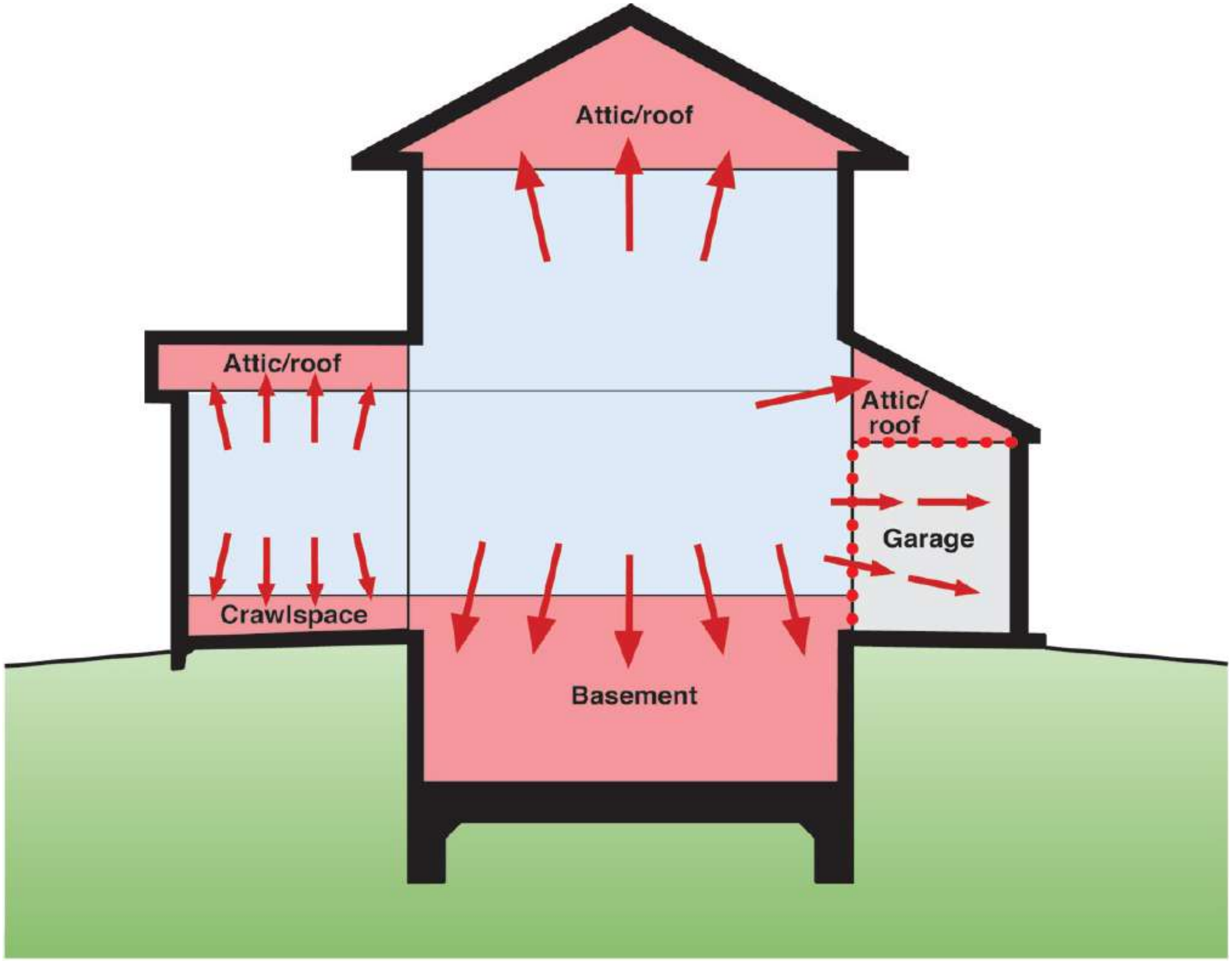
Joseph Lstiburek, Ph.D., P.Eng, ASHRAE Fellow

Building Science

Adventures In Building Science

Basements

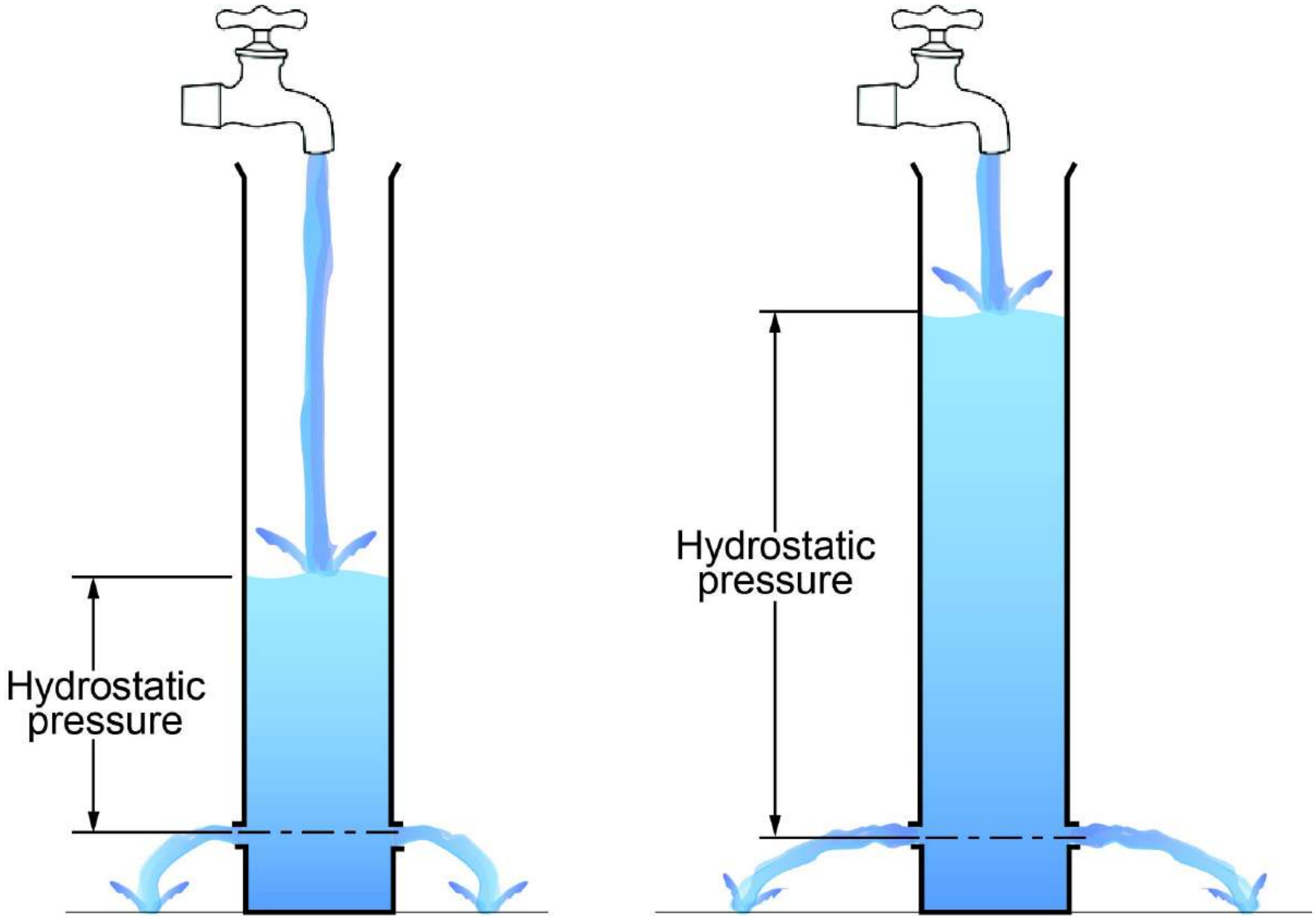


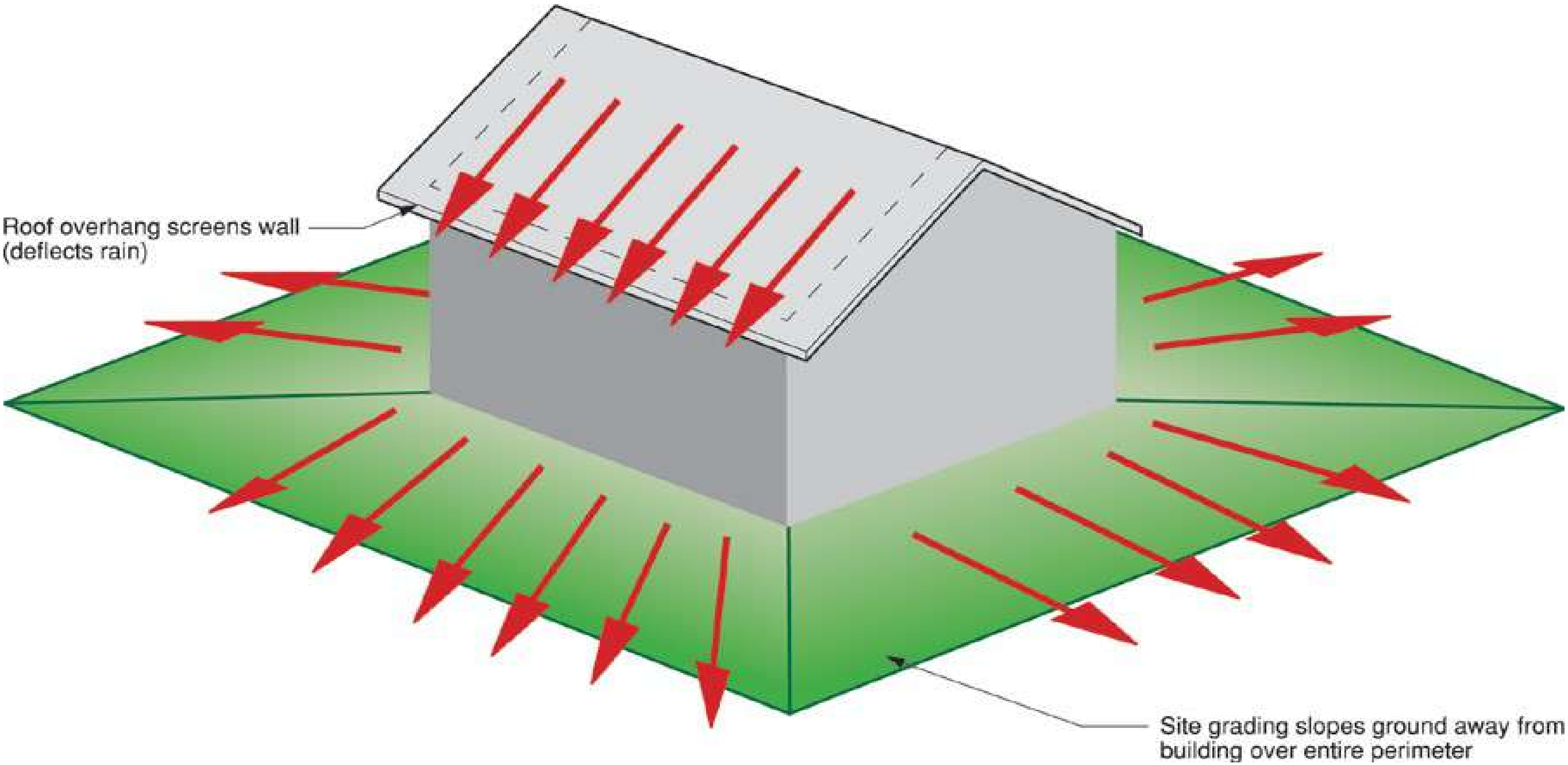
Expansion of Conditioned Space

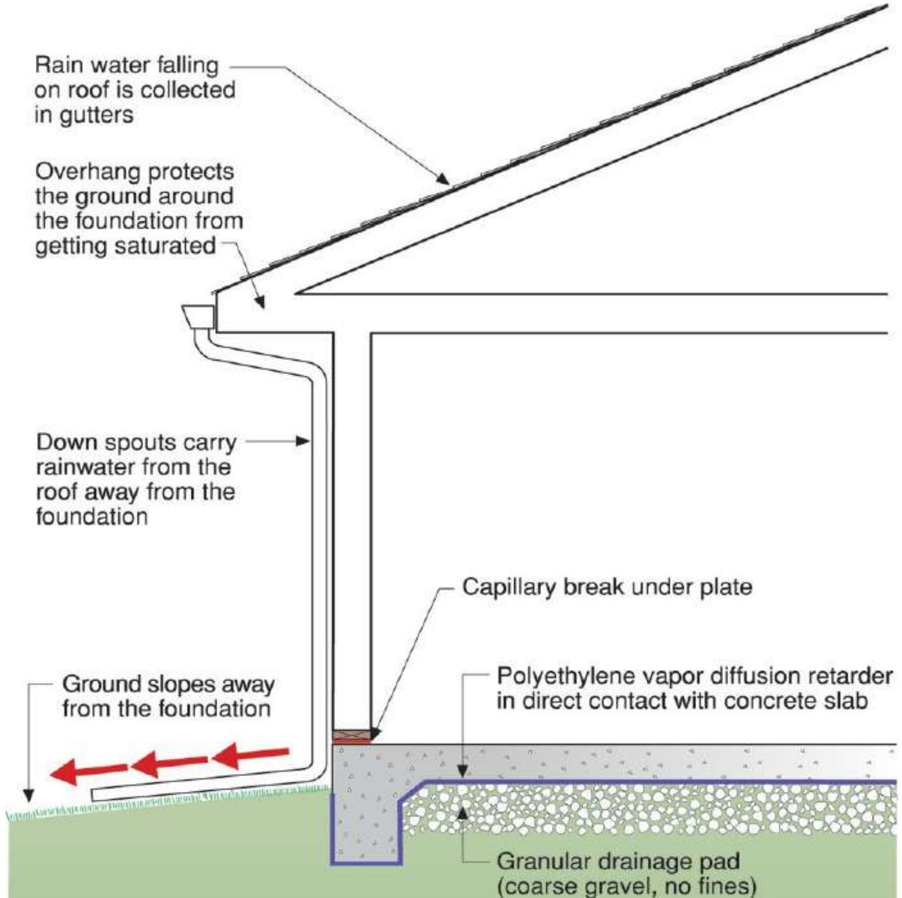
- Conditioned space boundaries moving towards exterior surfaces of building
- Garage isolated from house by air barrier/pressure boundary
- Garage ventilated and conditioned independently of rest of conditioned spaces

Mechanisms of Flow

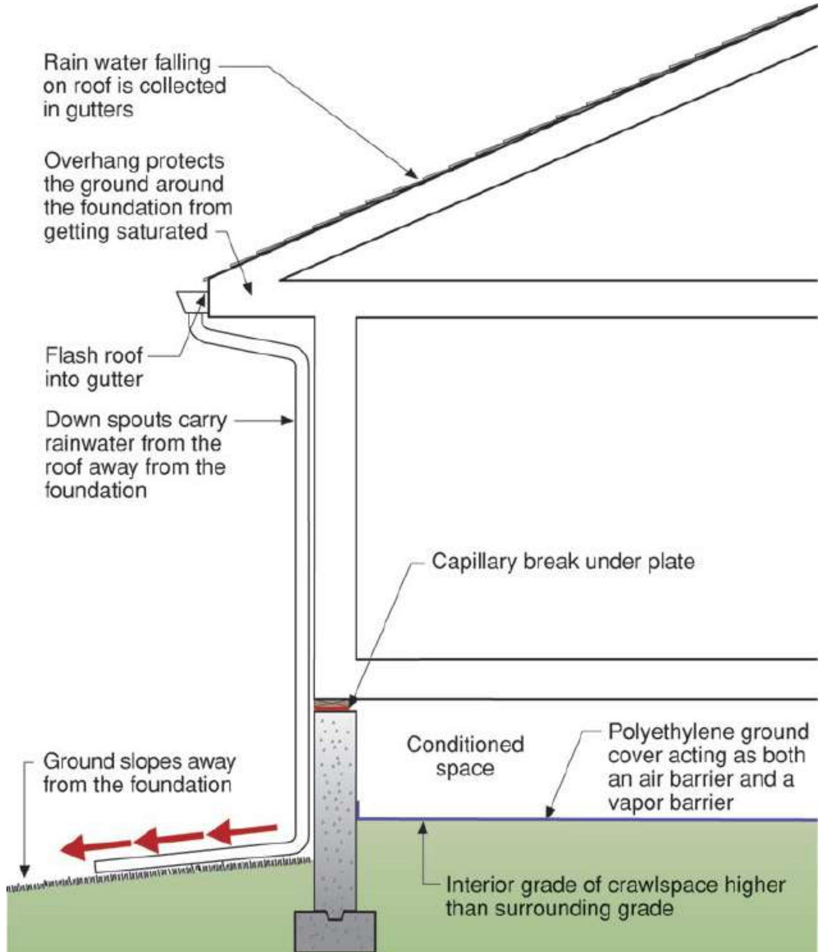
- Liquid Gravitational Hydrostatic Pressure
  Capillary Suction Pressure
  Osmosis Solute Concentration
- Vapor Diffusion Vapor Pressure
  Convective Air Pressure


Hydrostatic pressure
Hydrostatic pressure

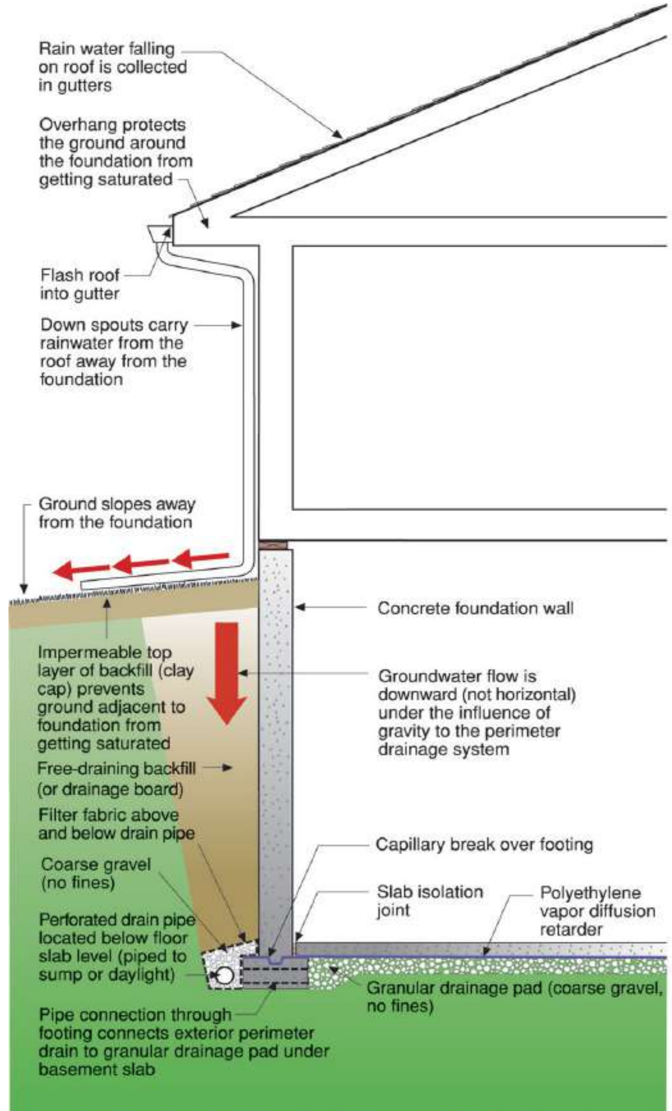

Roof overhang screens wall
(deflects rain)
Site grading slopes ground away from
building over entire perimeter



- 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 ($\cong$ 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

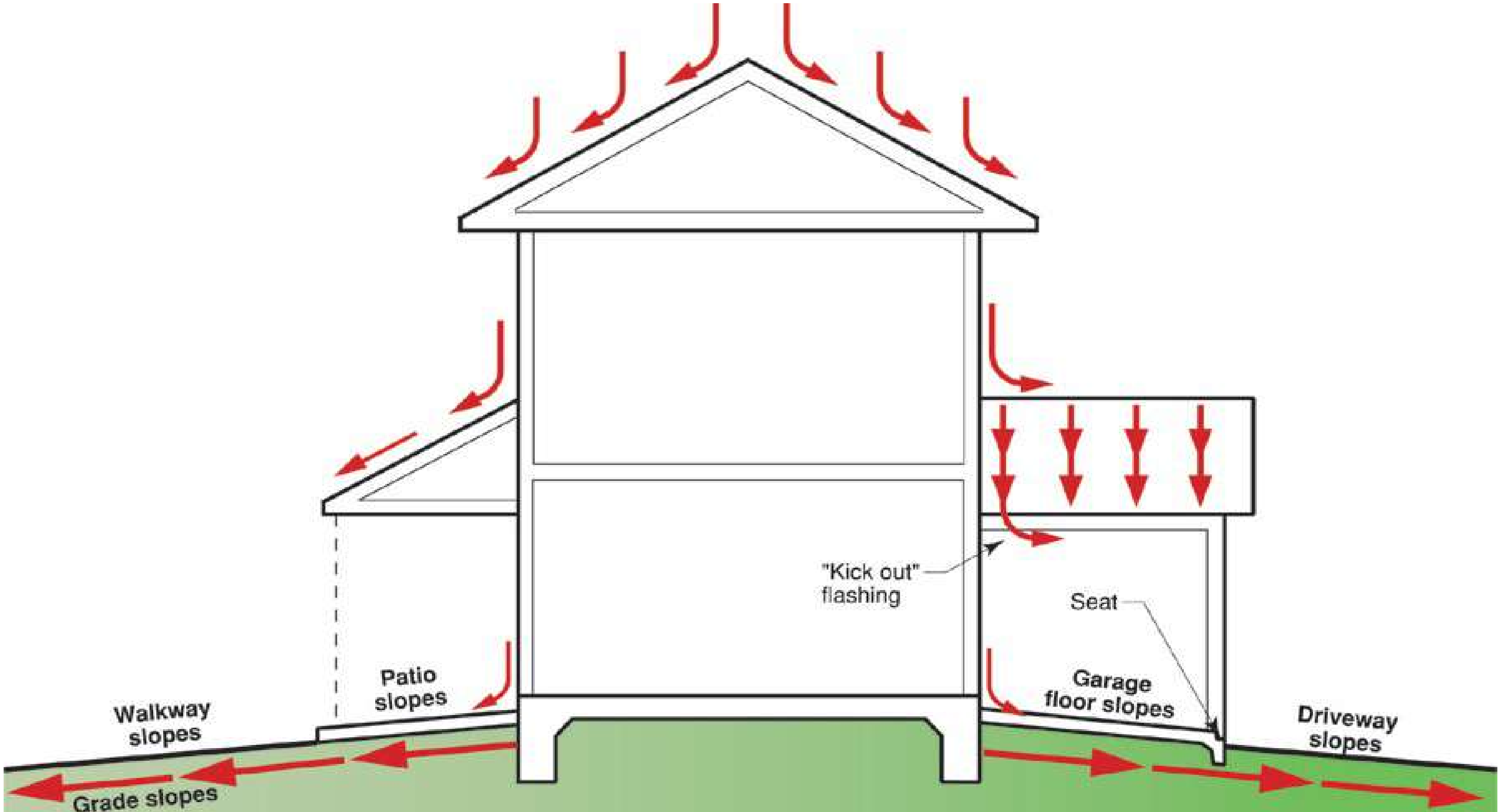


- Keep rain water away from the foundation perimeter
- If the interior crawlspace is lower than the exterior grade, a sub-grade perimeter footing drain is necessary as in a basement foundation
- The crawlspace is conditioned space; it is part of the "interior" of the building and should be heated, cooled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

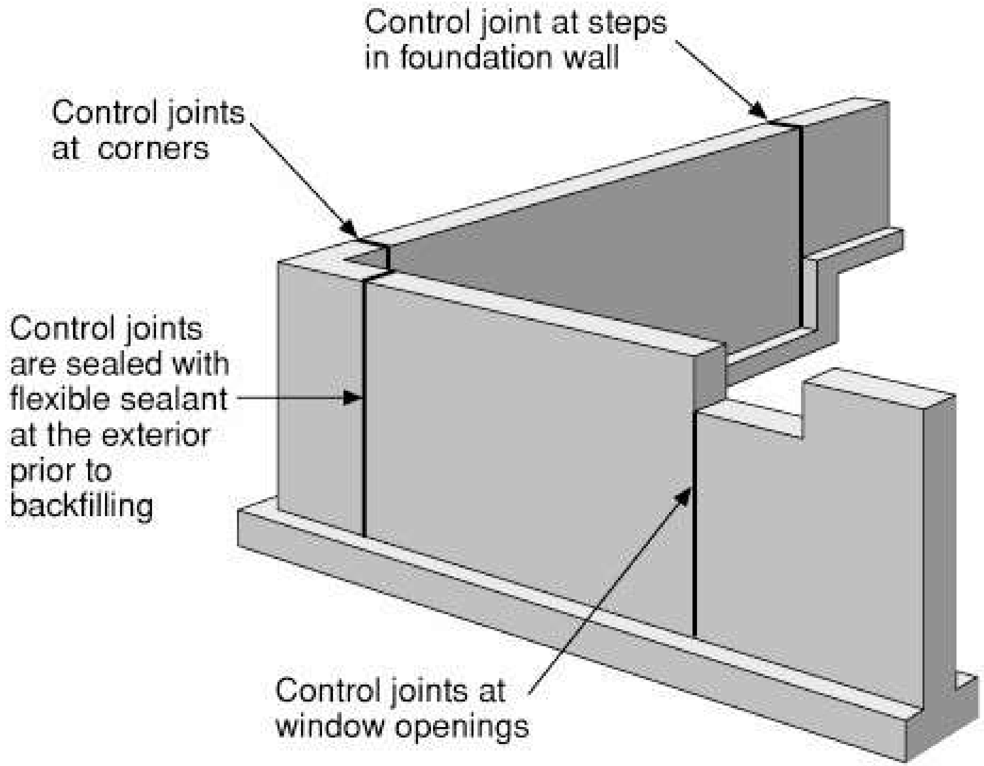


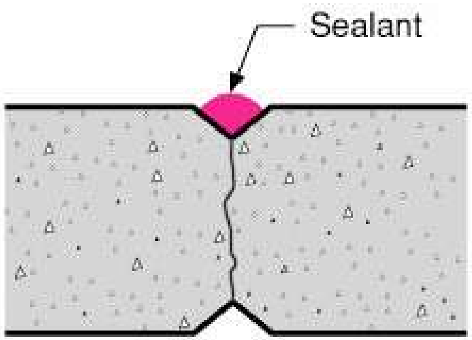
- Keep rain water away from the foundation perimeter
- Drain groundwater away in sub-grade perimeter footing drains before it gets to the foundation wall


DELTA-MS
DELTA-MS
DELTA-MS

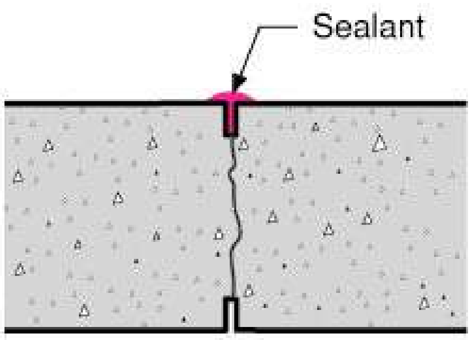


- Patios and decks lower than floors and slope away from building
- Garage floor lower than main floor and slope away from building
- Driveway lower than garage floor and slope away from building
- Grade lower than main floor and slope away from building
- Stoops and walkways lower than main floor and slope away from building
- Kick out flashings or diverters direct water away from walls at roof/wall intersections

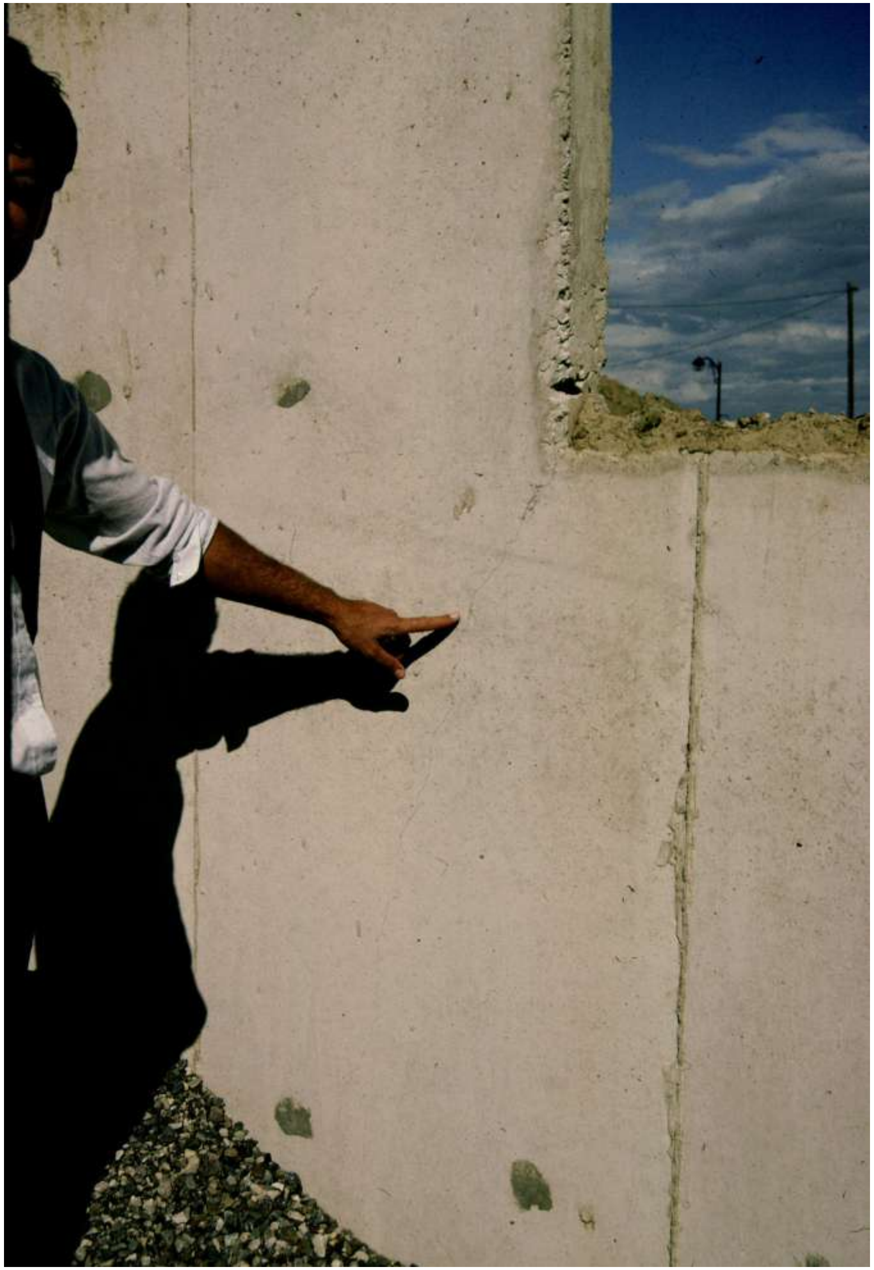


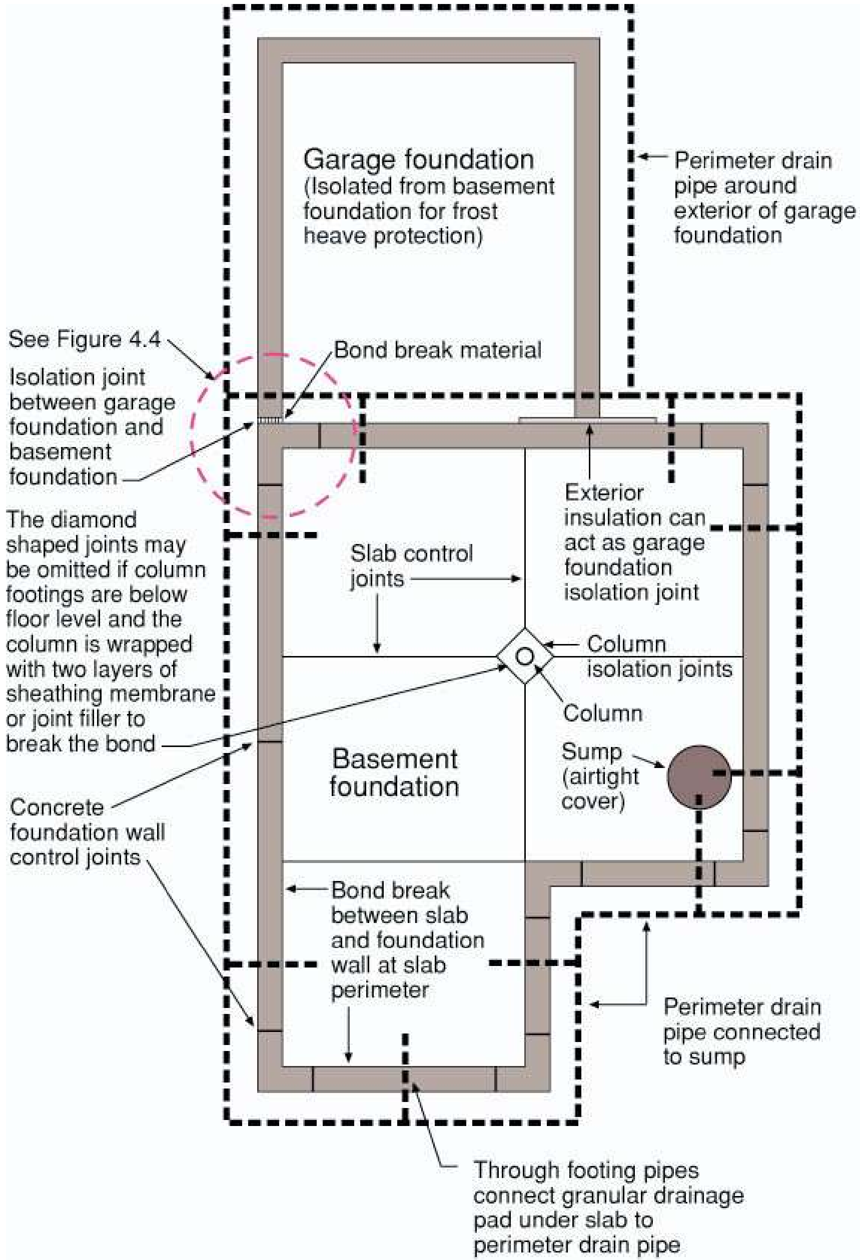


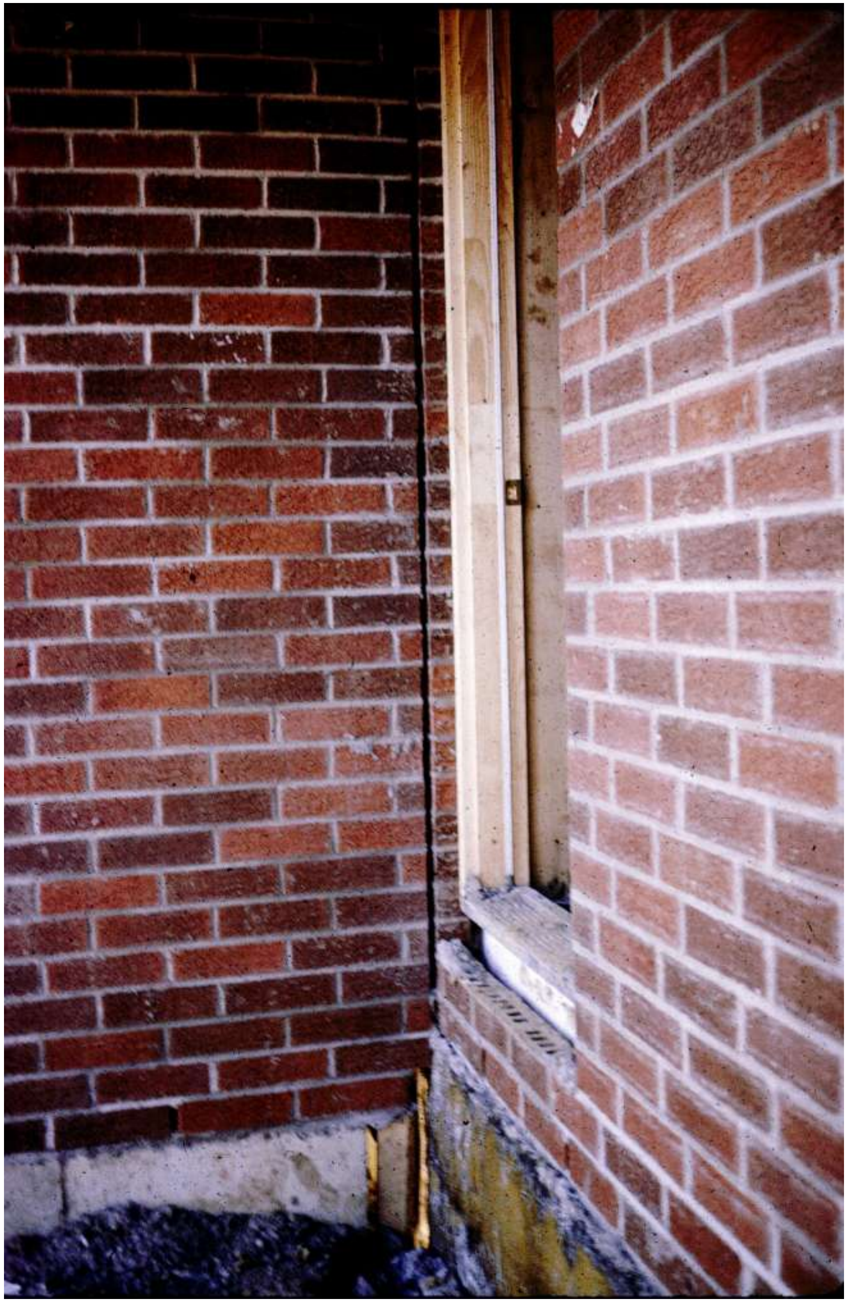
Diagonally cut 2 x 2's in forms
provide goose neck joint

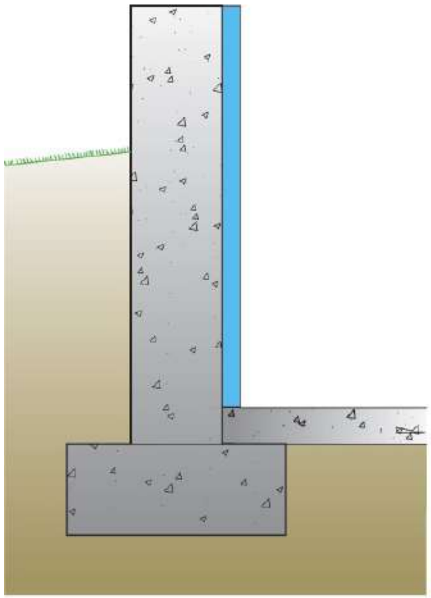


Saw cut joint

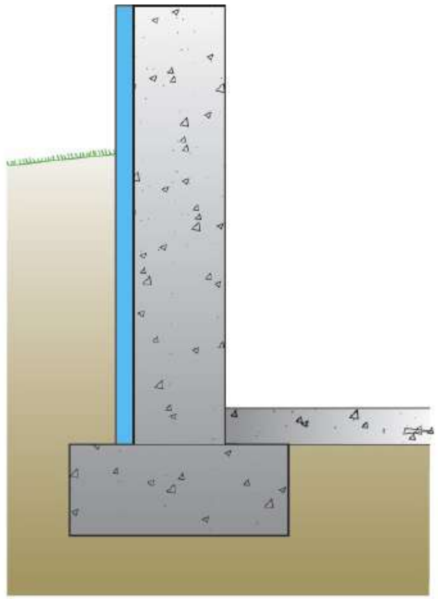



Garage foundation
(Isolated from basement foundation for frost heave protection)
Perimeter drain pipe around exterior of garage foundation
See Figure 4.4
Bond break material
Isolation joint between garage foundation and basement foundation
Exterior insulation can act as garage foundation isolation joint
The diamond shaped joints may be omitted if column footings are below floor level and the column is wrapped with two layers of sheathing membrane or joint filler to break the bond
Slab control joints
Column isolation joints
Column
Sump (airtight cover)
Basement foundation
Concrete foundation wall control joints
Bond break between slab and foundation wall at slab perimeter
Perimeter drain pipe connected to sump
Through footing pipes connect granular drainage pad under slab to perimeter drain pipe

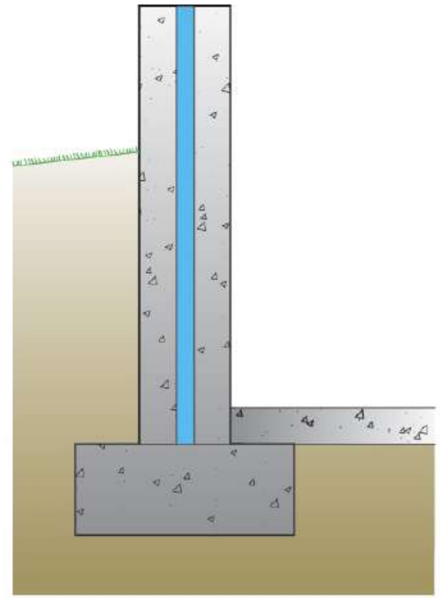




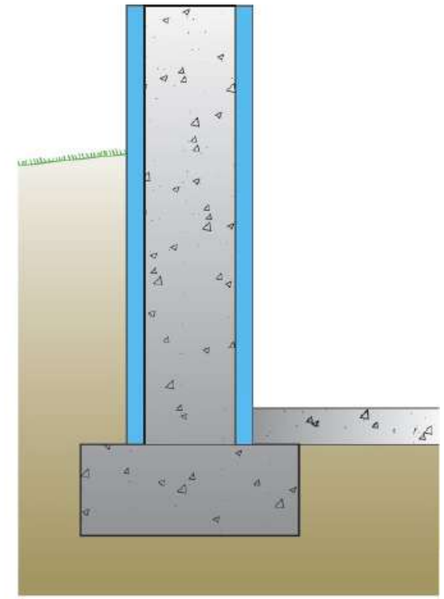
Internally Insulated Basement



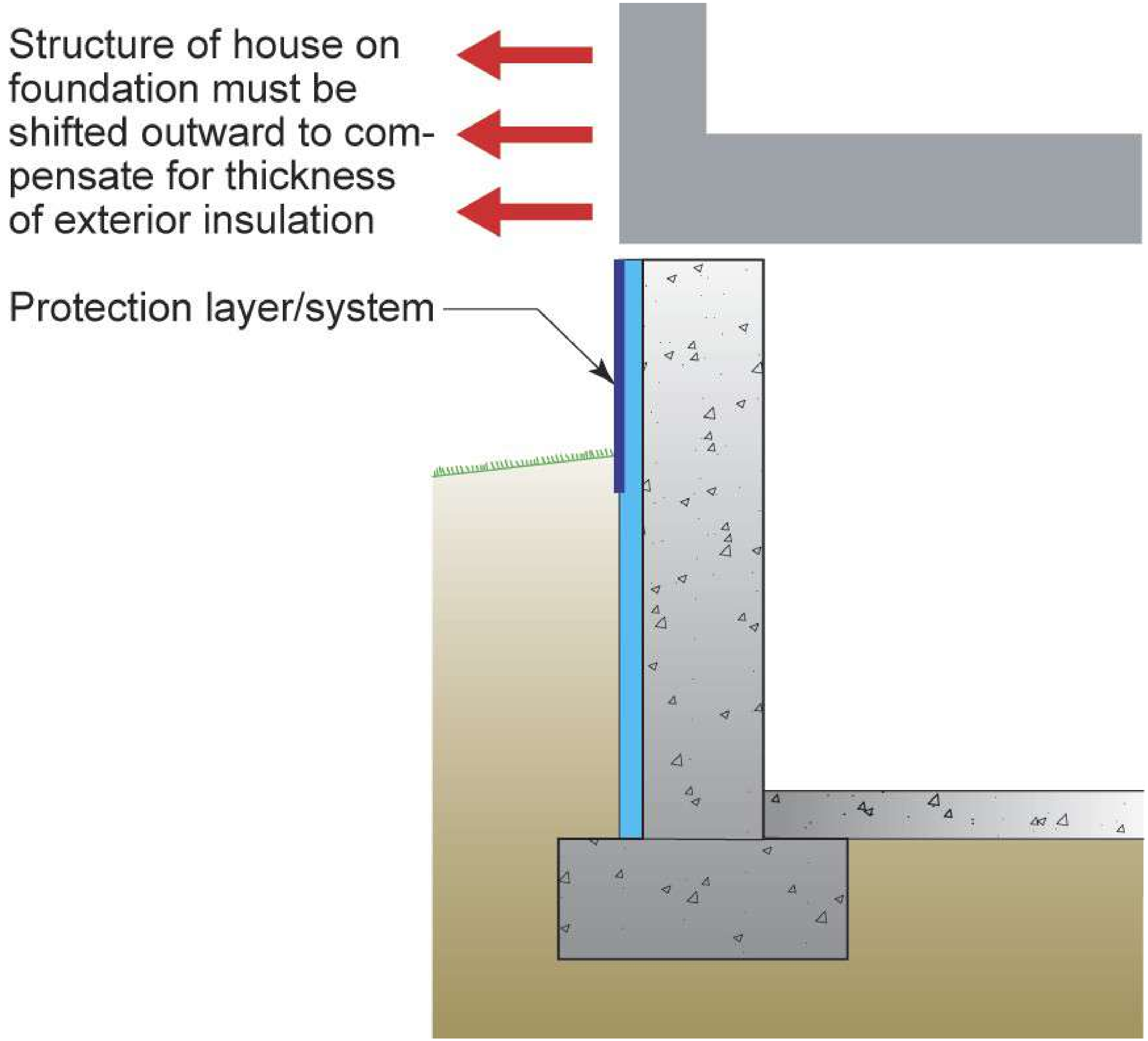
Externally Insulated Basement



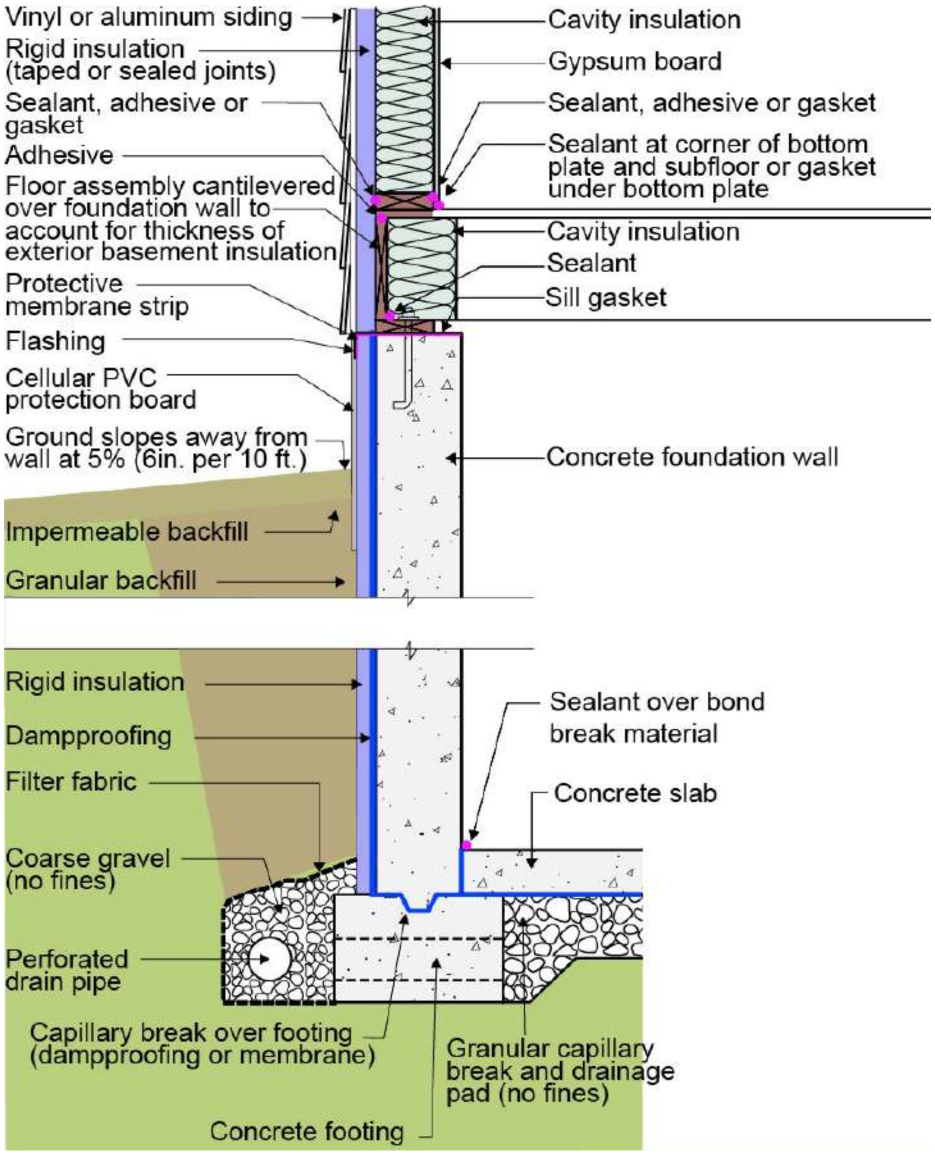
Basement Insulated in the Middle



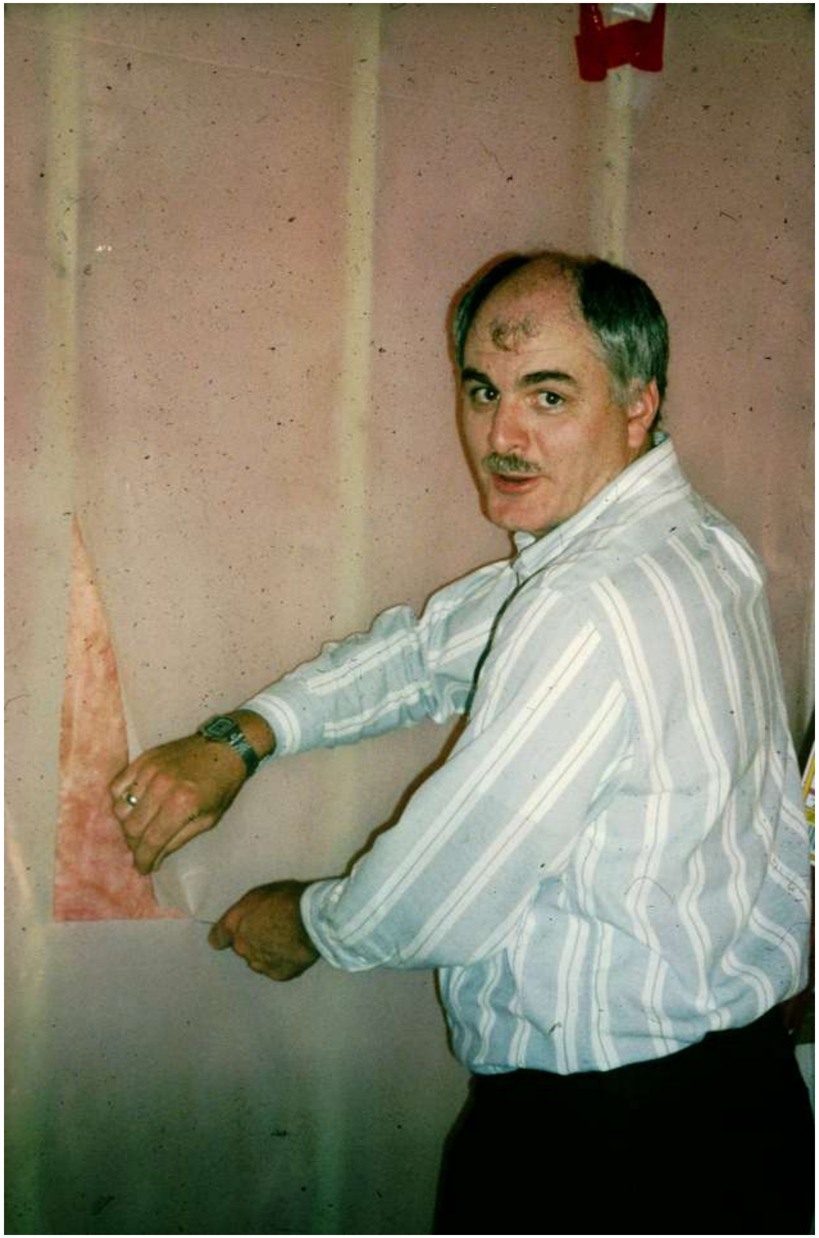
Basement Insulated Both Externally and Internally


Structure of house on foundation must be shifted outward to compensate for thickness of exterior insulation
Protection layer/system


STYROFOAM
Foundation
Coating Kit
27



Vinyl or aluminum siding
Rigid insulation (taped or sealed joints)
Sealant, adhesive or gasket
Adhesive
Floor assembly cantilevered over foundation wall to account for thickness of exterior basement insulation
Protective membrane strip
Flashing
Cellular PVC protection board
Ground slopes away from wall at 5% (6in. per 10 ft.)
Impermeable backfill
Granular backfill
Rigid insulation
Dampproofing
Filter fabric
Coarse gravel (no fines)
Perforated drain pipe
Capillary break over footing (dampproofing or membrane)
Concrete footing
Granular capillary break and drainage pad (no fines)
Cavity insulation
Gypsum board
Sealant, adhesive or gasket
Sealant at corner of bottom plate and subfloor or gasket under bottom plate
Cavity insulation
Sealant
Sill gasket
Concrete foundation wall
Sealant over bond break material
Concrete slab

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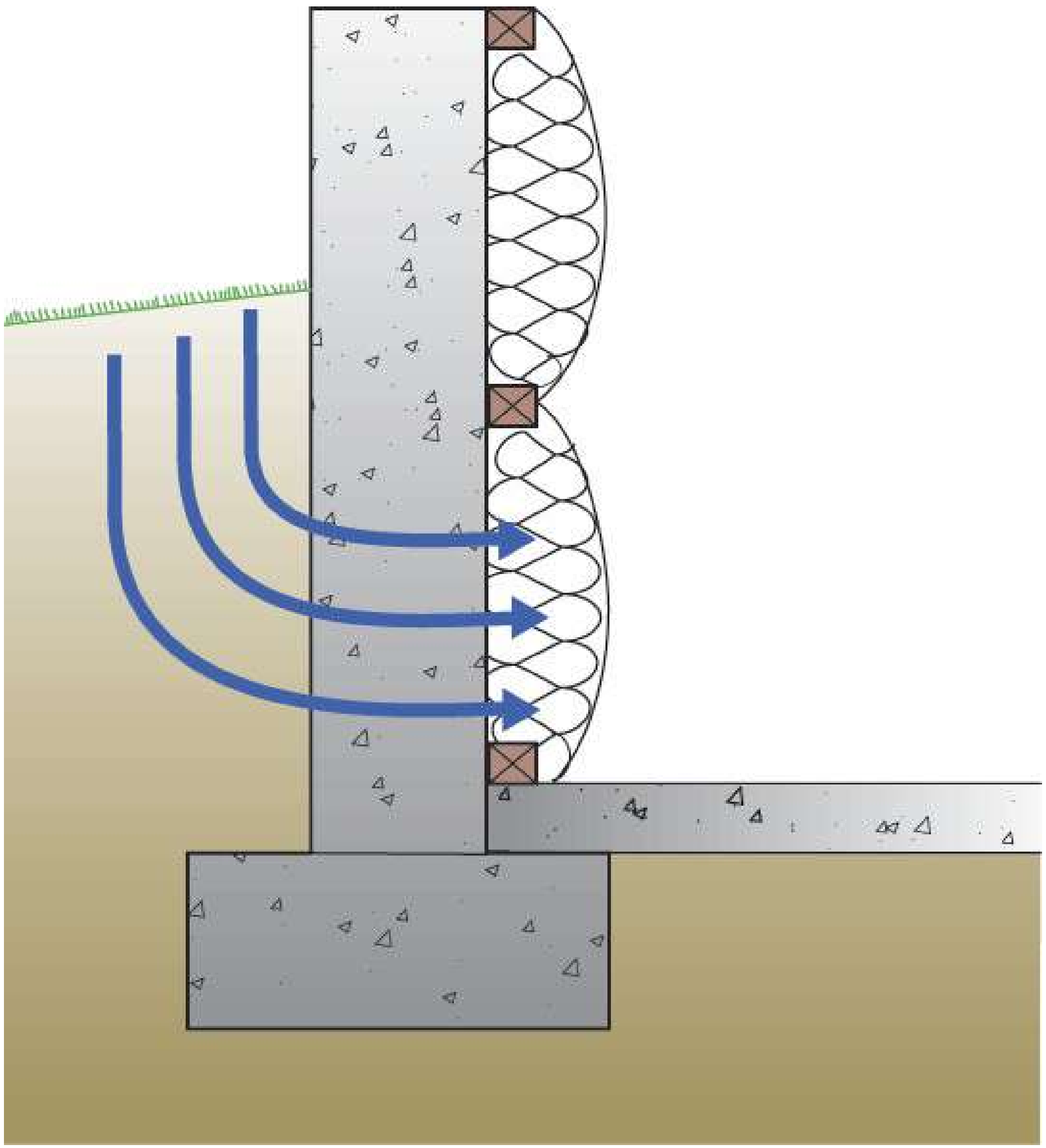
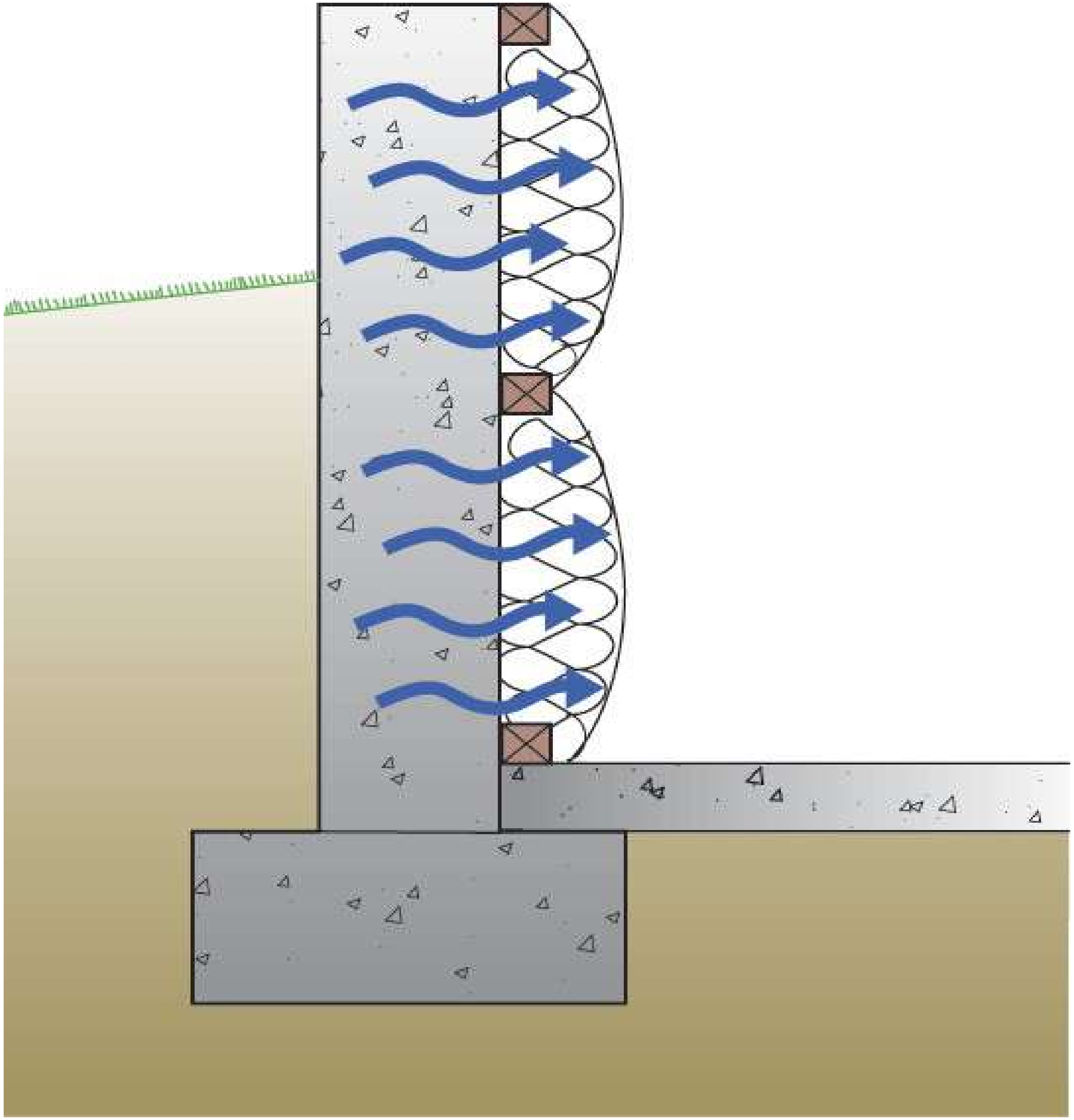
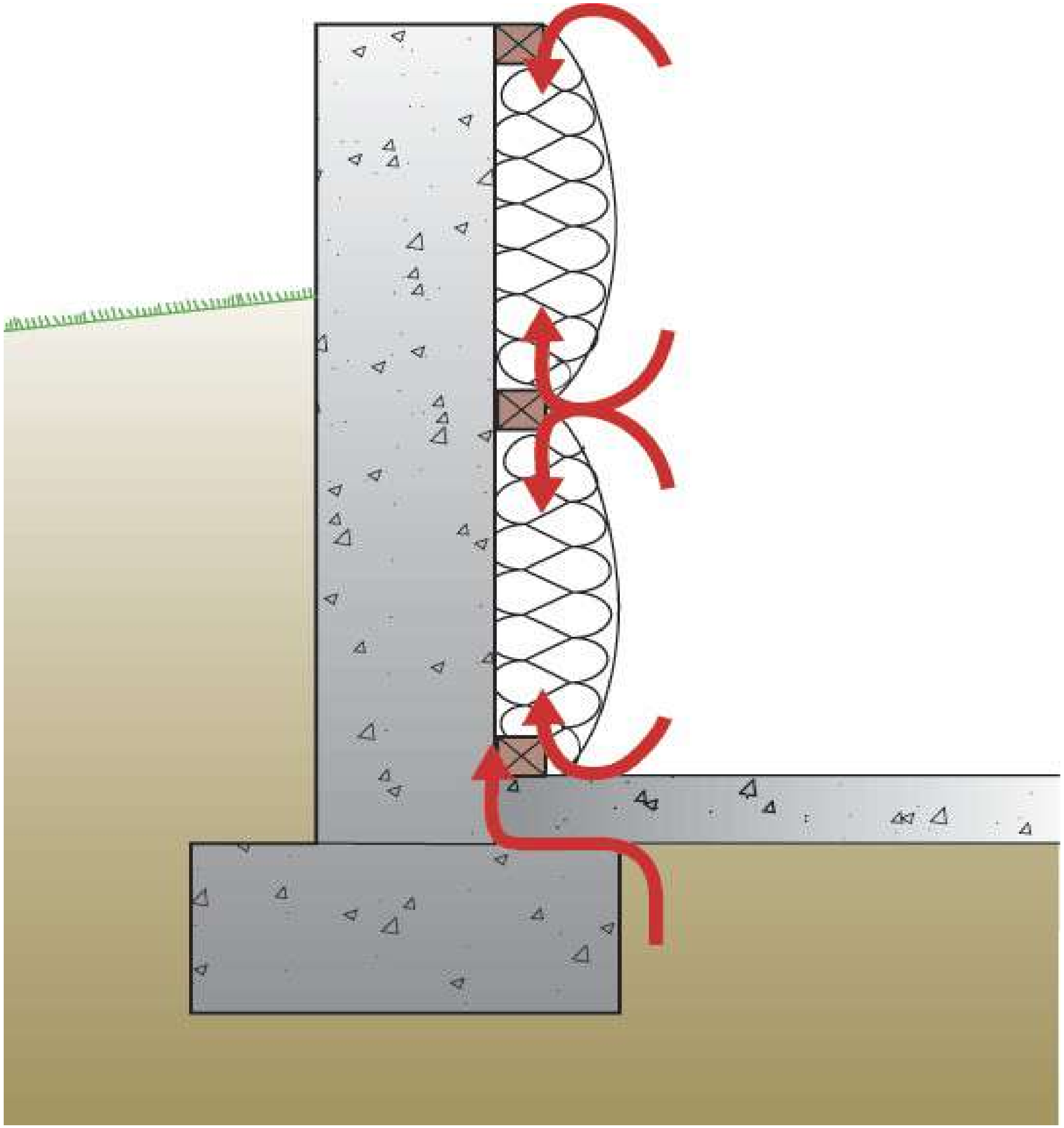
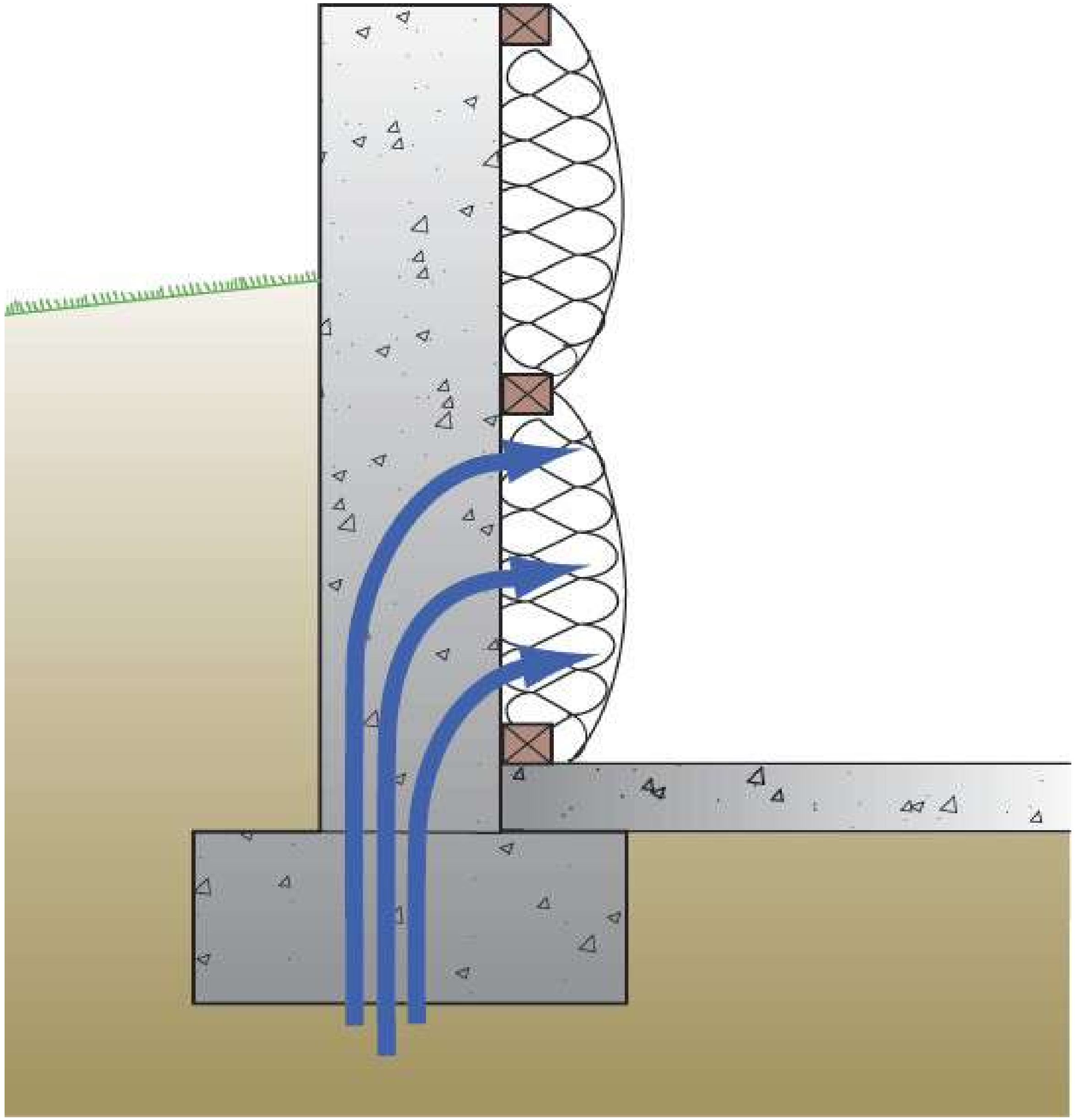
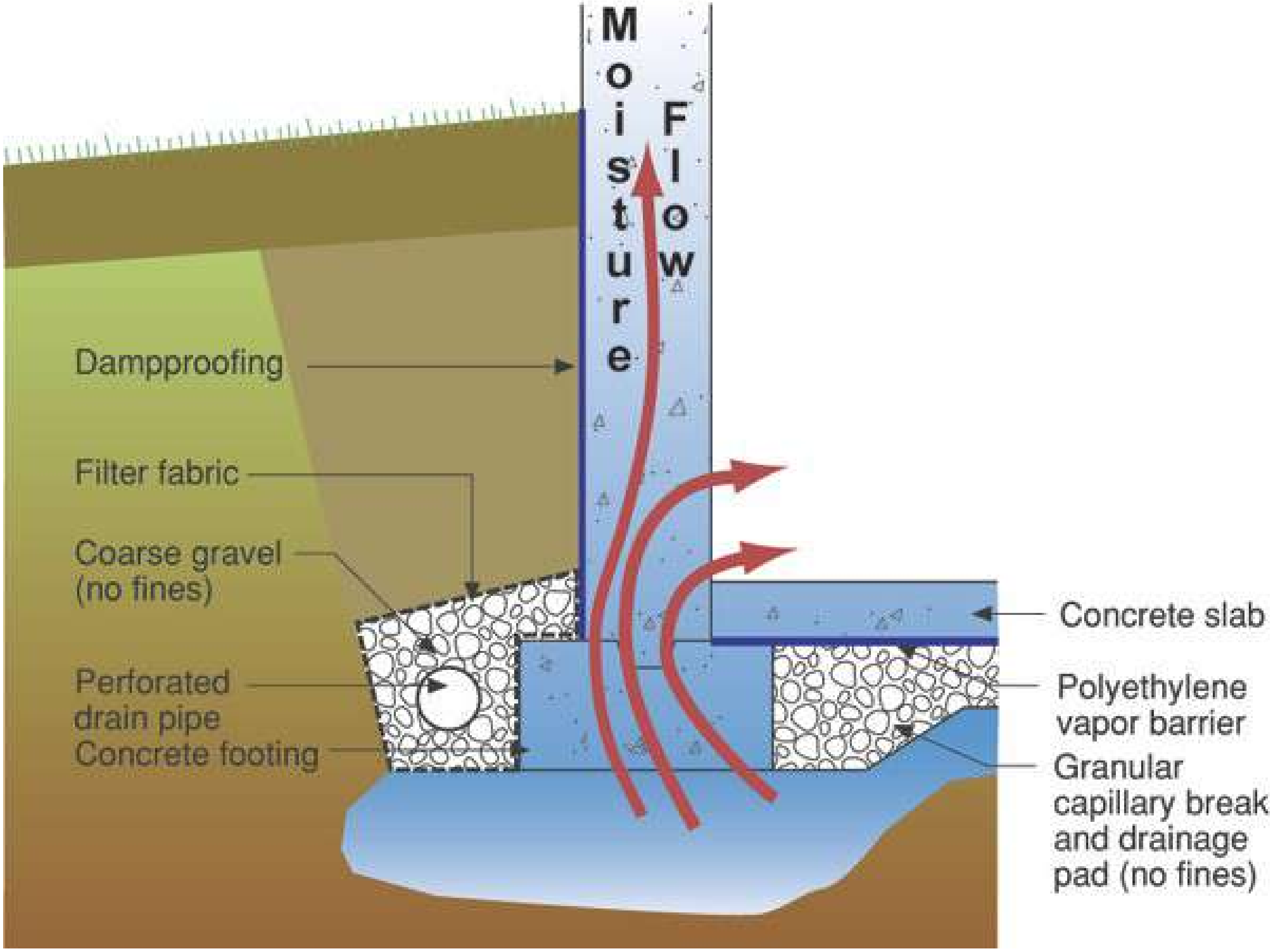
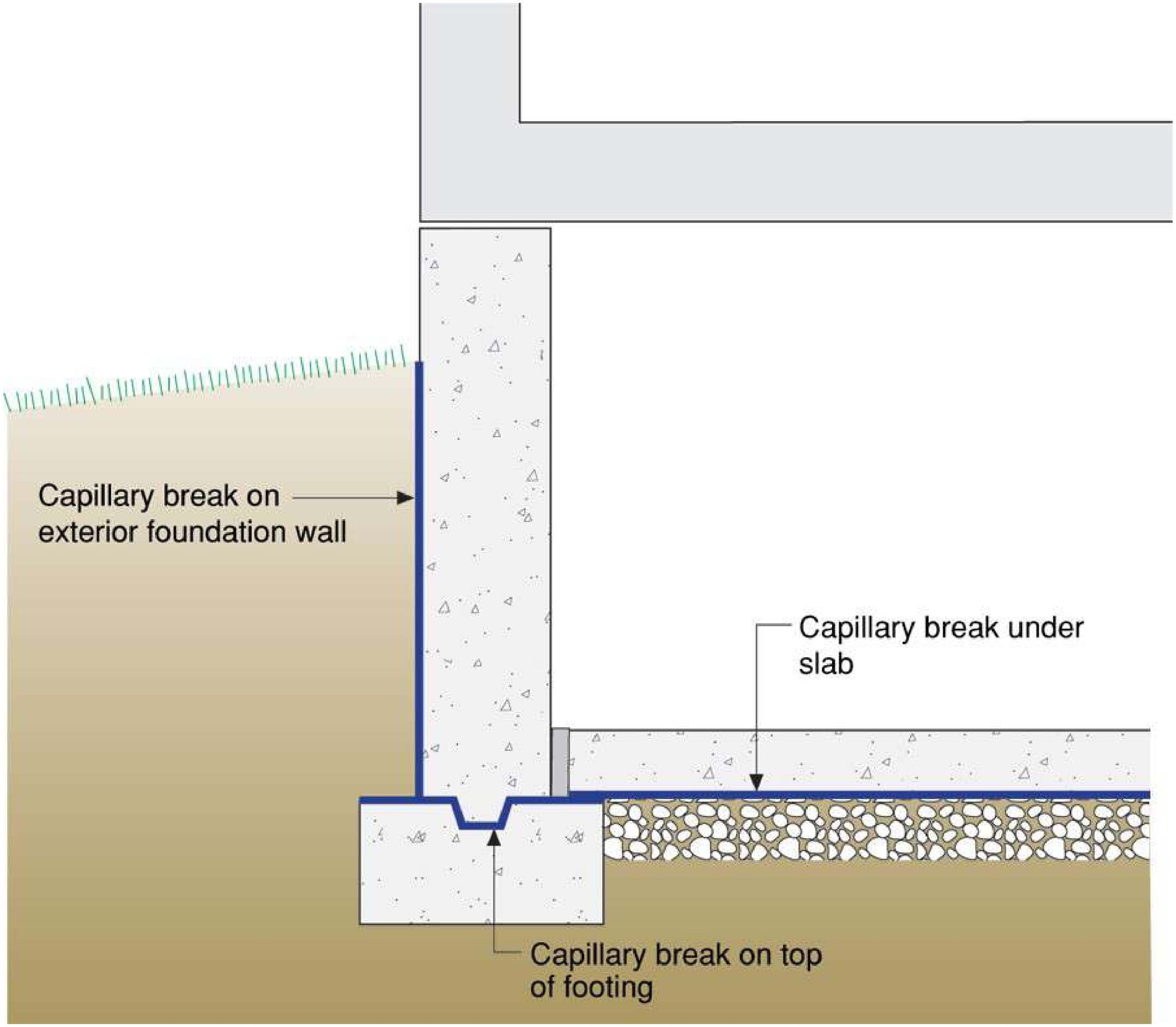


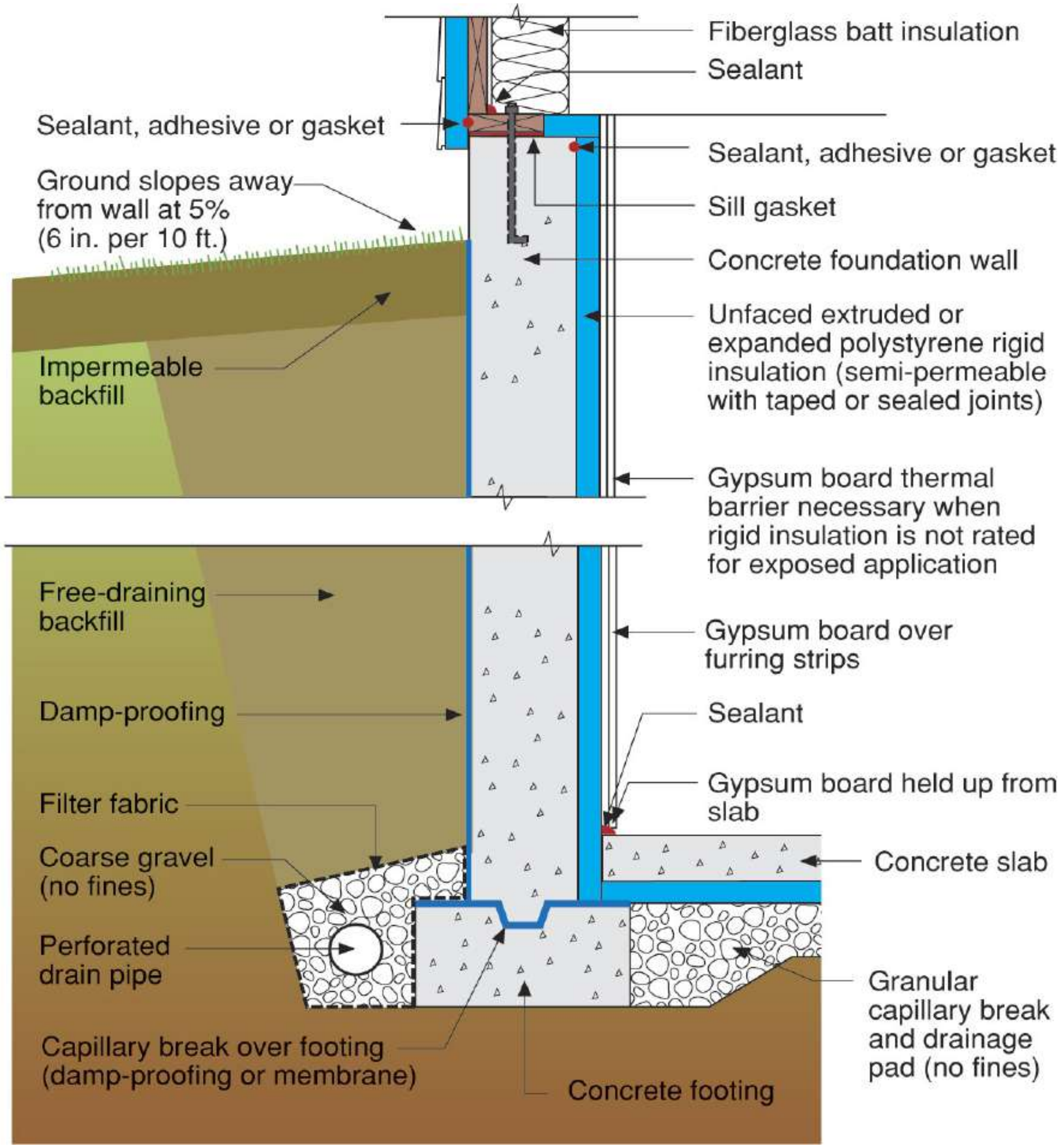




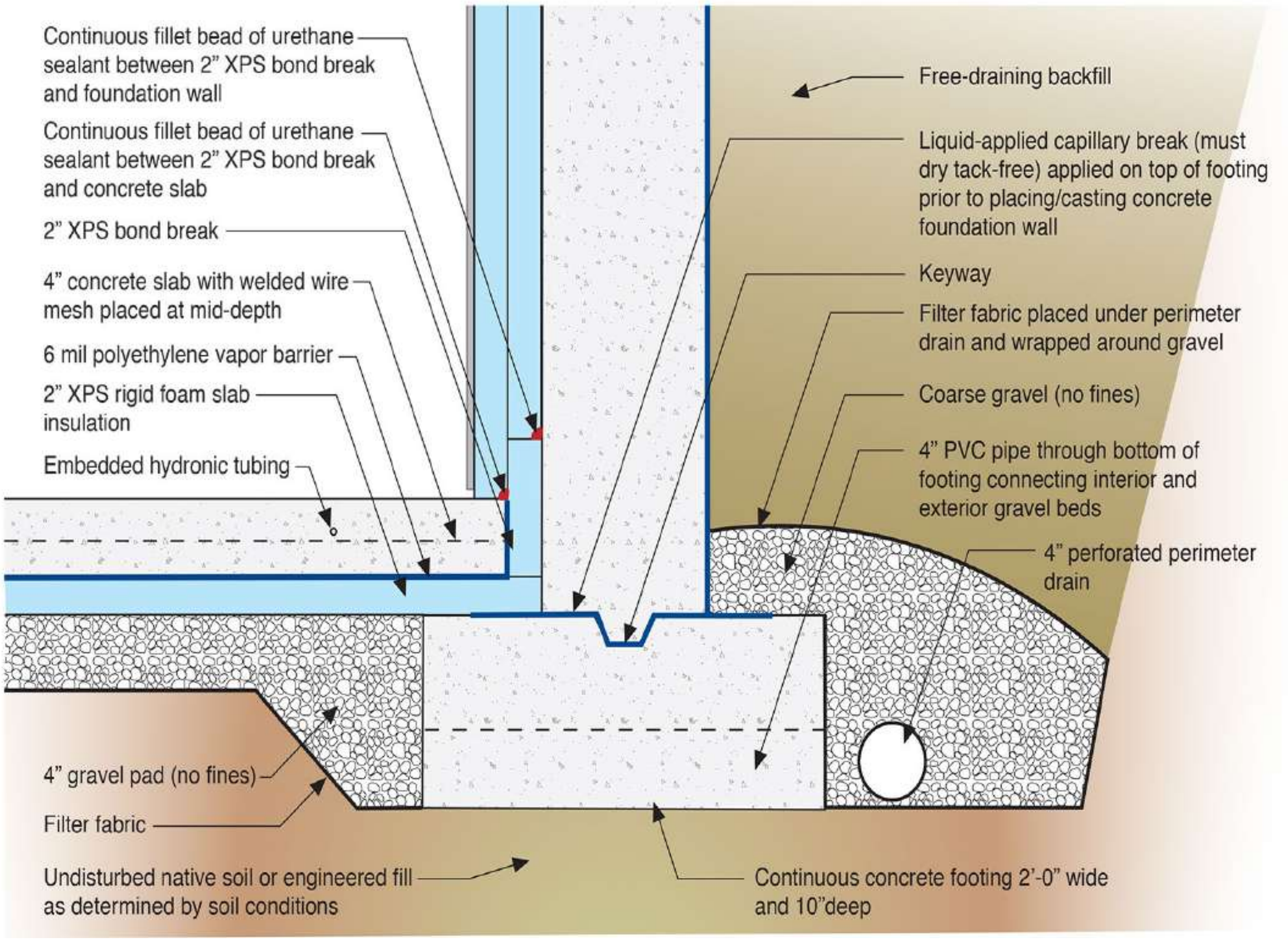


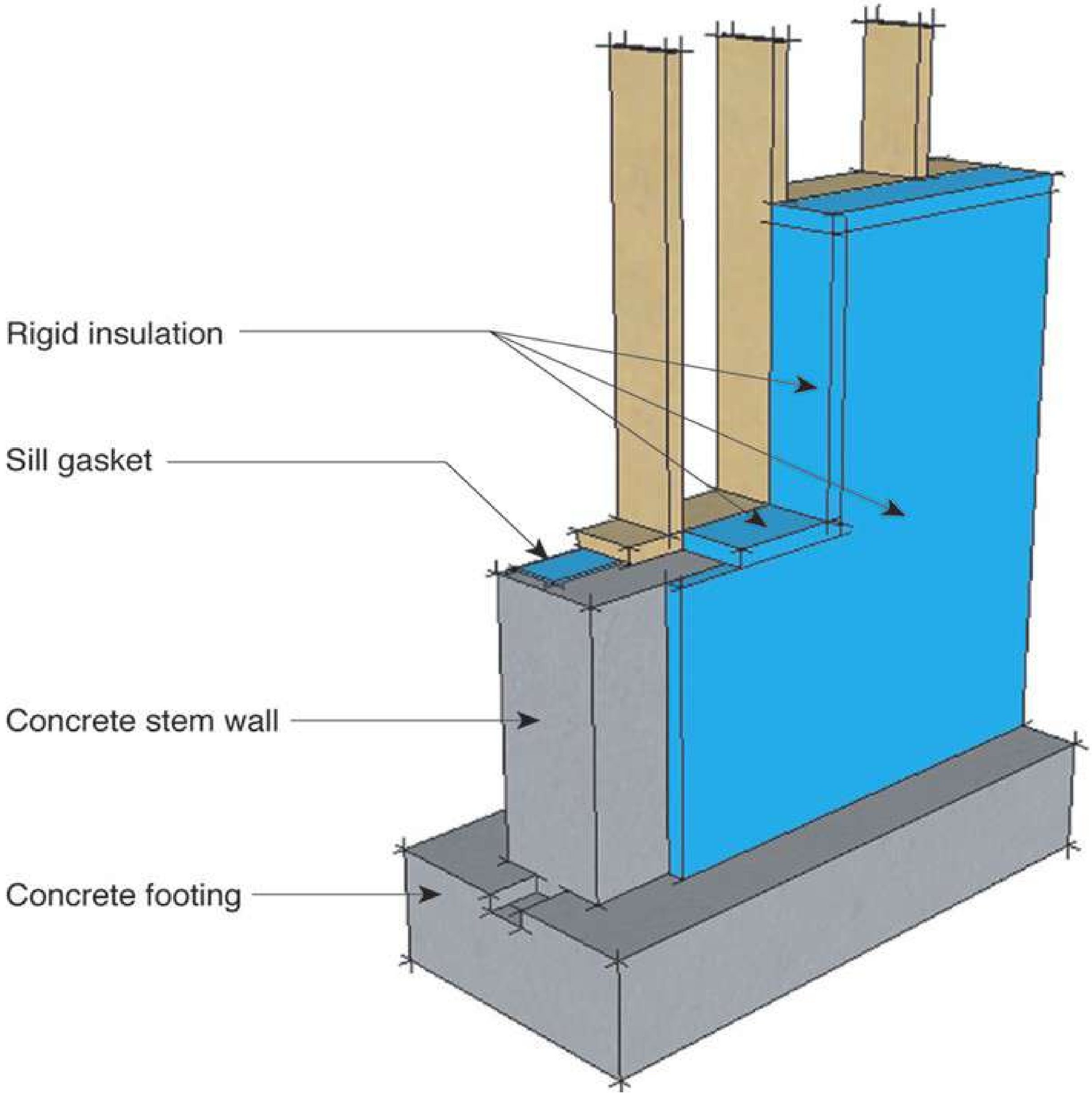

Moisture Flow
Dampproofing
Filter fabric
Coarse gravel (no fines)
Perforated drain pipe
Concrete footing
Concrete slab
Polyethylene vapor barrier
Granular capillary break and drainage pad (no fines)

