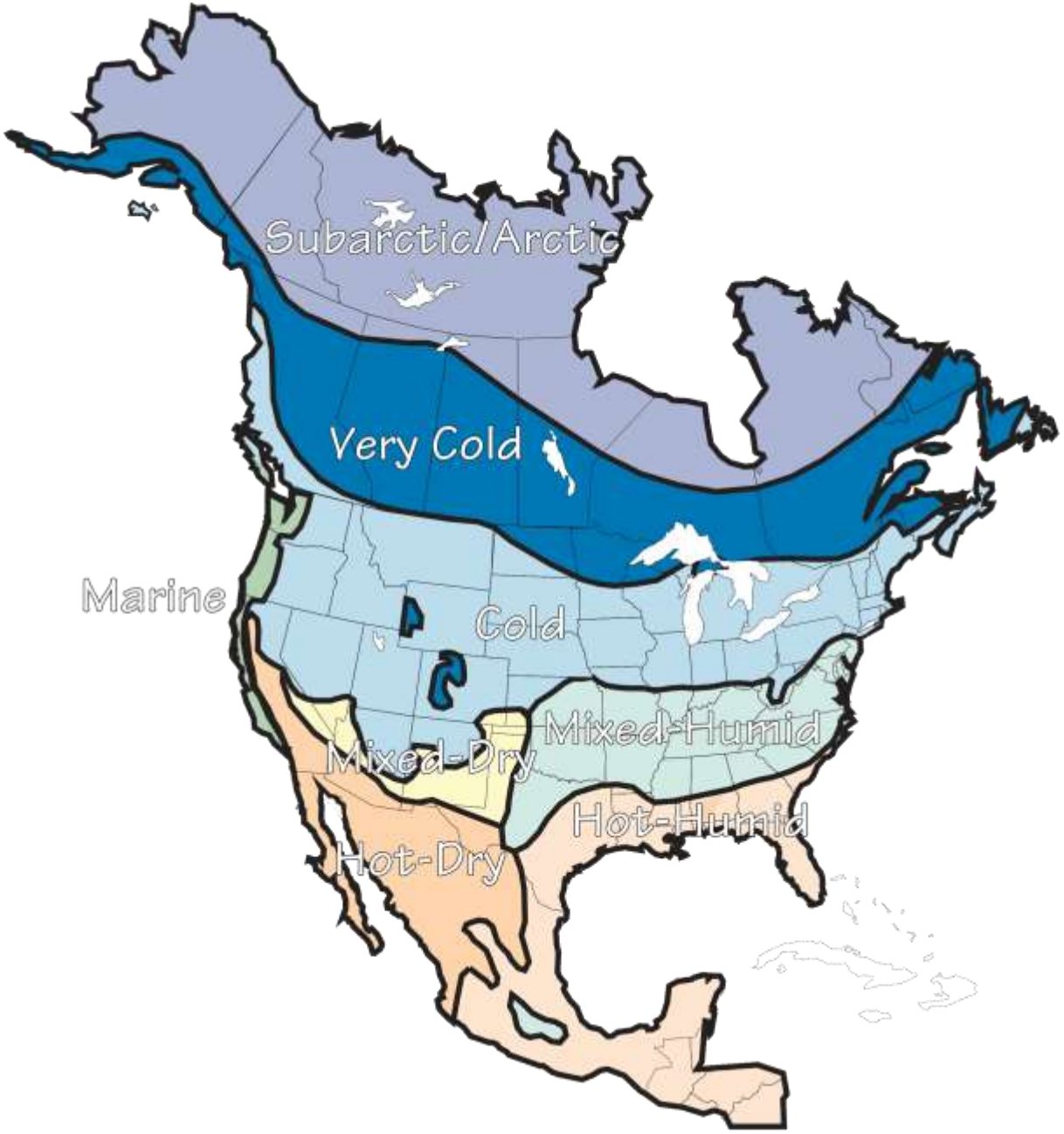
Freeze-Thaw Damage

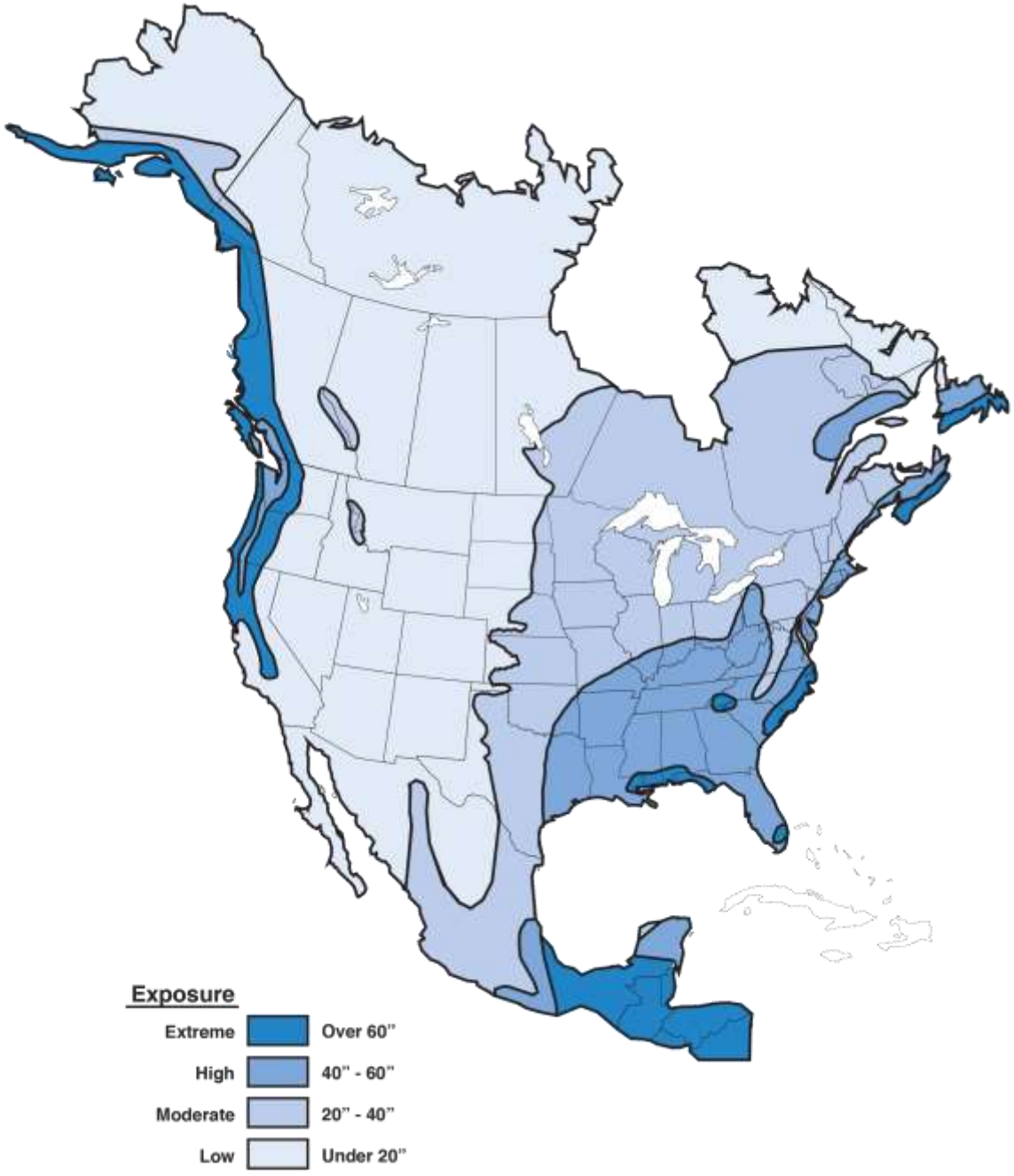
Freeze-Thaw Damage

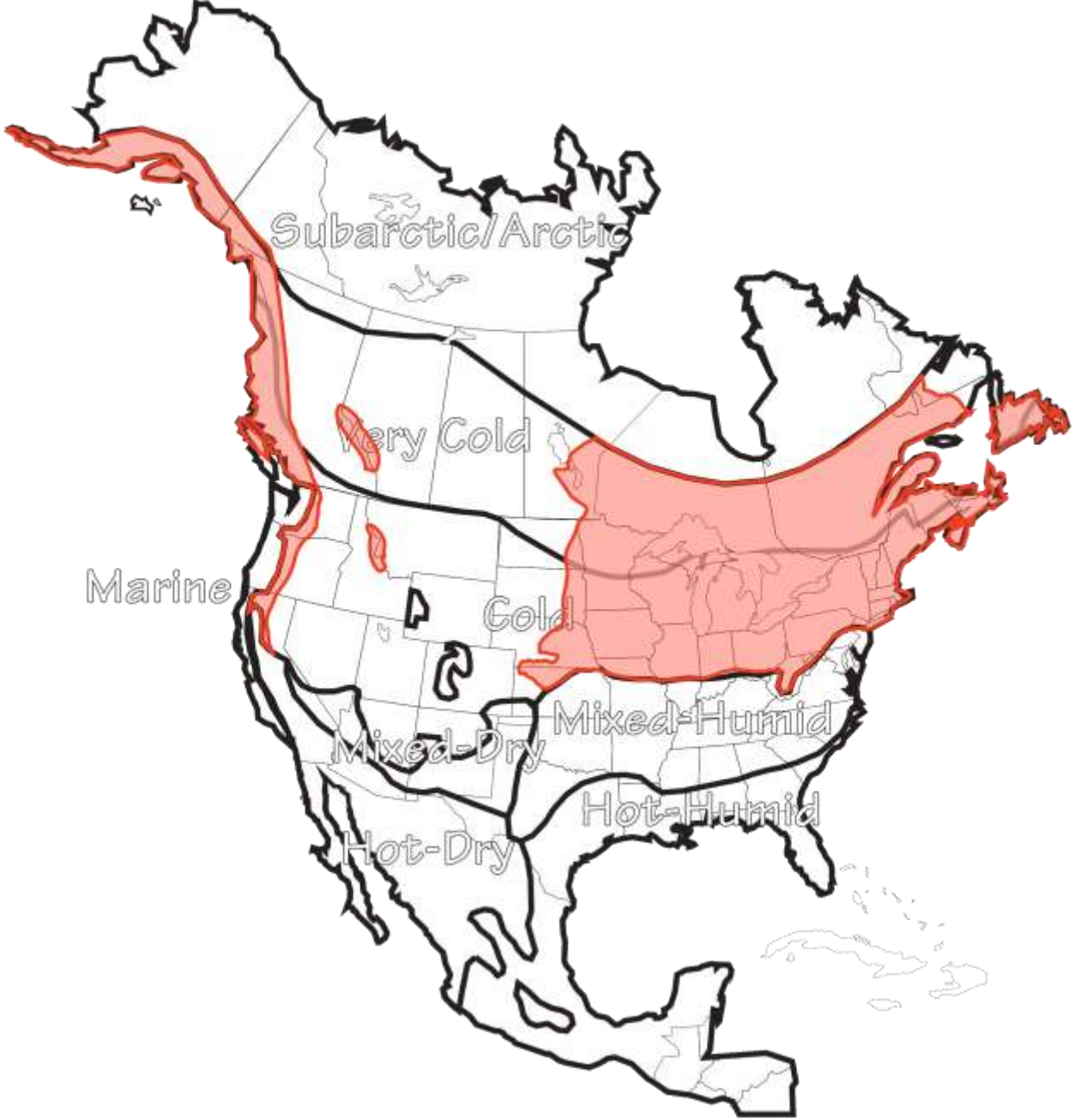
Freezing Temperatures

Water

Susceptible Brick


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

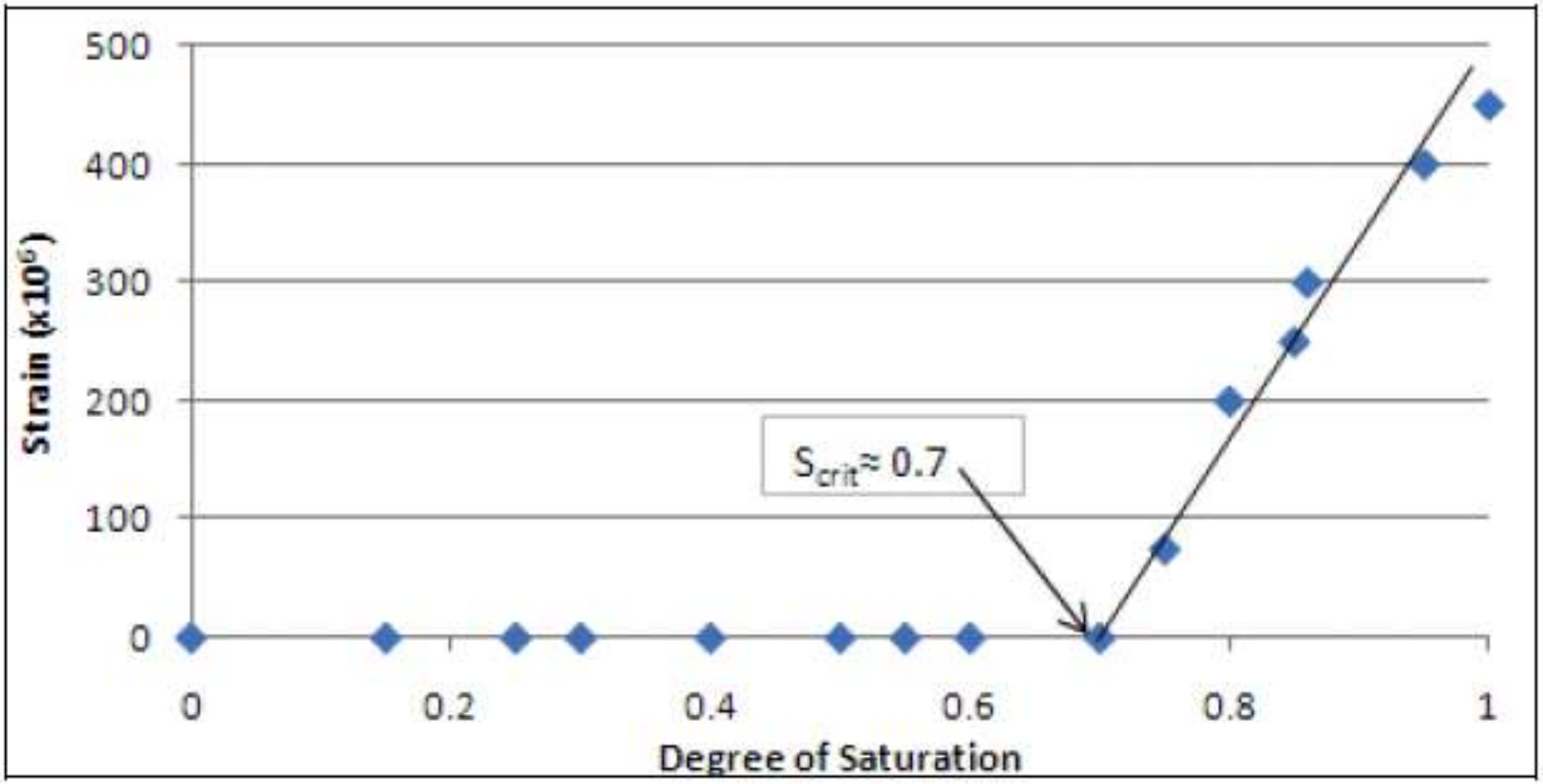

Exposure
Extreme
Over 60"
High
40" - 60"
Moderate
20" - 40"
Low
Under 20"


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

Susceptible Brick

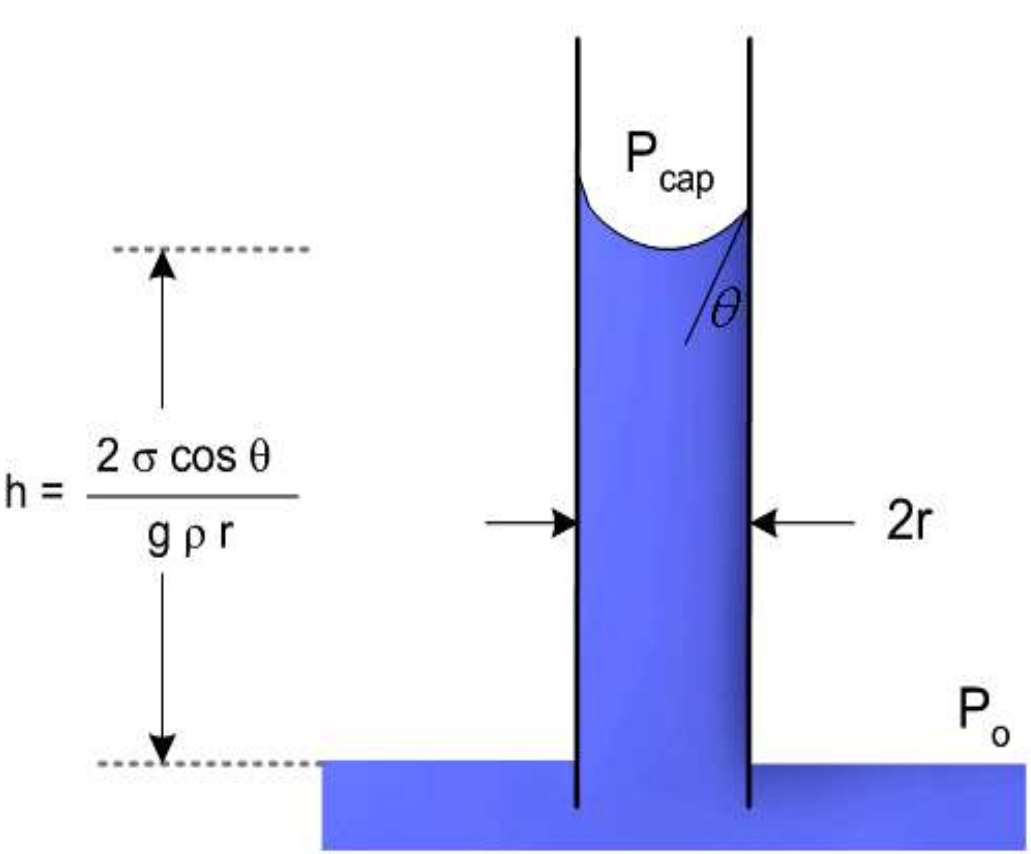
Firing Temperature

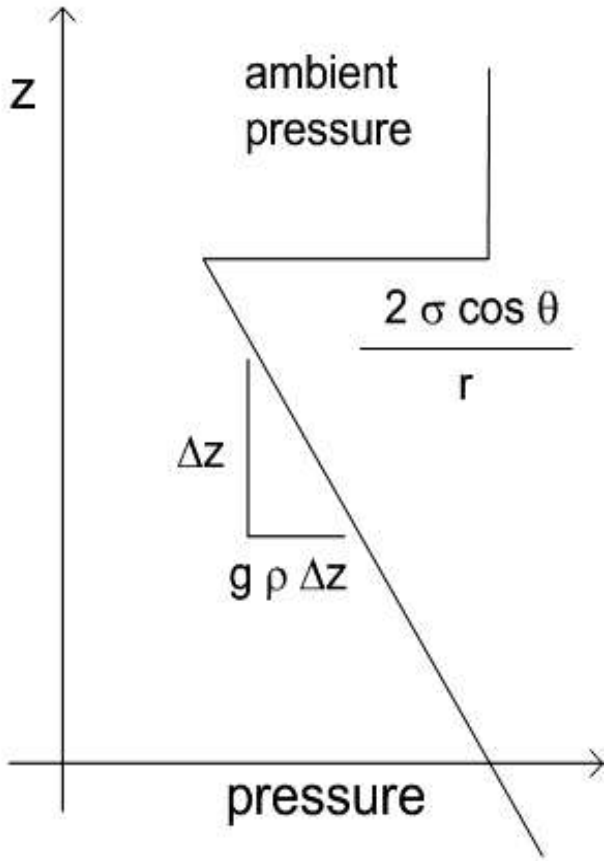
Vitrification


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

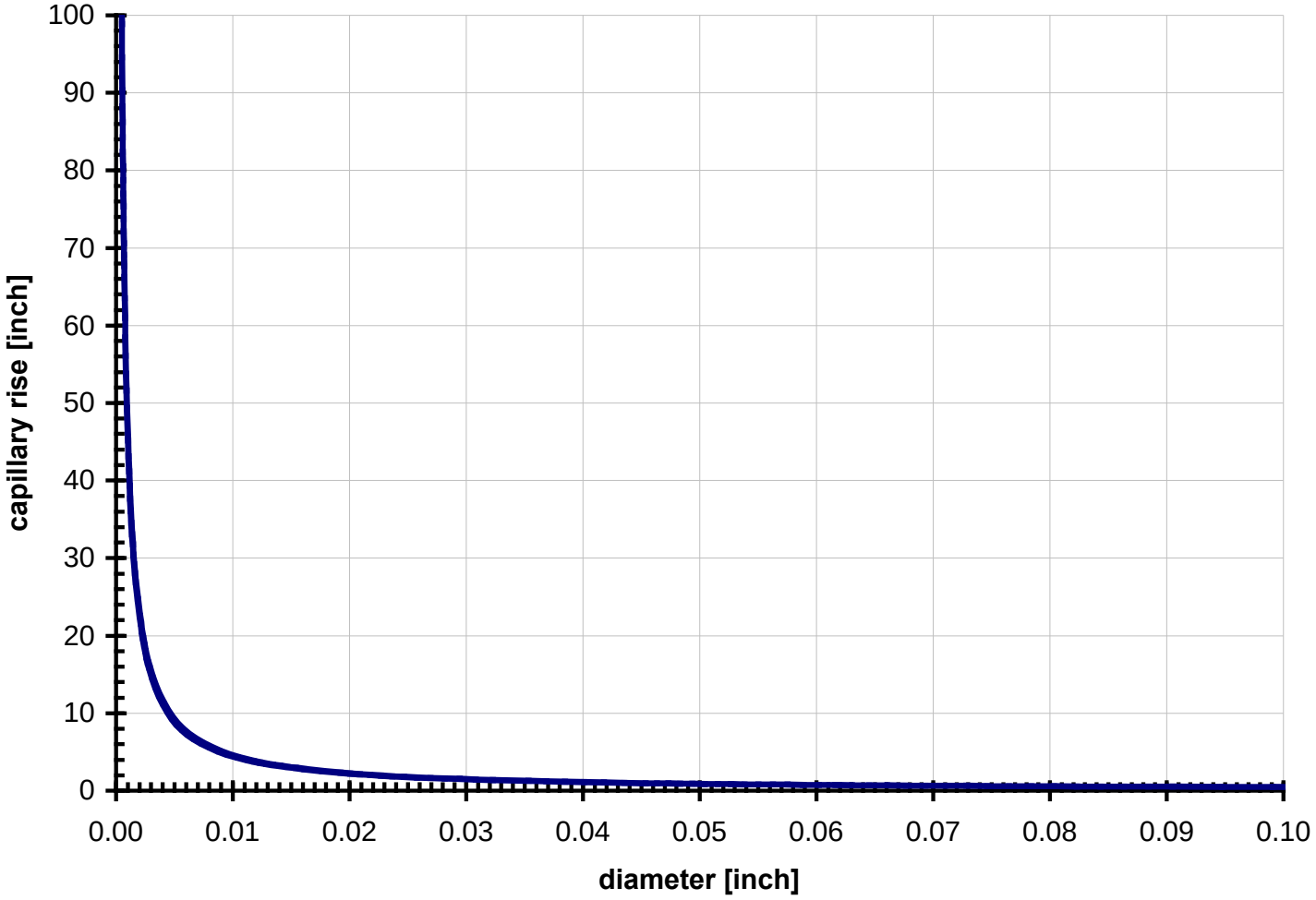
3.84295
3-4" ASIMETO .00005"

