

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

# Building Science

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## Wood Frame Residential

presented by [www.buildingscience.com](http://www.buildingscience.com)

# Deep Energy Retrofits

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## What does this mean?

# Deep Energy Retrofits

What does this mean?

Net zero ready...

# Deep Energy Retrofits

What does this mean?

Net zero ready...

Get to net zero with conservation and renewables...70:30

# Deep Energy Retrofits

70:30

Climate Zones 4,5 and 6....

5 – 10 – 20 – 40 – 60 @ 1.5

ERV

.....plus.....







# Deep Energy Retrofits

What does this mean?

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Get to net zero with conservation and renewables...70:30

What About Carbon?

## Deep Energy Retrofits

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What About Carbon?

Ugh!!!!

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What About Carbon?

Ugh!!!!

What About Energy Storage?

## Deep Energy Retrofits

What does this mean?

Net zero ready...

Get to net zero with conservation and renewables...70:30

What About Carbon?

Ugh!!!!

What About Energy Storage?

Double Ugh!!!!

Don't Kill Anyone....

Don't Kill The Building....

Carbon Monoxide

Soil Gas

Mold

VOC's

# Energy Flow













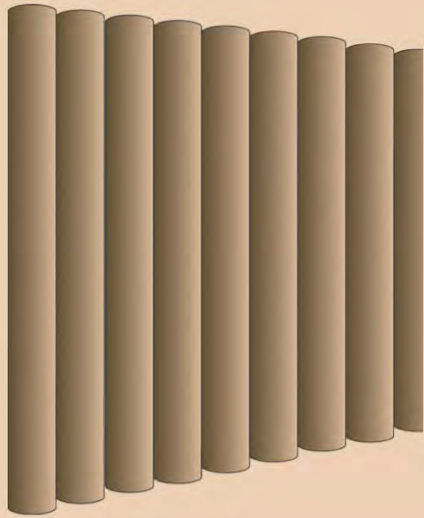
# Important Not To Kill Anyone

# Important Not To Kill Anyone

## Sealed Combustion Appliances

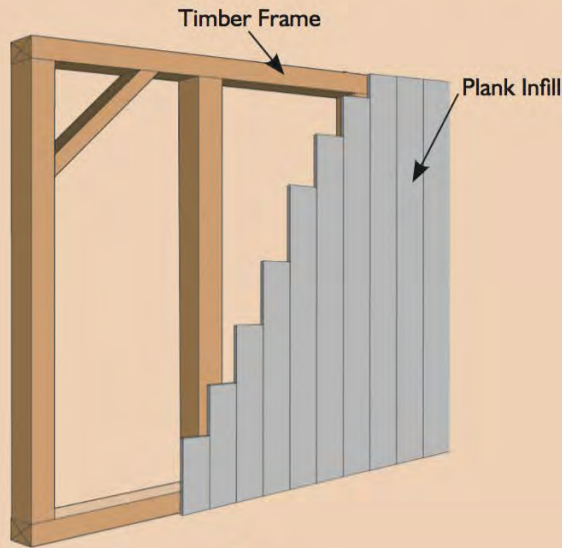
# History – some perspective.....

# One Thousand Years of Evolution: A Timeline



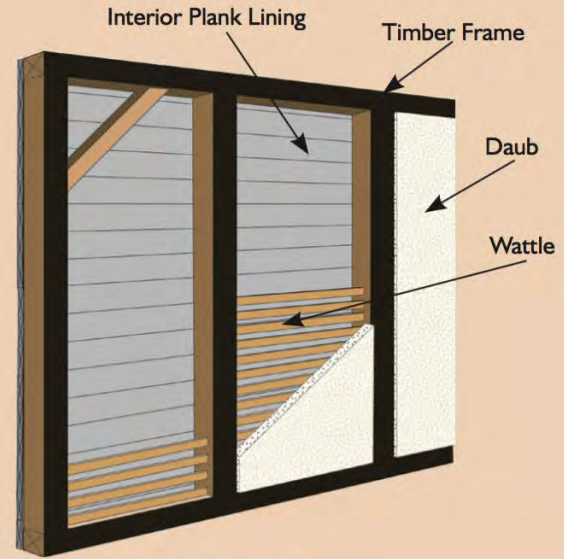
**900 C.E.**

Palisade wall: Closely spaced posts embedded in the ground.



**1200**

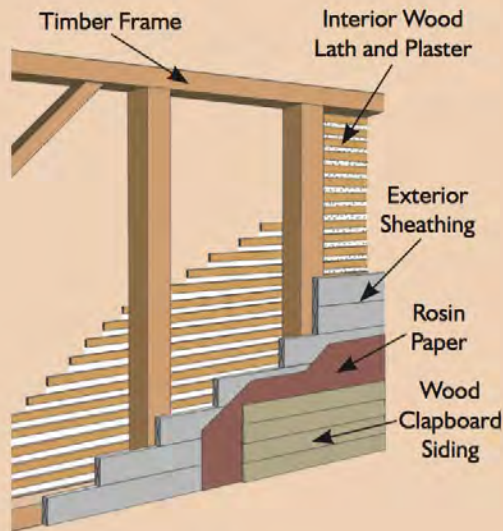
Timber frame: Stave construction, timber four-sided frame with vertical exterior weatherboards.



**1600**

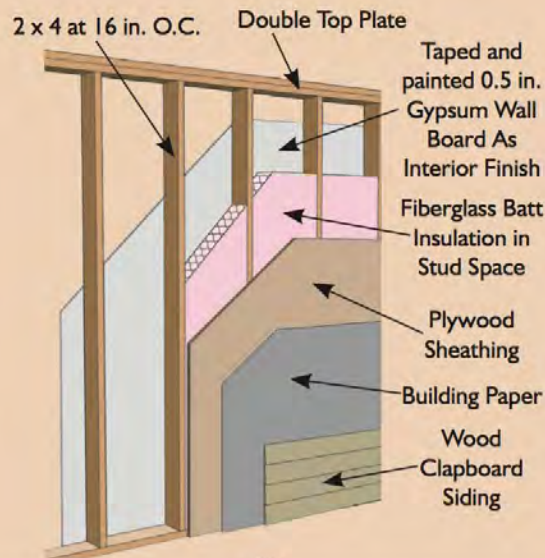
Wattle and daub: Tar coated exposed frame with an early pre-evolutionary version of exterior stucco—Neanderthal Stucco. Board sheathing inner lining.





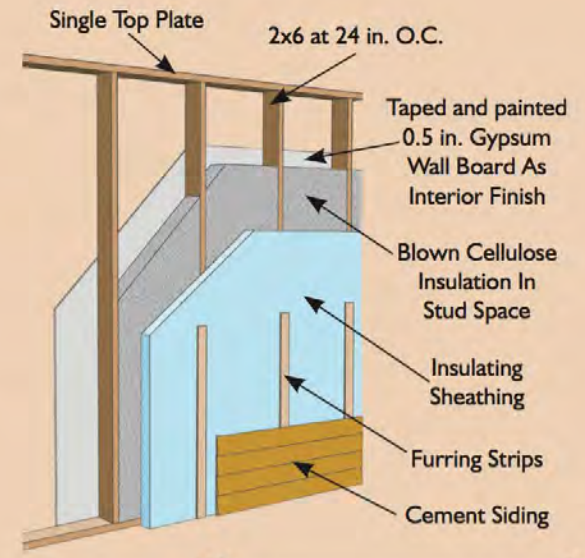
### 1900

Clapboard timber frame: Typical 1900 New England timber frame with plaster and lath interior lining and exterior board sheathing, rosin paper and clapboards.



### 1950

Platform frame: Typical 1950 American wood frame assembly with plywood sheathing and an interior gypsum board lining.



### 1990

Advanced frame: Insulating sheathing over 2x6 advanced frame.

# Control Layers

Water Control Layer

Air Control Layer

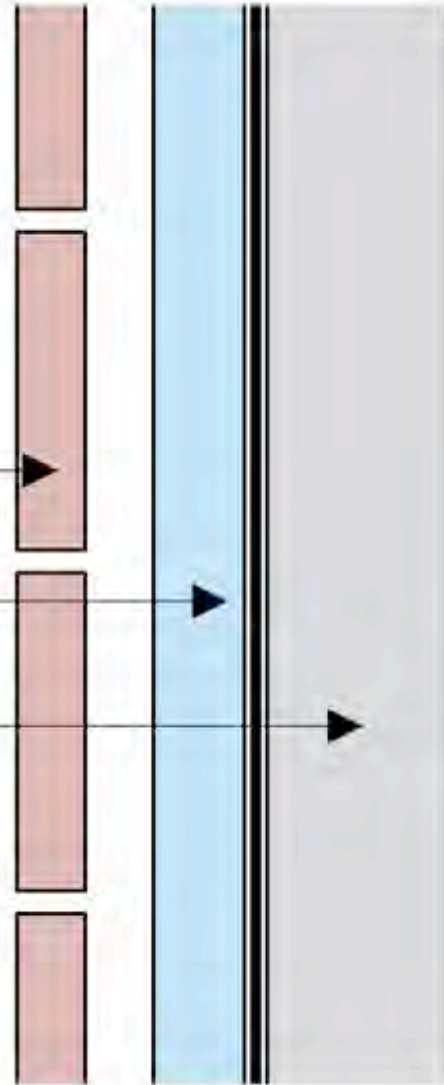
Vapor Control Layer

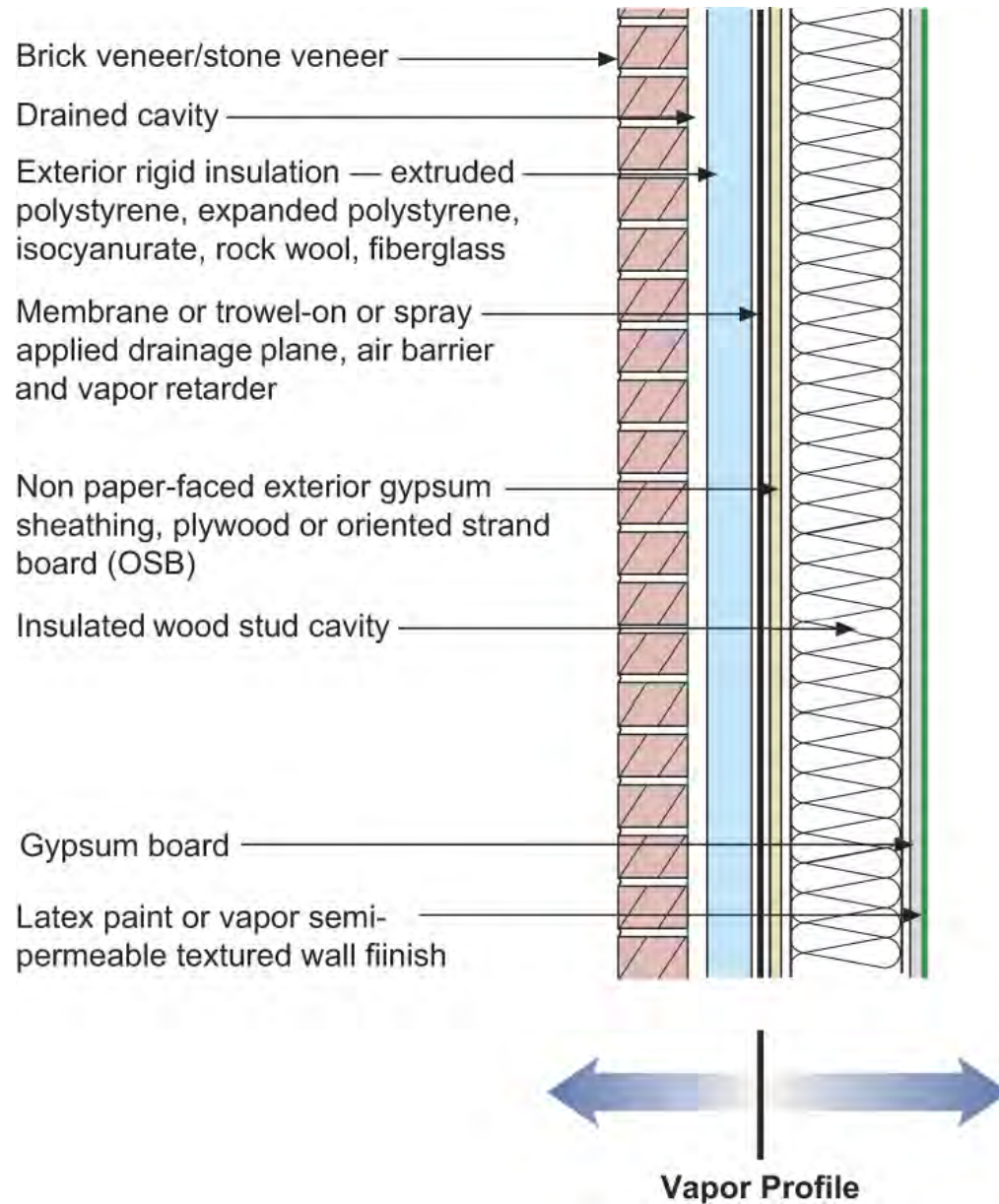
Thermal Control Layer

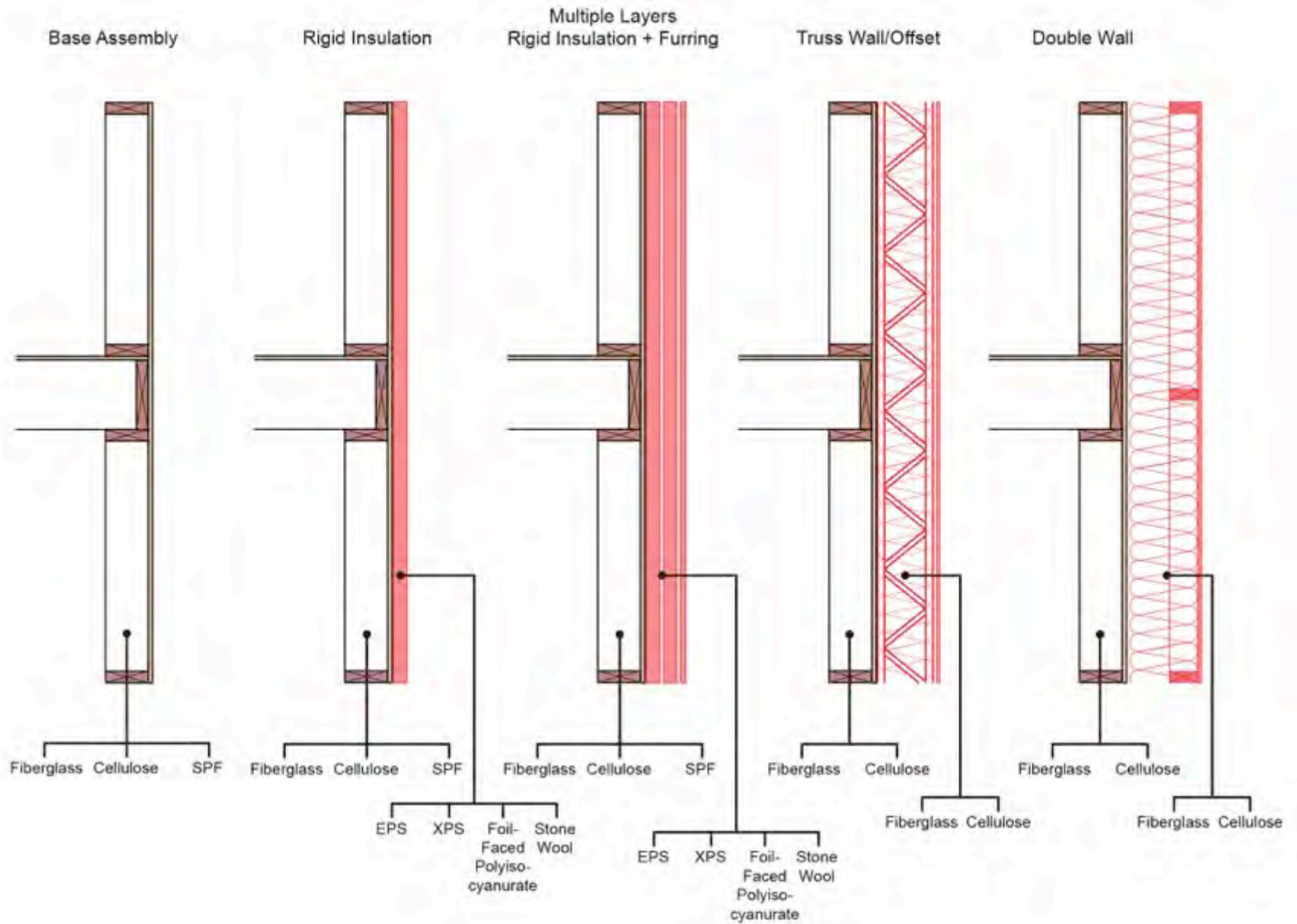
Cladding

Control layers

Structure











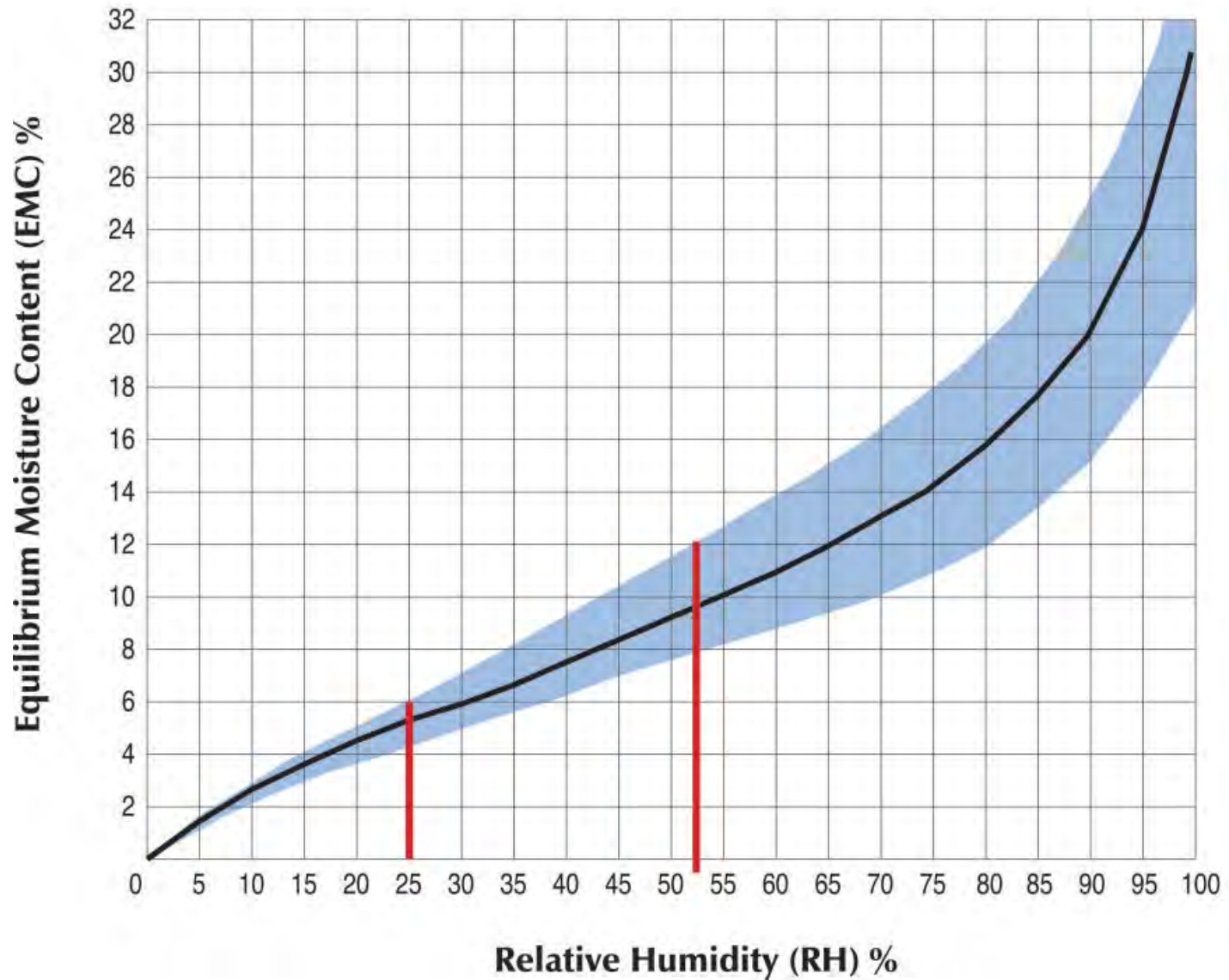


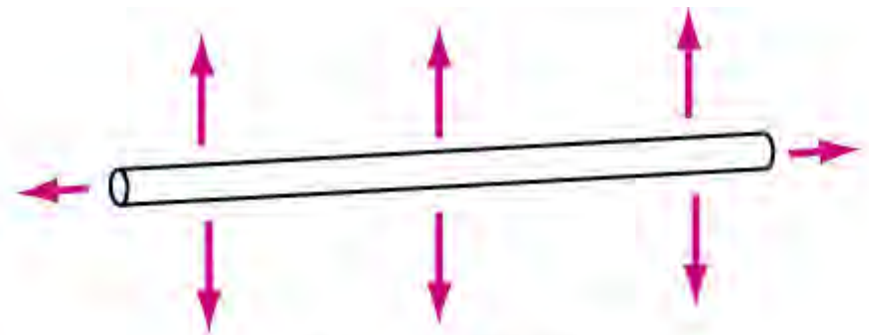
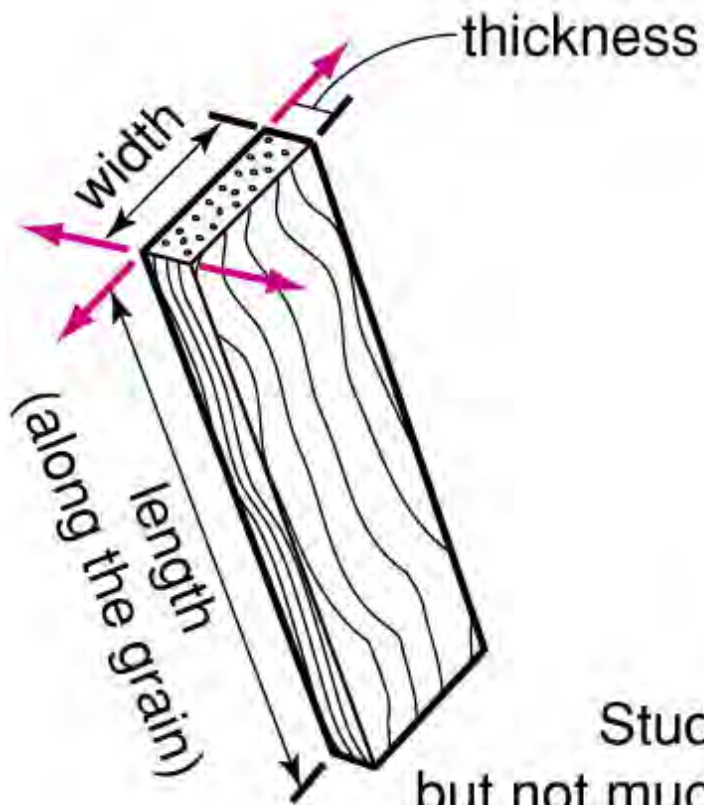




# Wood is Weird

# Moisture Content vs. Relative Humidity

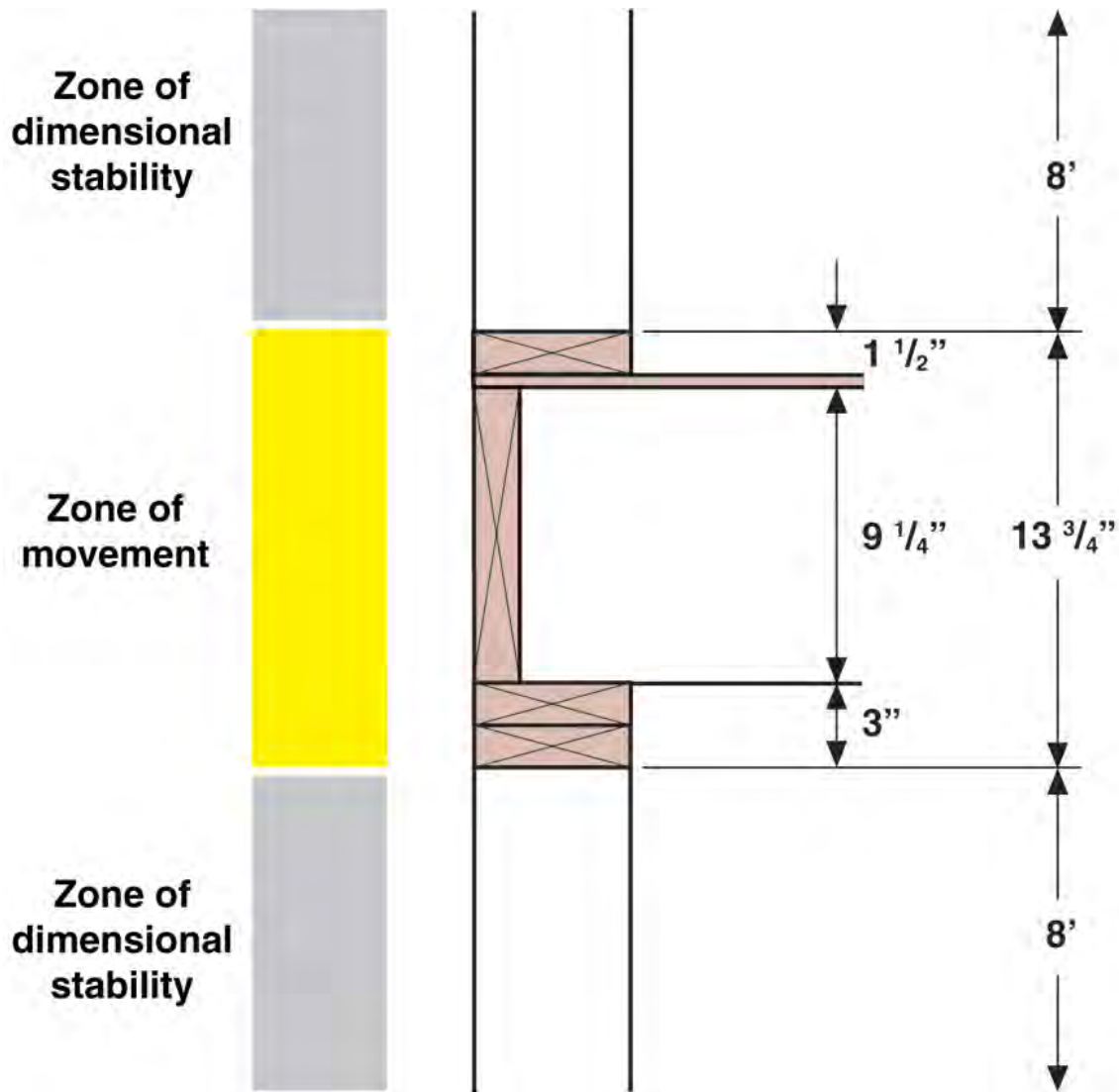


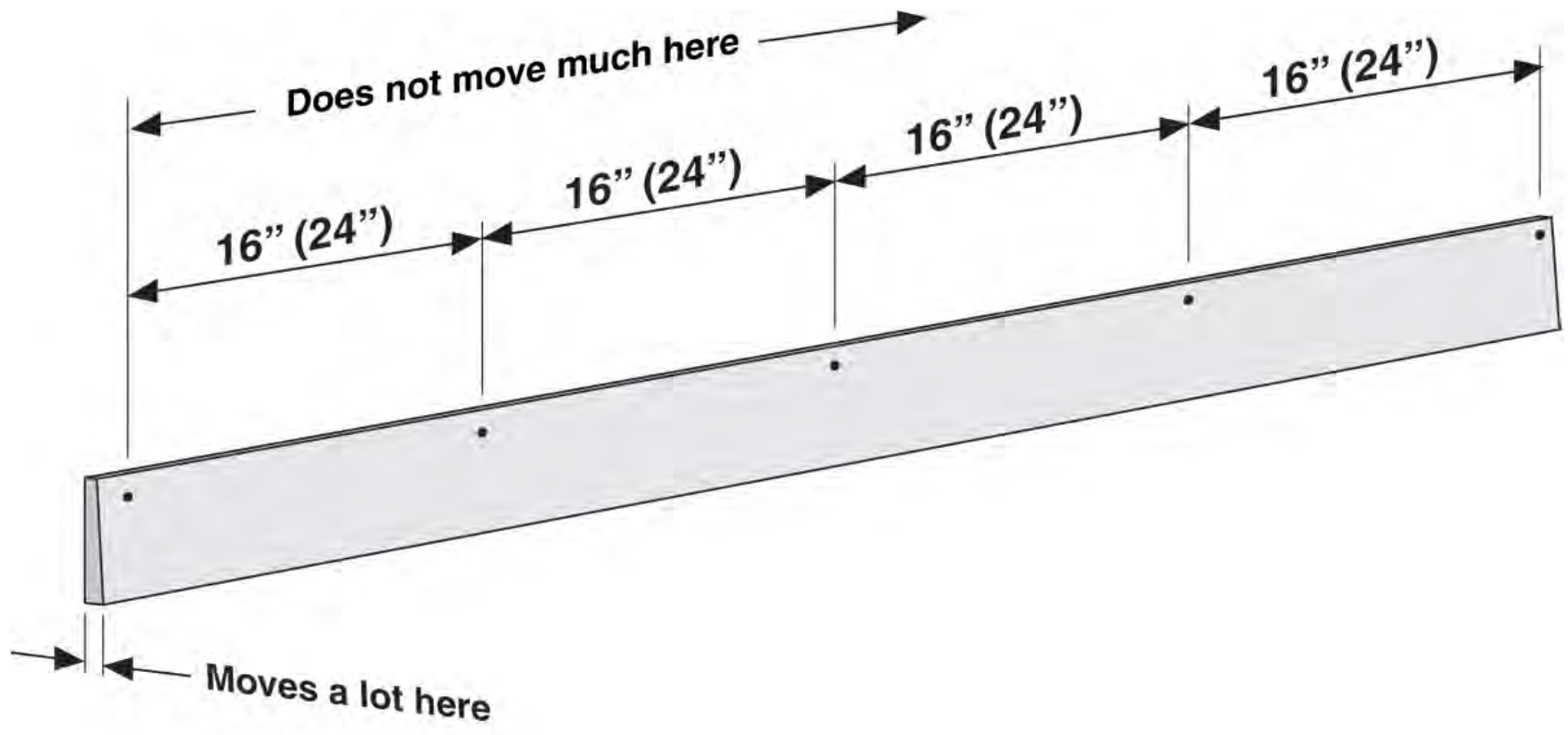


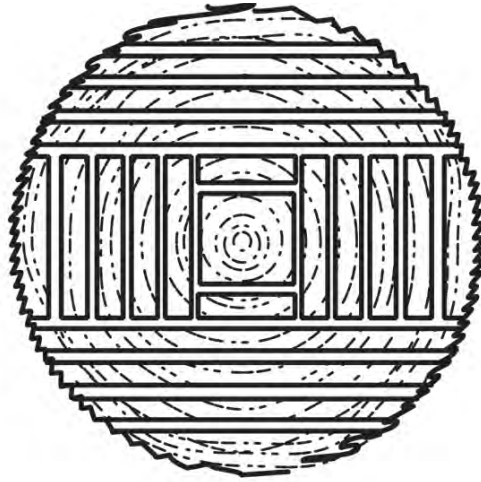
Wood Fiber

Fibers get much thicker than longer when they pick up moisture

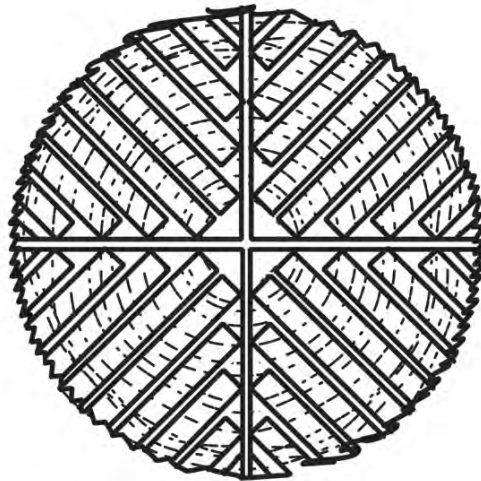
Studs get much wider and thicker, but not much longer, when they pick up moisture





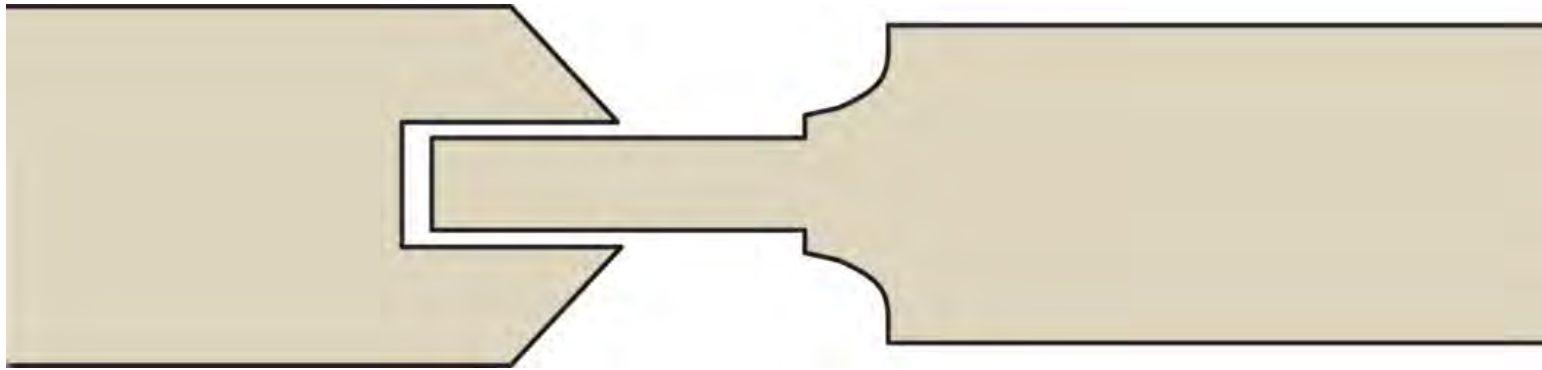


**Plain sawn  
log**



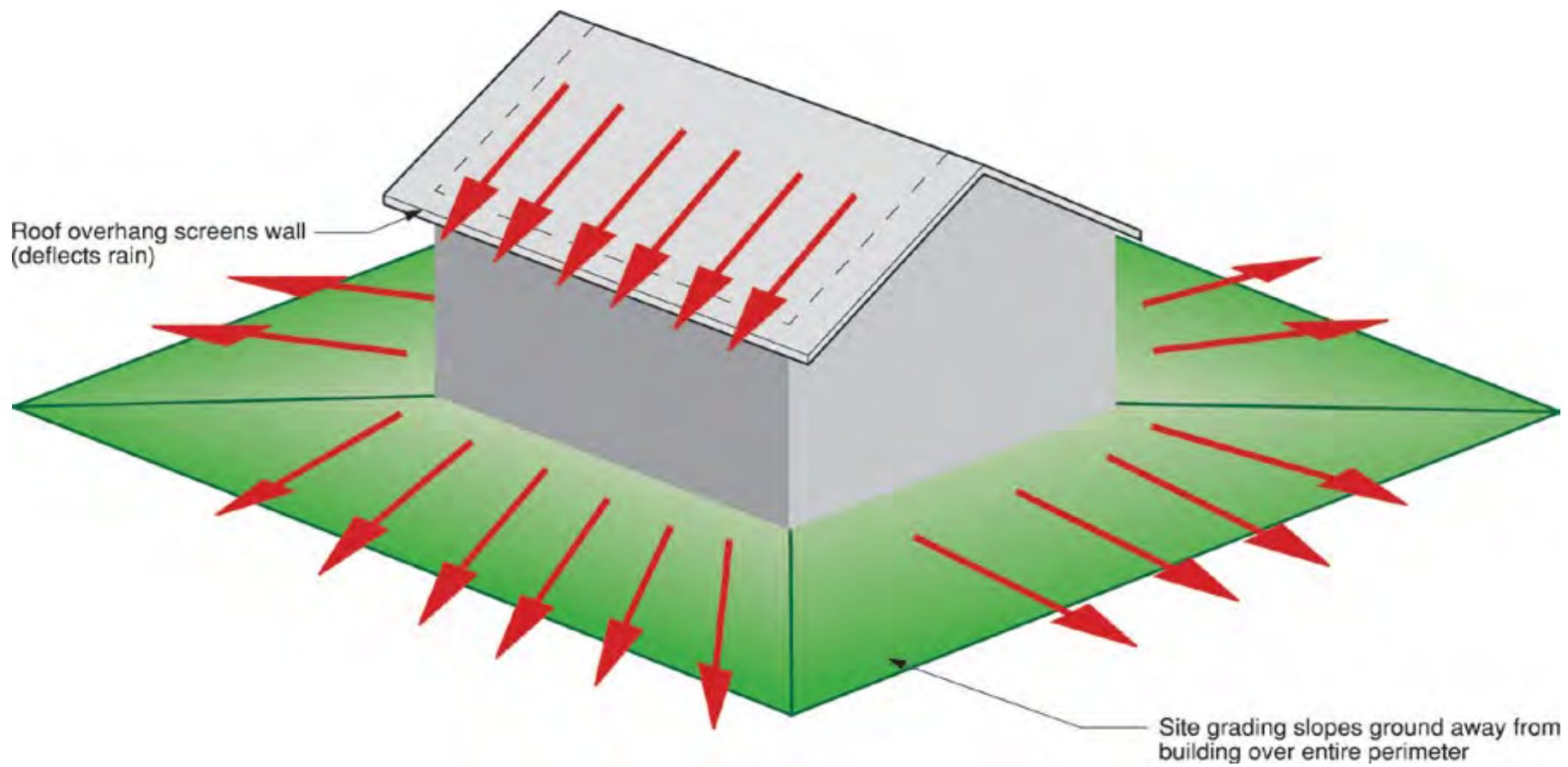
**Quarter sawn  
log**

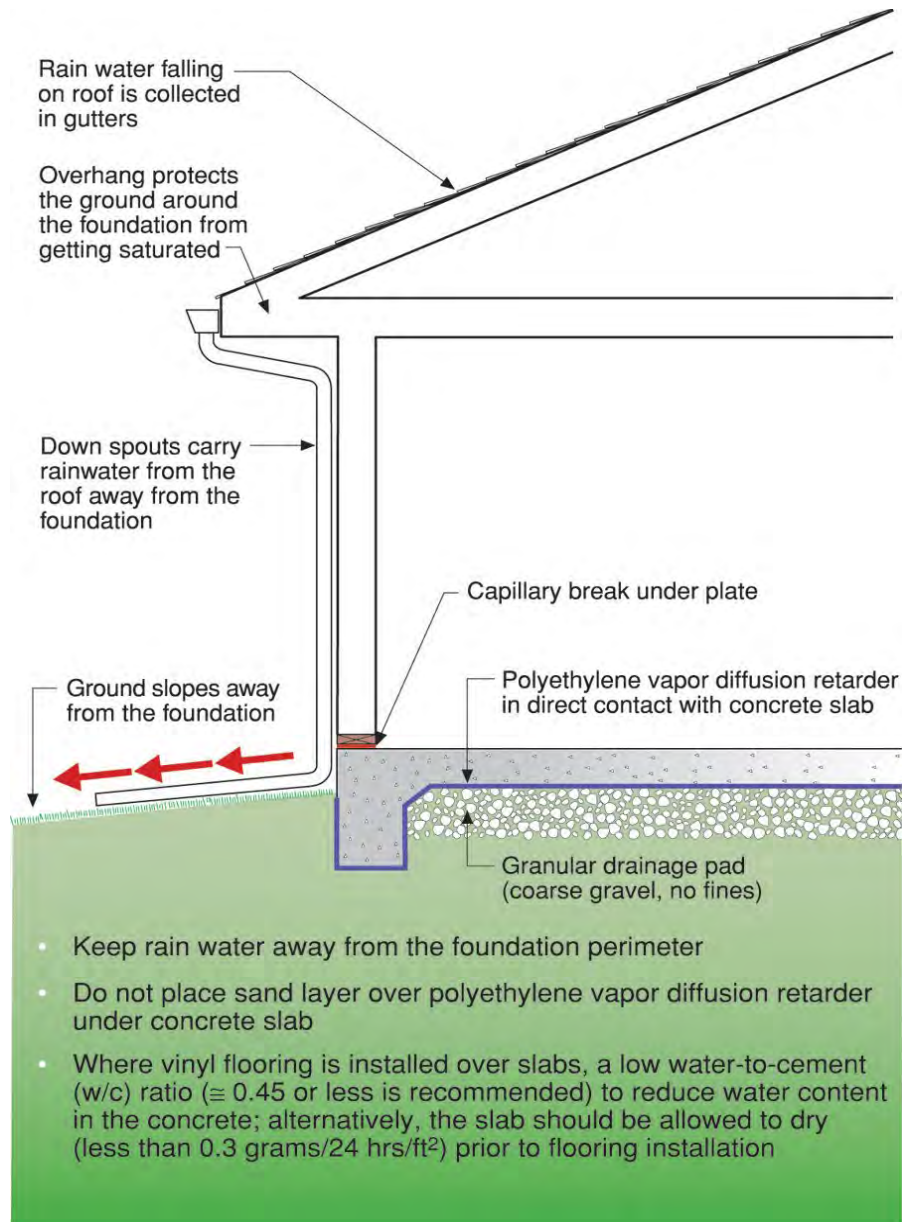


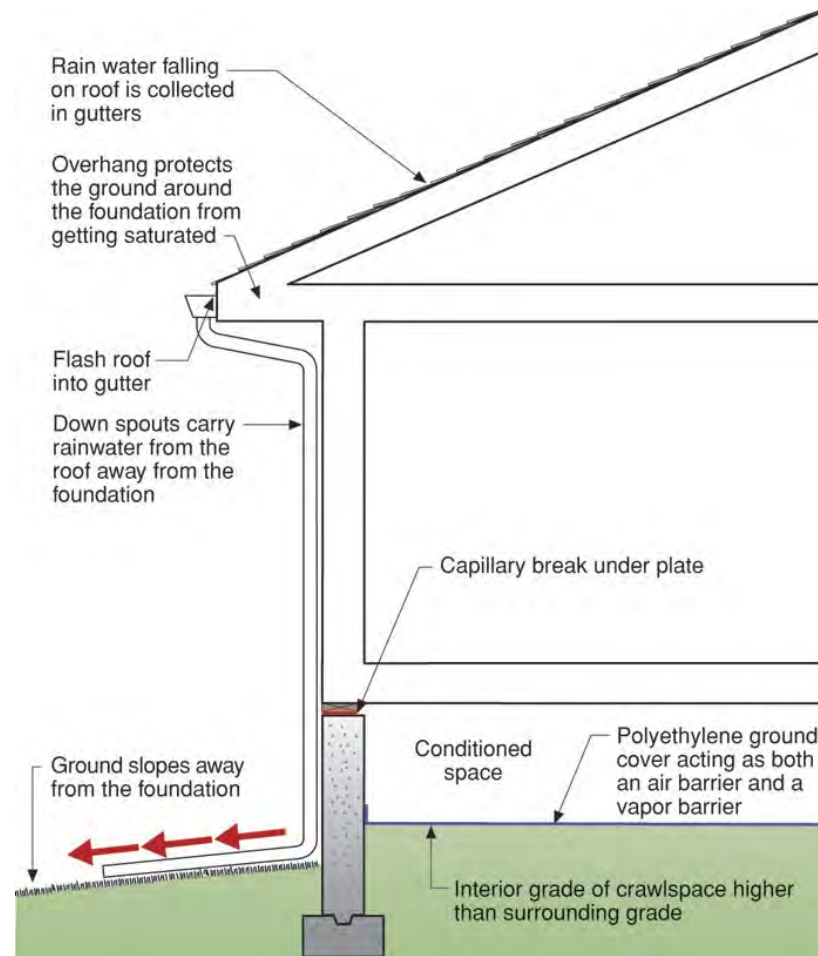




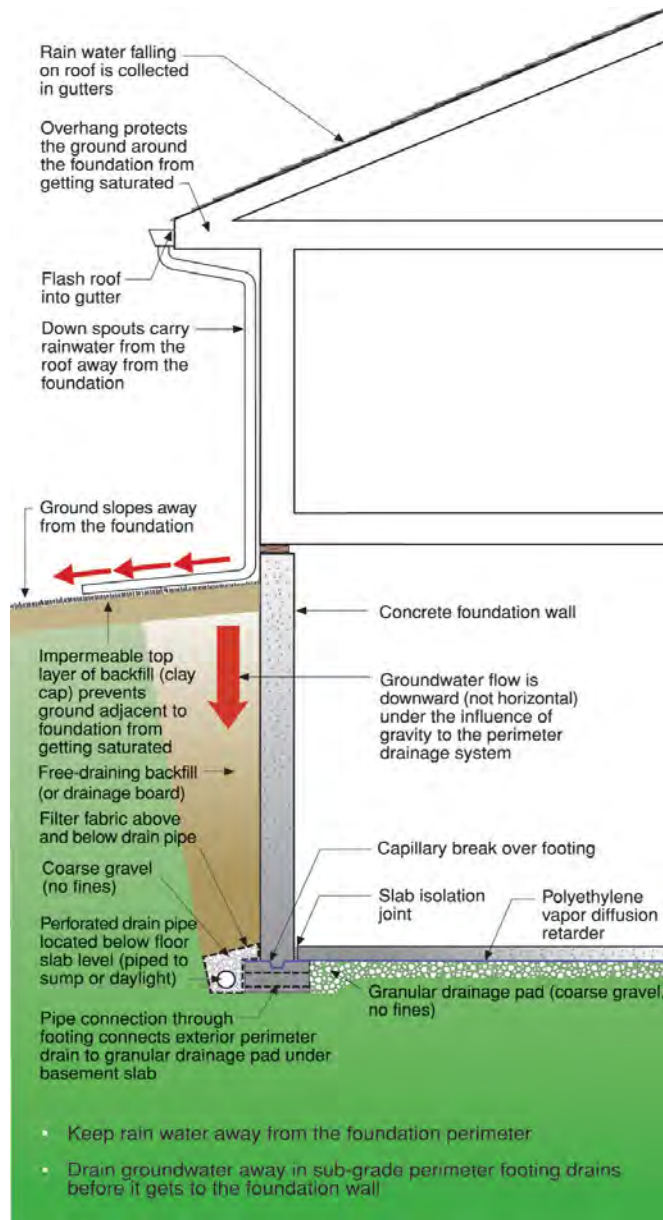
# Foundations





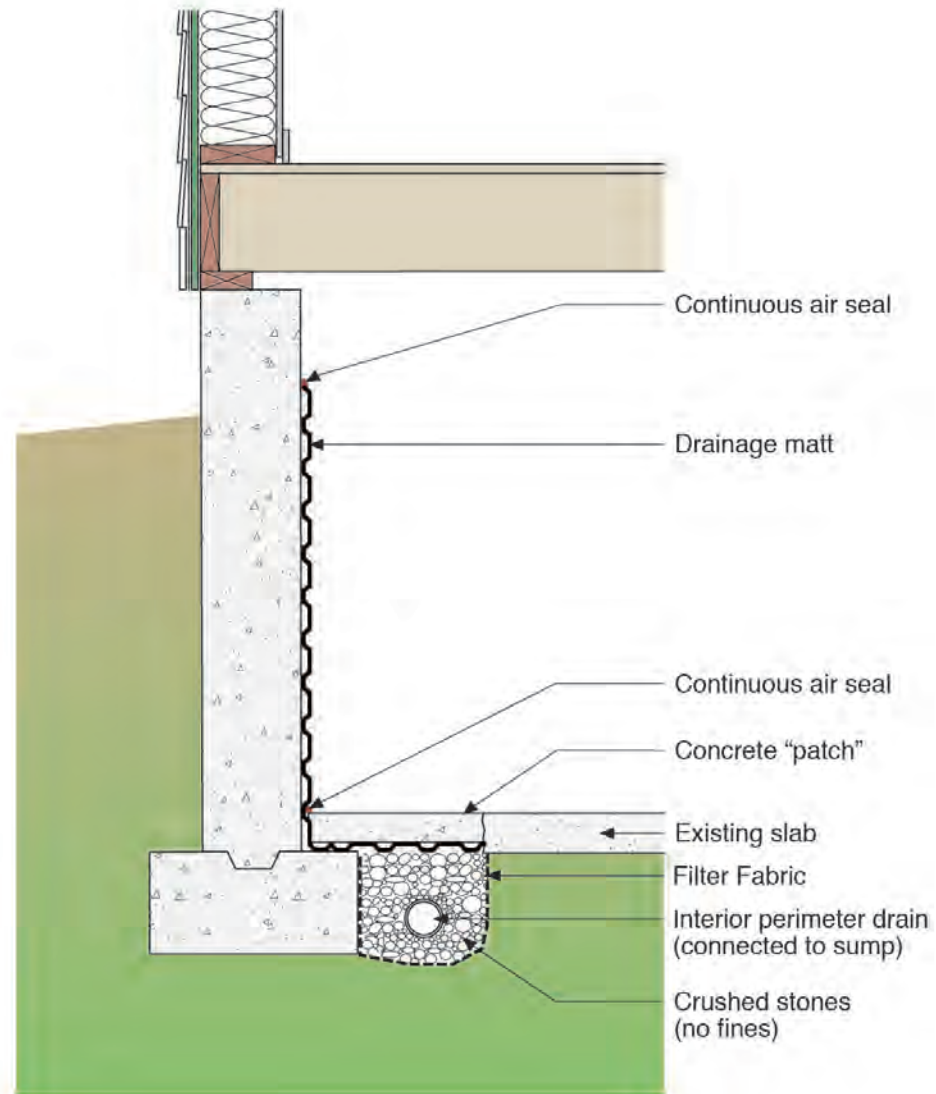


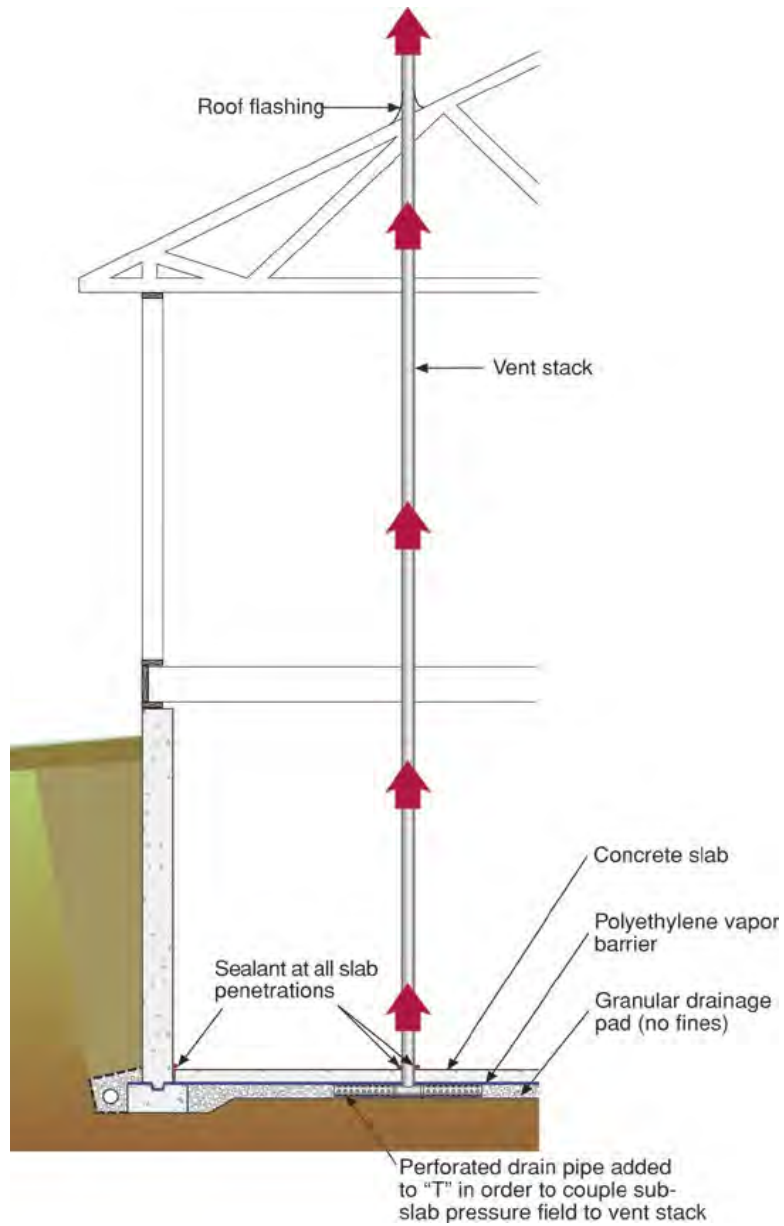
- Keep rain water away from the foundation perimeter
- If the interior crawlspace is lower than the exterior grade, a sub-grade perimeter footing drain is necessary as in a basement foundation
- The crawlspace is conditioned space; it is part of the "interior" of the building and should be heated, cooled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

