

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

Building Science

Adventures In Building Science

www.buildingscience.com

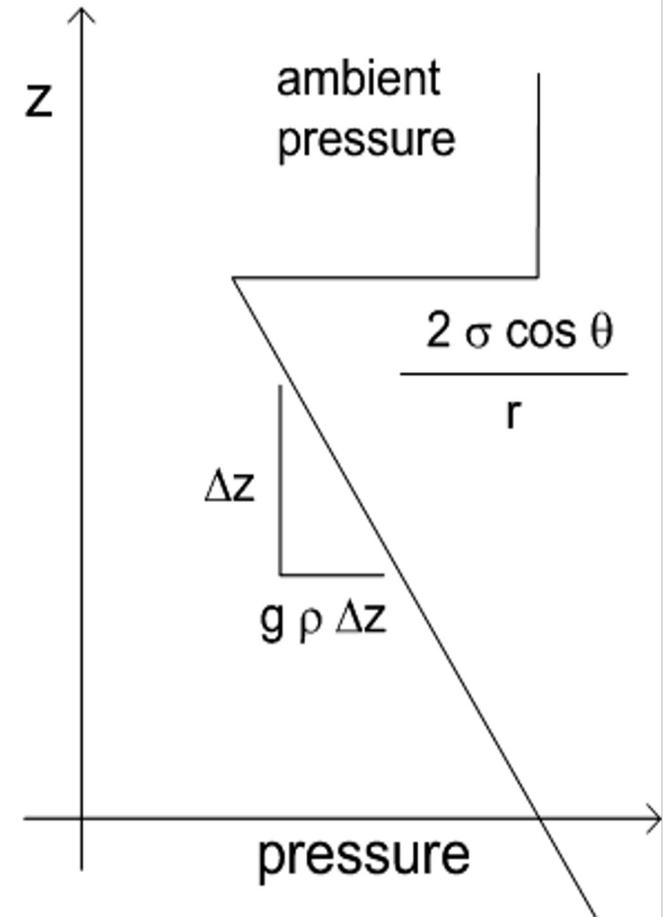
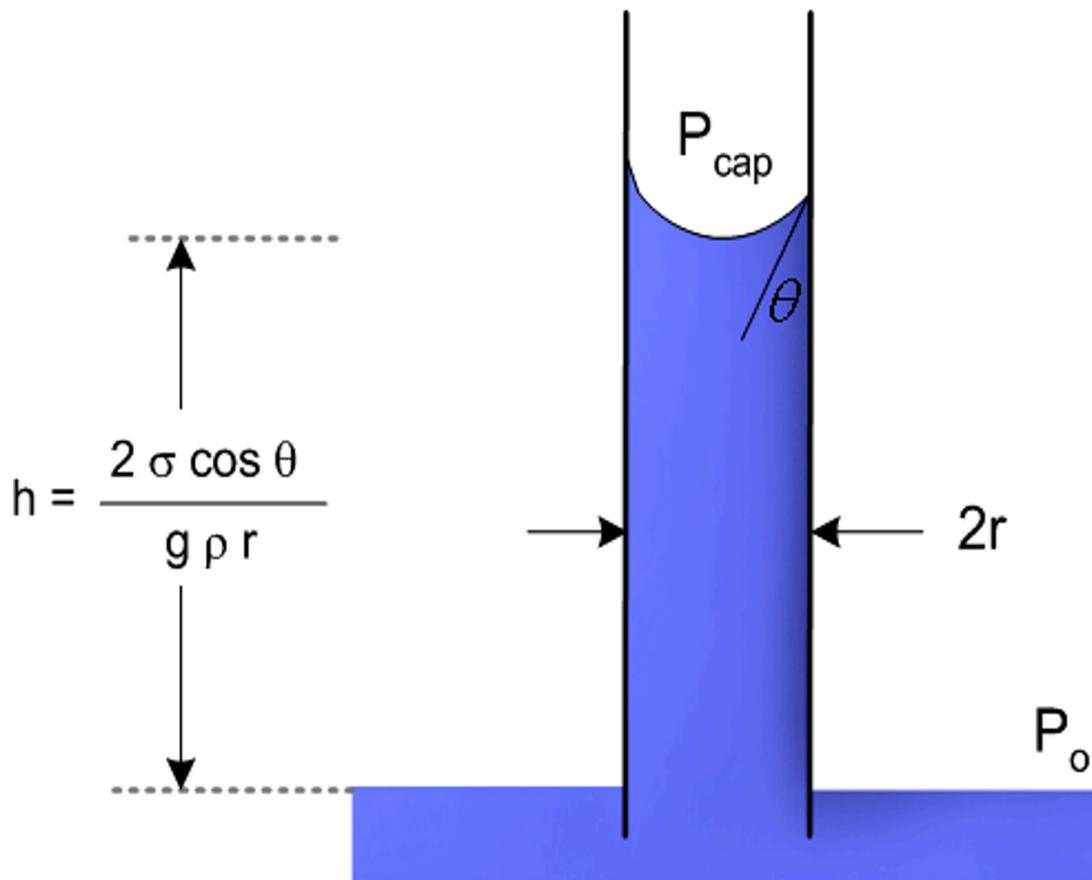
Capillarity

William Thomson – Lord Kelvin

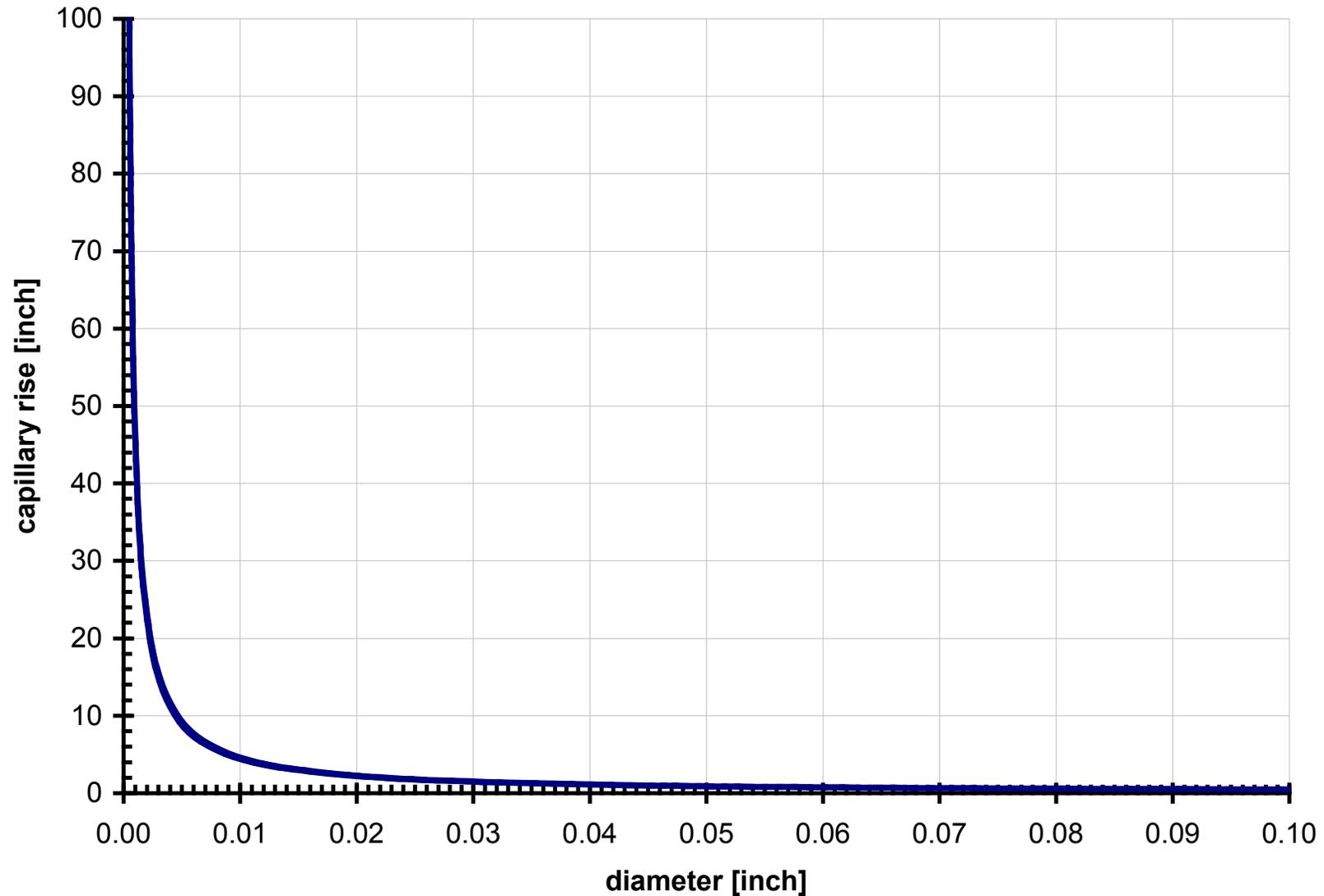
Kelvin Equation

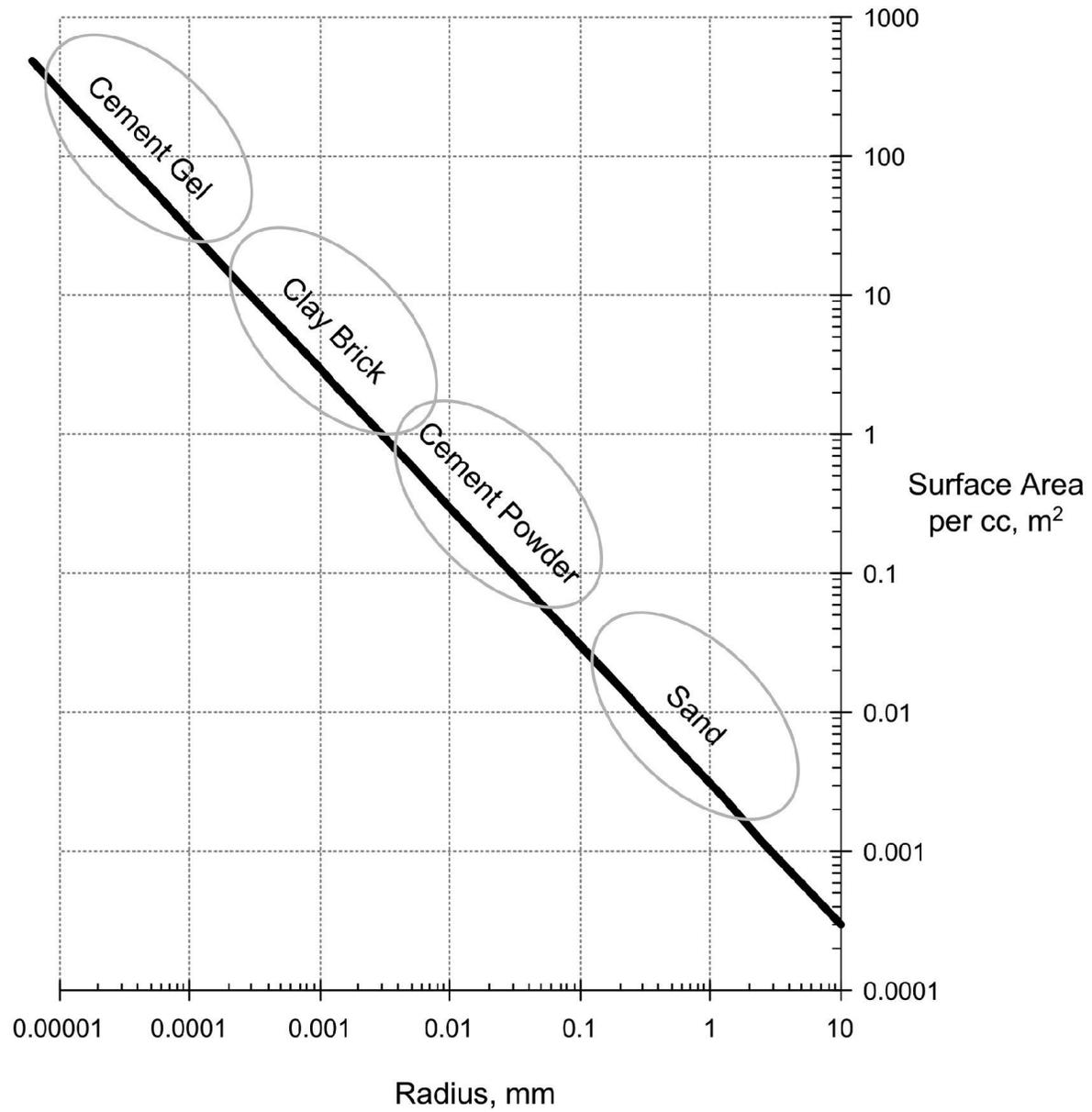
$$\ln \frac{p}{p_0} = \frac{2\gamma V_m}{rRT}$$

Calculating capillary rise



Capillary rise versus diameter





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



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

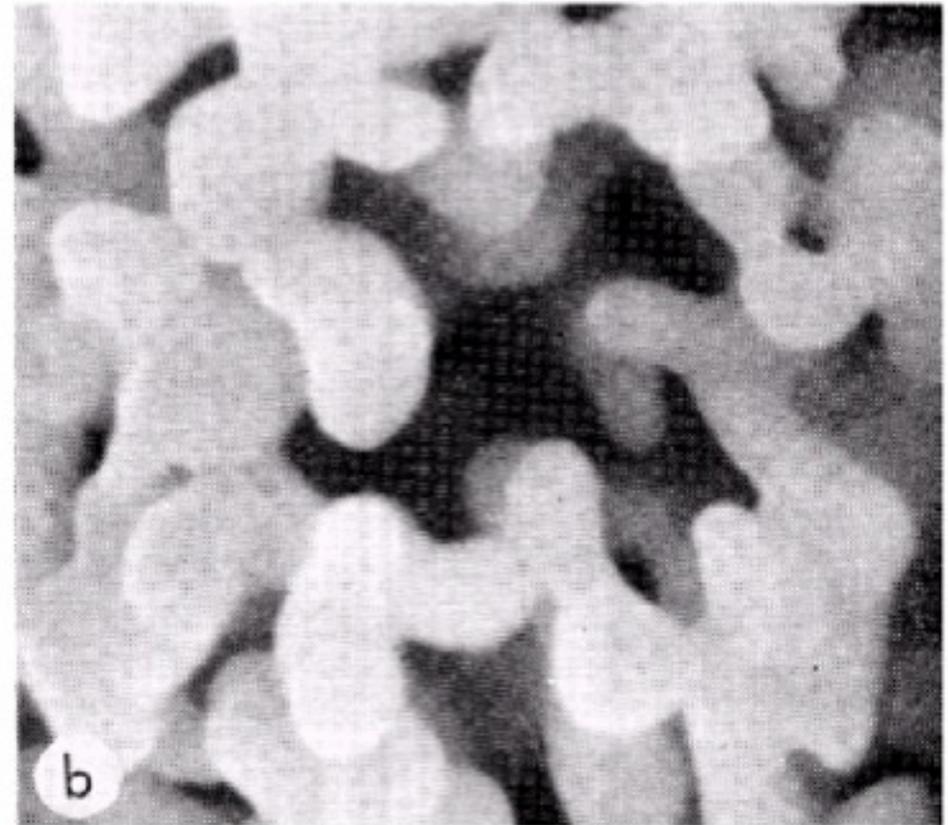
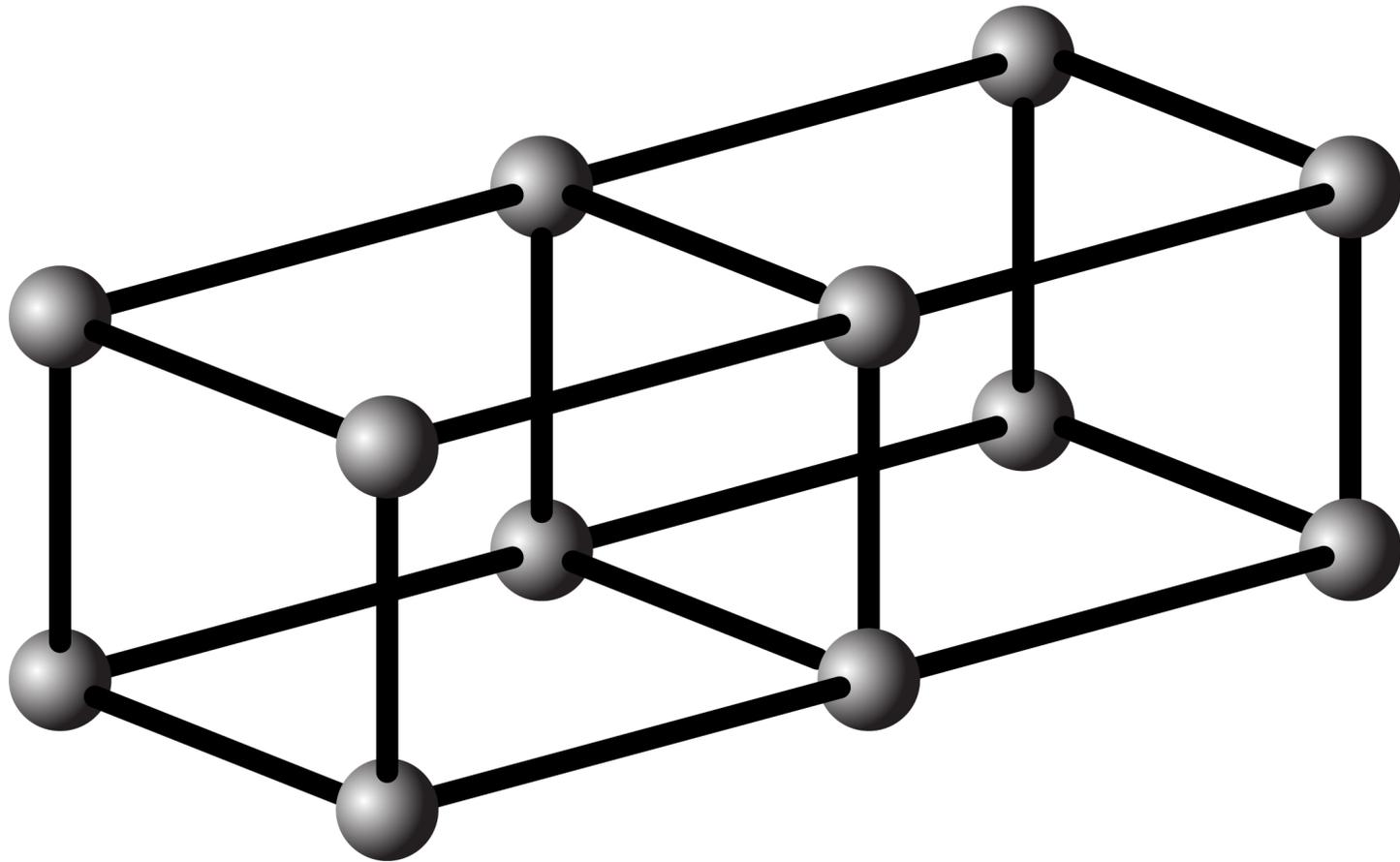
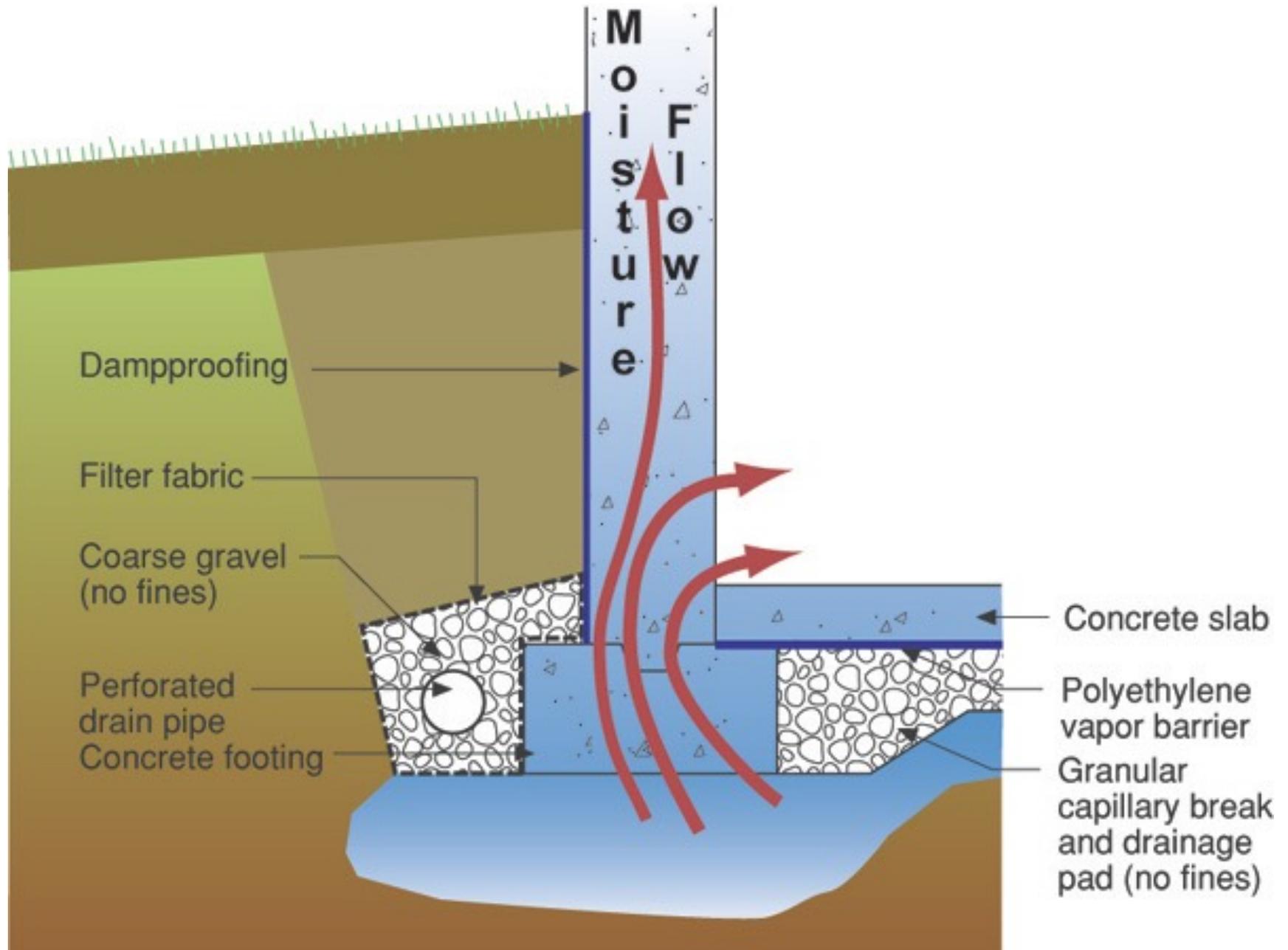
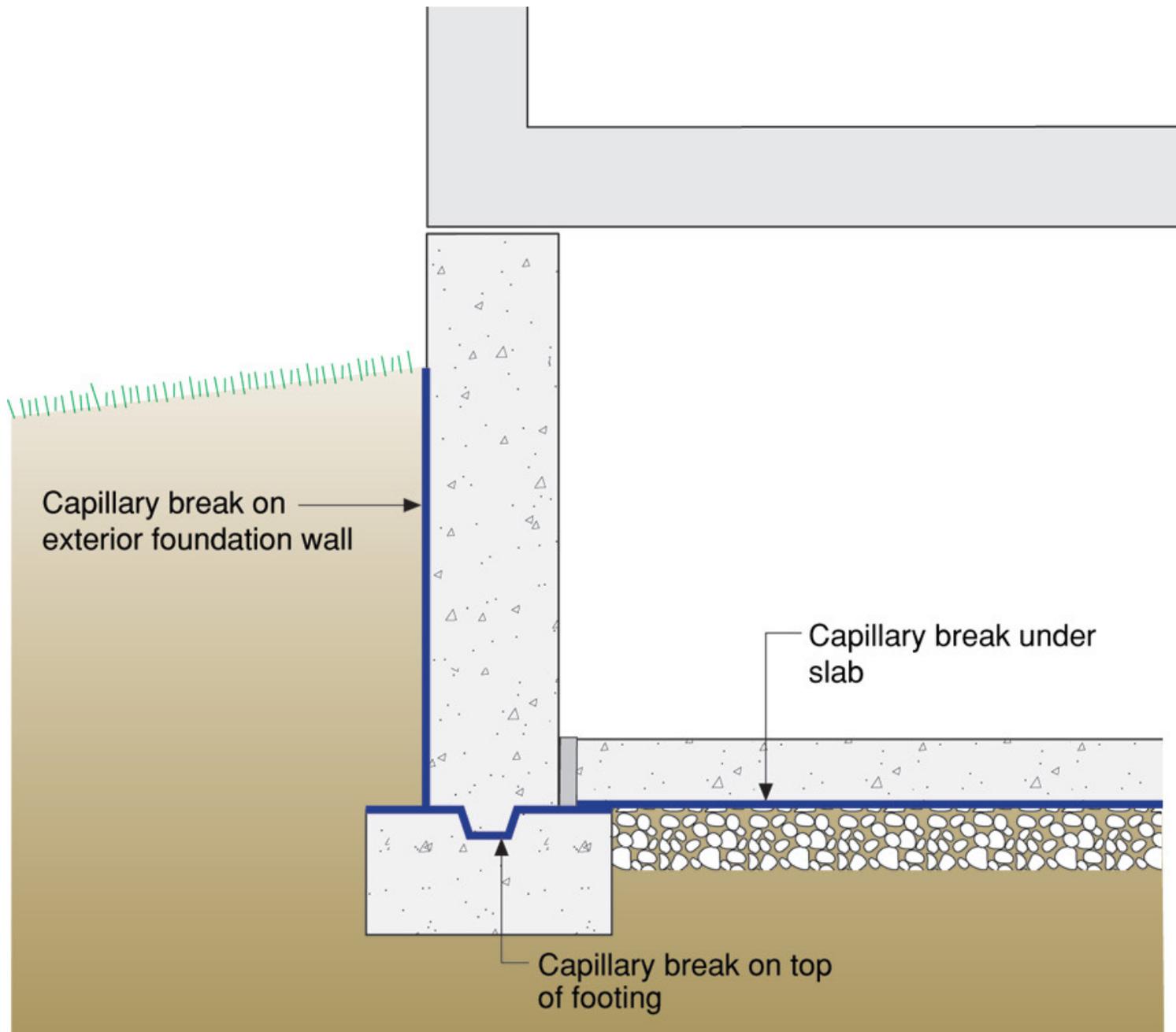


Figure 1b. Brick, sintered clay, porosity 40 per cent.



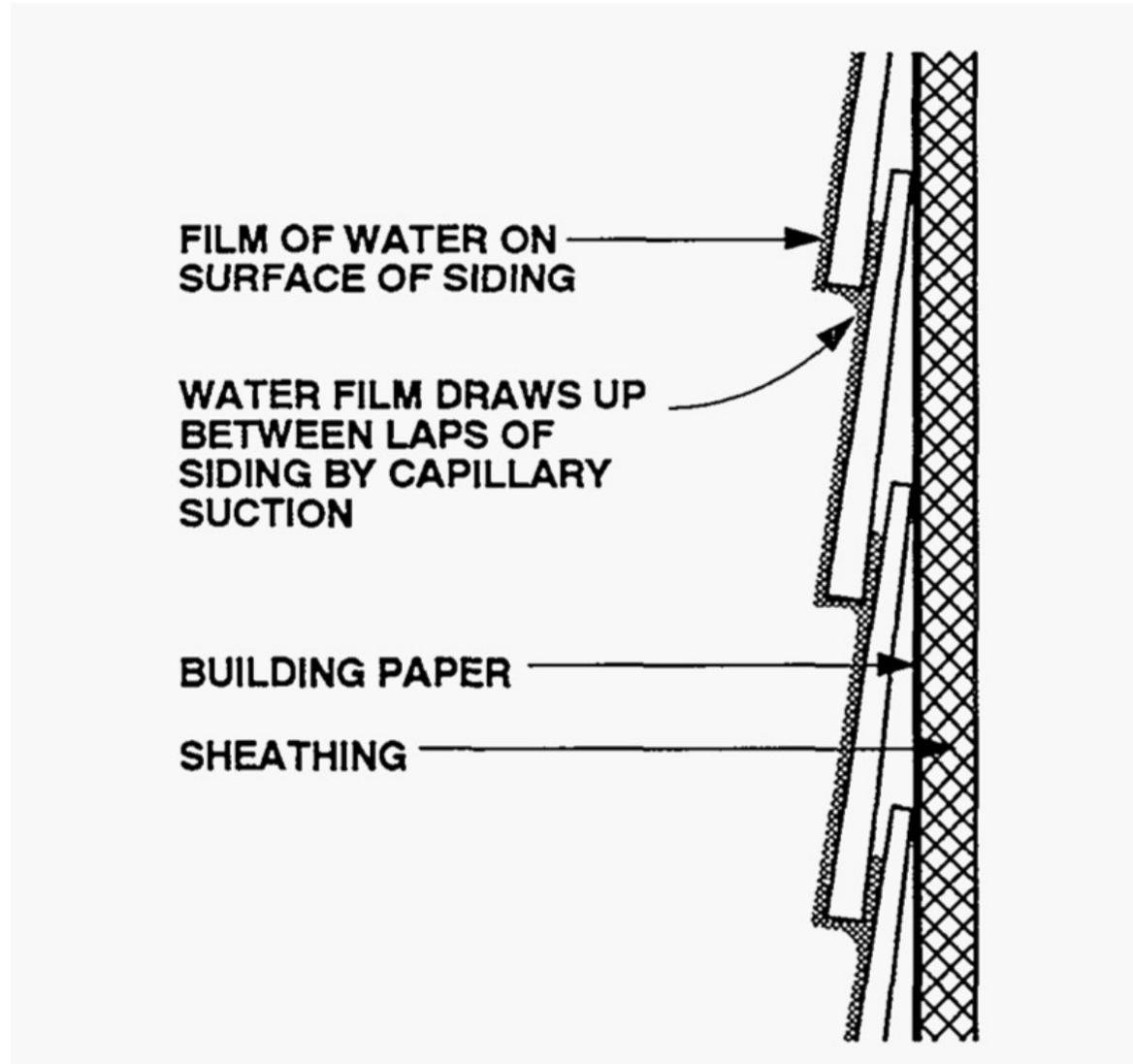




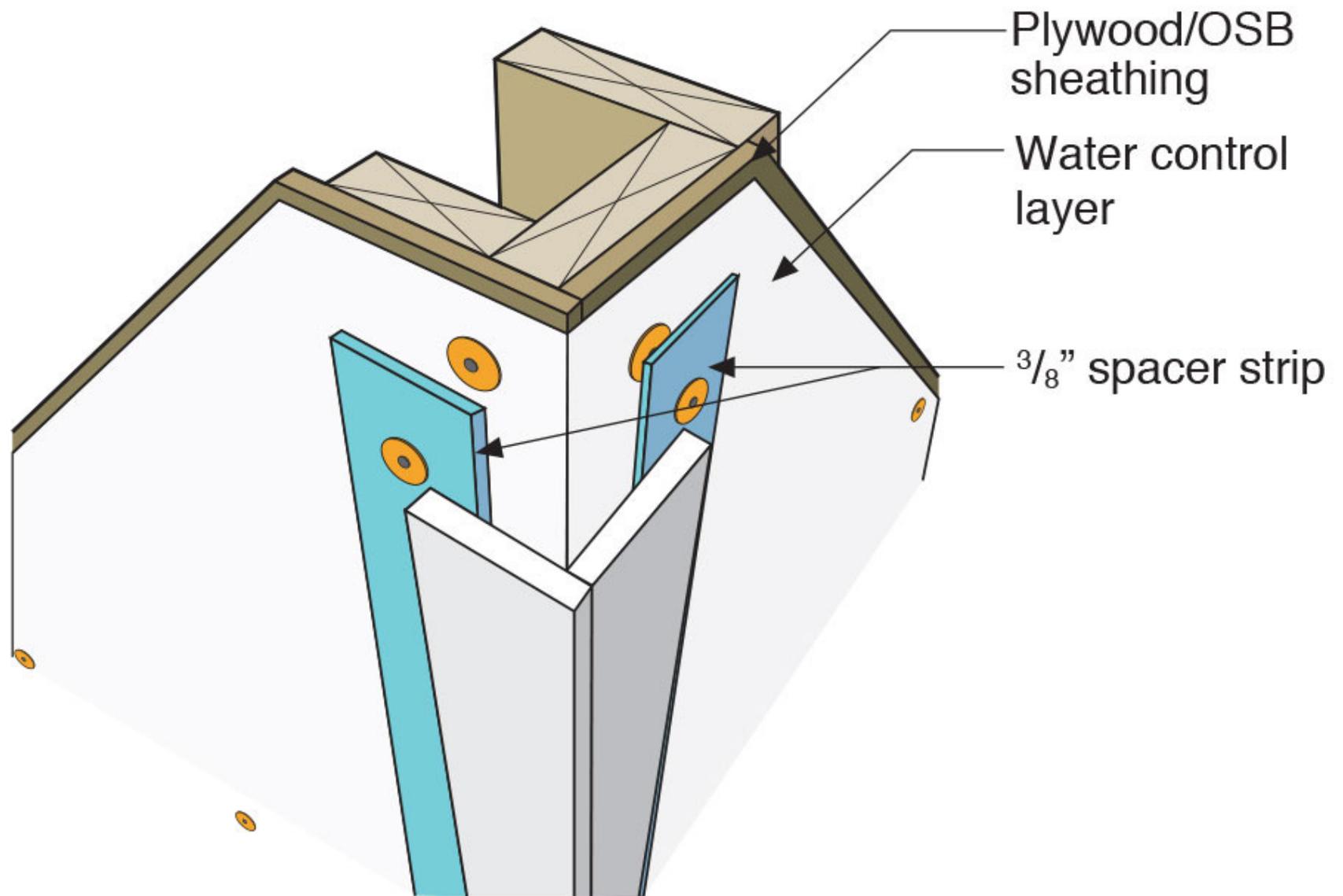


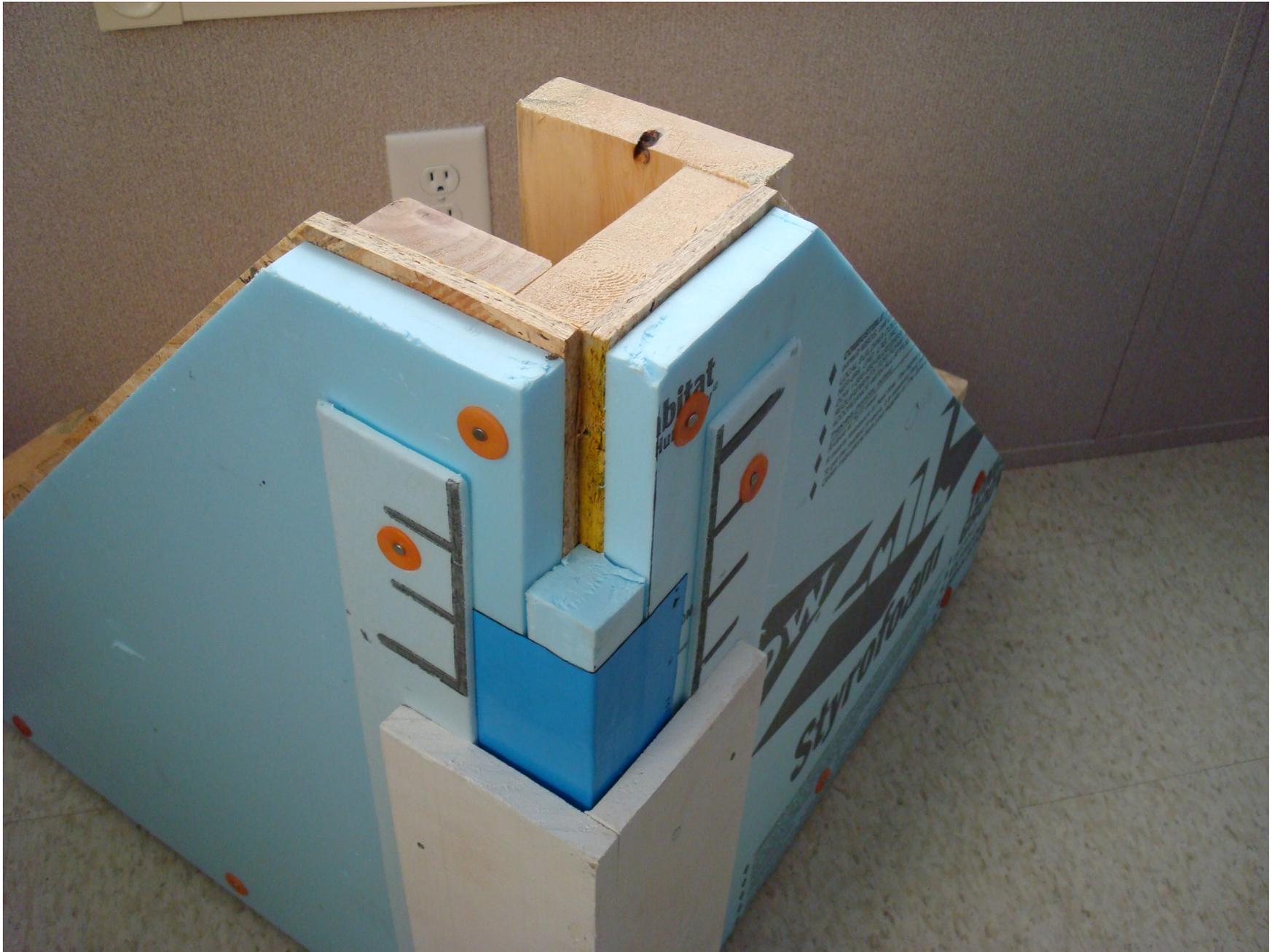
Siding Laps













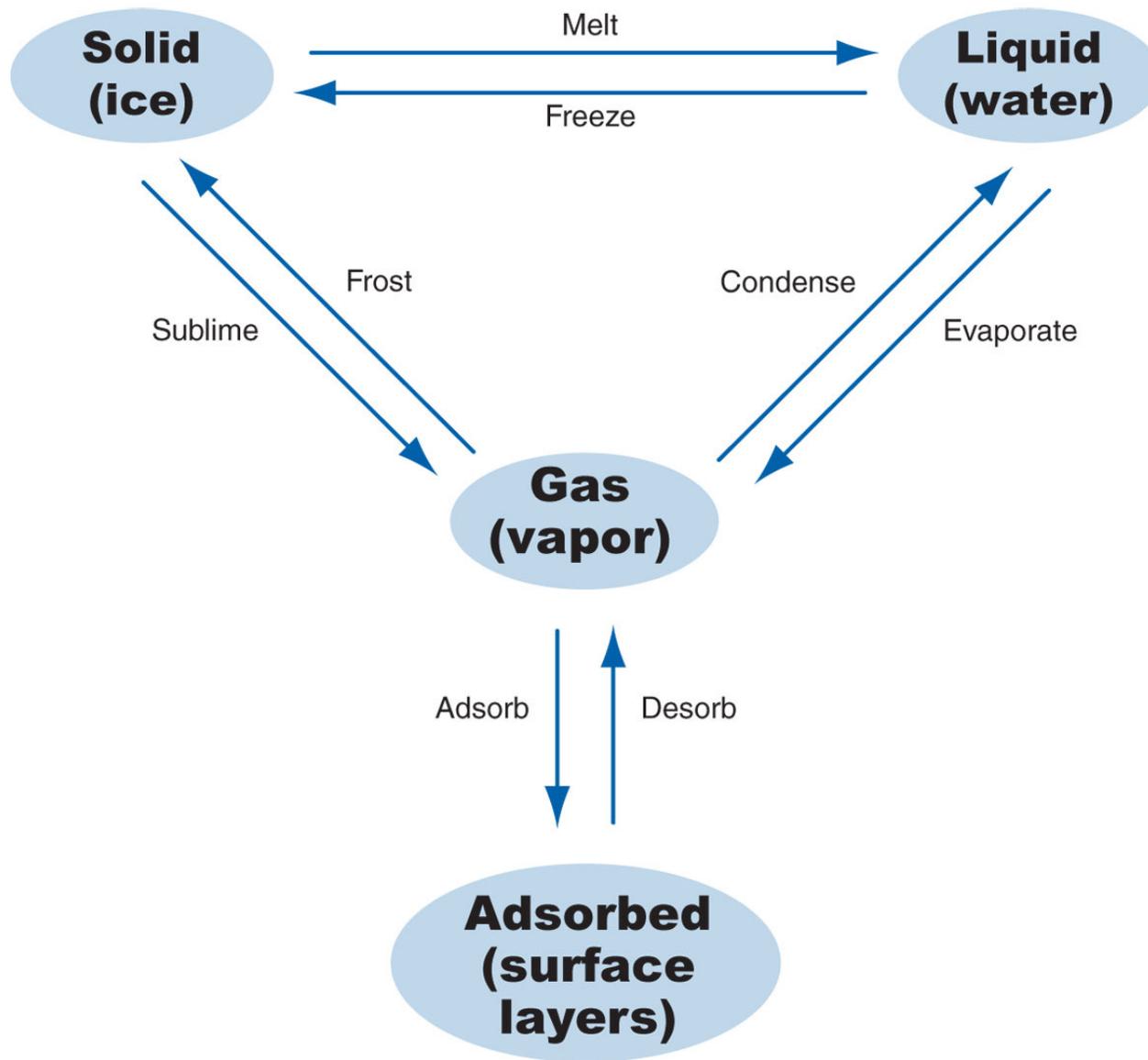


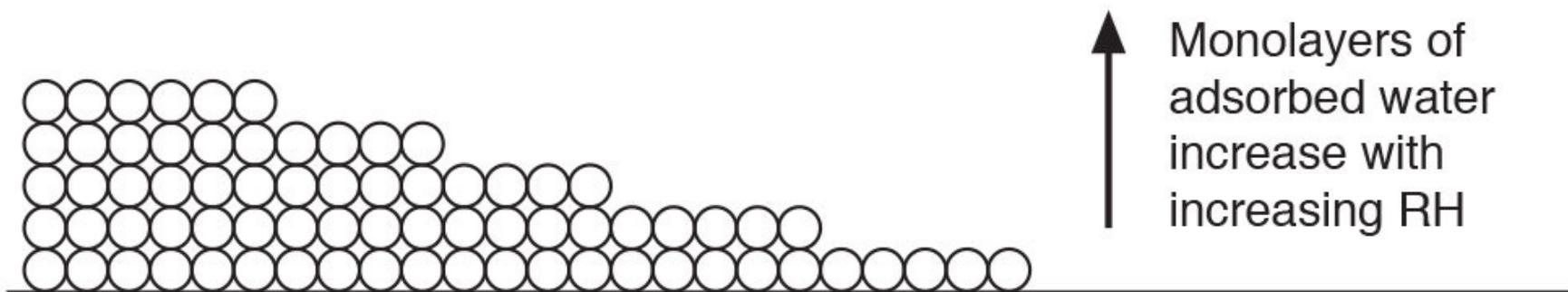


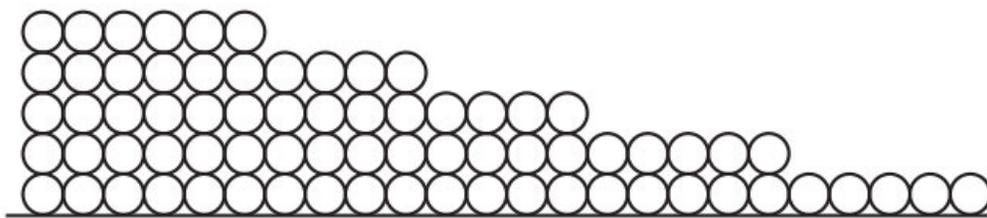


Kelvin Equation Again....

$$\ln \frac{p}{p_0} = \frac{2\gamma V_m}{rRT}$$

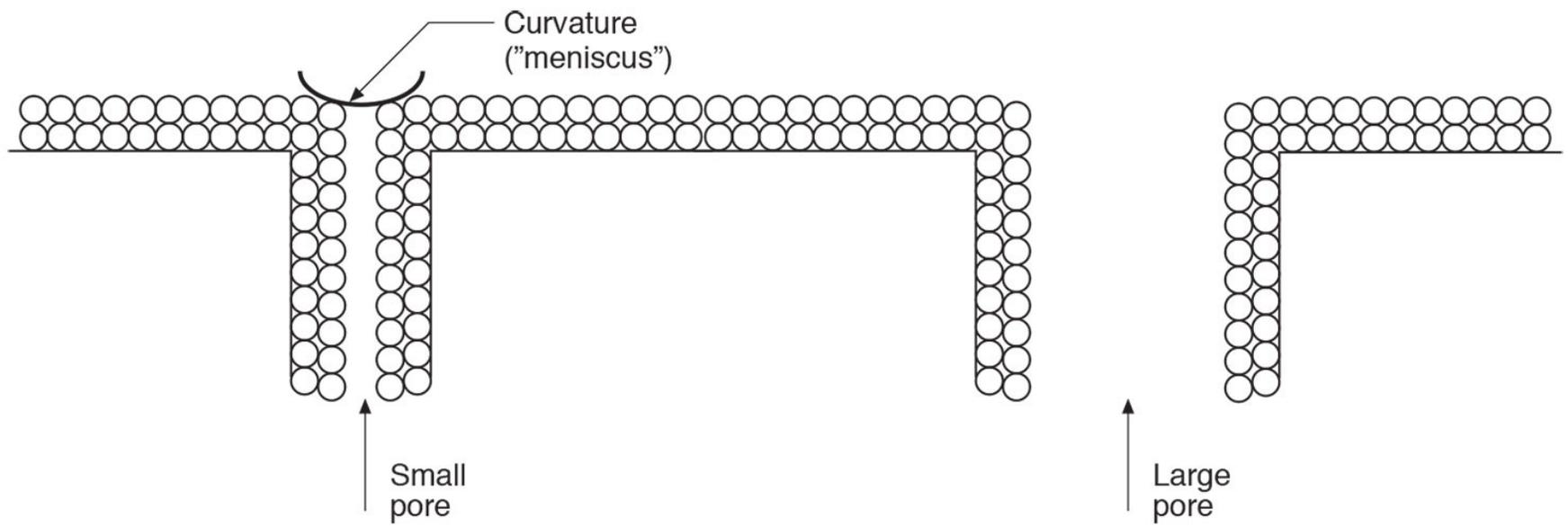






Monolayers
flow along surface
following concentration gradient







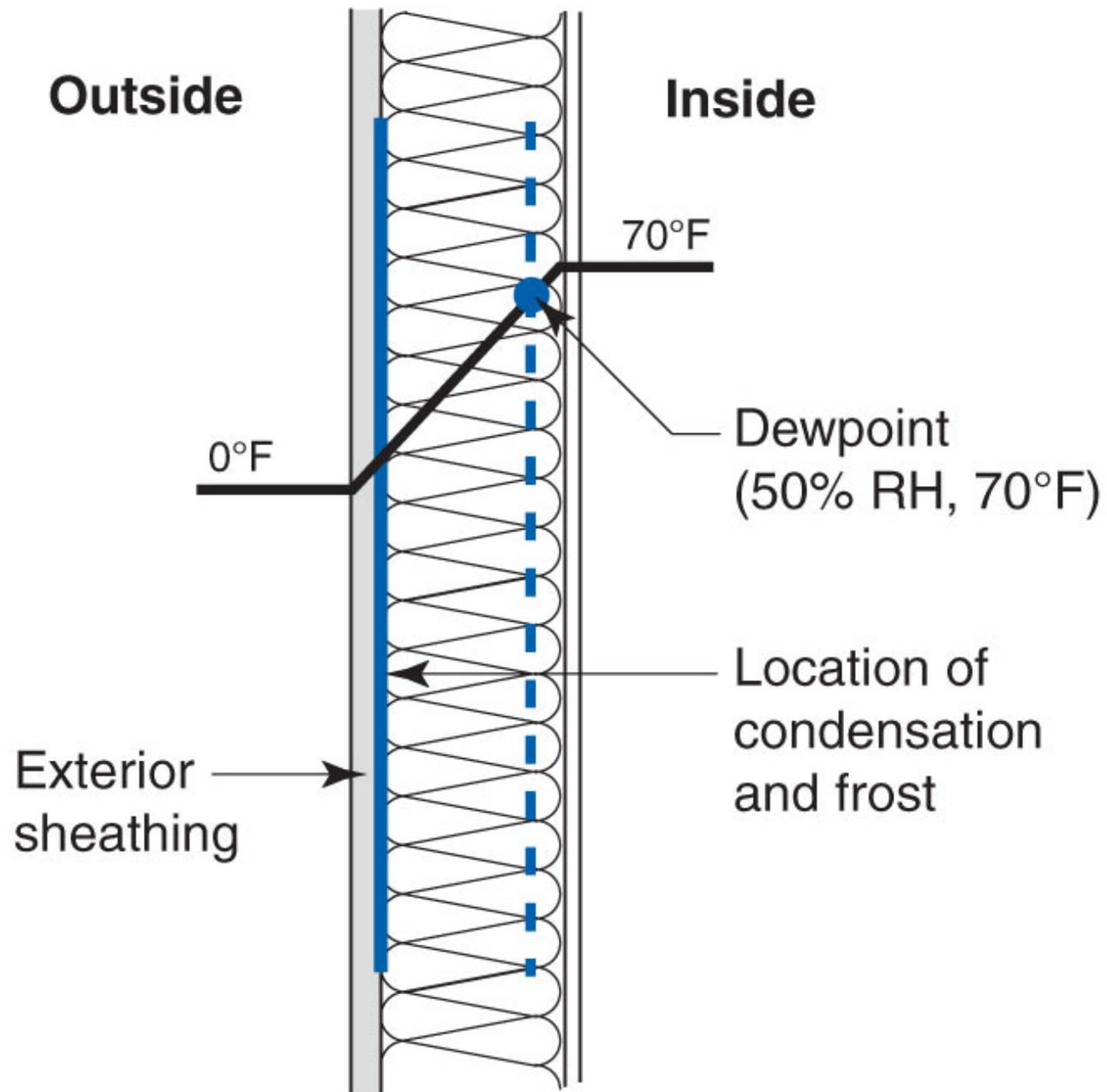
The Myth of the Dew Point

The Myth of the Dew Point

1 Btu to change 1 lb of water 1 degree F

144 Btu's to change 1 lb of water to 1 lb of ice (latent heat of fusion)

970 Btu's to change 1 lb of water to 1 lb of water vapor (latent heat of vaporization)

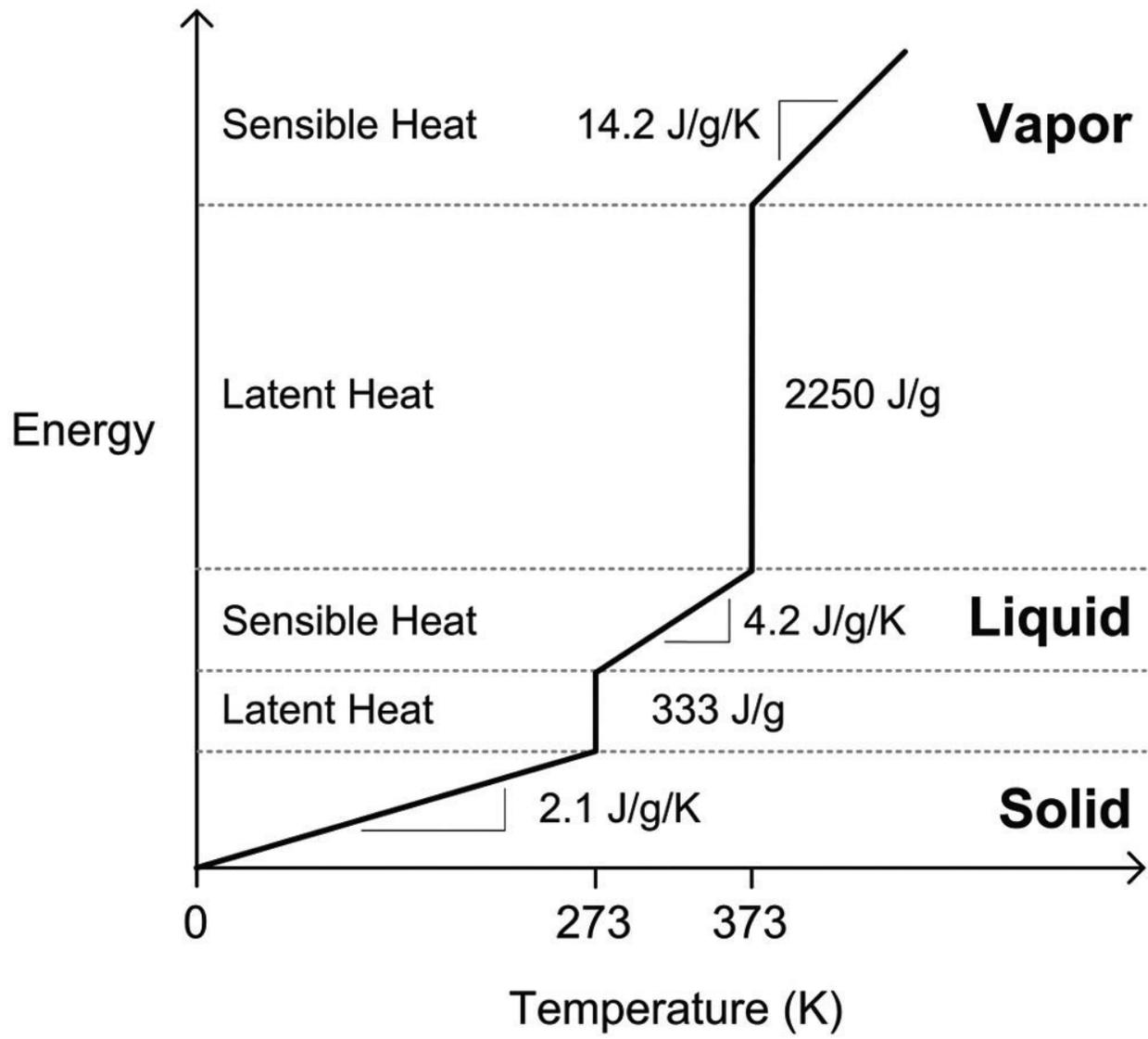


The Myth of the Dew Point

Need two things...dew point temperature and a condensing surface...something with sufficient thermal mass to handle the change in phase energy...