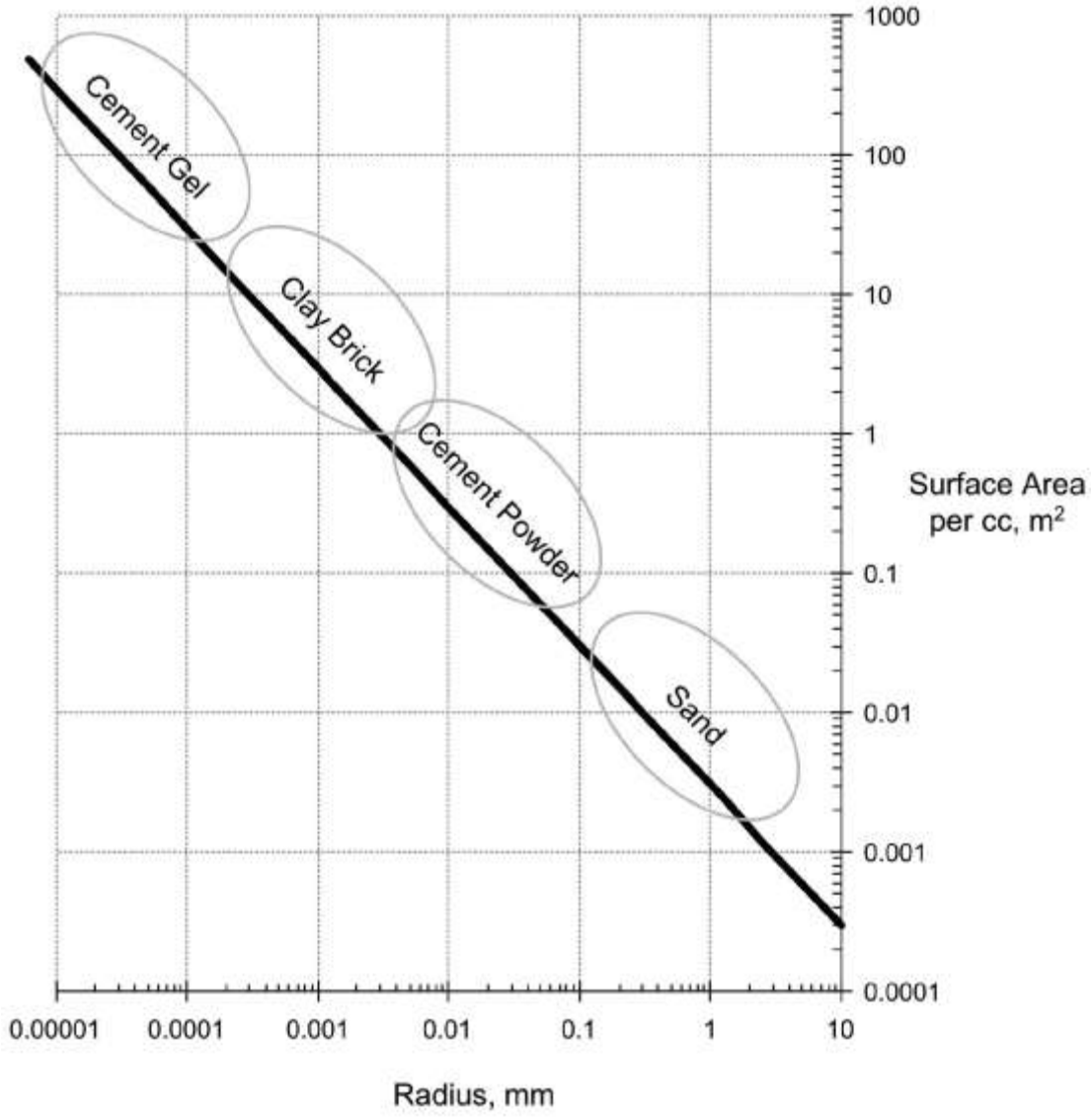
Calculating capillary rise





Capillary rise versus diameter





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

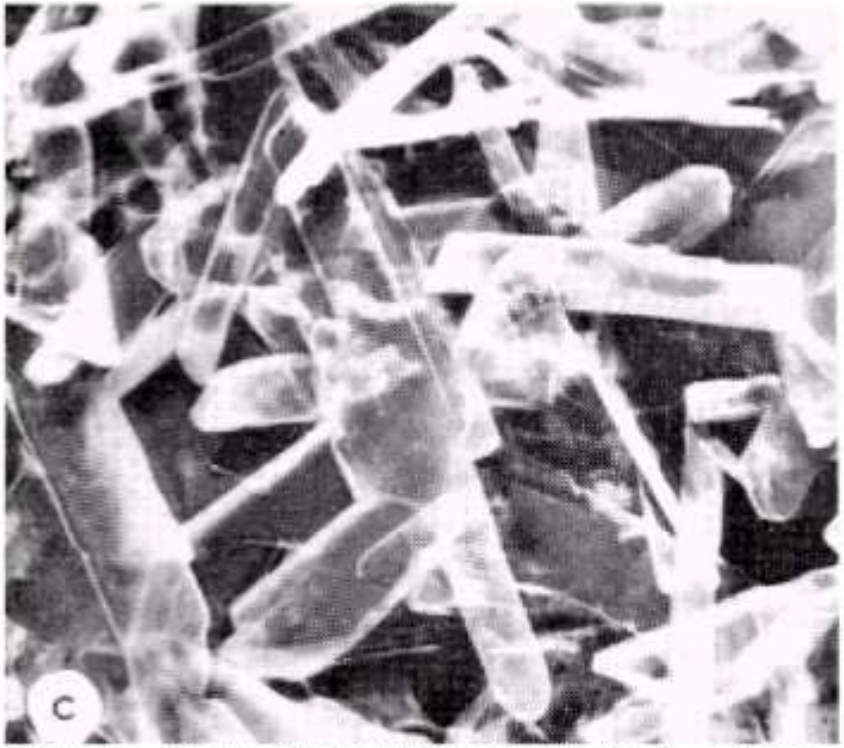


Figure 1c. Gypsum, hydrated from plaster of paris and water, porosity 30 per cent.

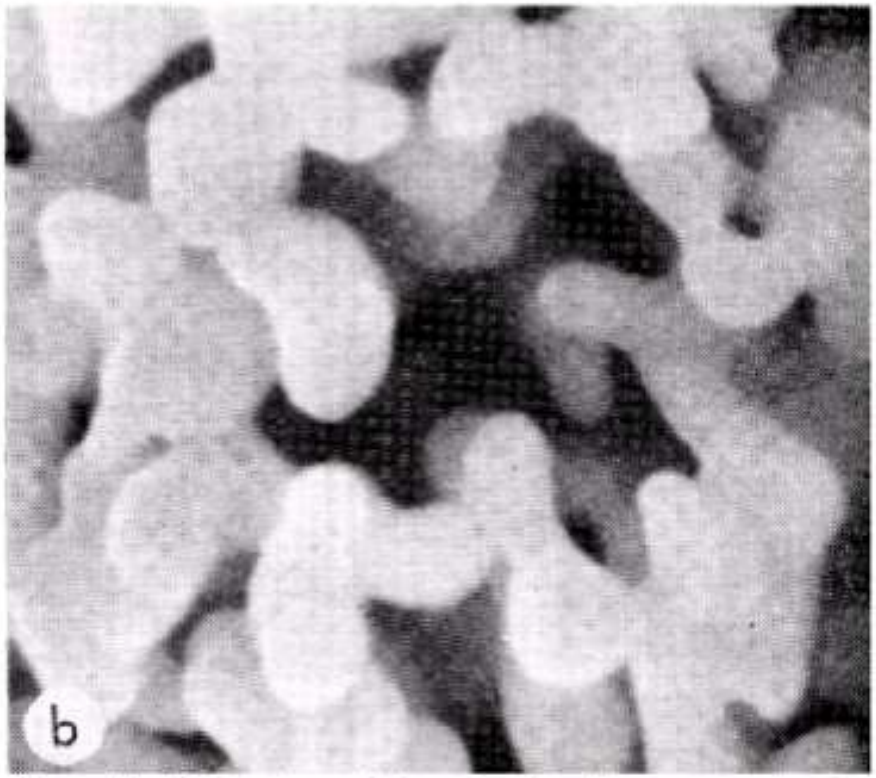
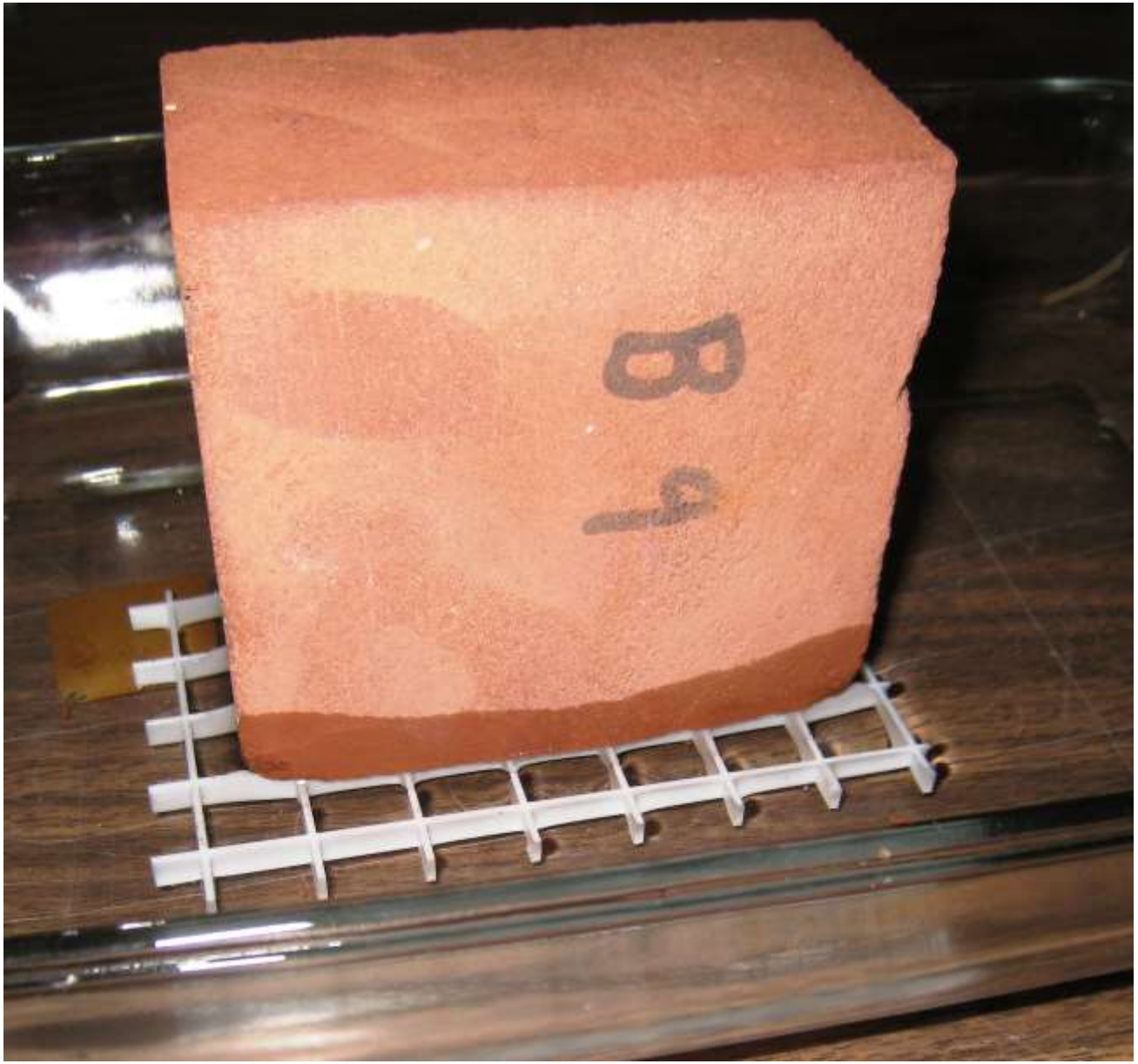
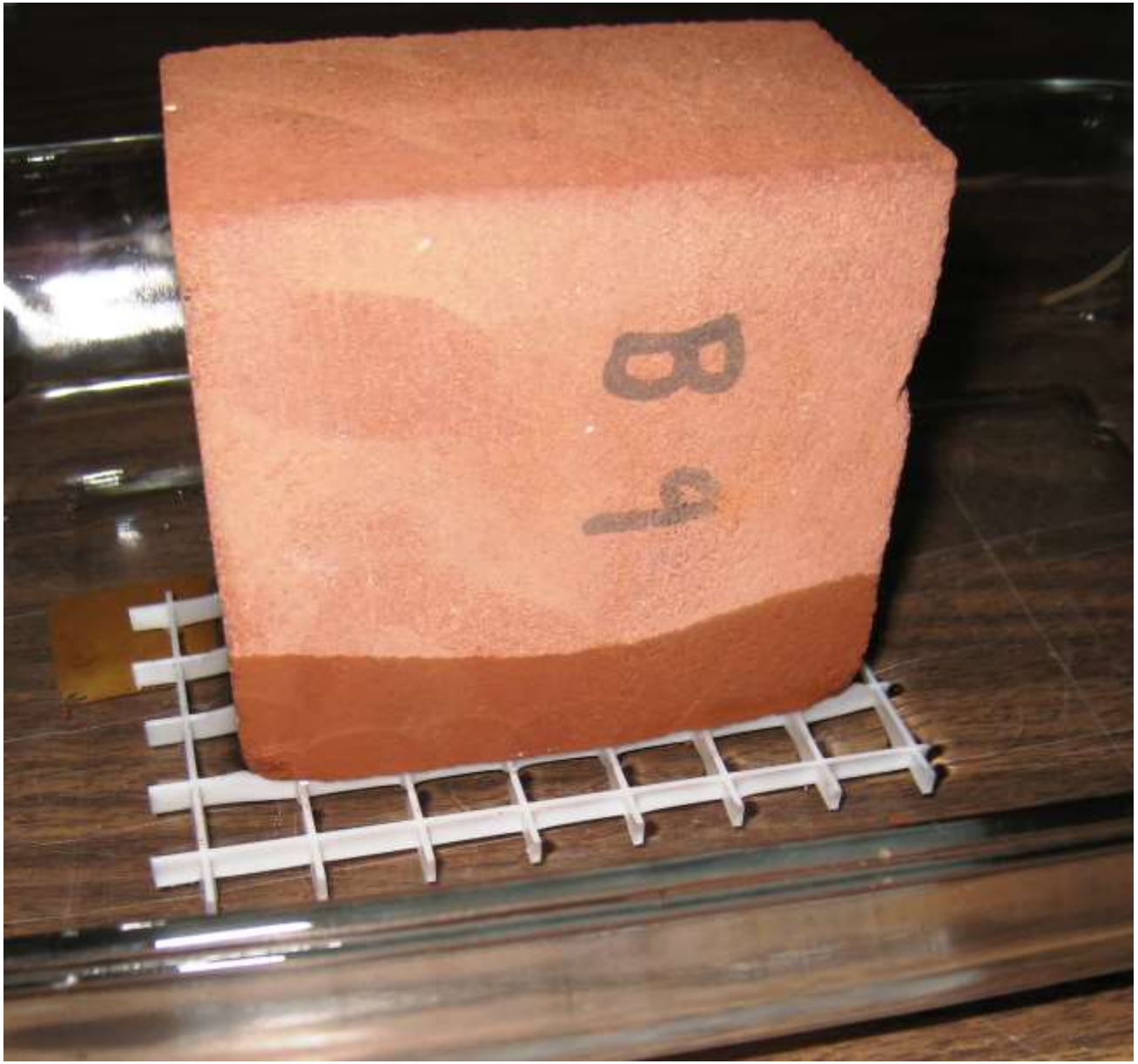
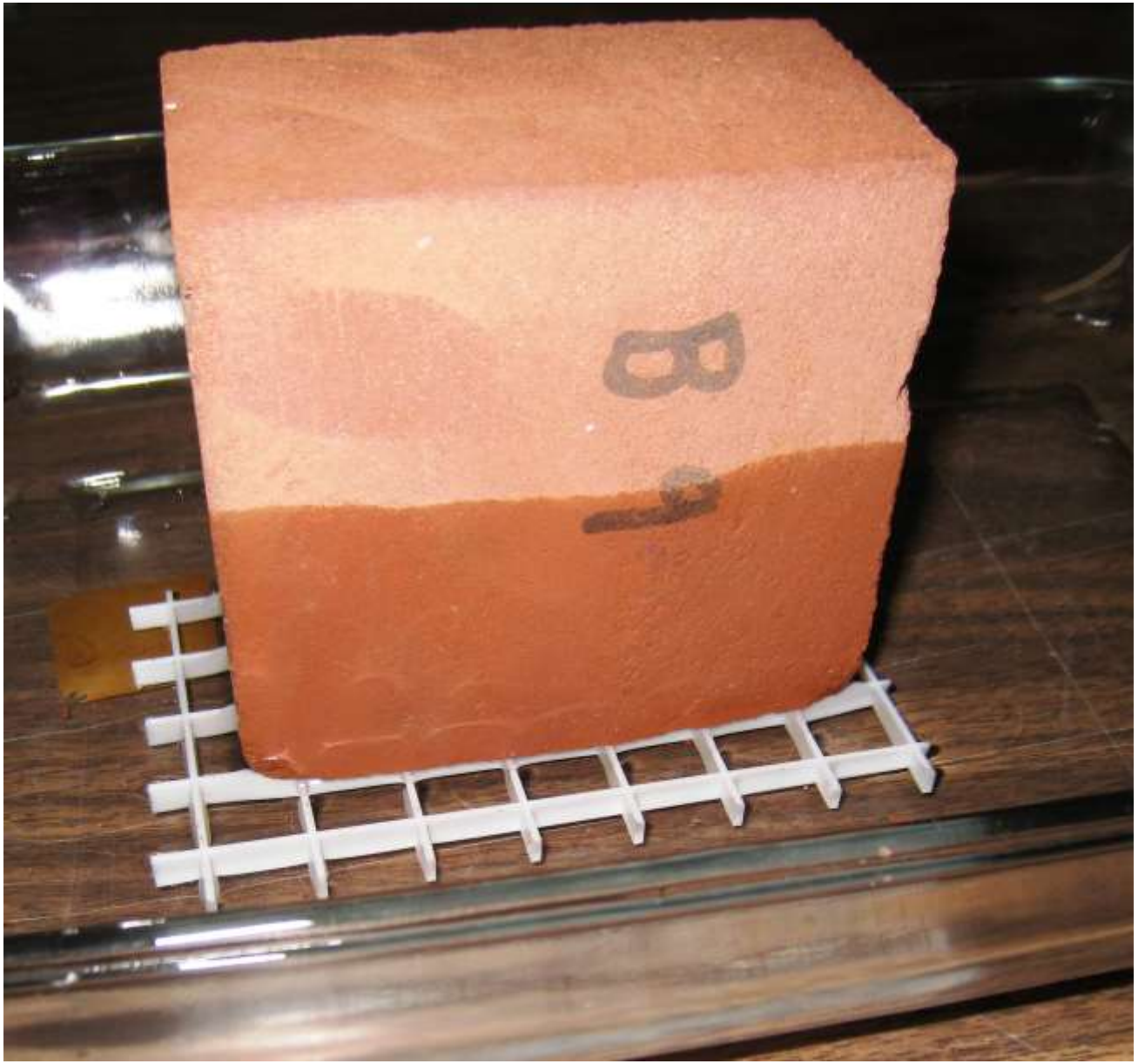
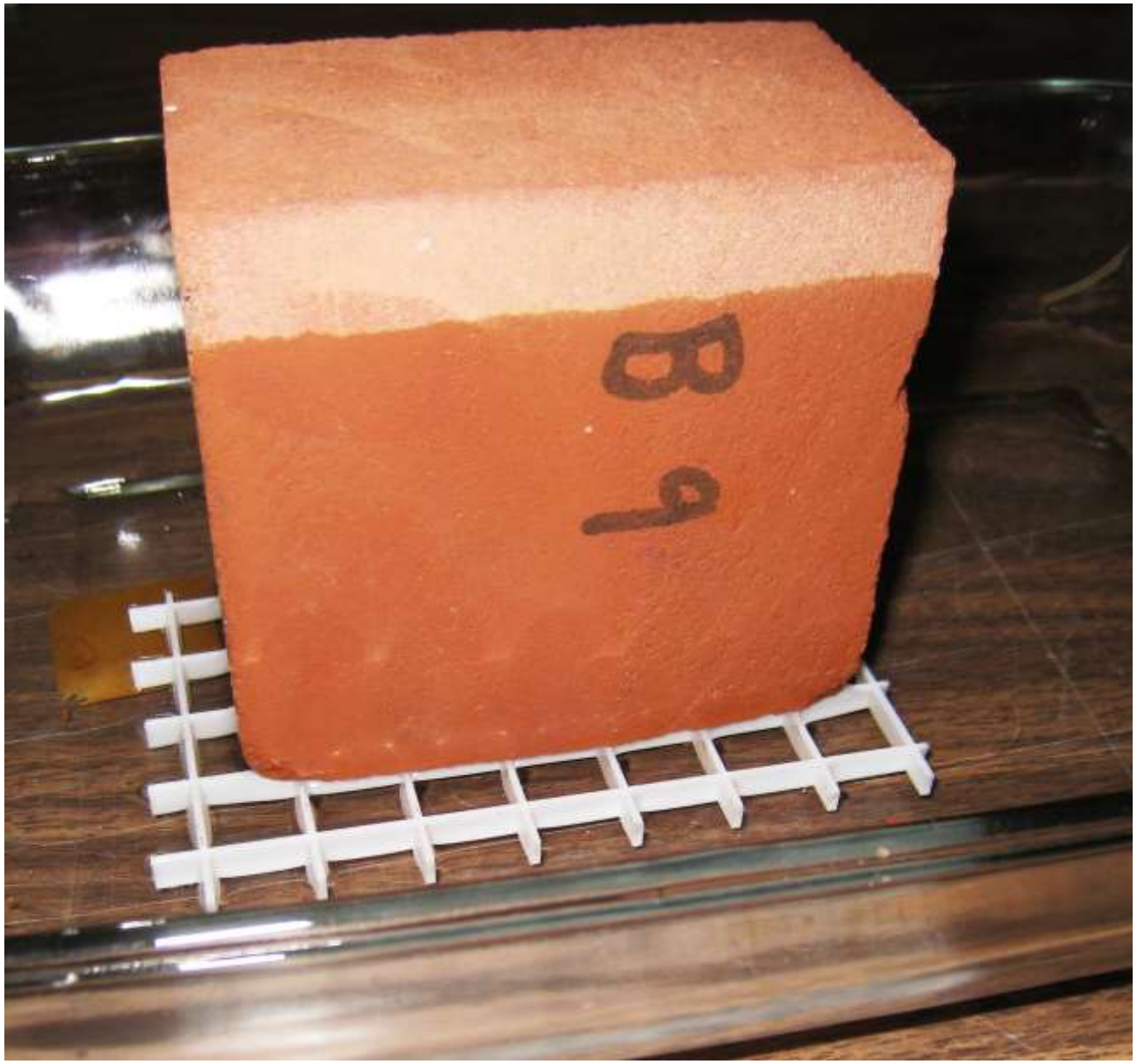


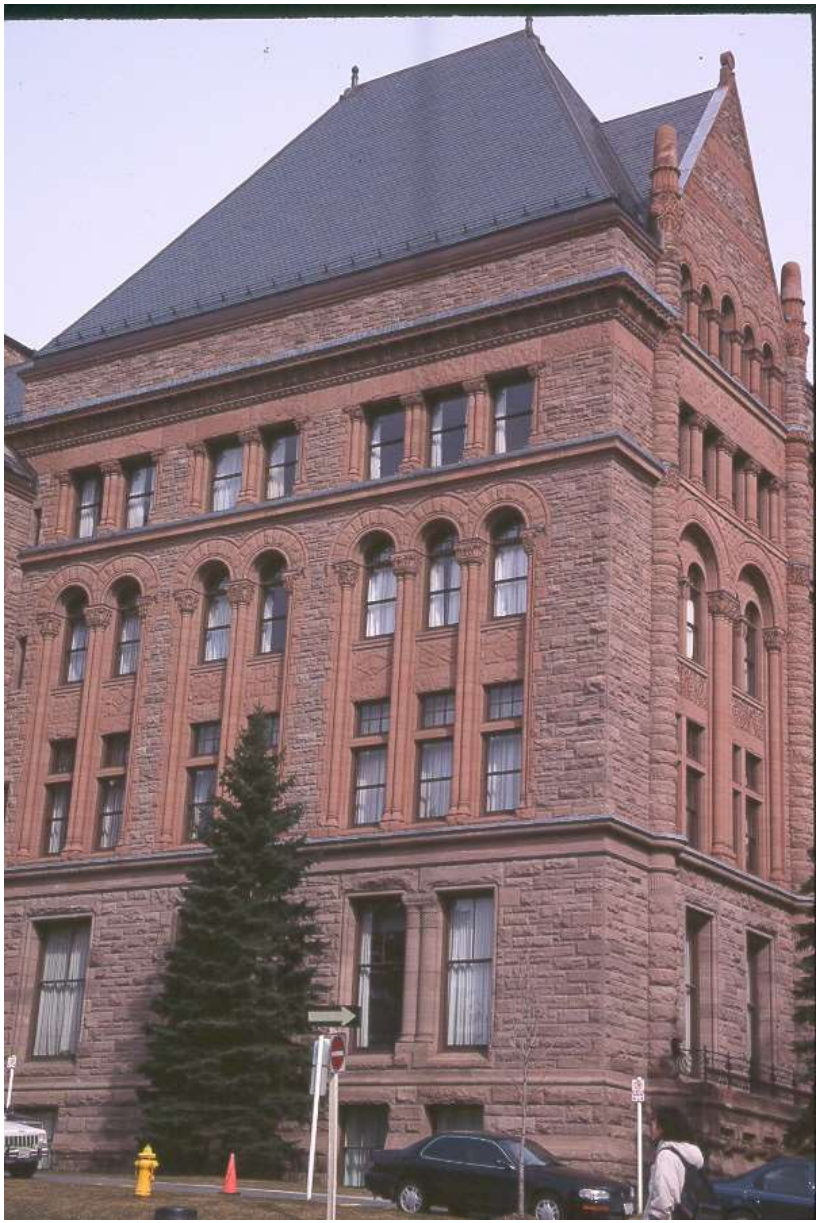
Figure 1b. Brick, sintered clay, porosity 40 per cent.