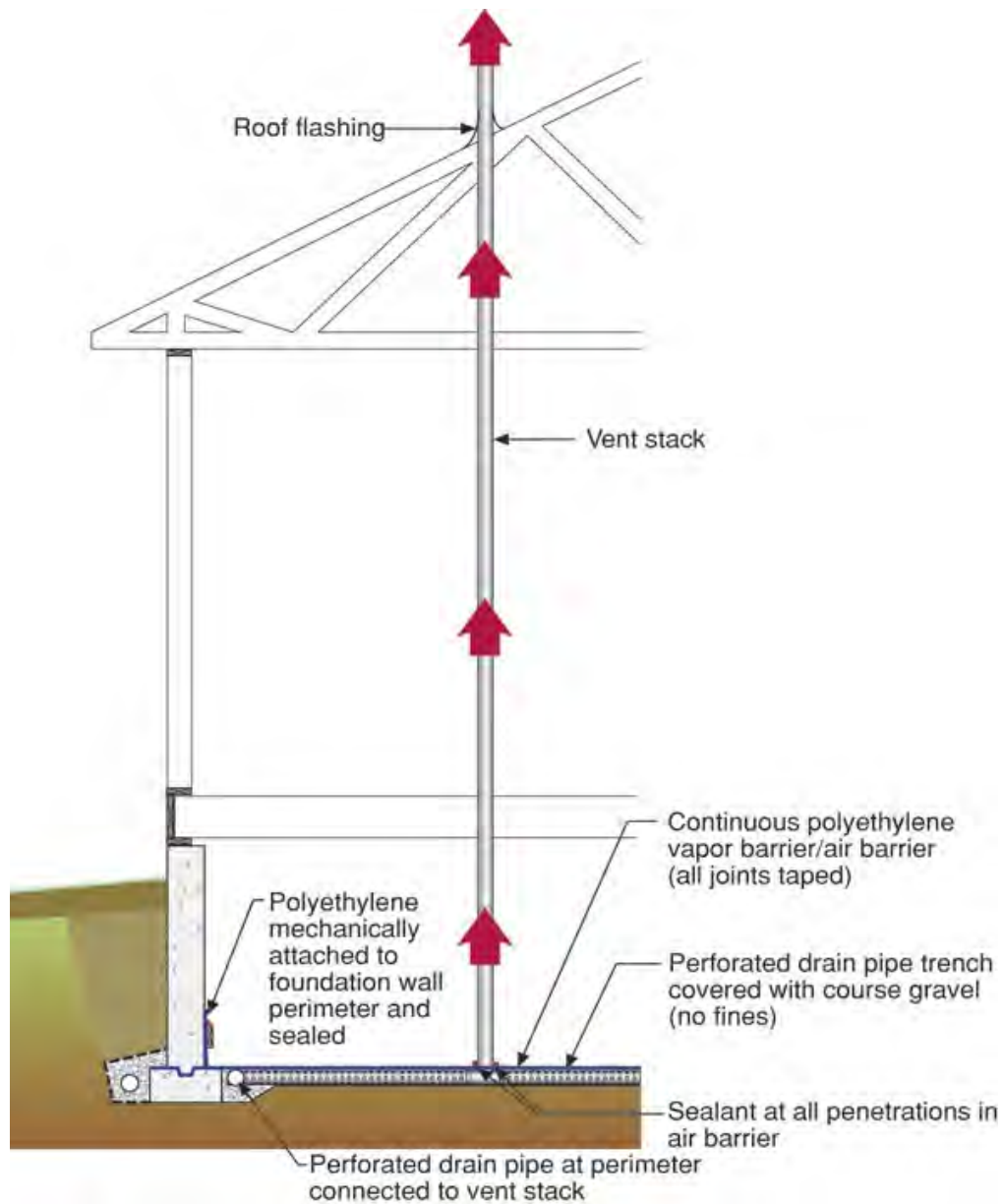


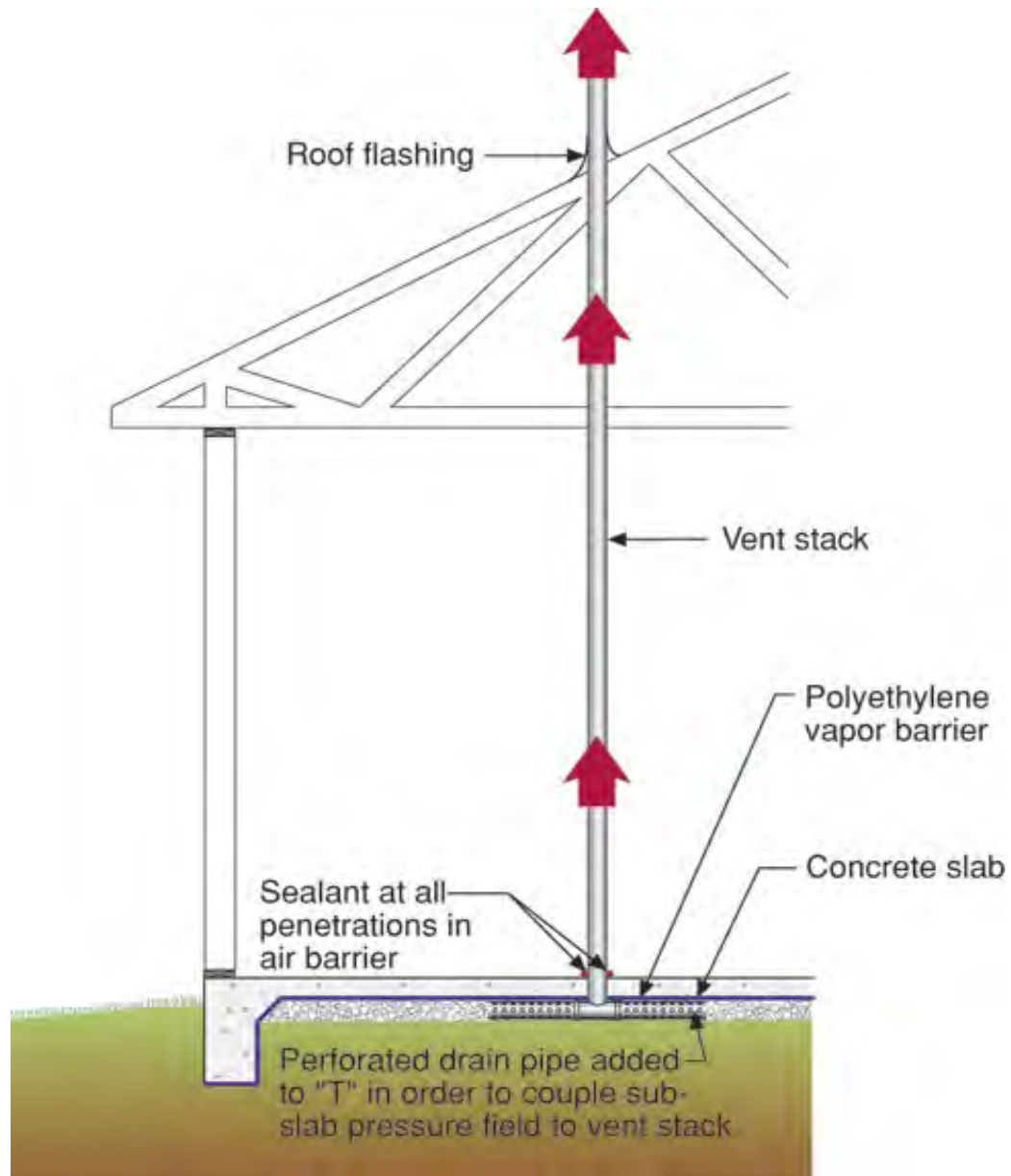






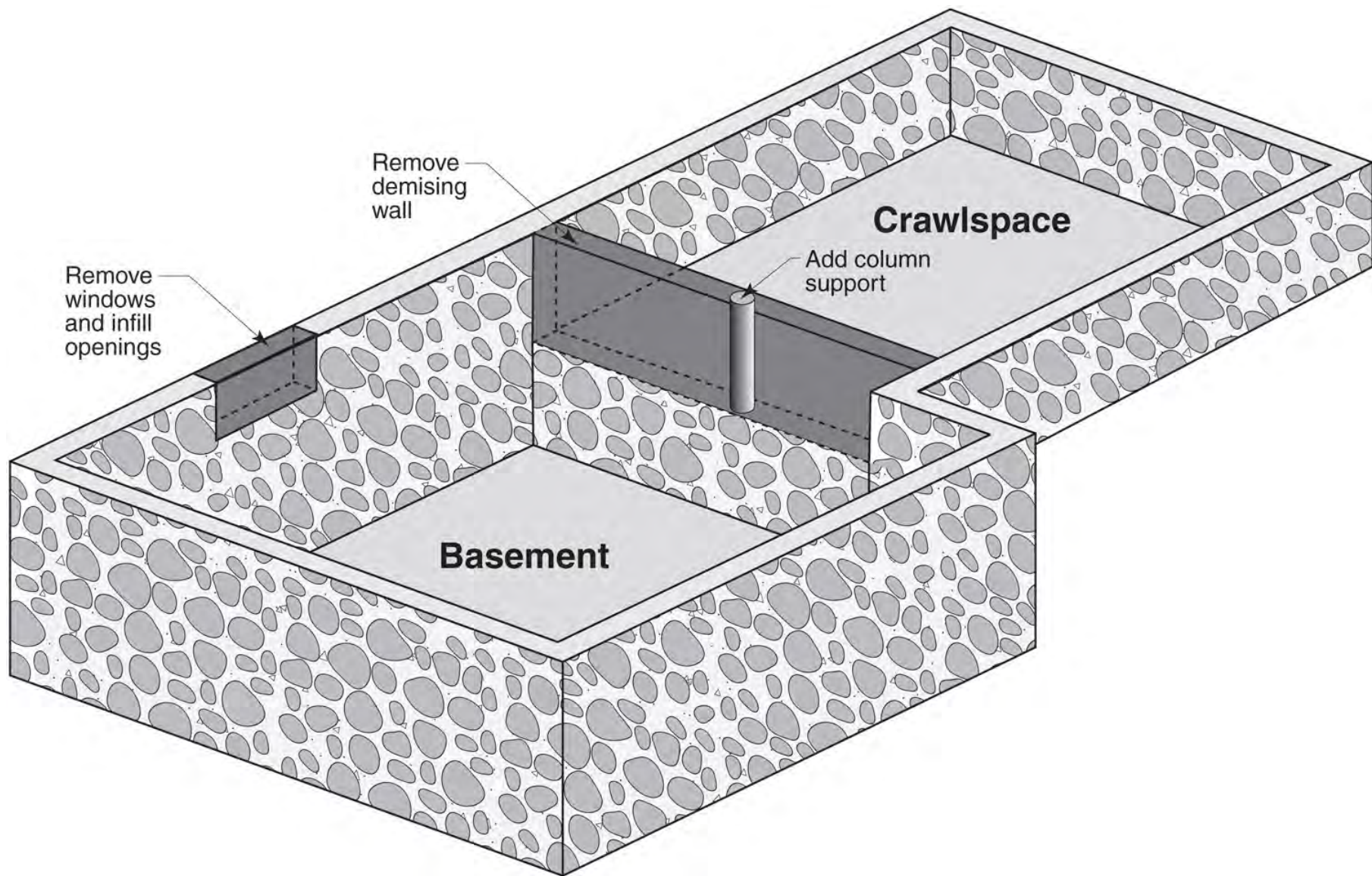






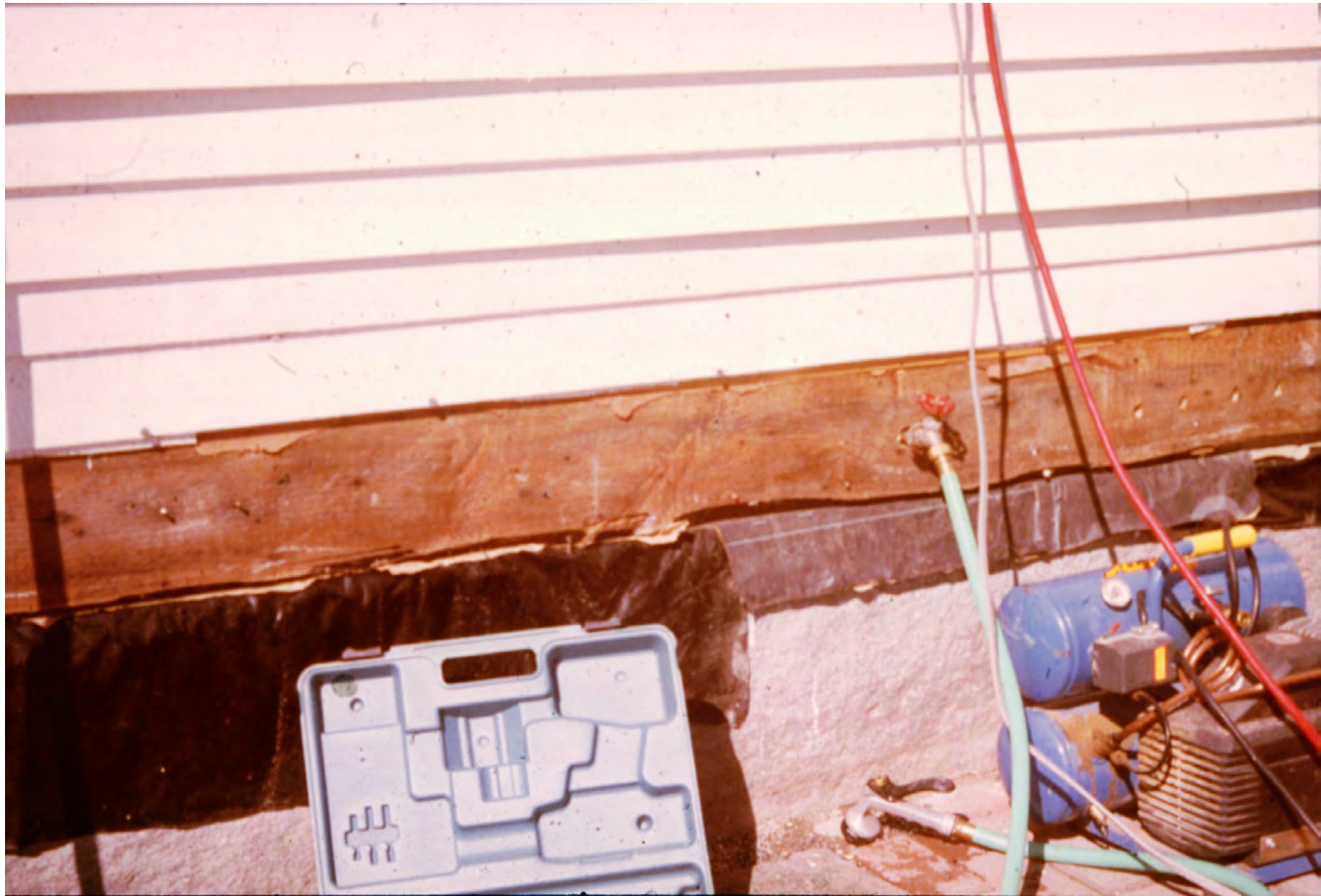
# Basements







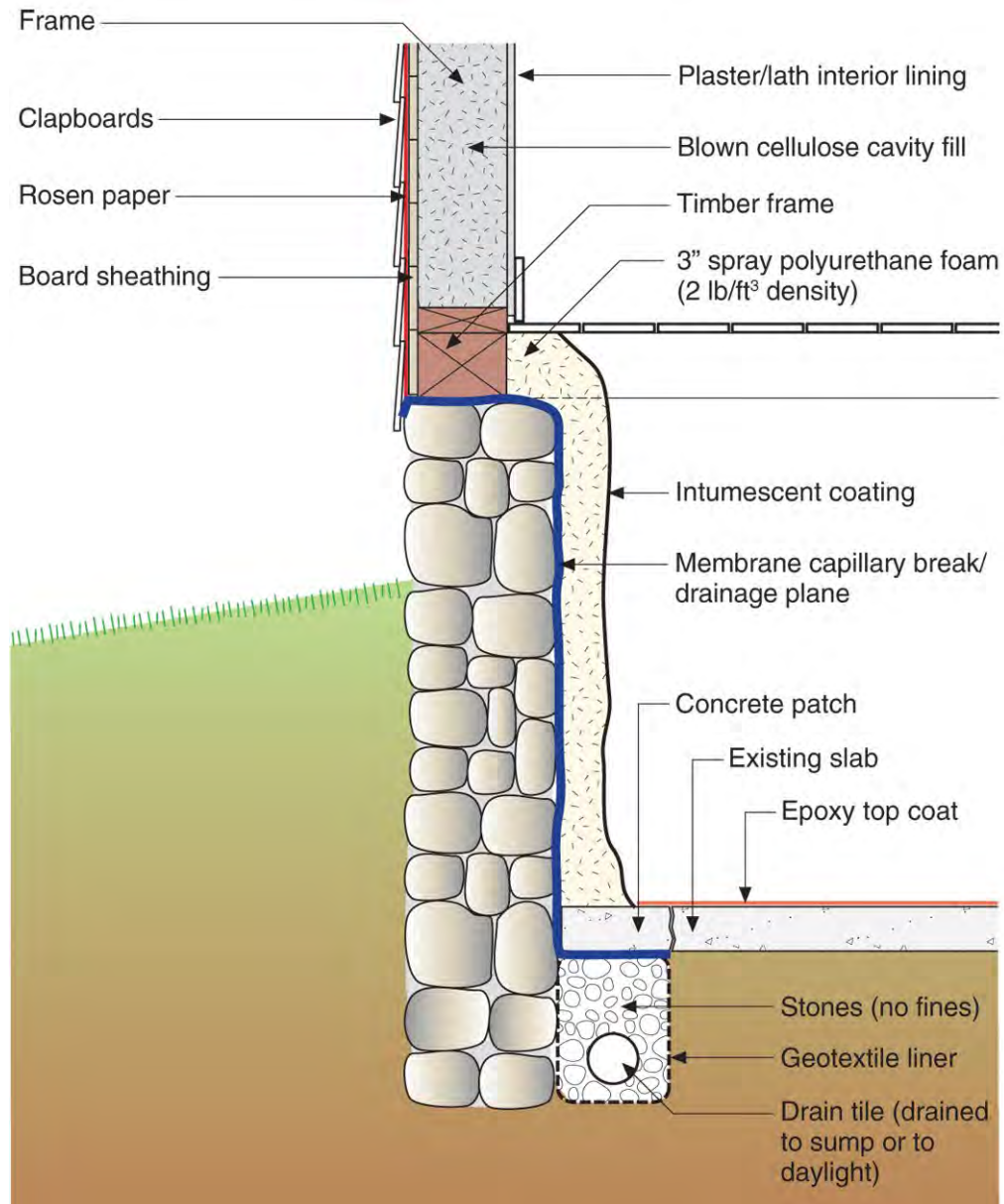




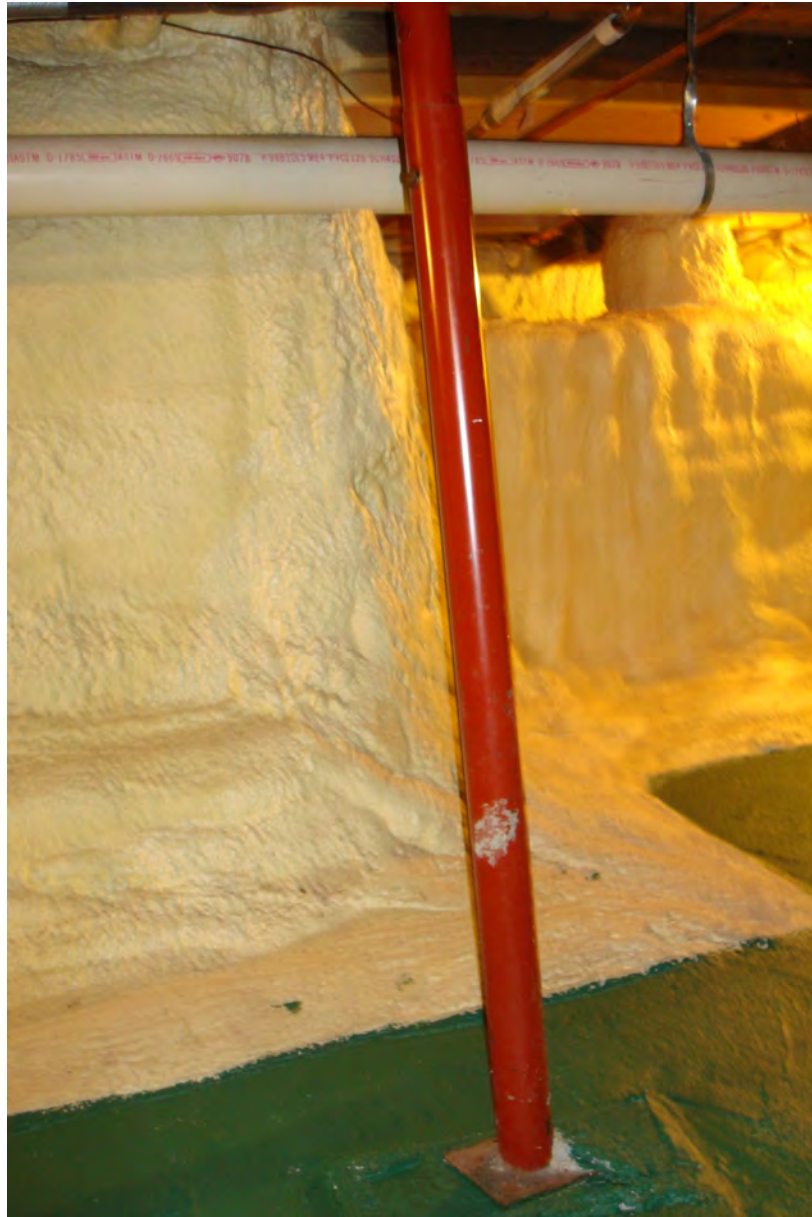






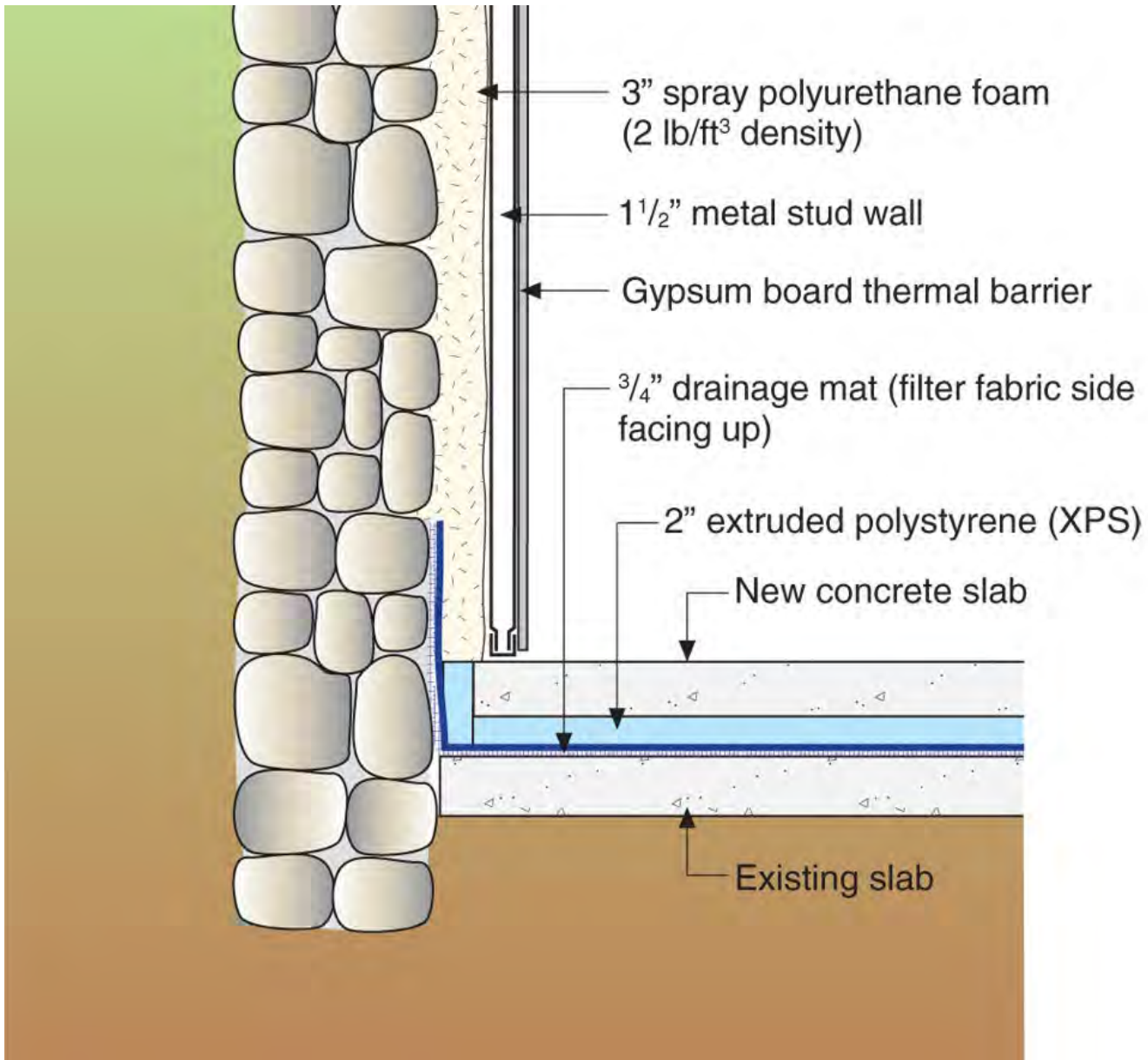






















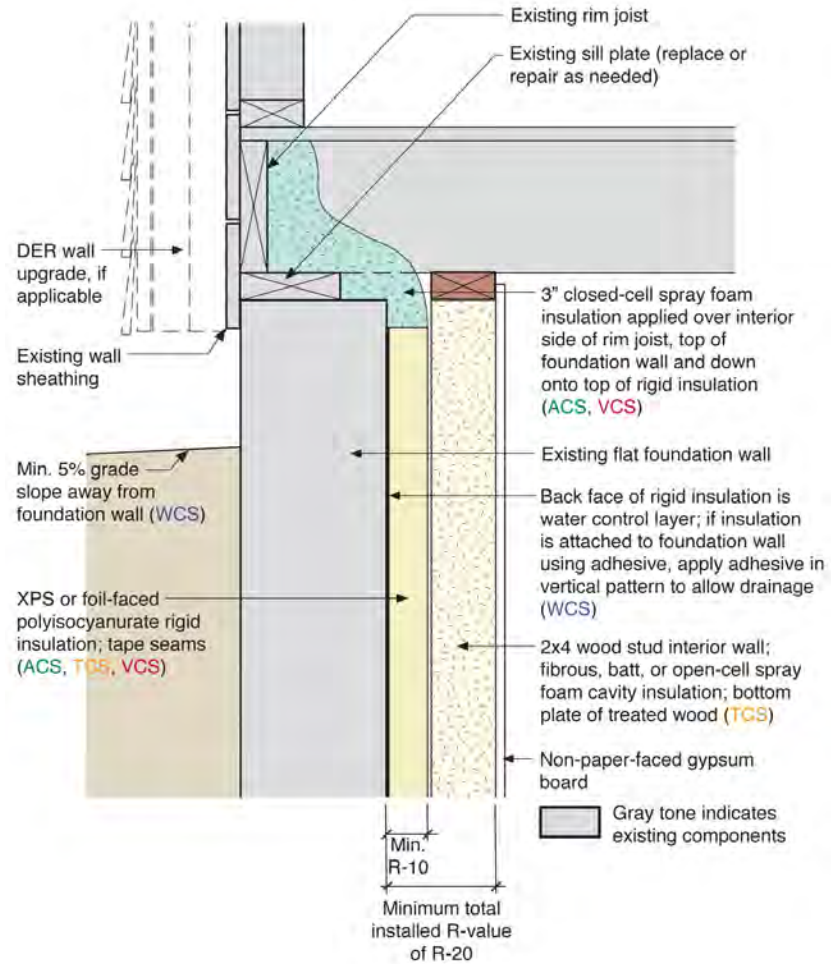


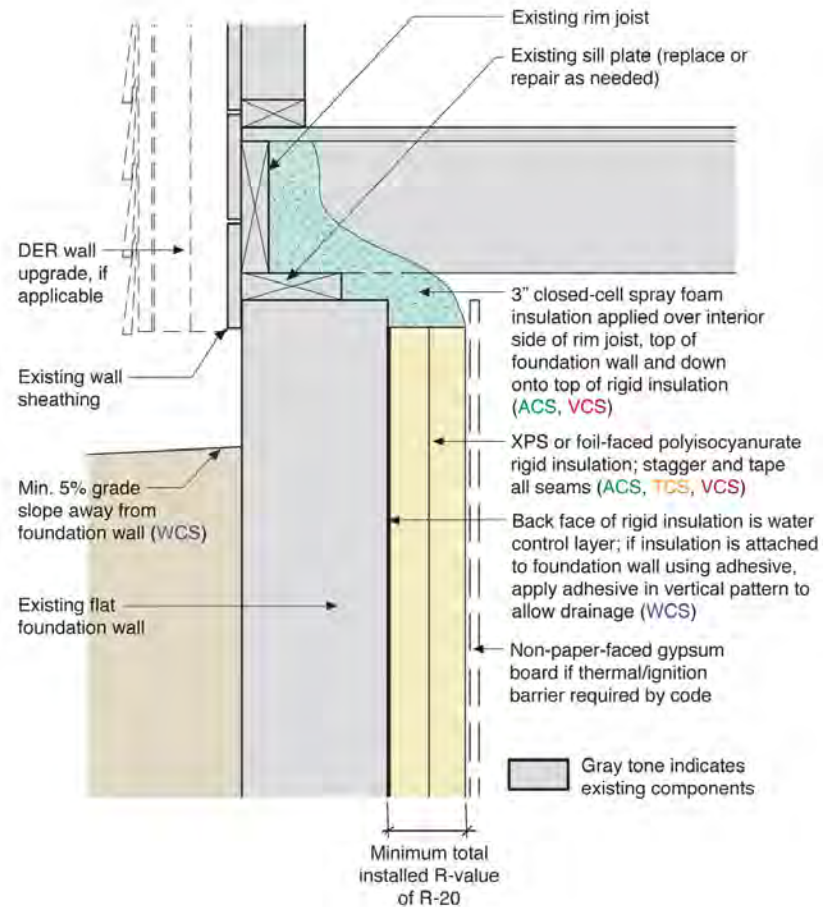




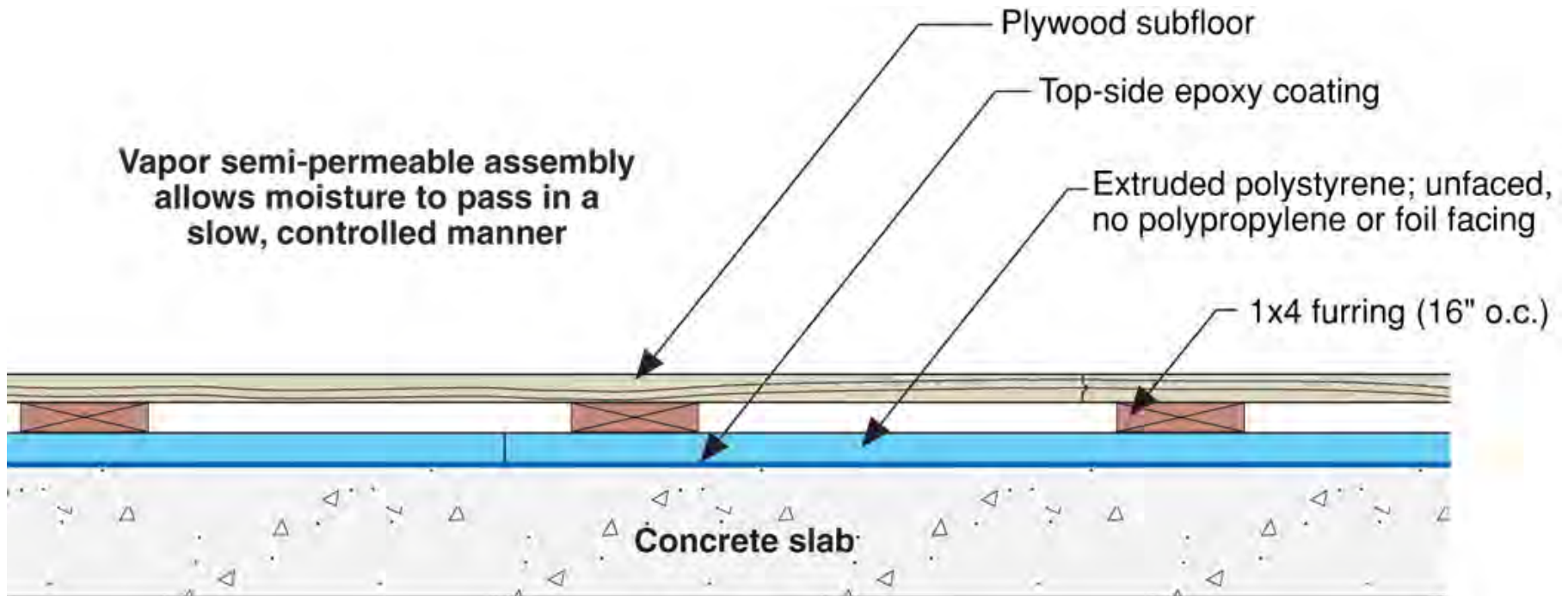








**Vapor semi-permeable assembly  
allows moisture to pass in a  
slow, controlled manner**

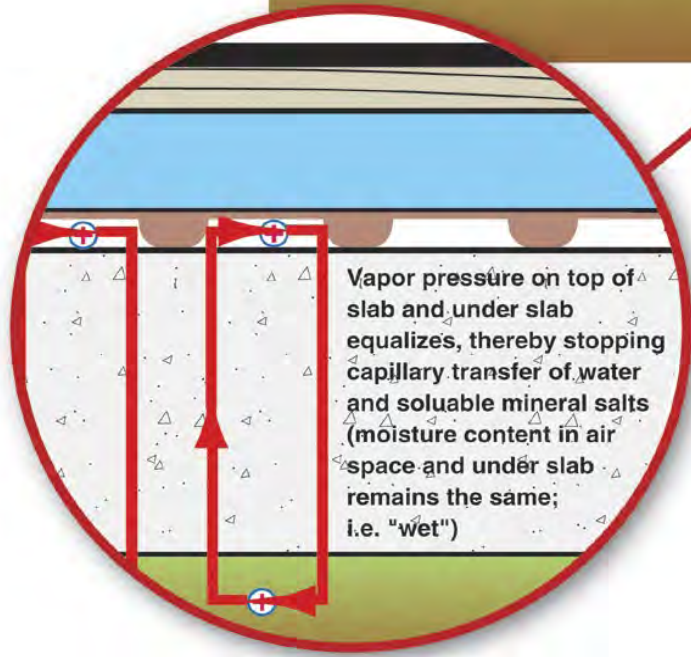
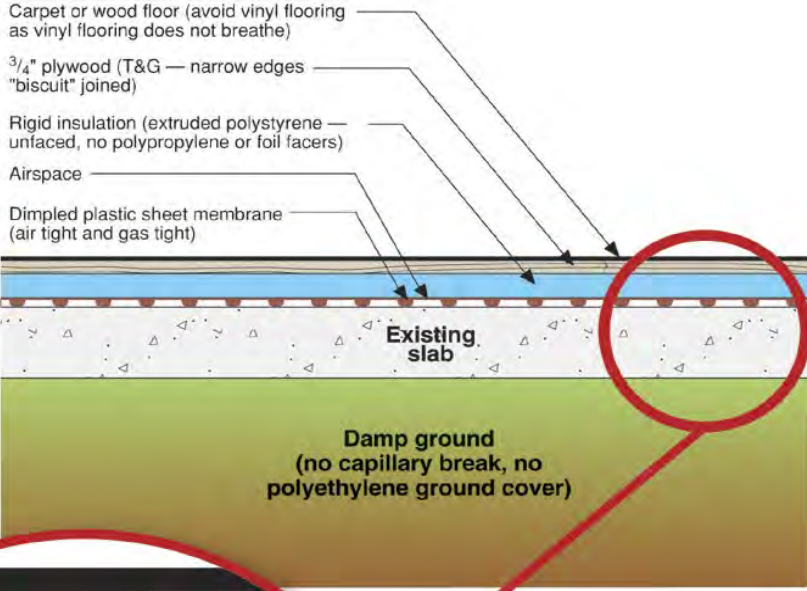