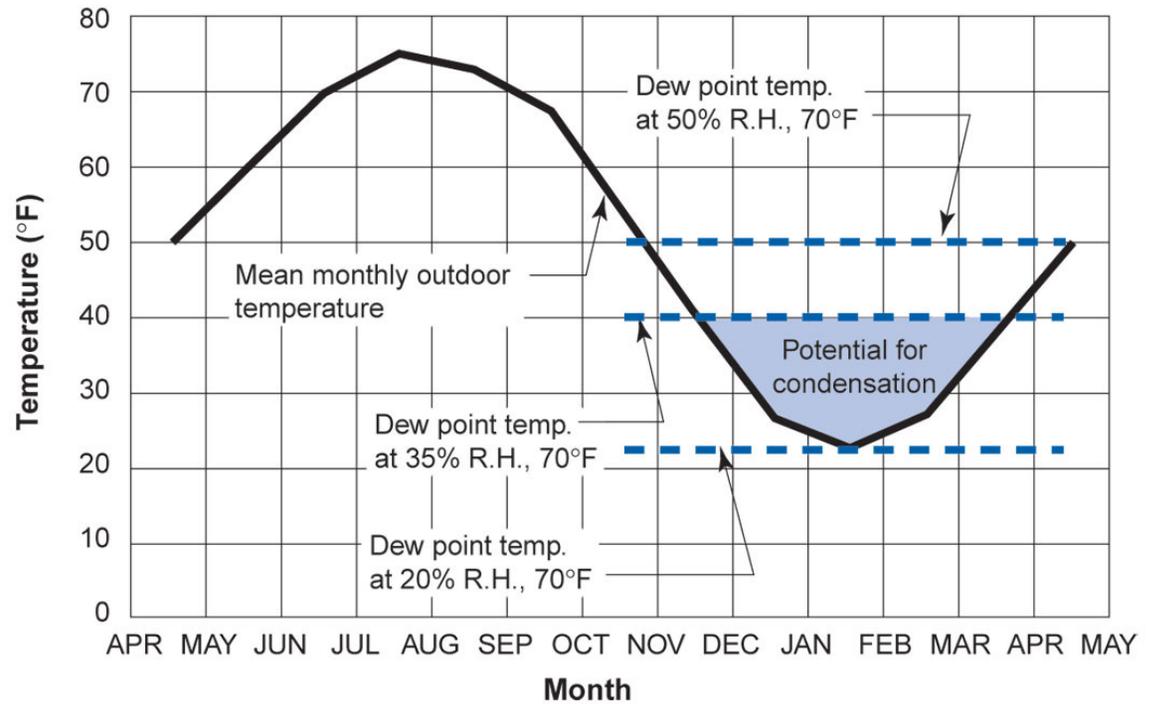
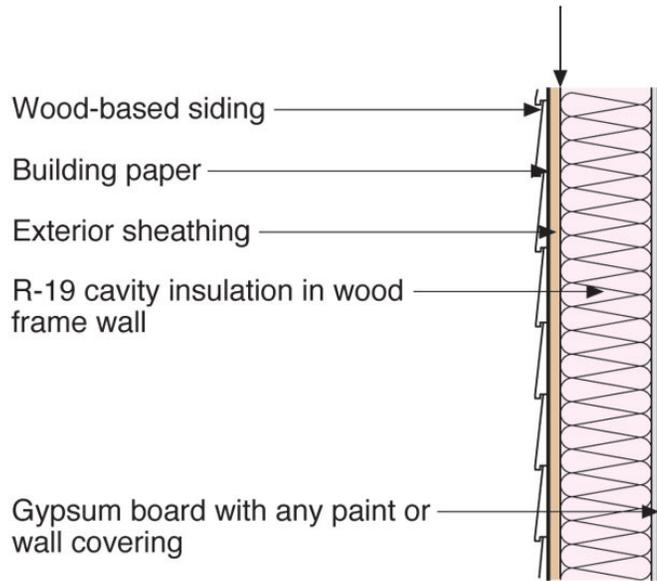




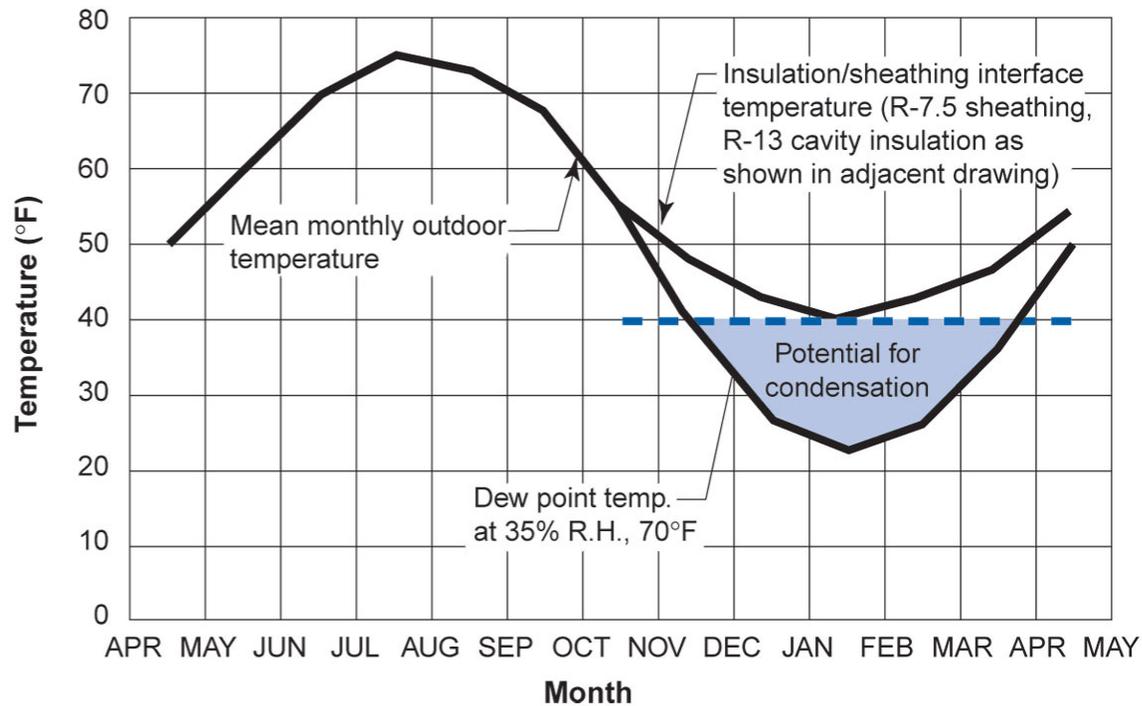
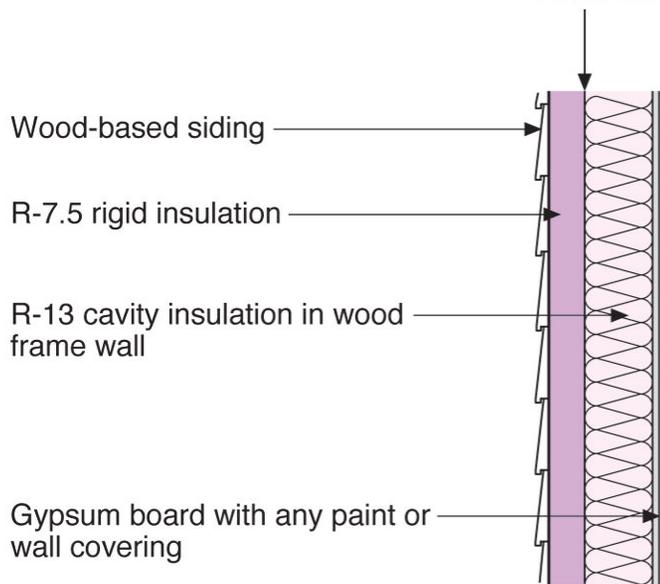


Simple linearized energy-temperature relation for water
 From Straube & Burnett, 2005

The inside face of the exterior sheathing is the condensing surface of interest



The inside face of the insulating sheathing is the condensing surface of interest



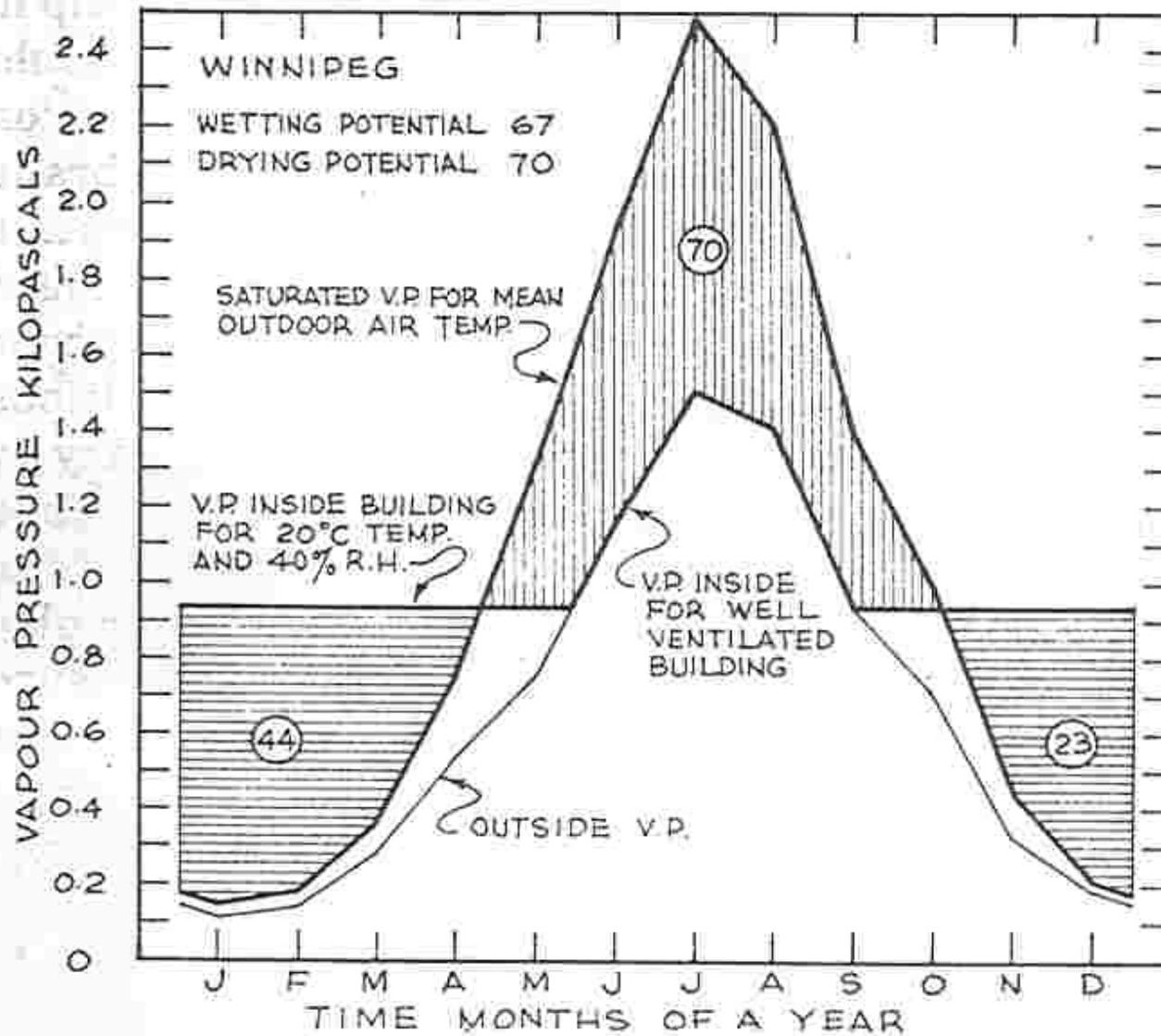
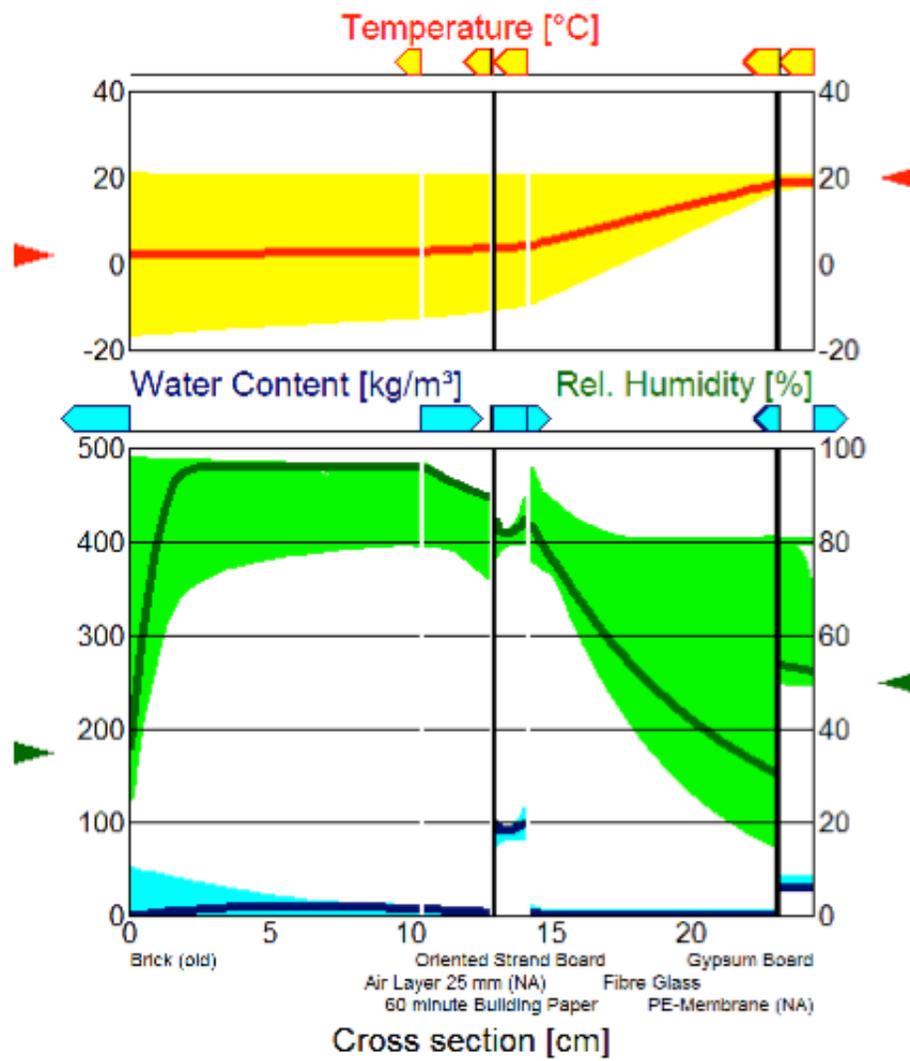


Figure 8-7. Outside vapour pressure, saturated vapour pressure and inside vapour pressure for Winnipeg.



WUFI® 3.3 Pro. IBP
Run

16 Feb
2001

0% 100%

Run

Stop

Pause

00:00:00

0 cm 10 cm

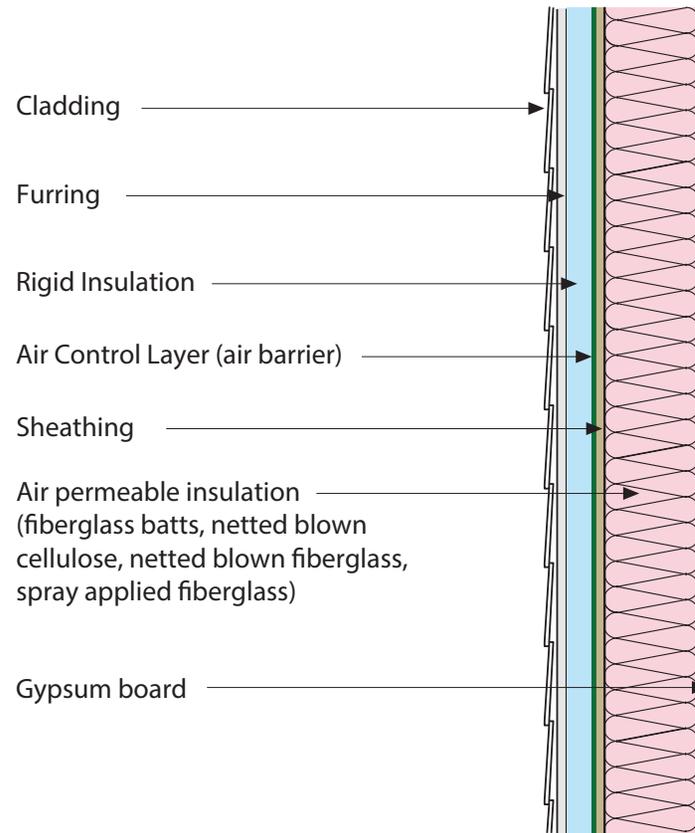
? Help

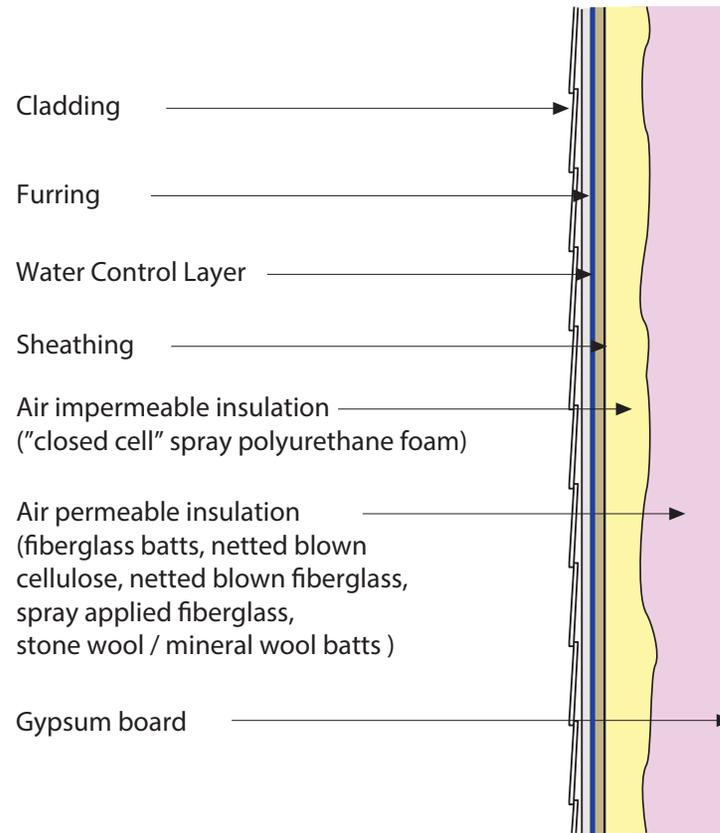
Print

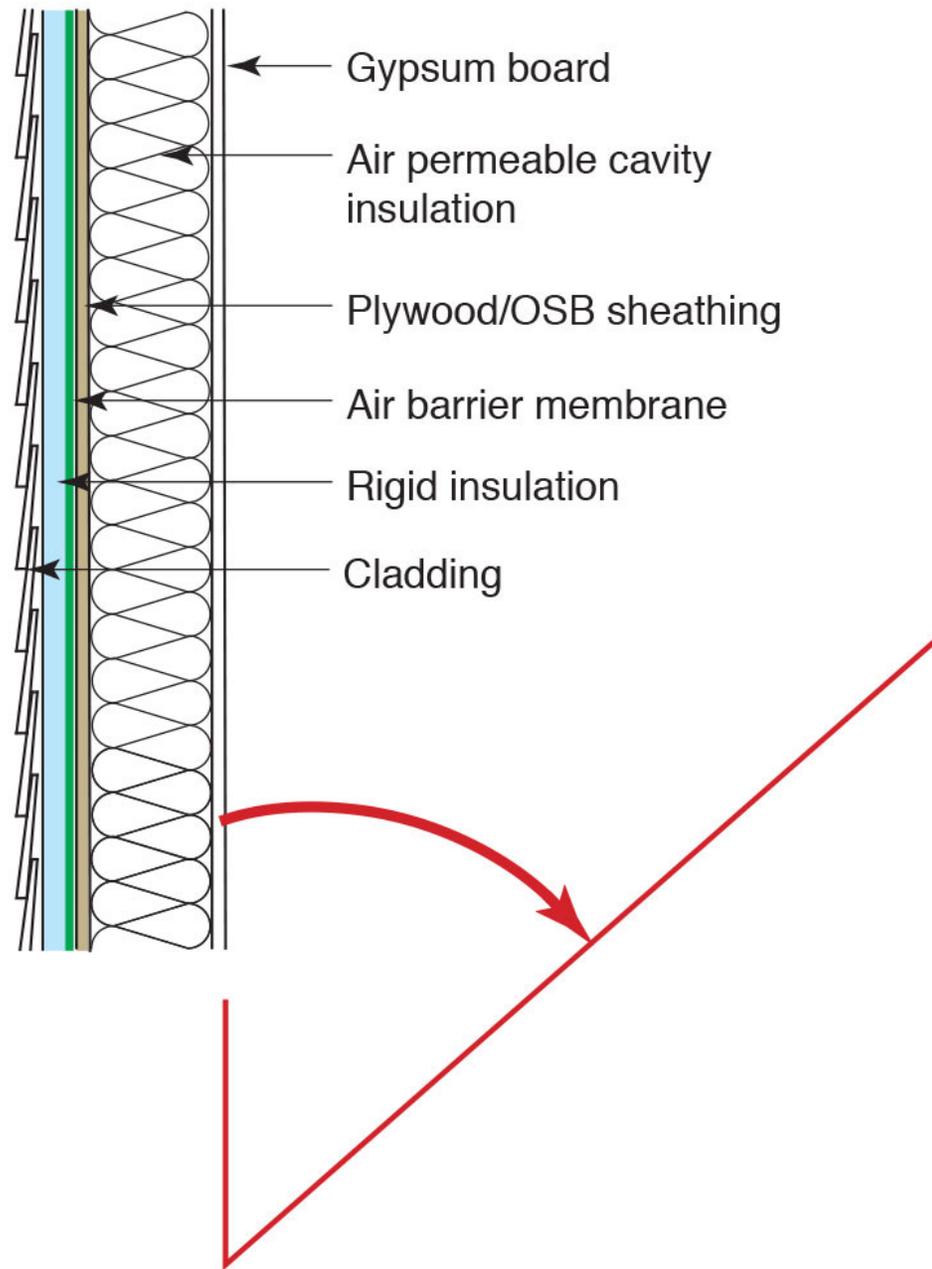
Insulation for Condensation Control*

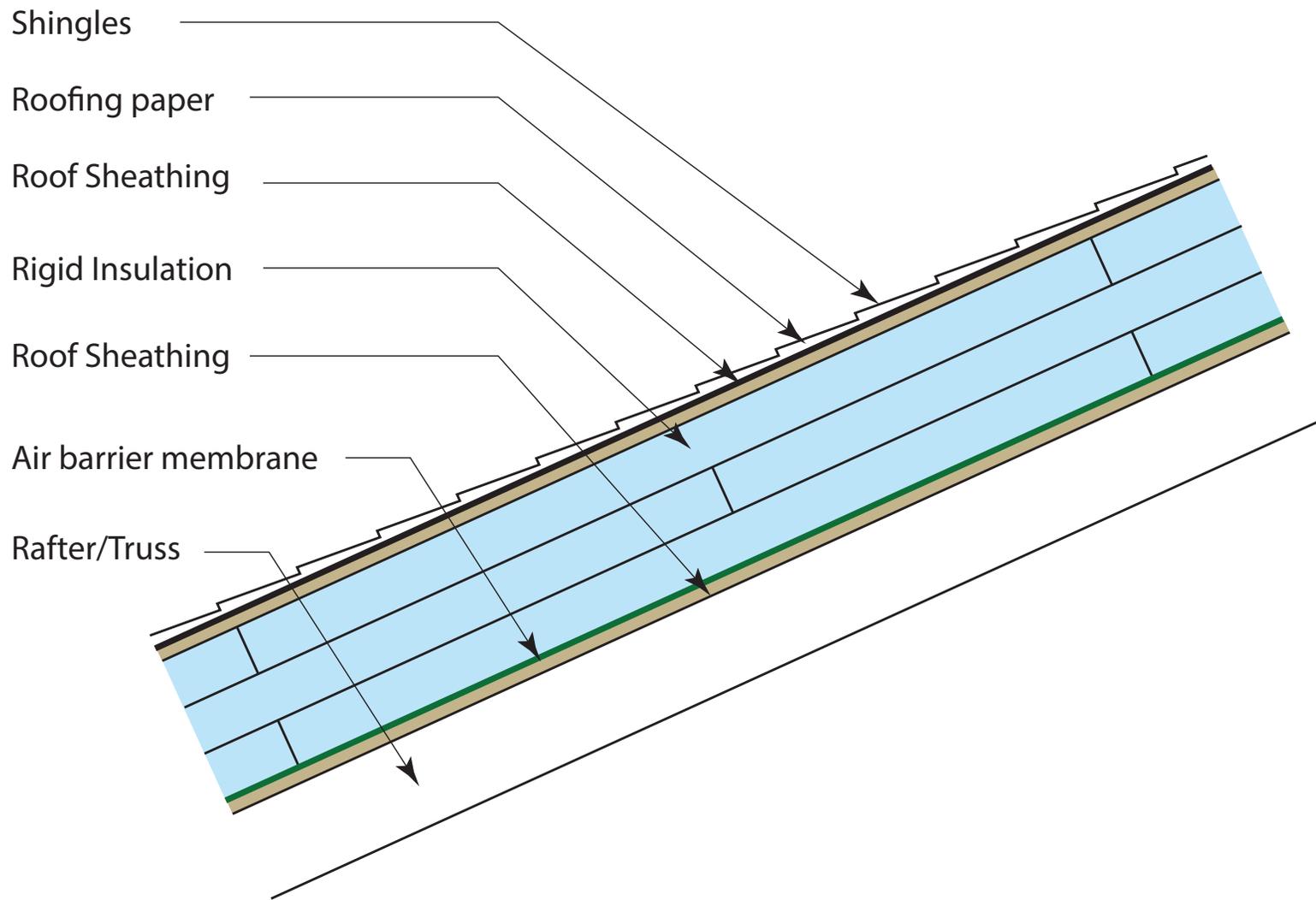
Climate Zone	Rigid Board or Air Impermeable Insulation	Total Cavity Insulation	Total Wall Assembly Insulation	Ratio of Rigid Board Insulation or Air Impermeable R-Value to Total Insulation R-Value
4C	R-2.5	R-13	R-15.5	15%
	R-3.75	R-20	R-23.75	15%
5	R-5	R-13	R-18	30%
	R-7.5	R-20	R-27.5	30%
6	R-7.5	R-13	R-20.5	35%
	R-11.25	R-20	R-31.25	35%
7	R-10	R-13	R-28	45%
	R-15	R-20	R-35	45%
8	R-15	R-13	R-28	50%
	R-20	R-20	R-40	50%

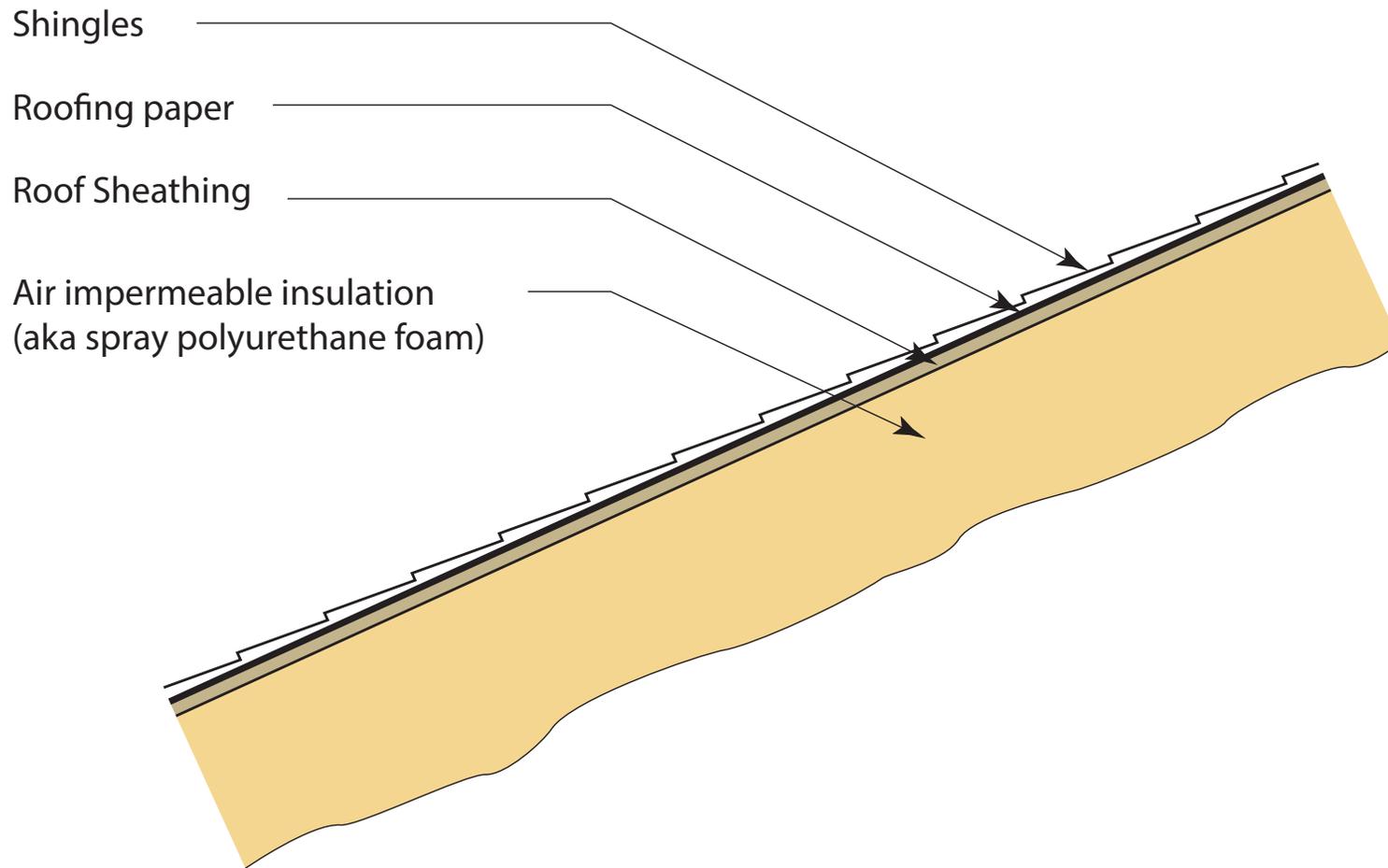
*Adapted from Table R 702.1 2015 International Residential Code

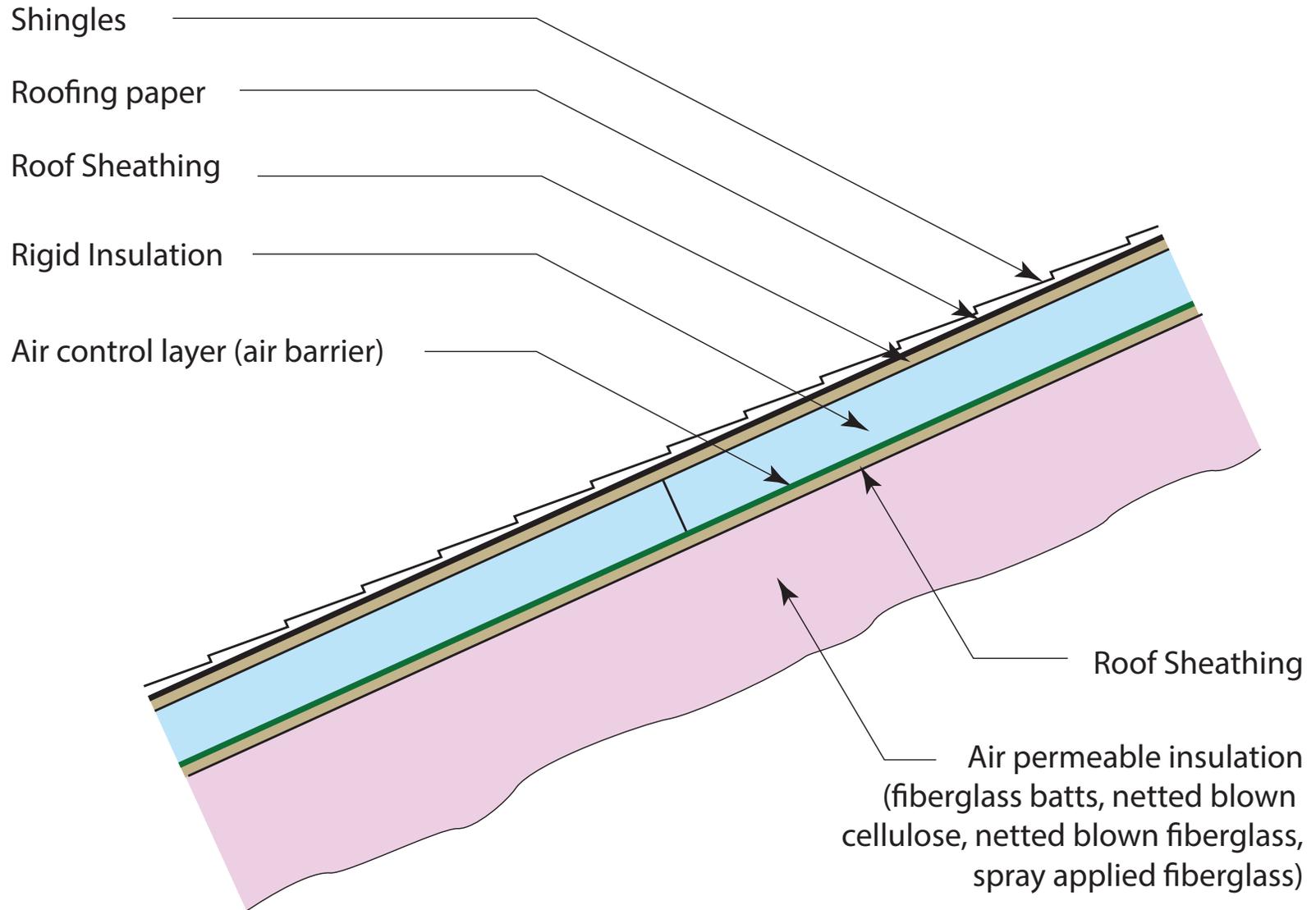










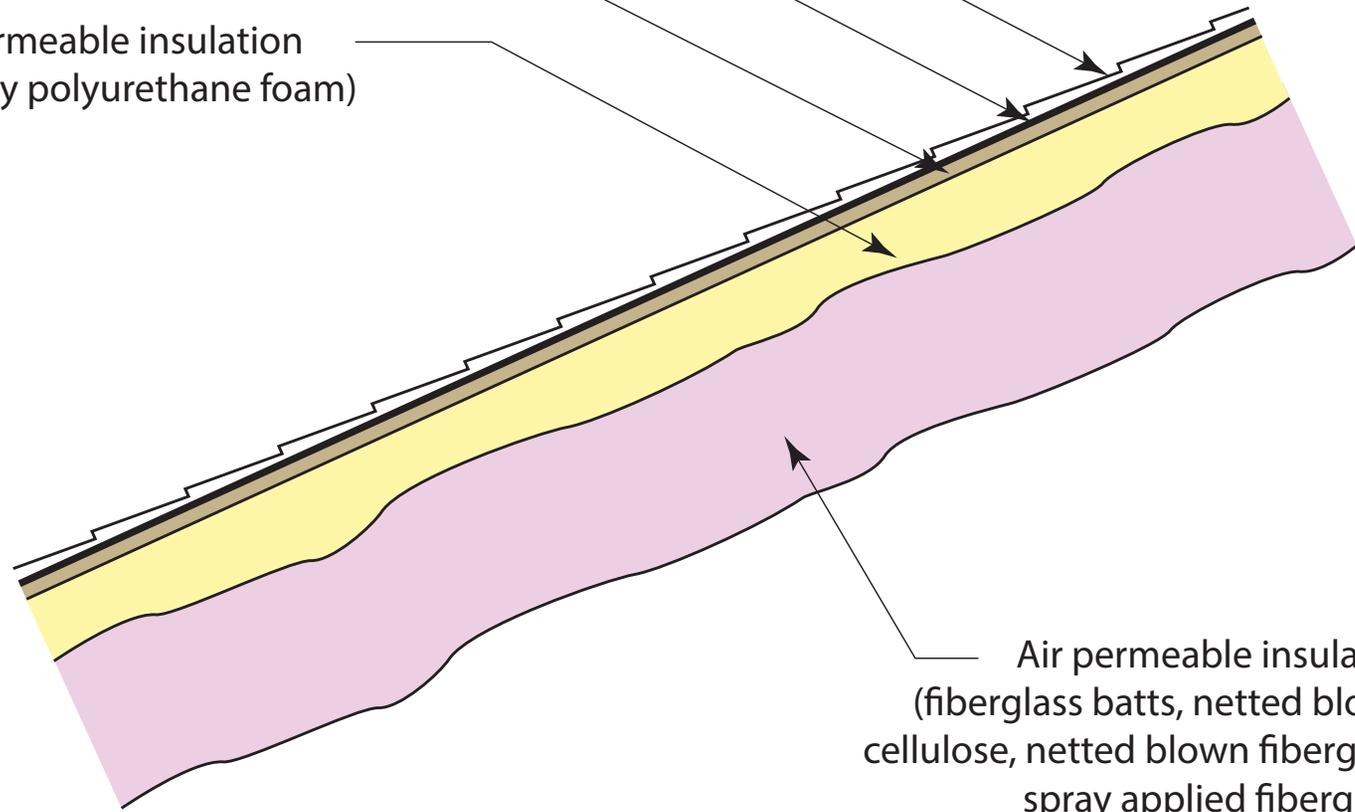


Shingles

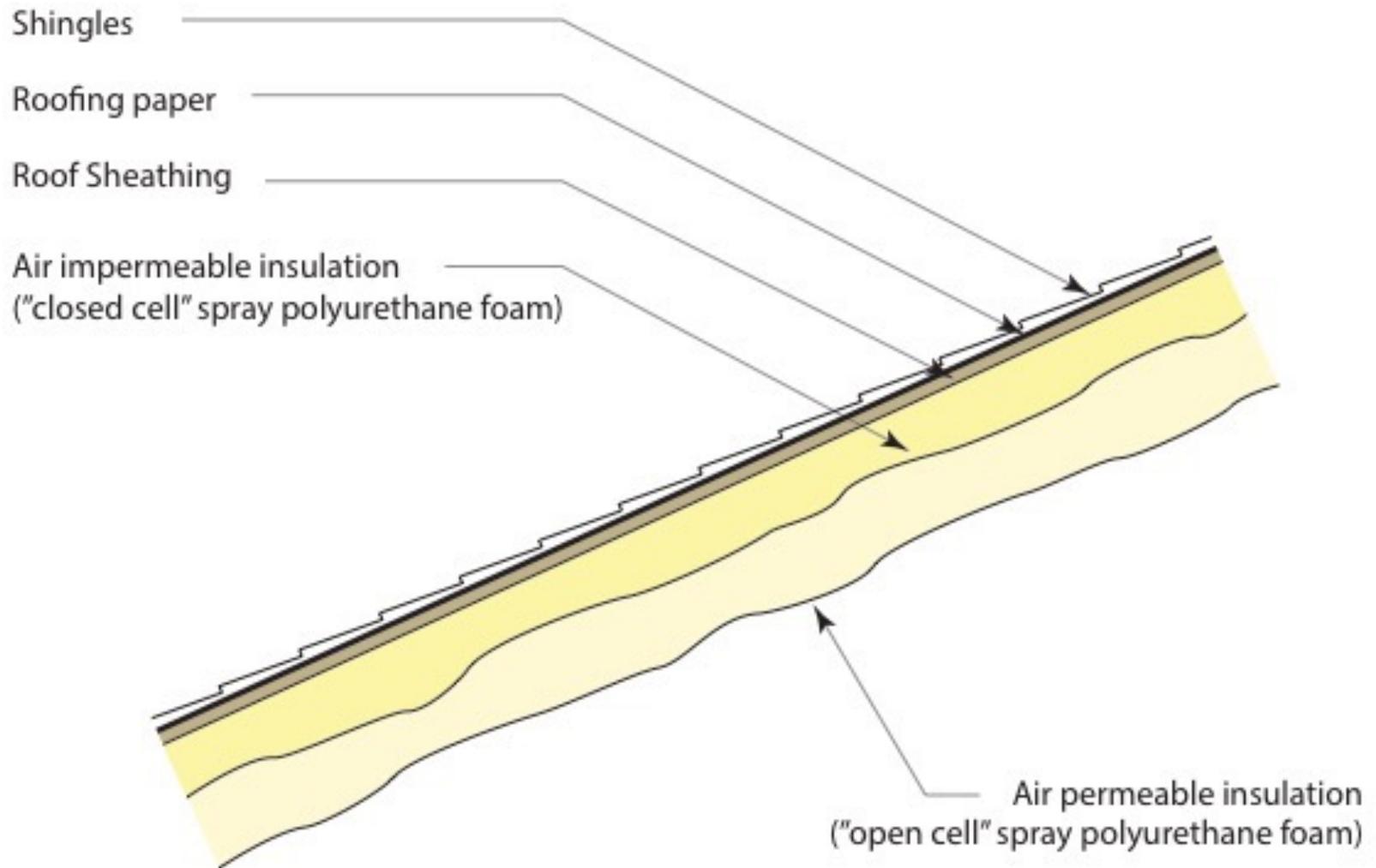
Roofing paper

Roof Sheathing

Air impermeable insulation
(aka spray polyurethane foam)



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

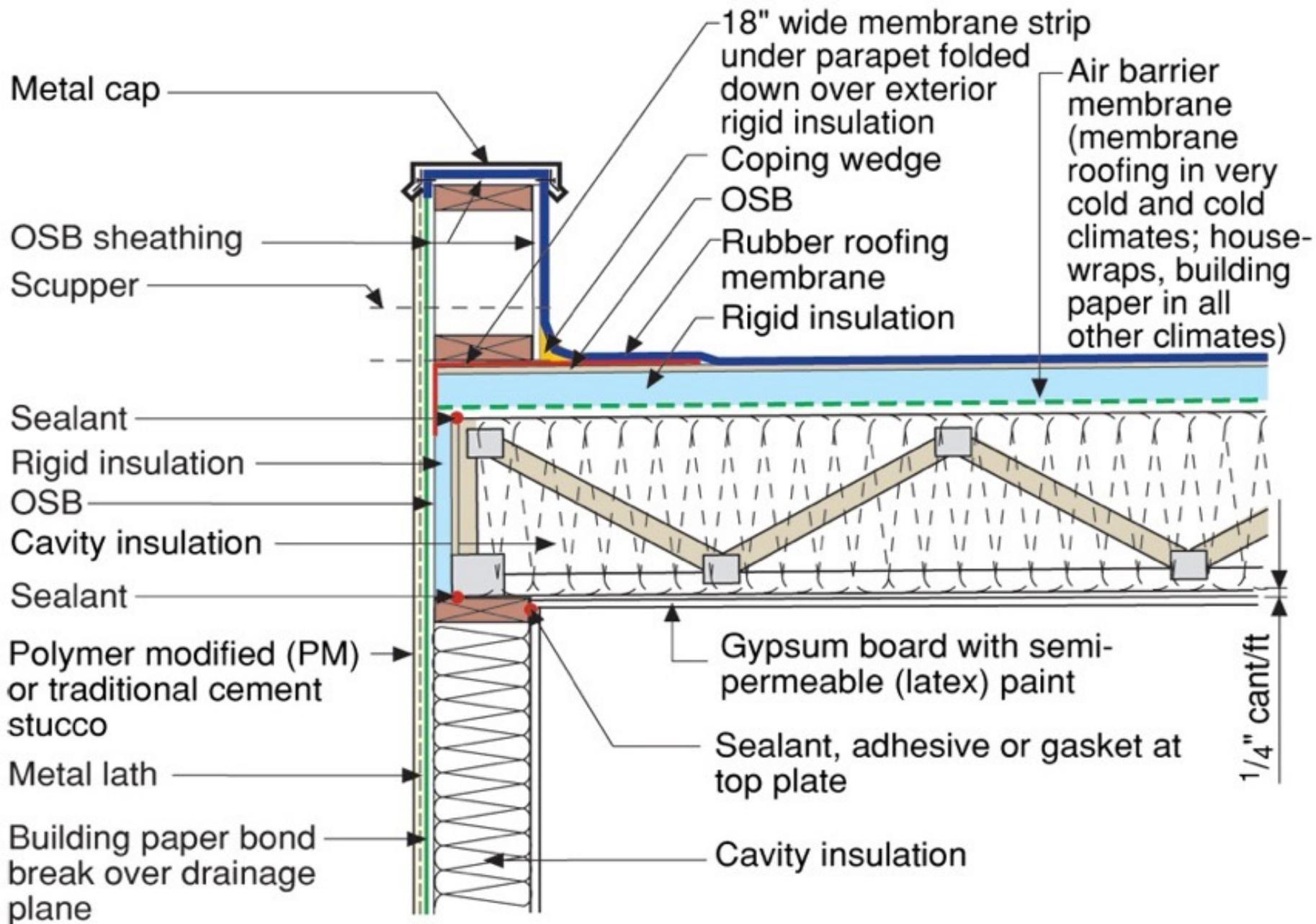


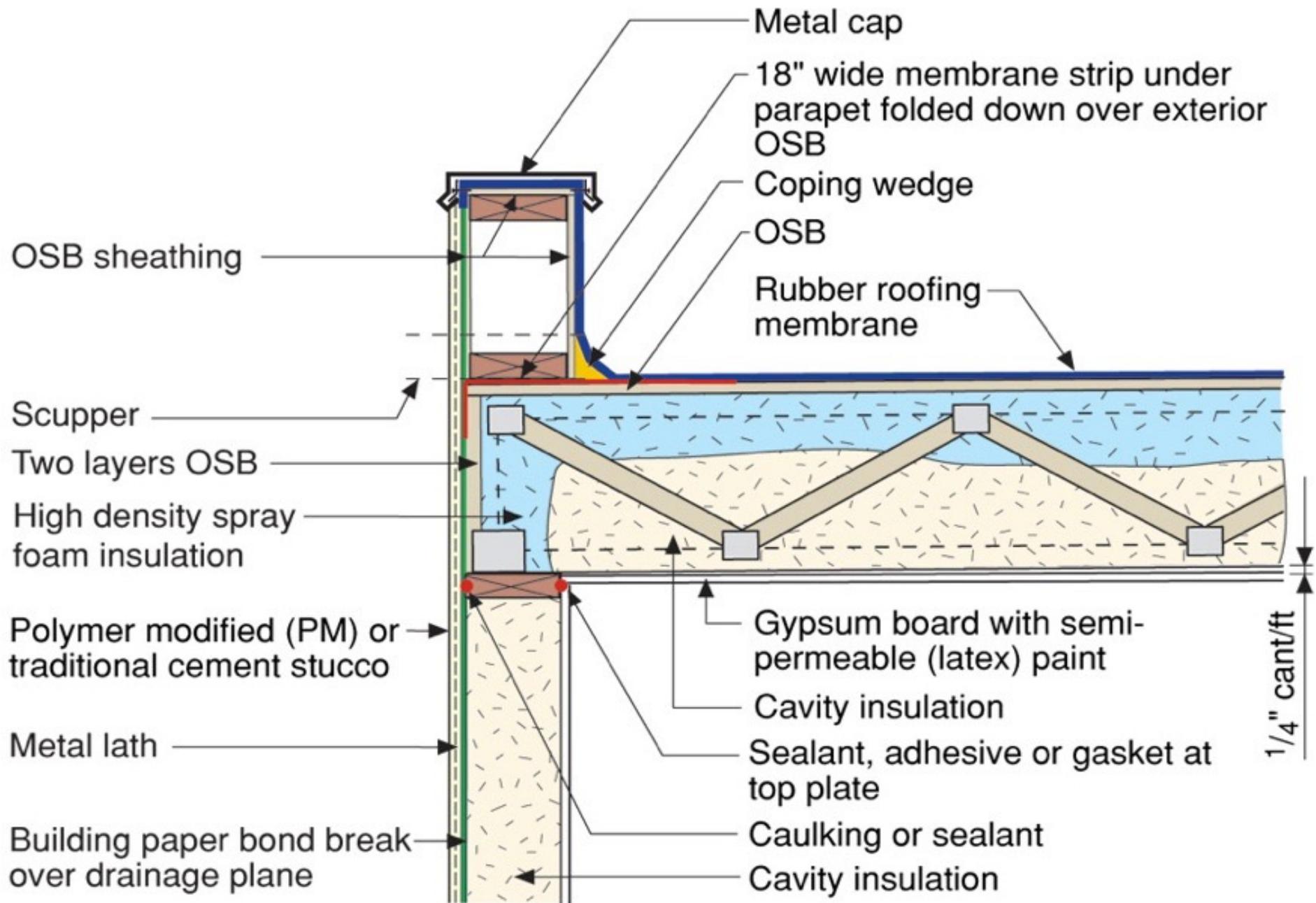
Insulation for Condensation Control*

Climate Zone	Rigid Board or Air Impermeable Insulation	Code Required R-Value	Ratio of Rigid Board Insulation or Air Impermeable R-Value to Total Insulation R-Value
1,2,3	R-5	R-38	10%
4C	R-10	R-49	20%
4A, 4B	R-15	R-49	30%
5	R-20	R-49	40%
6	R-25	R-49	50%
7	R-30	R-49	60%
8	R-35	R-49	70%

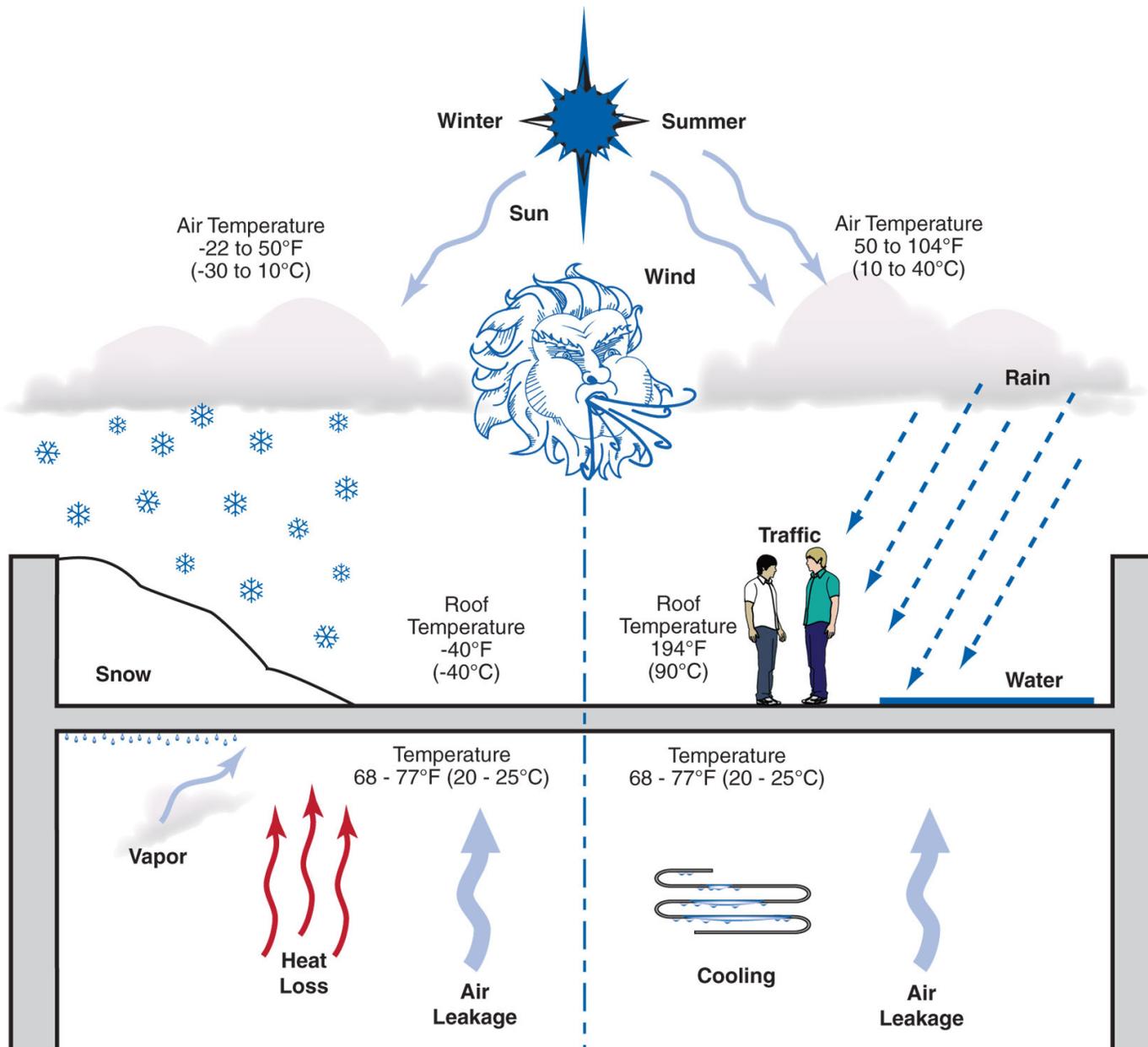
*Adapted from Table R 806.5 2015 International Residential Code

Table 1

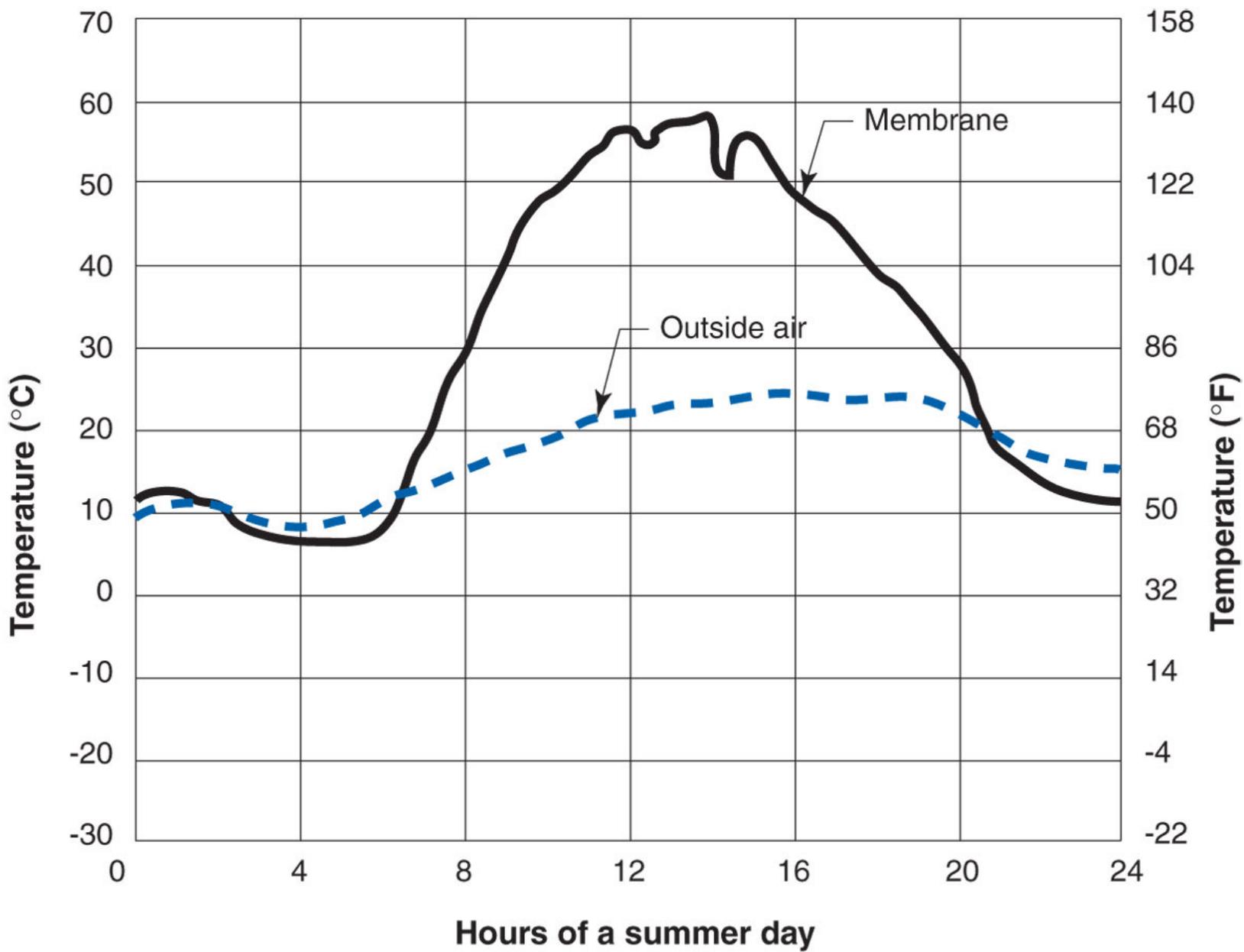




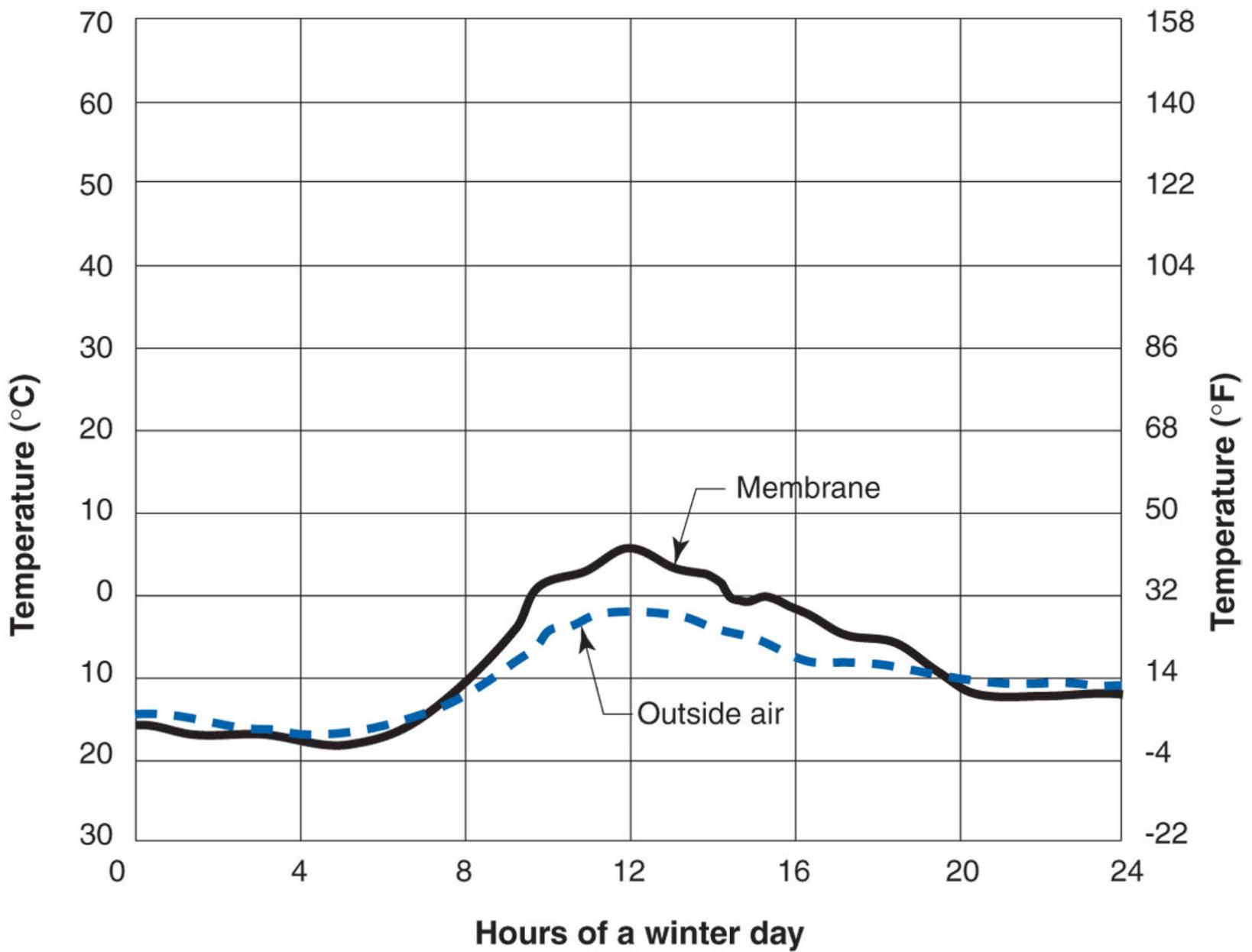
Roofs and Ice Dams



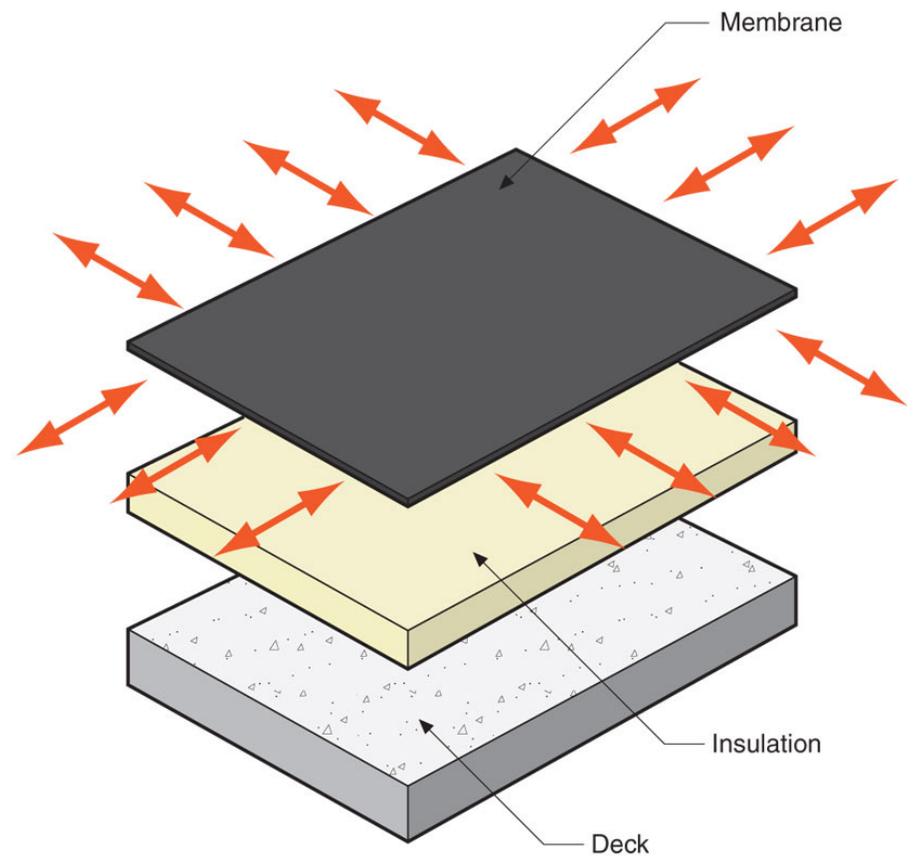
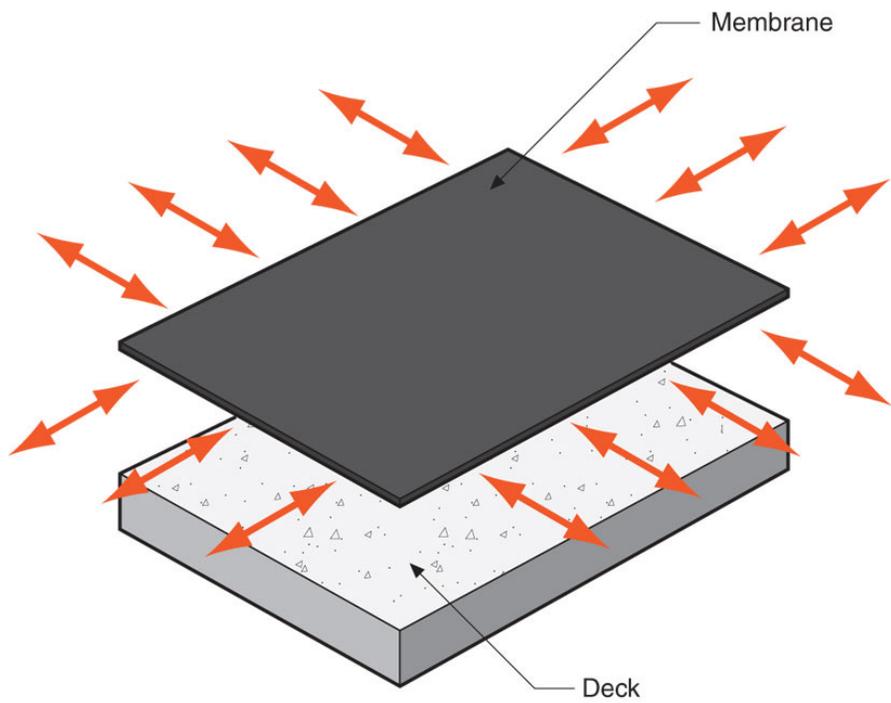
Adapted from Baker, M.; *Roofs*, 1980;
 Courtesy National Research Council of Canada