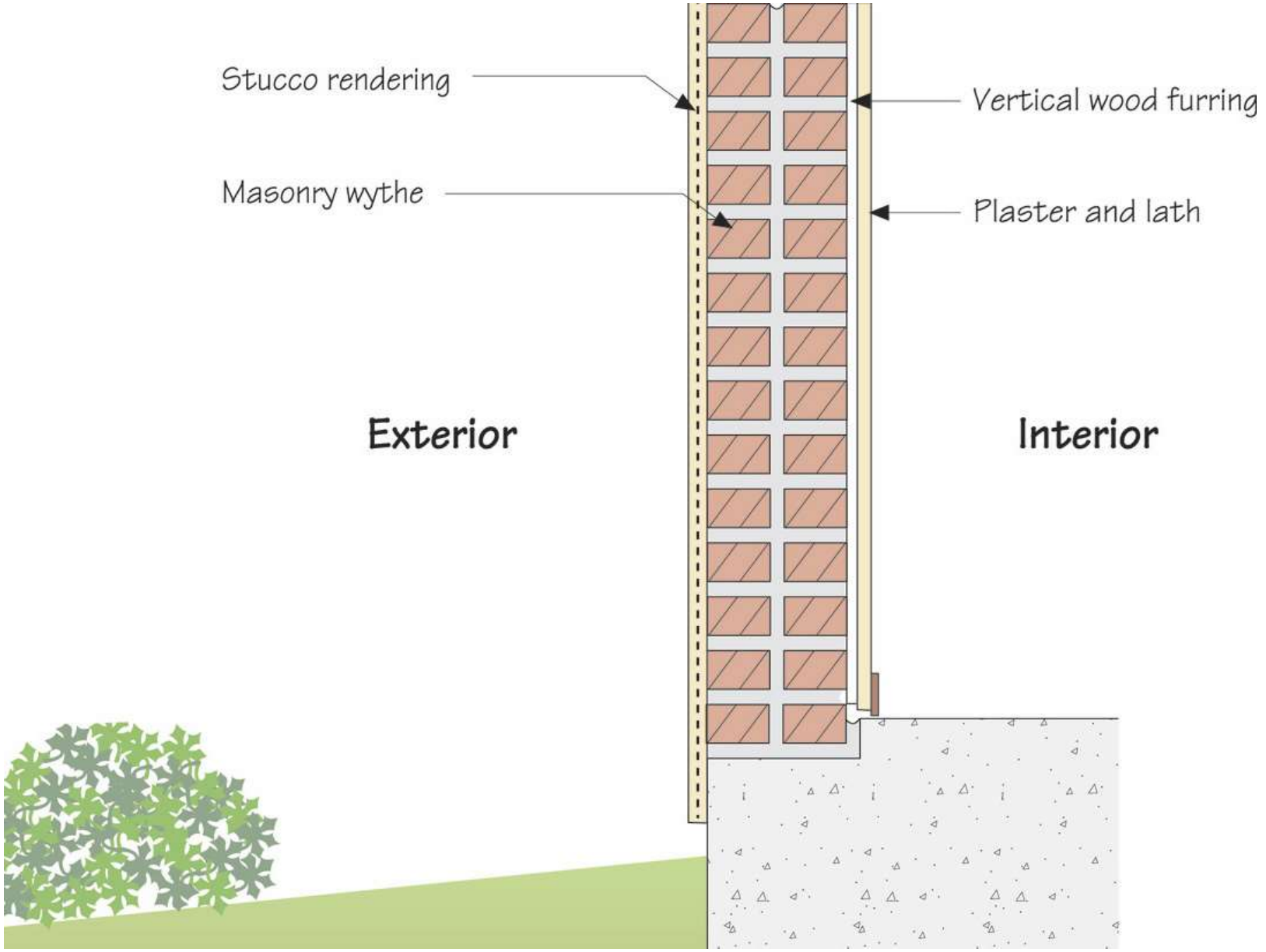


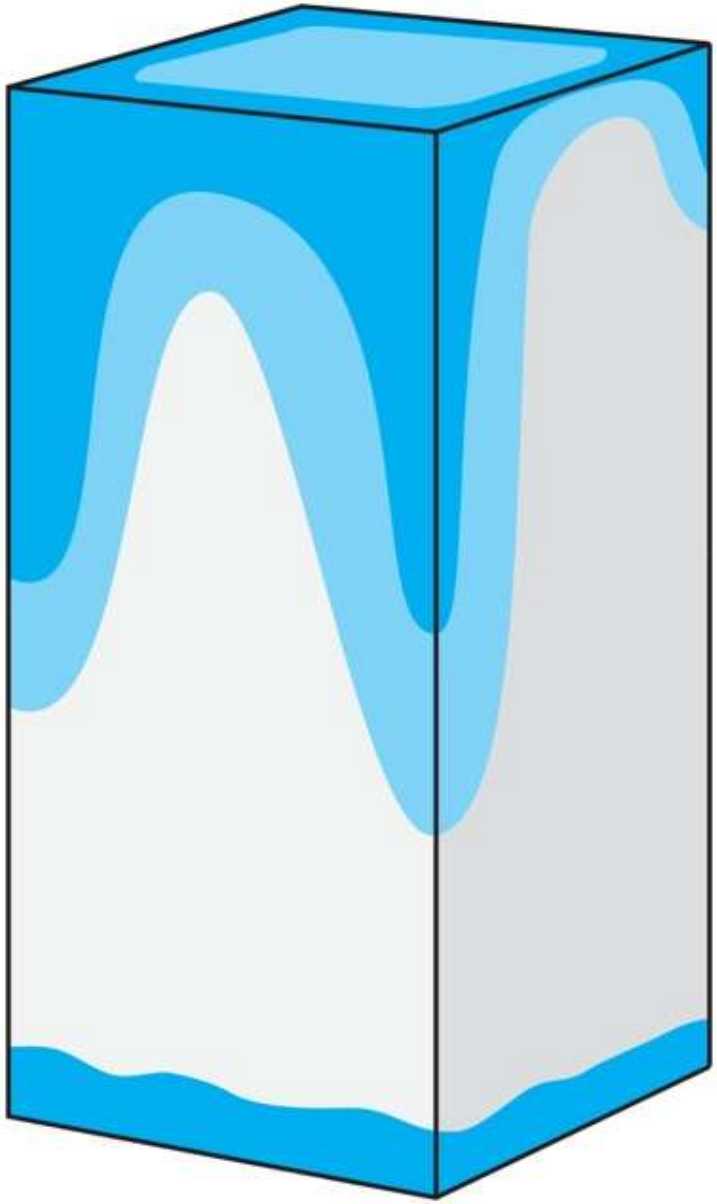


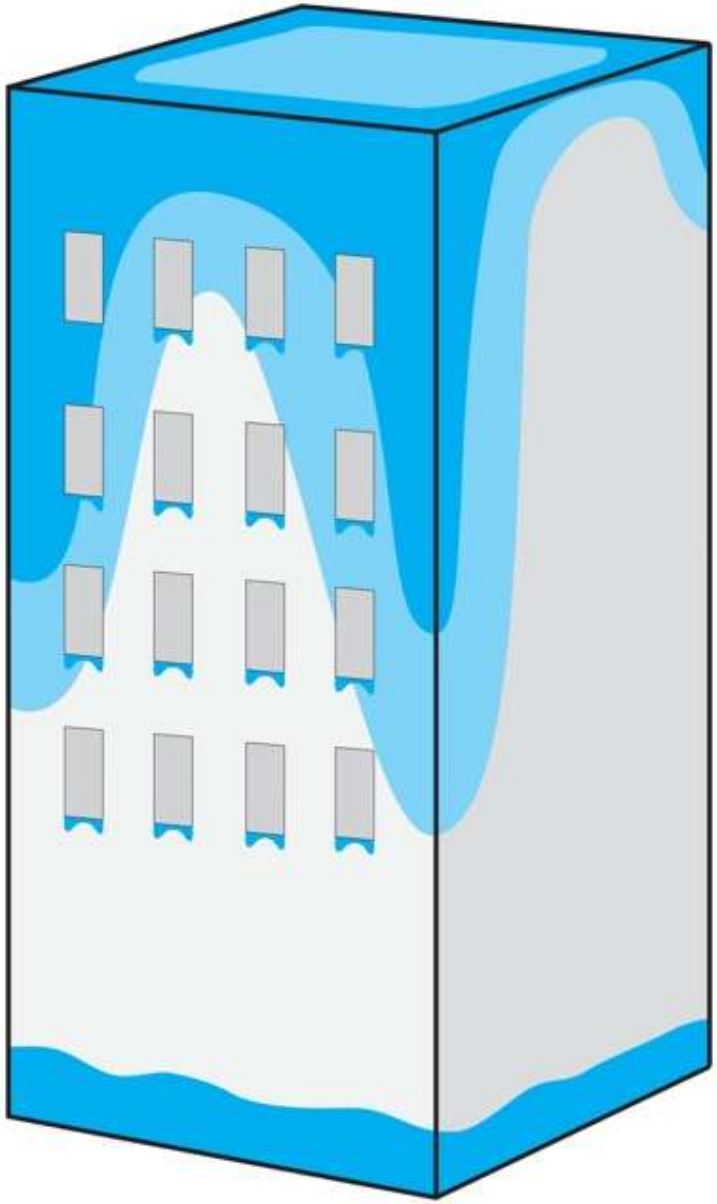



B
9

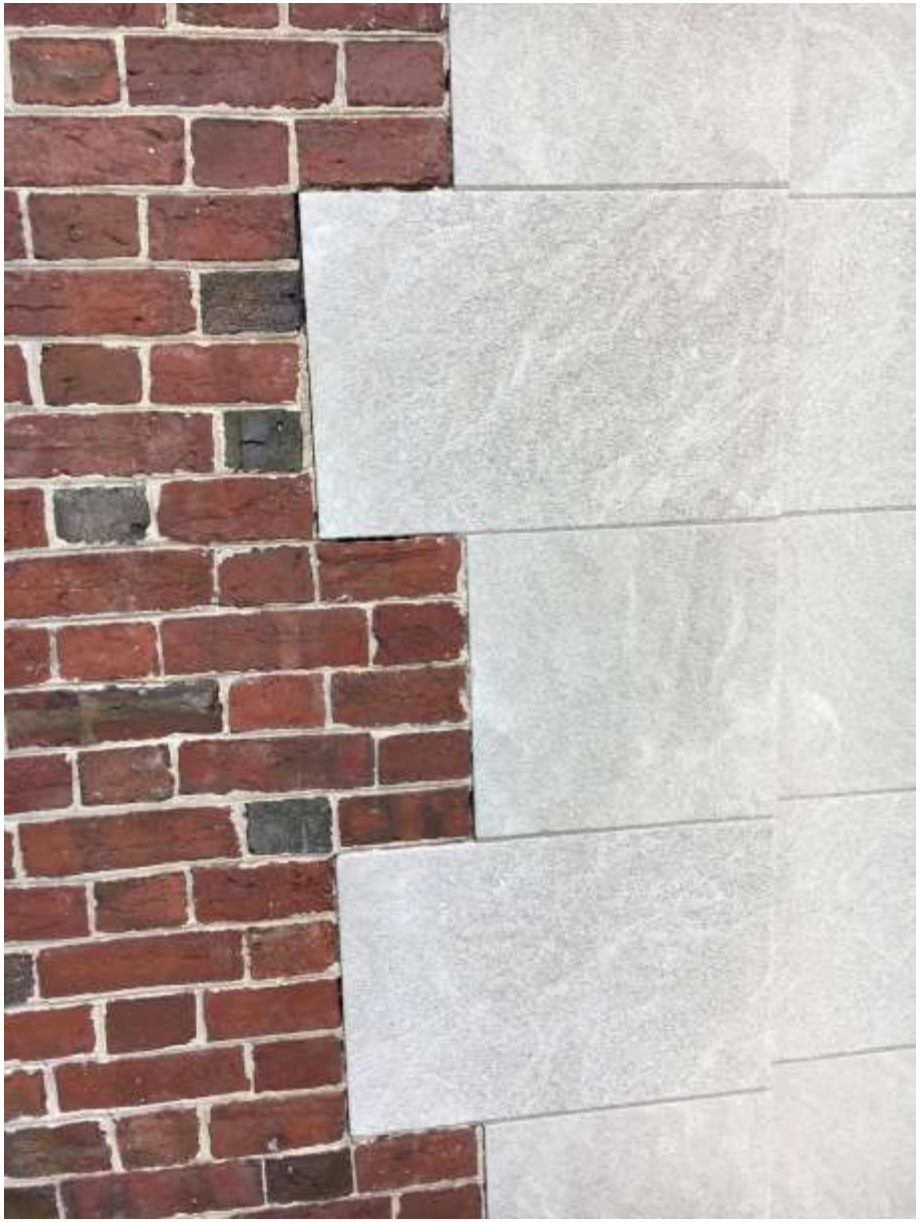



Stucco rendering
Masonry wythe
Vertical wood furring
Plaster and lath
Exterior
Interior