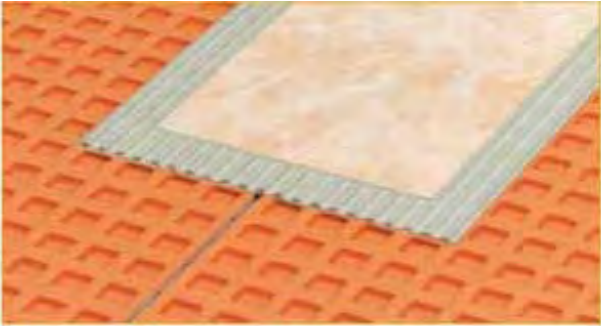


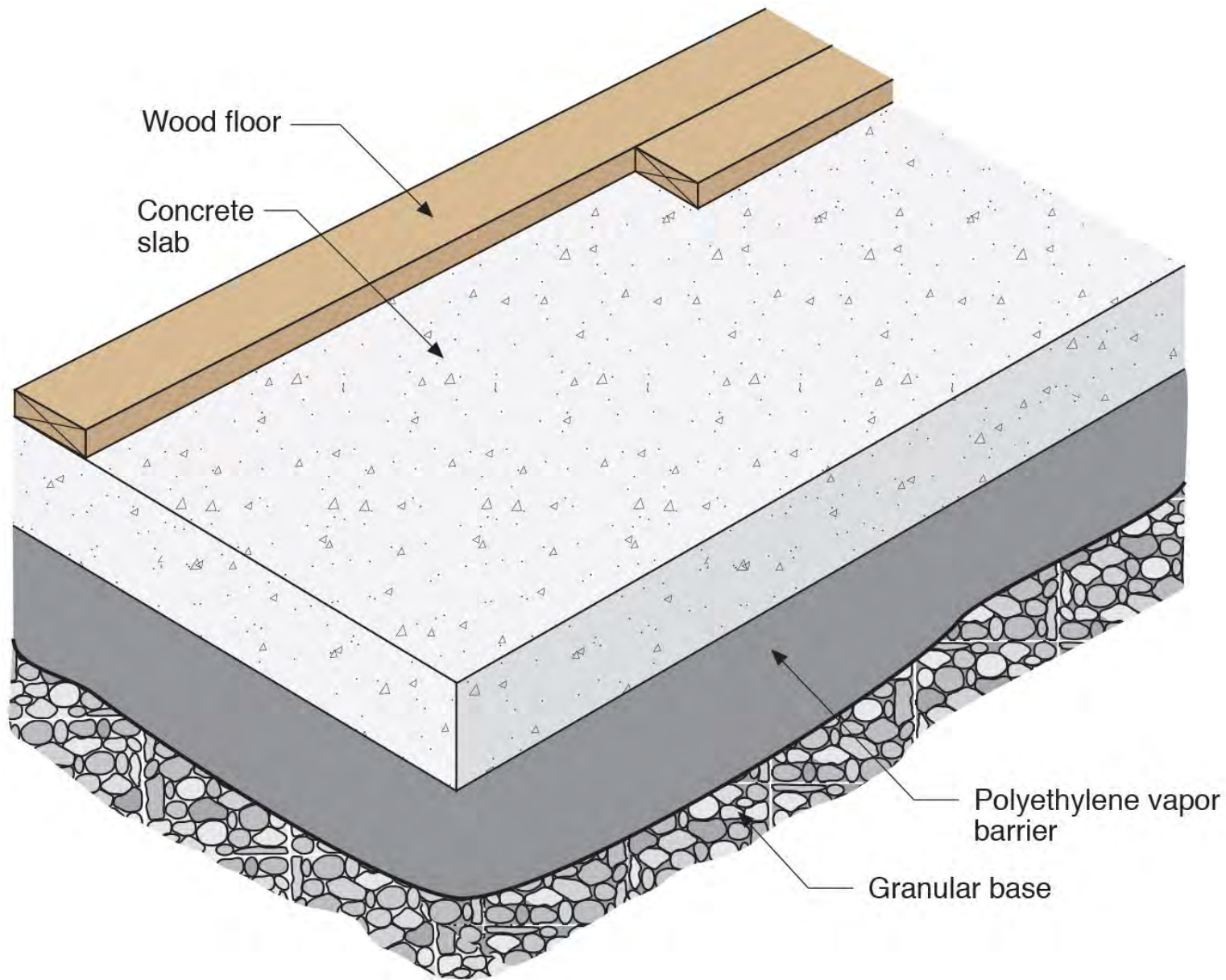


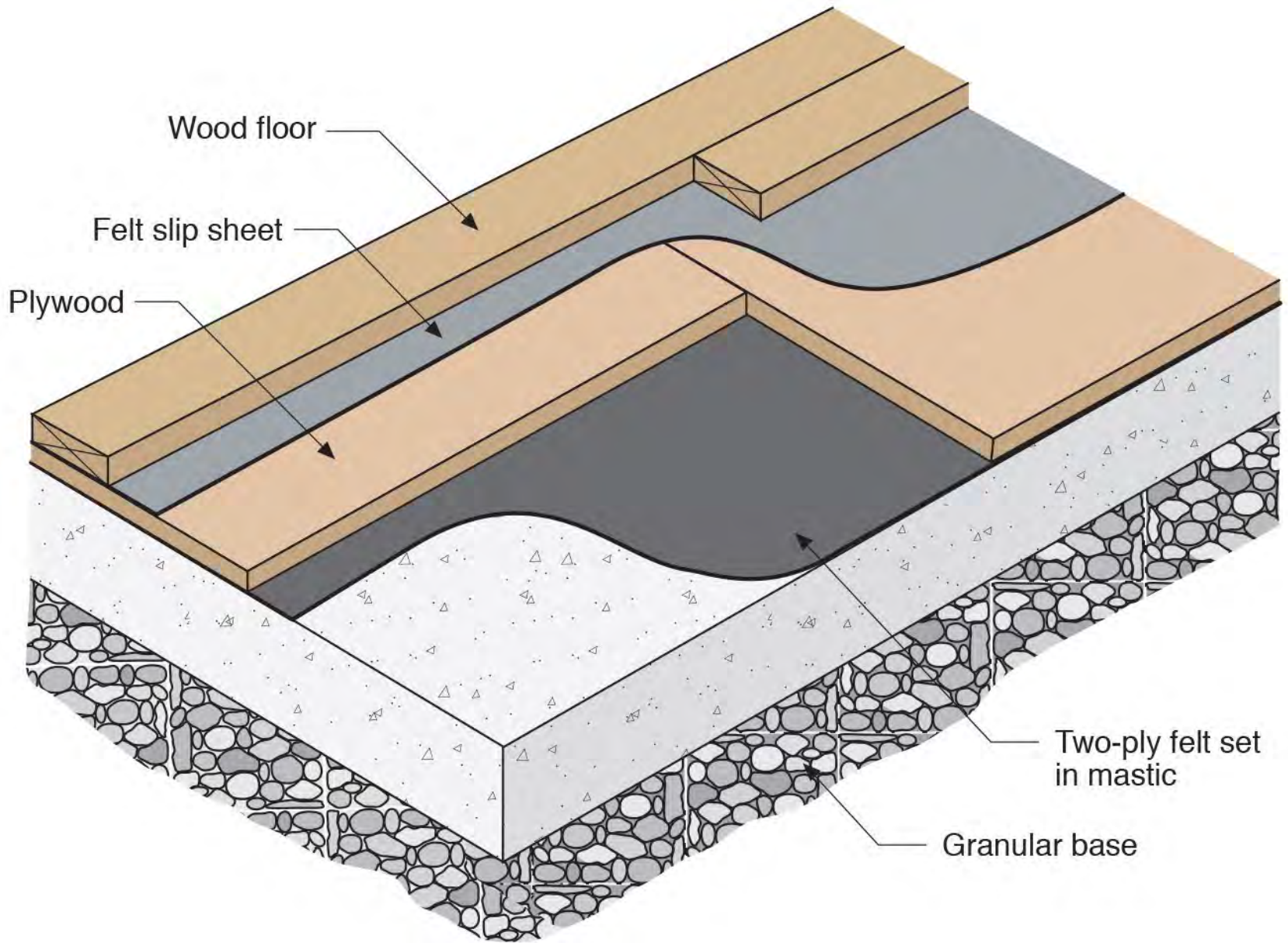






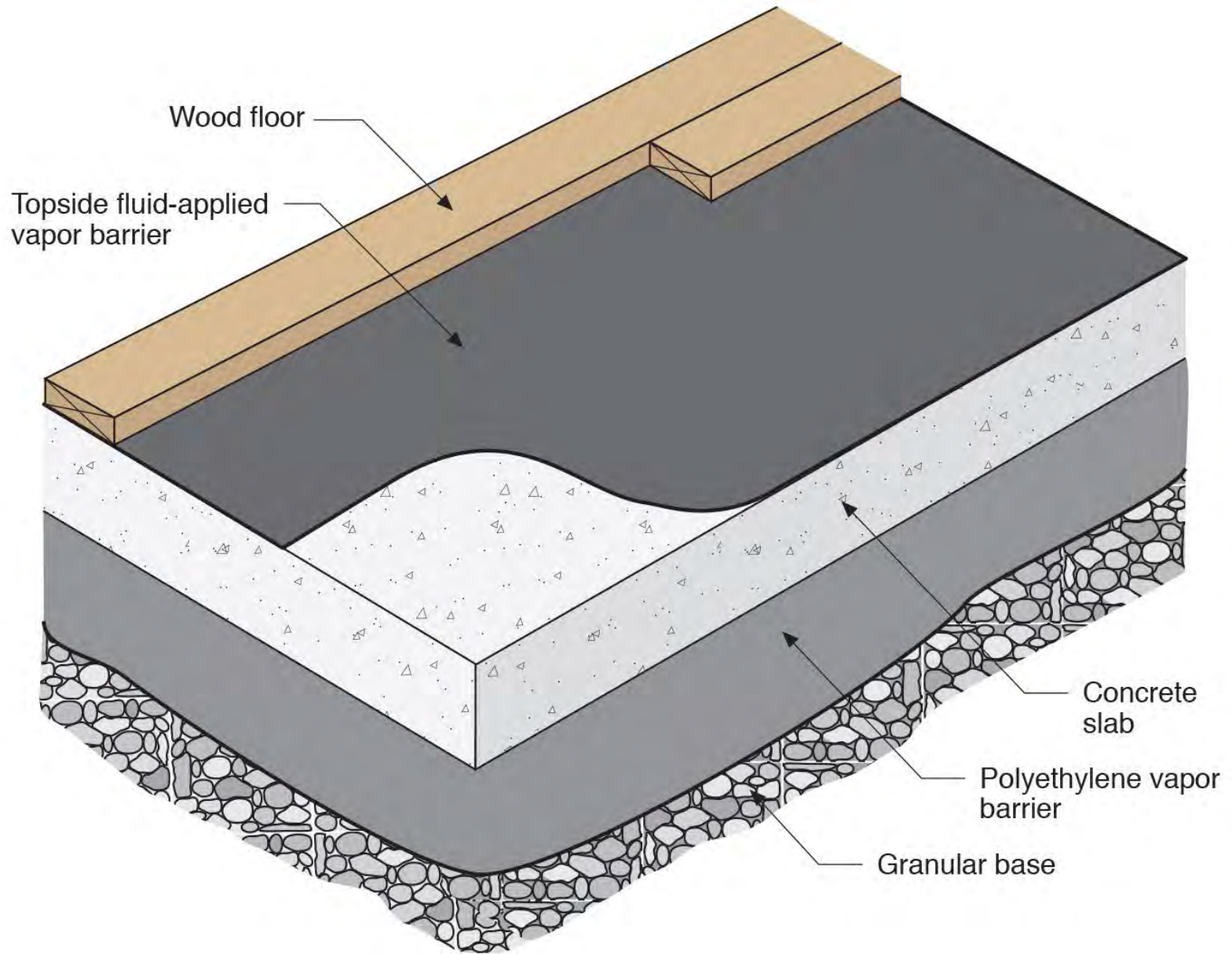




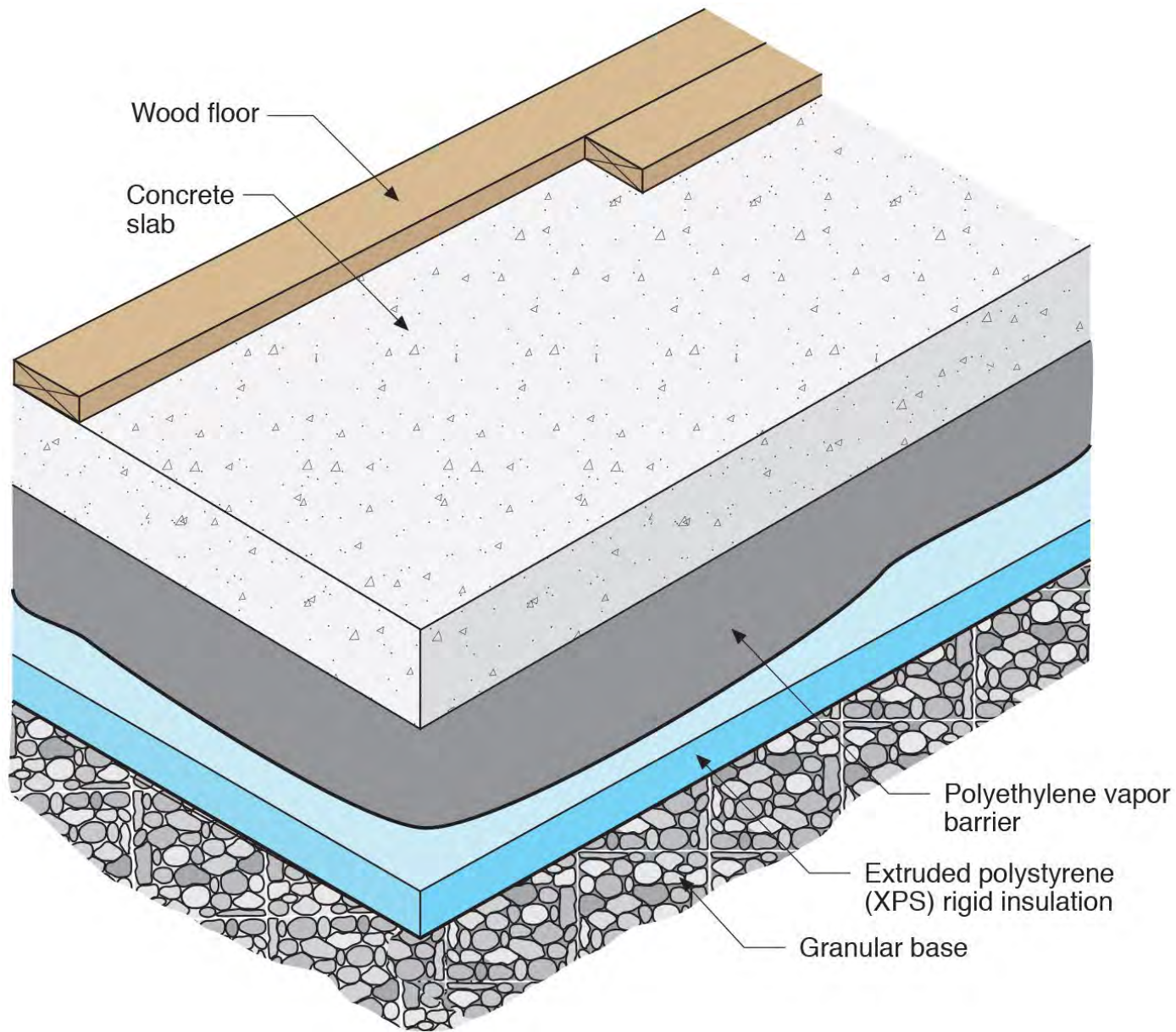


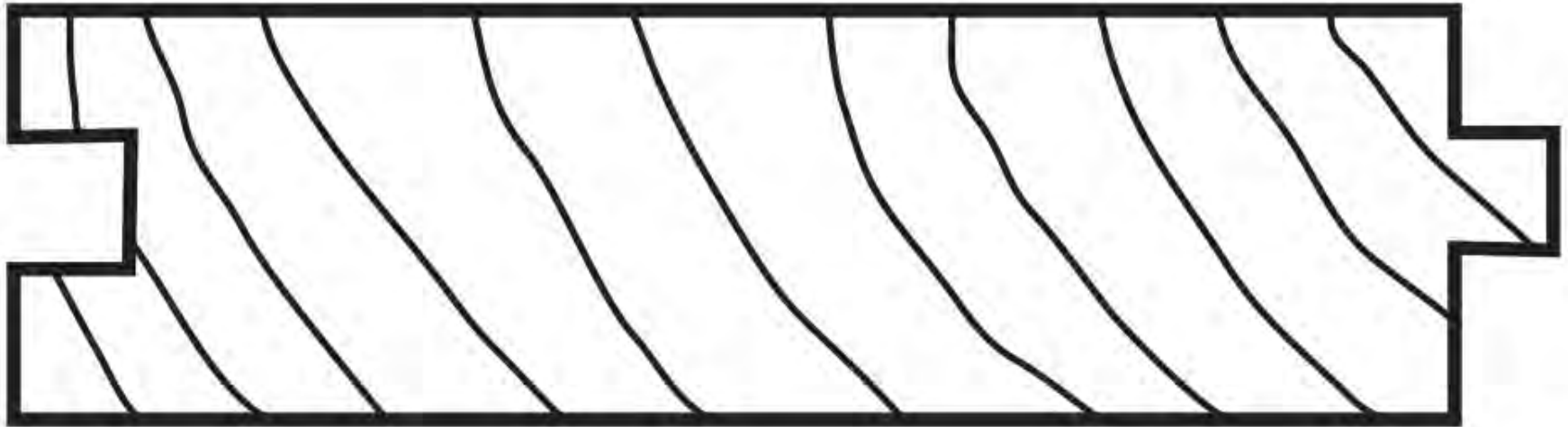




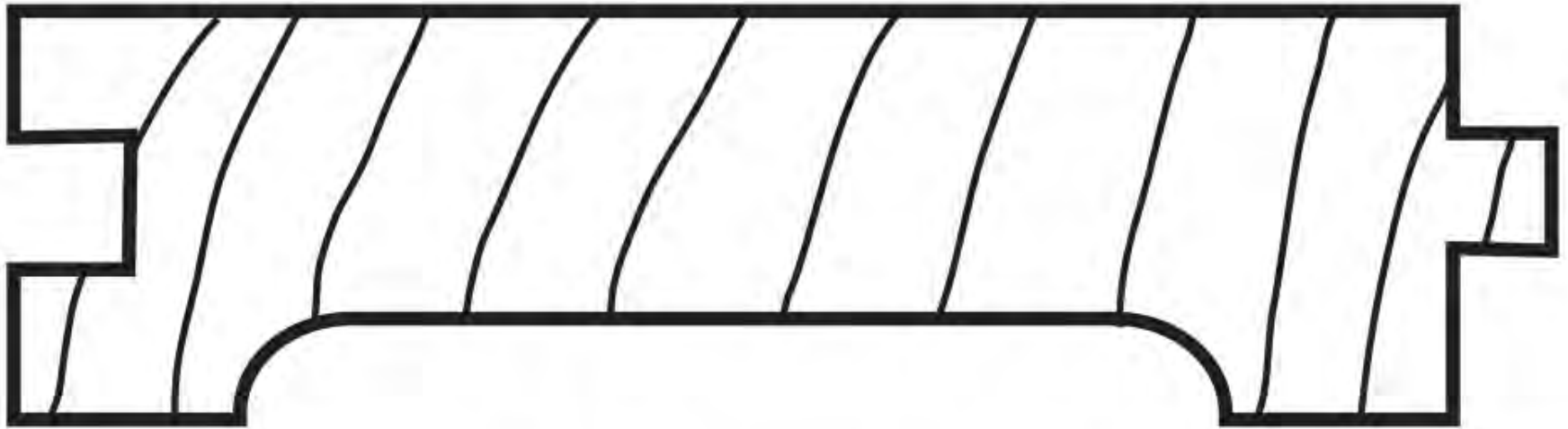




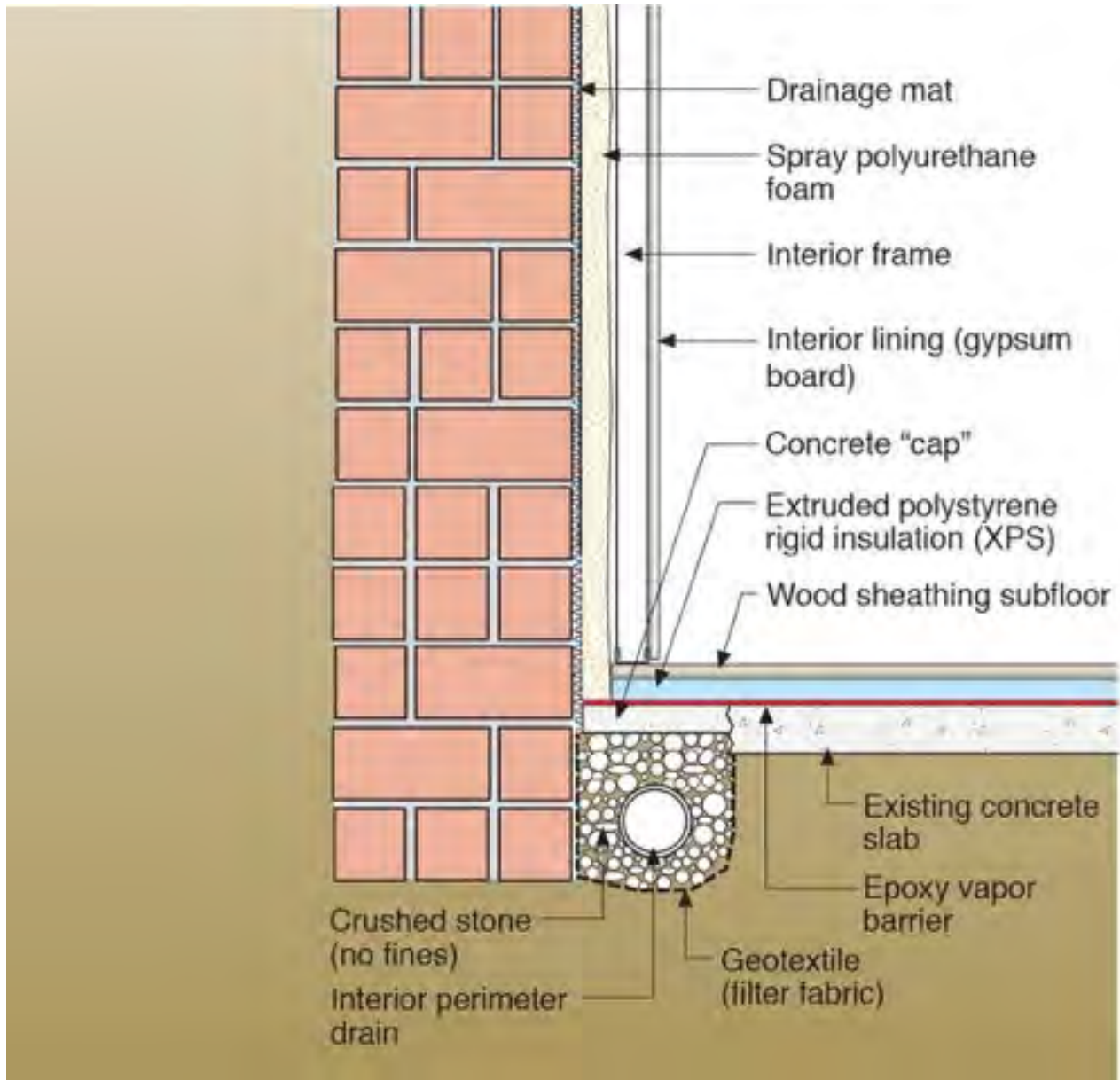


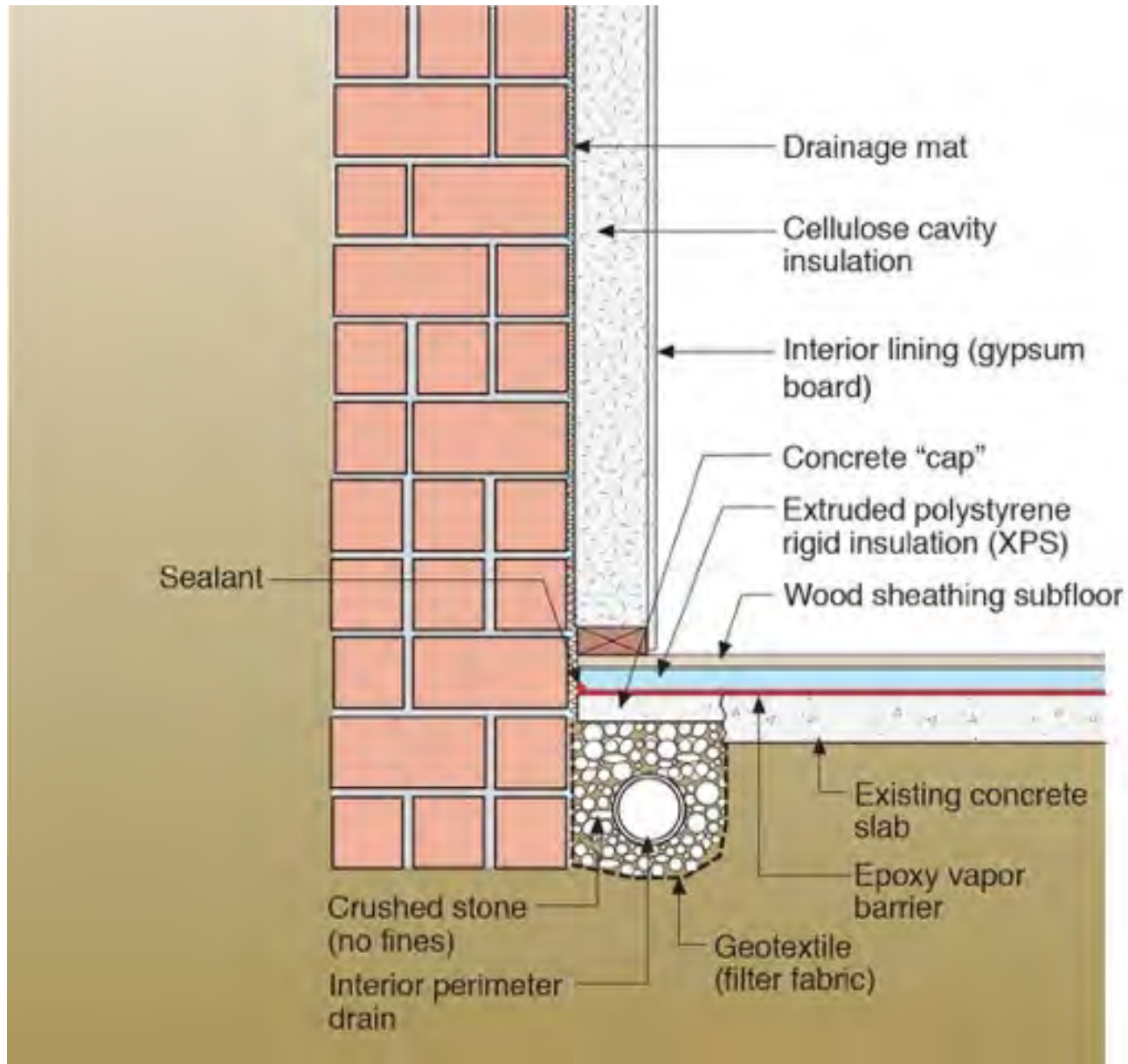


**Plain**

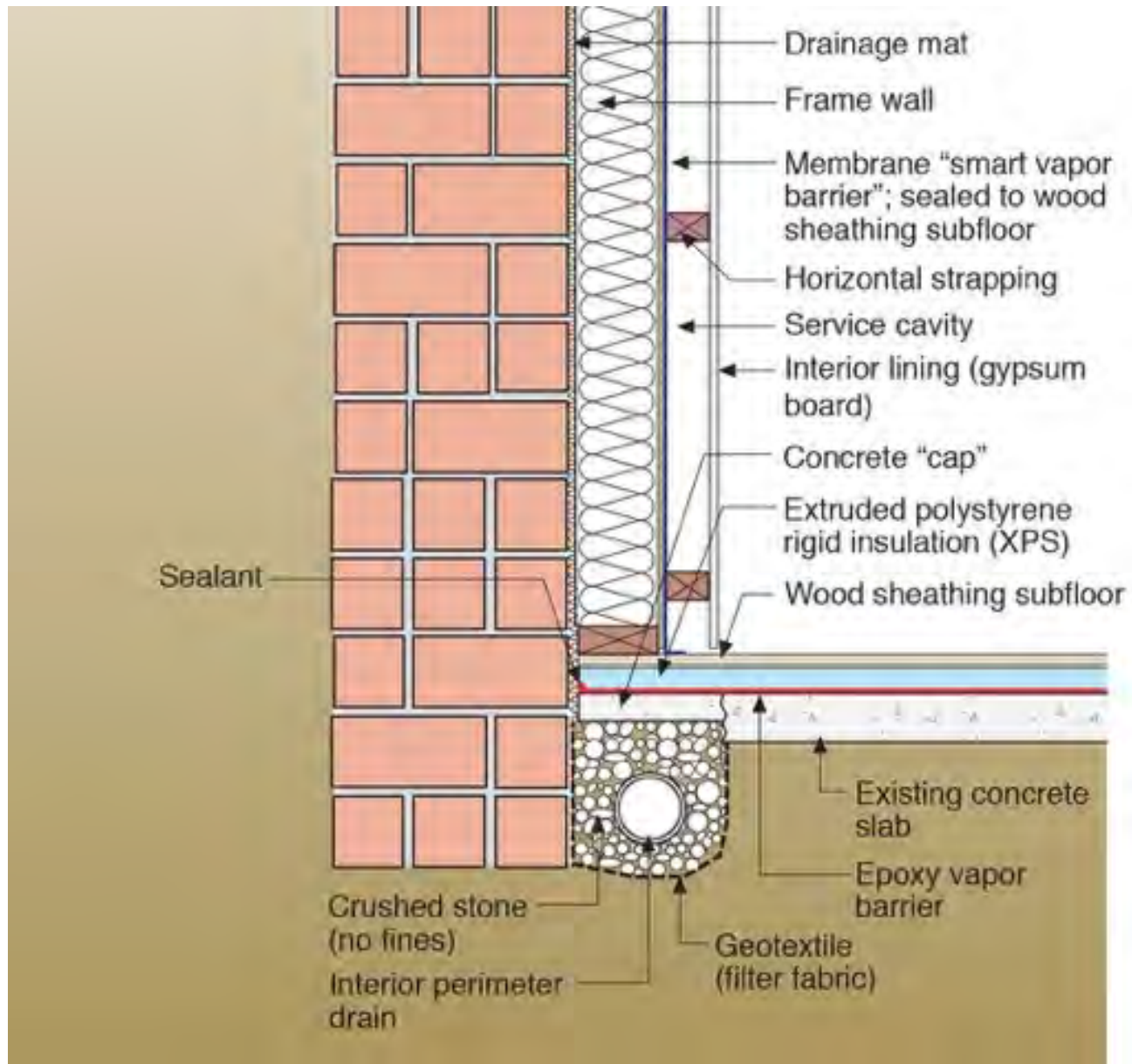


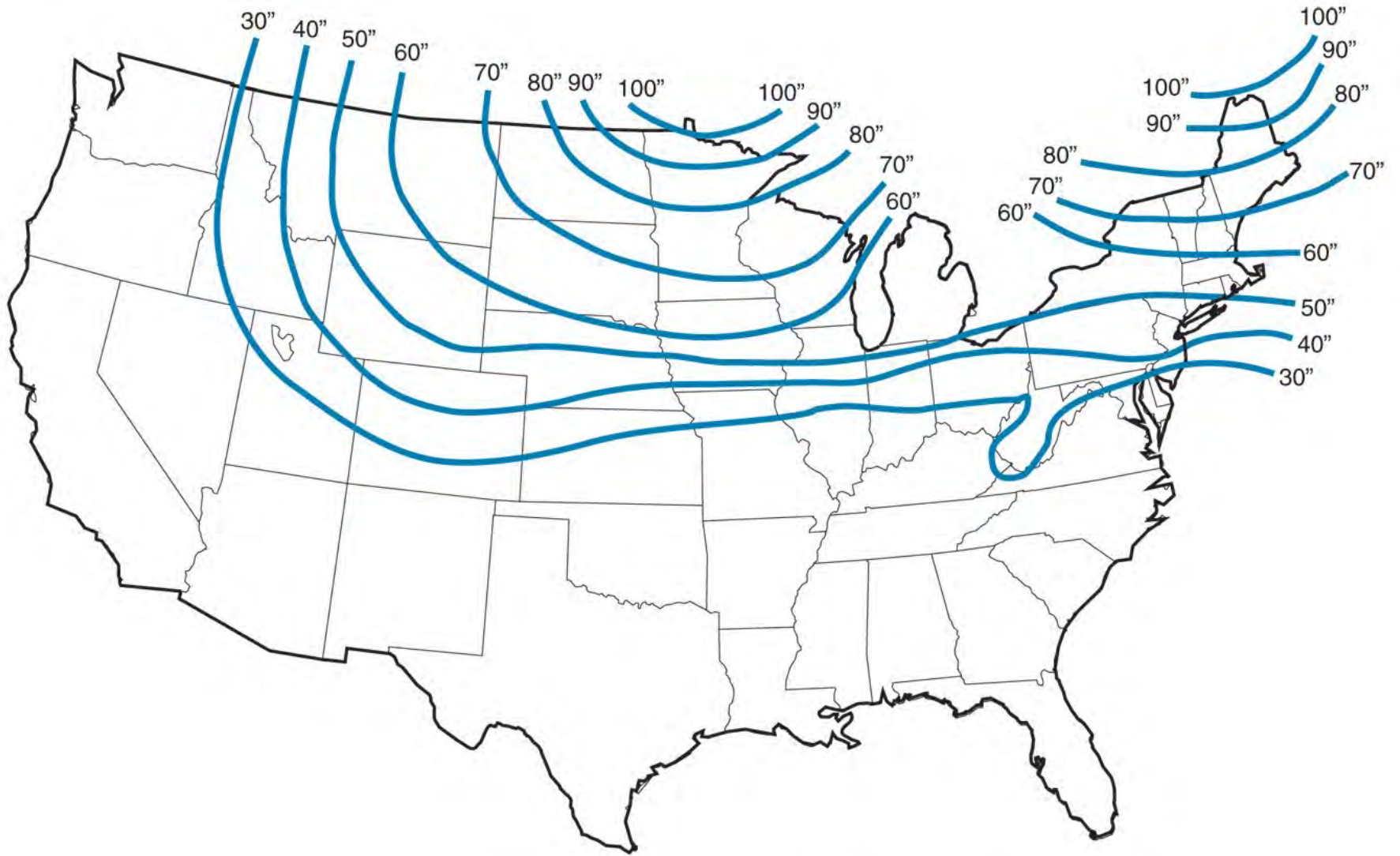
# Hollow Back



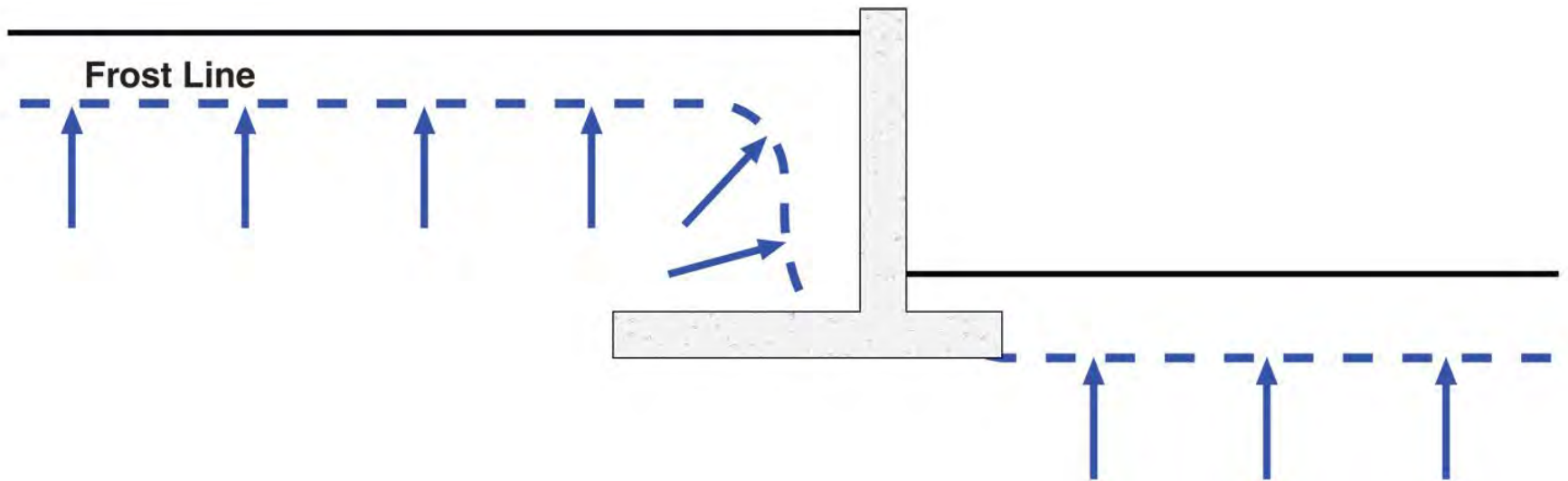


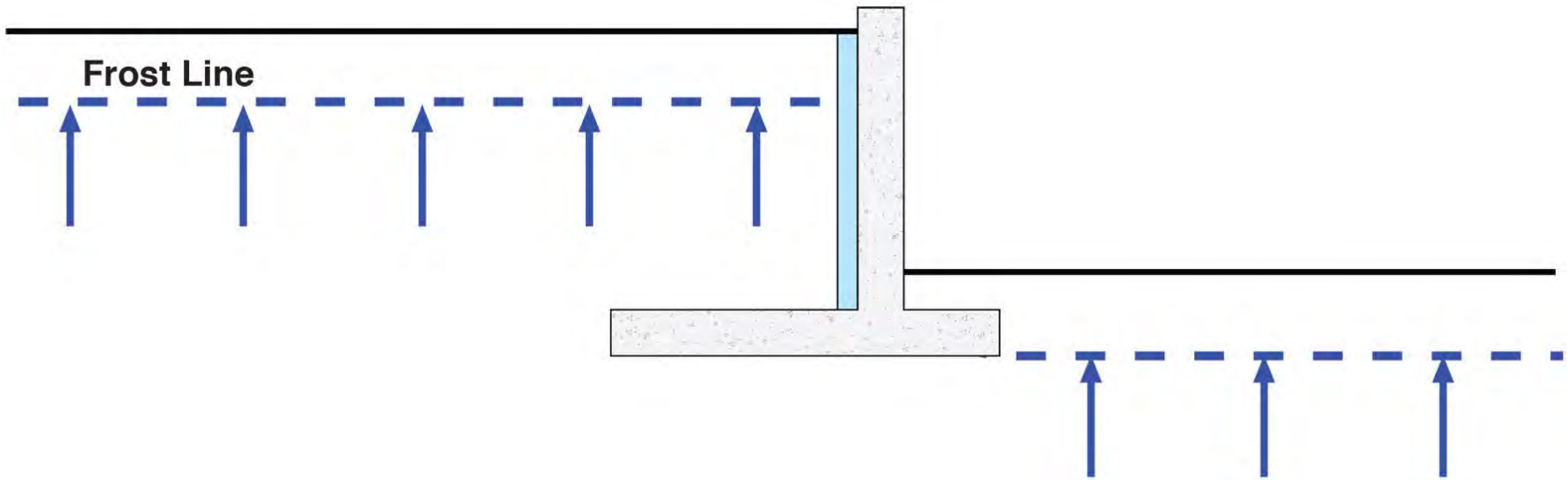




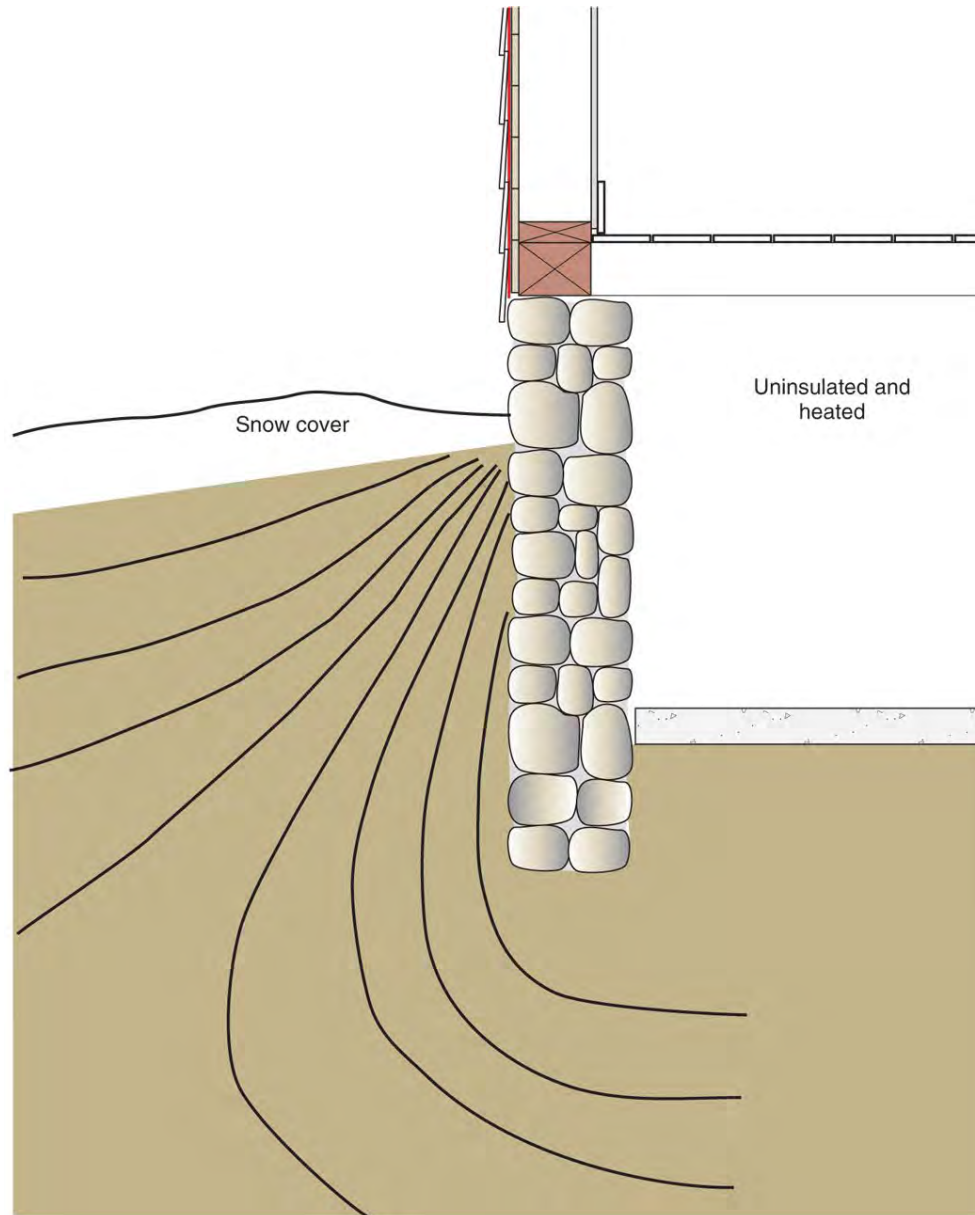


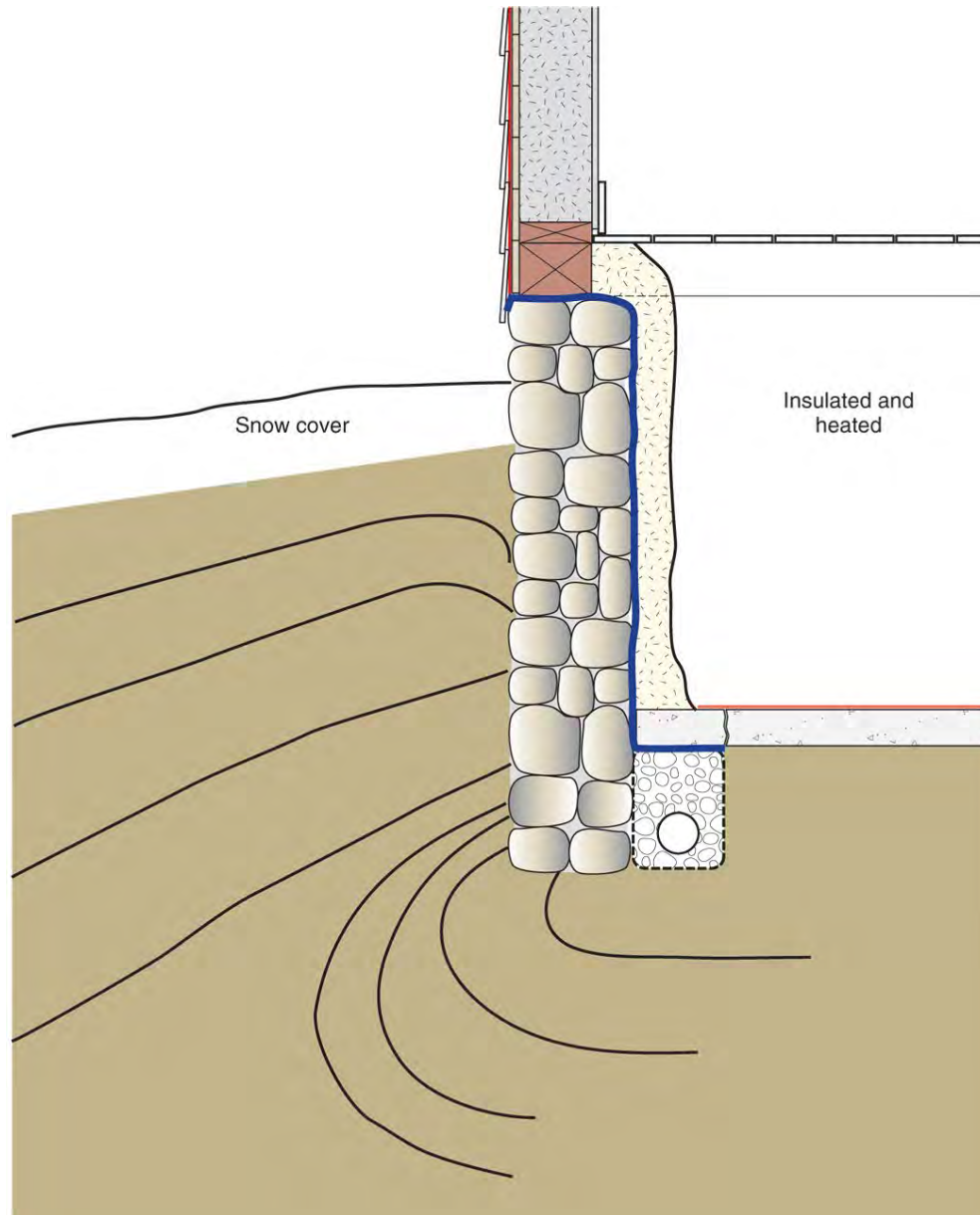
From the US Army Corps Engineers Extreme Frost Penetration (in inches) based on state averages.

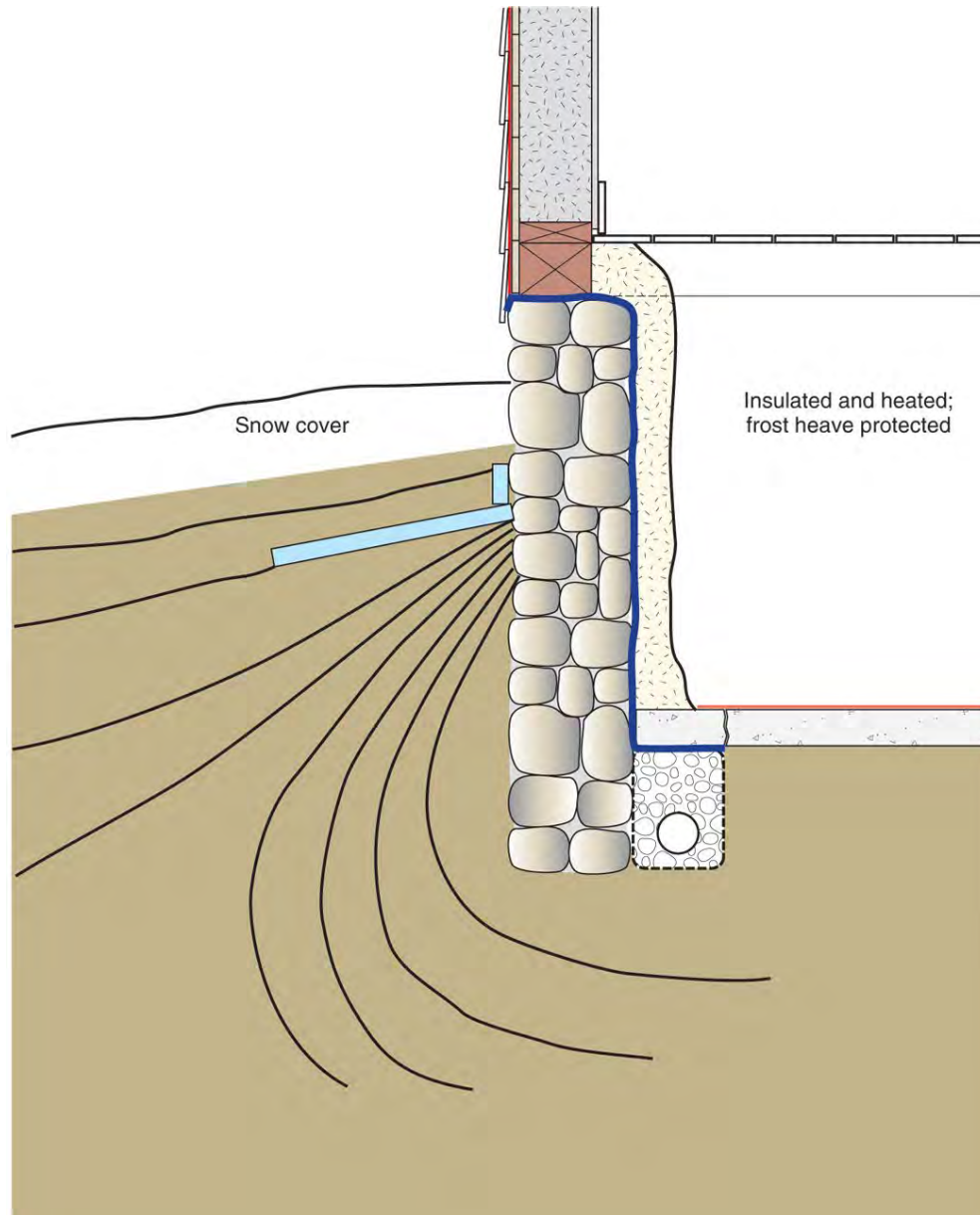




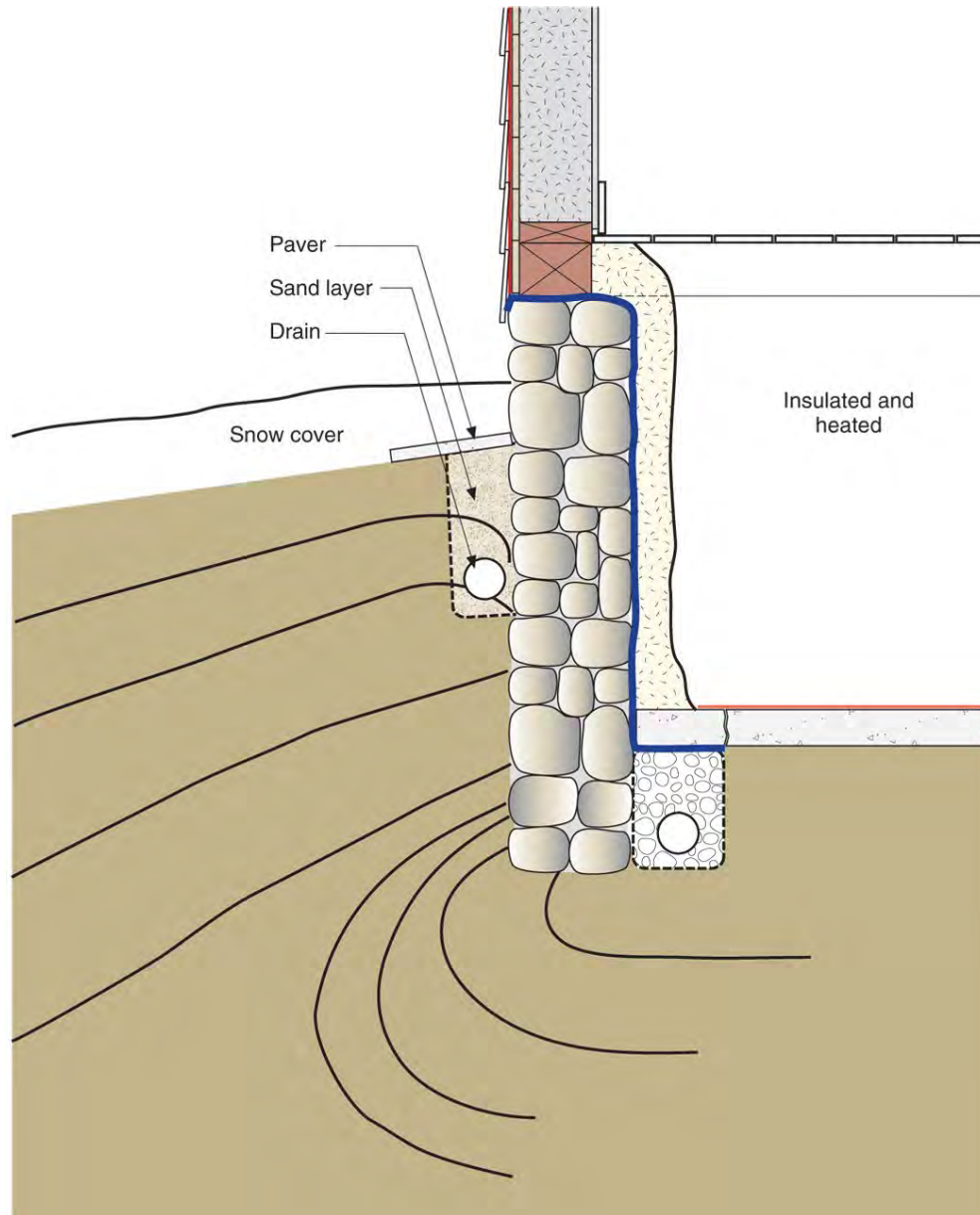


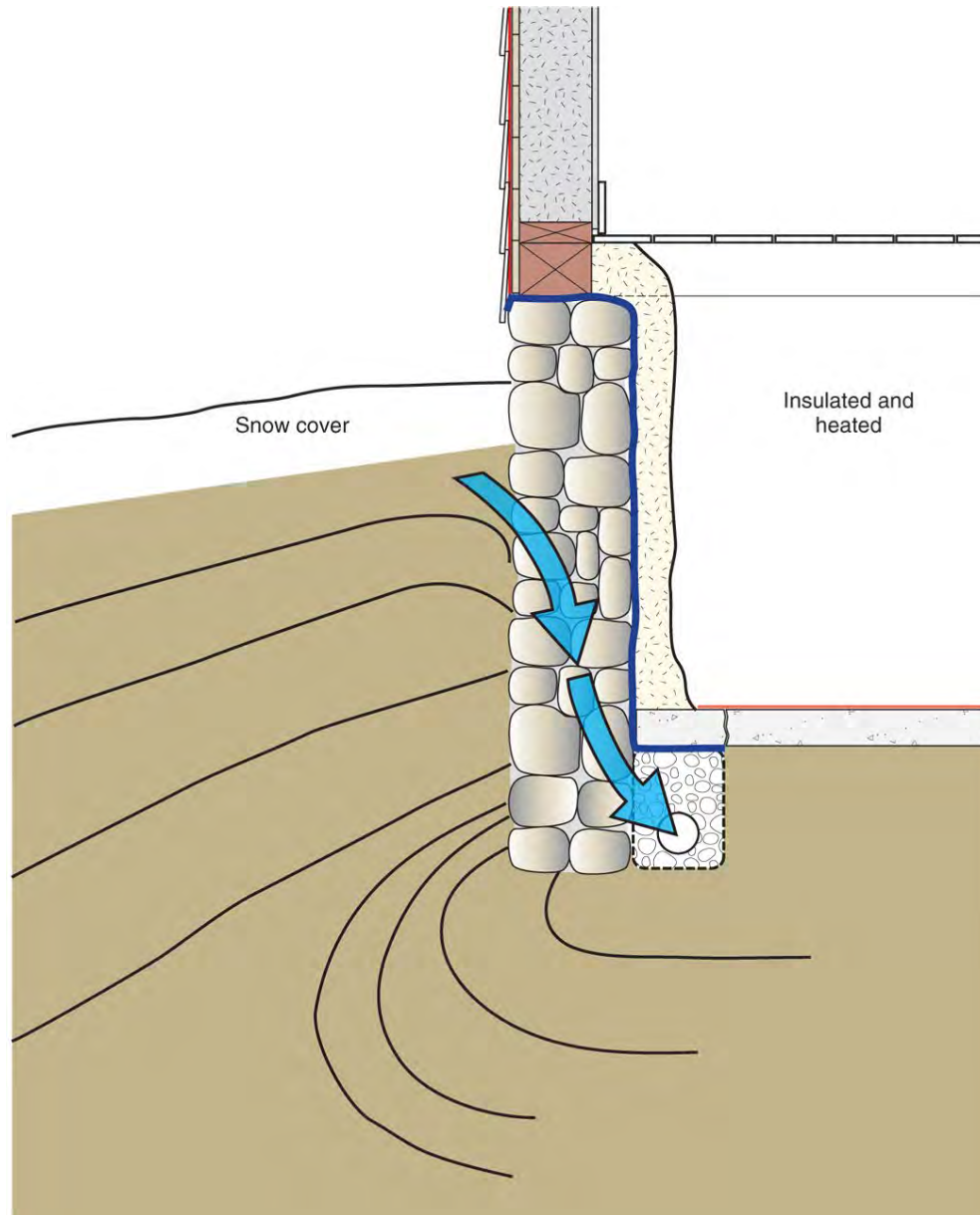












# Crawl Spaces

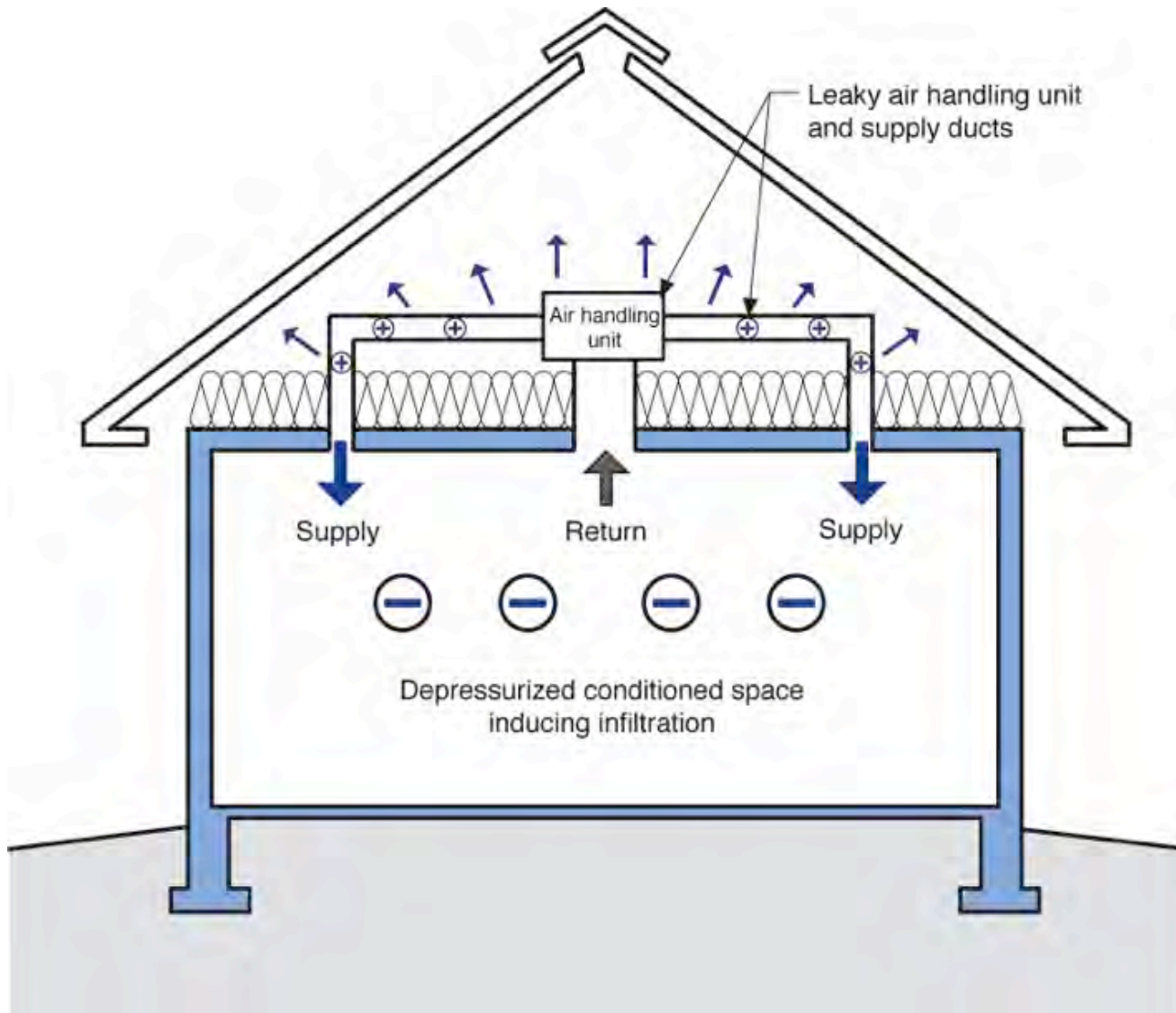
Crawl spaces must be completely connected to either the outside or the inside

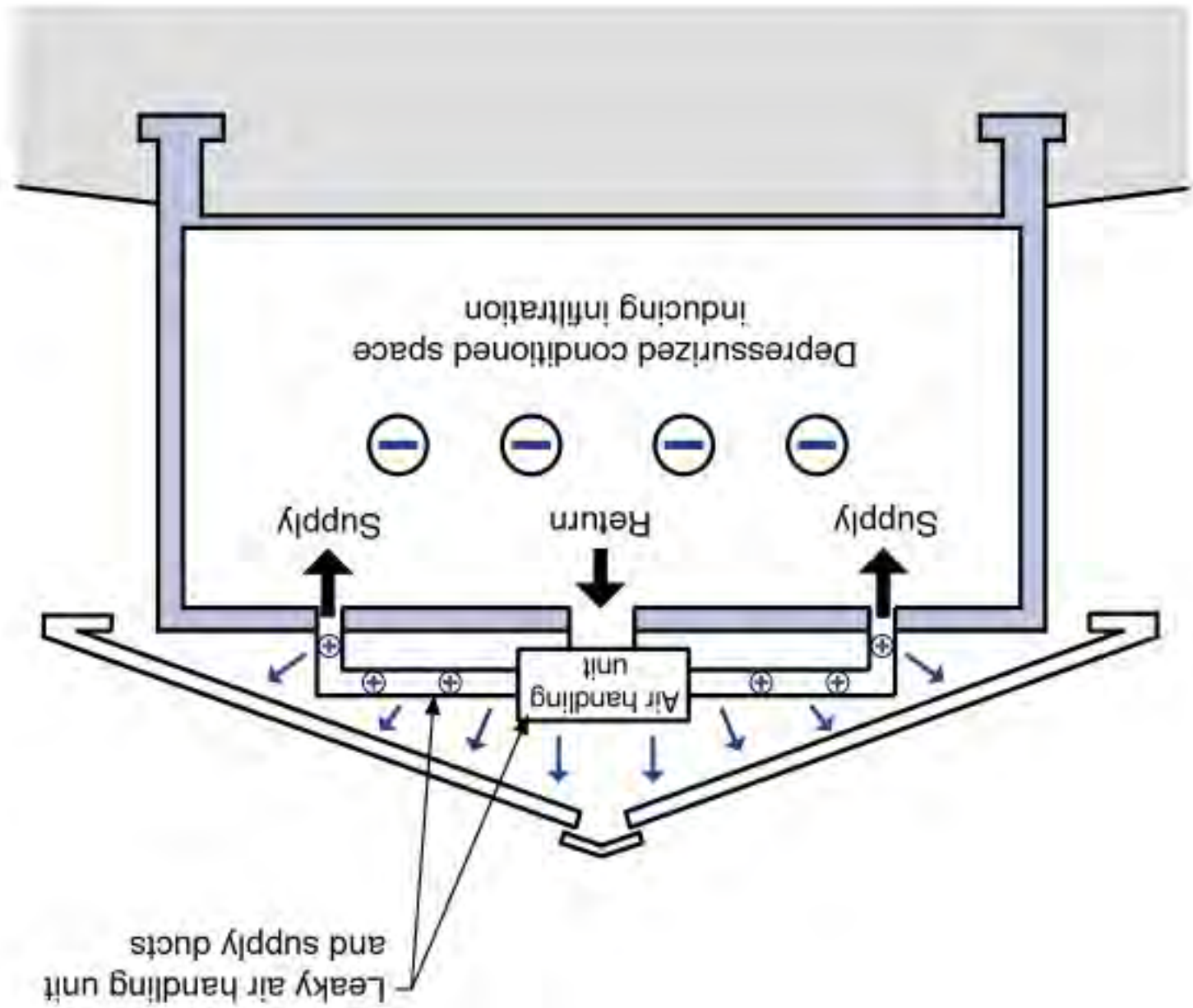
Crawl spaces must be completely connected to either the outside or the inside