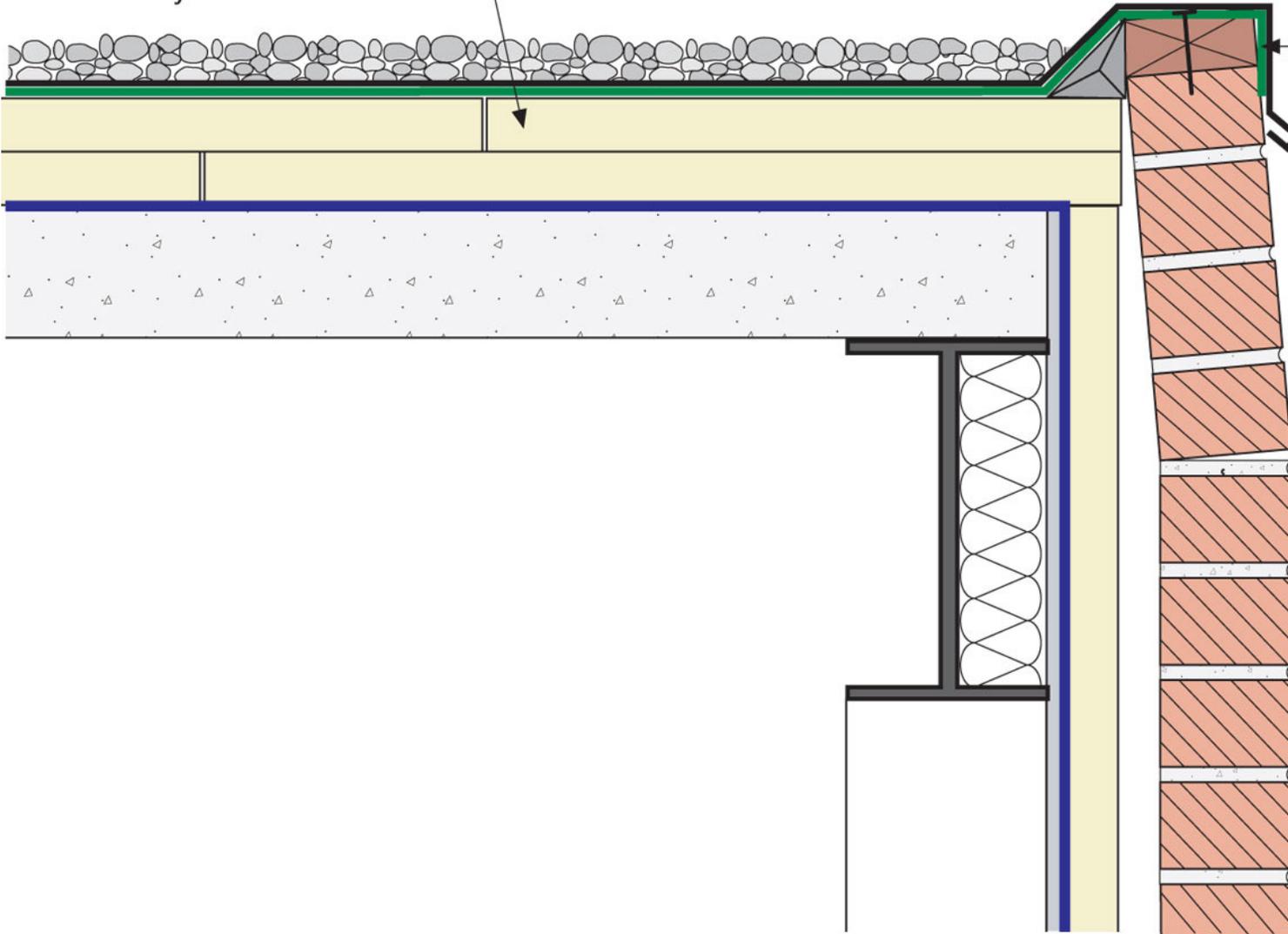
From Baker, M.; *Roofs*, 1980



From Baker, M.; *Roofs*, 1980

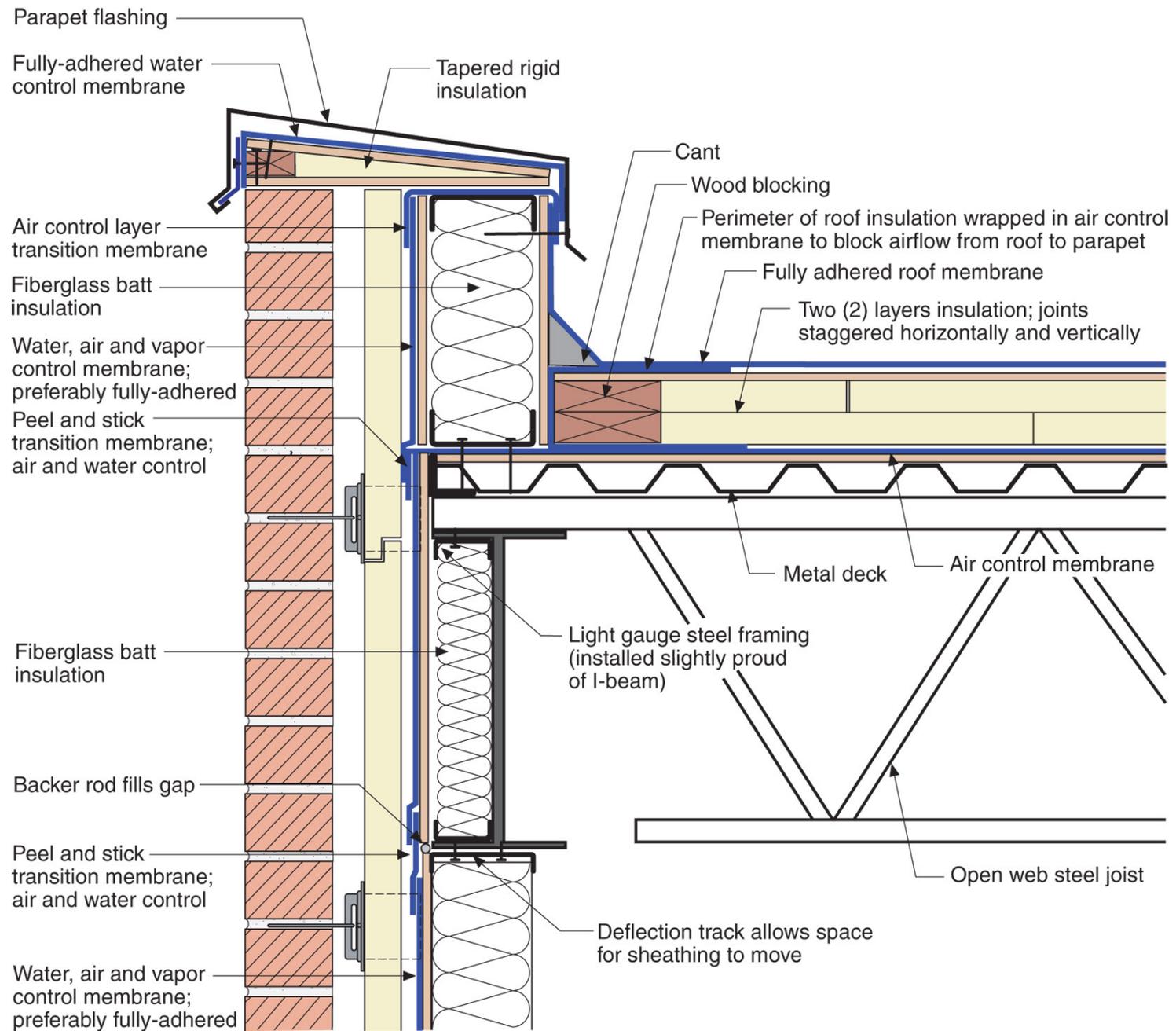


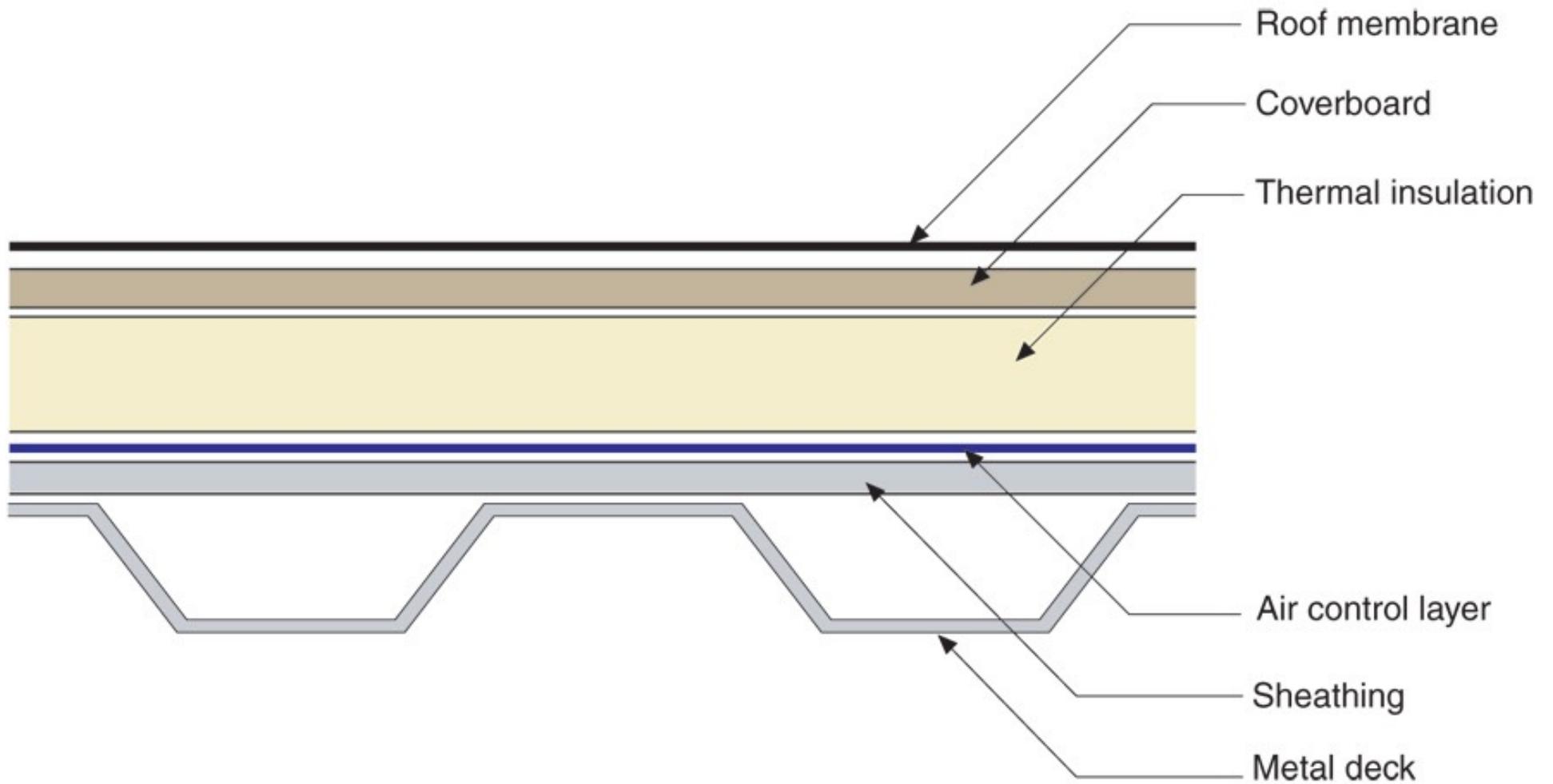
Insulation moved because of poor adhesion to deck and between layers

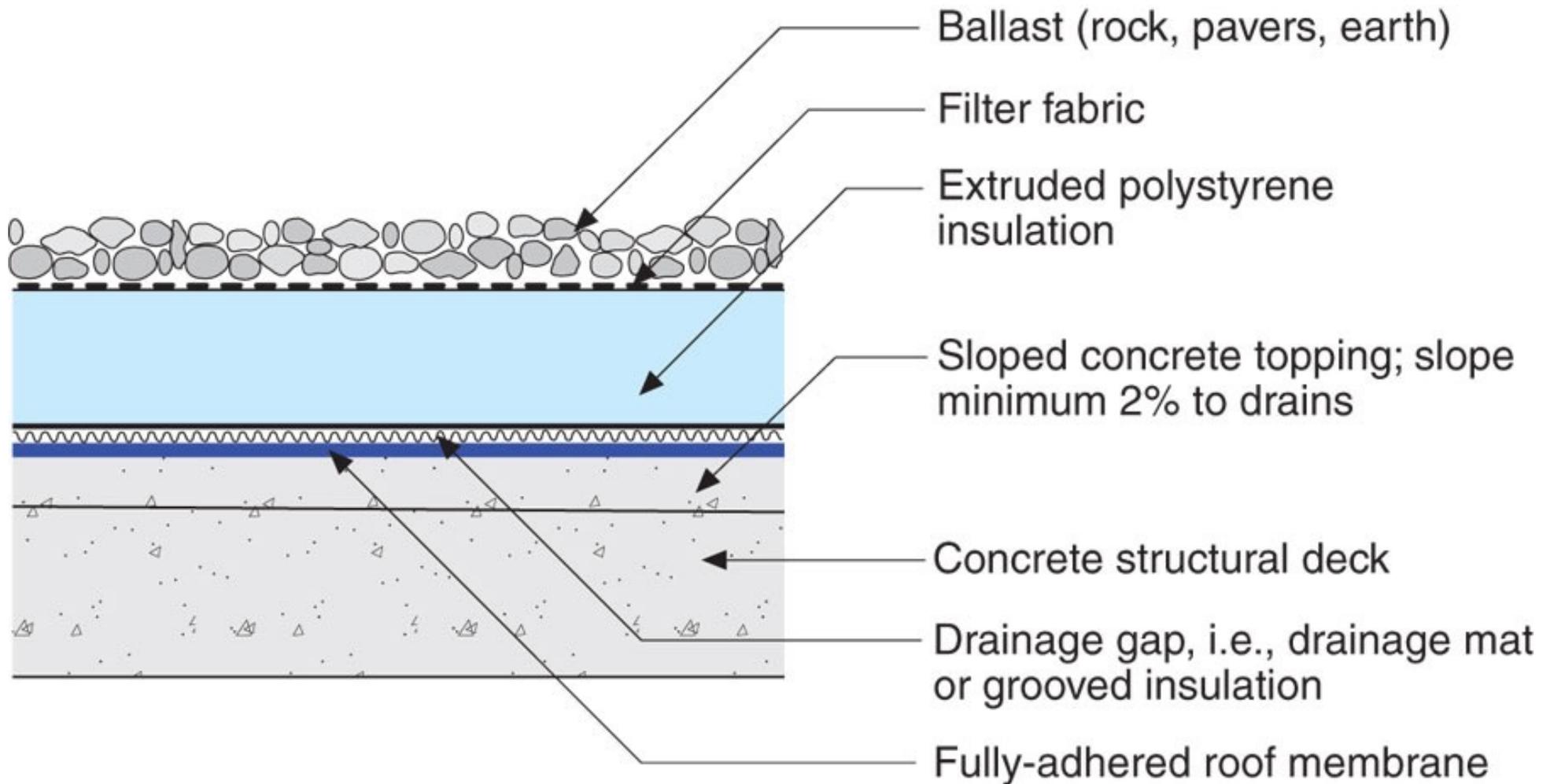


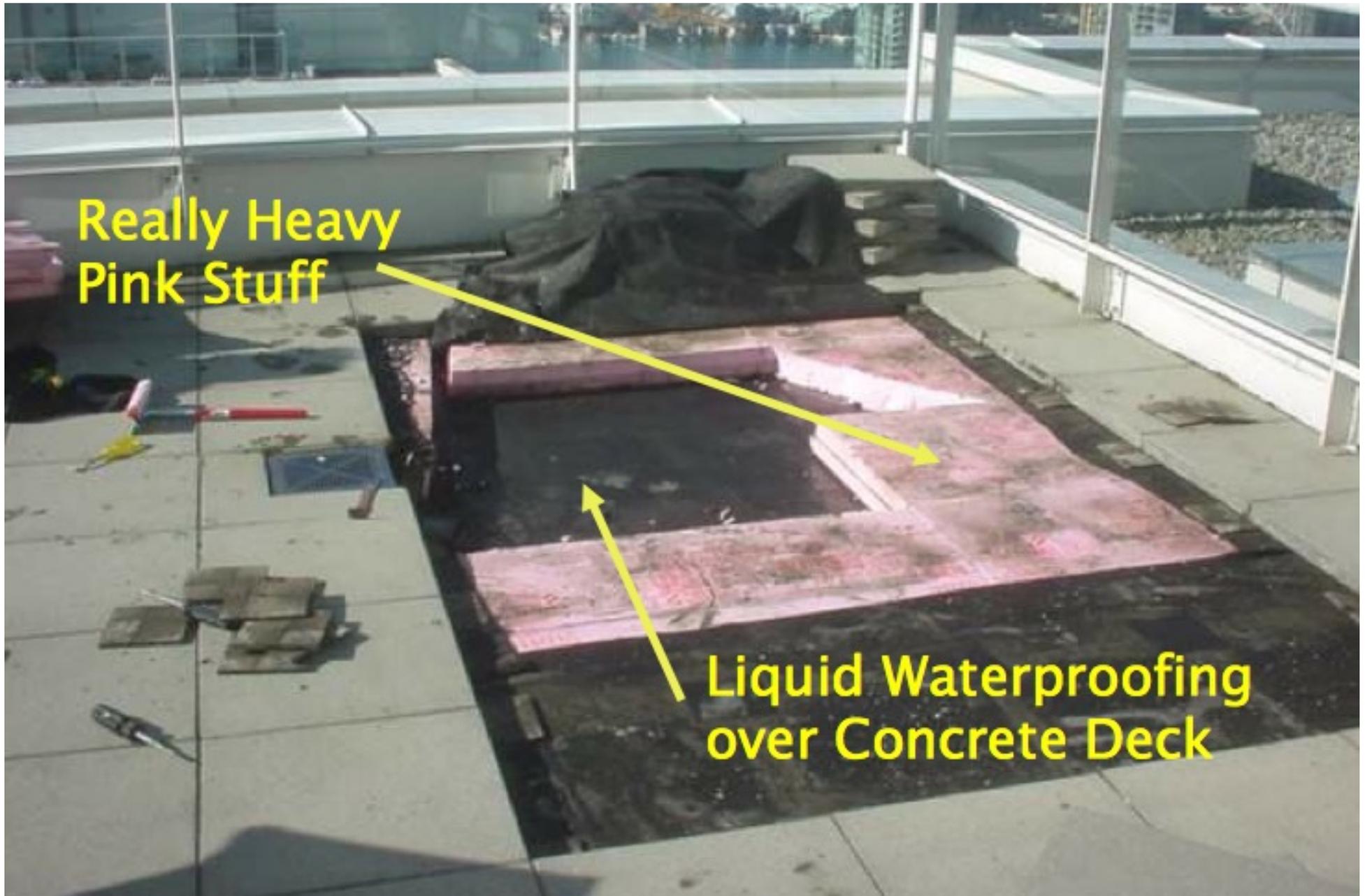
Top four courses of brick and wood blocking pulled inward by contracting membrane

*Adapted from Baker, M.; Roofs, 1980;
Courtesy National Research Council of Canada*



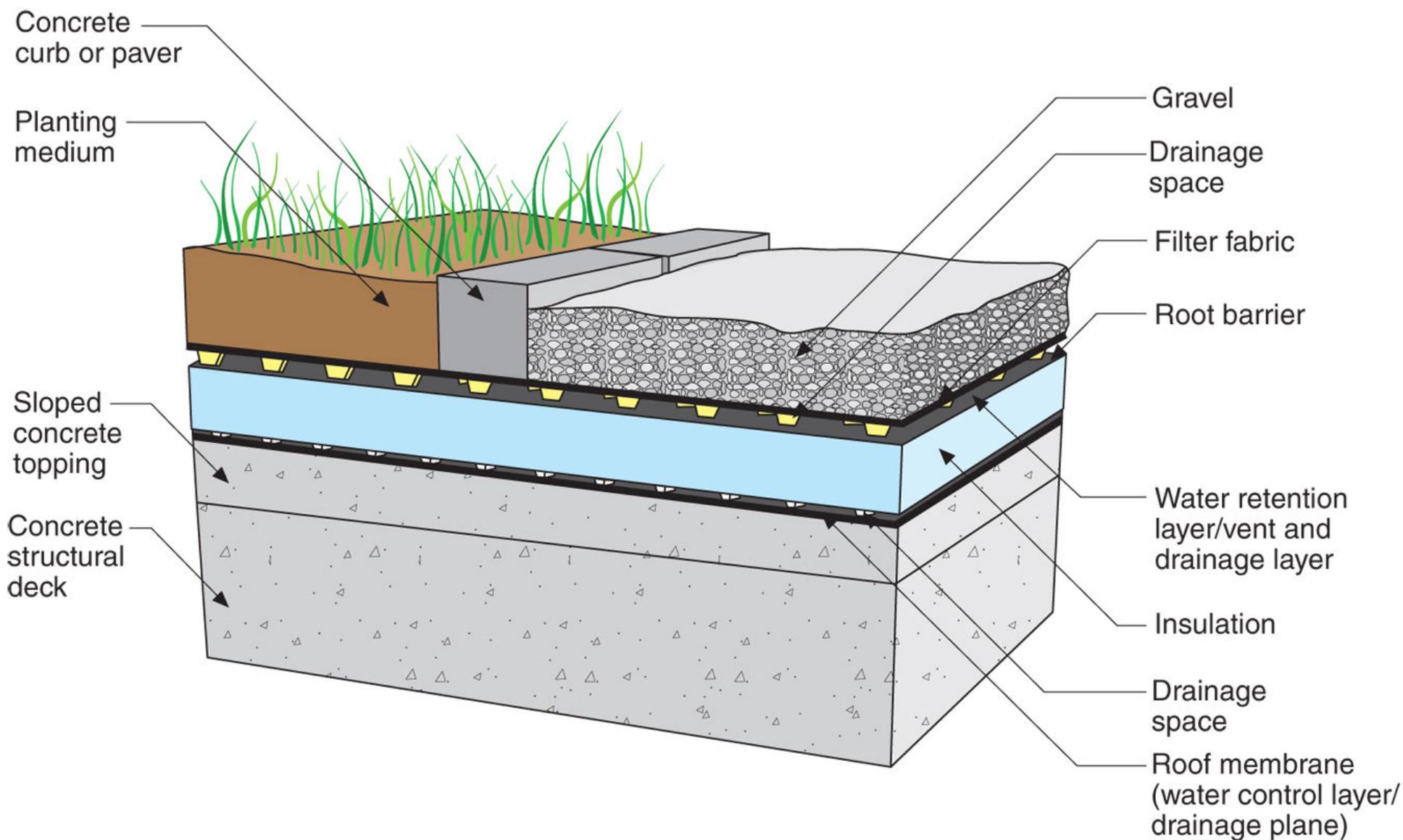




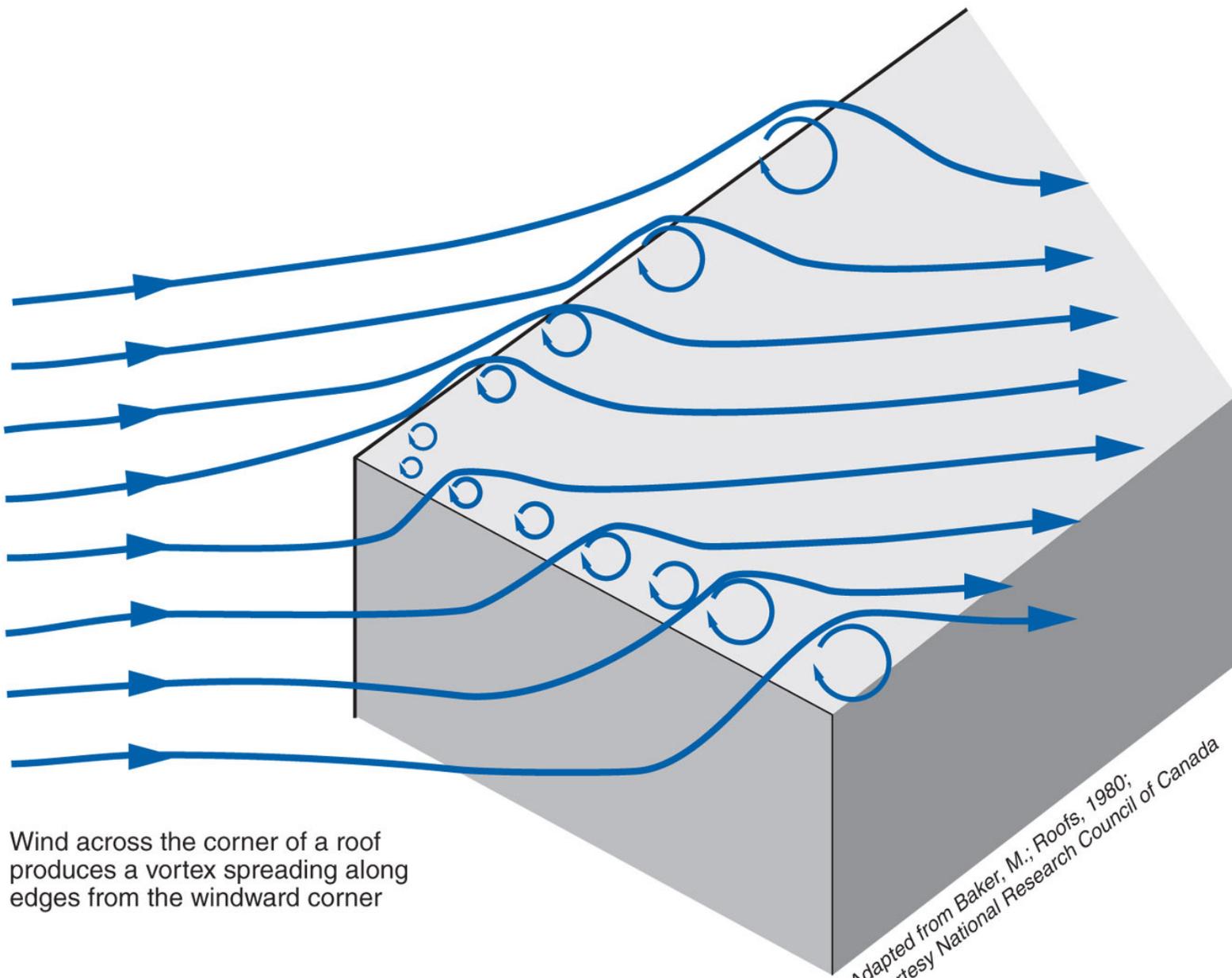


**Really Heavy
Pink Stuff**

**Liquid Waterproofing
over Concrete Deck**

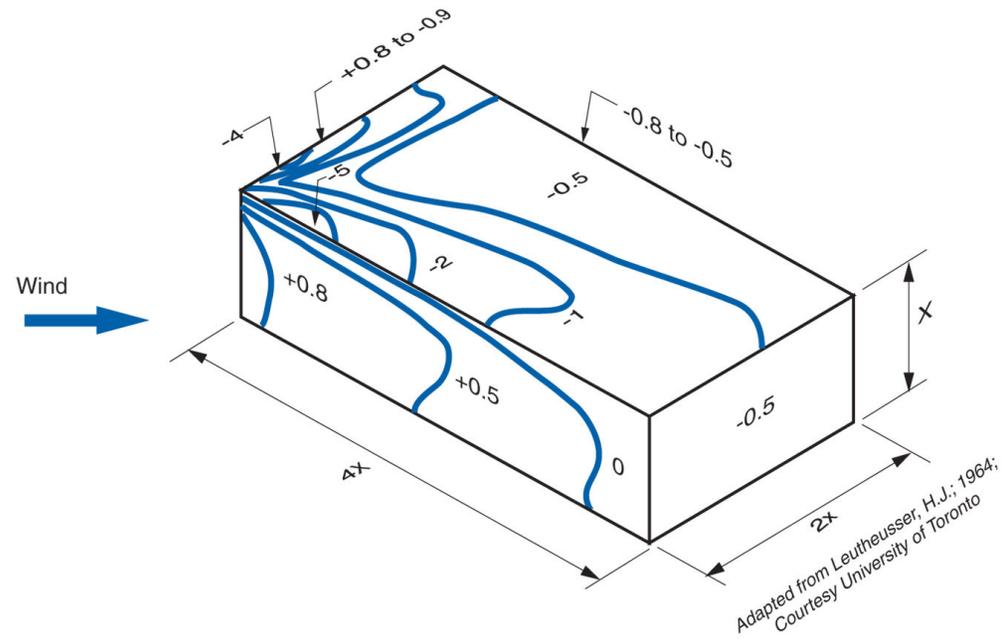
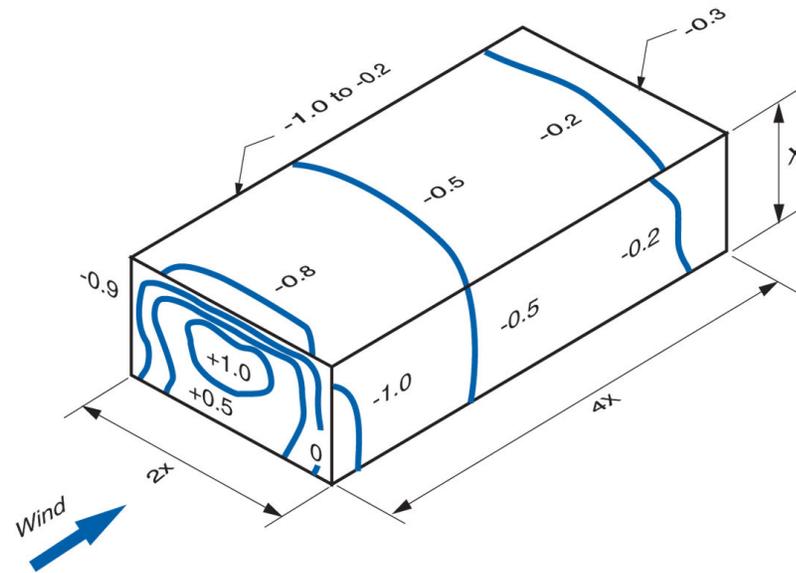




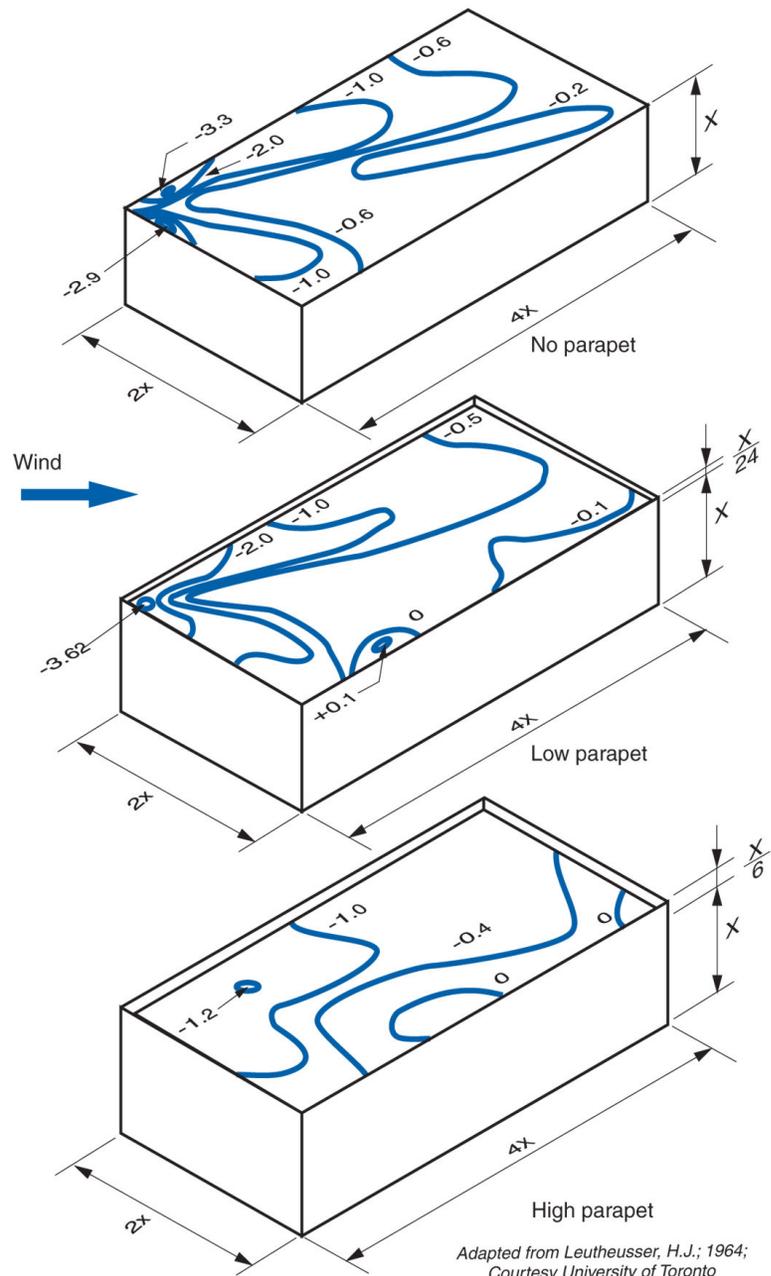


Wind across the corner of a roof produces a vortex spreading along edges from the windward corner

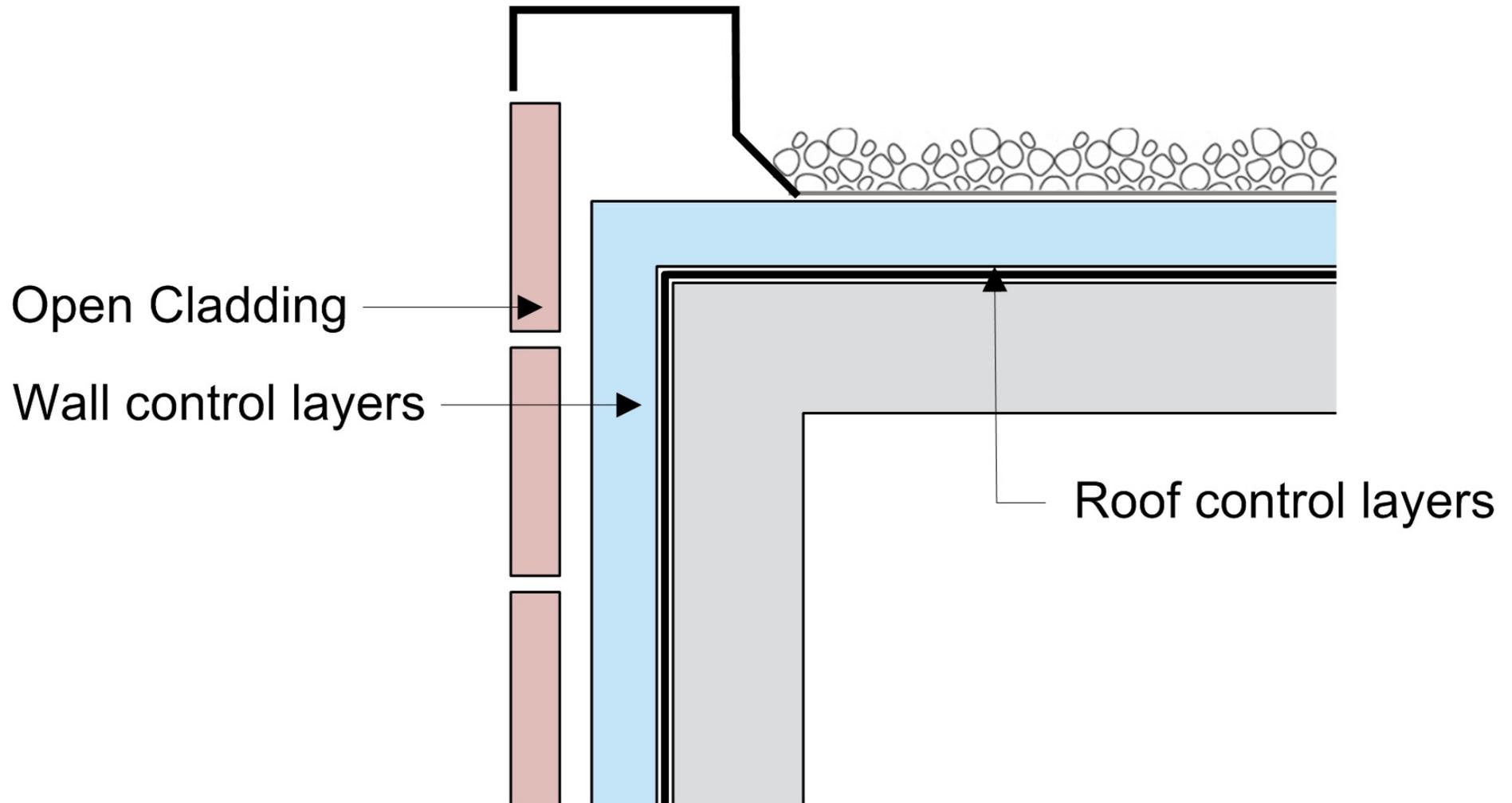
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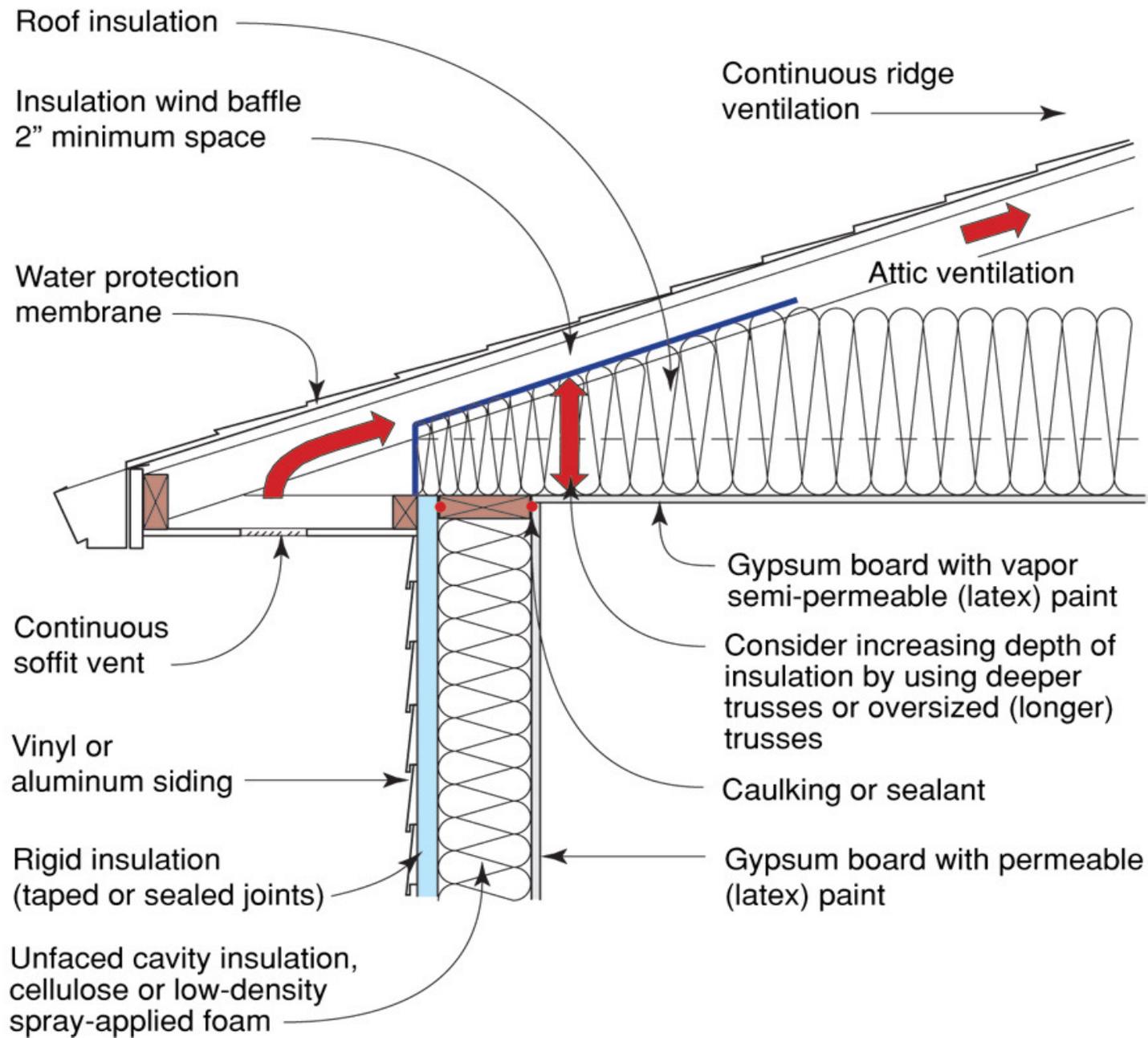


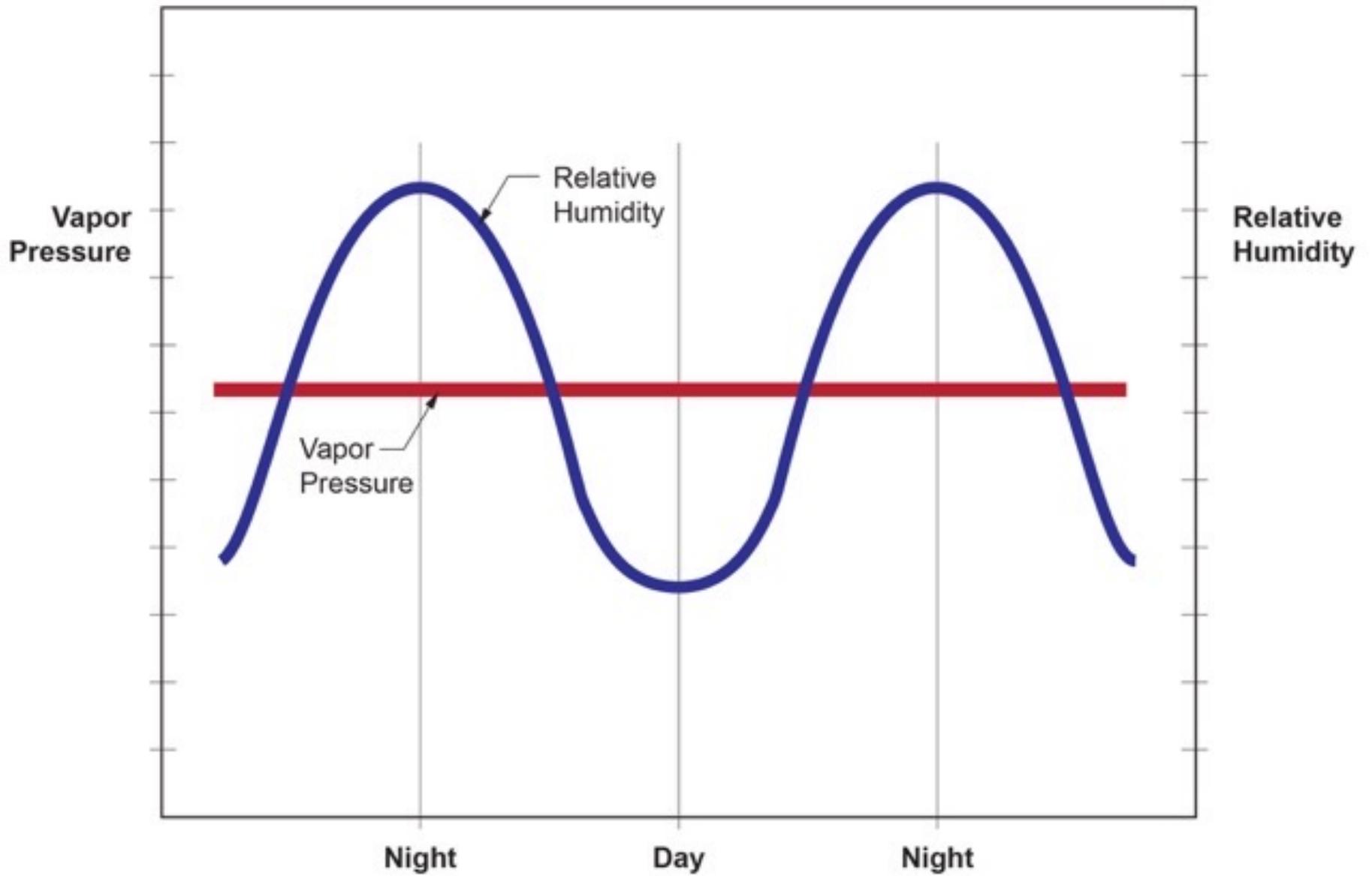
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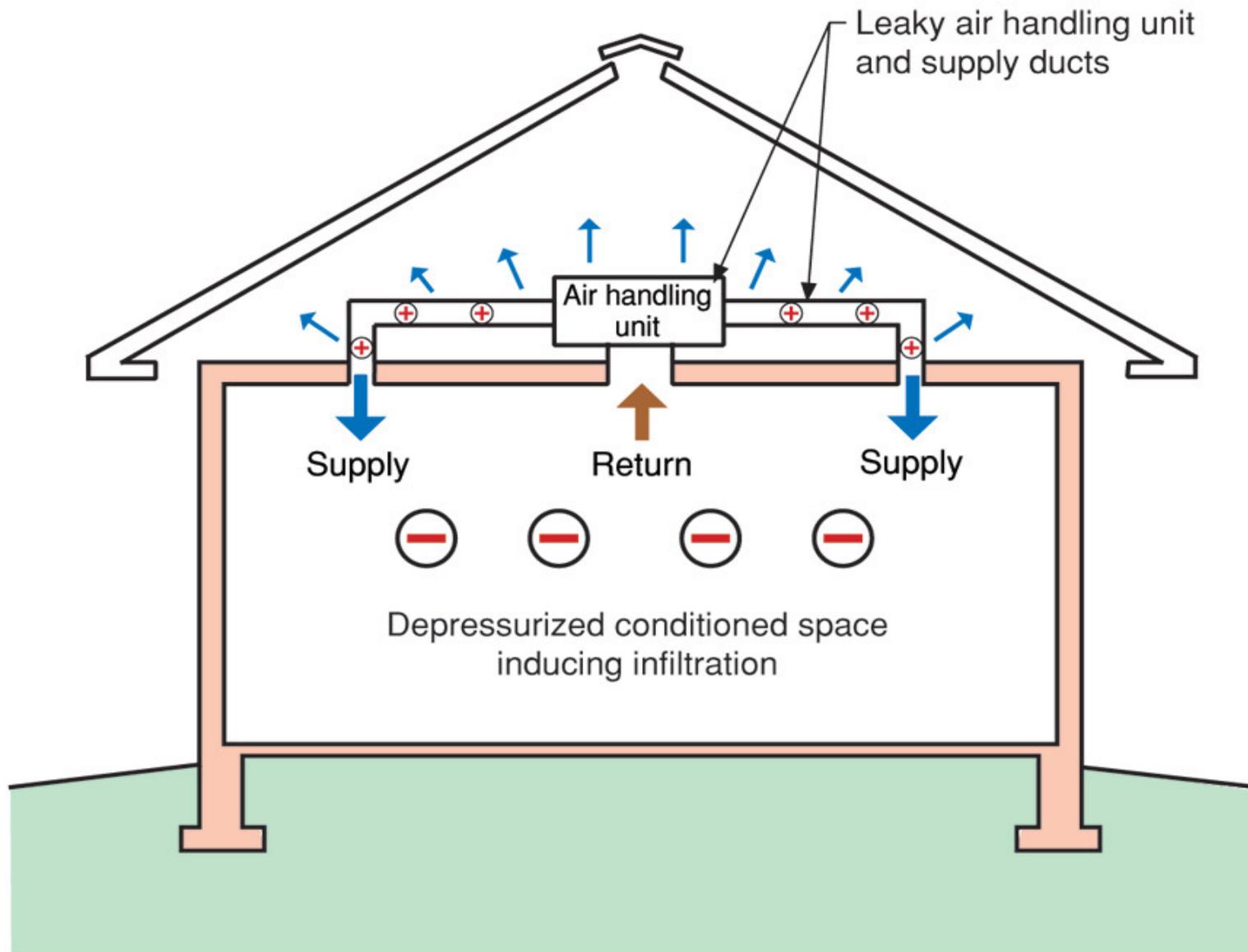










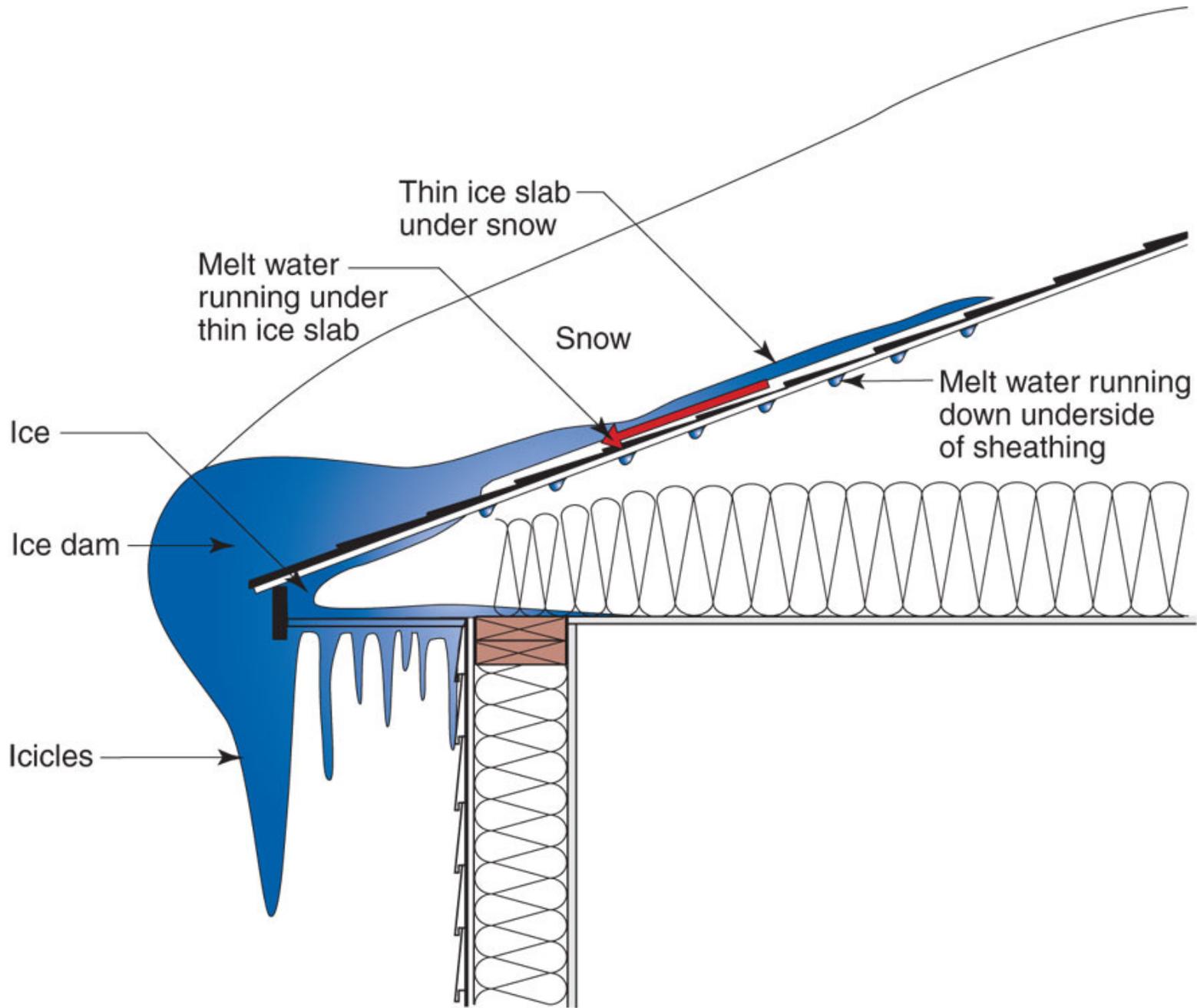


Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.