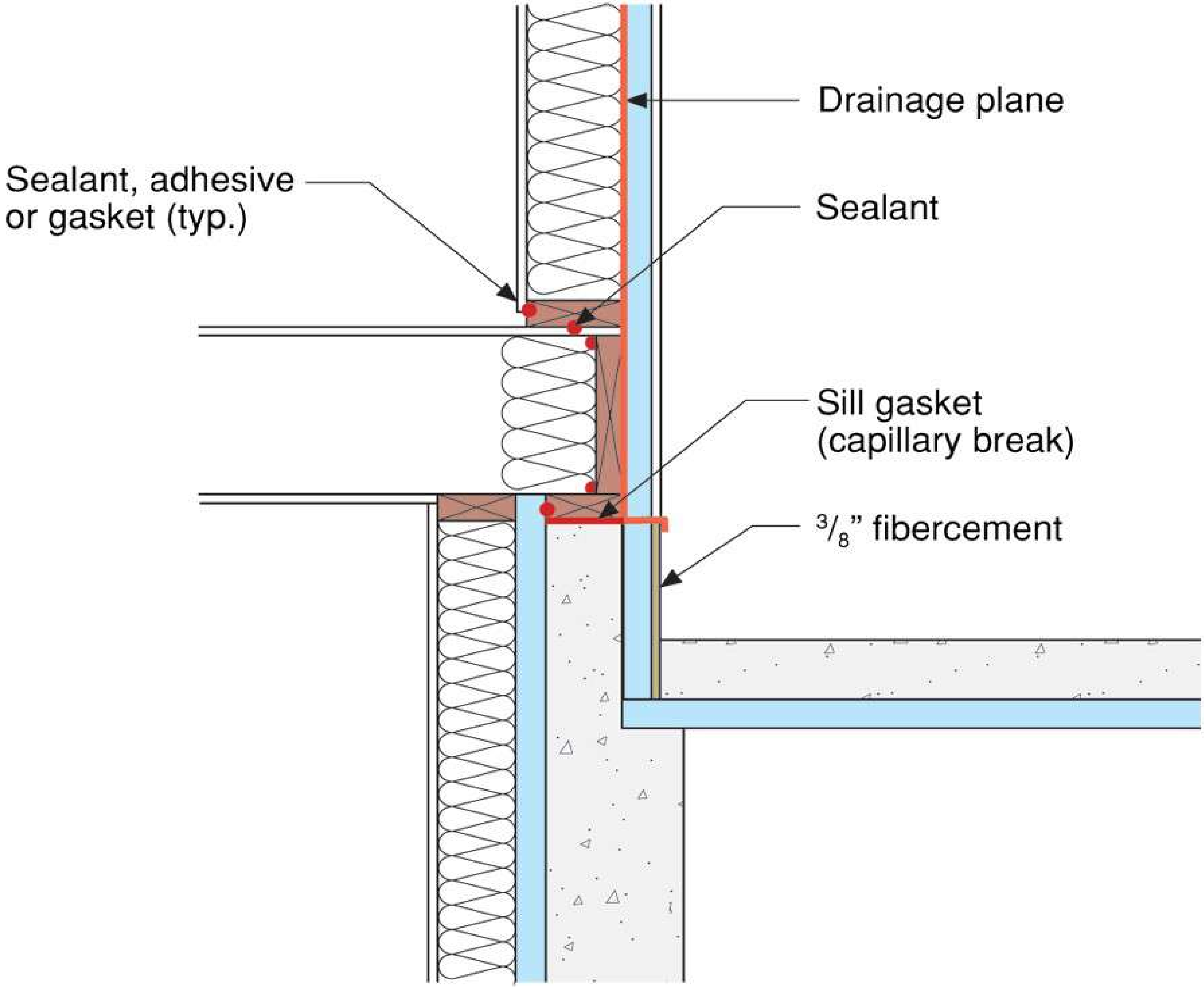

Capillary break on exterior foundation wall
Capillary break under slab
Capillary break on top of footing

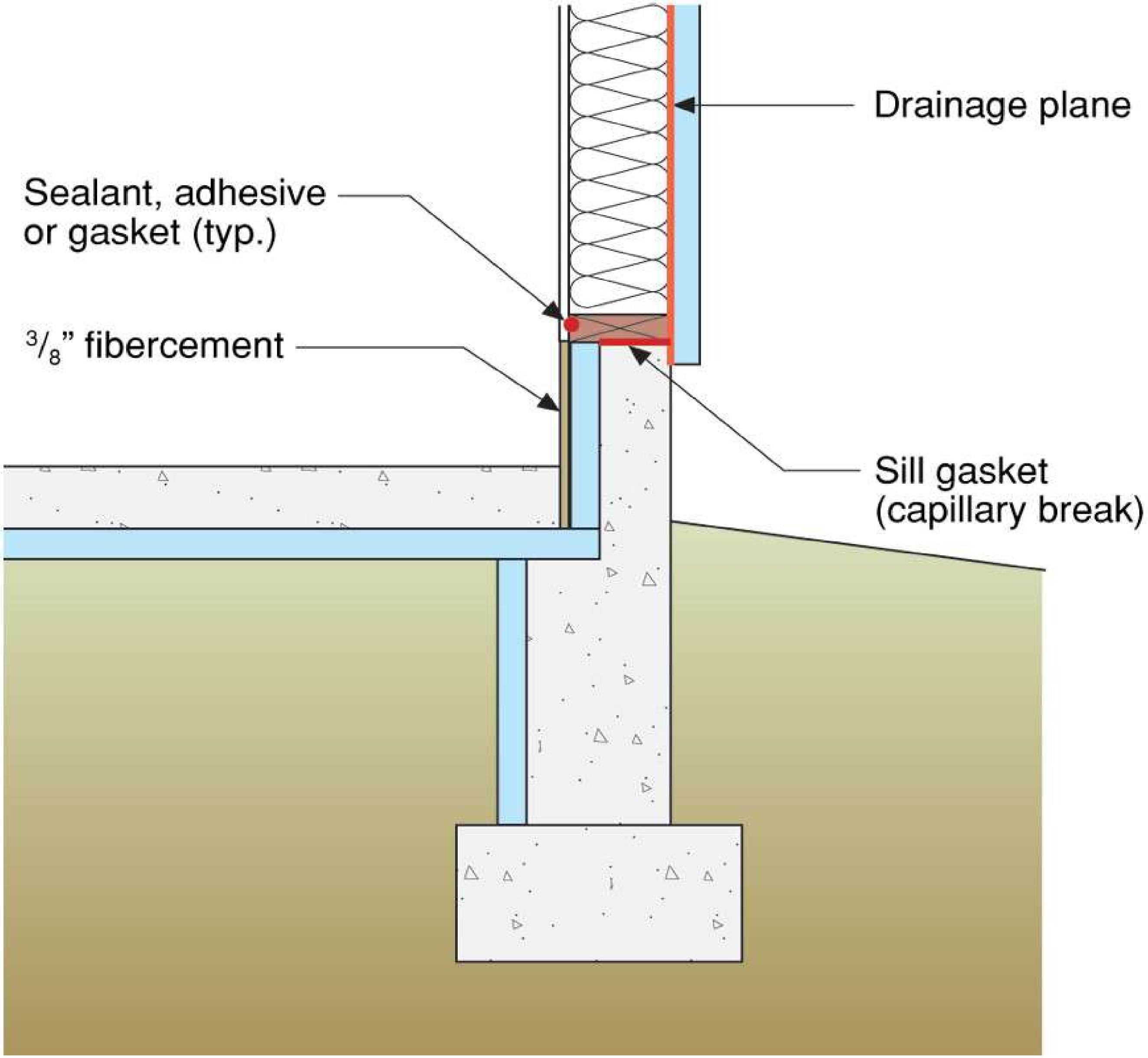


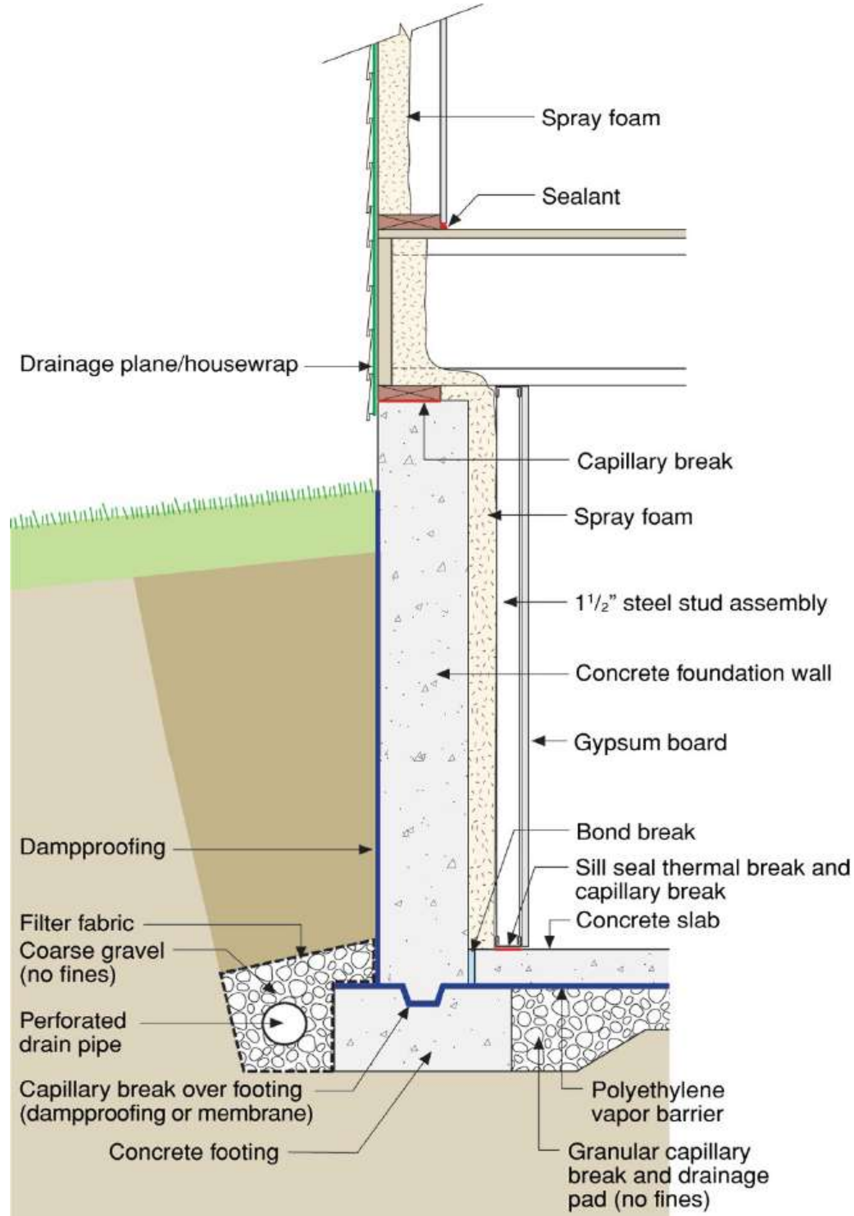
Fiberglass batt insulation
Sealant
Sealant, adhesive or gasket
Sealant, adhesive or gasket
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Sill gasket
Concrete foundation wall
Unfaced extruded or expanded polystyrene rigid insulation (semi-permeable with taped or sealed joints)
Impermeable backfill
Gypsum board thermal barrier necessary when rigid insulation is not rated for exposed application
Free-draining backfill
Gypsum board over furring strips
Damp-proofing
Sealant
Gypsum board held up from slab
Filter fabric
Coarse gravel (no fines)
Concrete slab
Perforated drain pipe
Granular capillary break and drainage pad (no fines)
Capillary break over footing (damp-proofing or membrane)
Concrete footing

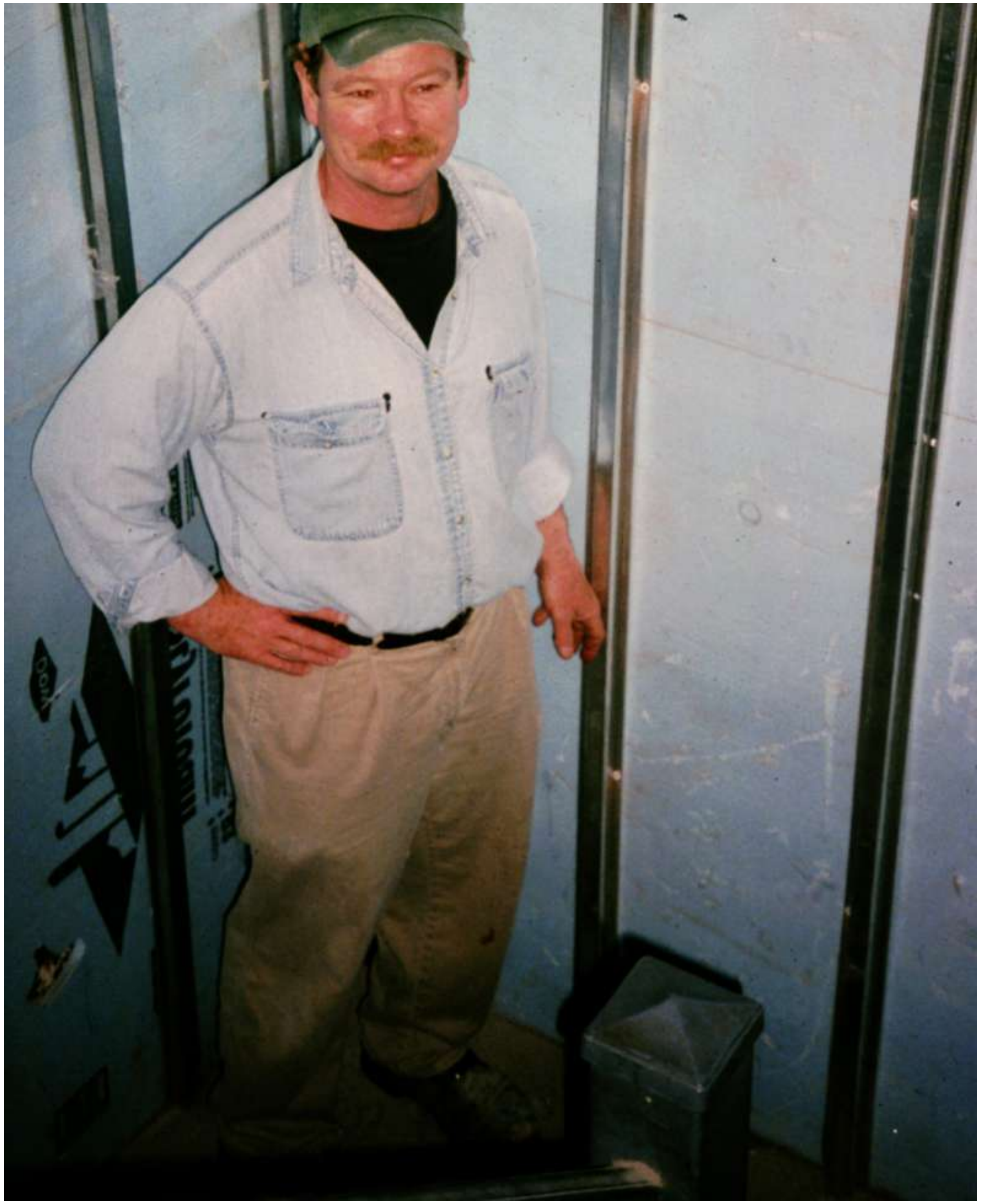

Continuous fillet bead of urethane sealant between 2" XPS bond break and foundation wall
Continuous fillet bead of urethane sealant between 2" XPS bond break and concrete slab
2" XPS bond break
4" concrete slab with welded wire mesh placed at mid-depth
6 mil polyethylene vapor barrier
2" XPS rigid foam slab insulation
Embedded hydronic tubing
4" gravel pad (no fines)
Filter fabric
Undisturbed native soil or engineered fill as determined by soil conditions
Free-draining backfill
Liquid-applied capillary break (must dry tack-free) applied on top of footing prior to placing/casting concrete foundation wall
Keyway
Filter fabric placed under perimeter drain and wrapped around gravel
Coarse gravel (no fines)
4" PVC pipe through bottom of footing connecting interior and exterior gravel beds
4" perforated perimeter drain
Continuous concrete footing 2'-0" wide and 10"deep


Rigid insulation
Sill gasket
Concrete stem wall
Concrete footing


Drainage plane
Sealant, adhesive or gasket (typ.)
Sealant
Sill gasket (capillary break)
3/8" fibercement


Drainage plane
Sealant, adhesive
or gasket (typ.)
3/8" fibercement
Sill gasket
(capillary break)


Spray foam
Sealant
Drainage plane/housewrap
Capillary break
Spray foam
1 1/2" steel stud assembly
Concrete foundation wall
Gypsum board
Bond break
Sill seal thermal break and capillary break
Concrete slab
Dampproofing
Filter fabric
Coarse gravel (no fines)
Perforated drain pipe
Capillary break over footing (dampproofing or membrane)
Concrete footing
Polyethylene vapor barrier
Granular capillary break and drainage pad (no fines)



Crawl Spaces

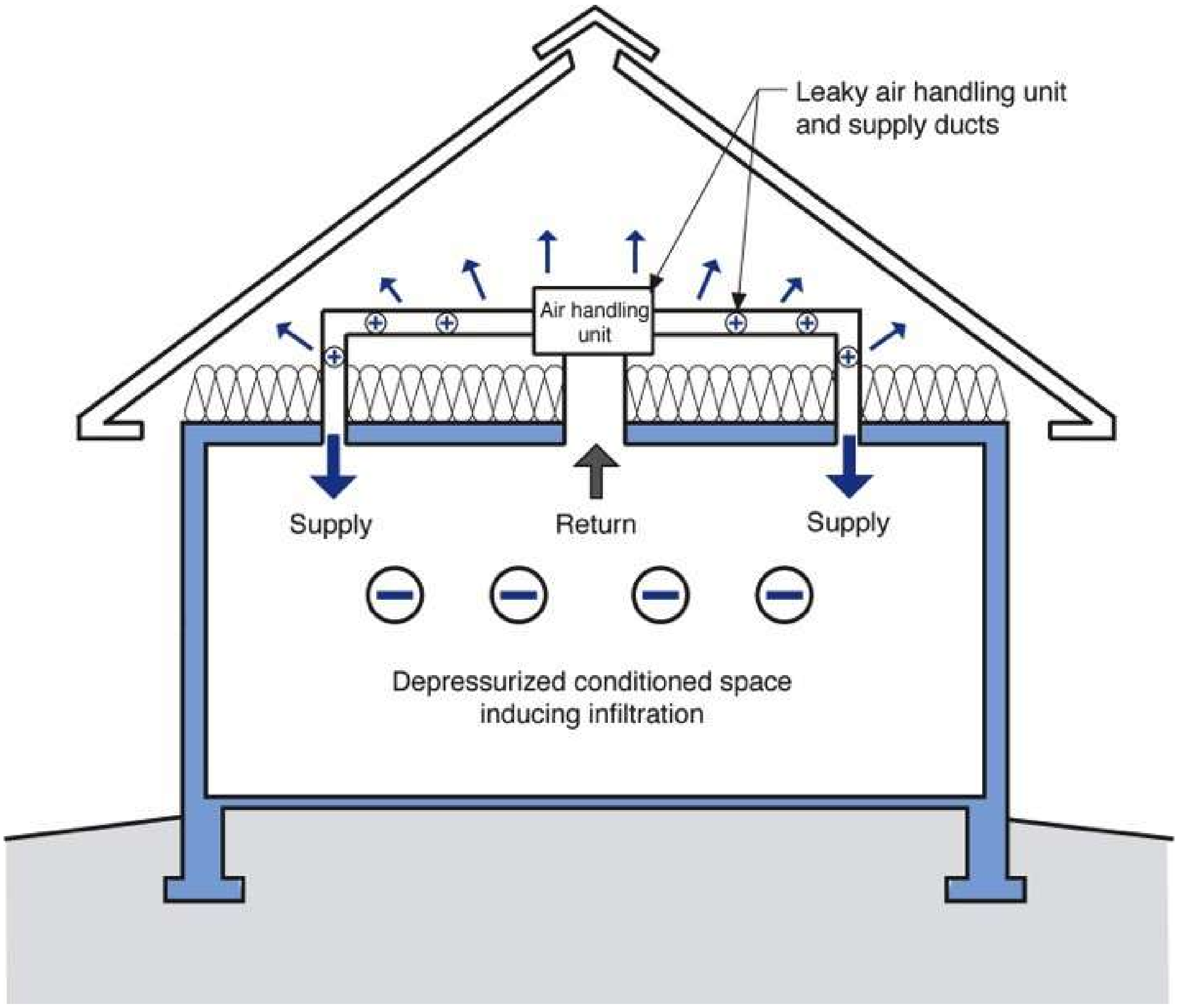
Crawl spaces must be completely connected to either the outside or the inside

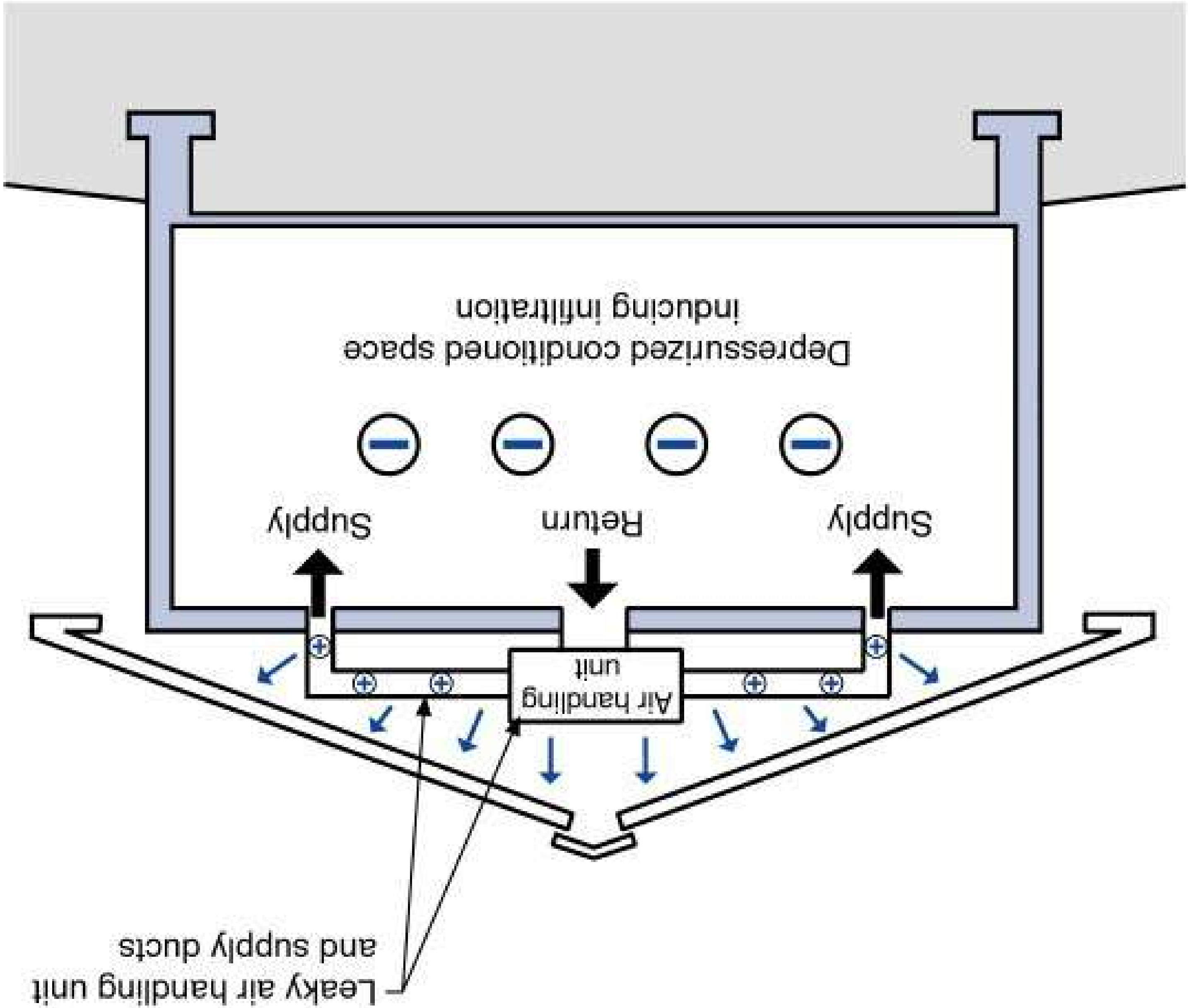
Crawl spaces must be completely connected to either the outside or the inside

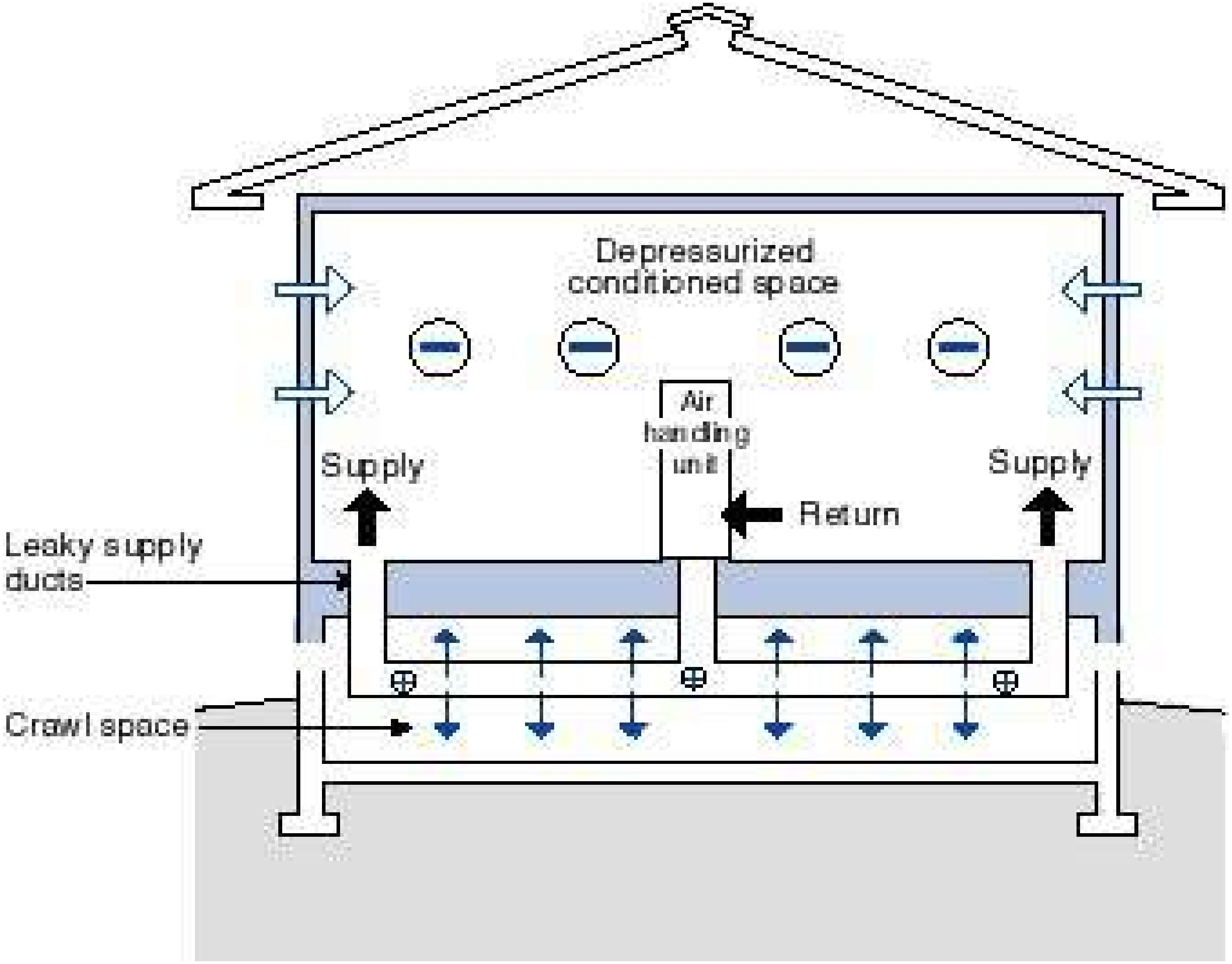
Vented crawl spaces work

Unvented conditioned crawl spaces work

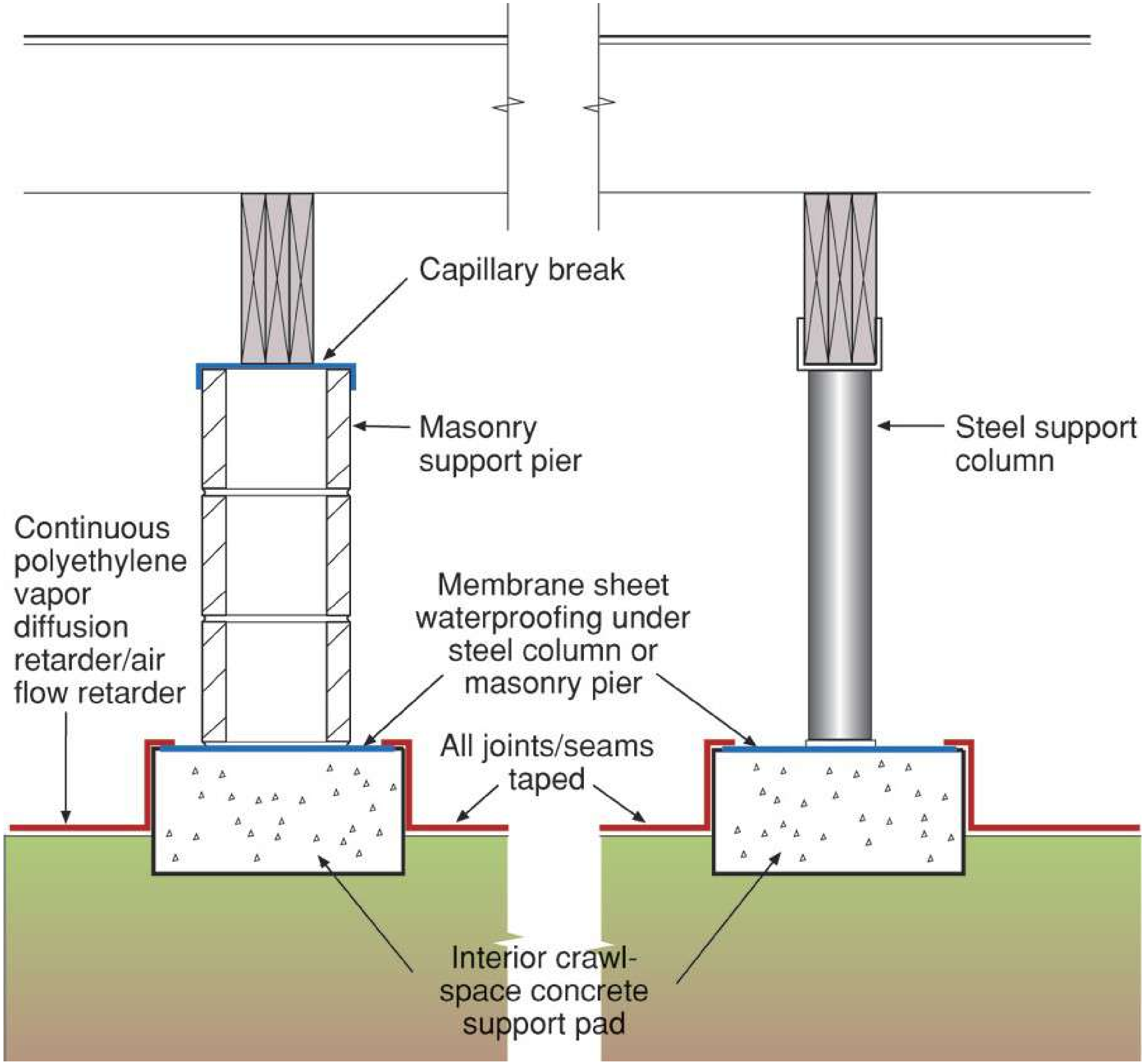
Don’t Do Stupid Things


Leaky air handling unit
and supply ducts
Air handling
unit
Supply
Return
Supply
Depressurized conditioned space
inducing infiltration


Depressurized conditioned space
inducing infiltration
Supply
Return
Supply
Air handling
unit
Leaky air handling unit
and supply ducts


Depressurized
conditioned space
Air
handling
unit
Supply
Supply
Return
Leaky supply
ducts
Crawl space

Smart Thing


Capillary break
Masonry support pier
Steel support column
Continuous polyethylene vapor diffusion retarder/air flow retarder
Membrane sheet waterproofing under steel column or masonry pier
All joints/seams taped
Interior crawl-space concrete support pad

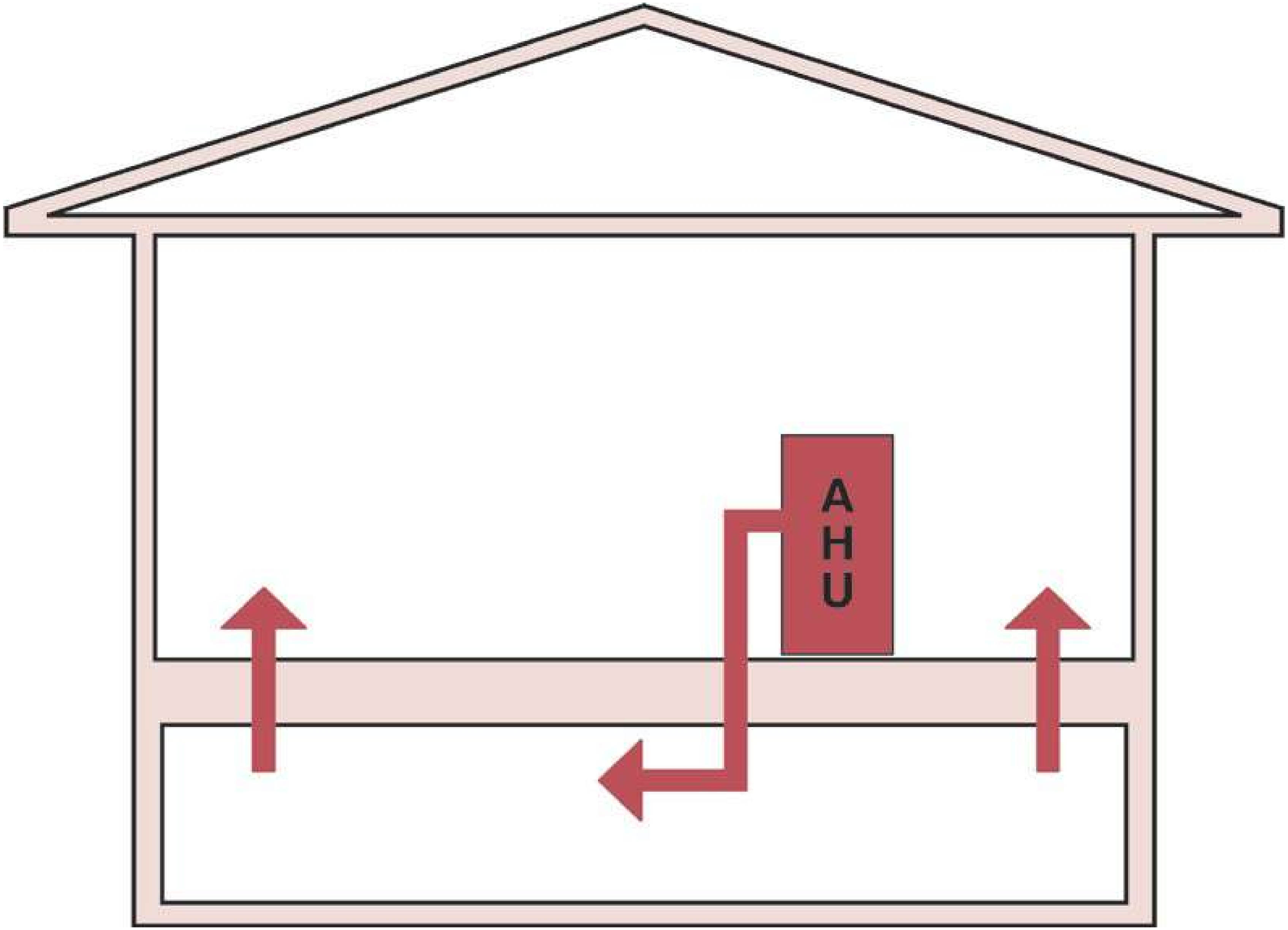
Conditioned Crawlspaces Not Unvented Crawlspaces

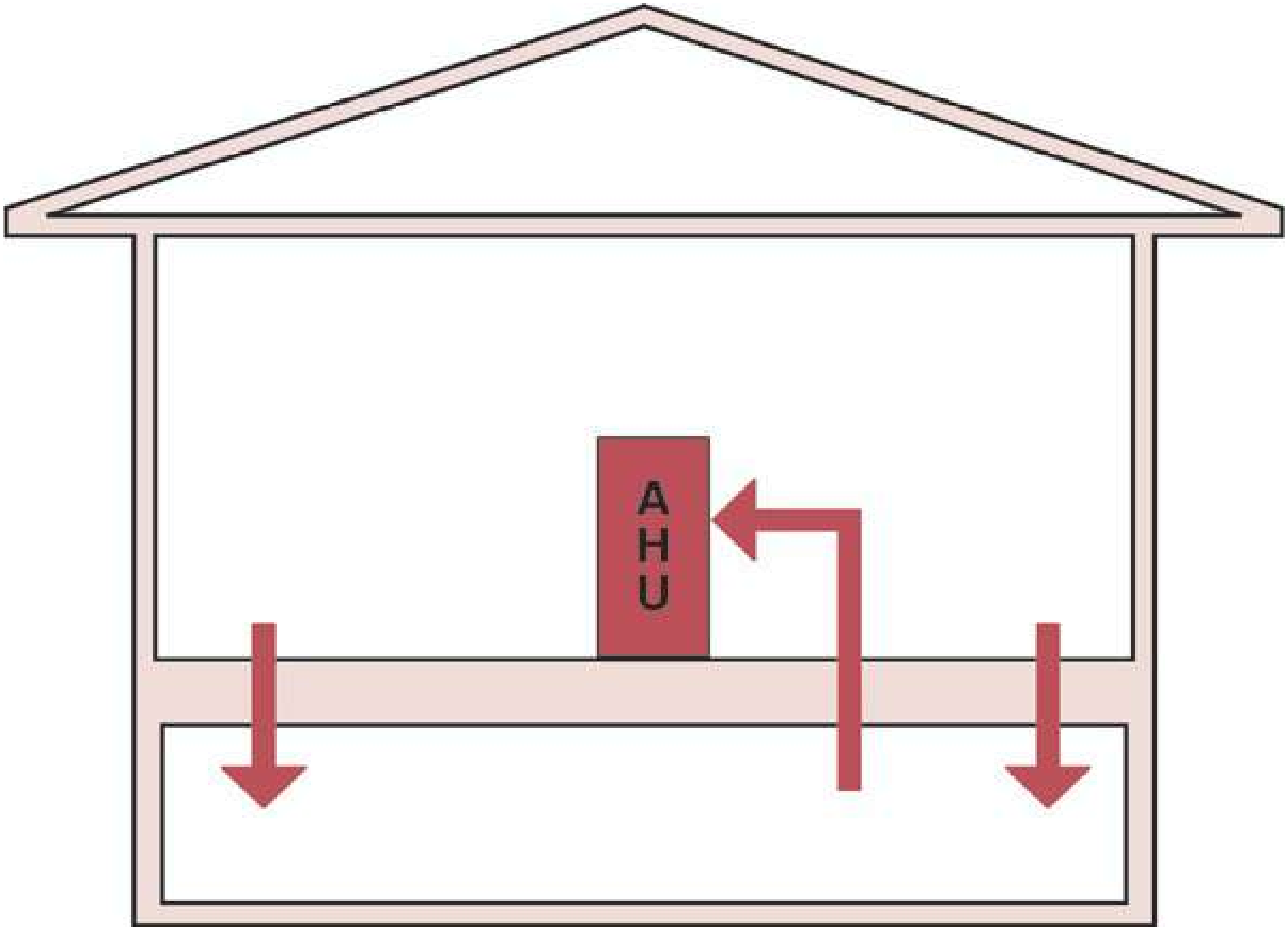
Need Supply Air

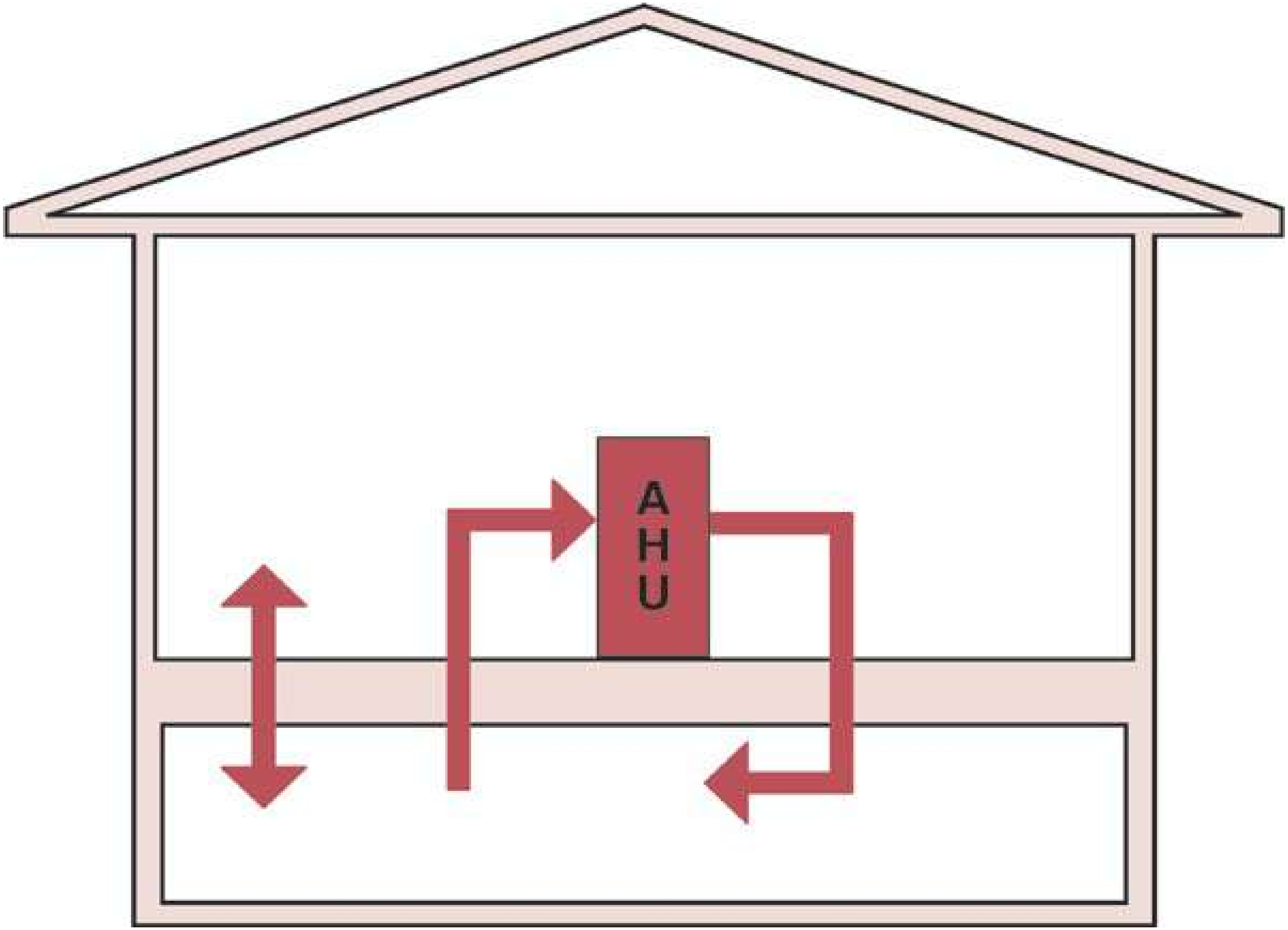
50 cfm/1000 ft2 of Crawlspace Area

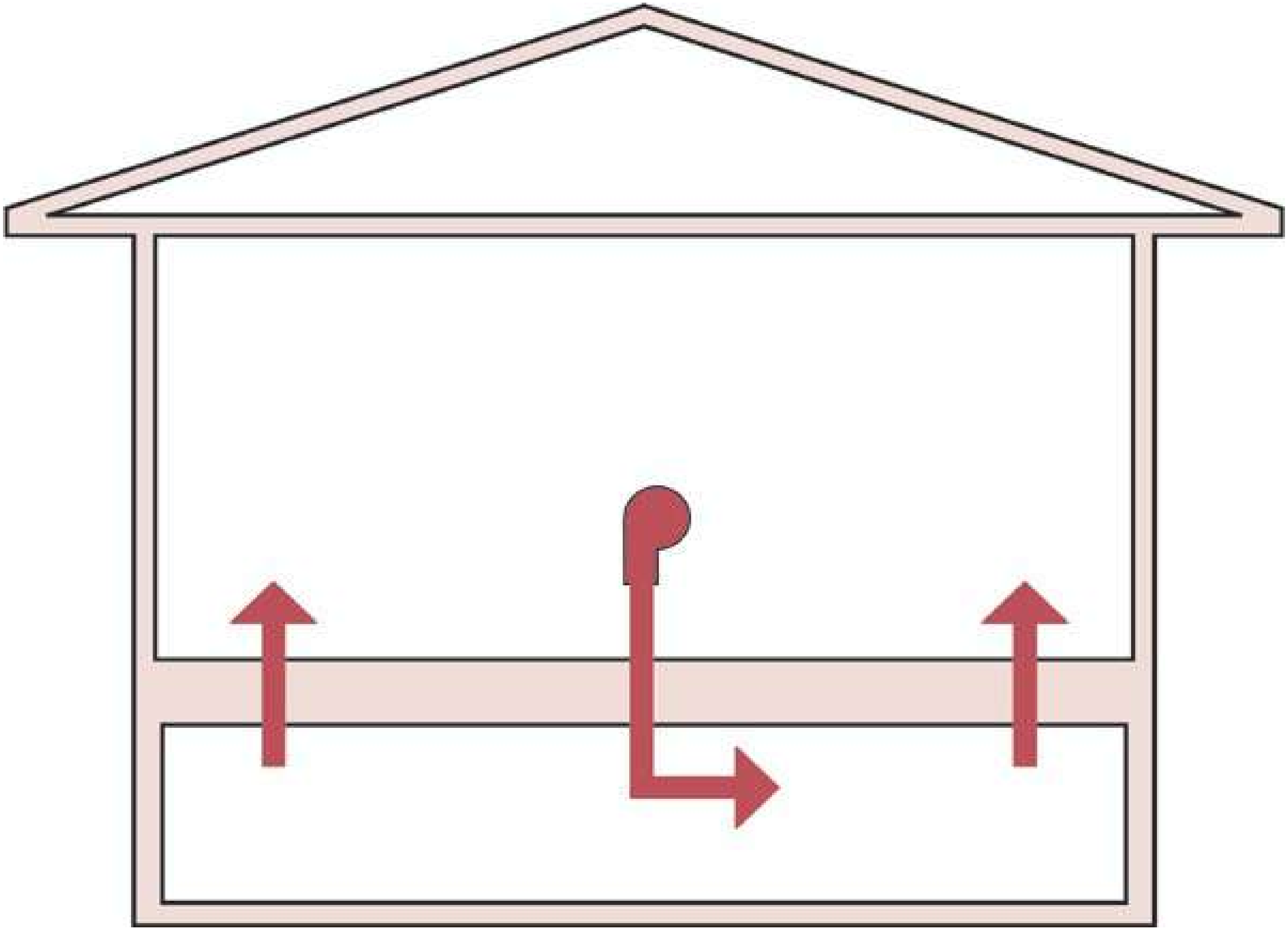
Or

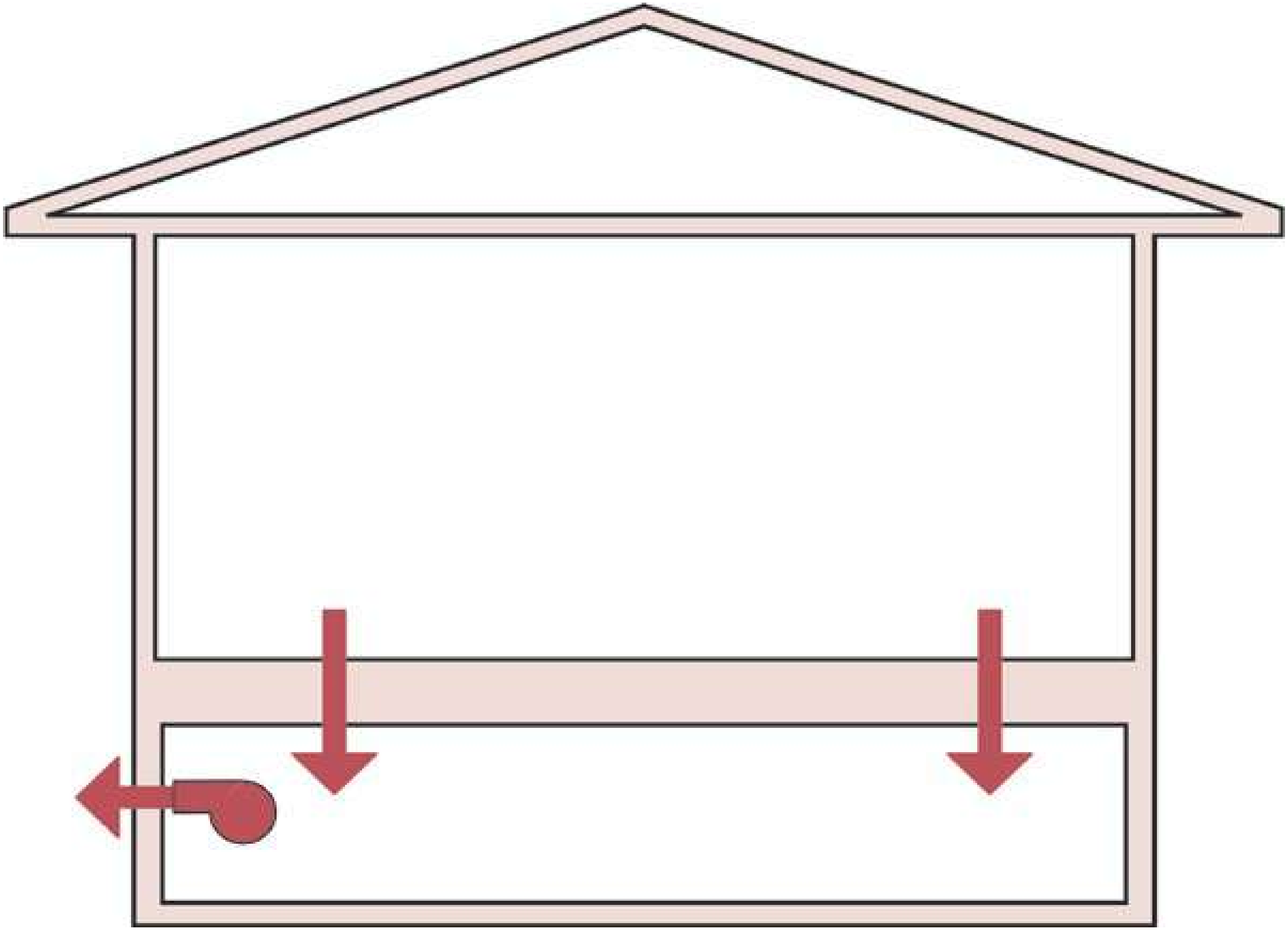
Dehumidification

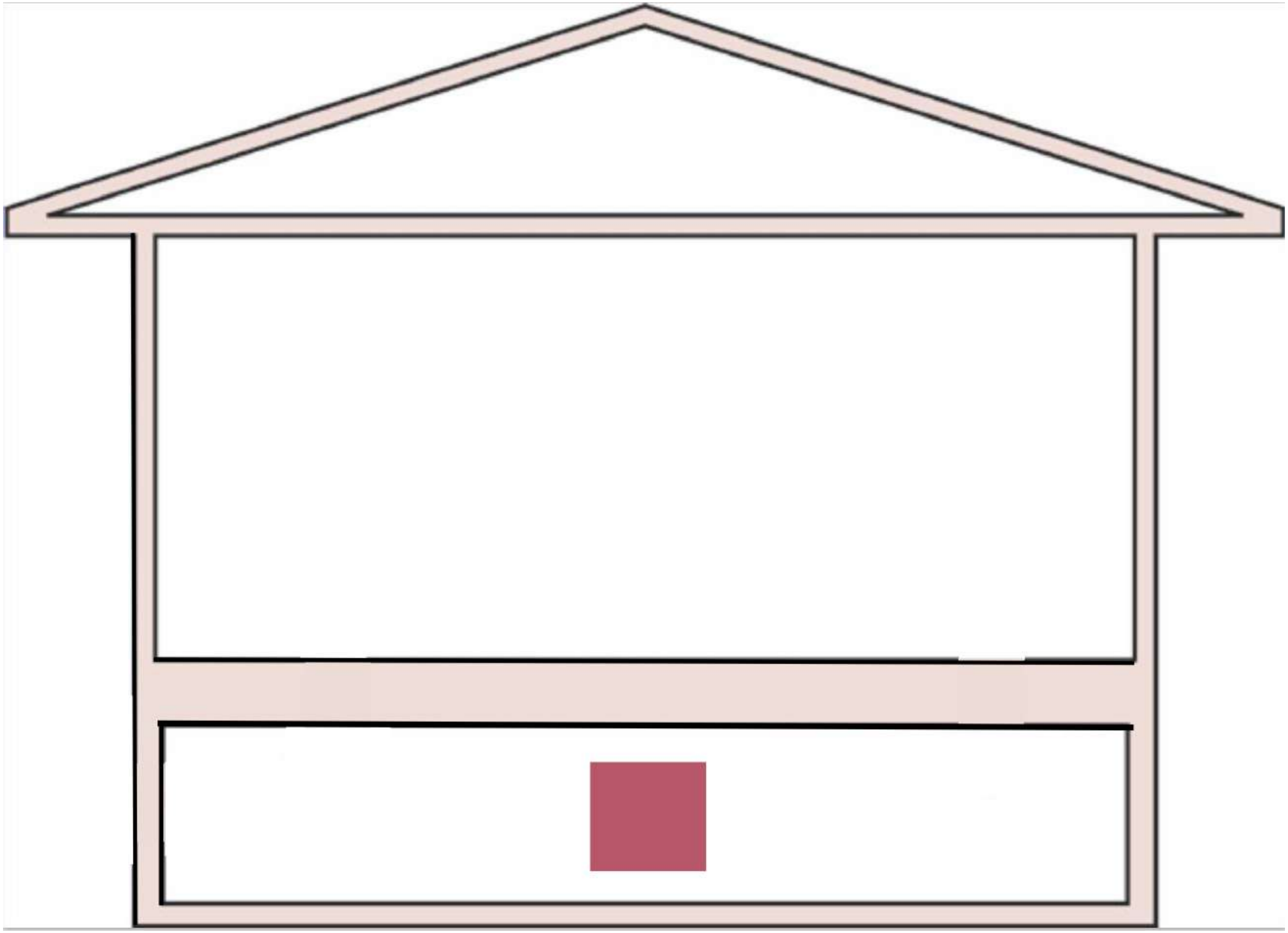

AHU

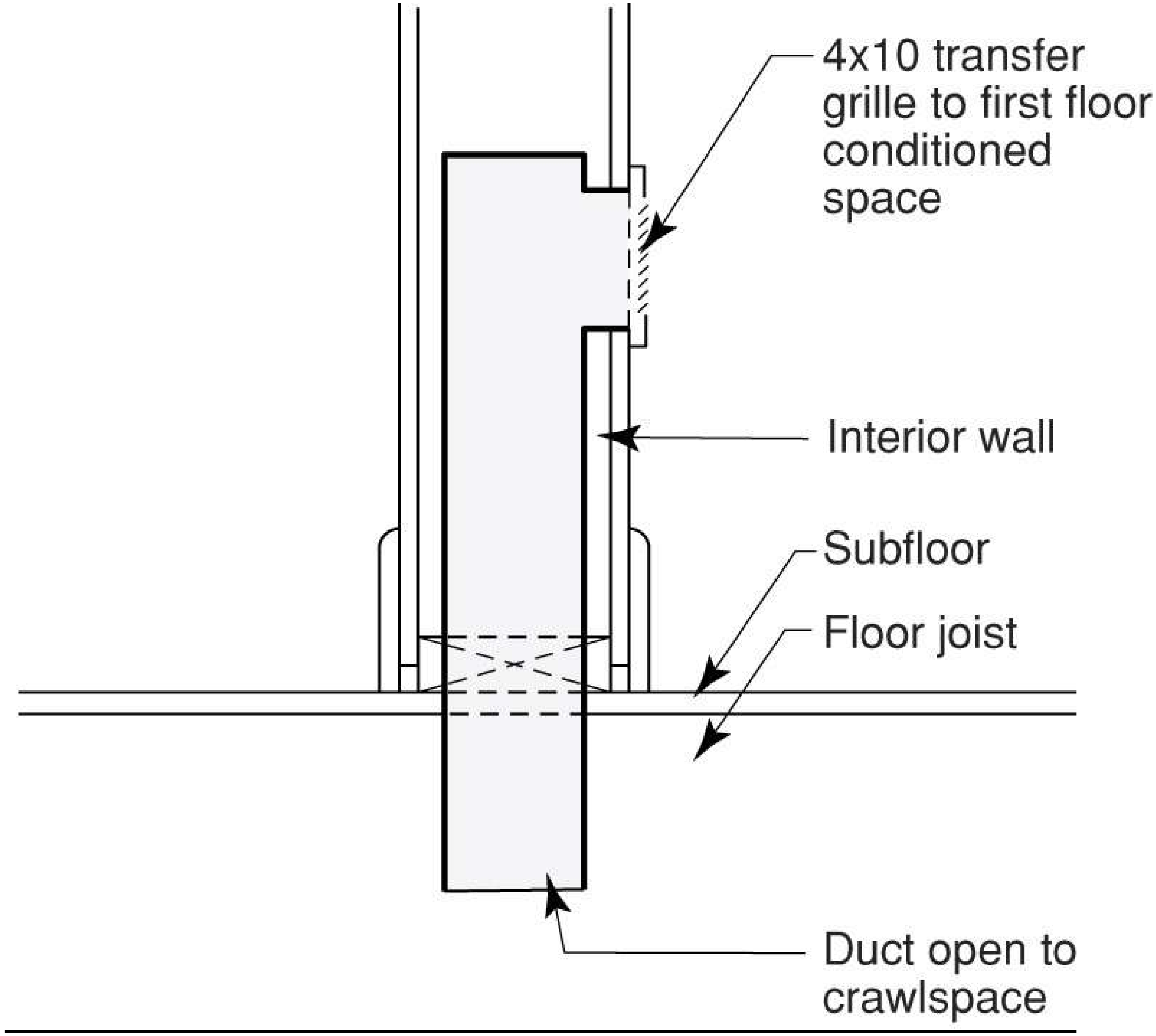

AHU


AHU

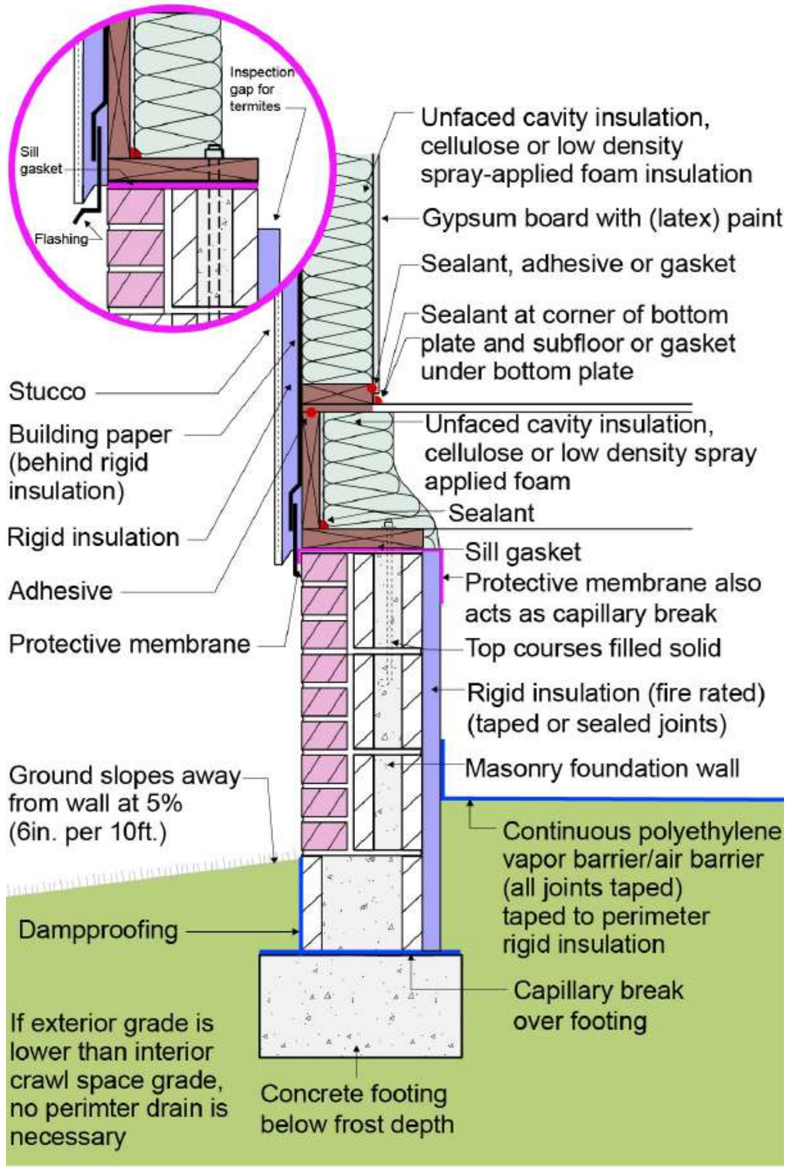




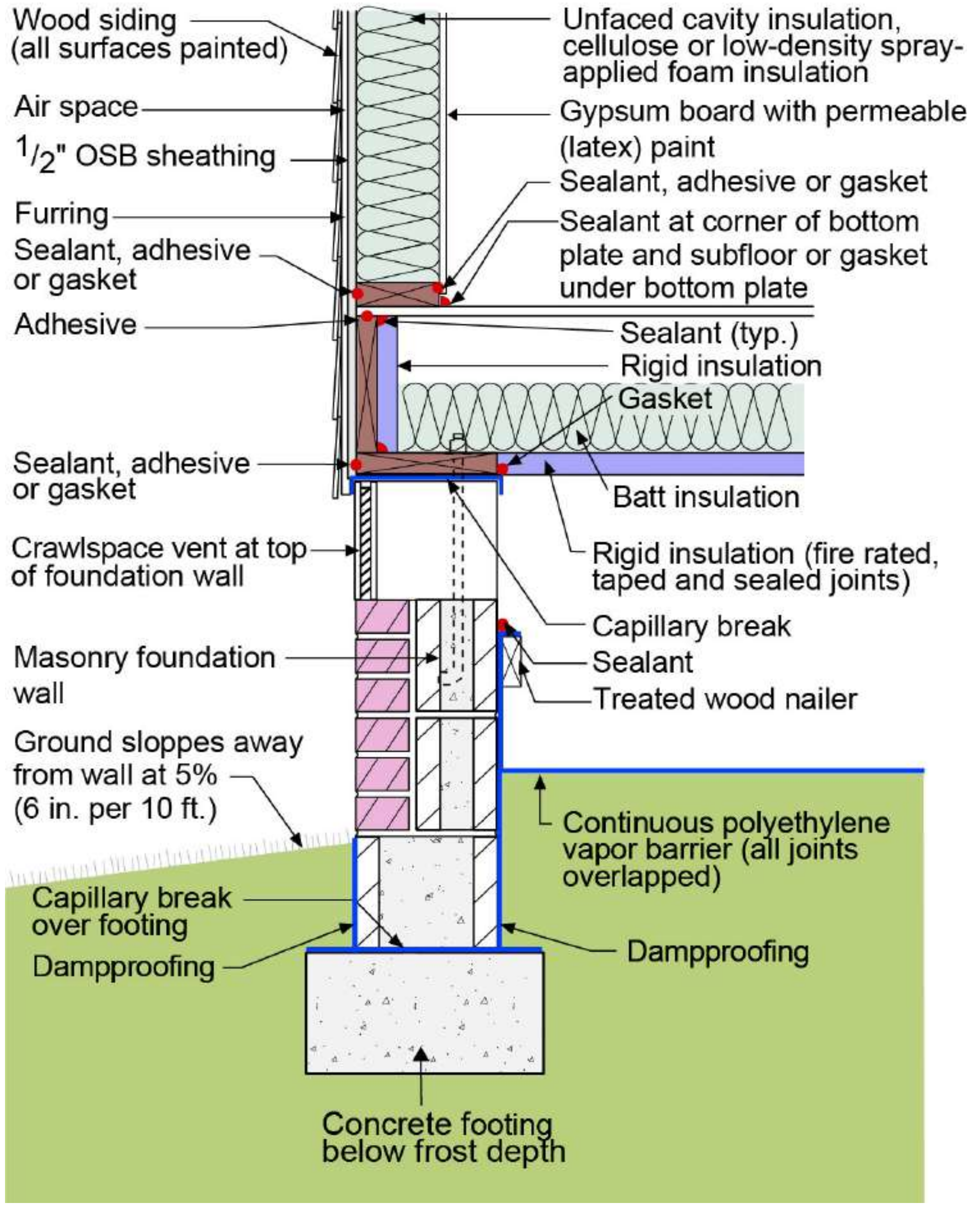



4x10 transfer grille to first floor conditioned space
Interior wall
Subfloor
Floor joist
Duct open to crawlspace

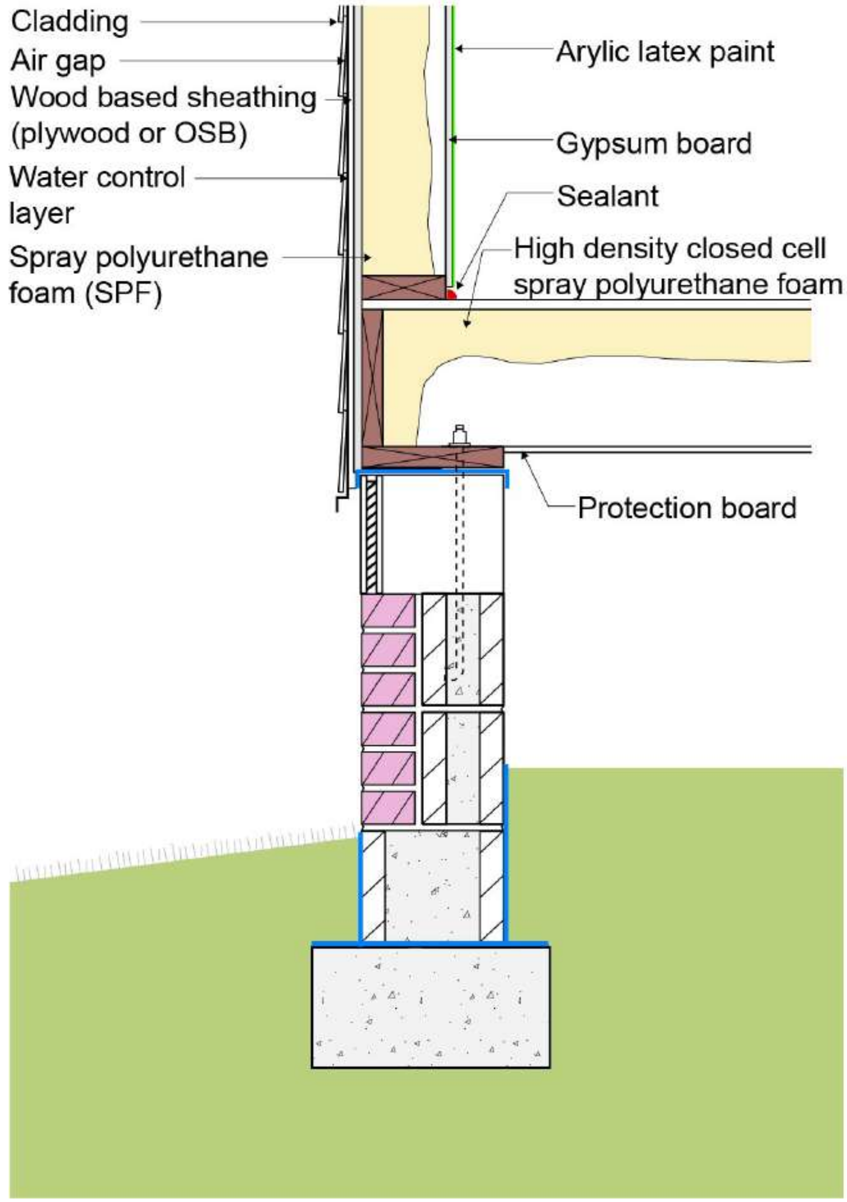
Alternative Detail

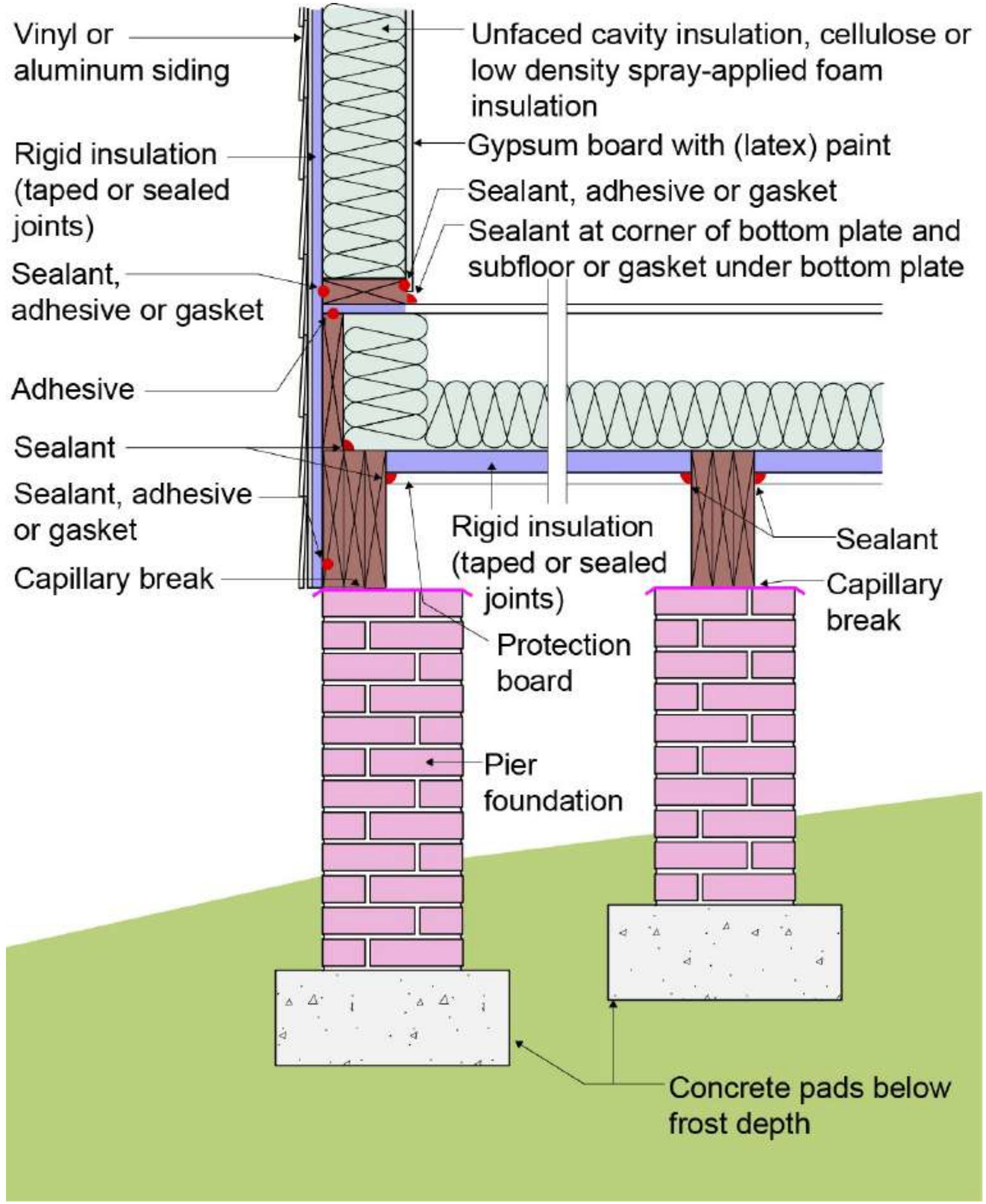


Smart Thing



Wood siding (all surfaces painted)
Air space
1/2" OSB sheathing
Furring
Sealant, adhesive or gasket
Adhesive
Sealant, adhesive or gasket
Crawlspace vent at top of foundation wall
Masonry foundation wall
Ground sloppes away from wall at 5% (6 in. per 10 ft.)
Capillary break over footing
Dampproofing
Unfaced cavity insulation, cellulose or low-density spray-applied foam insulation
Gypsum board with permeable (latex) paint
Sealant, adhesive or gasket
Sealant at corner of bottom plate and subfloor or gasket under bottom plate
Sealant (typ.)
Rigid insulation
Gasket
Batt insulation
Rigid insulation (fire rated, taped and sealed joints)
Capillary break
Sealant
Treated wood nailer
Continuous polyethylene vapor barrier (all joints overlapped)
Dampproofing
Concrete footing below frost depth


Cladding
Air gap
Wood based sheathing (plywood or OSB)
Water control layer
Spray polyurethane foam (SPF)
Arylic latex paint
Gypsum board
Sealant
High density closed cell spray polyurethane foam
Protection board


Vinyl or aluminum siding
Unfaced cavity insulation, cellulose or low density spray-applied foam insulation
Gypsum board with (latex) paint
Rigid insulation (taped or sealed joints)
Sealant, adhesive or gasket
Sealant at corner of bottom plate and subfloor or gasket under bottom plate
Sealant, adhesive or gasket
Adhesive
Sealant
Sealant, adhesive or gasket
Rigid insulation (taped or sealed joints)
Sealant
Capillary break
Capillary break
Protection board
Pier foundation
Concrete pads below frost depth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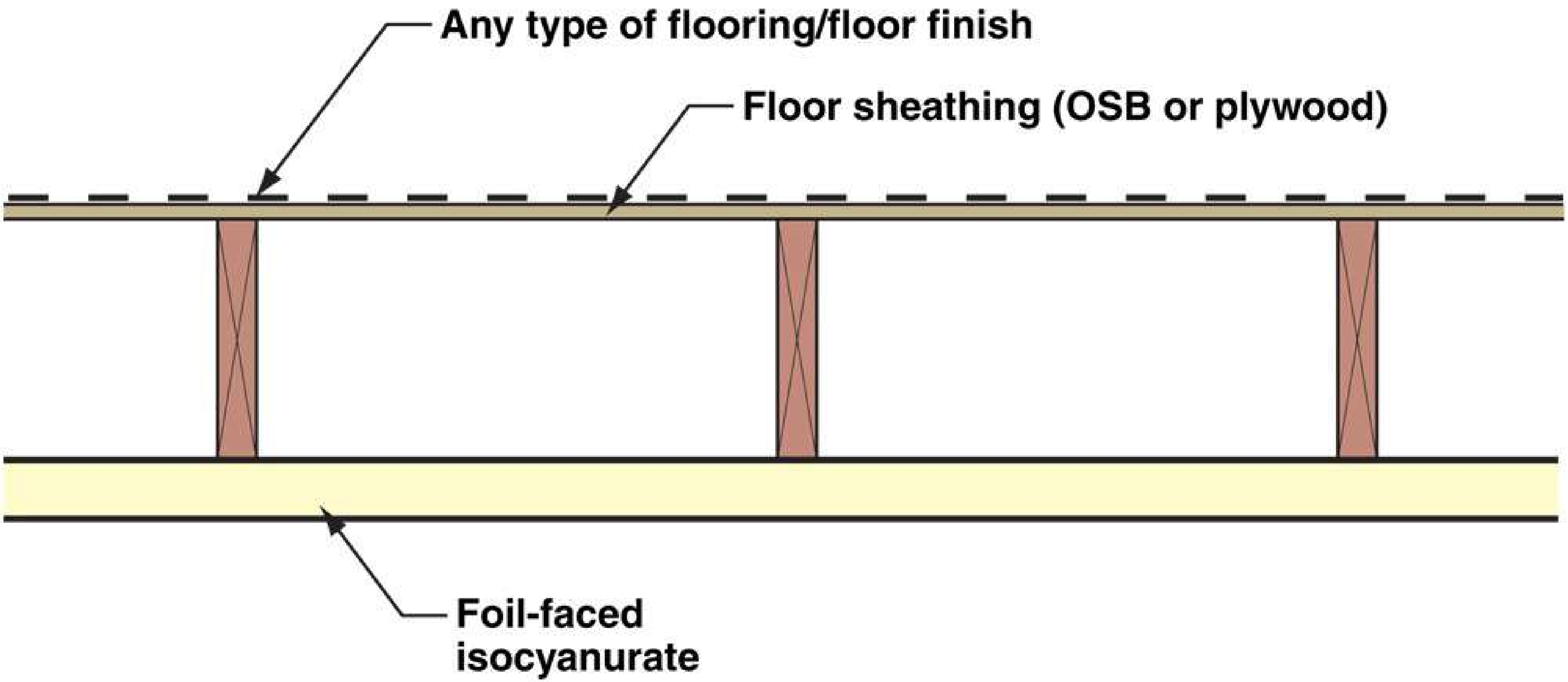
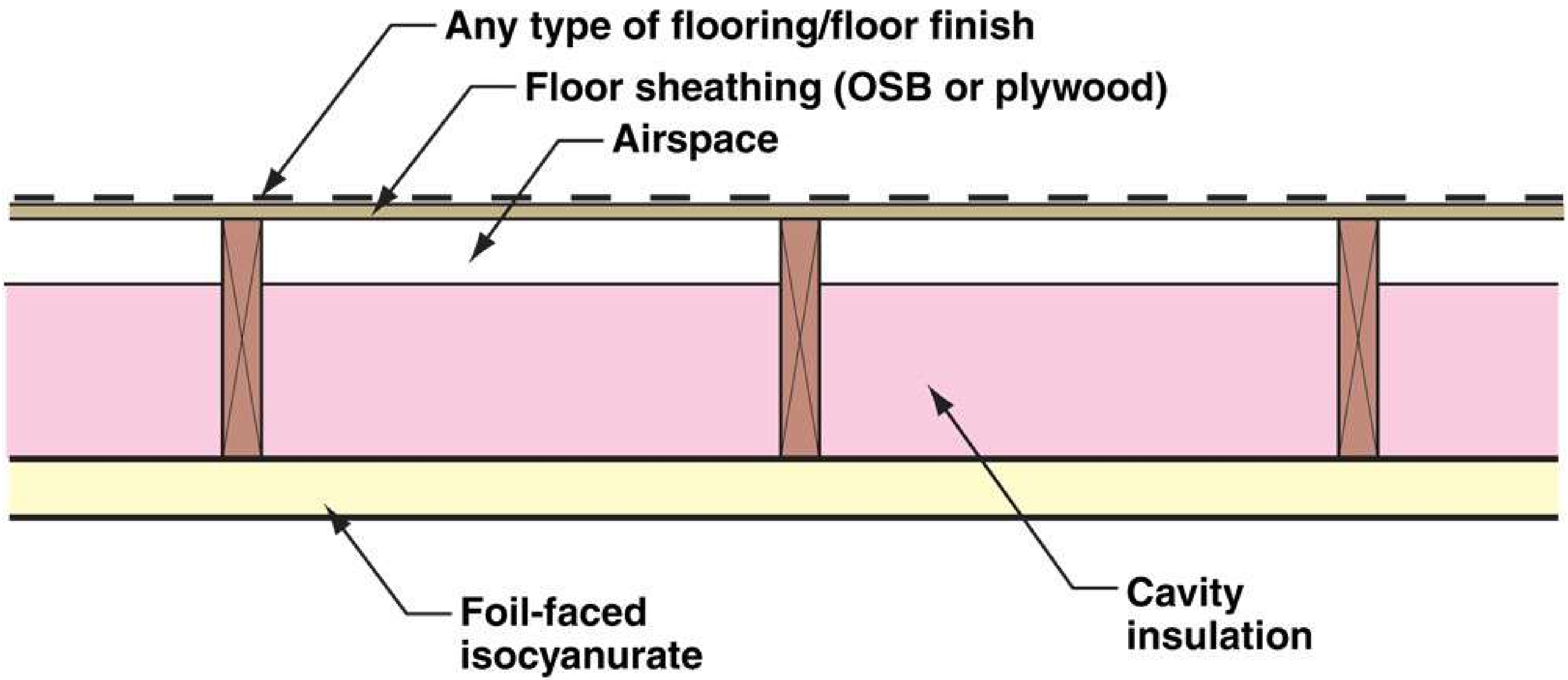
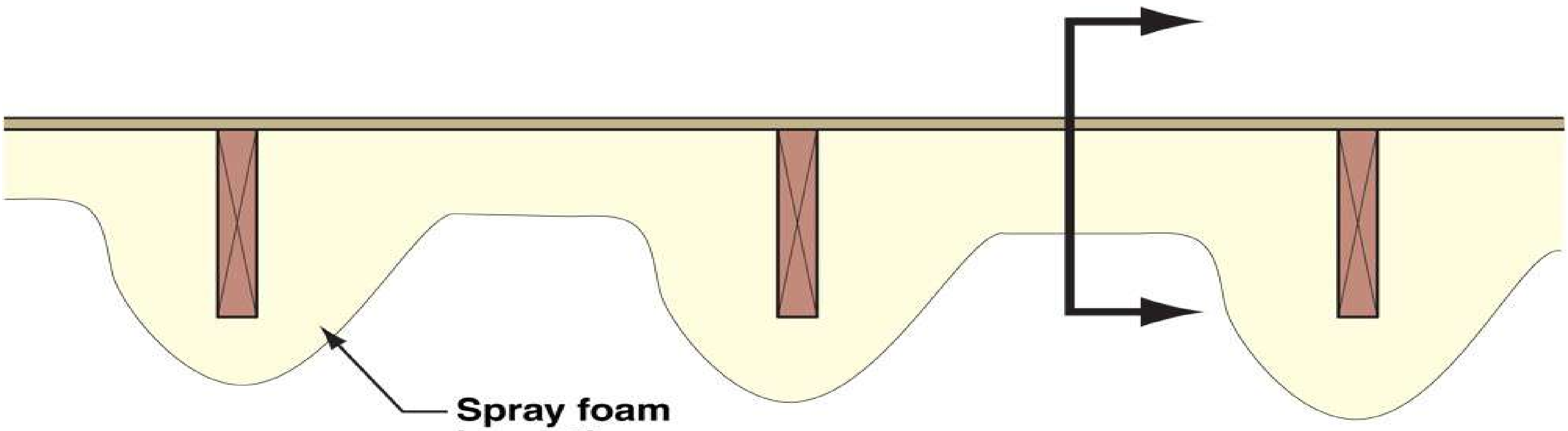
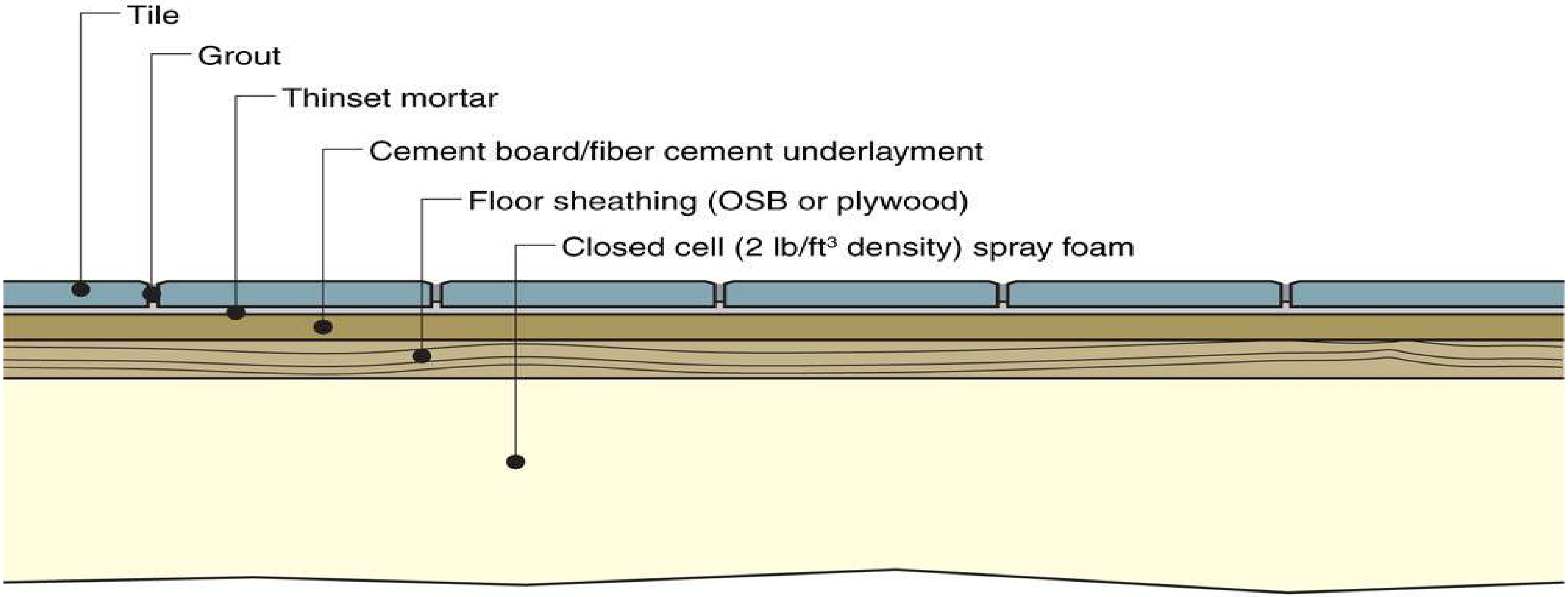
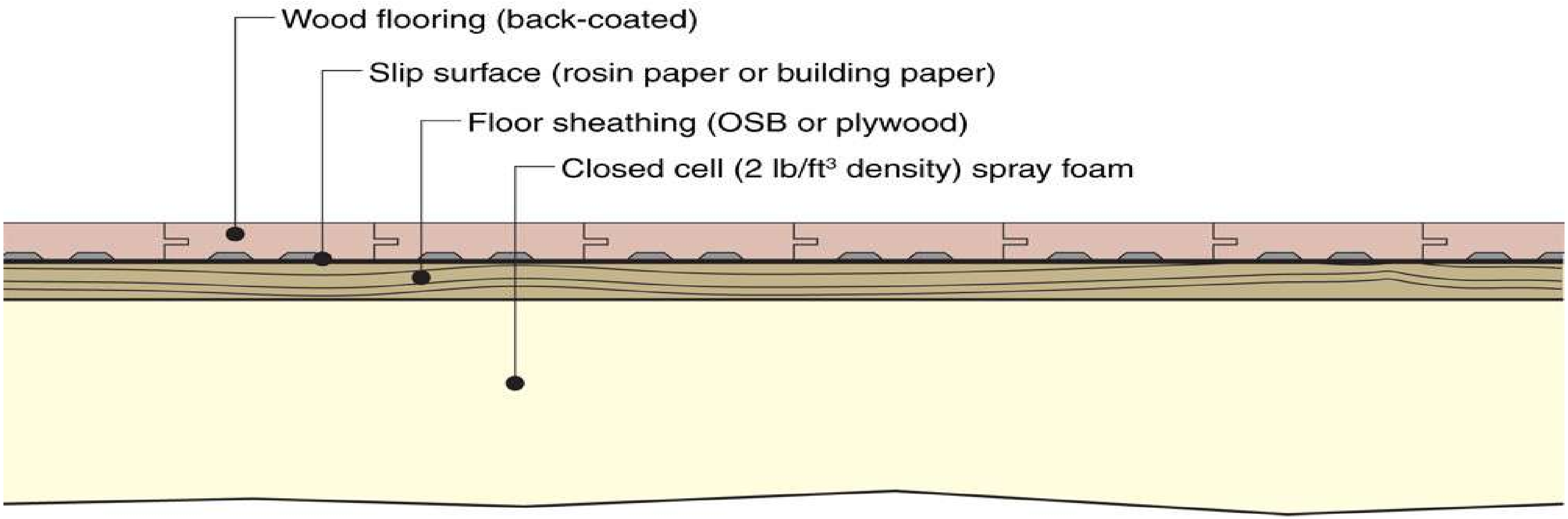
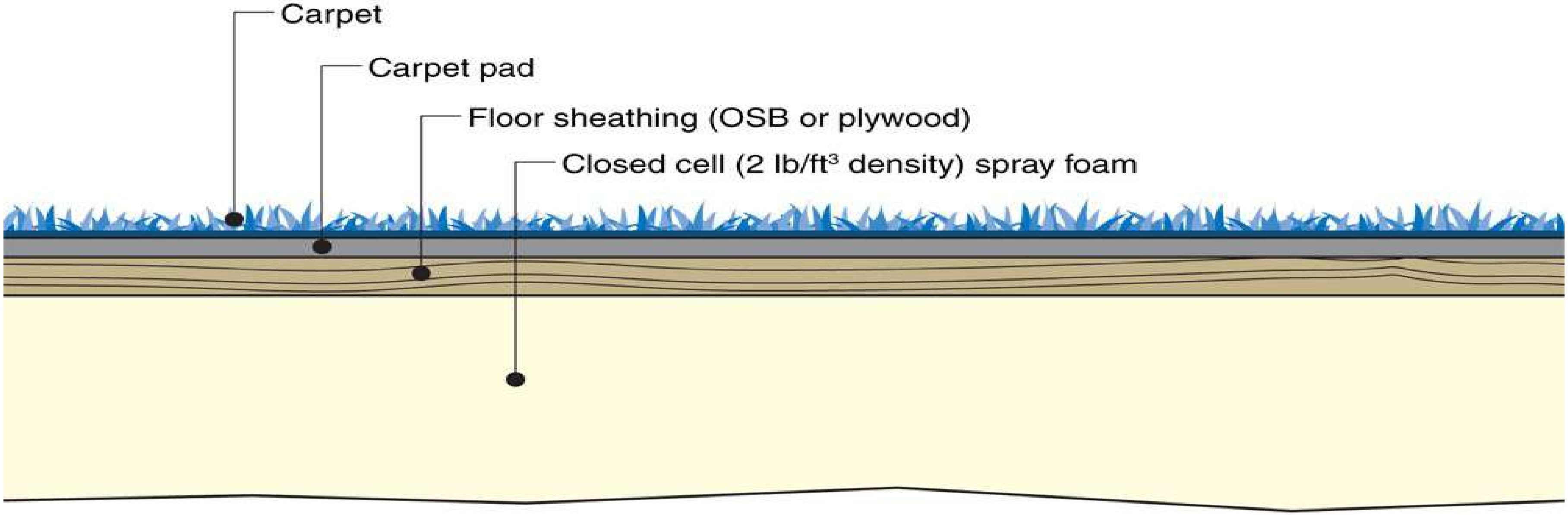