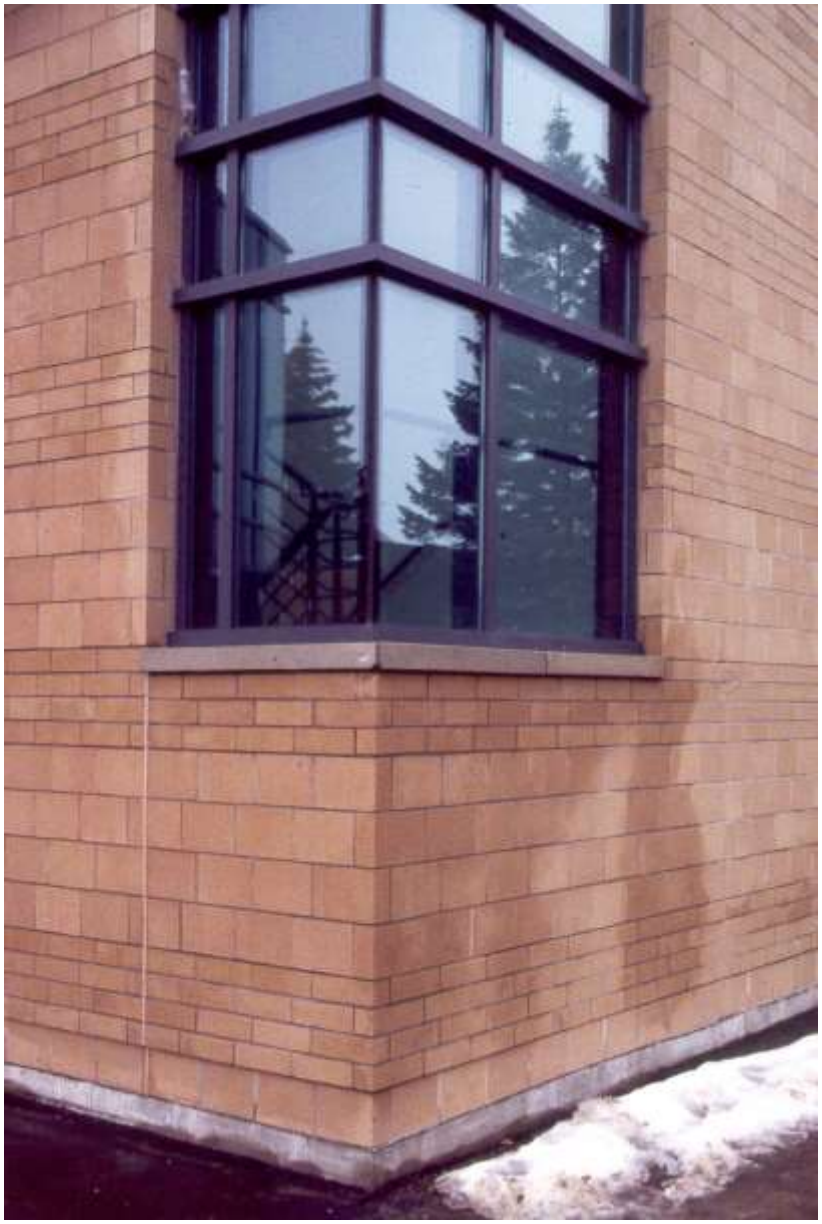




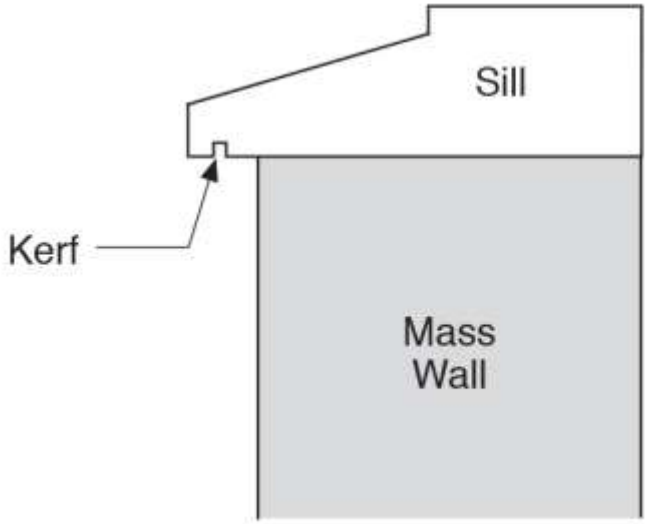
Lafayette
PHOENIX
(212) 963-9304

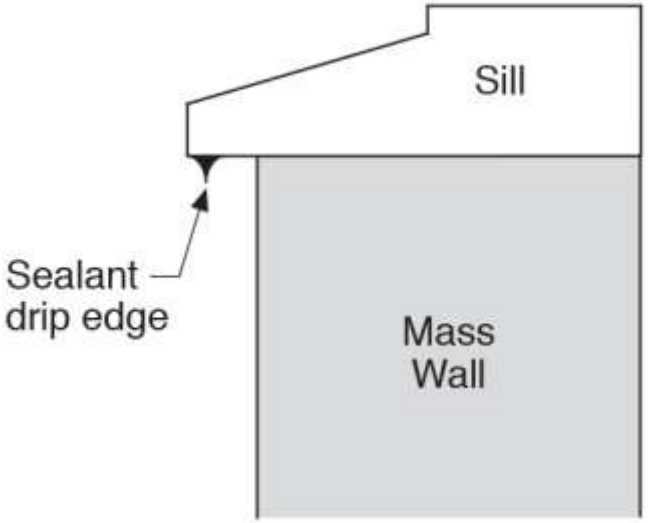


Retail
Space



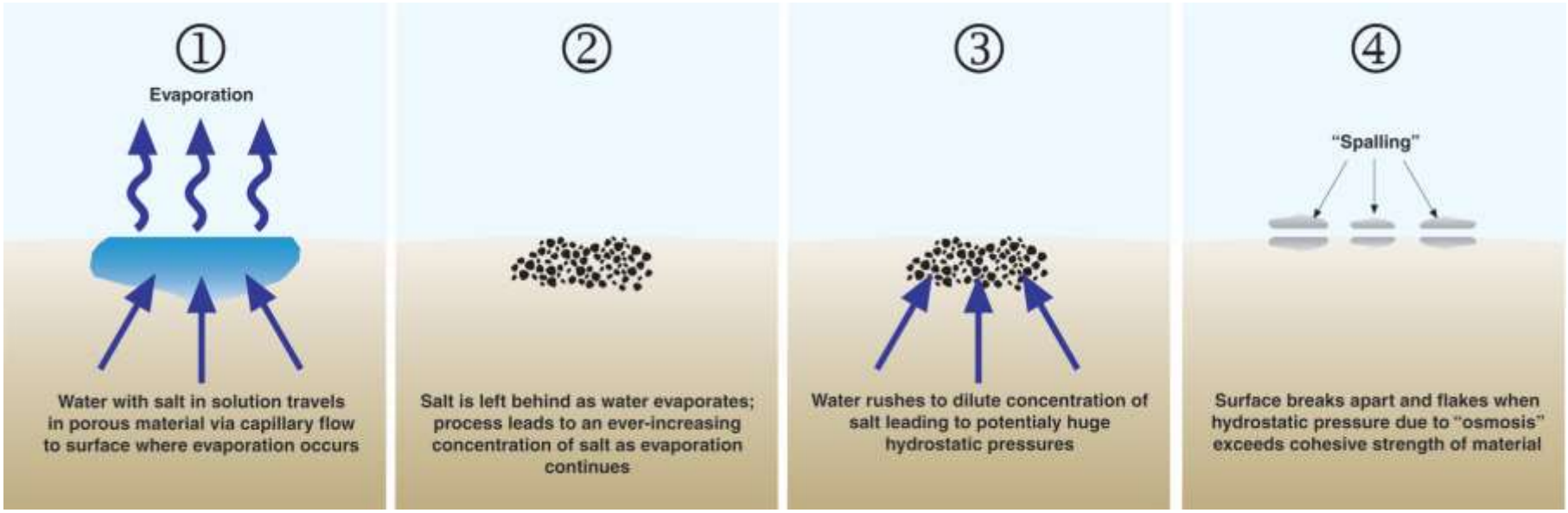
metabo


Sill
Kerf
Mass
Wall


Sill
Sealant
drip edge
Mass
Wall

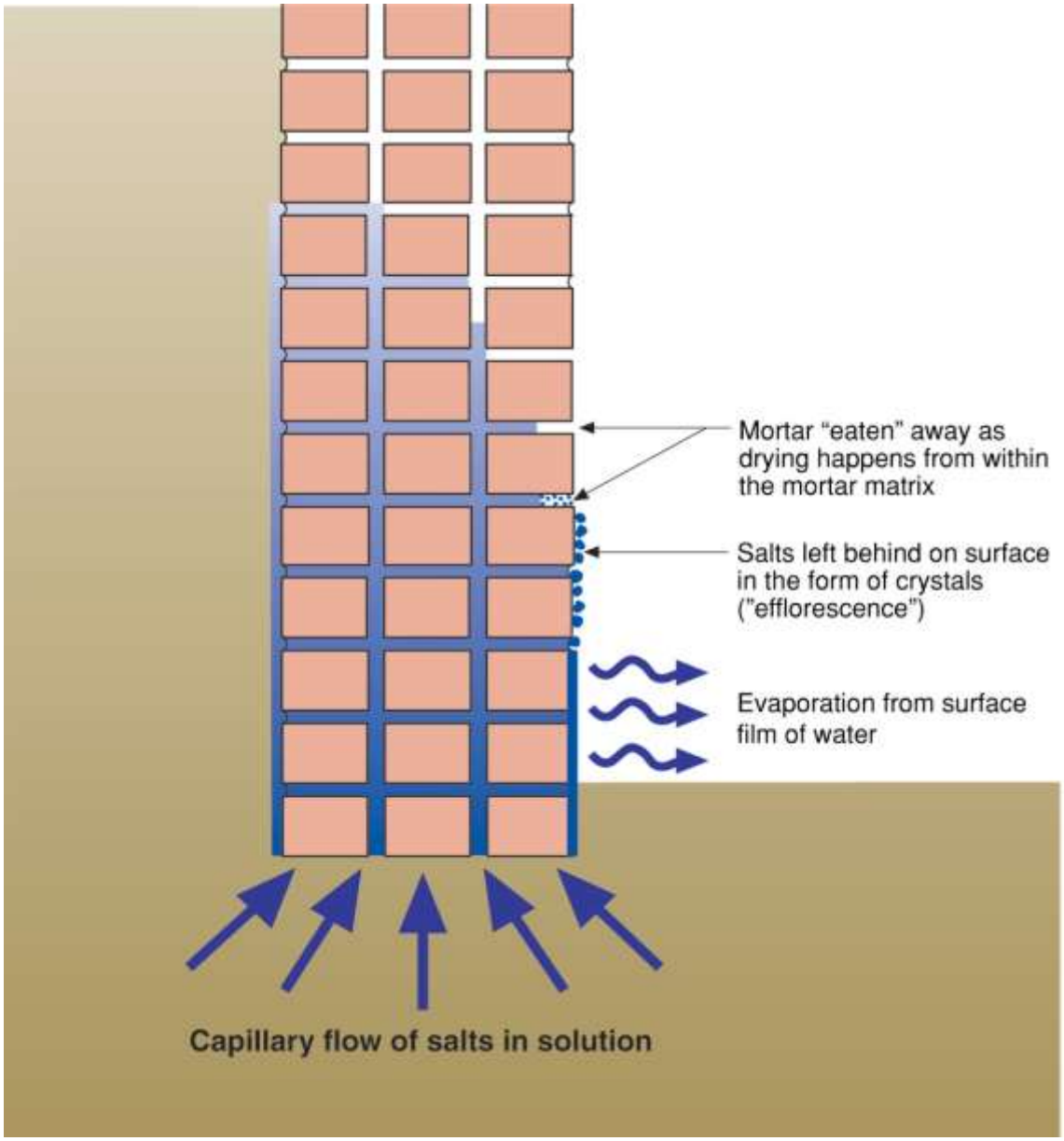
418

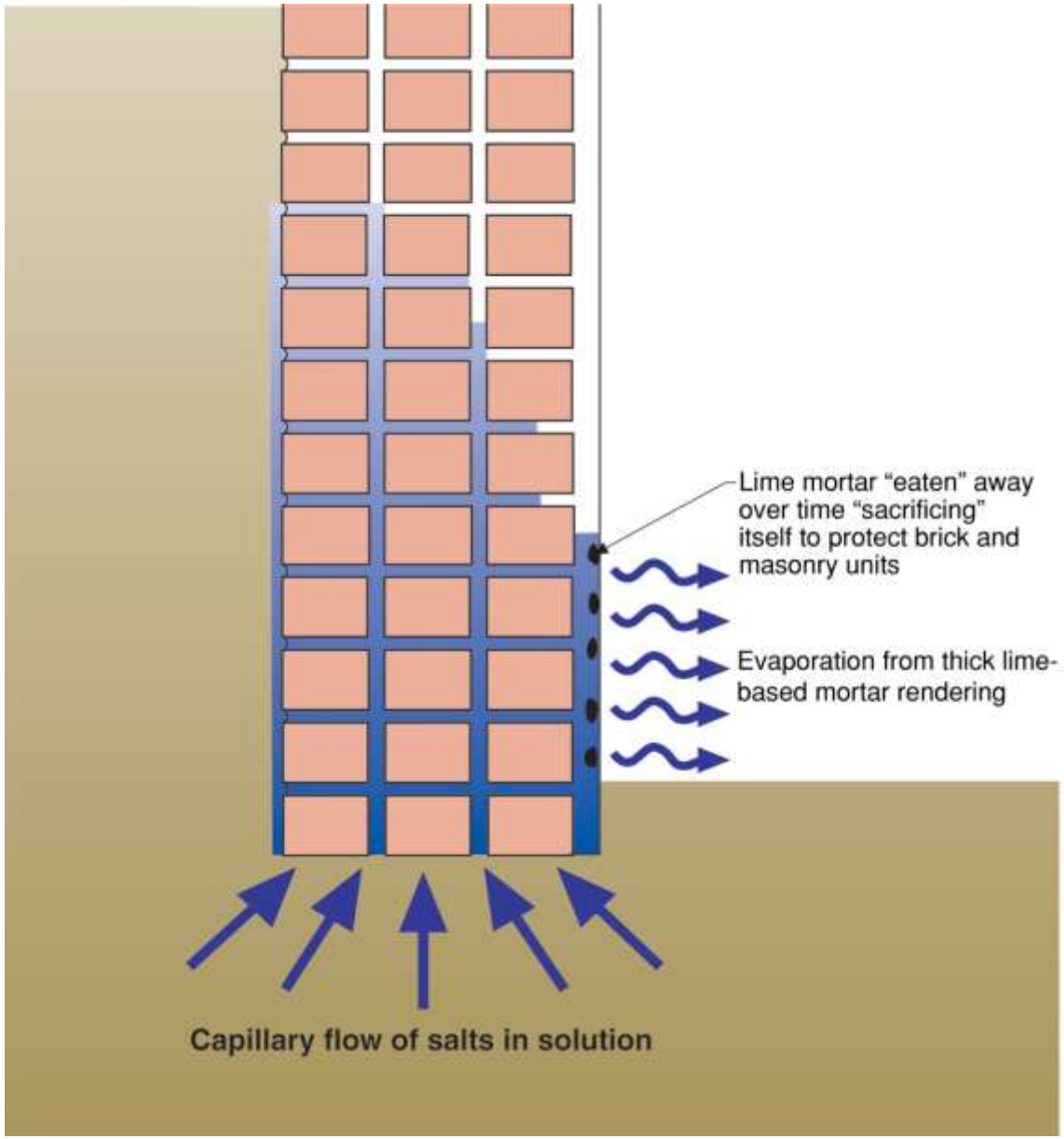
Ruc
Saint-Dizier


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

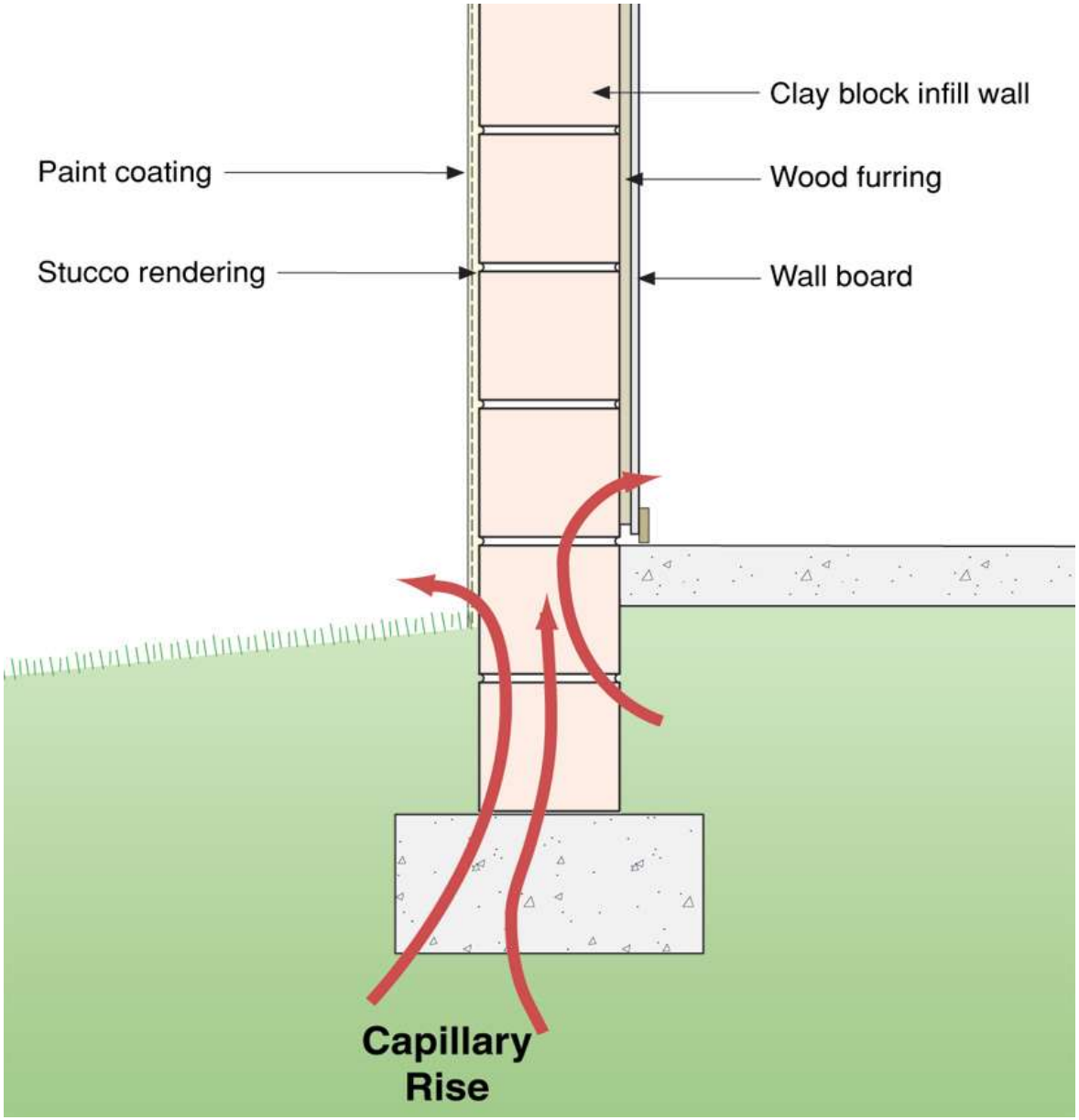
- Diffusion Vapor Pressure 3 to 5 psi
- Capillary Pressure 300 to 500 psi
- Osmosis Pressure 3,000 to 5,000 psi

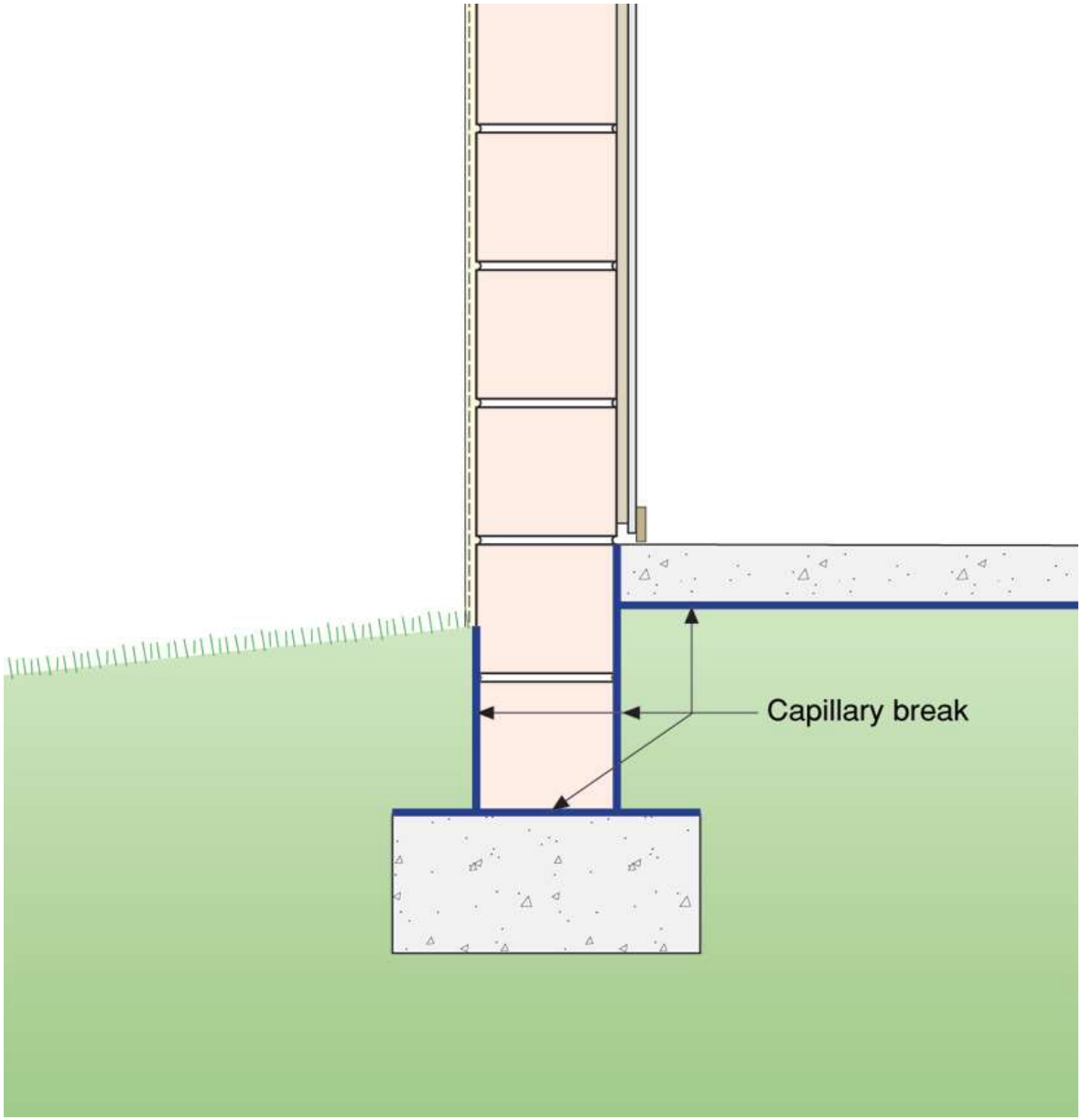

Mortar "eaten" away as drying happens from within the mortar matrix
Salts left behind on surface in the form of crystals ("efflorescence")
Evaporation from surface film of water
Capillary flow of salts in solution

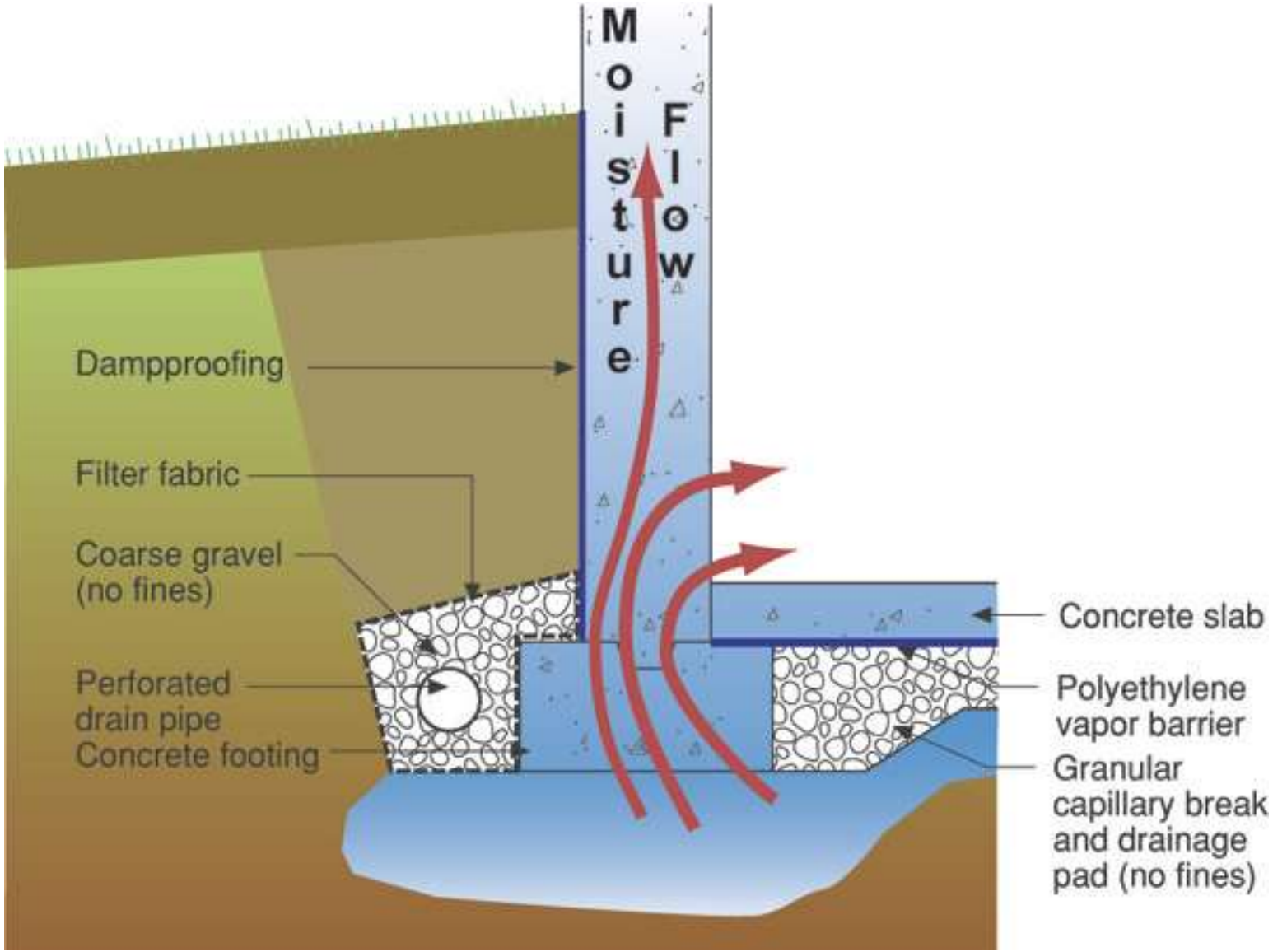

Lime mortar "eaten" away over time "sacrificing" itself to protect brick and masonry units
Evaporation from thick lime-based mortar rendering
Capillary flow of salts in solution

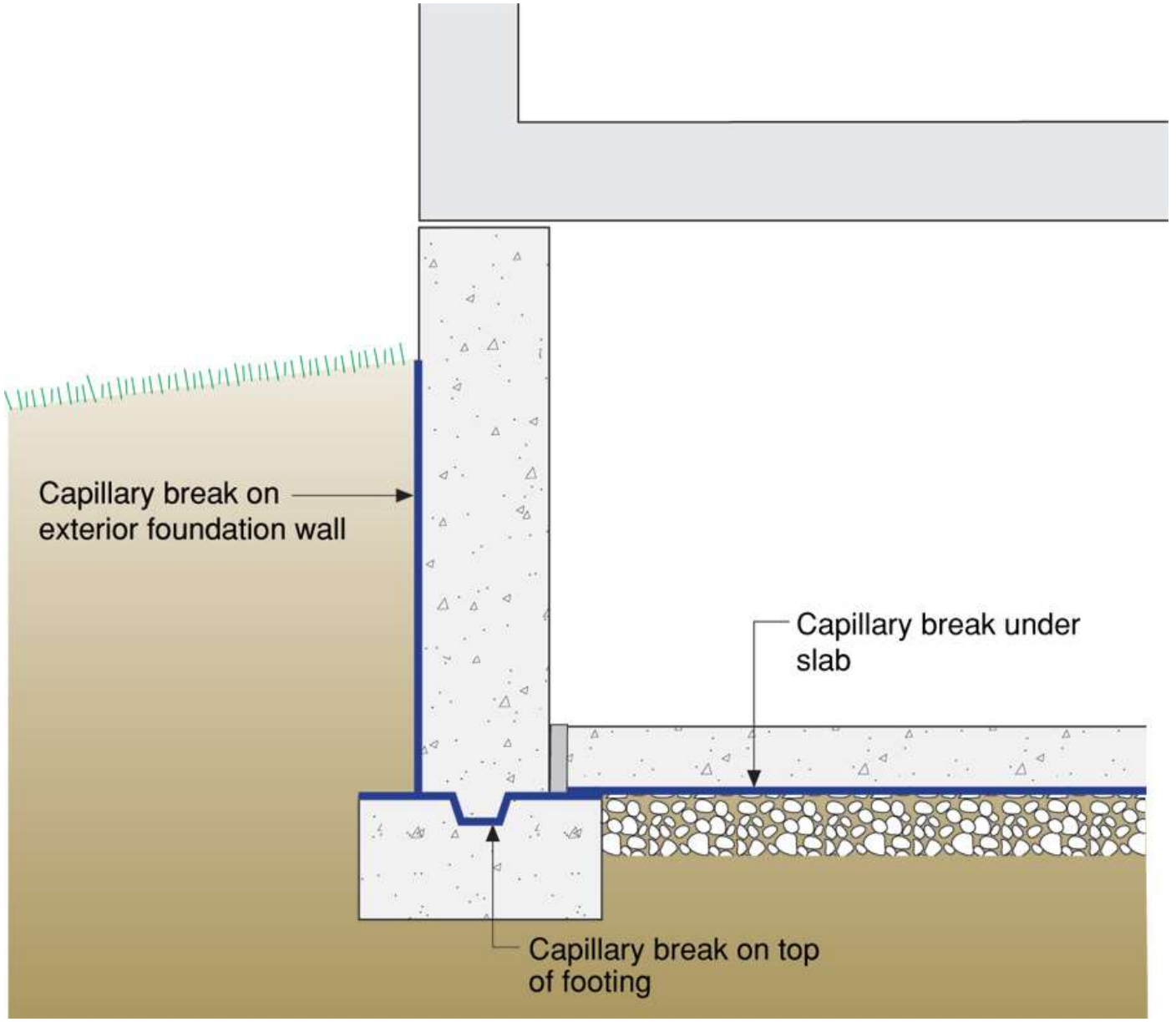
RA 200
RA 200
RA 200
RA 200
RA 200

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

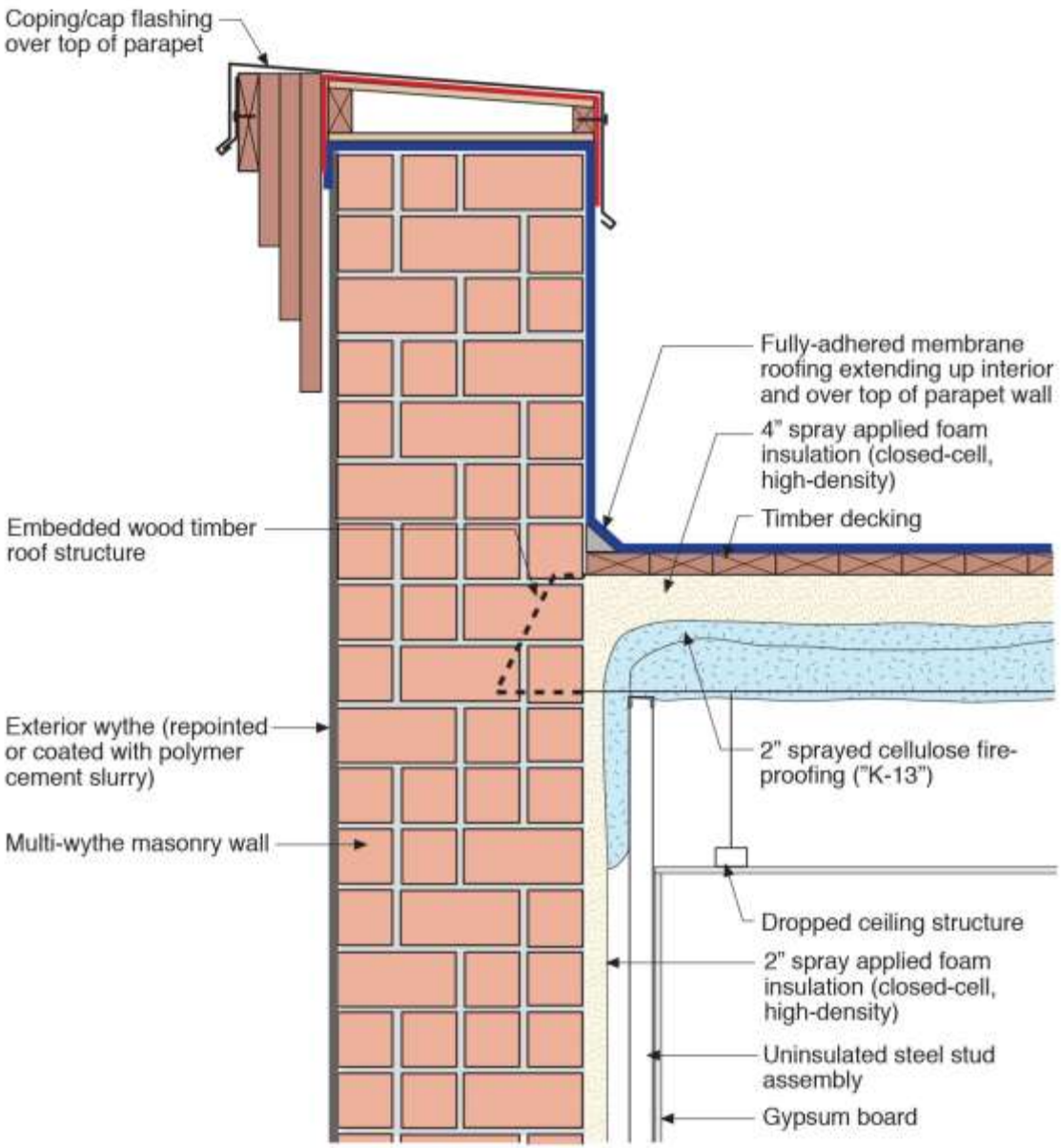

Clay block infill wall
Paint coating
Wood furring
Stucco rendering
Wall board
Capillary
Rise