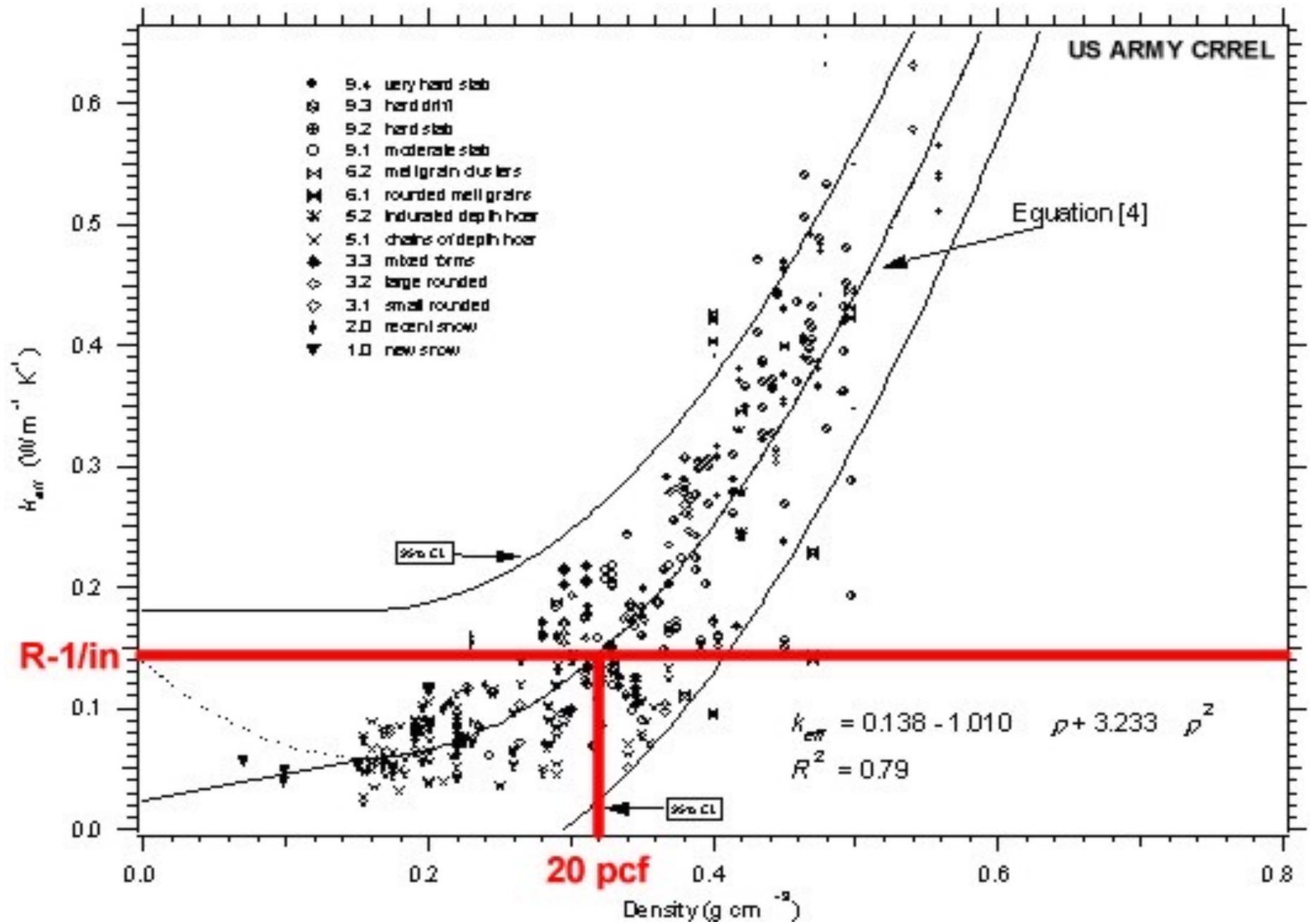






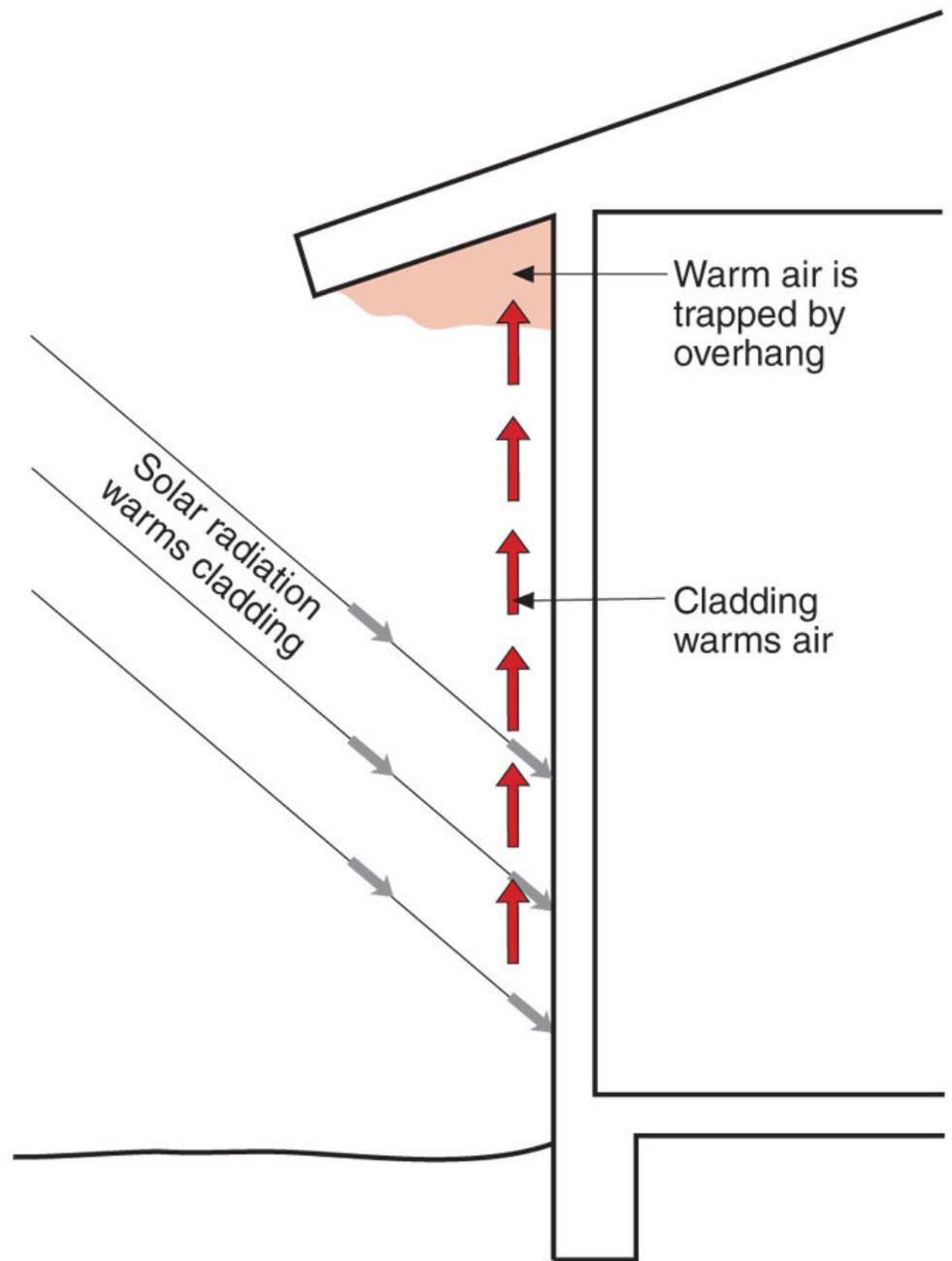












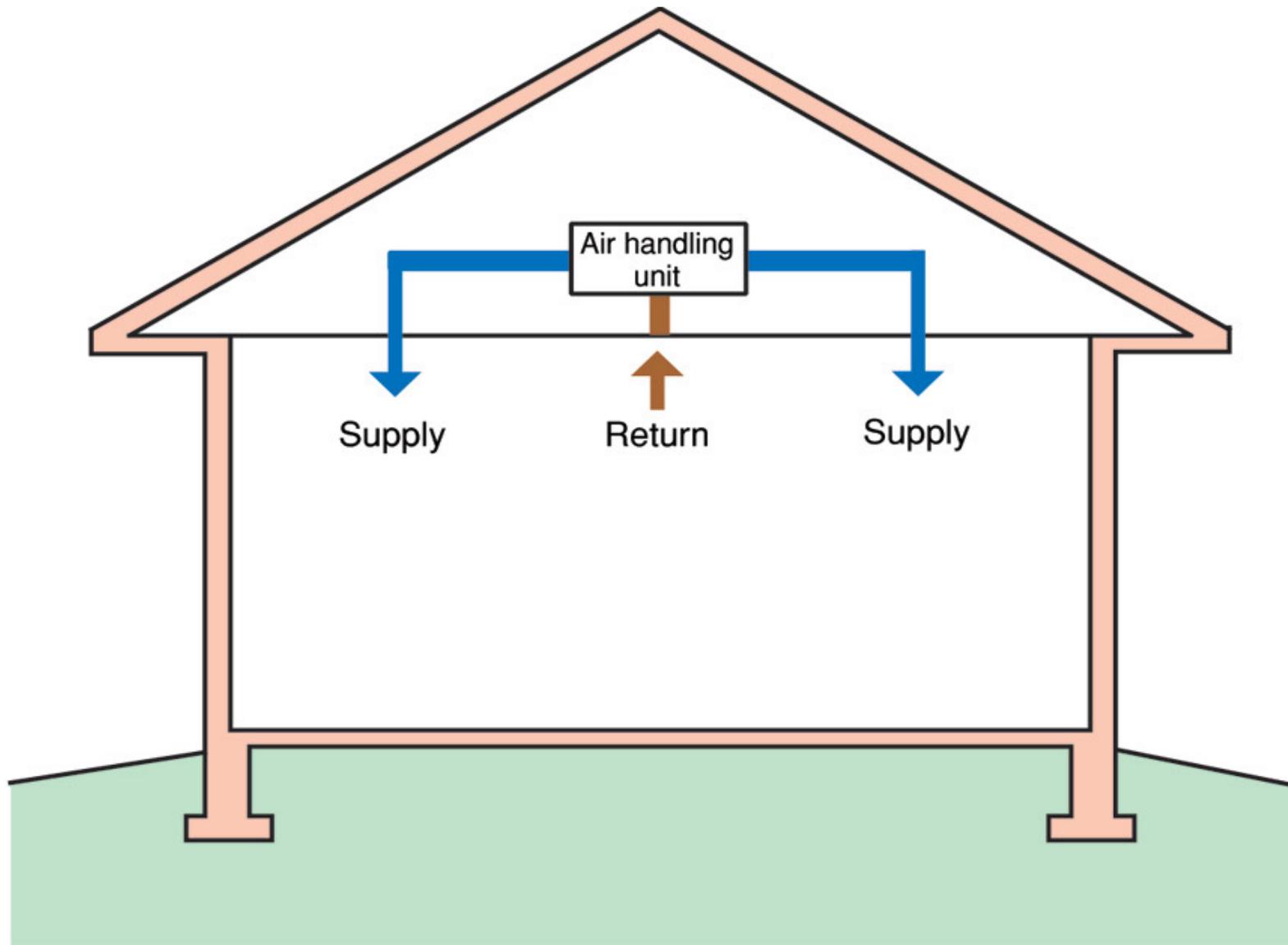




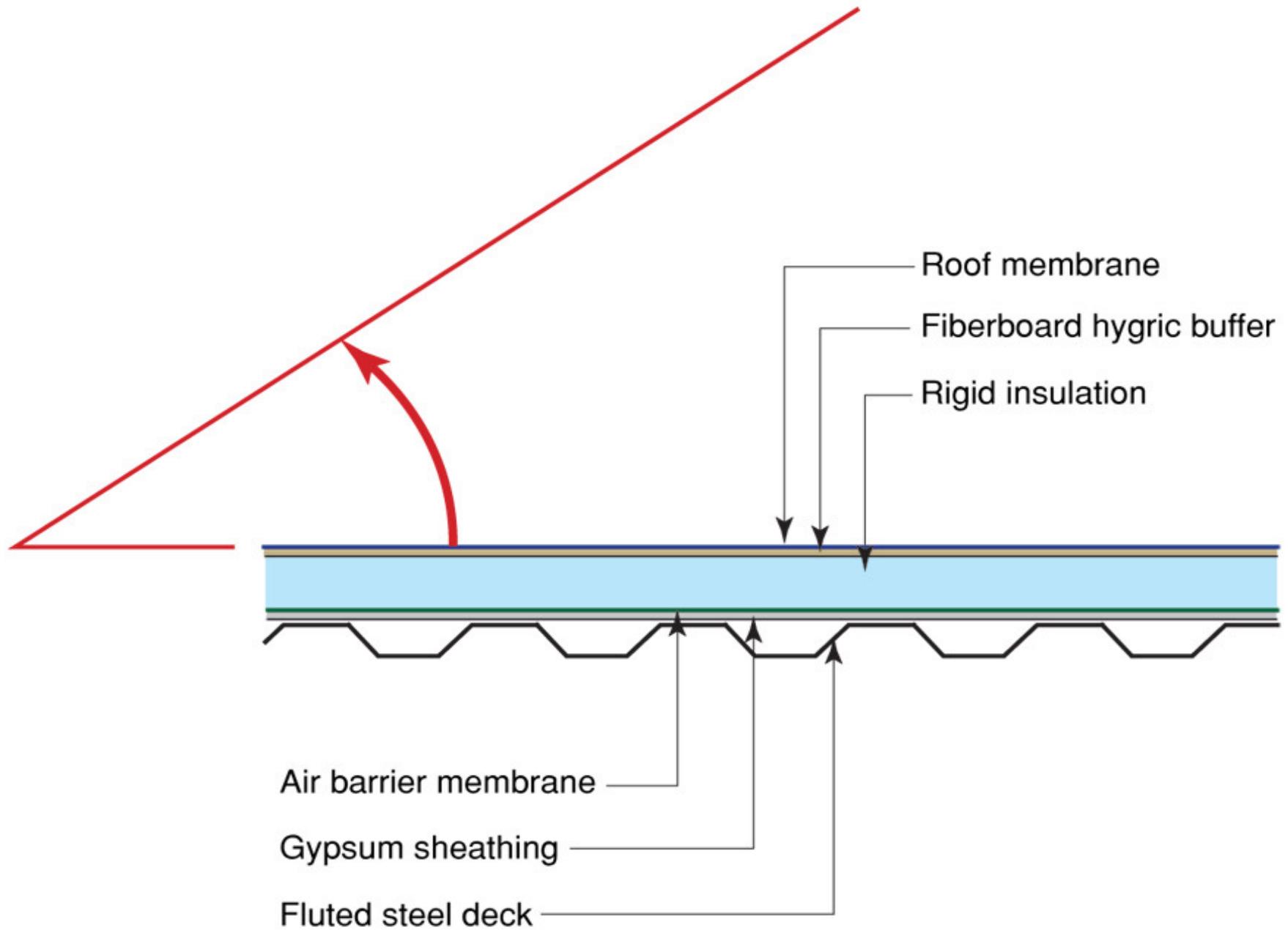


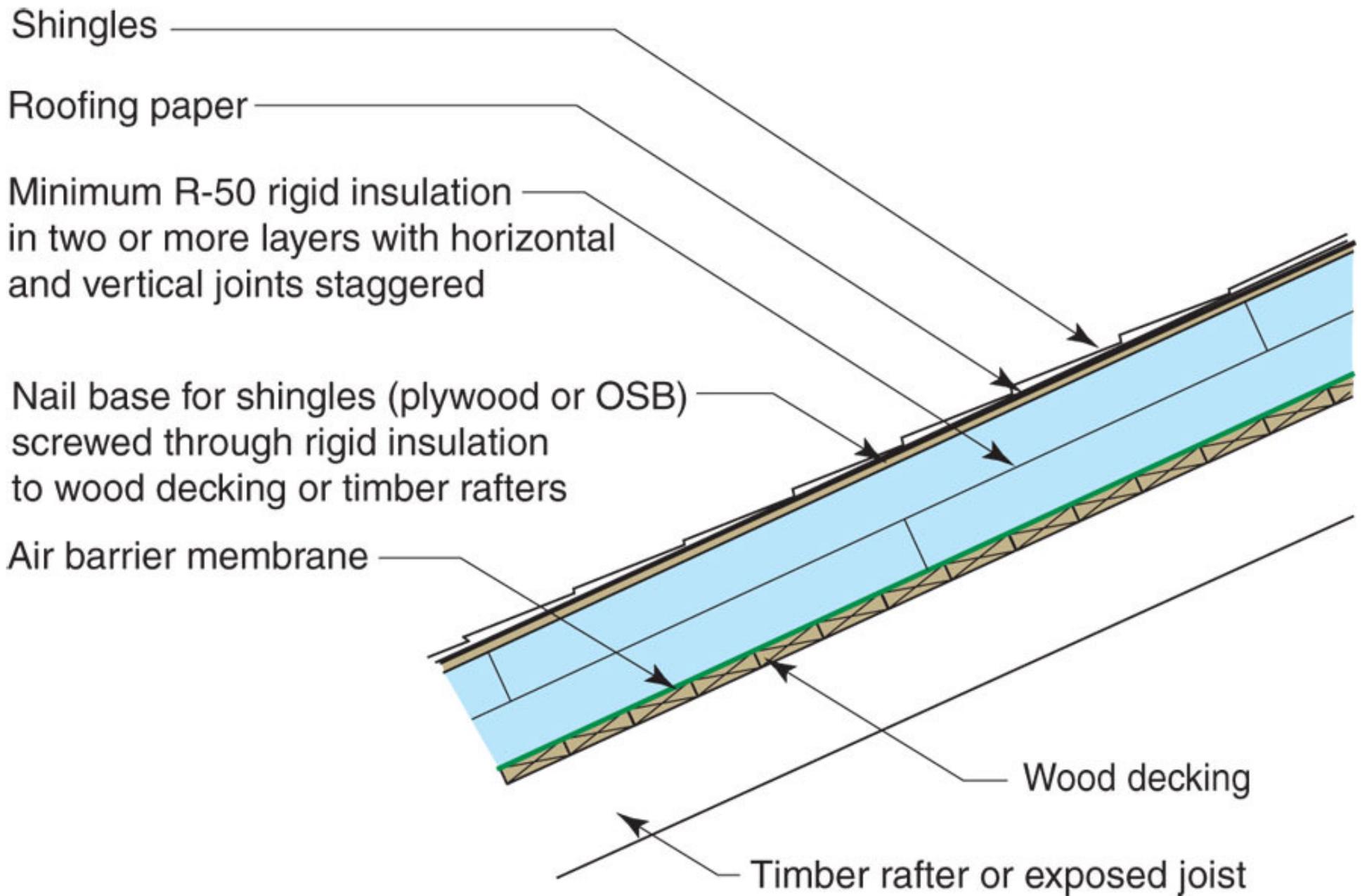


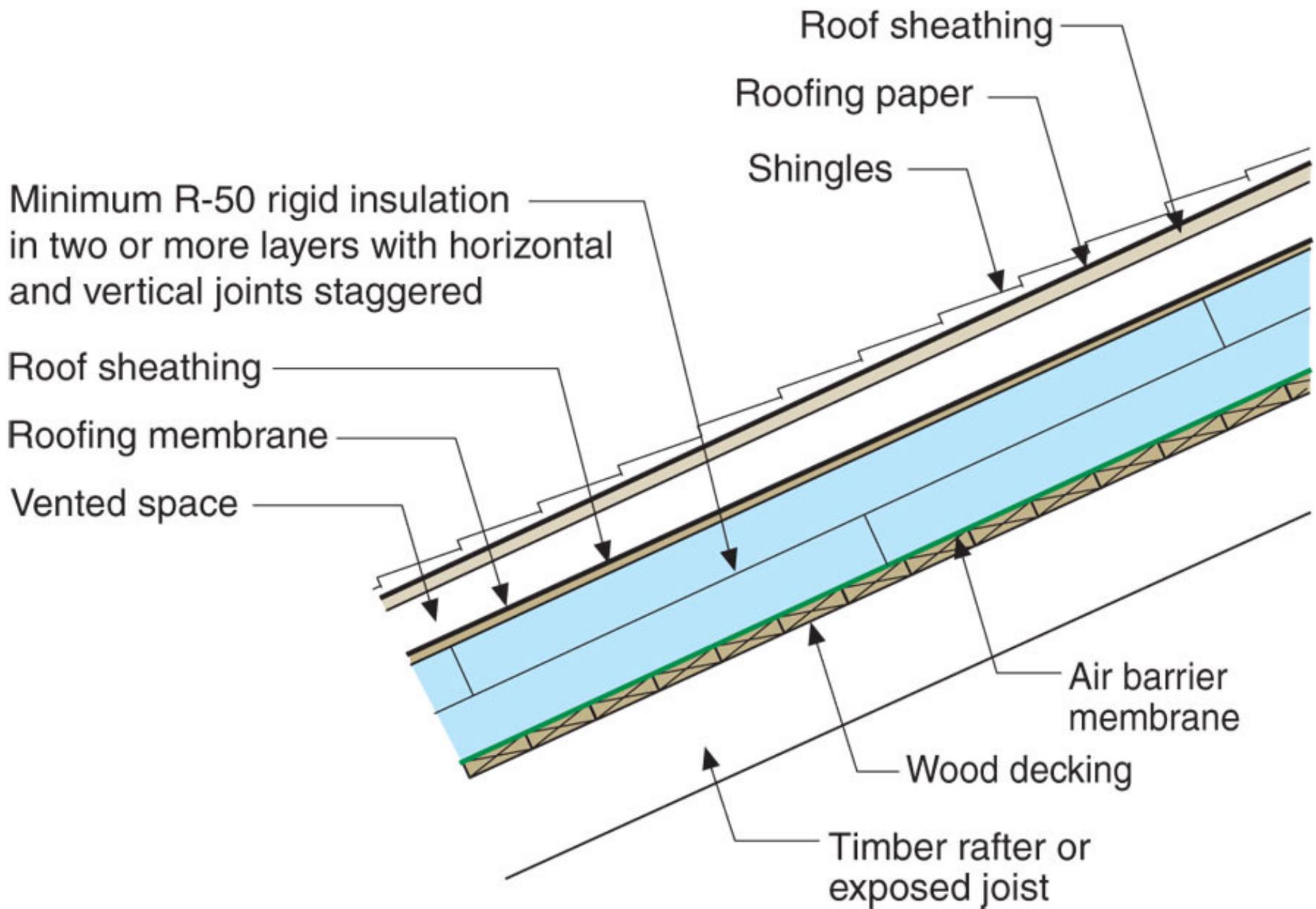


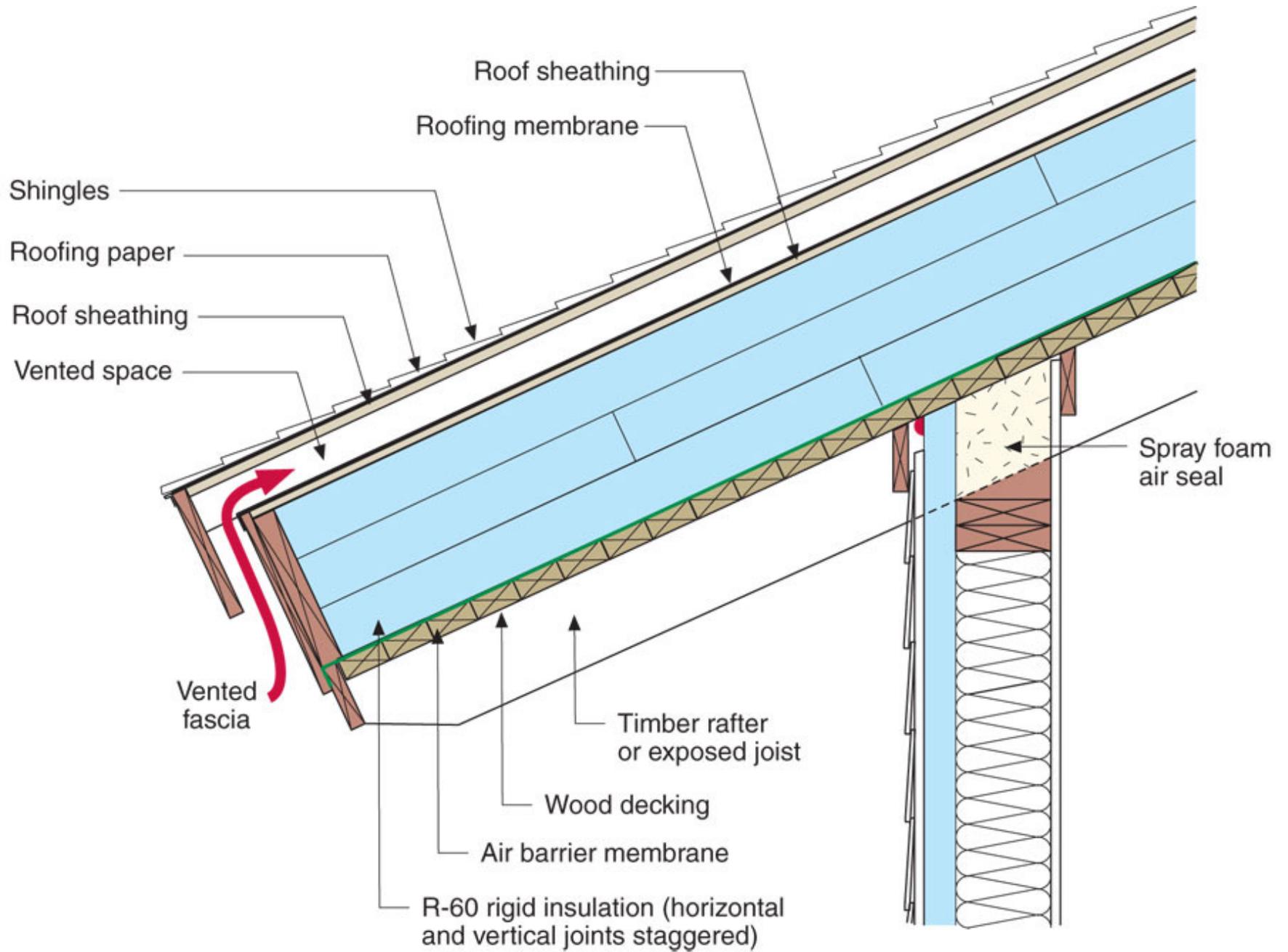


Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.





























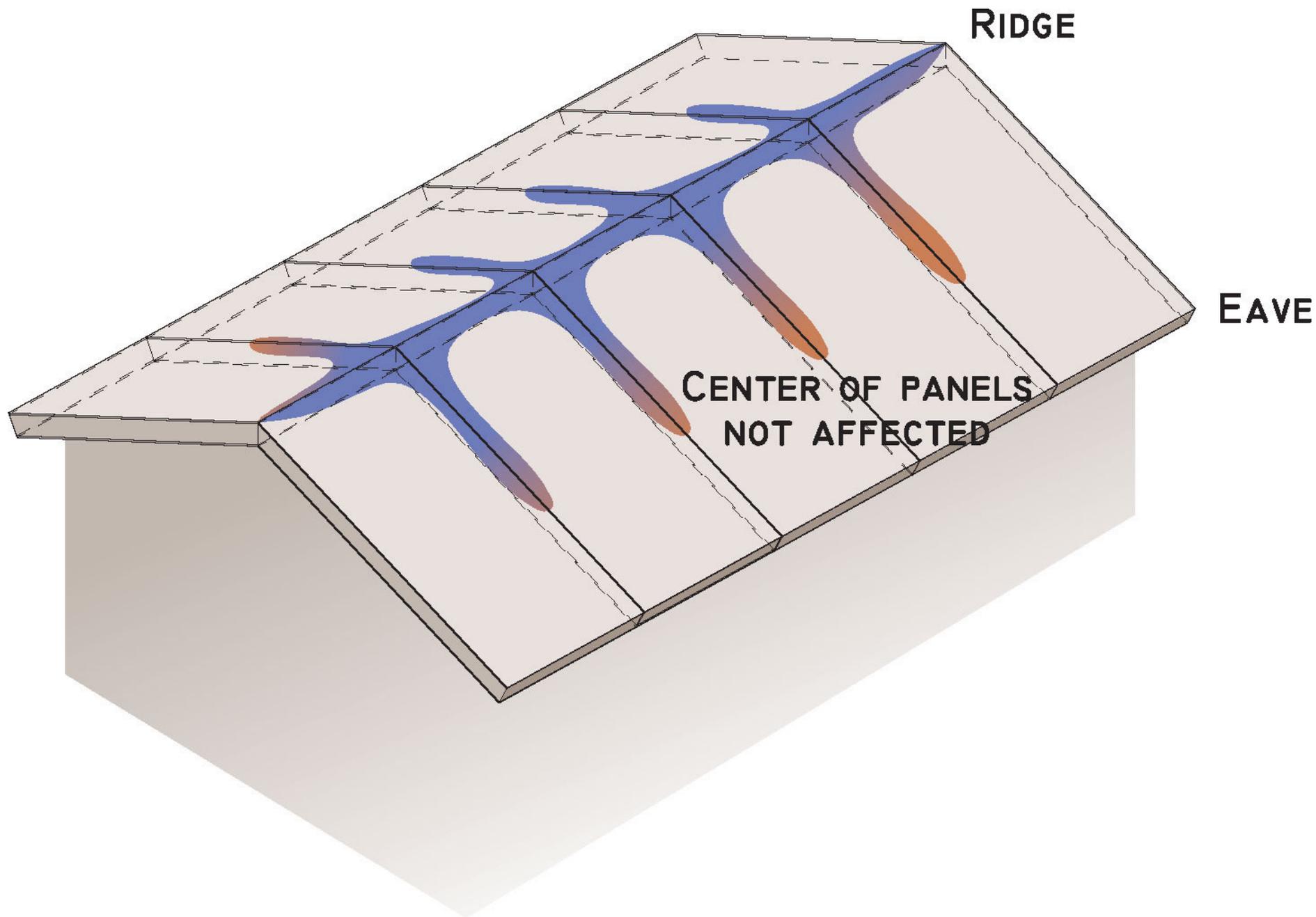




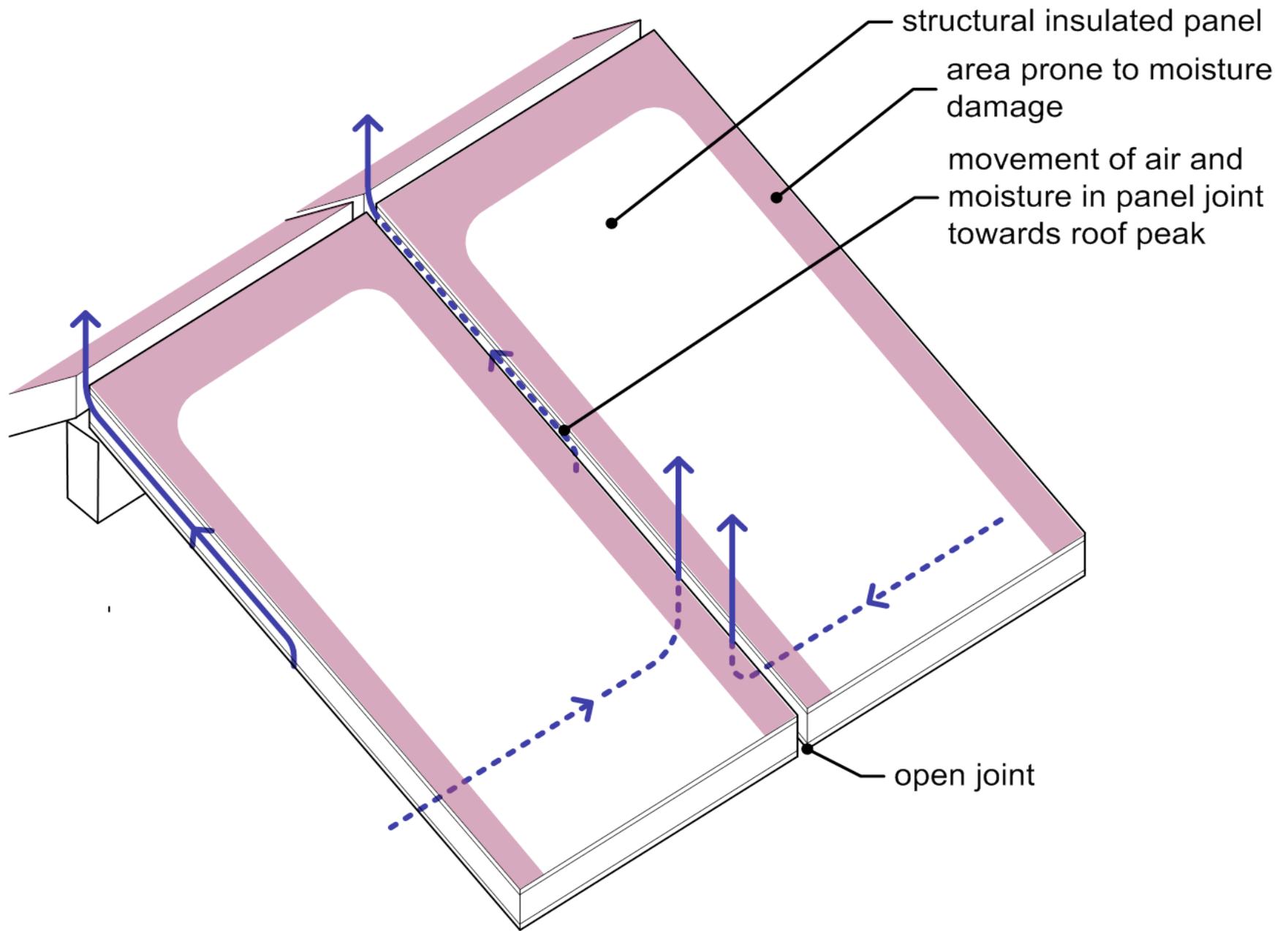












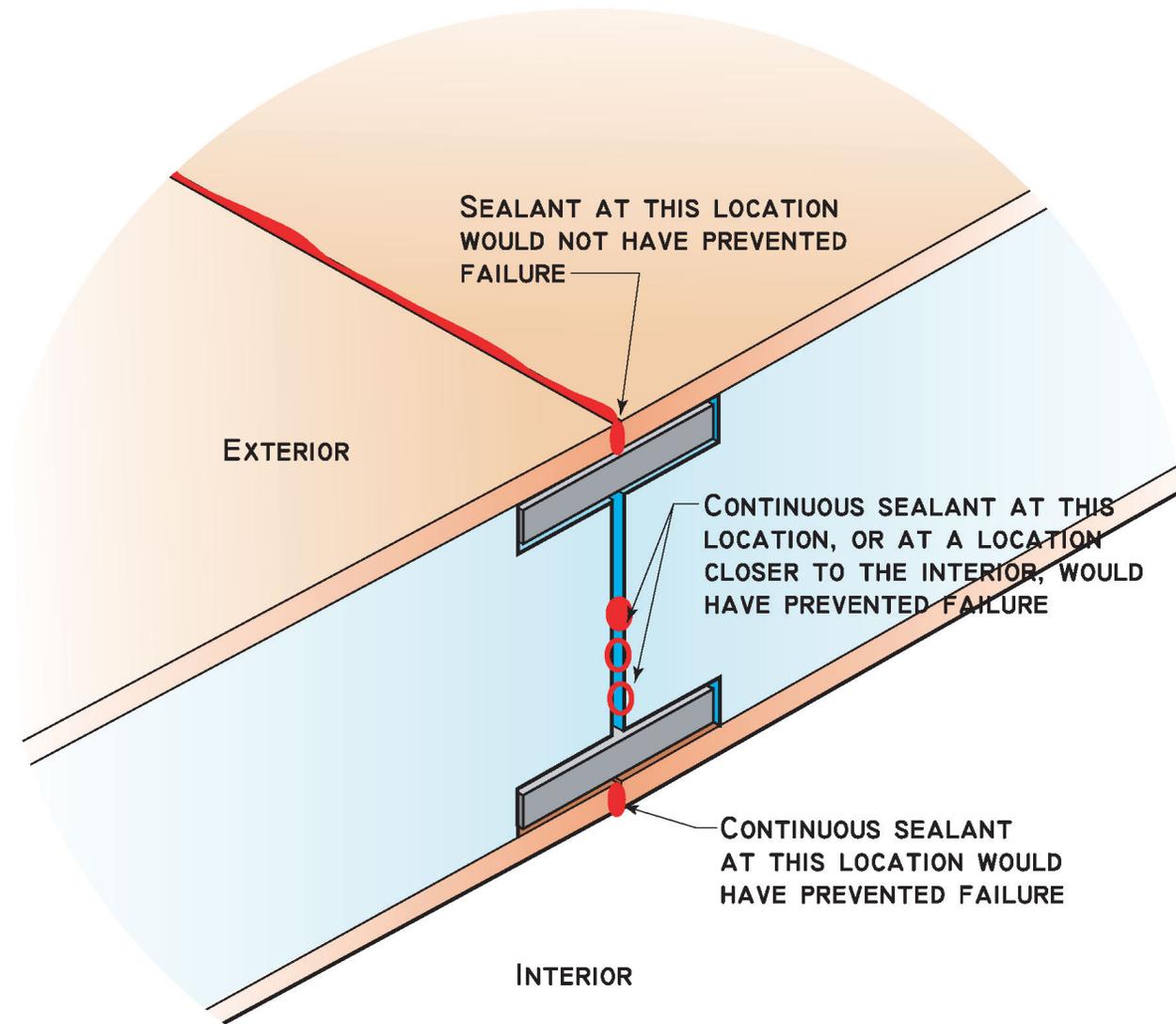












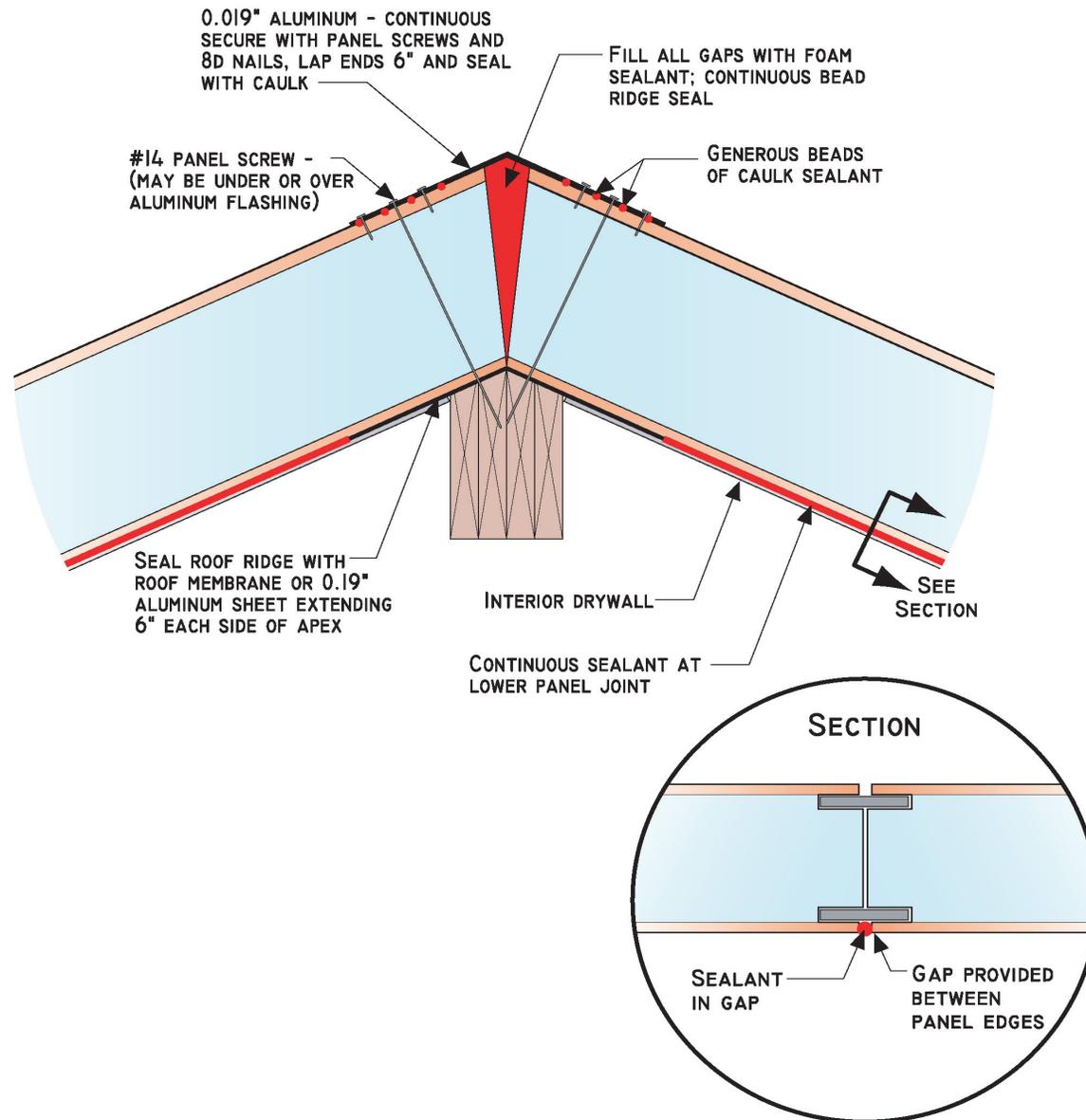


Figure 1

- Remove strip of OSB from each side of ridge

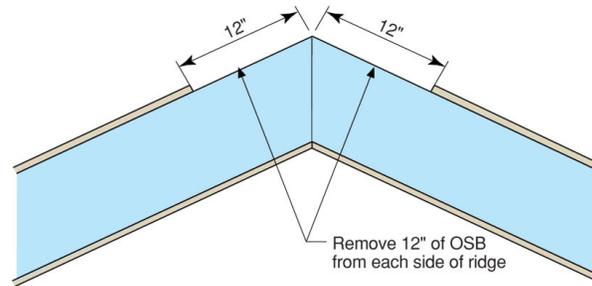


Figure 2

- Create air seal with strip of Tyvek® (tape seams of Tyvek®)
- Hold Tyvek® sheet in place with metal strapping

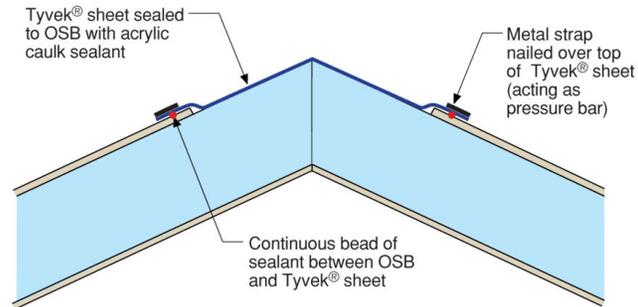
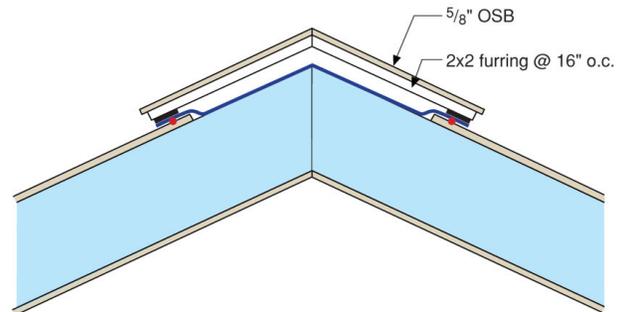


Figure 3

- Construct wood ridge vent with 2x2 furring
- Use Cobra® Ridge Vent roll mesh at edges of vent to control insect entry





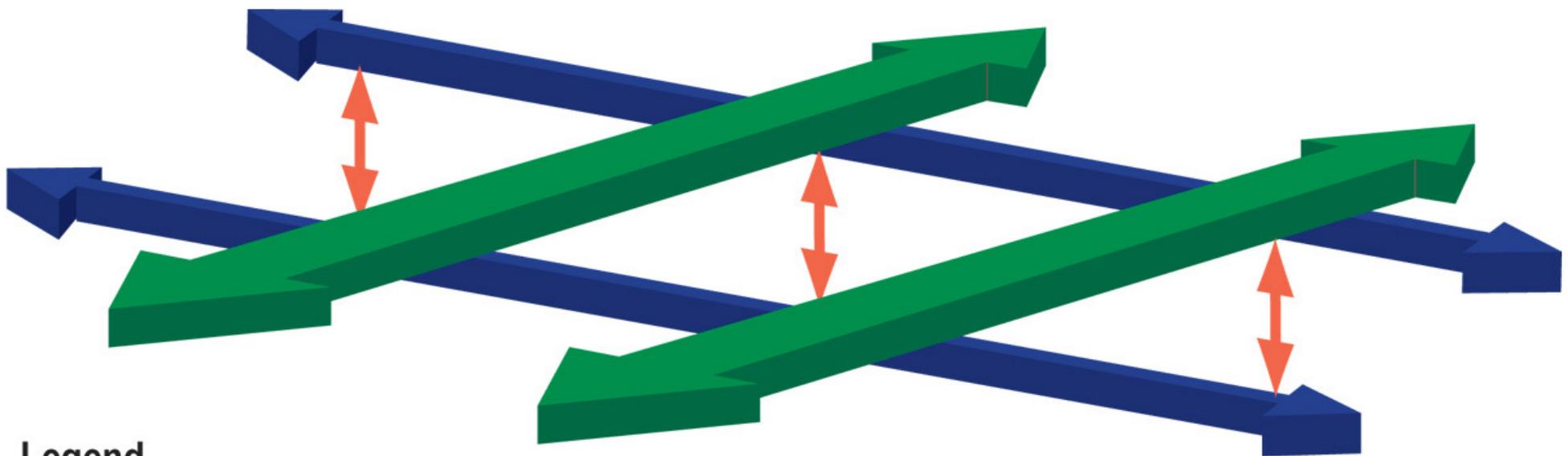






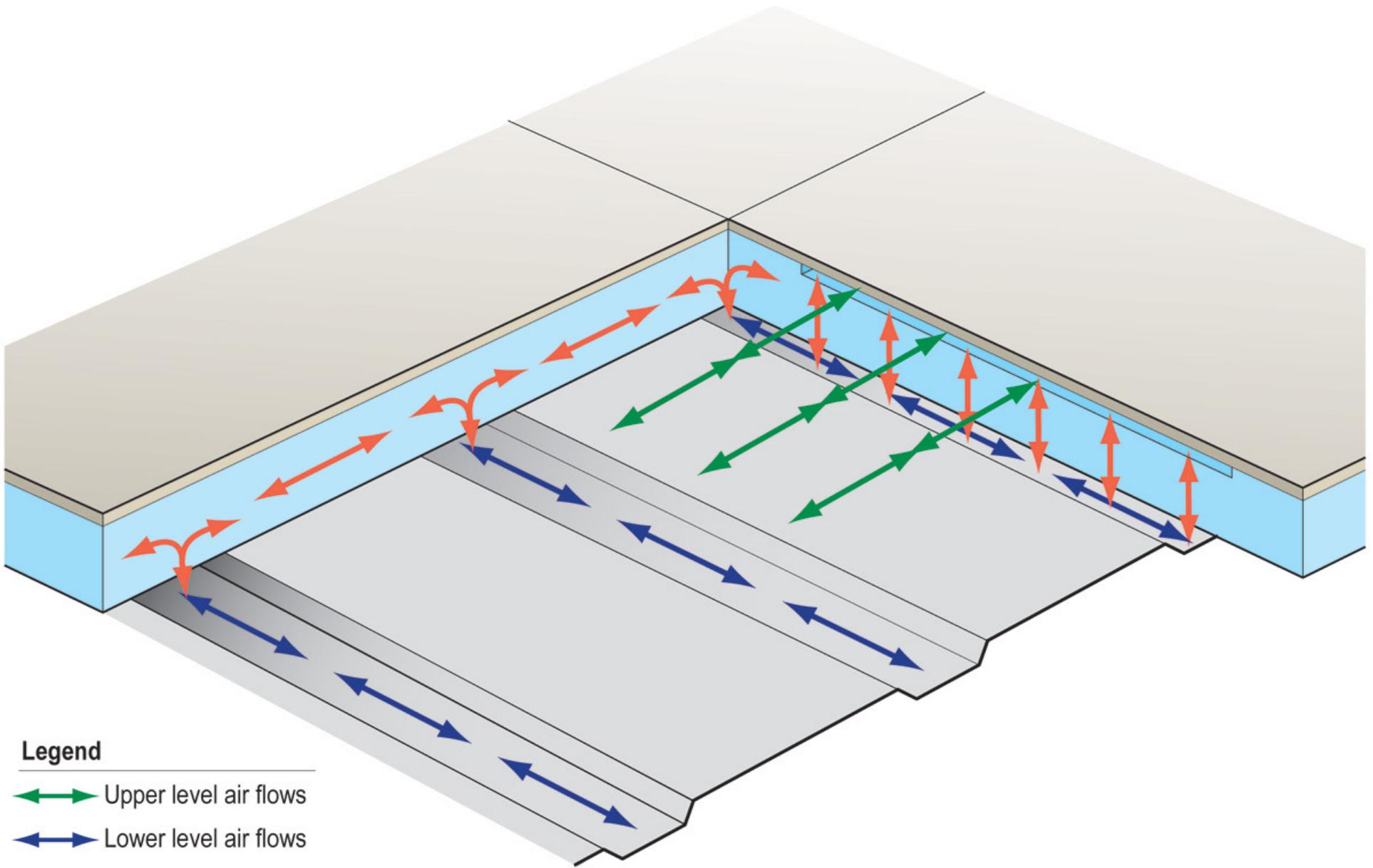






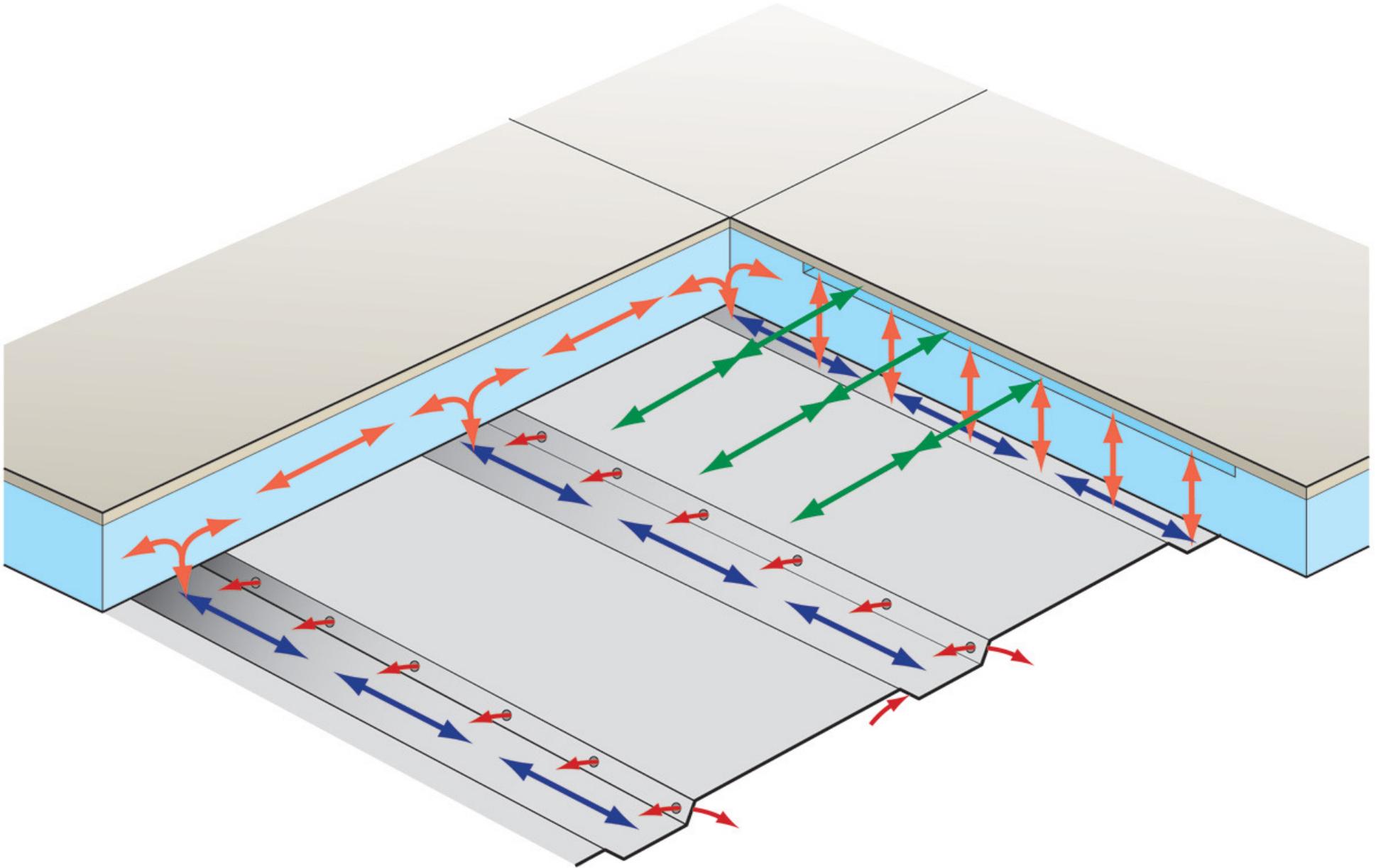
Legend

- ←→ Upper level air flows
- ←→ Lower level air flows
- ↕ Air flow at panel joints

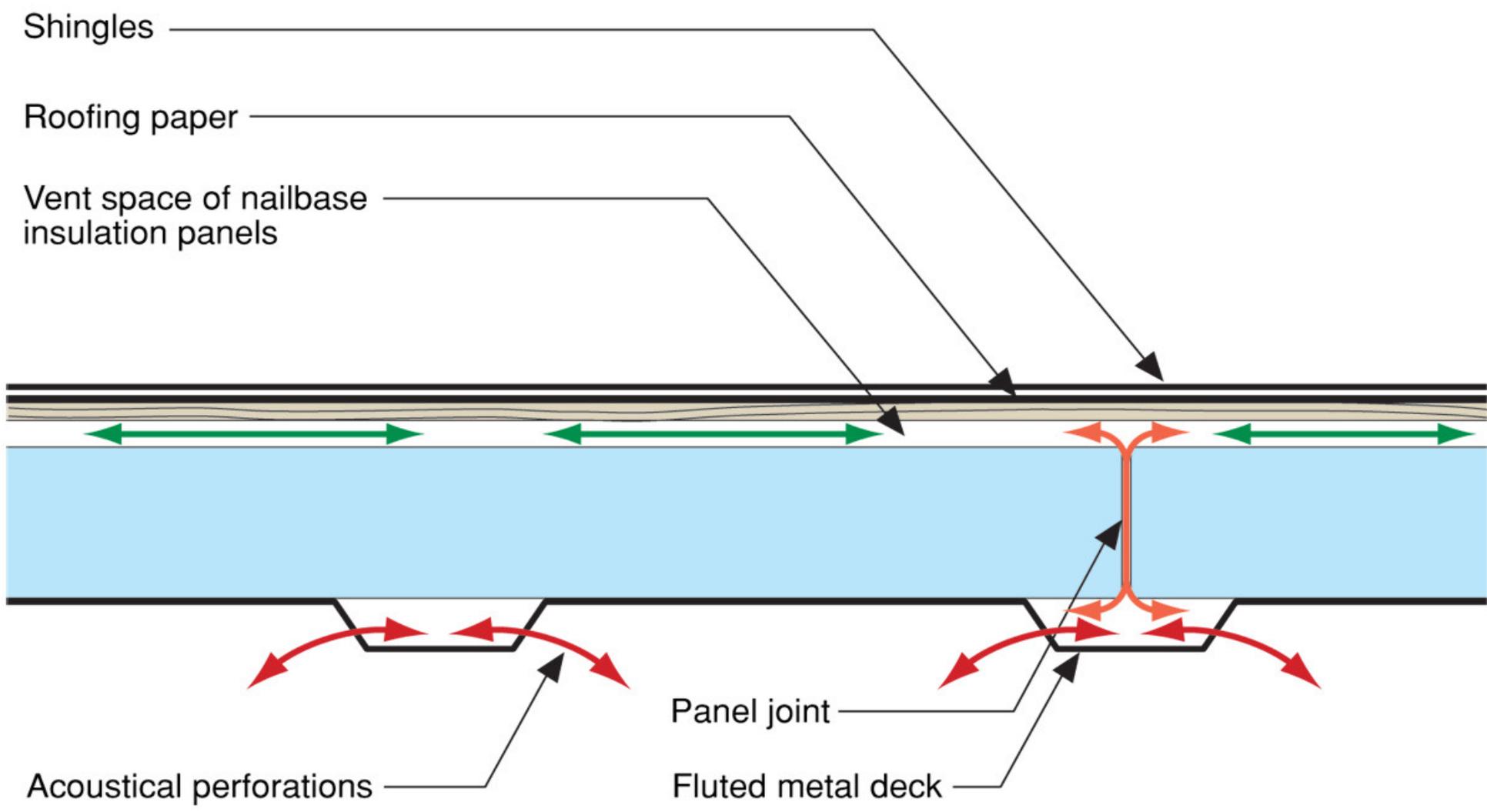


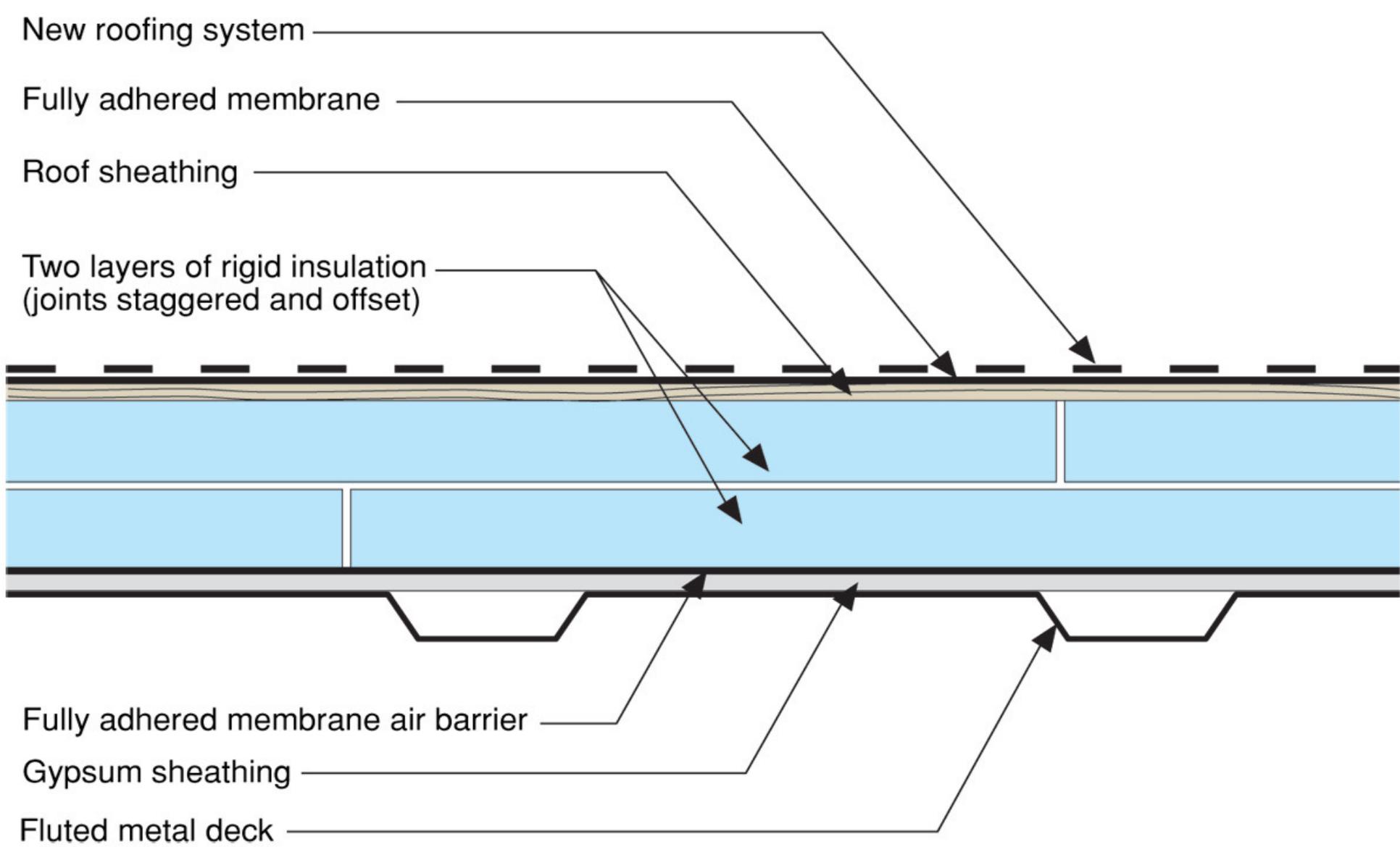
Legend

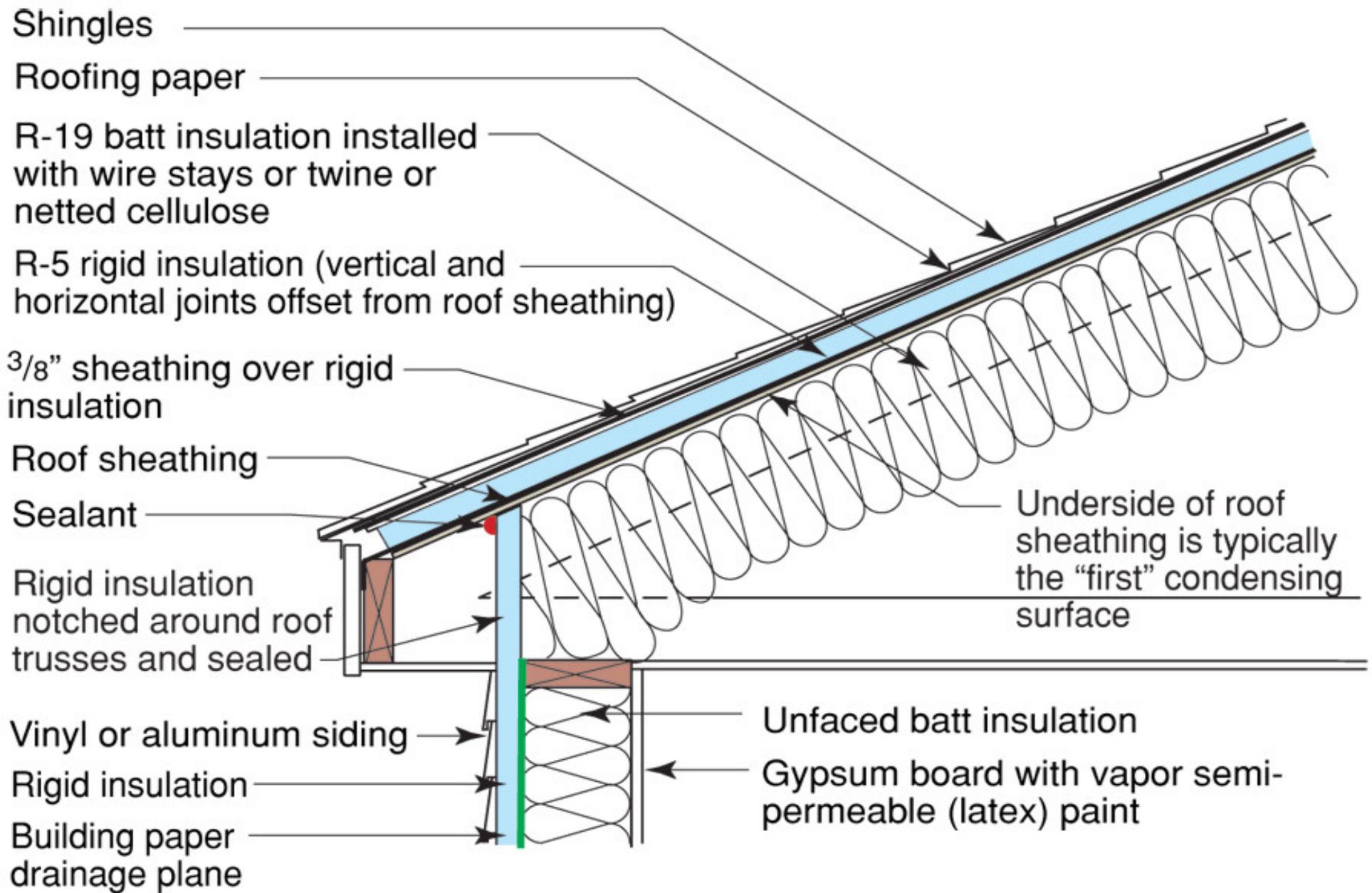
-  Upper level air flows
-  Lower level air flows
-  Air flow at panel joints connecting uppr and lower air flows