Vented crawl spaces work

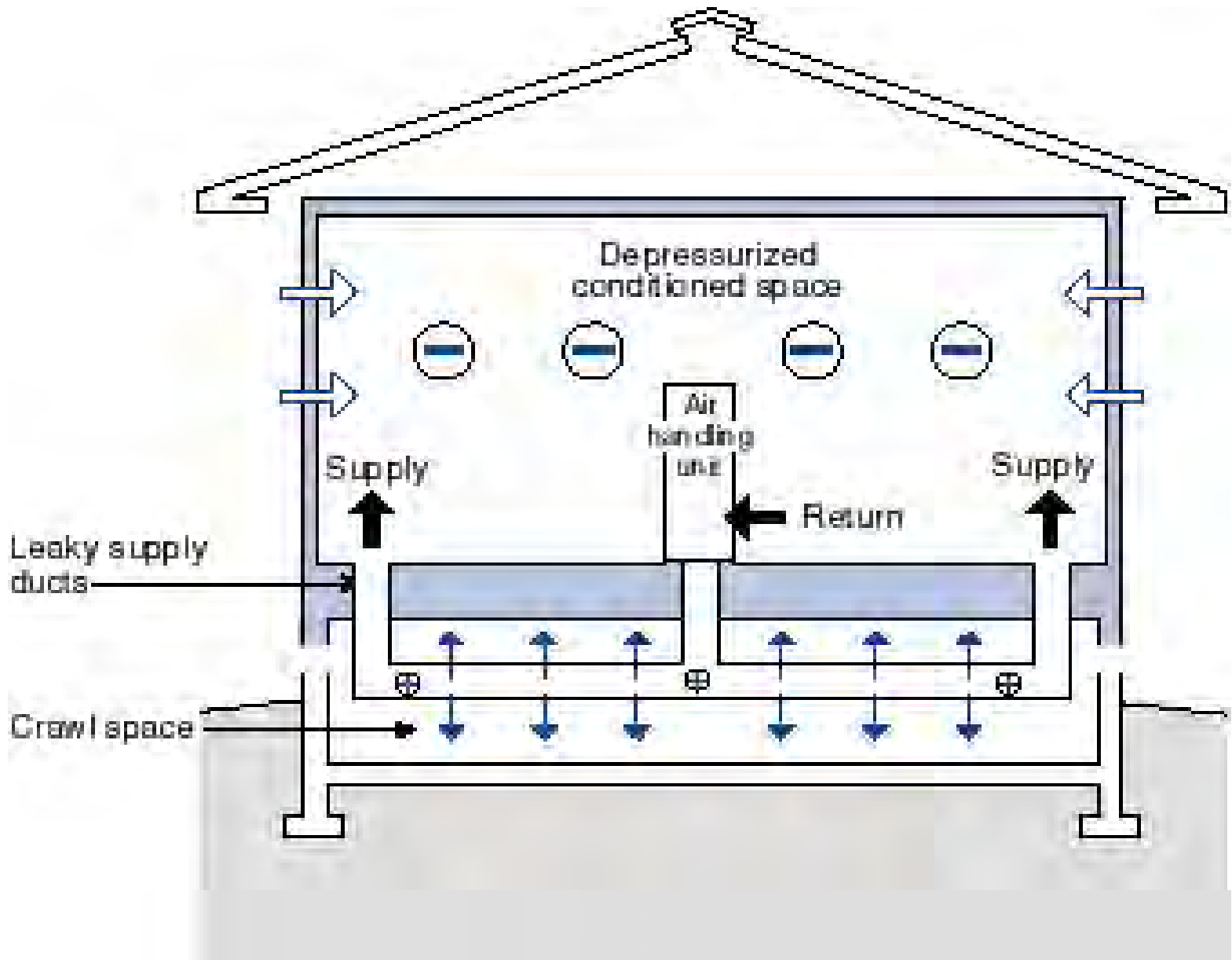
Unvented conditioned crawl spaces work

Don't Do Stupid Things









# Smart Thing













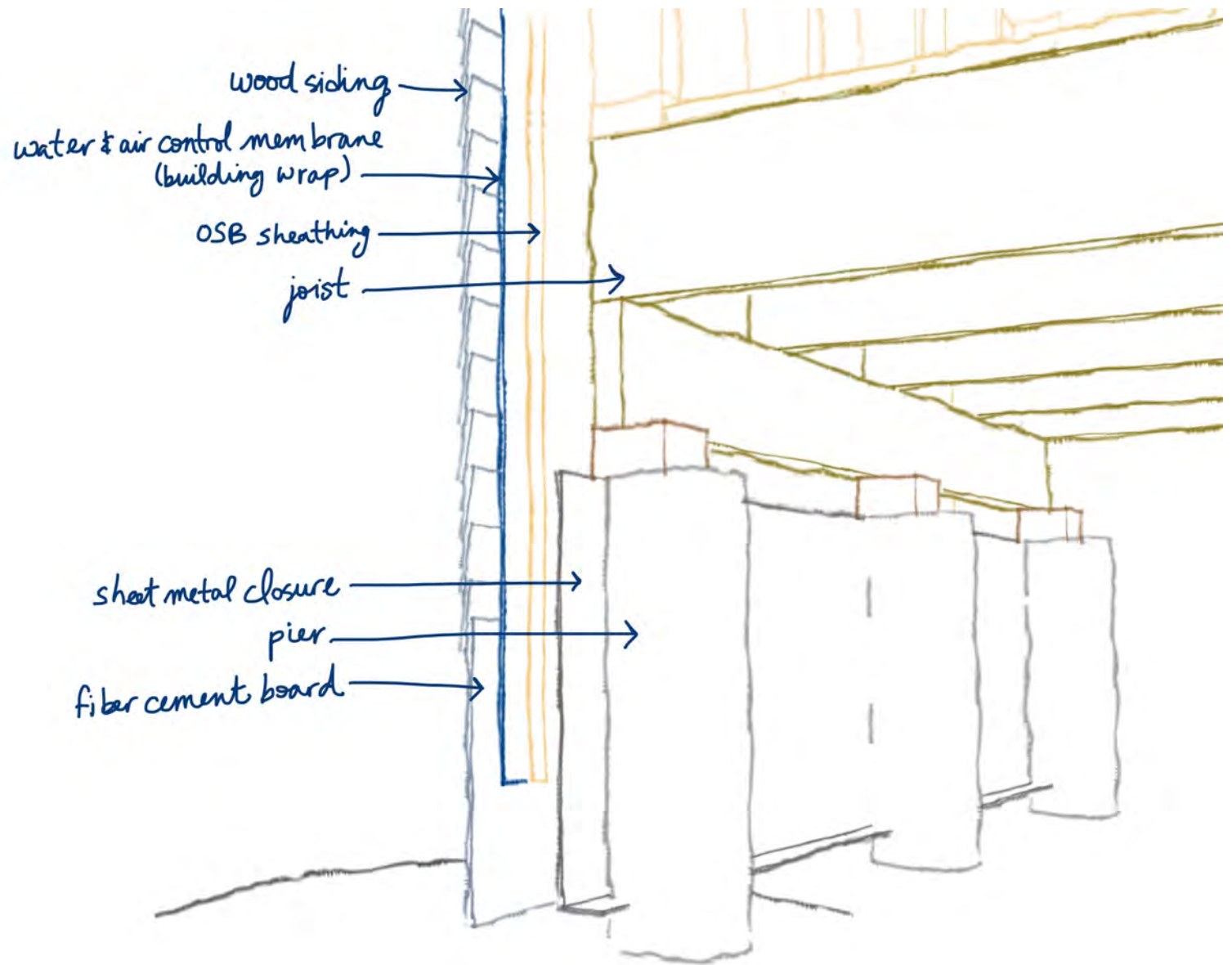




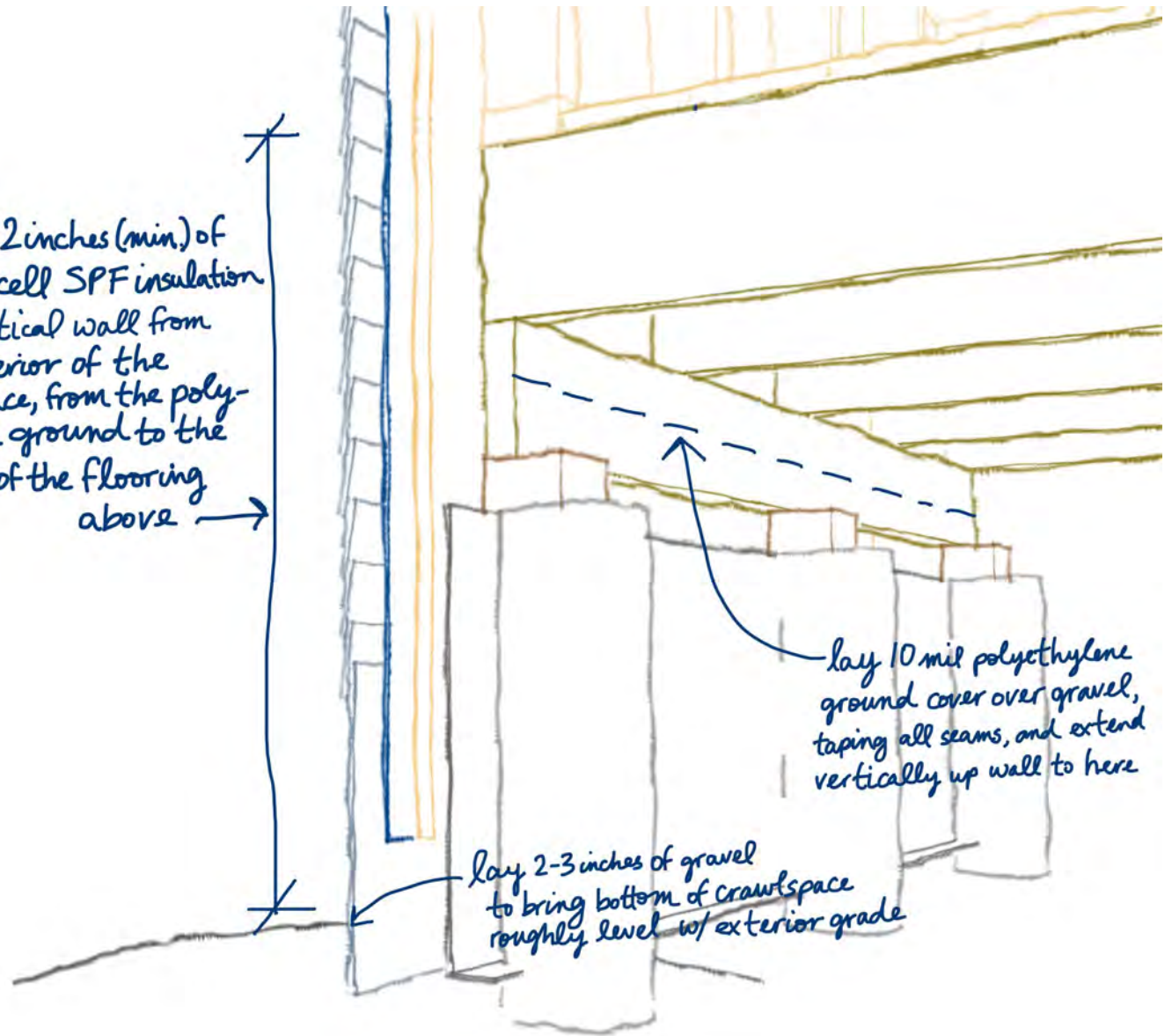






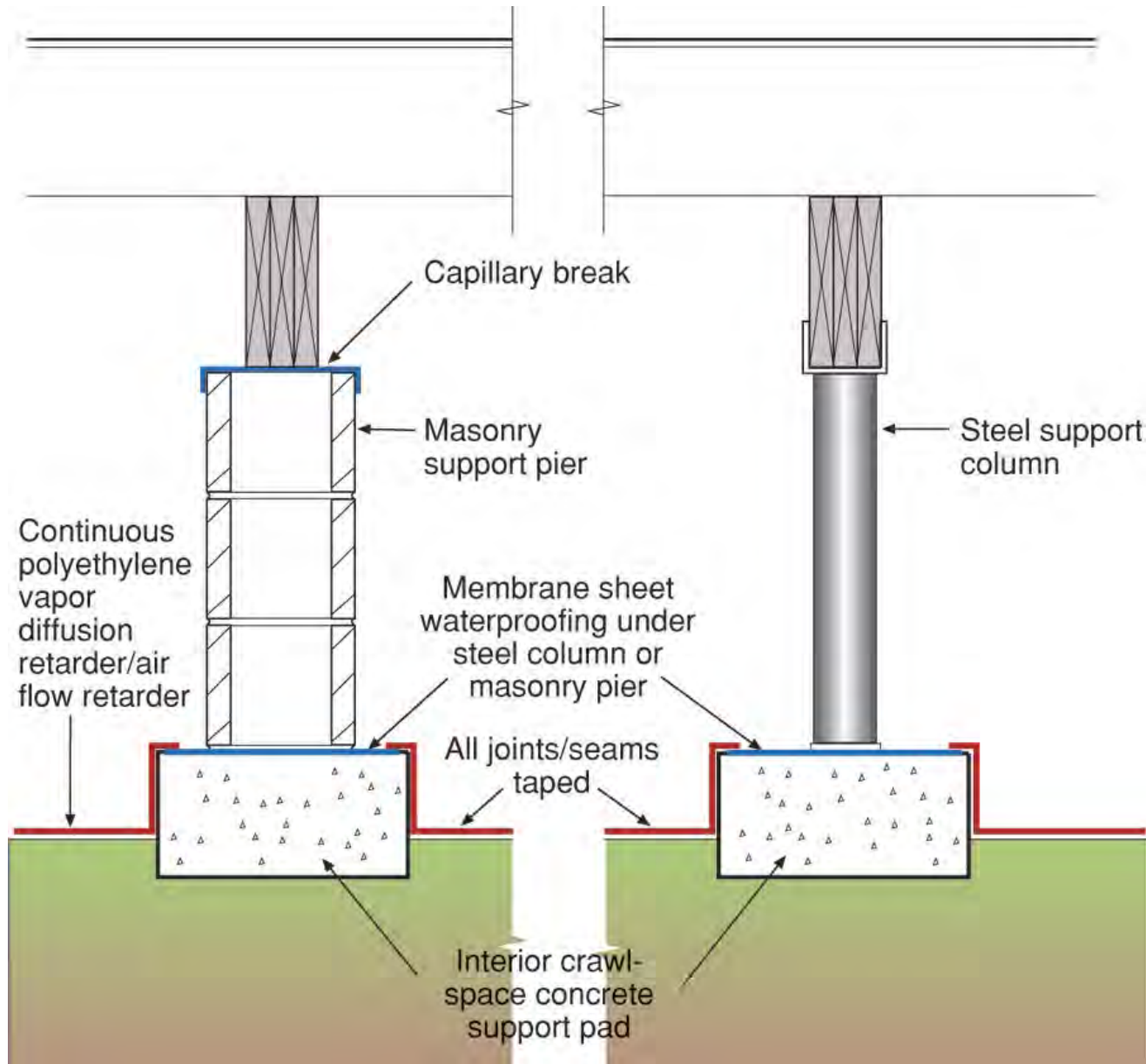


Apply 2 inches (min.) of closed cell SPF insulation over vertical wall from the interior of the crawlspace, from the poly-covered ground to the bottom of the flooring above →



lay 10 mil polyethylene ground cover over gravel, taping all seams, and extend vertically up wall to here

lay 2-3 inches of gravel to bring bottom of crawlspace roughly level w/ exterior grade



Conditioned Crawlspace Not Unvented  
Crawlspace

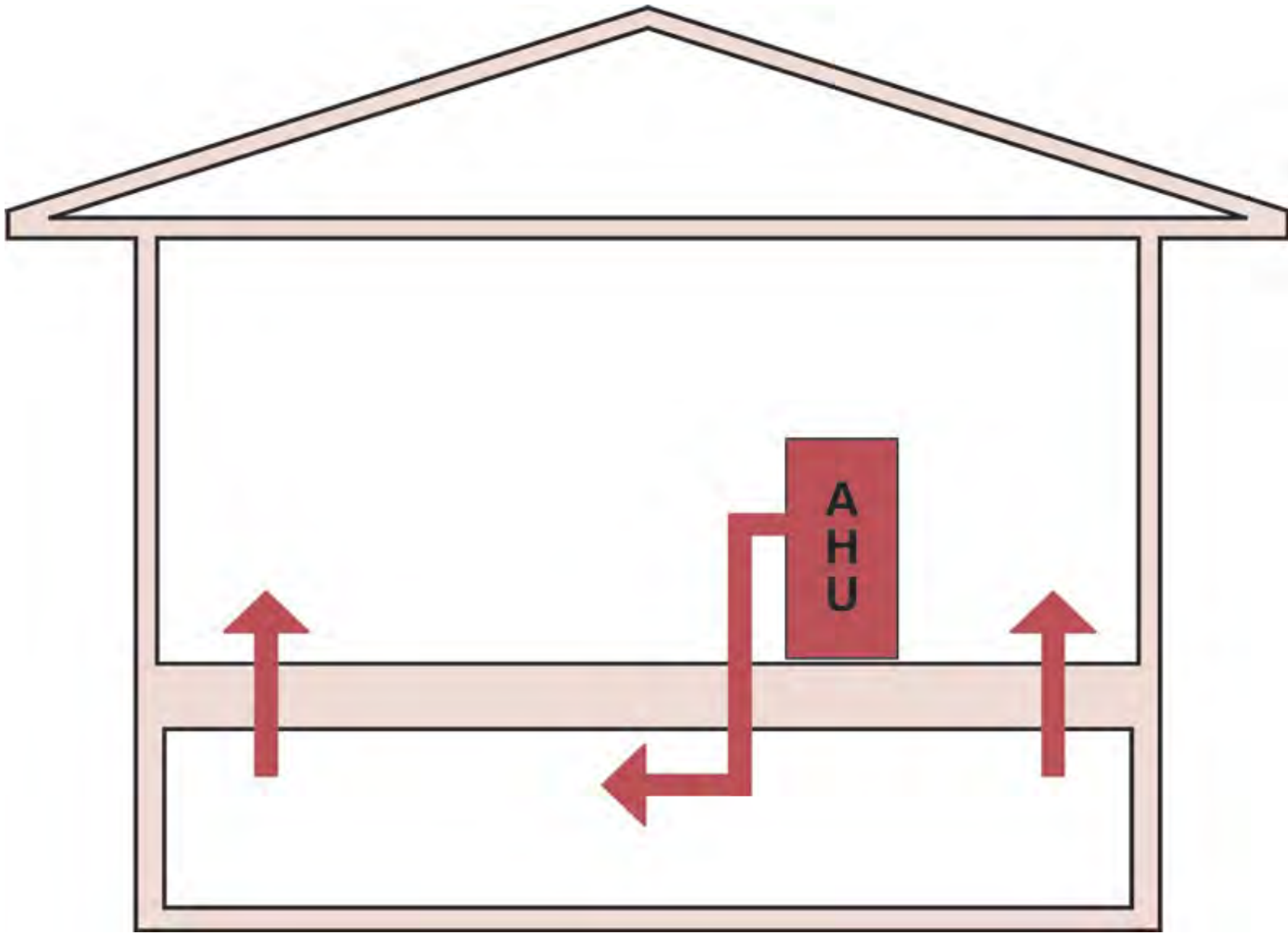
Need Supply Air

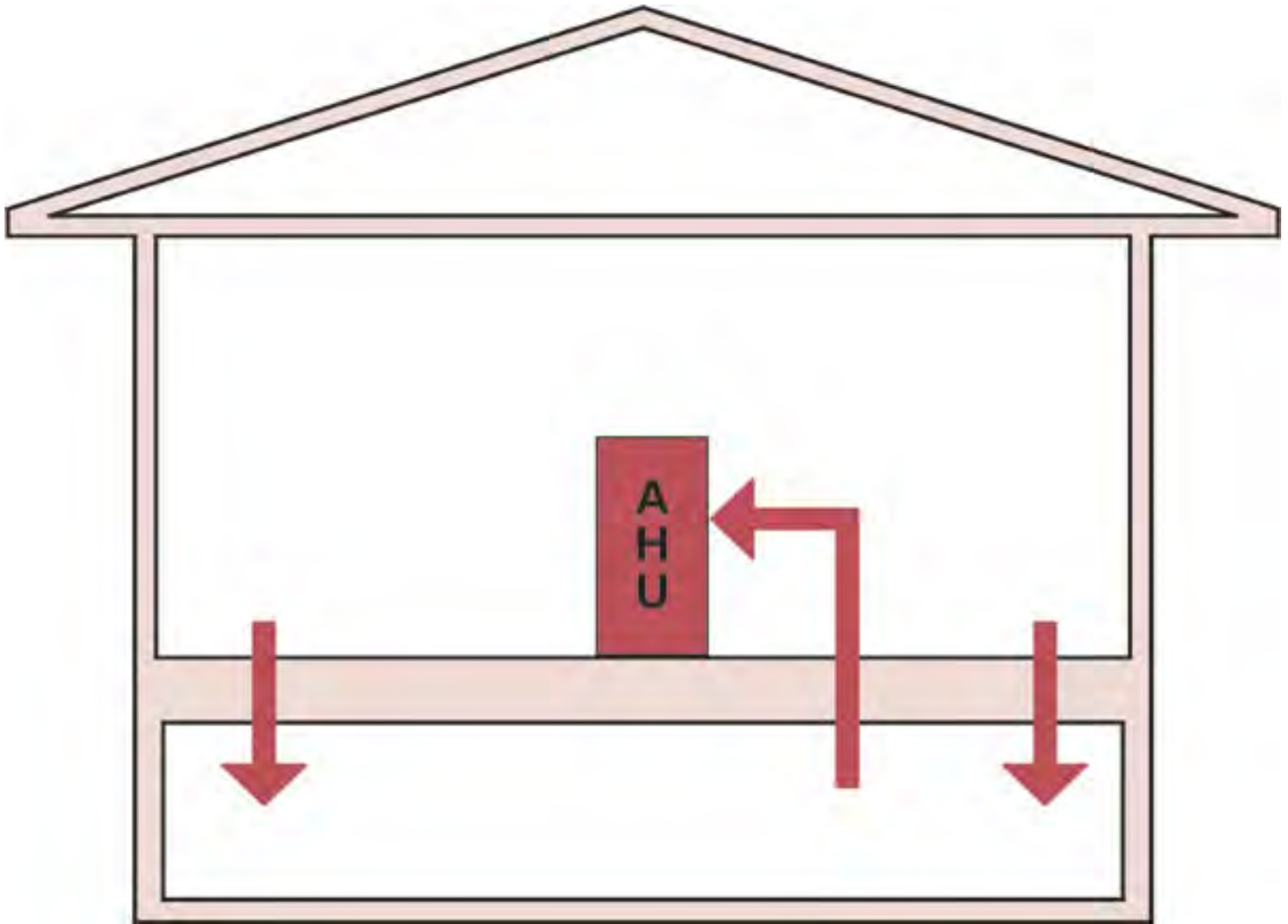
50 cfm/1000 ft<sup>2</sup> of Crawlspace Area