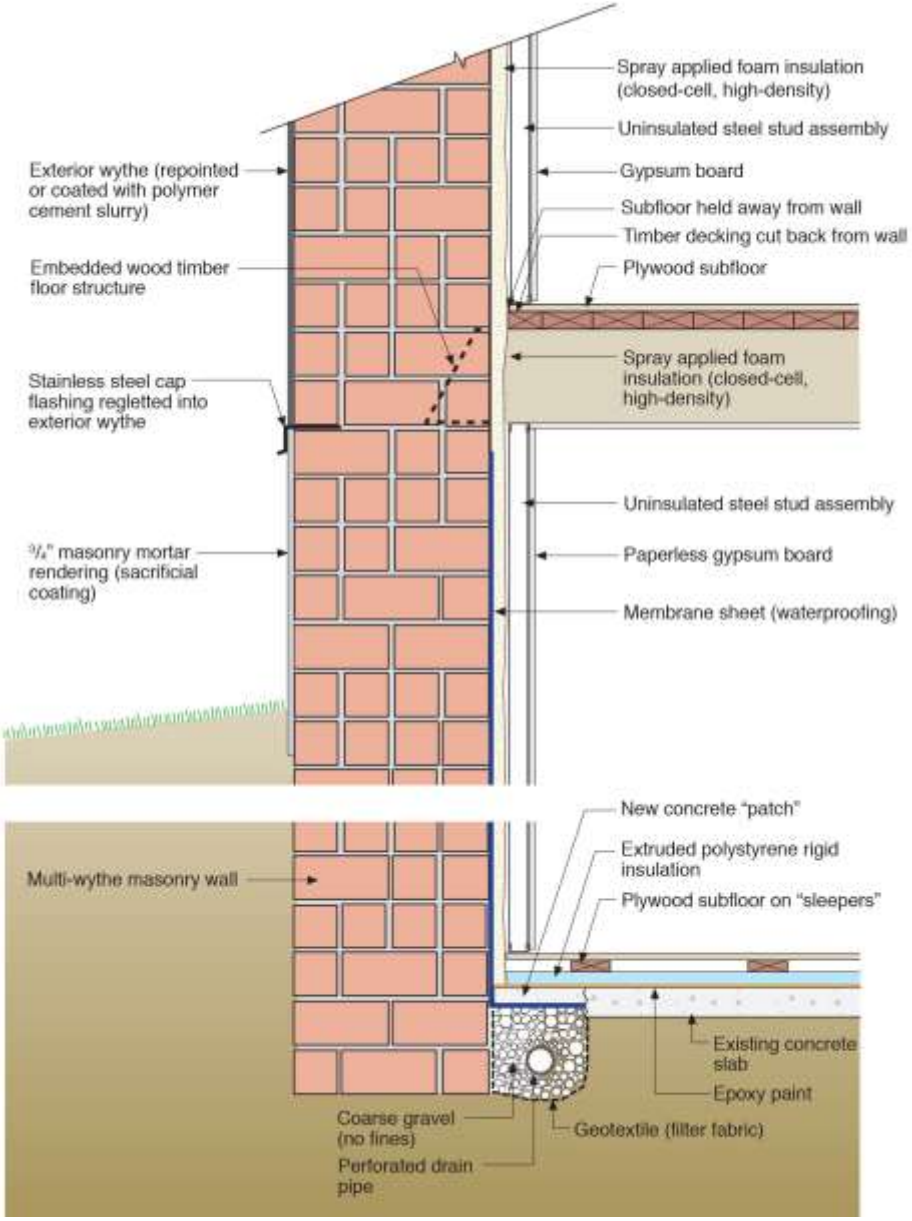

Capillary break

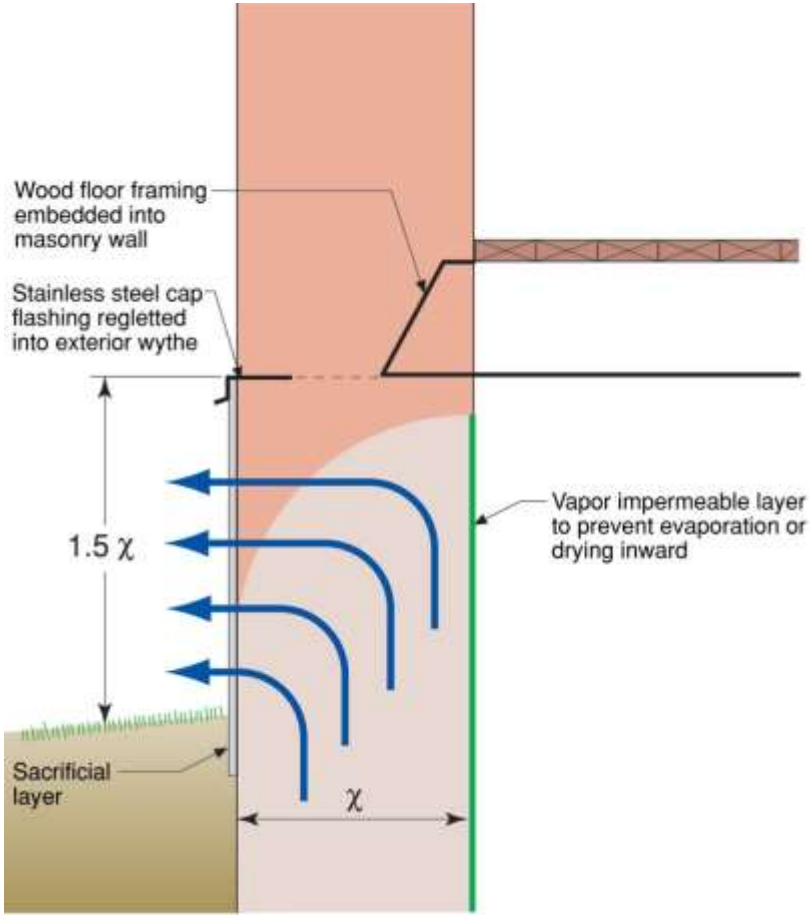

Moisture Flow
Dampproofing
Filter fabric
Coarse gravel
(no fines)
Perforated
drain pipe
Concrete footing
Concrete slab
Polyethylene
vapor barrier
Granular
capillary break
and drainage
pad (no fines)

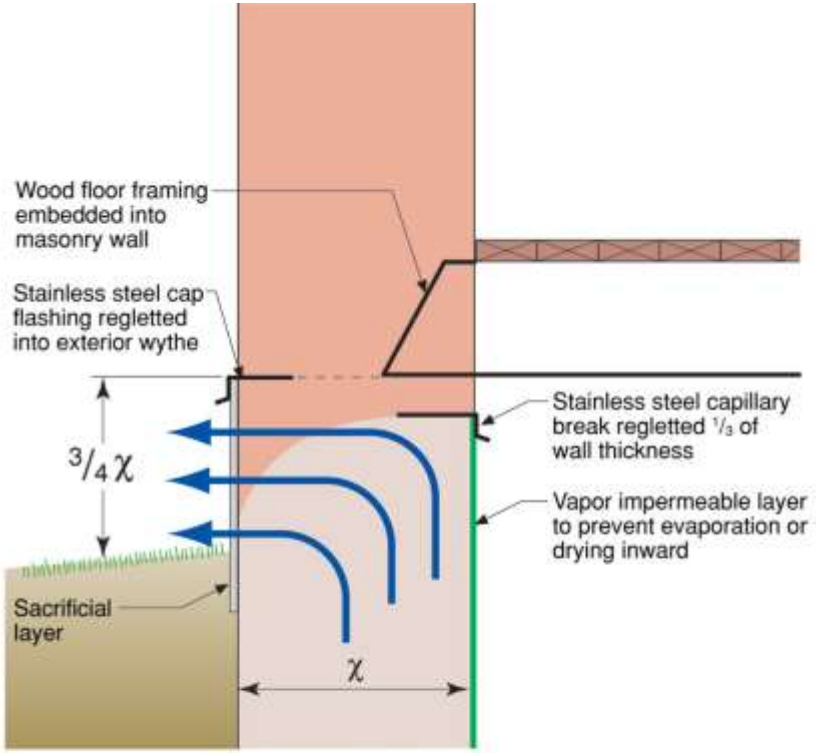

Capillary break on
exterior foundation wall
Capillary break under
slab
Capillary break on top
of footing

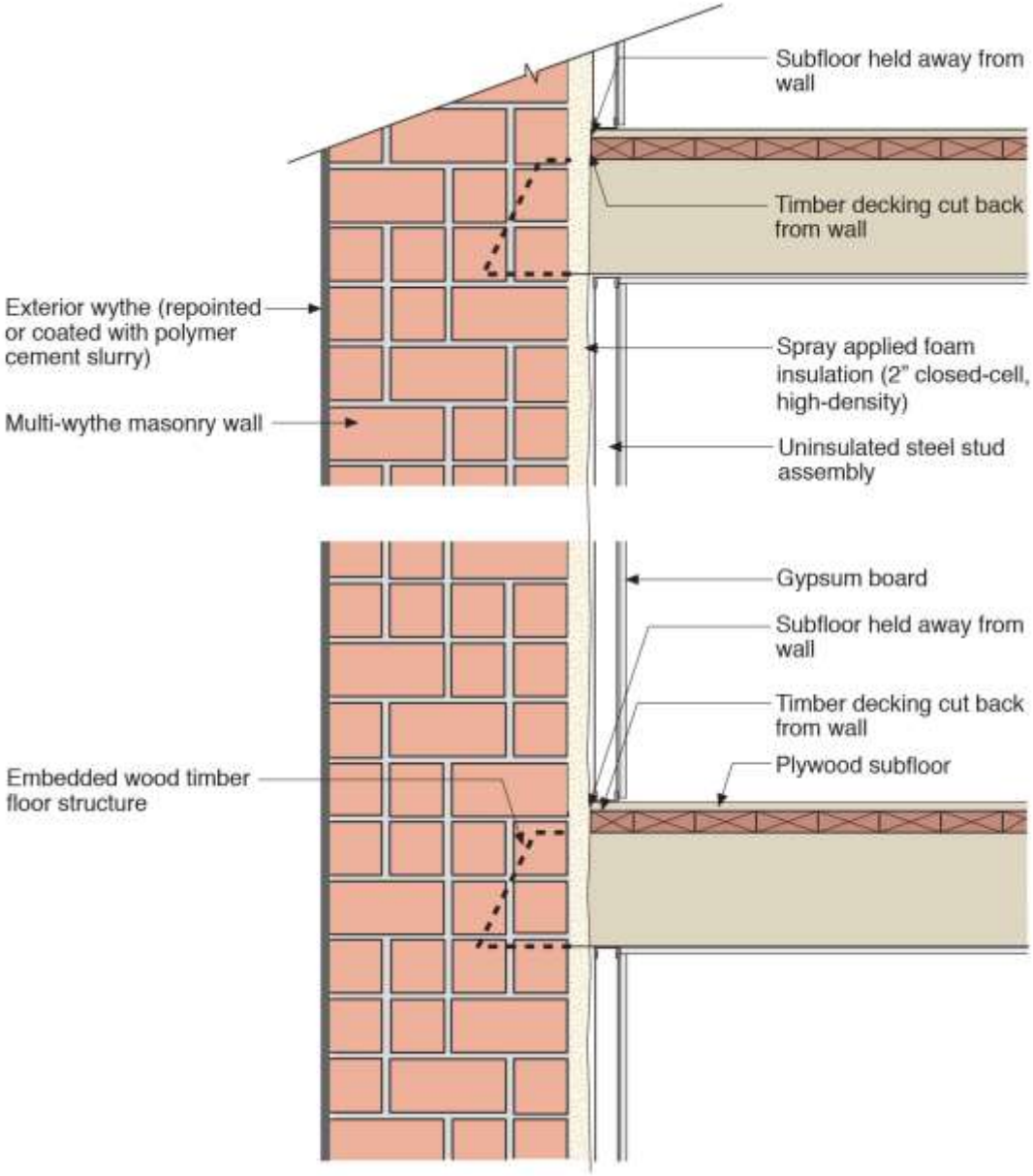
WEST SIDE VILLAGE
113 North 13th Street
An RPM Managed Community
113

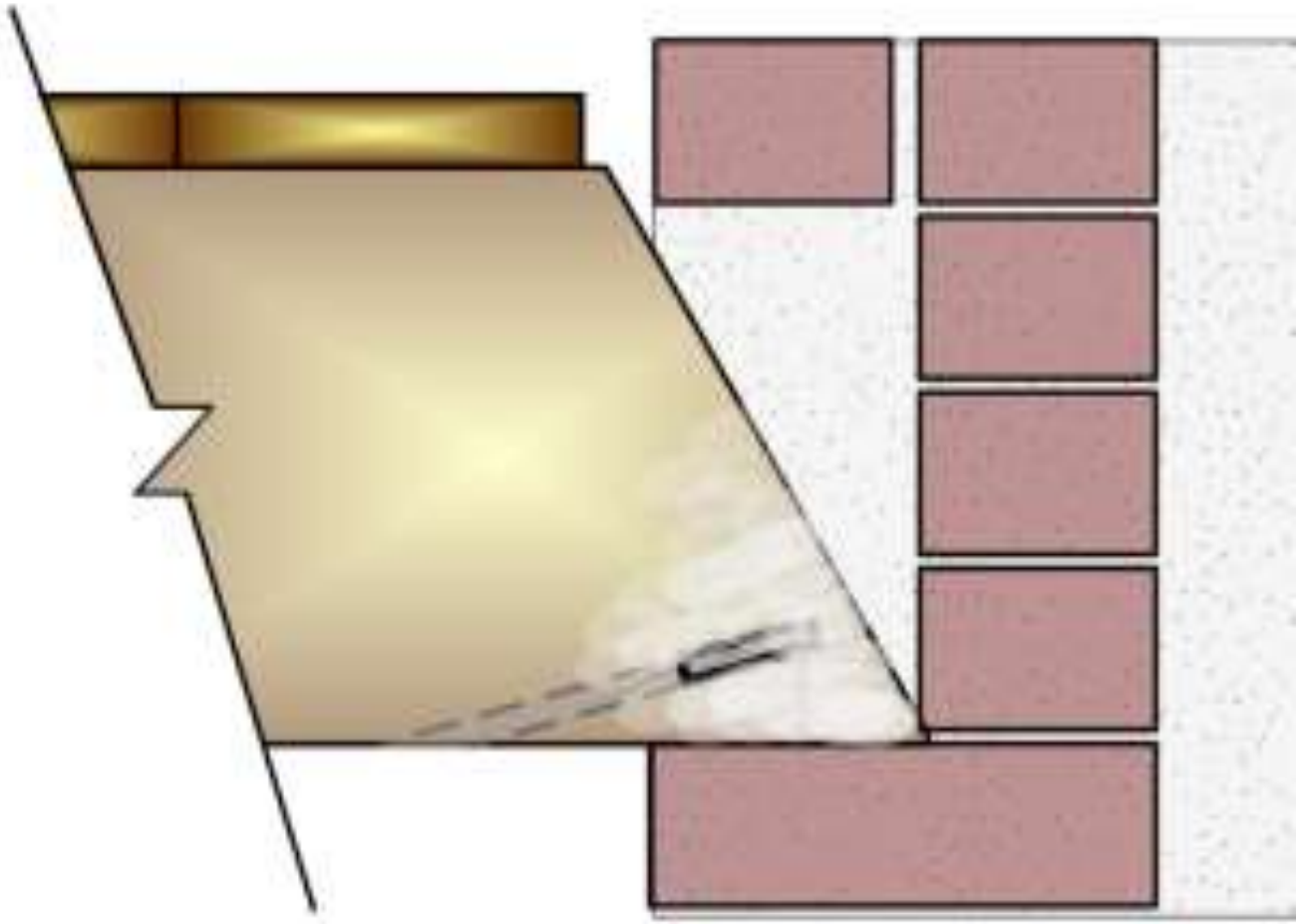

Coping/cap flashing over top of parapet
Fully-adhered membrane roofing extending up interior and over top of parapet wall
4" spray applied foam insulation (closed-cell, high-density)
Timber decking
Embedded wood timber roof structure
Exterior wythe (repointed or coated with polymer cement slurry)
Multi-wythe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

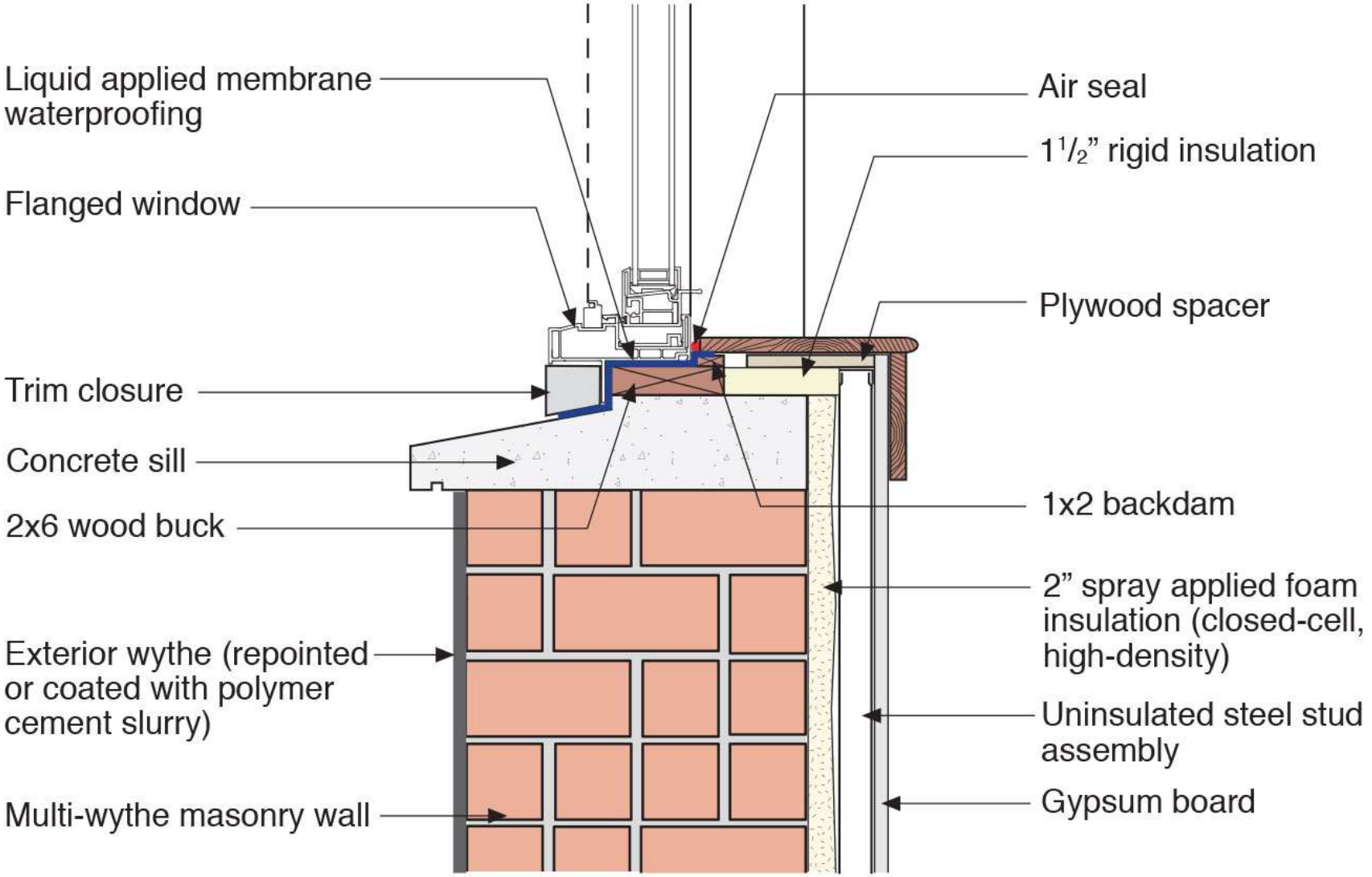

Spray applied foam insulation (closed-cell, high-density)
Uninsulated steel stud assembly
Gypsum board
Subfloor held away from wall
Timber decking cut back from wall
Plywood subfloor
Exterior wythe (repointed or coated with polymer cement slurry)
Embedded wood timber floor structure
Spray applied foam insulation (closed-cell, high-density)
Stainless steel cap flashing regletted into exterior wythe
Uninsulated steel stud assembly
¾" masonry mortar rendering (sacrificial coating)
Paperless gypsum board
Membrane sheet (waterproofing)
New concrete "patch"
Extruded polystyrene rigid insulation
Multi-wythe masonry wall
Plywood subfloor on "sleepers"
Existing concrete slab
Epoxy paint
Coarse gravel (no fines)
Geotextile (filter fabric)
Perforated drain pipe

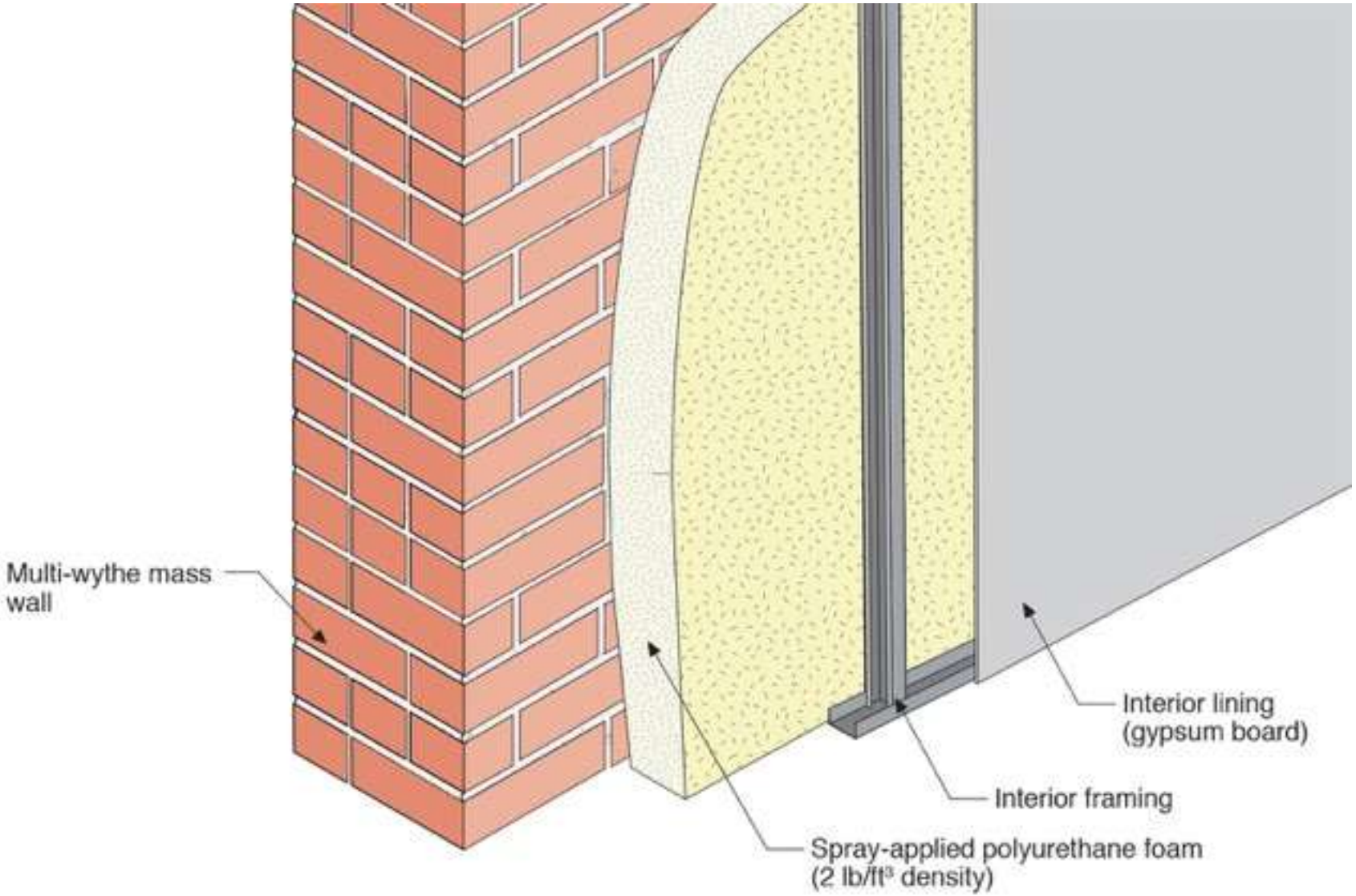

Wood floor framing embedded into masonry wall
Stainless steel cap flashing regletted into exterior wythe
1.5 χ
Vapor impermeable layer to prevent evaporation or drying inward
Sacrificial layer
χ

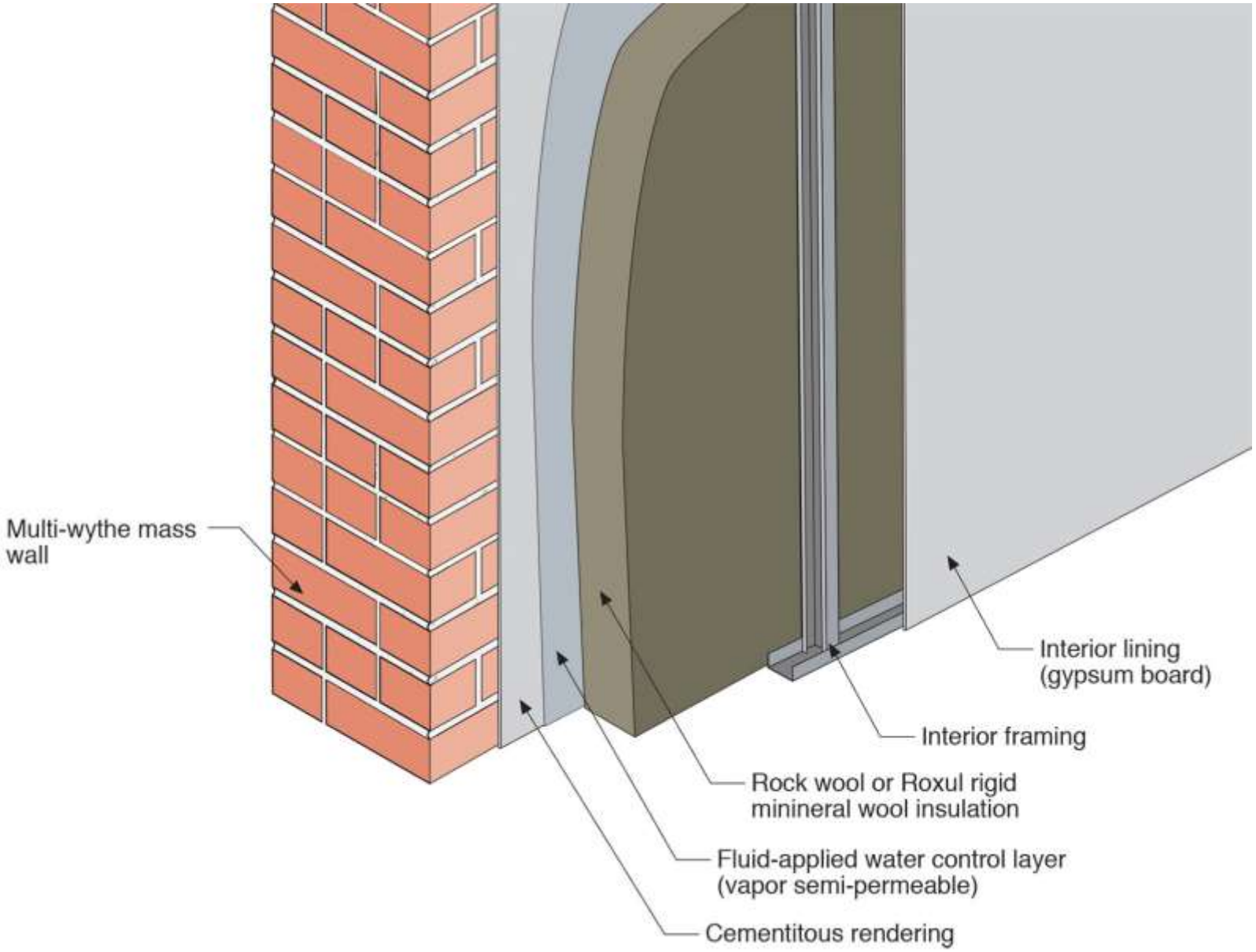

Wood floor framing embedded into masonry wall
Stainless steel cap flashing regletted into exterior wythe
3/4 χ
Stainless steel capillary break regletted 1/3 of wall thickness
Vapor impermeable layer to prevent evaporation or drying inward
Sacrificial layer
χ