Any type of flooring/floor finish
Floor sheathing (OSB or plywood)
Foil-faced
isocyanurate

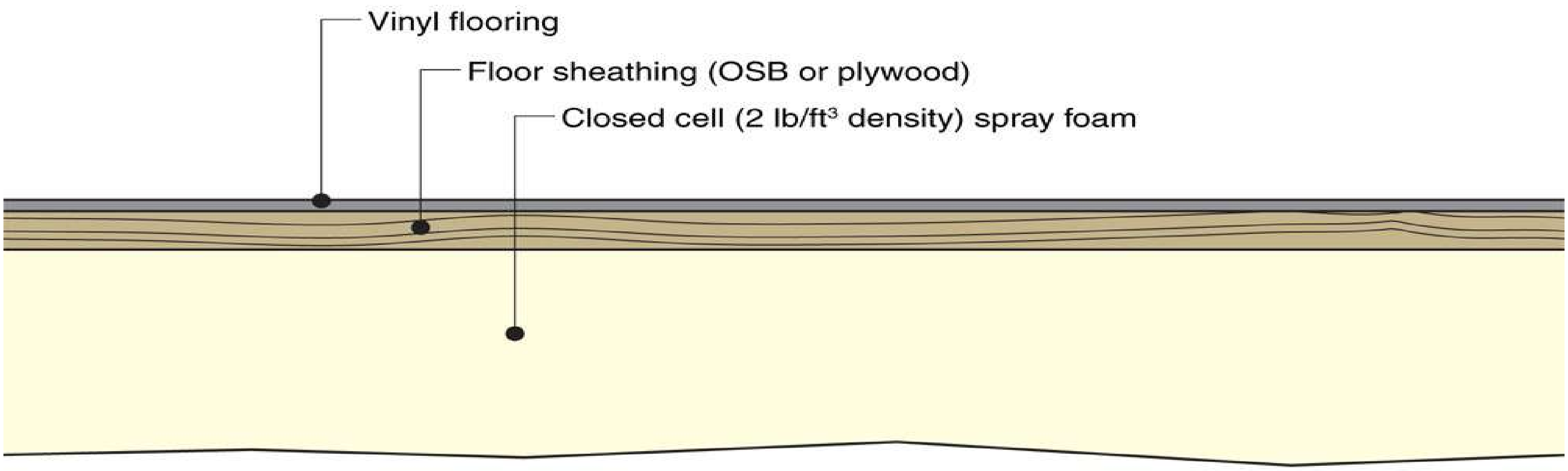

Any type of flooring/floor finish
Floor sheathing (OSB or plywood)
Airspace
Foil-faced isocyanurate
Cavity insulation

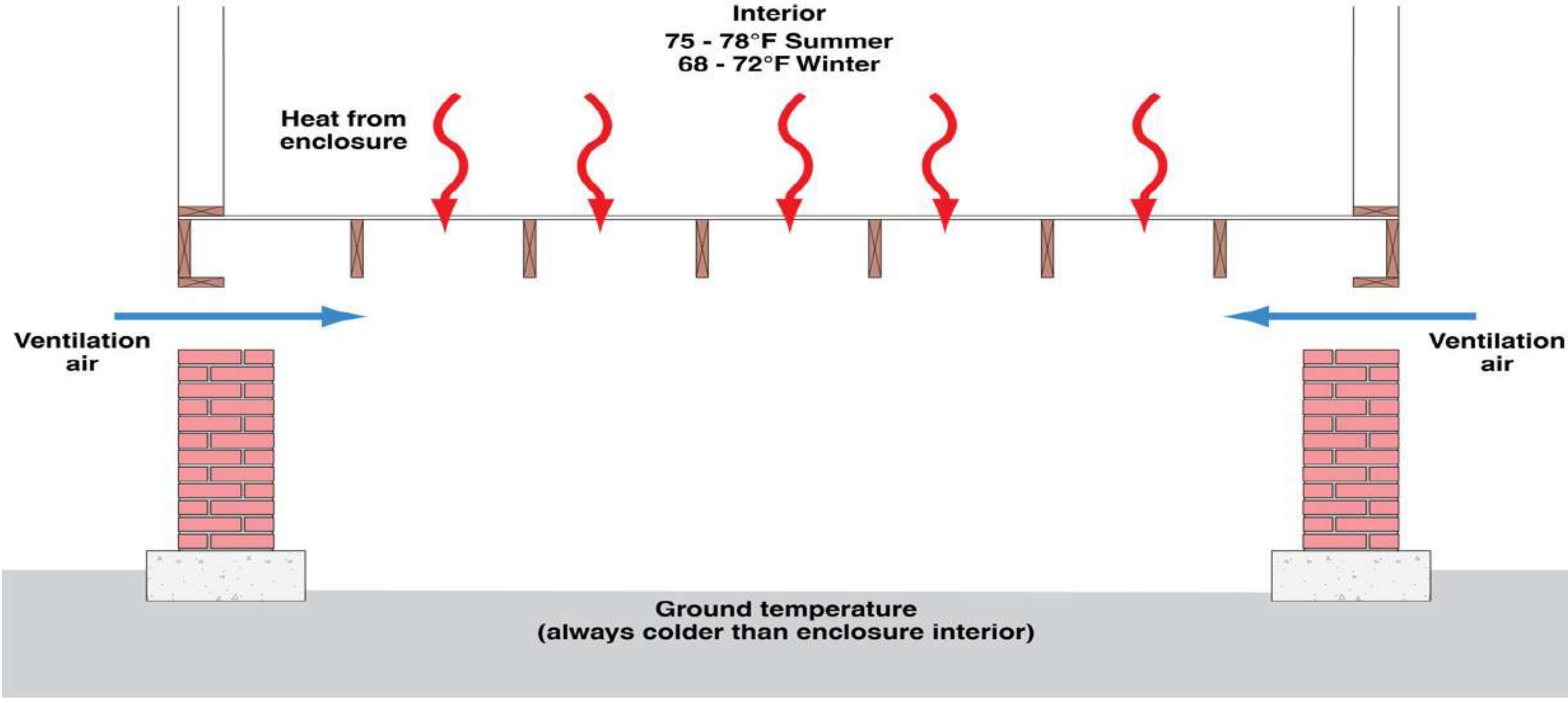

Spray foam
insulation

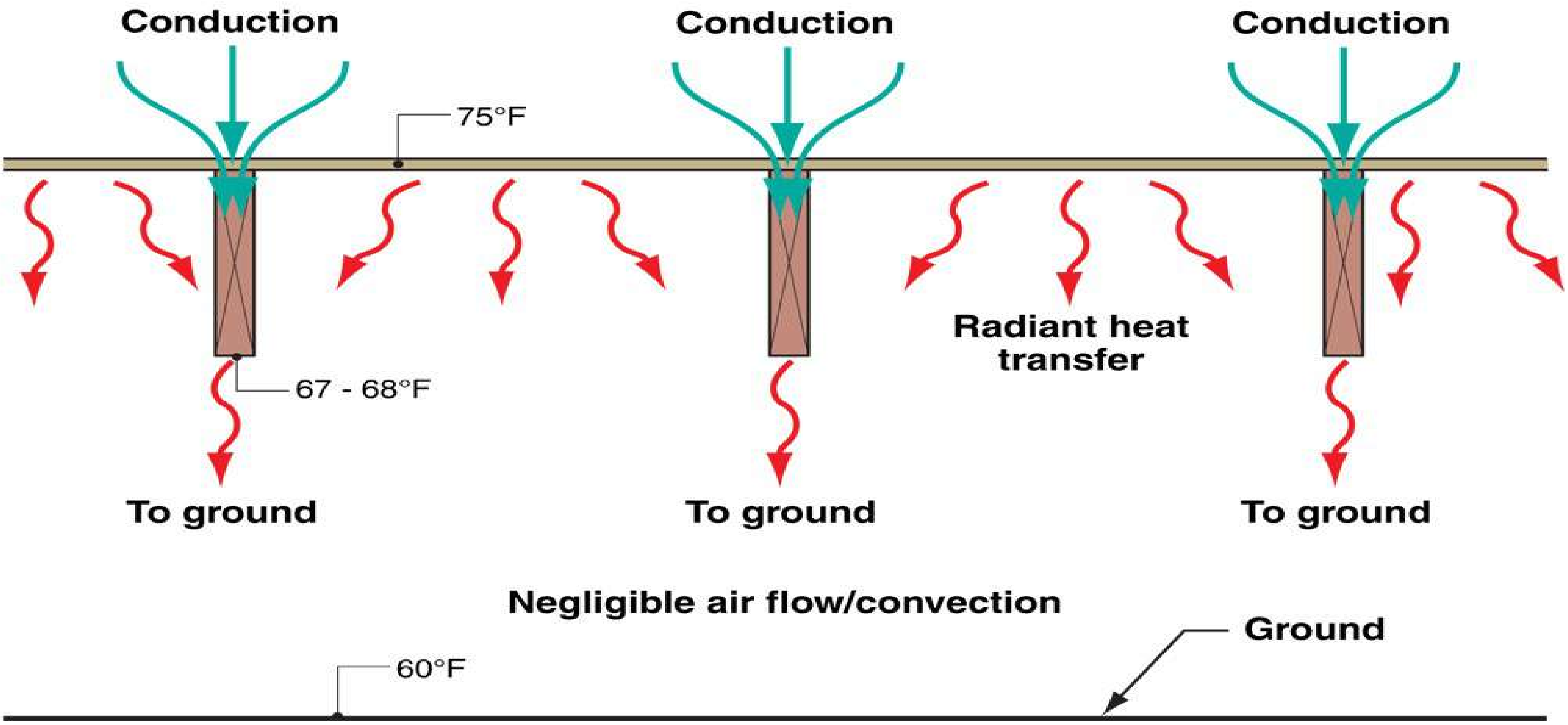

Tile
Grout
Thinset mortar
Cement board/fiber cement underlayment
Floor sheathing (OSB or plywood)
Closed cell (2 lb/ft³ density) spray foam

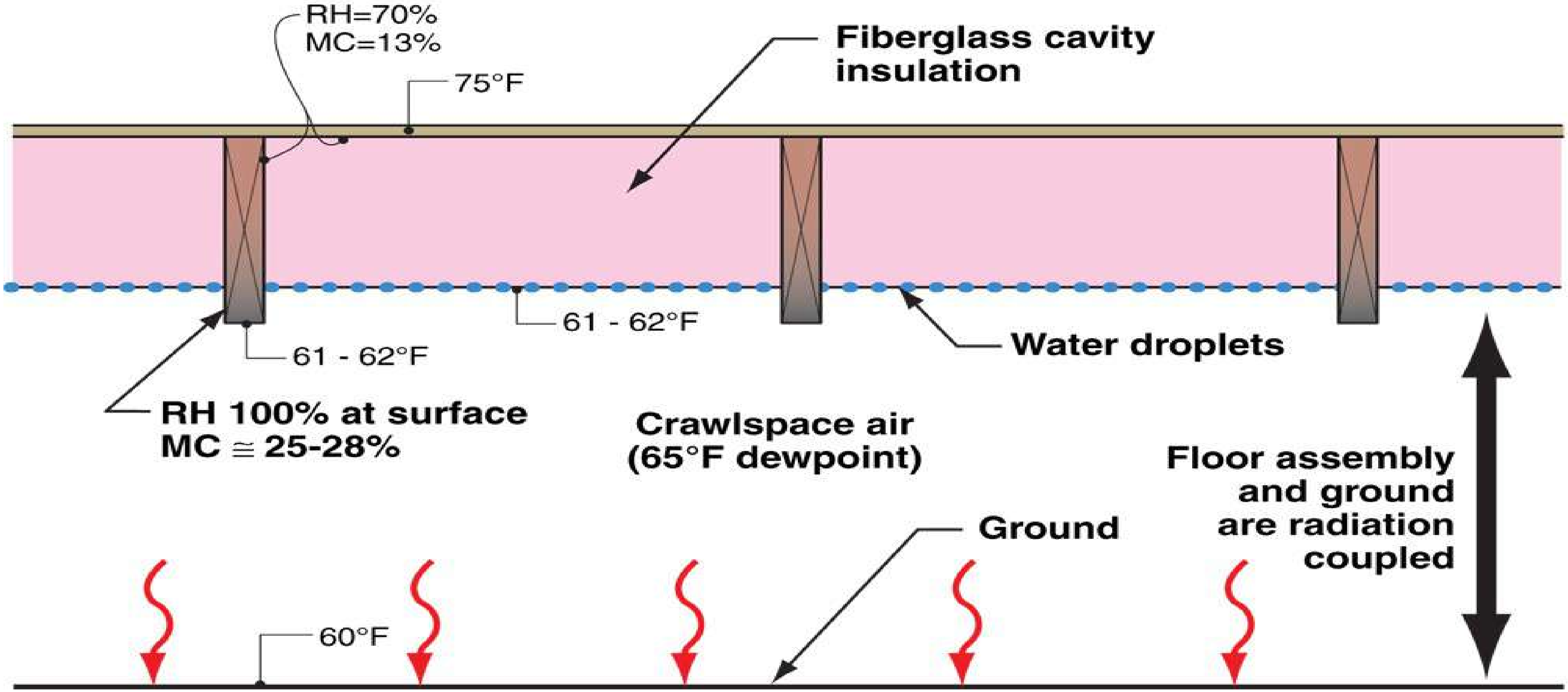

Wood flooring (back-coated)
Slip surface (rosin paper or building paper)
Floor sheathing (OSB or plywood)
Closed cell (2 lb/ft³ density) spray foam


Carpet
Carpet pad
Floor sheathing (OSB or plywood)
Closed cell (2 lb/ft³ density) spray foam

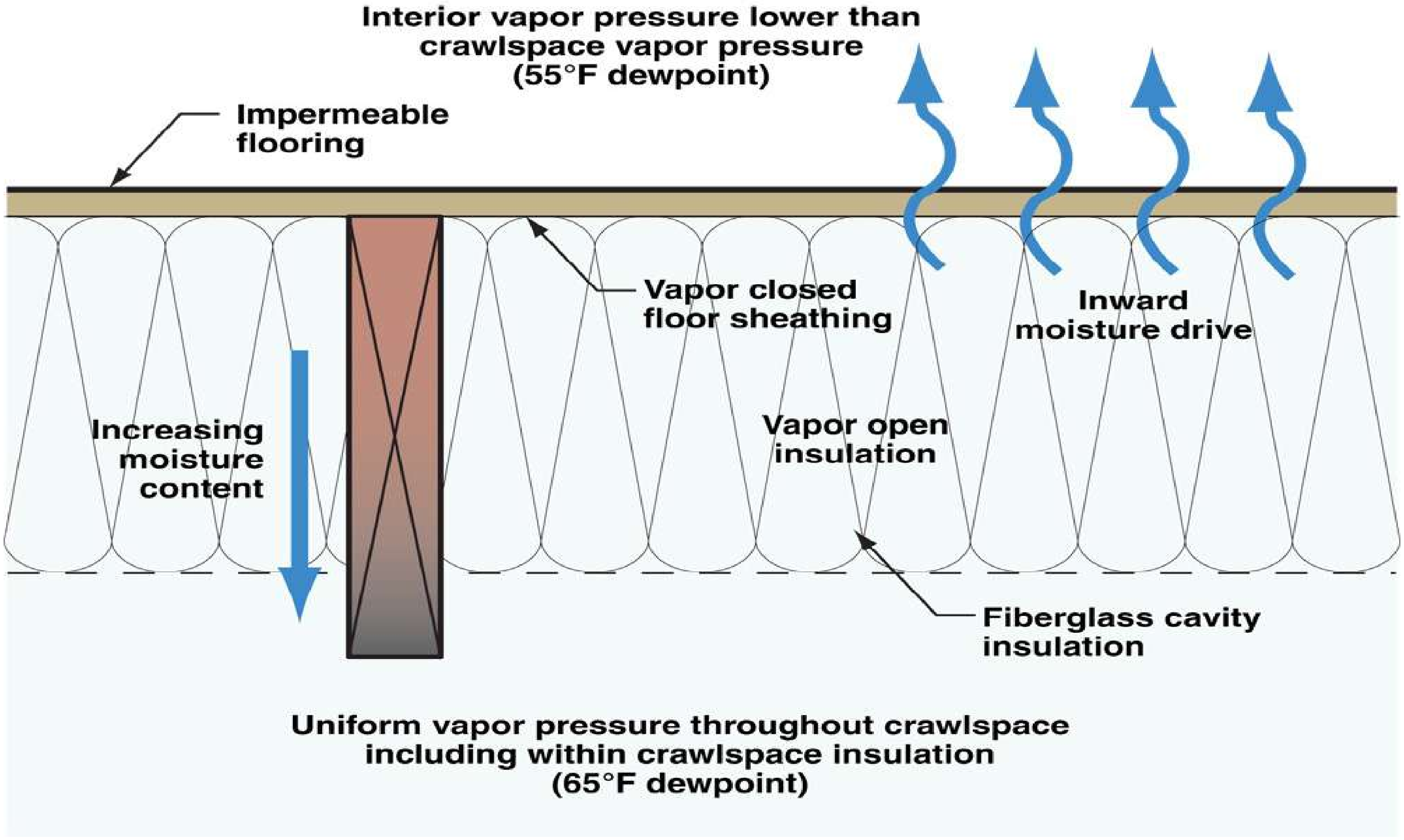

Vinyl flooring
Floor sheathing (OSB or plywood)
Closed cell (2 lb/ft³ density) spray foam

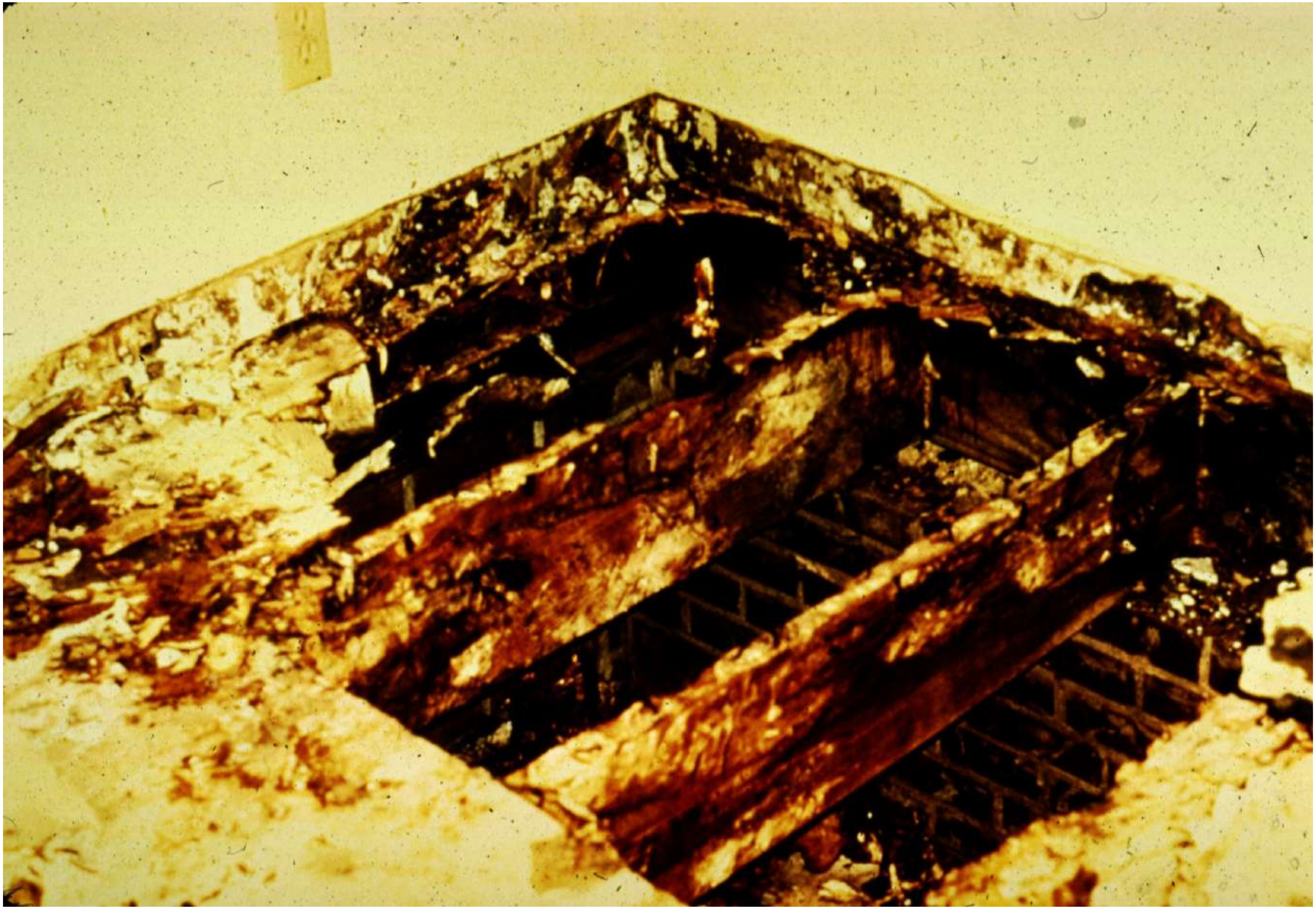

Interior
75 - 78°F Summer
68 - 72°F Winter
Heat from enclosure
Ventilation air
Ventilation air
Ground temperature
(always colder than enclosure interior)

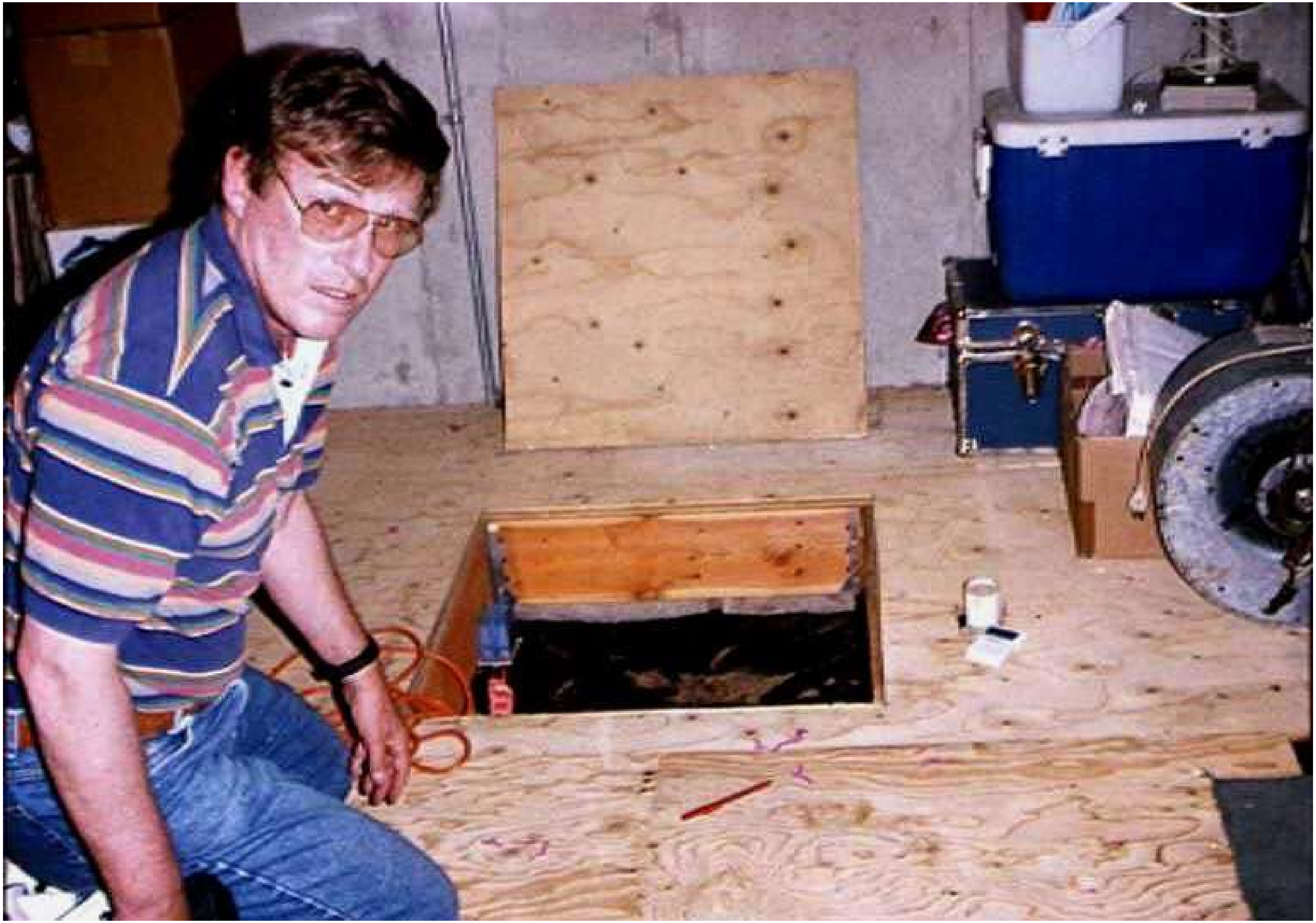

Conduction
Conduction
Conduction
75°F
Radiant heat transfer
67 - 68°F
To ground
To ground
To ground
Negligible air flow/convection
Ground
60°F



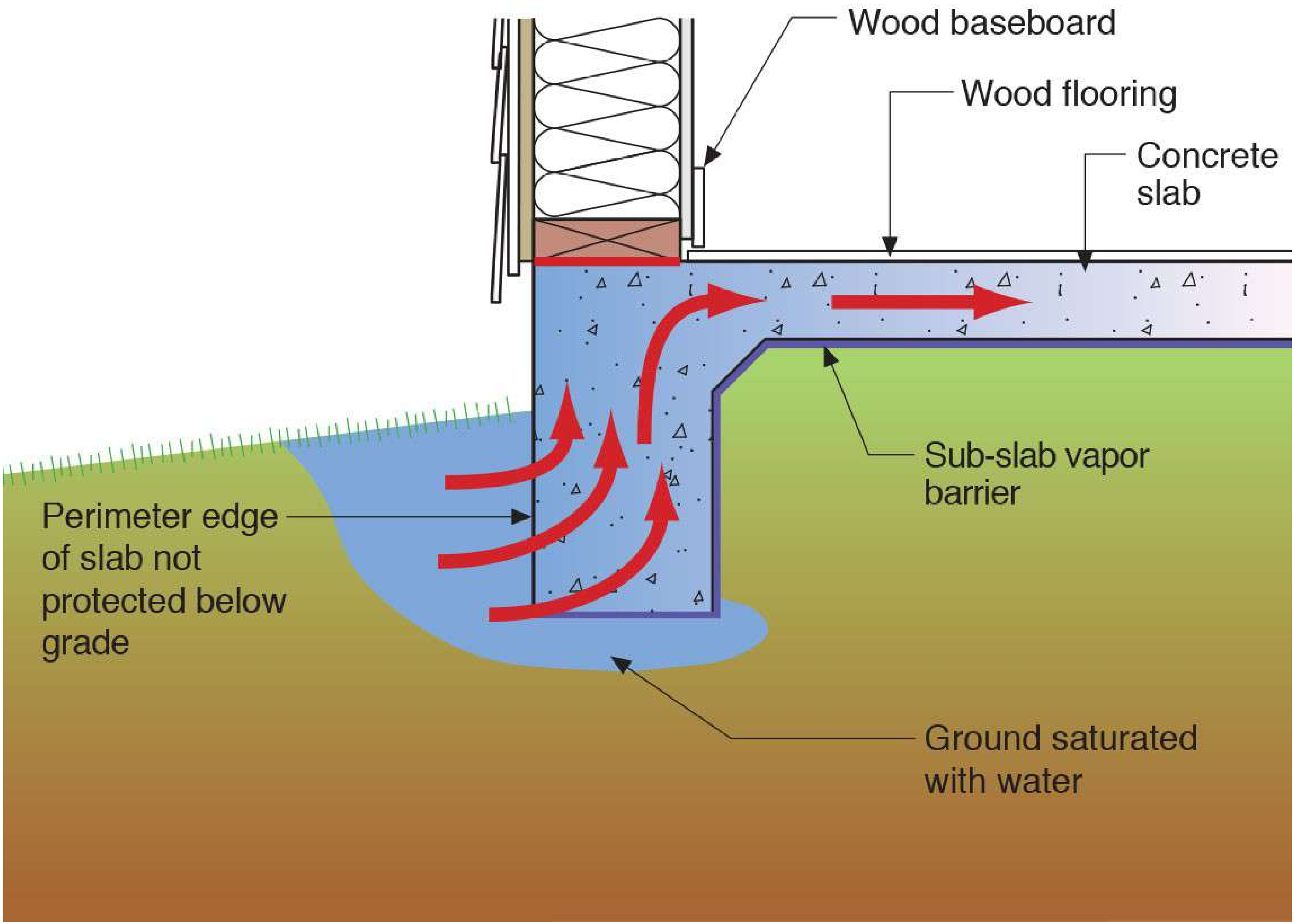
RH=70%
MC=13%
75°F
Fiberglass cavity insulation
61 - 62°F
61 - 62°F
Water droplets
RH 100% at surface
MC ≅ 25-28%
Crawlspace air (65°F dewpoint)
Floor assembly and ground are radiation coupled
Ground
60°F


Interior vapor pressure lower than crawlspace vapor pressure (55°F dewpoint)
Impermeable flooring
Vapor closed floor sheathing
Inward moisture drive
Increasing moisture content
Vapor open insulation
Fiberglass cavity insulation
Uniform vapor pressure throughout crawlspace including within crawlspace insulation (65°F dewpoint)



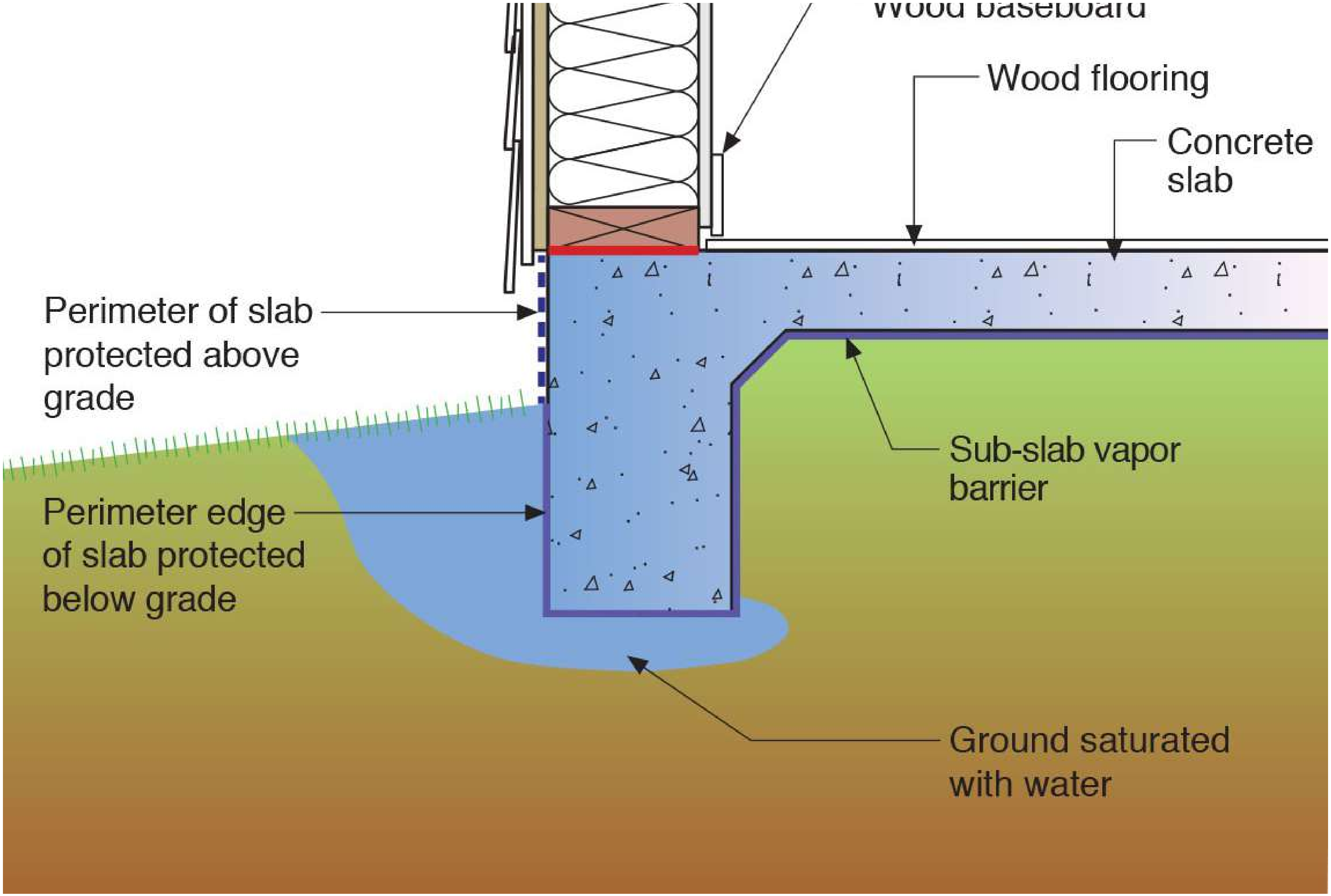


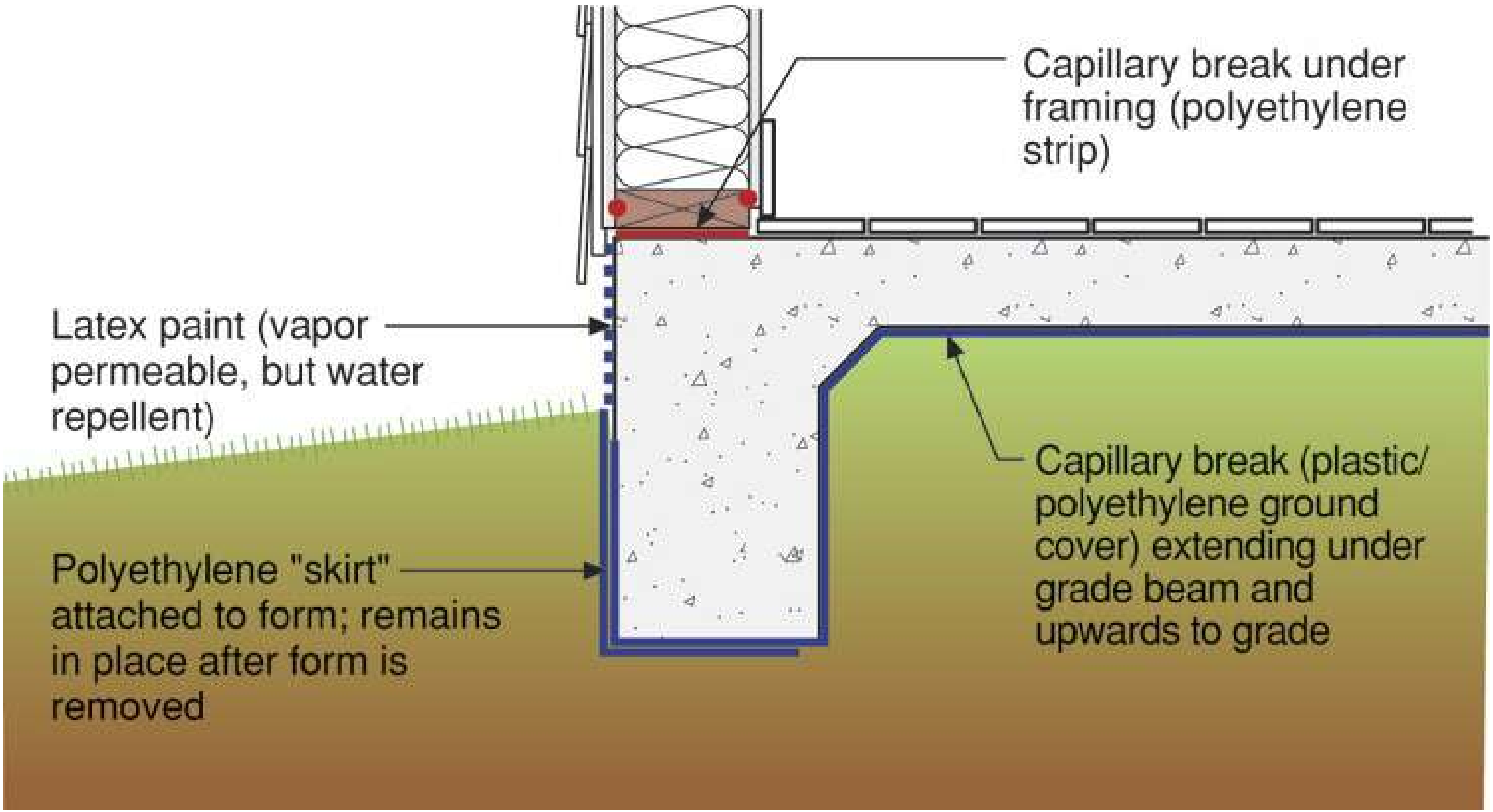
Slabs


Wood baseboard
Wood flooring
Concrete slab
Sub-slab vapor barrier
Perimeter edge of slab not protected below grade
Ground saturated with water


25
U-HAUL

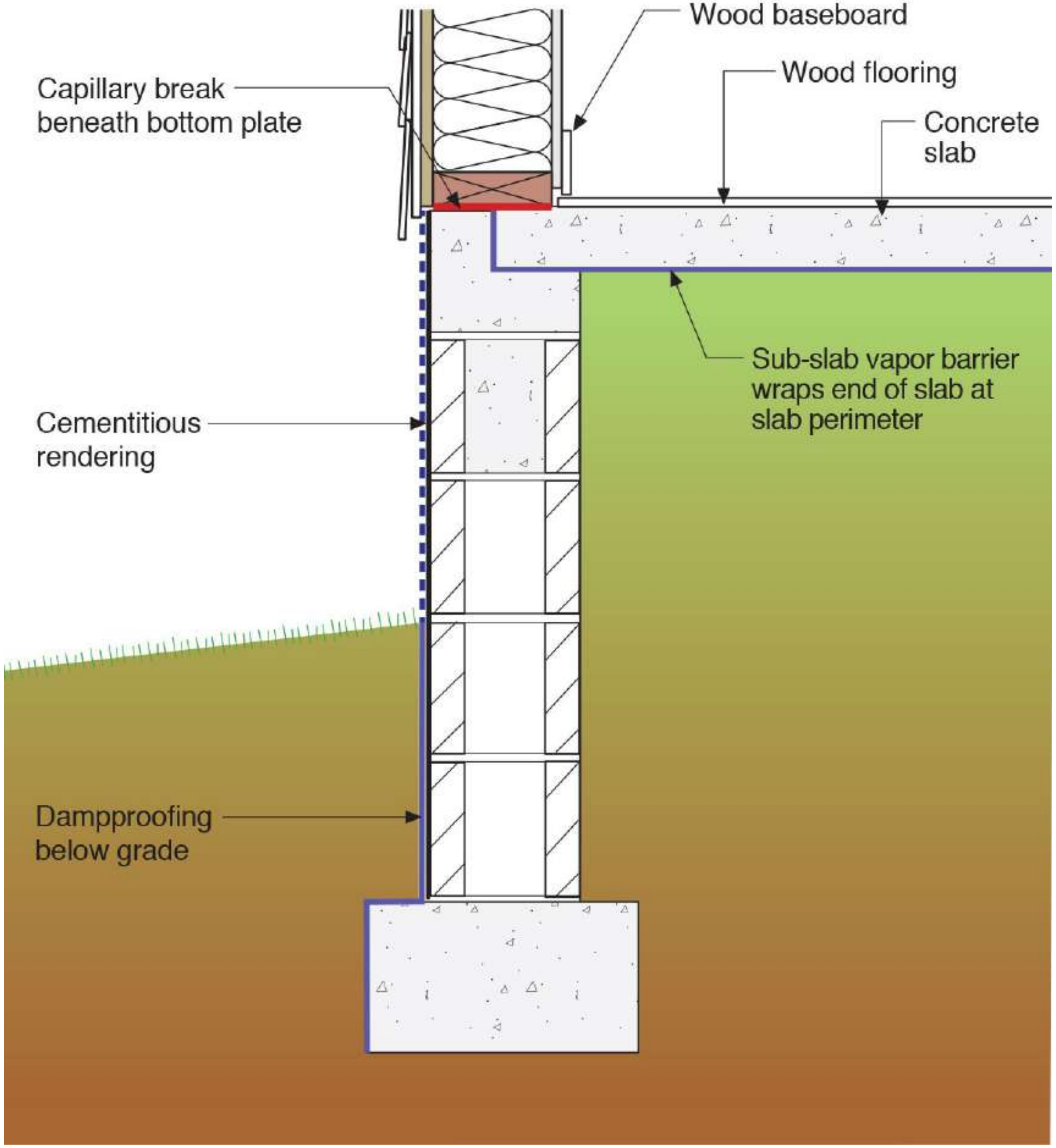

FORD

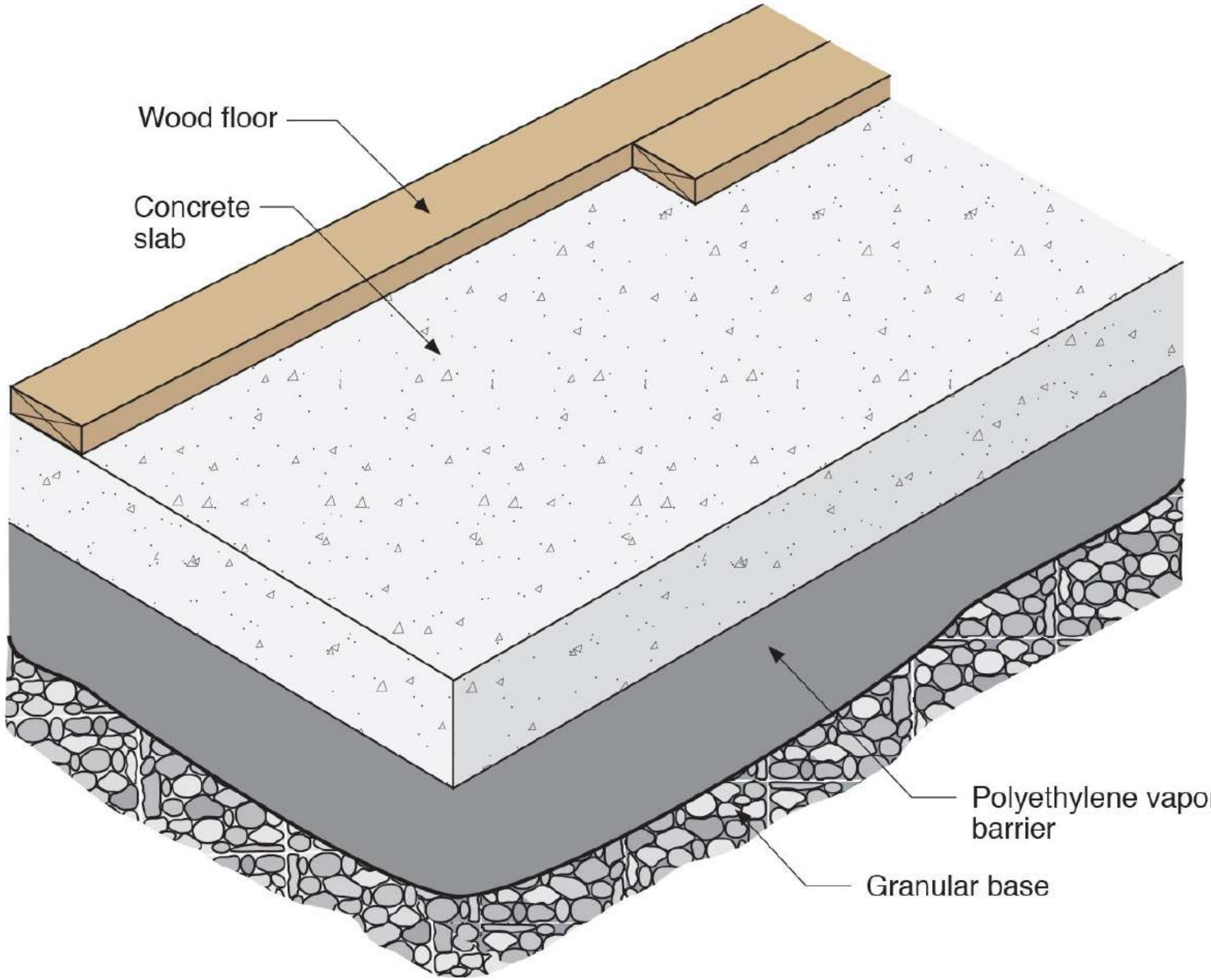

Wood baseboard
Wood flooring
Concrete slab
Perimeter of slab protected above grade
Sub-slab vapor barrier
Perimeter edge of slab protected below grade
Ground saturated with water

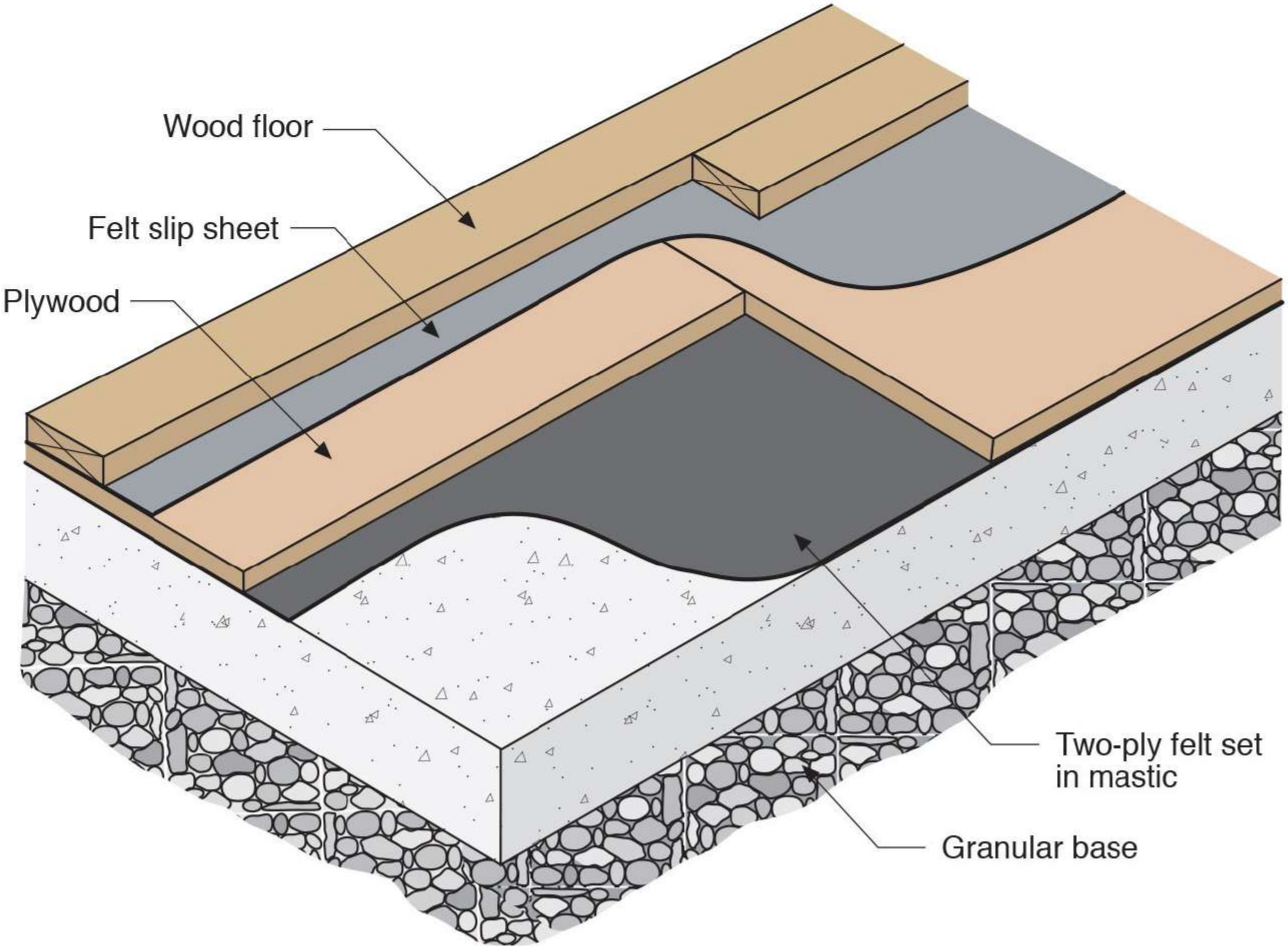


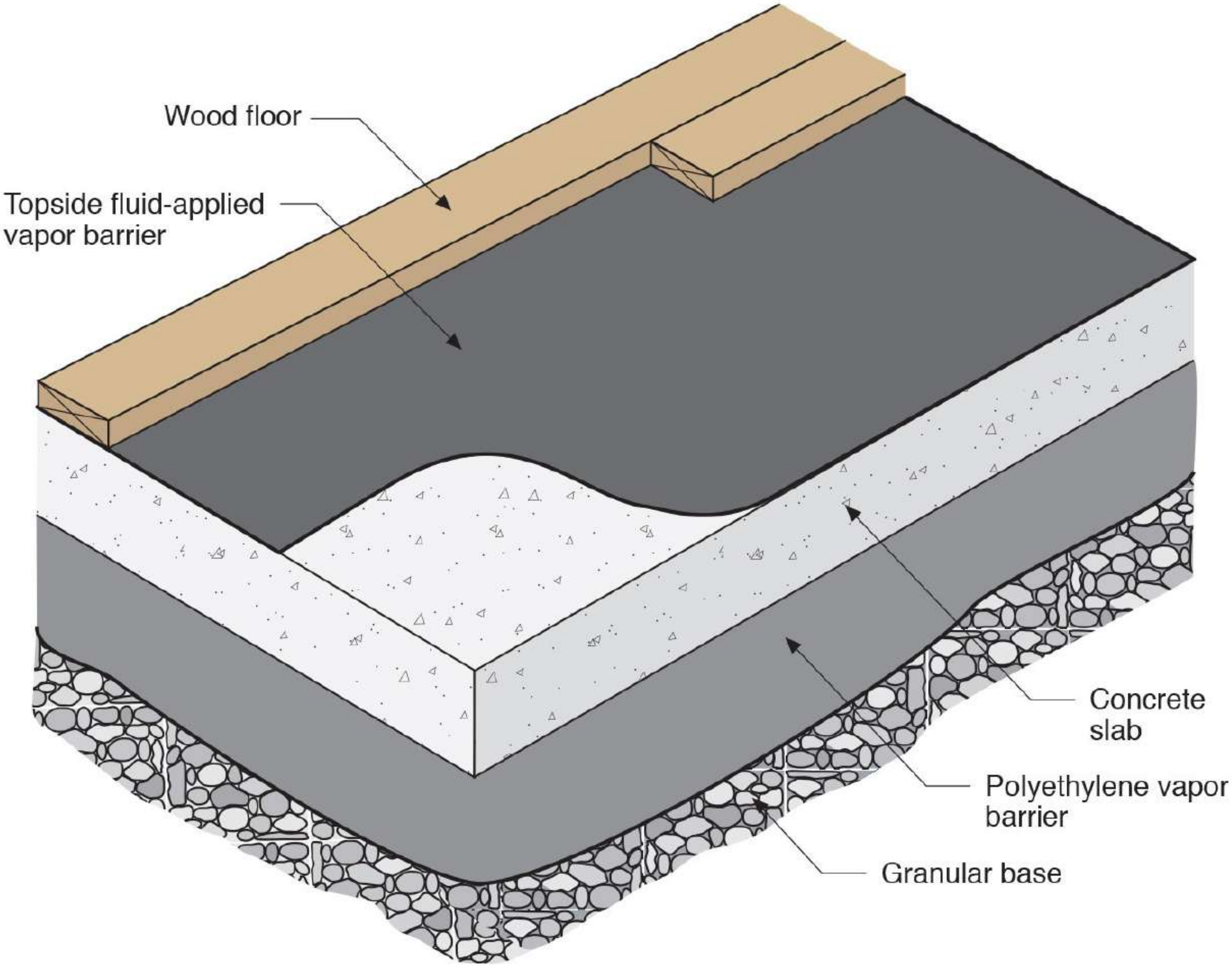
Capillary break under framing (polyethylene strip)
Latex paint (vapor permeable, but water repellent)
Polyethylene "skirt" attached to form; remains in place after form is removed
Capillary break (plastic/ polyethylene ground cover) extending under grade beam and upwards to grade


Cheetos

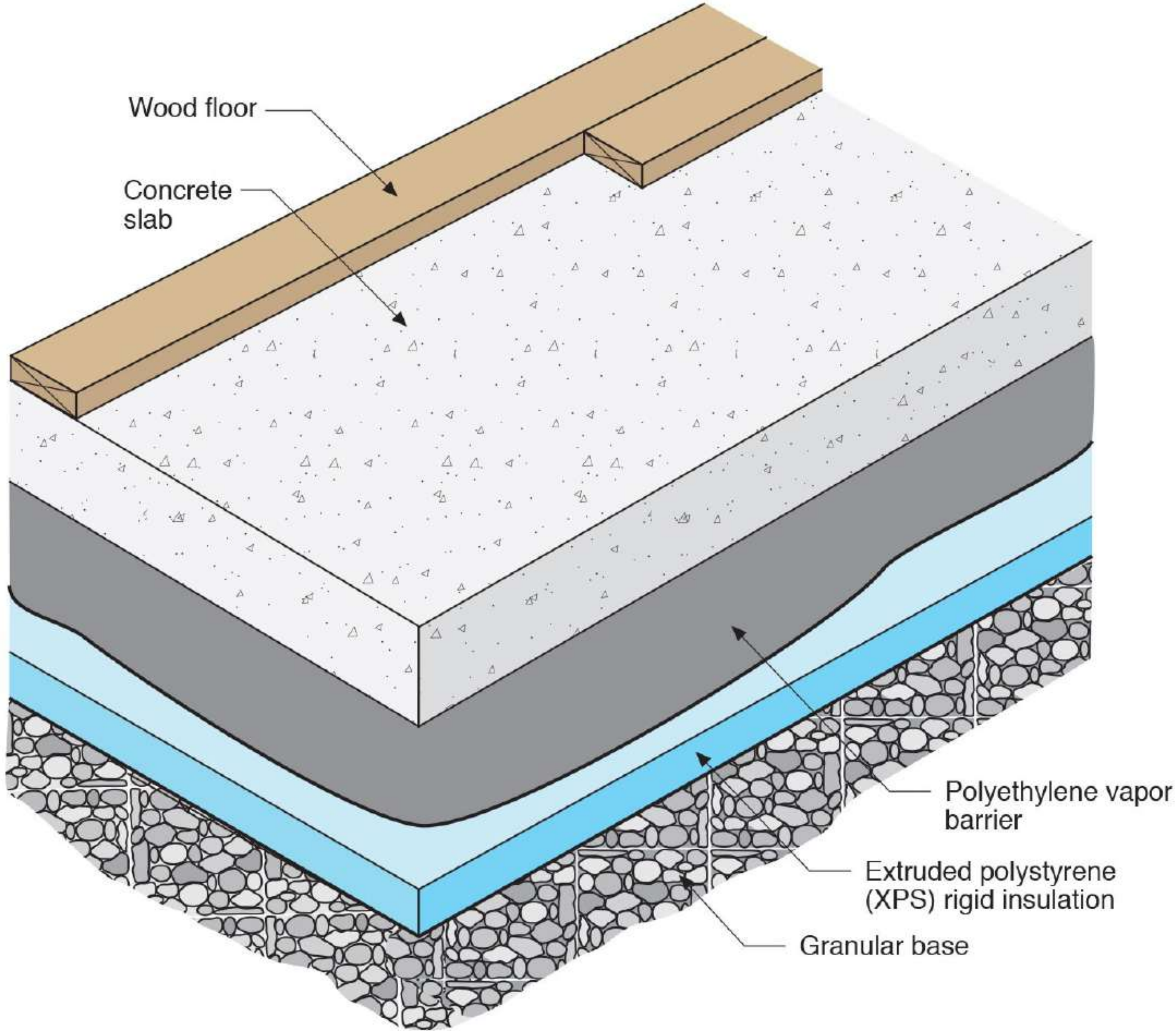

Wood baseboard
Wood flooring
Concrete slab
Capillary break beneath bottom plate
Sub-slab vapor barrier wraps end of slab at slab perimeter
Cementitious rendering
Dampproofing below grade


Wood floor
Concrete slab
Polyethylene vapor barrier
Granular base

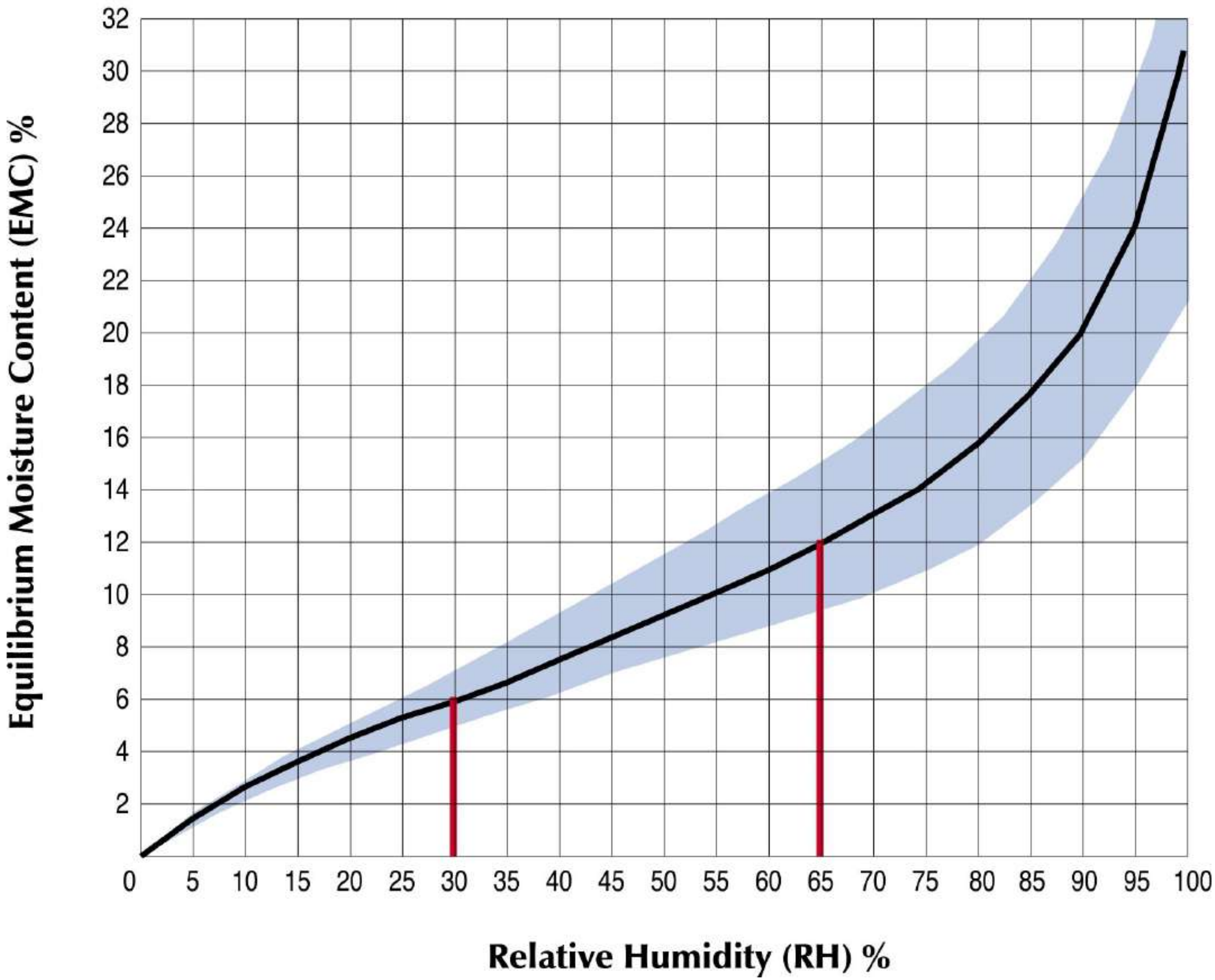

Wood floor
Felt slip sheet
Plywood
Two-ply felt set in mastic
Granular base

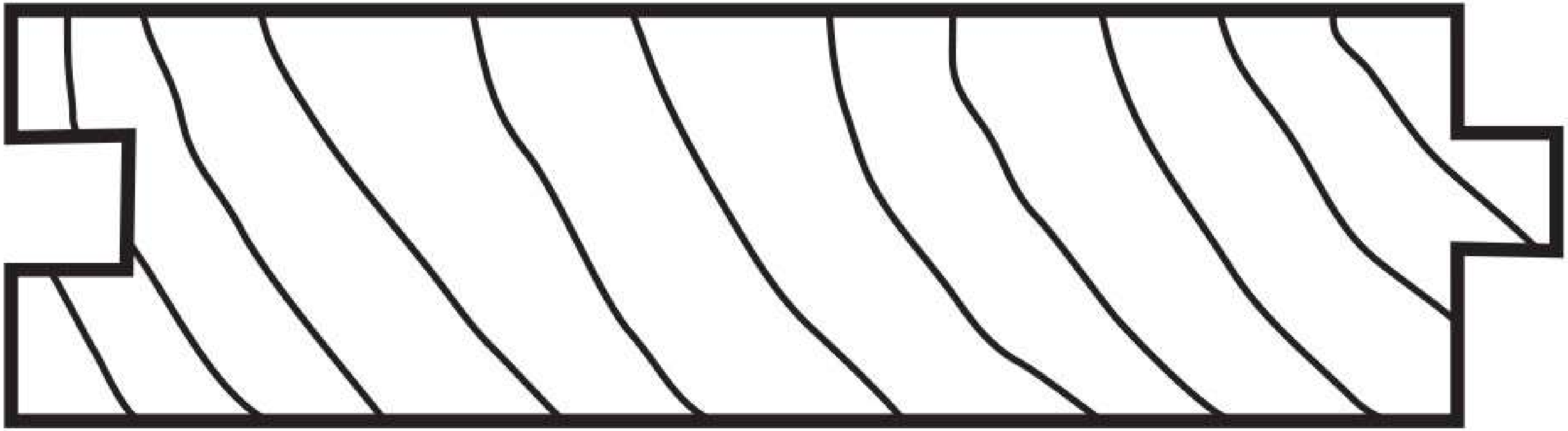

Wood floor
Topside fluid-applied vapor barrier
Concrete slab
Polyethylene vapor barrier
Granular base


COLA

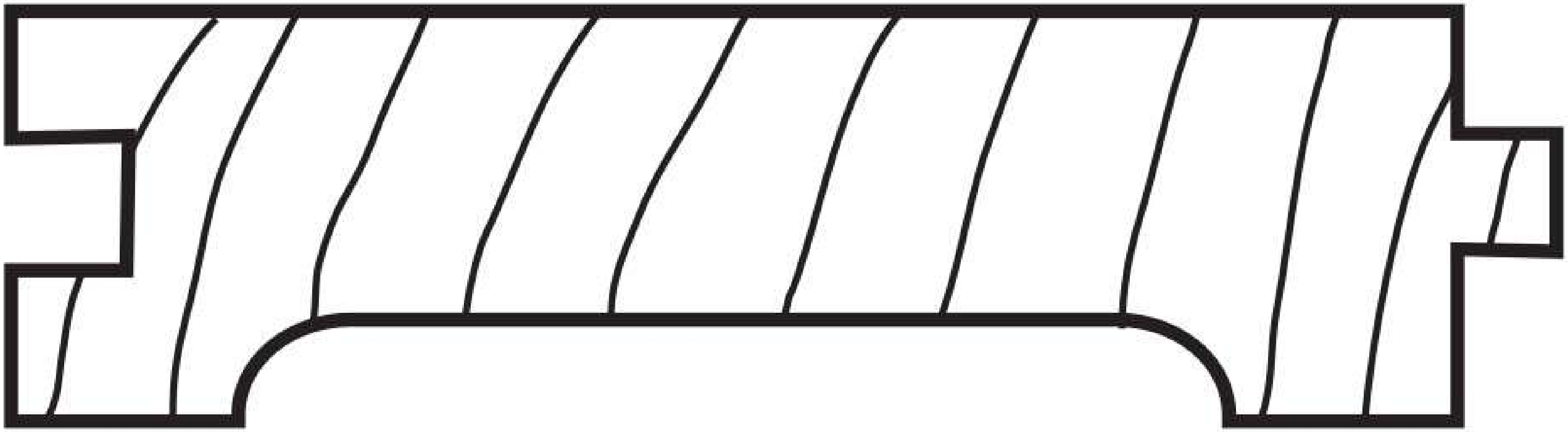

Wood floor
Concrete slab
Polyethylene vapor barrier
Extruded polystyrene (XPS) rigid insulation
Granular base

Moisture Content vs. Relative Humidity

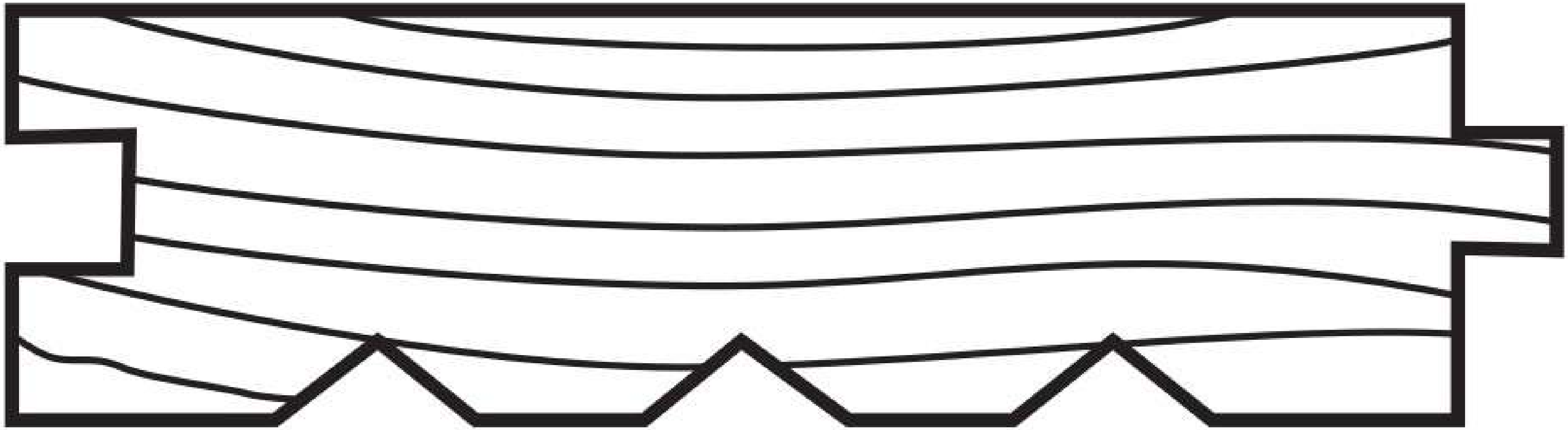




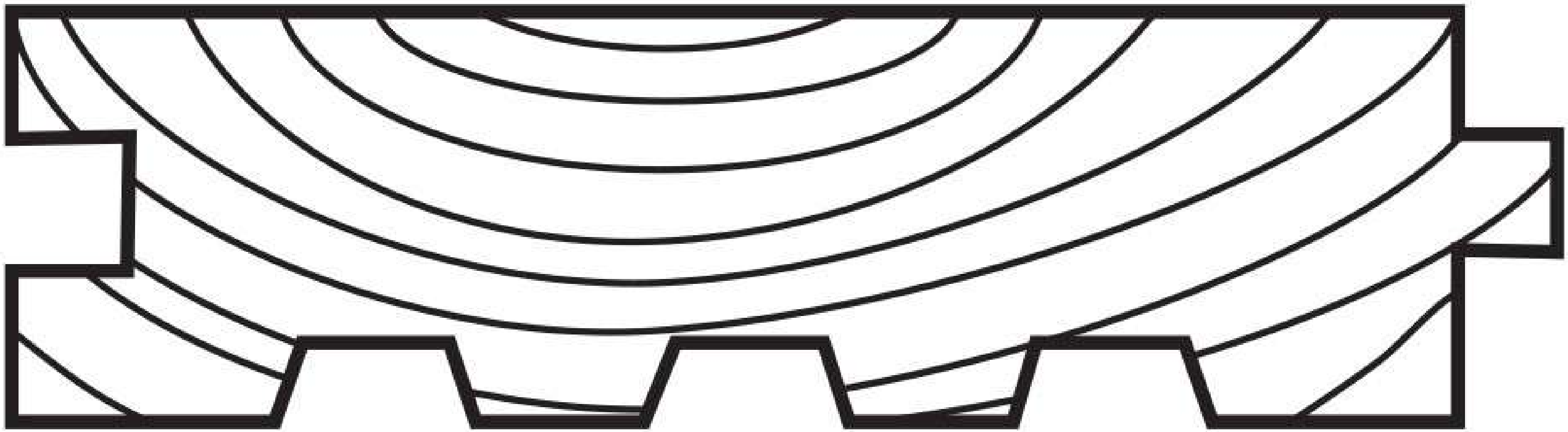
Plain



Hollow Back

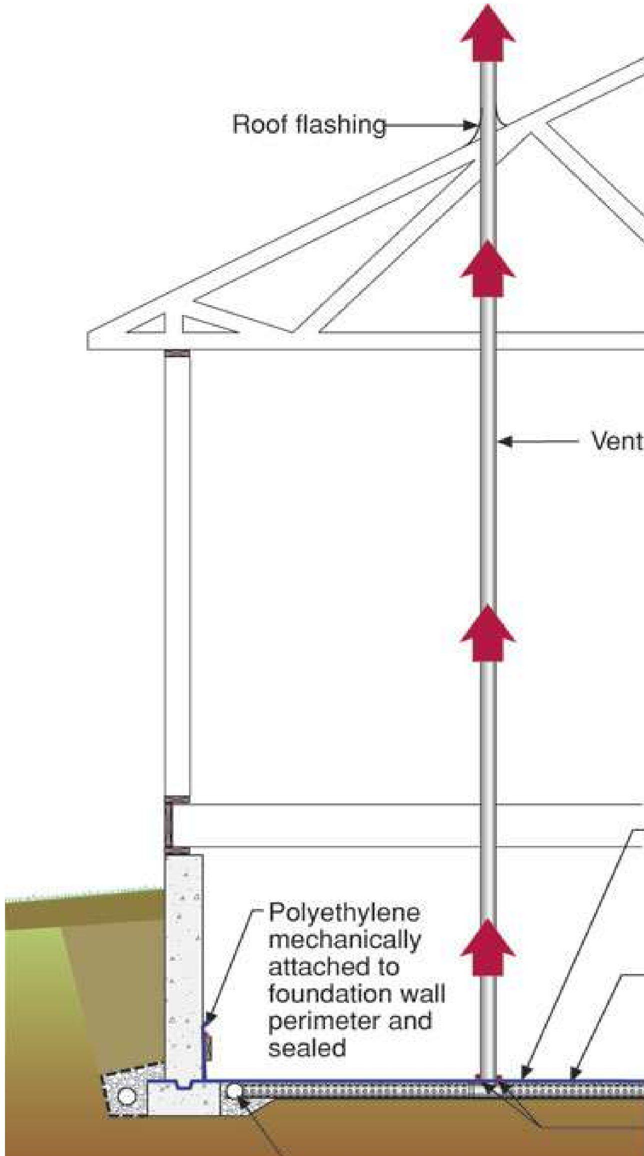


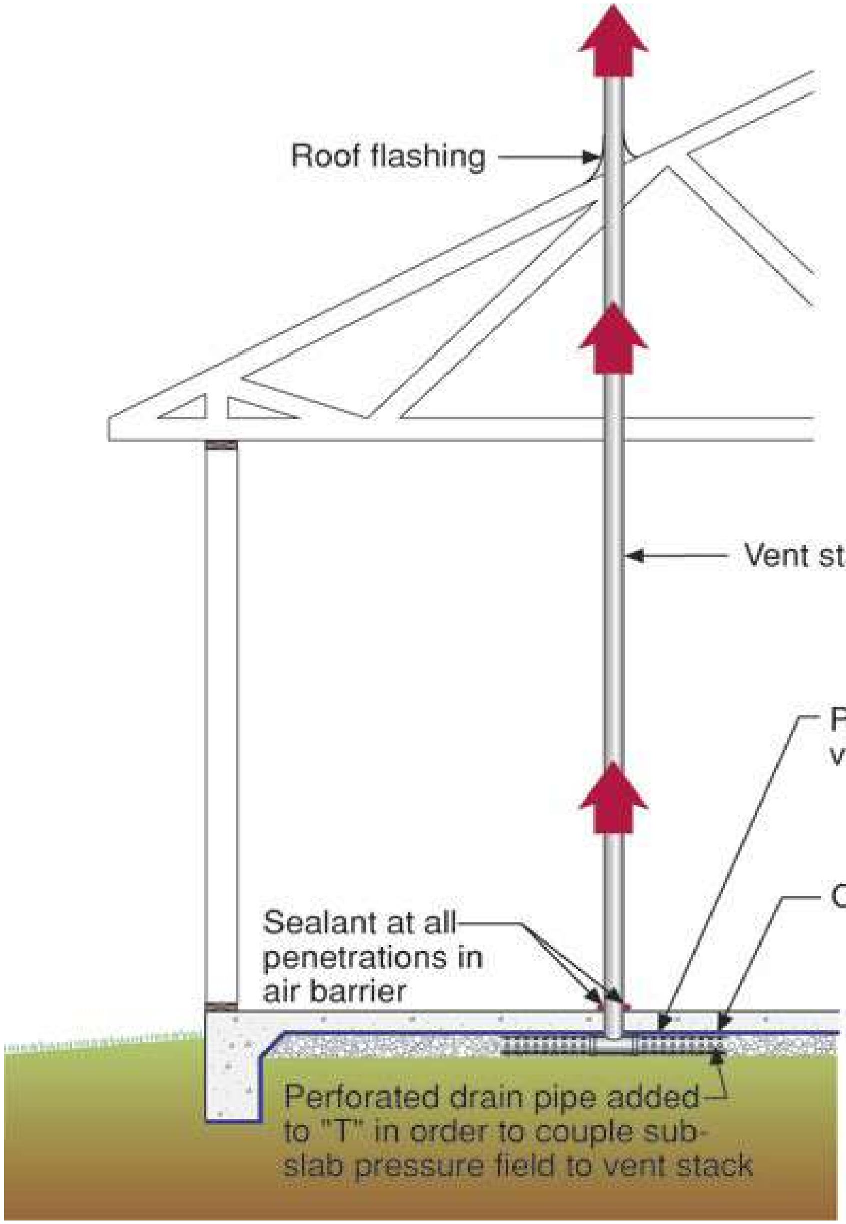
Scratch Back

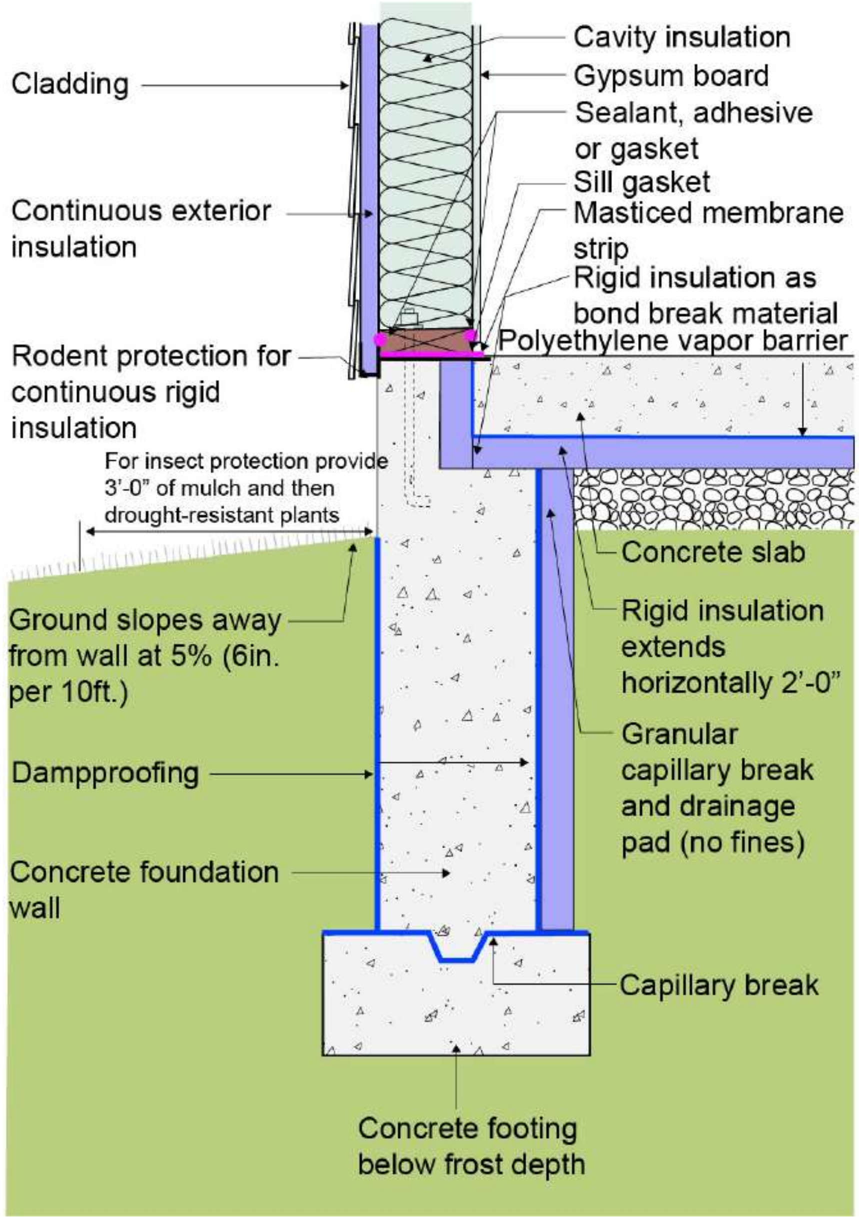


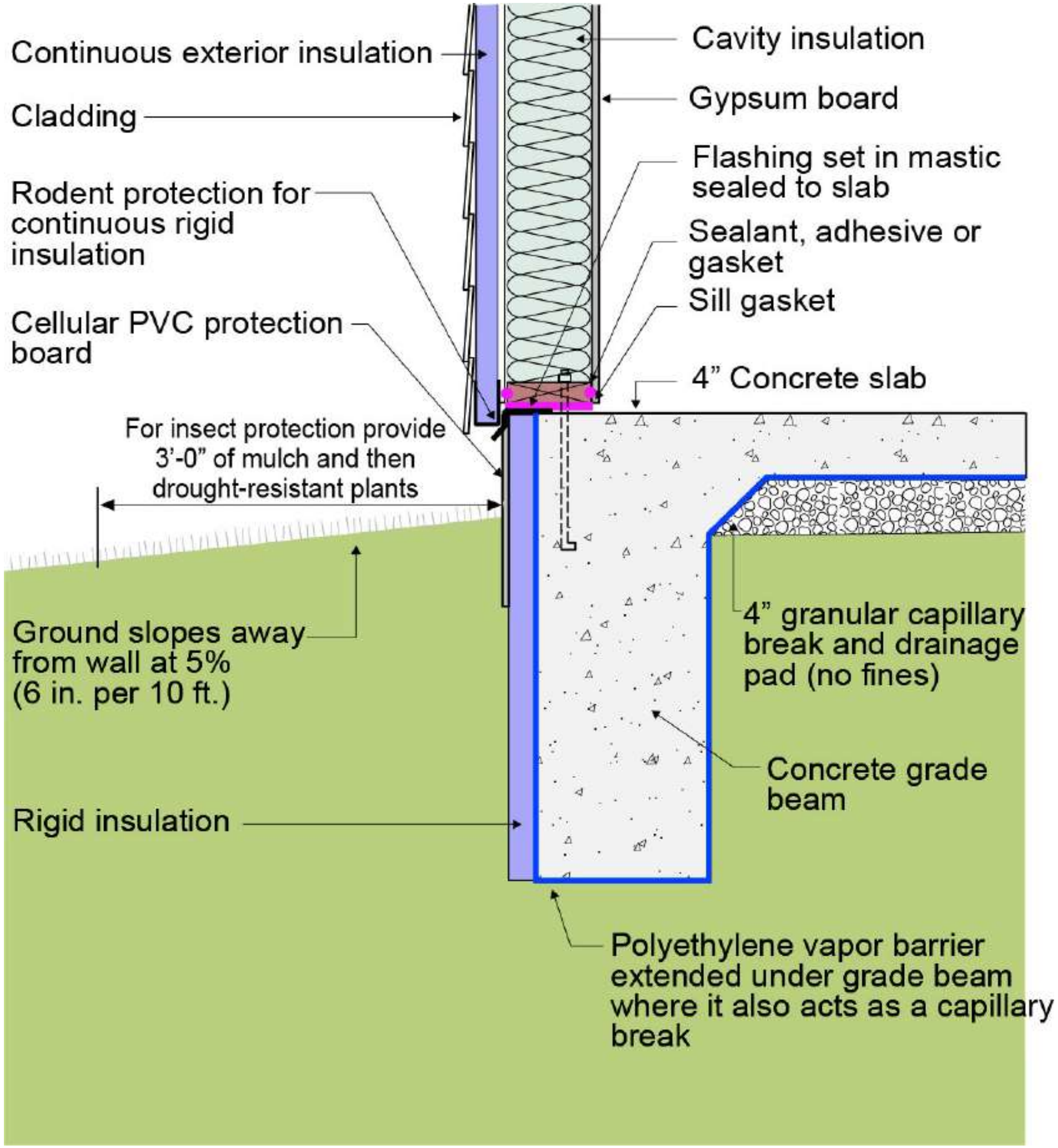
Hollow or Scratch Back


SHEETROCK
All Purpose
Joint Compound

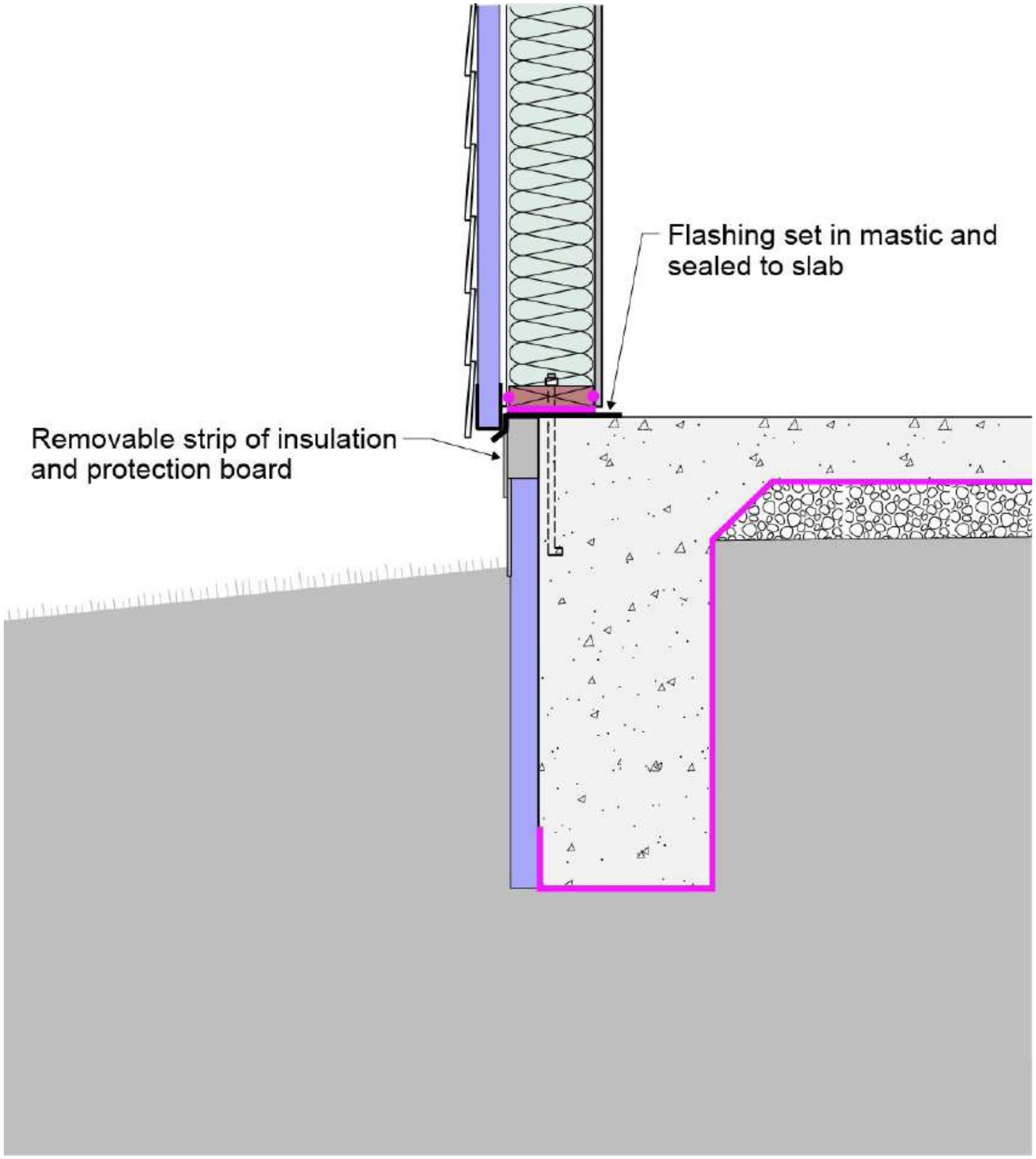

Roof flashing
Vent stack
Continuous polyethylene
vapor barrier/air barrier
(all joints taped)
Polyethylene
mechanically
attached to
foundation wall
perimeter and
sealed
Perforated drain pipe trench
covered with course gravel
(no fines)
Sealant at all penetrations in
air barrier
Perforated drain pipe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