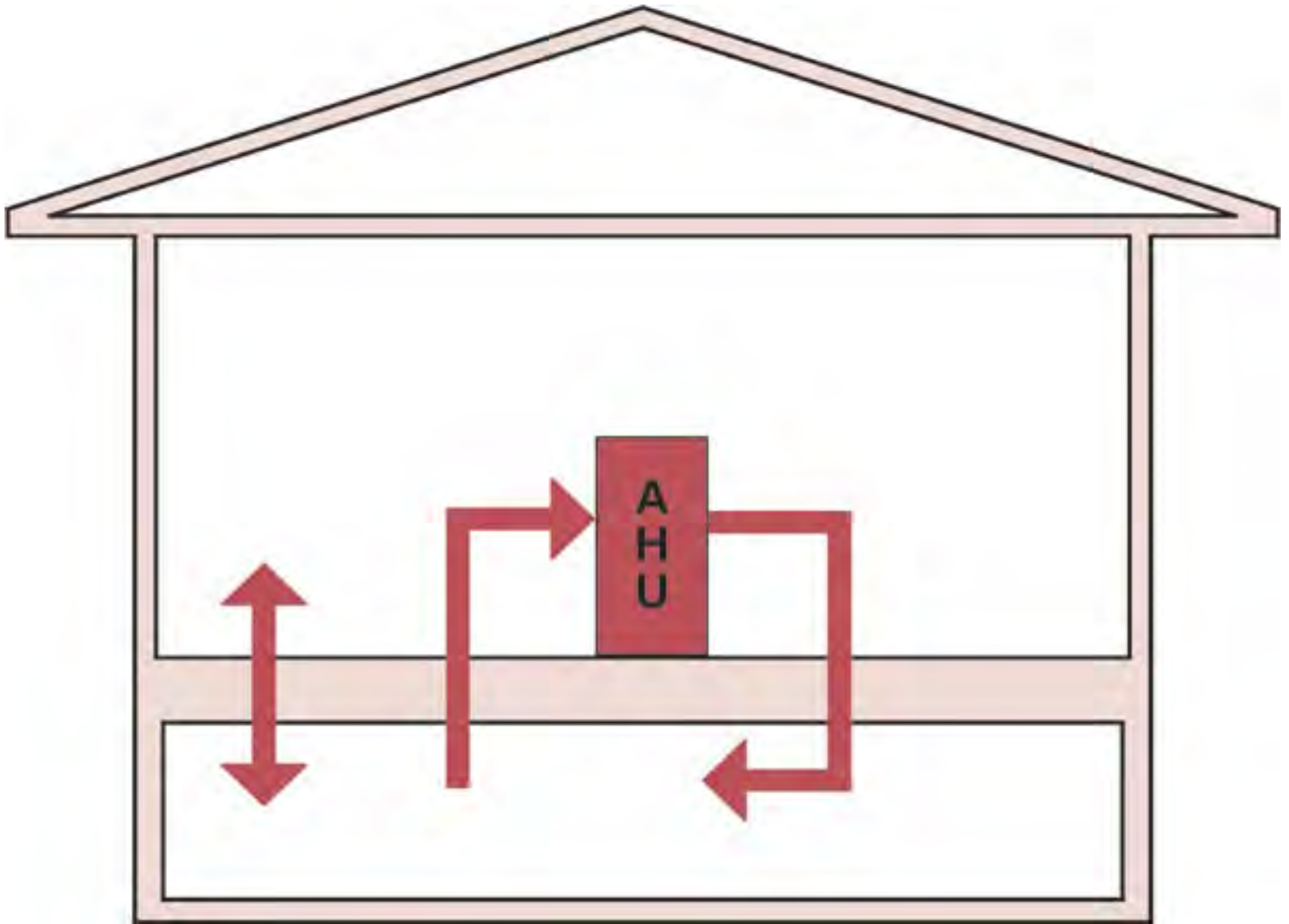
Or

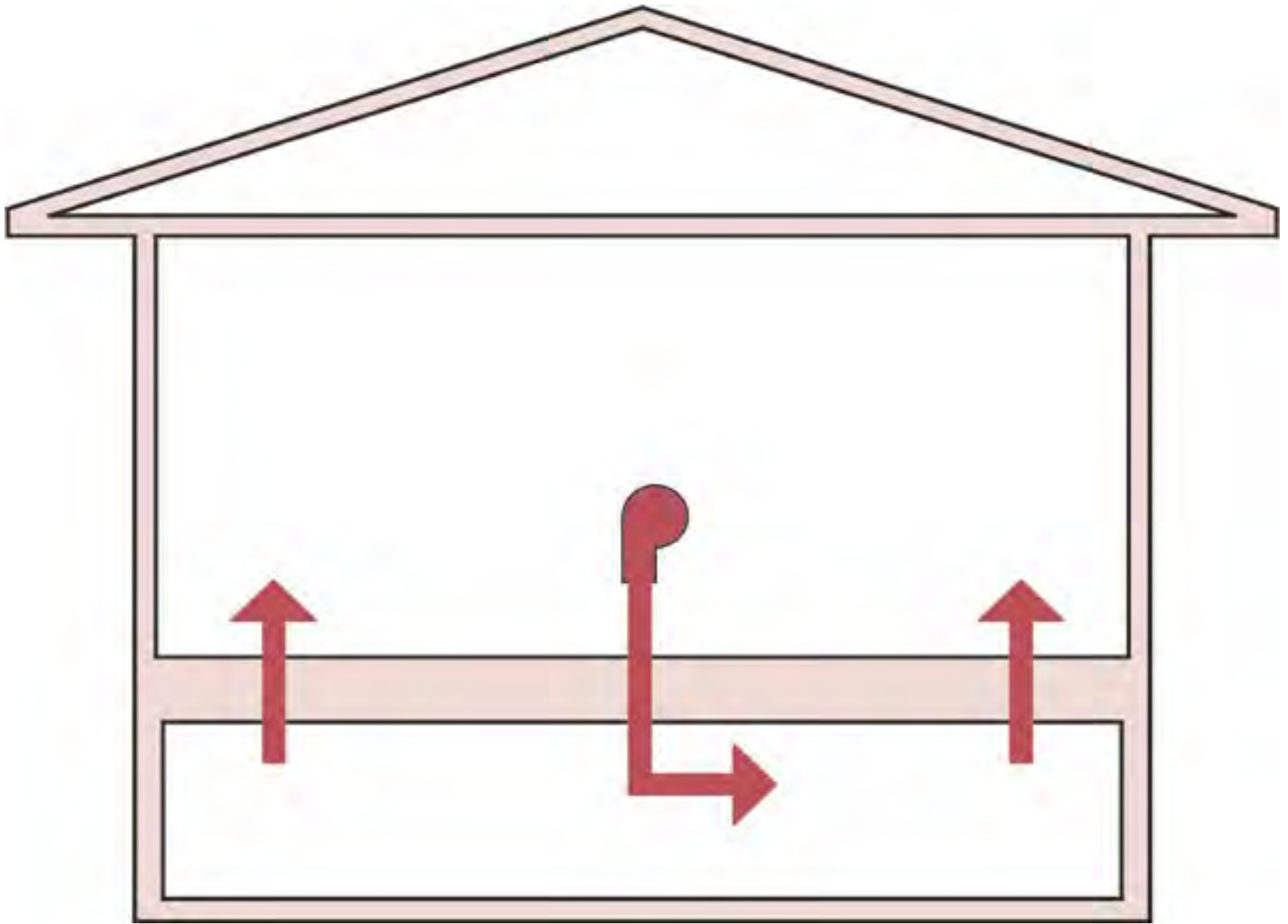
Dehumidification

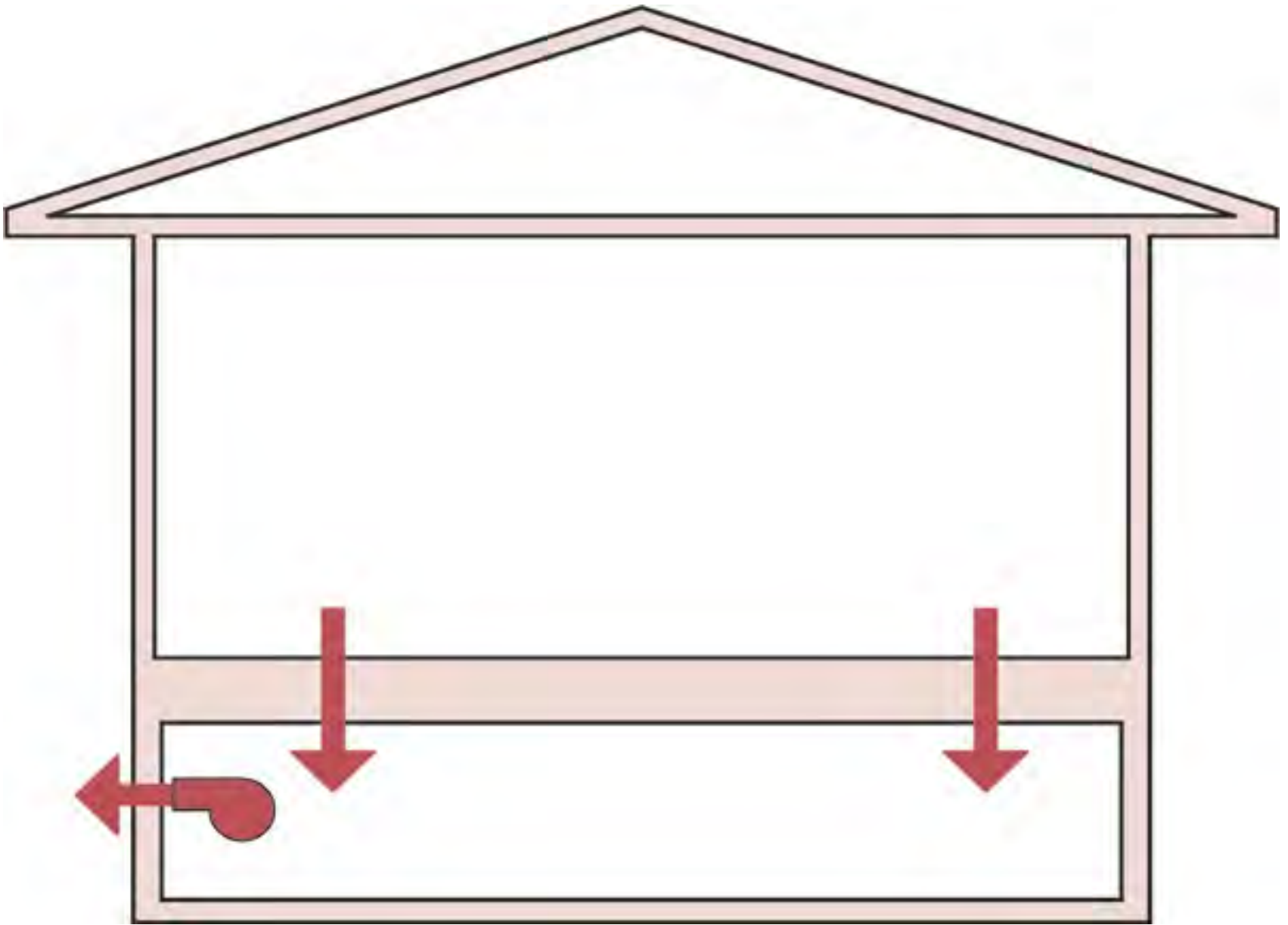


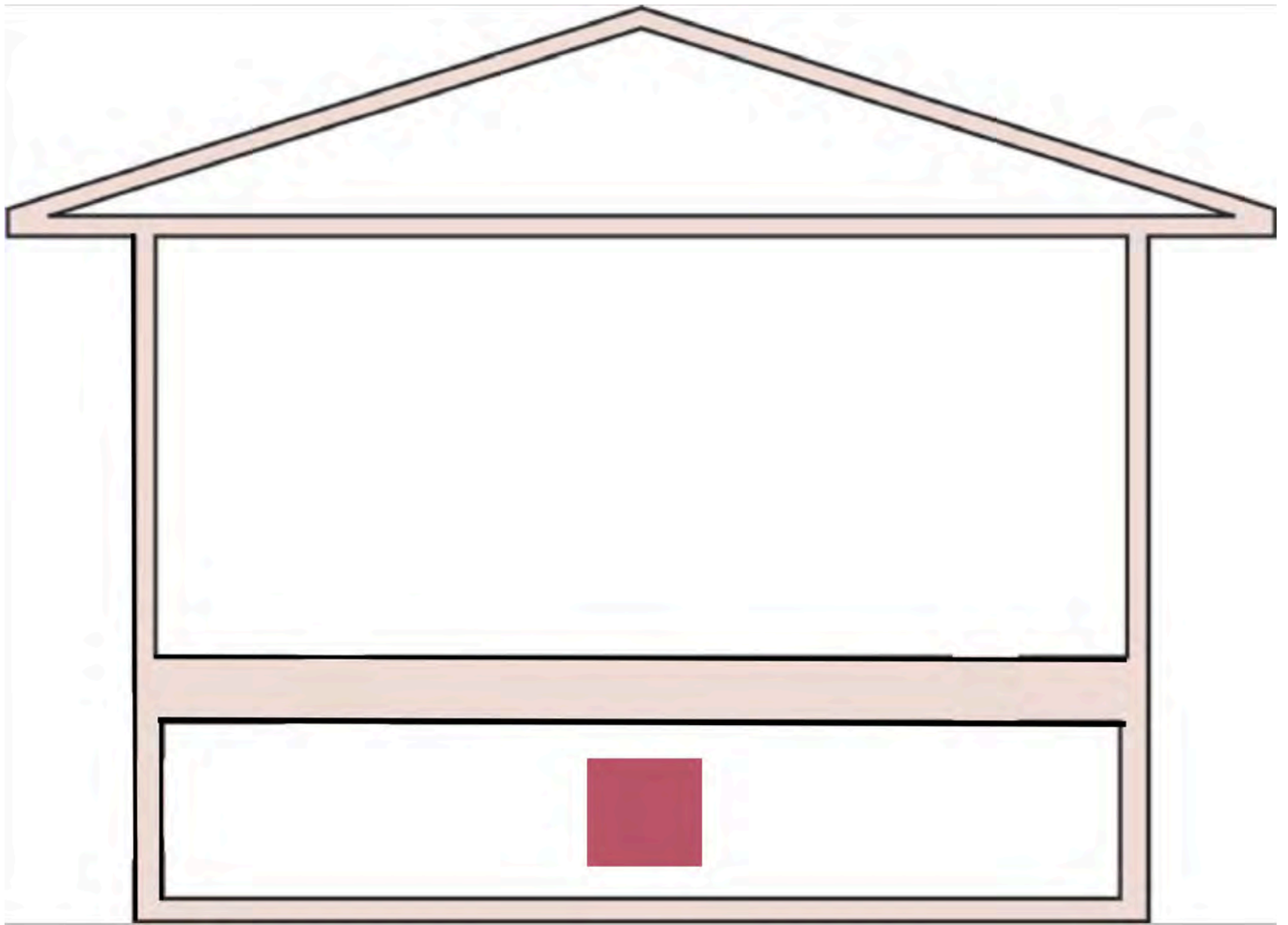


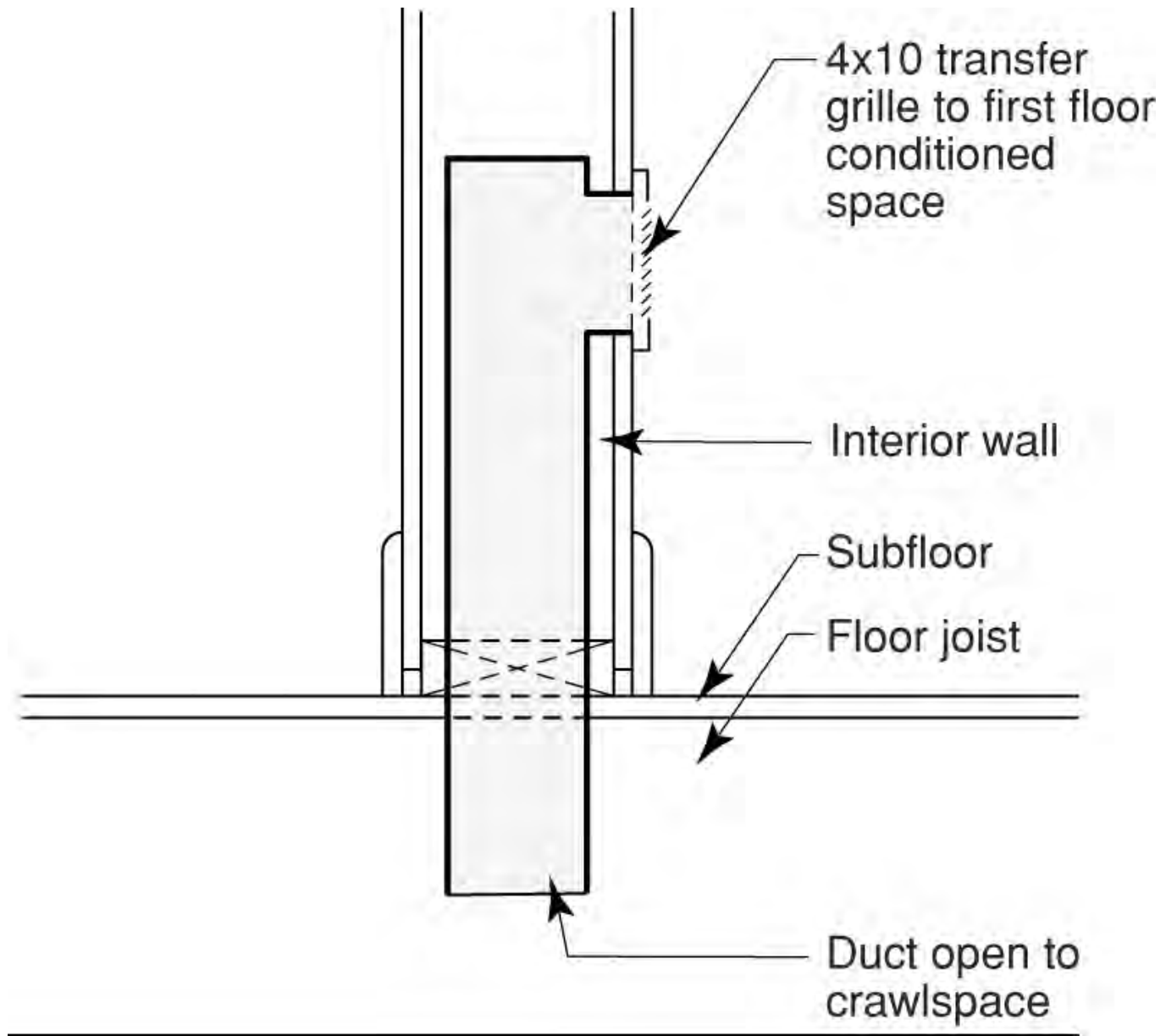


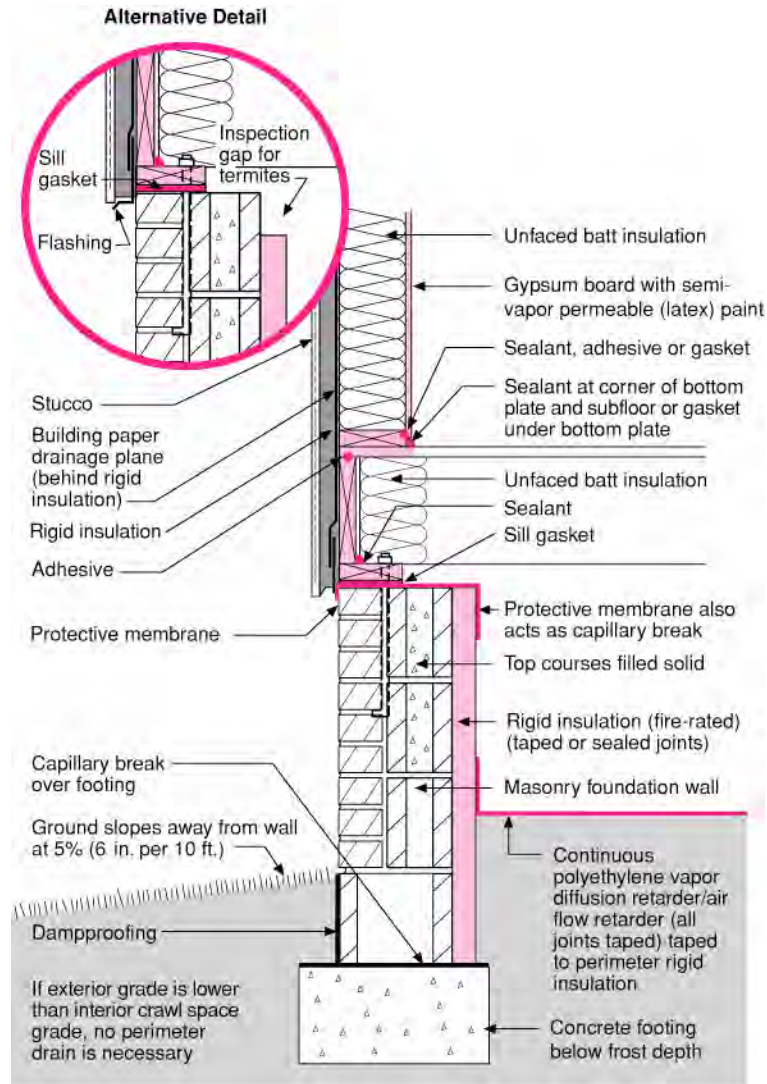




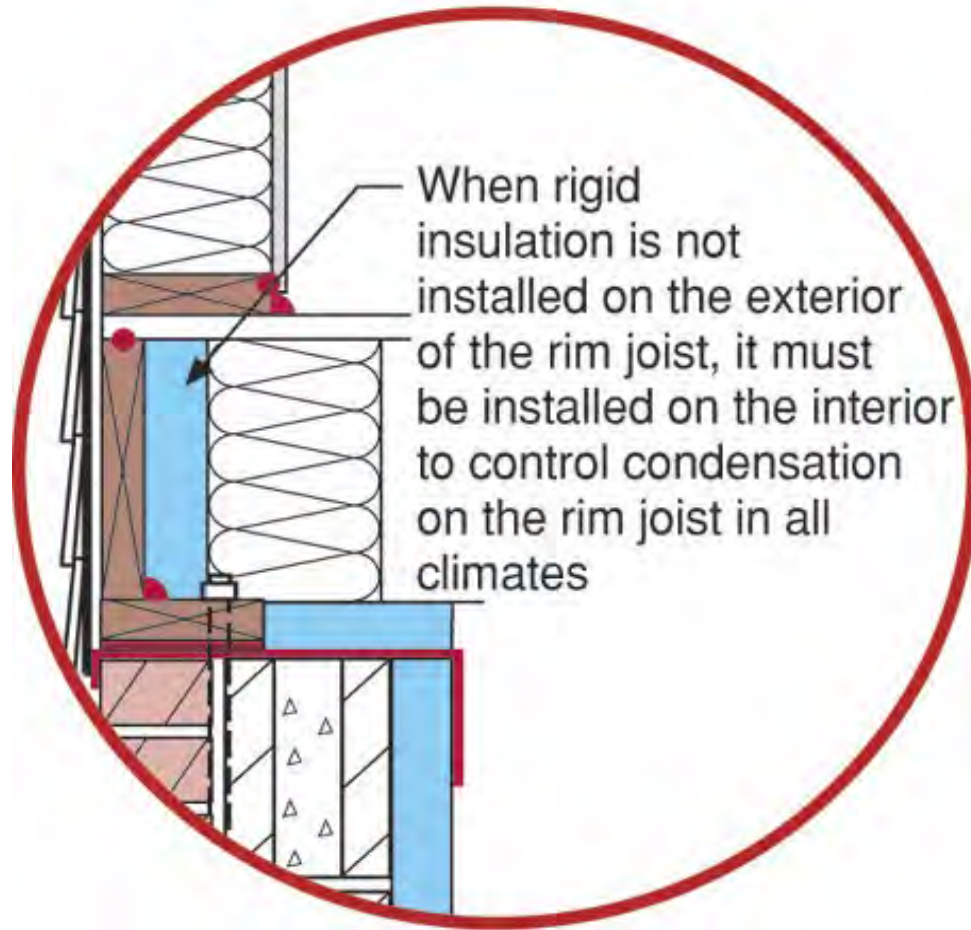




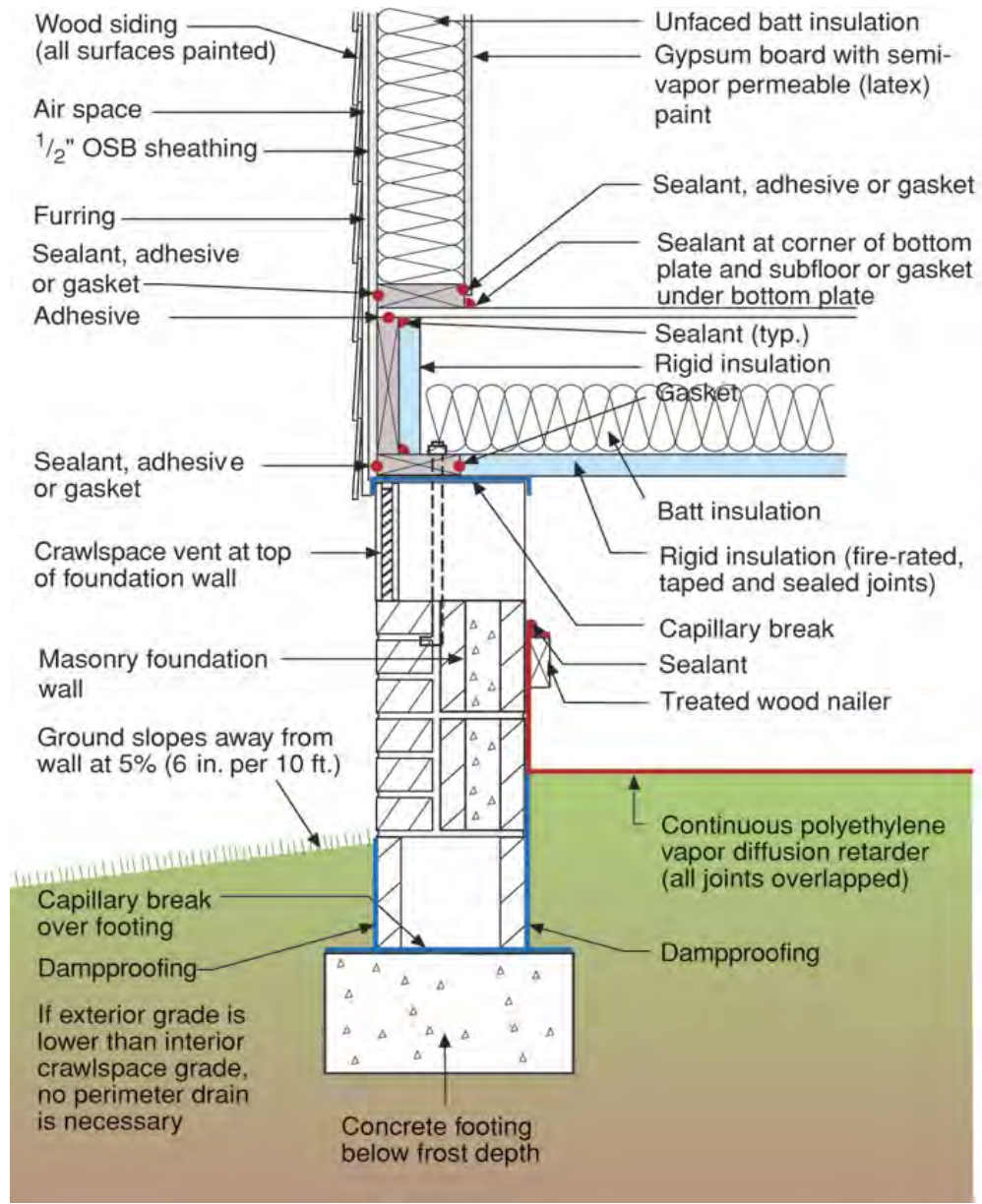








# Smart Thing

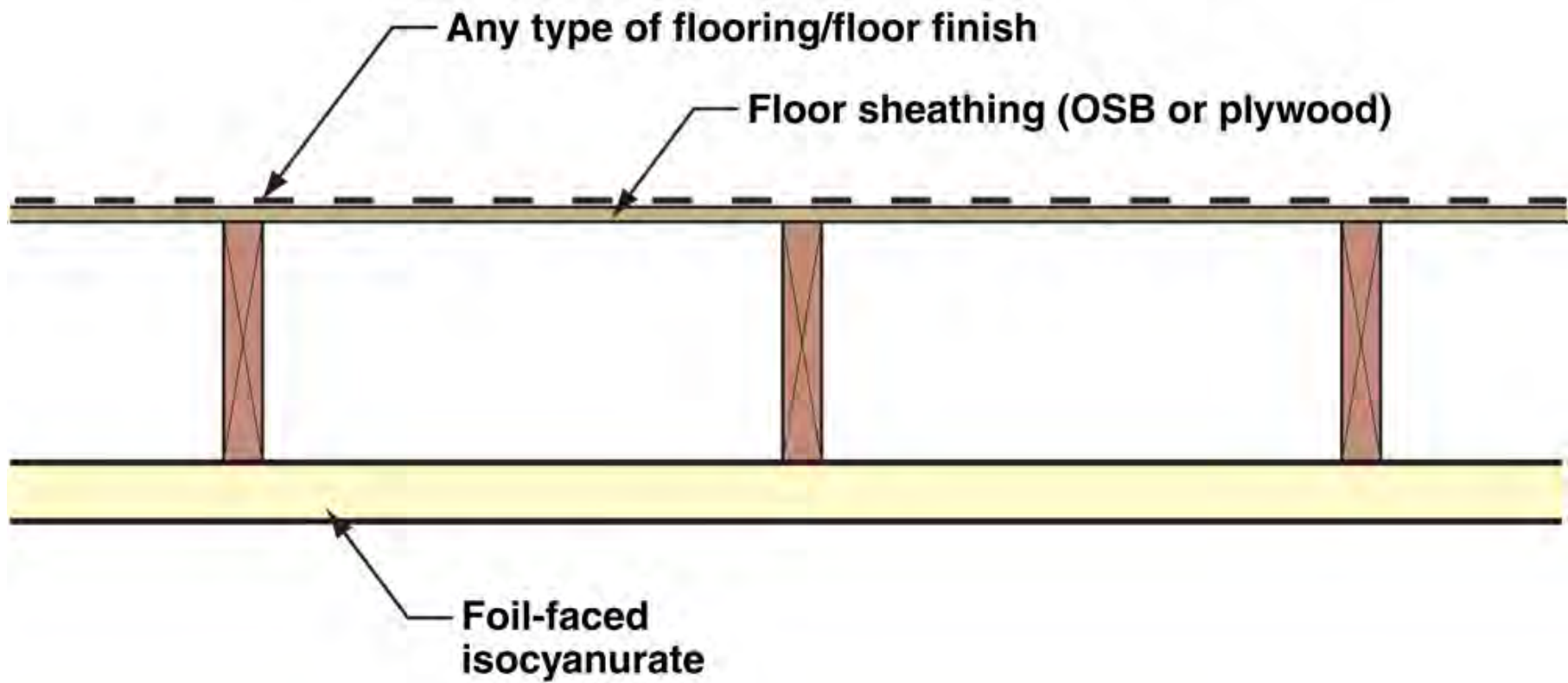




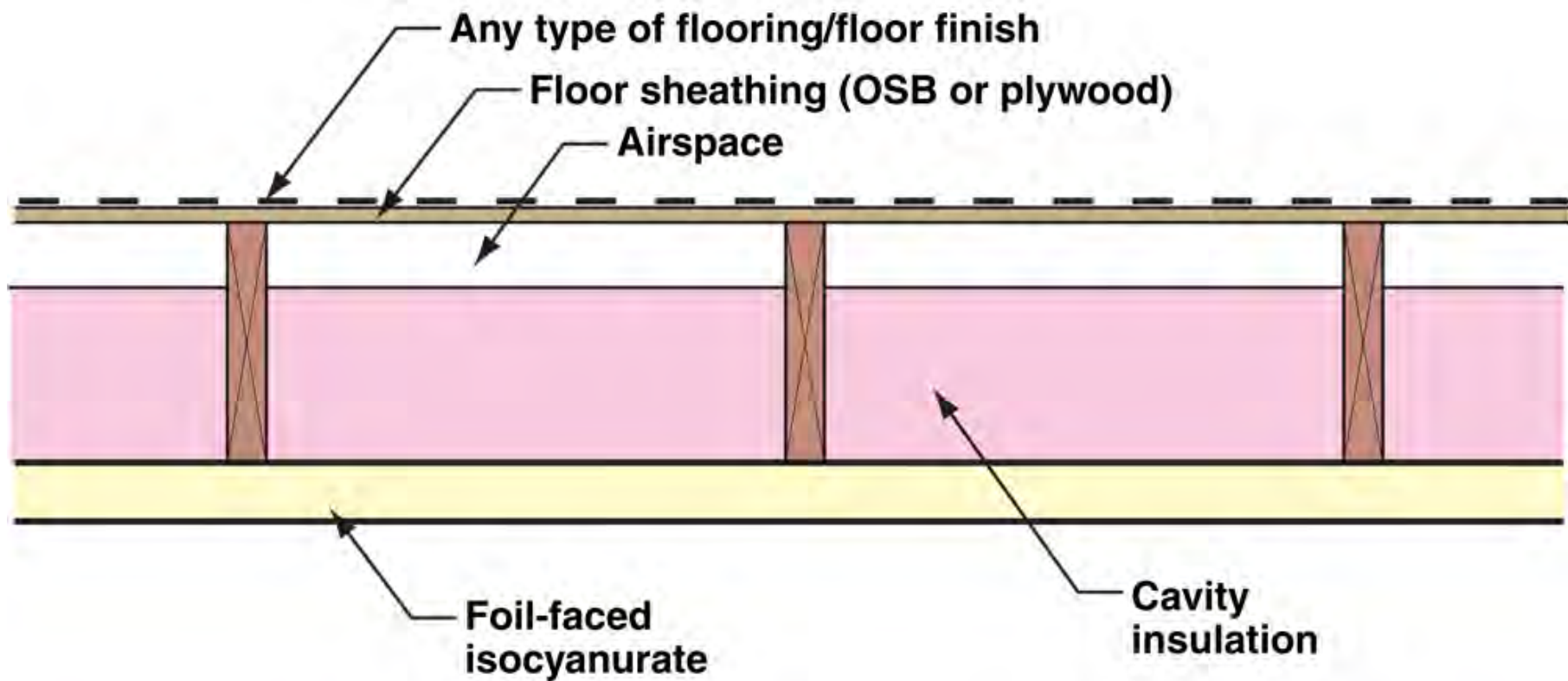


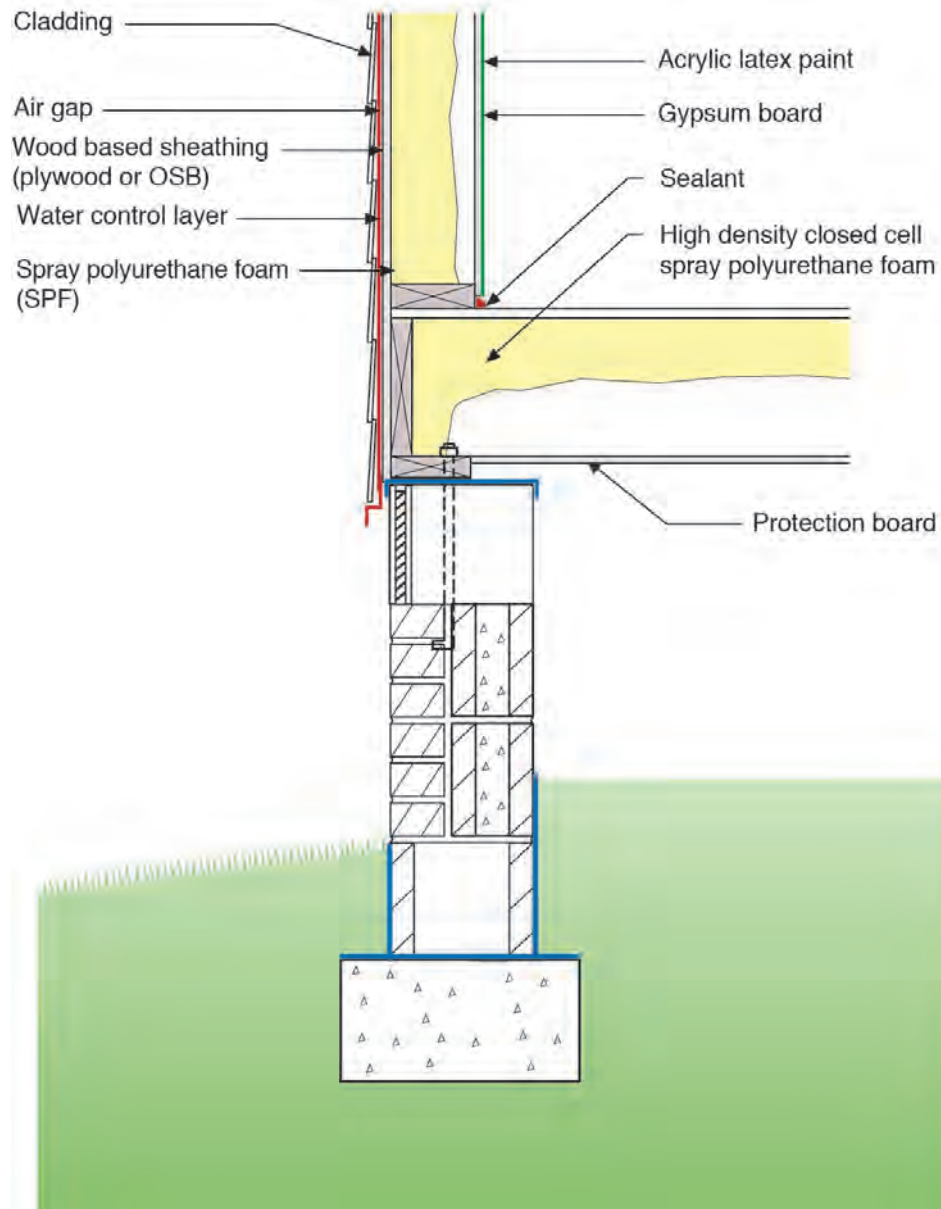


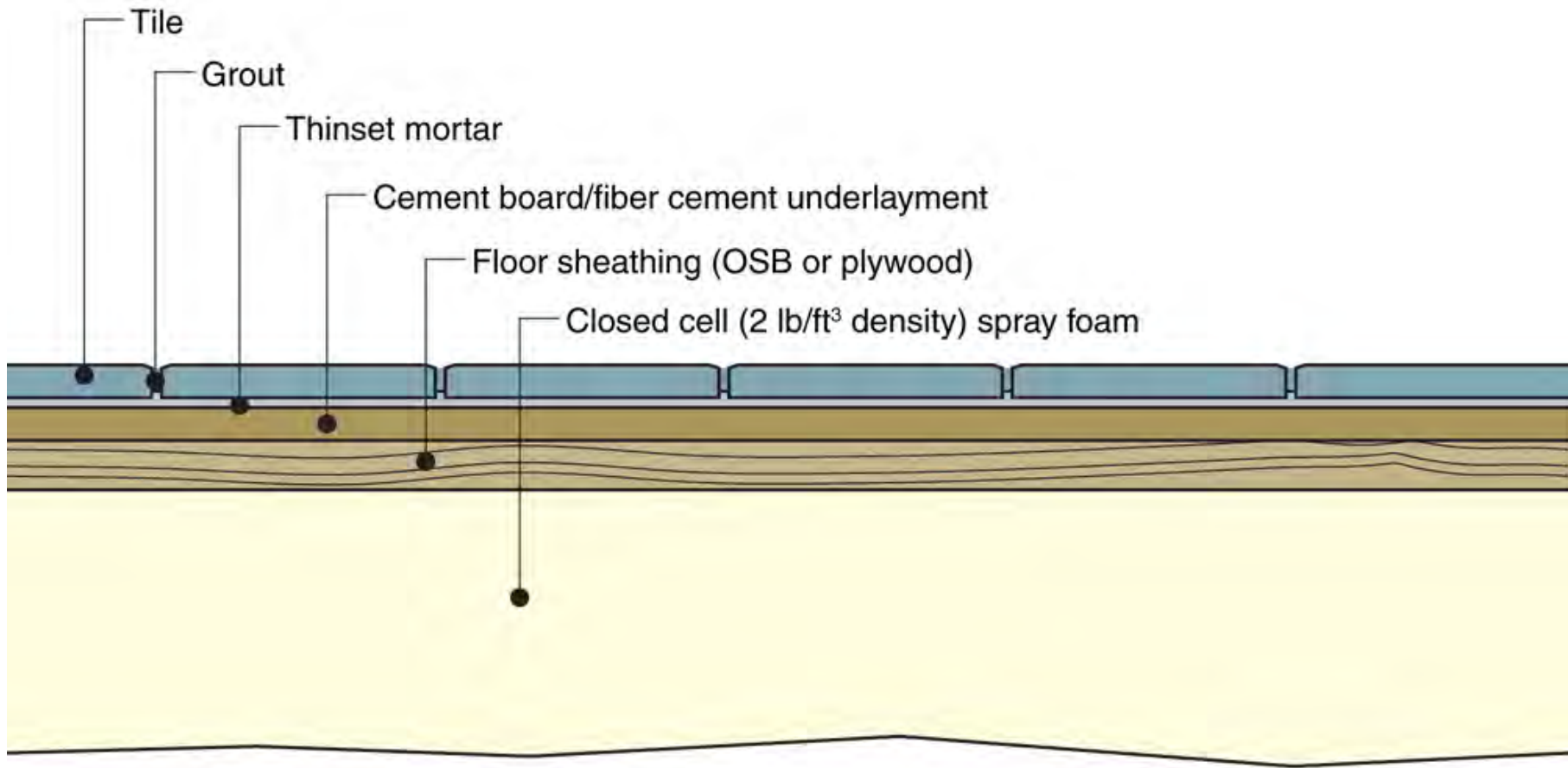


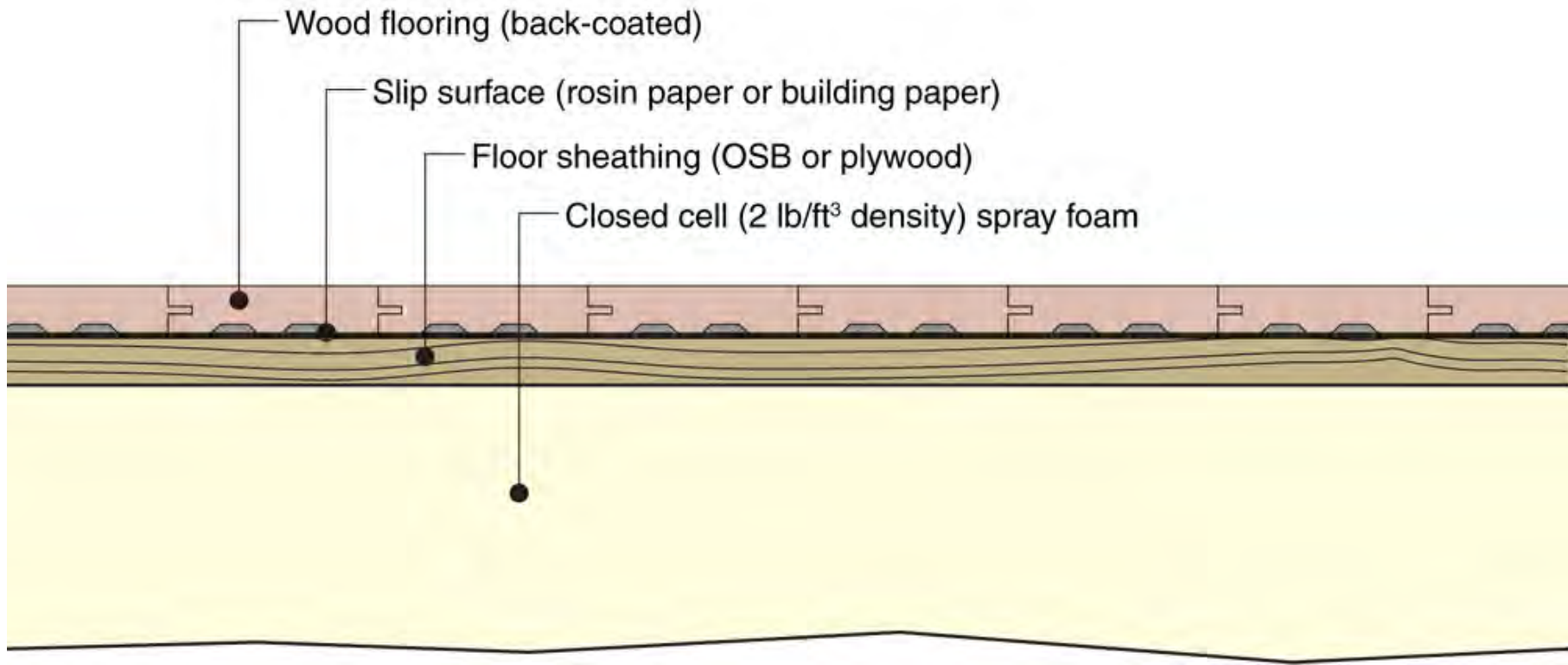


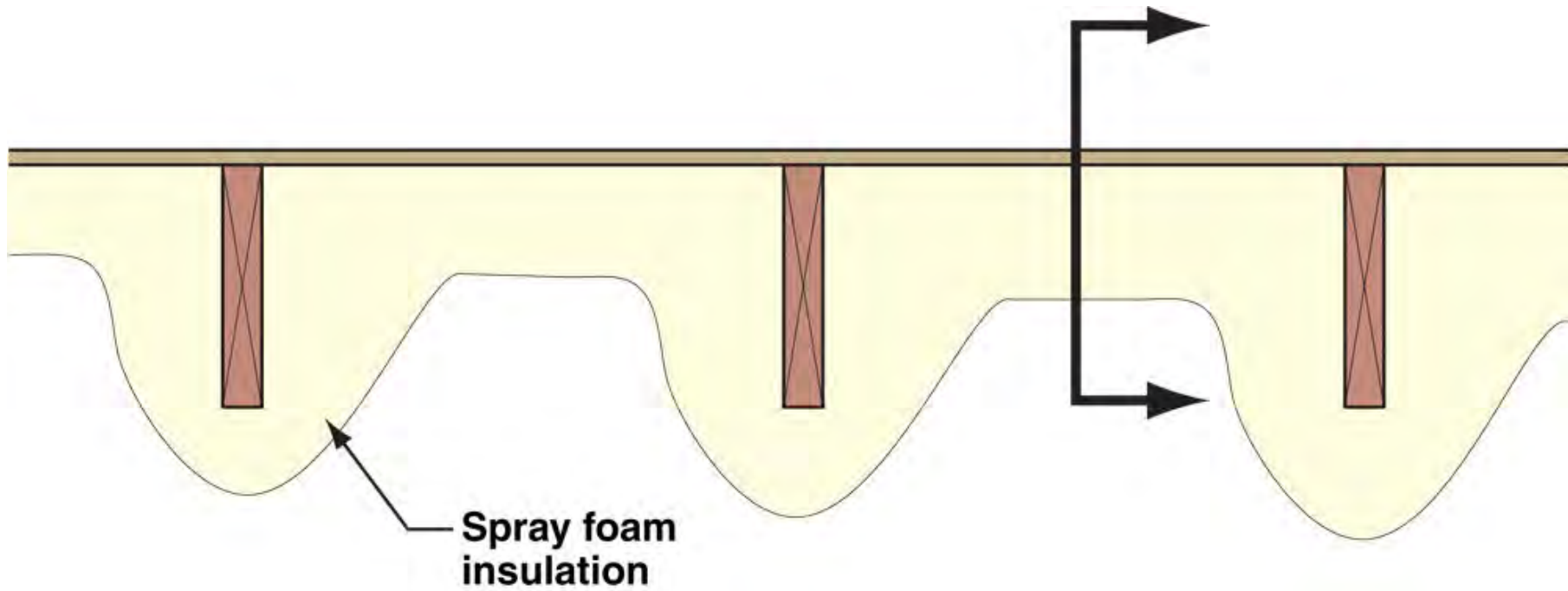




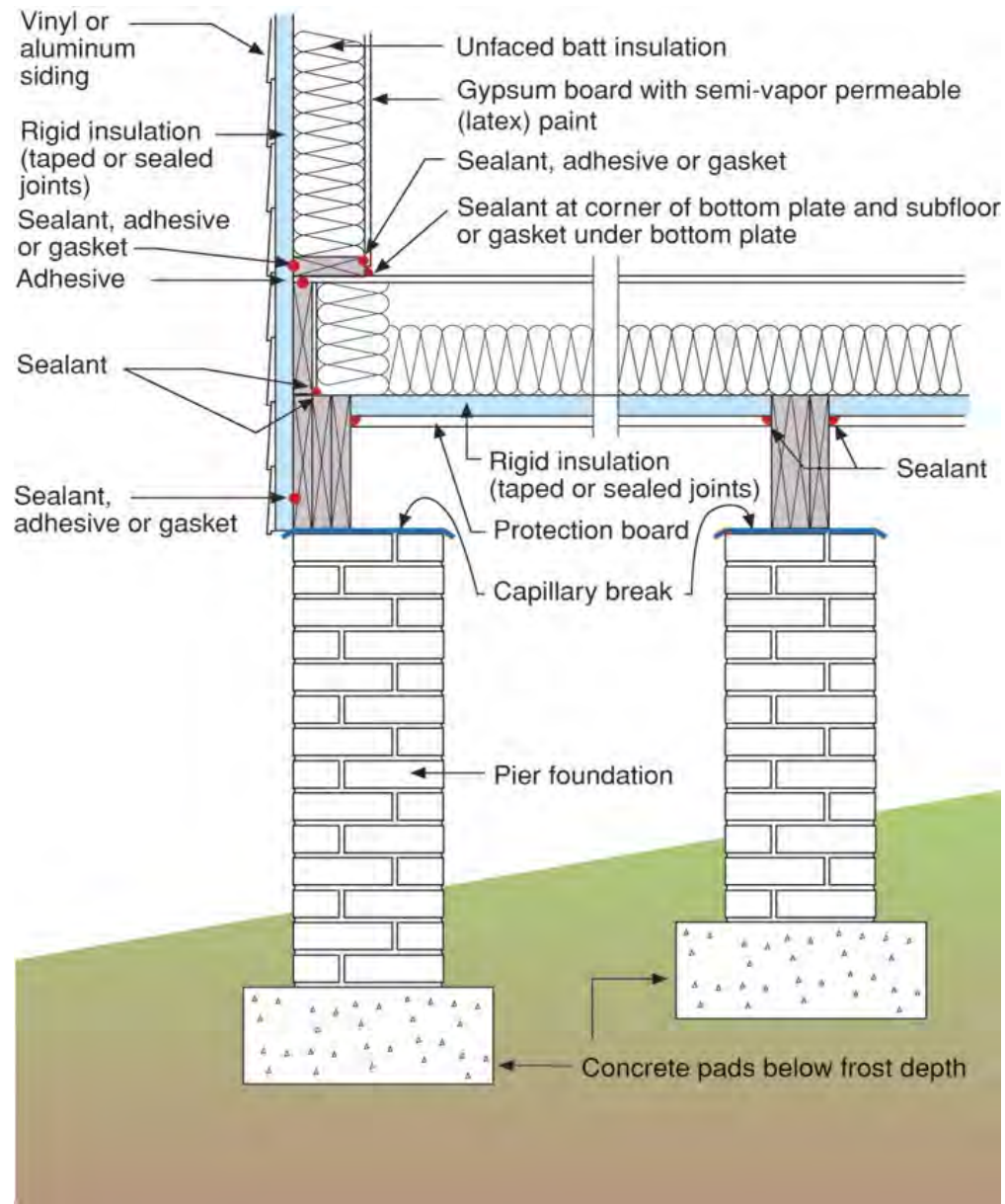








# Pier Foundations











# Slab Foundations

# Slab Foundations

Same approaches as basement slabs

# Windows

Windows

Innies

Outies





































# Walls



















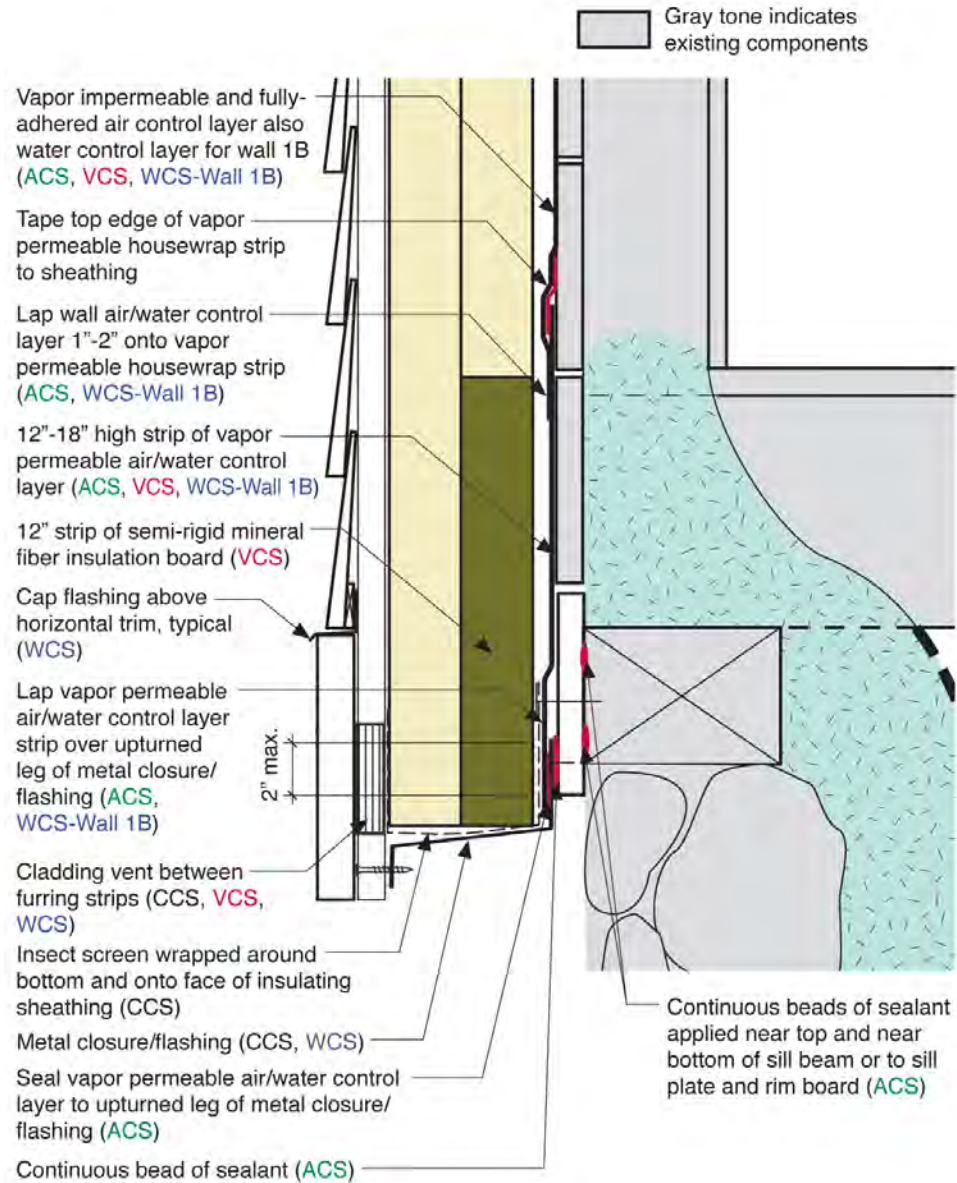




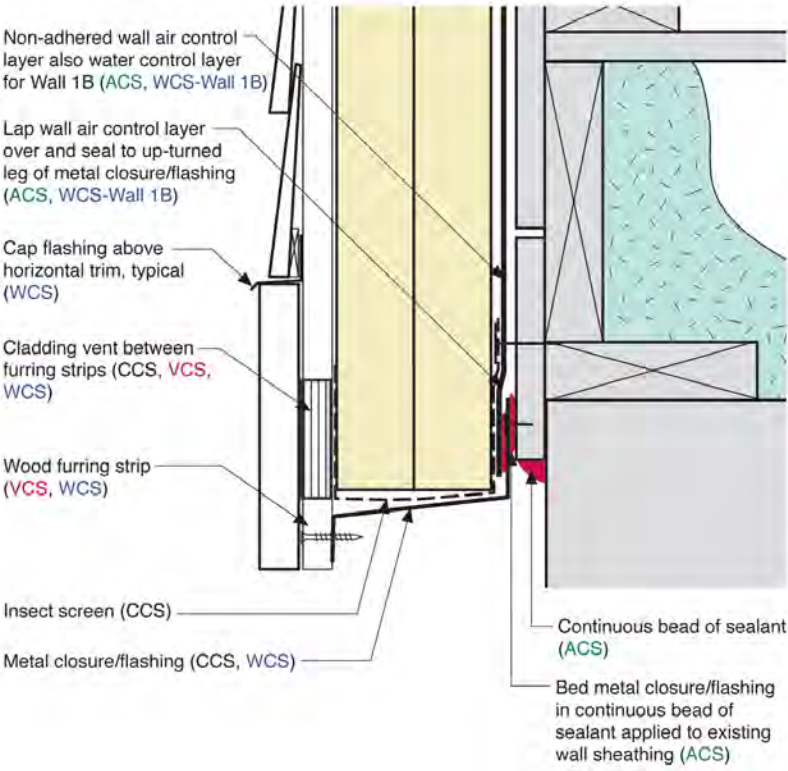


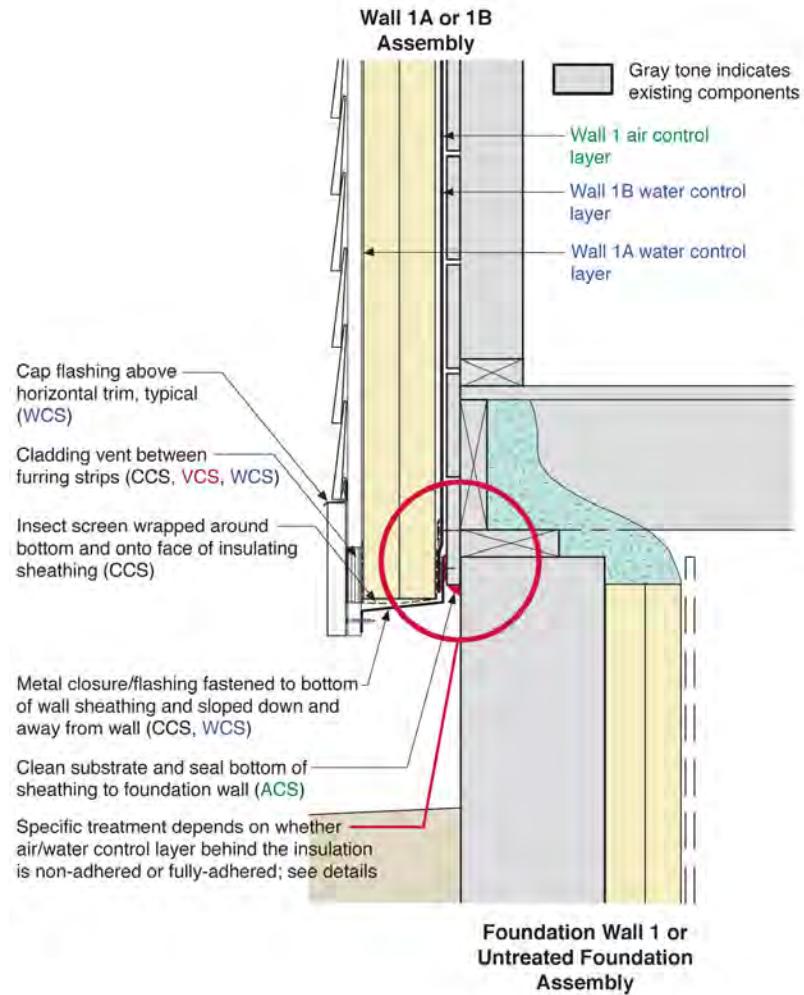






Gray tone indicates existing components







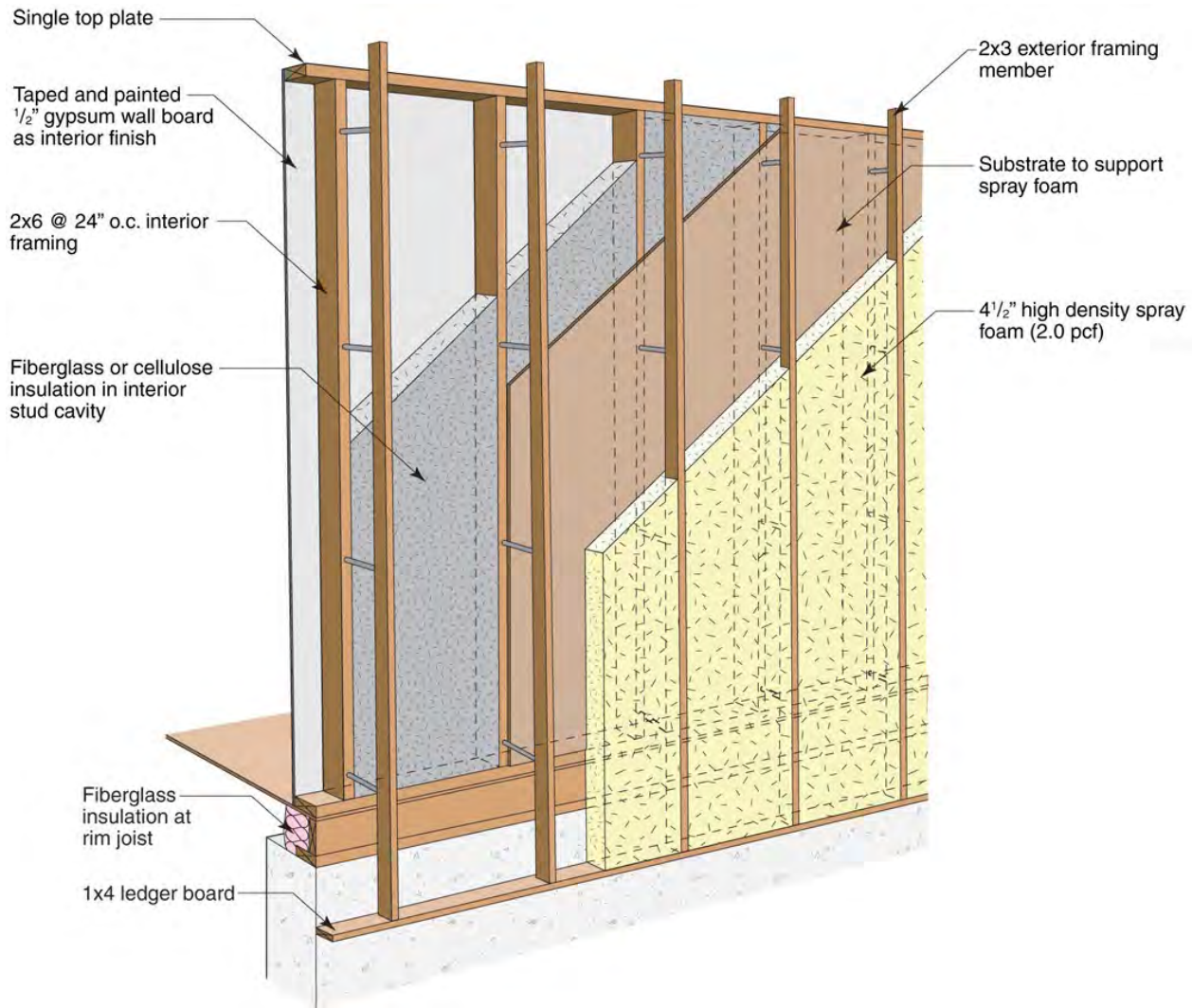






















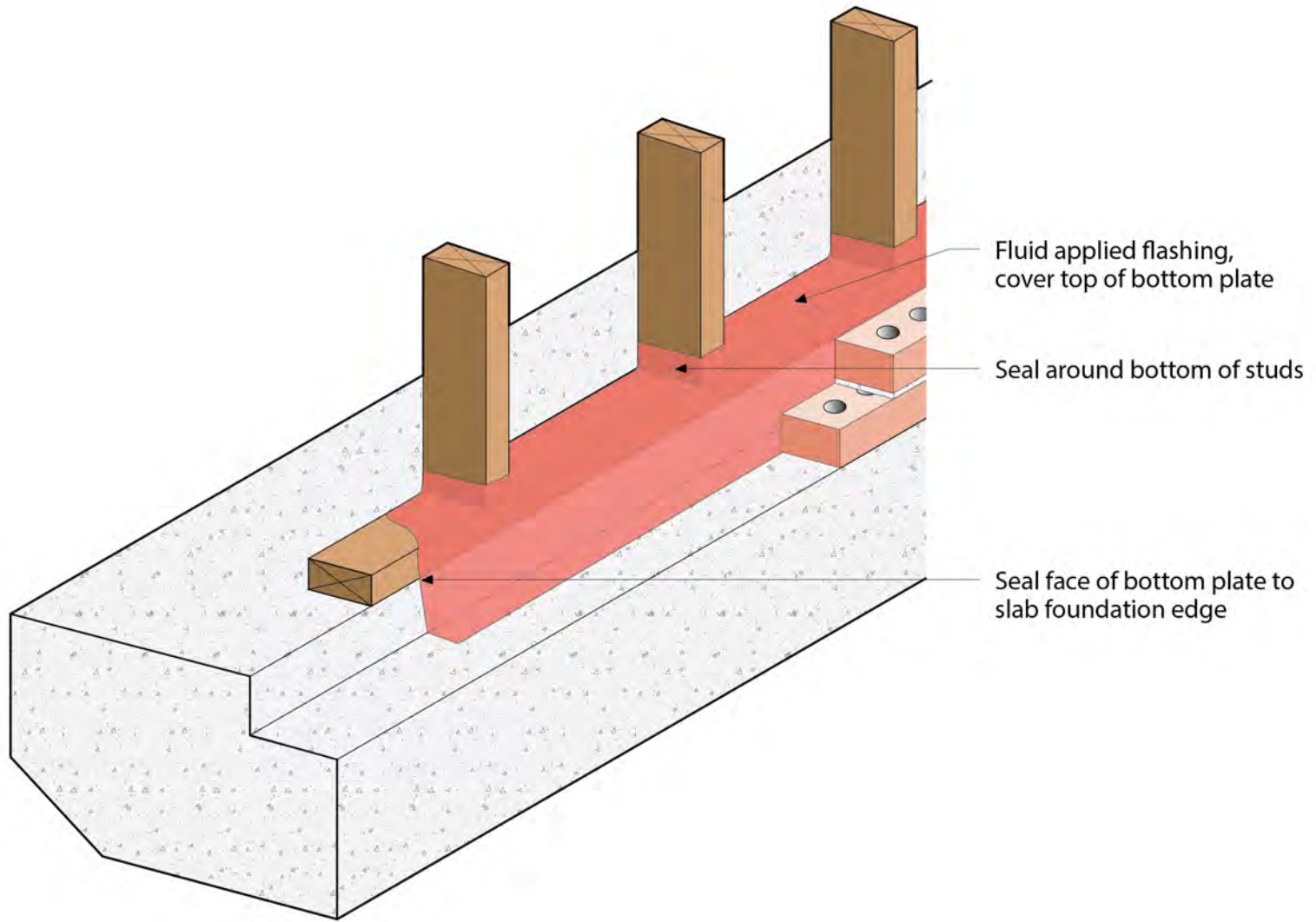


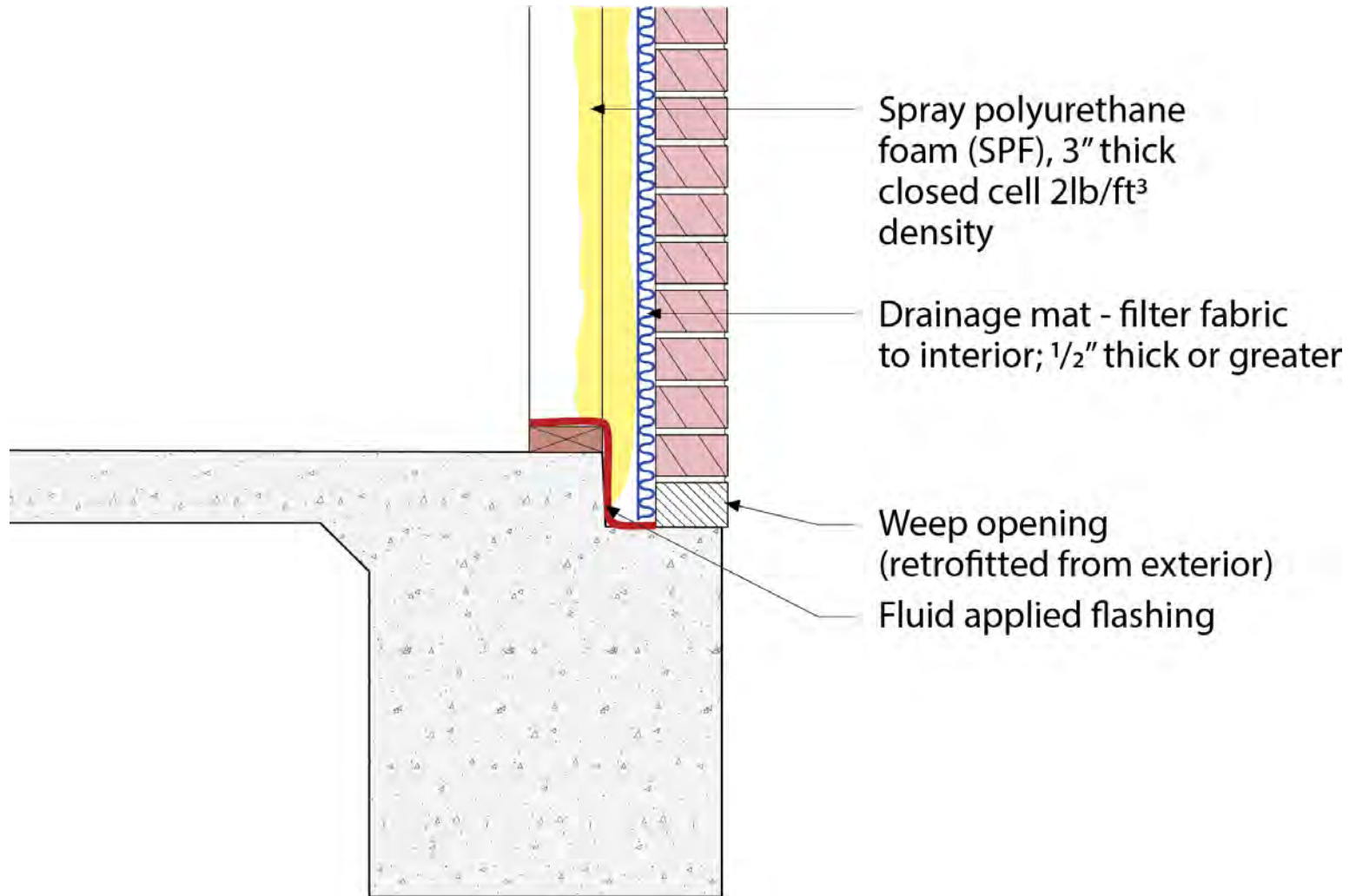


Houston, we have a problem....









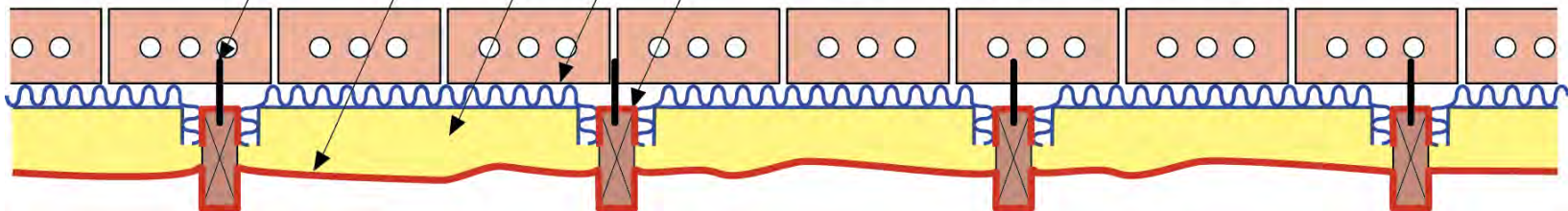
Existing brick ties

Acrylic latex paint over all surfaces prior to installation of interior gypsum board

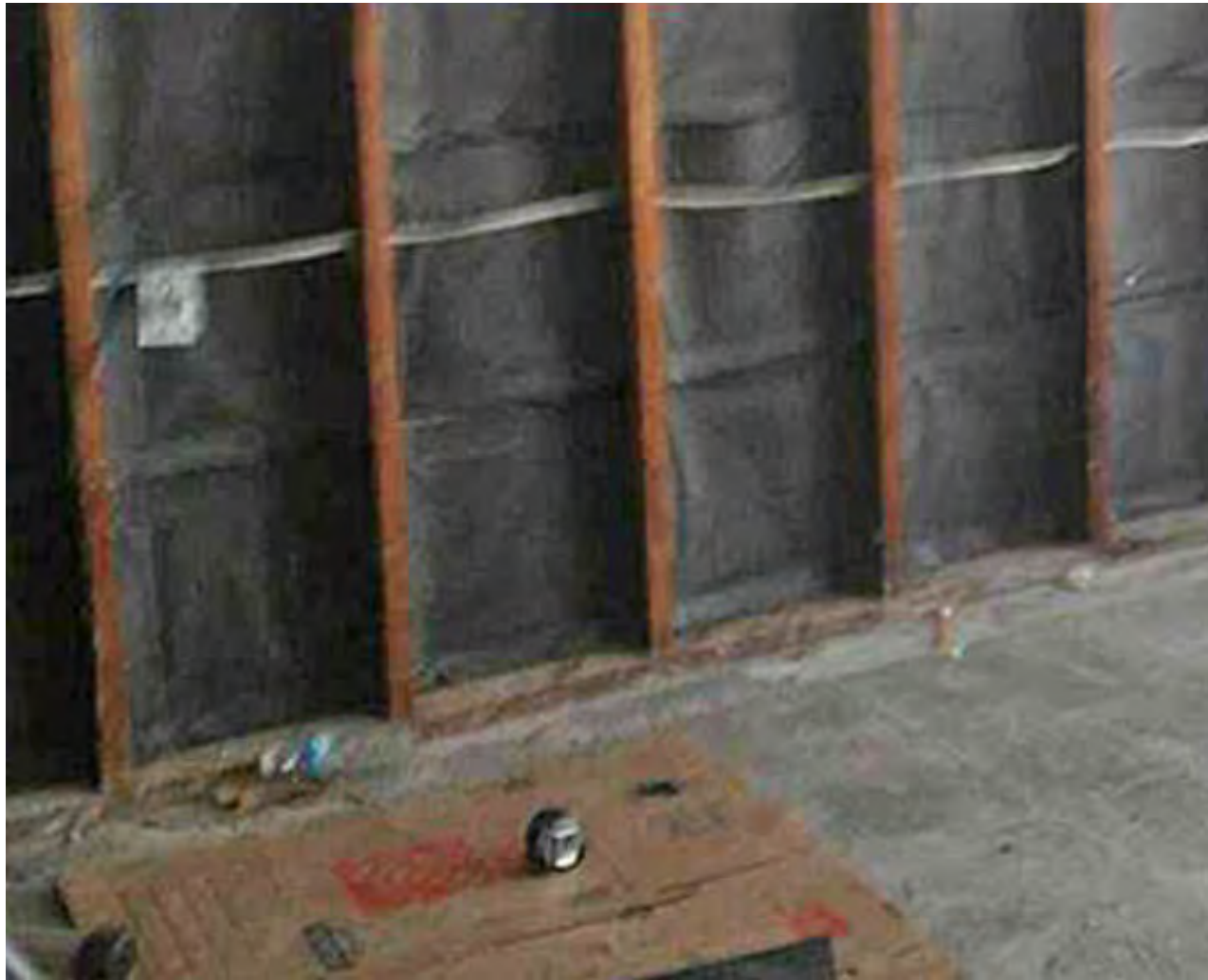
Spray polyurethane foam (SPF), 3" thick closed cell 2lb/ft<sup>3</sup> density