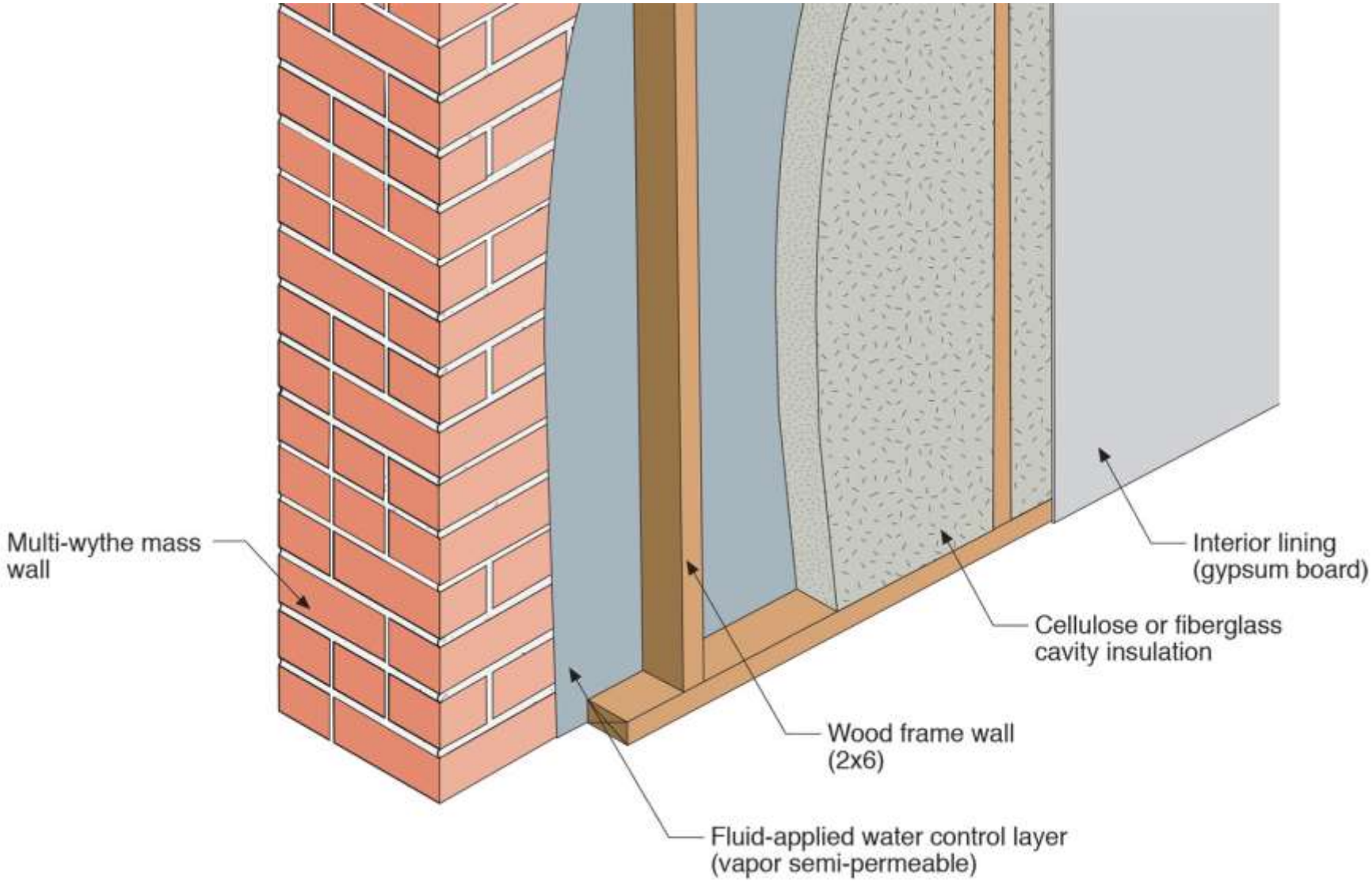

Subfloor held away from wall
Timber decking cut back from wall
Exterior wythe (repointed or coated with polymer cement slurry)
Spray applied foam insulation (2" closed-cell, high-density)
Multi-wythe masonry wall
Uninsulated steel stud assembly
Gypsum board
Subfloor held away from wall
Timber decking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

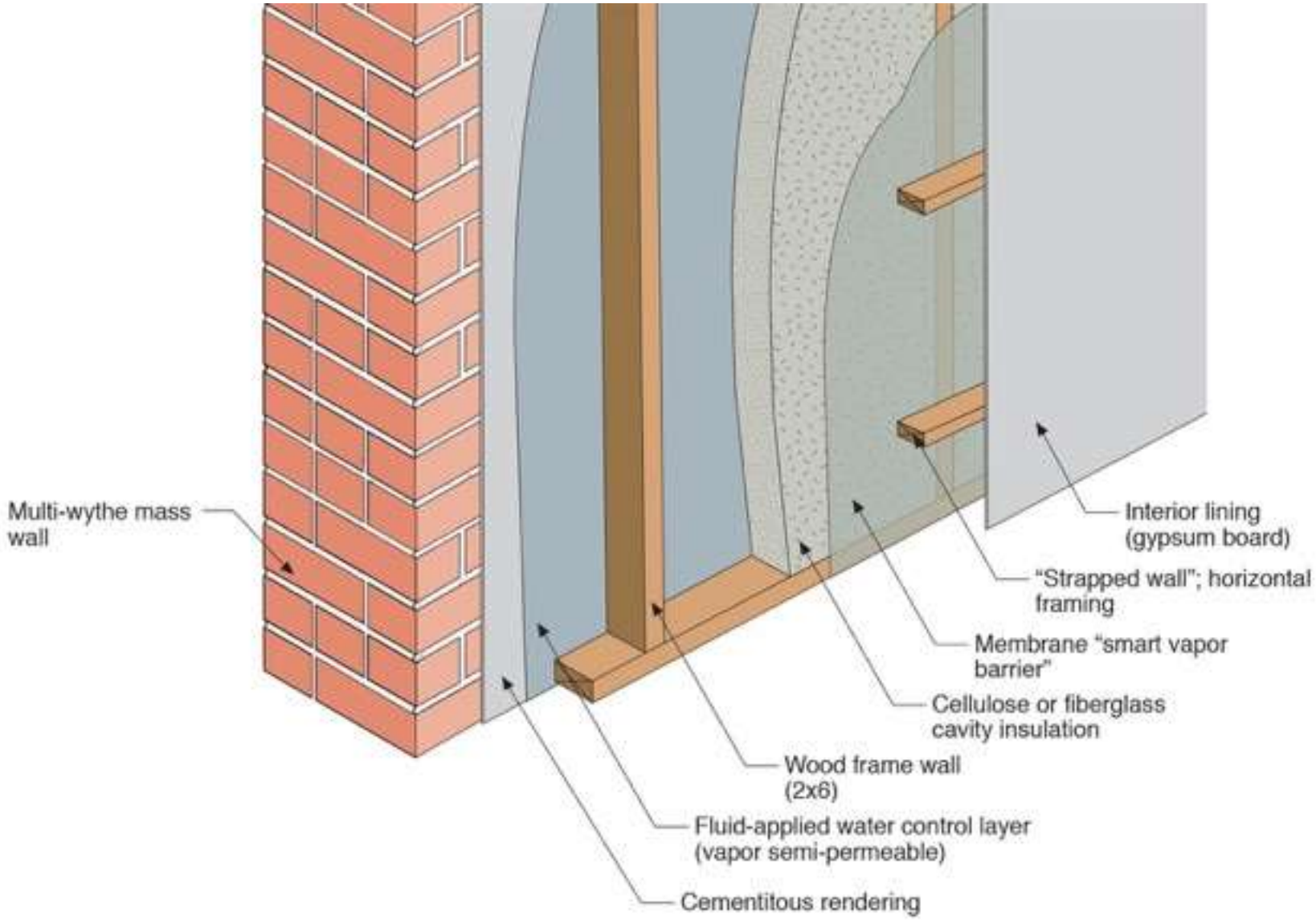


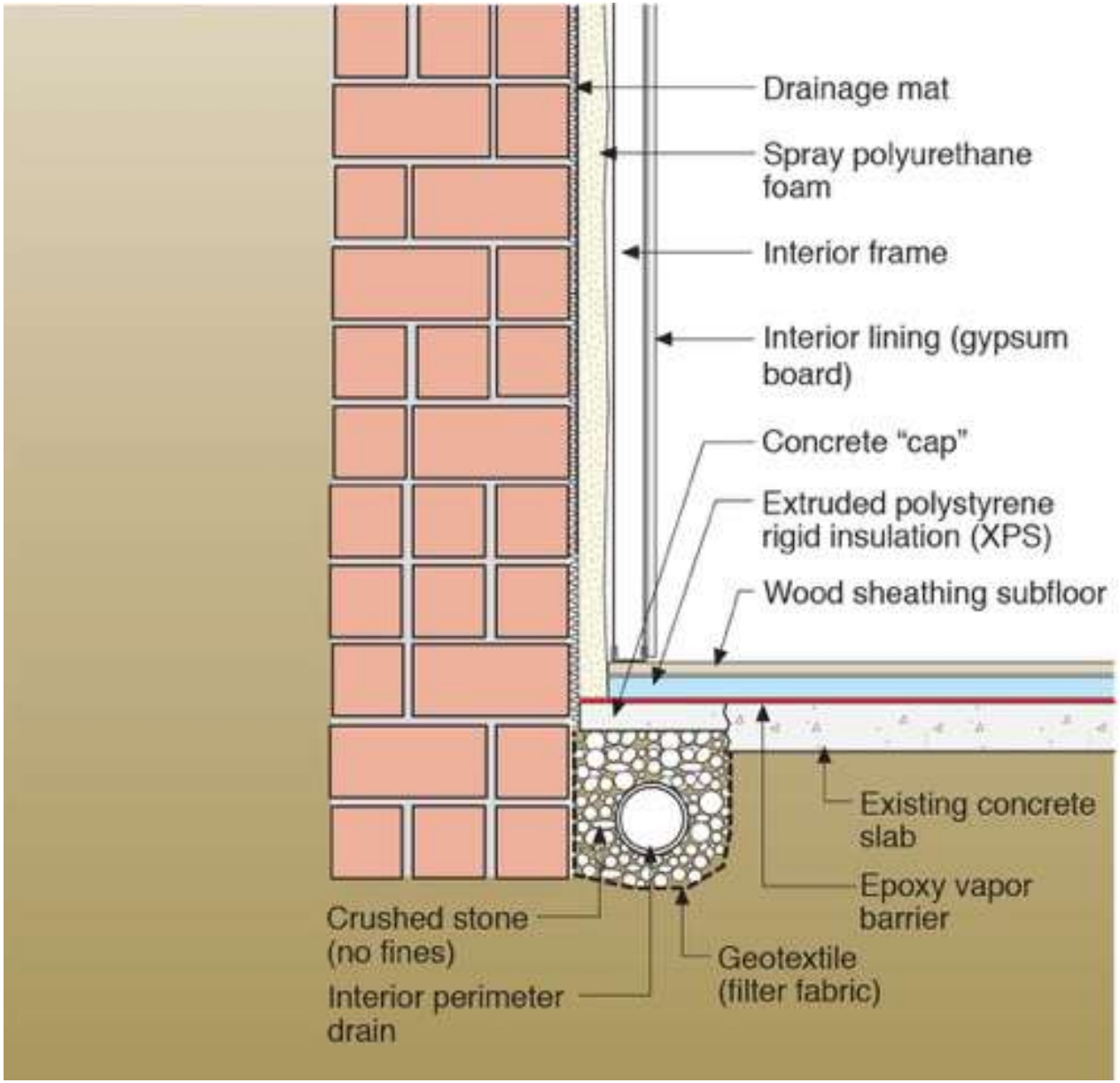

Liquid applied membrane waterproofing
Flanged window
Trim closure
Concrete sill
2x6 wood buck
Exterior wythe (repointed or coated with polymer cement slurry)
Multi-wythe masonry wall
Air seal
1½" rigid insulation
Plywood spacer
1x2 backdam
2" spray applied foam insulation (closed-cell, high-density)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

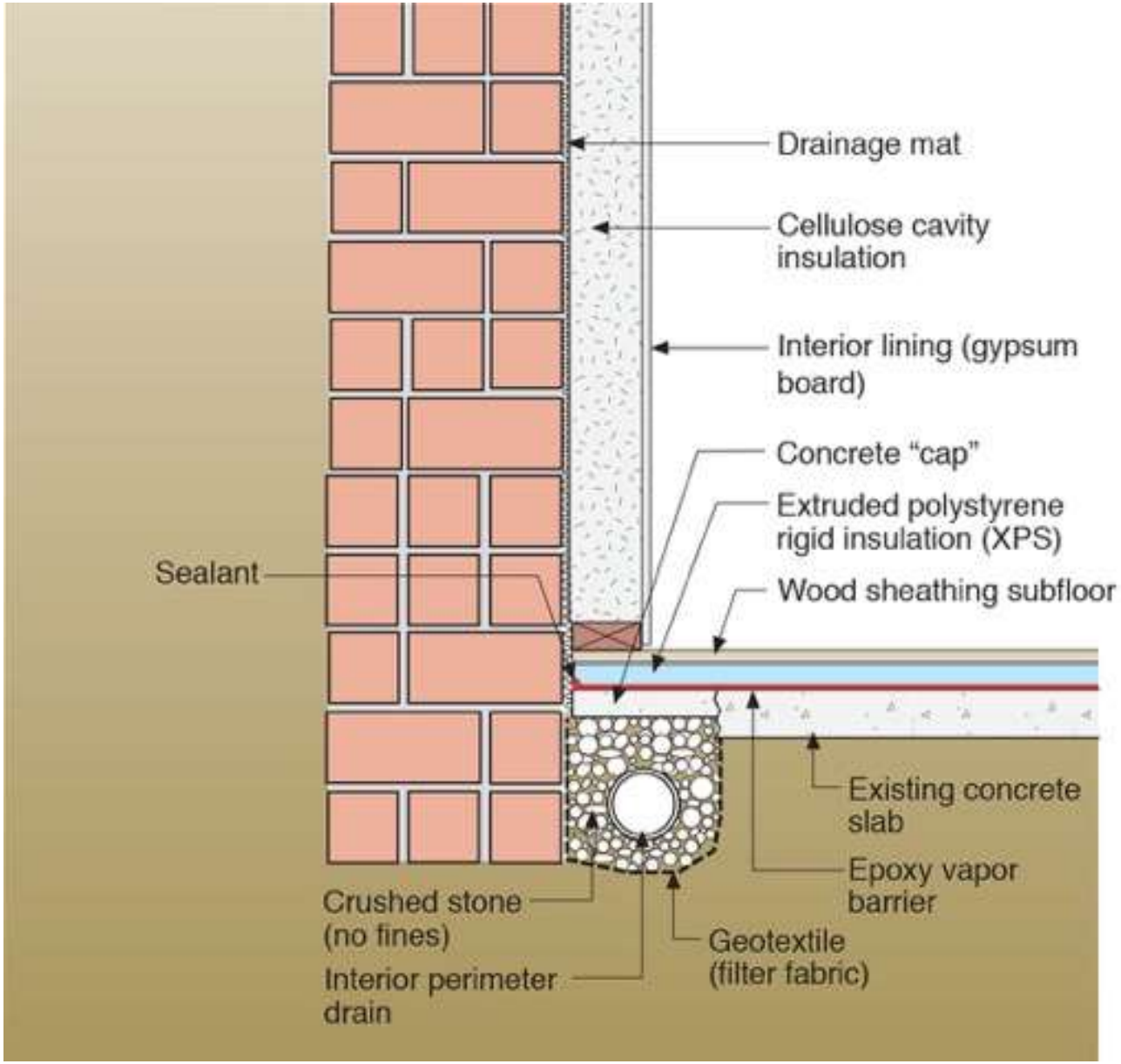

Multi-wythe mass wall
Interior lining (gypsum board)
Interior framing
Spray-applied polyurethane foam (2 lb/ft³ density)

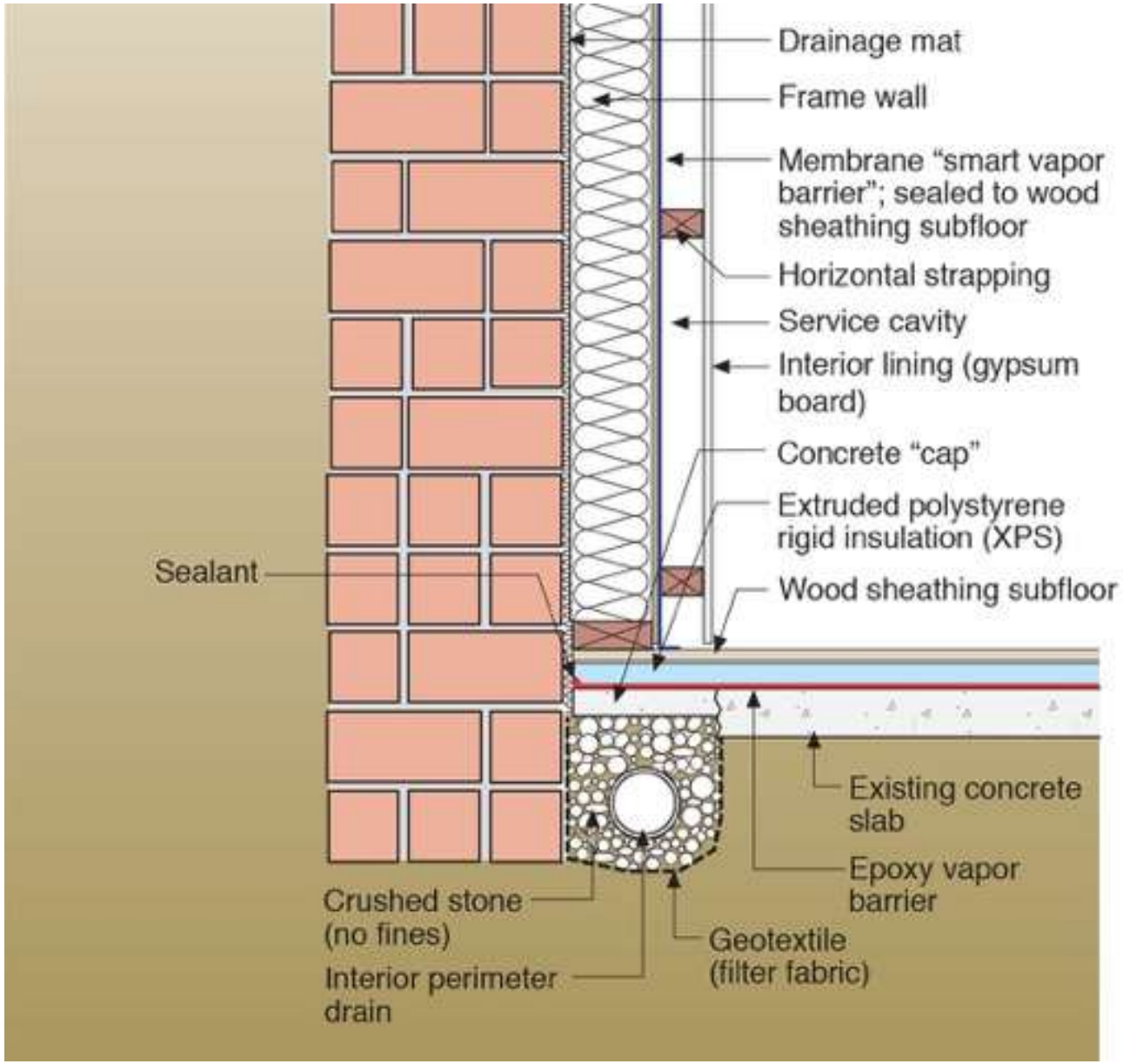

Multi-wythe mass wall
Interior lining (gypsum board)
Interior framing
Rock wool or Roxul rigid minineral wool insulation
Fluid-applied water control layer (vapor semi-permeable)
Cementitous rendering


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

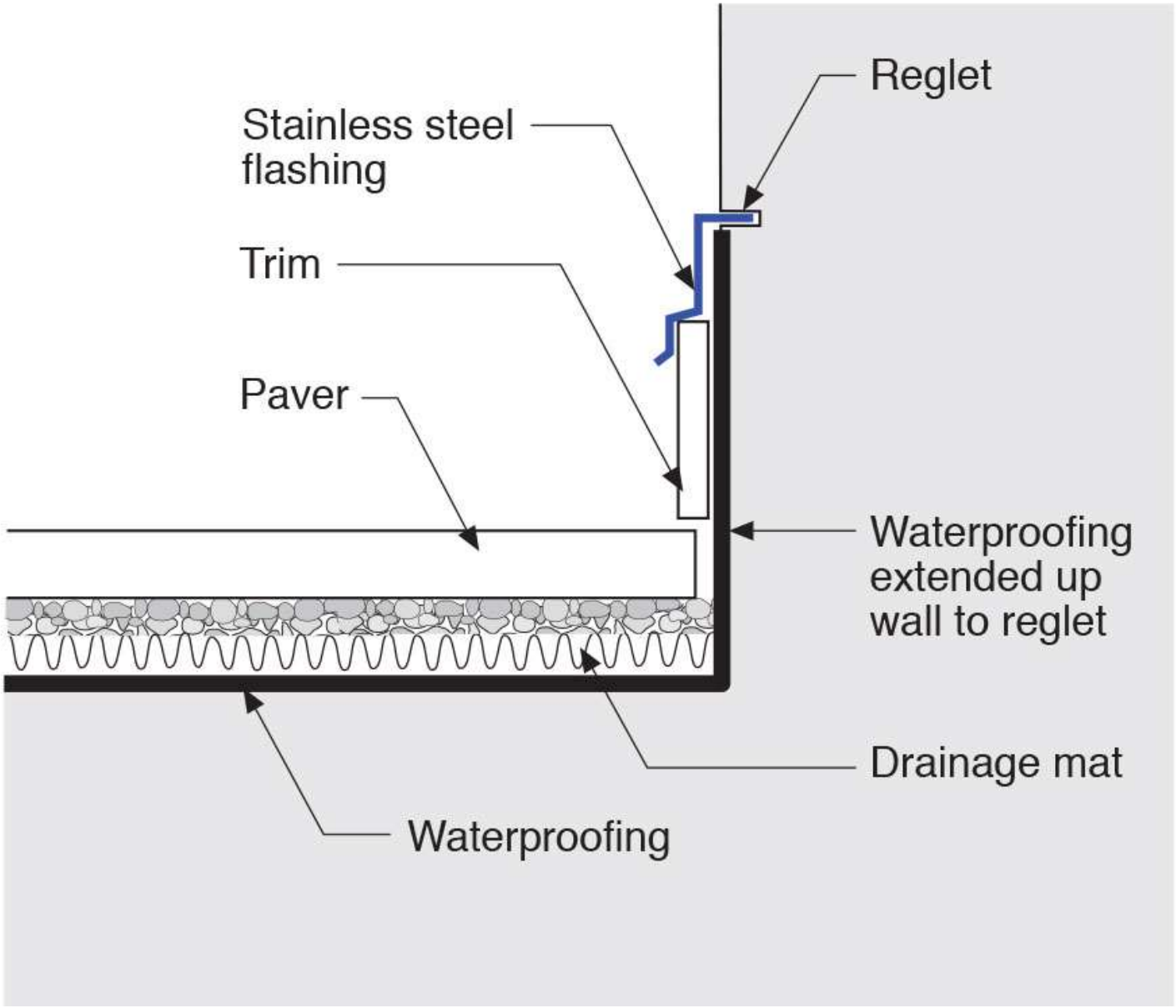

Drainage mat
Spray polyurethane foam
Interior frame
Interior lining (gypsum board)
Concrete "cap"
Extruded polystyrene rigid insulation (XPS)
Wood sheathing subfloor
Existing concrete slab
Epoxy vapor barrier
Geotextile (filter fabric)
Crushed stone (no fines)
Interior perimeter drain