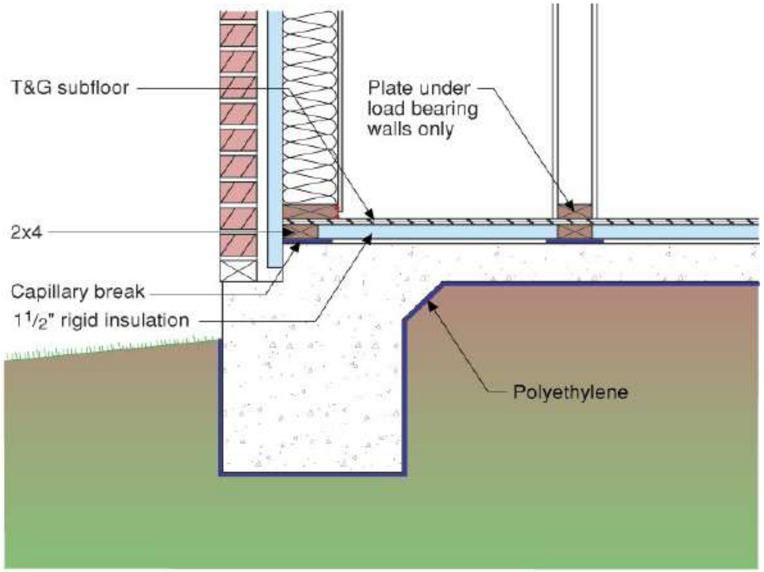

Roof flashing
Vent stack
Polyethylene vapor barrier
Concrete slab
Sealant at all penetrations in air barrier
Perforated drain pipe added to "T" in order to couple sub-slab pressure field to vent stack

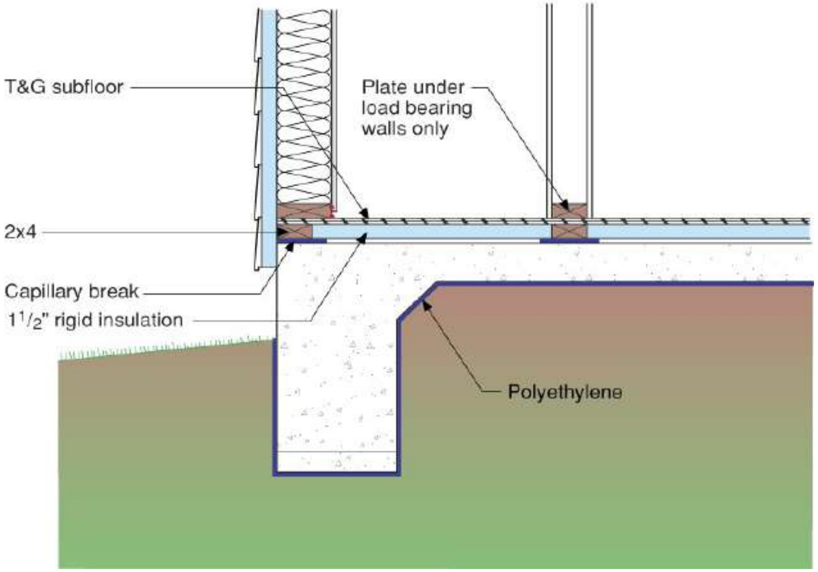

Cavity insulation
Gypsum board
Sealant, adhesive or gasket
Sill gasket
Masticed membrane strip
Rigid insulation as bond break material
Polyethylene vapor barrier
Cladding
Continuous exterior insulation
Rodent protection for continuous rigid insulation
For insect protection provide 3'-0" of mulch and then drought-resistant plants
Concrete slab
Rigid insulation extends horizontally 2'-0"
Granular capillary break and drainage pad (no fines)
Ground slopes away from wall at 5% (6in. per 10ft.)
Dampproofing
Concrete foundation wall
Capillary break
Concrete footing below frost depth

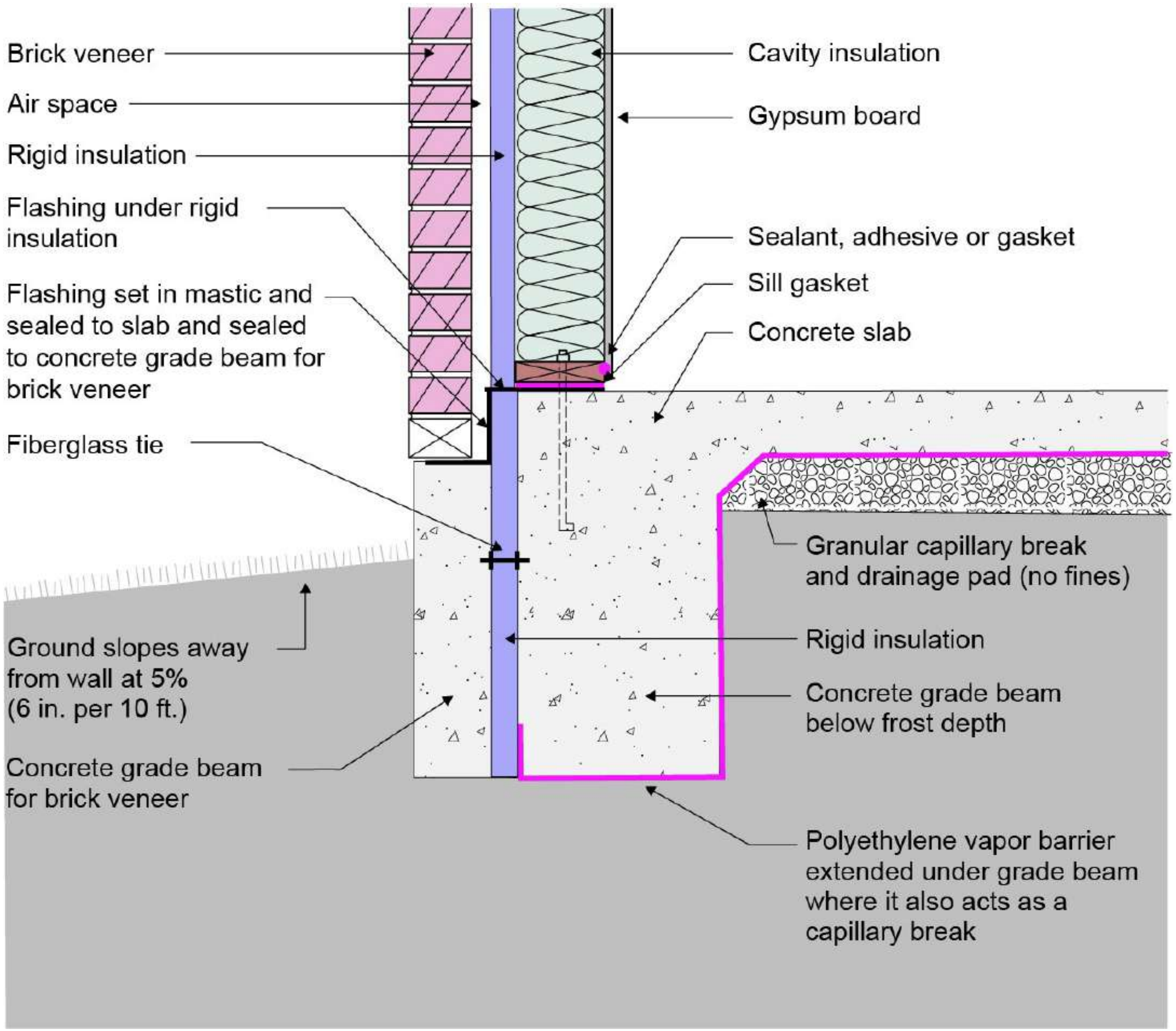


Continuous exterior insulation
Cladding
Rodent protection for continuous rigid insulation
Cellular PVC protection board
For insect protection provide 3'-0" of mulch and then drought-resistant plants
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Rigid insulation
Cavity insulation
Gypsum board
Flashing set in mastic sealed to slab
Sealant, adhesive or gasket
Sill gasket
4" Concrete slab
4" granular capillary break and drainage pad (no fines)
Concrete grade beam
Polyethylene vapor barrier extended under grade beam where it also acts as a capillary break

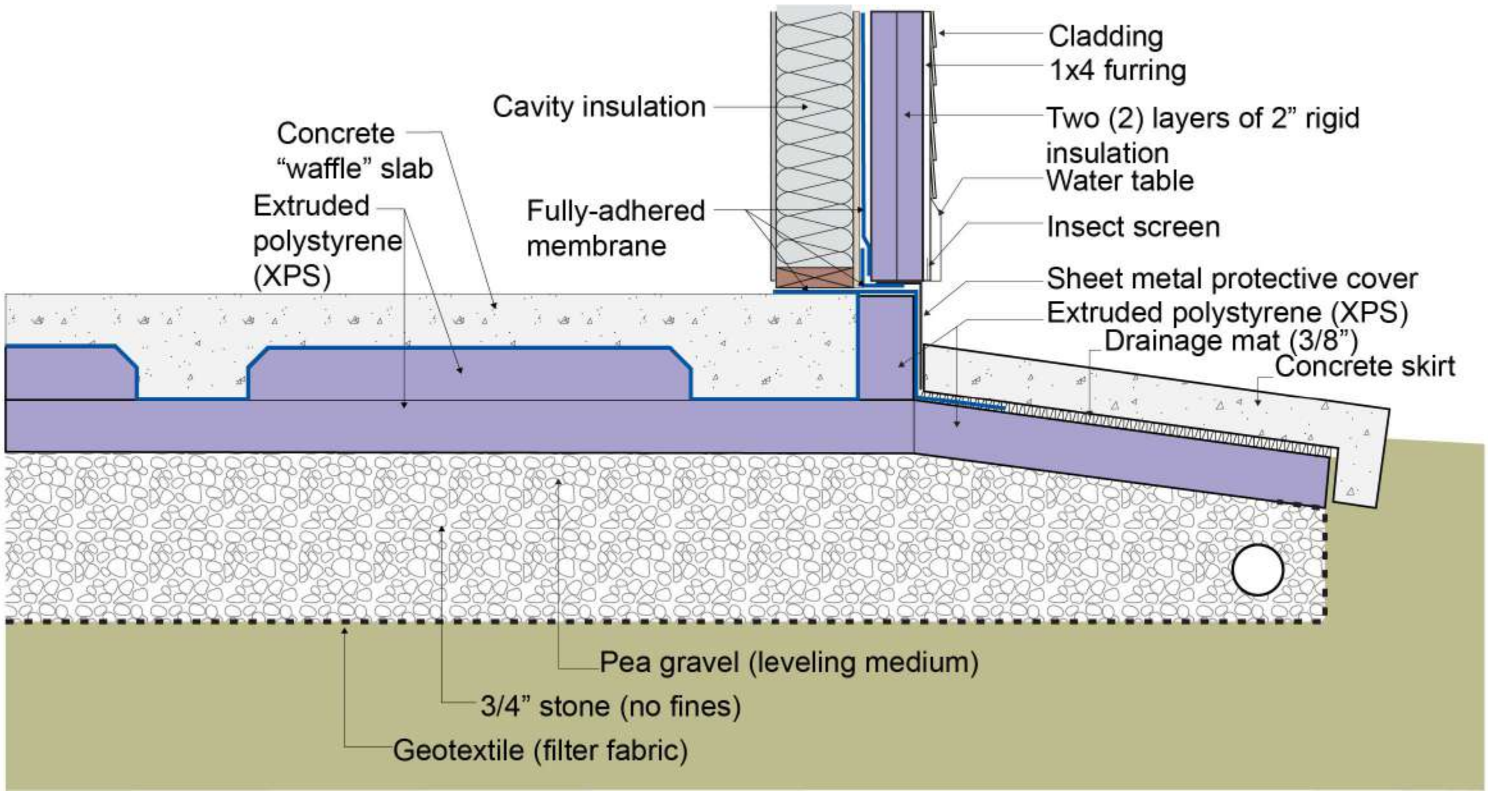

Flashing set in mastic and
sealed to slab
Removable strip of insulation
and protection board


T&G subfloor
Plate under load bearing walls only
2x4
Capillary break
$1^1/_2$" rigid insulation
Polyethylene


T&G subfloor
Plate under load bearing walls only
2x4
Capillary break
$1^1/_2$" rigid insulation
Polyethylene



Brick veneer
Air space
Rigid insulation
Flashing under rigid insulation
Flashing set in mastic and sealed to slab and sealed to concrete grade beam for brick veneer
Fiberglass tie
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Concrete grade beam for brick veneer
Cavity insulation
Gypsum board
Sealant, adhesive or gasket
Sill gasket
Concrete slab
Granular capillary break and drainage pad (no fines)
Rigid insulation
Concrete grade beam below frost depth
Polyethylene vapor barrier extended under grade beam where it also acts as a capillary break


Cladding
1x4 furring
Cavity insulation
Two (2) layers of 2” rigid insulation
Concrete “waffle” slab
Water table
Extruded polystyrene (XPS)
Fully-adhered membrane
Insect screen
Sheet metal protective cover
Extruded polystyrene (XPS)
Drainage mat (3/8”)
Concrete skirt
Pea gravel (leveling medium)
3/4” stone (no fines)
Geotextile (filter fabric)

Stucco Failures

Stucco Evolved As A Barrier System

Exterior Insulation Finish Systems
EIFS

Exterior Insulation Finish Systems

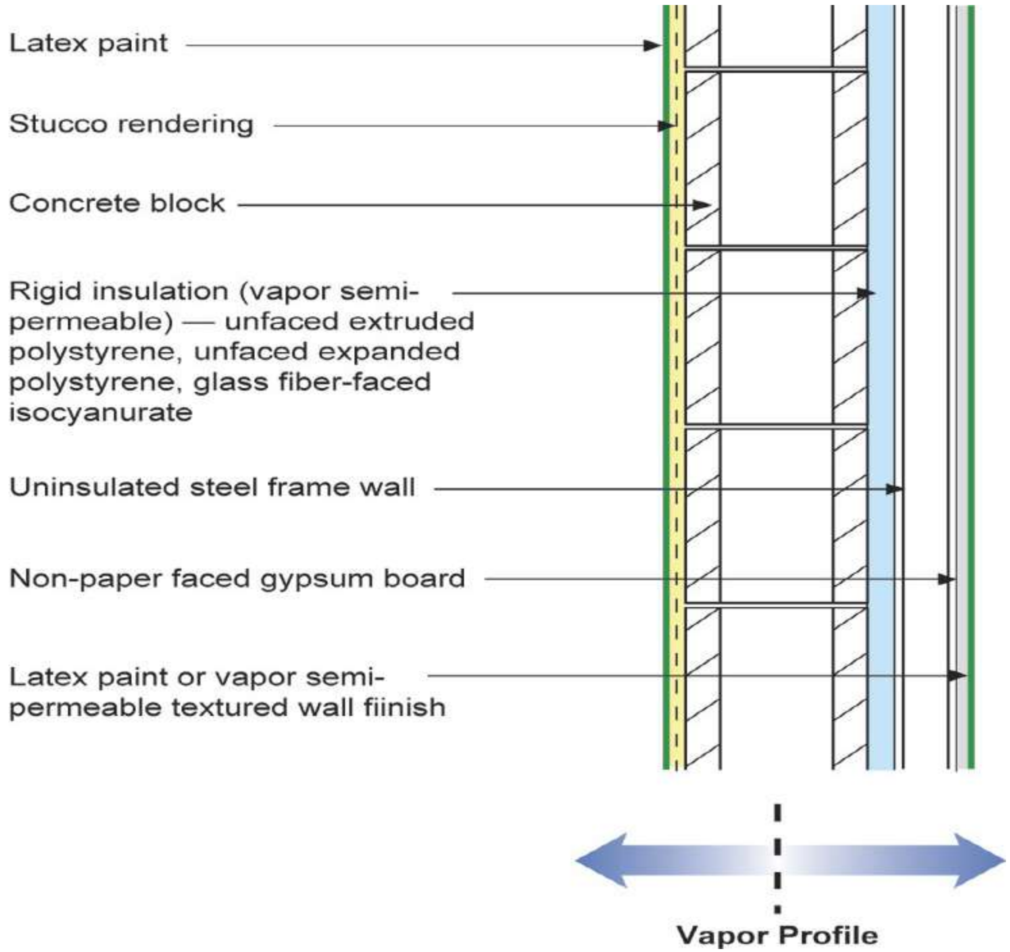
EIFS

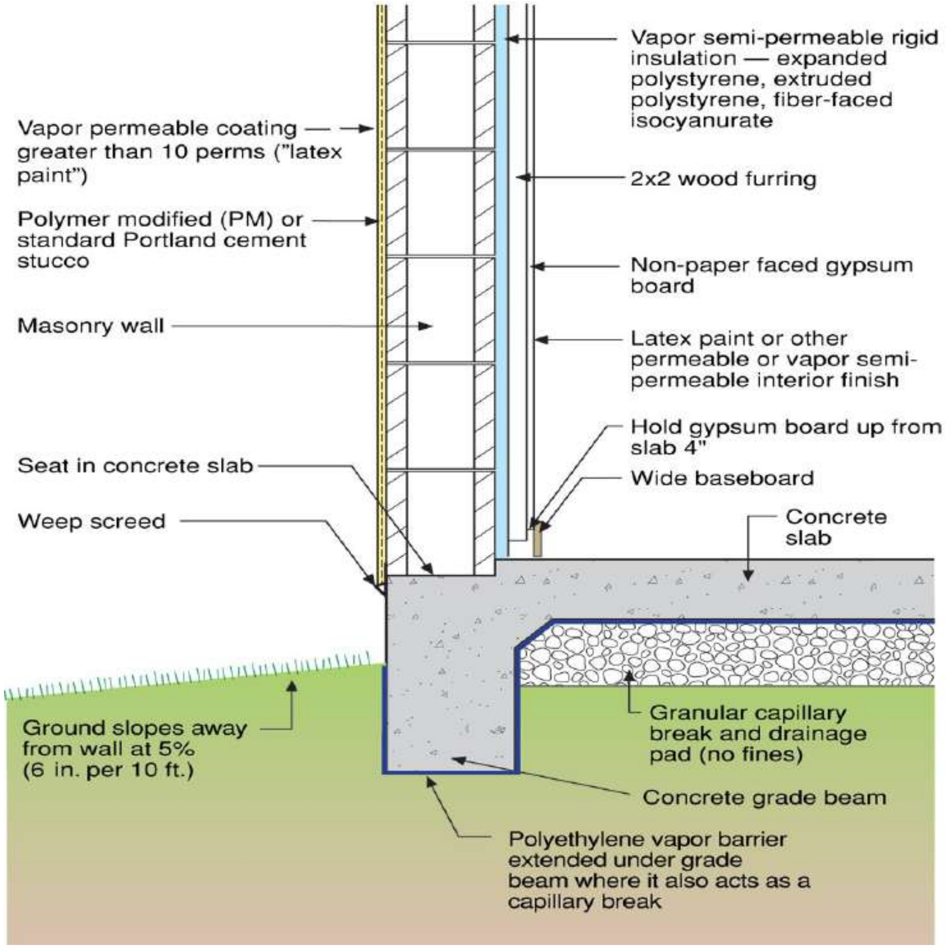
Barrier System

Face-Sealed Not Water Managed


BUILT BY
EDDIE EVANS
CONSTRUCTION
1994

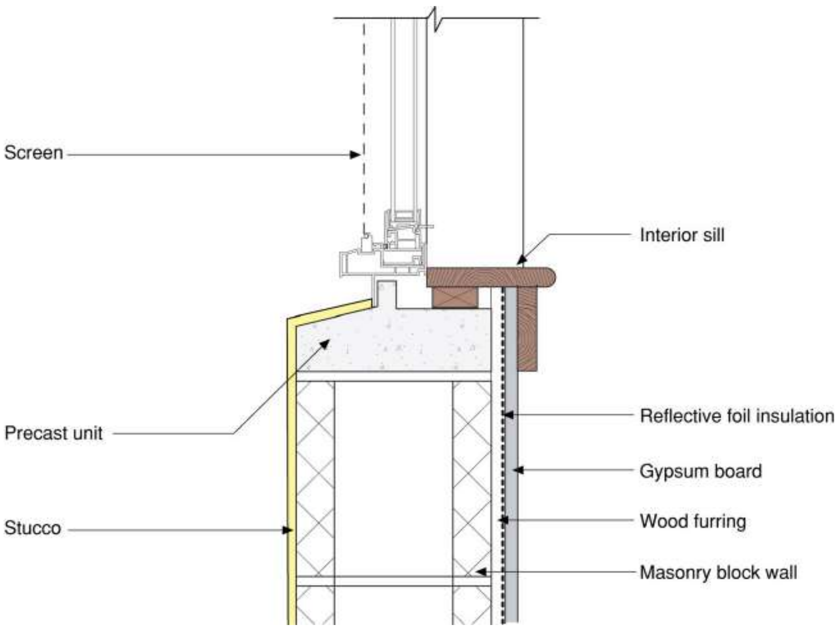
Can Barrier or Face Seal Work?

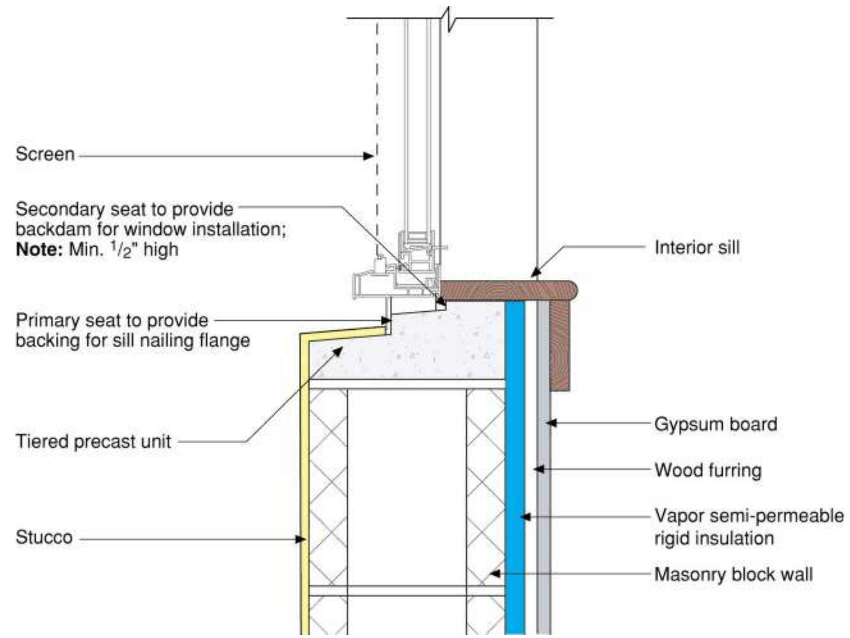

Latex paint
Stucco rendering
Concrete block
Rigid insulation (vapor semi-permeable) — unfaced extruded polystyrene, unfaced expanded polystyrene, glass fiber-faced isocyanurate
Uninsulated steel frame wall
Non-paper faced gypsum board
Latex paint or vapor semi-permeable textured wall fiinish
Vapor Profile



Vapor semi-permeable rigid insulation — expanded polystyrene, extruded polystyrene, fiber-faced isocyanurate
Vapor permeable coating — greater than 10 perms ("latex paint")
2x2 wood furring
Polymer modified (PM) or standard Portland cement stucco
Non-paper faced gypsum board
Masonry wall
Latex paint or other permeable or vapor semi-permeable interior finish
Hold gypsum board up from slab 4"
Seat in concrete slab
Wide baseboard
Weep screed
Concrete slab
Ground slopes away from wall at 5% (6 in. per 10 ft.)
Granular capillary break and drainage pad (no fines)
Concrete grade beam
Polyethylene vapor barrier extended under grade beam where it also acts as a capillary break


Styrofoam
SCOREBOARD
Styrofoam
SCOREBOARD


Screen
Interior sill
Precast unit
Reflective foil insulation
Gypsum board
Stucco
Wood furring
Masonry block wall


Screen
Secondary seat to provide backdam for window installation; **Note:** Min. 1/2" high
Interior sill
Primary seat to provide backing for sill nailing flange
Gypsum board
Tiered precast unit
Wood furring
Vapor semi-permeable rigid insulation
Stucco
Masonry block wall

Reminder…

Don’t Do Stupid Things


CertainTeed
R19
AL FOL

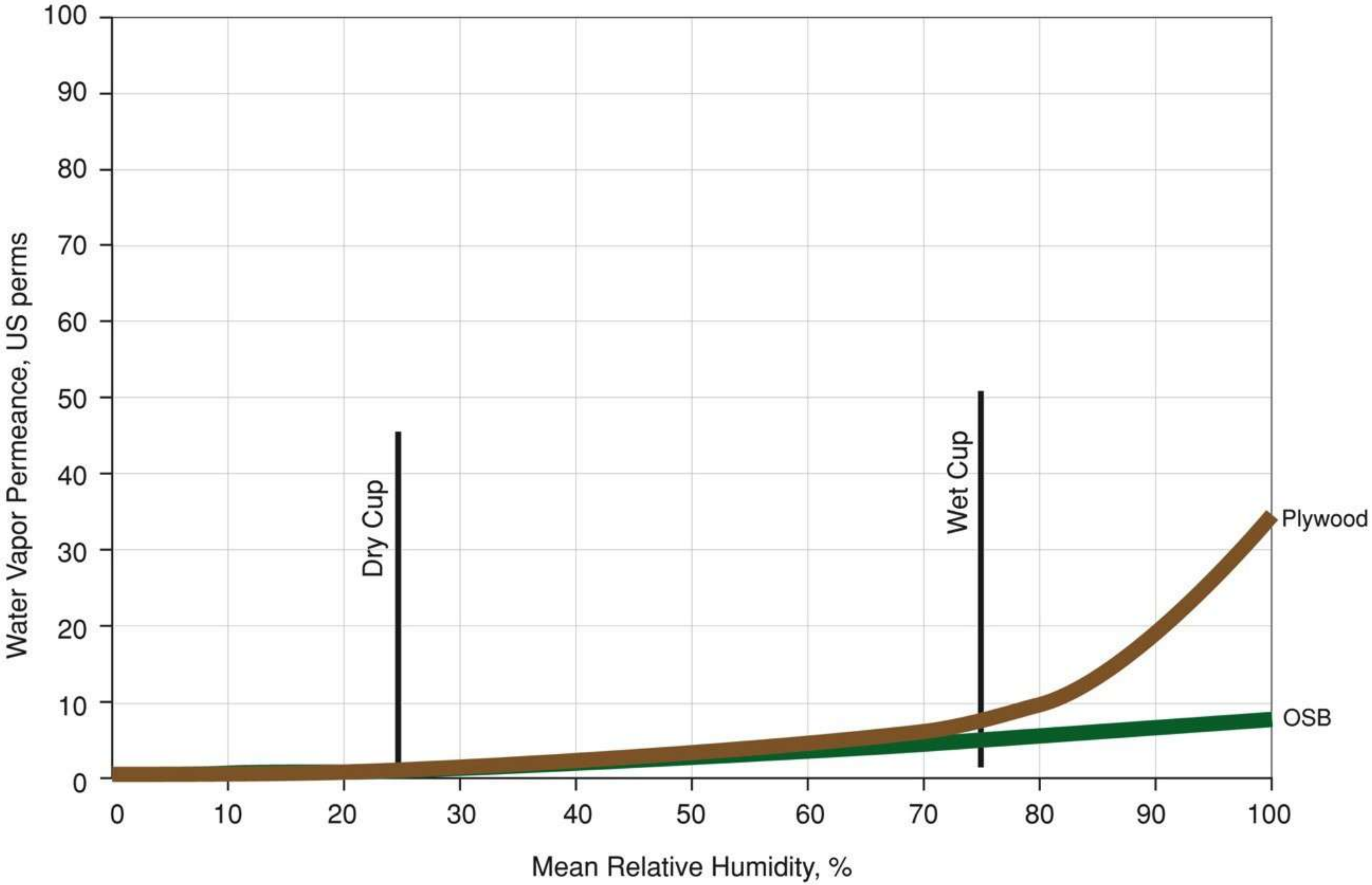
What Is Going On With Stucco?

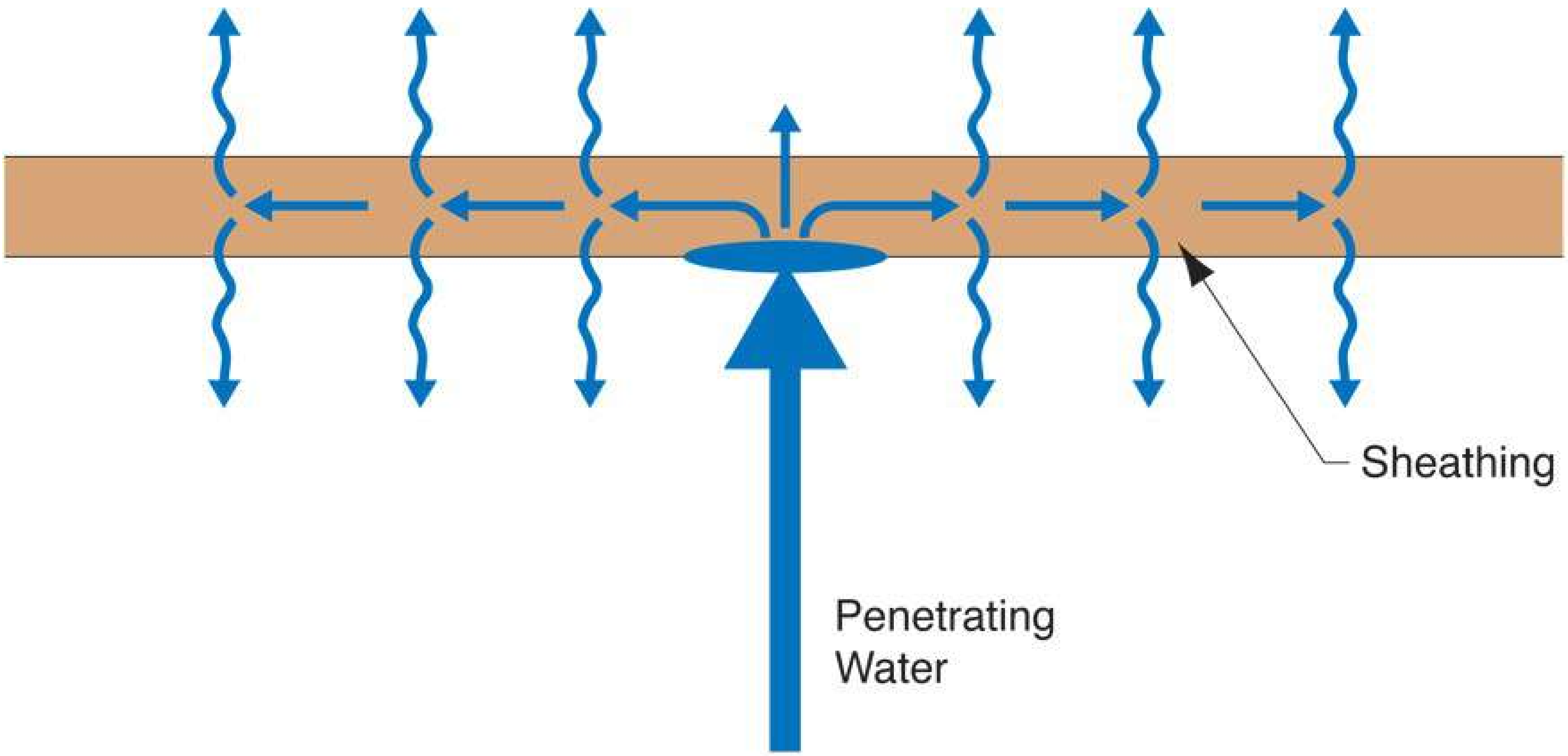
Materials

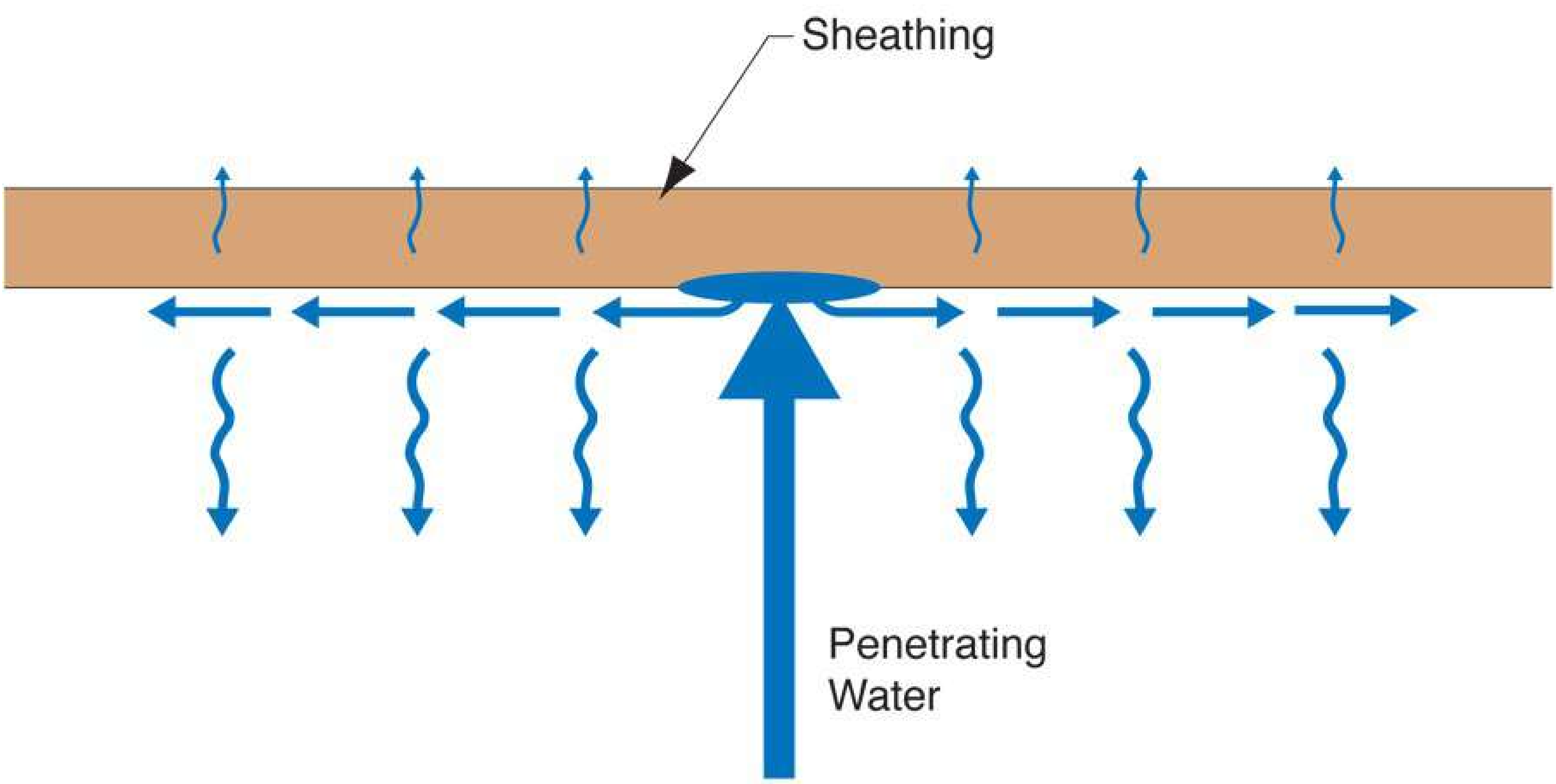
Inward Vapor Drive

Energy

Water Vapor Permeance of Sheathing Materials



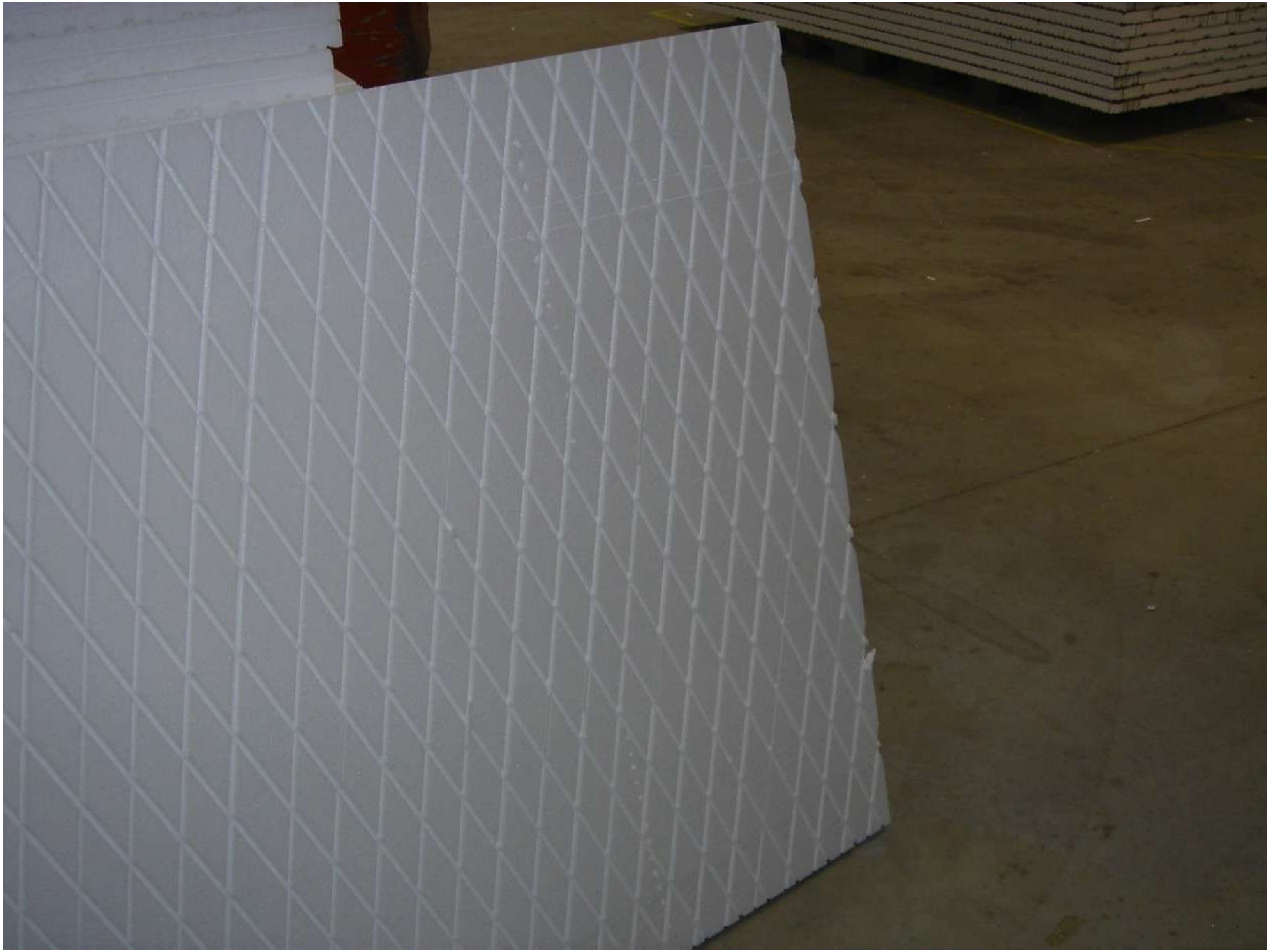

Sheathing
Penetrating
Water


Sheathing
Penetrating Water

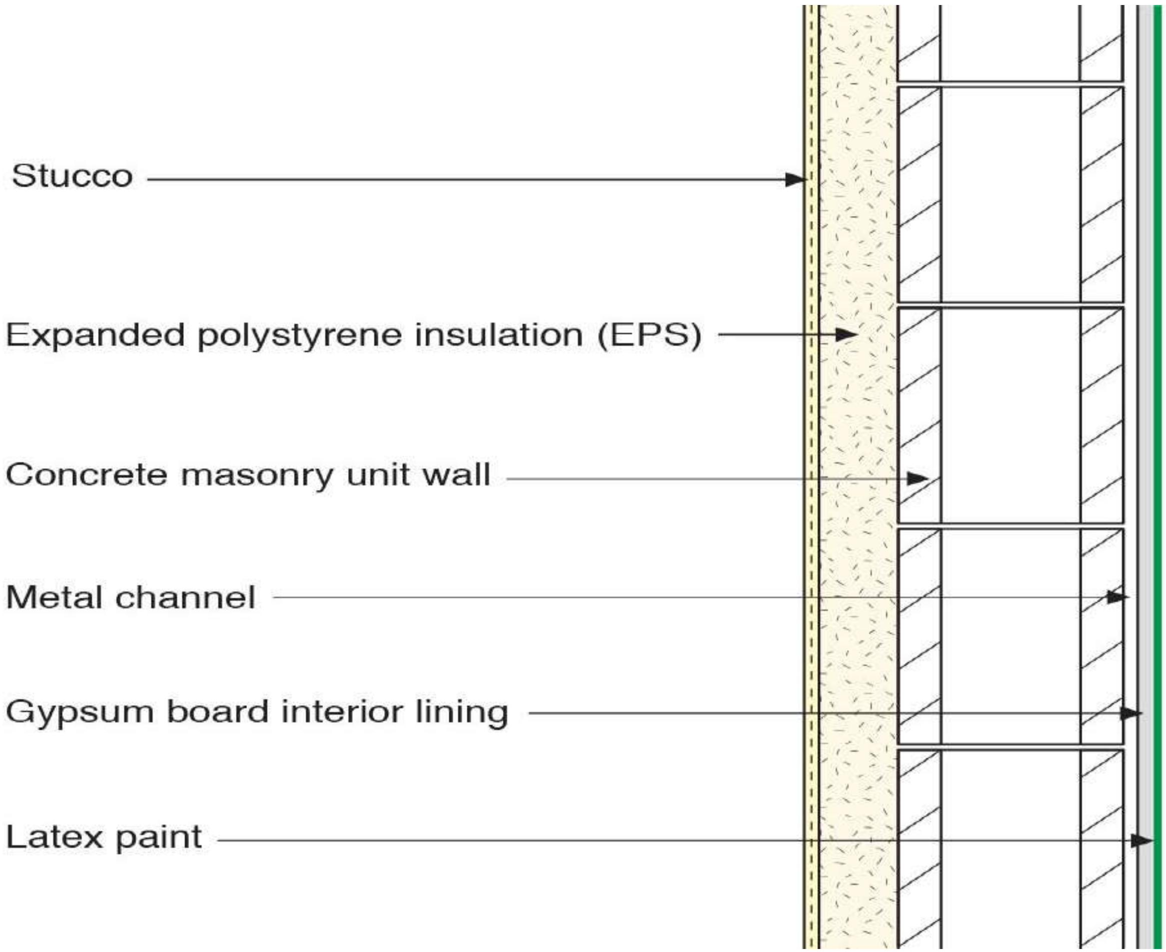
Rain Screen

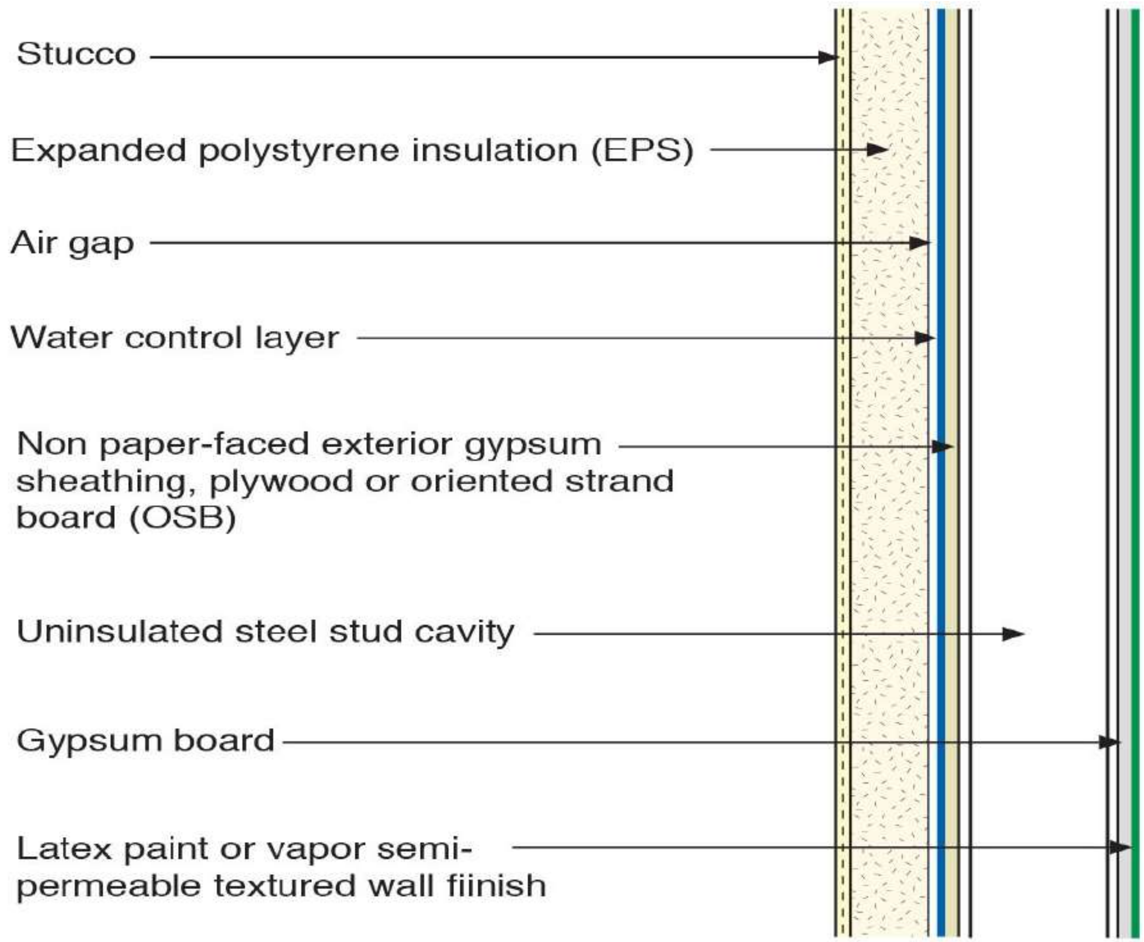

Tyvek
HomeWrap
Tyvek
HomeWrap
DUPONT
Tyvek
HomeWrap

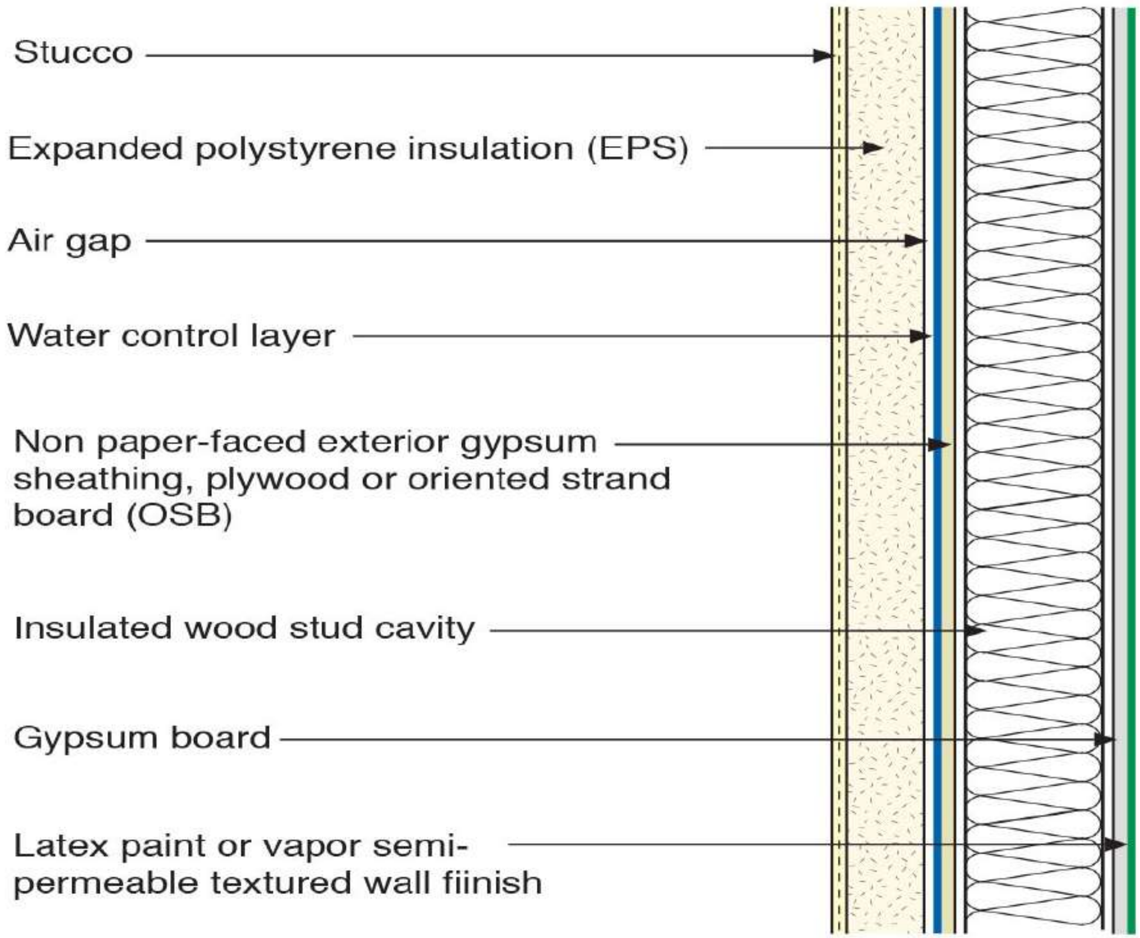

Tyvek
Tyvek
Tape
PONT



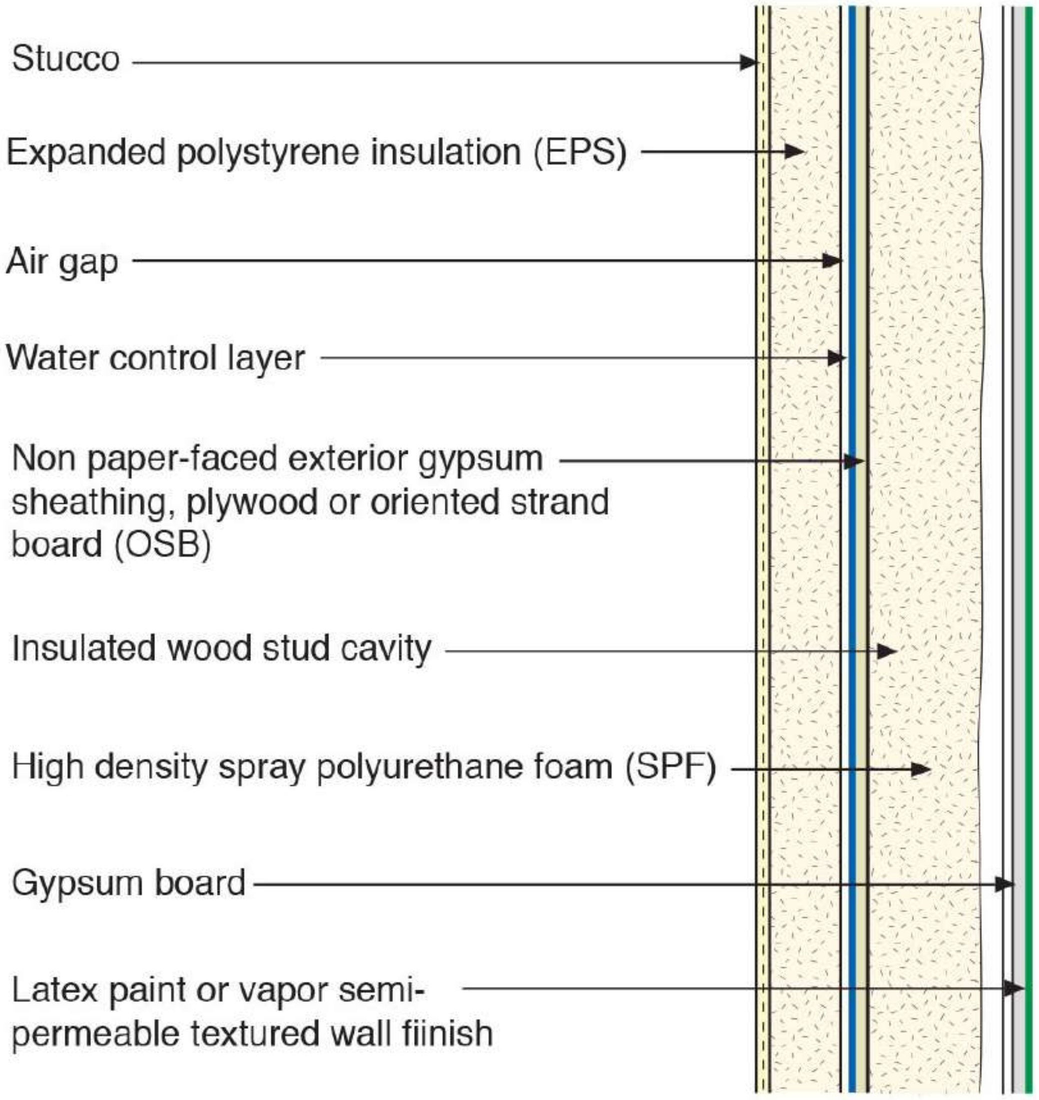
EIFS No Longer Has Issues


Stucco
Expanded polystyrene insulation (EPS)
Concrete masonry unit wall
Metal channel
Gypsum board interior lining
Latex paint


Stucco
Expanded polystyrene insulation (EPS)
Air gap
Water control layer
Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)
Uninsulated steel stud cavity
Gypsum board
Latex paint or vapor semi-permeable textured wall fiinish



Stucco
Expanded polystyrene insulation (EPS)
Air gap
Water control layer
Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)
Insulated wood stud cavity
Gypsum board
Latex paint or vapor semi-permeable textured wall fiinish


Stucco
Expanded polystyrene insulation (EPS)
Air gap
Water control layer
Non paper-faced exterior gypsum sheathing, plywood or oriented strand board (OSB)
Insulated wood stud cavity
High density spray polyurethane foam (SPF)
Gypsum board
Latex paint or vapor semi-permeable textured wall fiinish

Back To Stucco….


STO


DEC 3 2002

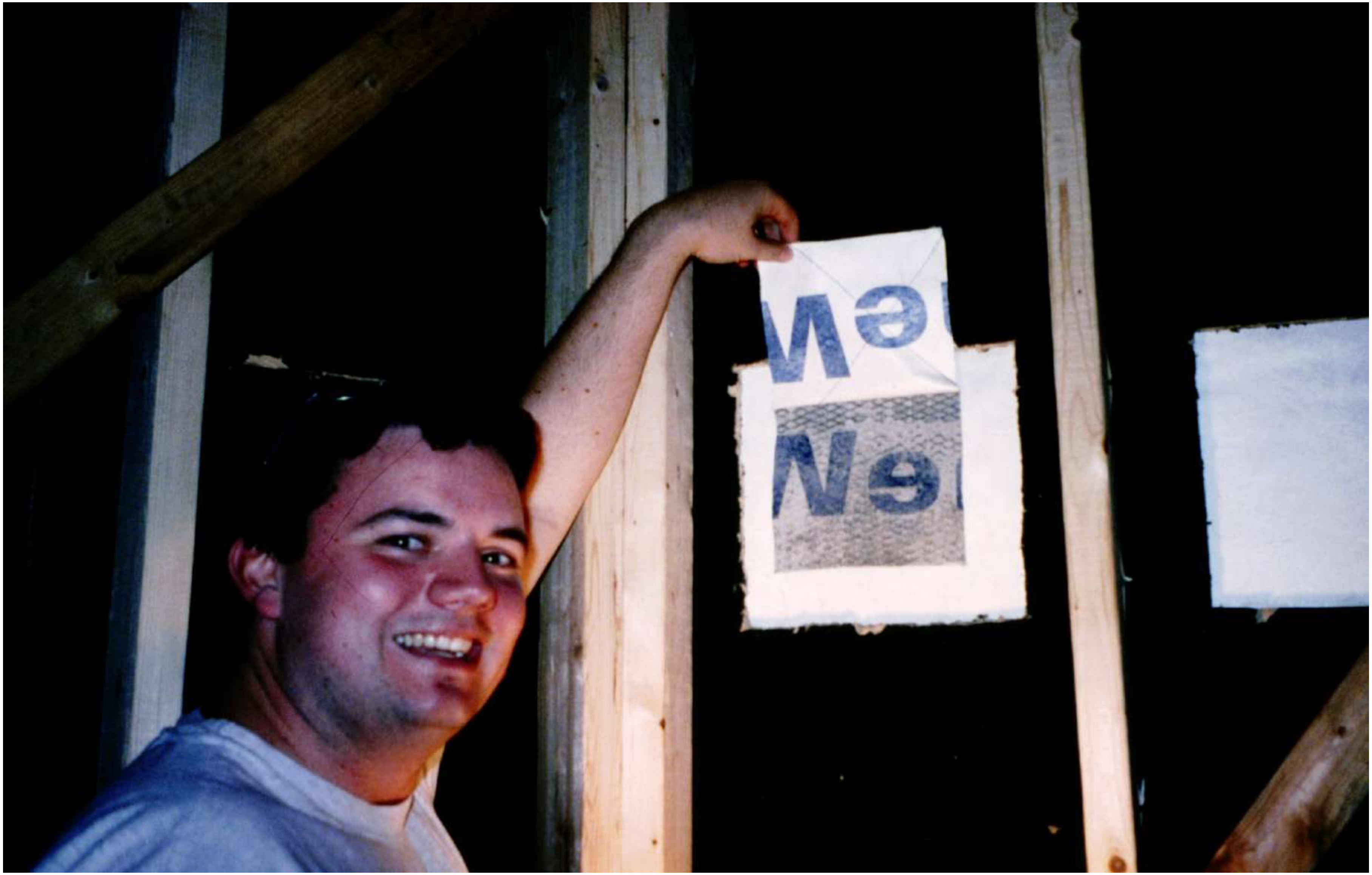

NO PARKING
Parking For Garage
Residents Only
10/24/2002

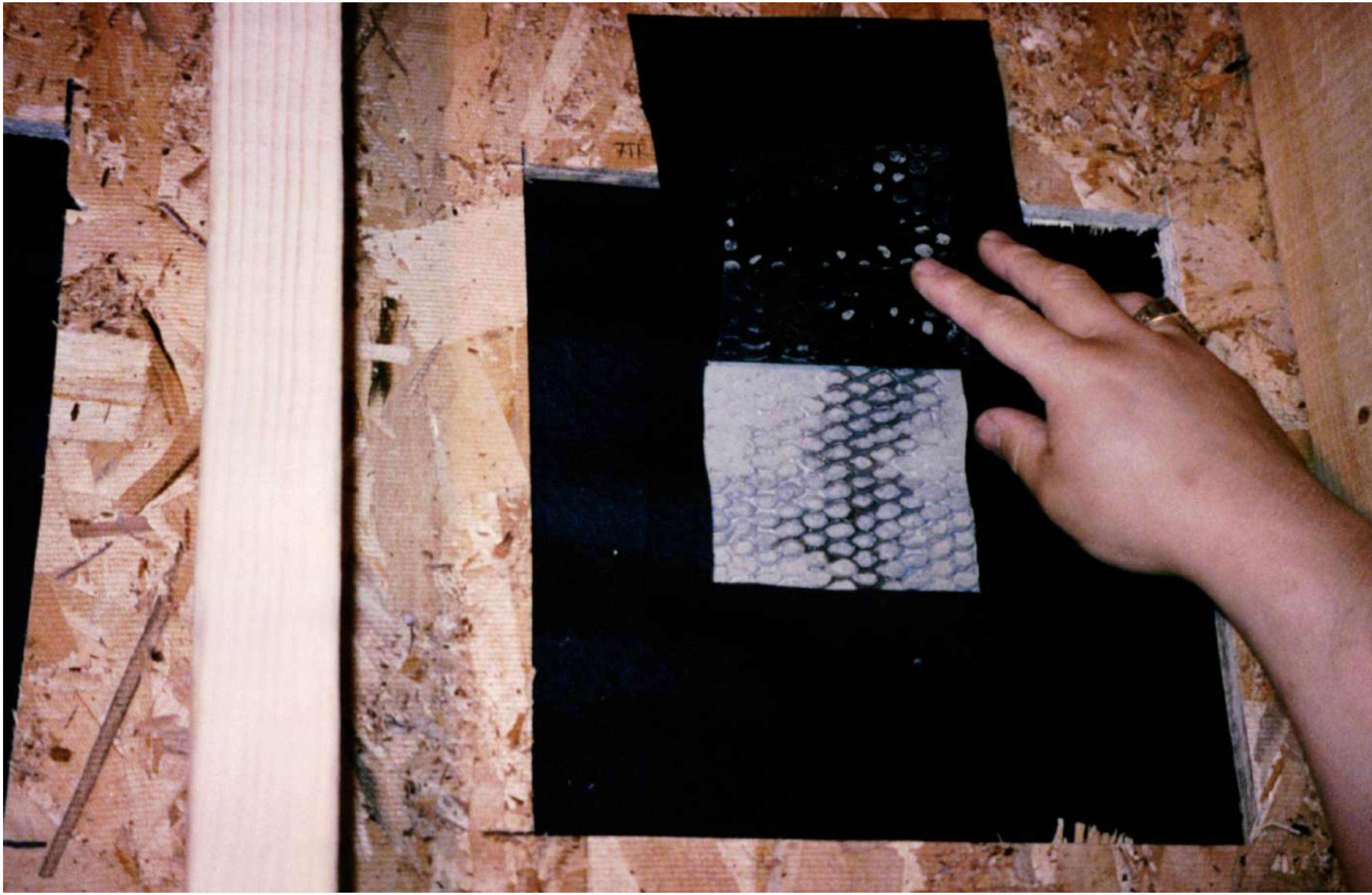

12/19/2002


10/24/2002

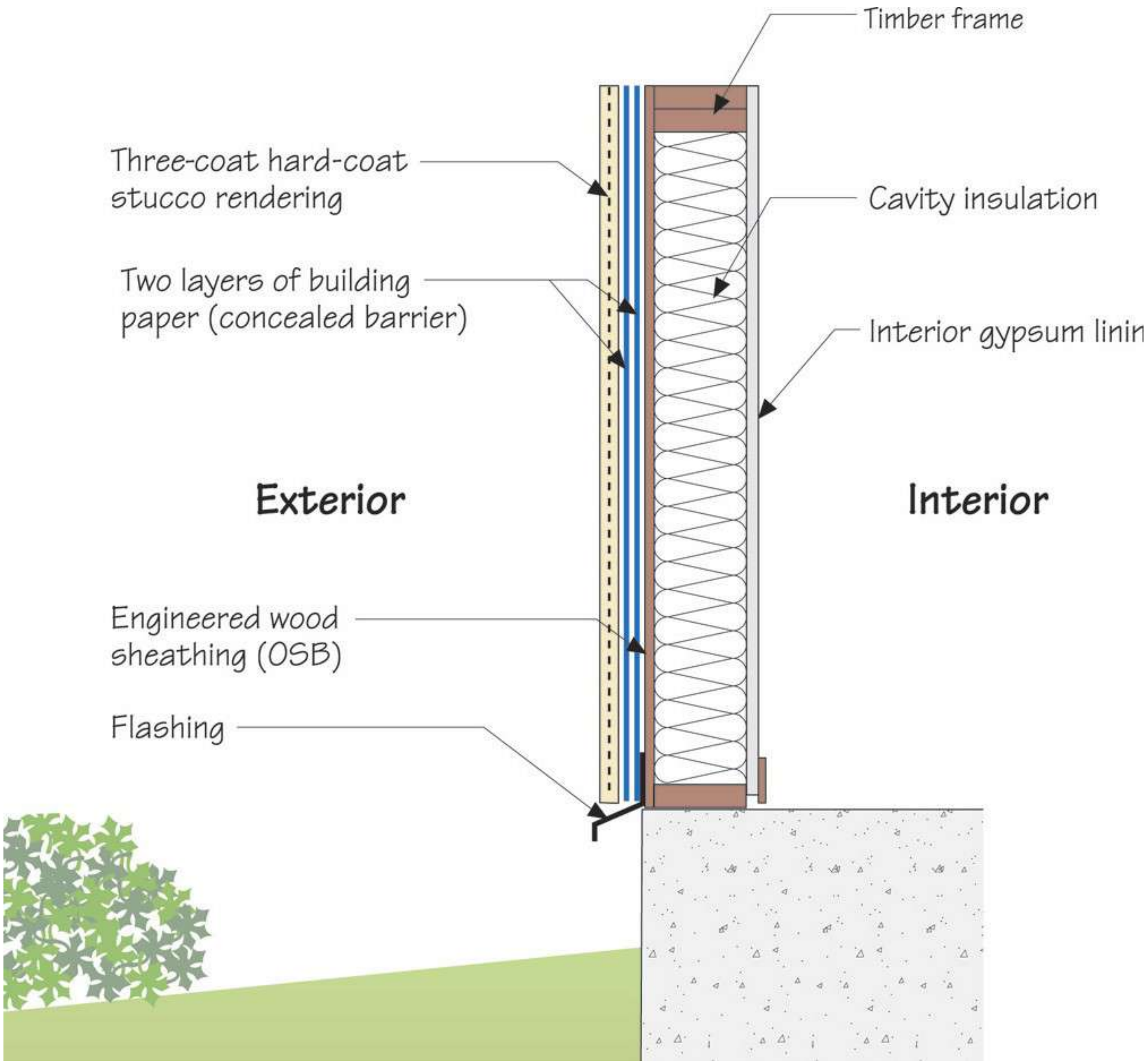

3514
Finish

Side Trip To My Backyard….



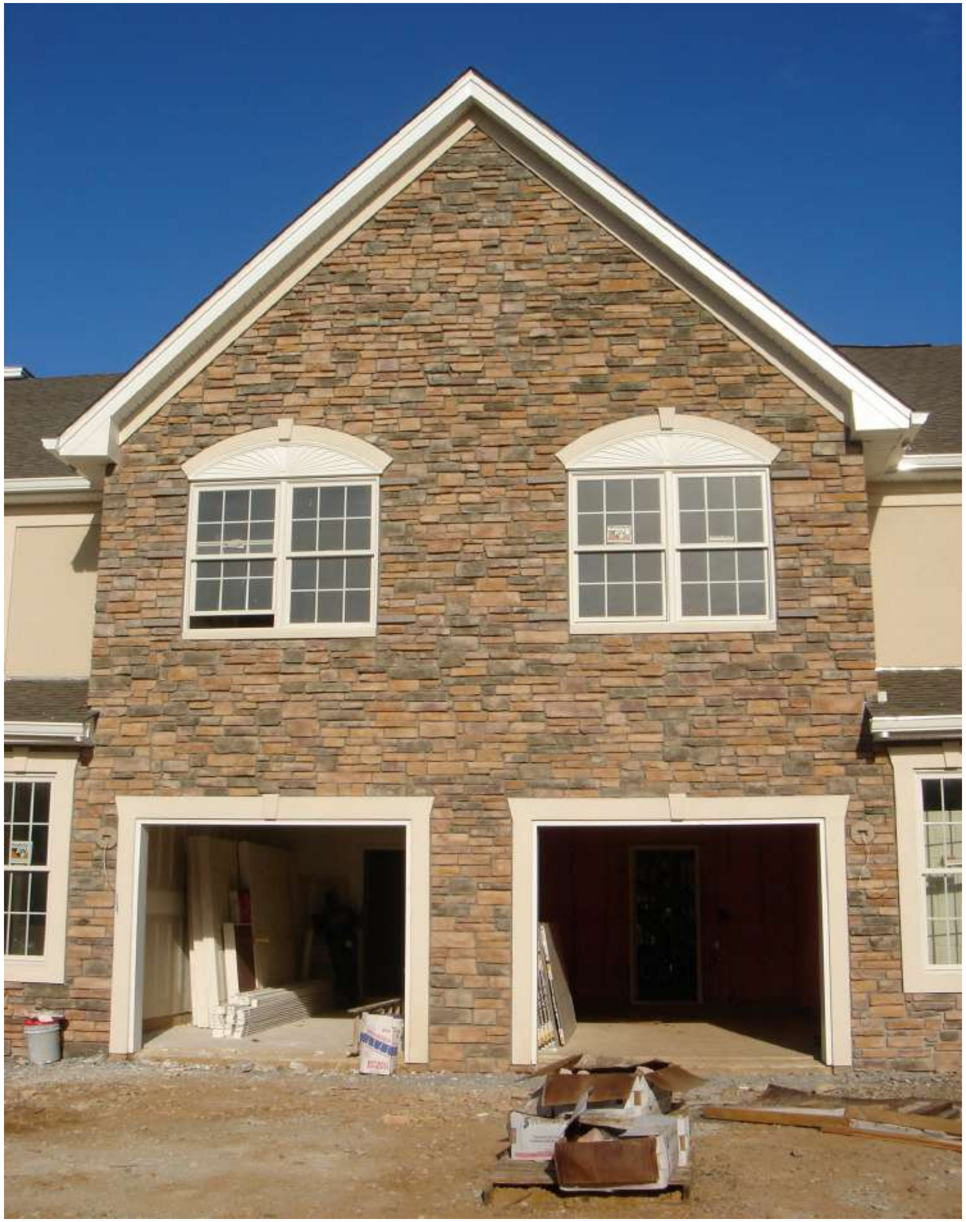



Gypsum
Dealers


Timber frame
Three-coat hard-coat stucco rendering
Cavity insulation
Two layers of building paper (concealed barrier)
Interior gypsum linin
Exterior
Interior
Engineered wood sheathing (OSB)
Flashing

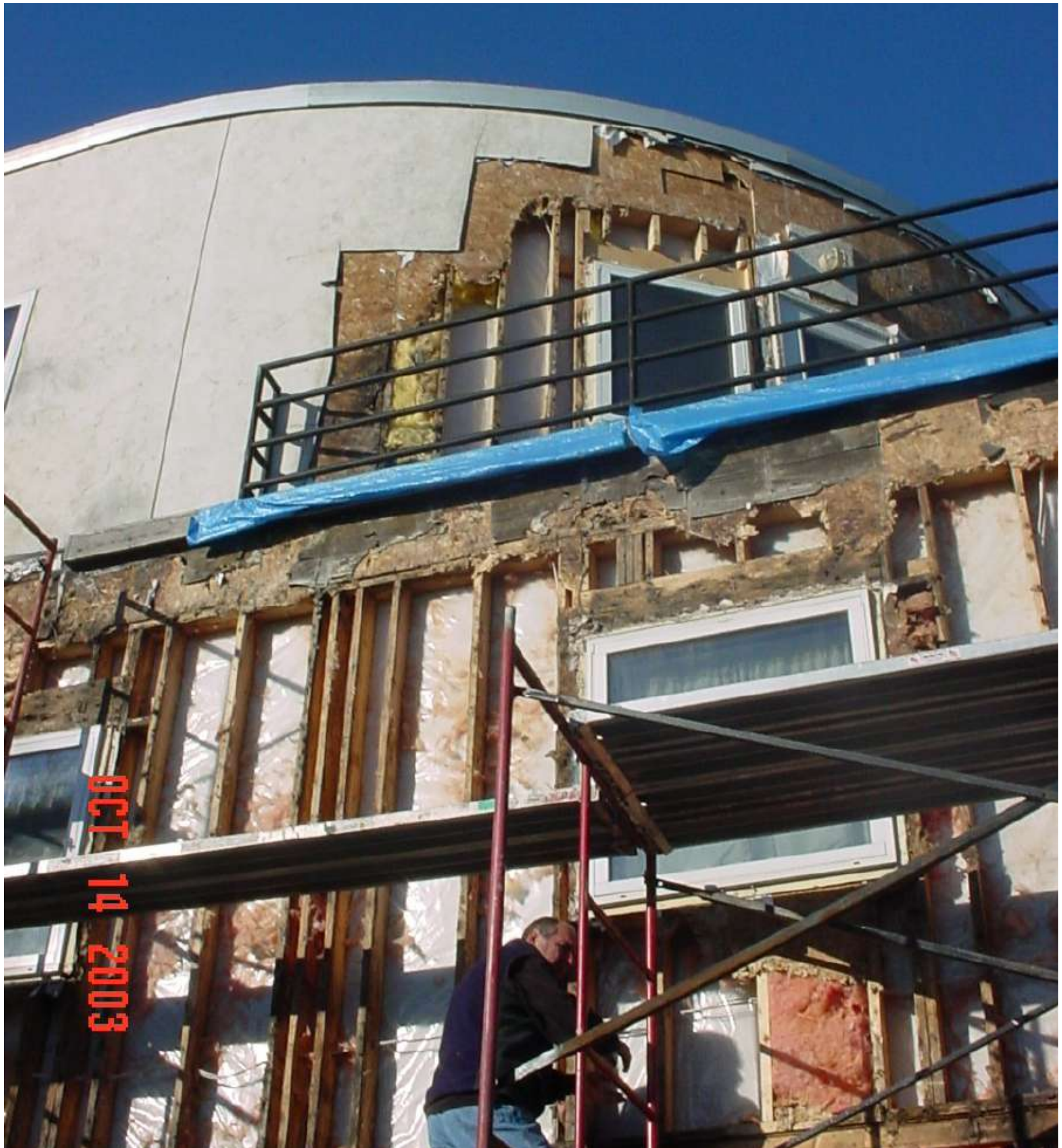
“Lumpy Stucco”….

Should Have Been The Big Warning….



Side Trip To Vancouver….


6'8" CLEARANCE 2.0m


OCT 14 2003


OCT 14 2003


OCT 14 2003

Back To America….Pennslyvania….

And Then Pretty Much Anywhere It Rains…


JLG ULTRA BO
1250AJP


LOWE'S

Back To Lumpy Stucco….

Easy Solution….