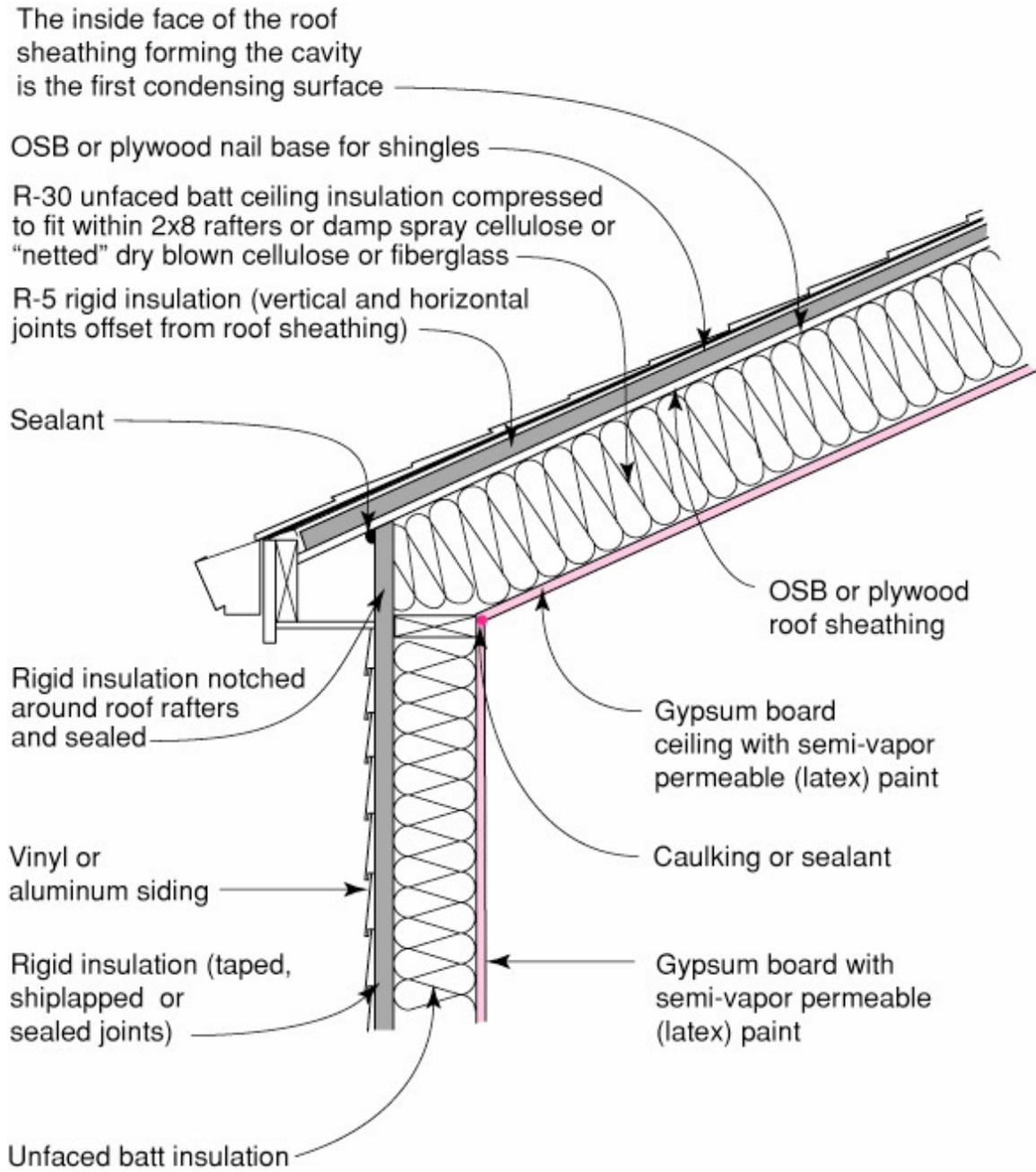


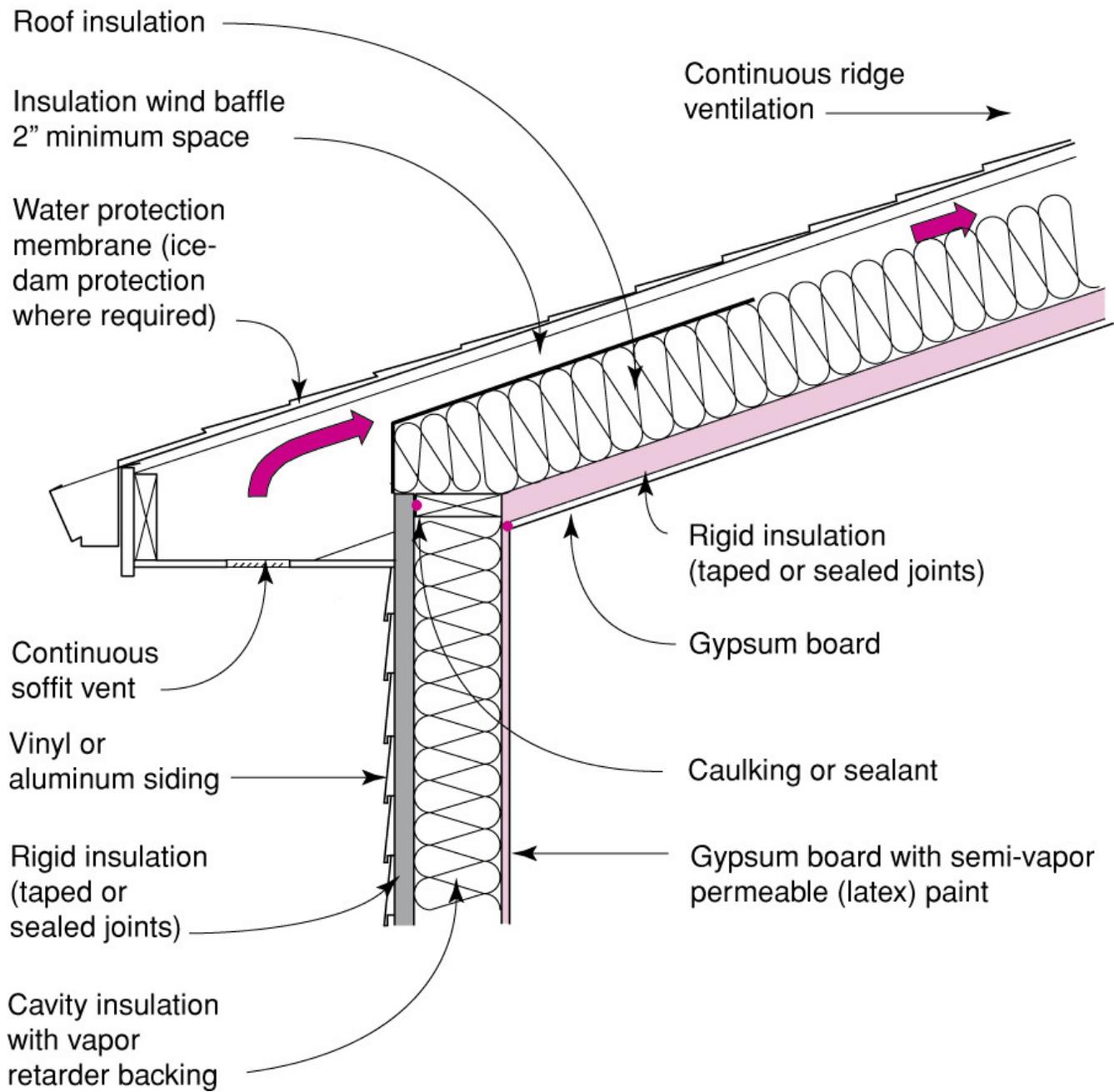


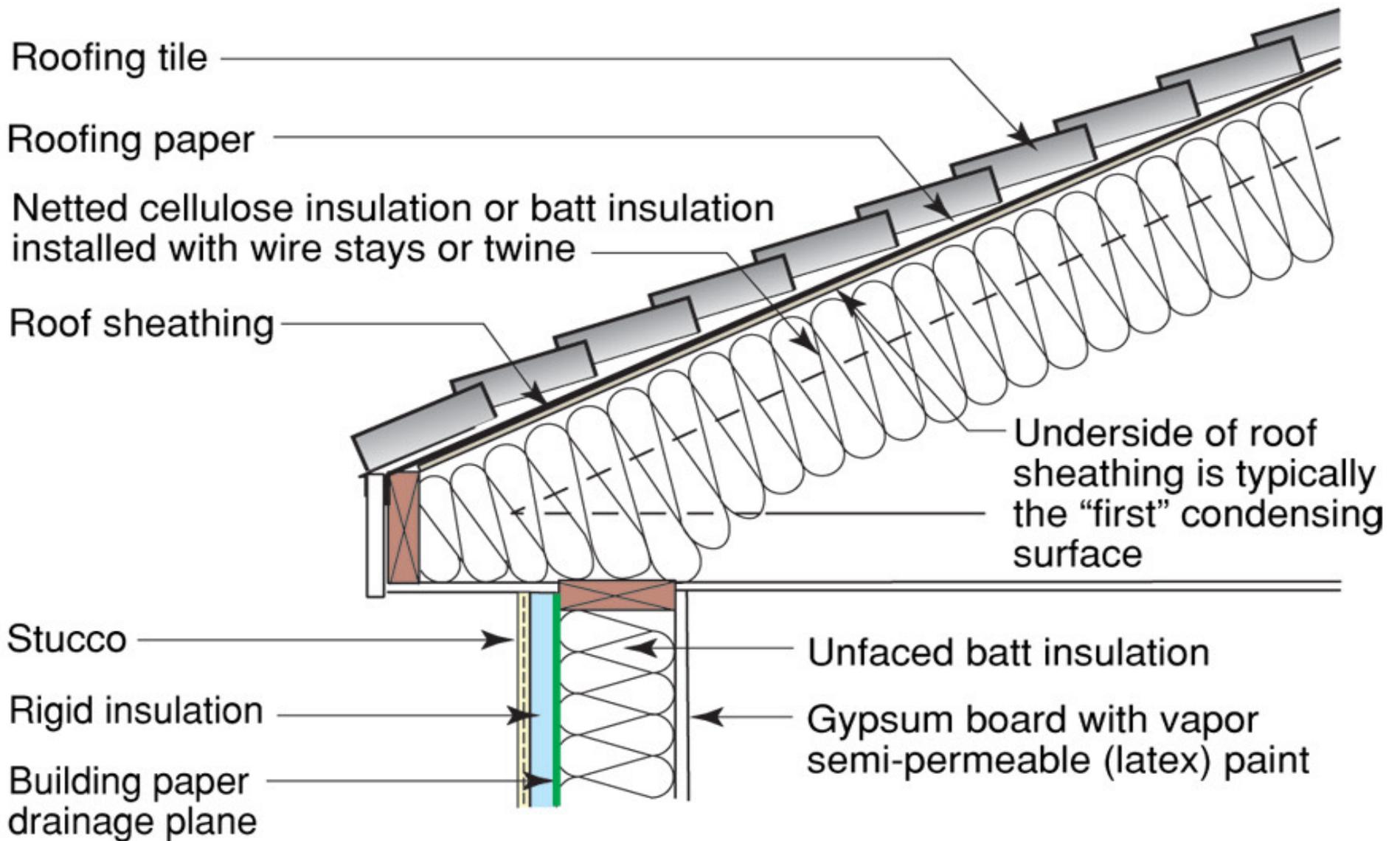








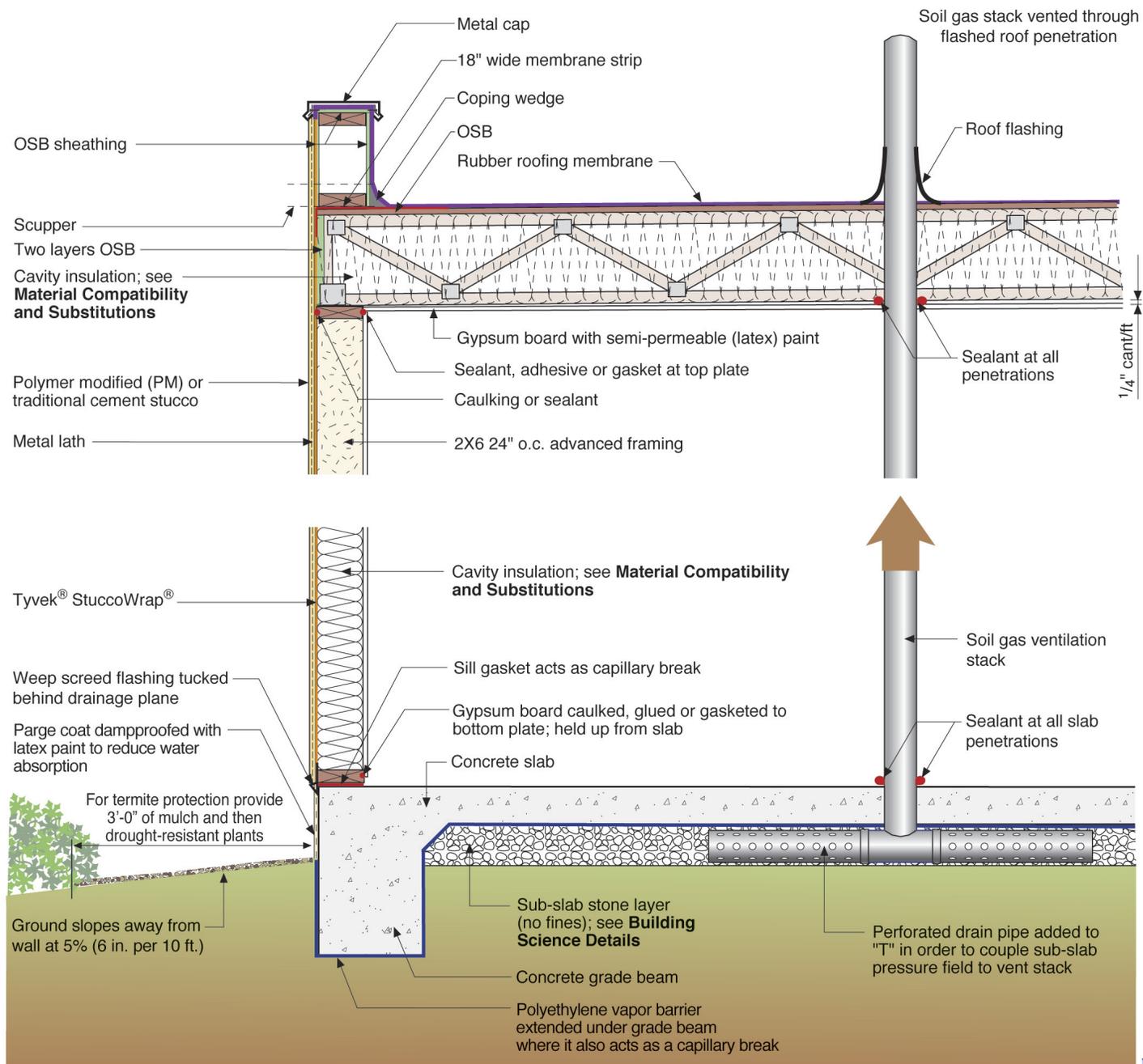


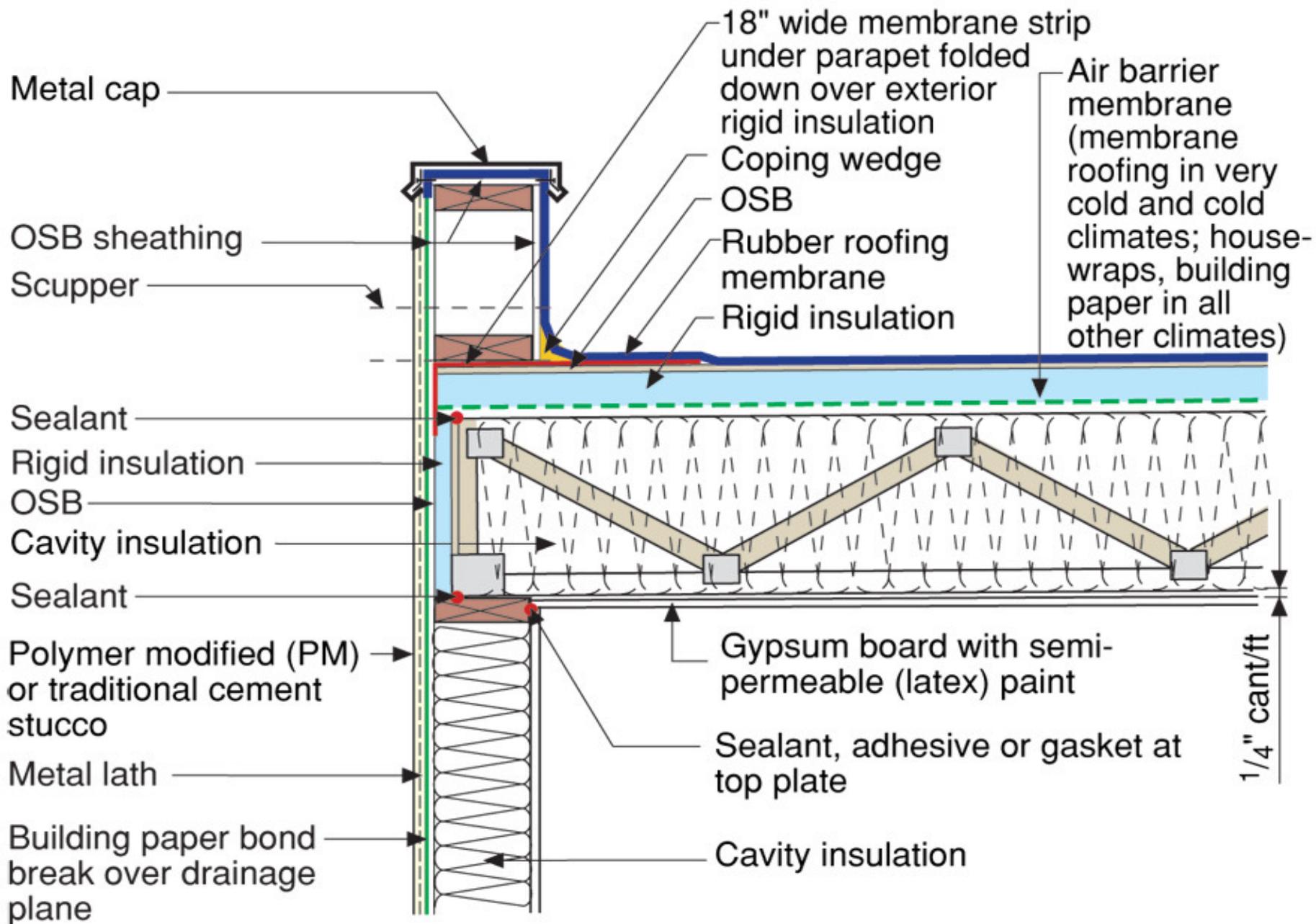


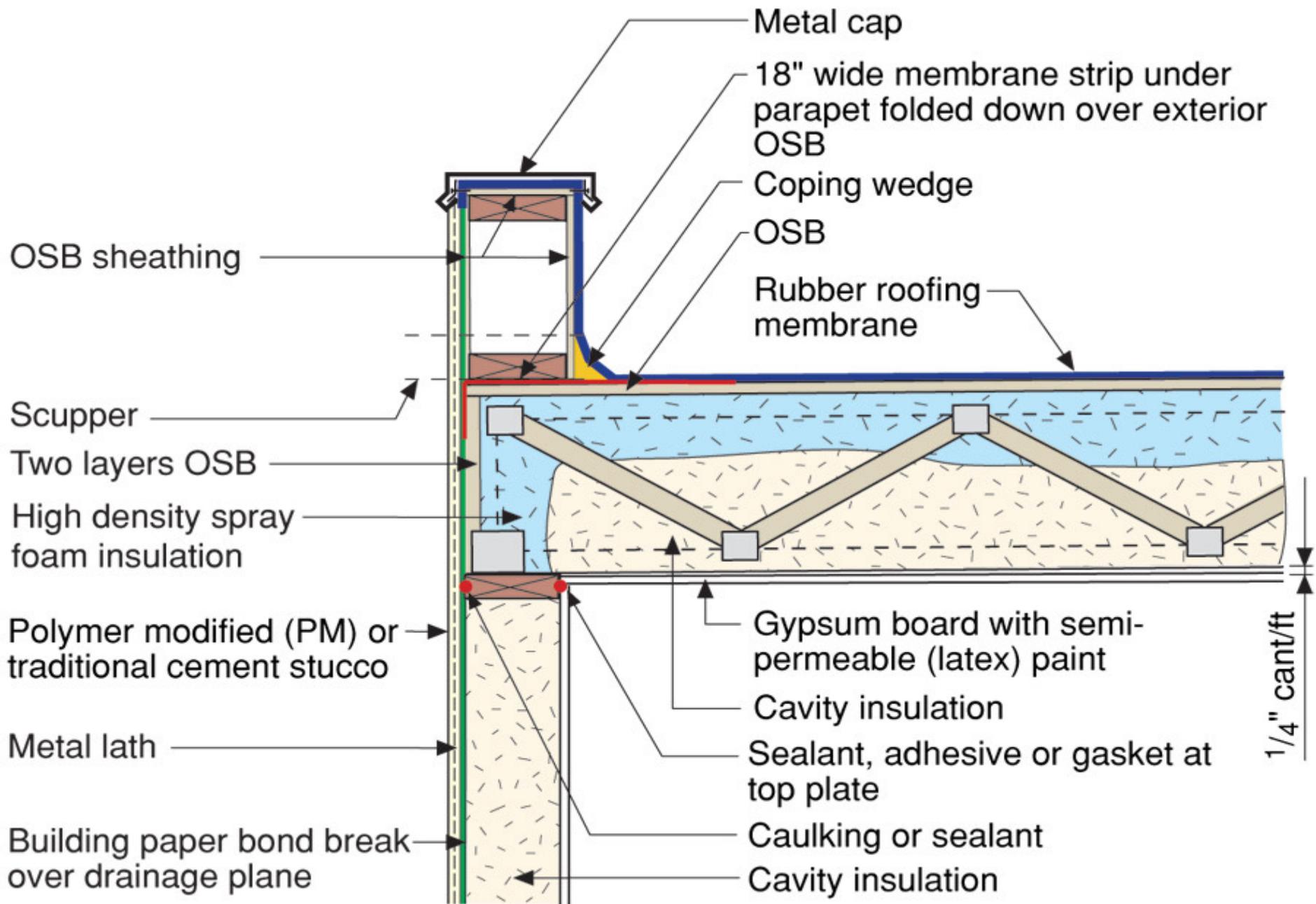




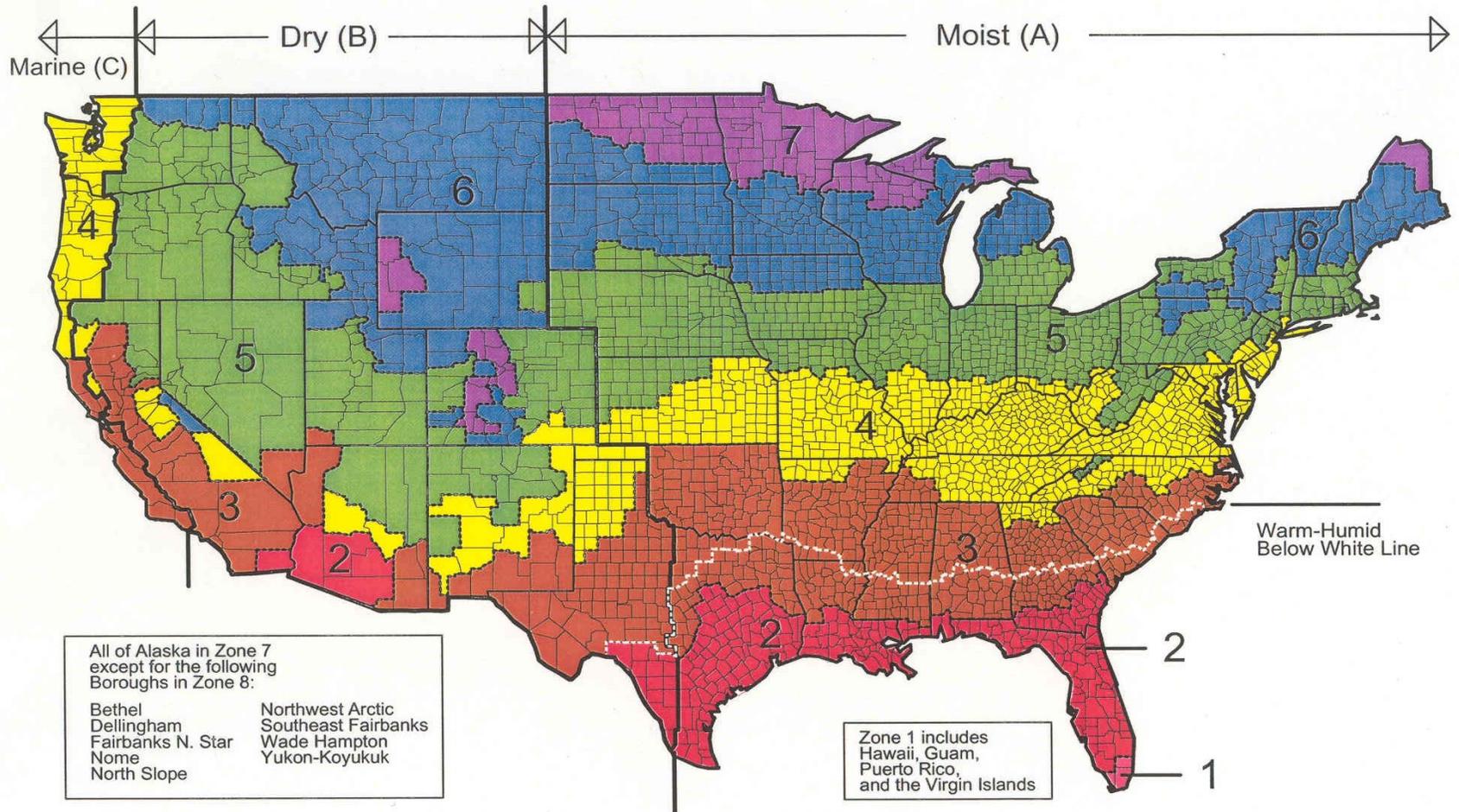




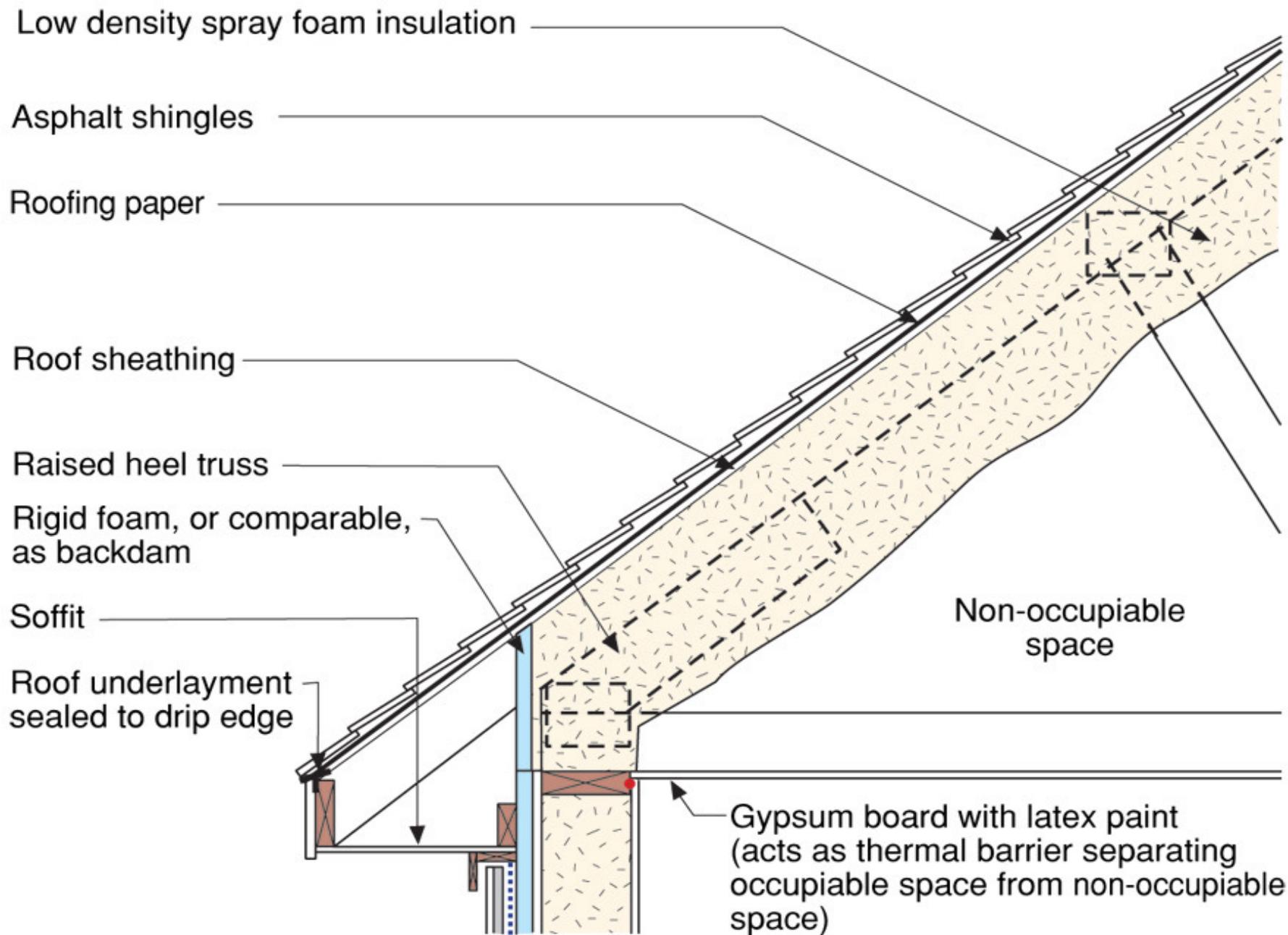




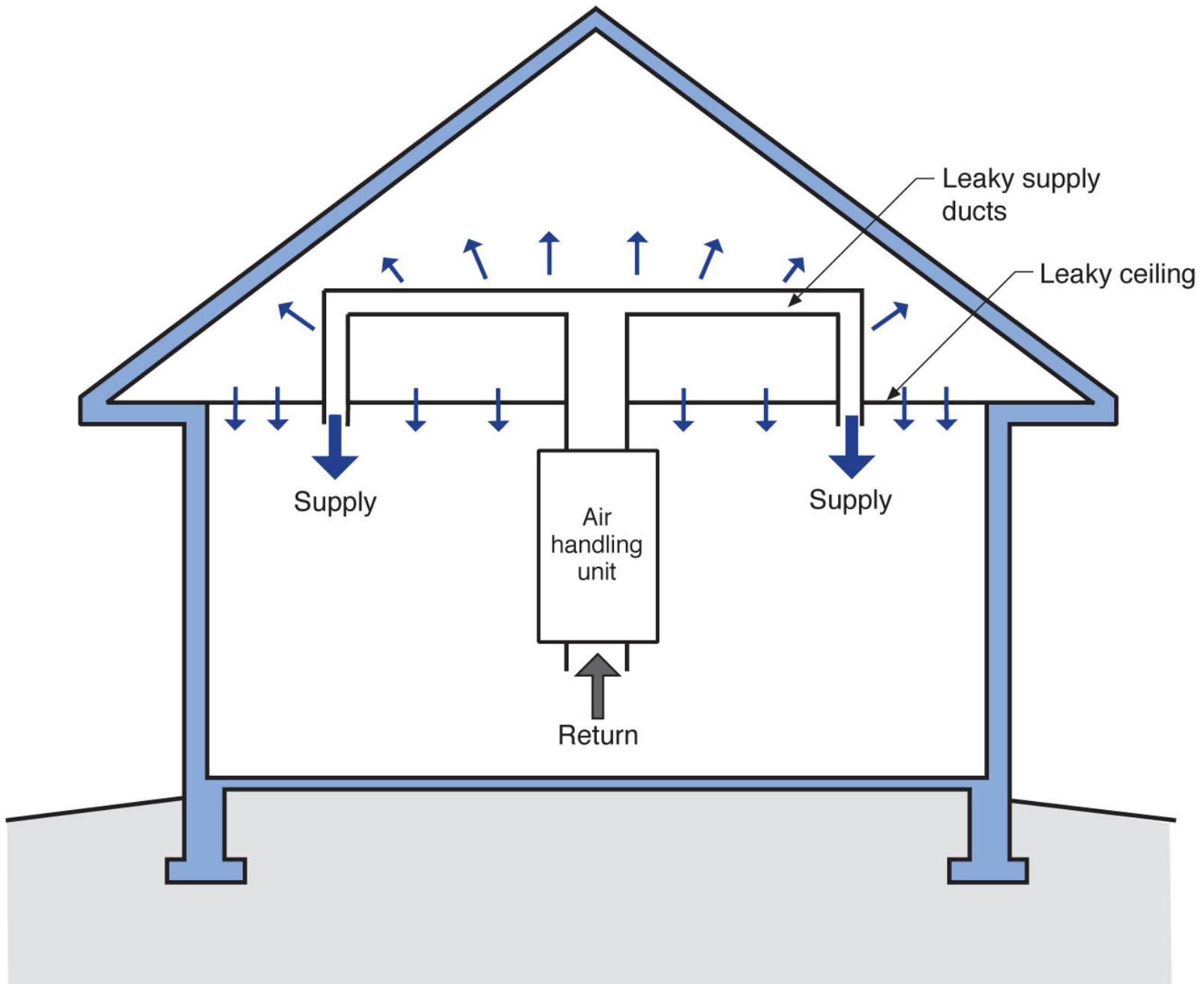
Map of DOE's Proposed Climate Zones



March 24, 2003









Conditioned Attics Not Unvented Attics Need Supply Air

Conditioned Attics Not Unvented Attics
Need Supply Air
50 cfm/1000 ft² of Attic

Hygric Buoyancy

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
		*	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
		**	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

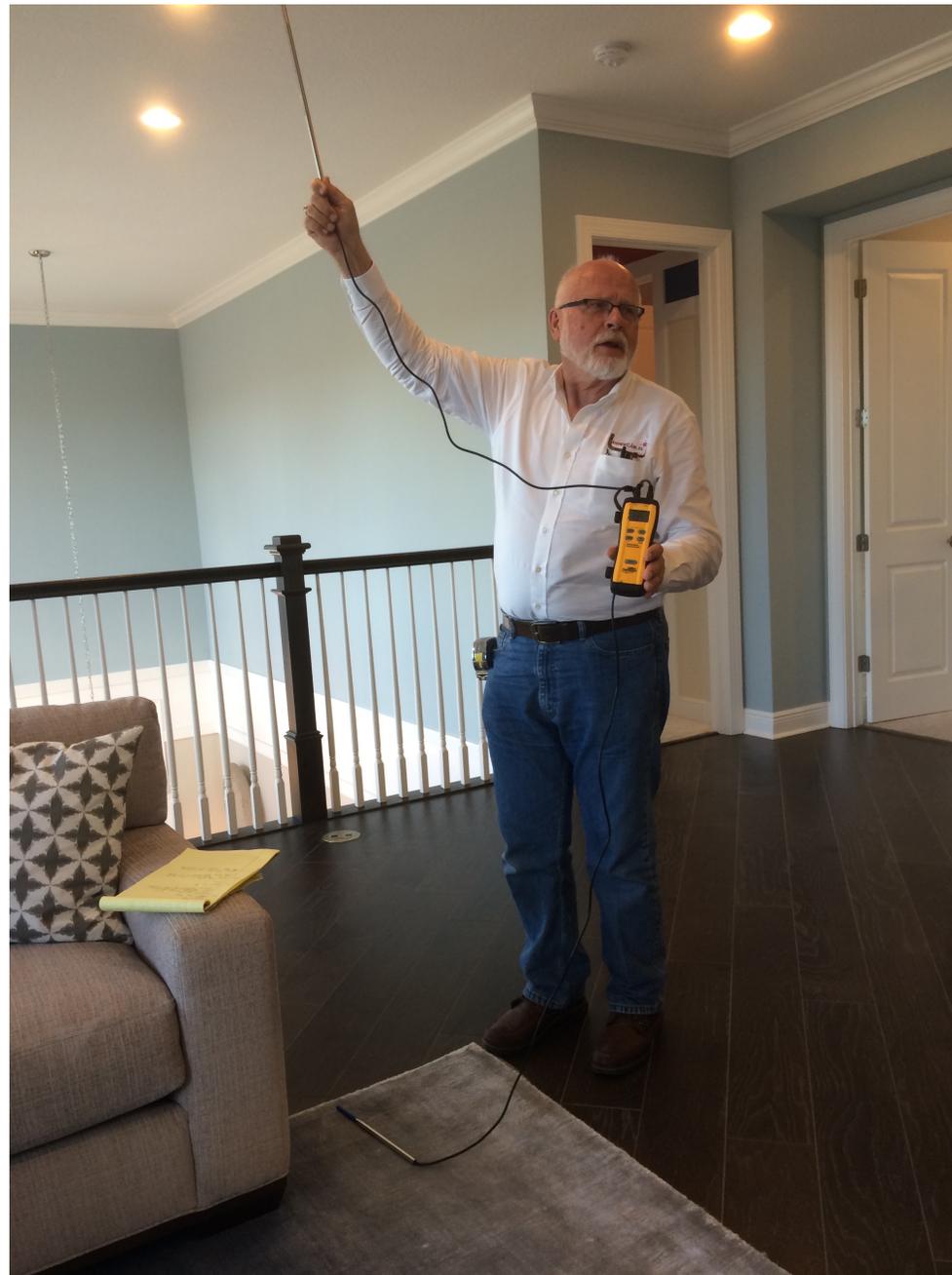
1 Atomic Number
H Symbol

Dry Air

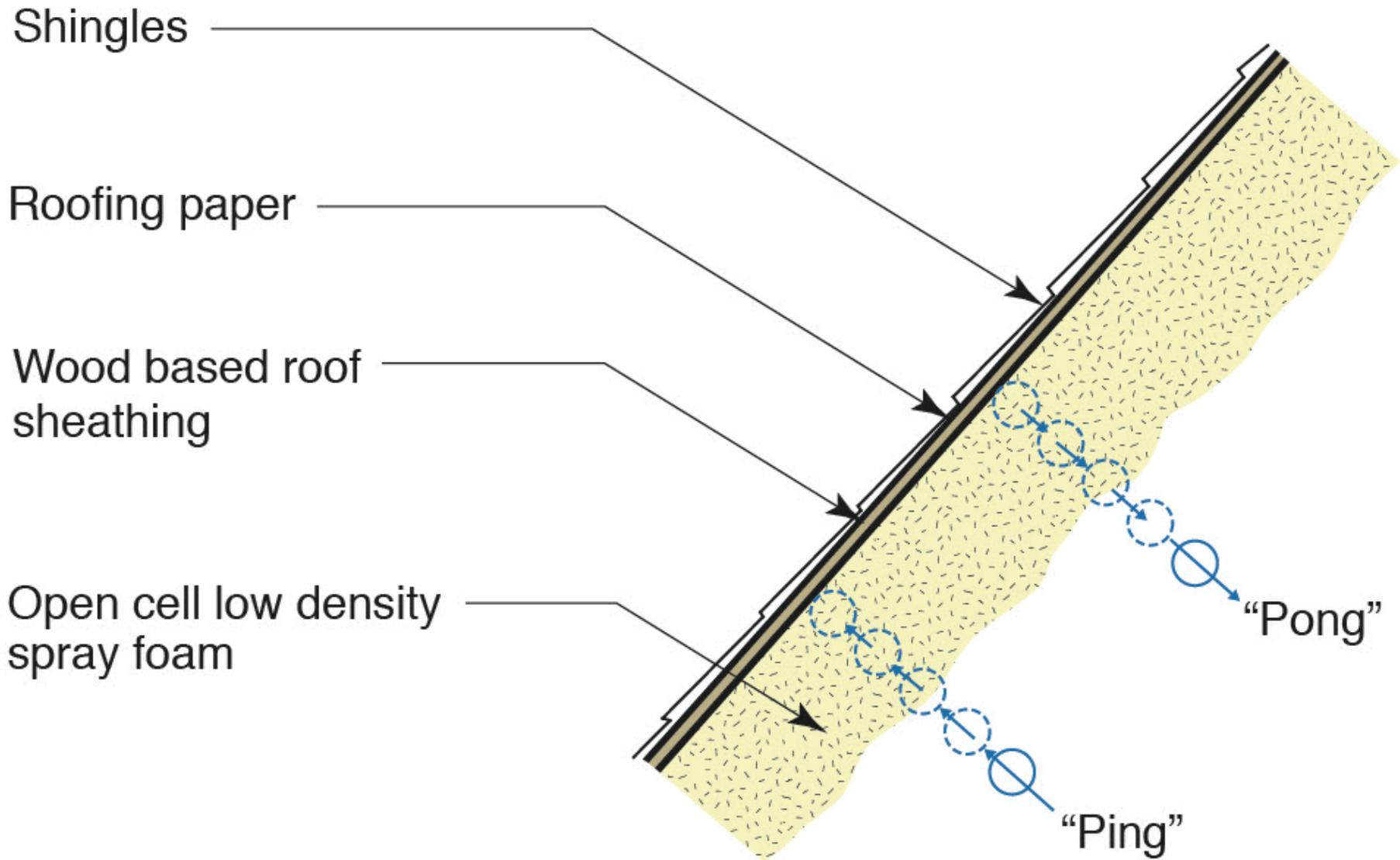
Oxygen	(21%)	16	O2	32
Nitrogen	(79%)	14	N2	28
				29

Moist Air

Oxygen	(21%)	16	O ₂	32
Nitrogen	(79%)	14	N ₂	28
Water	(tiny)		H ₂ O	18
		less than		29





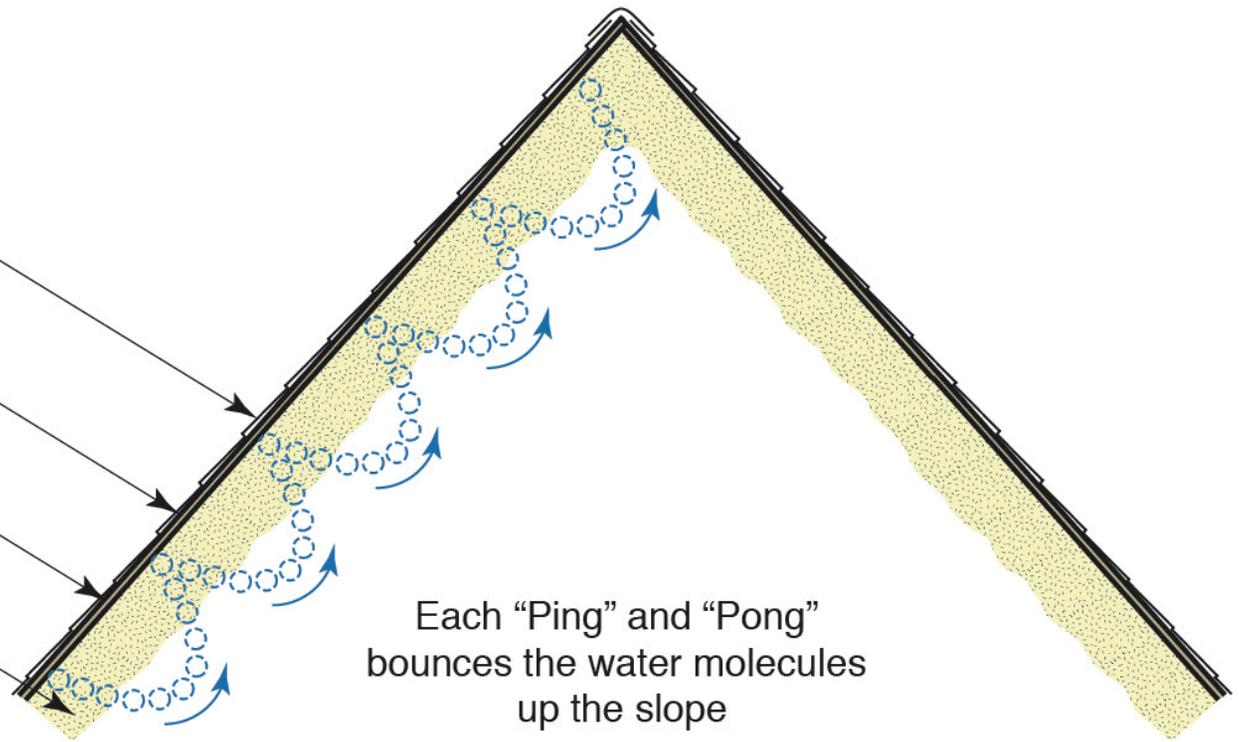


Shingles

Roofing paper

Wood based roof sheathing

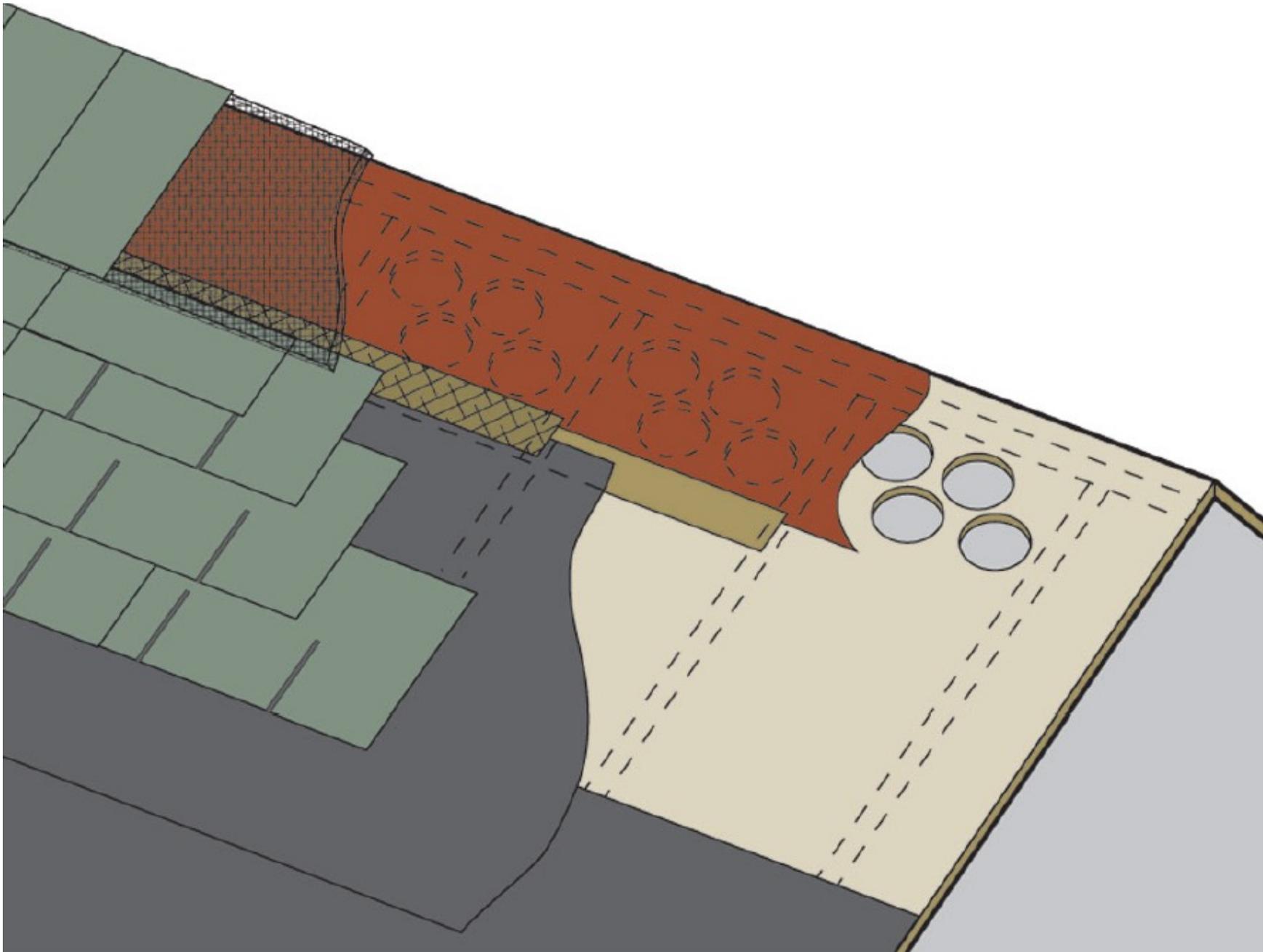
Open cell low density spray foam

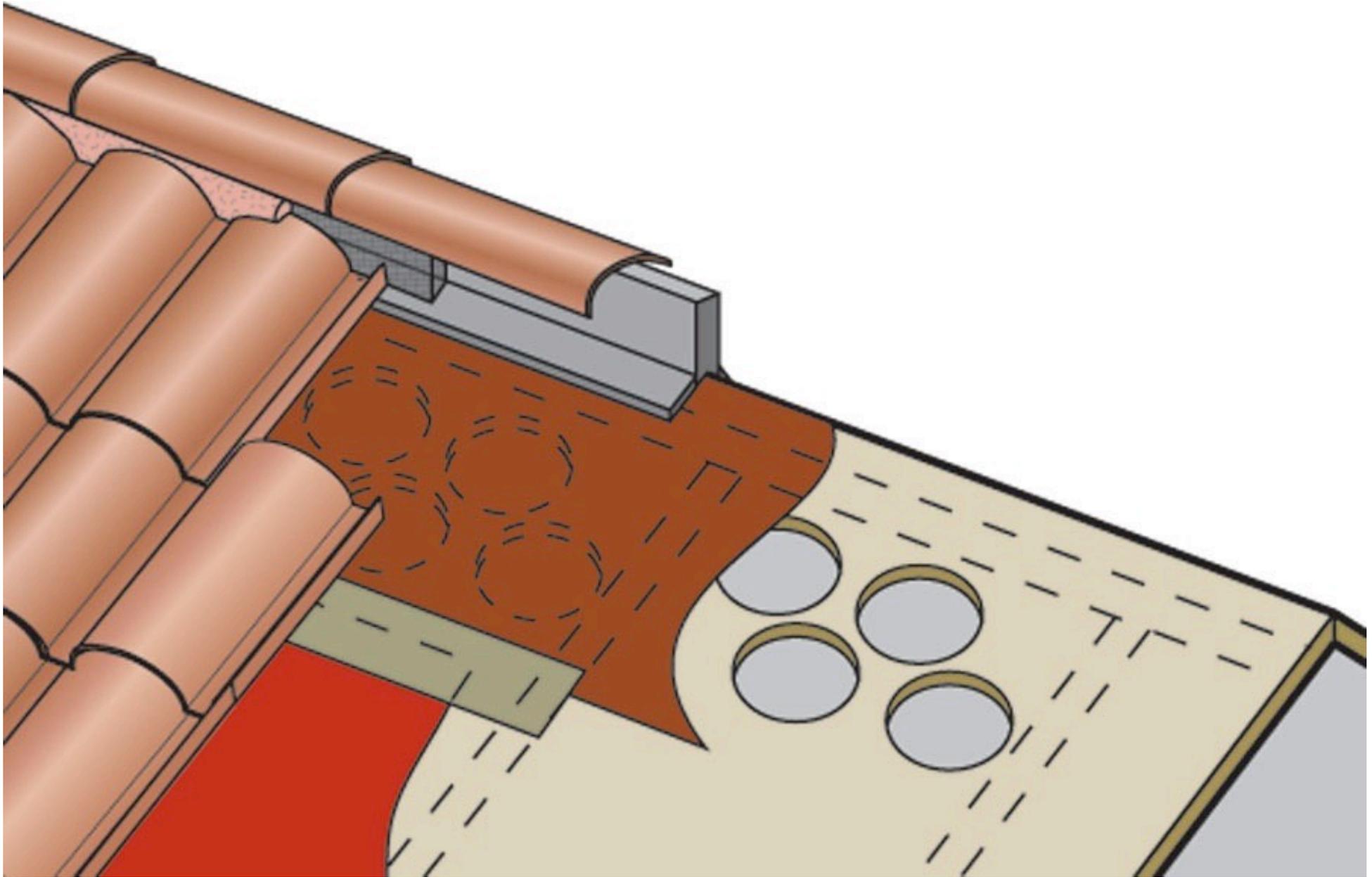


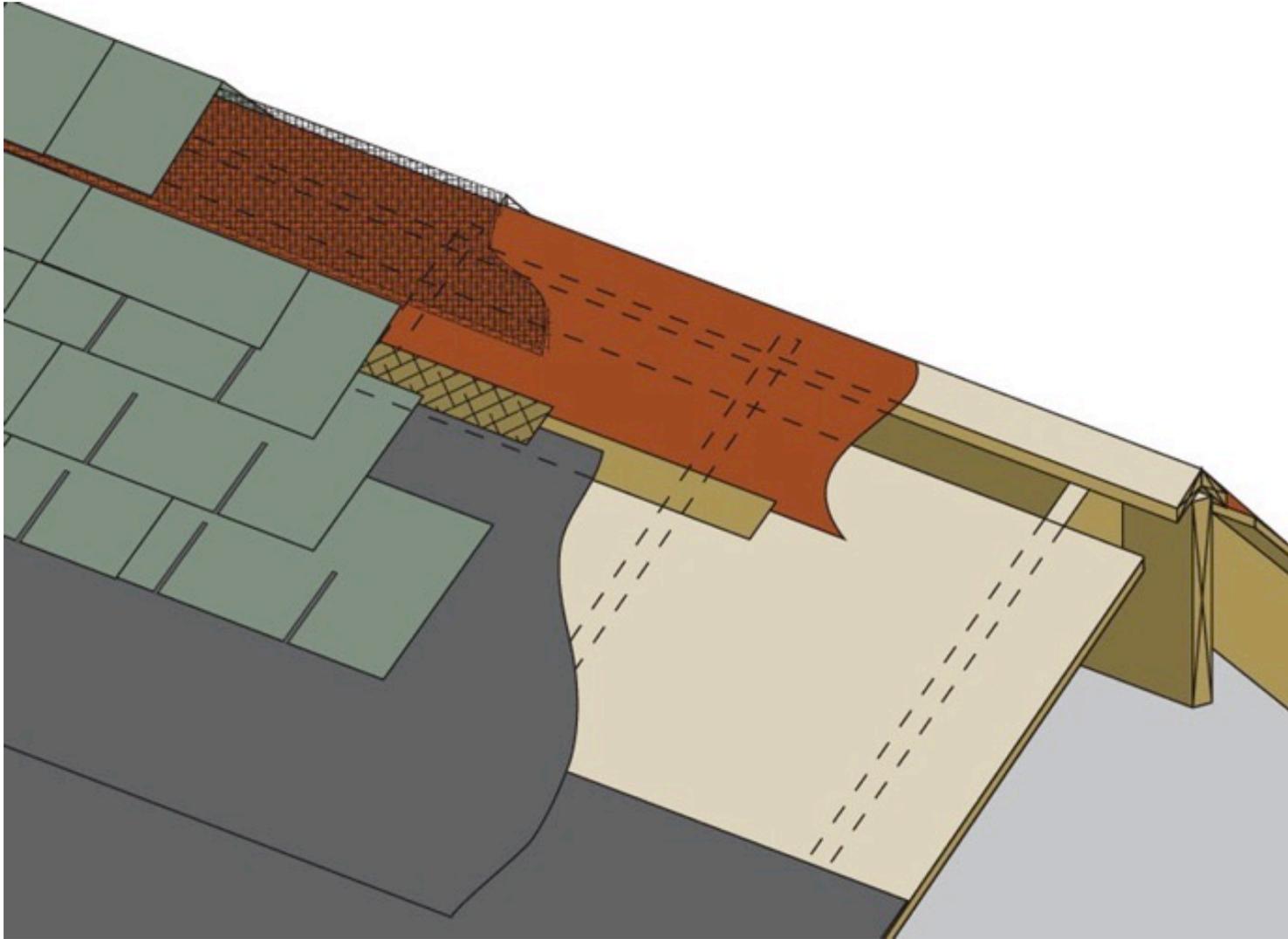
Each "Ping" and "Pong"
bounces the water molecules
up the slope

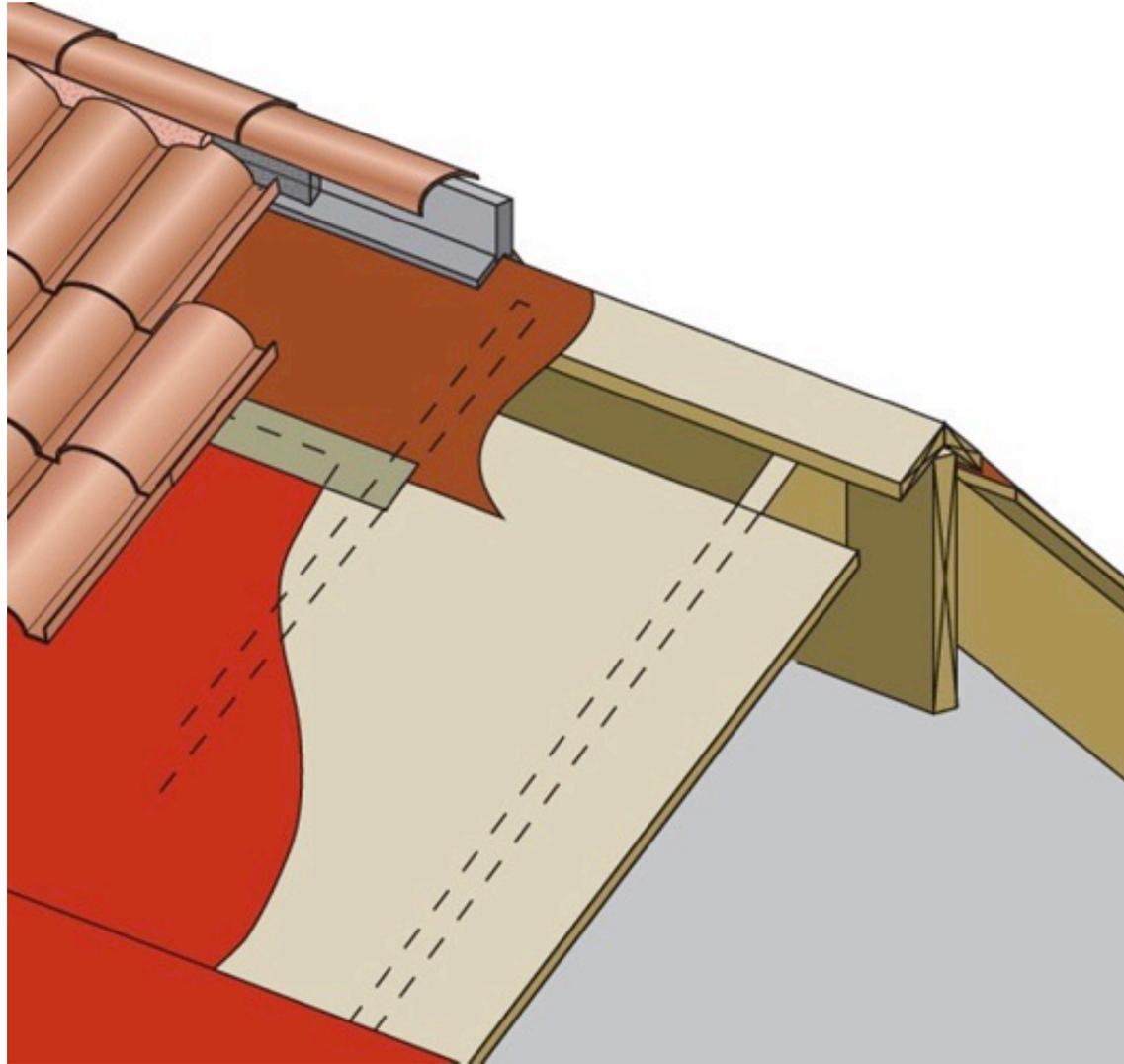




























Code Change

R806.5 Unvented attic and unvented attic enclosed rafter assemblies.