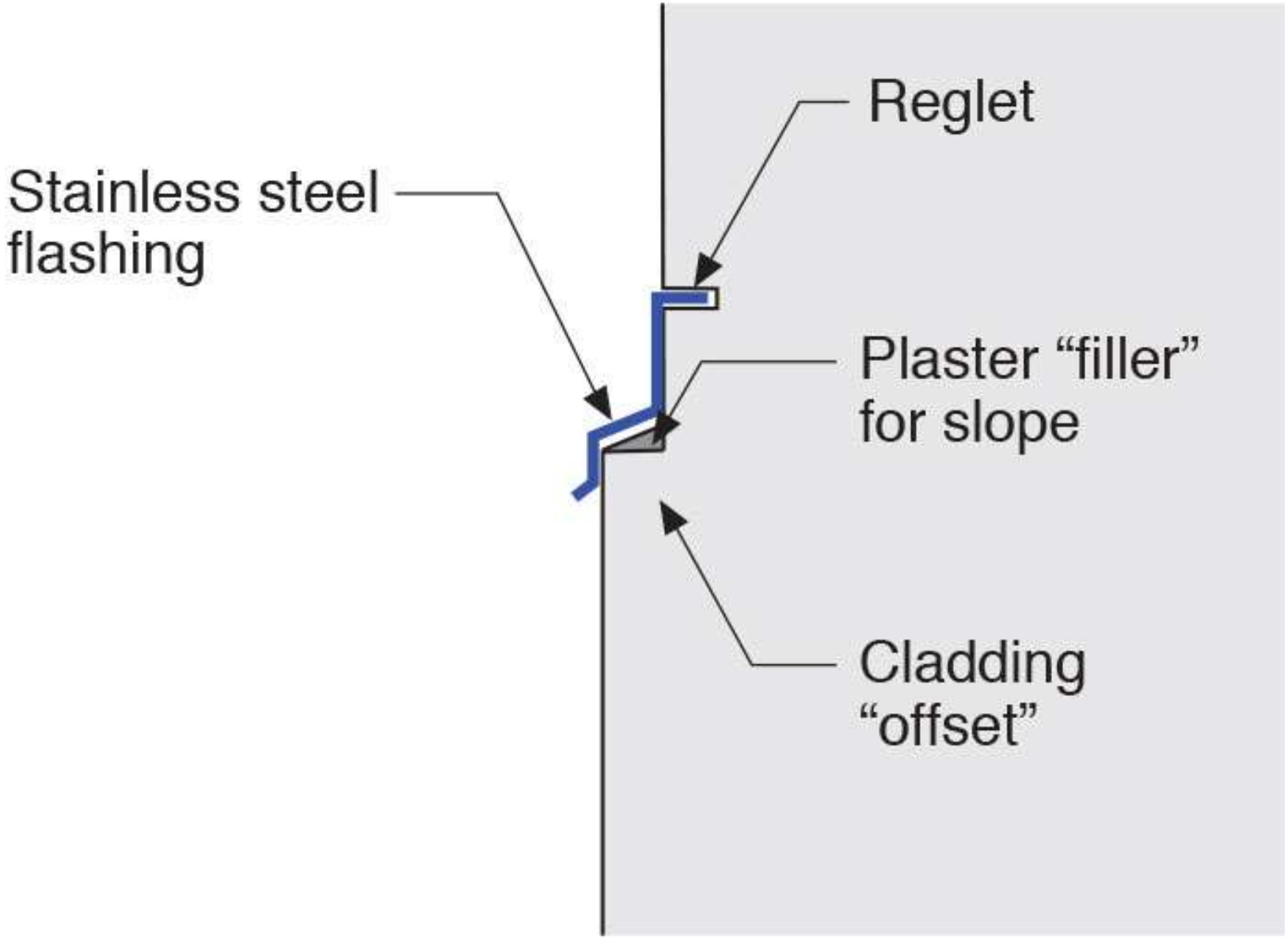

Drainage mat
Cellulose cavity insulation
Interior lining (gypsum board)
Concrete "cap"
Extruded polystyrene rigid insulation (XPS)
Sealant
Wood sheathing subfloor
Existing concrete slab
Epoxy vapor barrier
Crushed stone (no fines)
Interior perimeter drain
Geotextile (filter fabric)

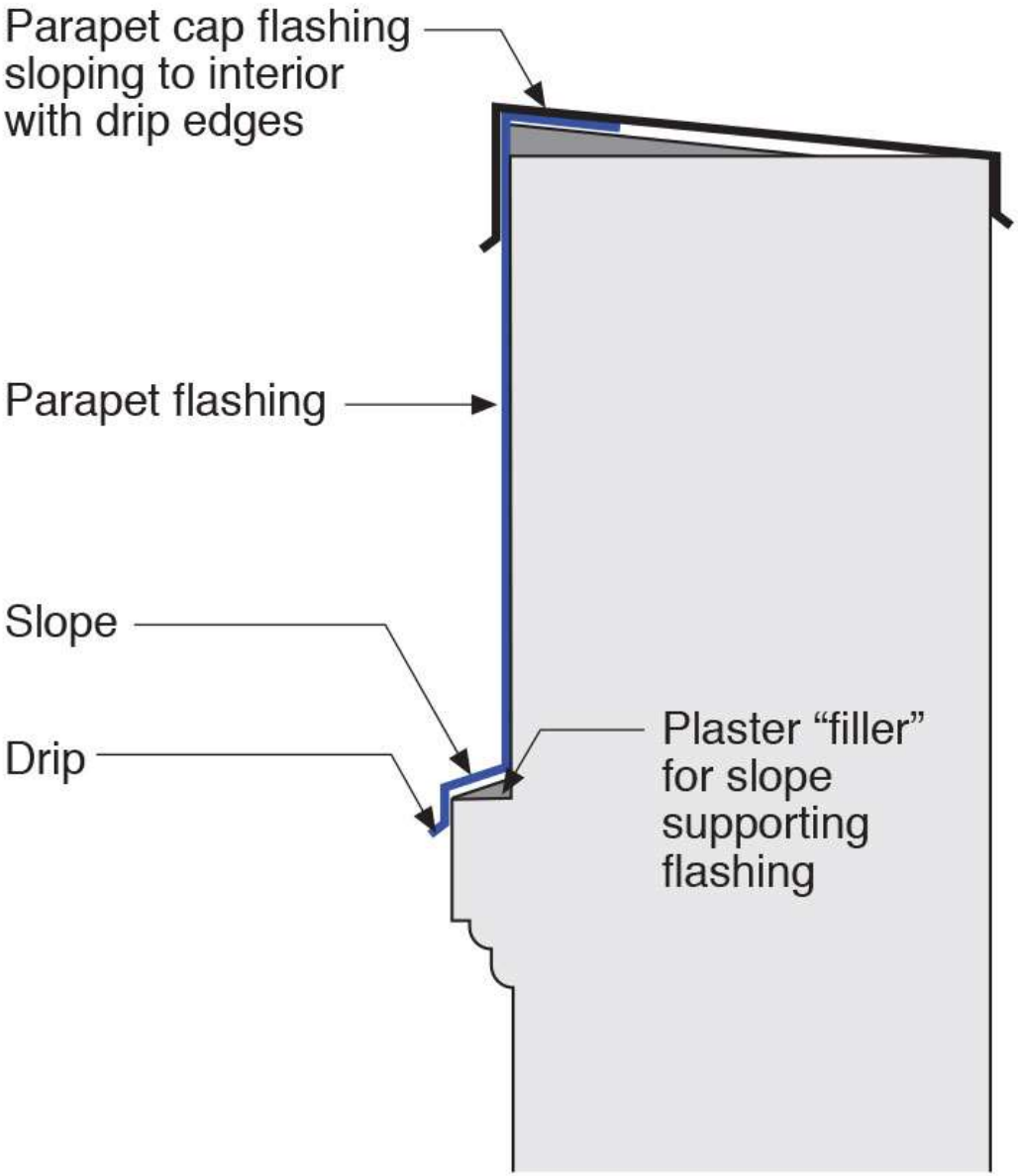

Drainage mat
Frame wall
Membrane "smart vapor barrier"; sealed to wood sheathing subfloor
Horizontal strapping
Service cavity
Interior lining (gypsum board)
Concrete "cap"
Extruded polystyrene rigid insulation (XPS)
Sealant
Wood sheathing subfloor
Existing concrete slab
Epoxy vapor barrier
Crushed stone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

DISTRICT OF COLUMBIA COURT OF APPEALS

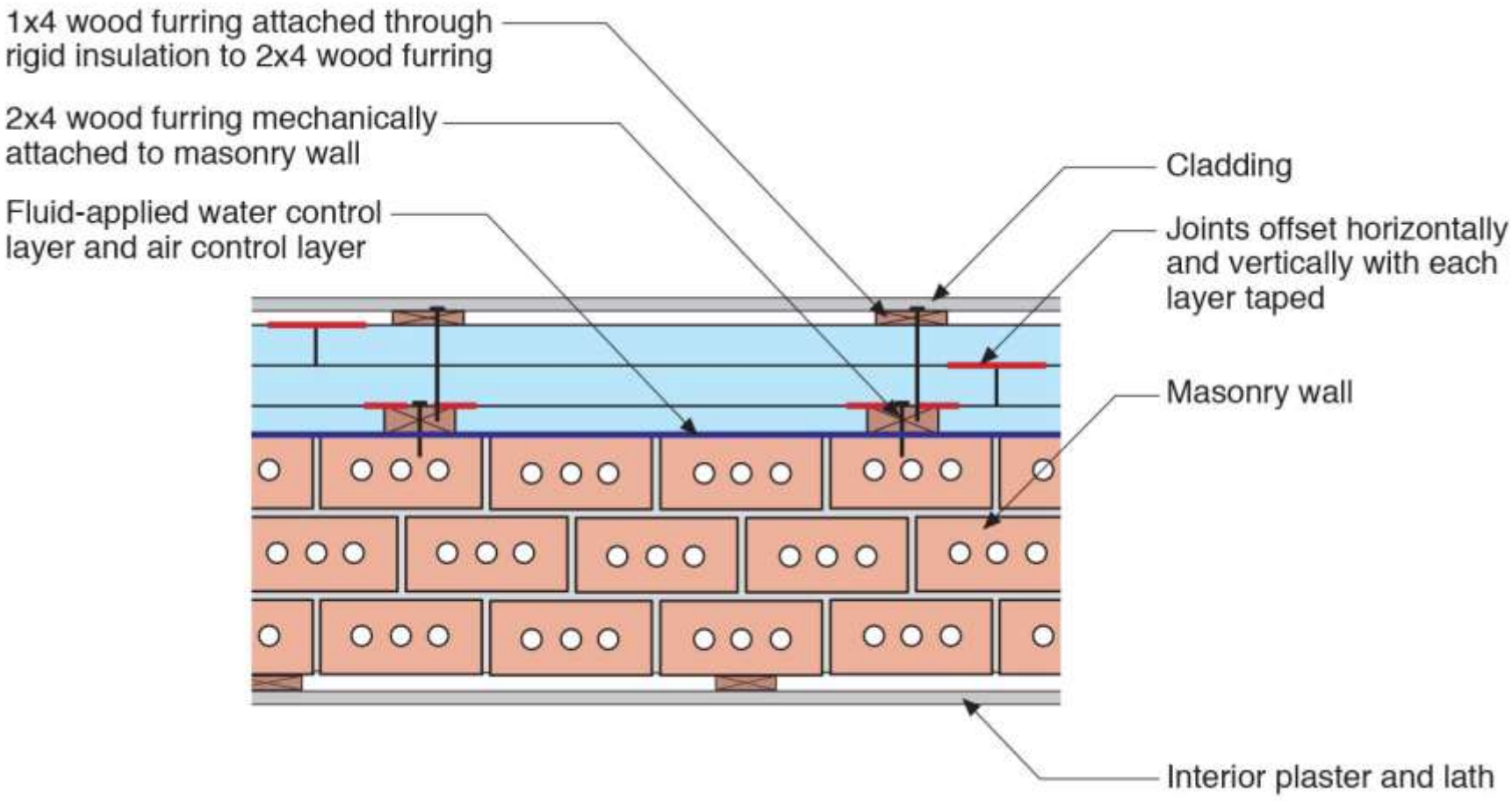
EXIT


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

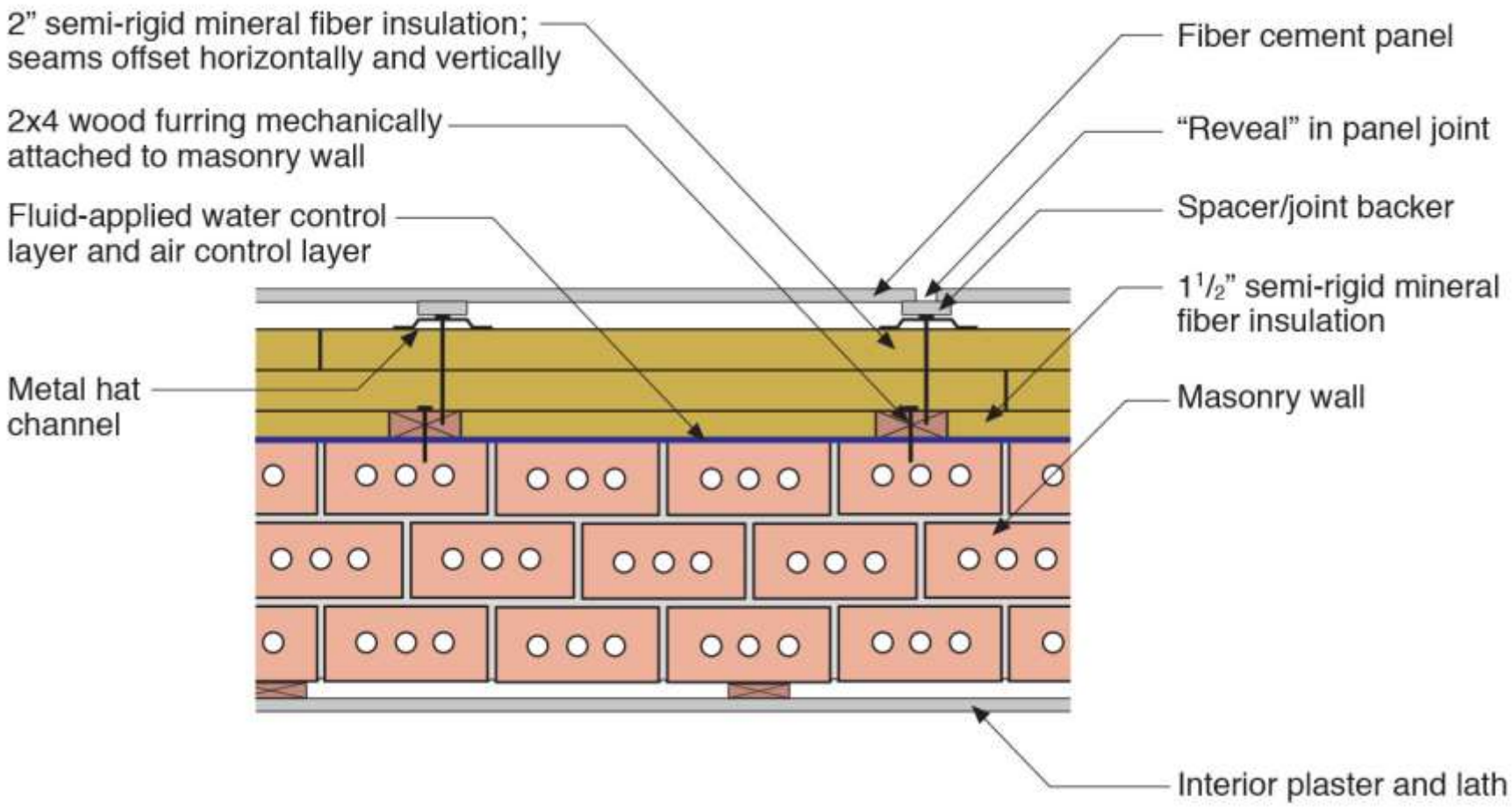

Reglet
Stainless steel
flashing
Plaster “filler”
for slope
Cladding
“offset”

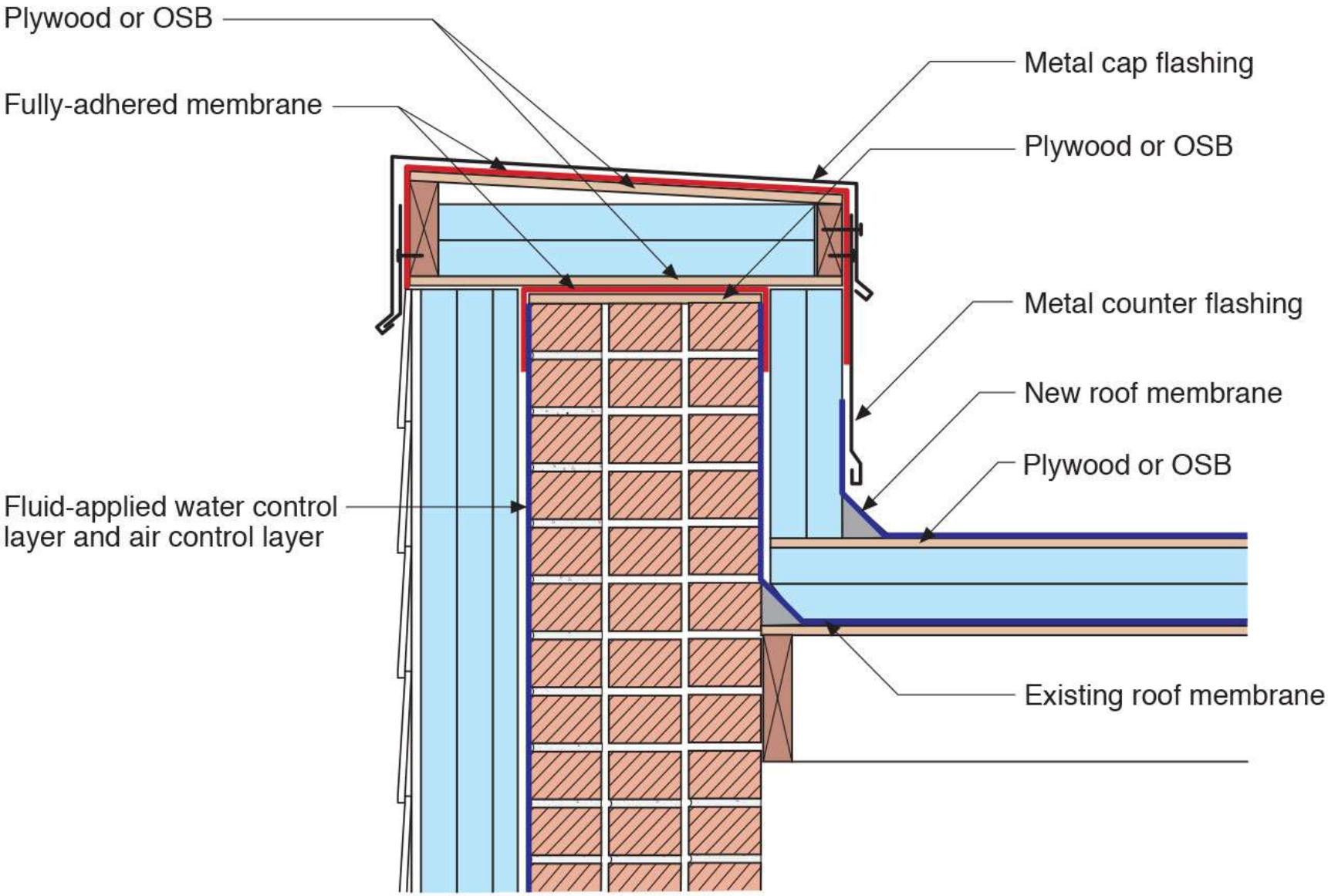

Parapet cap flashing sloping to interior with drip edges
Parapet flashing
Slope
Drip
Plaster “filler” for slope supporting flashing

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

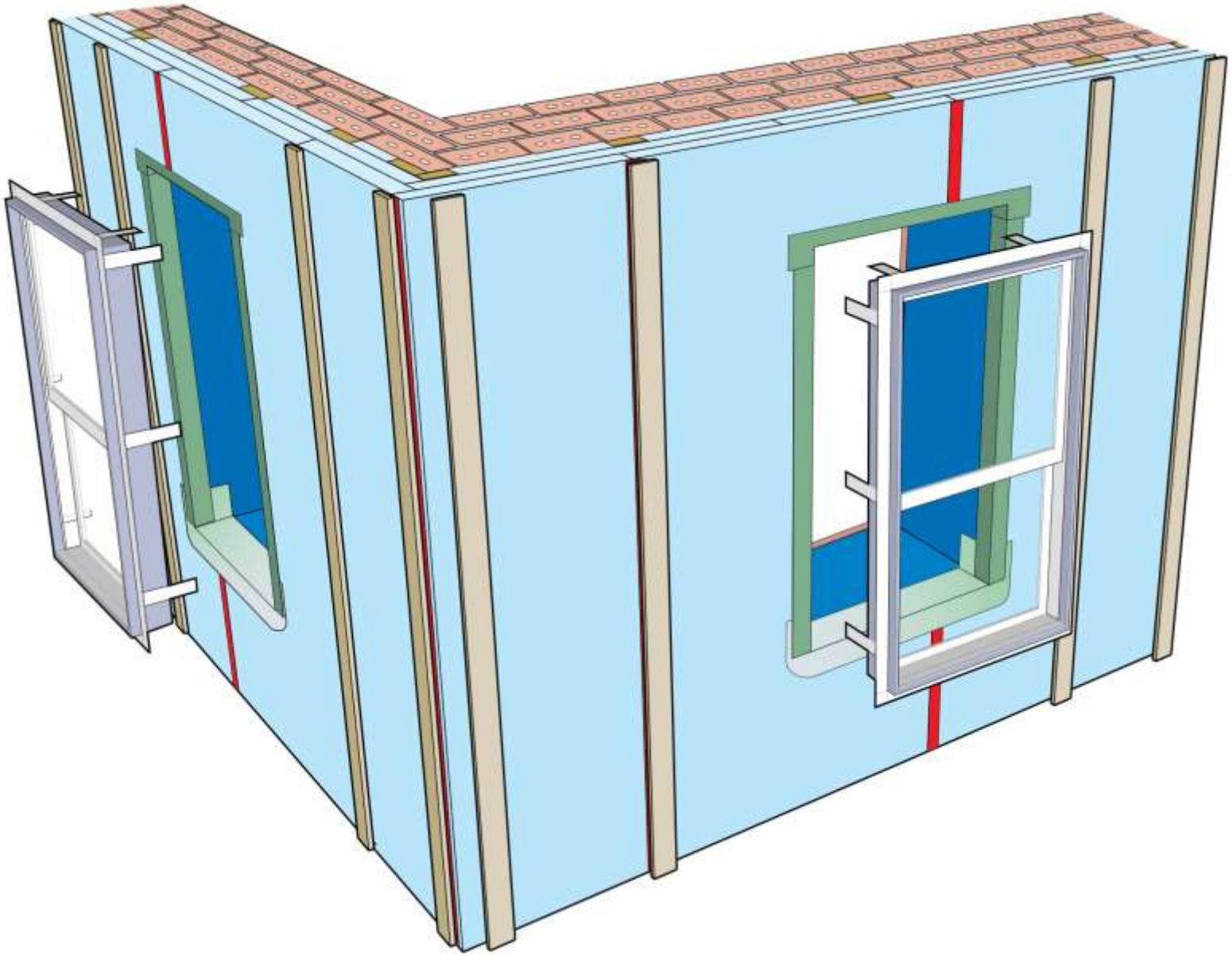

2” semi-rigid mineral fiber insulation; seams offset horizontally and vertically
2x4 wood furring mechanically attached to masonry wall
Fluid-applied water control layer and air control layer
Metal hat channel
Fiber cement panel
“Reveal” in panel joint
Spacer/joint backer
1 1/2” semi-rigid mineral fiber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


Plywood or OSB
Fully-adhered membrane
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