Genie Z-60/34


TYVEK.COM

Inward Vapor Drive

Exterior Conditions

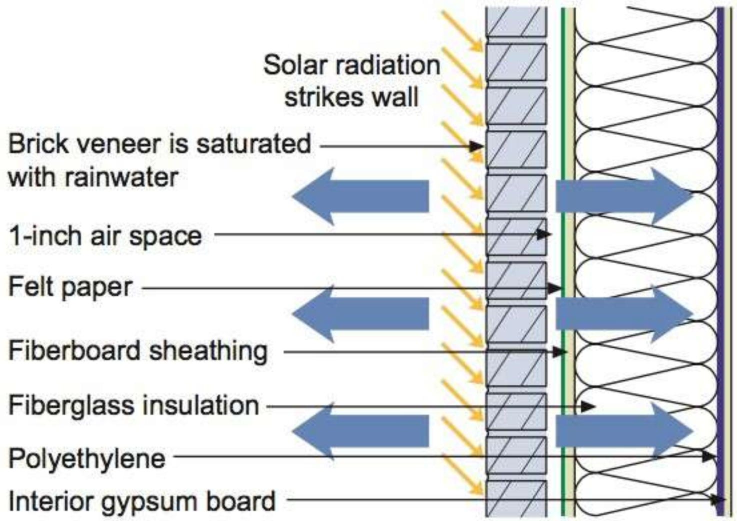
Temperature: 80°F
Relative humidity: 75%
Vapor pressure: 2.49 kPa

Conditions within Cavity:

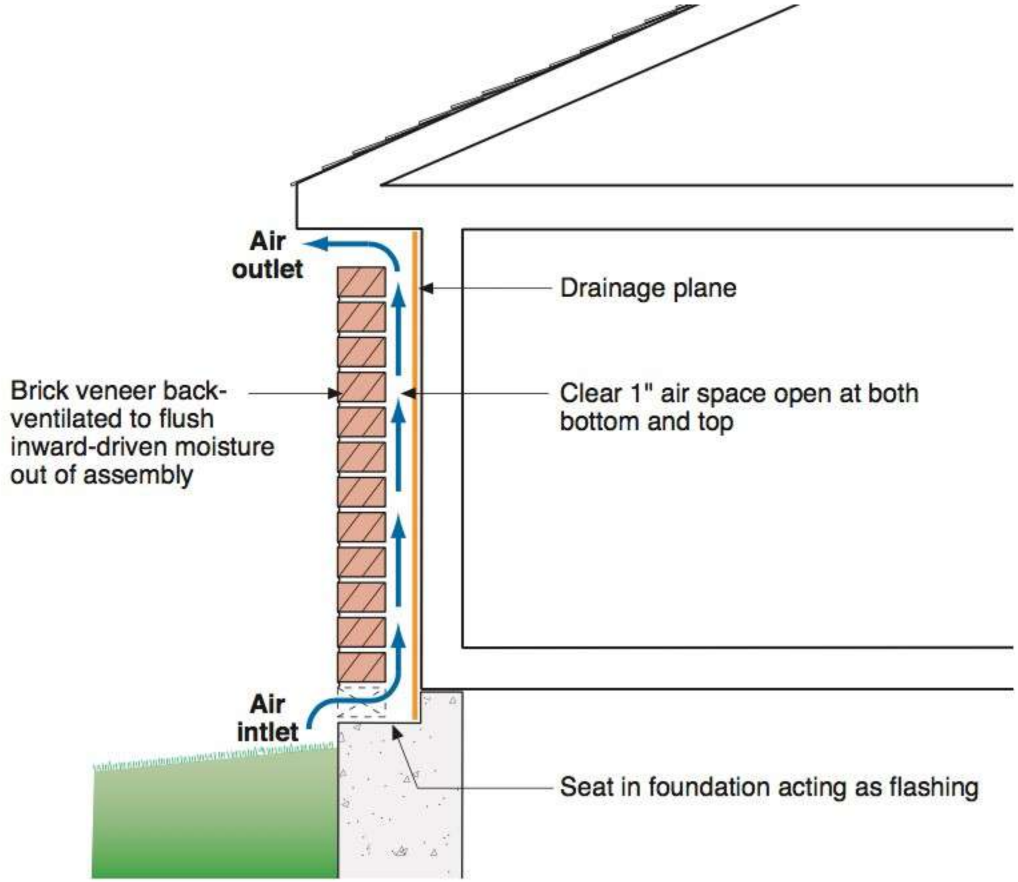
Temperature: 100°F
Relative humidity: 100%
Vapor pressure: 6.45 kPa

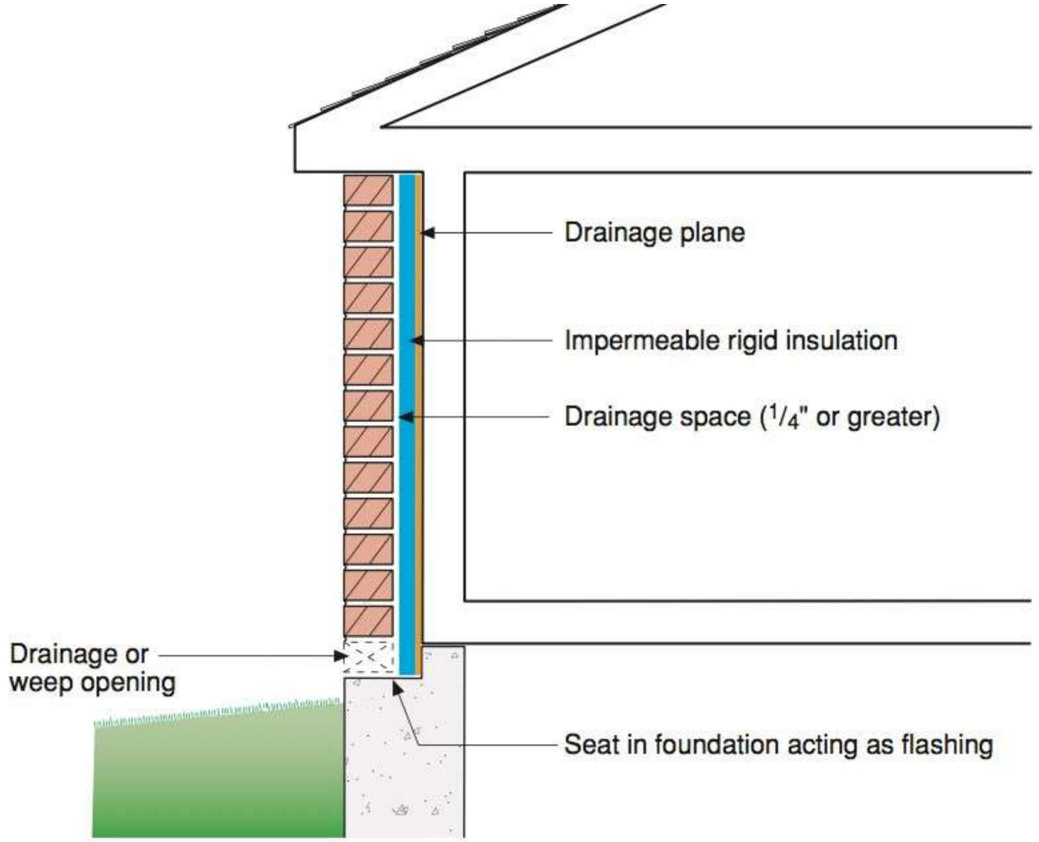
Interior Conditions

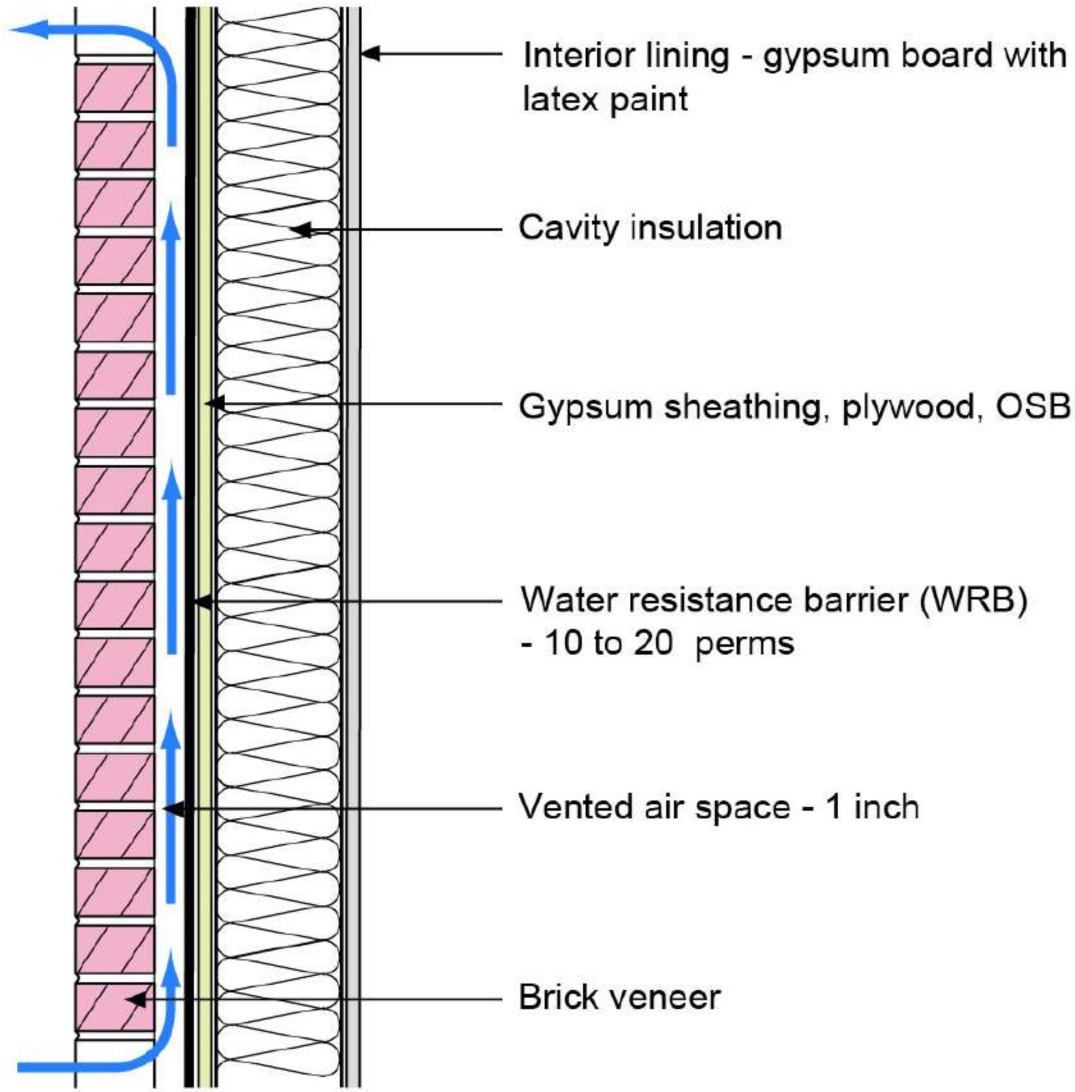
Temperature: 75°F
Relative humidity: 60%
Vapor pressure: 1.82 kPa

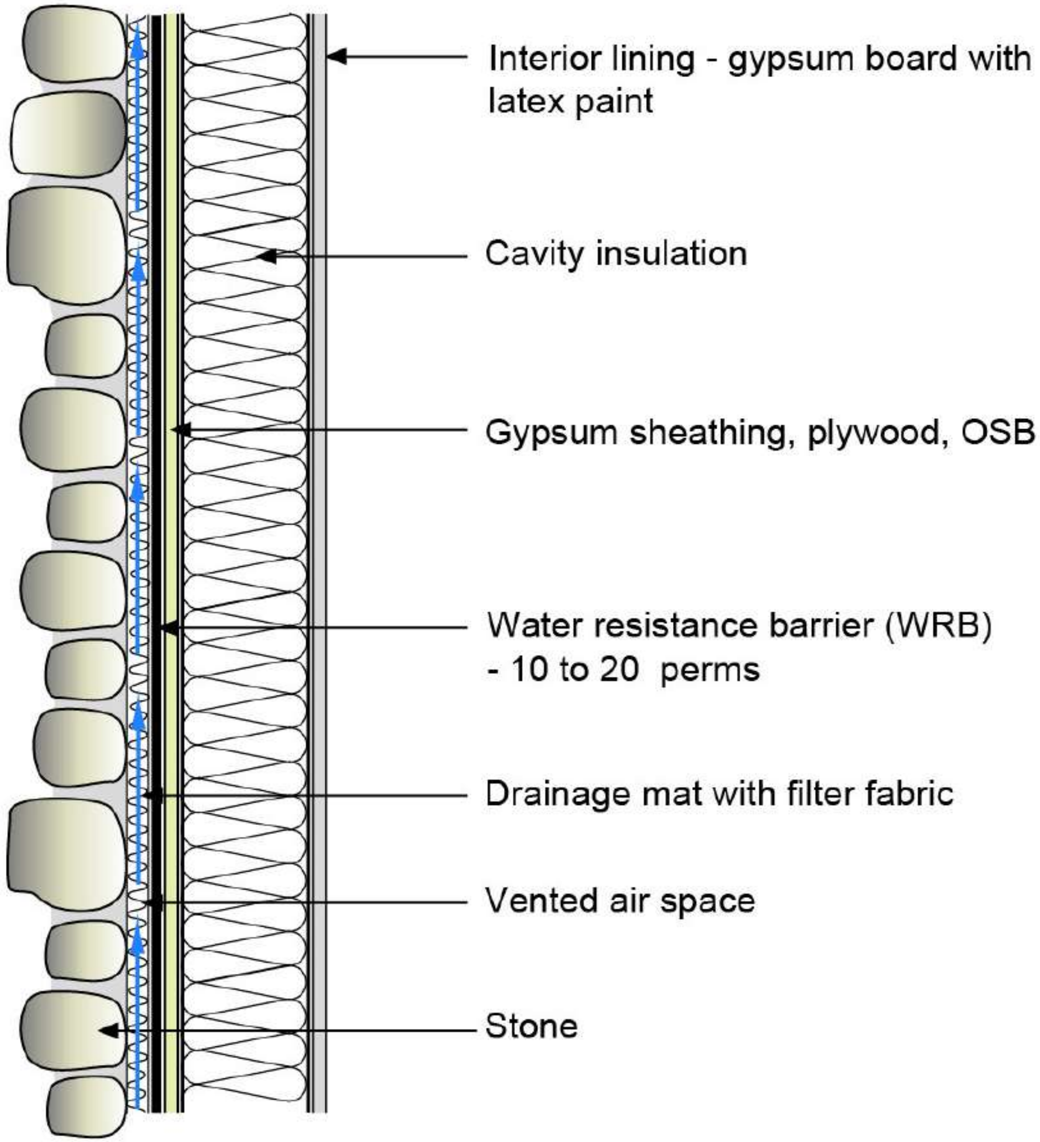


Vapor is driven both inward and outward by a high vapor pressure differential between the brick and the interior and the brick and the exterior.

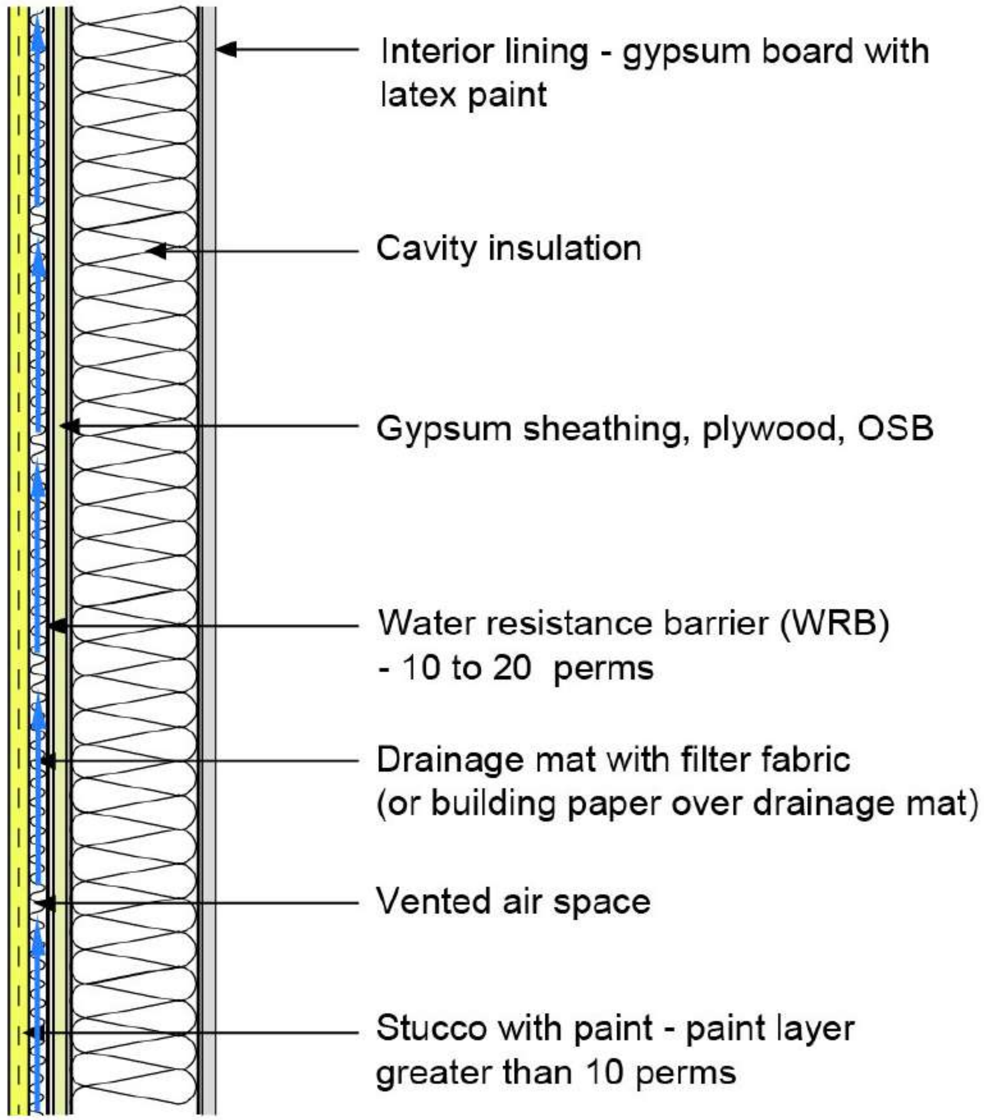

Air
outlet
Drainage plane
Brick veneer back-
ventilated to flush
inward-driven moisture
out of assembly
Clear 1" air space open at both
bottom and top
Air
intlet
Seat in foundation acting as flashing

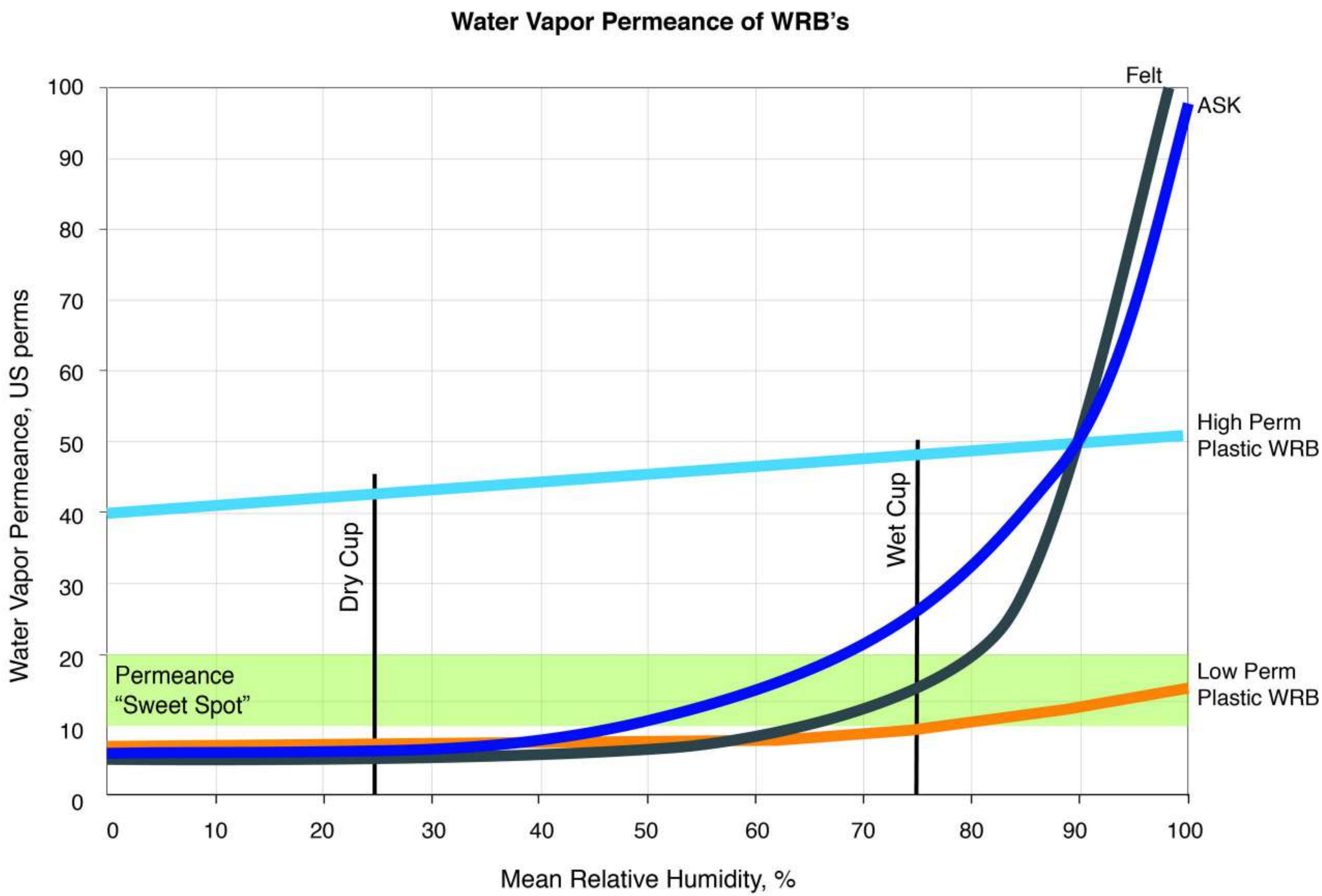

Drainage plane
Impermeable rigid insulation
Drainage space (1/4" or greater)
Drainage or
weep opening
Seat in foundation acting as flashing


Interior lining - gypsum board with latex paint
Cavity insulation
Gypsum sheathing, plywood, OSB
Water resistance barrier (WRB) - 10 to 20 perms
Vented air space - 1 inch
Brick veneer

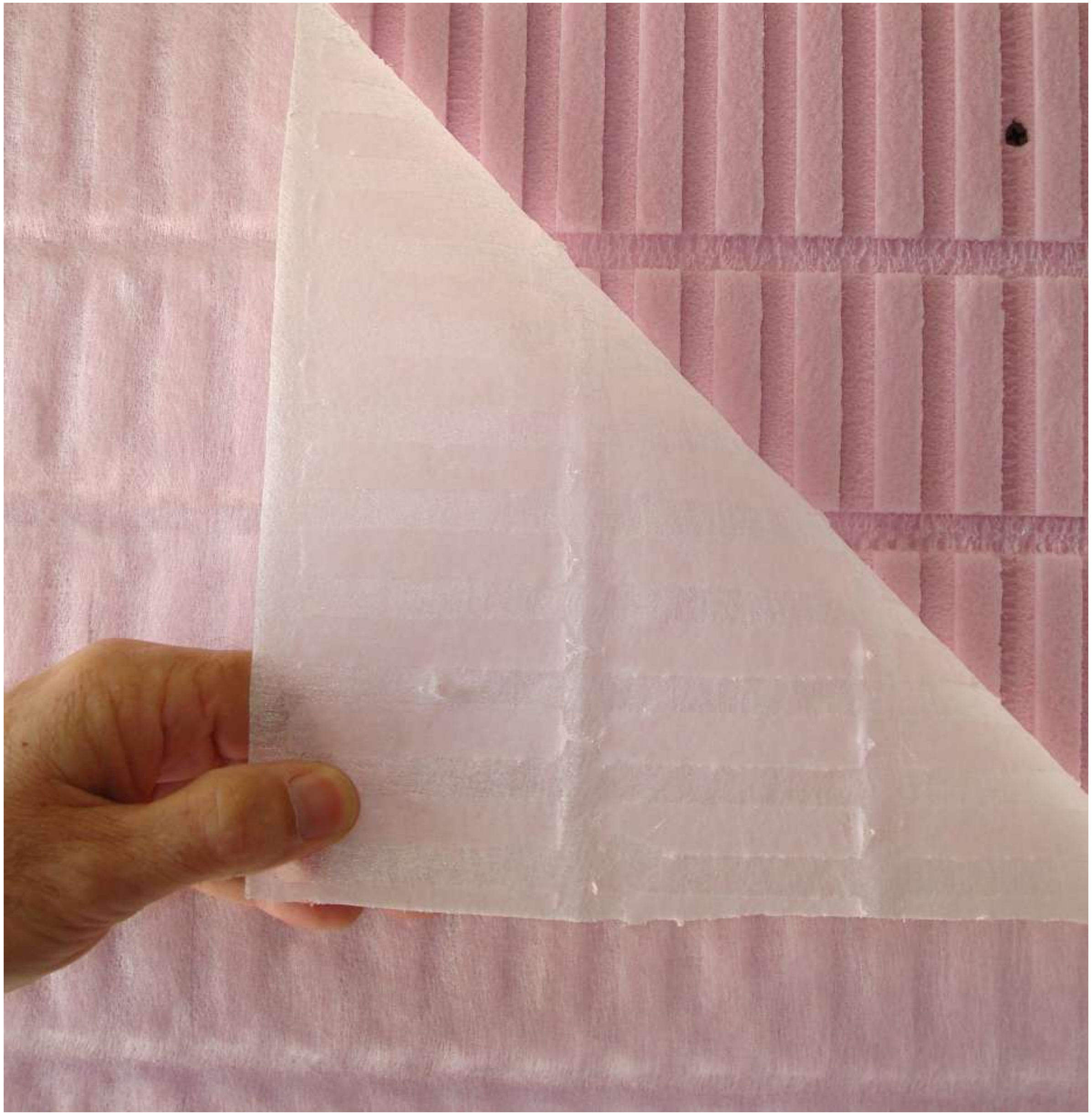


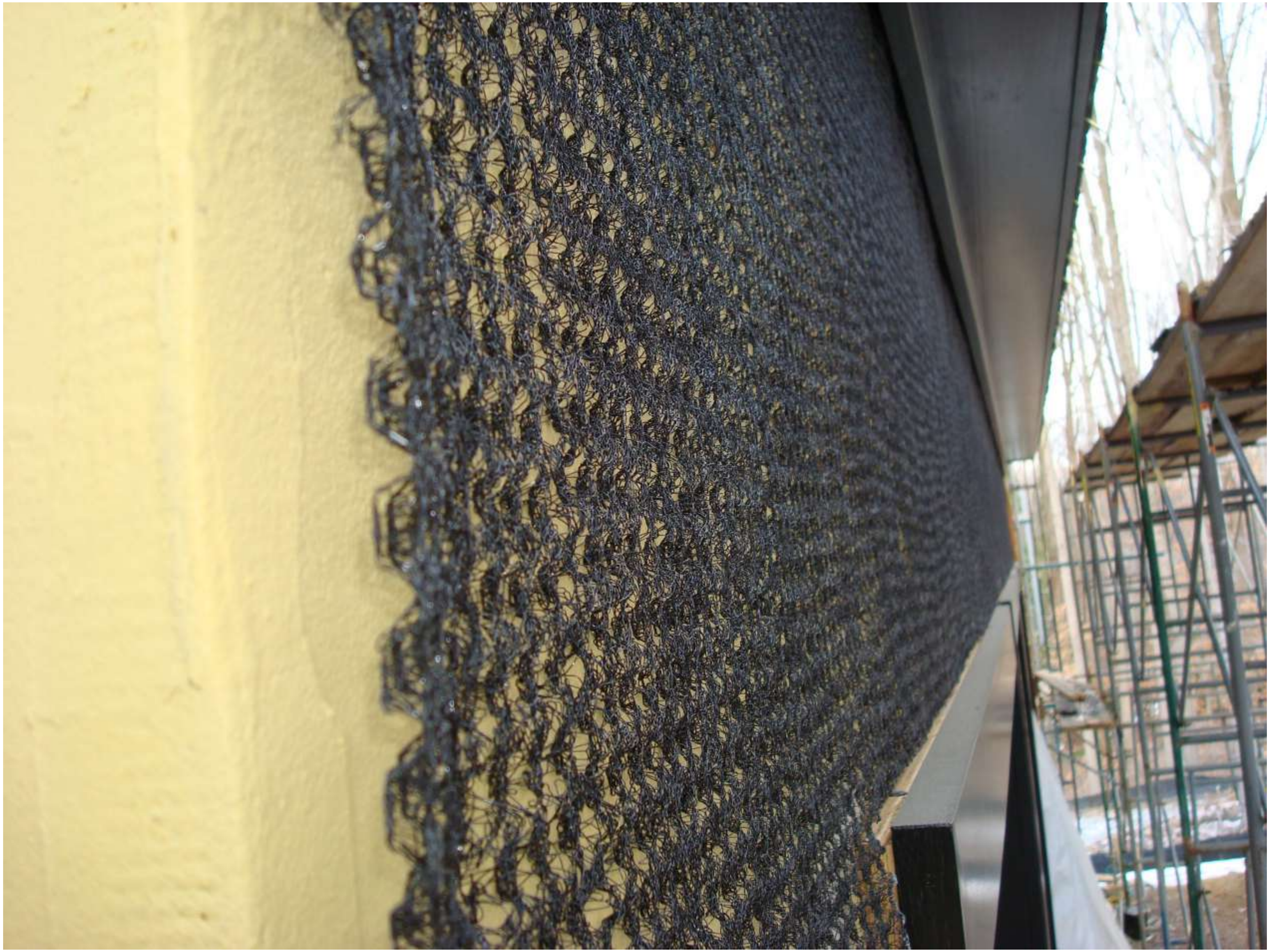
Interior lining - gypsum board with latex paint
Cavity insulation
Gypsum sheathing, plywood, OSB
Water resistance barrier (WRB) - 10 to 20 perms
Drainage mat with filter fabric
Vented air space
Stone


Interior lining - gypsum board with latex paint
Cavity insulation
Gypsum sheathing, plywood, OSB
Water resistance barrier (WRB) - 10 to 20 perms
Drainage mat with filter fabric (or building paper over drainage mat)
Vented air space
Stucco with paint - paint layer greater than 10 perms



Water Vapor Permeance of WRB's
Water Vapor Permeance, US perms
100
90
80
70
60
50
40
30
20
10
0
Mean Relative Humidity, %
0
10
20
30
40
50
60
70
80
90
100
Felt
ASK
High Perm
Plastic WRB
Low Perm
Plastic WRB
Dry Cup
Wet Cup
Permeance
"Sweet Spot"





Recommendations….

Provide a 1/4 inch air space behind all stucco in regions where it rains more than 20 inches per year

Provide a 1/4 inch air space behind all stucco over three stories

Don’t install interior vapor barriers

Air space can be reduced to 1/16 inch where inward vapor drive is limited

Recommendations….

Barrier works in Florida over block

Barrier does not work in Florida over OSB

Don’t install interior vapor barriers in Florida

Don’t drain a drained system into a barrier system

Pressures and IAQ

Definition of a Problem

People

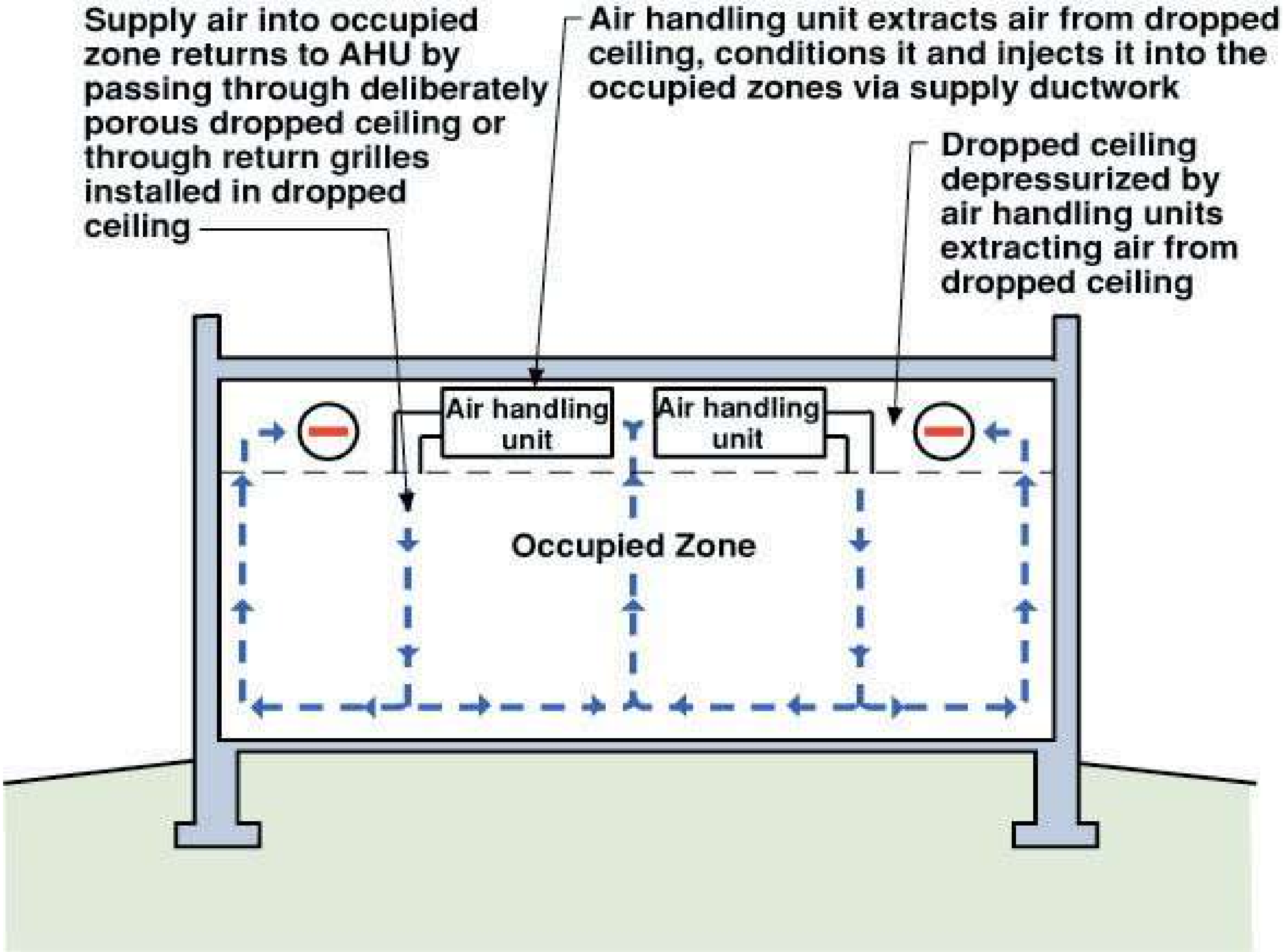
Pollutant (hot, wet, UV, ozone)

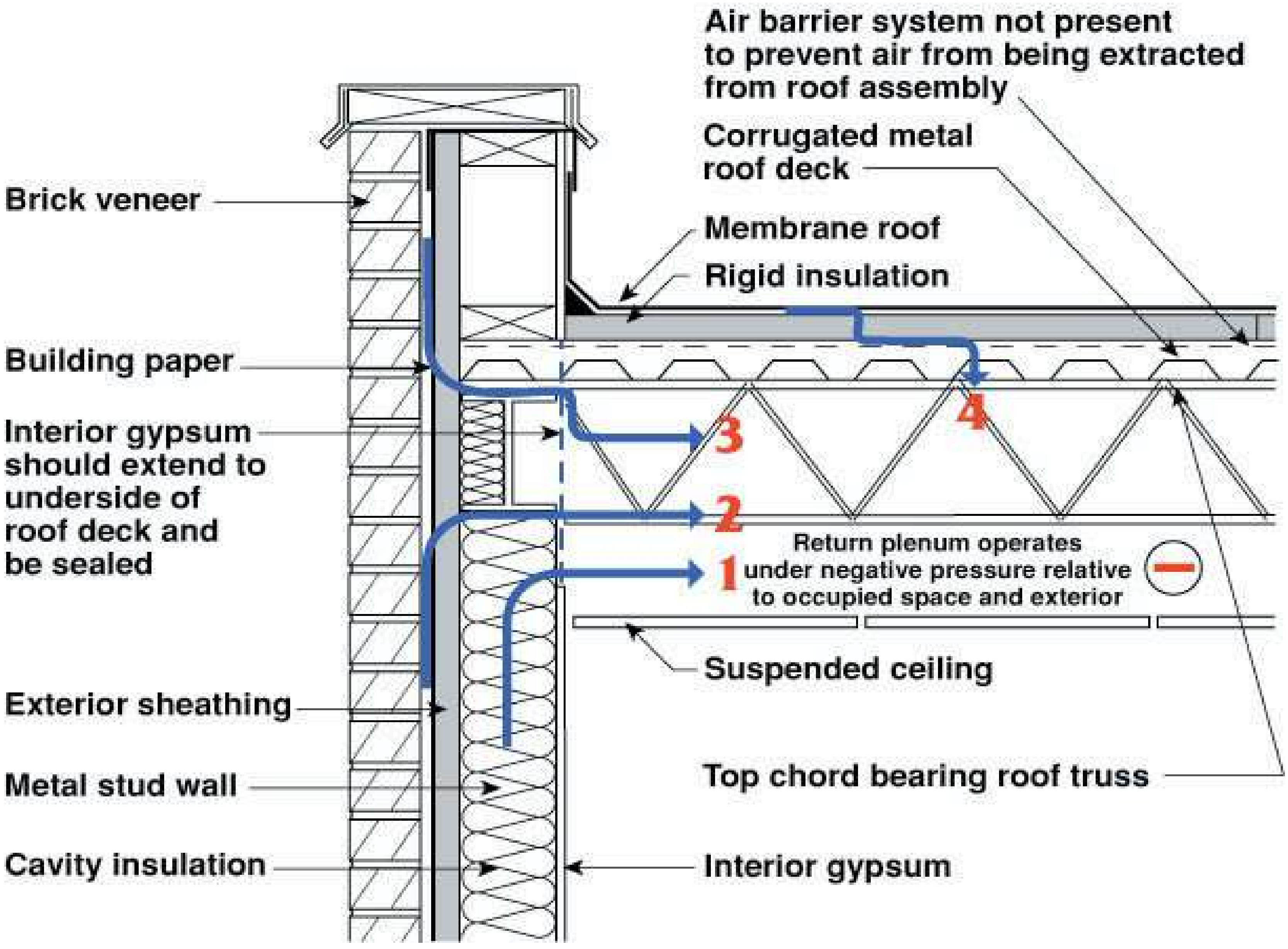
Path

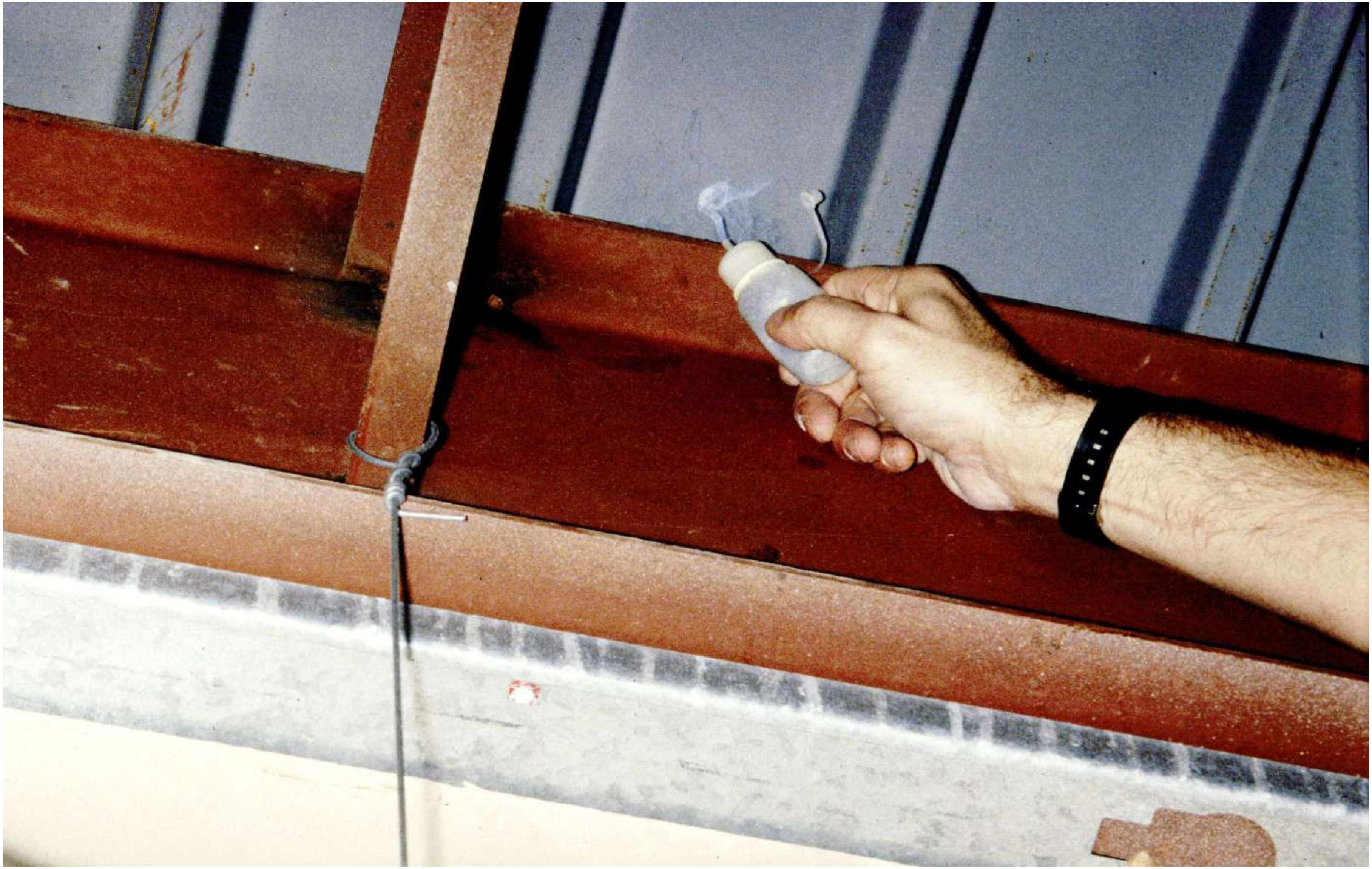
Pressure

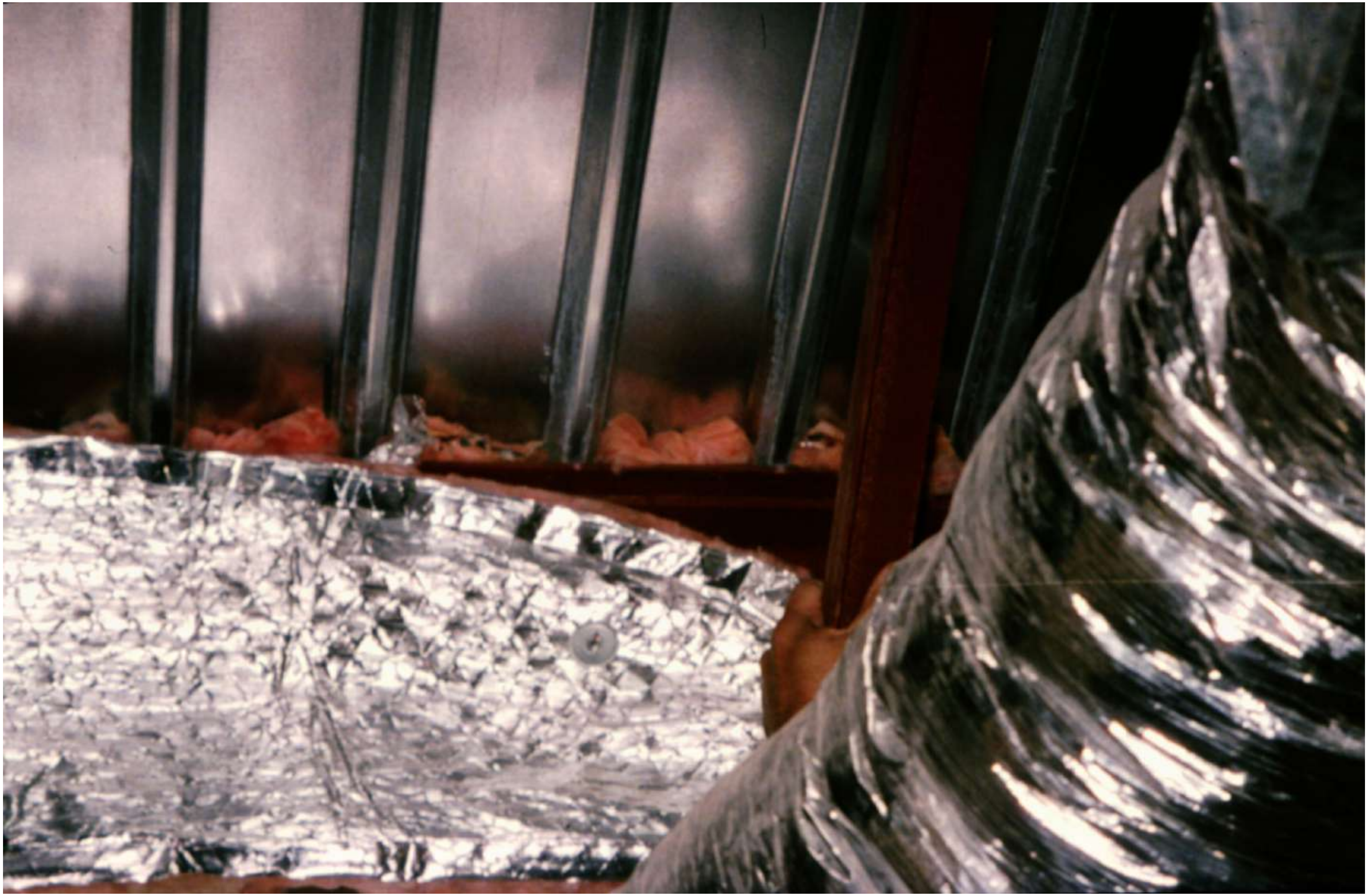

STOP


EXIT


Supply air into occupied zone returns to AHU by passing through deliberately porous dropped ceiling or through return grilles installed in dropped ceiling
Air handling unit extracts air from dropped ceiling, conditions it and injects it into the occupied zones via supply ductwork
Dropped ceiling depressurized by air handling units extracting air from dropped ceiling
Air handling unit
Air handling unit
Occupied Zone

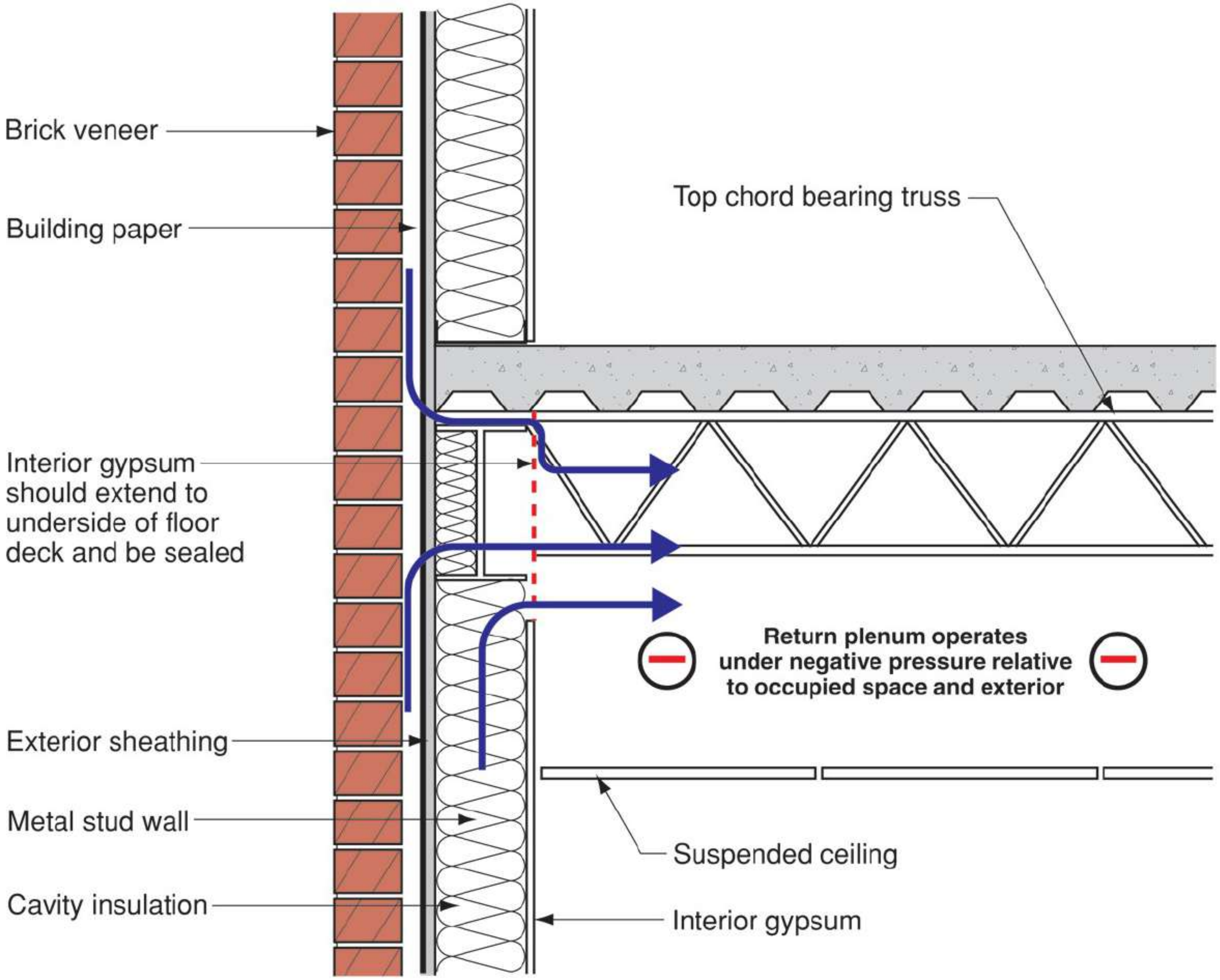

Air barrier system not present to prevent air from being extracted from roof assembly
Corrugated metal roof deck
Membrane roof
Rigid insulation
Brick veneer
Building paper
Interior gypsum should extend to underside of roof deck and be sealed
3
4
2
1
Return plenum operates under negative pressure relative to occupied space and exterior
Suspended ceiling
Exterior sheathing
Metal stud wall
Top chord bearing roof truss
Cavity insulation
Interior gypsum

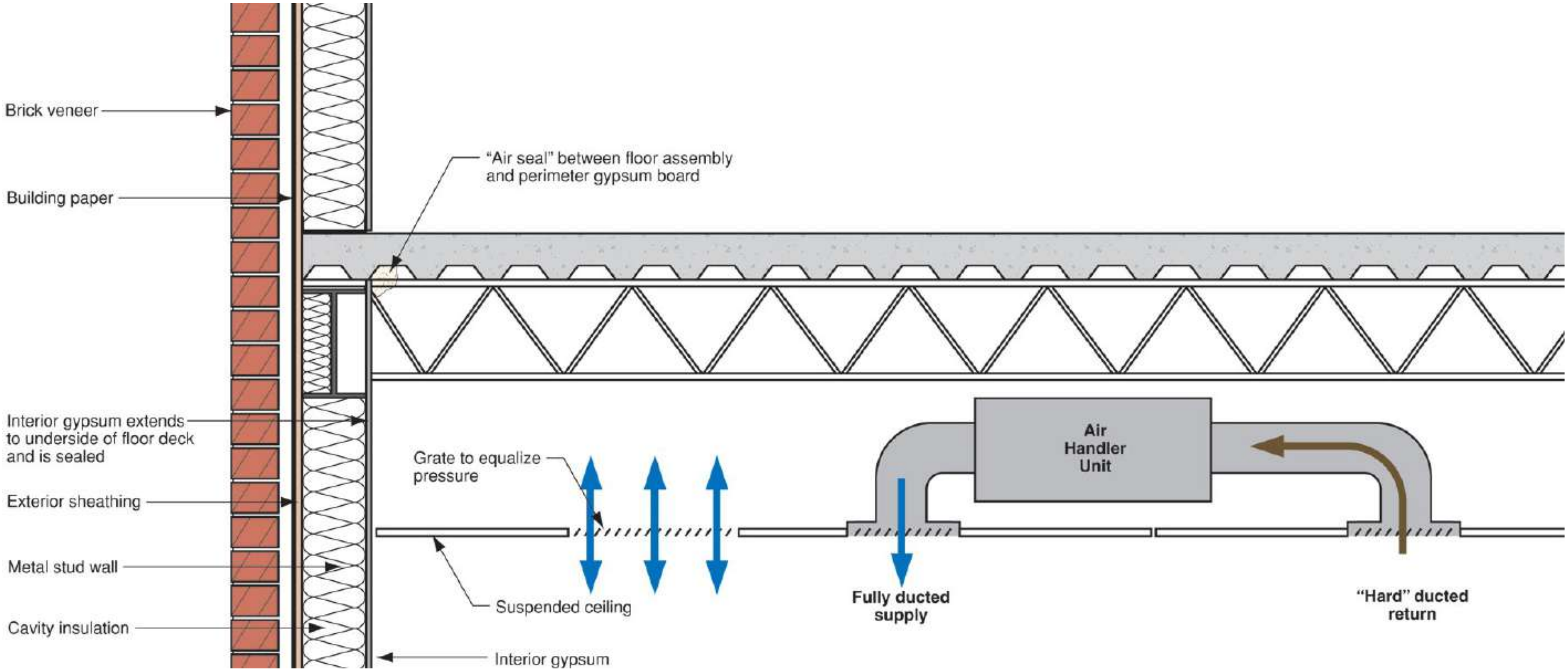


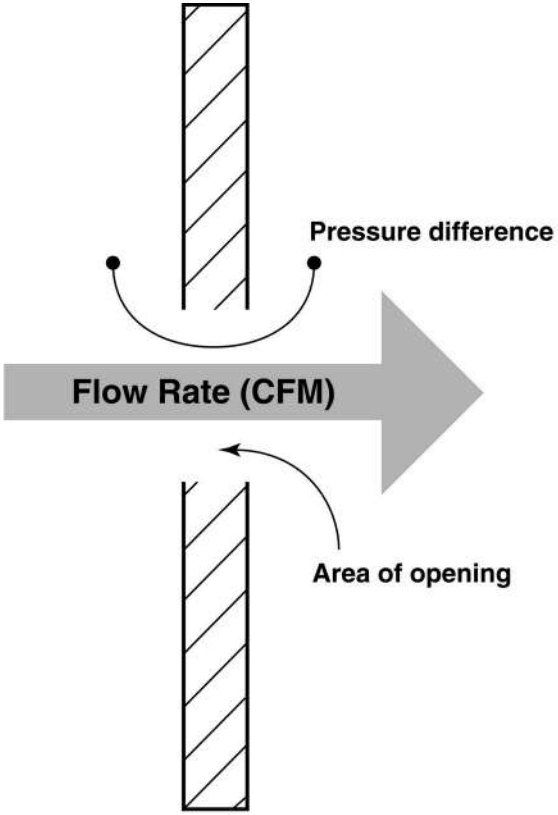



Tyvek

RE COMPANY


Brick veneer
Building paper
Top chord bearing truss
Interior gypsum should extend to underside of floor deck and be sealed
Return plenum operates under negative pressure relative to occupied space and exterior
Exterior sheathing
Metal stud wall
Cavity insulation
Suspended ceiling
Interior gypsum


Brick veneer
Building paper
"Air seal" between floor assembly
and perimeter gypsum board
Interior gypsum extends
to underside of floor deck
and is sealed
Exterior sheathing
Metal stud wall
Cavity insulation
Grate to equalize
pressure
Suspended ceiling
Interior gypsum
Air
Handler
Unit
Fully ducted
supply
"Hard" ducted
return



Air Flow

- Air flow depends on size of hole
- Air flow depends on pressure difference

  $$\text{Flow} \cong \text{Area} \times \sqrt{\Delta P} \times \text{Coefficient}$$
- Air flows from higher pressure to lower pressure

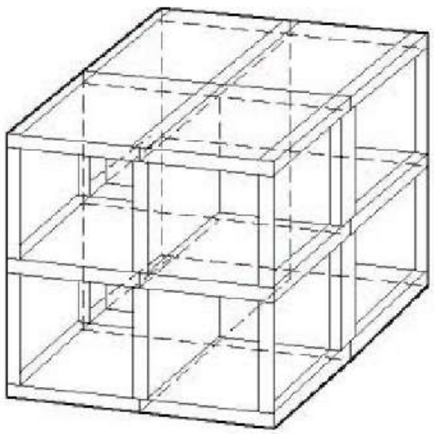


Figure 2.11
Three Dimensional Multi-Layer Multi-Cell Analogue

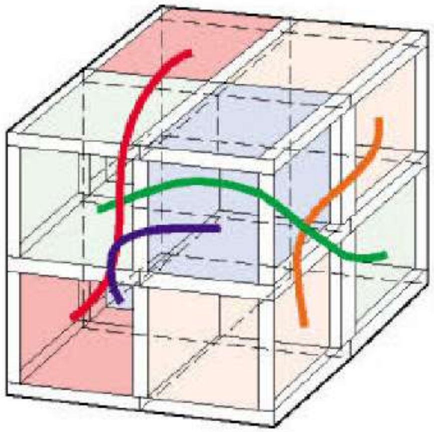
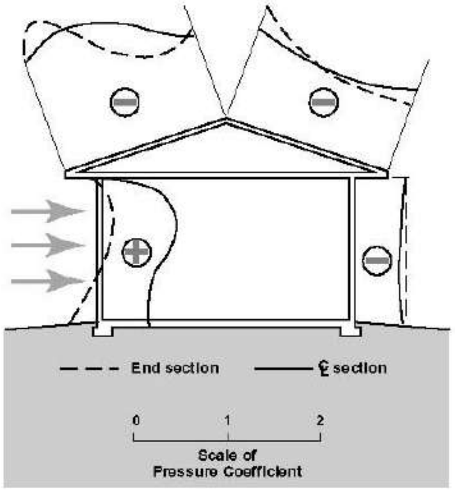


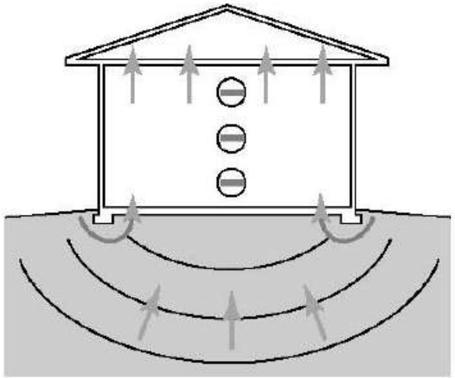
Figure 2.12
Three Dimensional Multi-Layer Multi-Cell Non-Contiguous Analogue

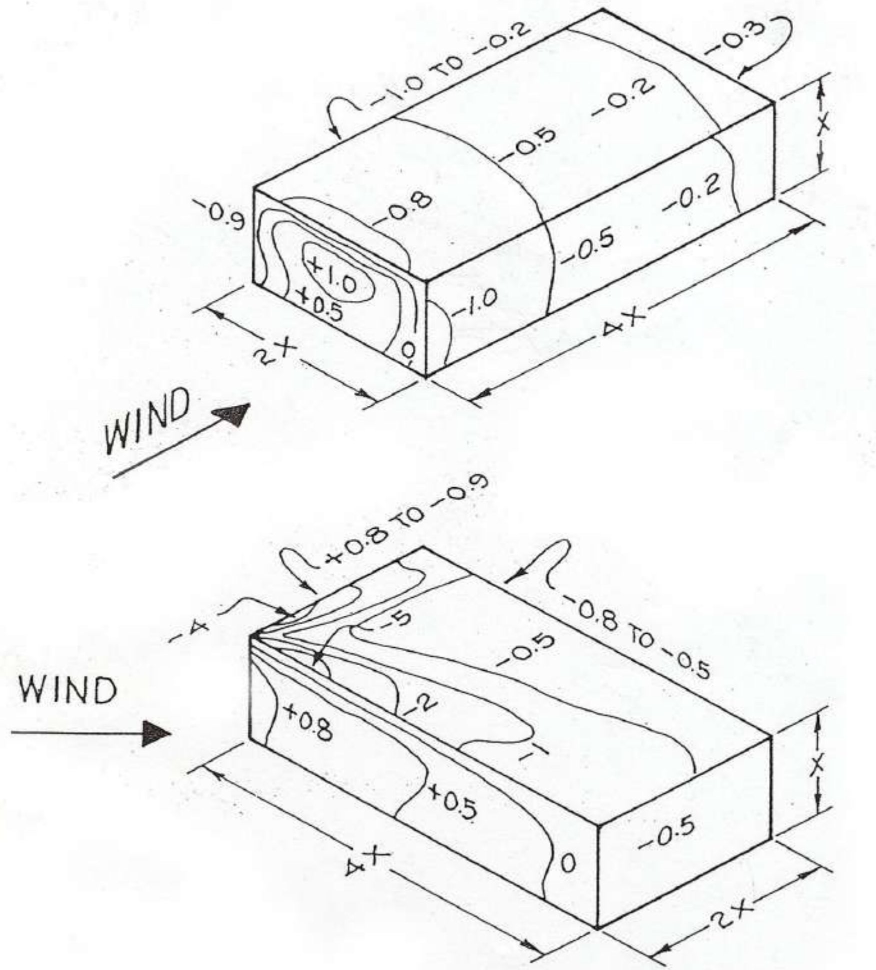
Figure 3.1
Exterior Air Pressure Field
(from Hutcheon & Handegord, 1983)



Distribution of pressures (+) and suctions (-) on a house with a low-sloped roof with wind perpendicular to eave

Figure 3.2
Exterior Air Pressure Field Extending Below Grade





Pressure coefficients on walls and roof of rectangular buildings without parapets.

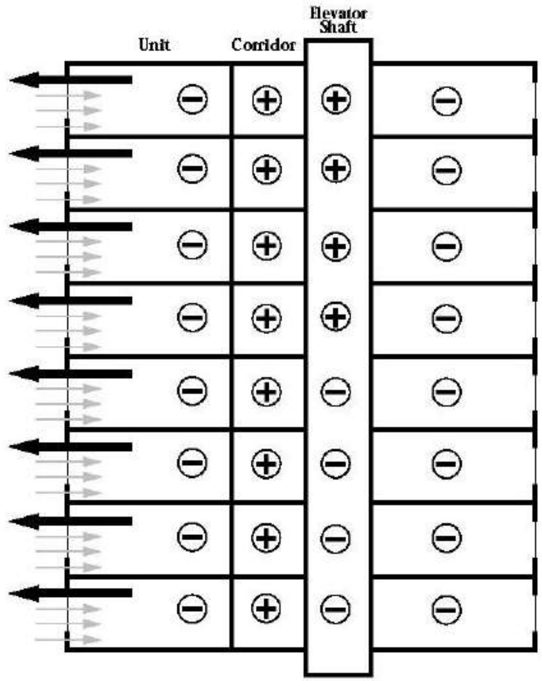


Figure 3.3
Interior Air Pressure Field

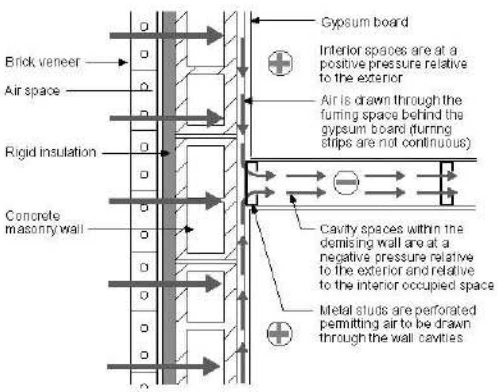


Figure 3.4
Interstitial Air Pressure Field

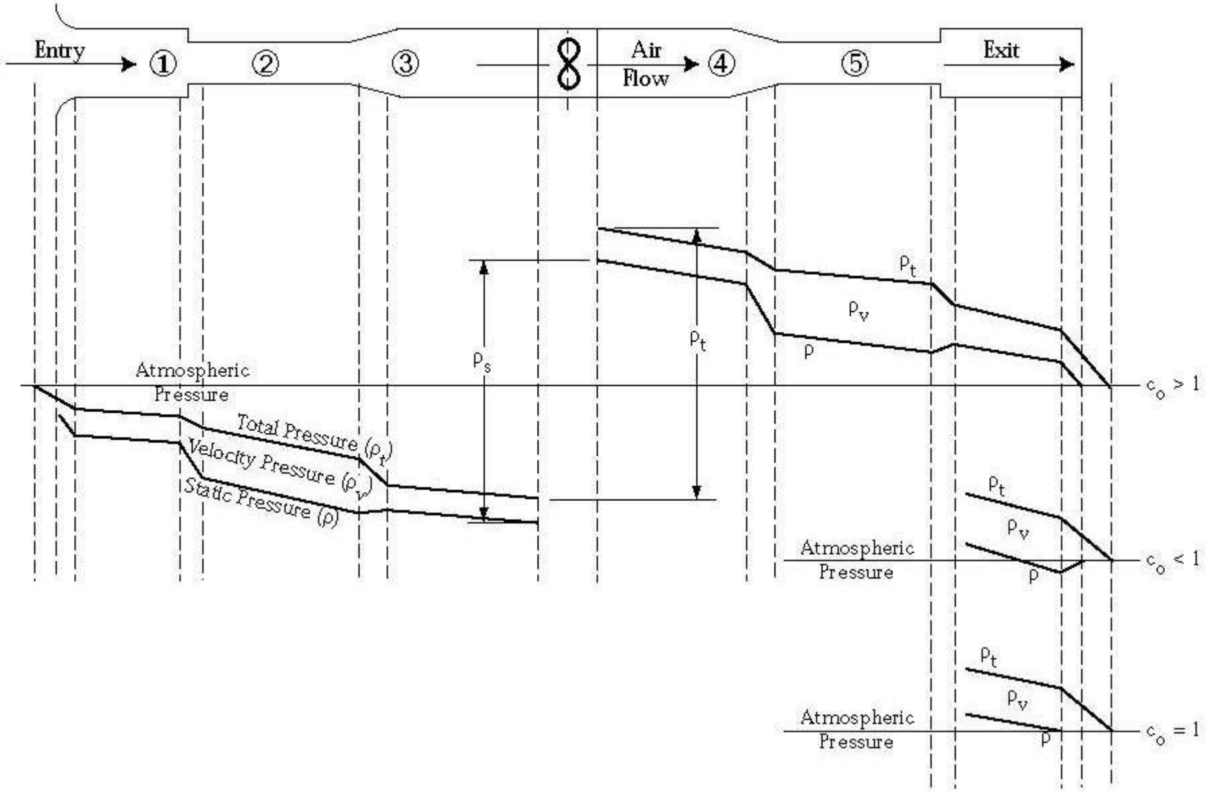


Figure 3.5
Air Conveyance System Air Pressure Field
(from Sauer & Howell, 1990)

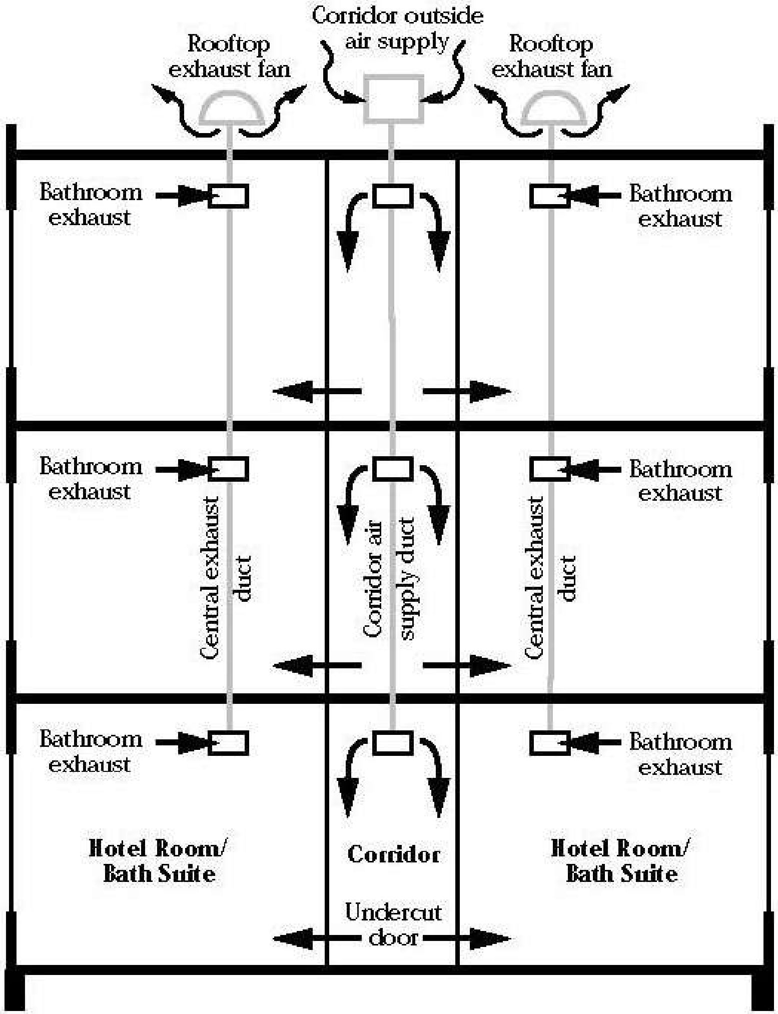
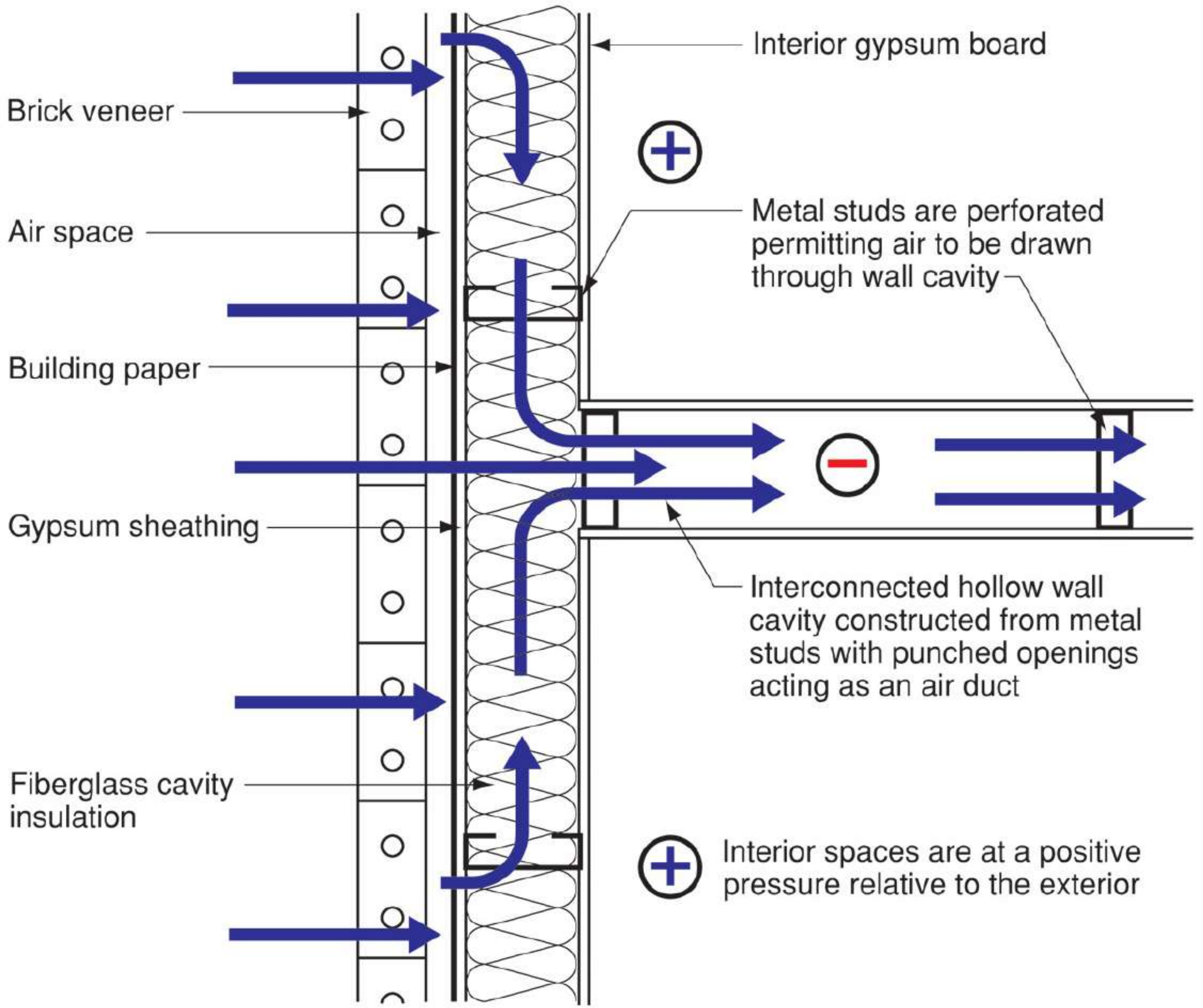
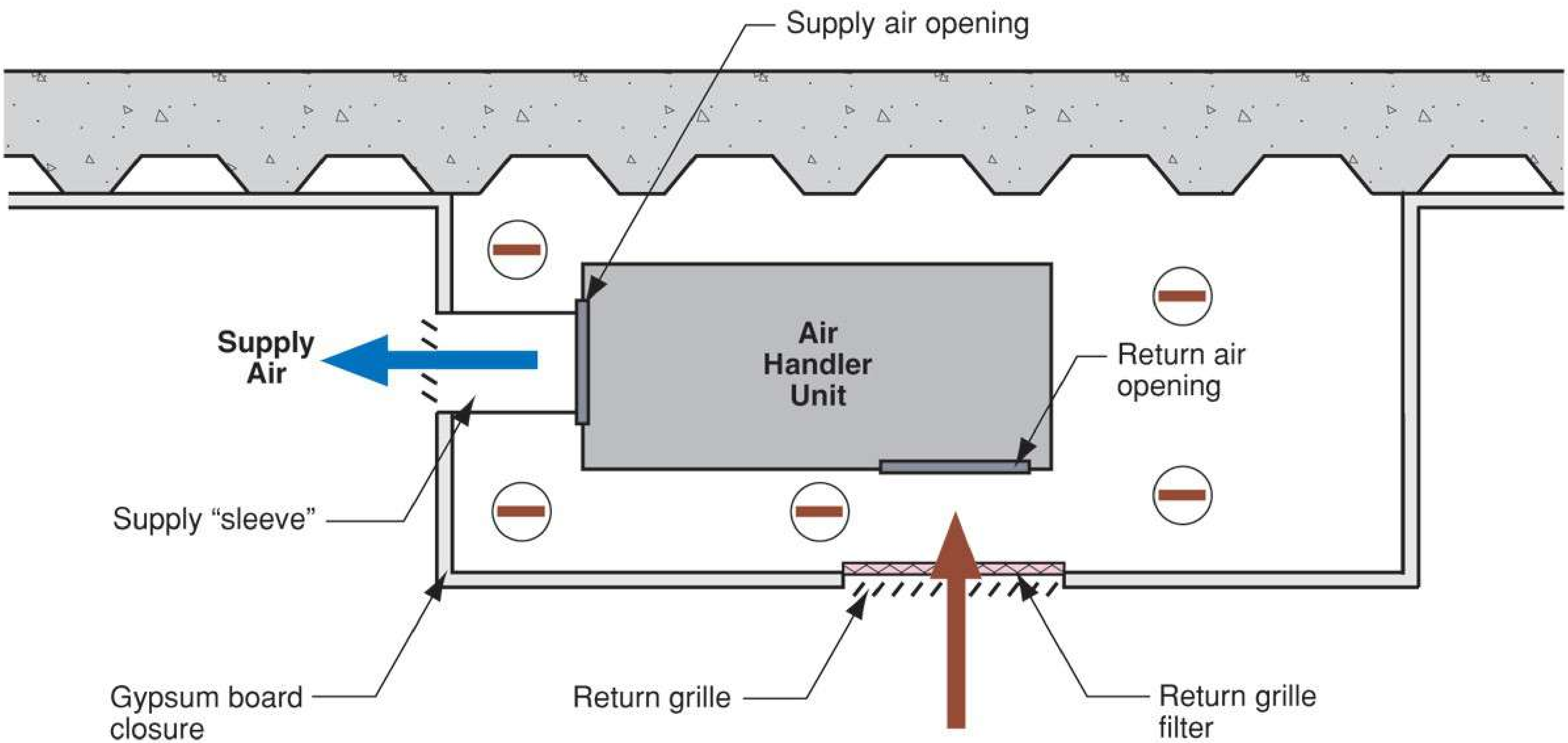


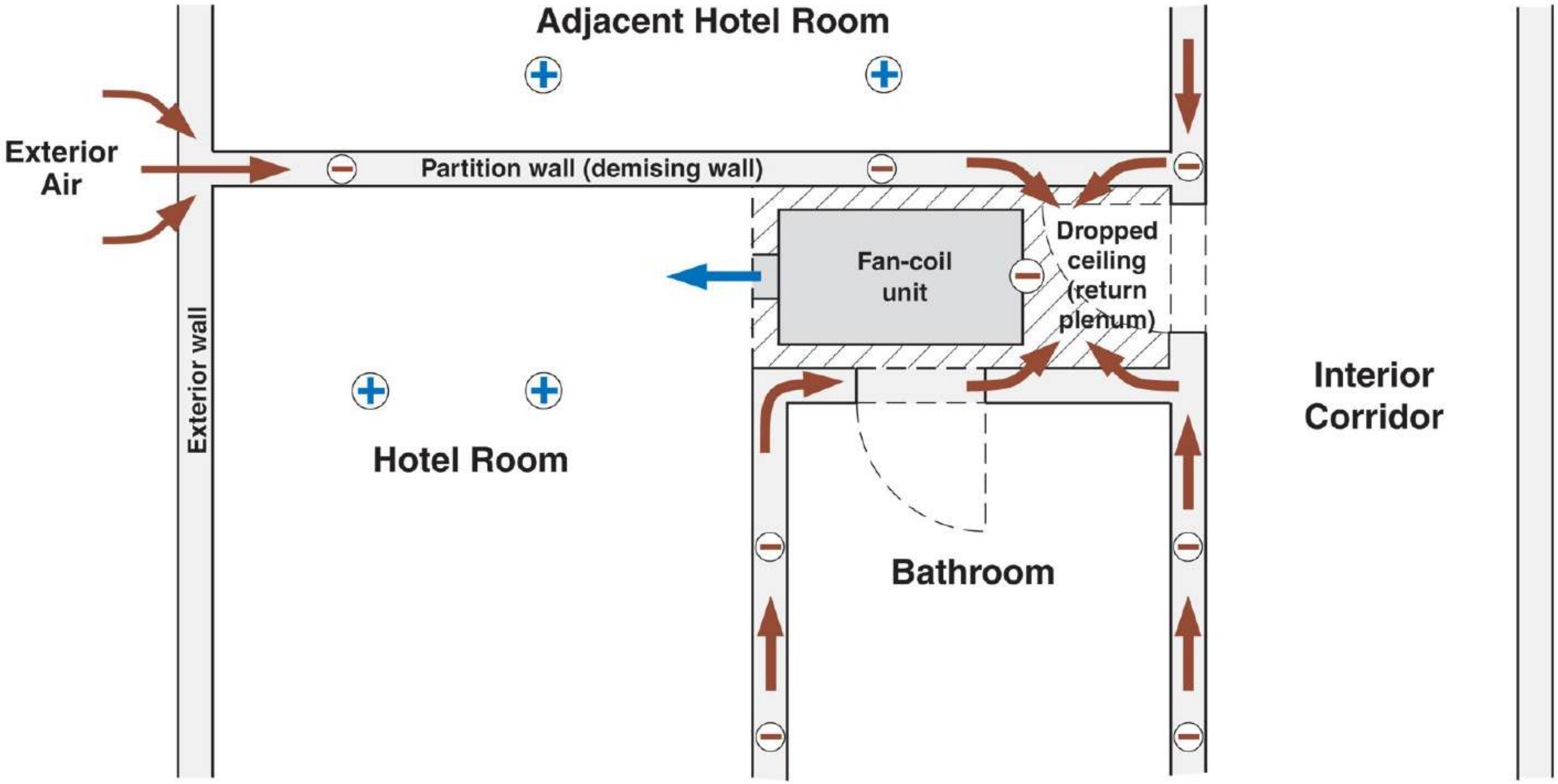
Figure 3.8

Hotel HVAC System

- Air exhausted from bathrooms via central rooftop exhaust fans
- Air supplied from corridors via undercut doors


Interior gypsum board
Brick veneer
Air space
Metal studs are perforated permitting air to be drawn through wall cavity
Building paper
Gypsum sheathing
Interconnected hollow wall cavity constructed from metal studs with punched openings acting as an air duct
Fiberglass cavity insulation
Interior spaces are at a positive pressure relative to the exterior


Supply air opening
Supply
Air
Air
Handler
Unit
Return air
opening
Supply "sleeve"
Gypsum board
closure
Return grille
Return grille
filter


Adjacent Hotel Room
Exterior
Air
Partition wall (demising wall)
Fan-coil
unit
Dropped
ceiling
(return
plenum)
Exterior wall
Hotel Room
Interior
Corridor
Bathroom

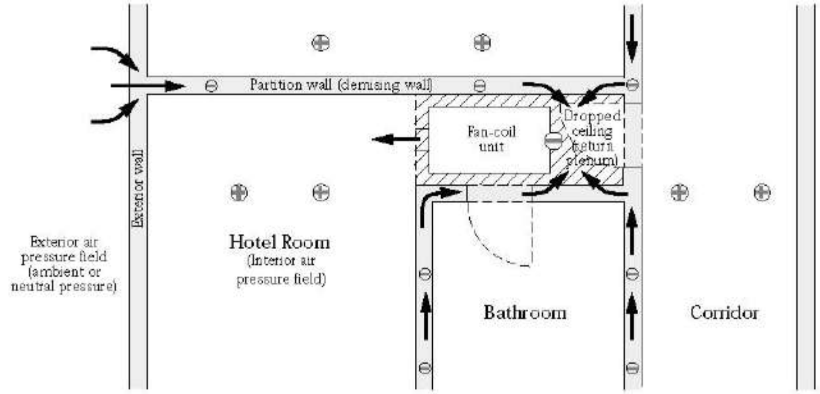


Figure 3.10
Pressure Field Due to Fan-Coil Unit
Plan View

- Room is at positive air pressure relative to exterior-driven air from corridor and air supplied to room from fan-coil unit pulling air from exterior through the demising wall
- Fan-coil unit depressurizes dropped ceiling assembly due to return plenum design
- Demising wall cavity pulled negative due to connection to dropped ceiling return plenum

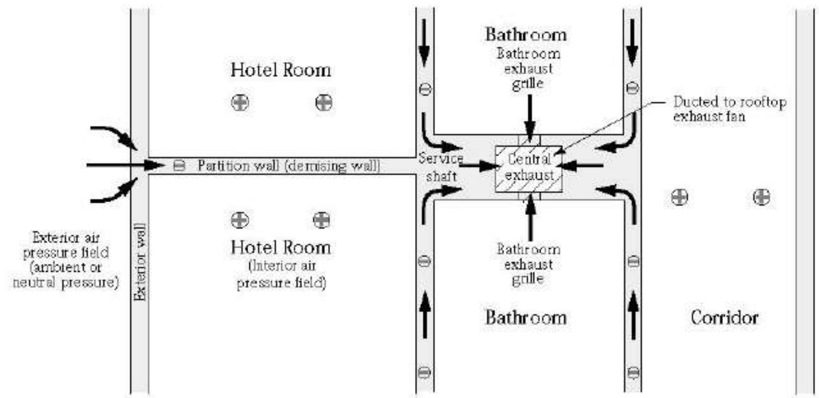
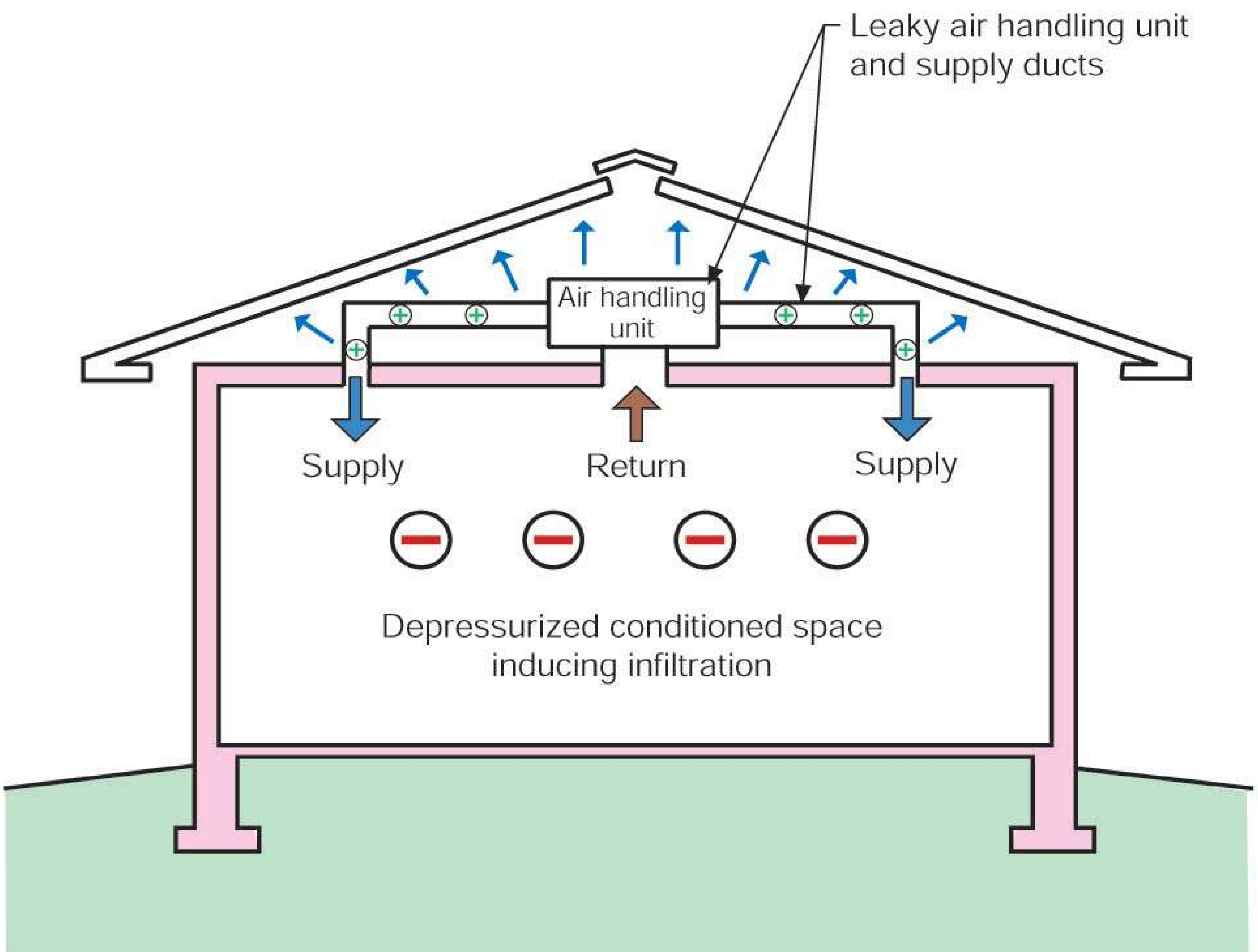