- vapor diffusion port
- port area 1:600 of the ceiling area
- vapor permeance greater than 20 perms
- roof slope greater than 3:12
- insulation under the roof deck or at the ceiling
- air supply 50 cfm/1000 ft² ceiling area when insulation installed directly under the roof deck
- Climate Zones 1, 2 and 3

Vapor Diffusion Port: A passageway for conveying water vapor from an unvented attic to the atmosphere.

Sweating Ducts

Sweating Ducts

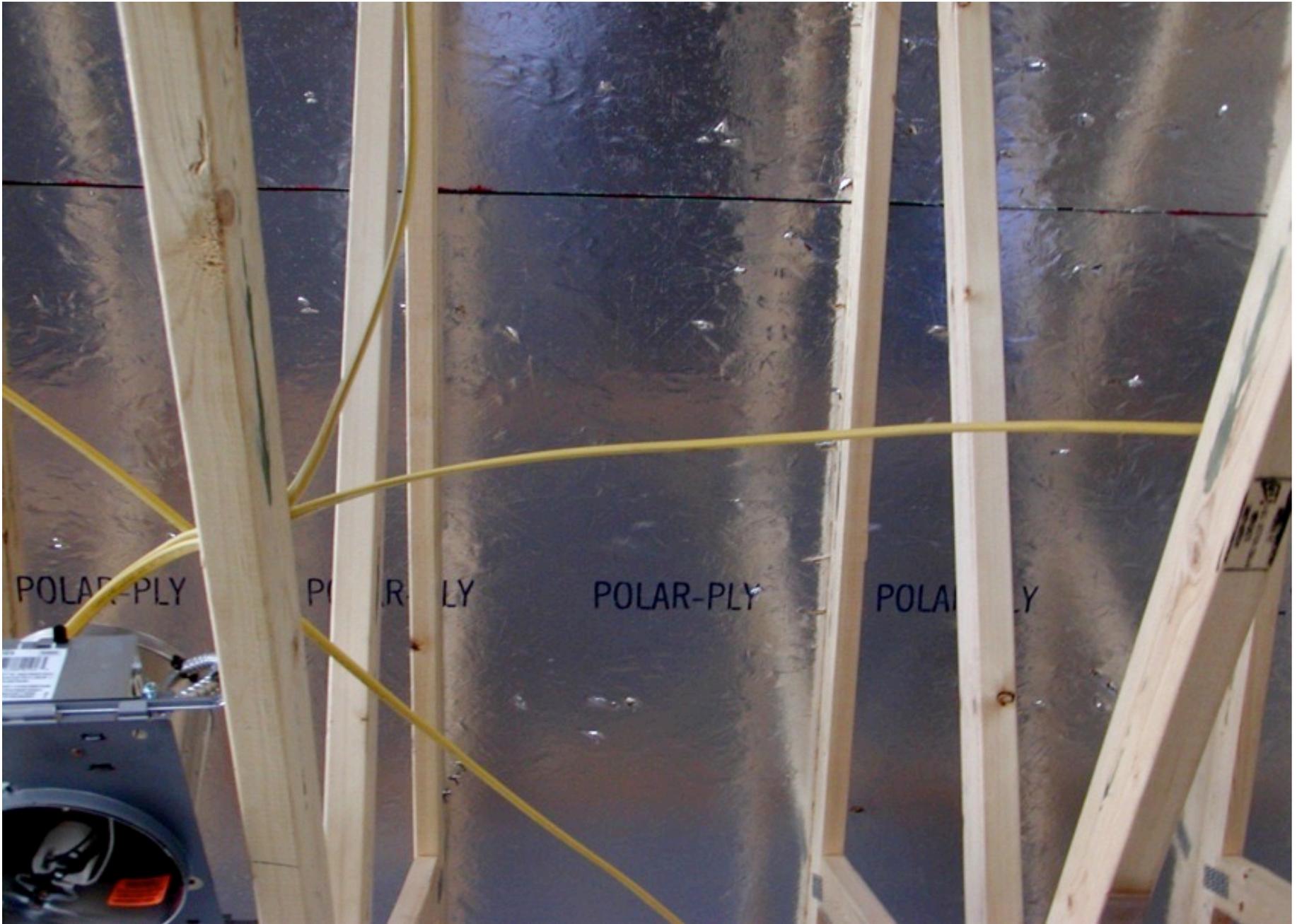
Light Colored Roofs

Cool Roofs

Radiant Barriers

ACCA Manual J, S and D

ASHRAE 62.2

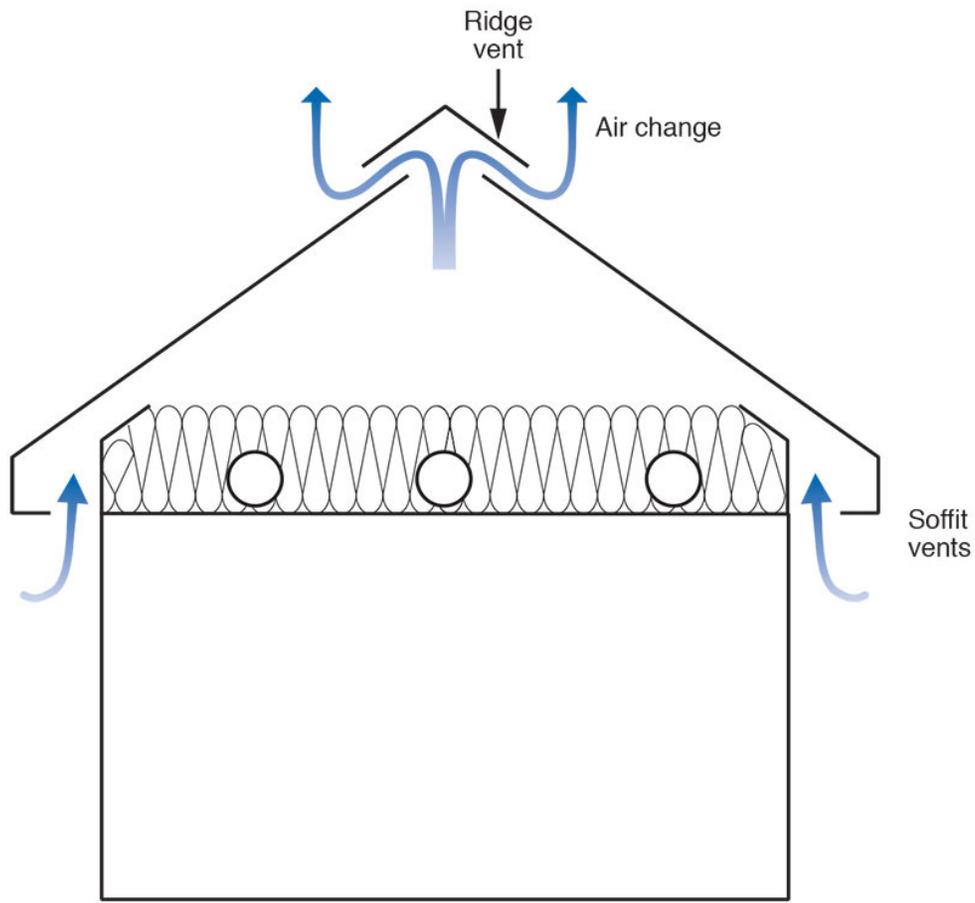




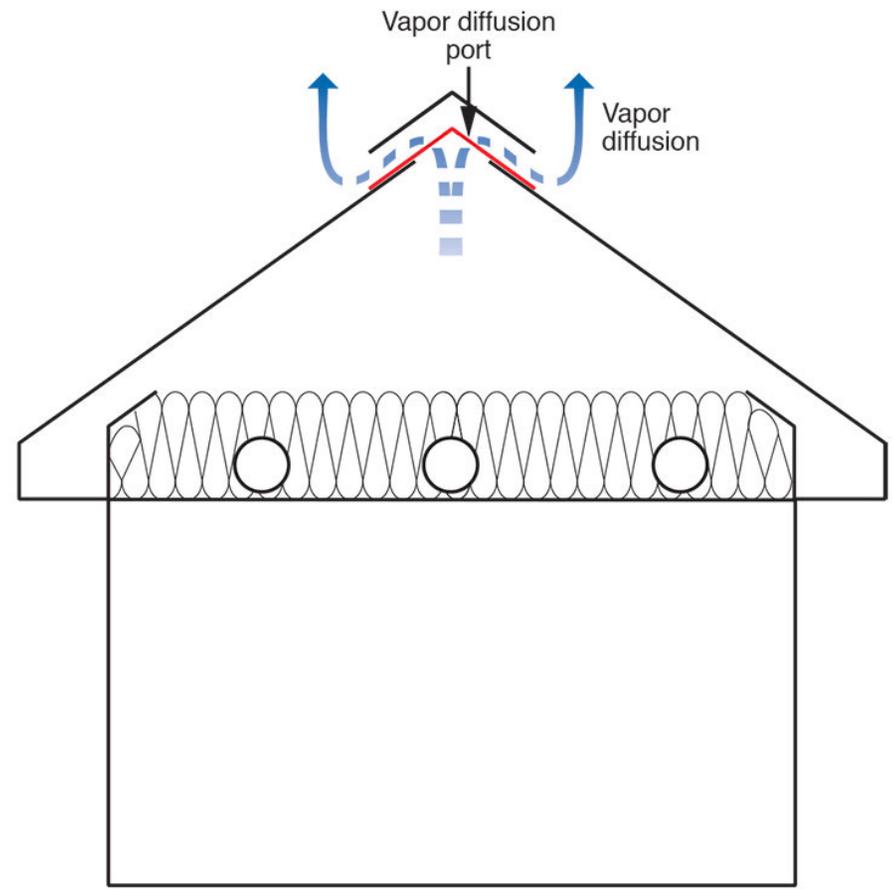








Classic vented attic



Unvented attic with vapor diffusion port













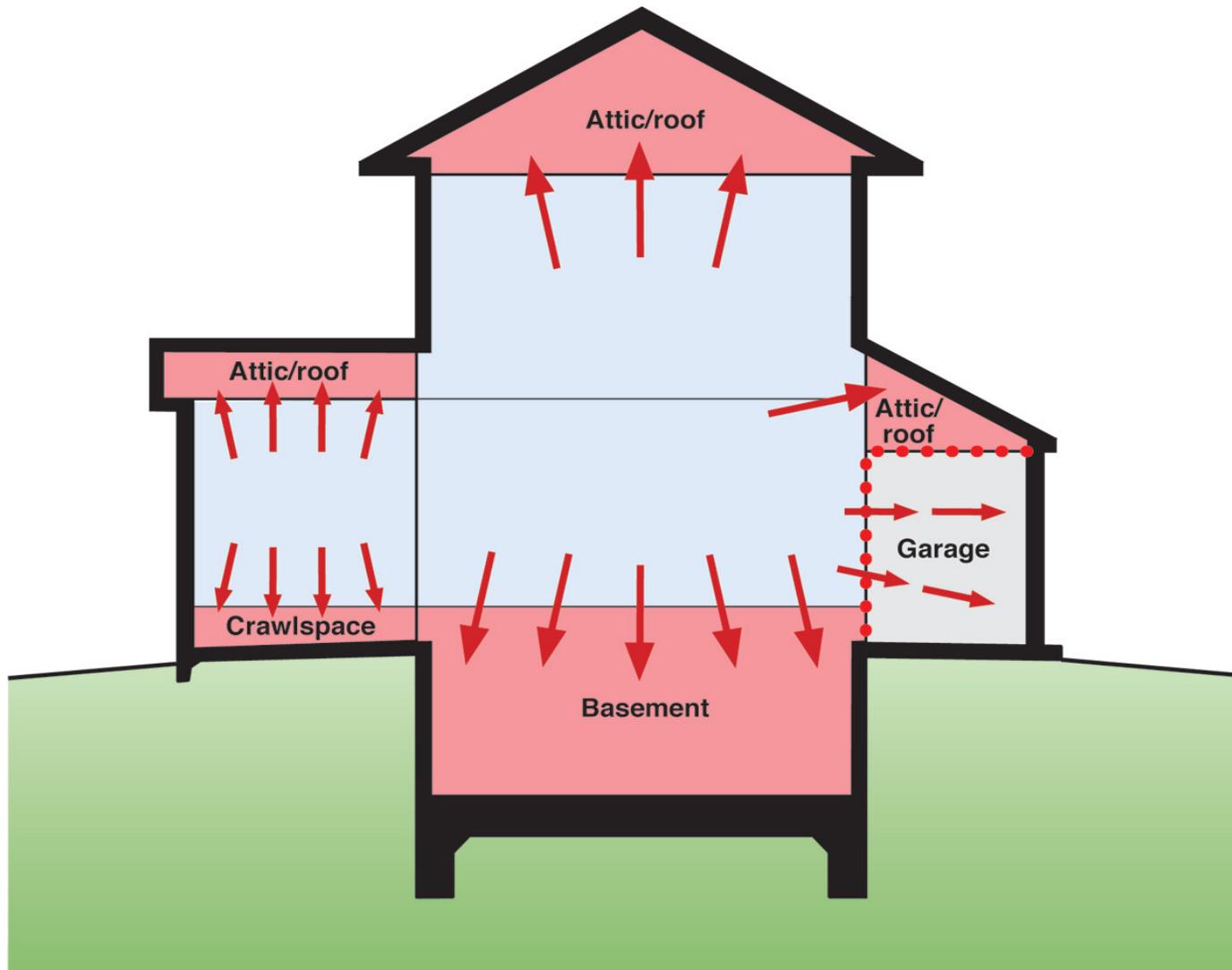






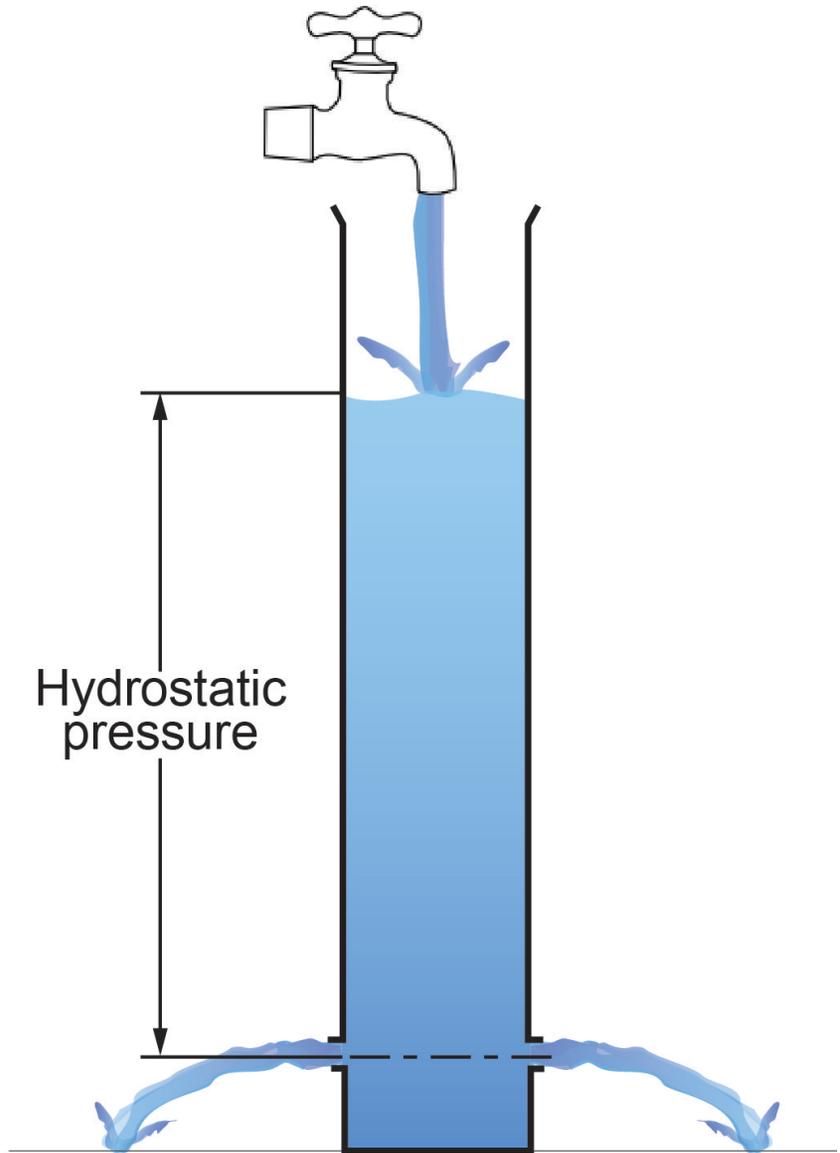
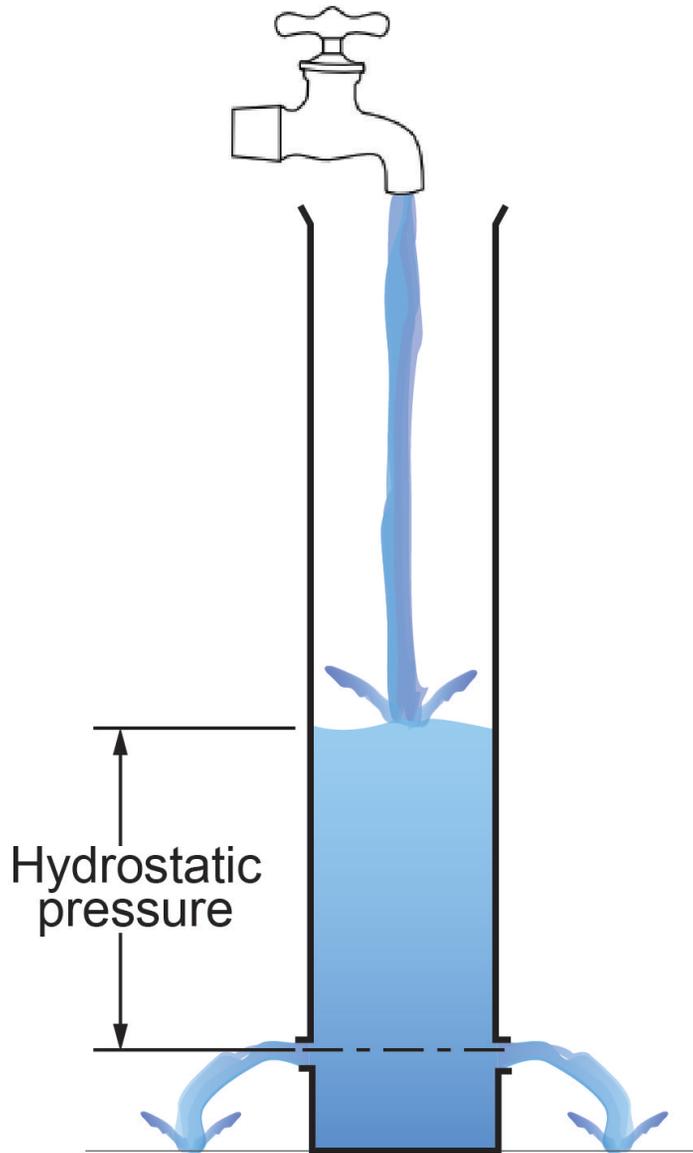


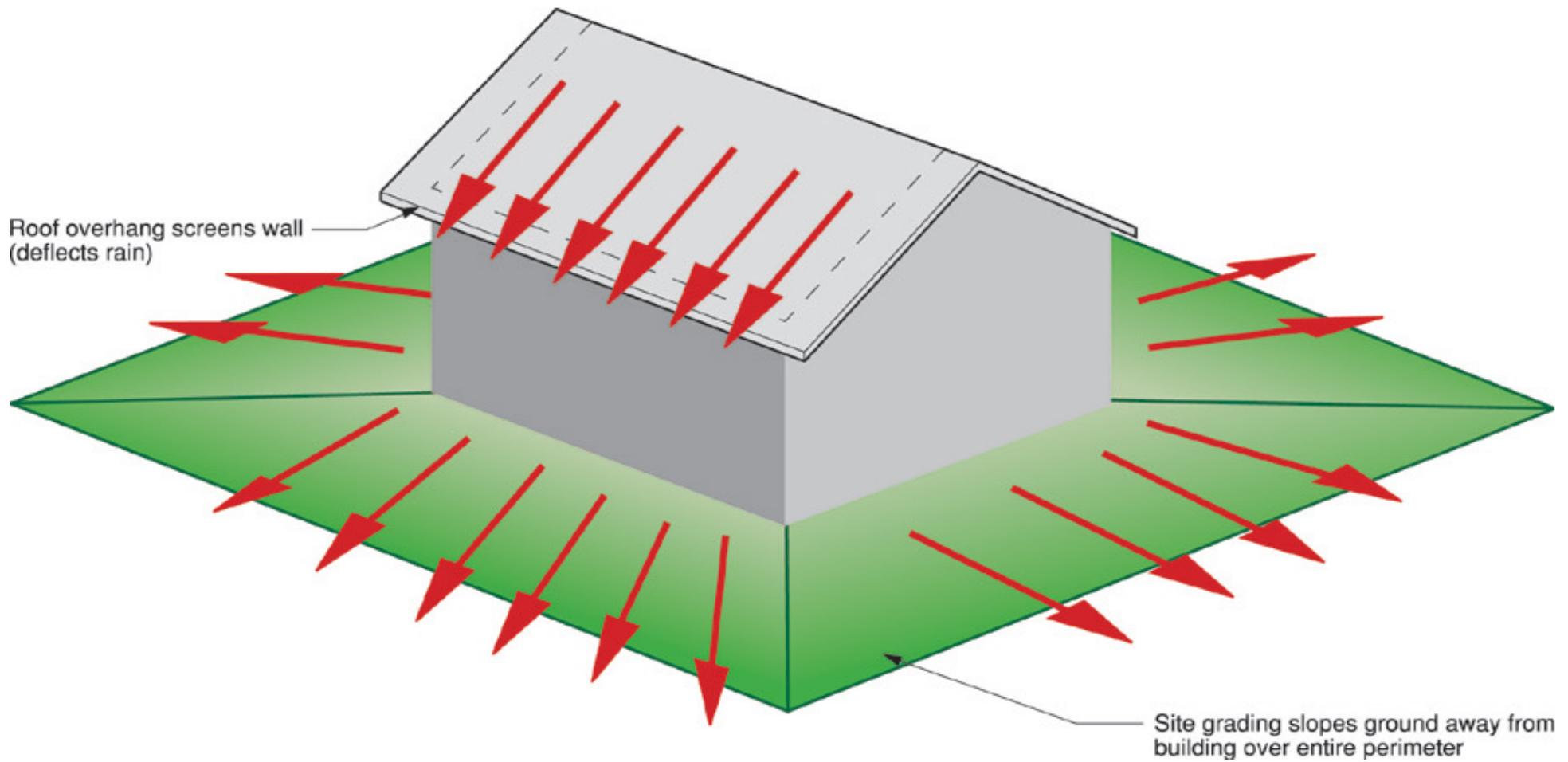
Basements

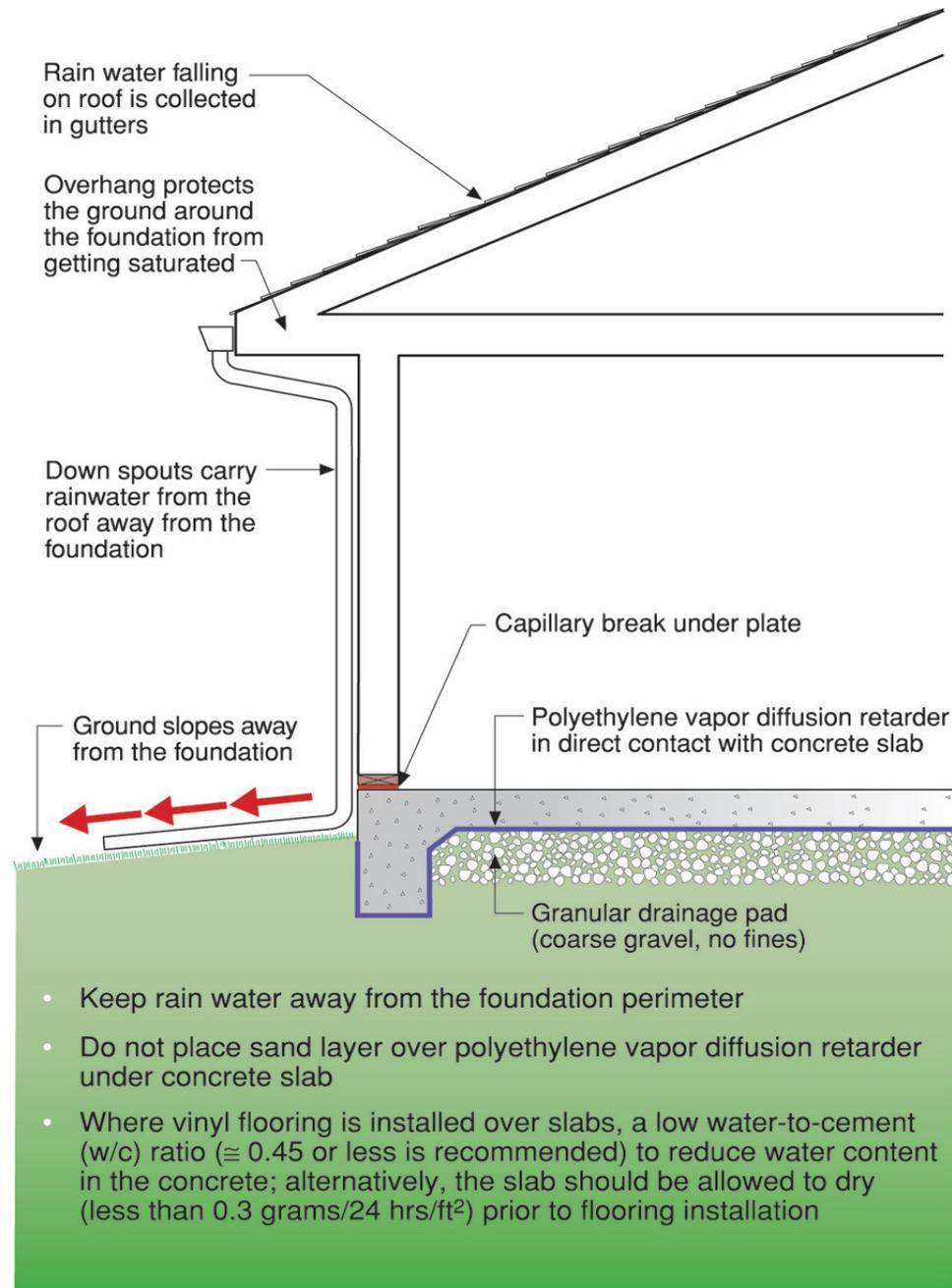


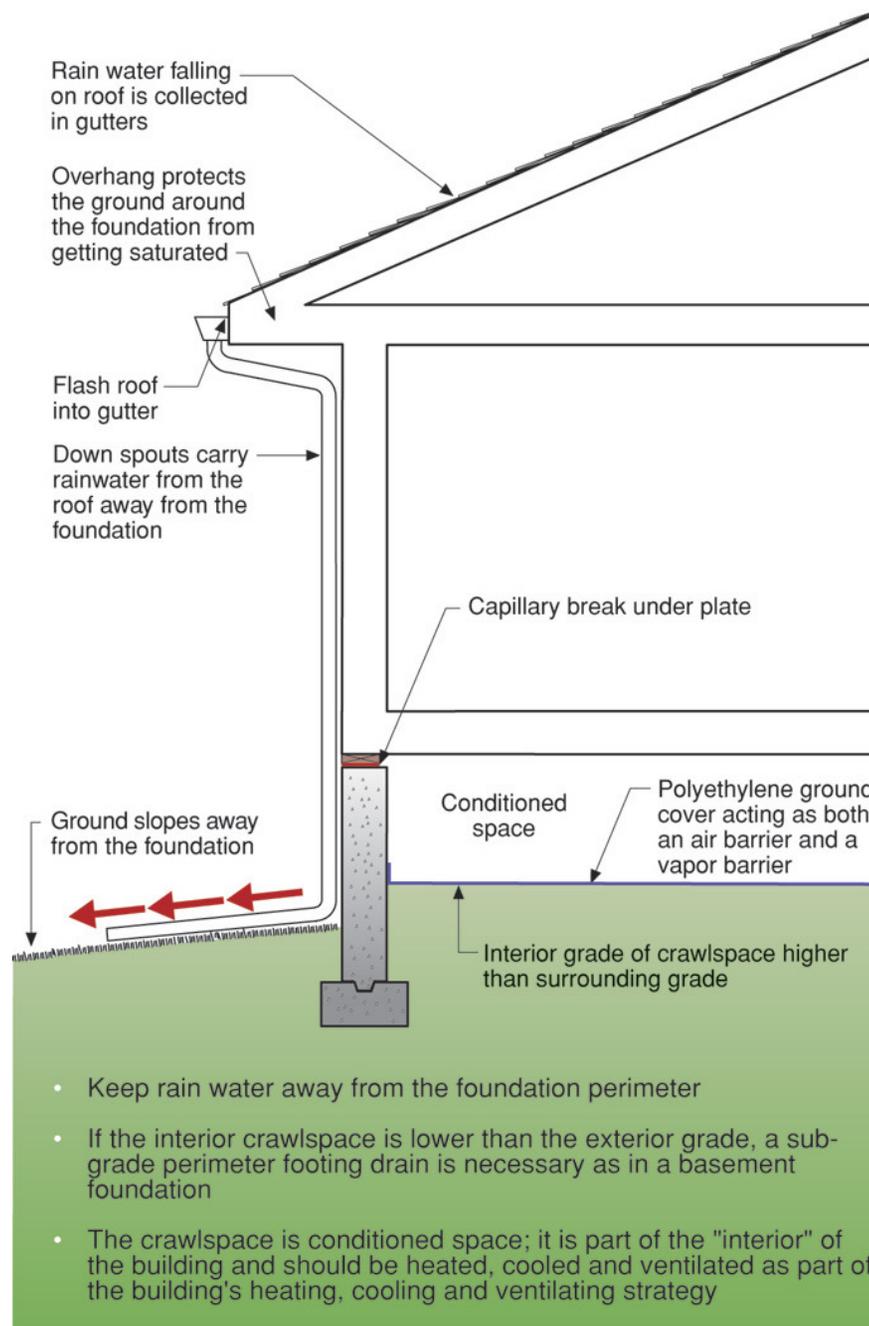
Expansion of Conditioned Space

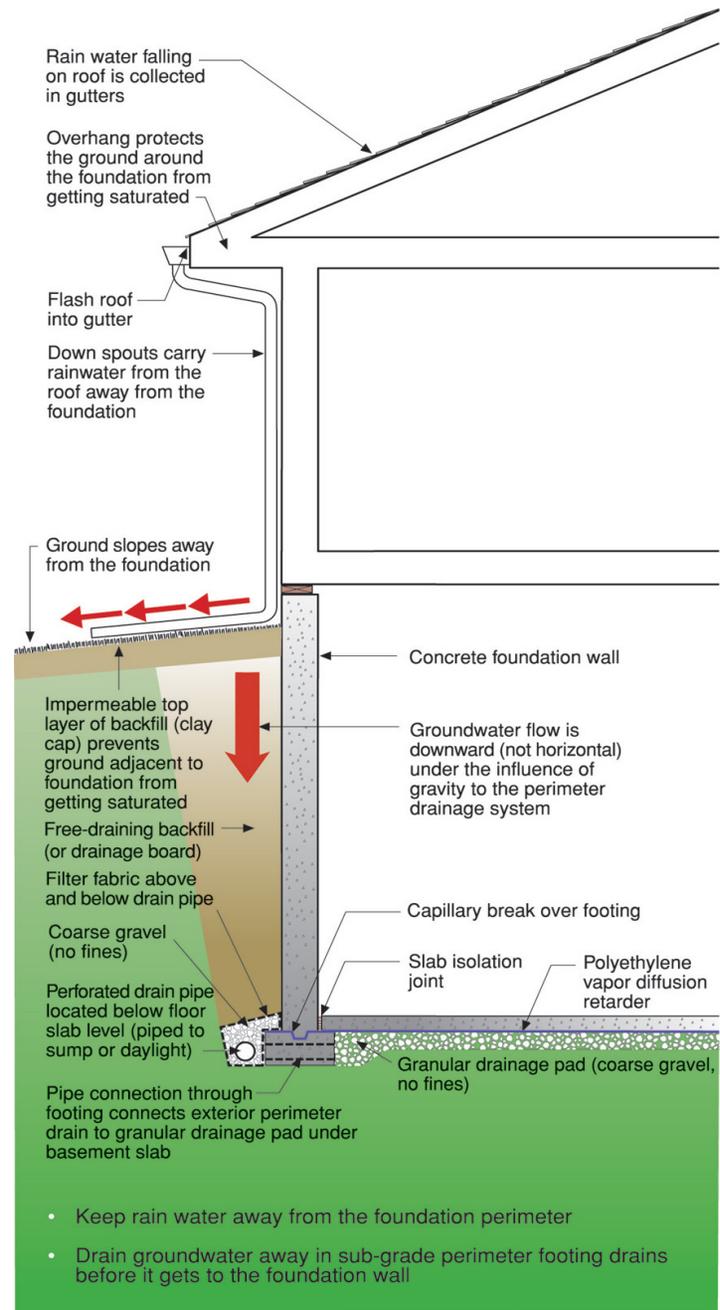
- Conditioned space boundaries moving towards exterior surfaces of building
- Garage isolated from house by air barrier/pressure boundary
- Garage ventilated and conditioned independently of rest of conditioned spaces



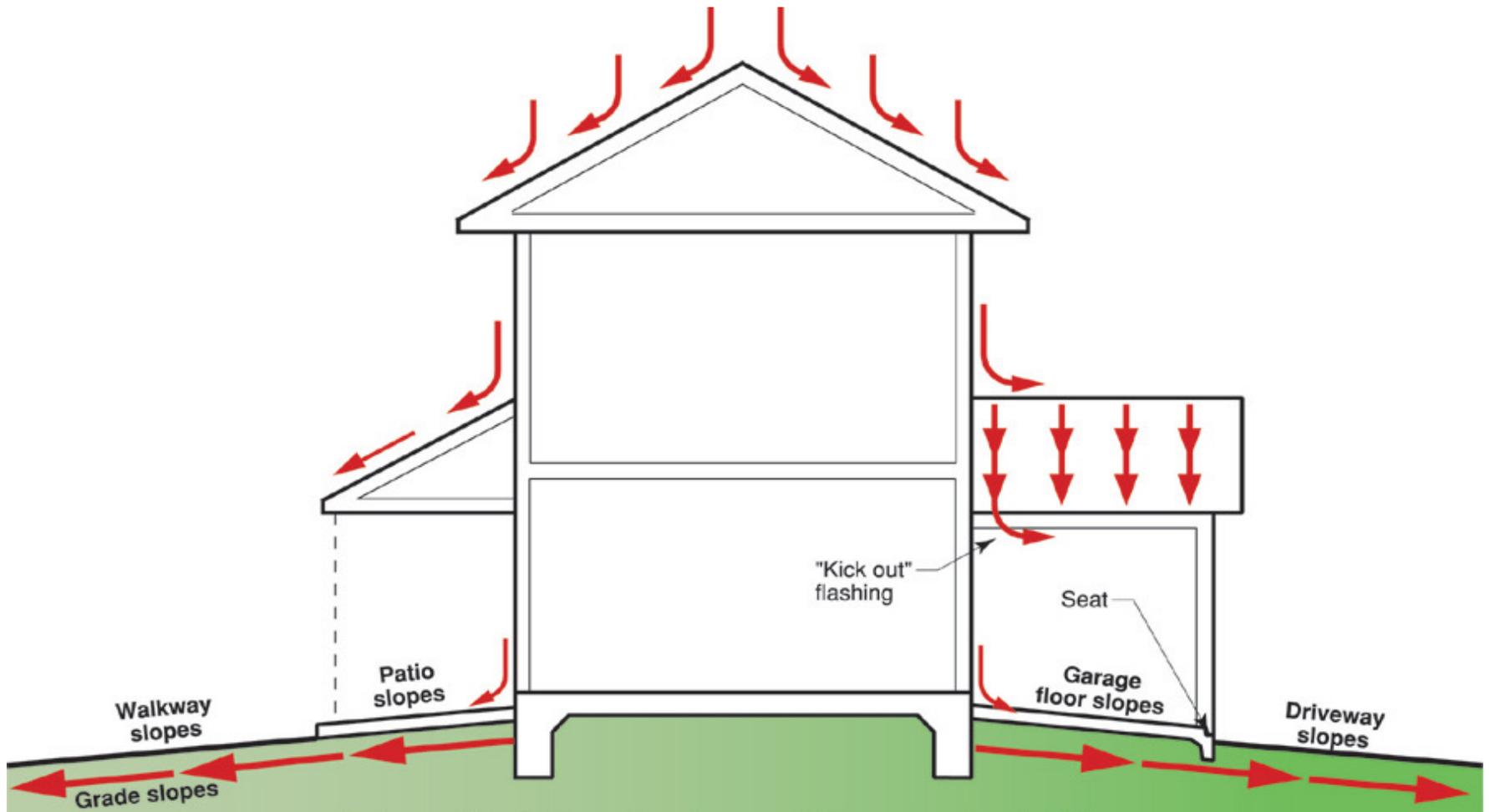




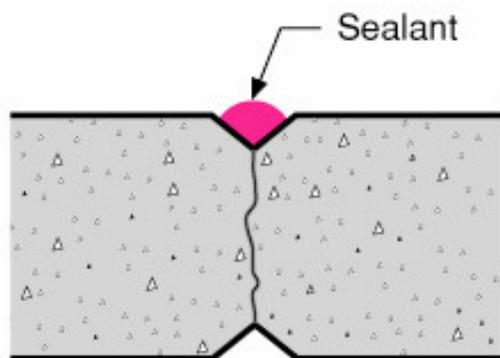
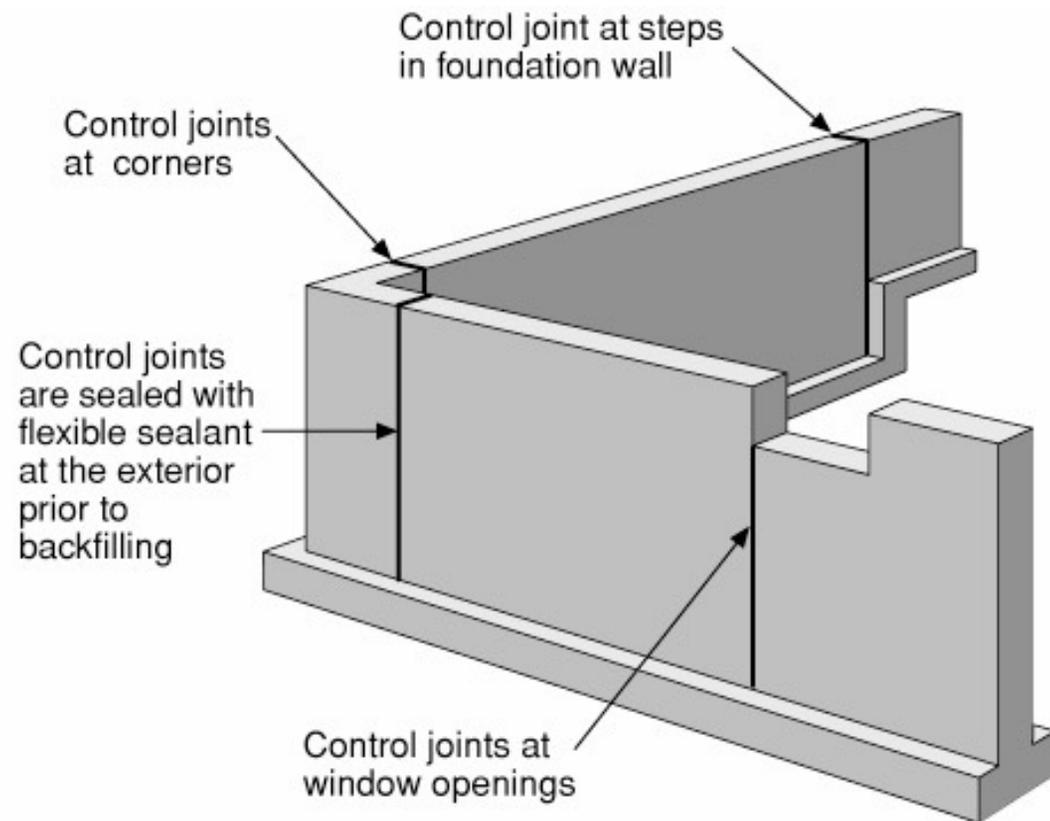




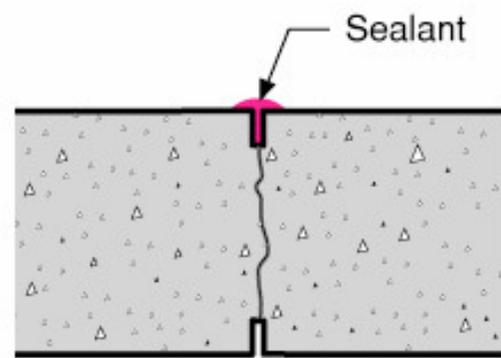




- Patios and decks lower than floors and slope away from building
- Garage floor lower than main floor and slope away from building
- Driveway lower than garage floor and slope away from building
- Grade lower than main floor and slope away from building
- Stoops and walkways lower than main floor and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



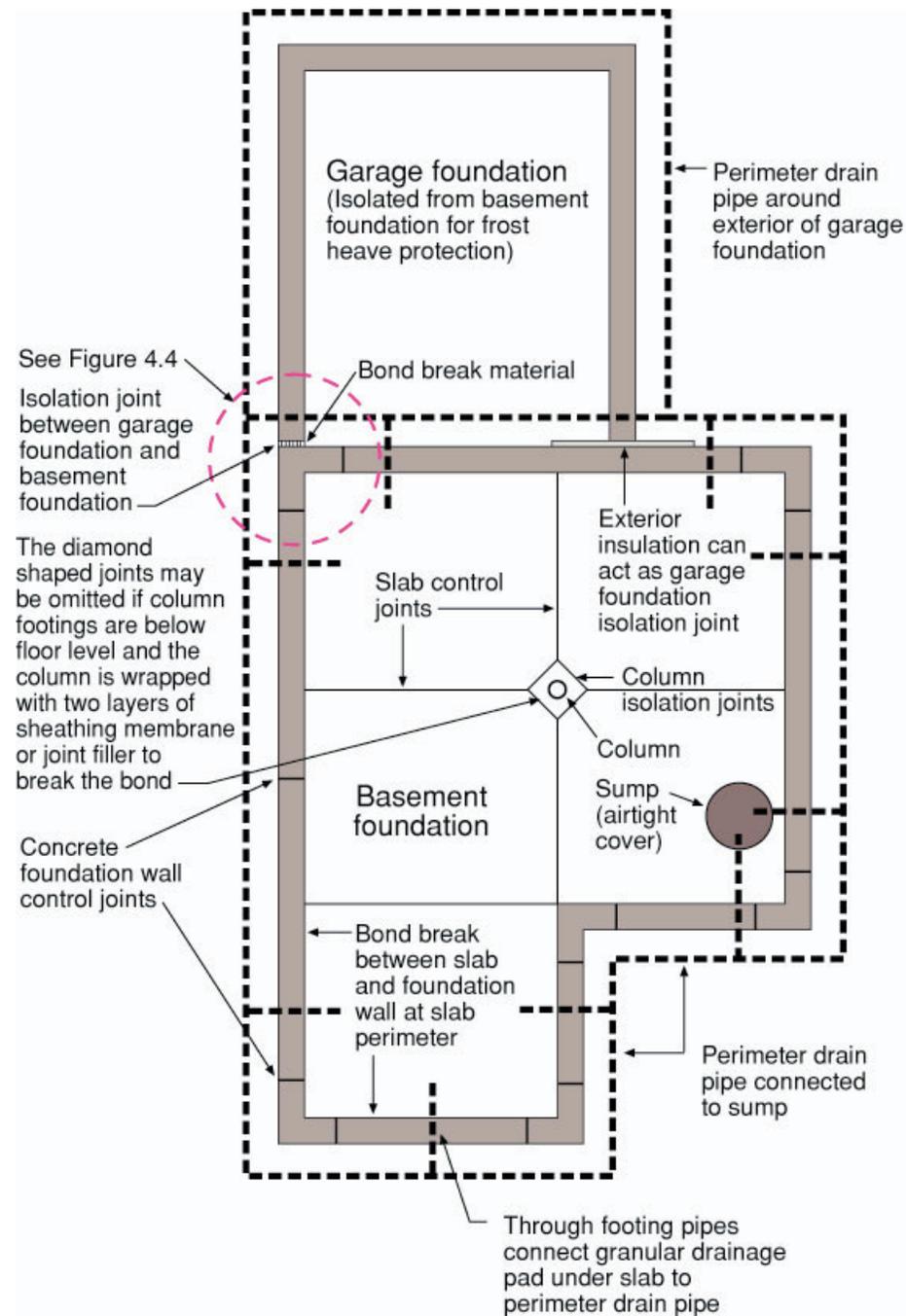
Diagonally cut 2 x 2's in forms provide goose neck joint



Saw cut joint



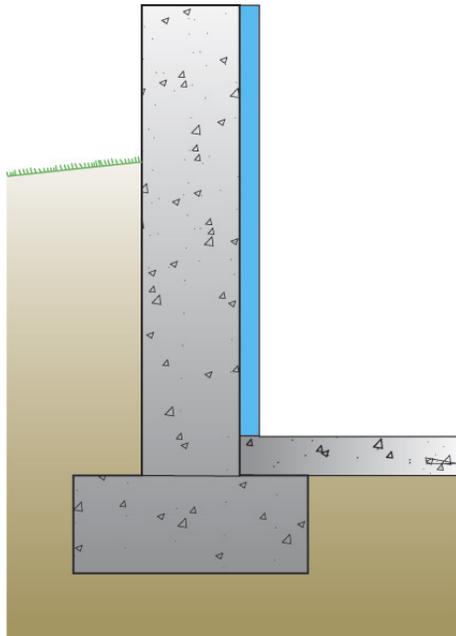




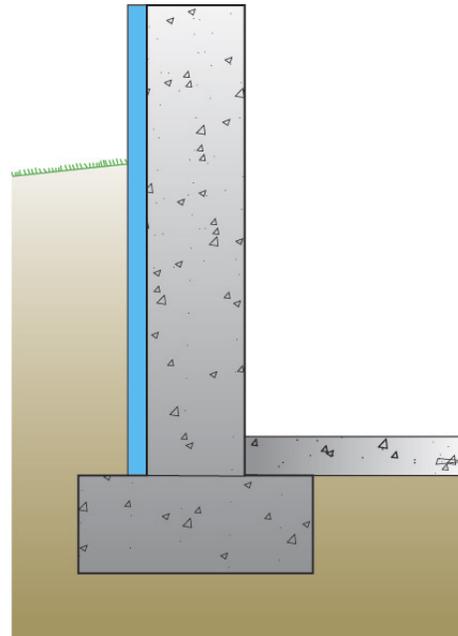




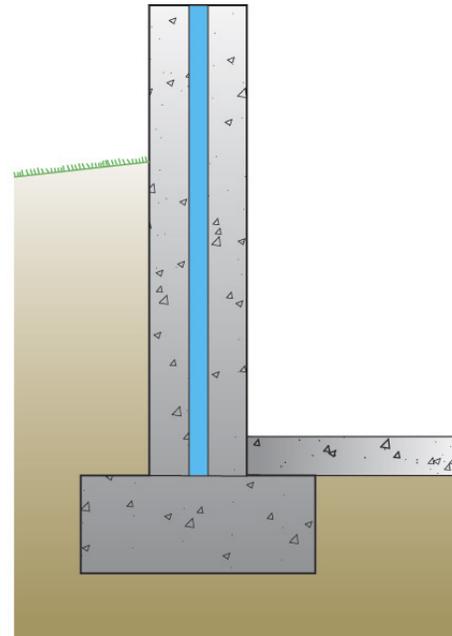




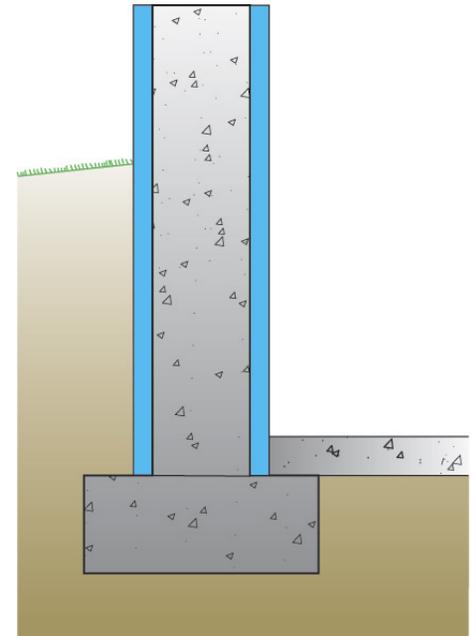
**Internally Insulated
Basement**



**Externally Insulated
Basement**



**Basement Insulated in
the Middle**

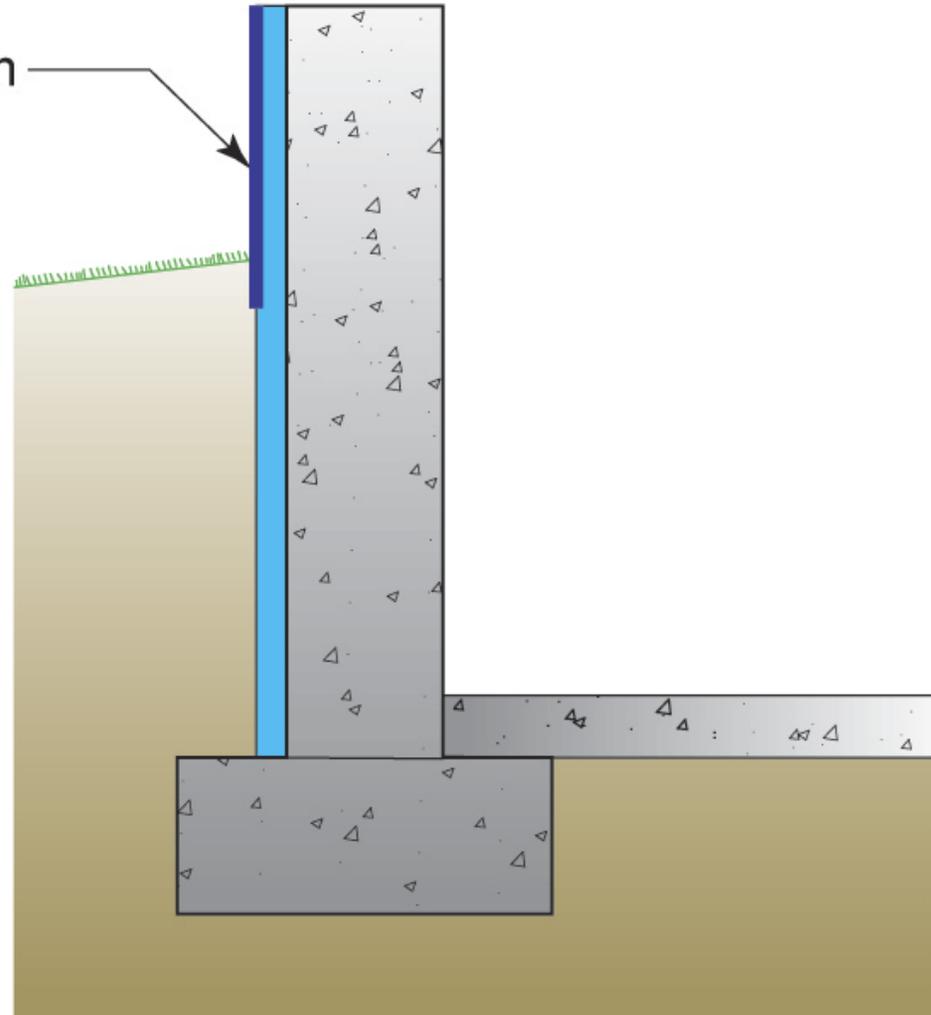


**Basement Insulated Both
Externally and Internally**

Structure of house on foundation must be shifted outward to compensate for thickness of exterior insulation