Drainage mat - filter fabric to interior; 1/2" thick or greater

Fluid applied flashing

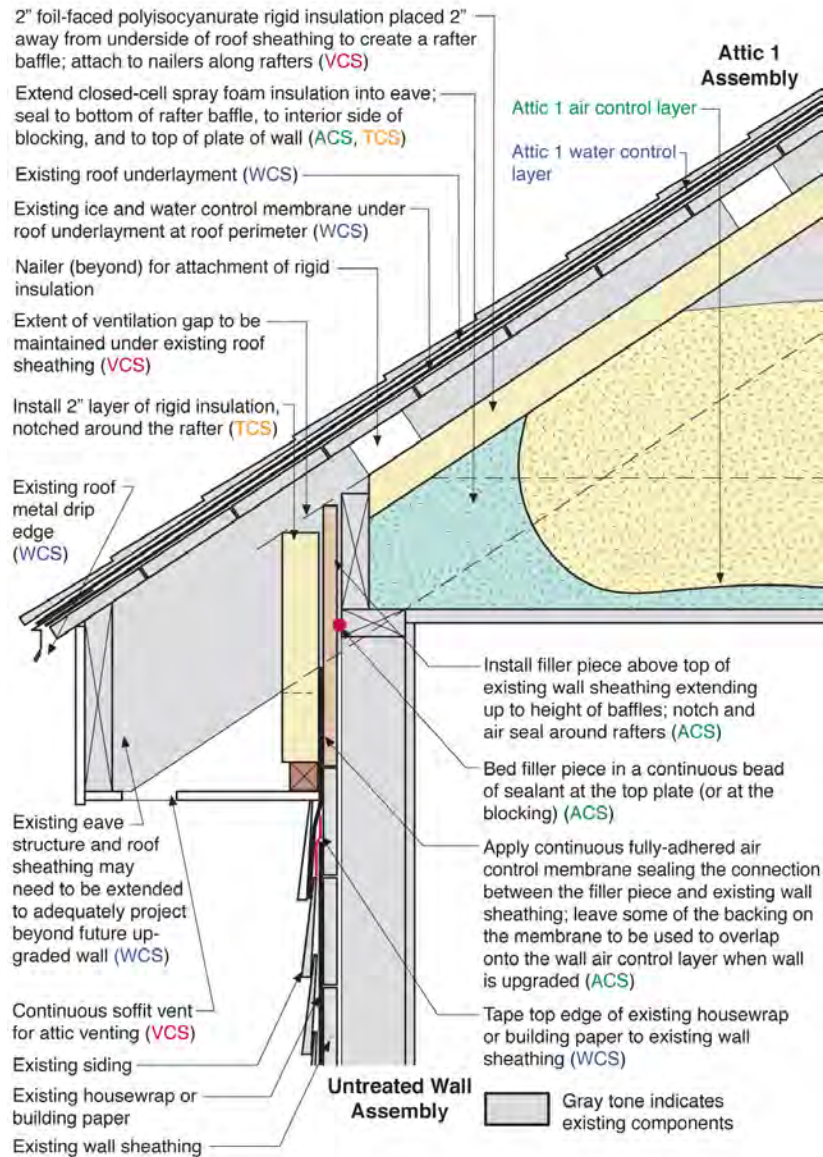


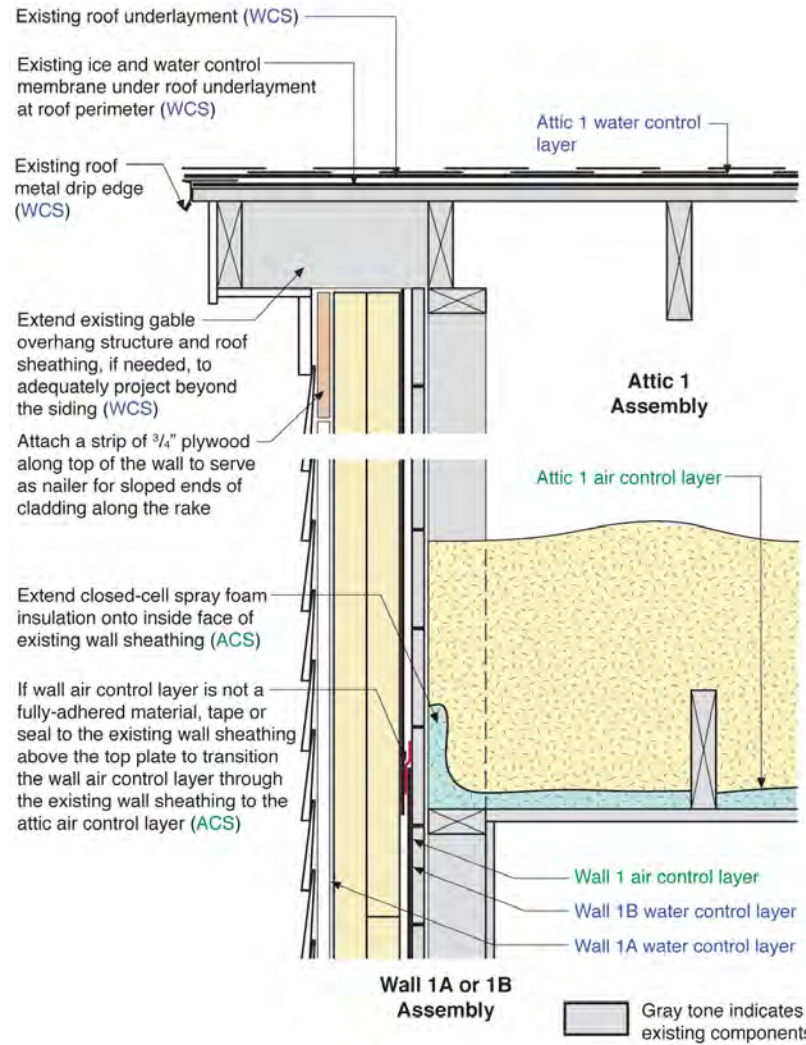


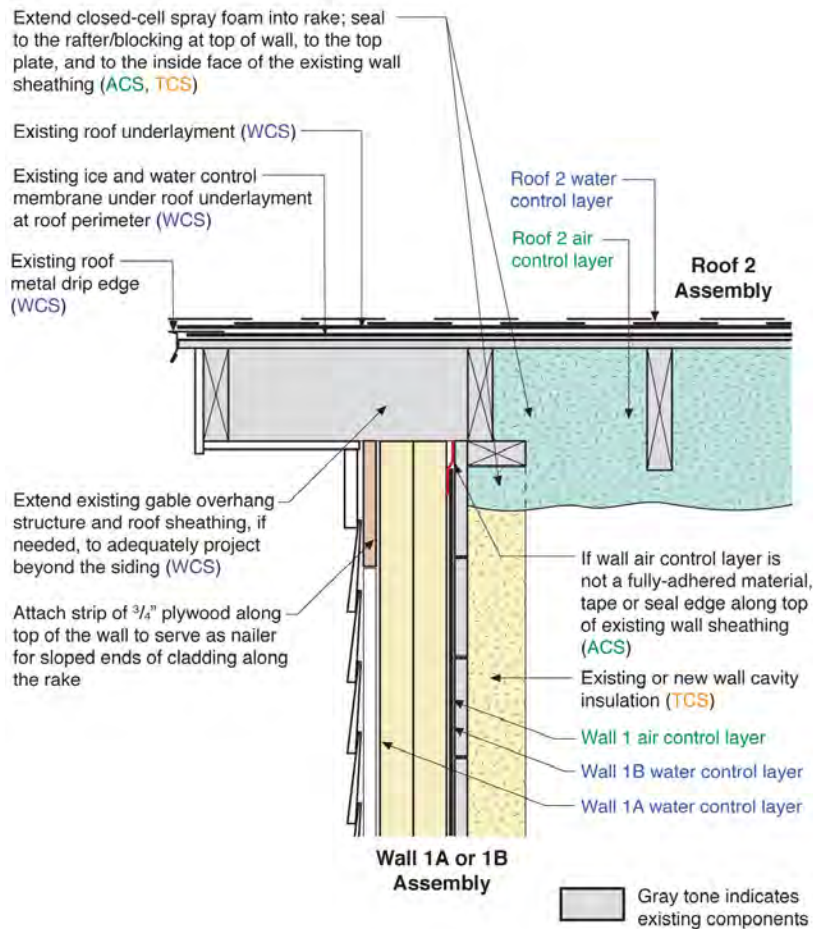


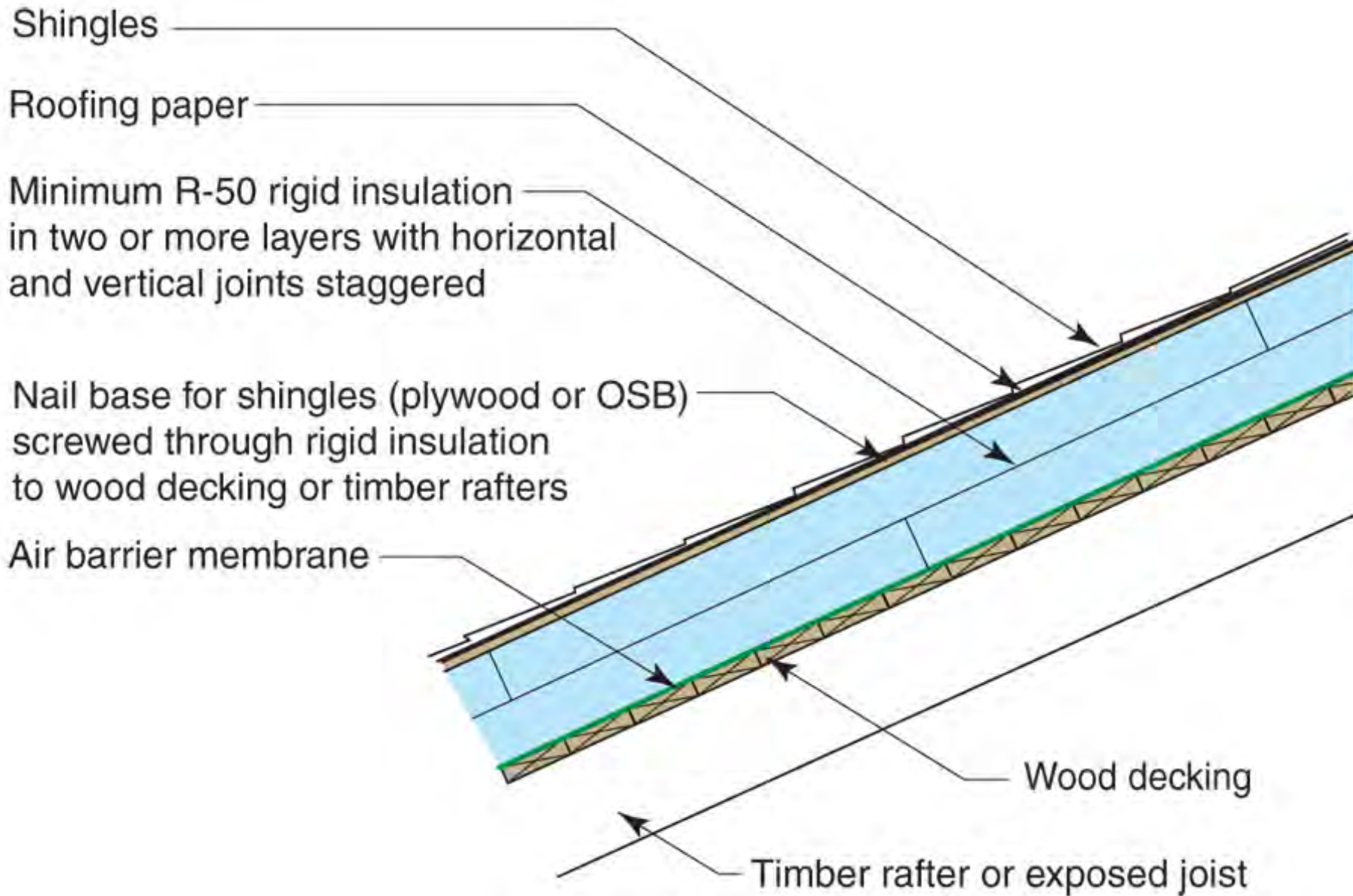


# Roofs



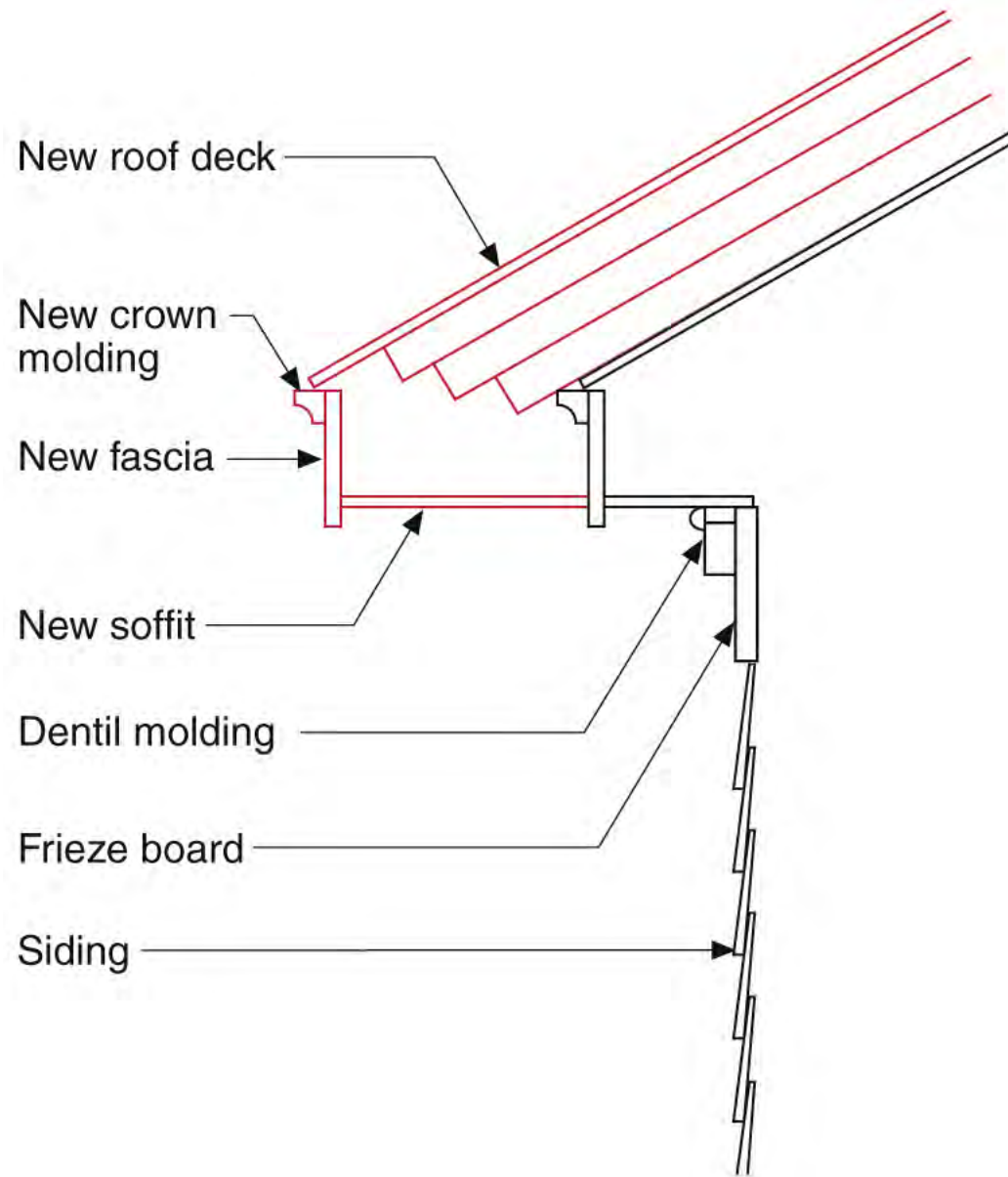


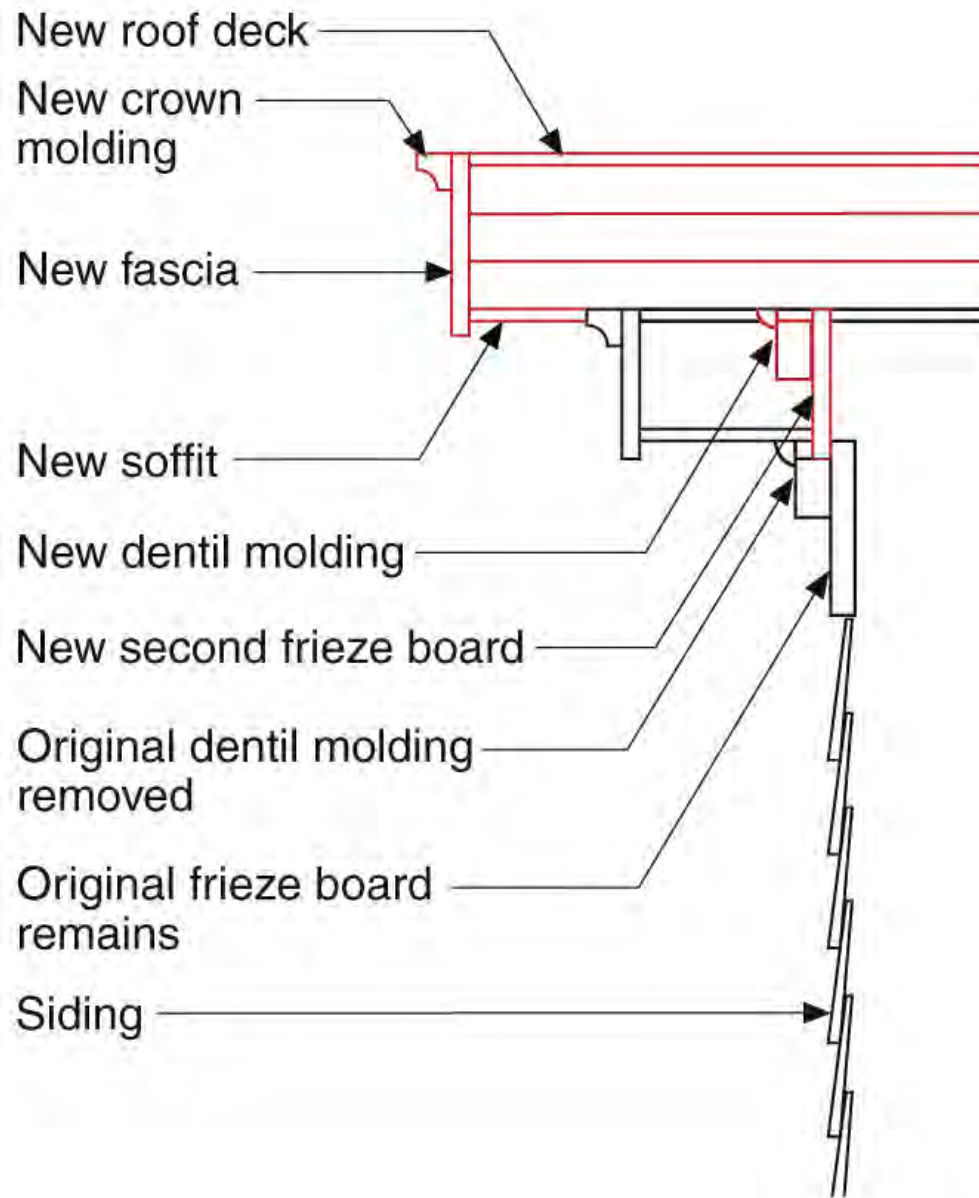


























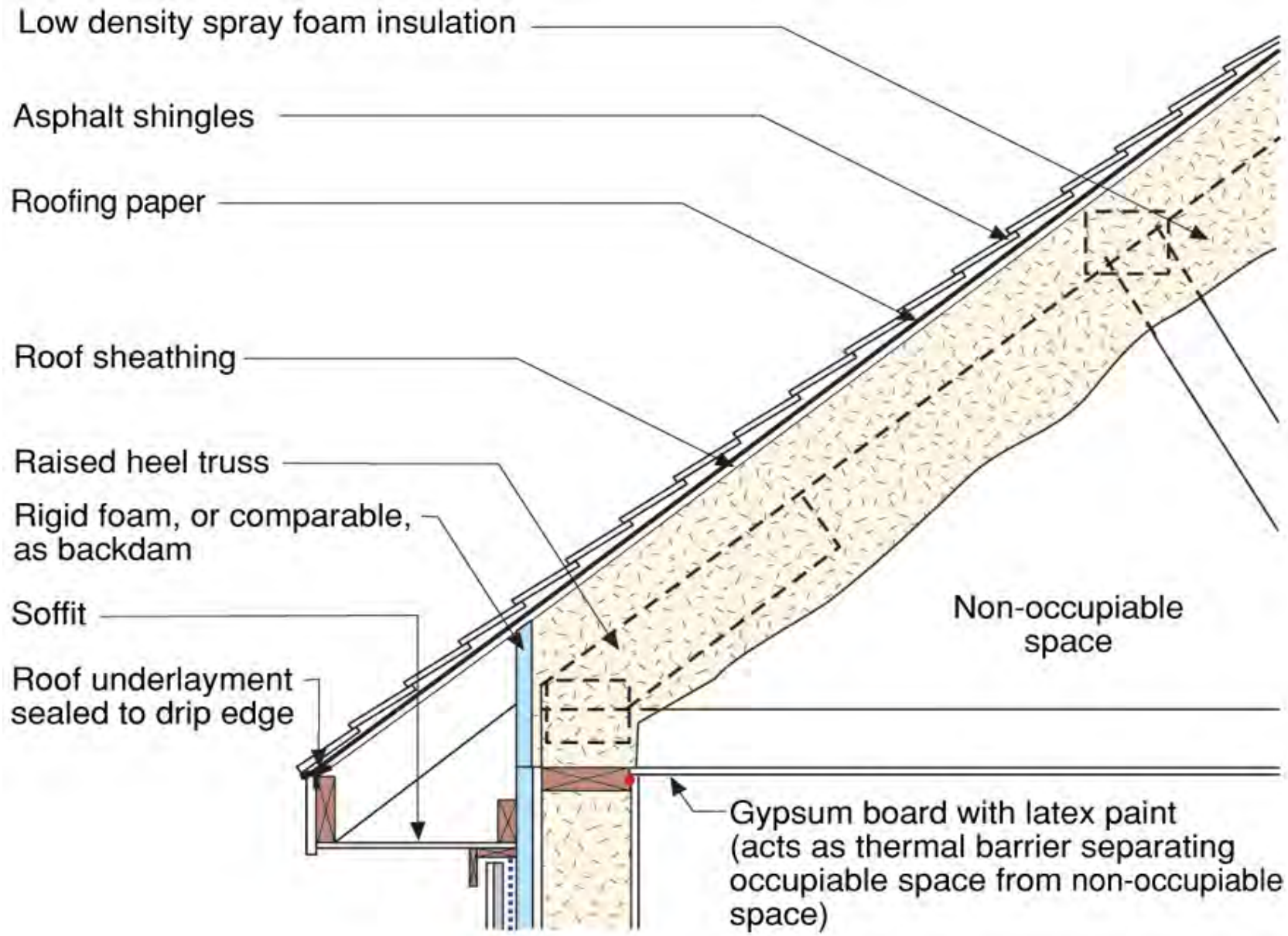




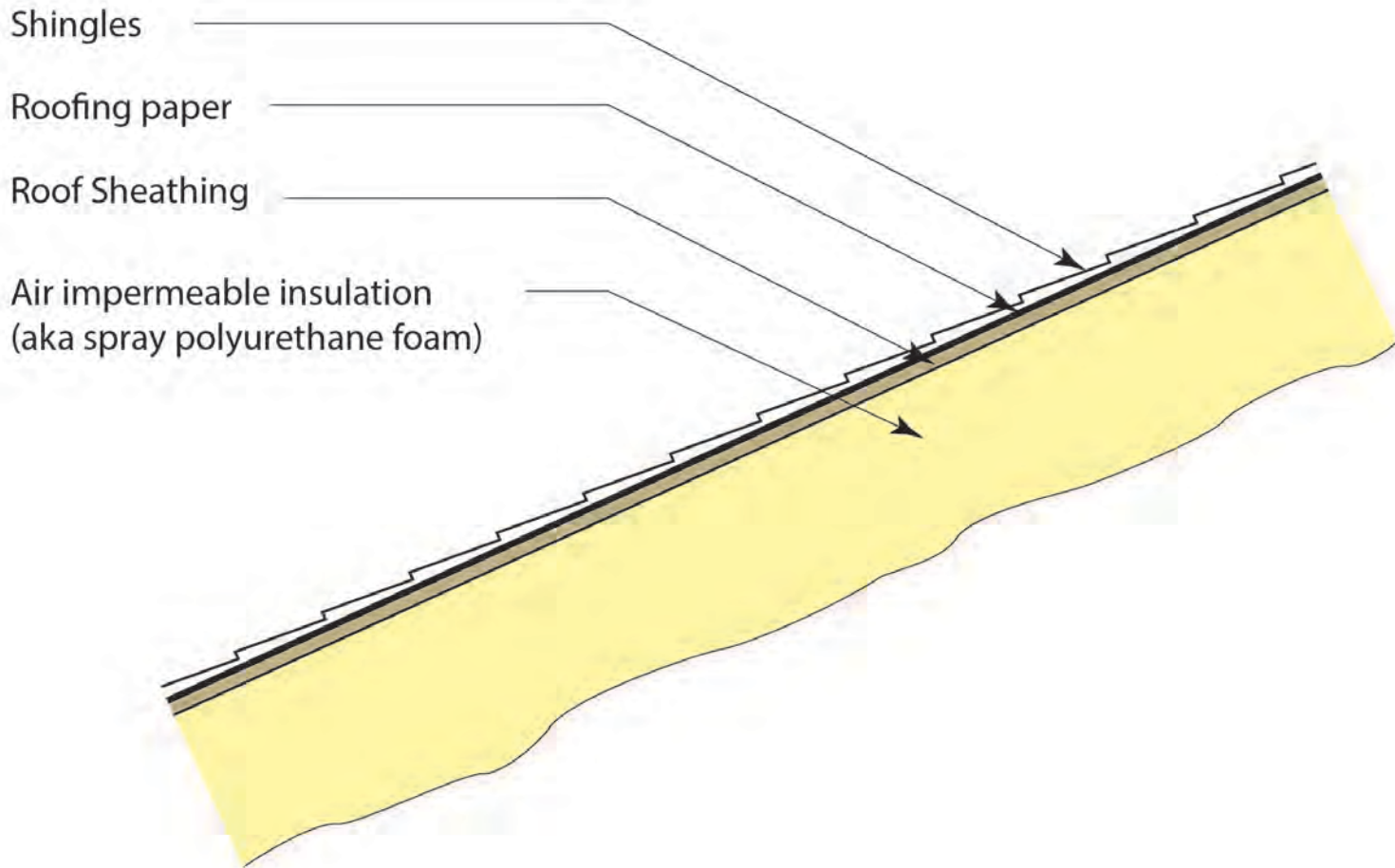




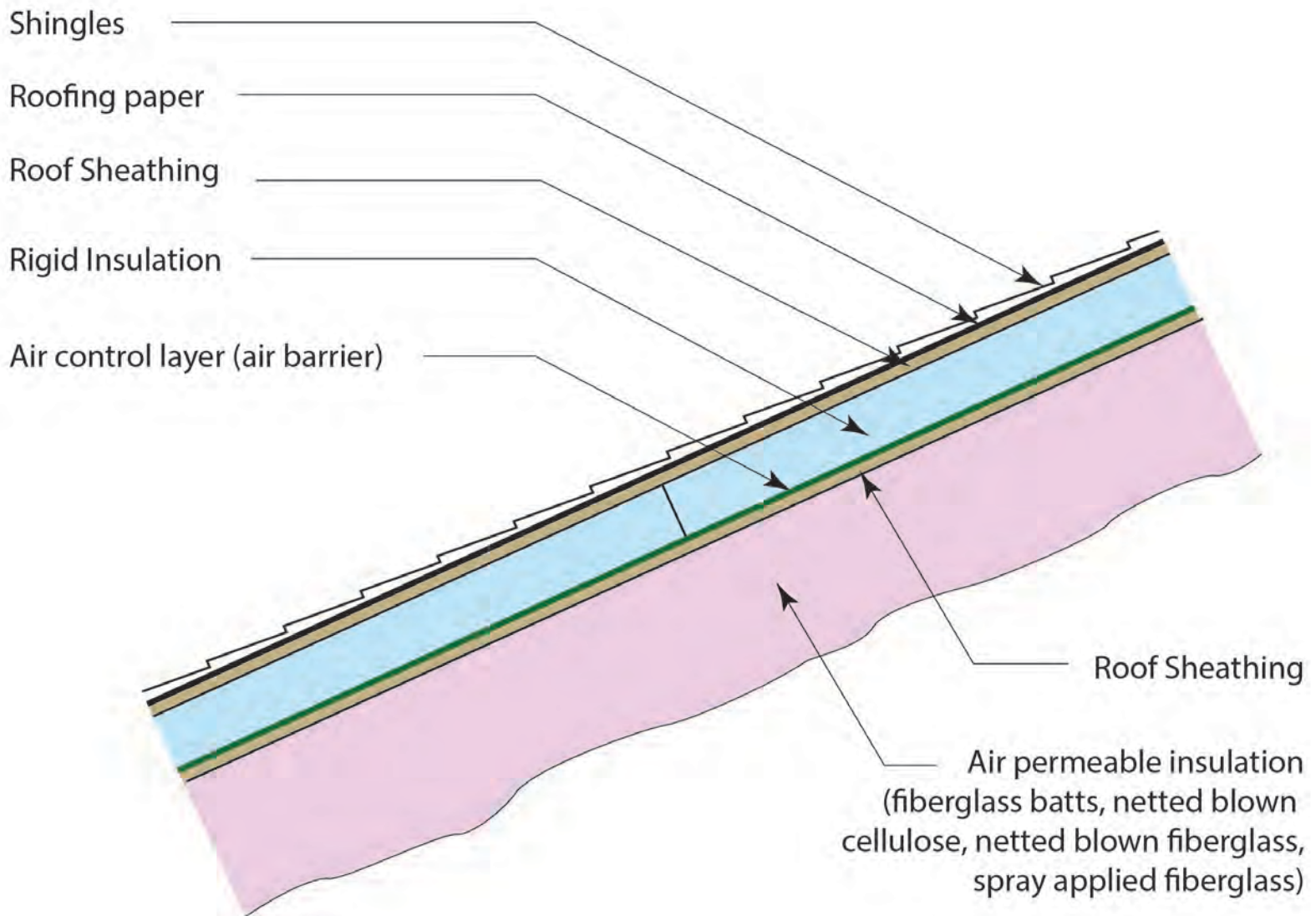










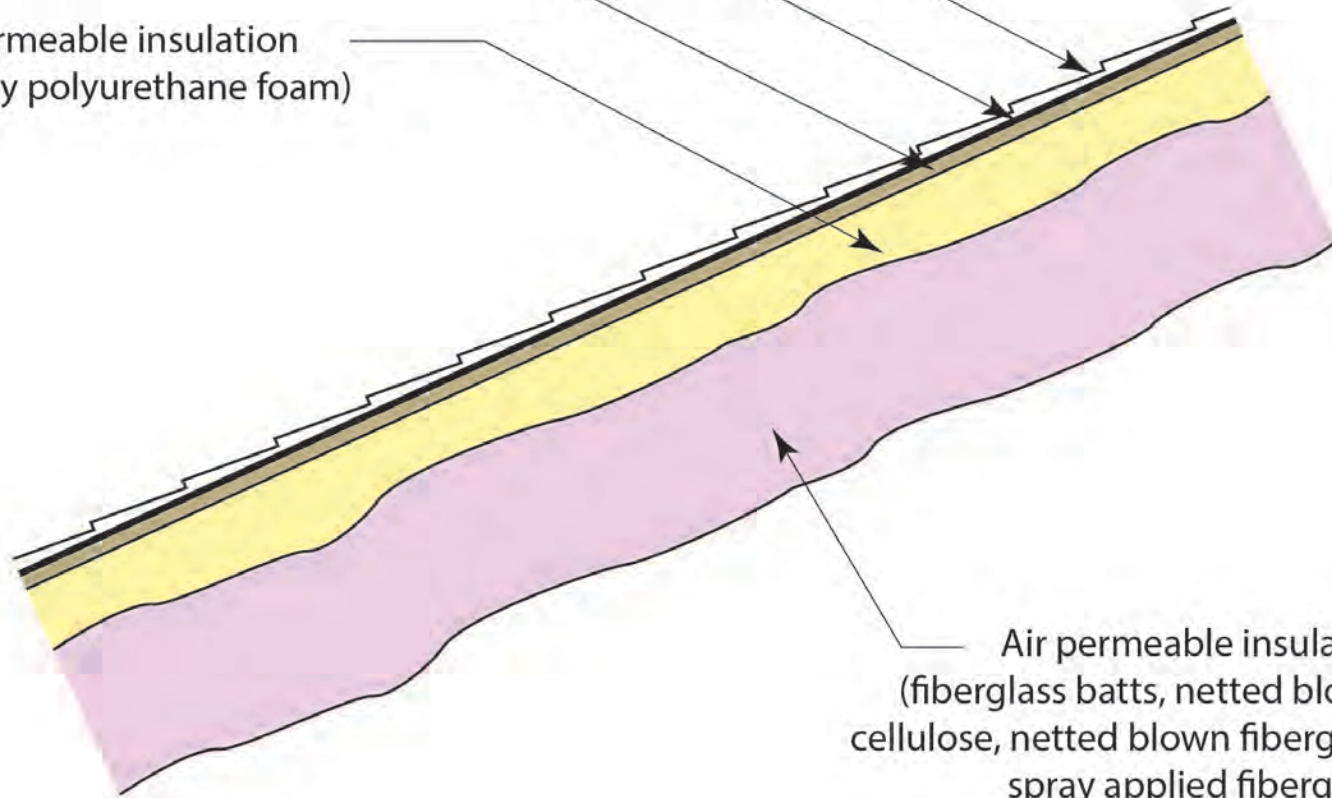


Shingles

Roofing paper

Roof Sheathing

Air impermeable insulation  
(aka spray polyurethane foam)



Air permeable insulation  
(fiberglass batts, netted blown  
cellulose, netted blown fiberglass,  
spray applied fiberglass)

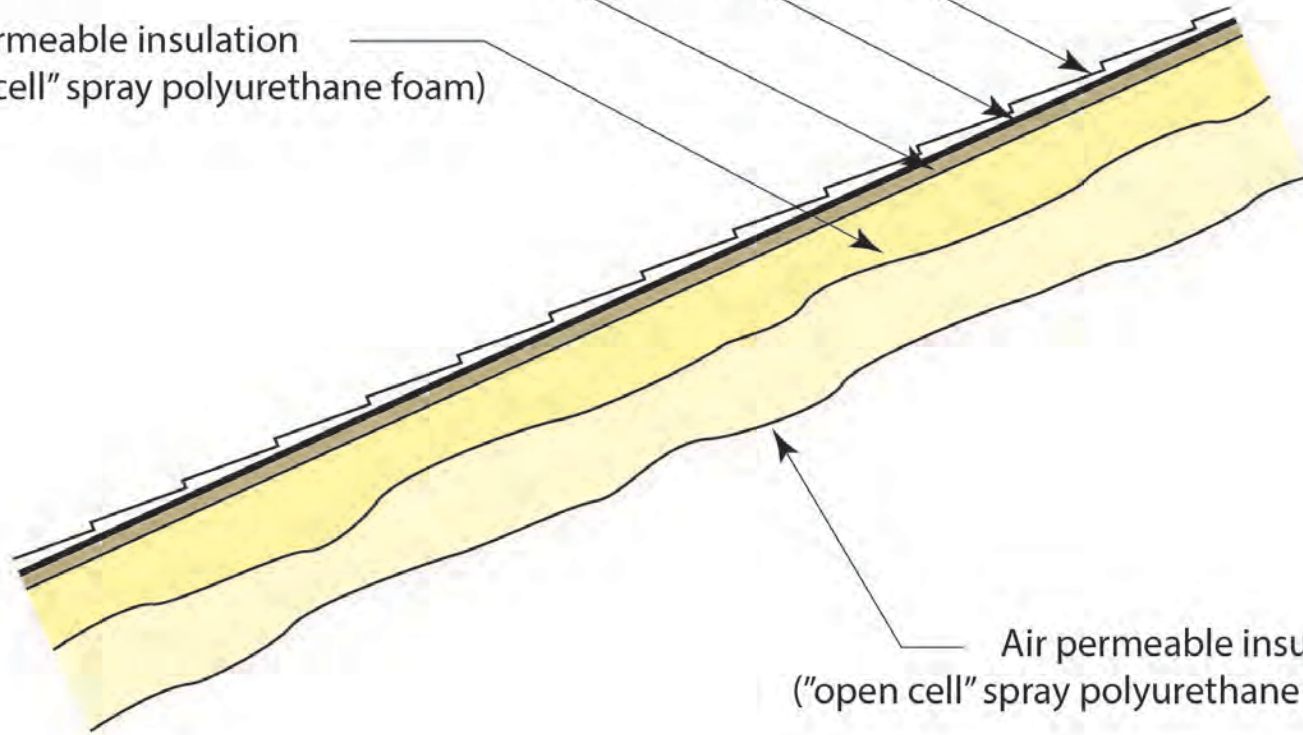
Shingles

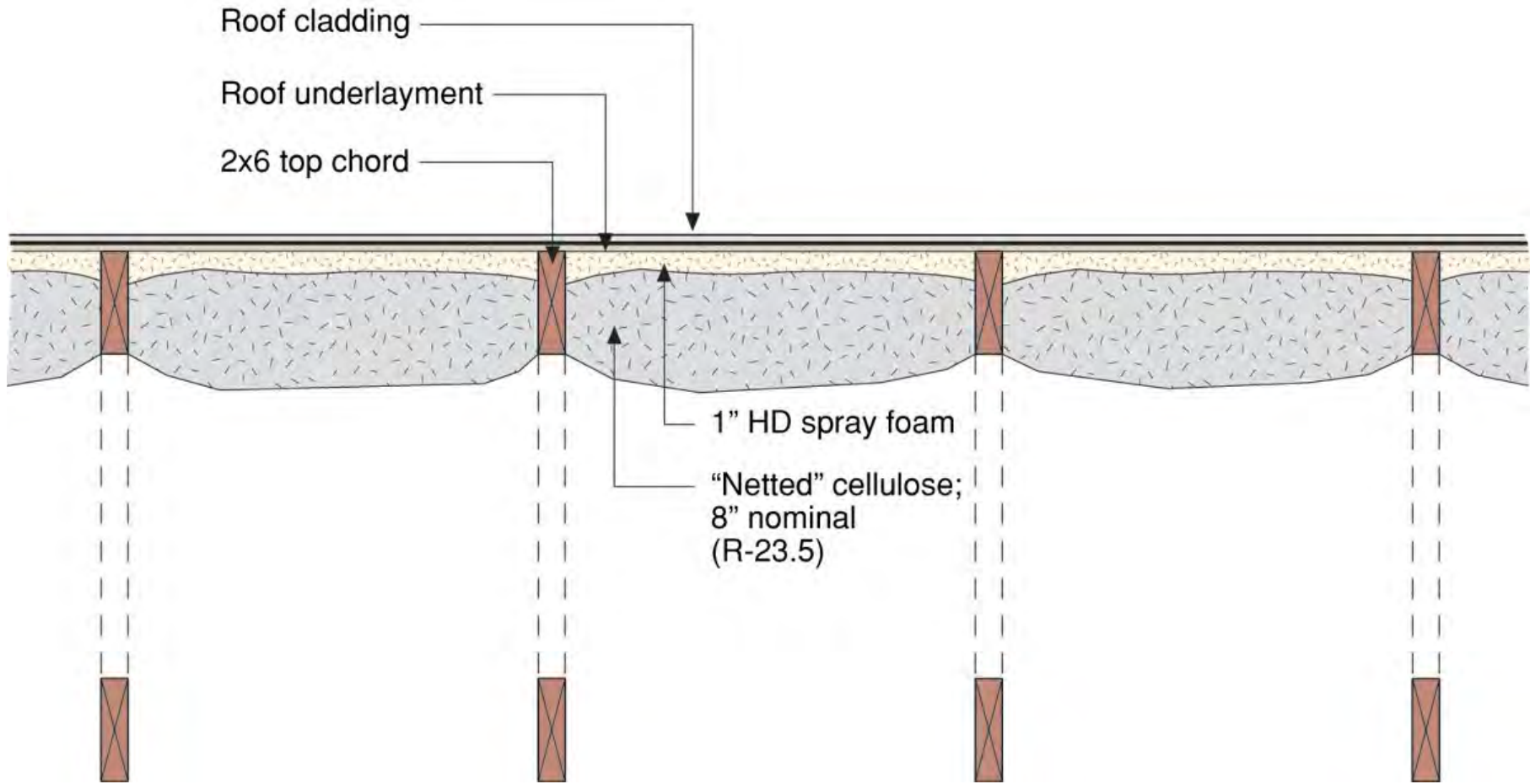
Roofing paper

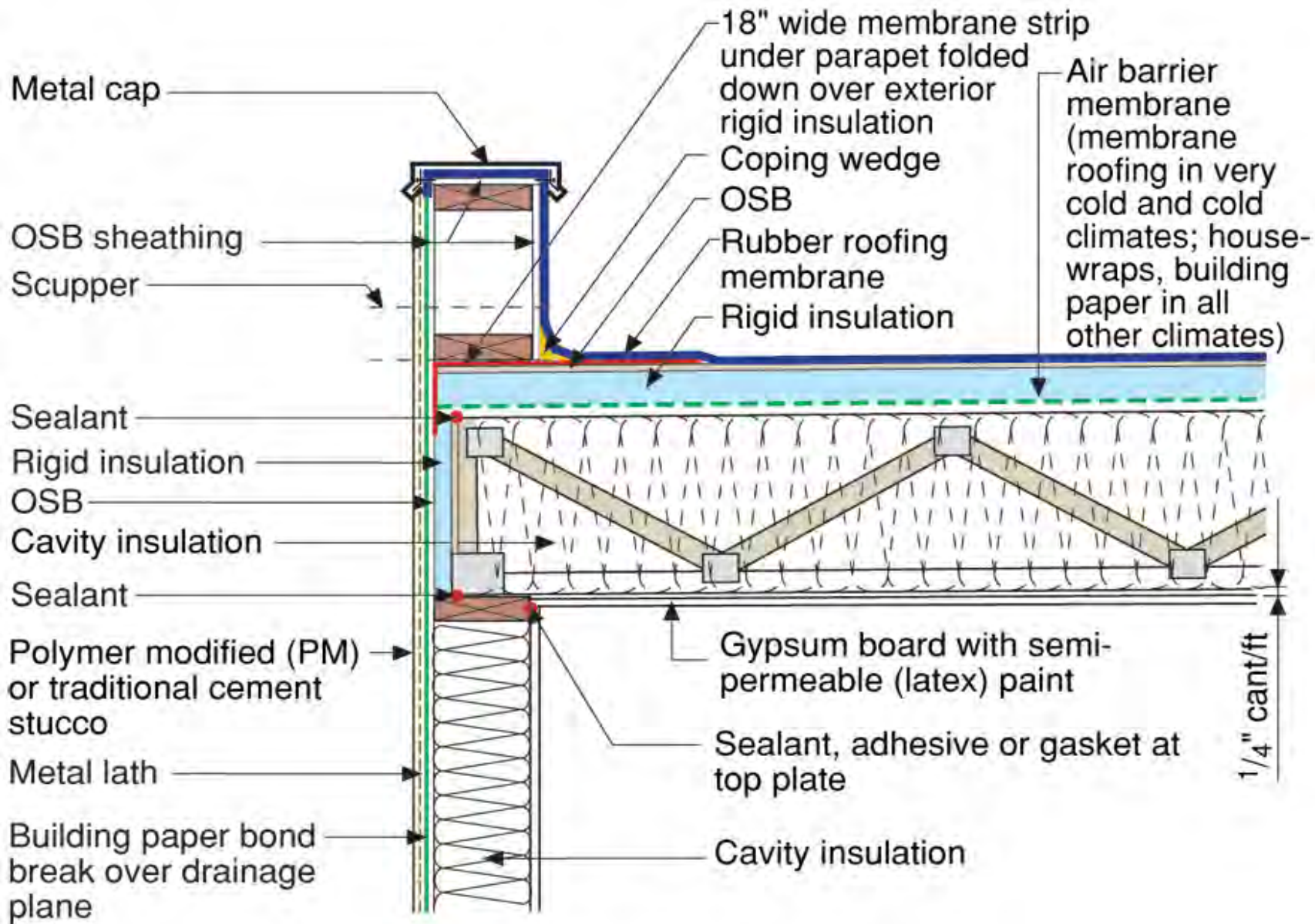
Roof Sheathing

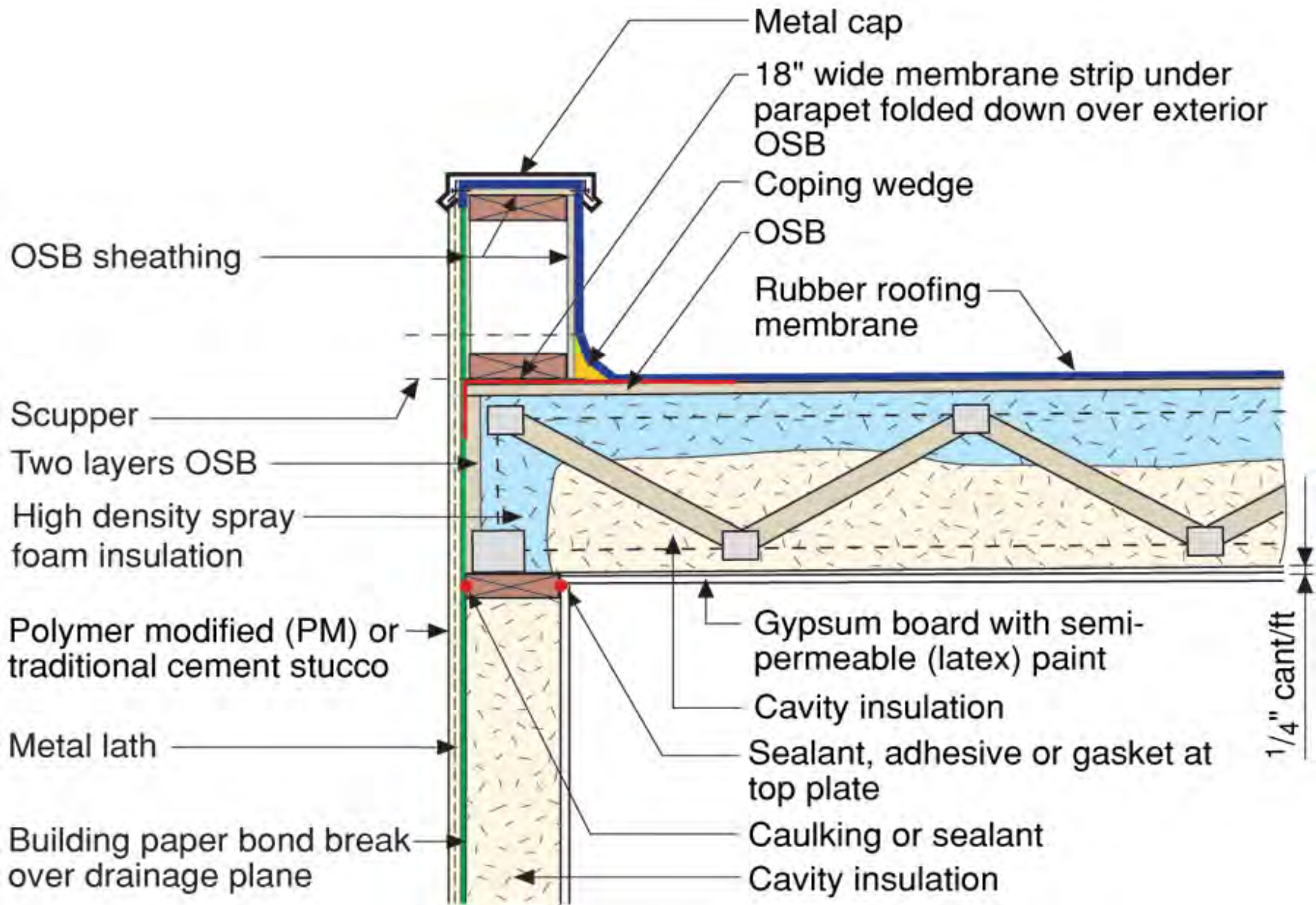
Air impermeable insulation  
("closed cell" spray polyurethane foam)

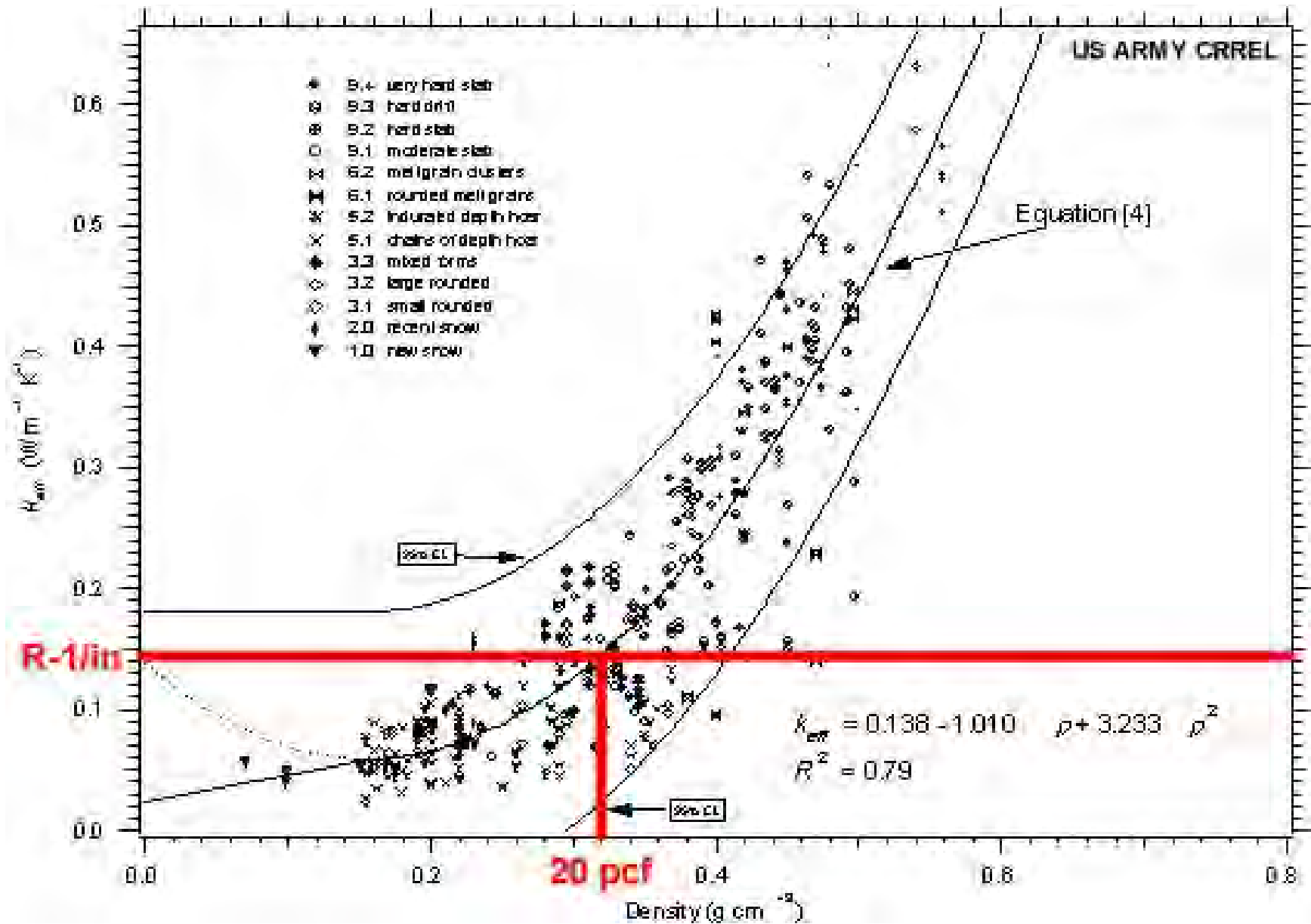
Air permeable insulation  
("open cell" spray polyurethane foam)





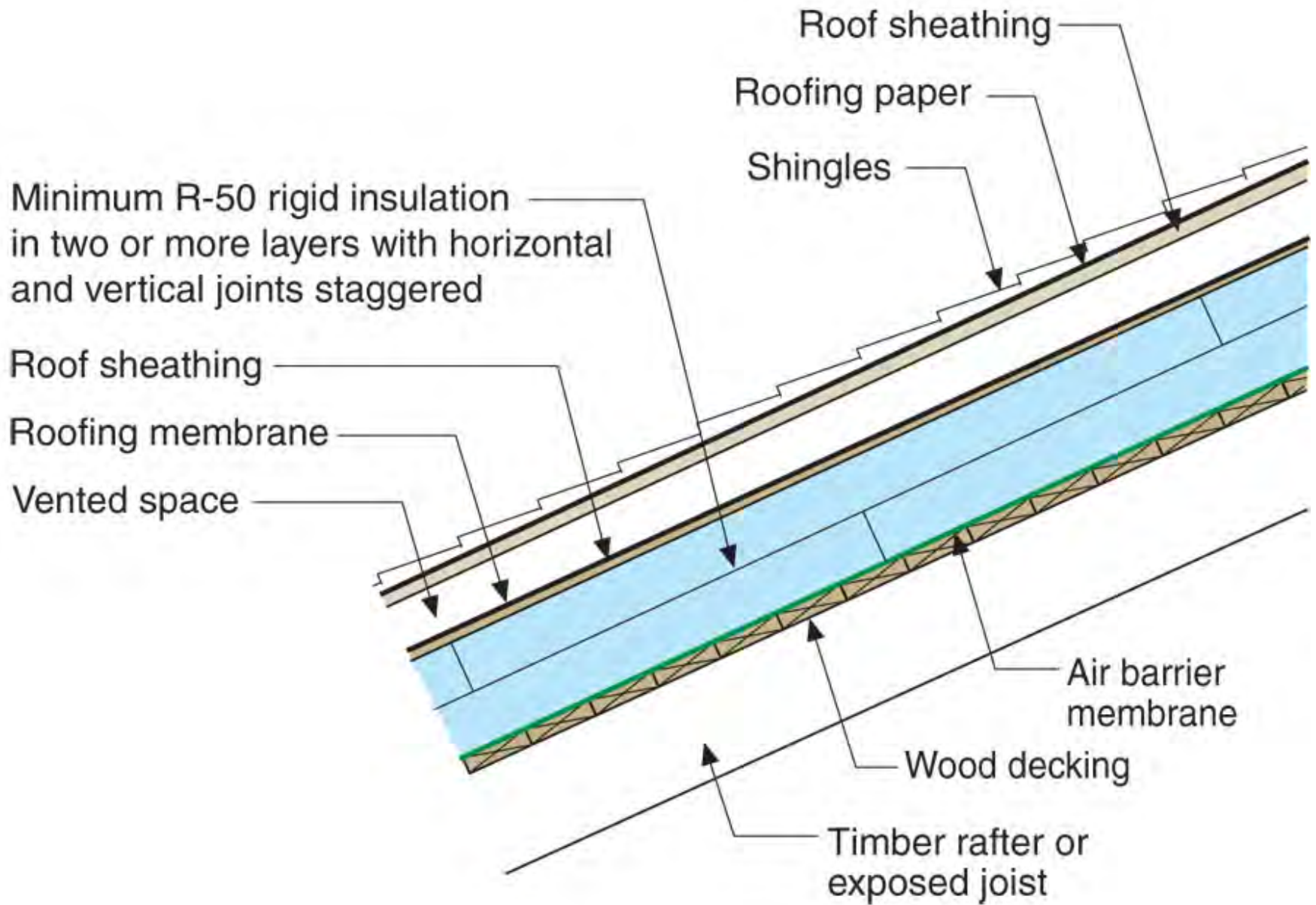










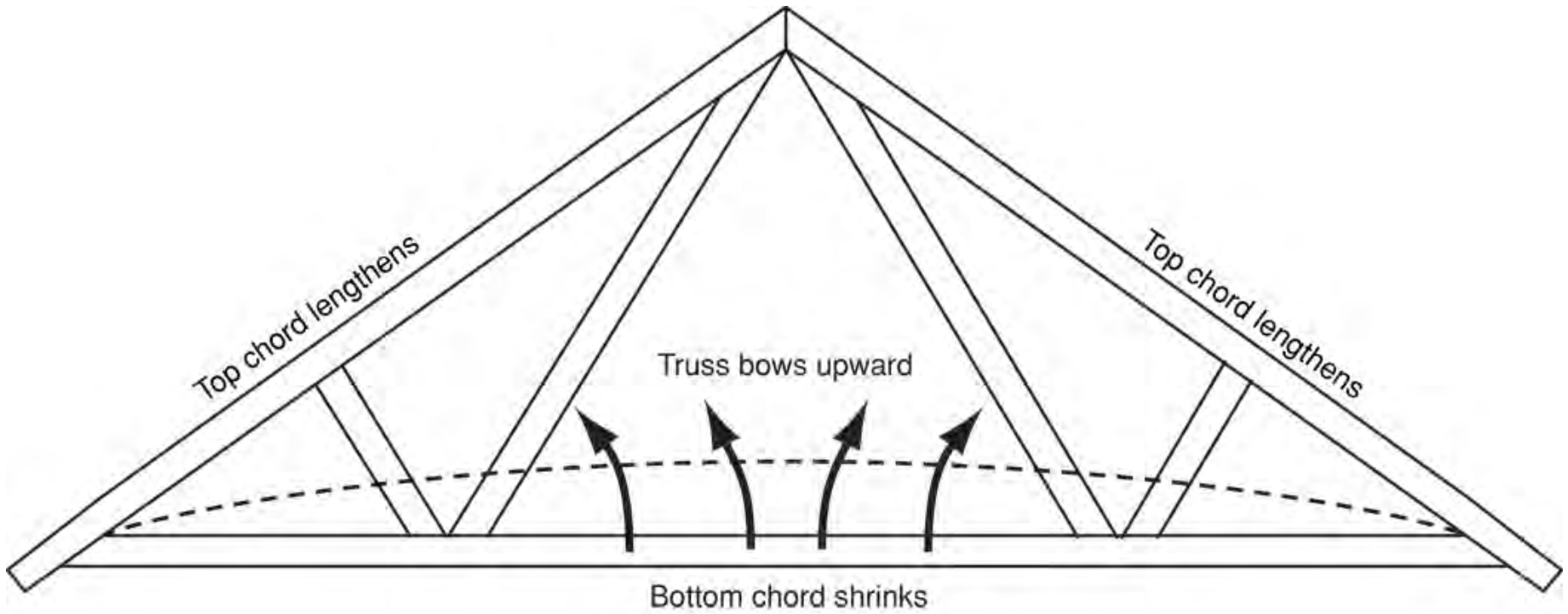


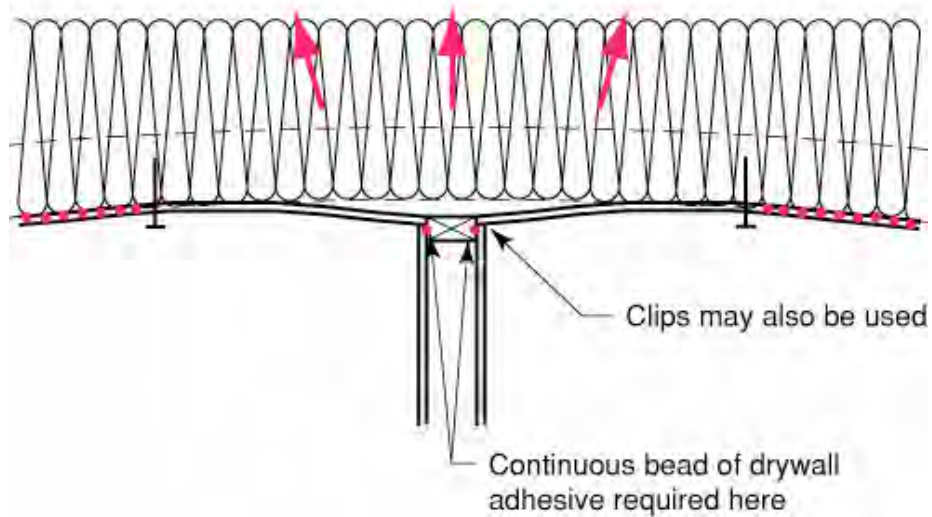
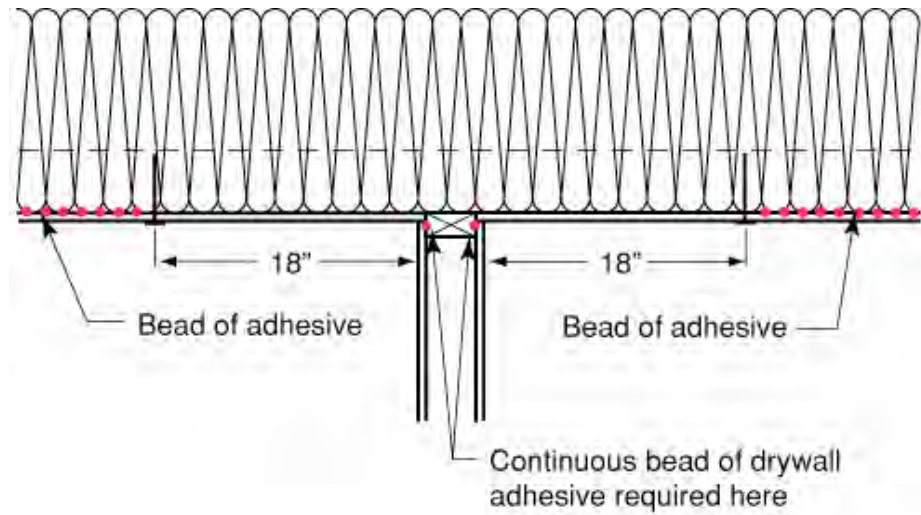
# Truss Uplift

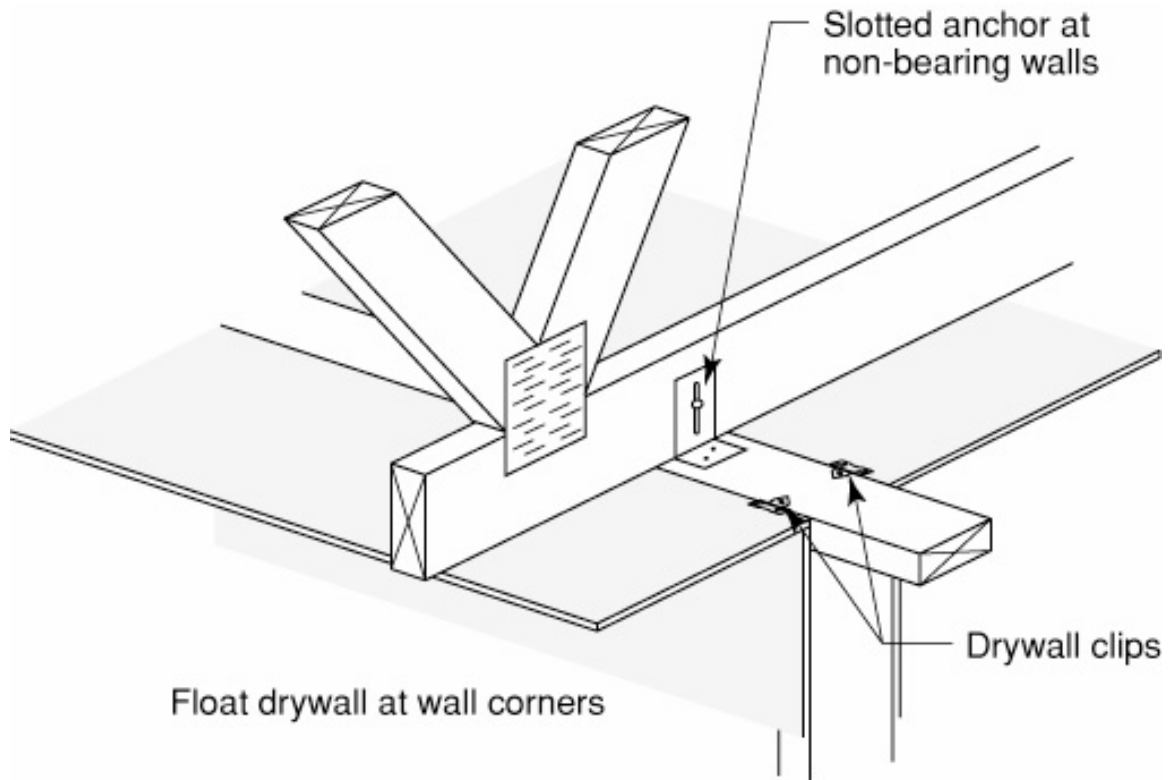










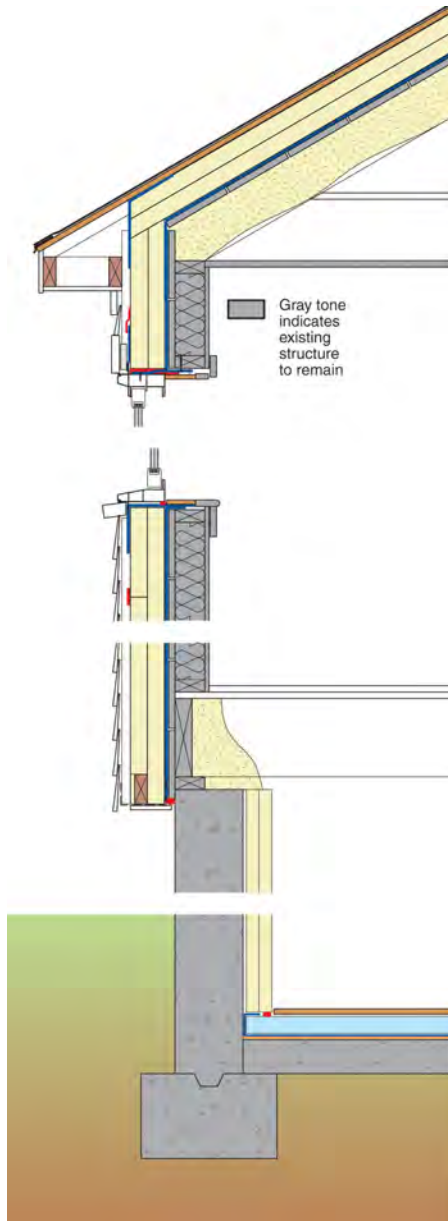








# Complete Enclosure



# 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

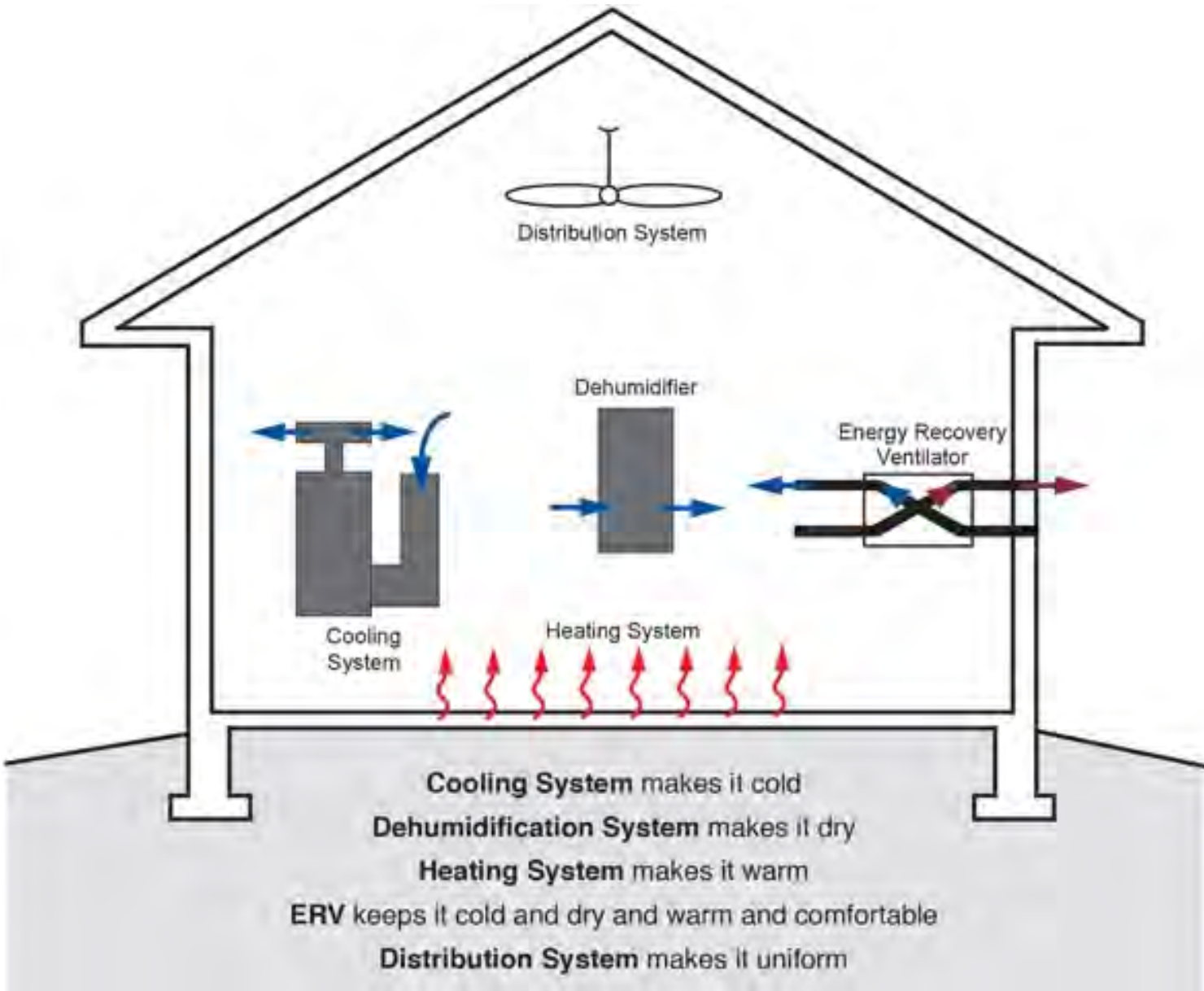
Heating System To Make It Warm

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.....