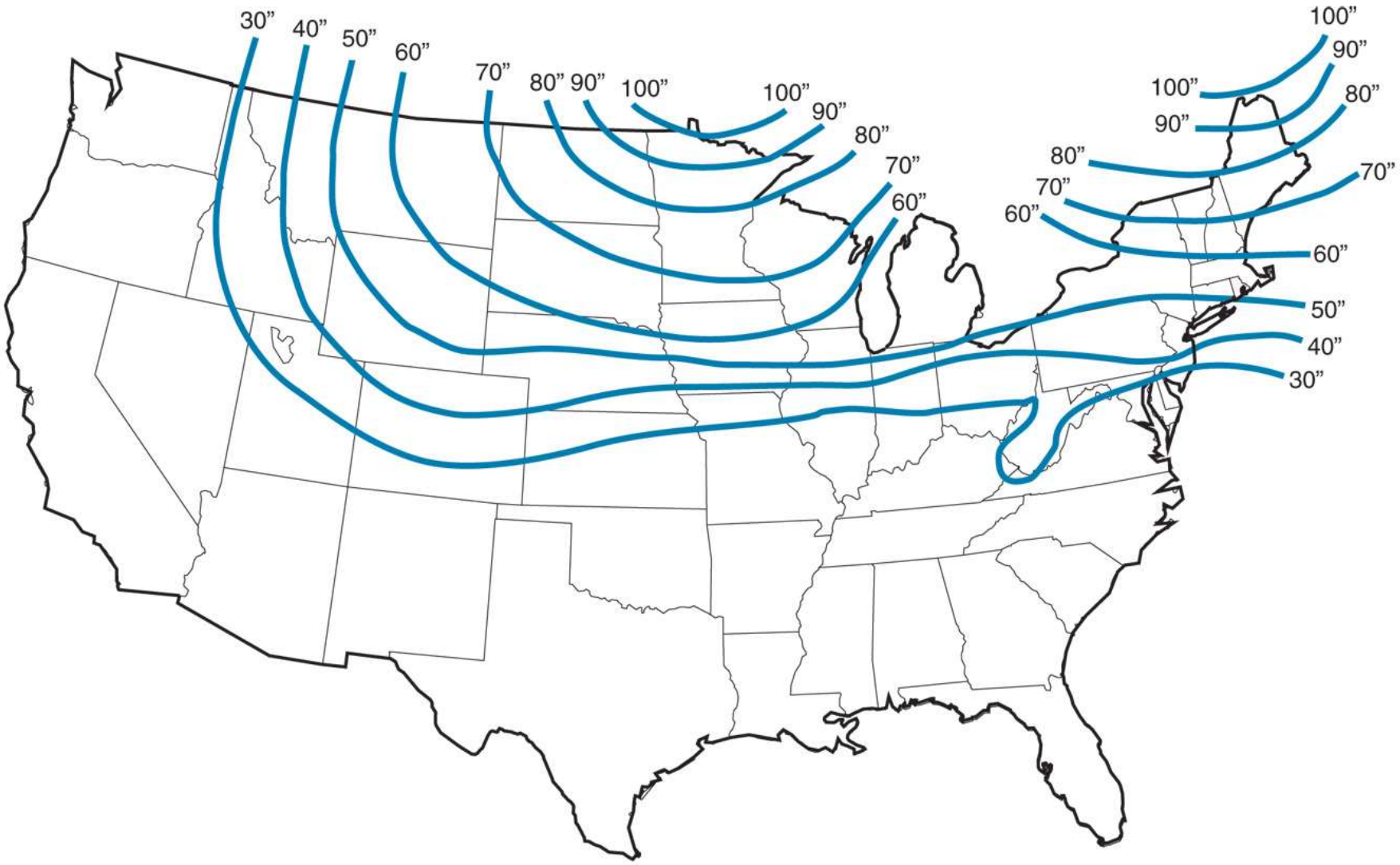
SPEED
HUMP

SPEED
HUMP

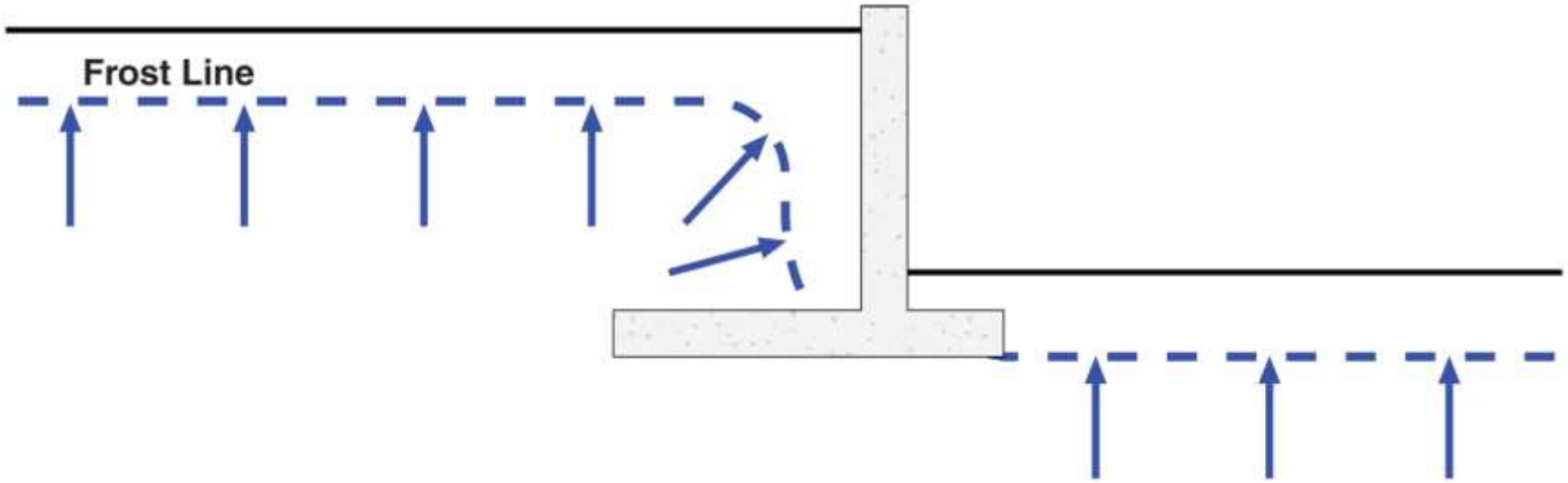
FOAMULAR

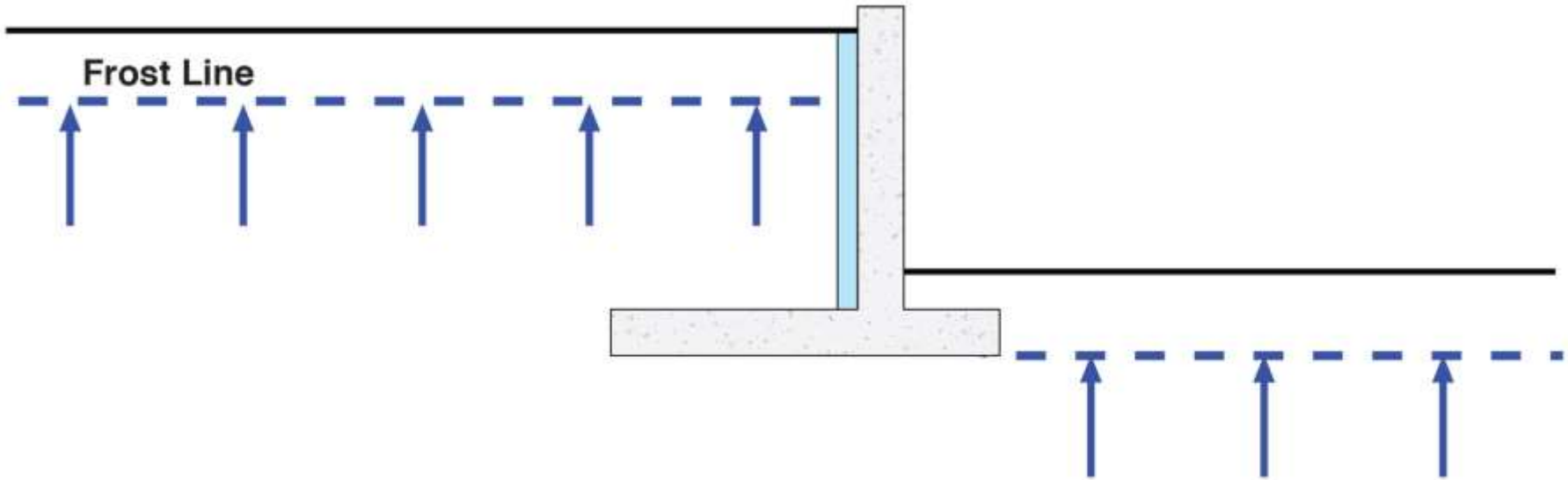


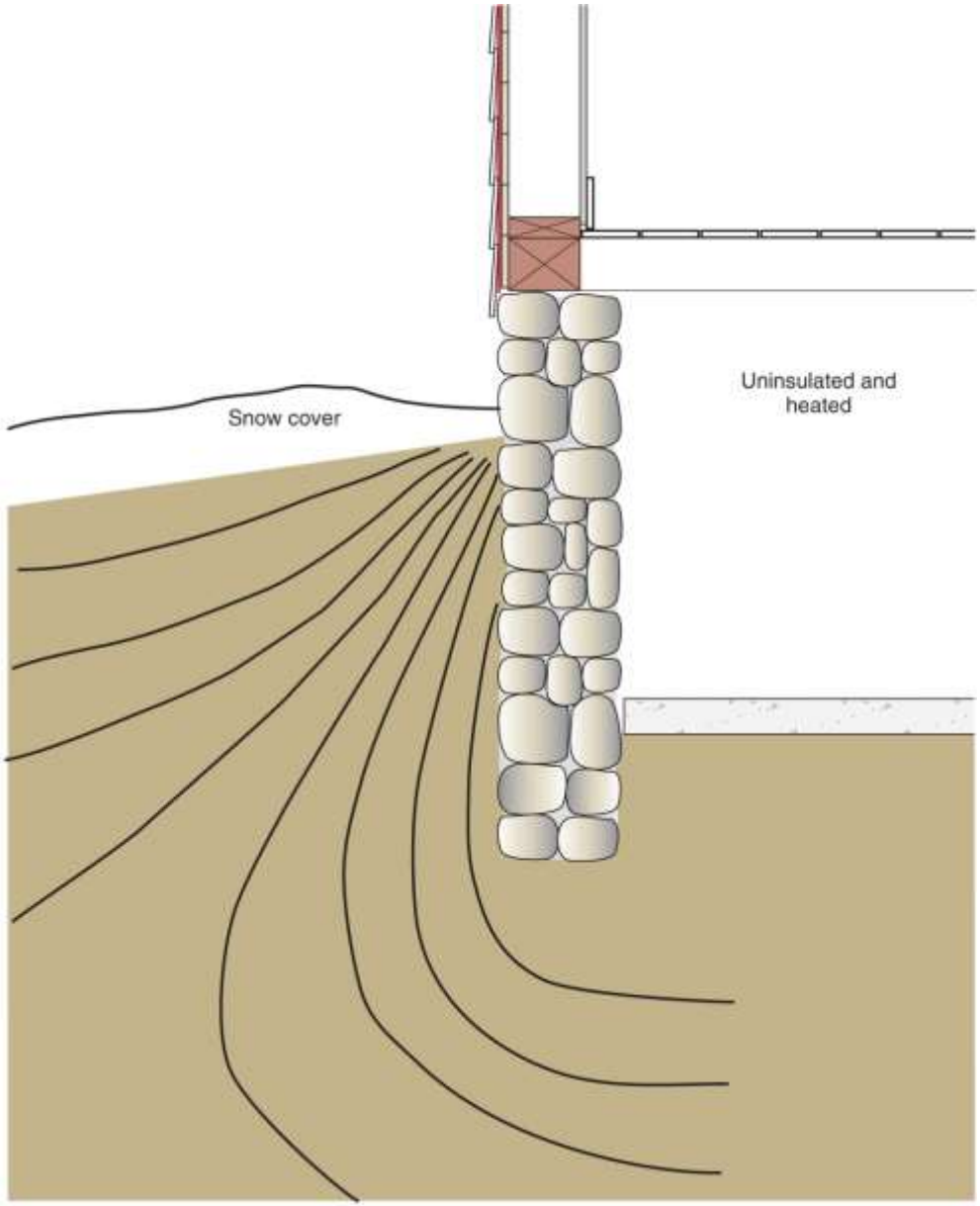
JLG

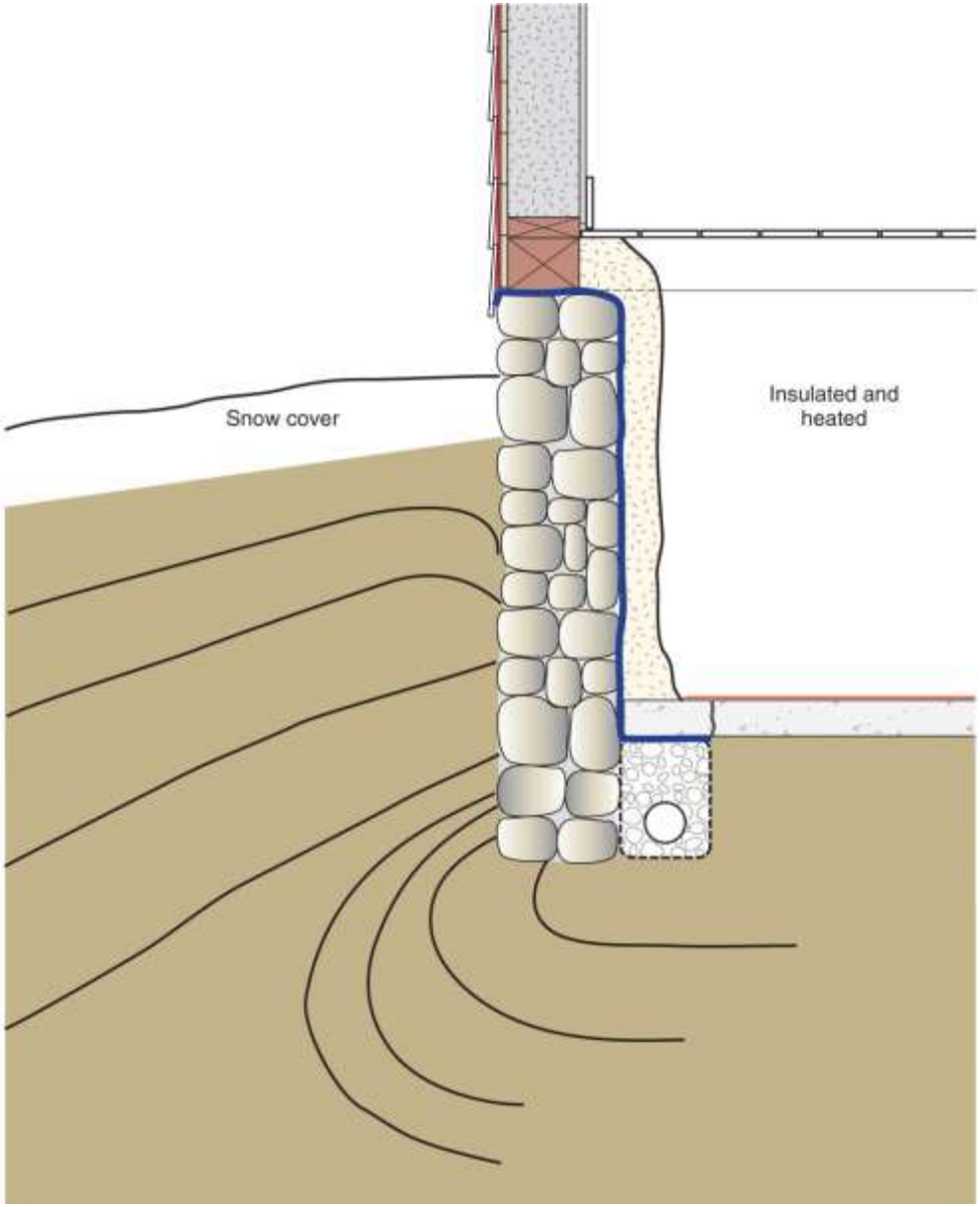


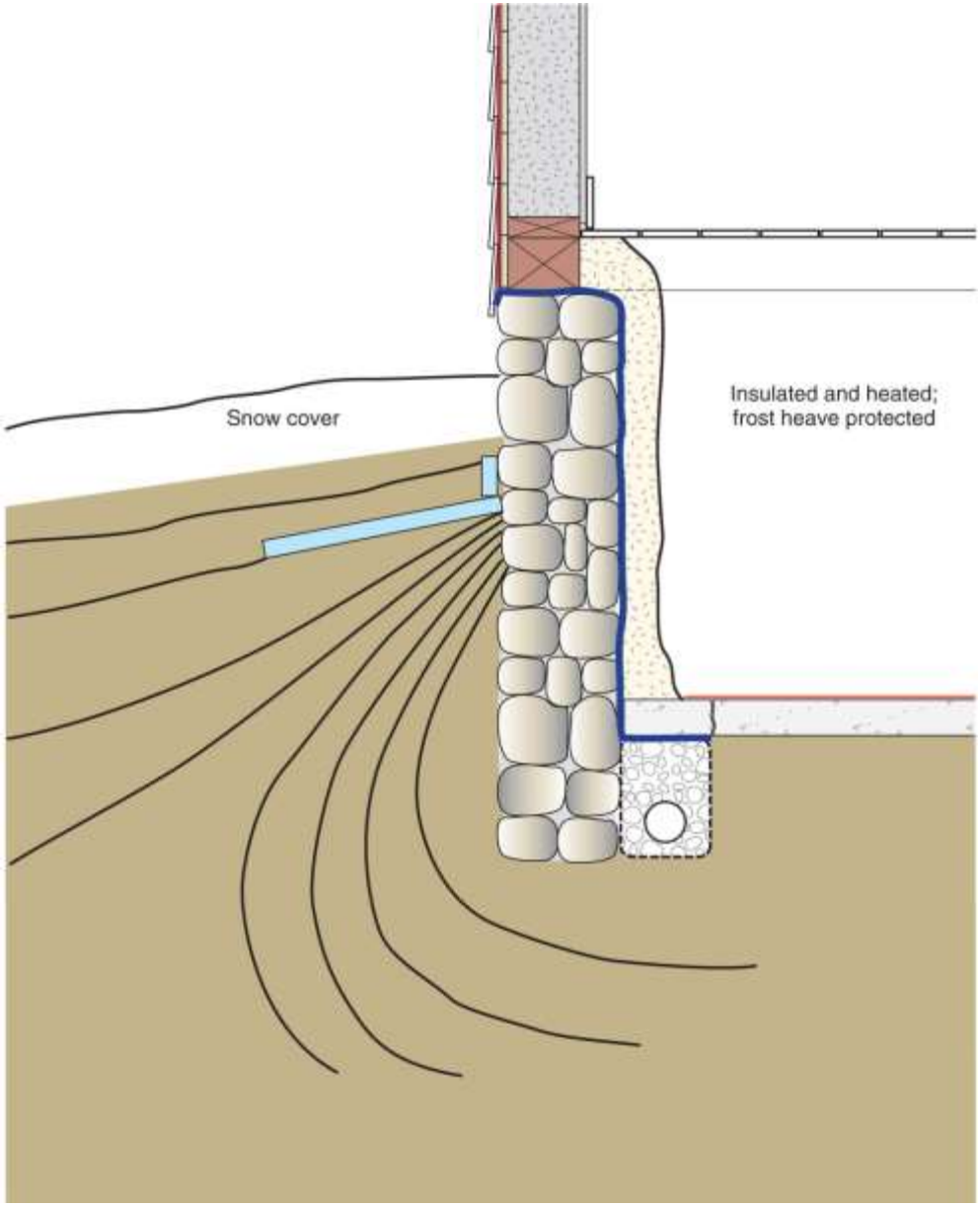
From the US Army Corps Engineers Extreme Frost Penetration
(in inches) based on state averages.

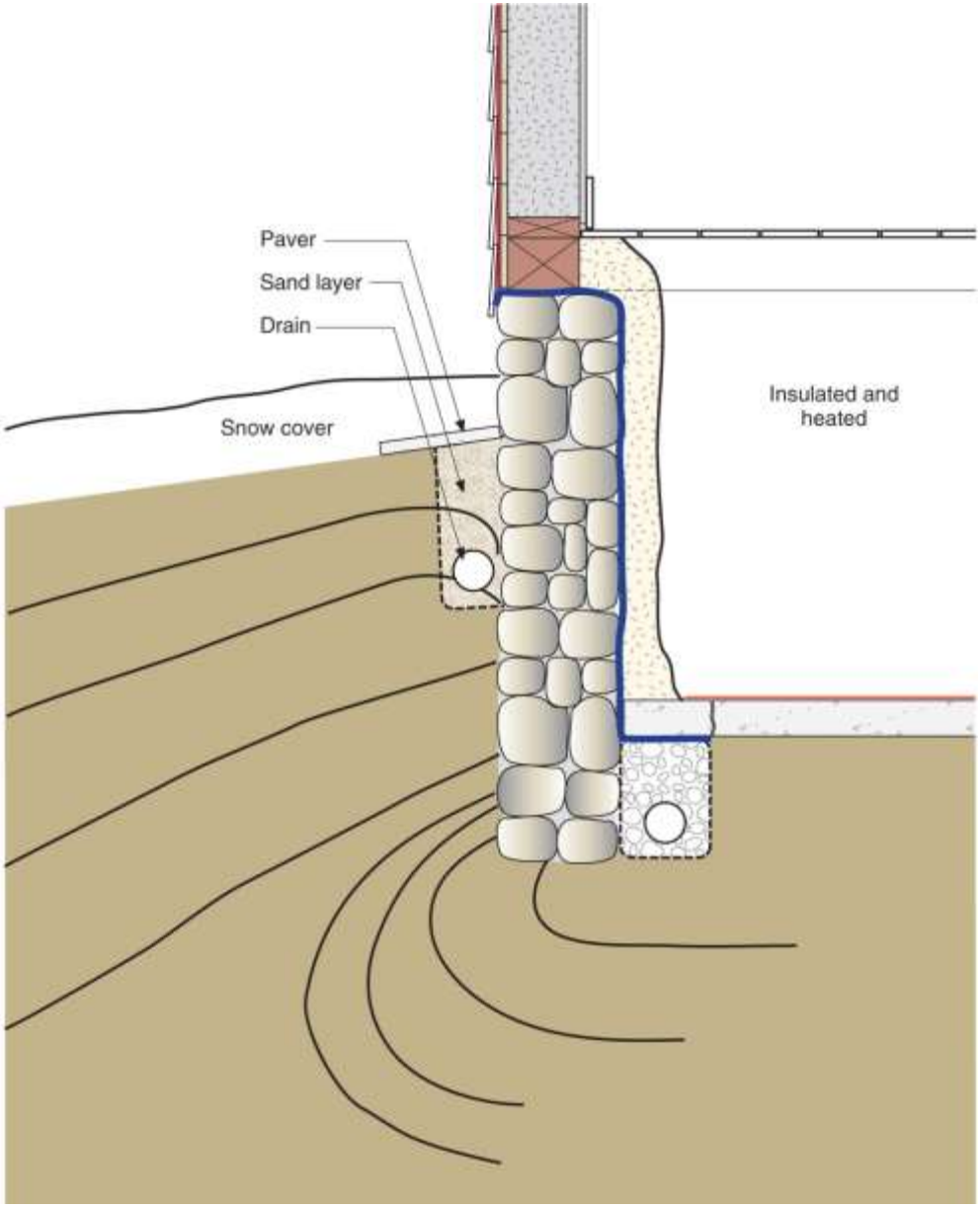

Frost Line

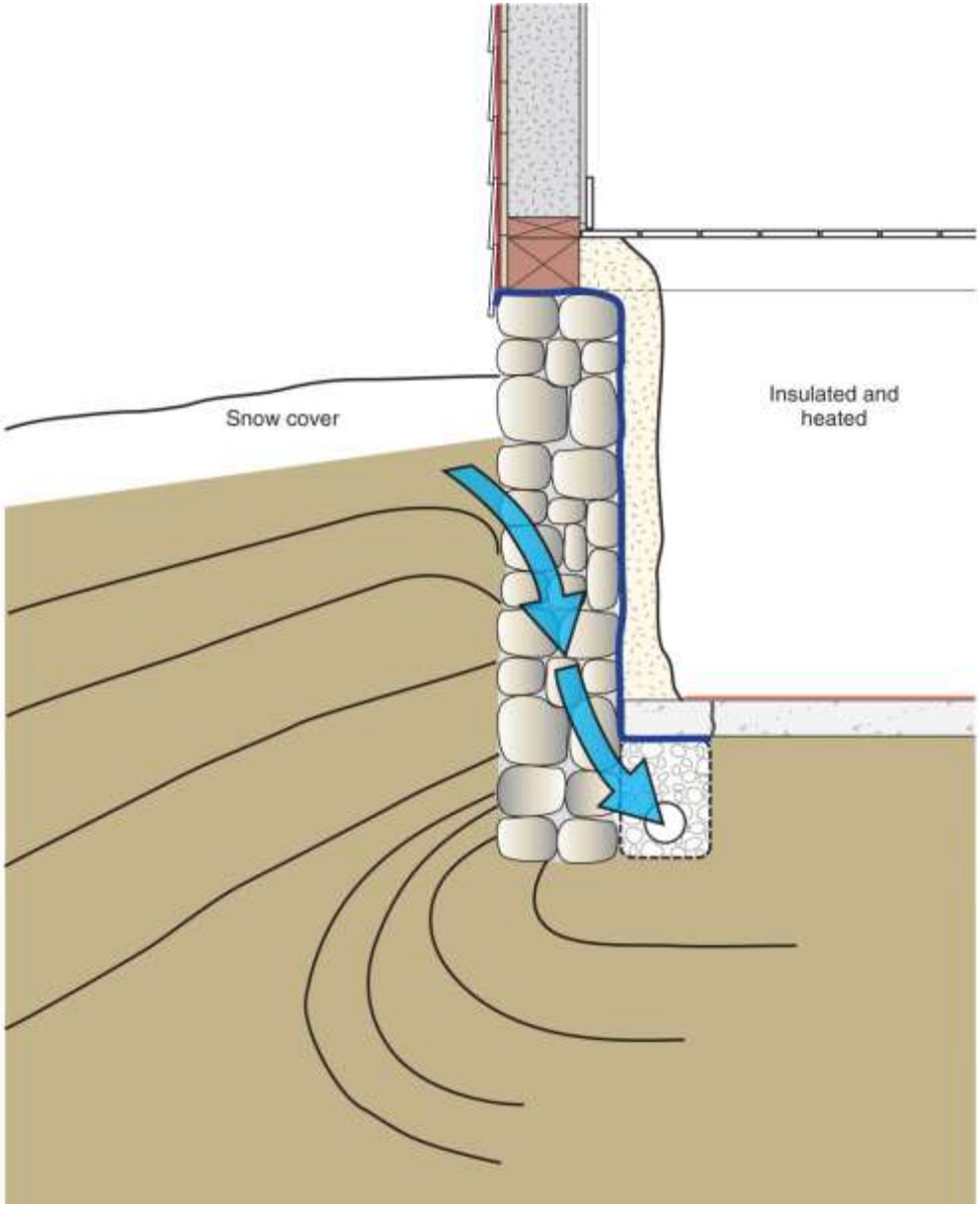

Frost Line


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