Protection layer/system







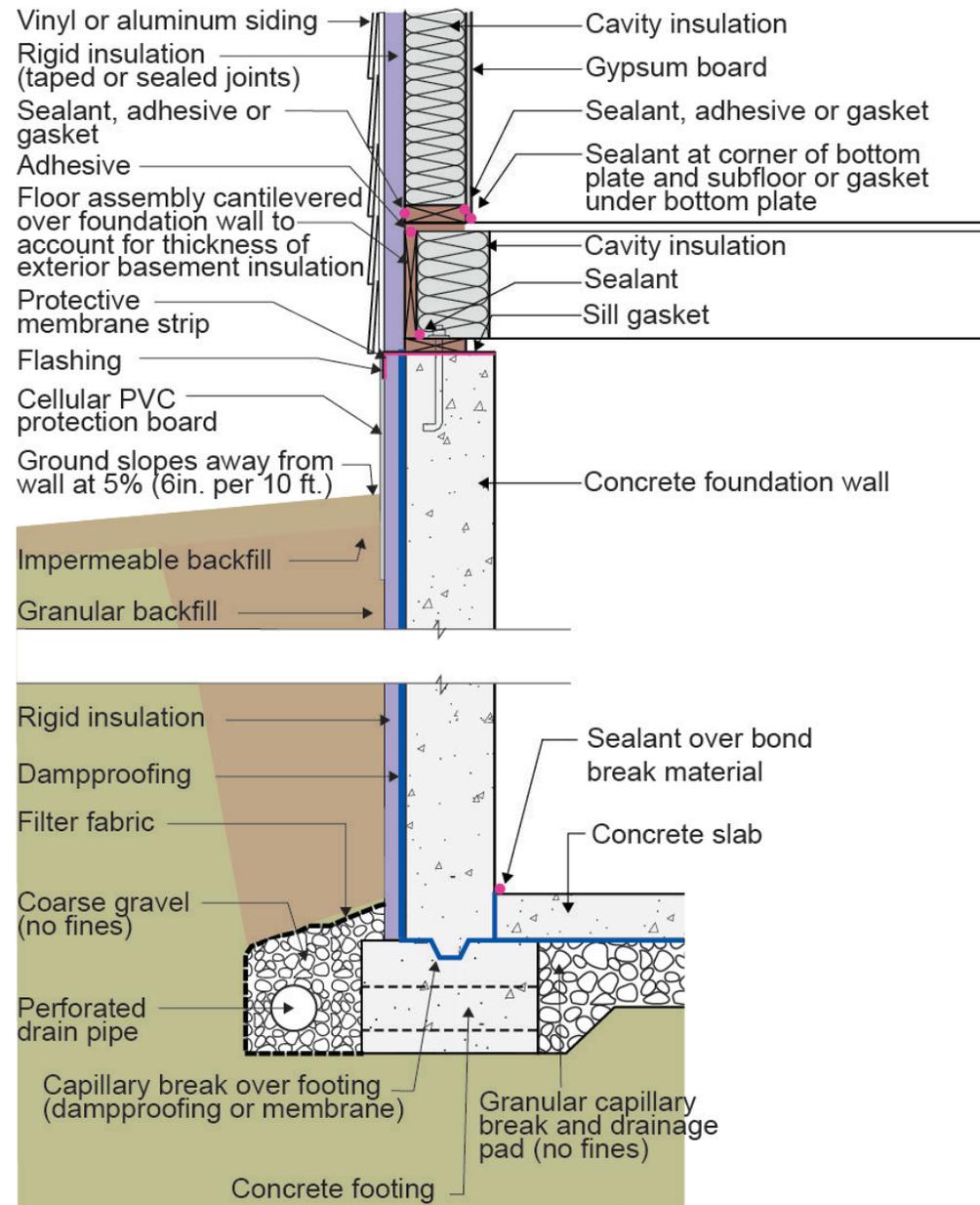


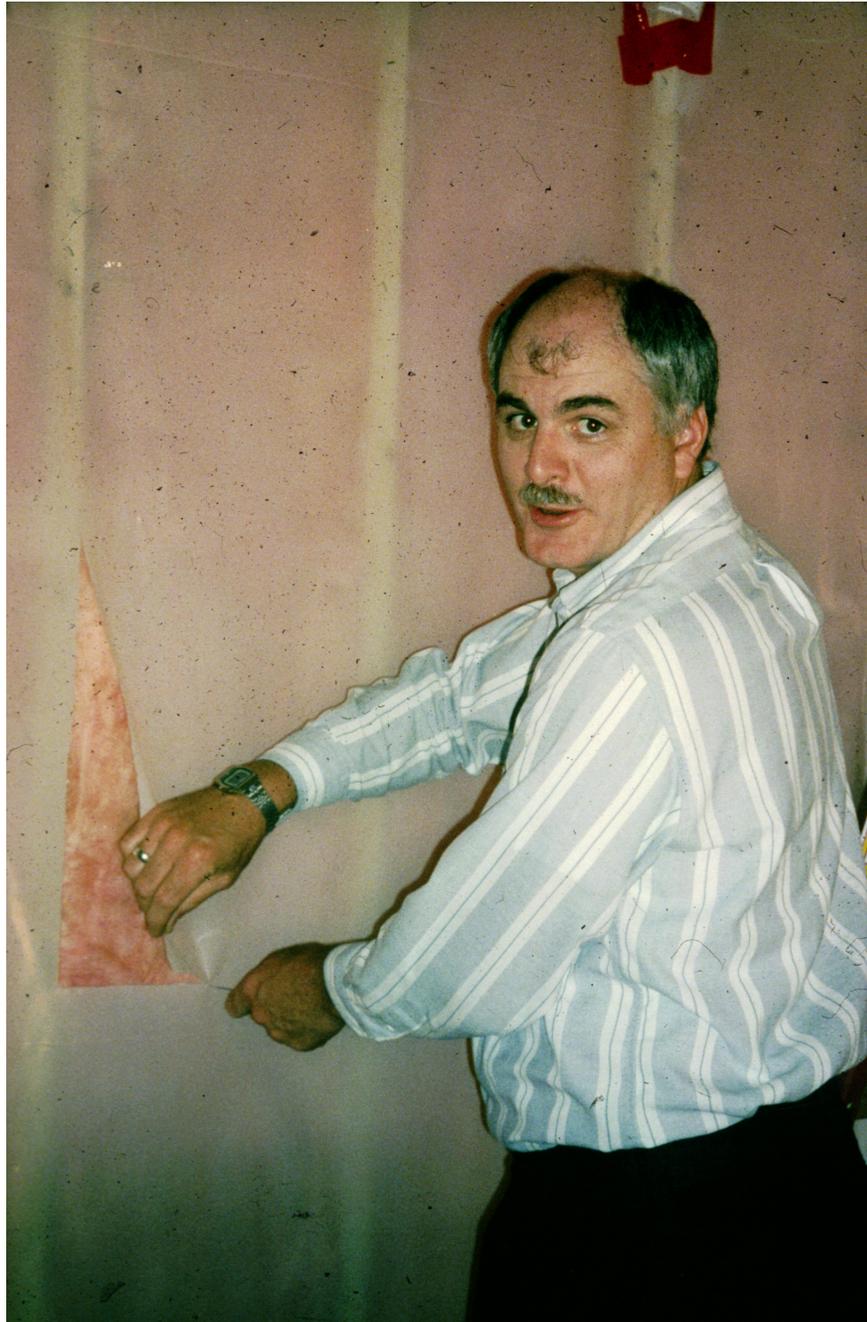




27







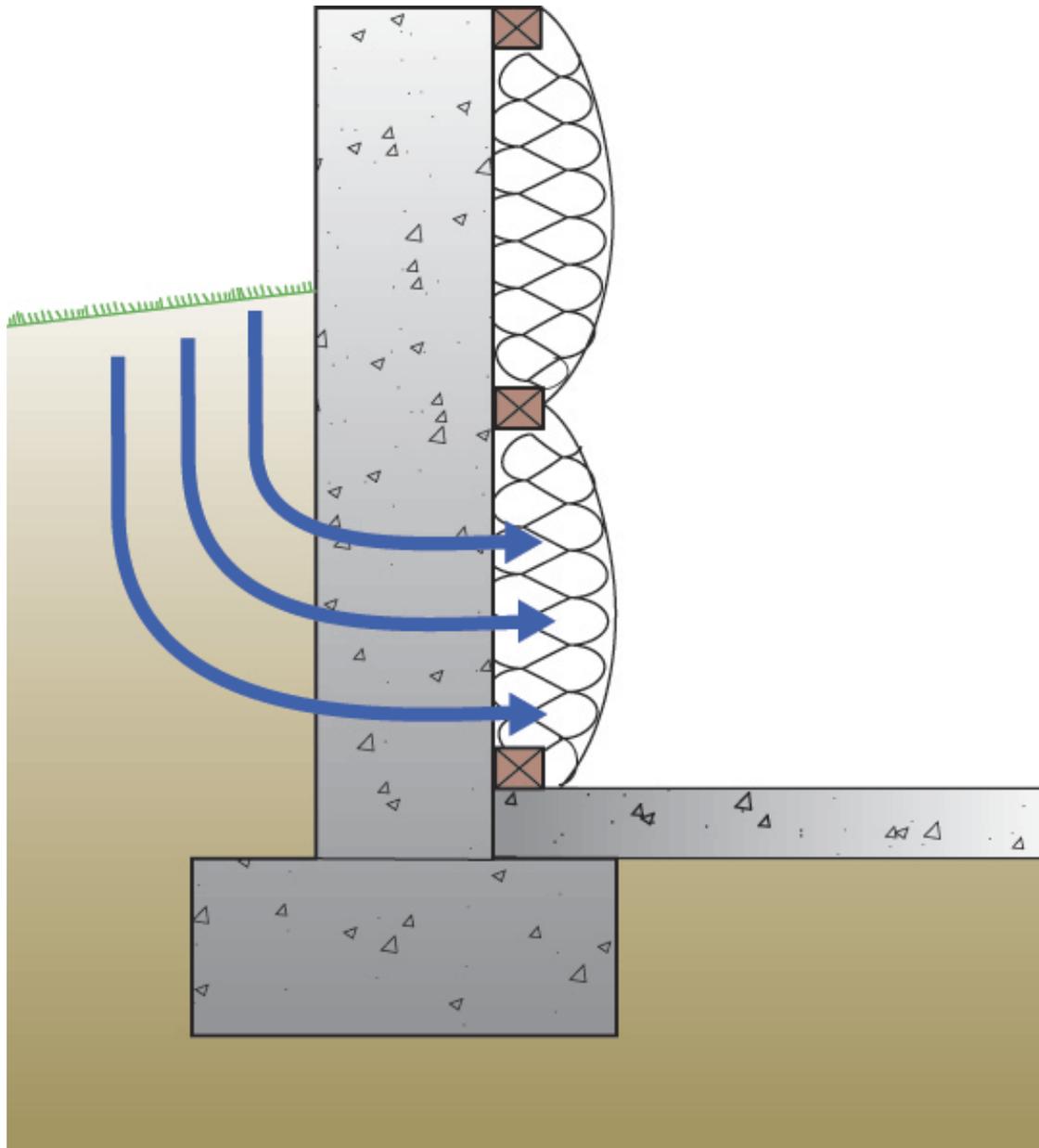


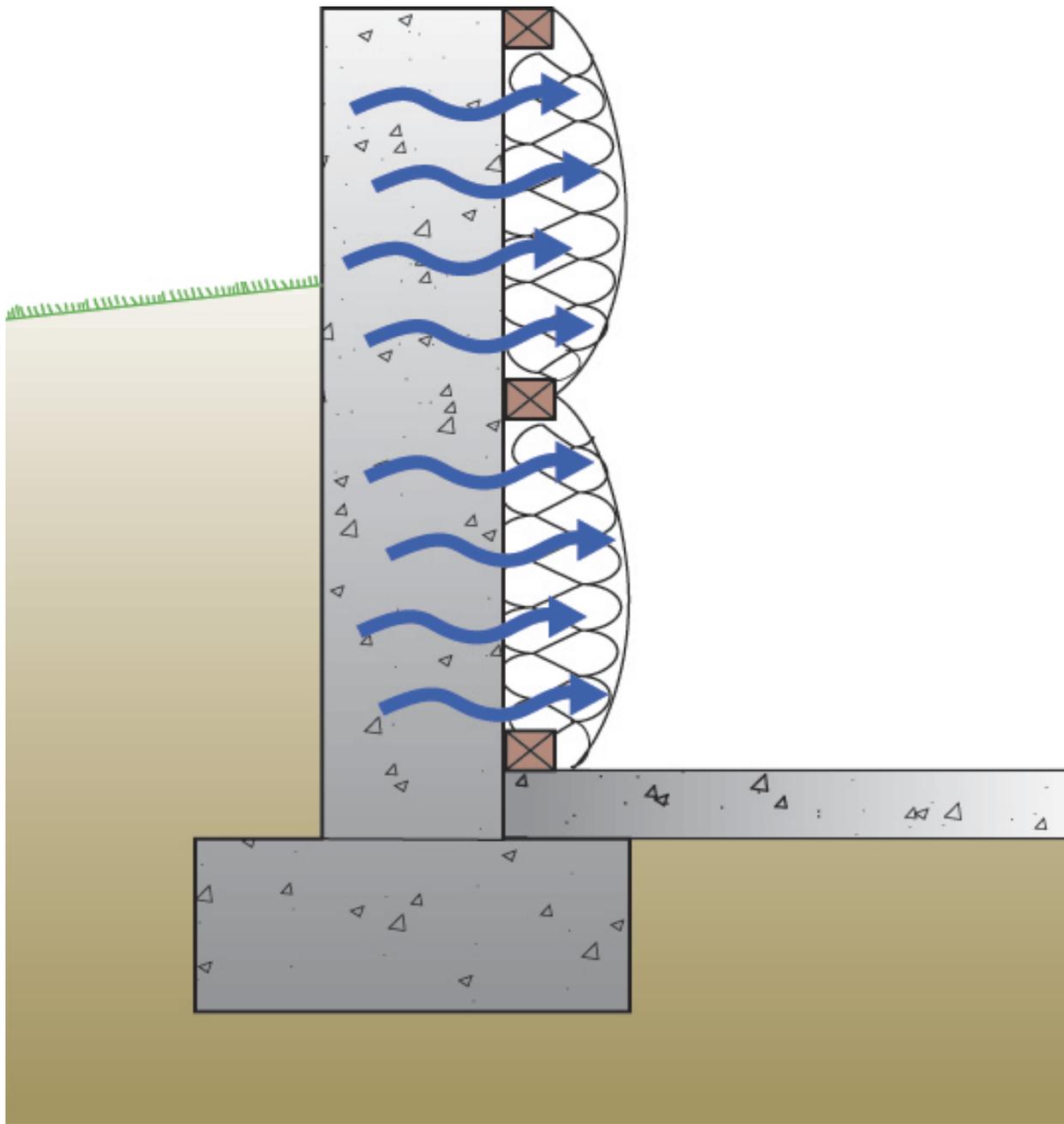


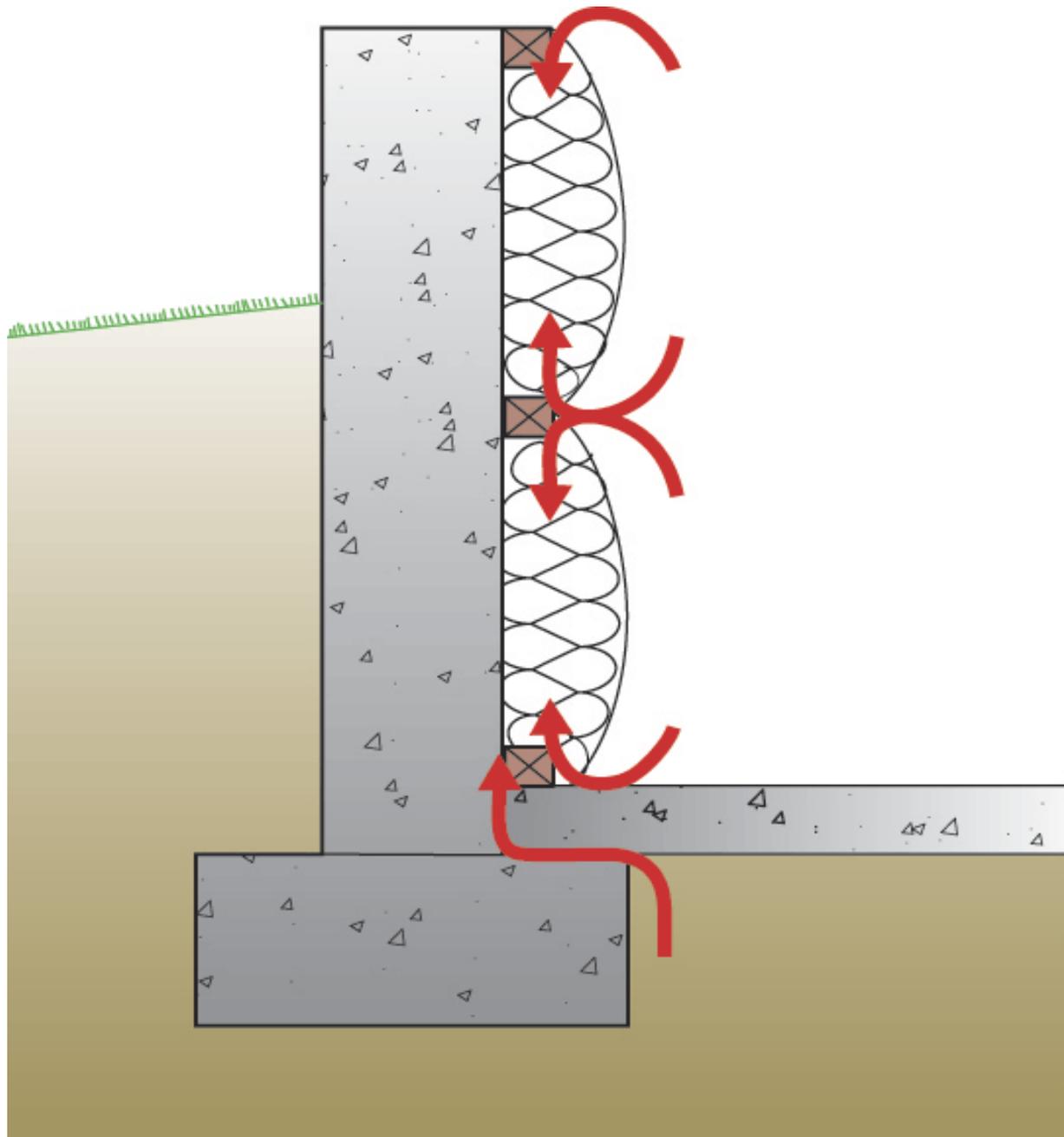


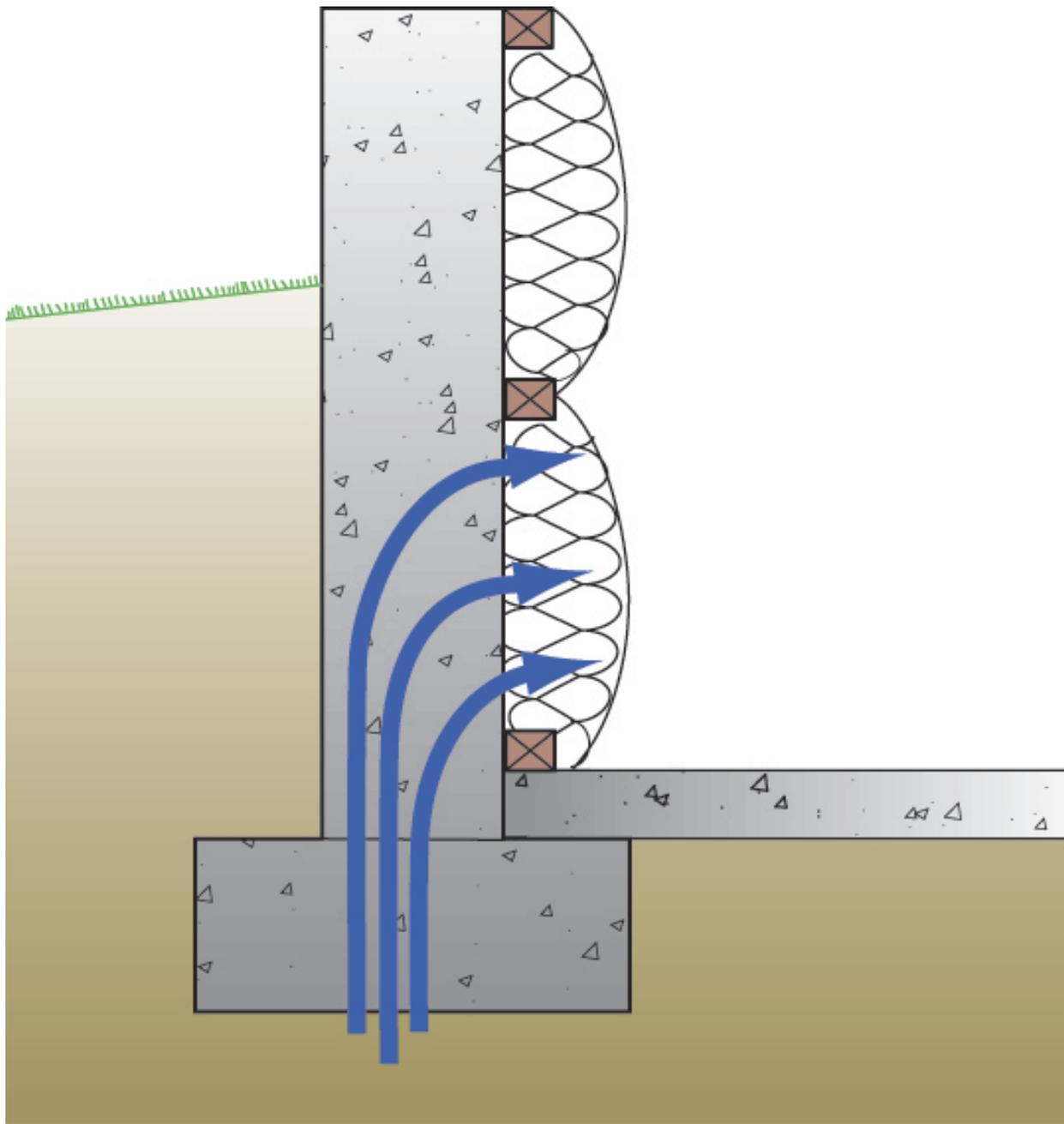


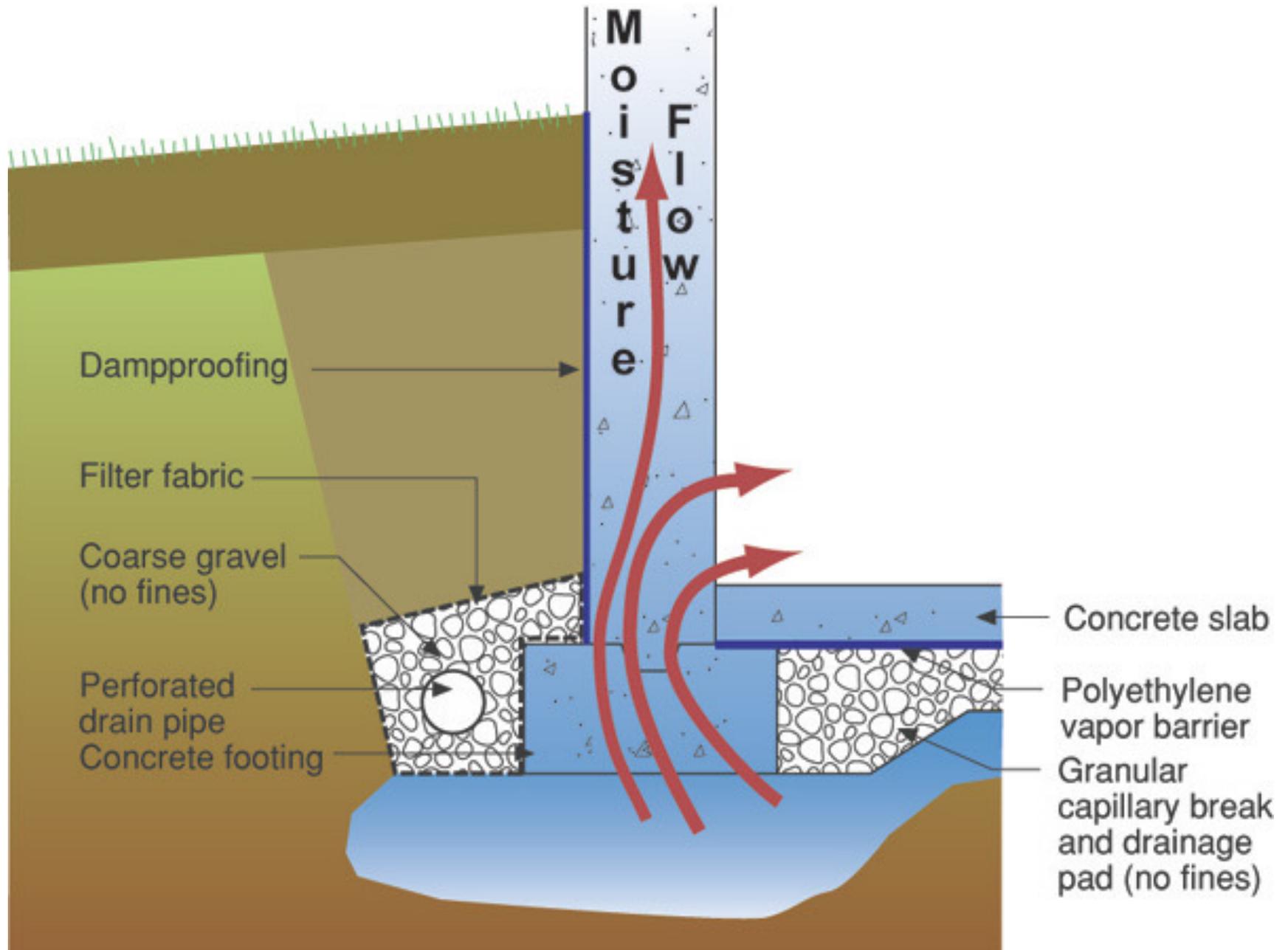


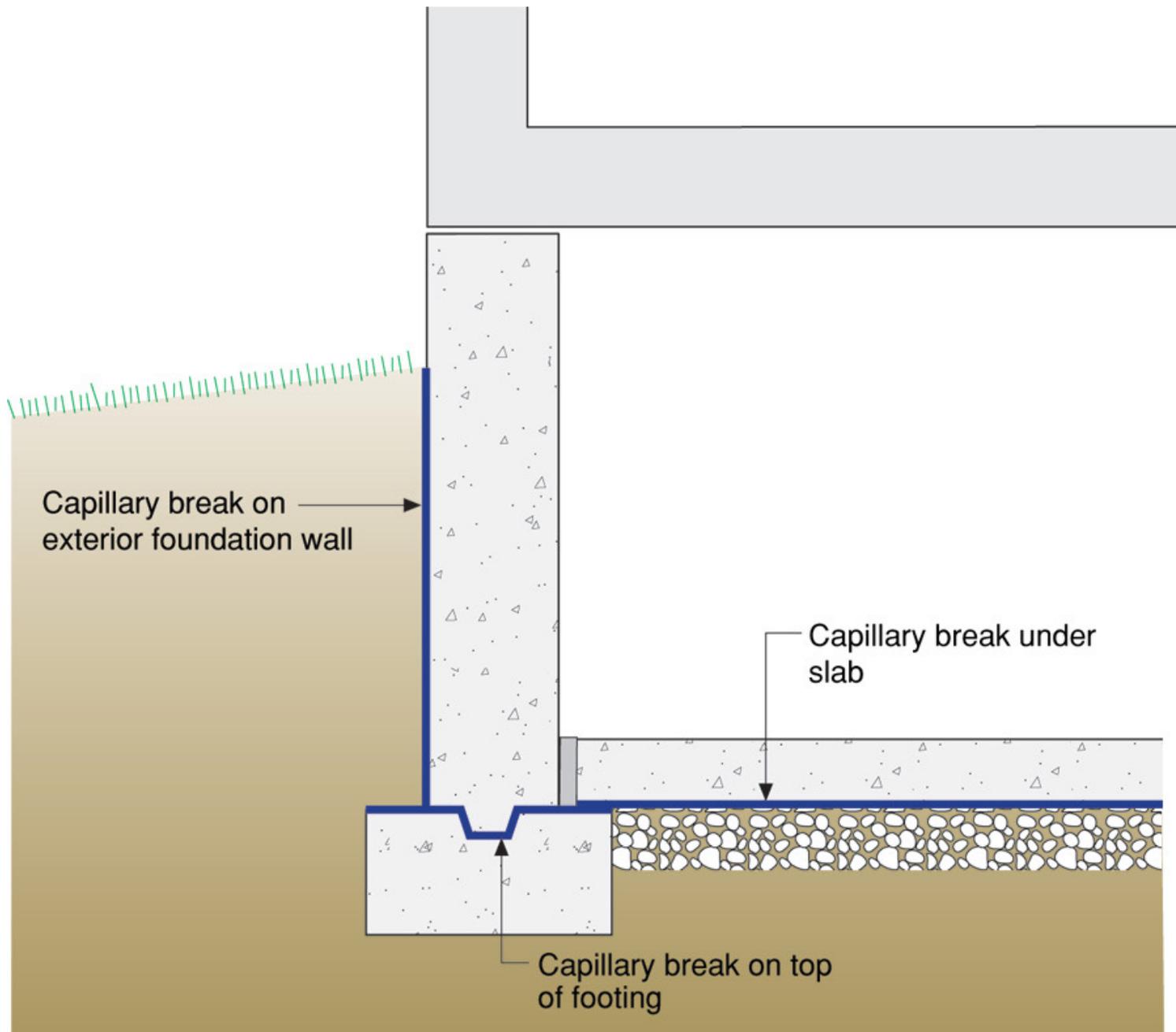


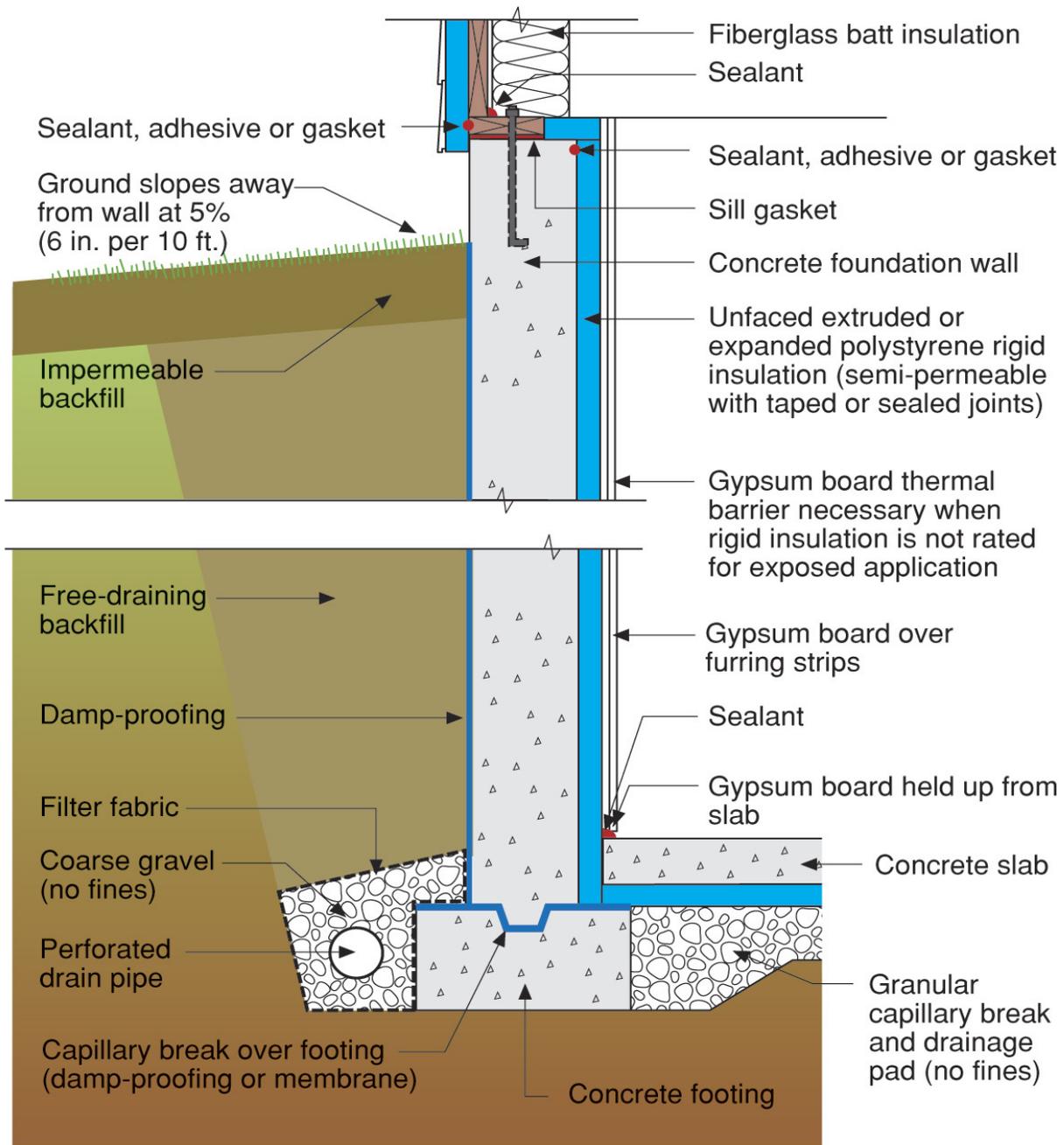






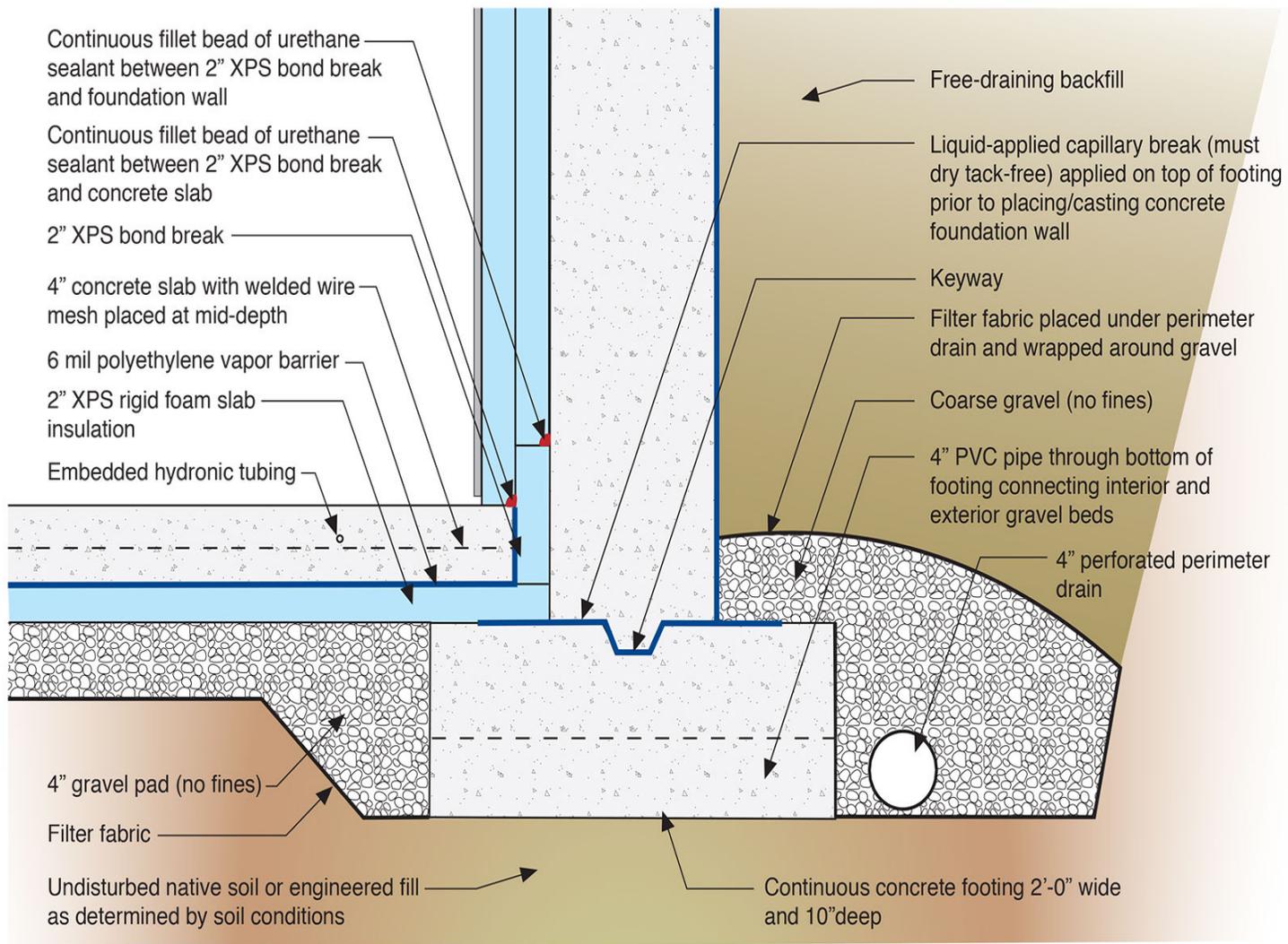




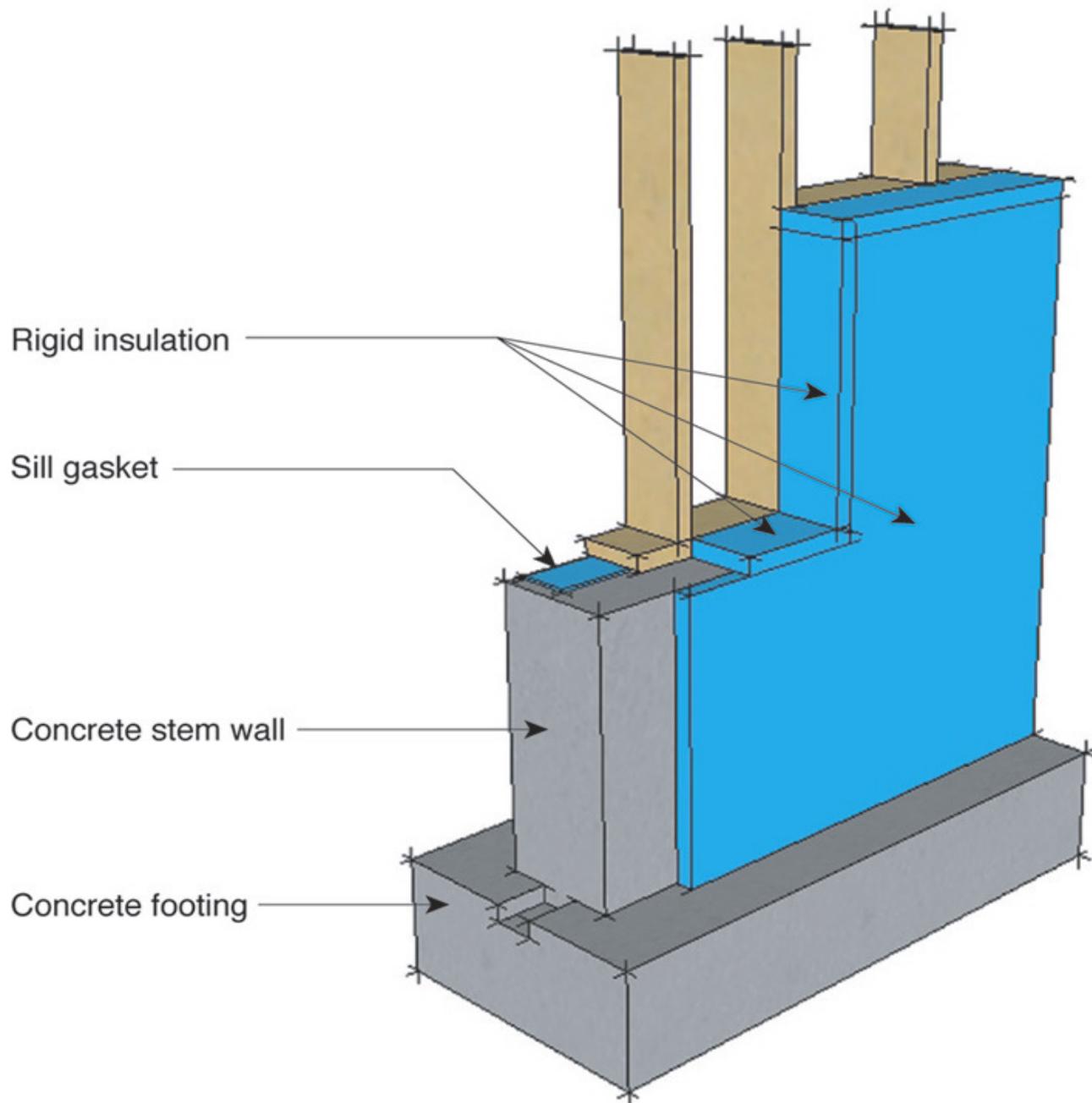


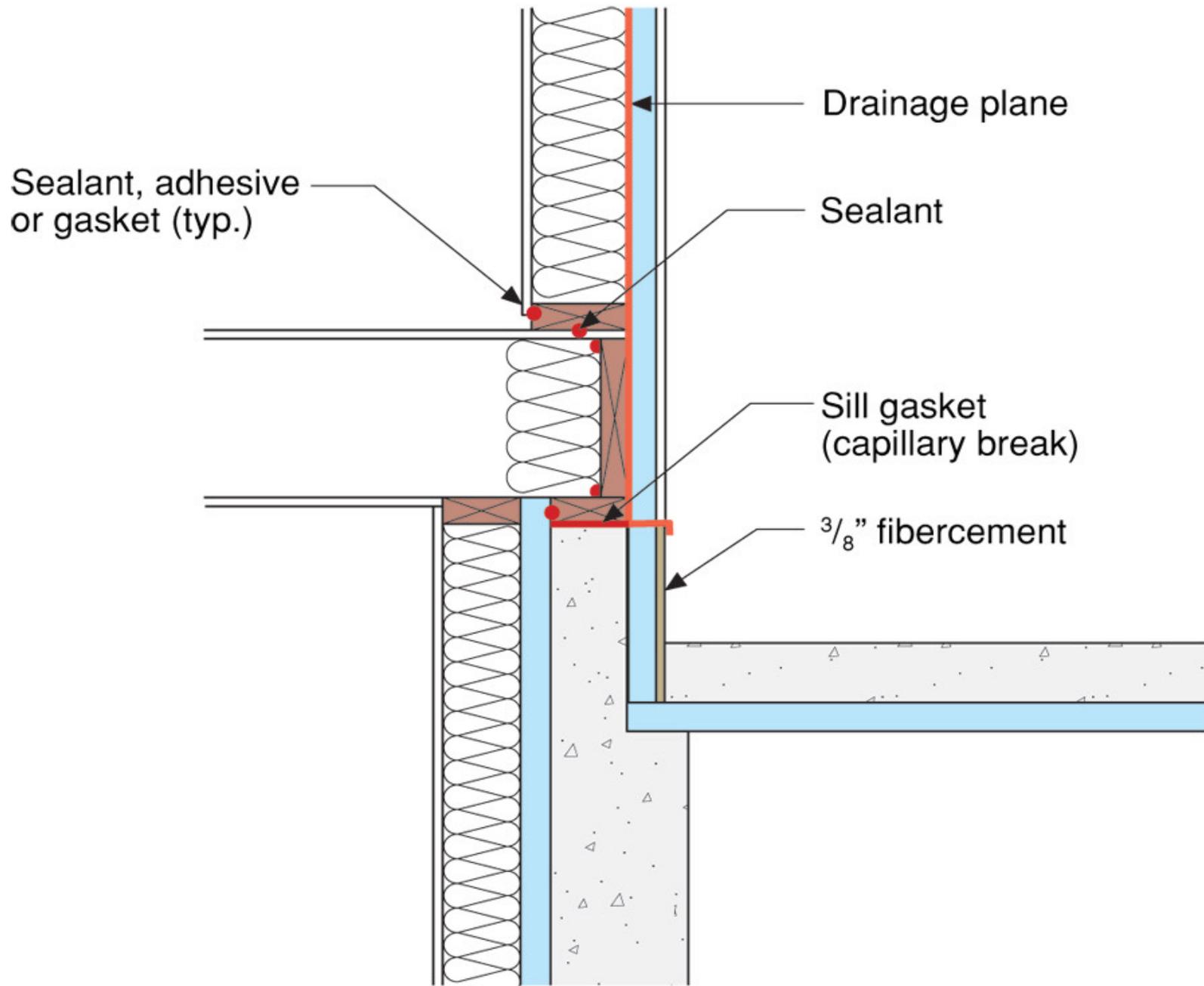


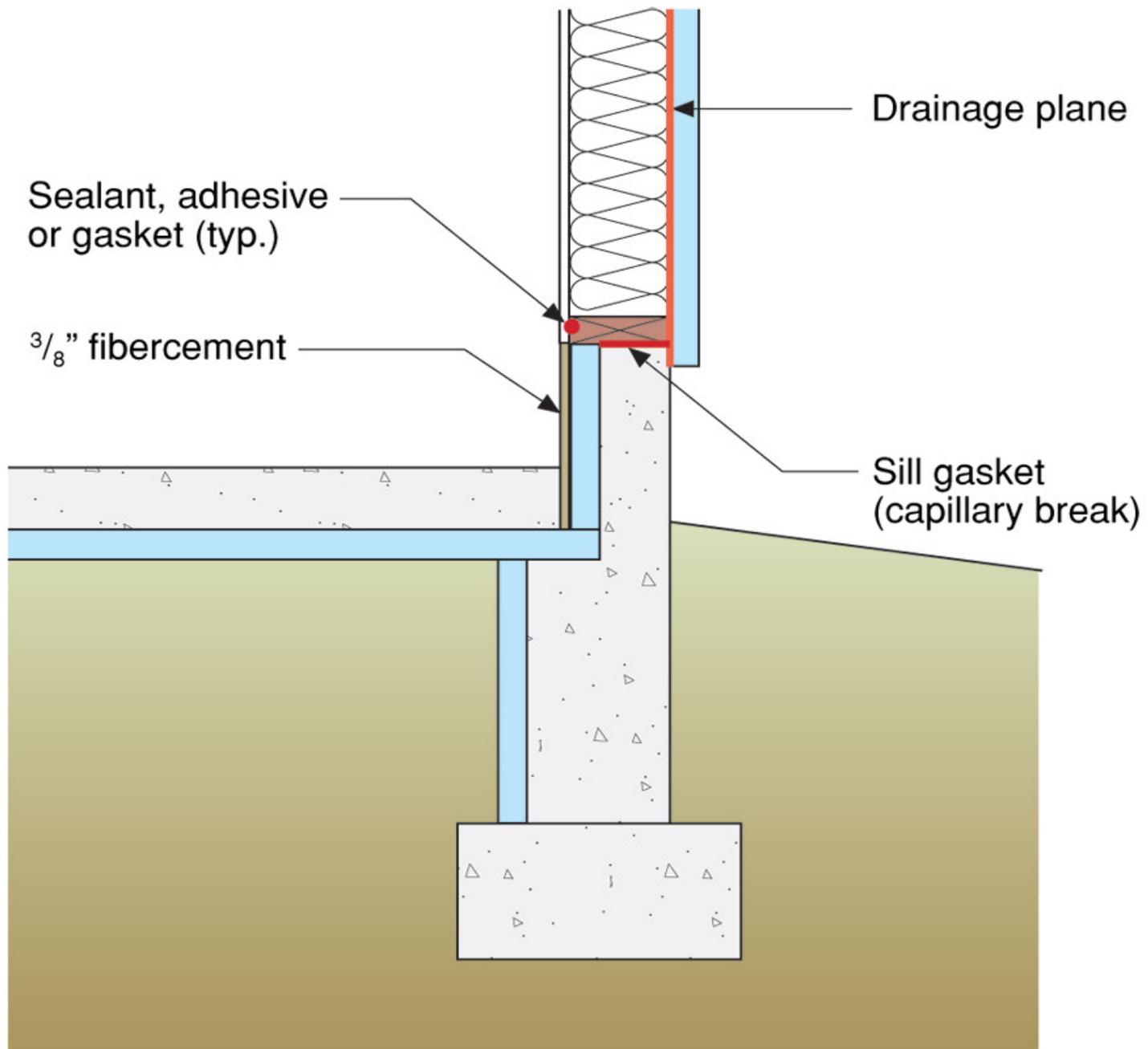


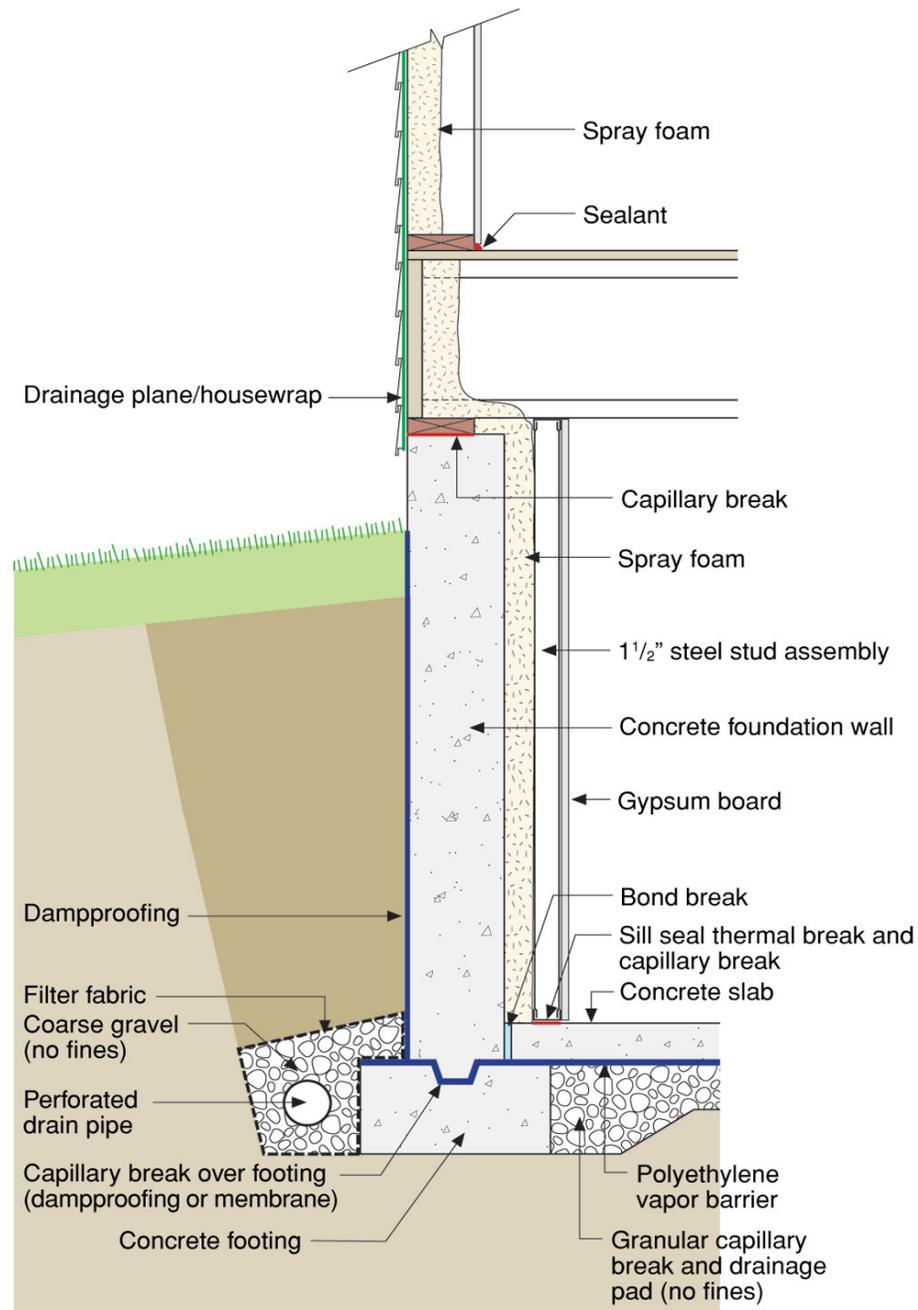


















Crawl Spaces

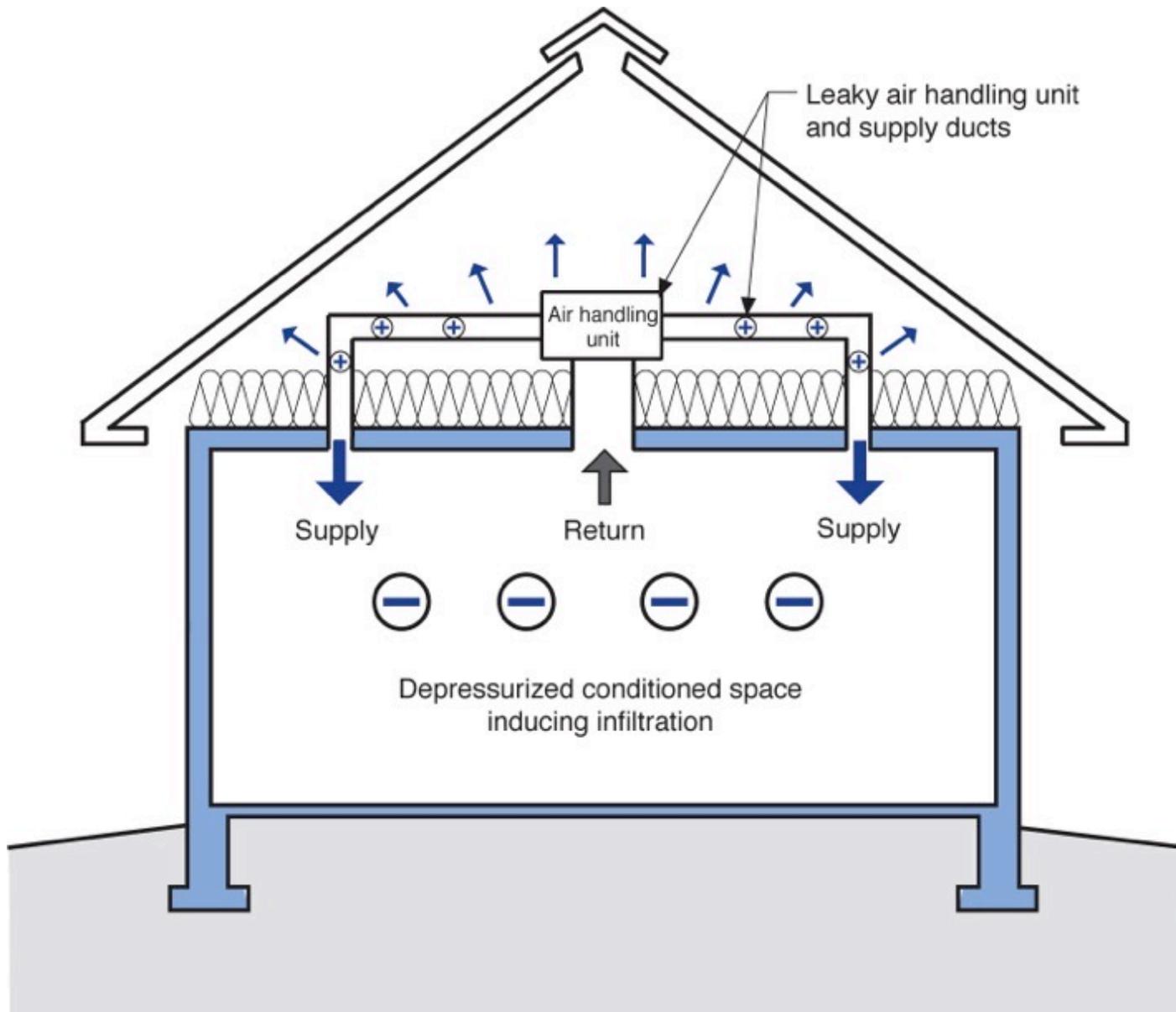
Crawl spaces must be completely connected to either the outside or the inside

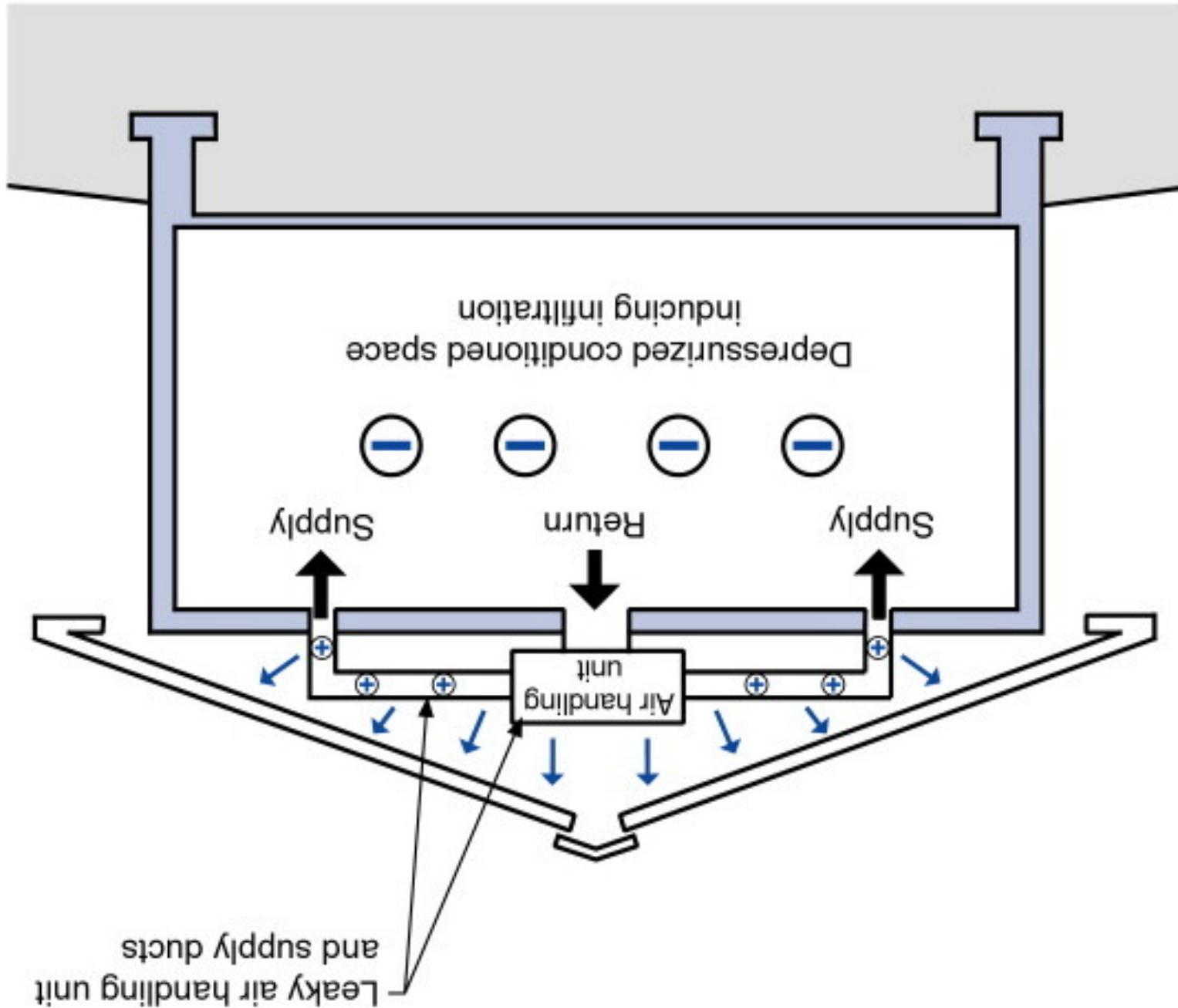
Crawl spaces must be completely connected to either the outside or the inside