# Build Tight - Ventilate Right

Build Tight - Ventilate Right  
How Tight?  
What's Right?

# Air Barrier Metrics

Material	0.02 l/(s-m <sup>2</sup> ) @ 75 Pa
Assembly	0.20 l/(s-m <sup>2</sup> ) @ 75 Pa
Enclosure	2.00 l/(s-m <sup>2</sup> ) @ 75 Pa 0.25 cfm/ft <sup>2</sup> @ 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

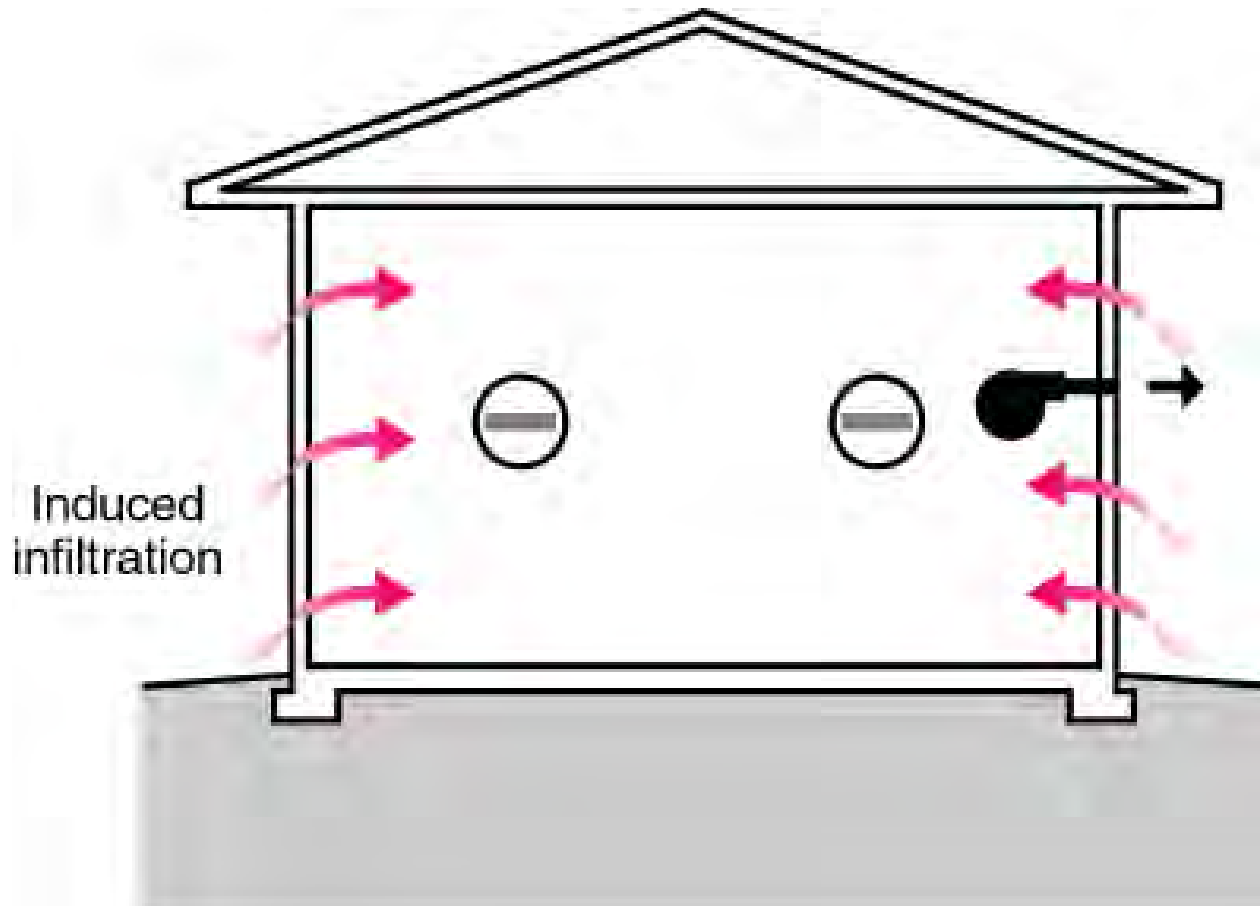
Exhaust Ventilation – with – No Distribution  
and No Mixing

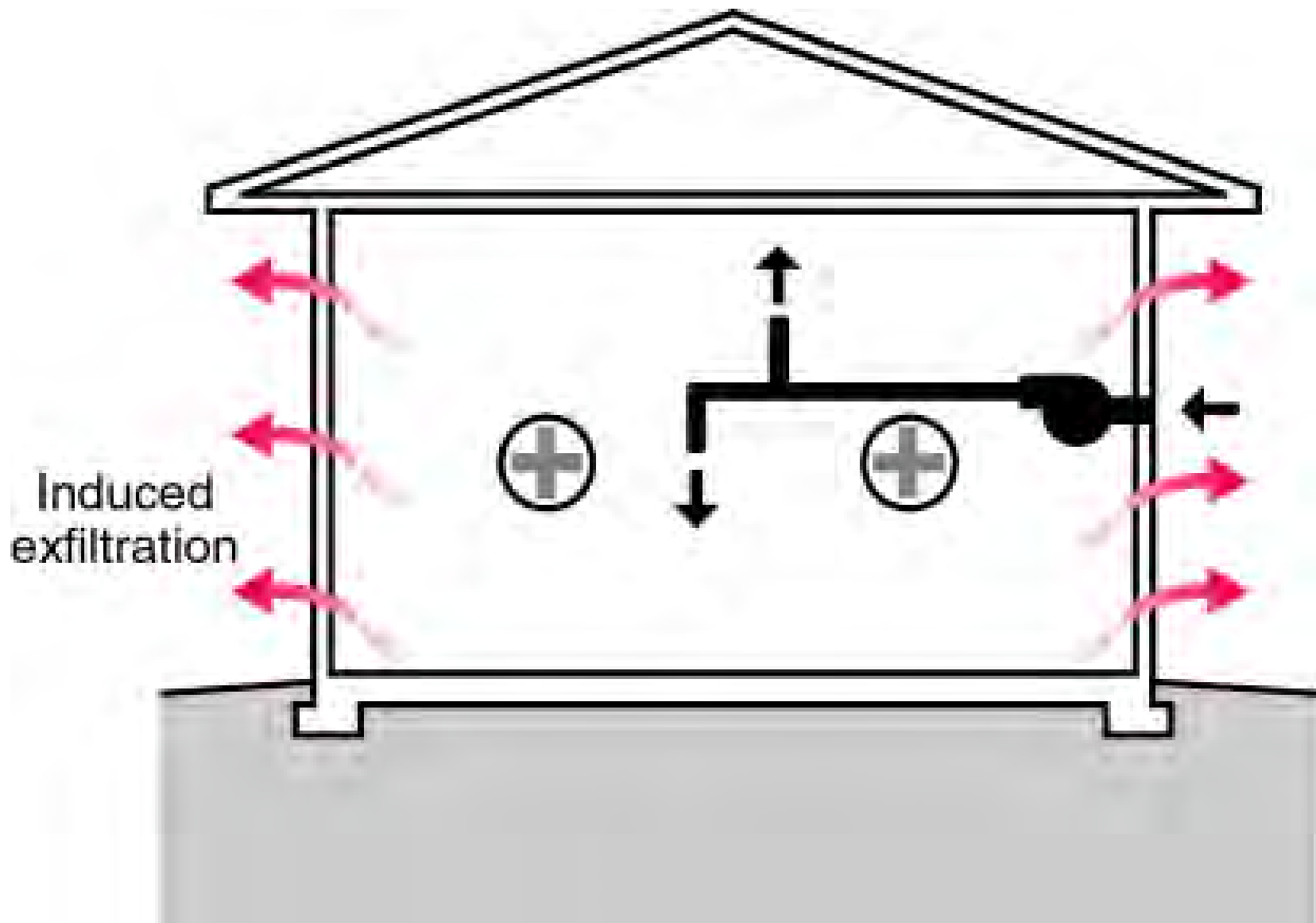
# Three Types of Controlled Ventilation Systems

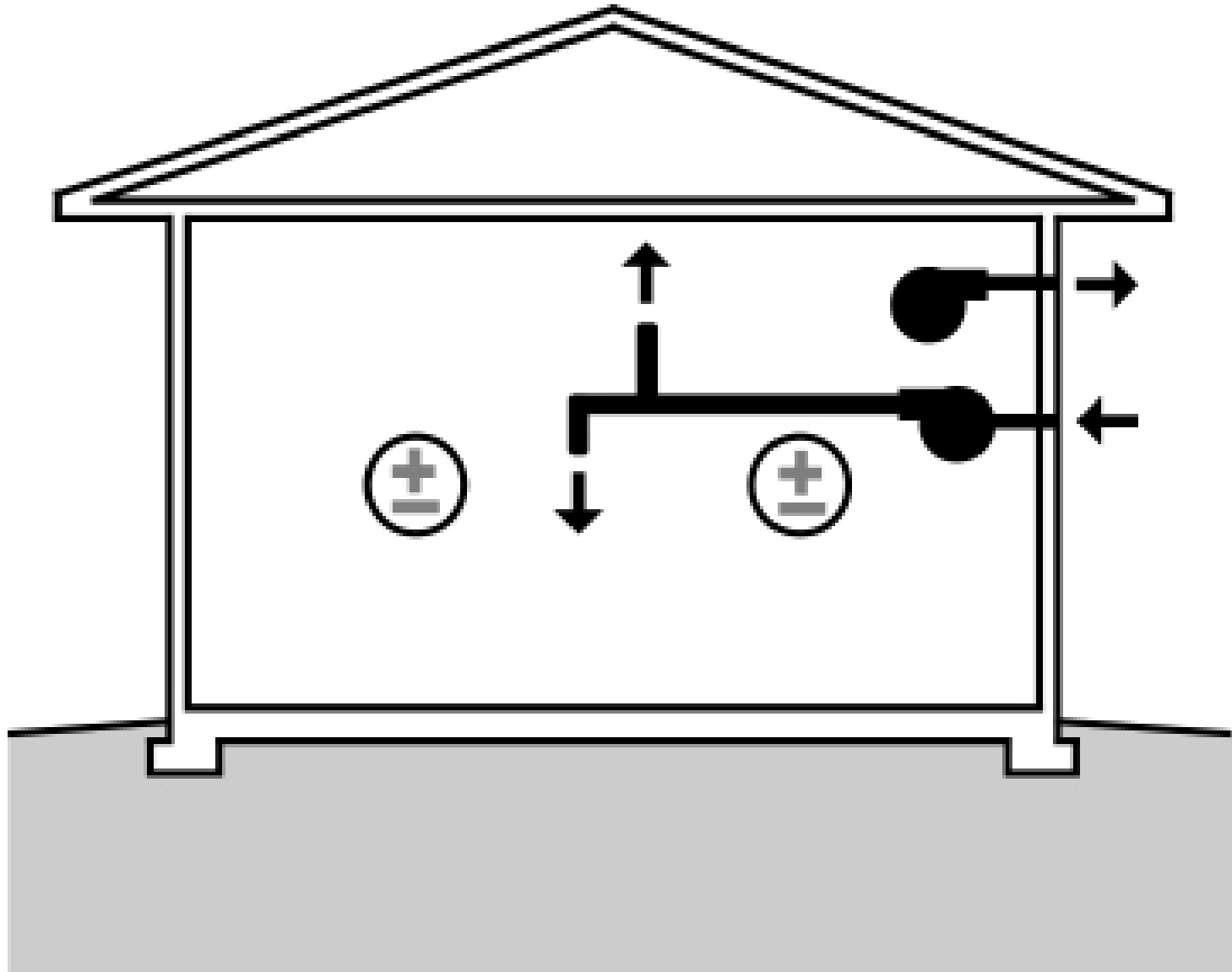
Exhaust Ventilation

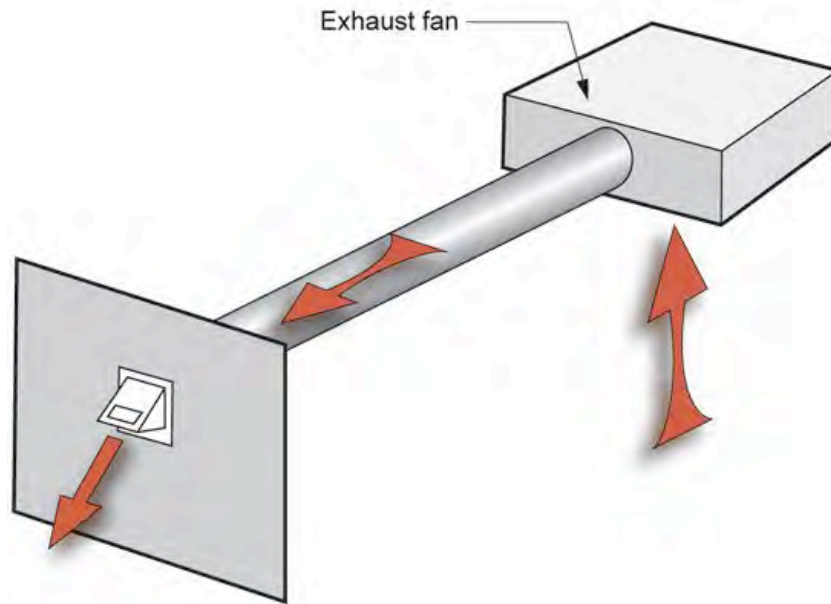
Supply Ventilation

Balanced Ventilation

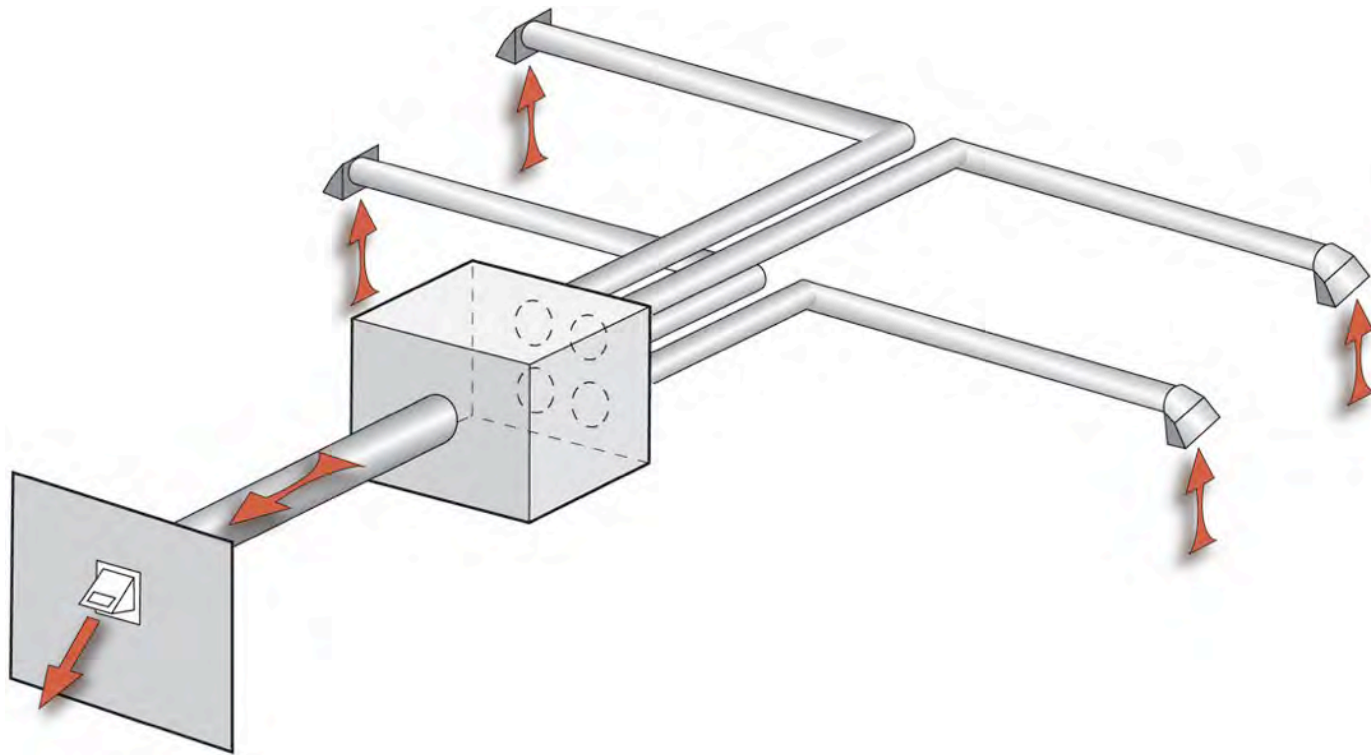


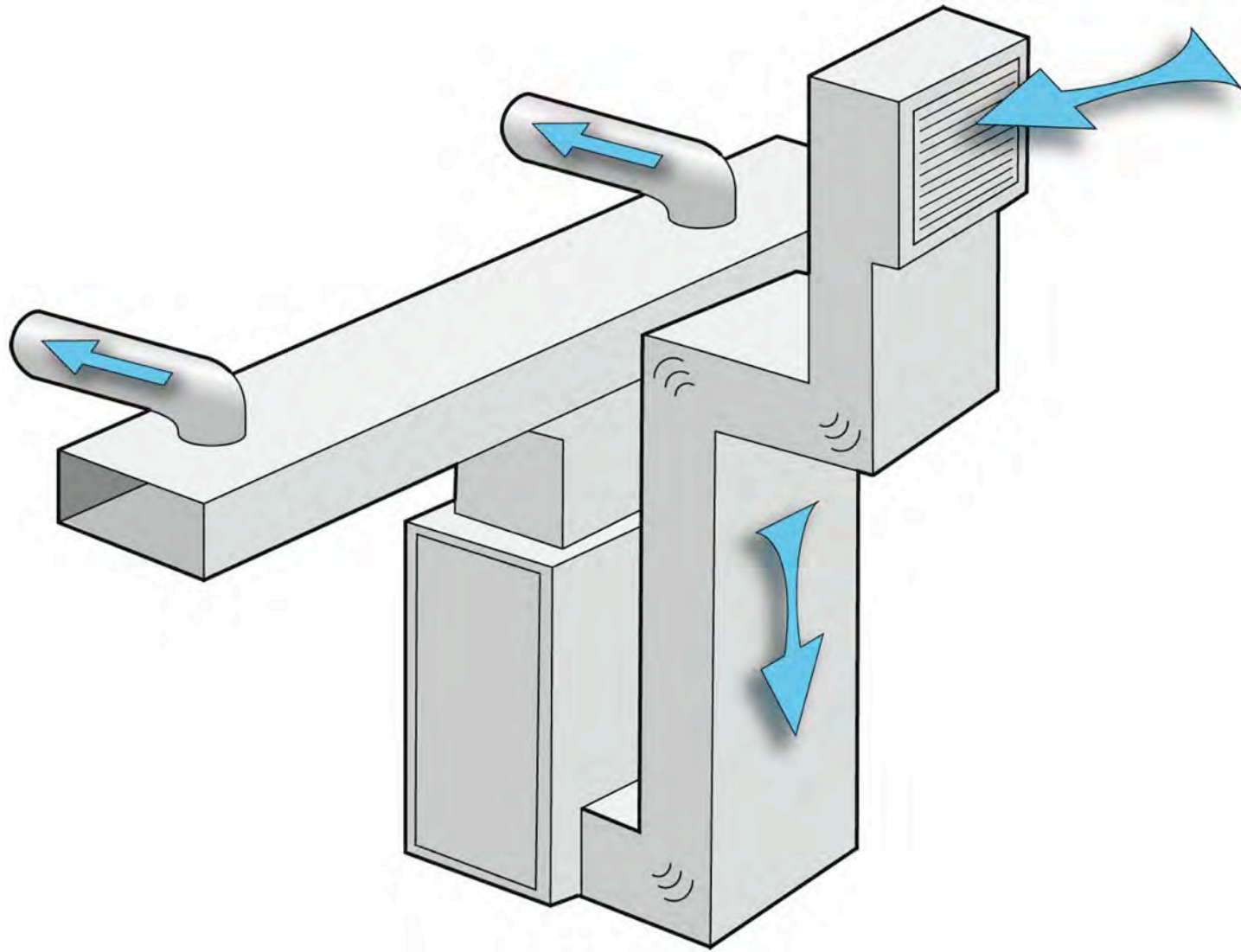


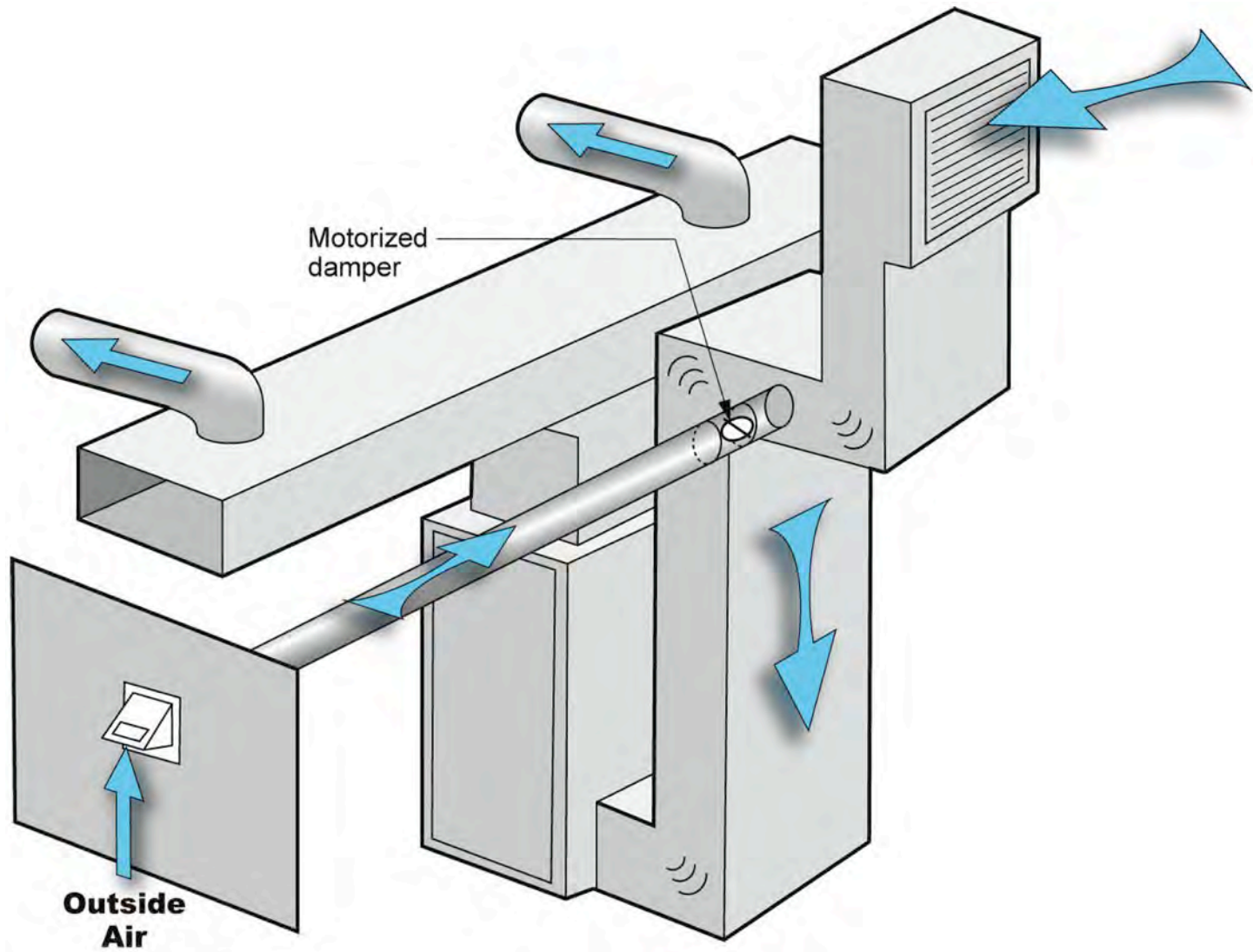


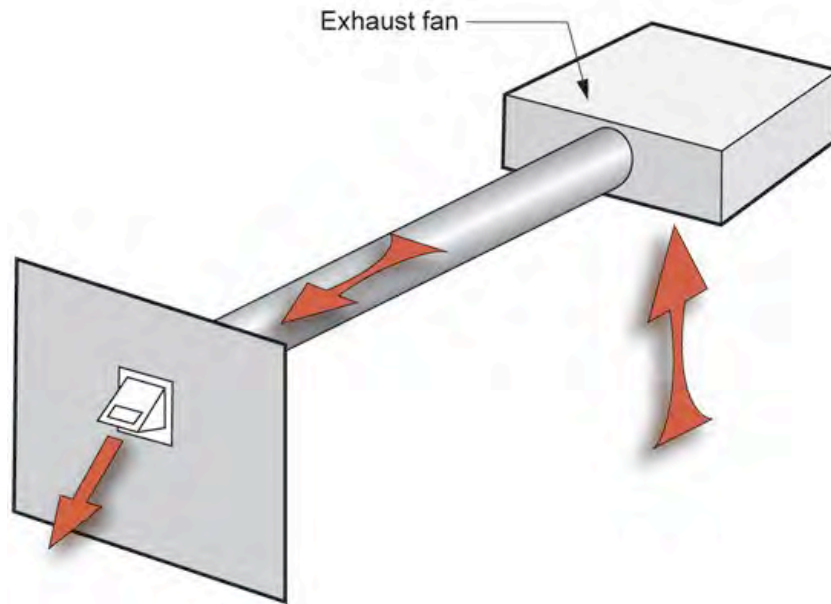


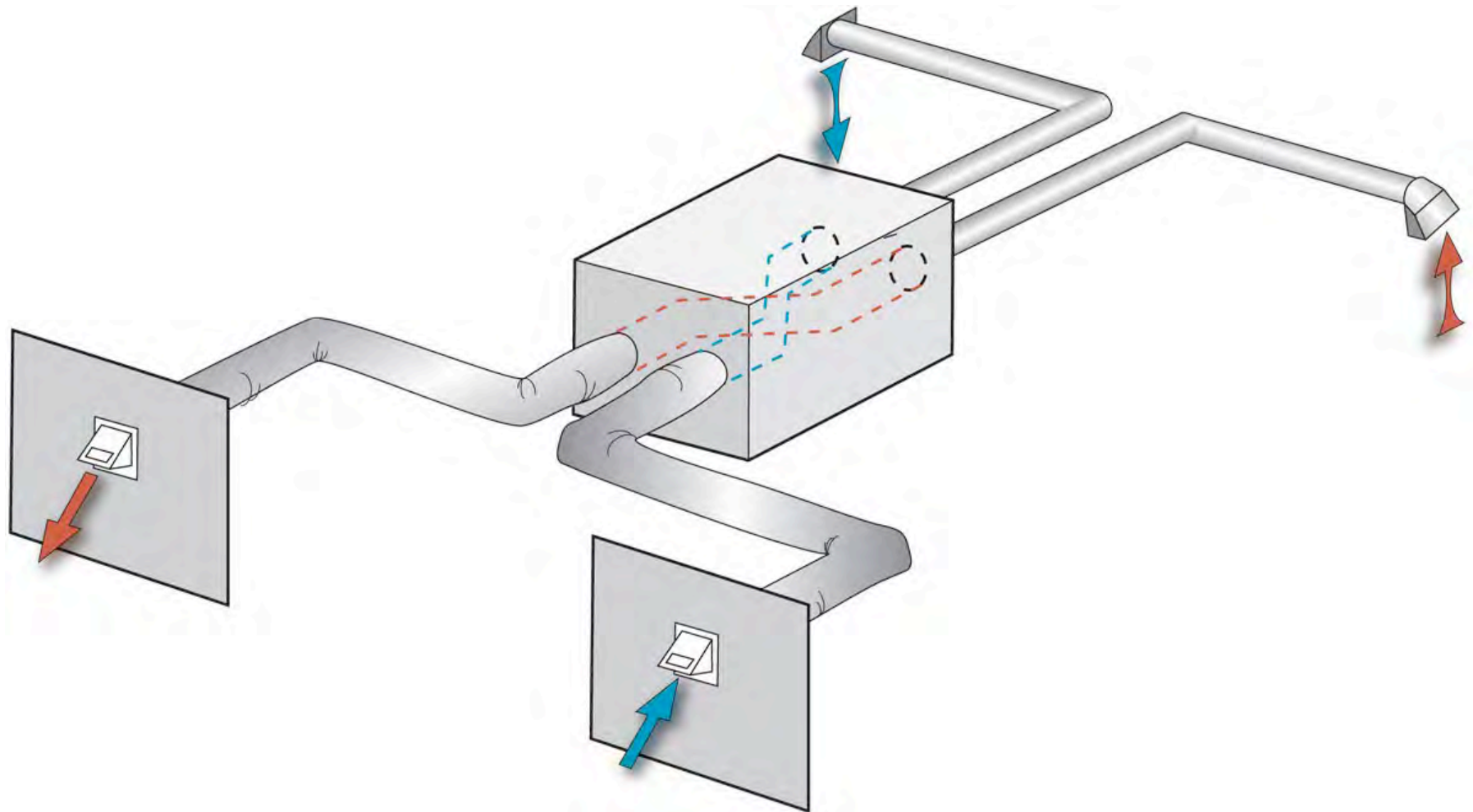












# Ventilation Rates Are Based on Odor Control

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Health Science Basis for Ventilation Rates is  
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Almost Nothing Cited Applies to Housing



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Almost Nothing Cited Applies to Housing

The Applicable Studies Focus on Dampness

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 2015 and 2018 calls 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

3 Bedroom House – 2,500 ft<sup>2</sup>

30 cfm plus 75 cfm

105 cfm

3 Bedroom House – 2,500 ft<sup>2</sup>

30 cfm plus 25 cfm

55 cfm

3 Bedroom House – 2,500 ft<sup>2</sup>

30 cfm plus 25 cfm

55 cfm

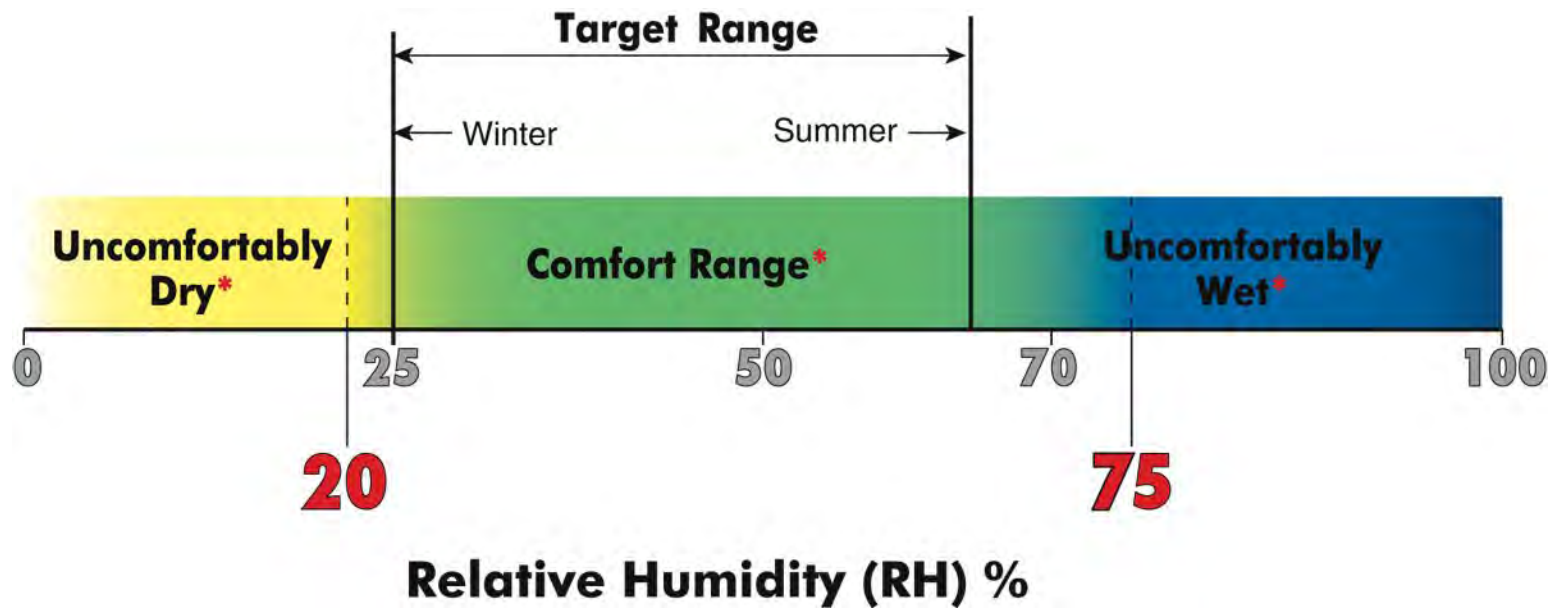
With Balanced and Distributed 30 percent  
credit