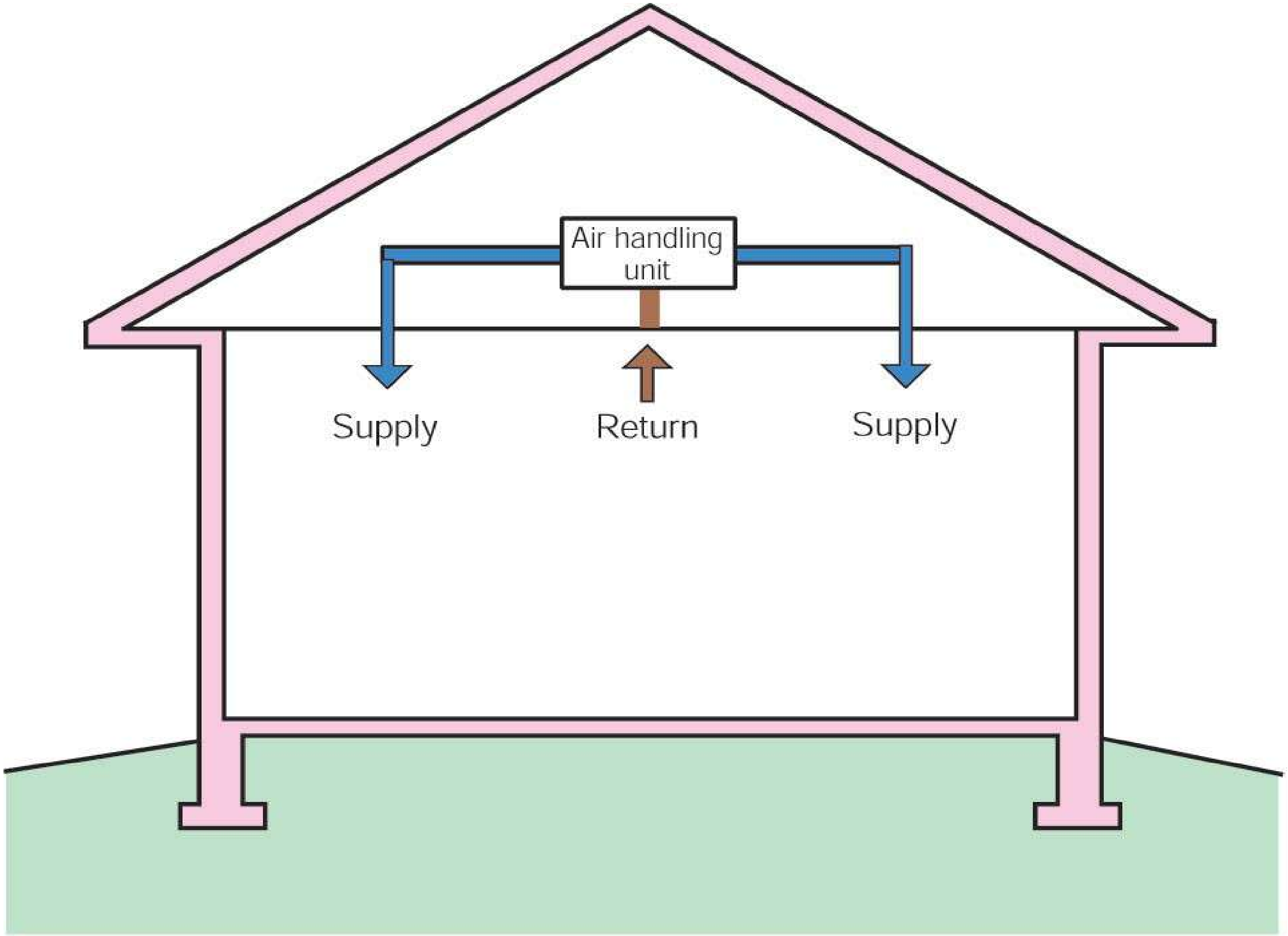
Figure 3.11
Pressure Field Due to Central Exhaust
Plan View

- Leakage of central exhaust duct pulls air out of service shaft depressurizing shaft and demising walls

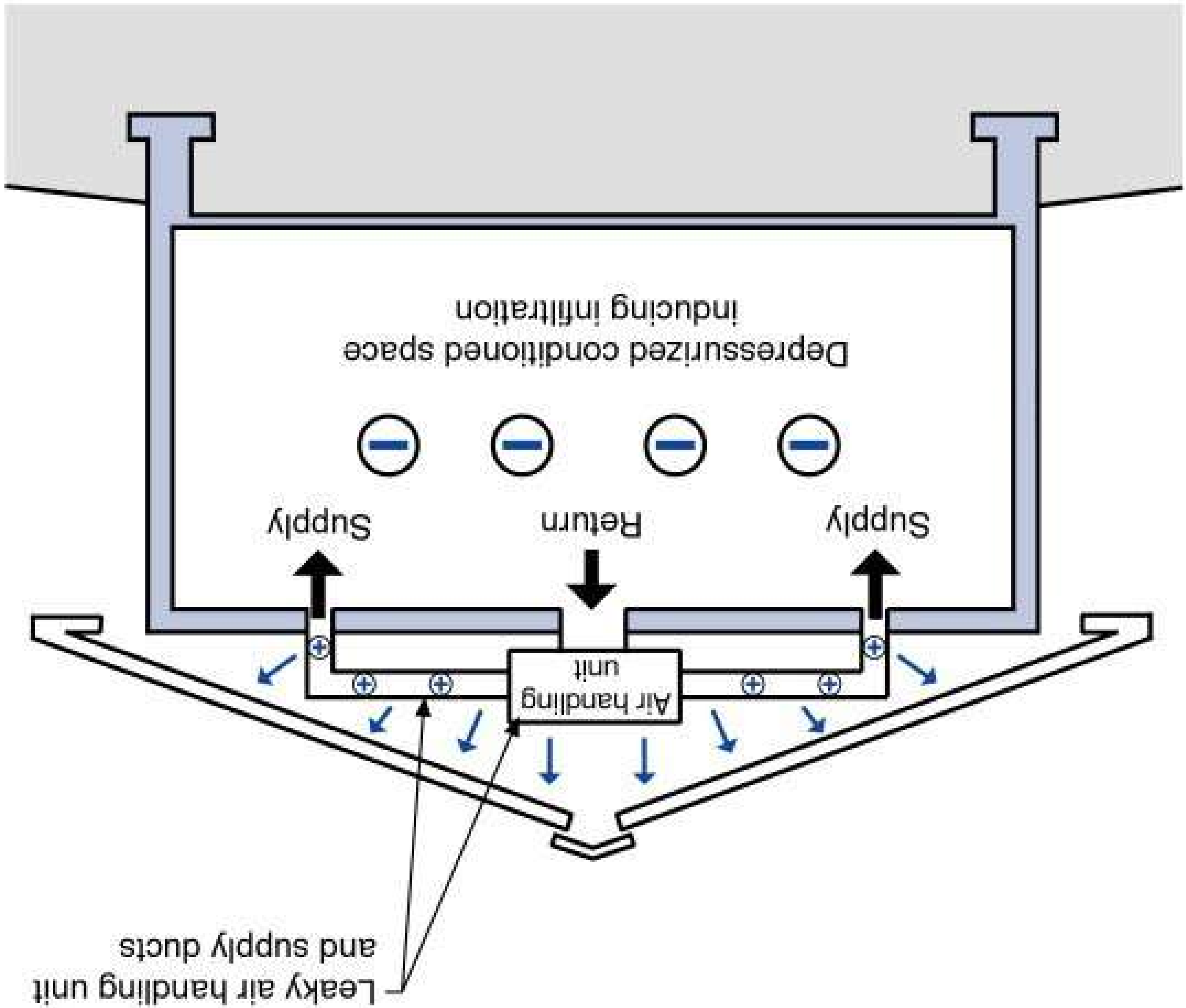

DAYS INN

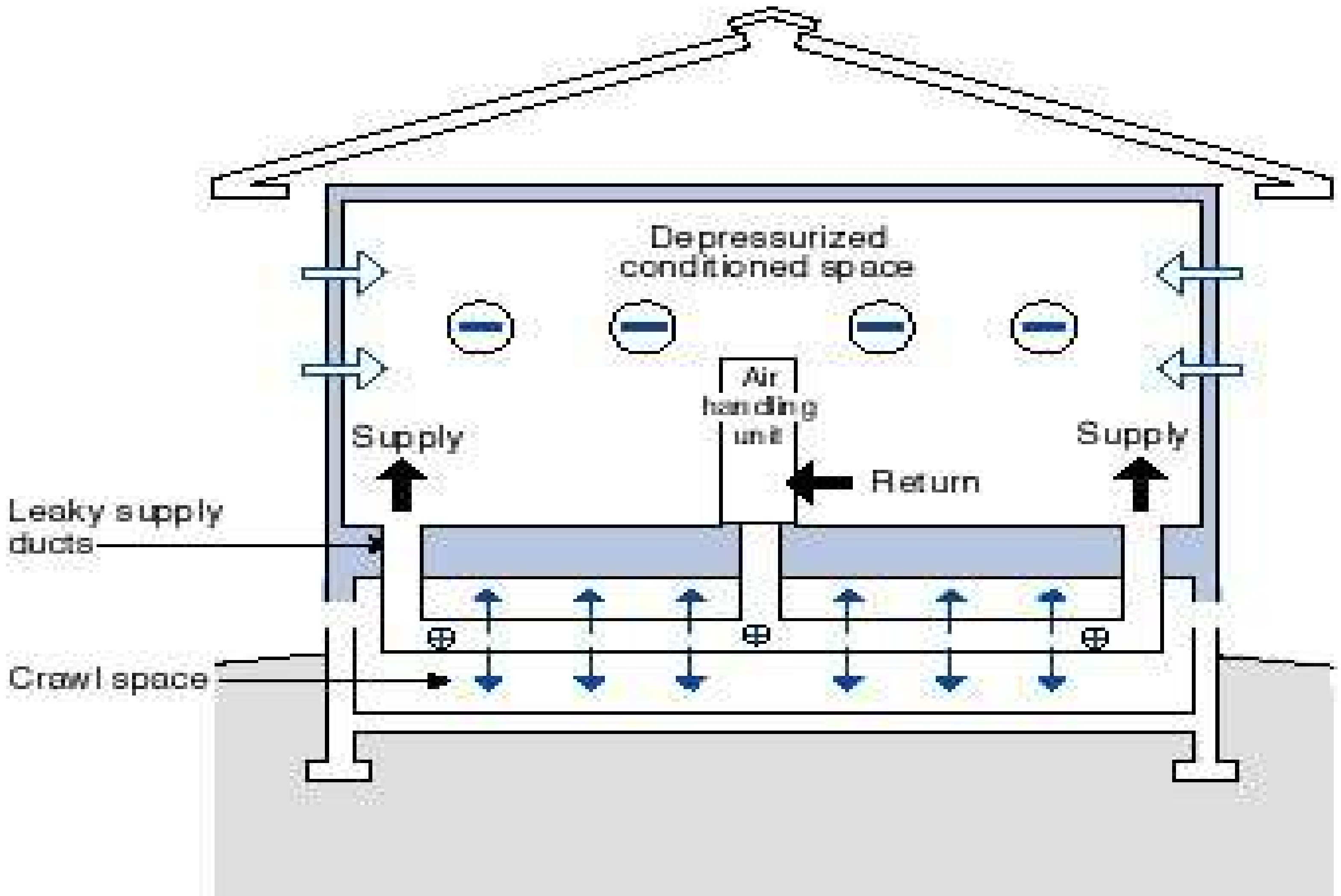


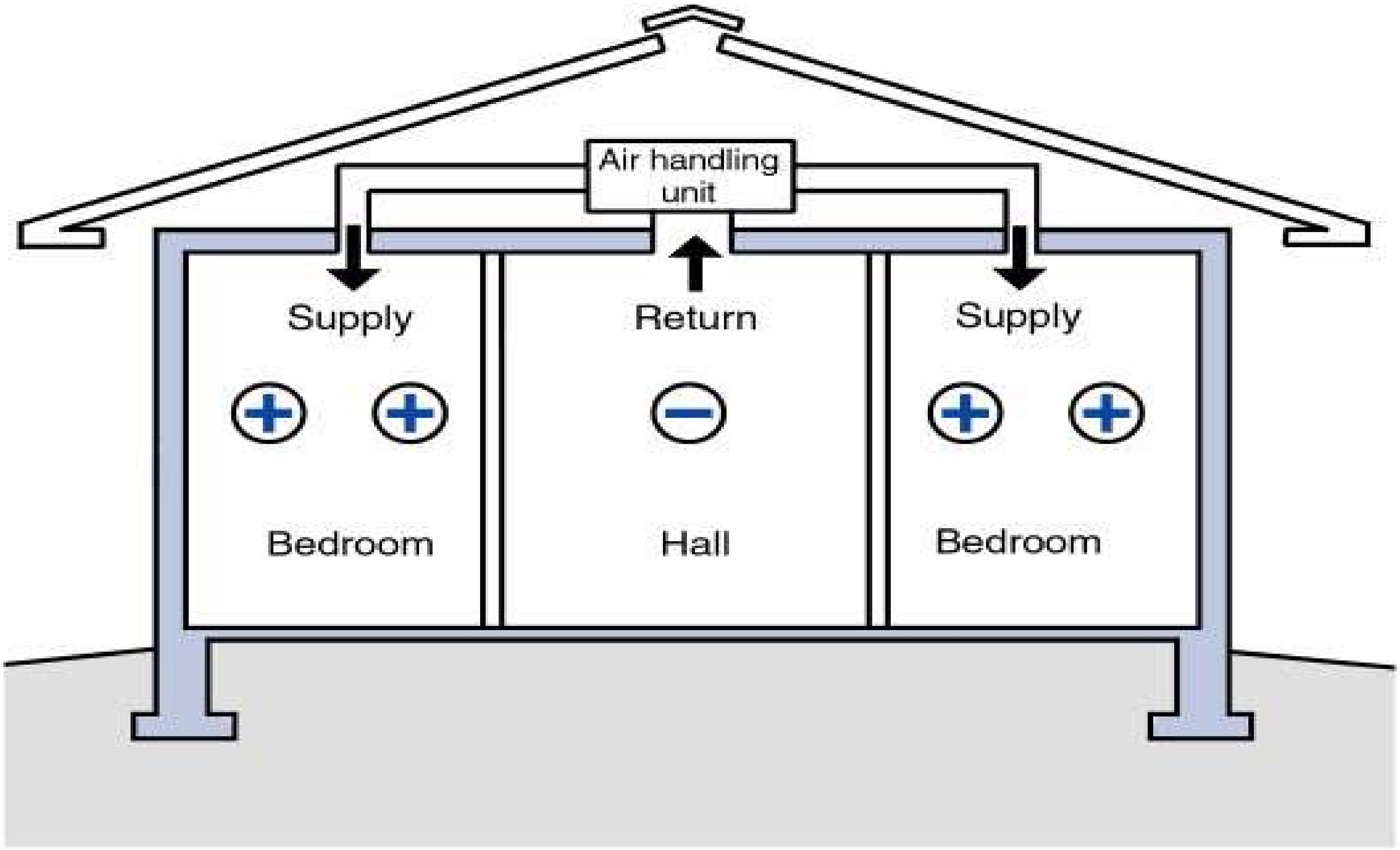
Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.



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

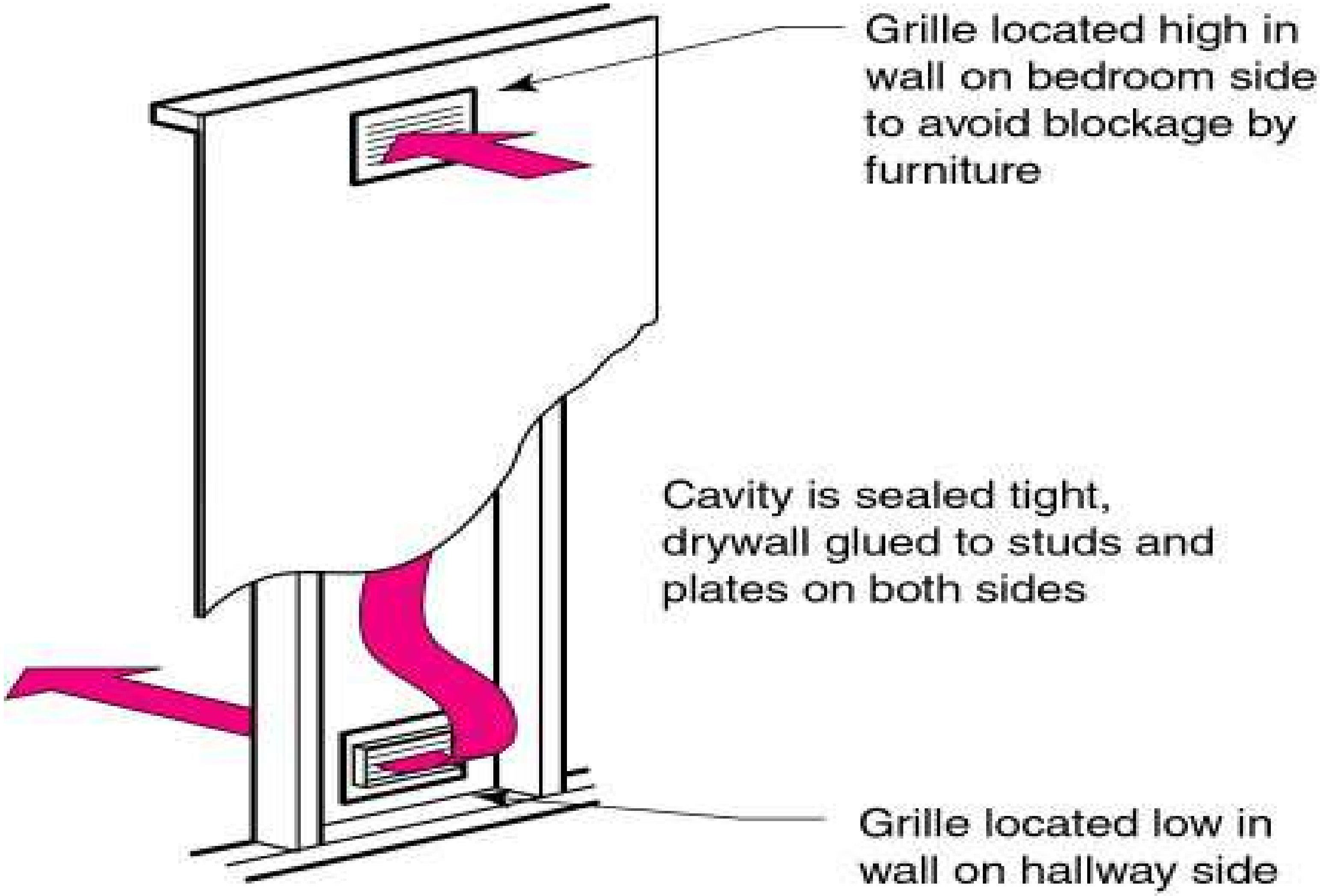

Depressurized conditioned space
inducing infiltration
Supply
Return
Supply
Air handling
unit
Leaky air handling unit
and supply ducts

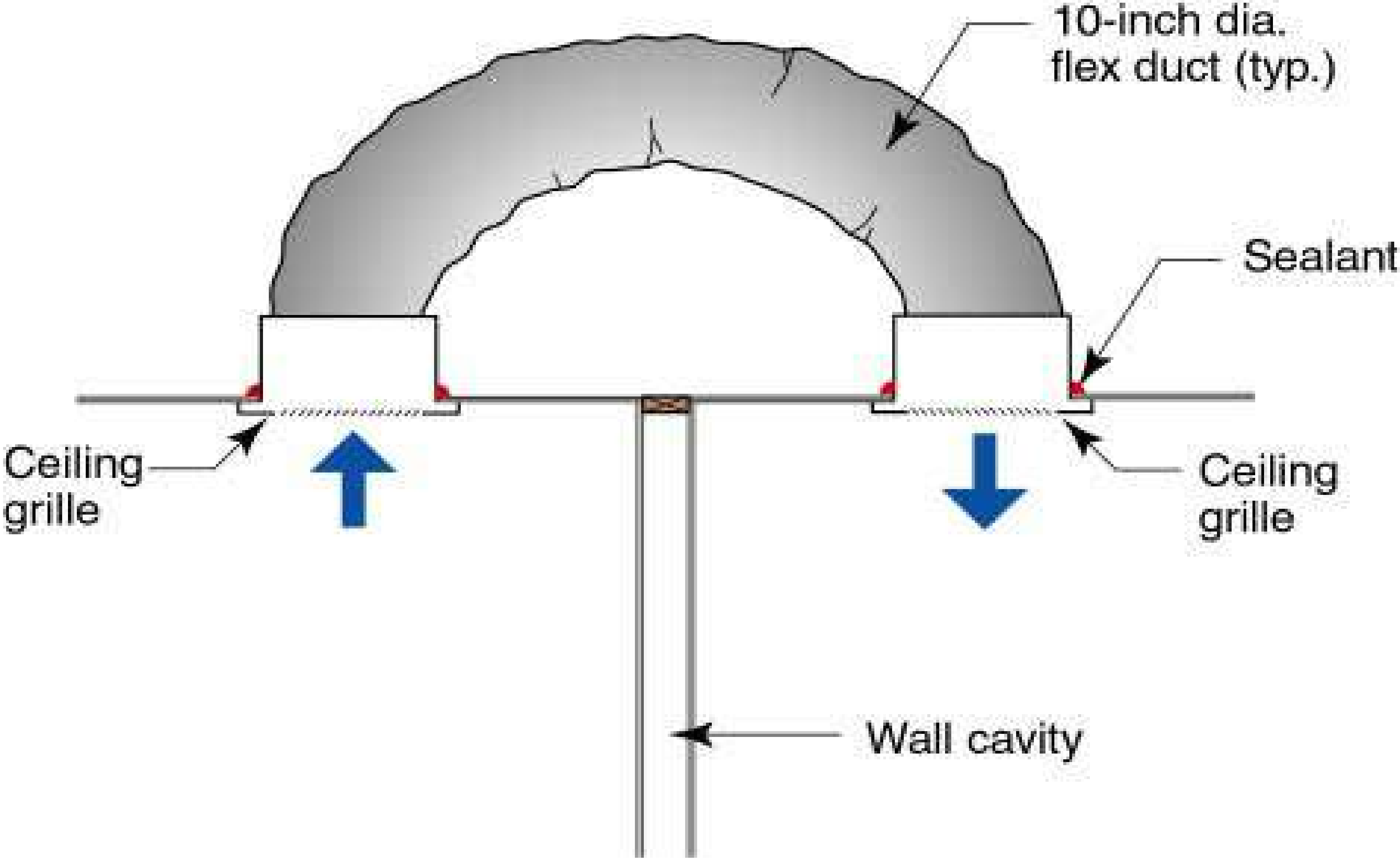

Depressurized
conditioned space
Air
handling
unit
Supply
Supply
Return
Leaky supply
ducts
Crawl space

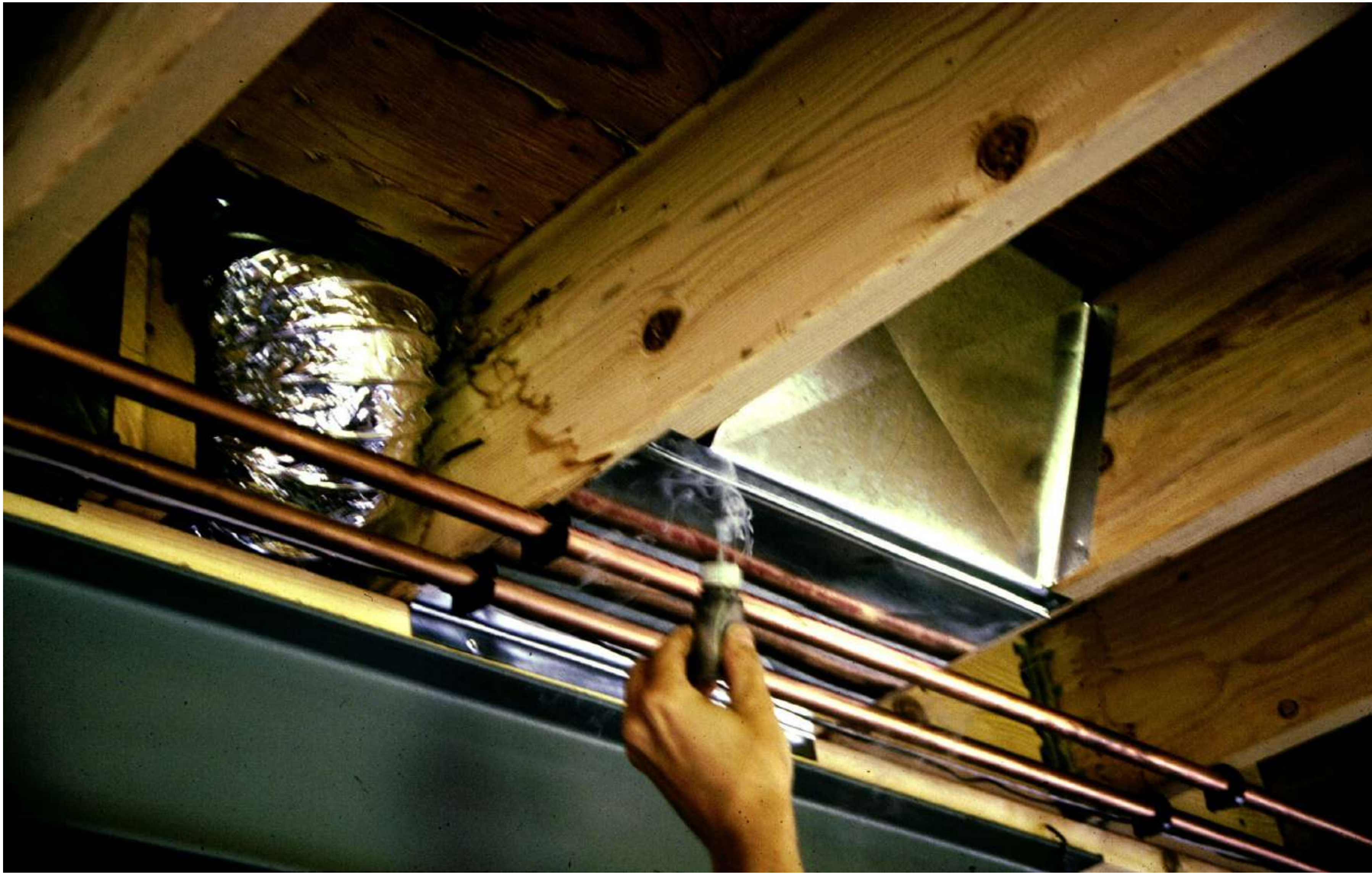

Air handling unit
Supply
Return
Supply
Bedroom
Hall
Bedroom

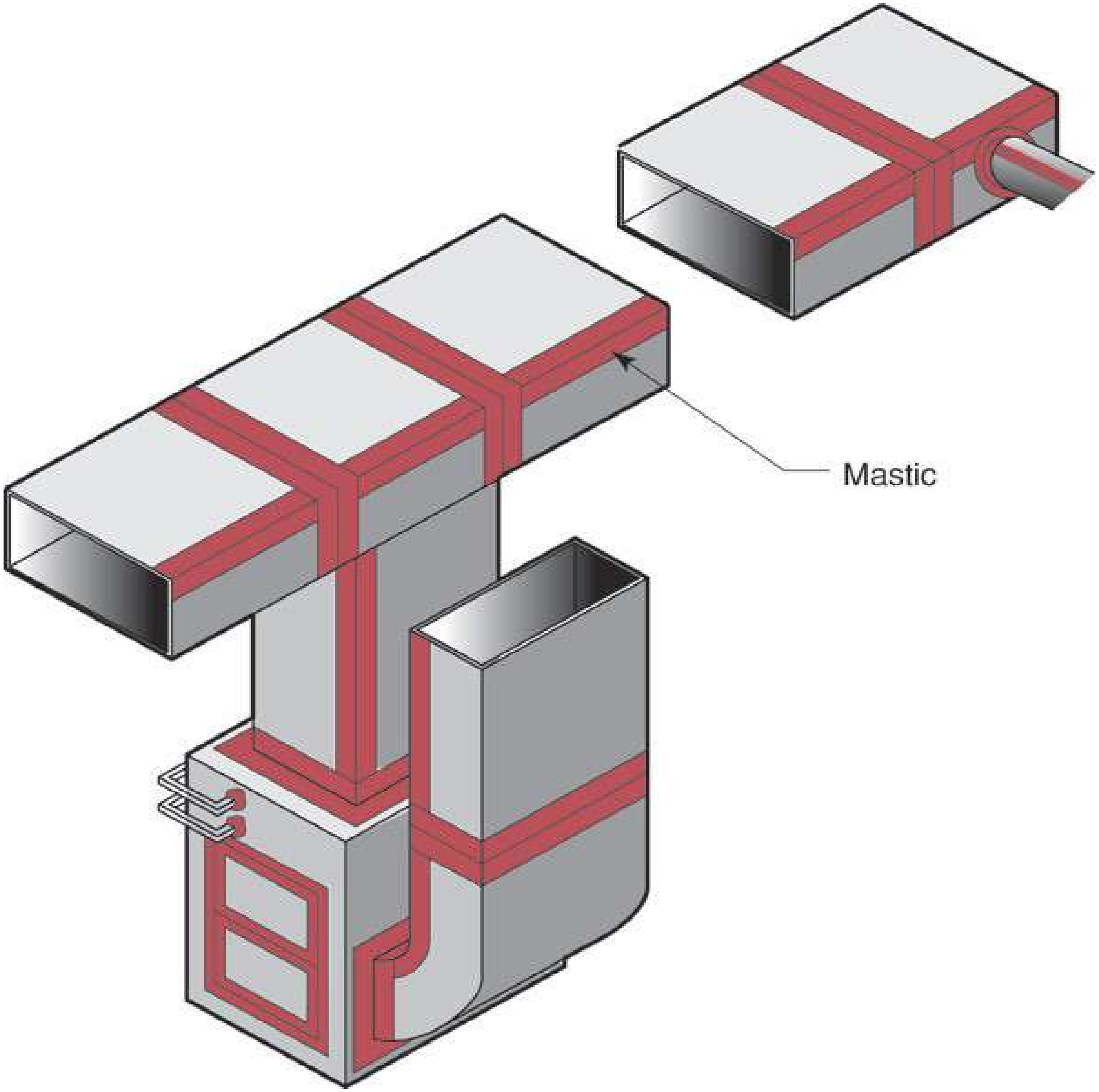

Richly
Scented Candle
EMPIRE

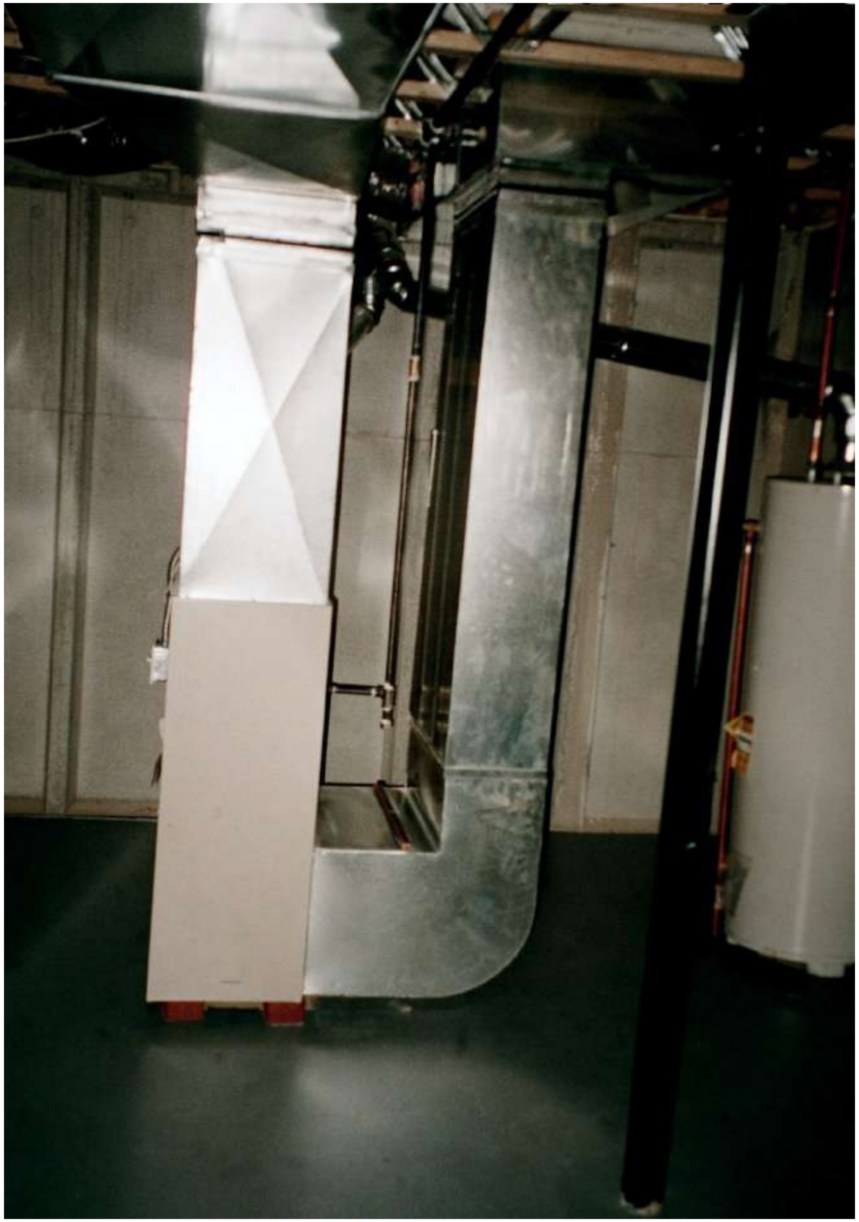

YANKEE
CINNAMON


Grille located high in wall on bedroom side to avoid blockage by furniture
Cavity is sealed tight, drywall glued to studs and plates on both sides
Grille located low in wall on hallway side


10-inch dia.
flex duct (typ.)
Sealant
Ceiling
grille
Ceiling
grille
Wall cavity




Mastic



Mechanical Systems

Mechanical Systems

Cooling System To Make It Cold

Mechanical Systems

Cooling System To Make It Cold

Dehumidification System To Make It Dry

Mechanical Systems

Cooling System To Make It Cold

Dehumidification System To Make It Dry

Heating System To Make It Warm

Mechanical Systems

Cooling System To Make It Cold

Dehumidification System To Make It Dry

Heating System To Make It Warm

Energy Recovery System To Keep It Cold and Dry and Warm and Comfortable

Mechanical Systems

Cooling System To Make It Cold

Dehumidification System To Make It Dry

Heating System To Make It Warm

Energy Recovery System To Keep It Cold and Dry and Warm and Comfortable

Distribution System To Make It Uniform

Mechanical Systems

Cooling System To Make It Cold

Dehumidification System To Make It Dry

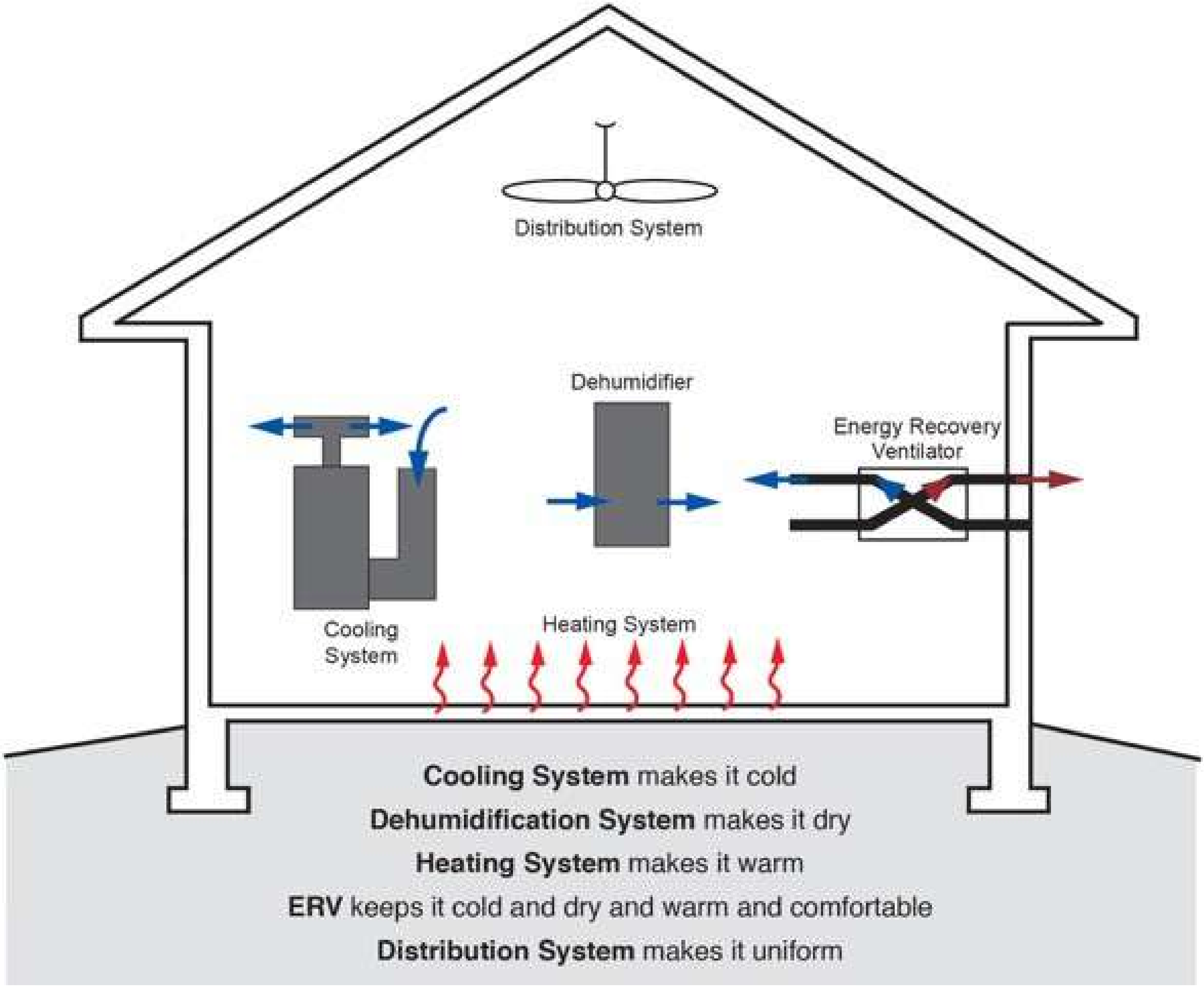
Heating System To Make It Warm

Energy Recovery System To Keep It Cold and Dry and Warm and Comfortable

Distribution System To Make It Uniform

Range Hoods Are A Special Kind of Hell

Don’t Try to Combine Them…...


Distribution System
Dehumidifier
Energy Recovery Ventilator
Cooling System
Heating System
Cooling System makes it cold
Dehumidification System makes it dry
Heating System makes it warm
ERV keeps it cold and dry and warm and comfortable
Distribution System makes it uniform

Build Tight - Ventilate Right

Build Tight - Ventilate Right

How Tight?

What’s Right?

Air Barrier Metrics

Material	0.02 l/(s-m2) @ 75 Pa
Assembly	0.20 l/(s-m2) @ 75 Pa
Enclosure	2.00 l/(s-m2) @ 75 Pa
	0.25 cfm/ft2 @ 50 Pa

Getting rid of big holes	3 ach@50
Getting rid of smaller holes	1.5 ach@50
Getting German	0.6 ach@50

Best

As Tight as Possible - with -

Balanced Ventilation

Energy Recovery

Distribution and Mixing

Source Control - Spot exhaust ventilation

Filtration

Material selection

Worst

Leaky - with – Nothing

Spot Ventilation in Bathroom/Kitchen

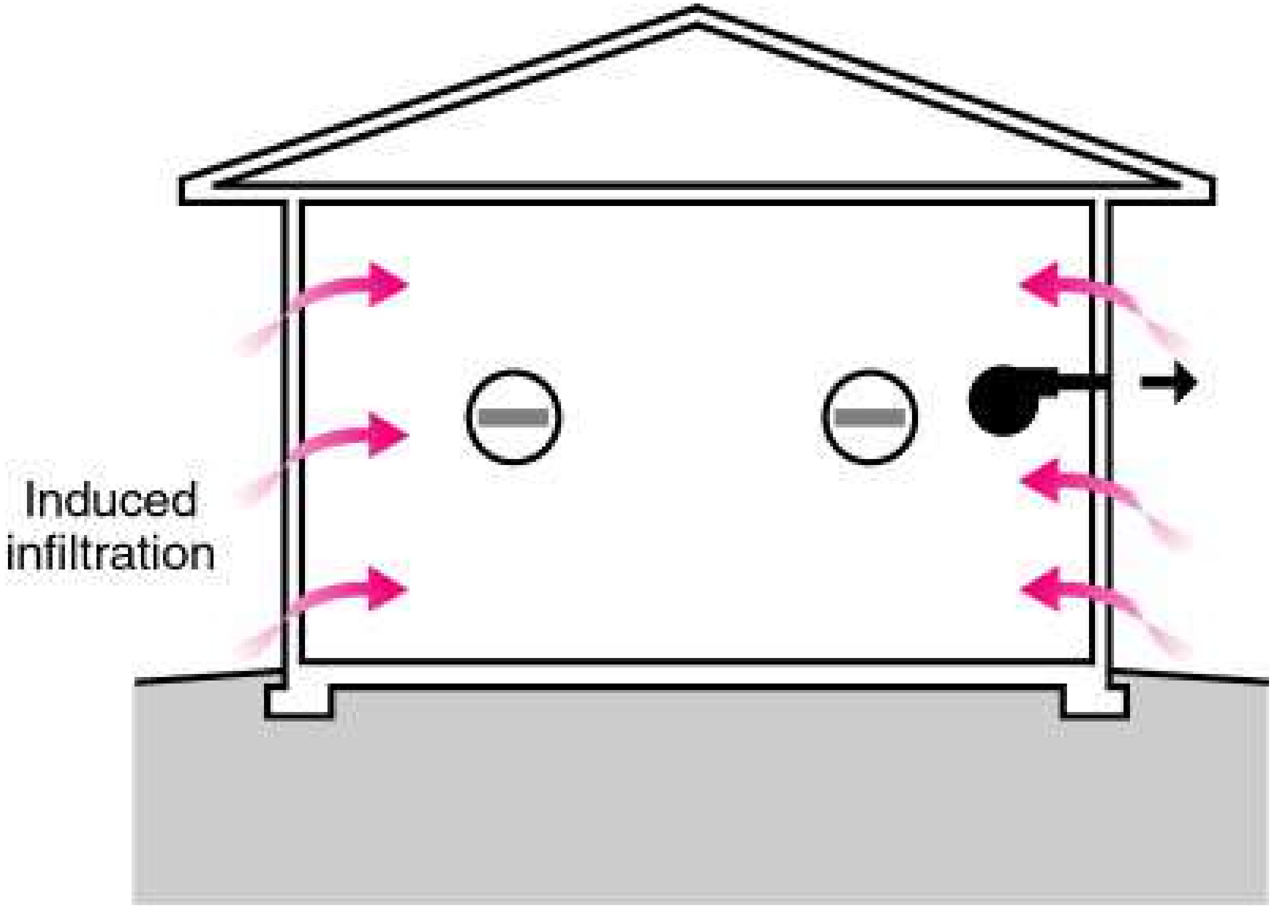
Exhaust Ventilation – with – No Distribution and No Mixing

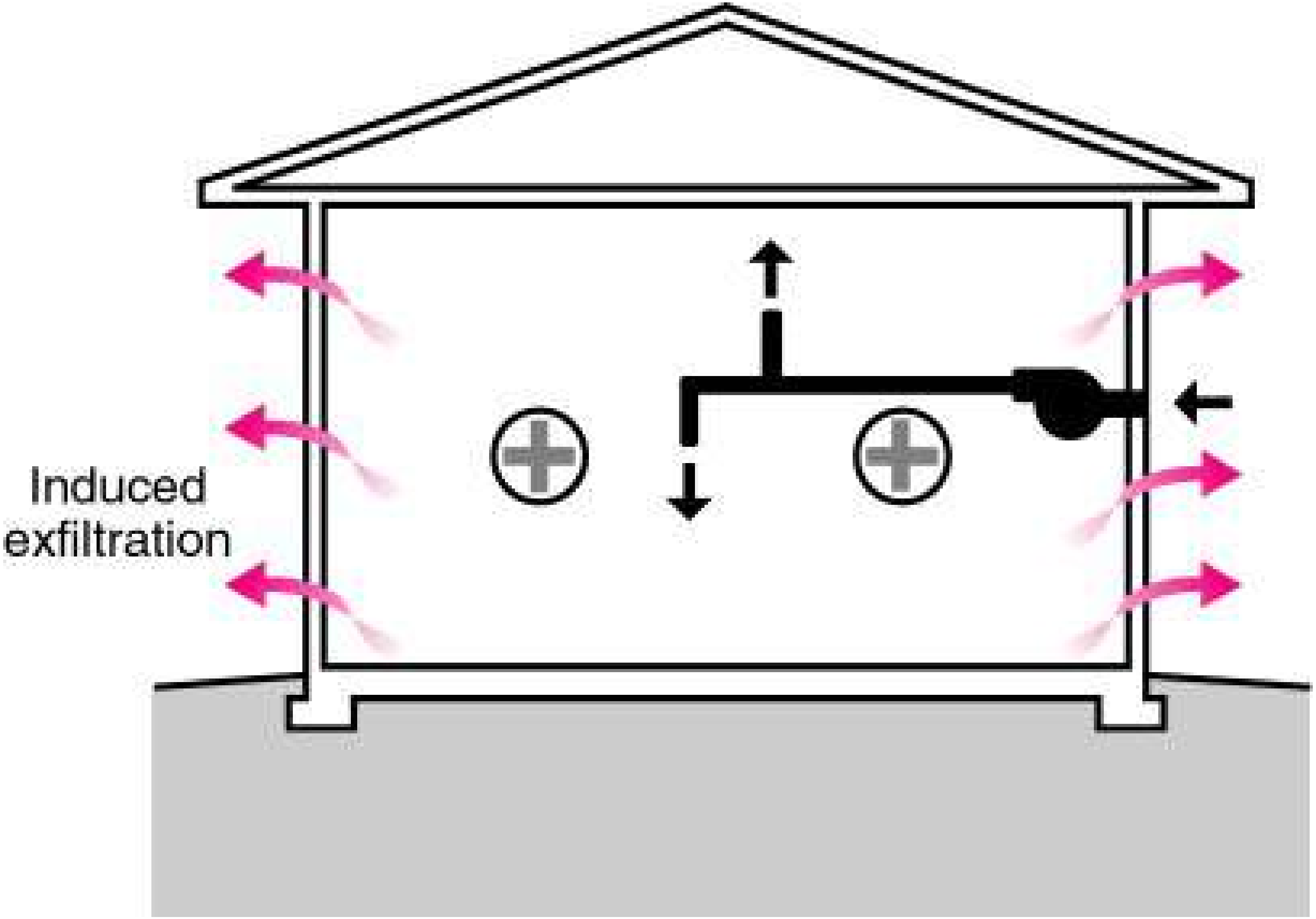
Three Types of Controlled Ventilation Systems

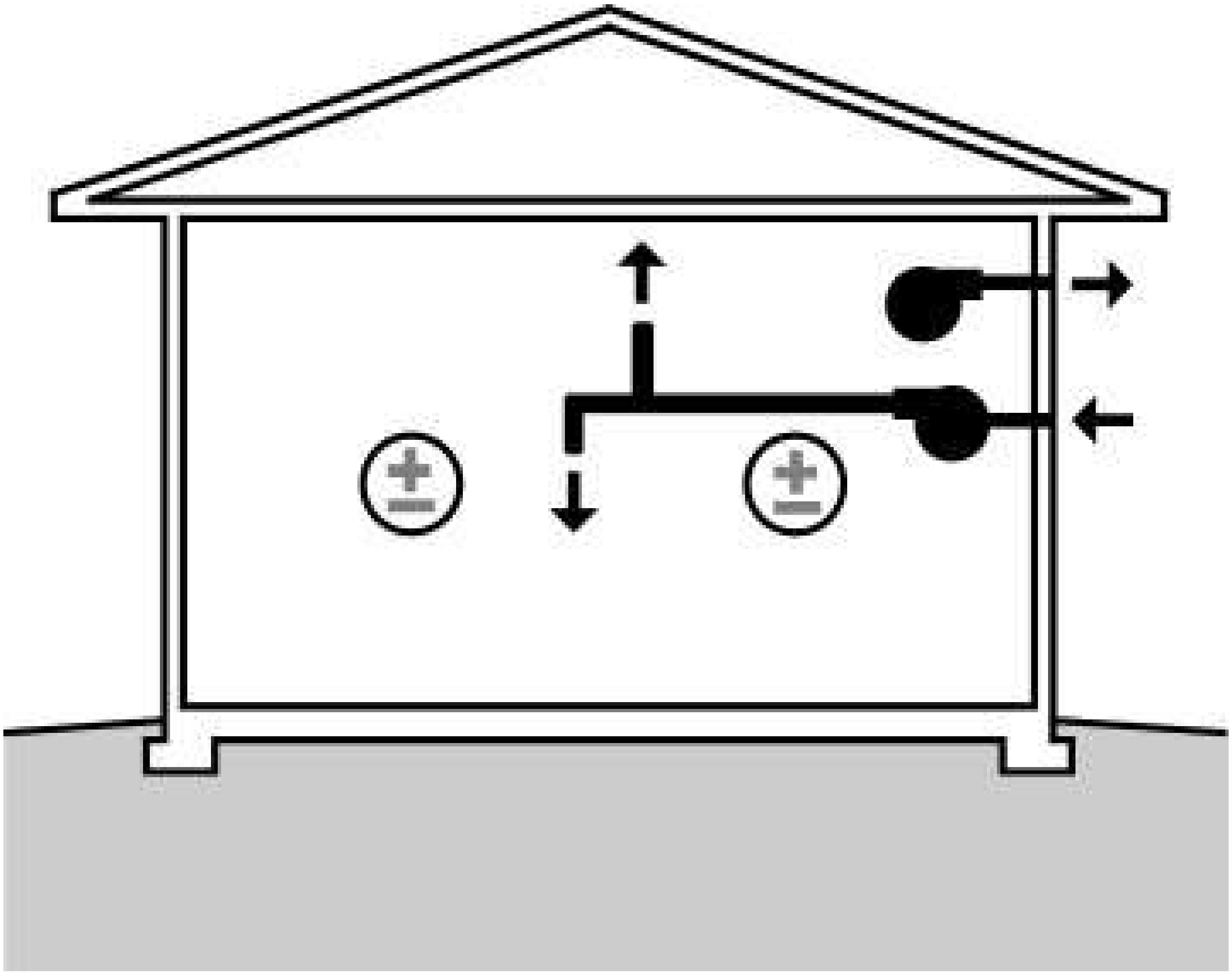
Exhaust Ventilation

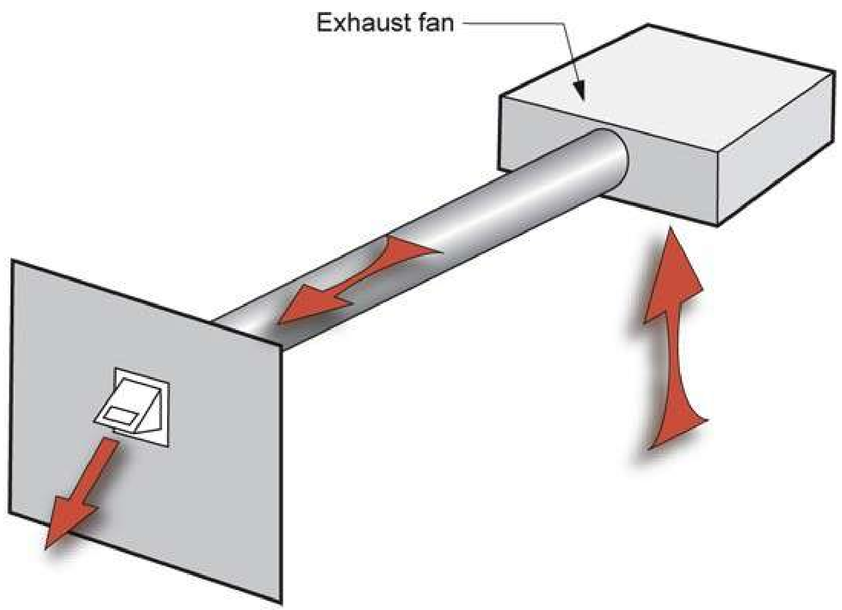
Supply Ventilation

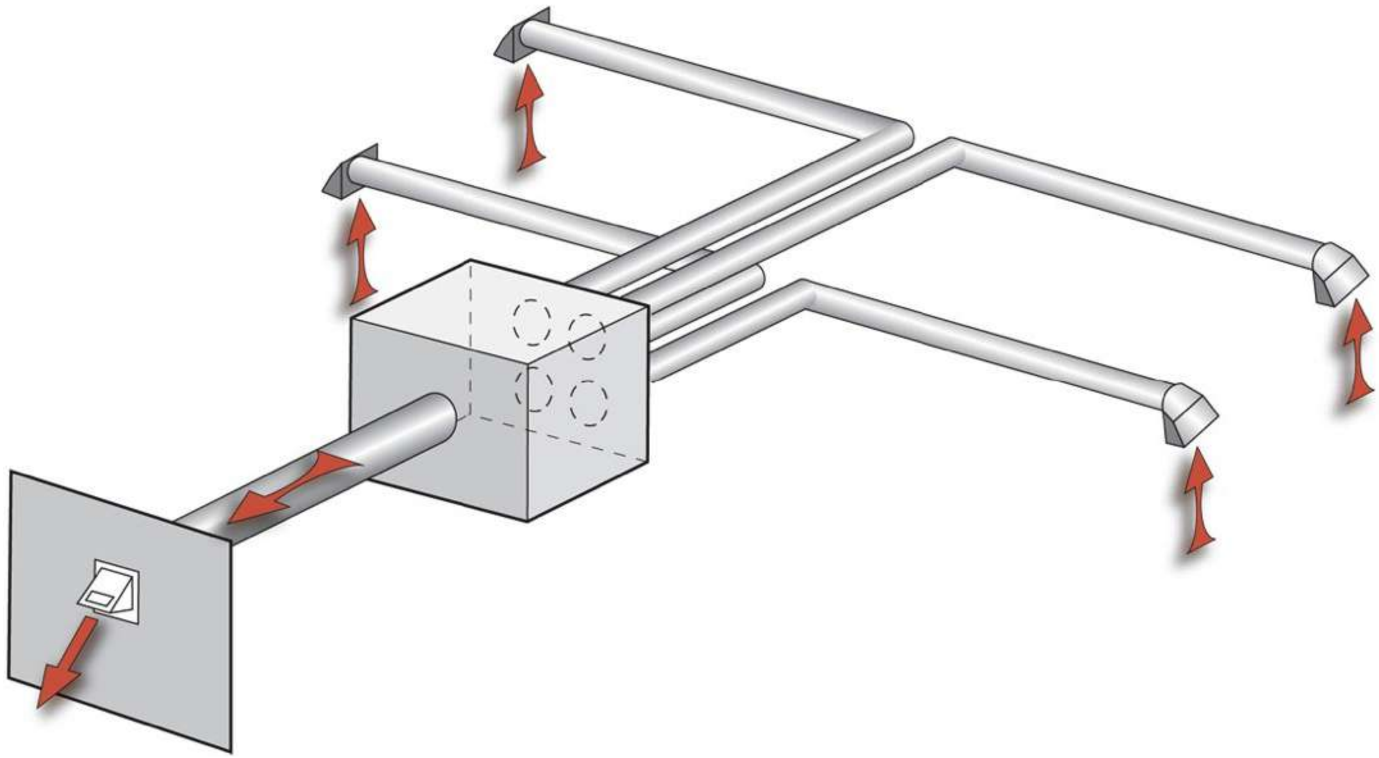
Balanced Ventilation

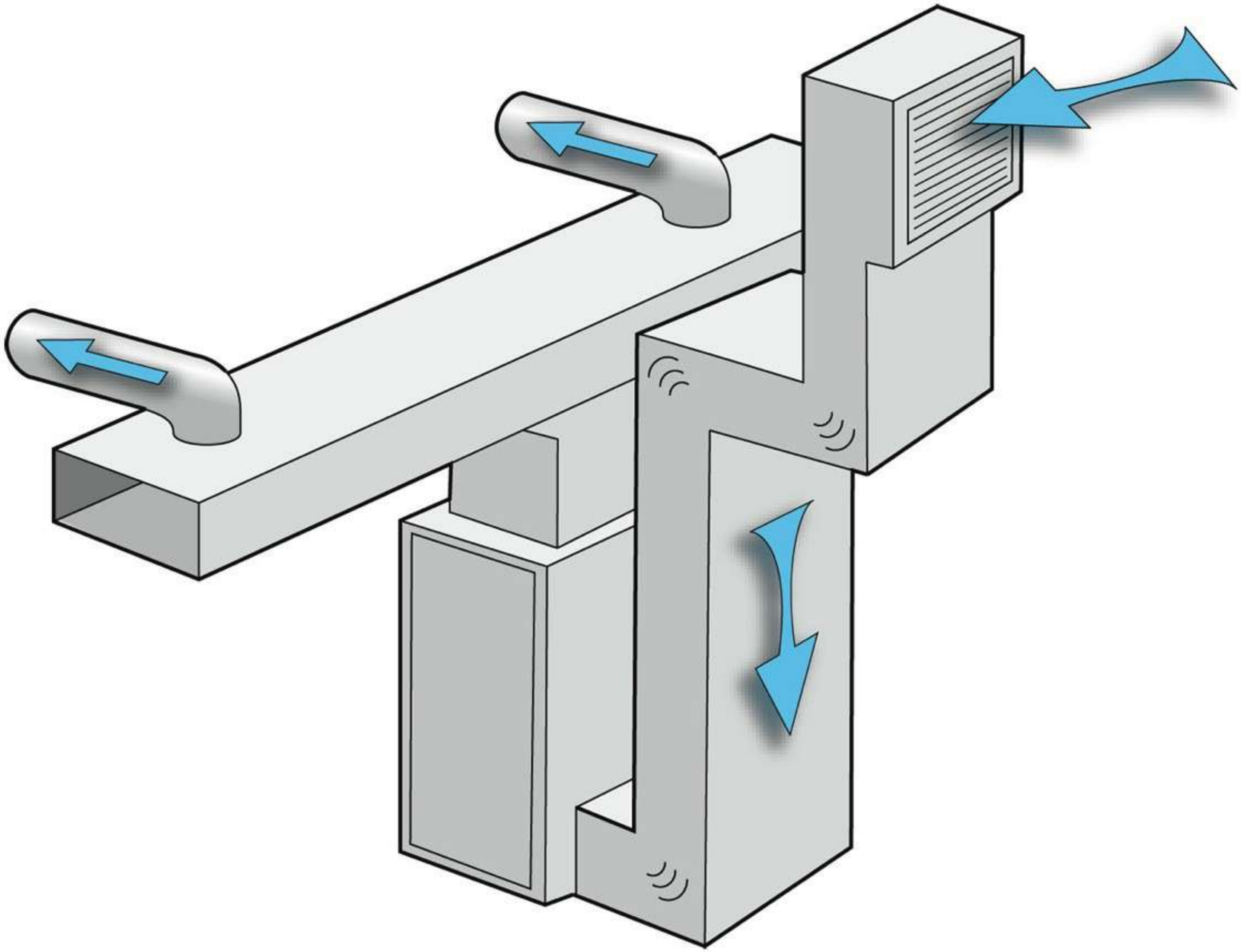

Induced
infiltration

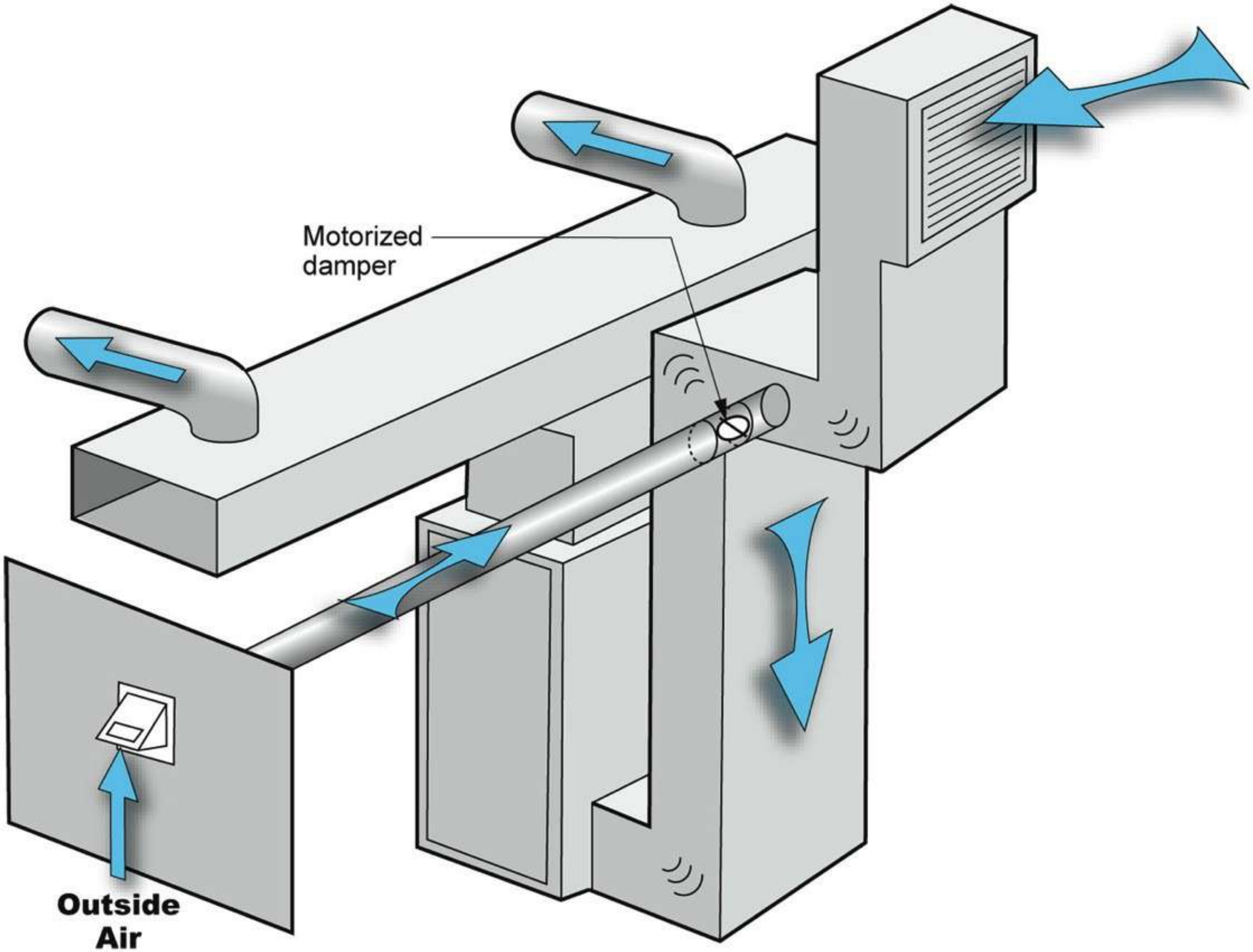

Induced
exfiltration

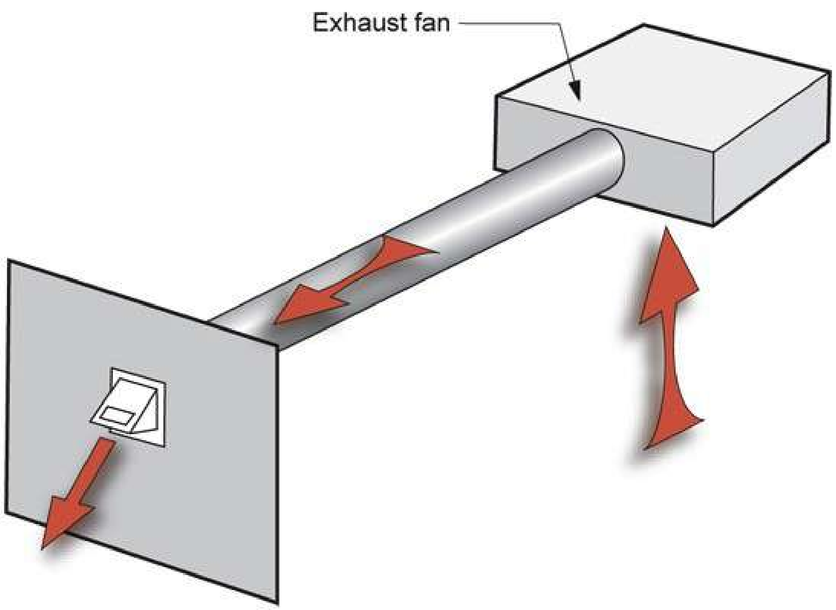


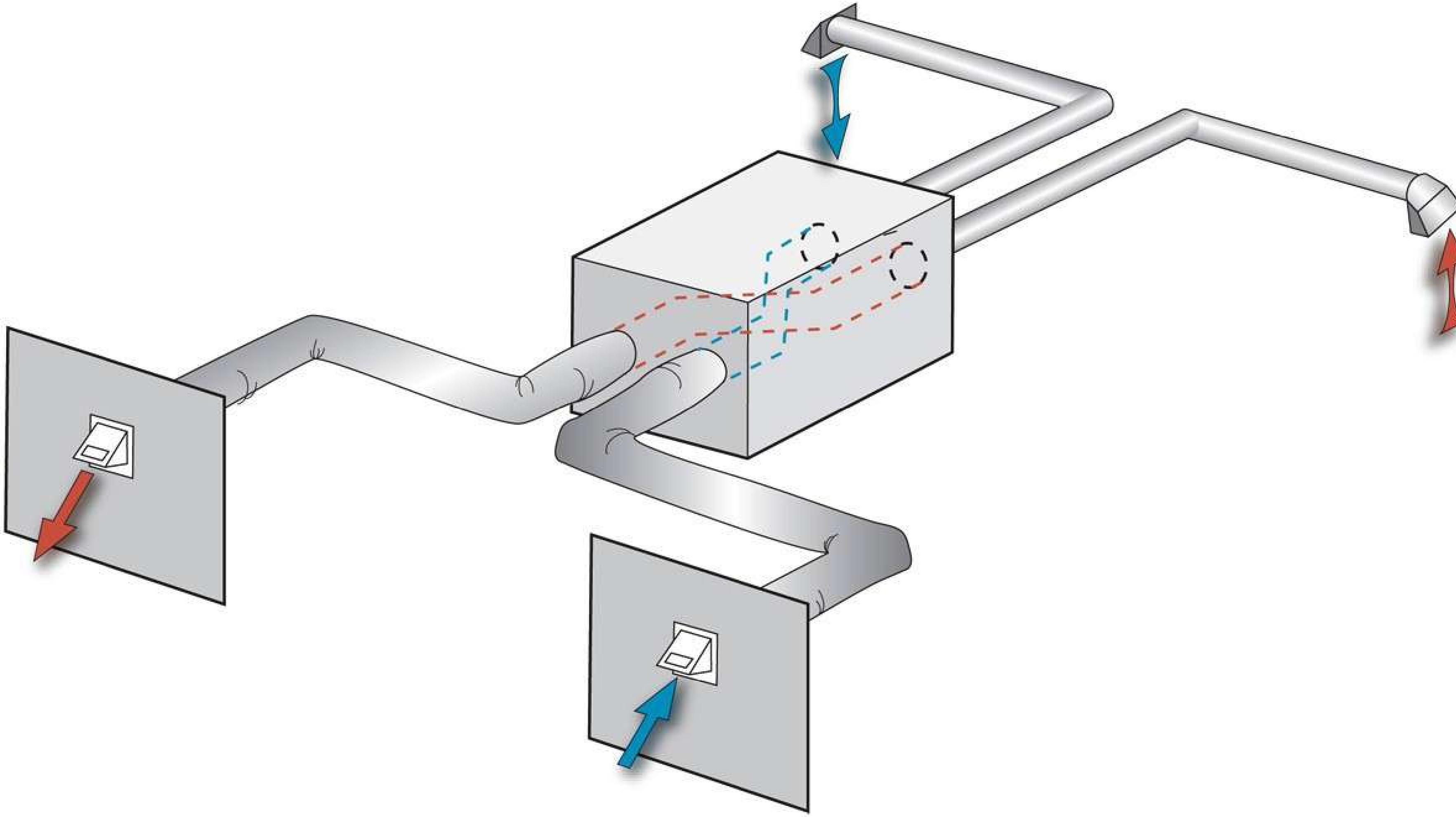

Exhaust fan






Motorized
damper
Outside
Air


Exhaust fan



Ventilation Rates Are Based on Odor Control

Ventilation Rates Are Based on Odor Control

Health Science Basis for Ventilation Rates is Extremely Limited

Ventilation Rates Are Based on Odor Control

Health Science Basis for Ventilation Rates is Extremely Limited

Almost Nothing Cited Applies to Housing

Ventilation Rates Are Based on Odor Control

Health Science Basis for Ventilation Rates is Extremely Limited

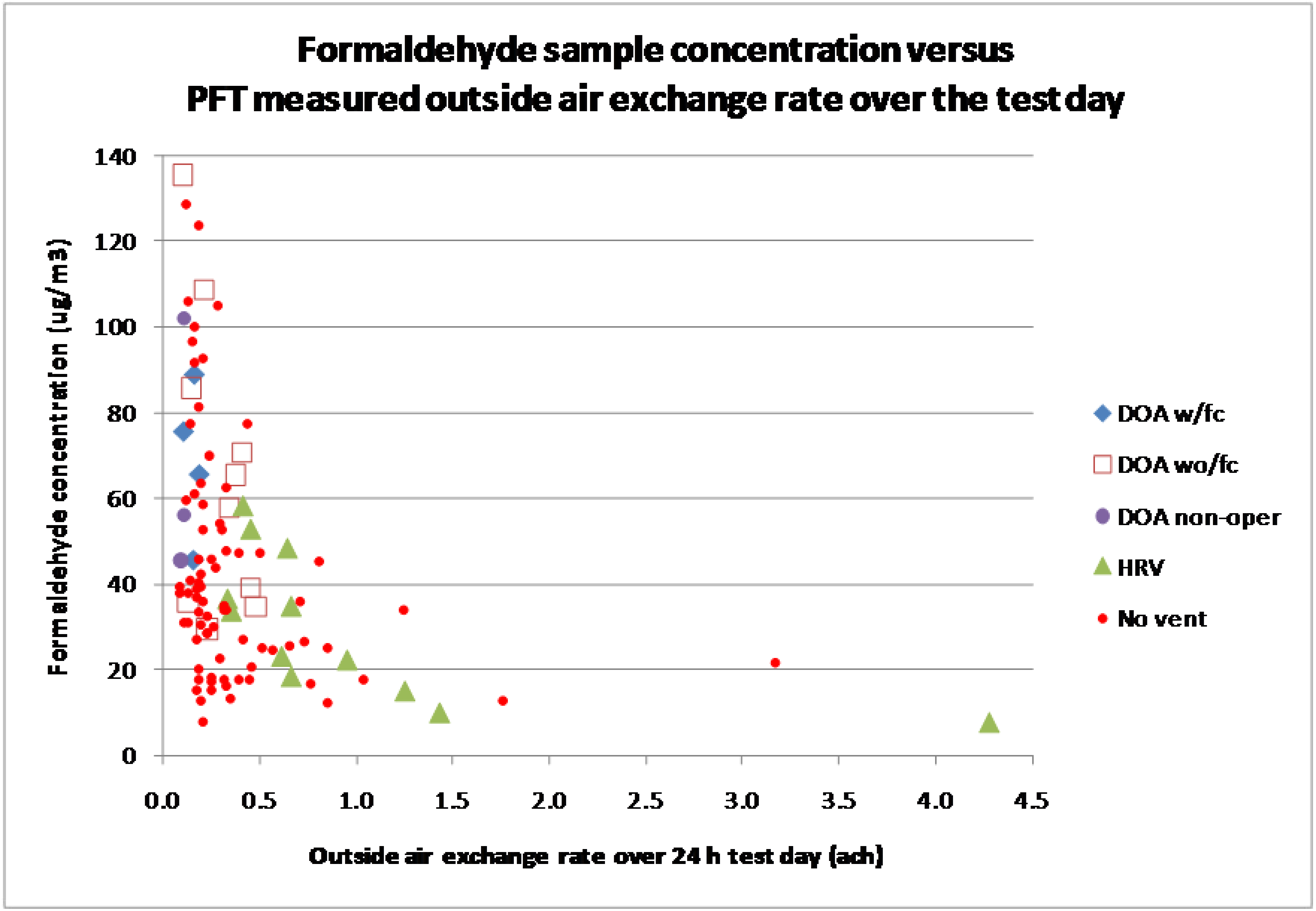
Almost Nothing Cited Applies to Housing

The Applicable Studies Focus on Dampness

House

2,000 ft^2
3 bedrooms
8 ft. ceiling
Volume: 16,000 ft^3

.35 ach	93 cfm
.30 ach	80 cfm
.25 ach	67 cfm
.20 ach	53 cfm
.15 ach	40 cfm


Formaldehyde sample concentration versus
PFT measured outside air exchange rate over the test day
Formaldehyde concentration (ug/m3)
0
20
40
60
80
100
120
140
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Outside air exchange rate over 24 h test day (ach)
DOA w/fc
DOA wo/fc
DOA non-oper
HRV
No vent

ASHRAE Standard 62.2 calls for 7.5 cfm per person plus 0.03 cfm per square foot of conditioned area

Occupancy is deemed to be the number of bedrooms plus one

ASHRAE Standard 62.2 calls for 7.5 cfm per person plus 0.03 cfm per square foot of conditioned area

Occupancy is deemed to be the number of bedrooms plus one

Outcome is often bad – part load humidity problems, dryness problems, energy problems

IRC 2018 and IRC 2021calls for 7.5 cfm per person plus 0.01 cfm per square foot of conditioned area

Occupancy is deemed to be the number of bedrooms plus one

A 30 % credit is provided if the ventilation system is “balanced” and provides distribution

3 Bedroom House – 2,500 ft2

30 cfm plus 75 cfm

105 cfm

3 Bedroom House – 2,500 ft2

30 cfm plus 25 cfm

55 cfm

3 Bedroom House – 2,500 ft2

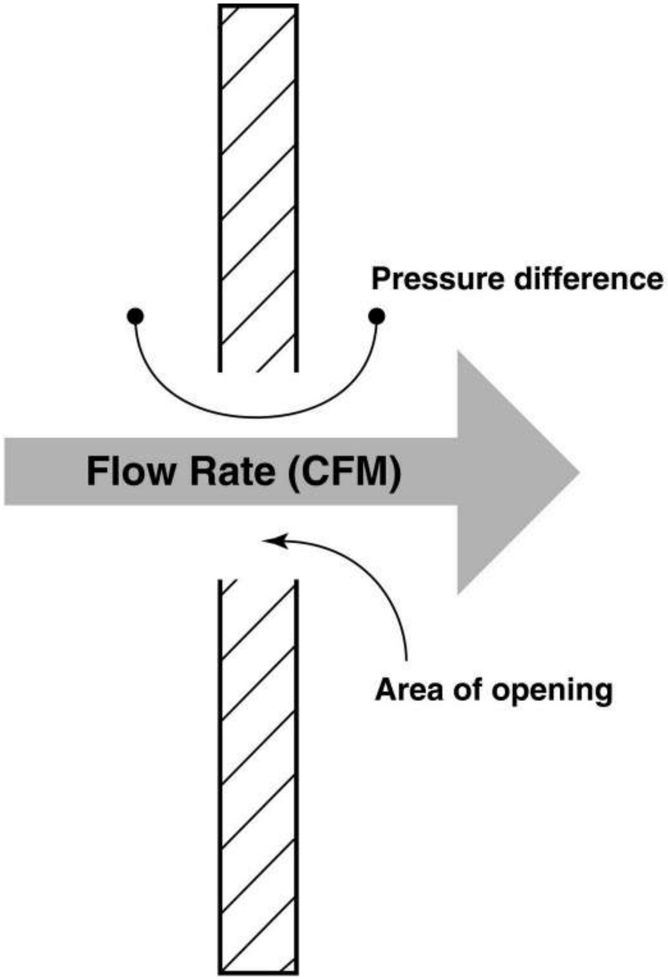
30 cfm plus 25 cfm

55 cfm

With Balanced and Distributed 30 percent credit

38.5 cfm

The Cult of The Blower Door

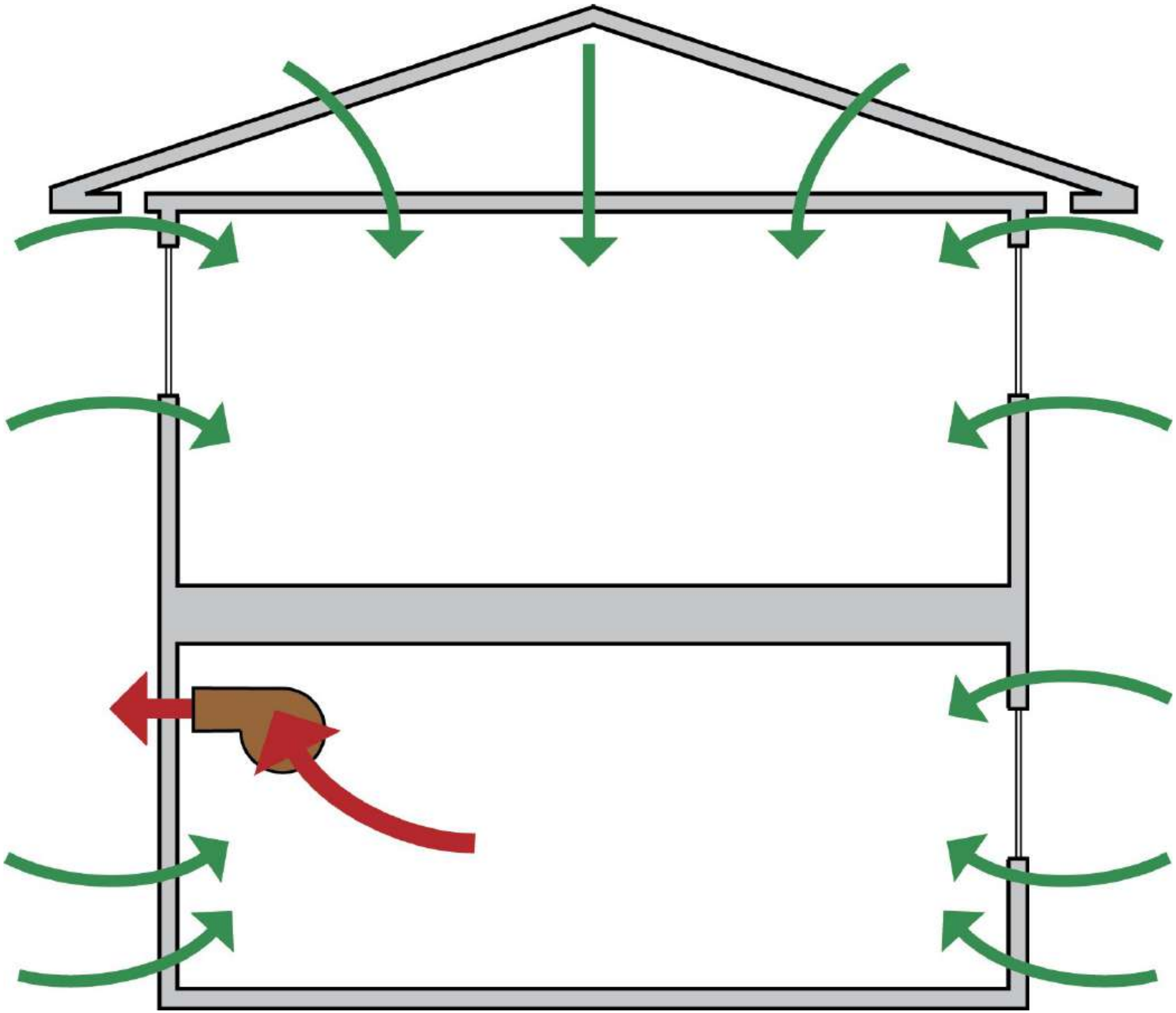

Pressure difference
Flow Rate (CFM)
Area of opening

Blower Door Can’t Get You The True ACH On A Short Term Basis – Hour, Day, Week

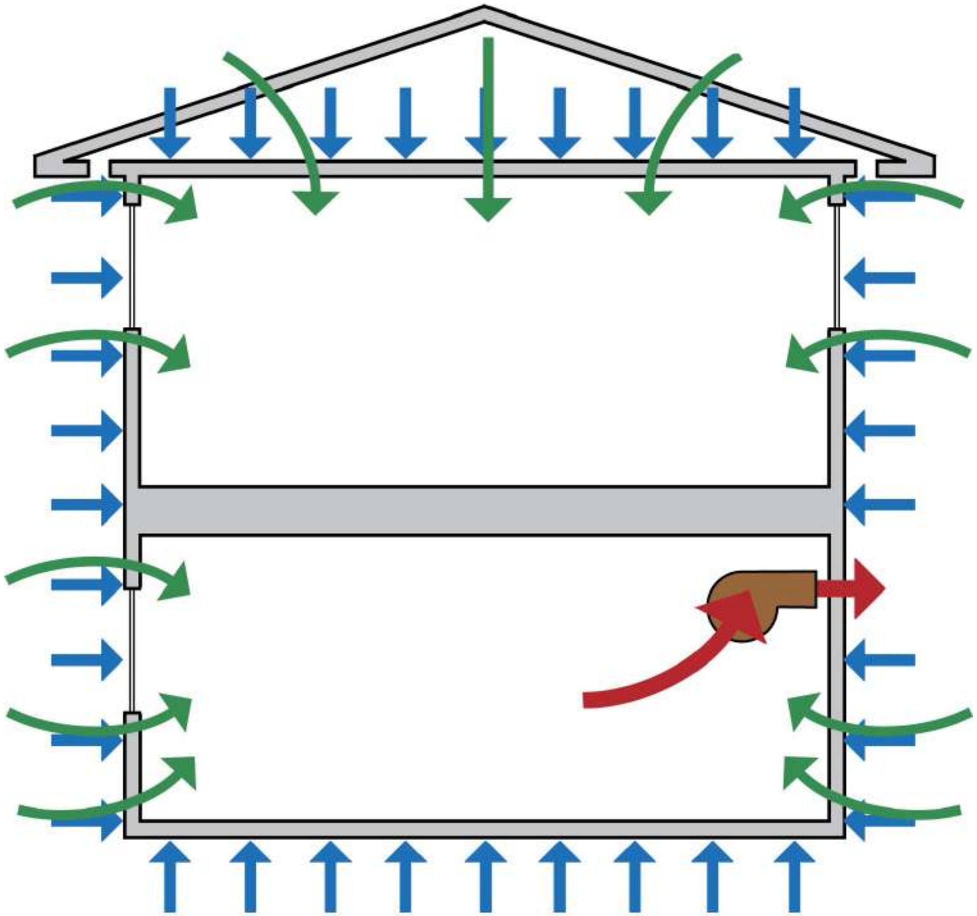
Don’t Know Where The Holes Are

Don’t Know The Type of Holes

Don’t Know The Pressure Across The Holes



$$\text{ELA} \approx \text{C} \times \frac{\text{Rate of flow}}{\sqrt{\text{Pressure difference}}}$$



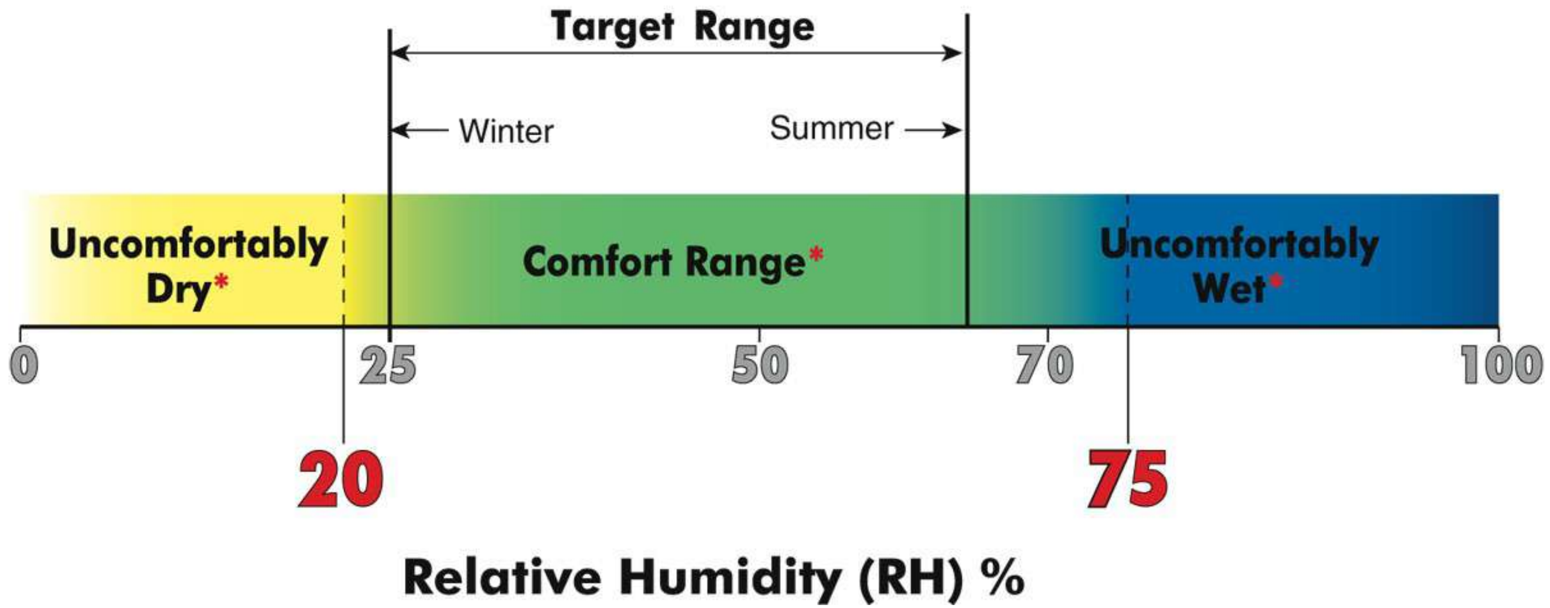
$$(\text{Meters})^2 \approx \frac{1}{780} \times \frac{\text{Litres per second}}{\sqrt{\text{Pascals}}}$$

Dilution Is Not The Solution To Indoor Pollution

Source Control

Dilution For People

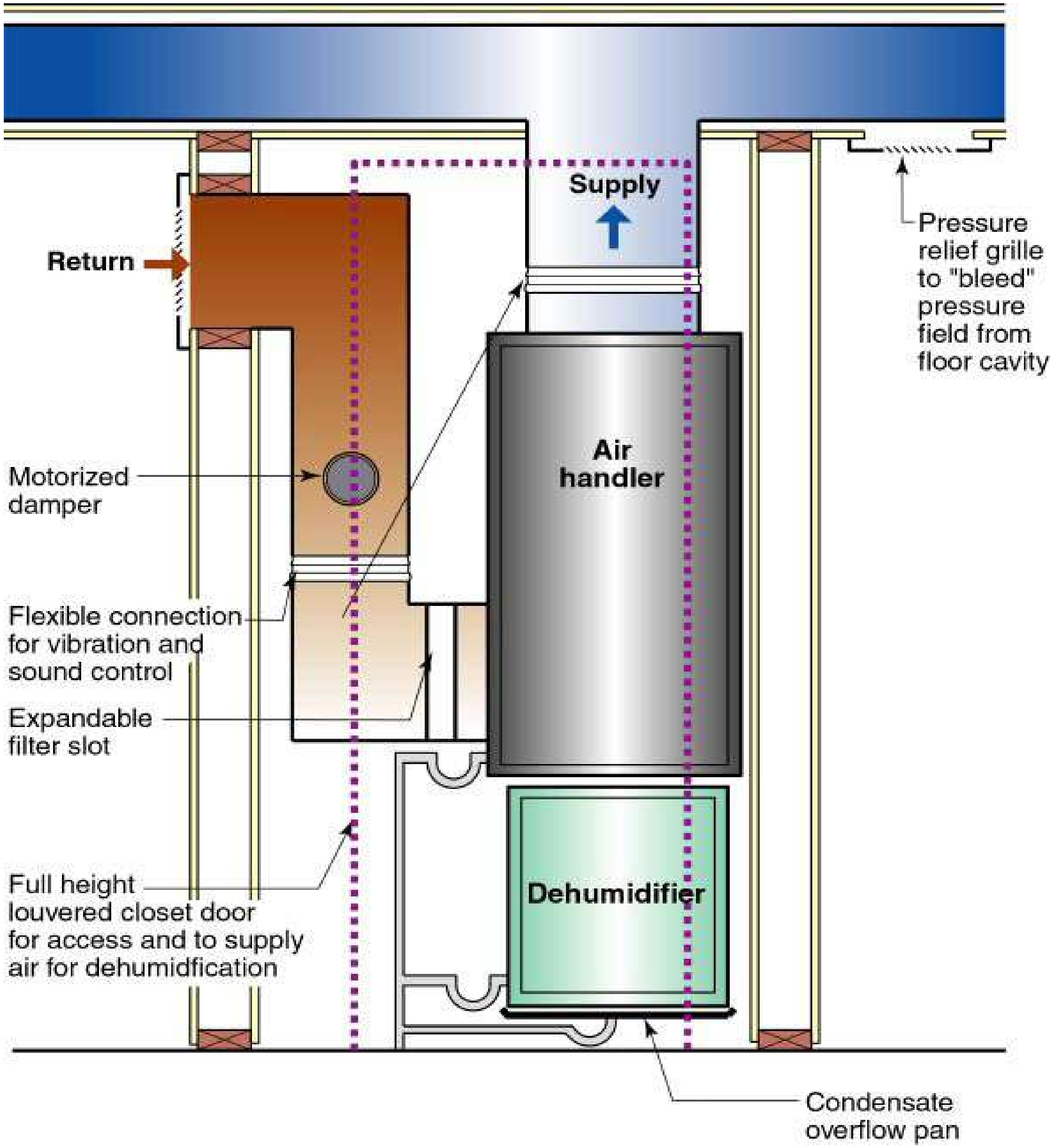
Source Control For The Building


Target Range
Winter
Summer
Uncomfortably Dry*
Comfort Range*
Uncomfortably Wet*
0
25
50
70
100
20
75
Relative Humidity (RH) %

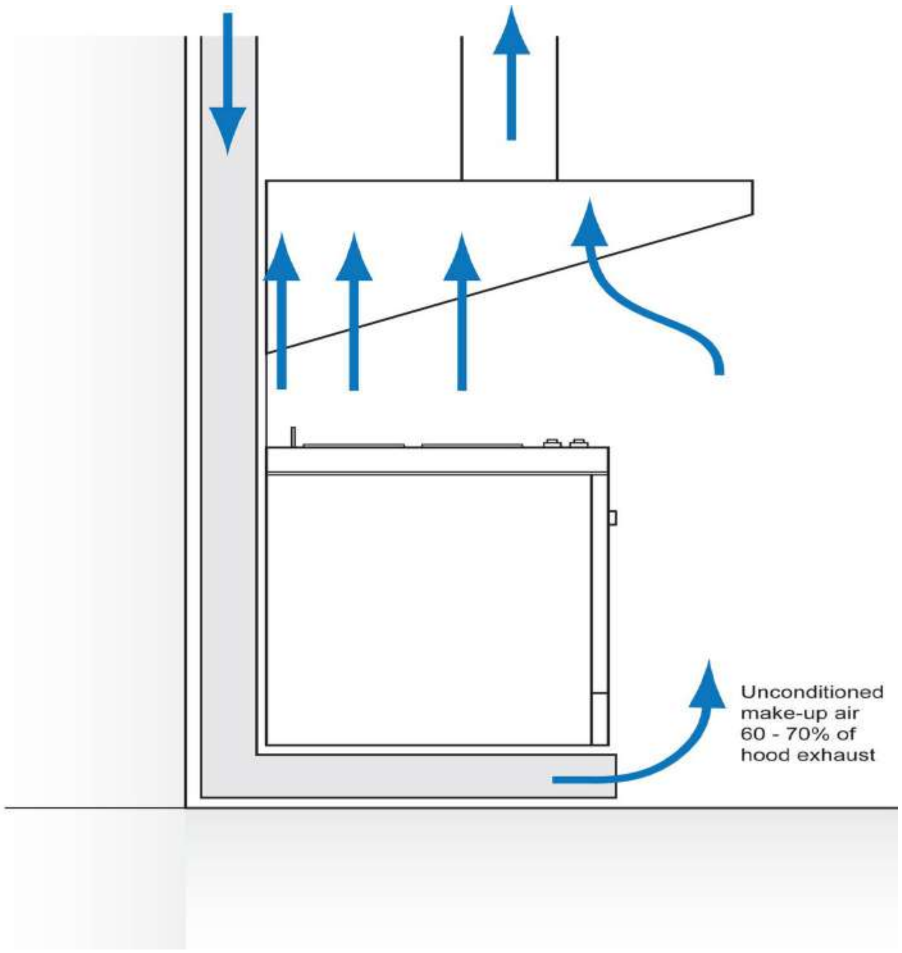
Recommended Range of Relative Humidity

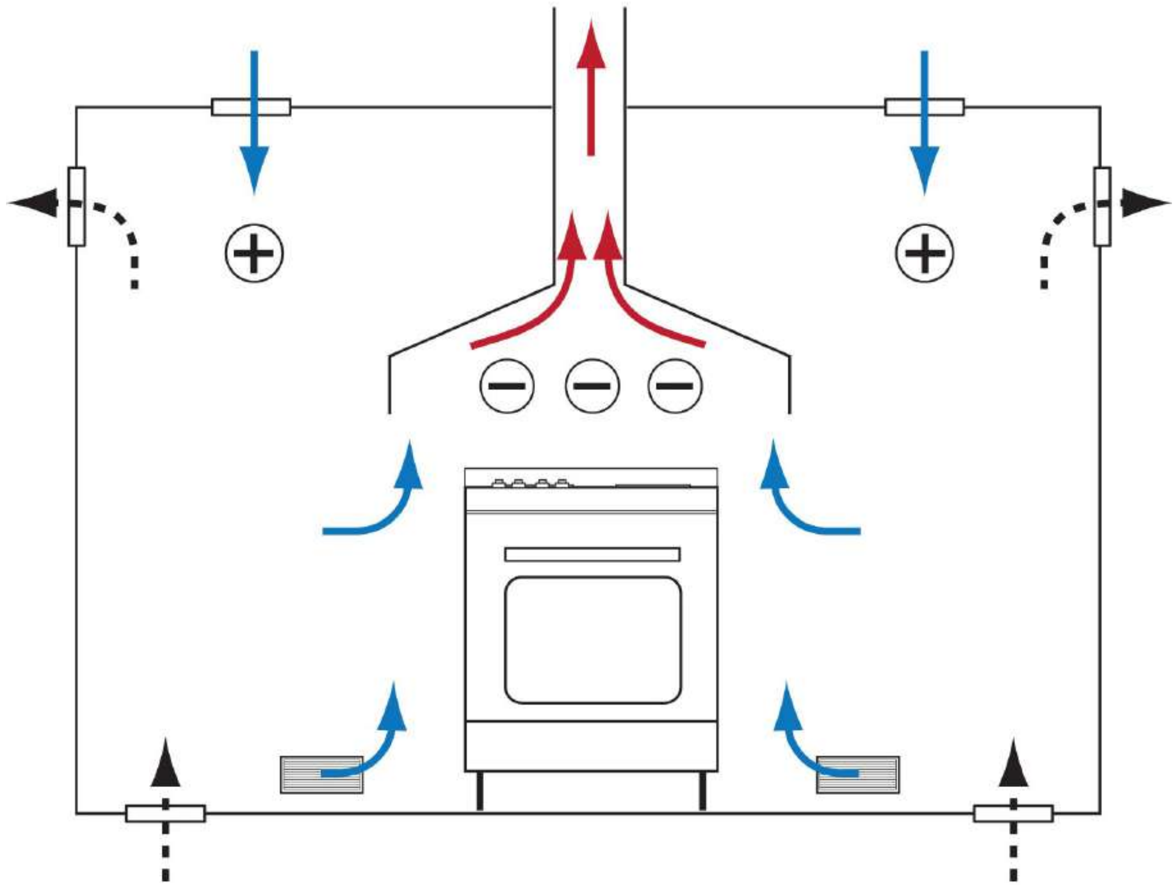
Above 25 percent during winter

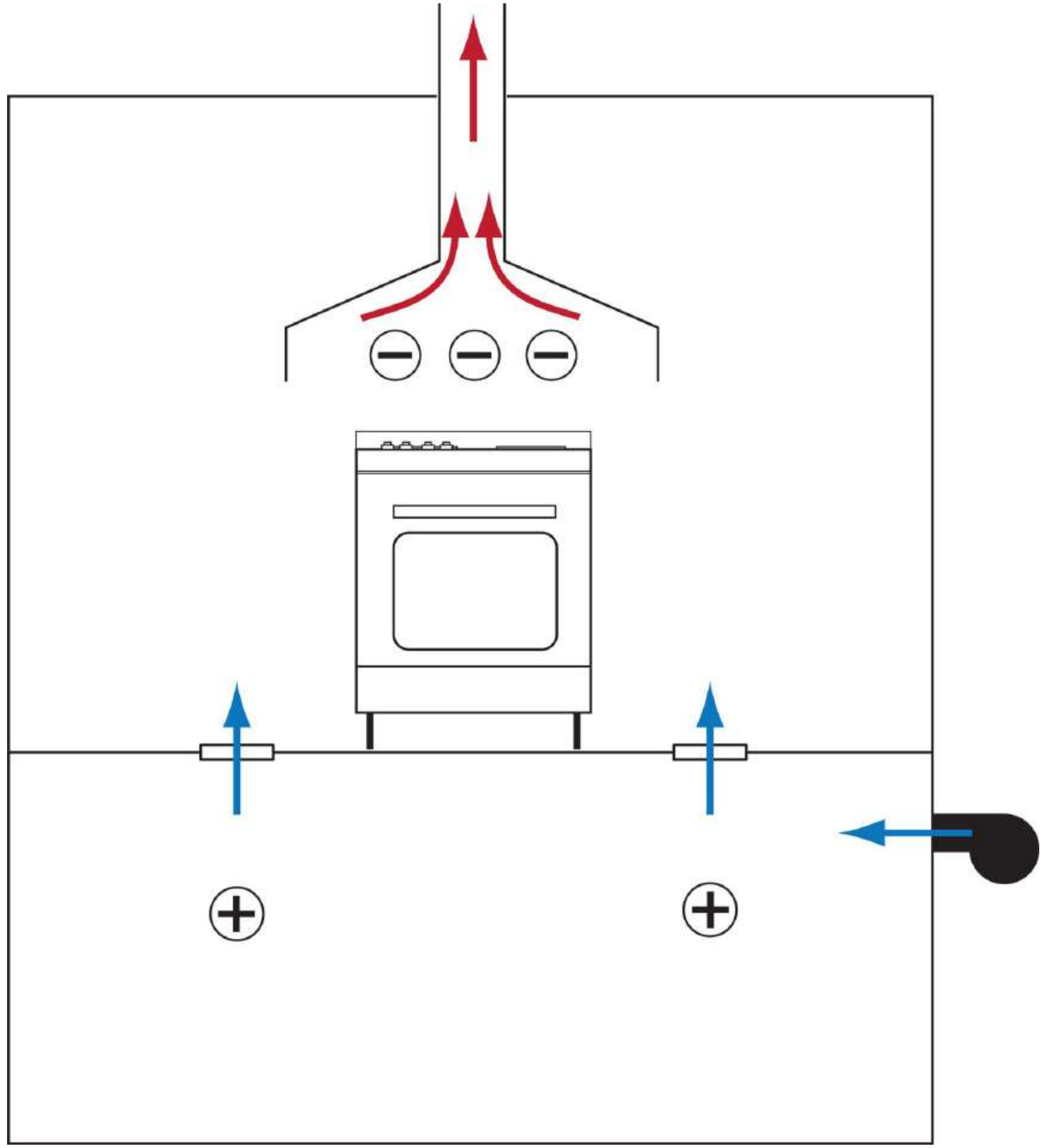
Below 70 percent during summer

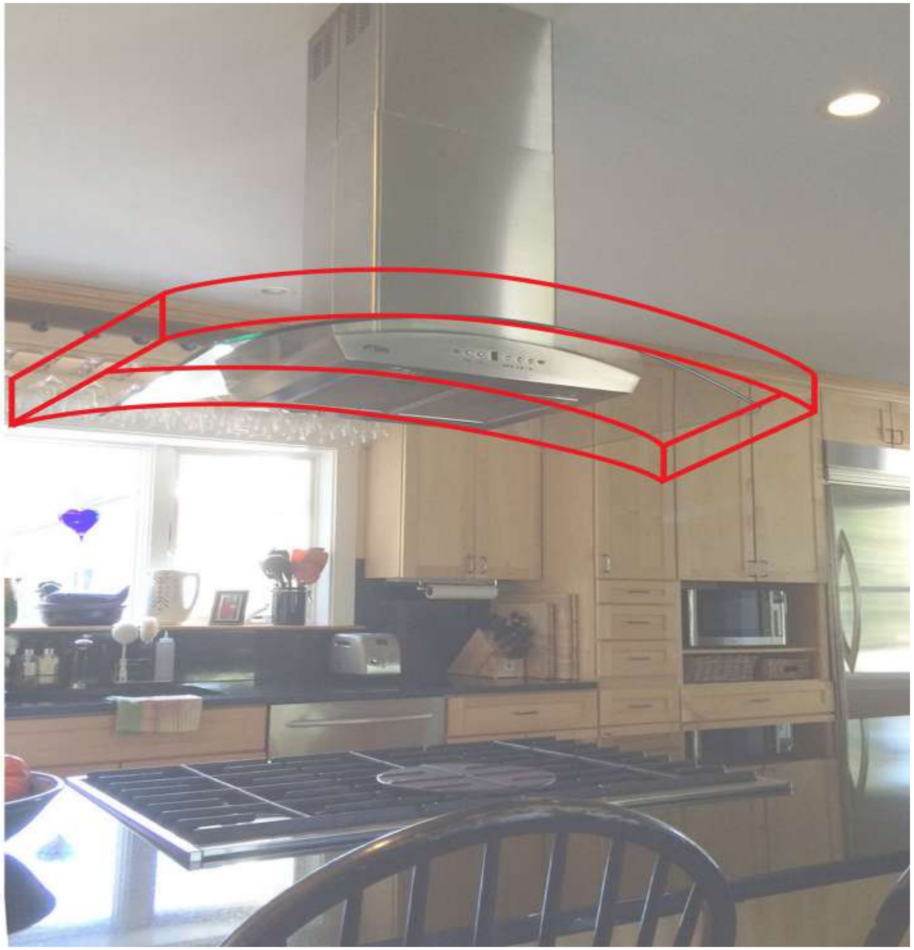

Supply
Return
Pressure relief grille to "bleed" pressure field from floor cavity
Air handler
Motorized damper
Flexible connection for vibration and sound control
Expandable filter slot
Dehumidifier
Full height louvered closet door for access and to supply air for dehumidfication
Condensate overflow pan

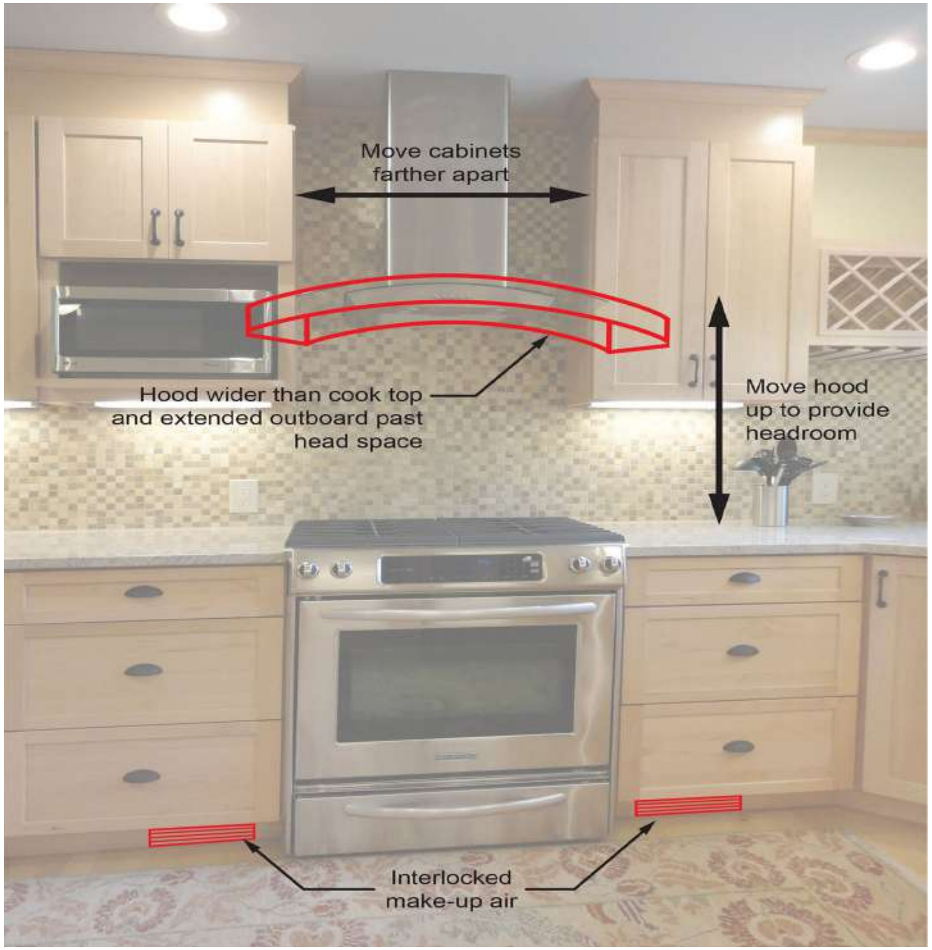
Kitchen Exhaust Hoods


Unconditioned
make-up air
60 - 70% of
hood exhaust







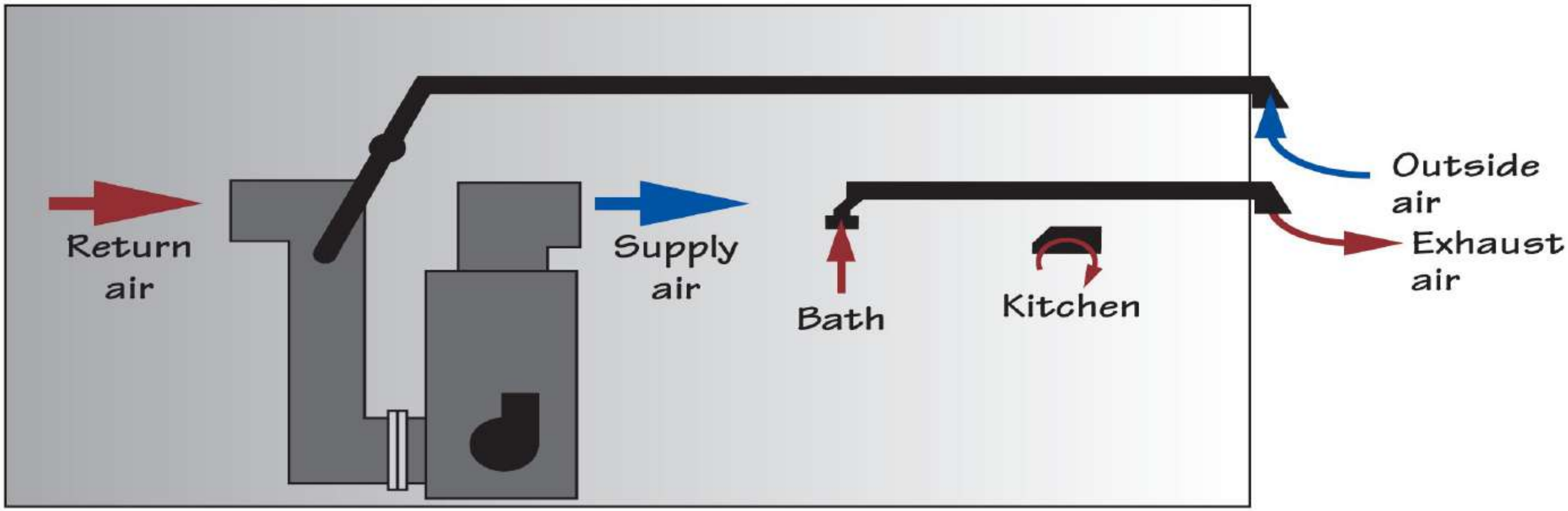

Move cabinets
farther apart
Hood wider than cook top
and extended outboard past
head space
Move hood
up to provide
headroom
Interlocked
make-up air

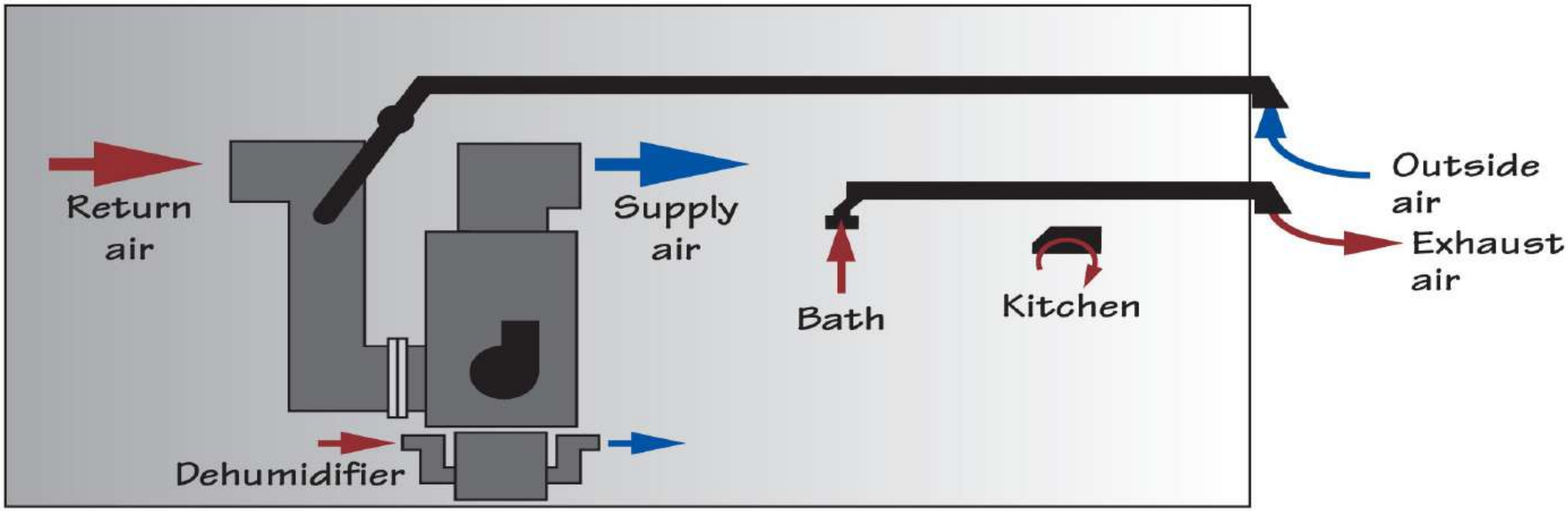
Clothes Dryers

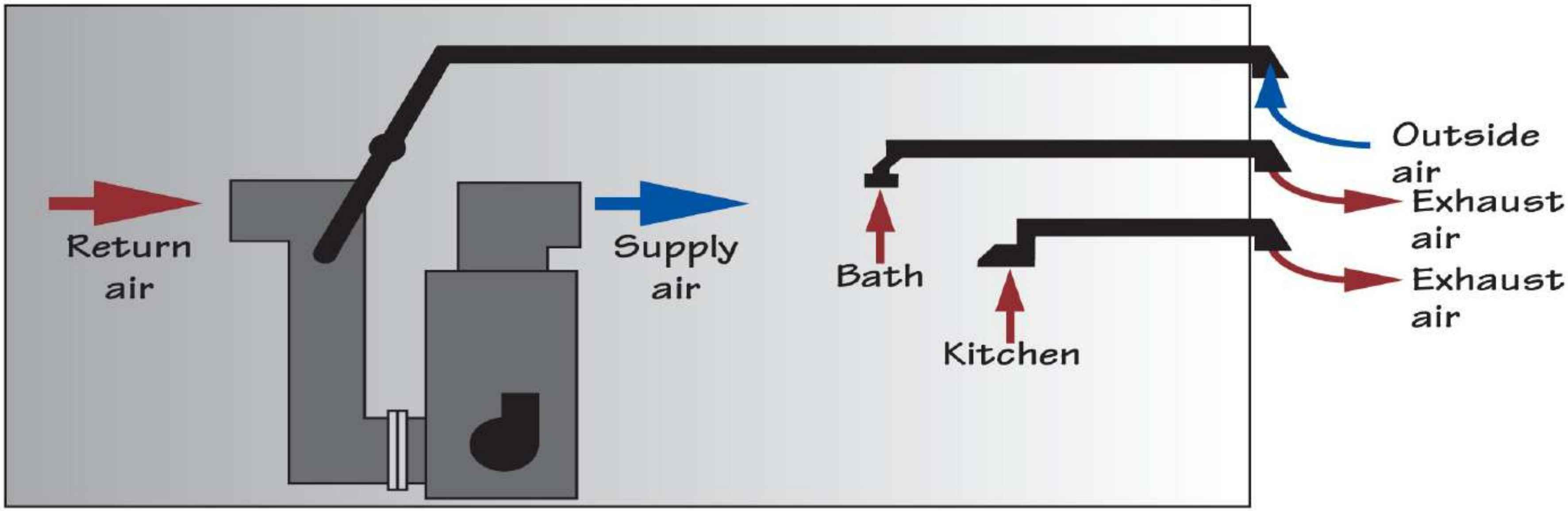

ASKO
ASKO
209

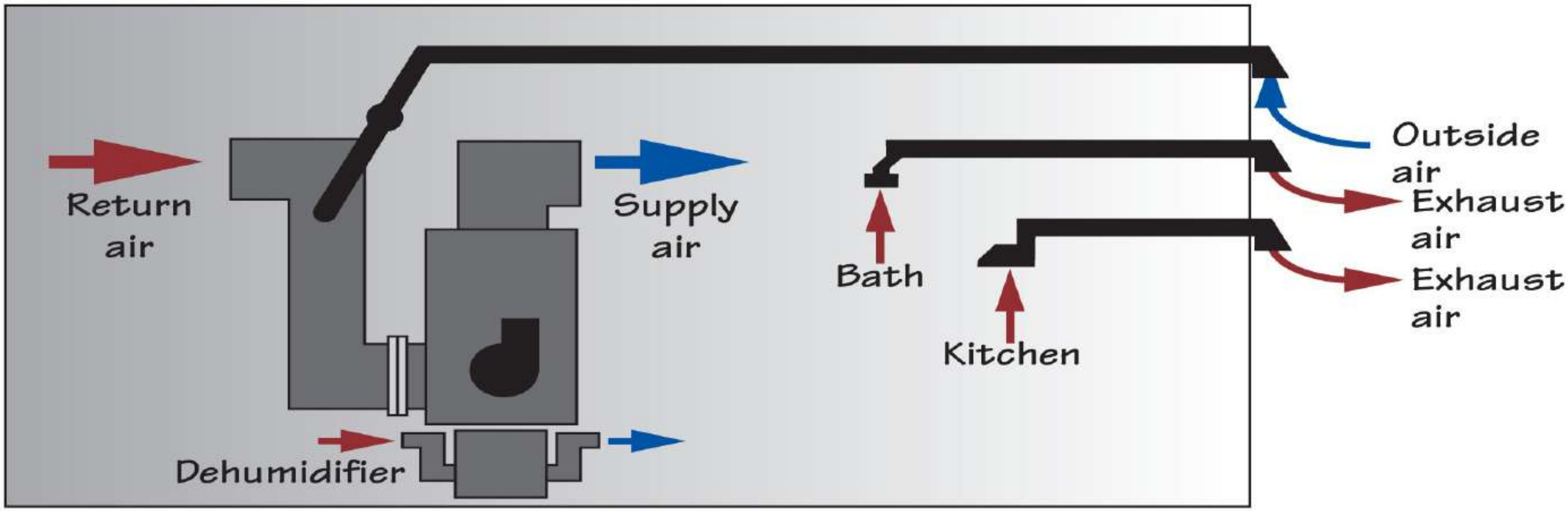
Fireplaces

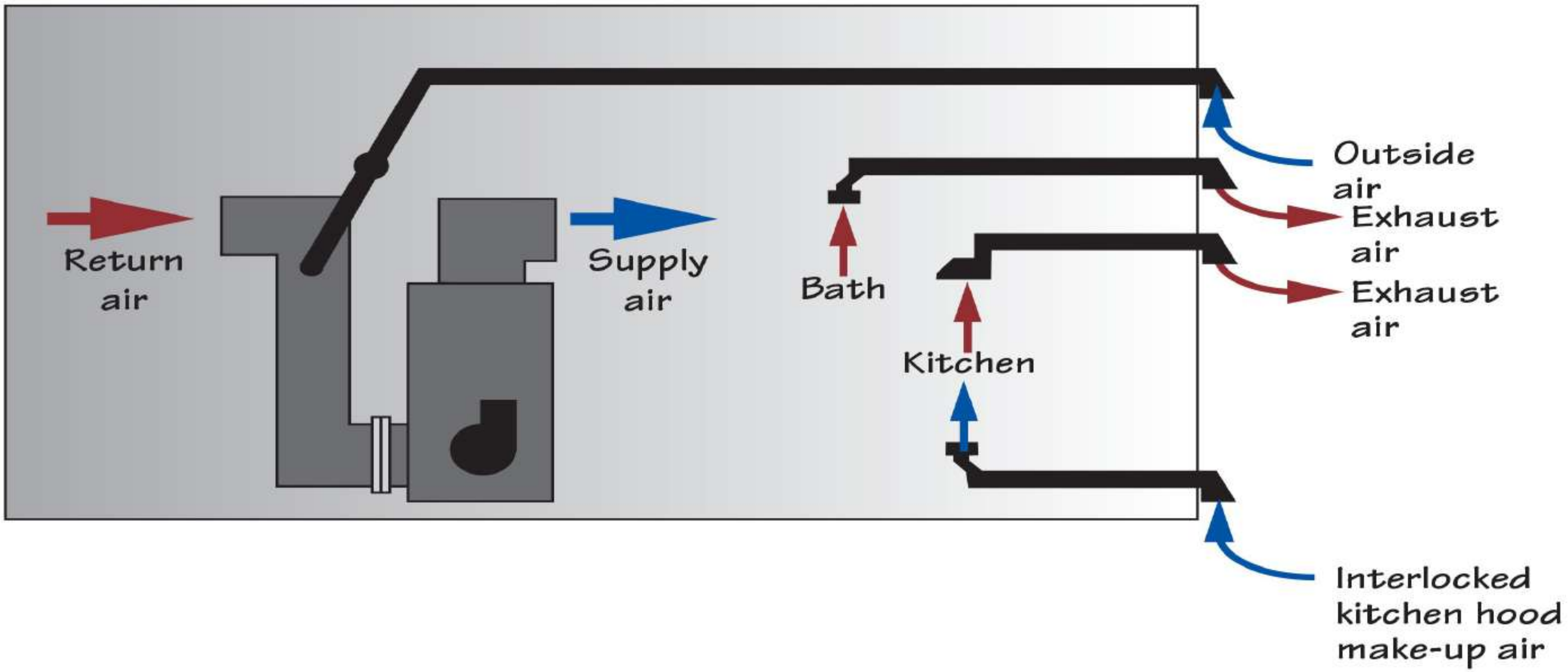
Approaches

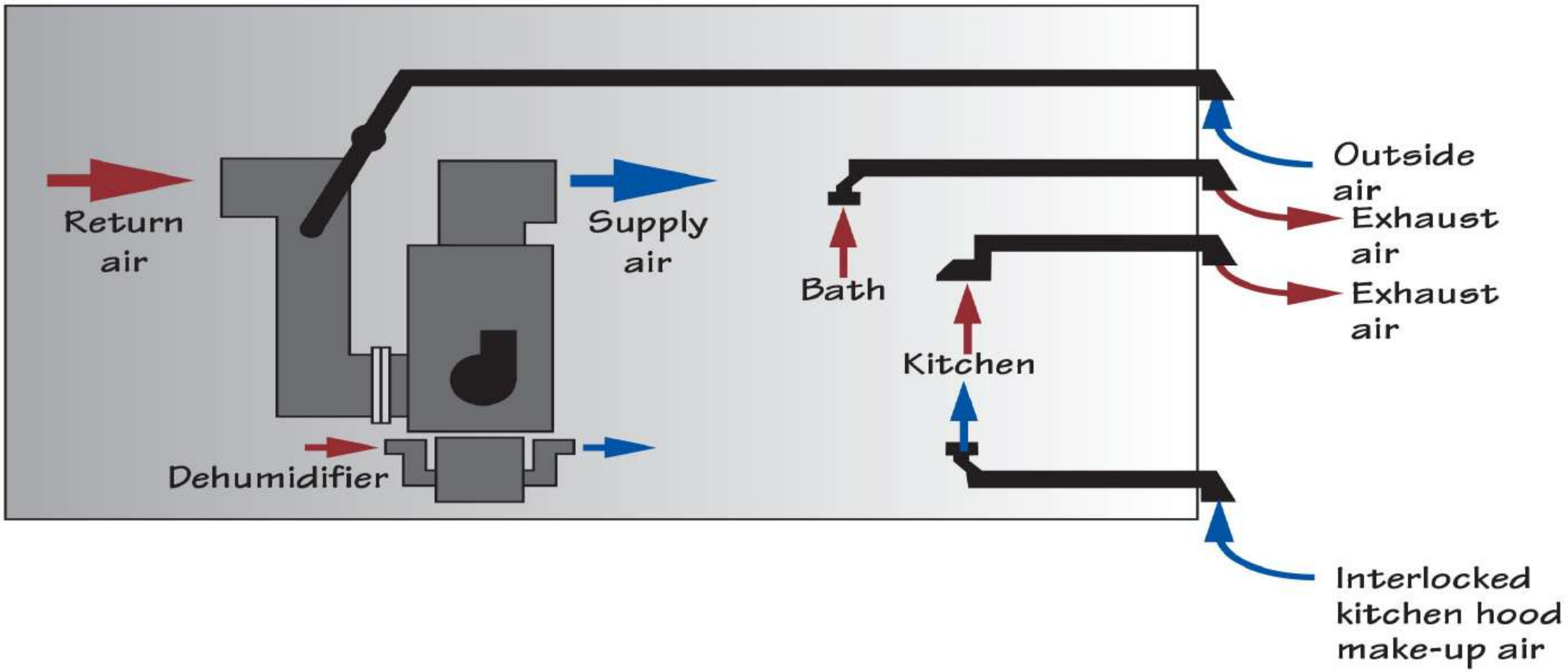

Return
air
Supply
air
Bath
Kitchen
Outside
air
Exhaust
air

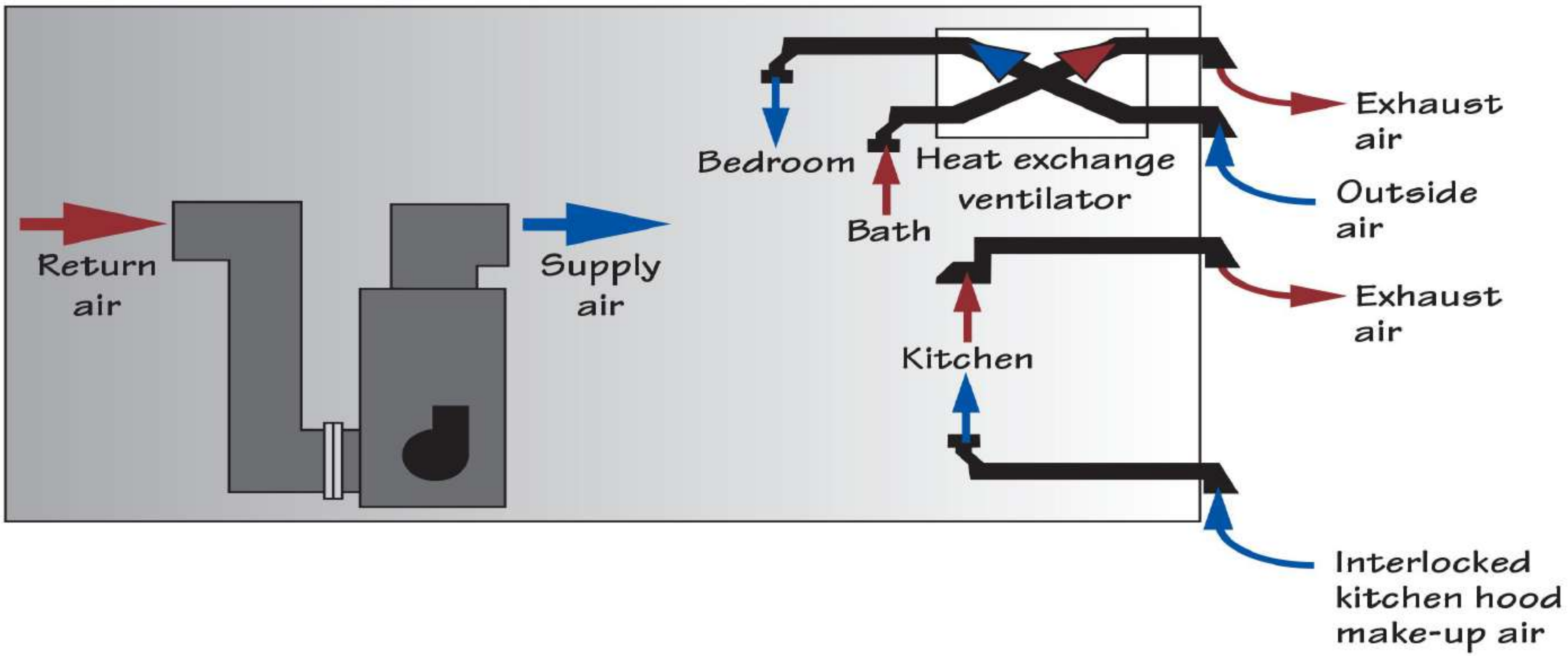

Return air
Supply air
Dehumidifier
Bath
Kitchen
Outside air
Exhaust air

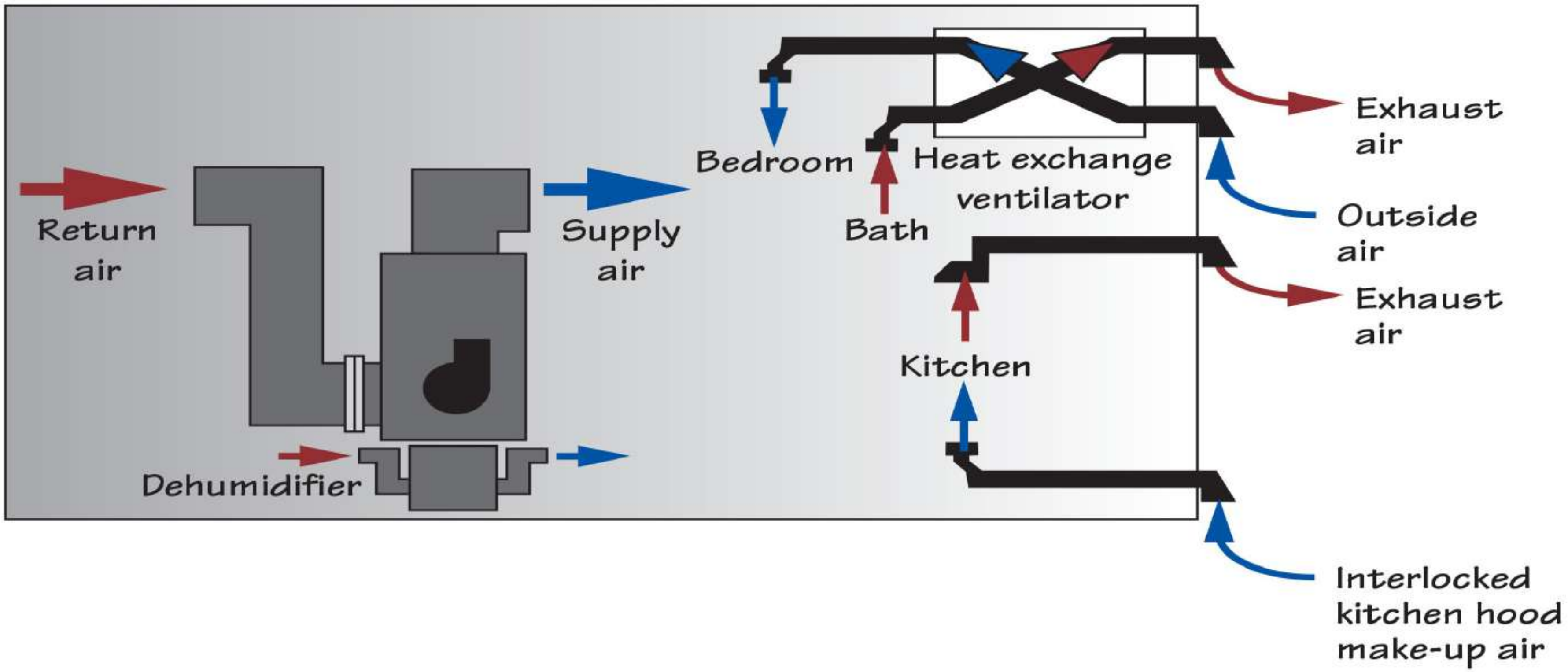

Return air
Supply air
Bath
Kitchen
Outside air
Exhaust air
Exhaust air

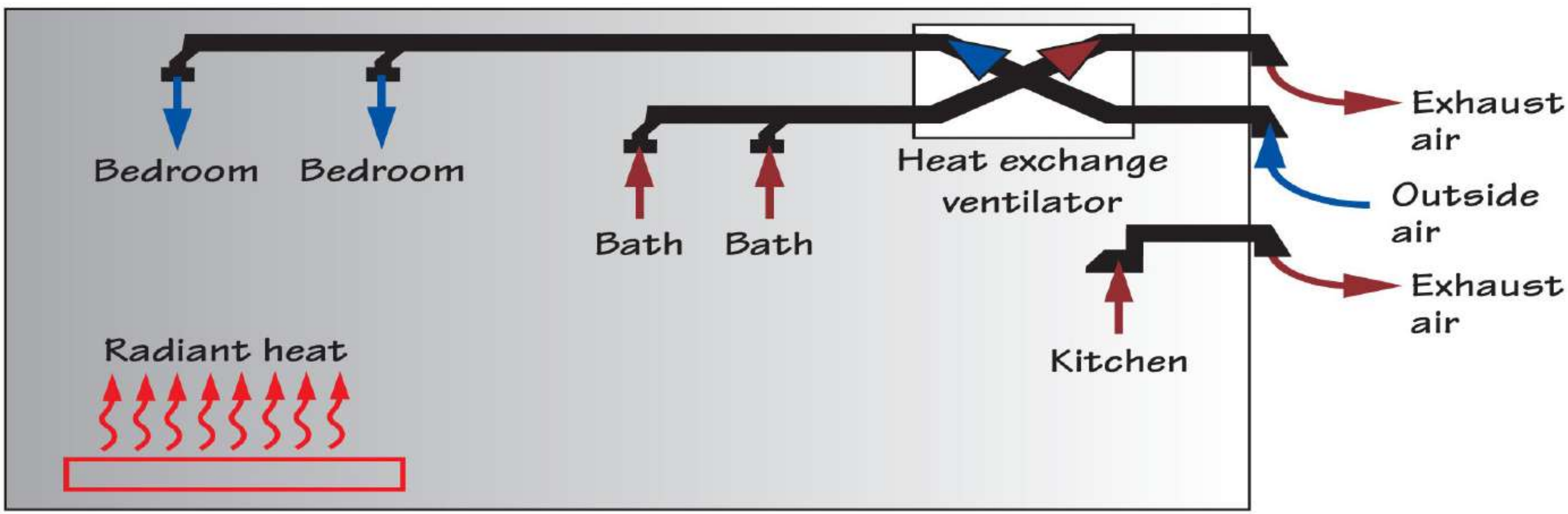

Return
air
Supply
air
Dehumidifier
Bath
Kitchen
Outside
air
Exhaust
air
Exhaust
air

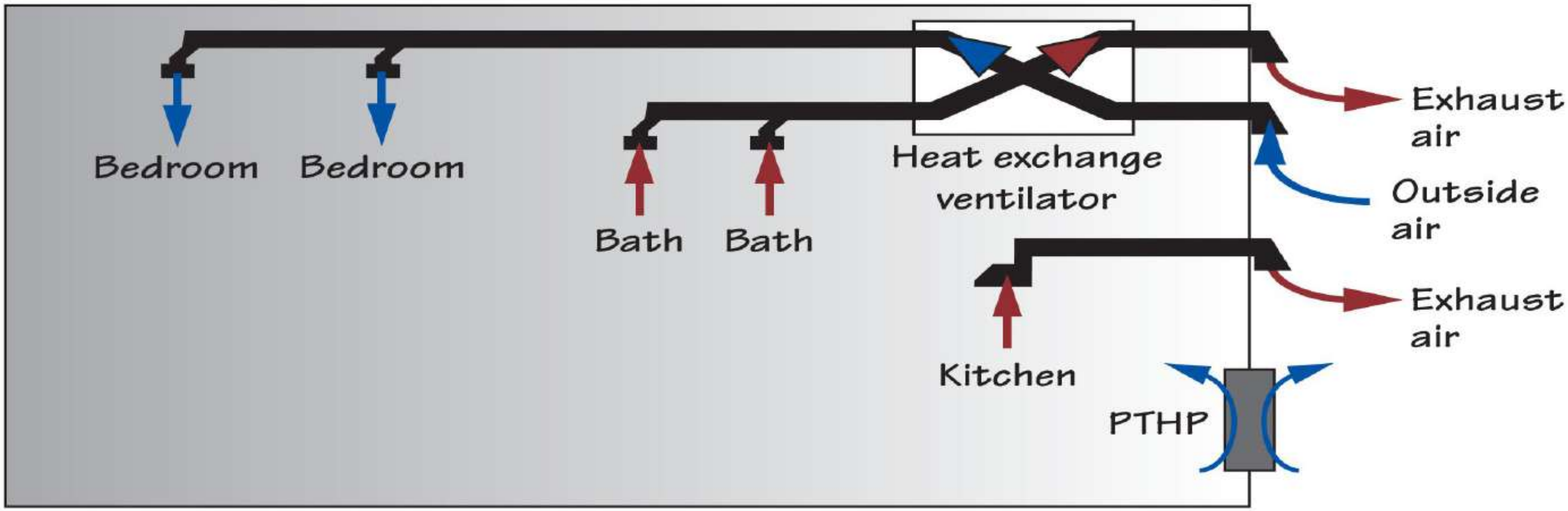

Return air
Supply air
Bath
Kitchen
Outside air
Exhaust air
Exhaust air
Interlocked kitchen hood make-up air

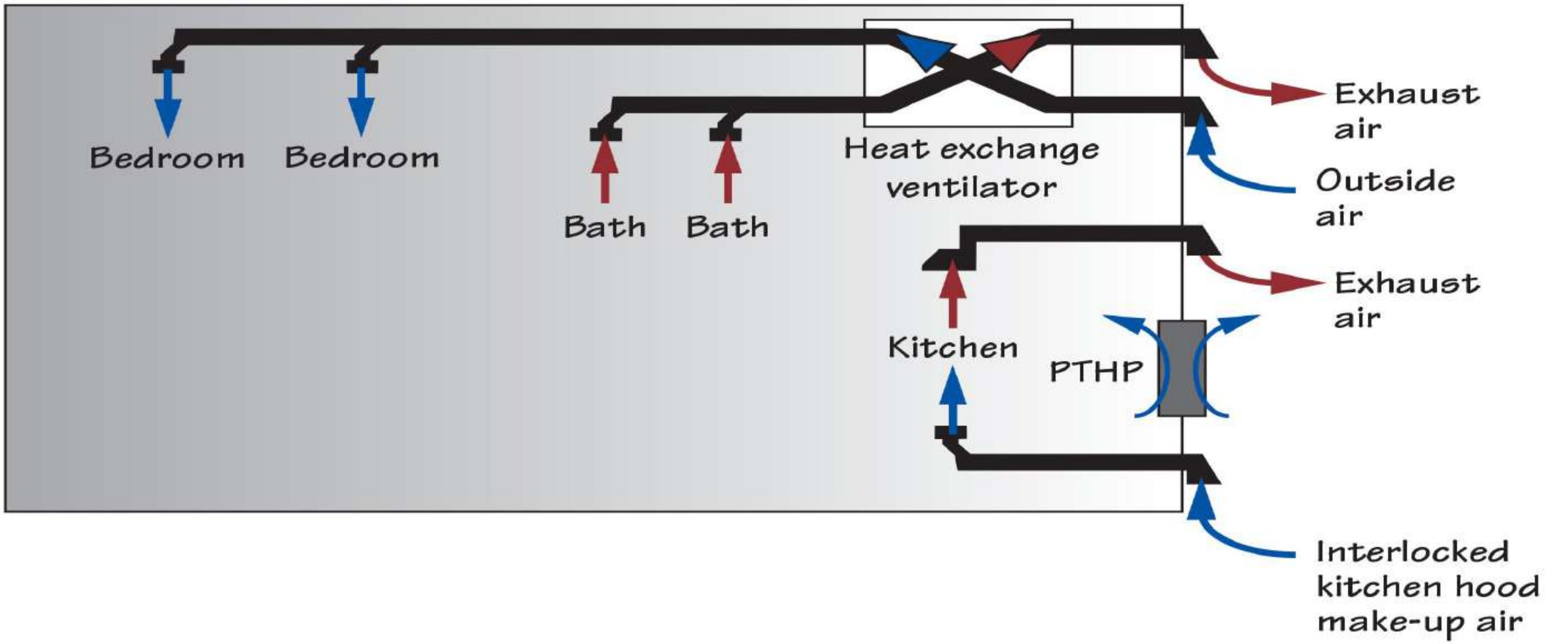

Return air
Supply air
Dehumidifier
Bath
Kitchen
Outside air
Exhaust air
Exhaust air
Interlocked kitchen hood make-up air

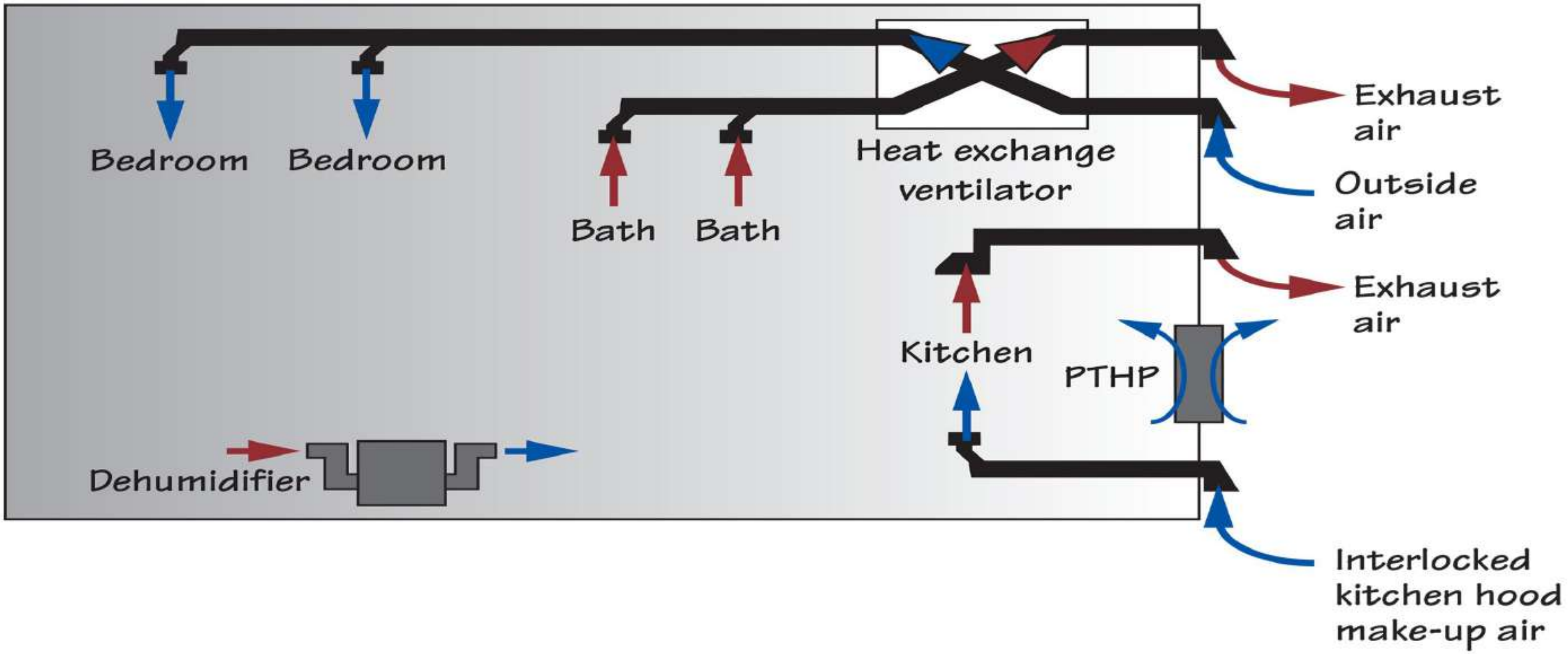

Return air
Supply air
Bedroom
Bath
Heat exchange ventilator
Exhaust air
Outside air
Kitchen
Exhaust air
Interlocked kitchen hood make-up air


Bedroom
Heat exchange
ventilator
Exhaust
air
Return
air
Supply
air
Bath
Outside
air
Exhaust
air
Kitchen
Dehumidifier
Interlocked
kitchen hood
make-up air

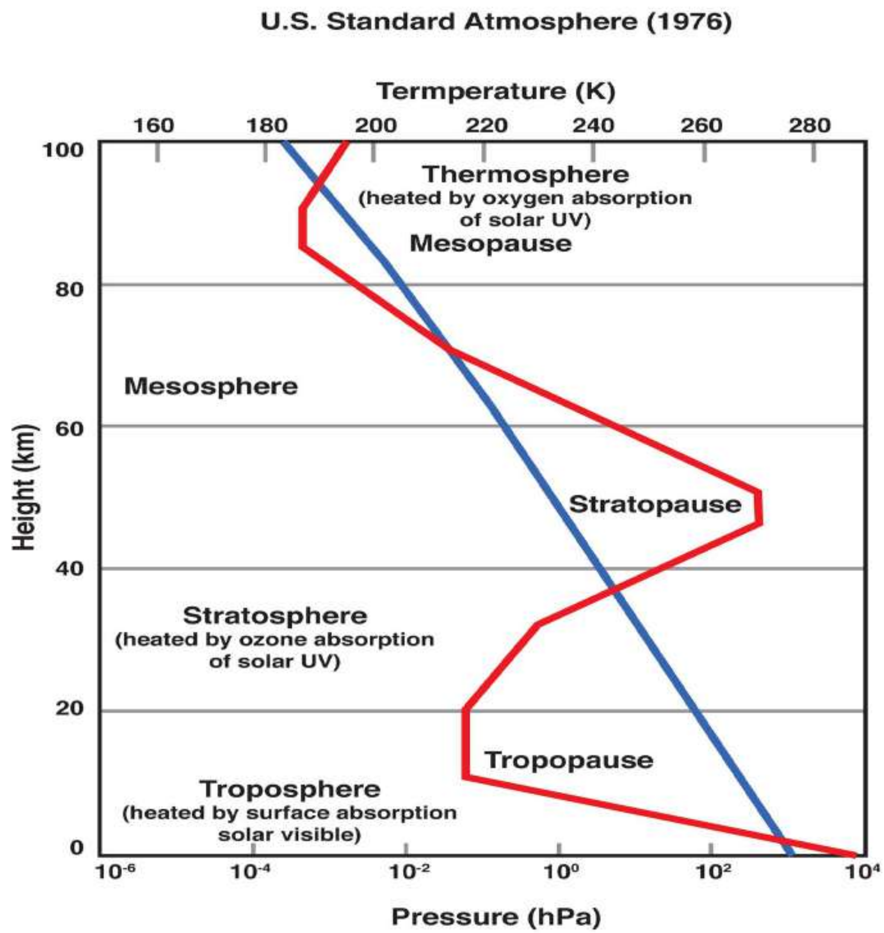

Bedroom
Bedroom
Bath
Bath
Heat exchange ventilator
Exhaust air
Outside air
Exhaust air
Kitchen
Radiant heat


Bedroom
Bedroom
Bath
Bath
Heat exchange ventilator
Exhaust air
Outside air
Exhaust air
Kitchen
PTHP


Bedroom
Bedroom
Bath
Bath
Heat exchange ventilator
Exhaust air
Outside air
Exhaust air
Kitchen
PTHP
Interlocked kitchen hood make-up air


Bedroom
Bedroom
Bath
Bath
Heat exchange ventilator
Exhaust air
Outside air
Exhaust air
Kitchen
PTHP
Dehumidifier
Interlocked kitchen hood make-up air

Lapse Rate


U.S. Standard Atmosphere (1976)
Termperature (K)
160
180
200
220
240
260
280
100
80
60
40
20
0
Height (km)
Thermosphere
(heated by oxygen absorption
of solar UV)
Mesopause
Mesosphere
Stratopause
Stratosphere
(heated by ozone absorption
of solar UV)
Tropopause
Troposphere
(heated by surface absorption
solar visible)
10-6
10-4
10-2
10^0
10^2
10^4
Pressure (hPa)

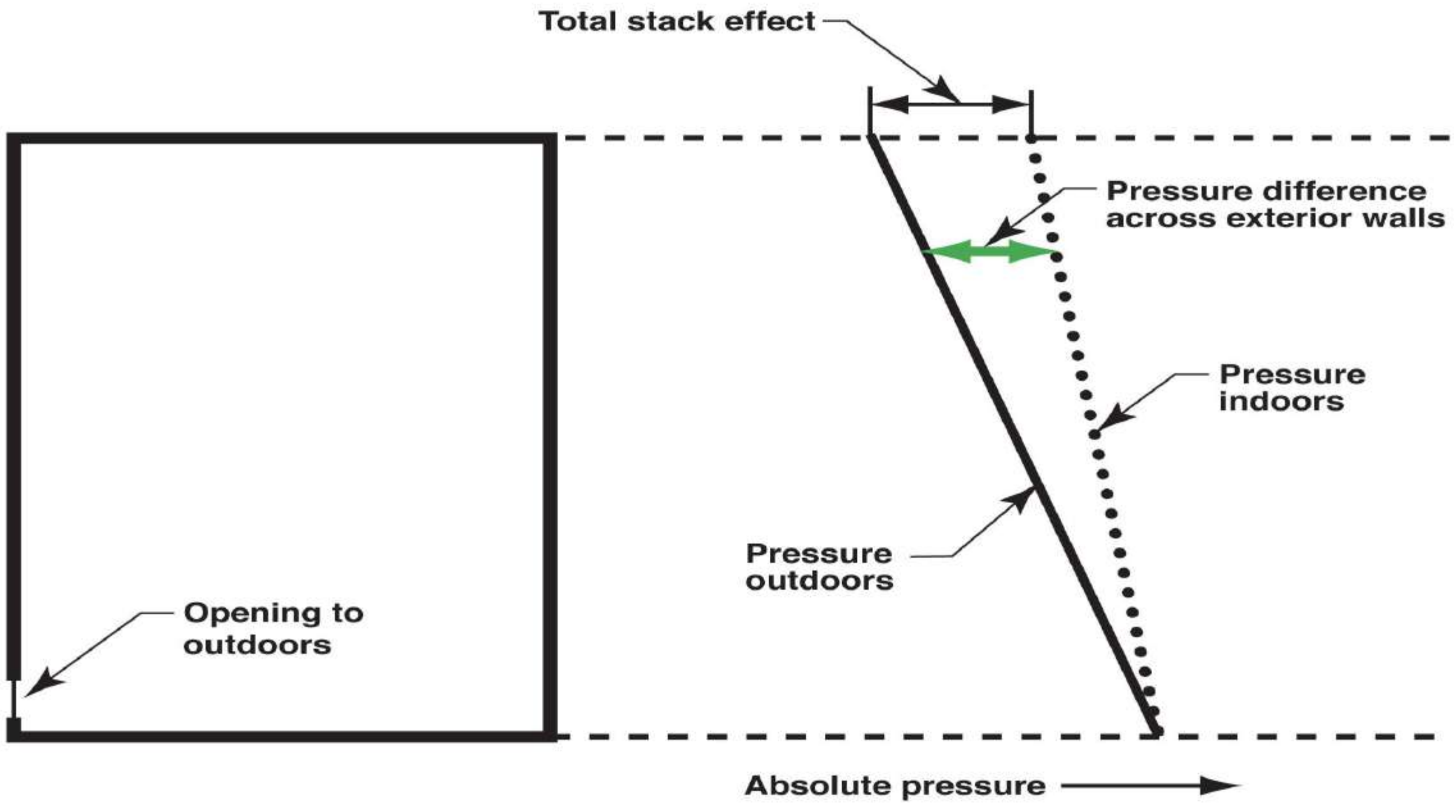


Figure 11.1: Building with no internal separations with opening at the bottom (Adapted from G.O. Handegord, 1998)

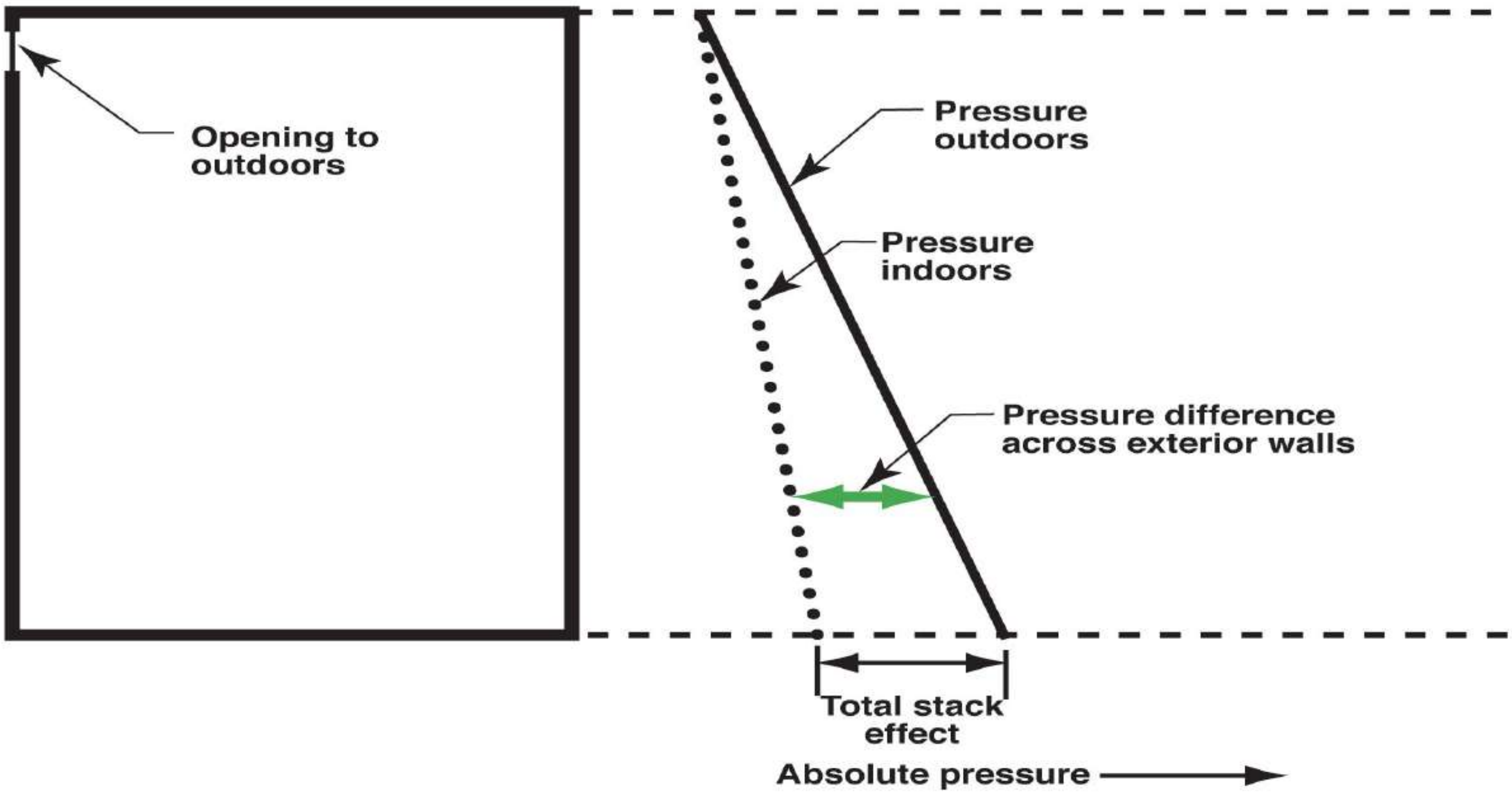


Figure 11.2: Building with no internal separations with opening at the top (Adapted from G.O. Handegord, 1998)

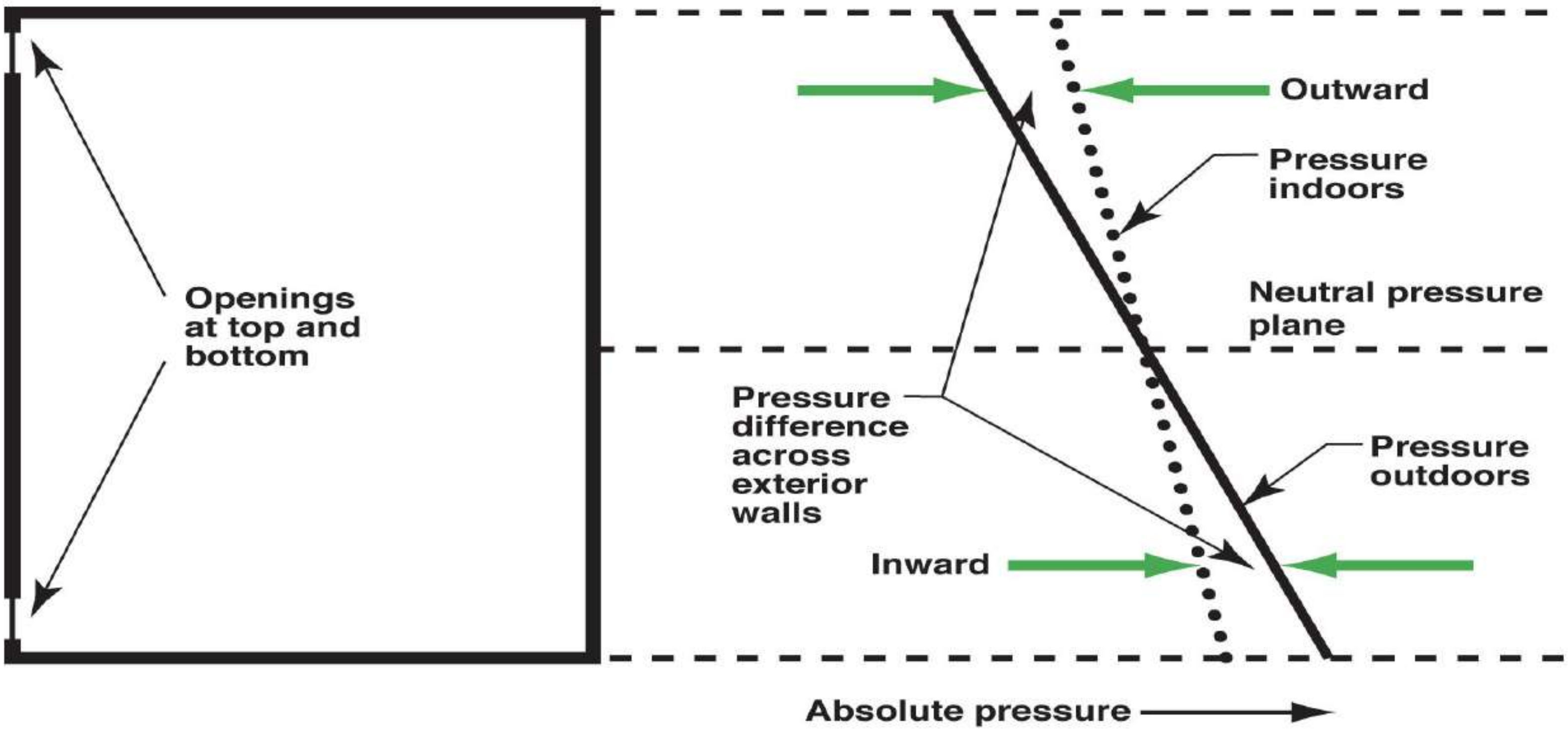


Figure 11.3: Building with no internal separations with openings at top and bottom (Adapted from G.O. Handegord, 1998)

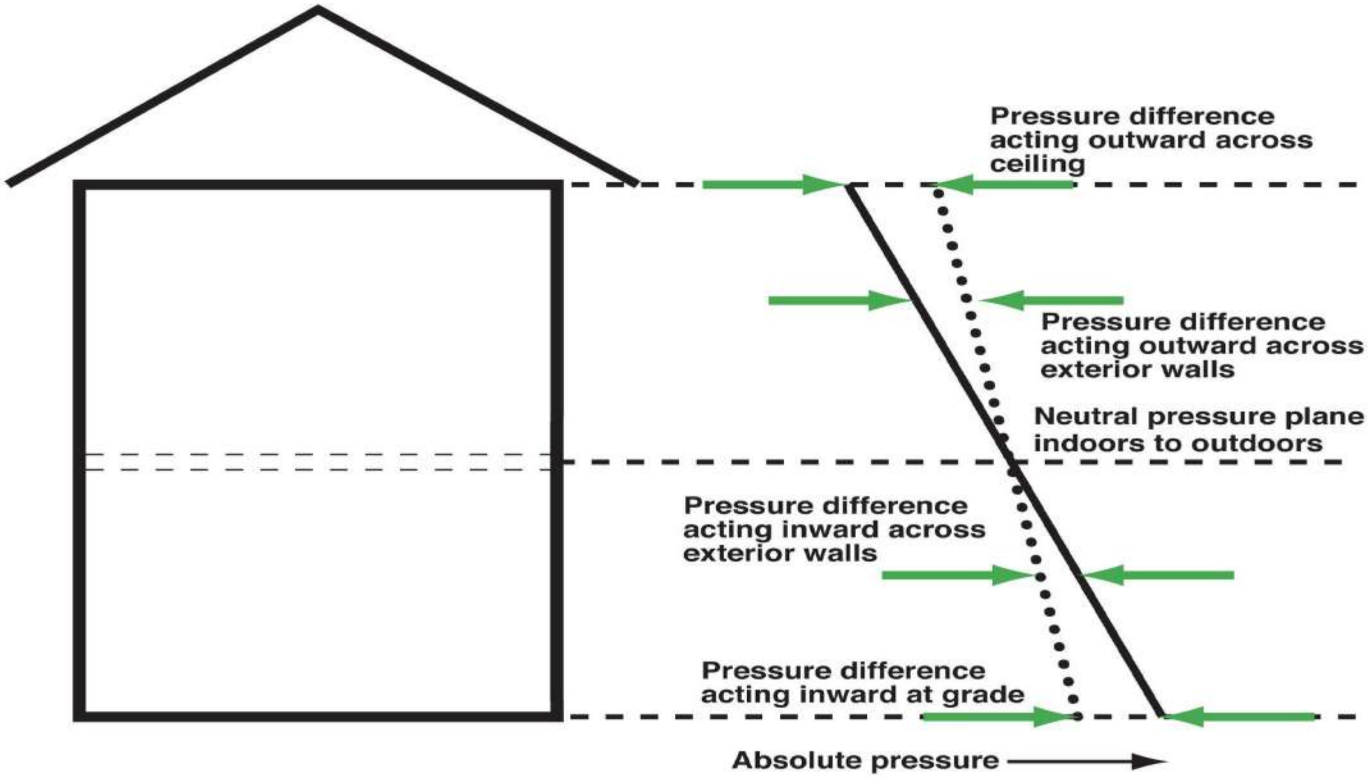


Figure 11.4: Basic two storey house with vented attic
(Adapted from G.O. Handegord, 1998)


POMPIERS NO. 3

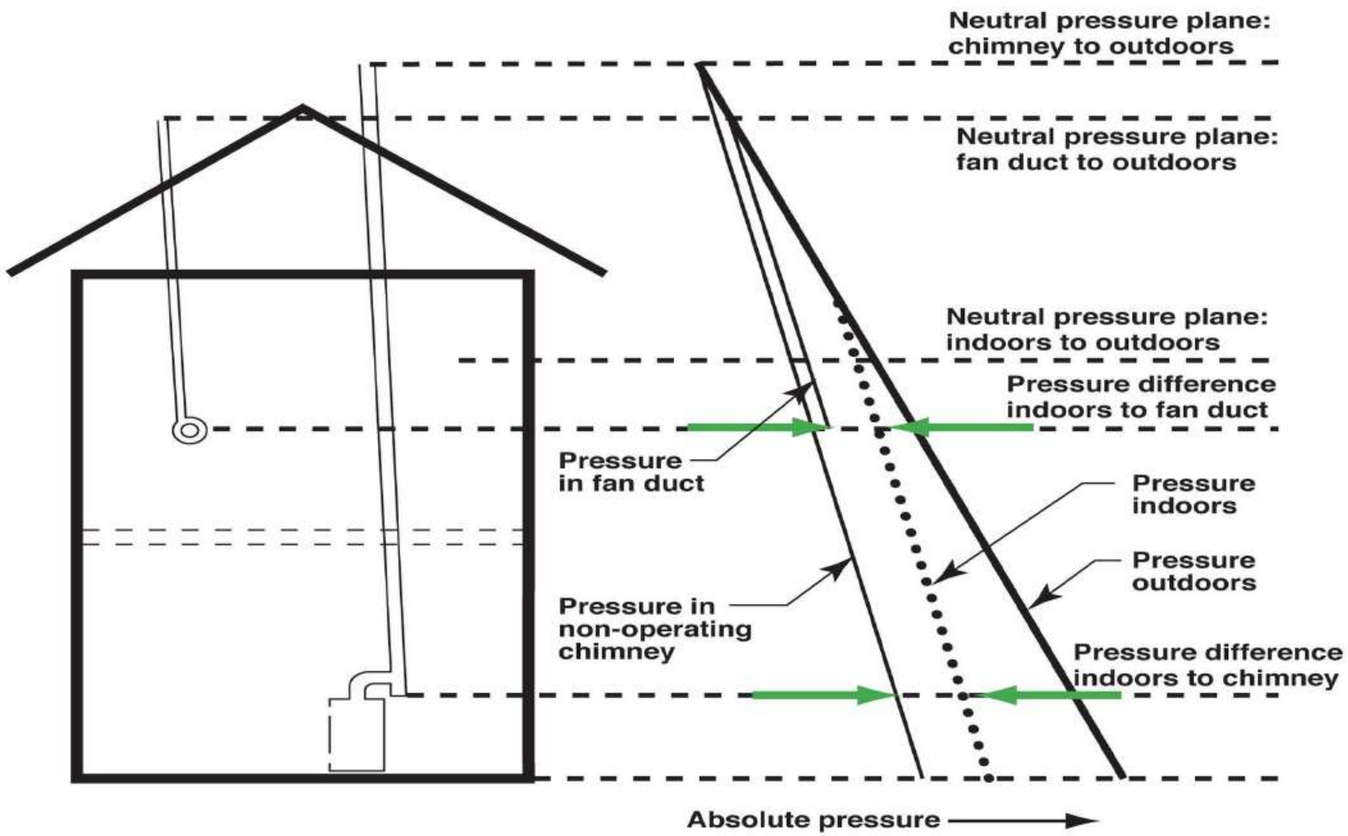


Figure 11.5: Two storey house with non-operating chimney and exhaust fan (Adapted from G.O. Handegord, 1998)

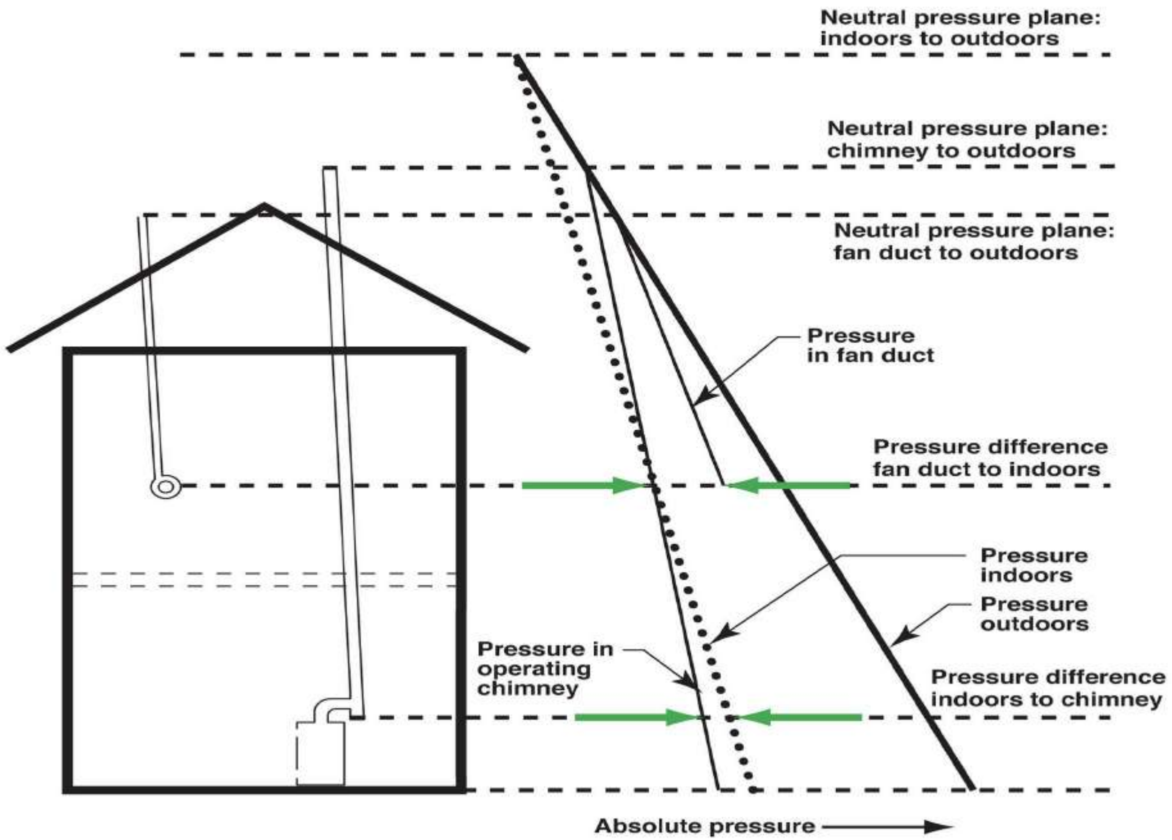
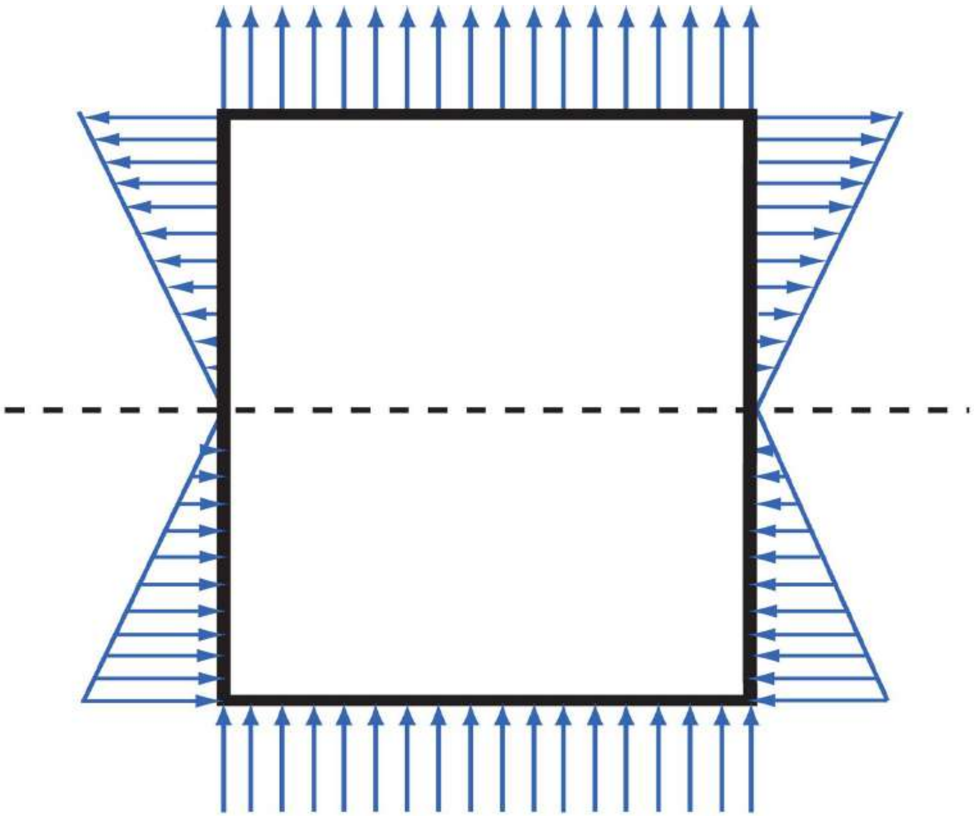
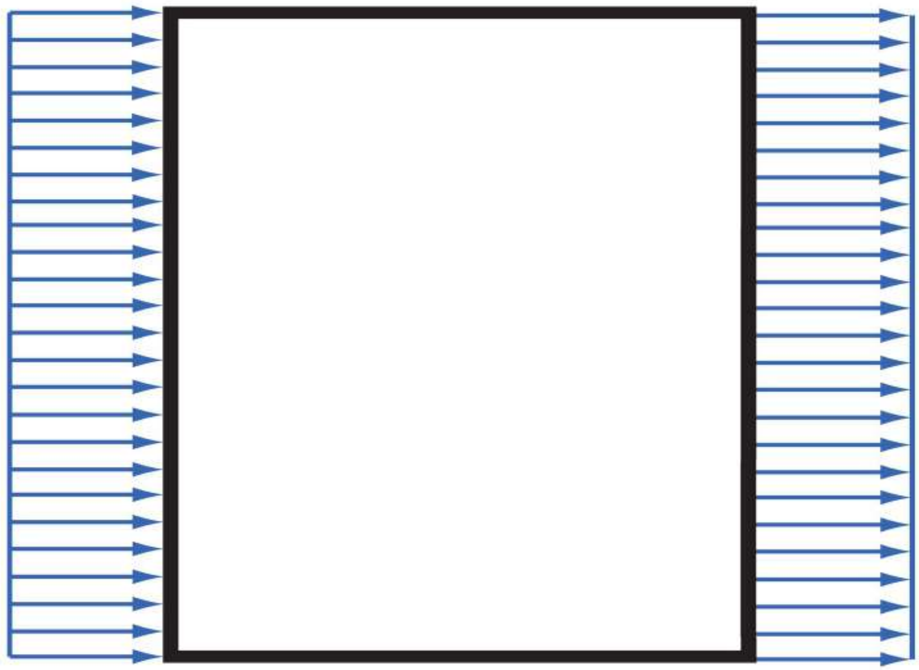