38.5 cfm

# Dilution For People

## Source Control For The Building

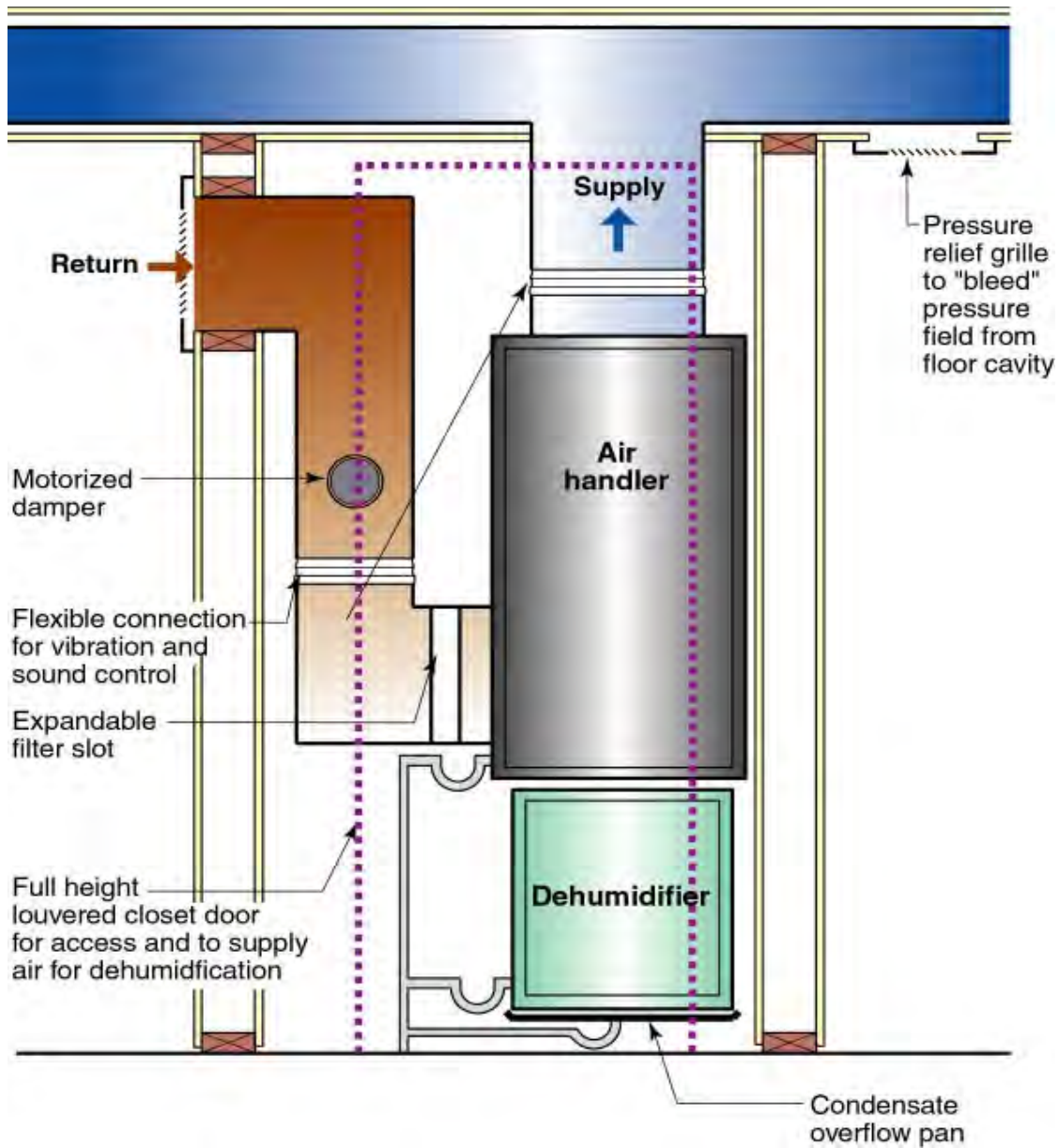




## Recommended Range of Relative Humidity

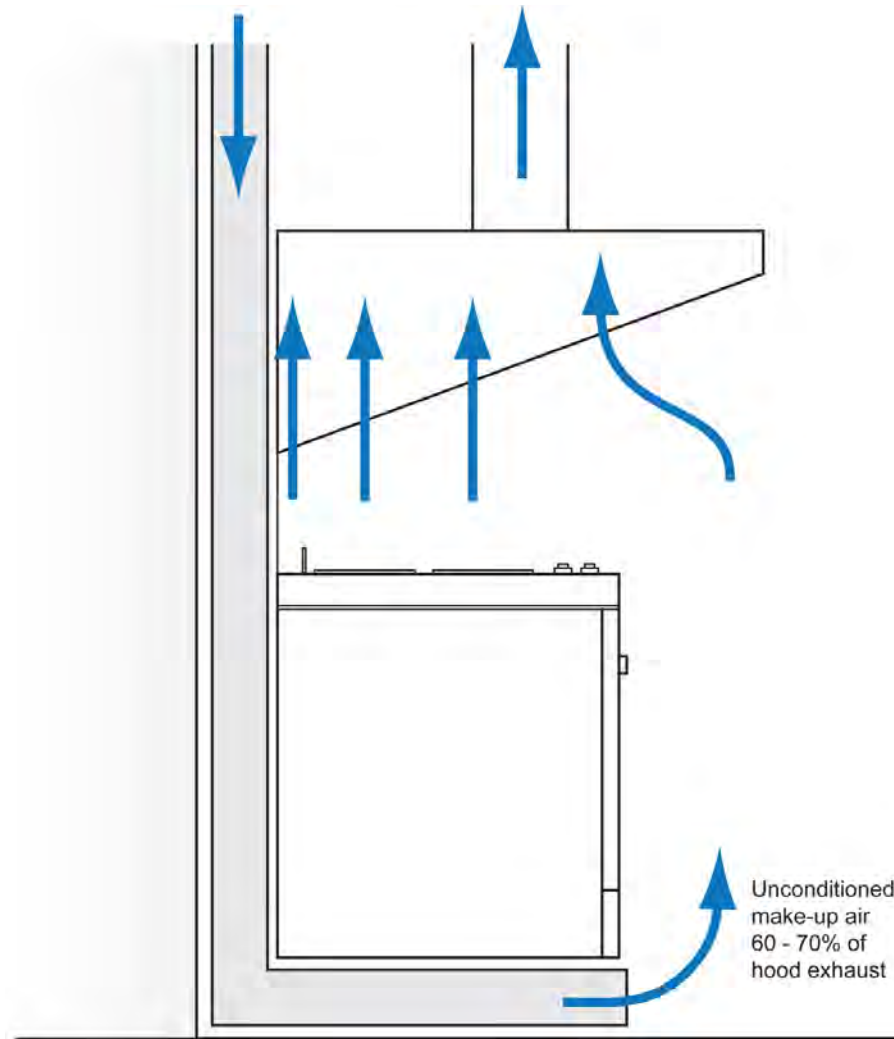
Above 25 percent during winter

Below 70 percent during summer

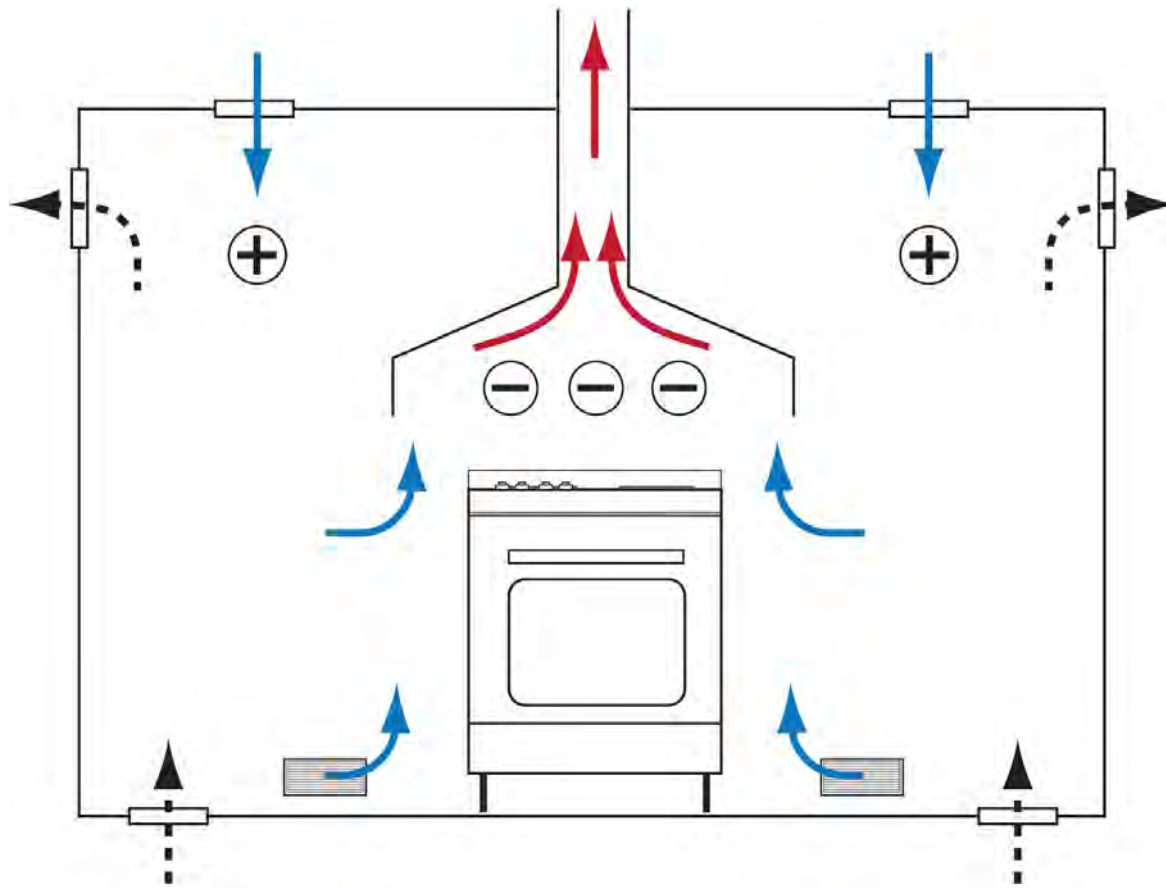




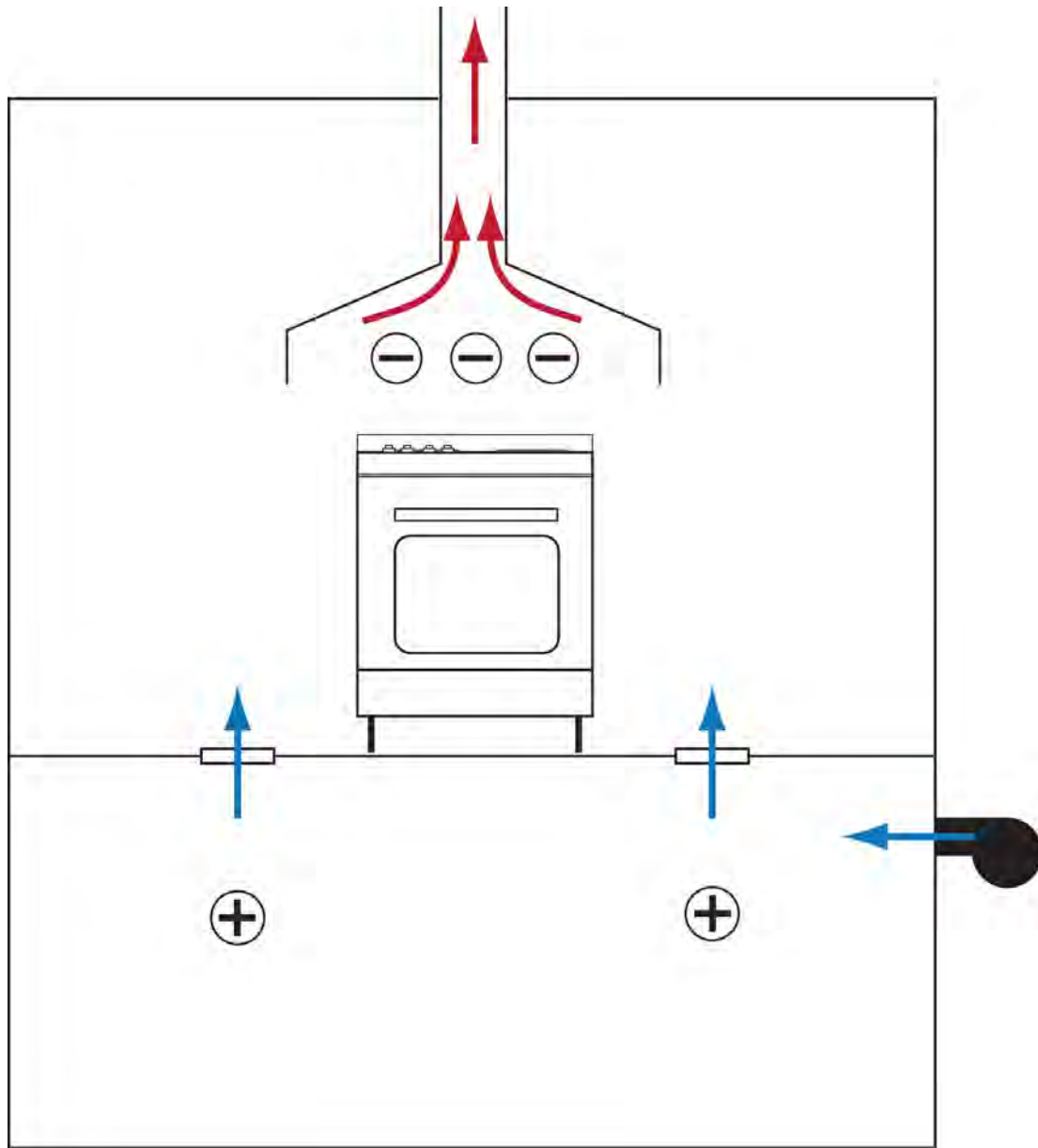
# Kitchen Exhaust Hoods











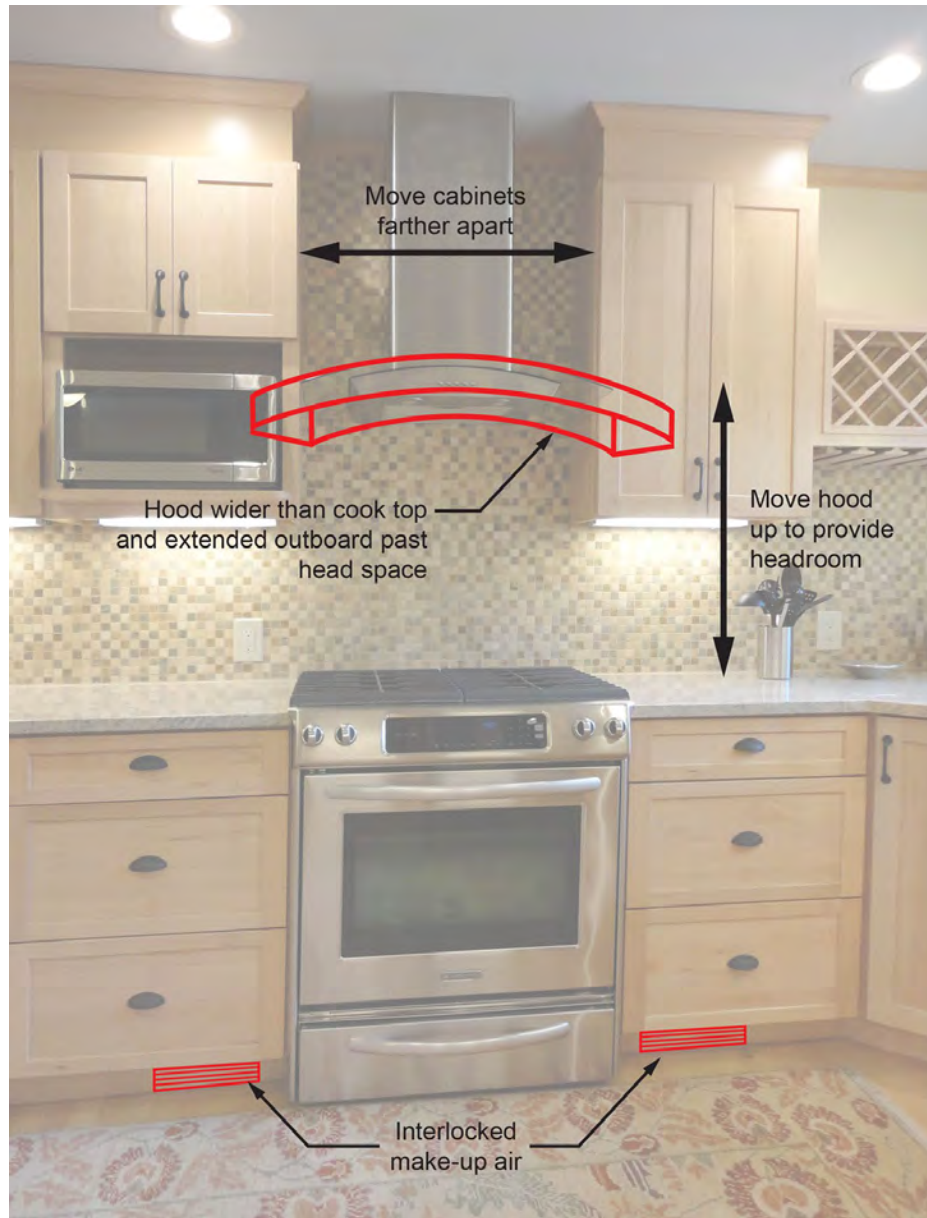


















# Clothes Dryers





# Fireplaces





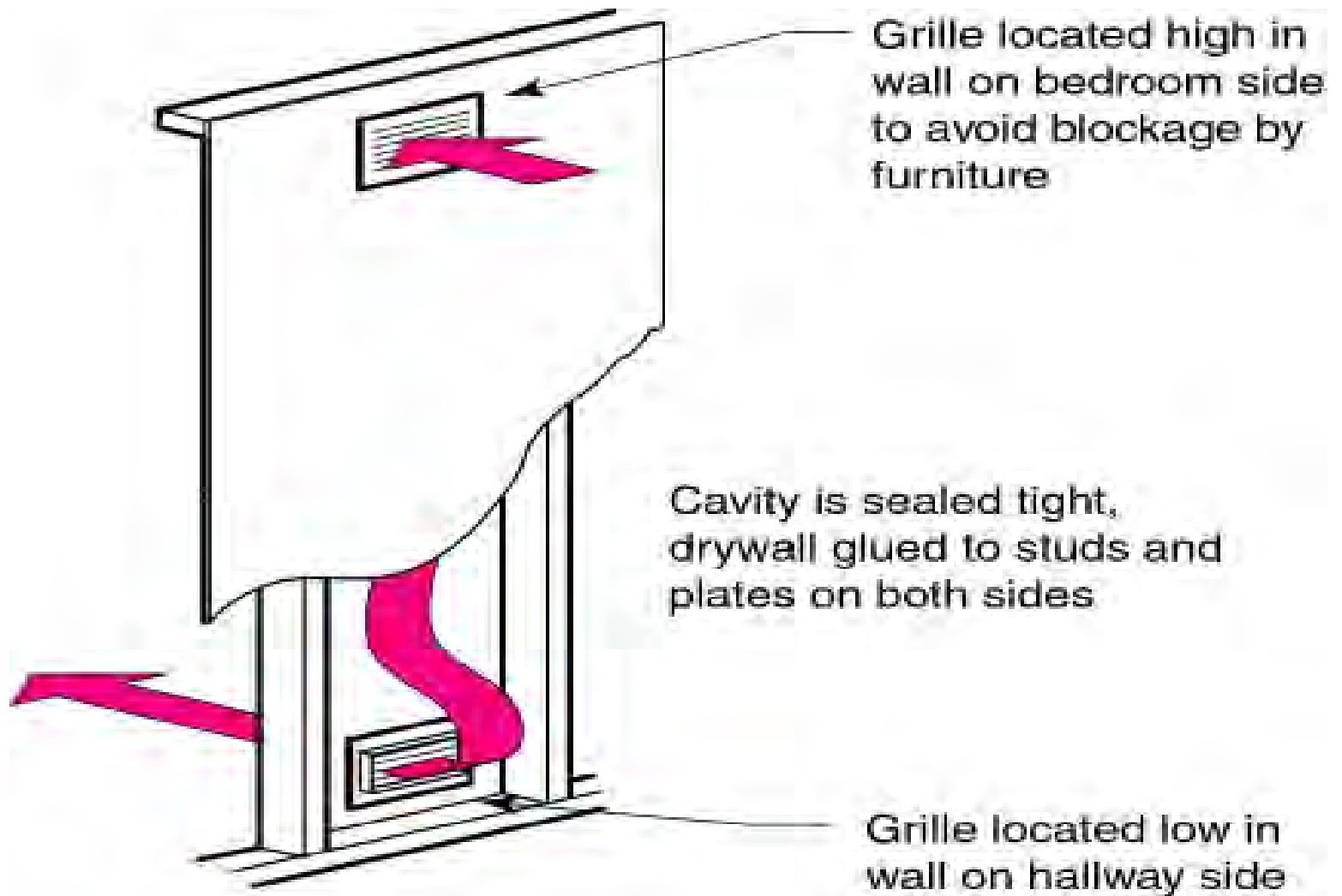




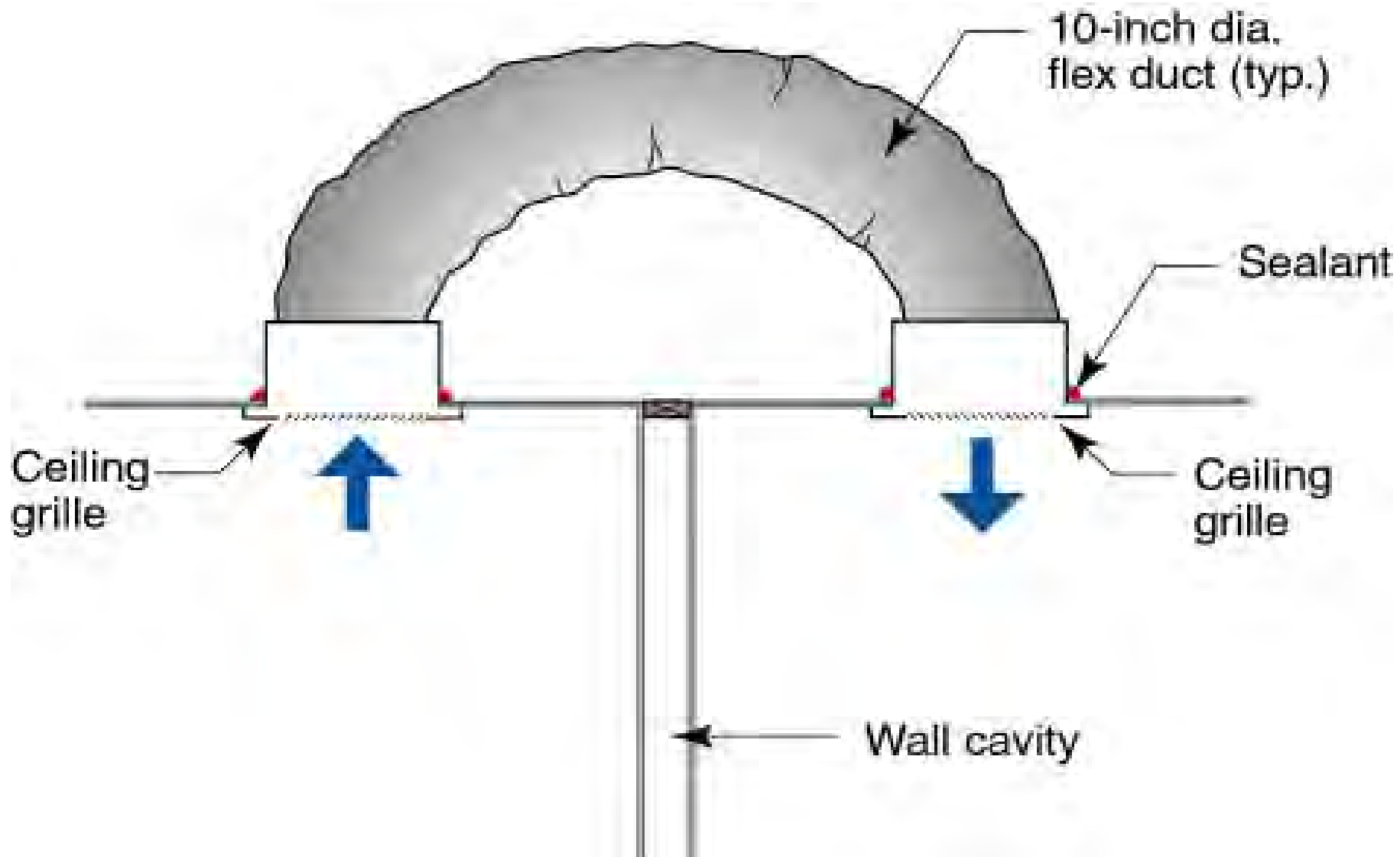


# Equalizing Pressures

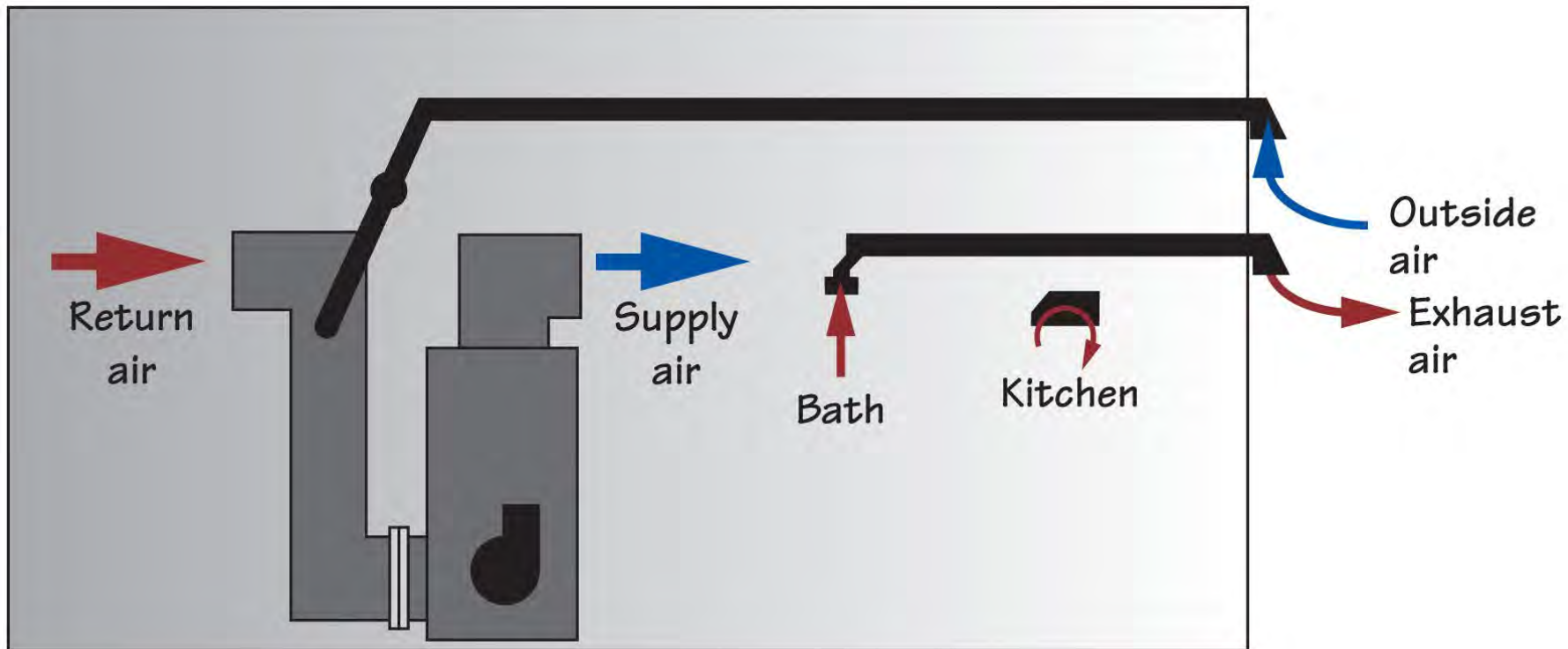




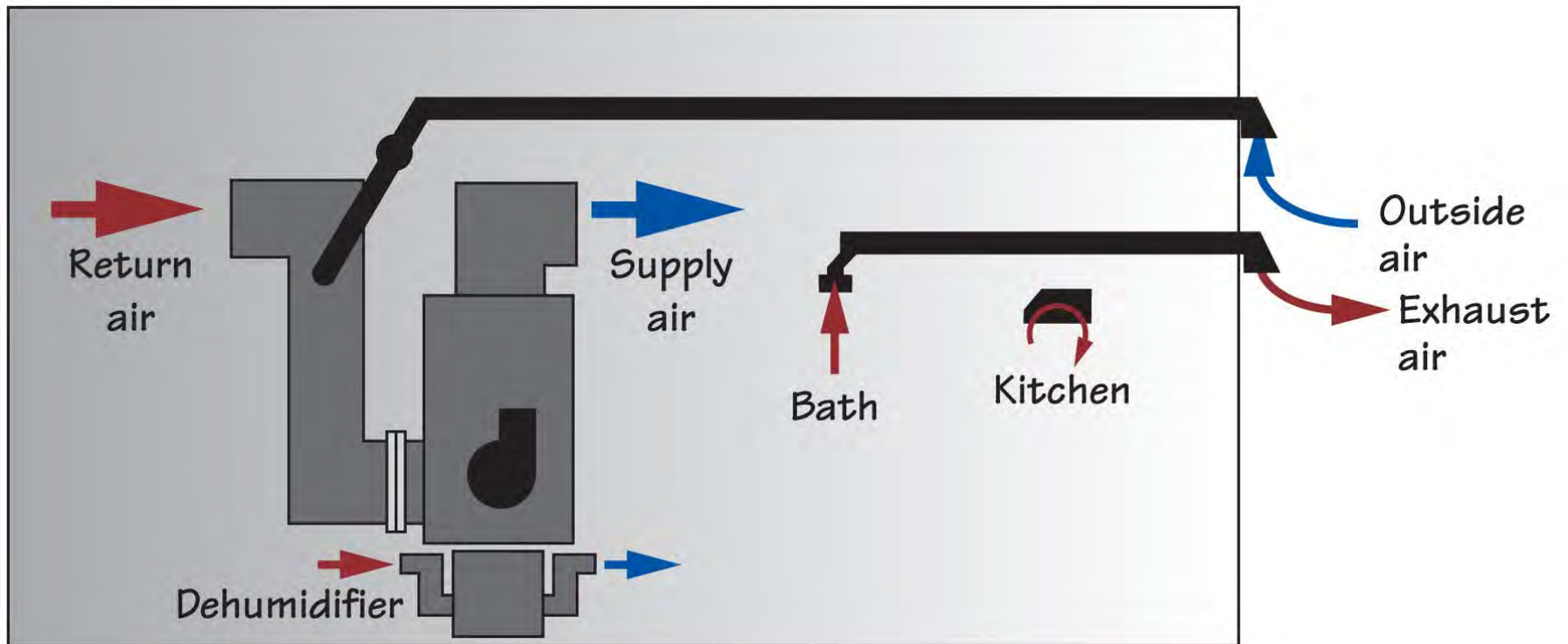


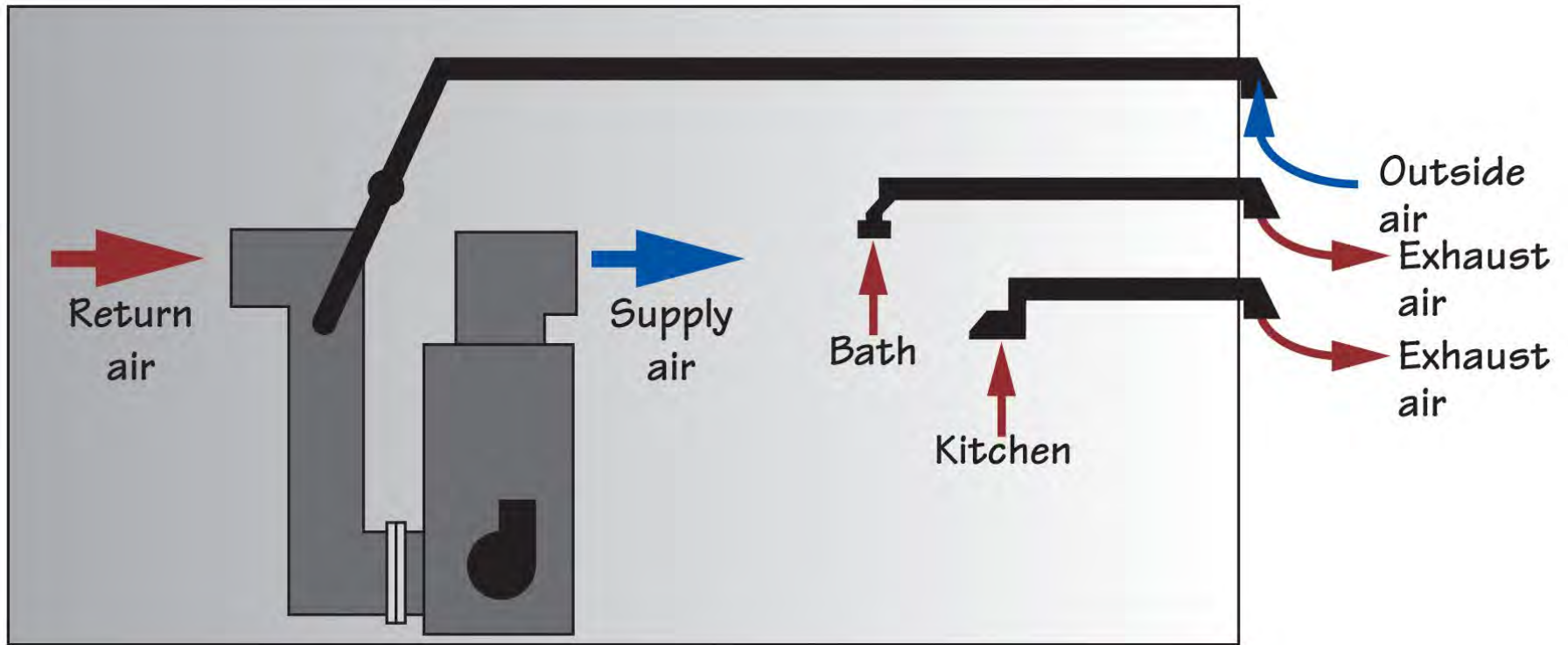


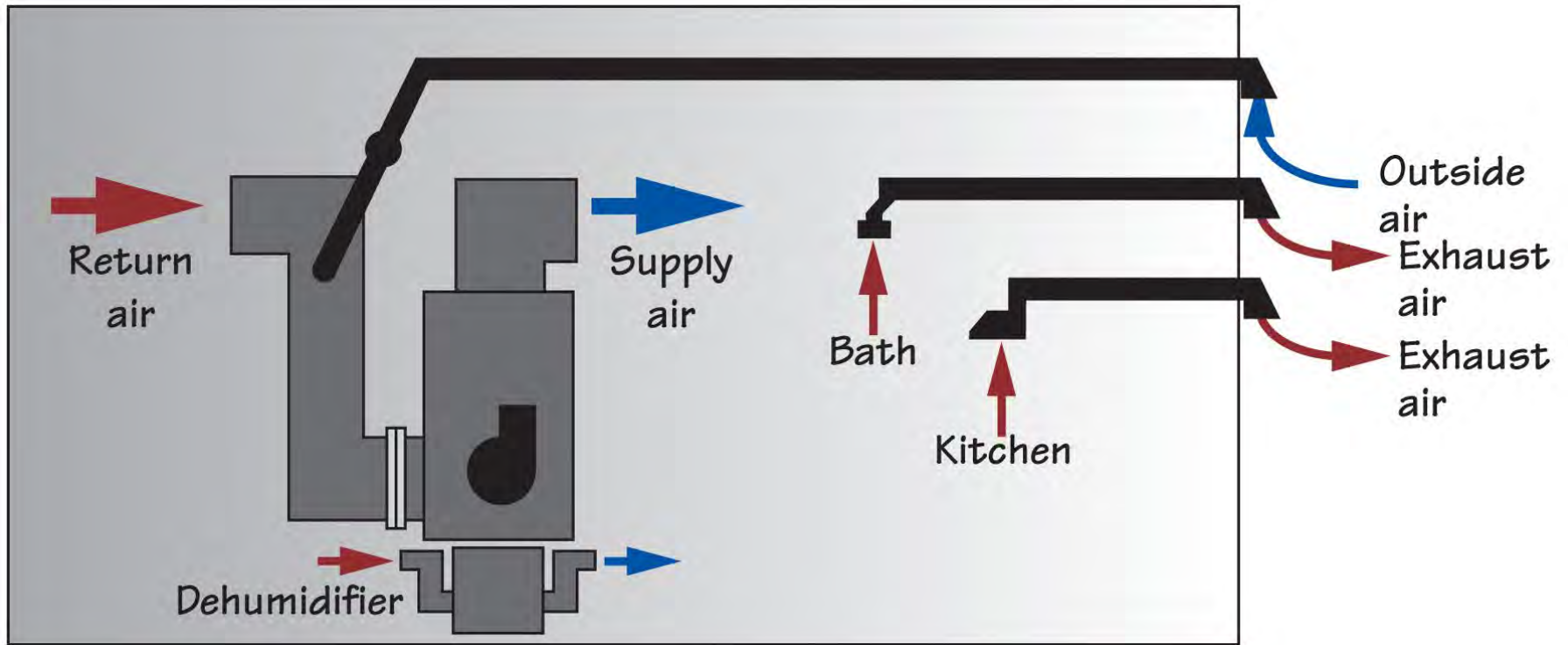
# Approaches

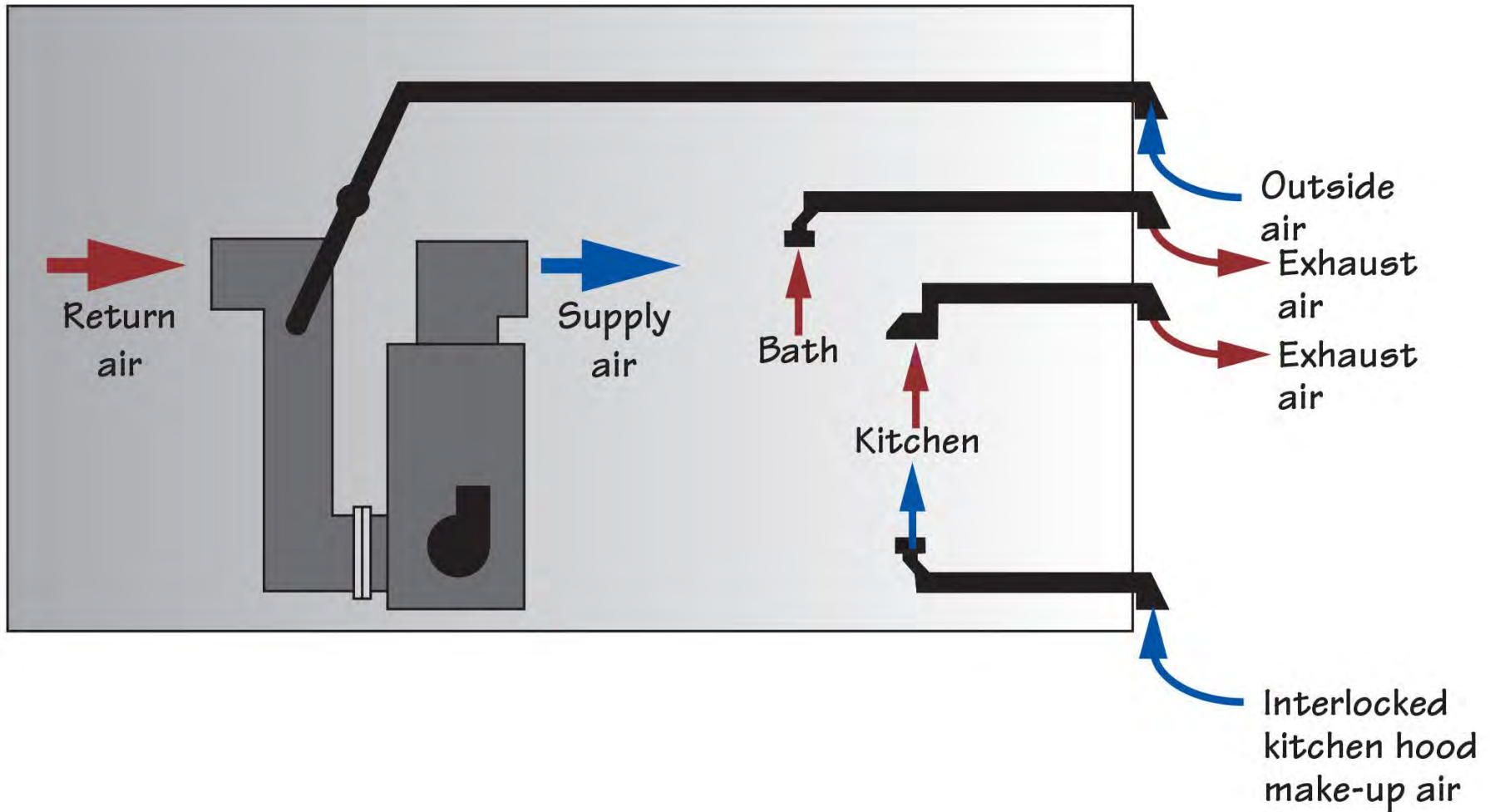


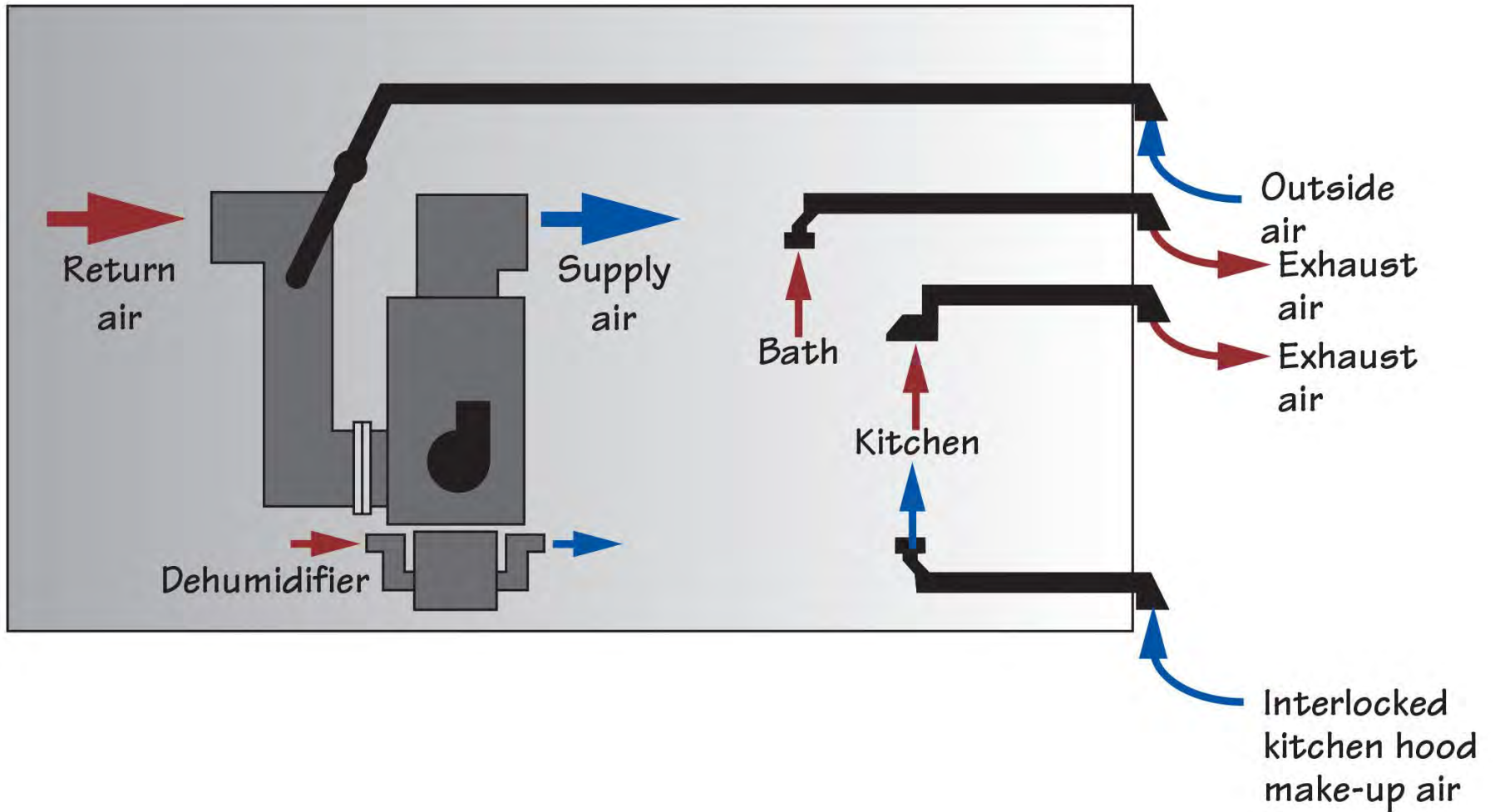


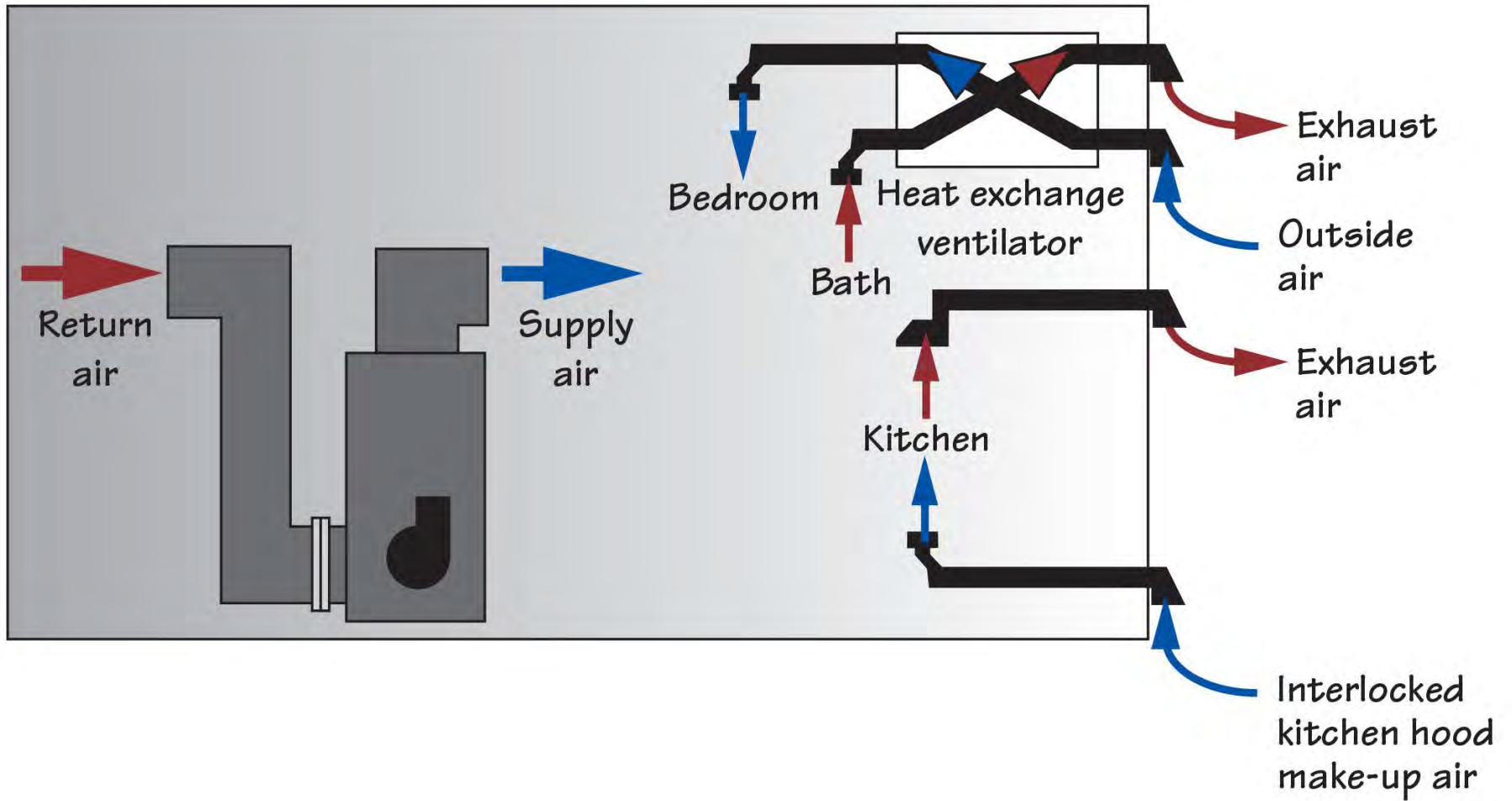


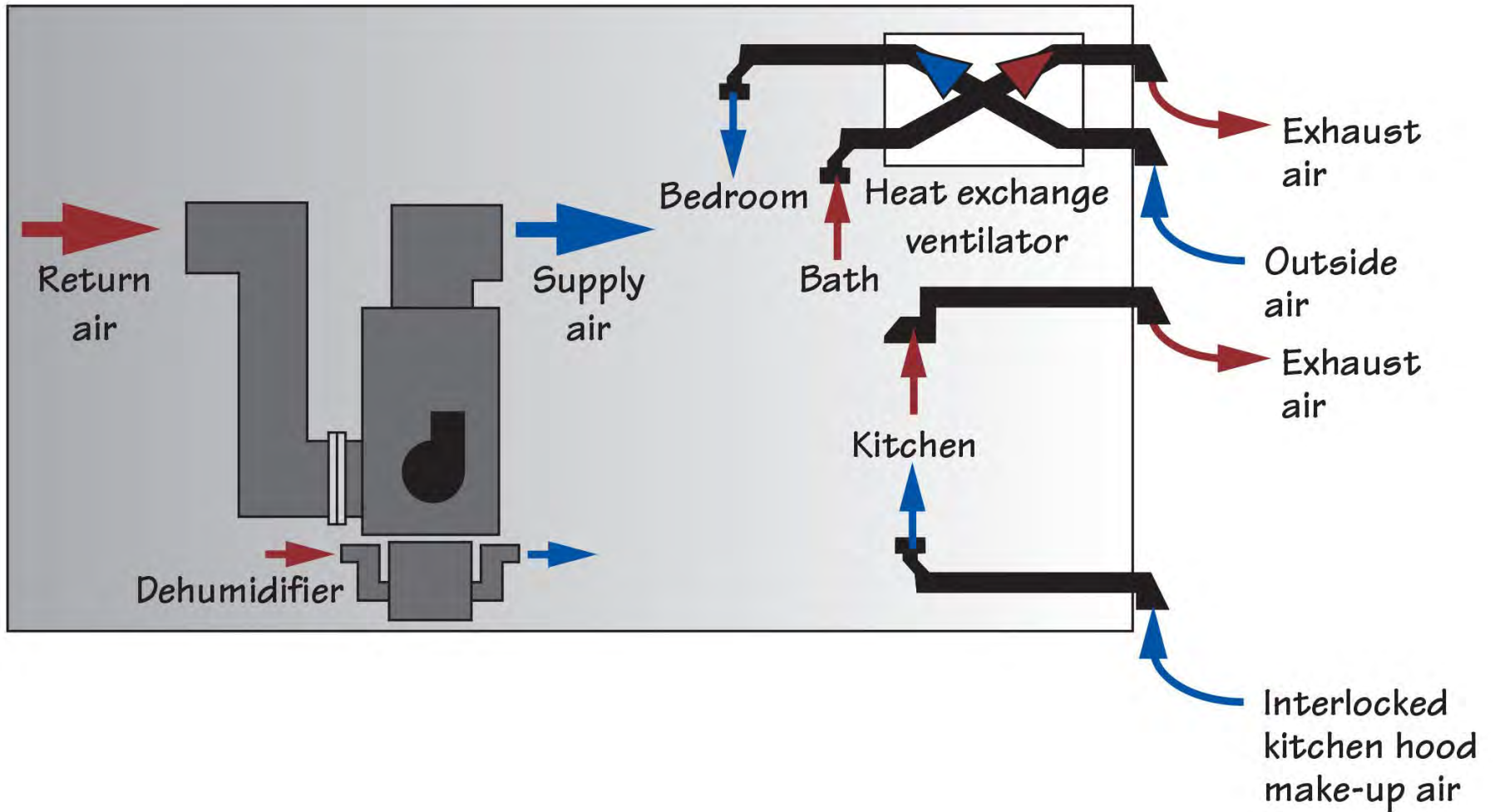


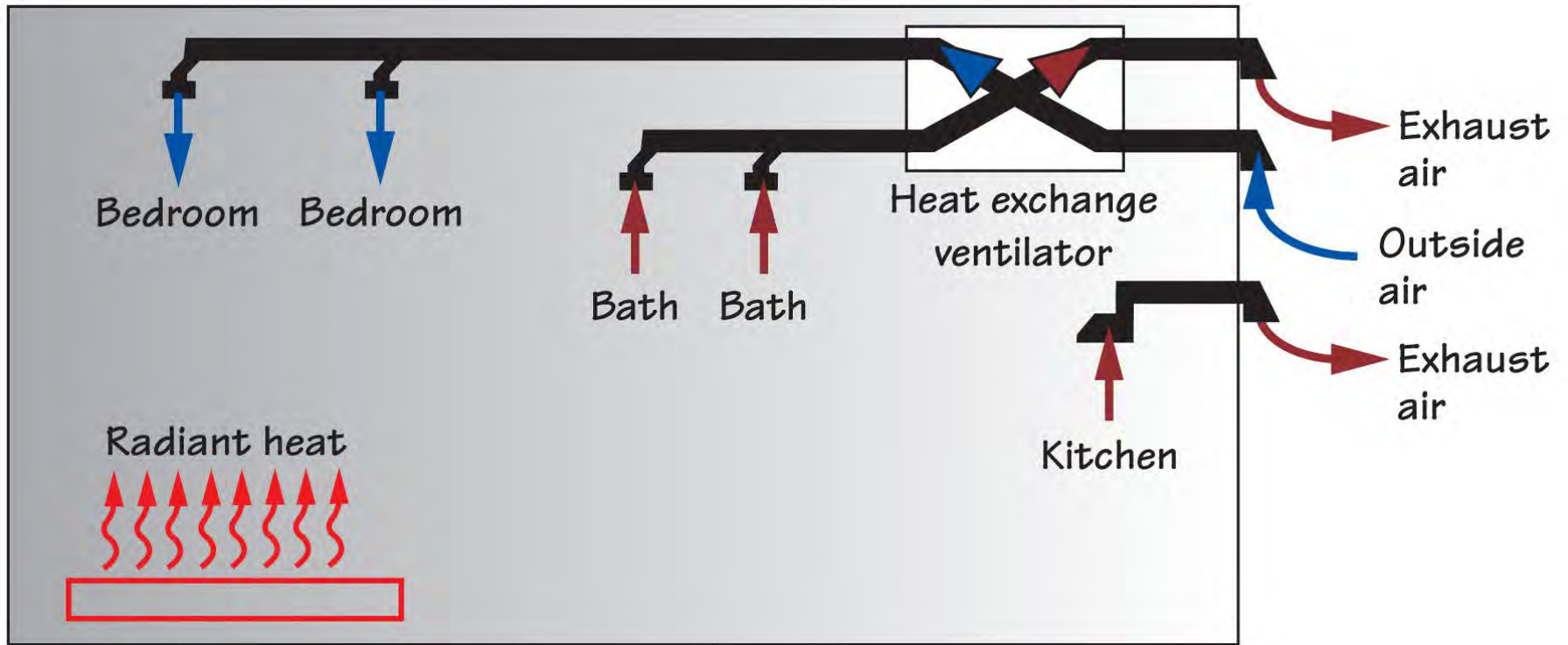




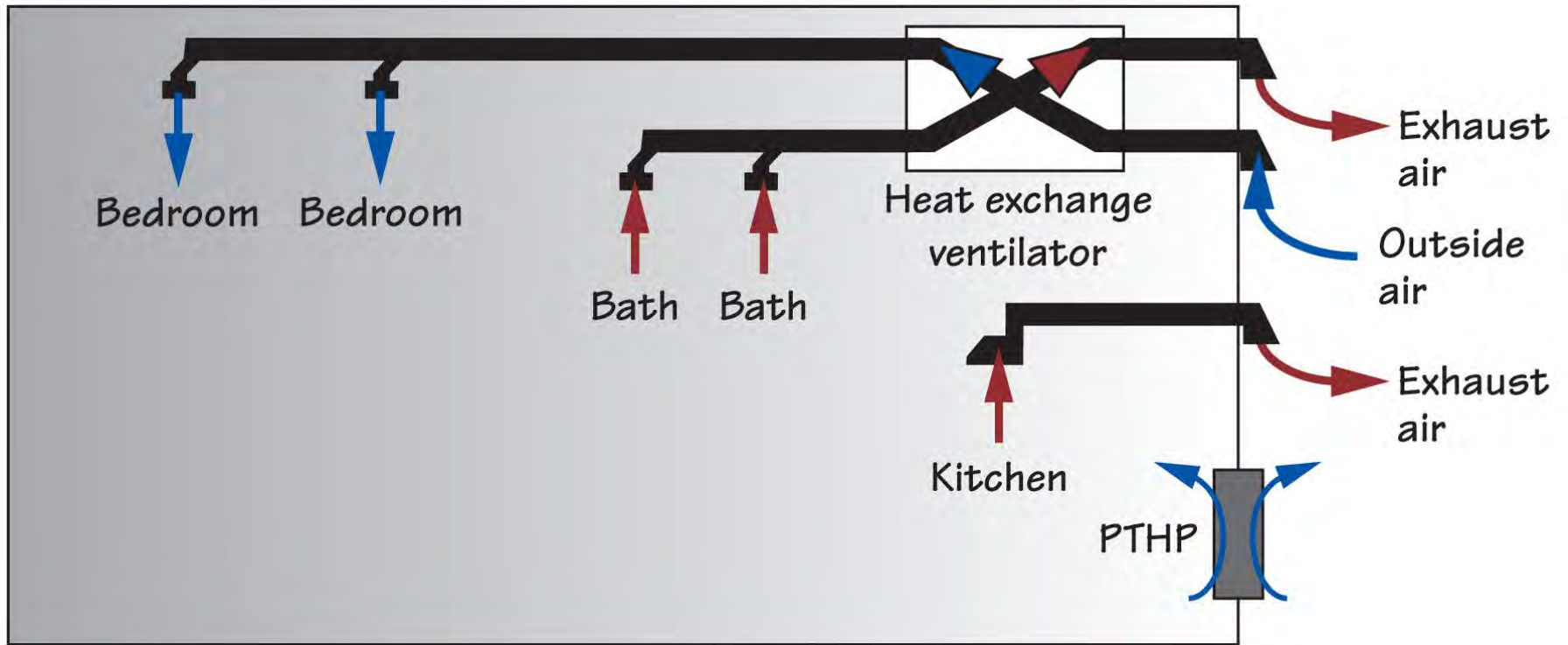


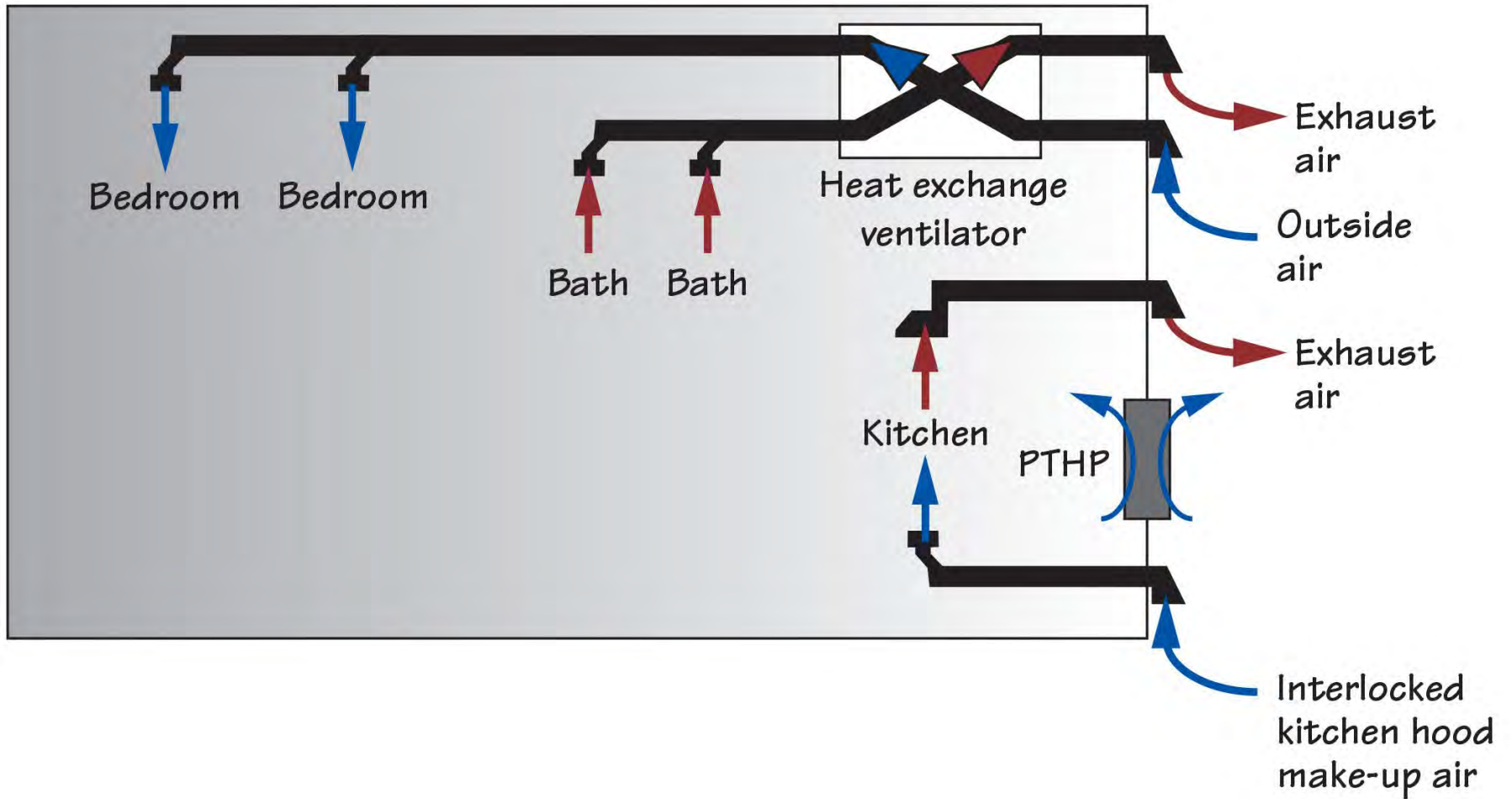


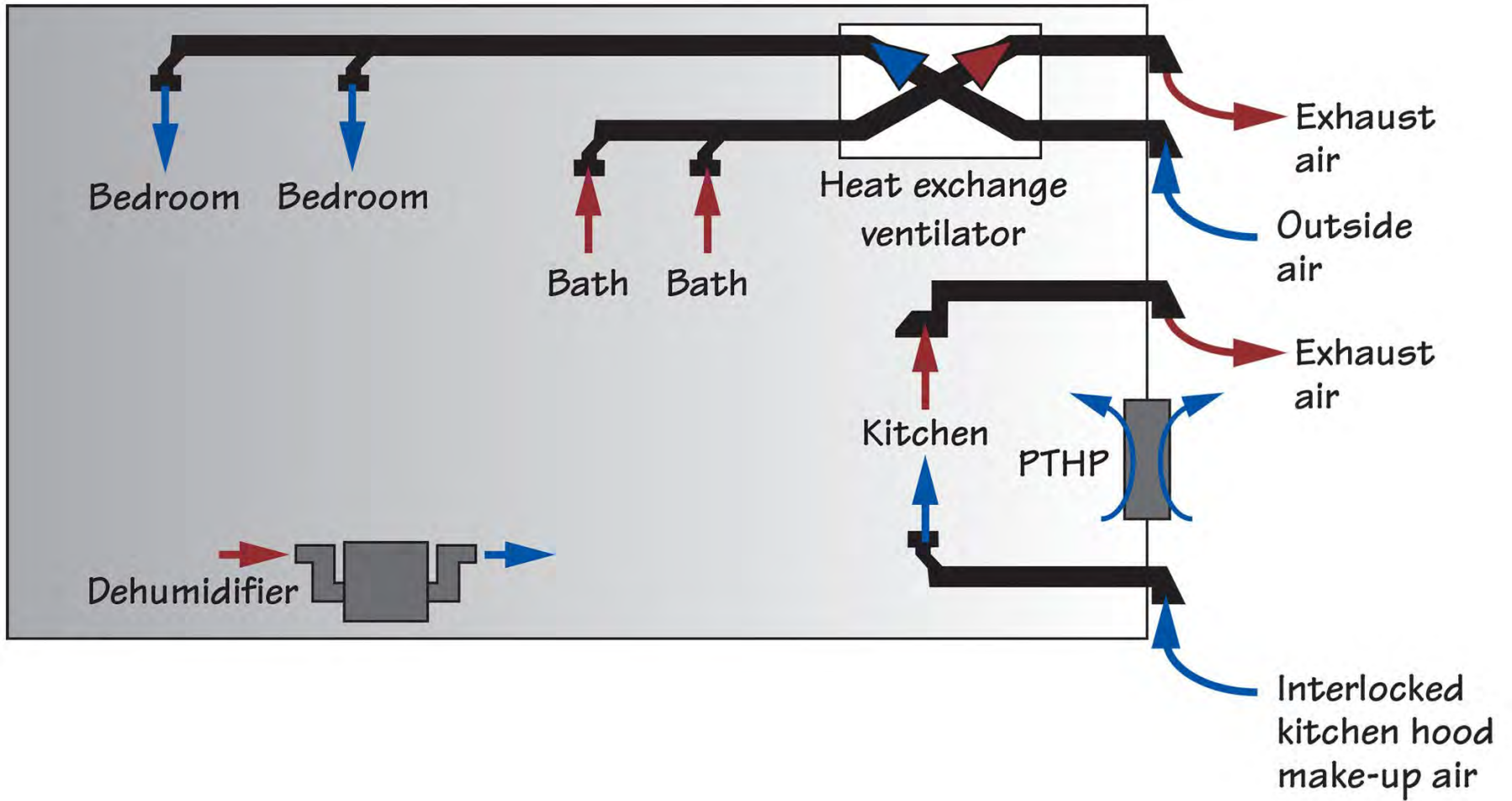














# Soil Gas....Again