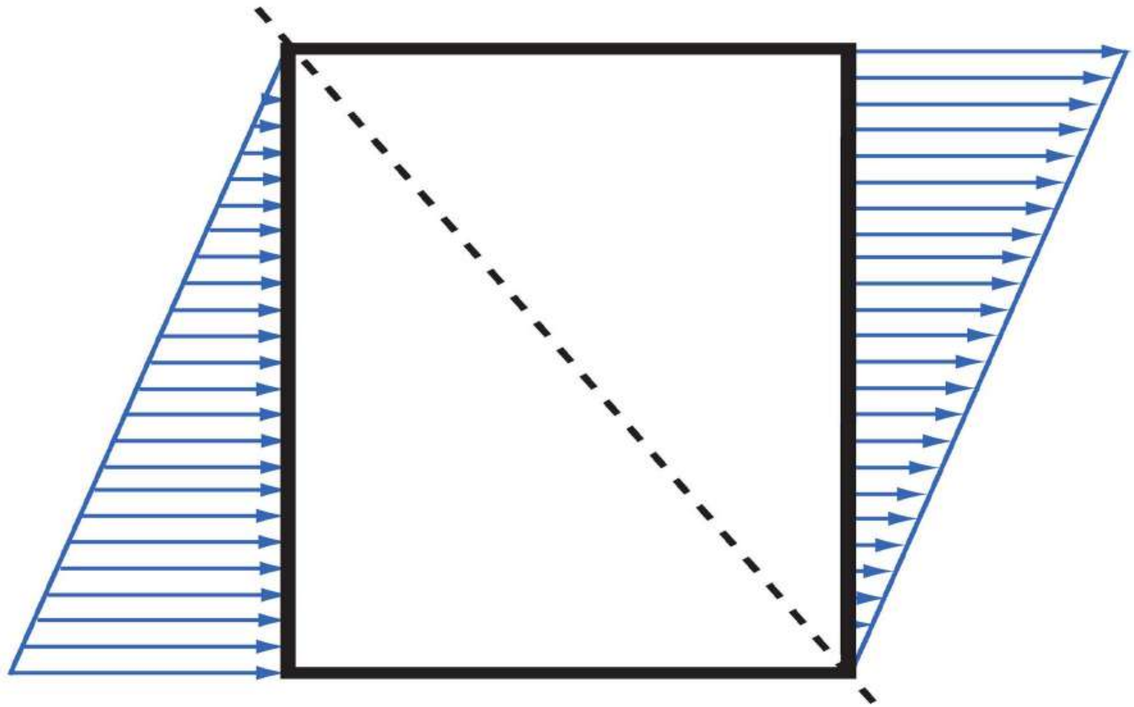
Figure 11.6: Two storey house with operating chimney (Adapted from G.O. Handegord, 1998)



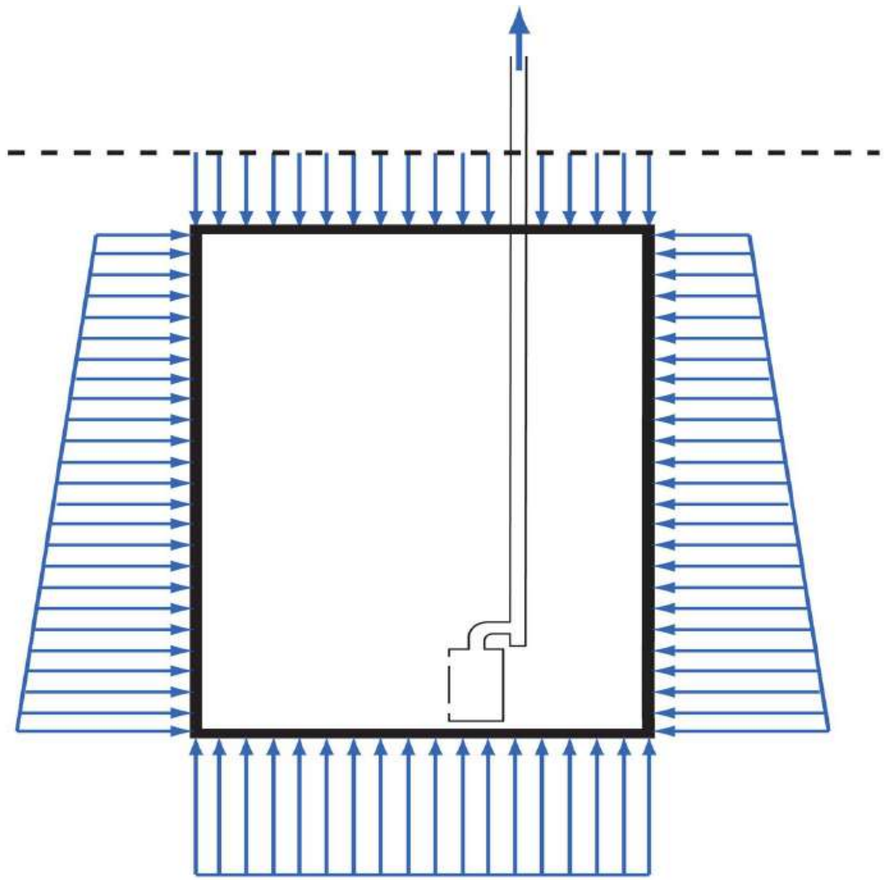
Stack effect



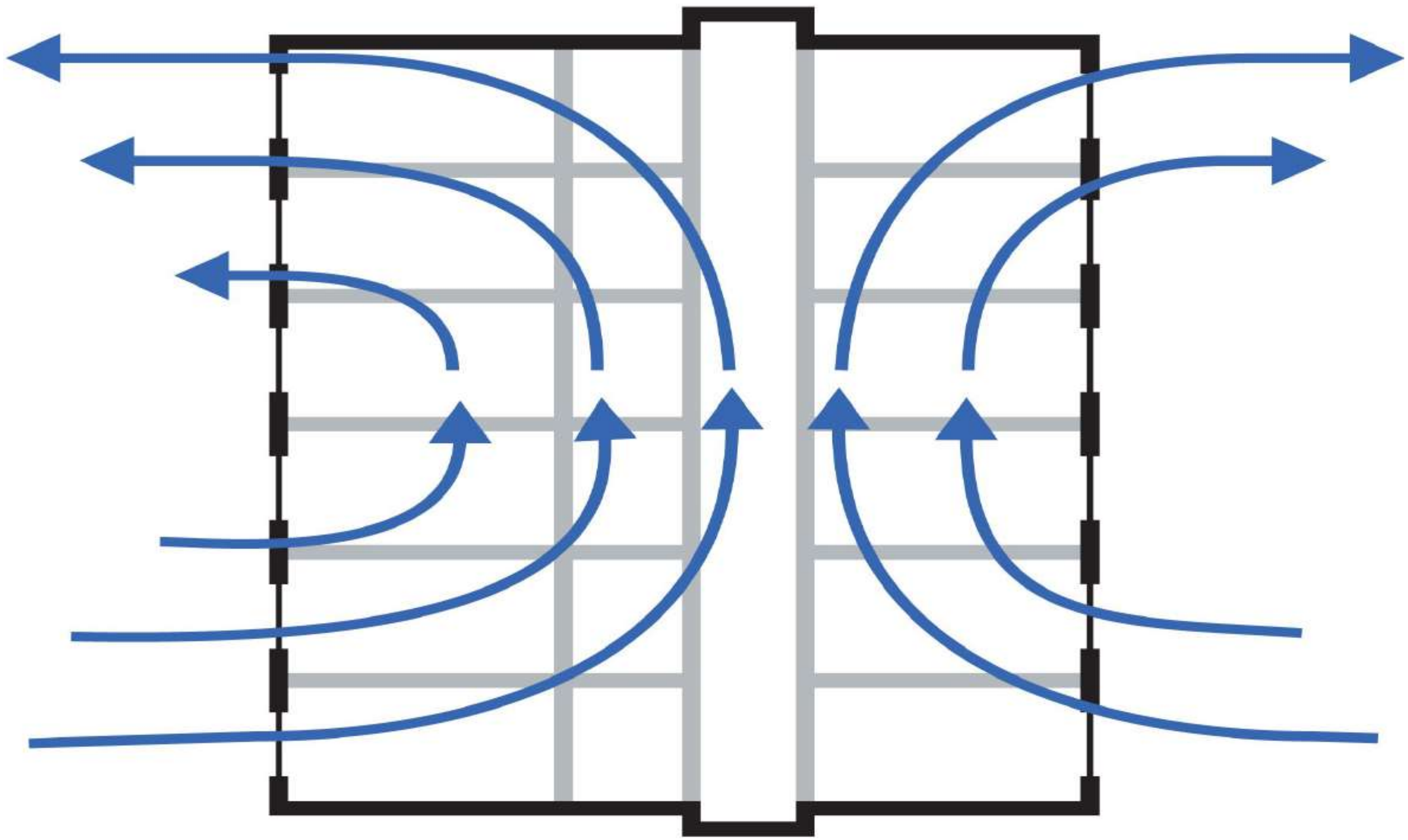
Wind

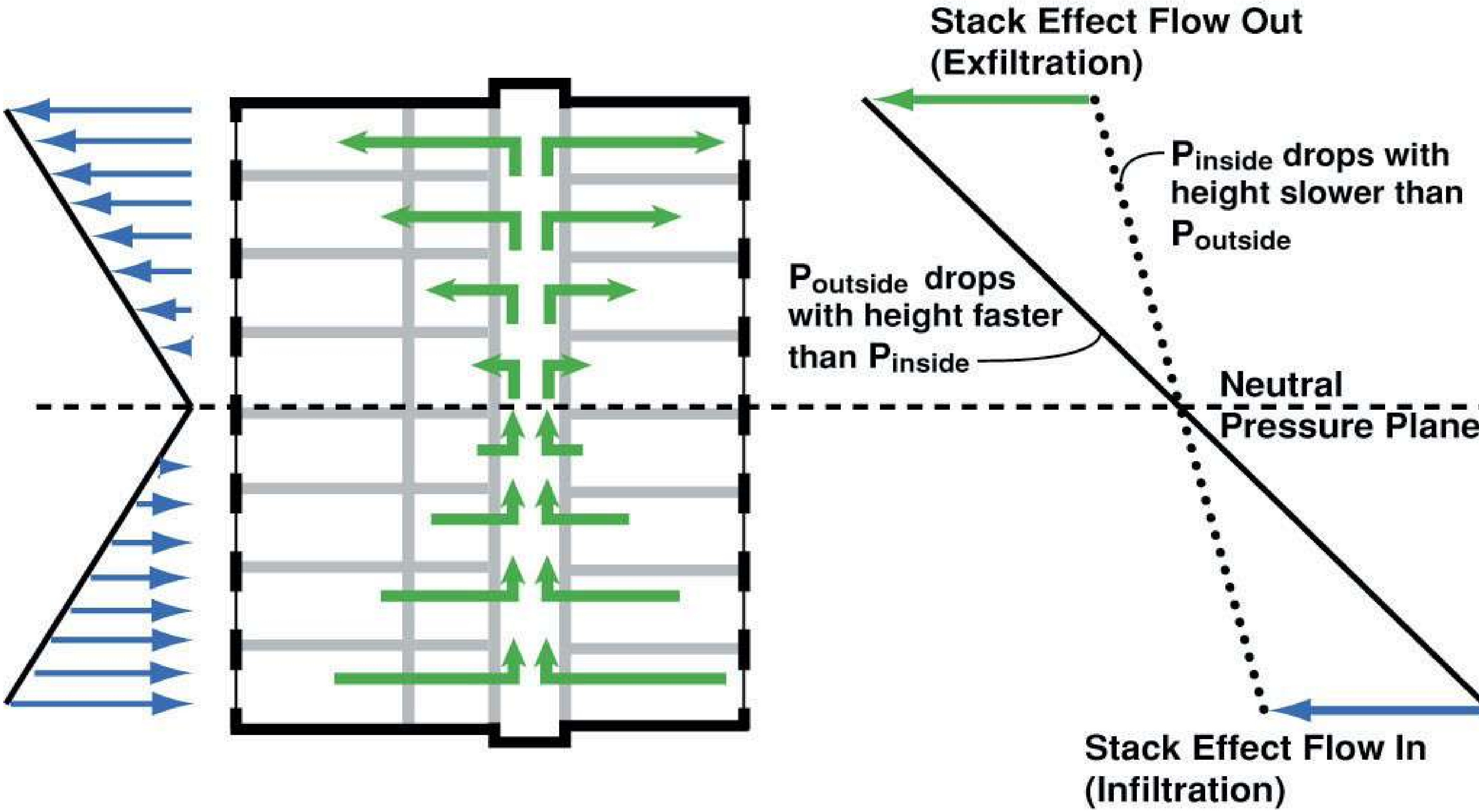


Stack effect and wind



Chimney effect




Stack Effect Flow Out
(Exfiltration)
P_{inside} drops with height slower than $P_{outside}$
$P_{outside}$ drops with height faster than P_{inside}
Neutral Pressure Plane
Stack Effect Flow In
(Infiltration)

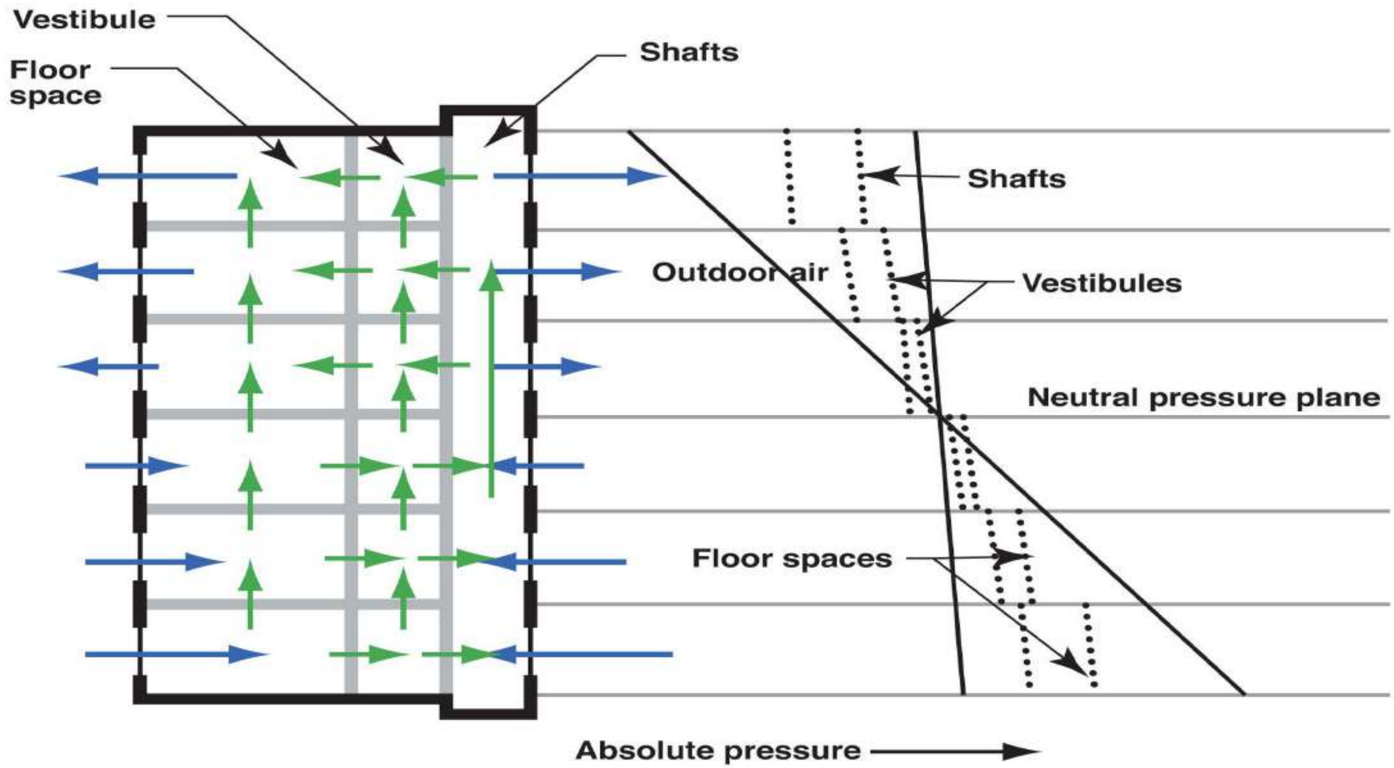


Figure 11.8: Stack effect pressures in high rise office building (Adapted from G.O. Handegord, 1998)

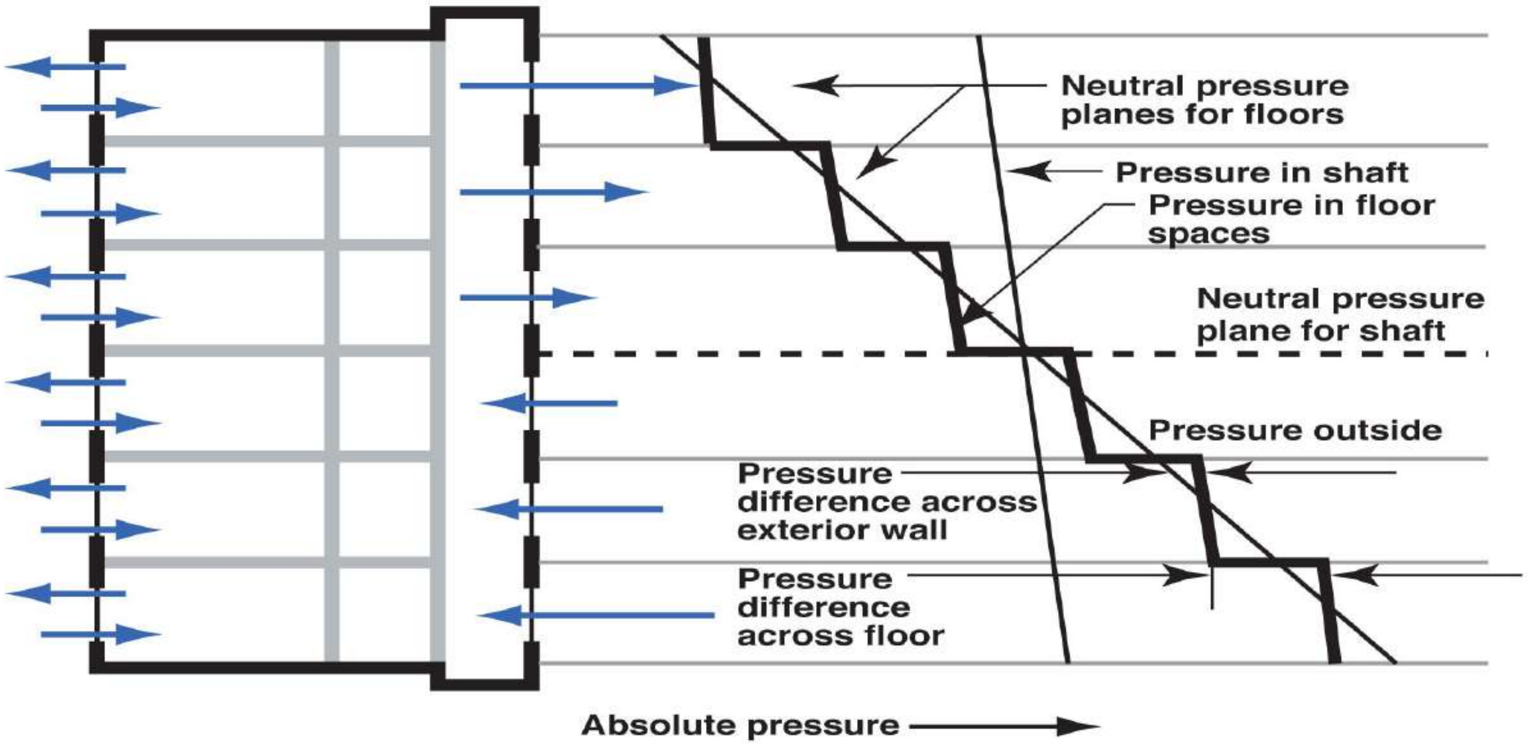


Figure 11.9: Multi-storey building with floor spaces isolated from vertical shafts (Adapted from G.O. Handegord, 1998)

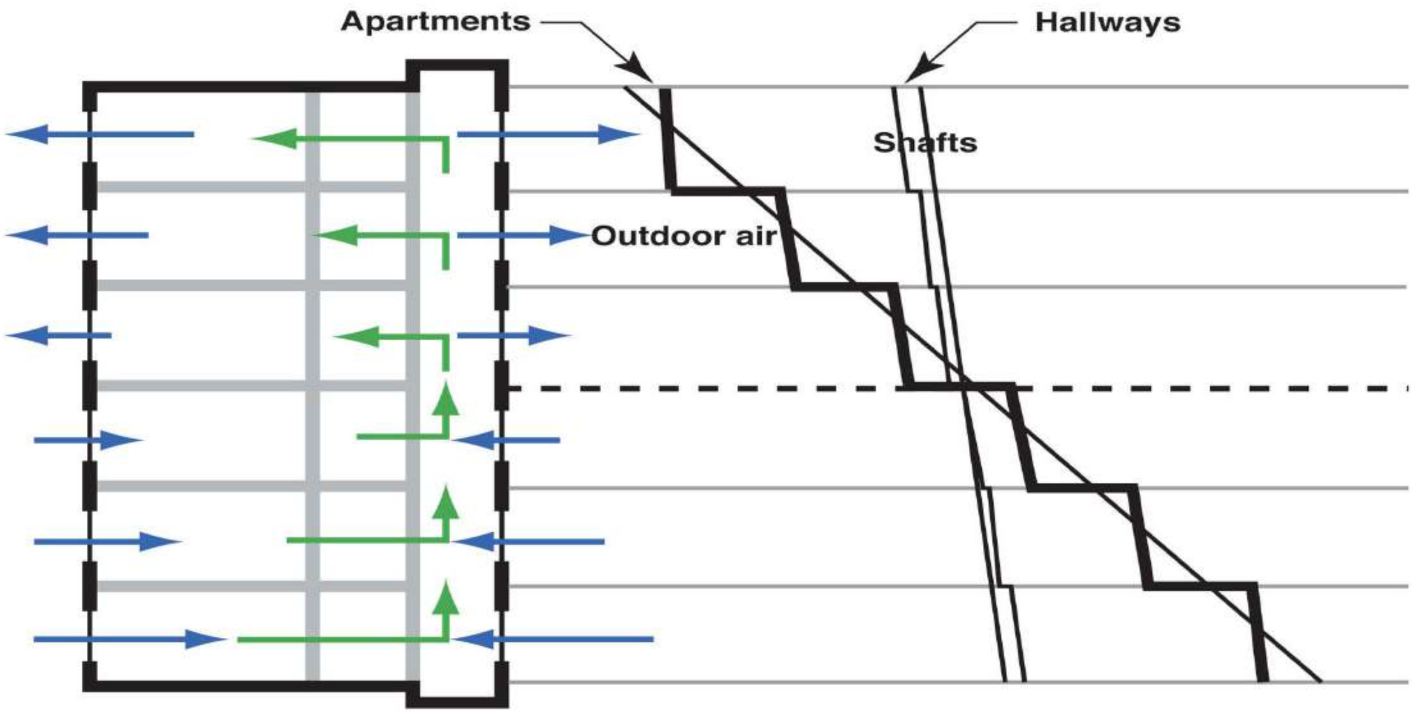
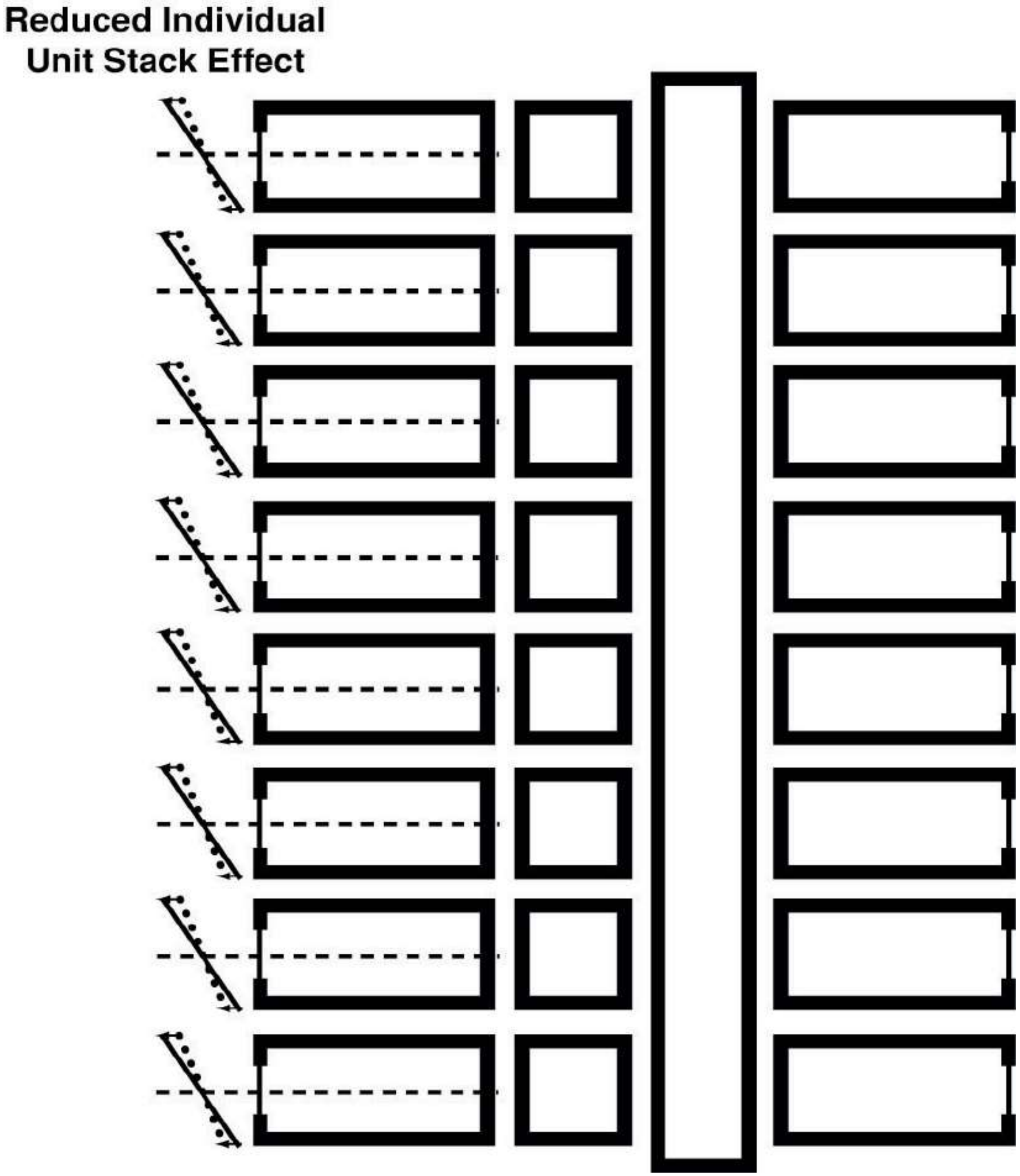
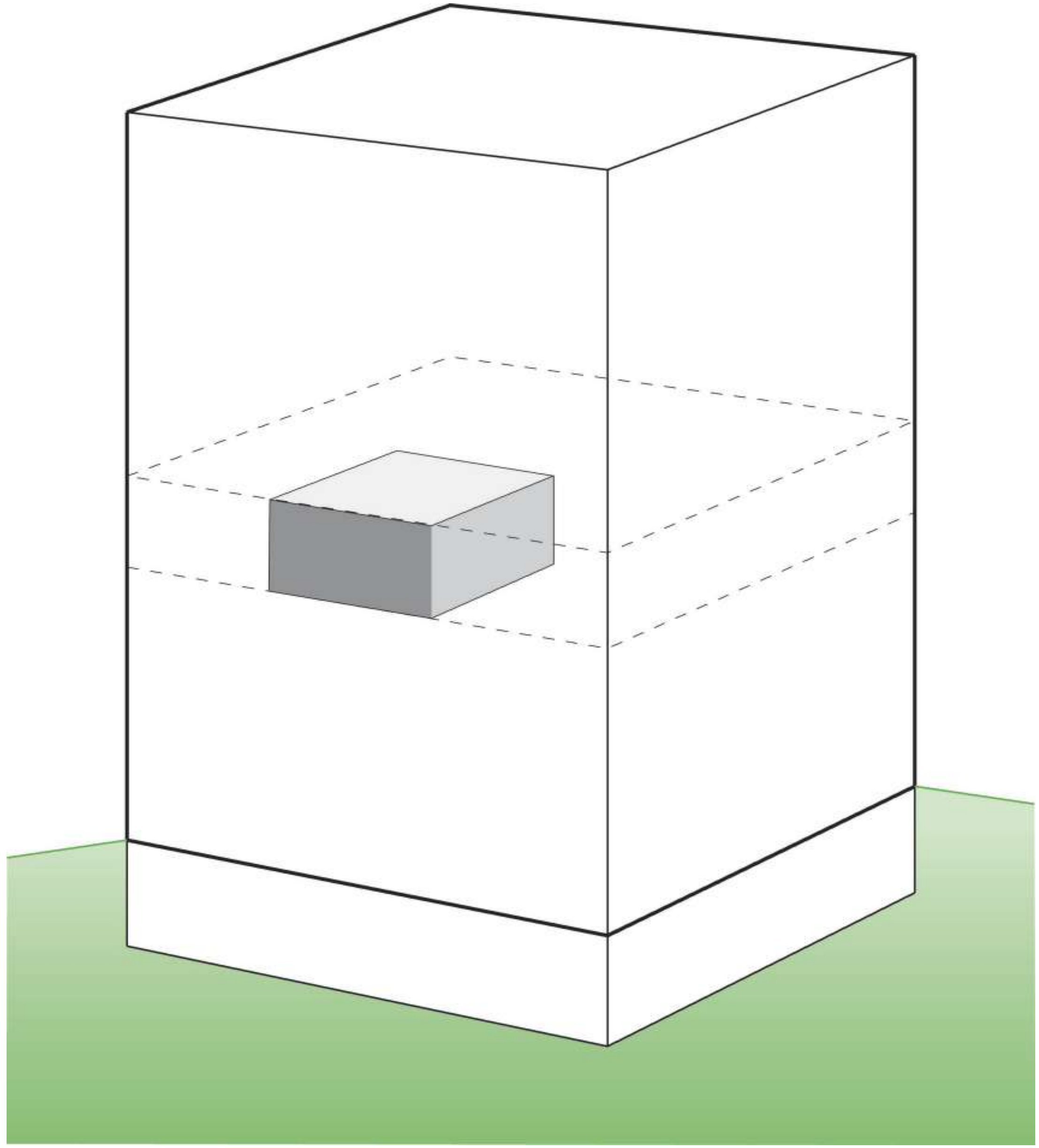
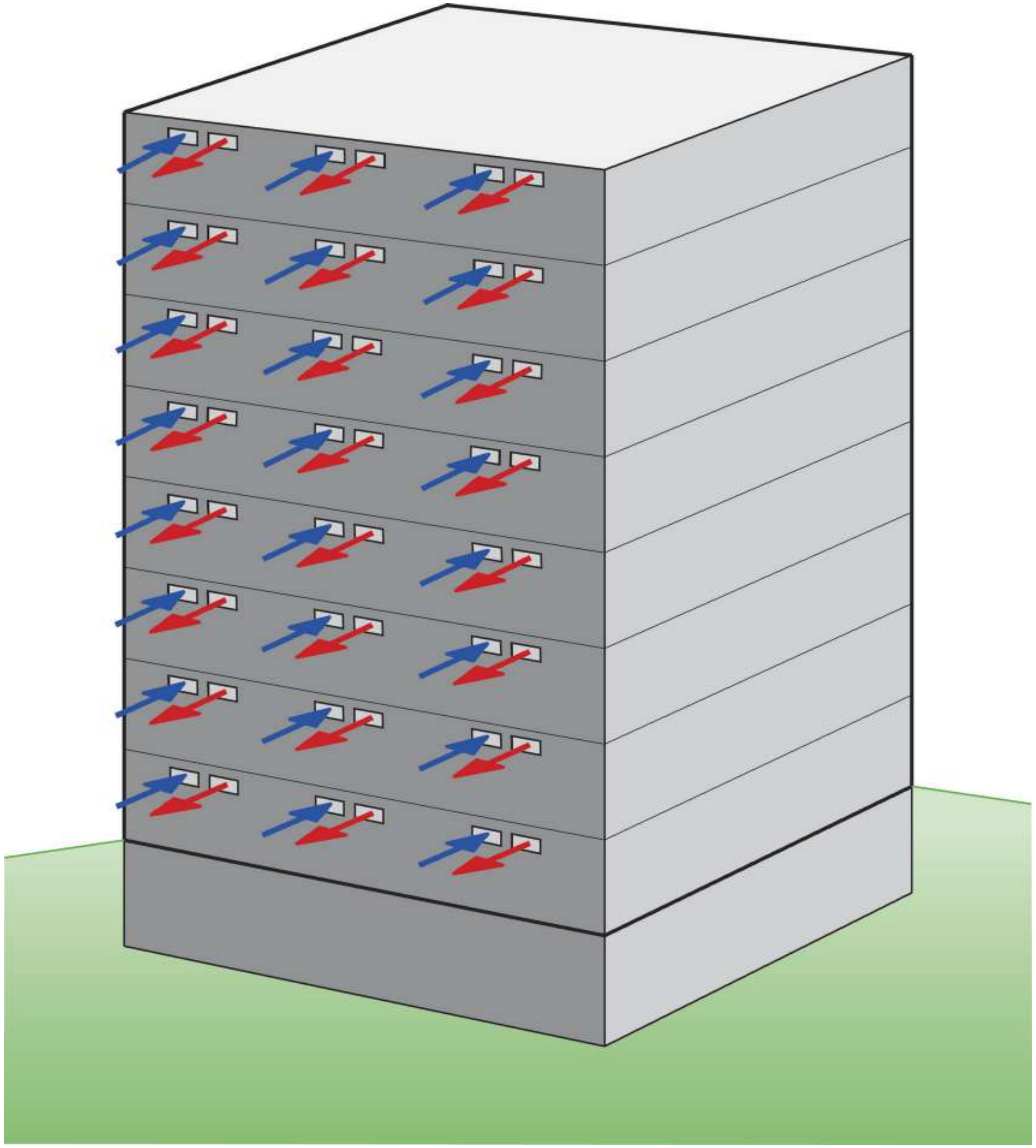
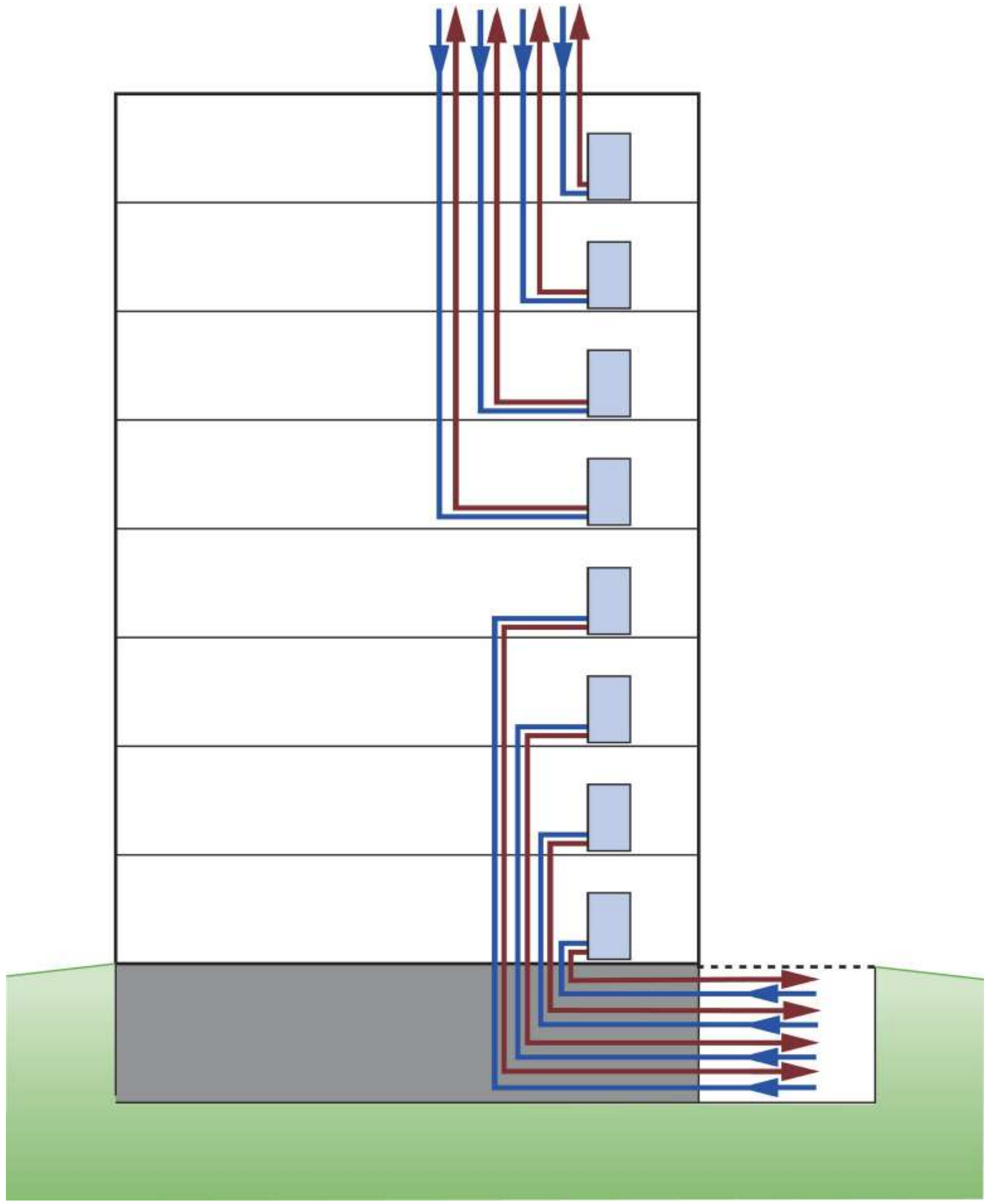


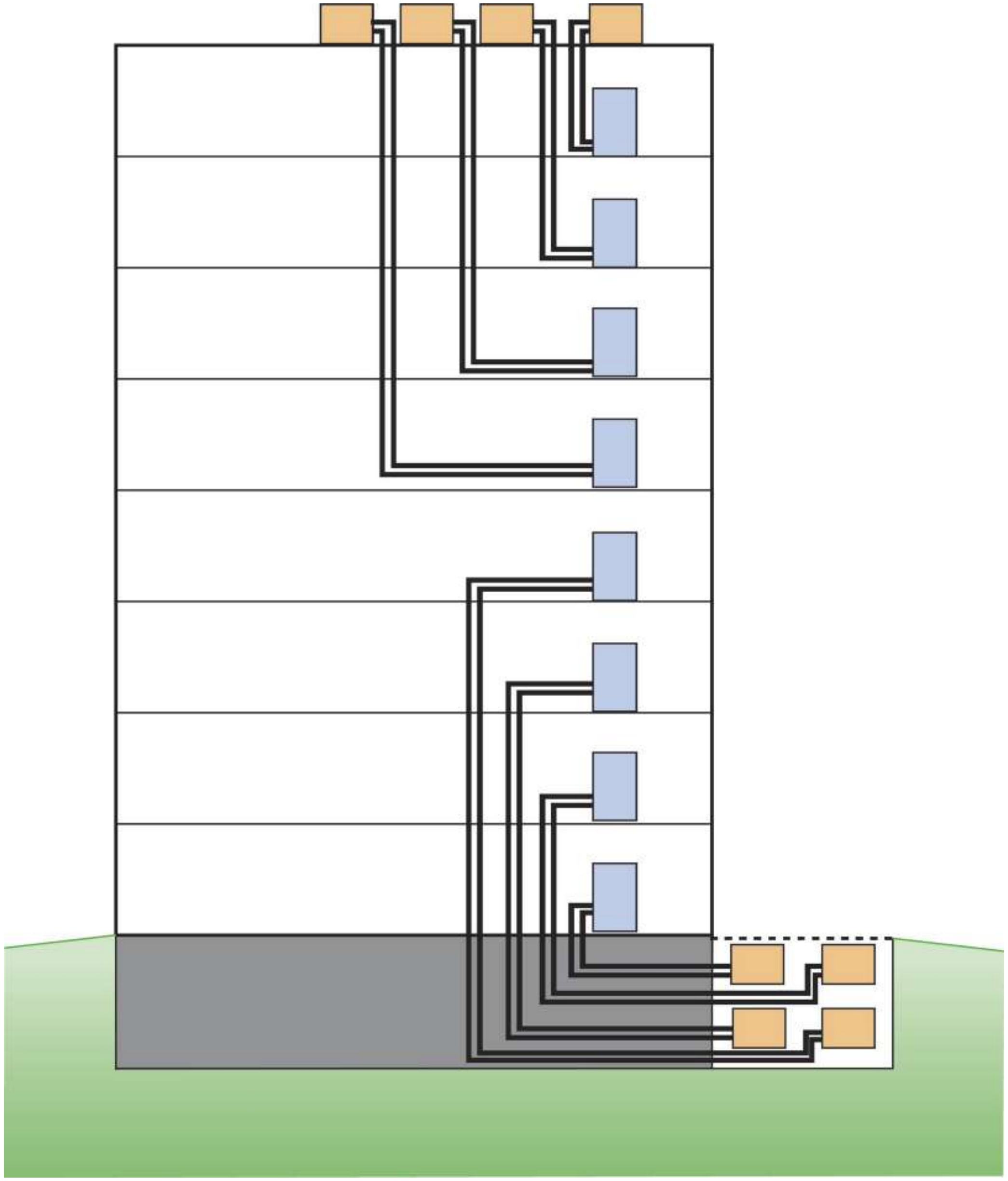
Figure 11.12: Apartment building with tighter apartment entry doors (Adapted from G.O. Handegord, 1998)

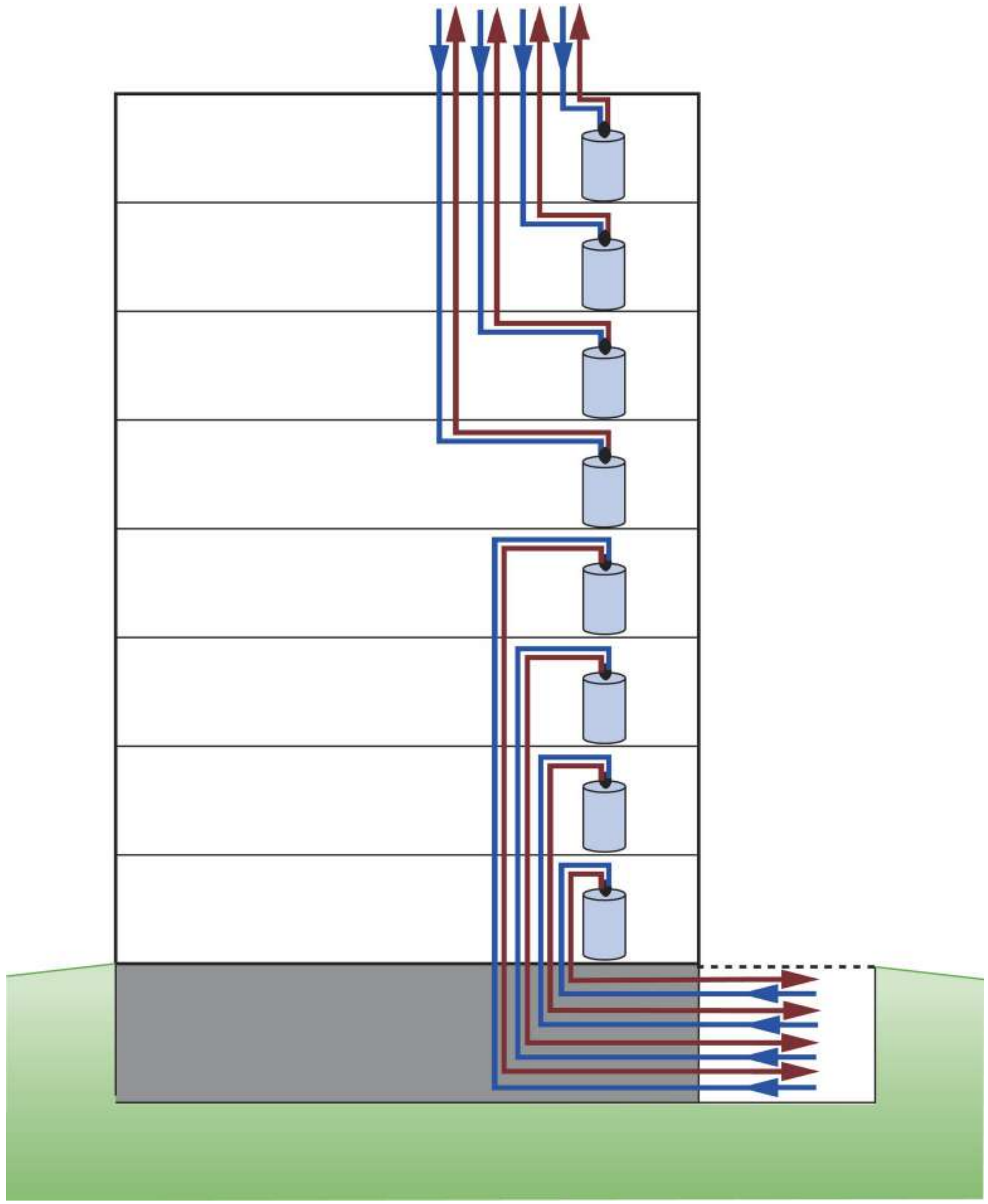

Reduced Individual
Unit Stack Effect









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YORK


EASTERN
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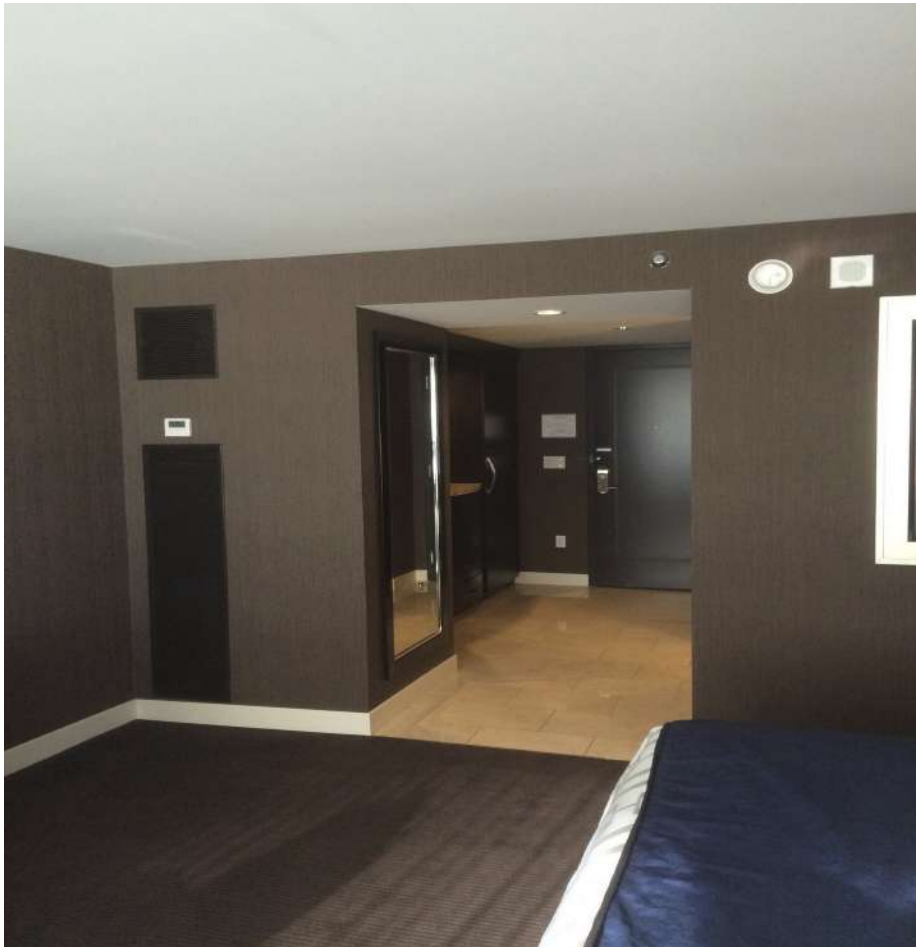
ANJAC FASHION BLDGS


A.O. Smith
EnergySaver
ENERGYGUIDE
8 23 '00

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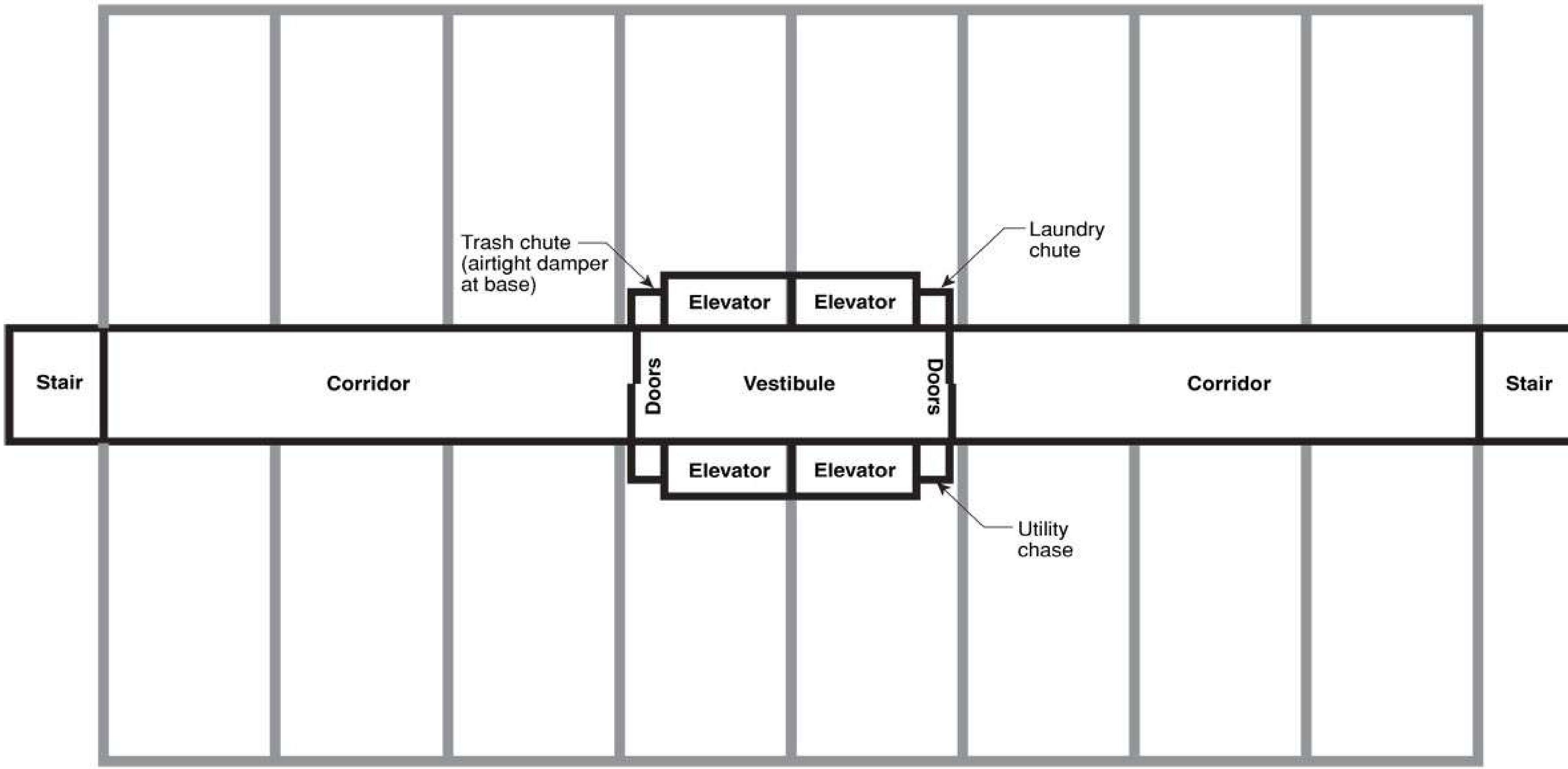
AHP
Heating And Air Conditioning

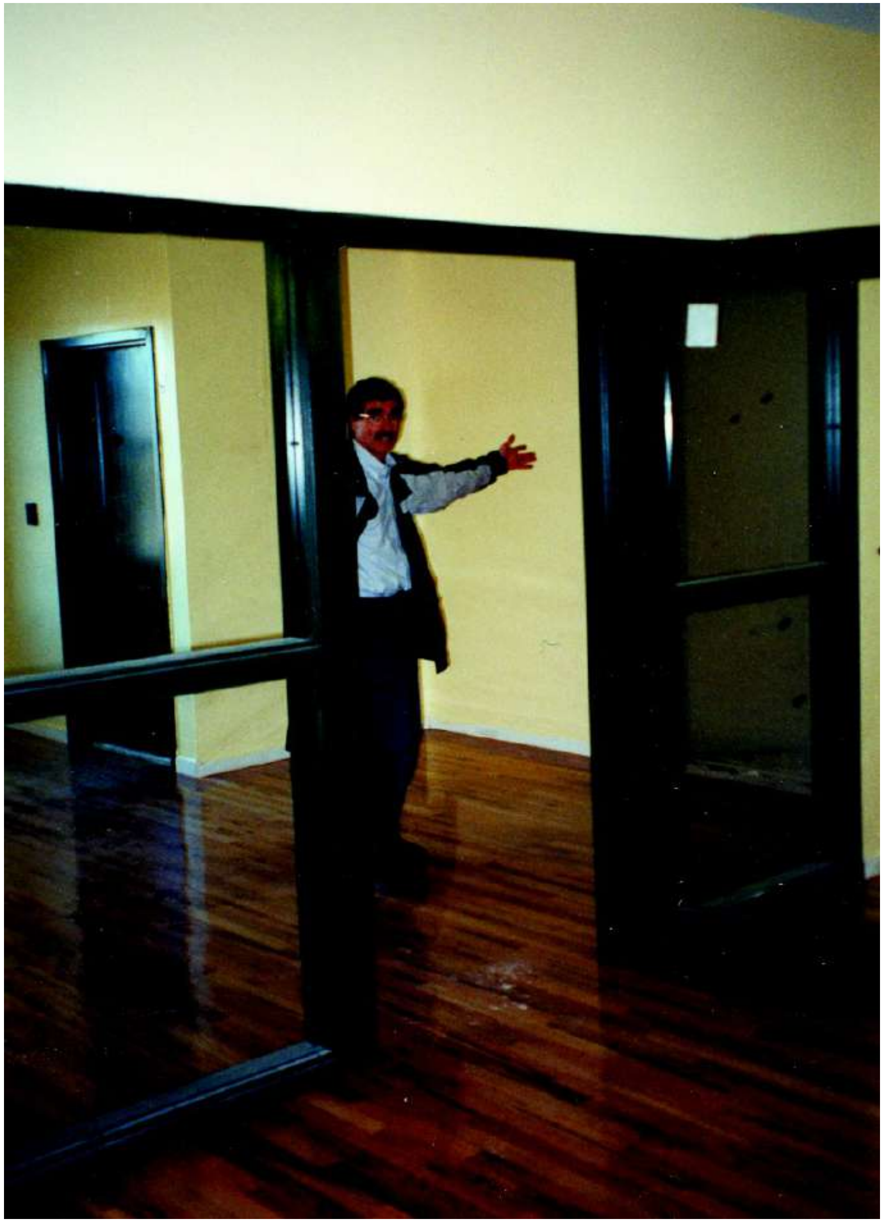

ENERGYGUIDE

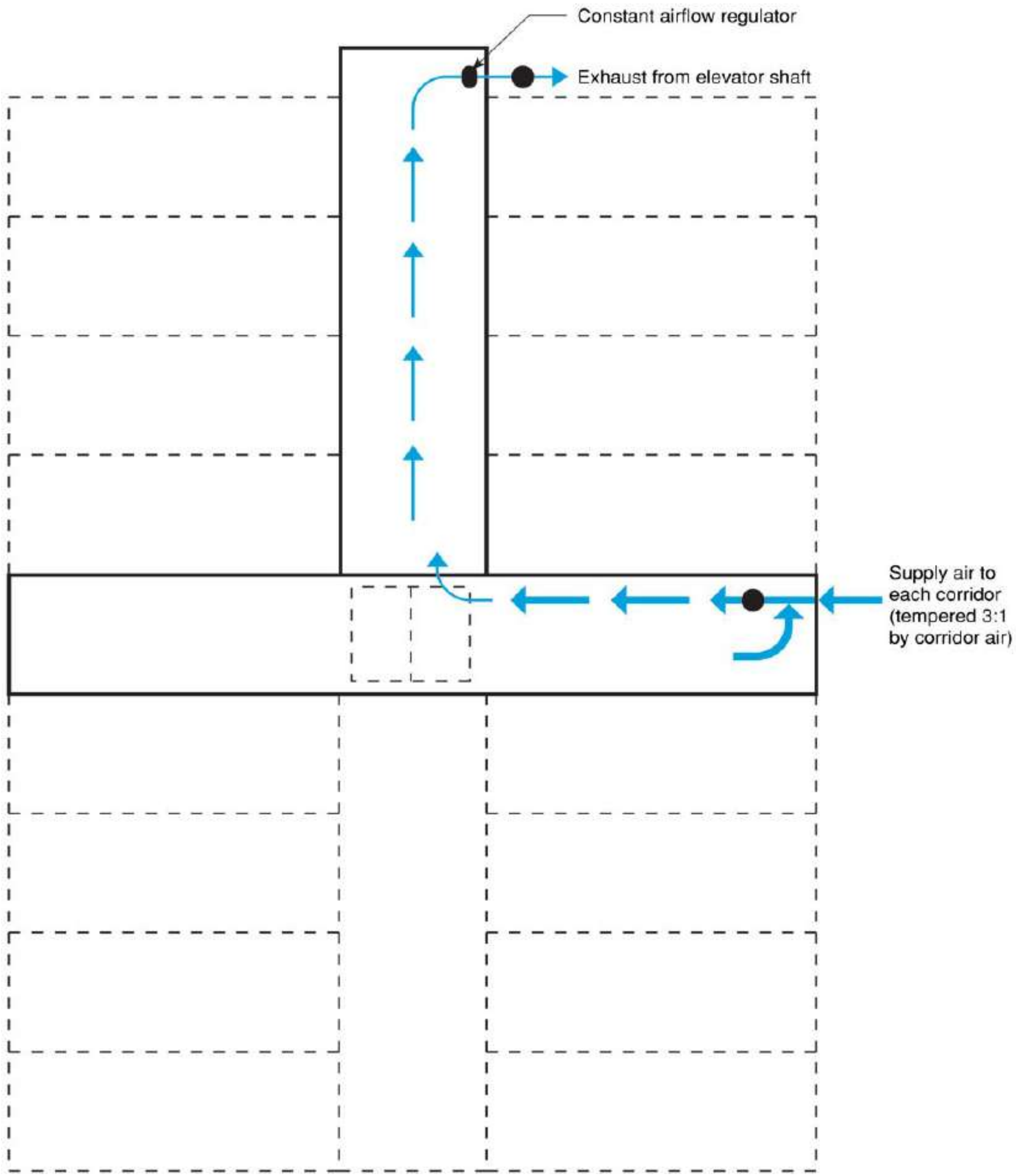

Rheem
EverKleen
ENERGYGUIDE

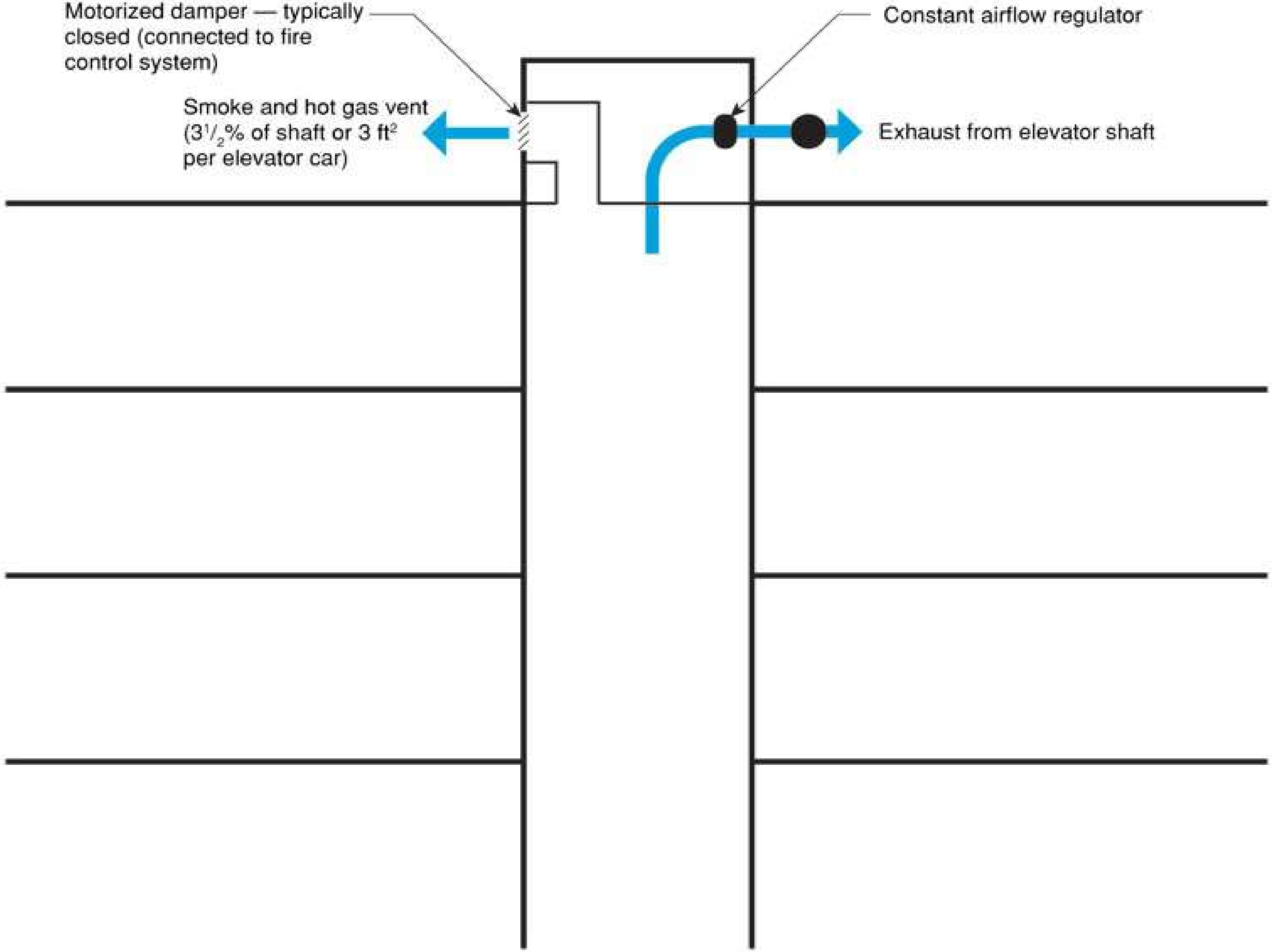

BOSTON
UNIVERSITY

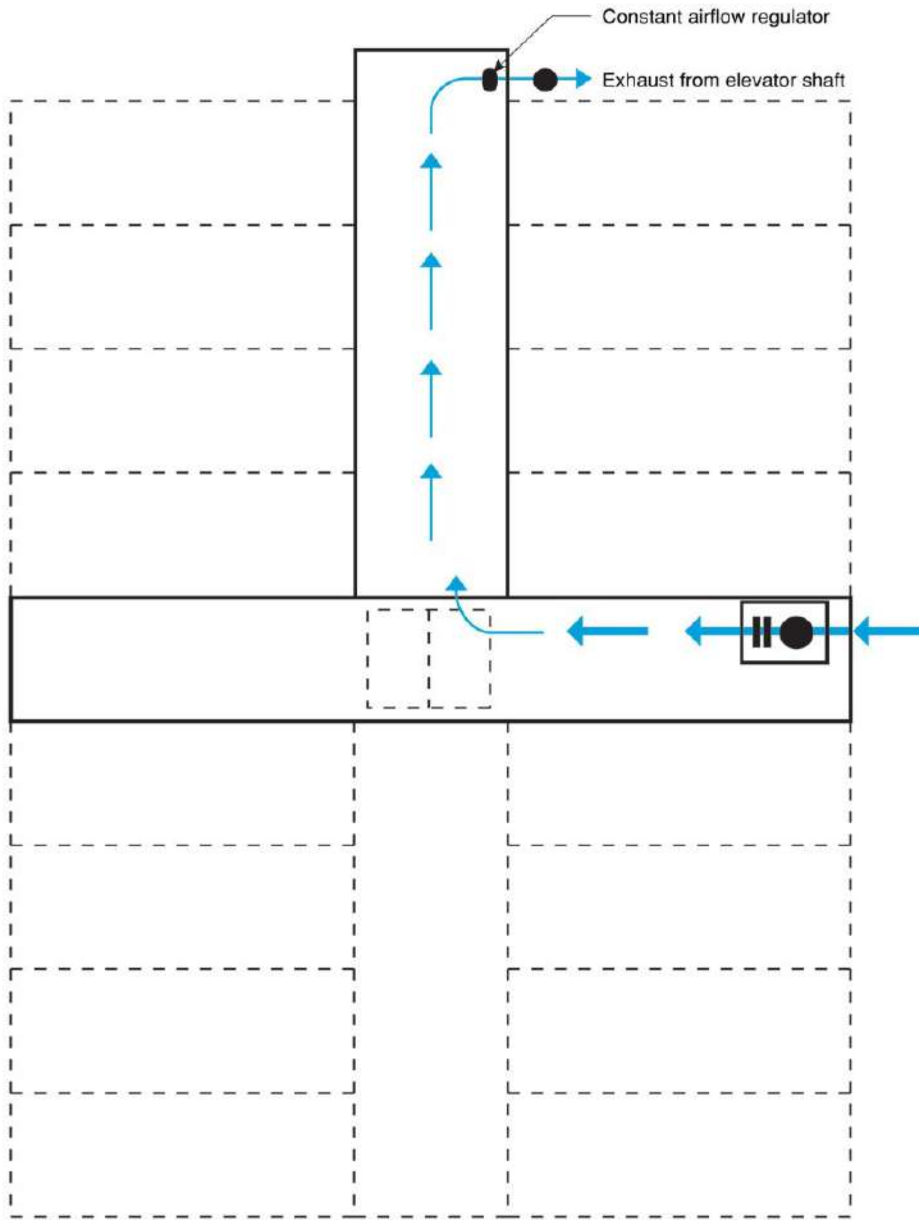


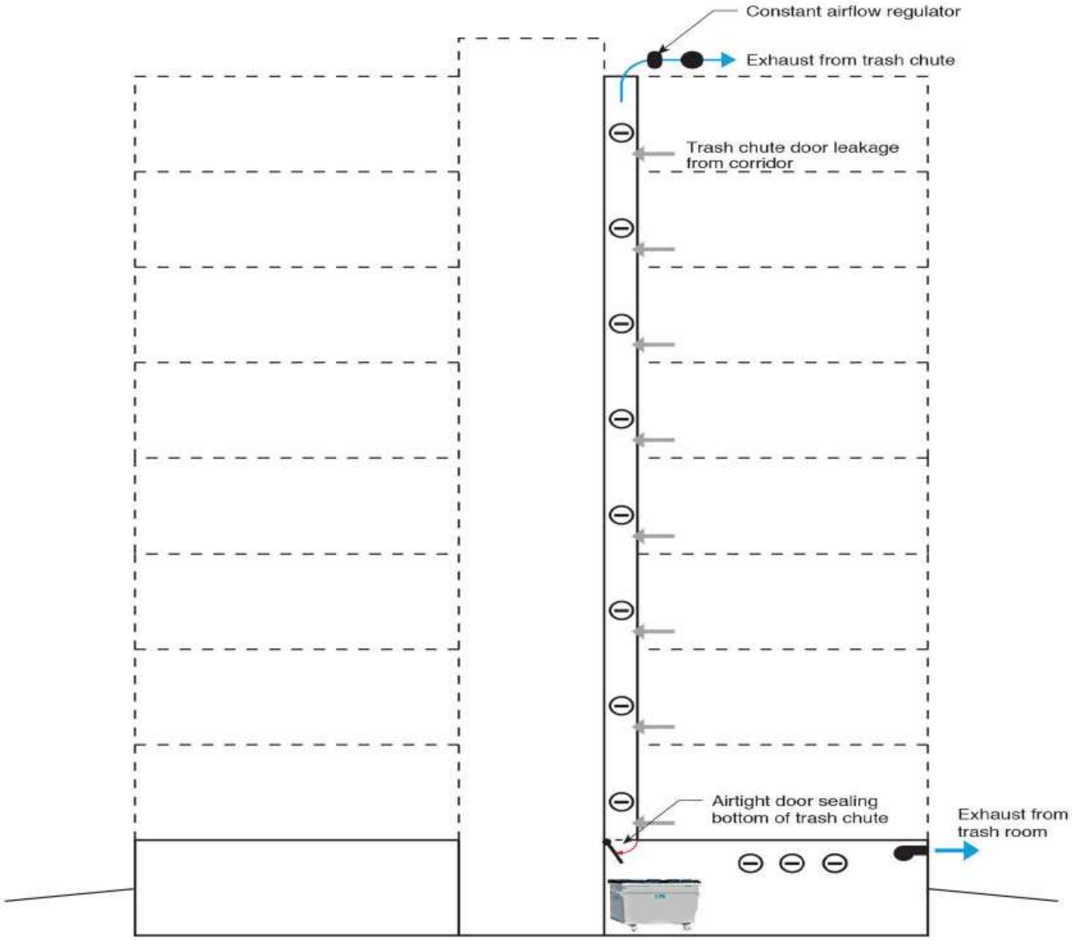
Trash chute (airtight damper at base)
Laundry chute
Elevator
Elevator
Stair
Corridor
Doors
Vestibule
Doors
Corridor
Stair
Elevator
Elevator
Utility chase

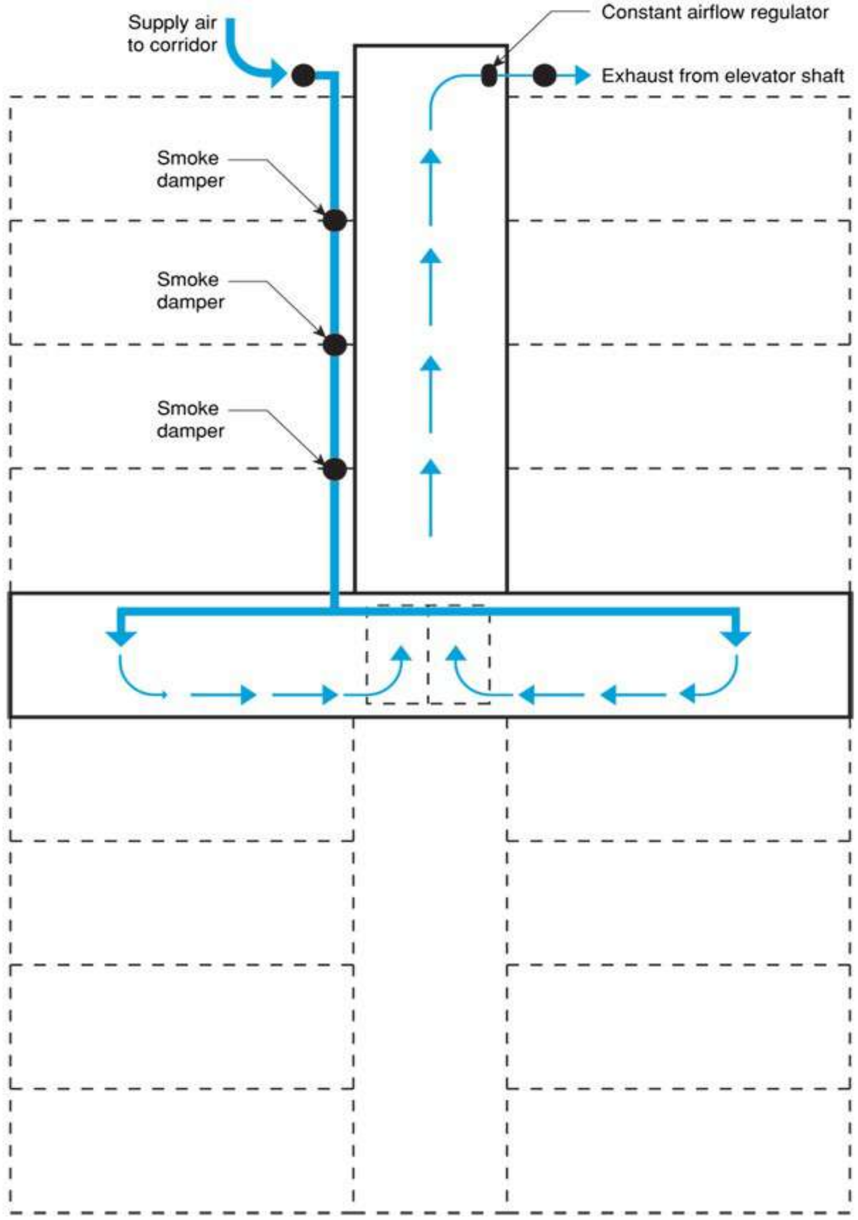


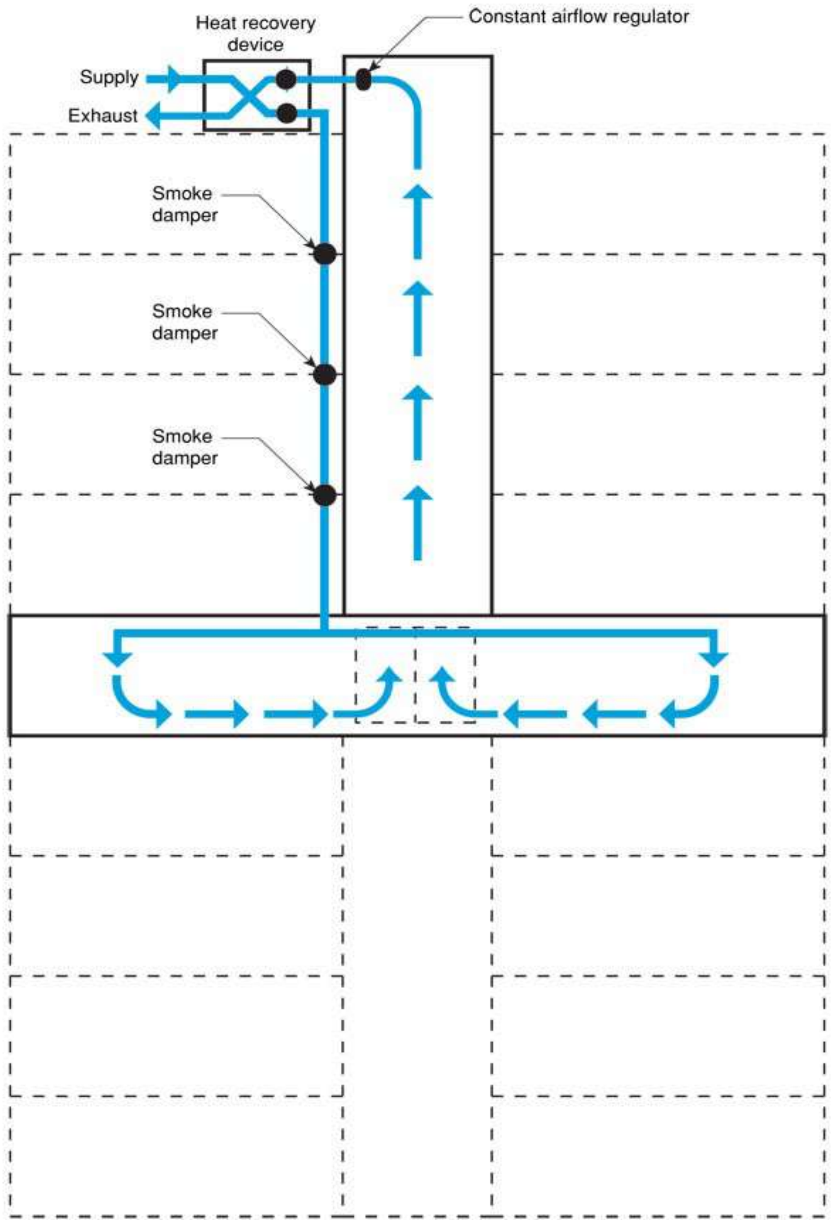

Constant airflow regulator
Exhaust from elevator shaft
Supply air to each corridor (tempered 3:1 by corridor air)

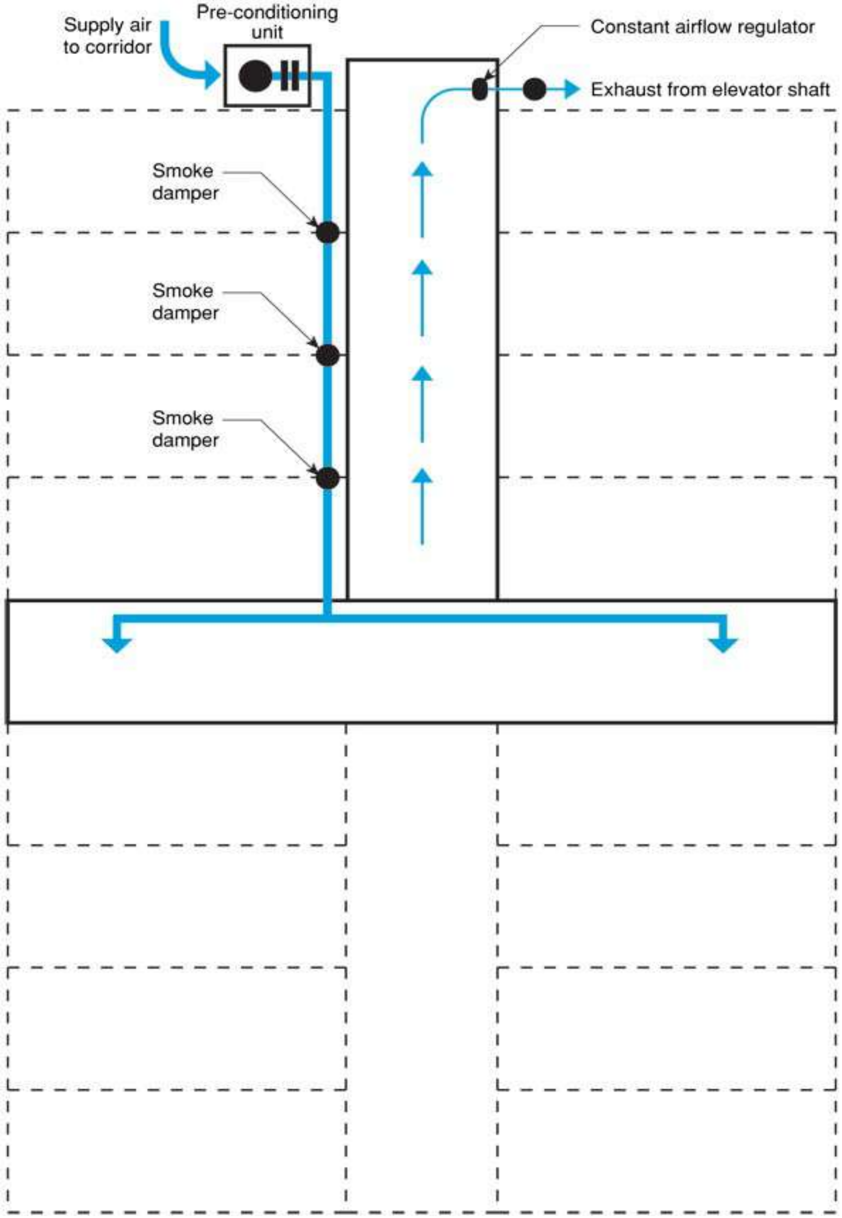

Motorized damper — typically closed (connected to fire control system)
Constant airflow regulator
Smoke and hot gas vent (3 1/2% of shaft or 3 ft² per elevator car)
Exhaust from elevator shaft


Constant airflow regulator
Exhaust from elevator shaft

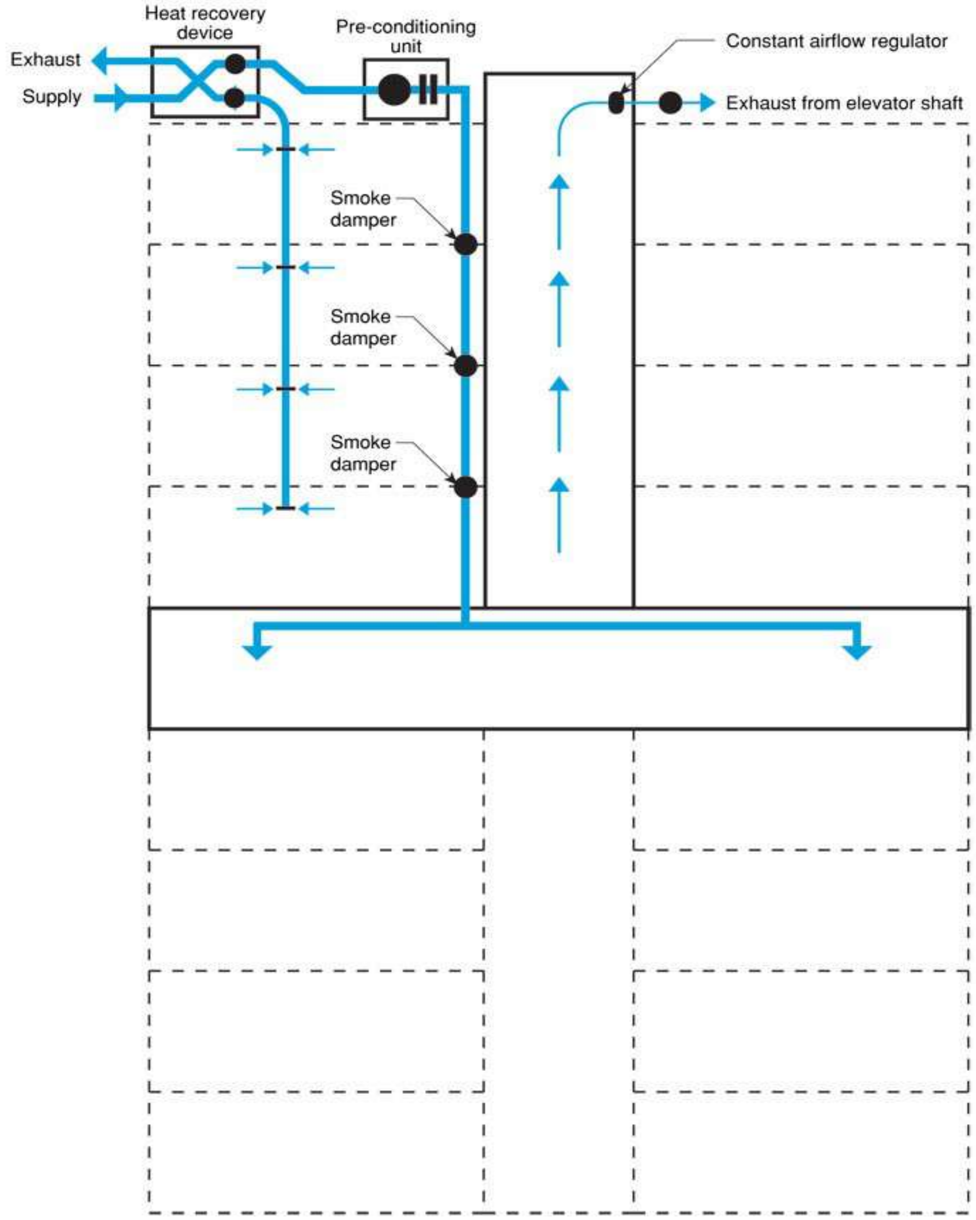

Constant airflow regulator
Exhaust from trash chute
Trash chute door leakage from corridor
Airtight door sealing bottom of trash chute
Exhaust from trash room


Supply air to corridor
Constant airflow regulator
Exhaust from elevator shaft
Smoke damper
Smoke damper
Smoke damper


Heat recovery device
Constant airflow regulator
Supply
Exhaust
Smoke damper
Smoke damper
Smoke damper



Supply air to corridor
Pre-conditioning unit
Constant airflow regulator
Exhaust from elevator shaft
Smoke damper
Smoke damper
Smoke damper


Heat recovery device
Pre-conditioning unit
Constant airflow regulator
Exhaust
Supply
Exhaust from elevator shaft
Smoke damper
Smoke damper
Smoke damper


EXIT