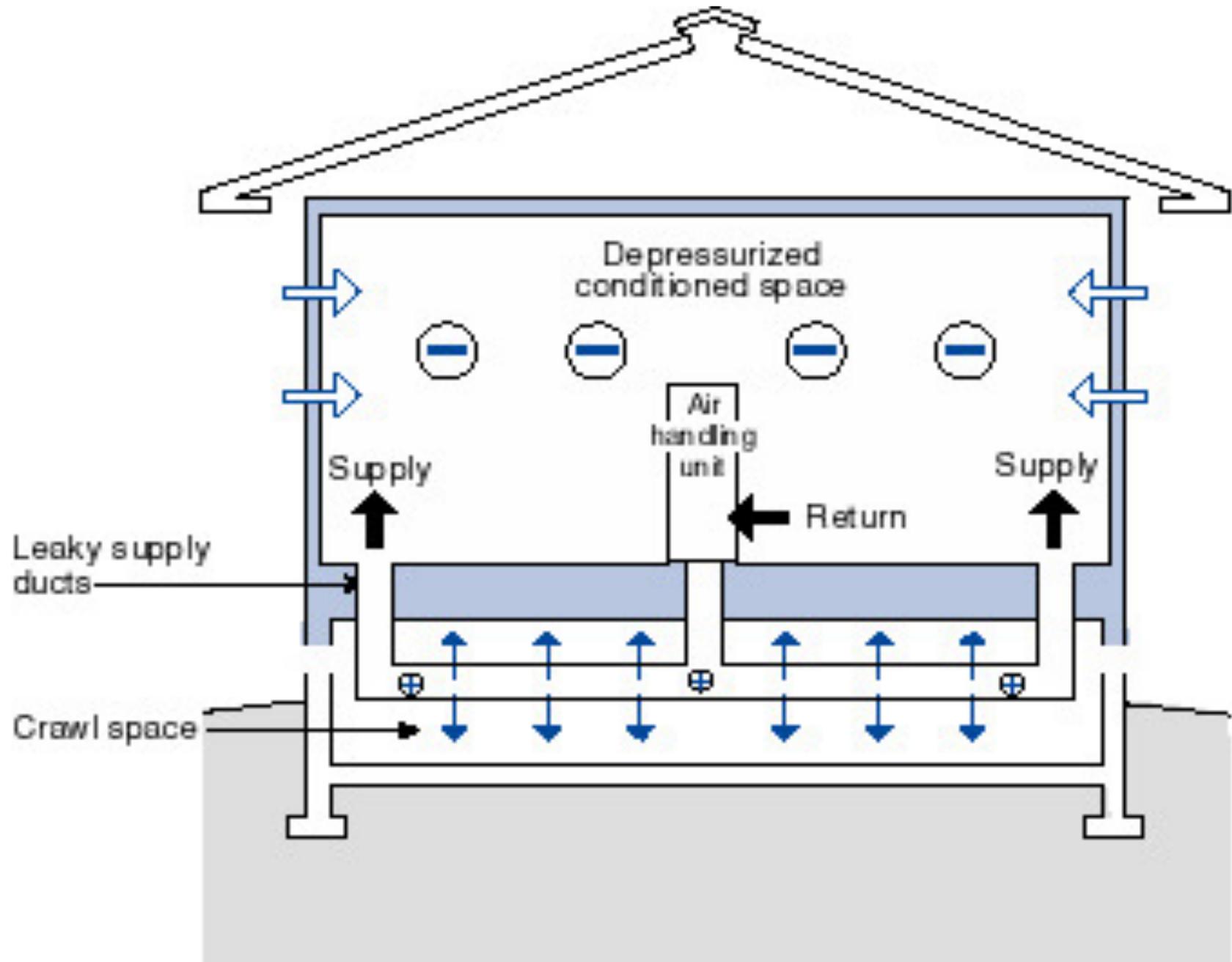
Vented crawl spaces work

Unvented conditioned crawl spaces work

Don't Do Stupid Things







Smart Thing



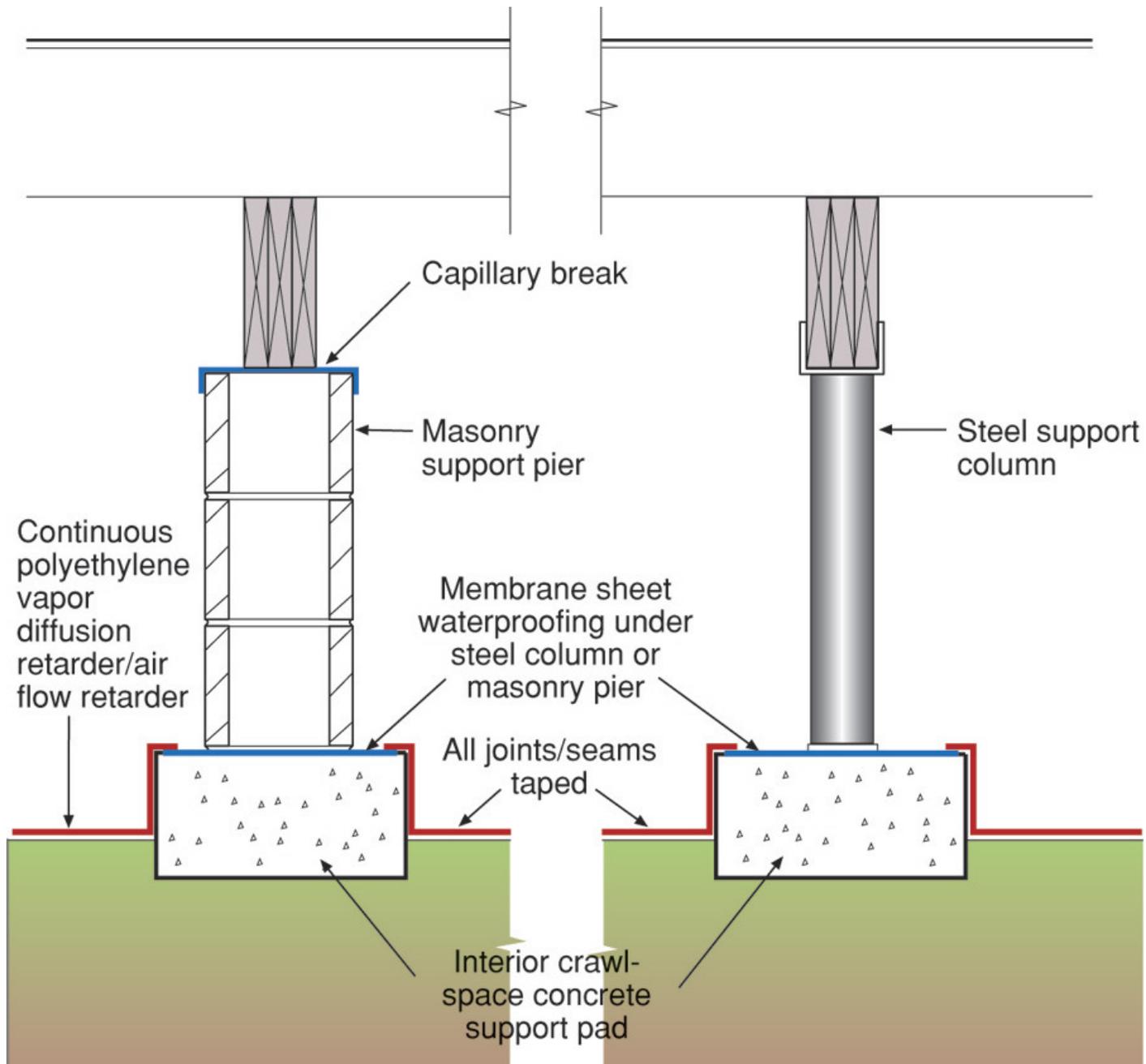












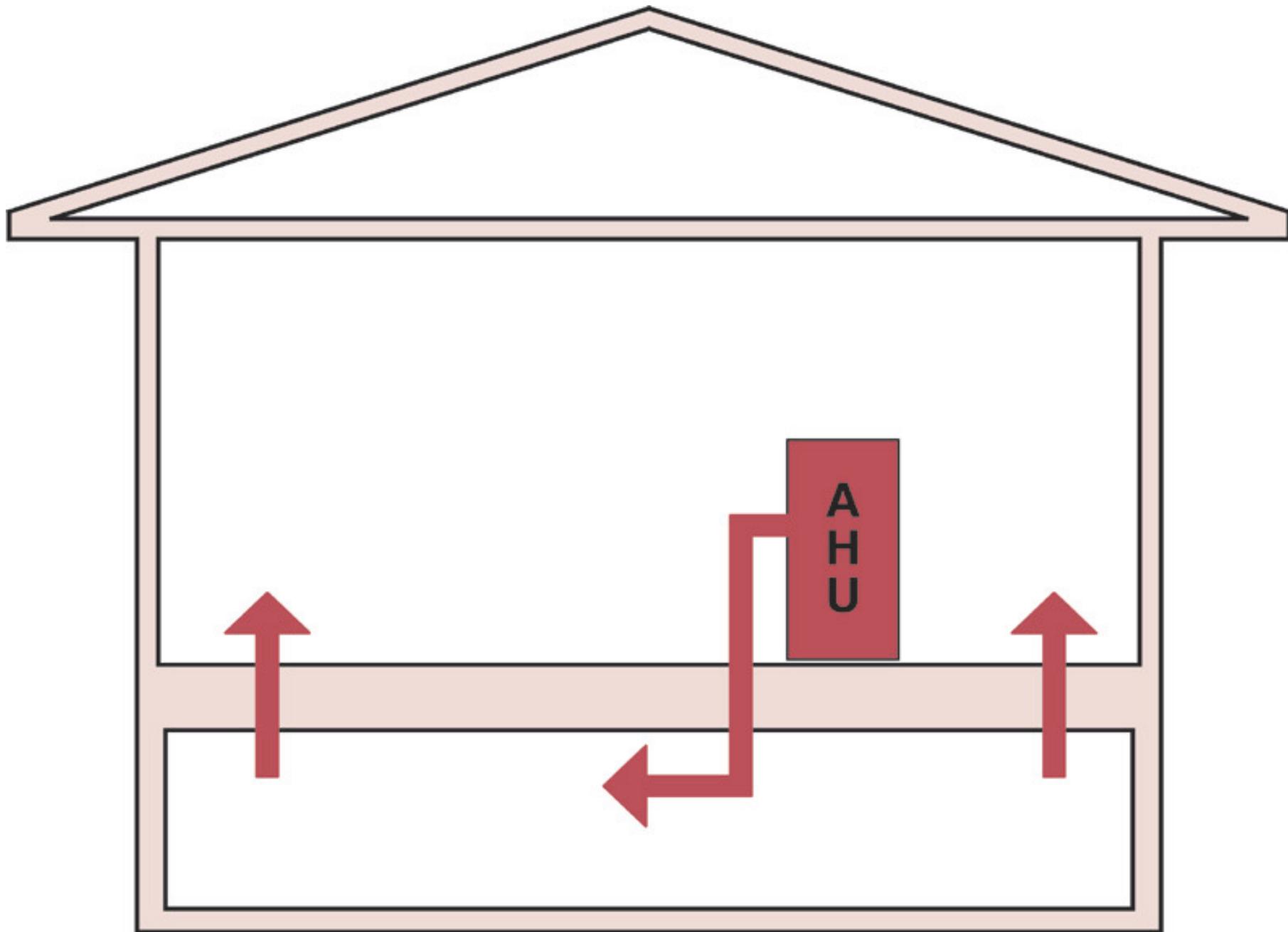
Conditioned Crawlspace Not Unvented
Crawlspace

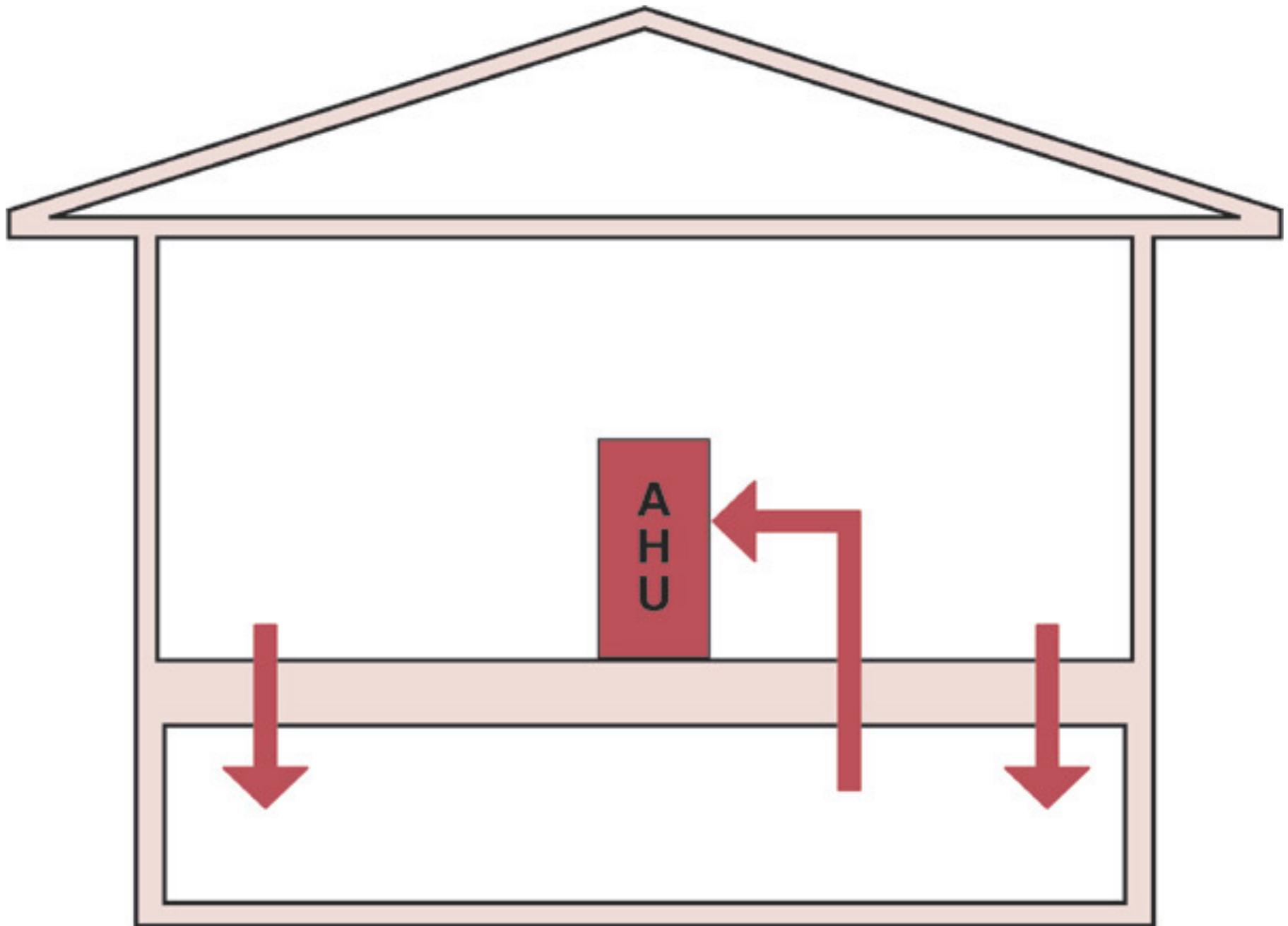
Need Supply Air

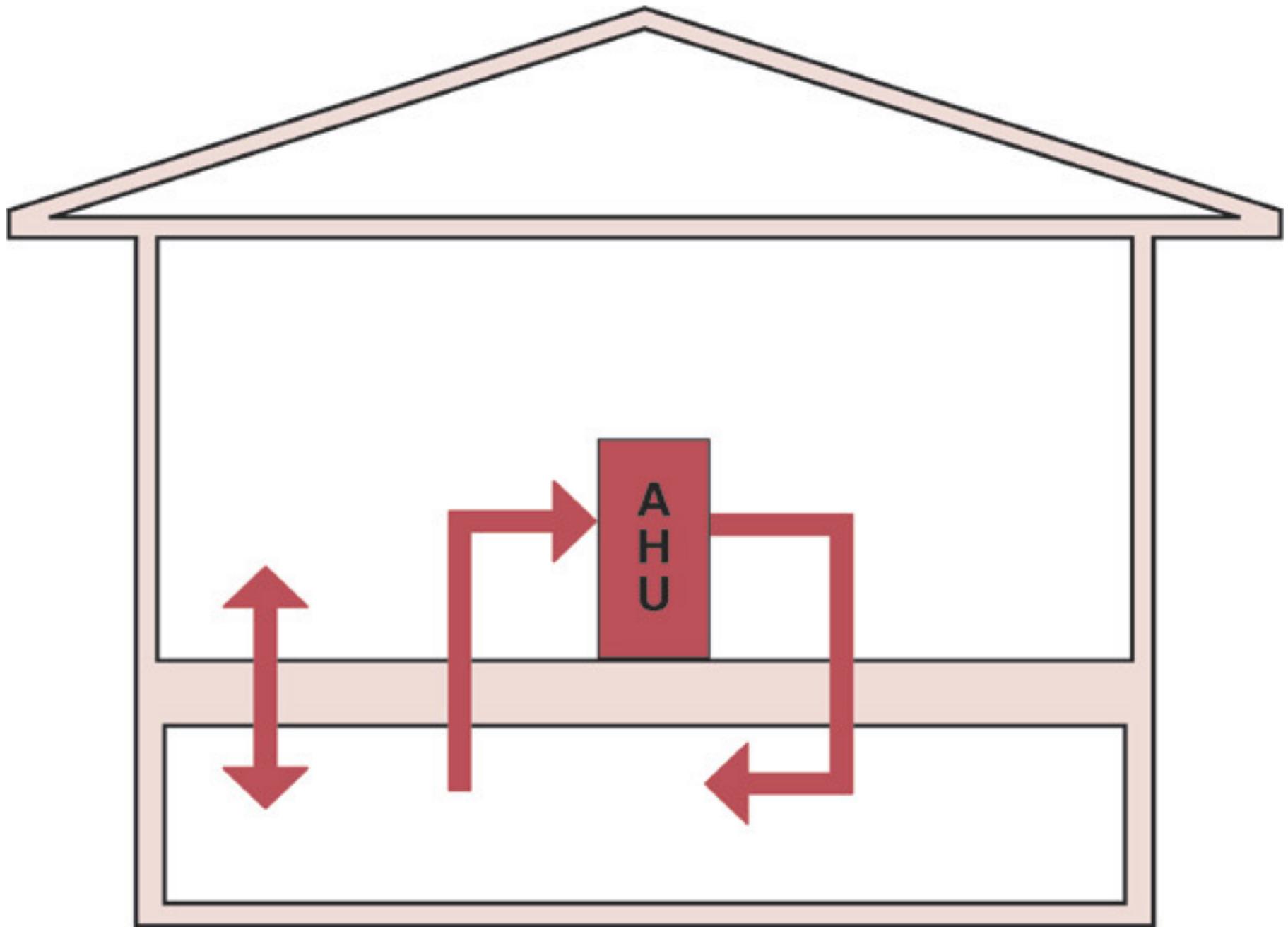
50 cfm/1000 ft² of Crawlspace Area

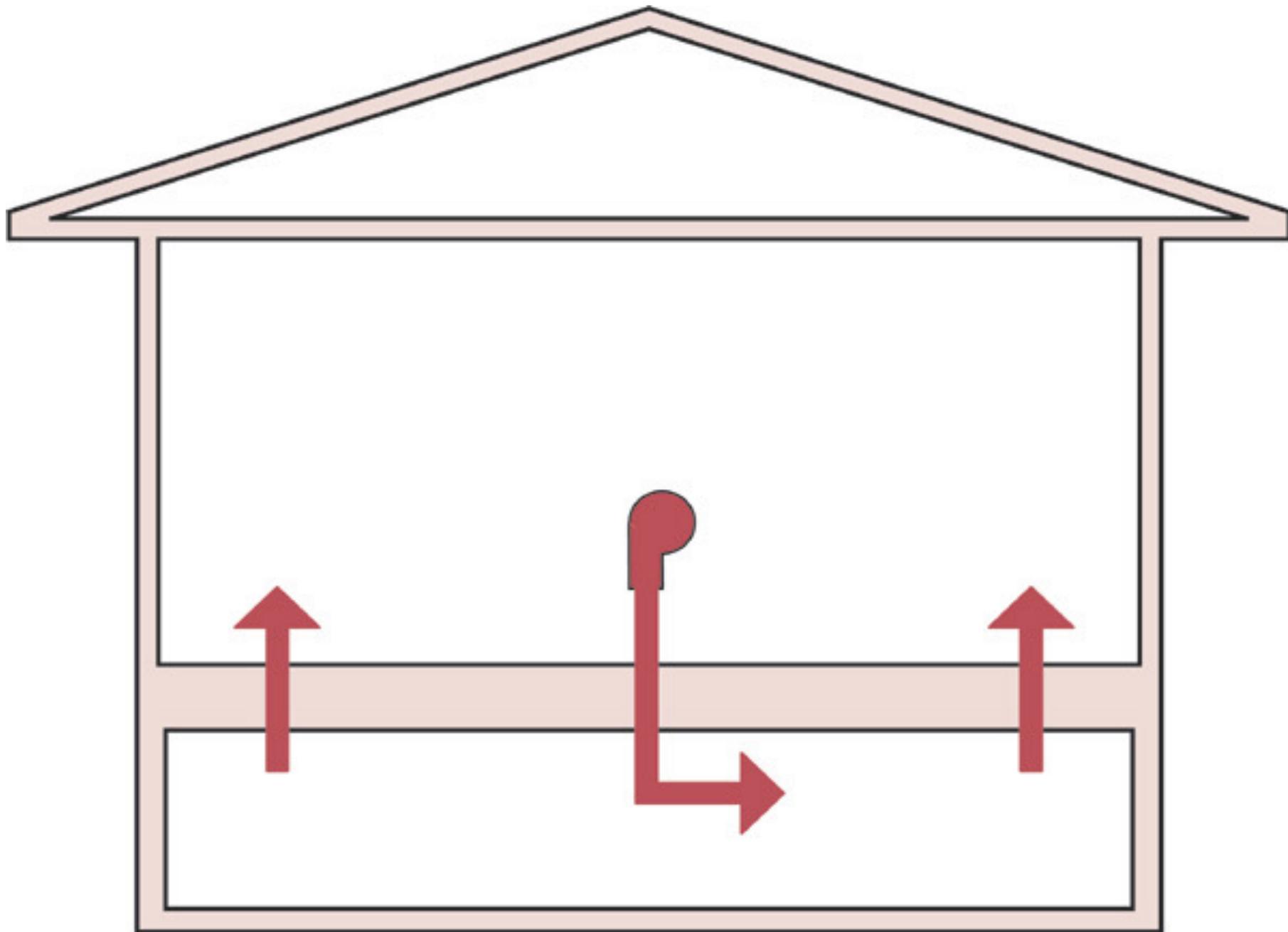
Or

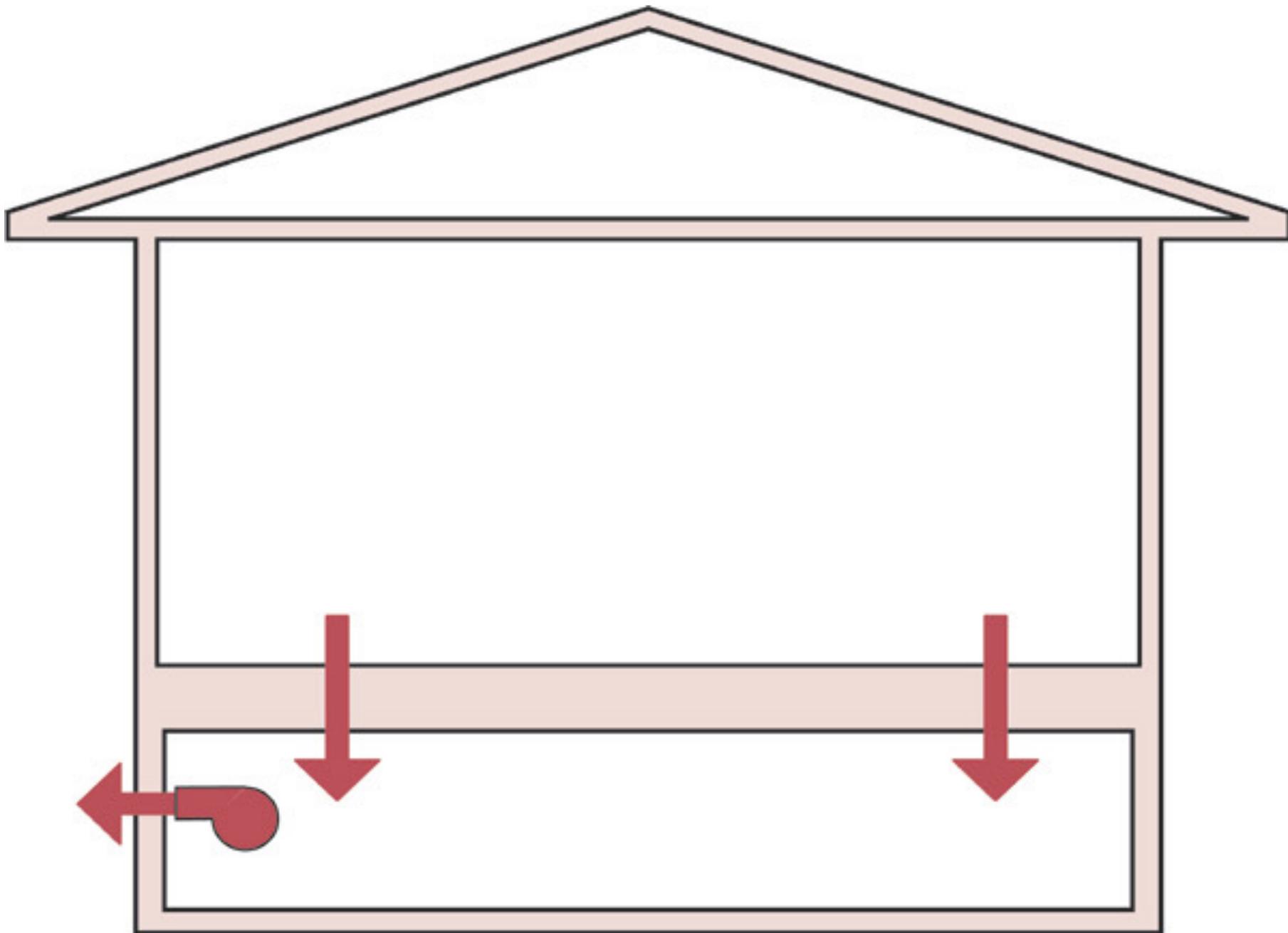
Dehumidification

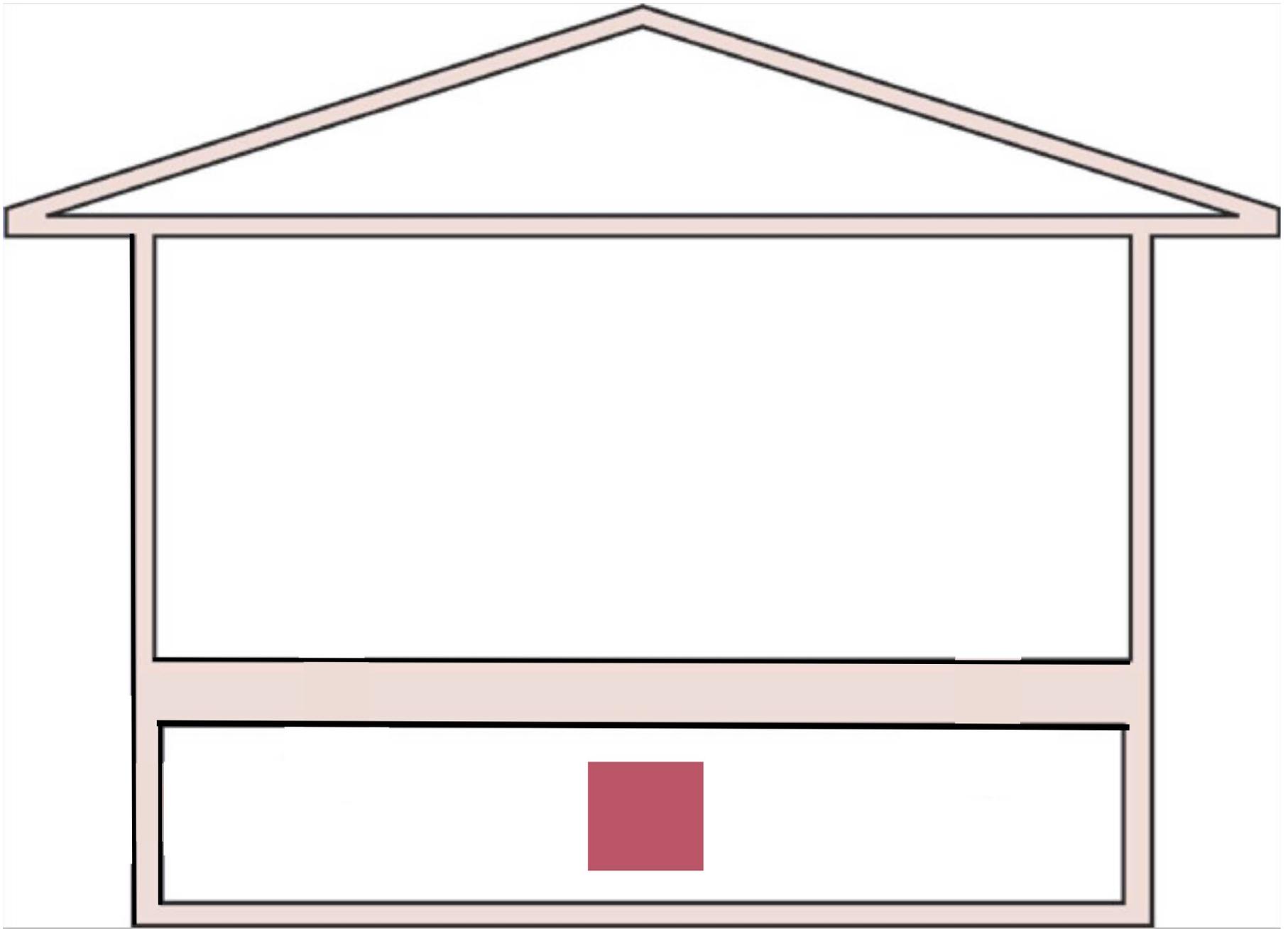


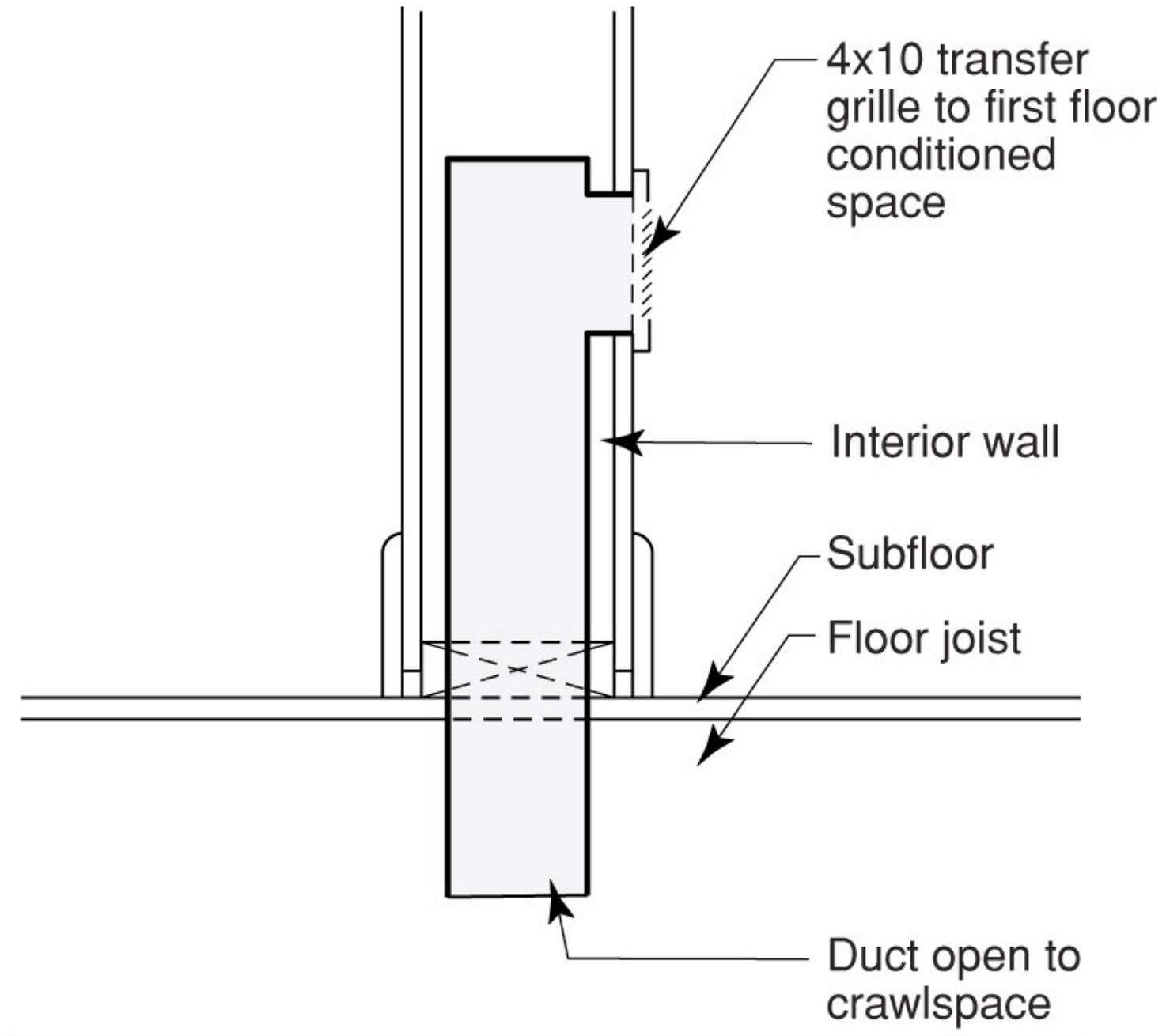




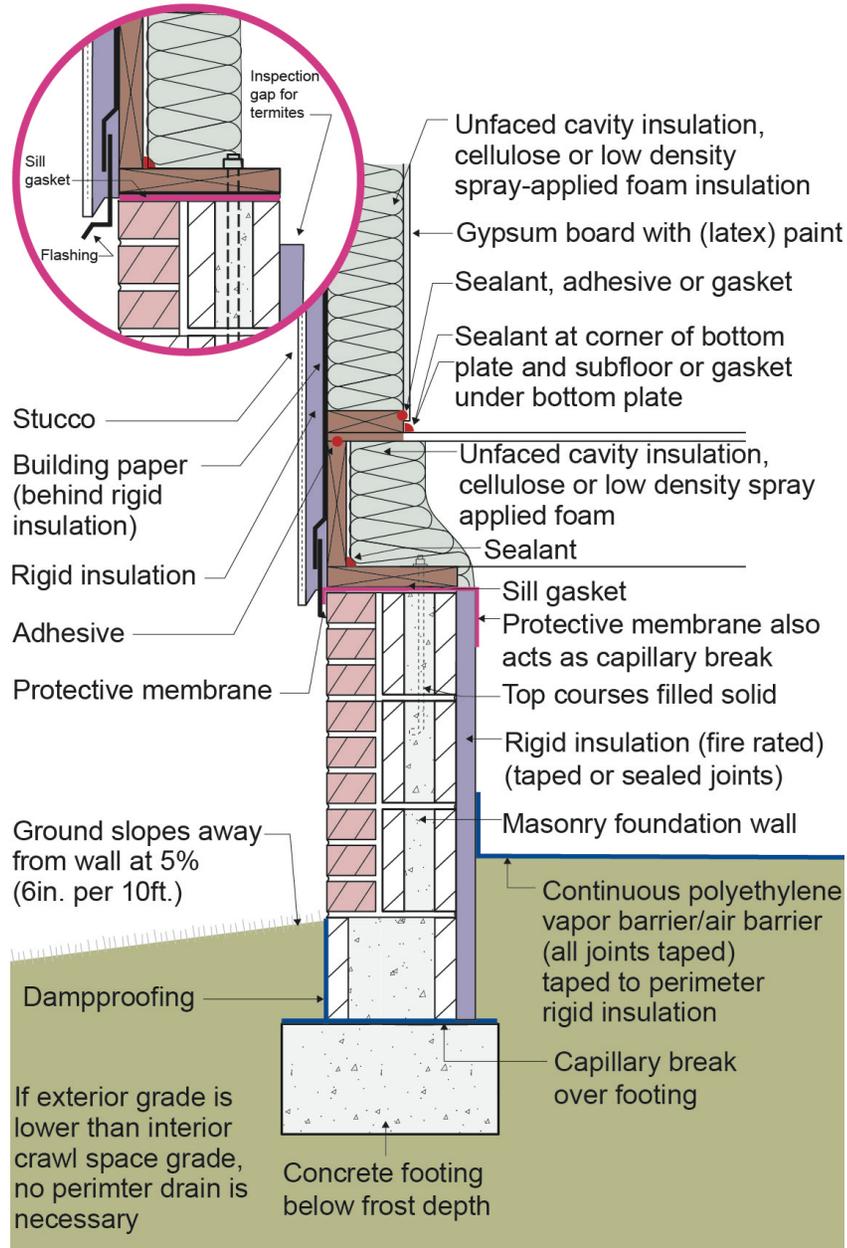




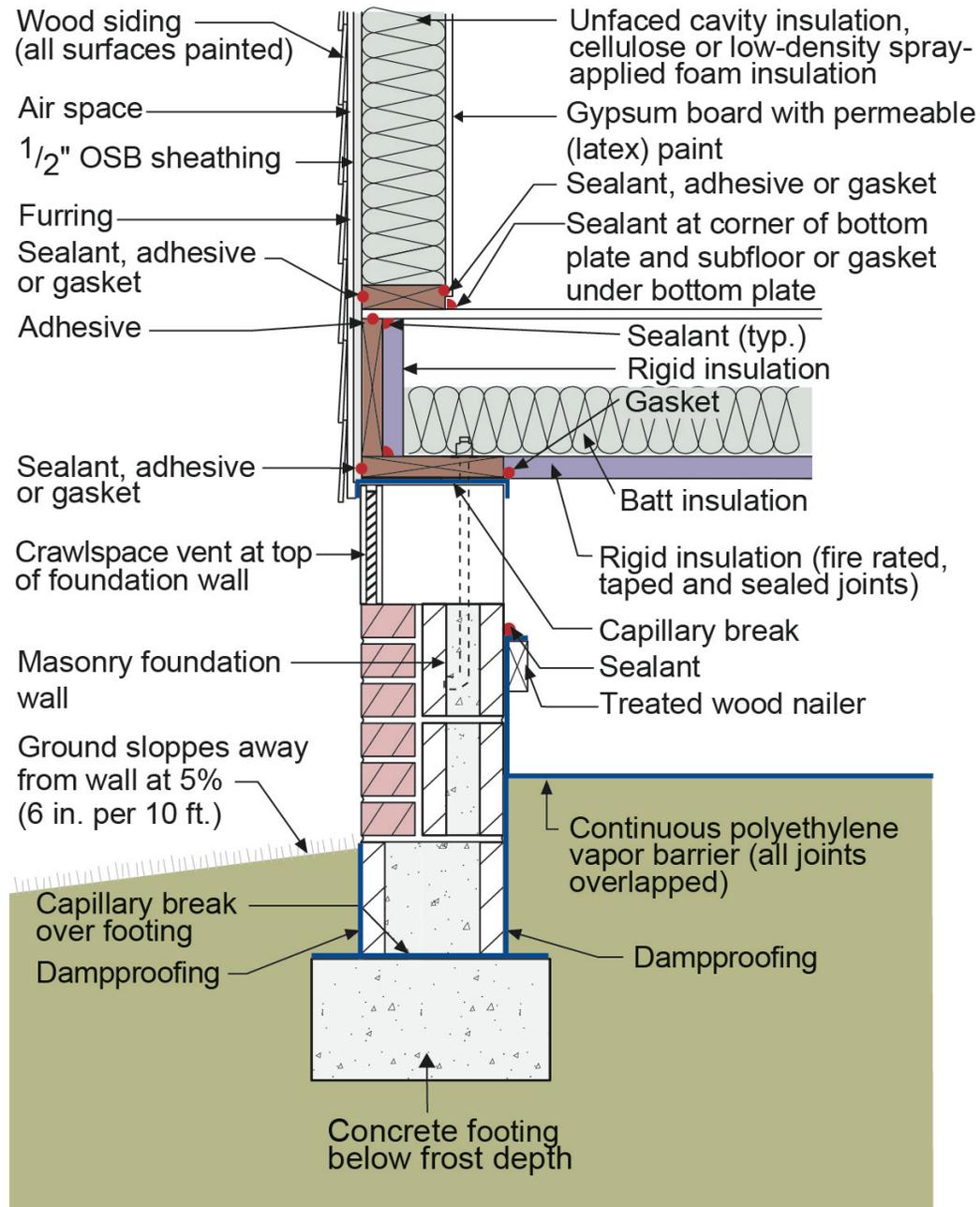


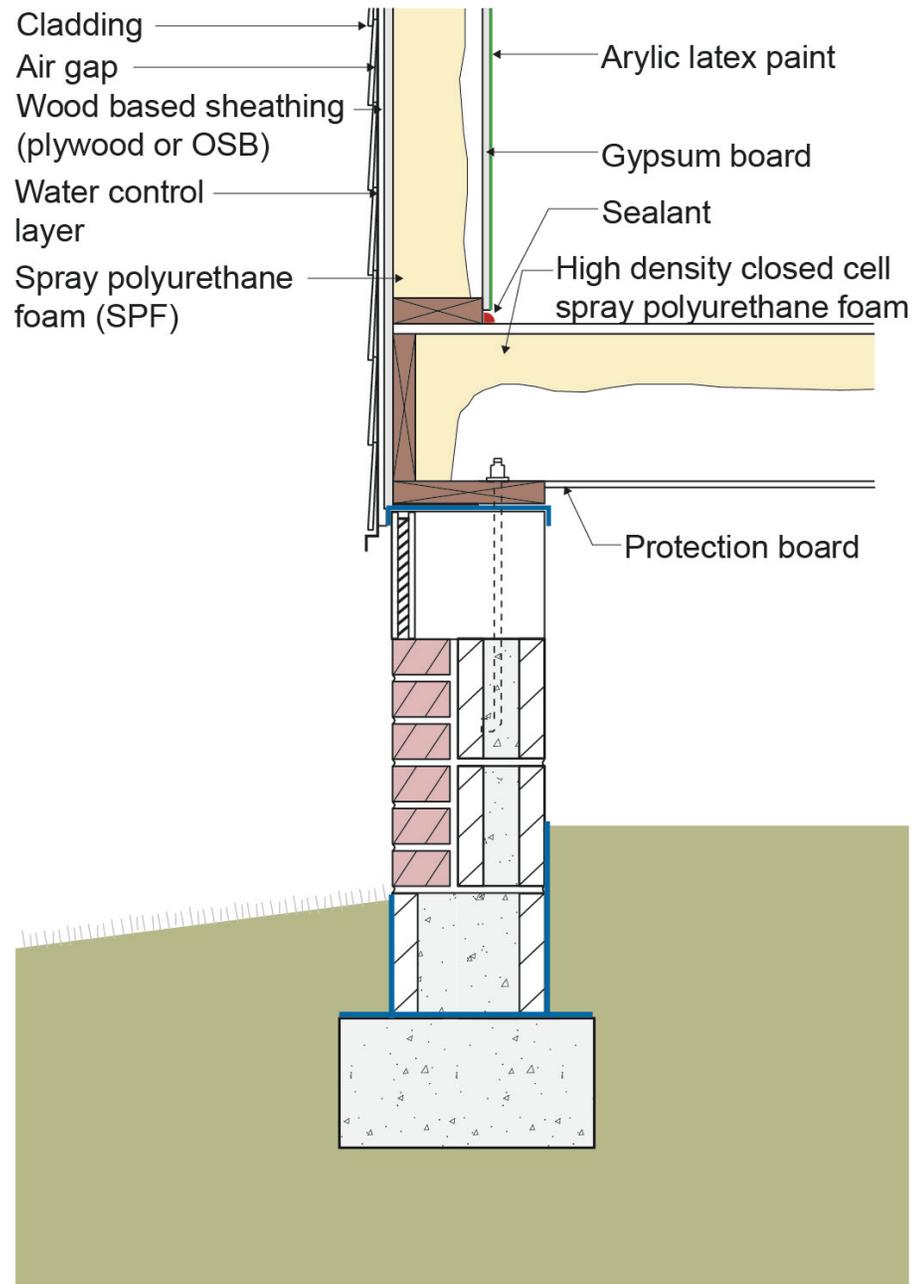


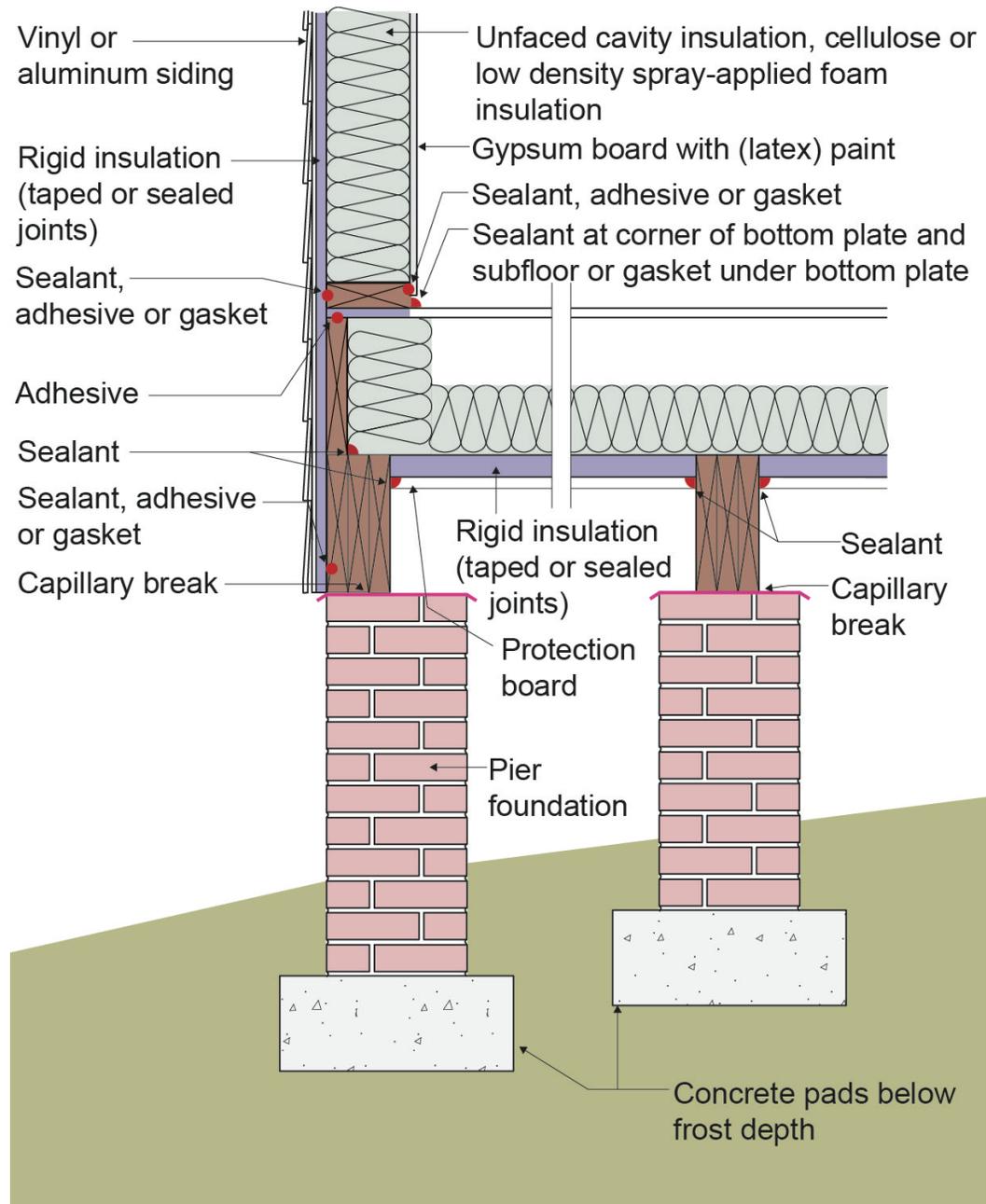
Alternative Detail



Smart Thing









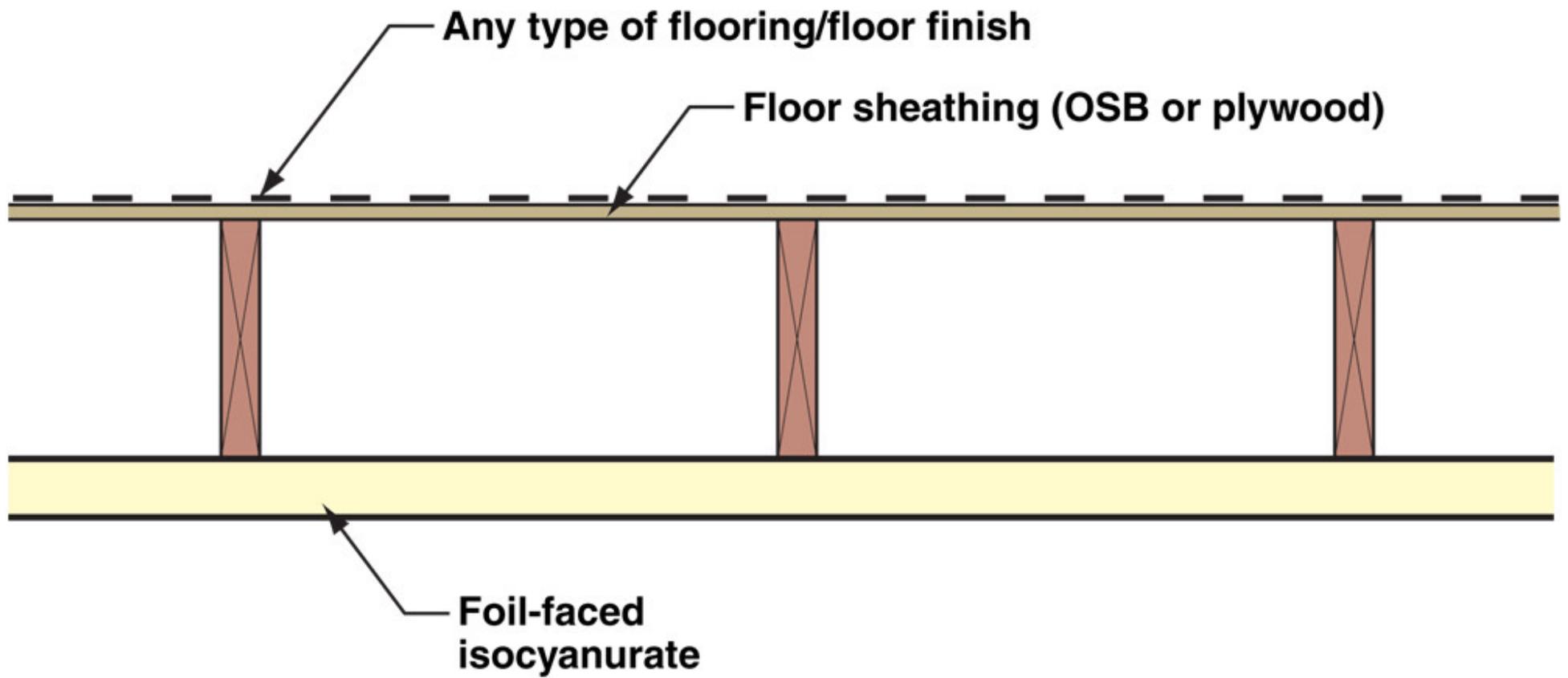


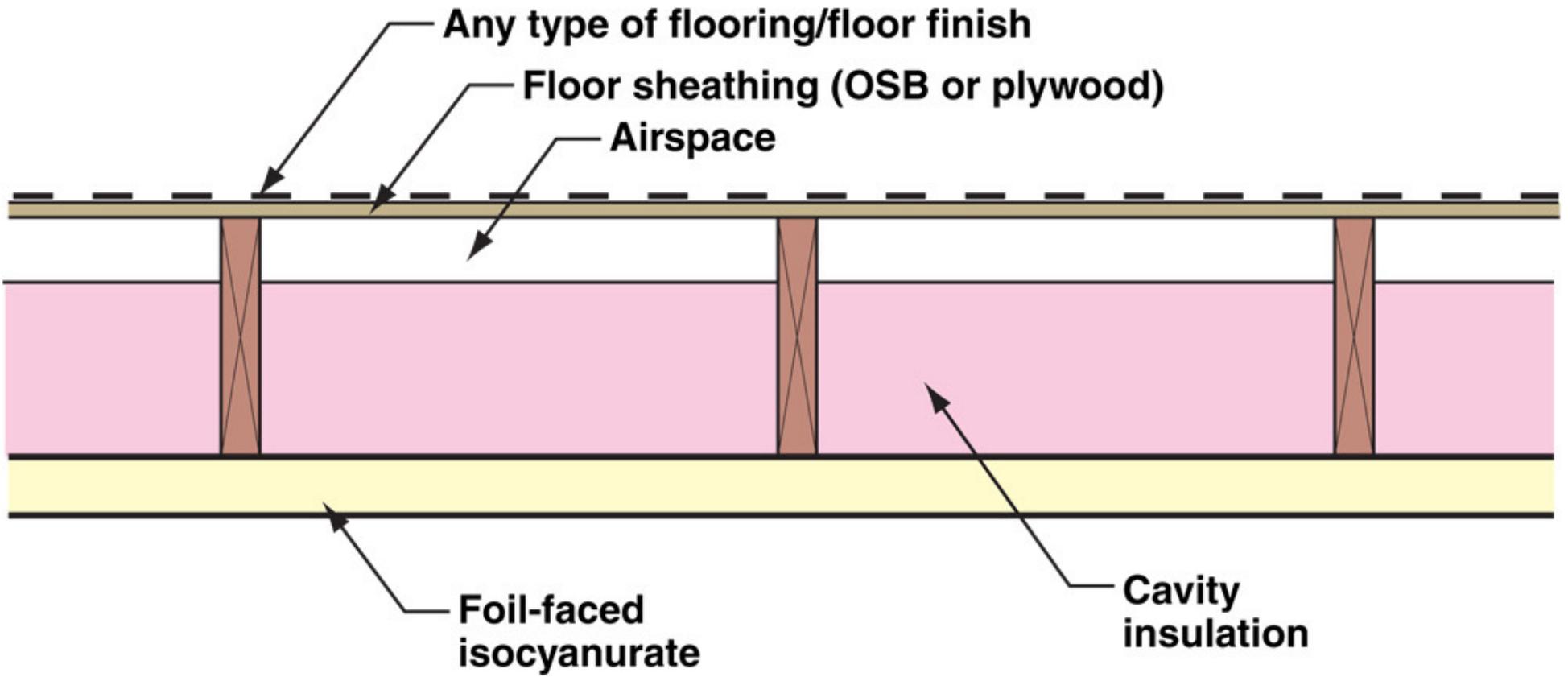


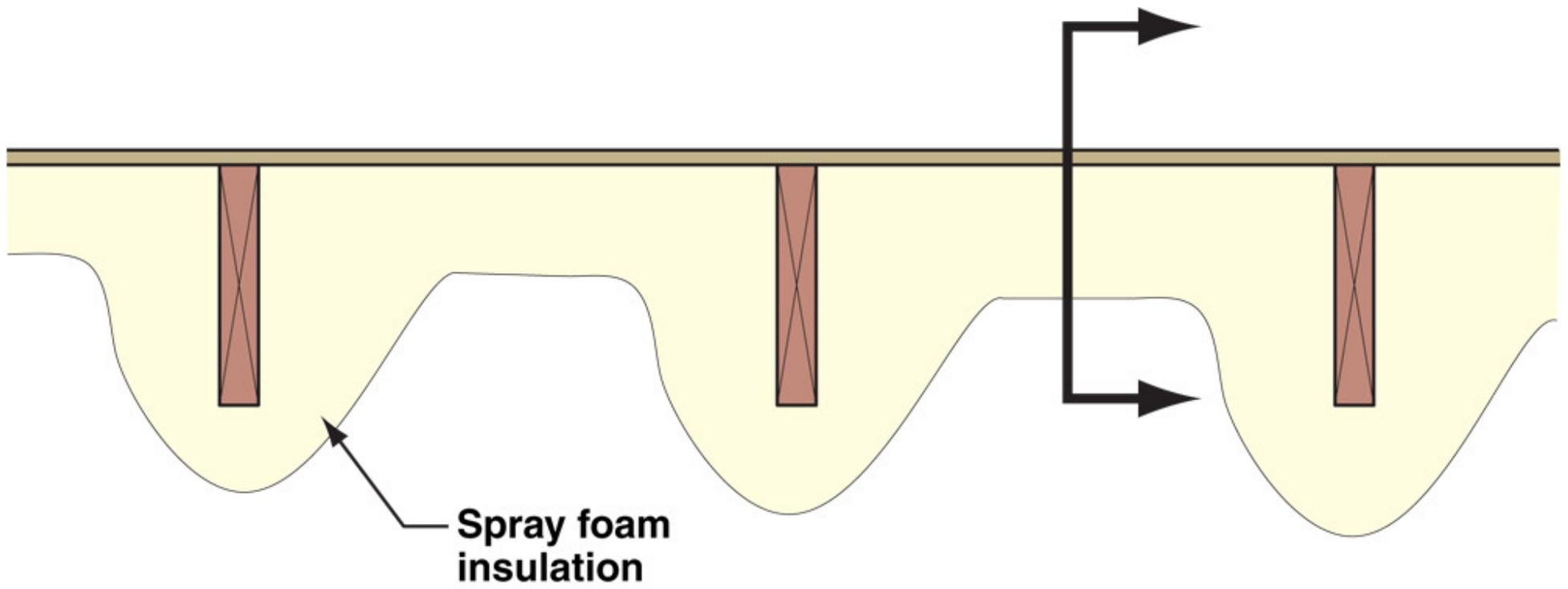


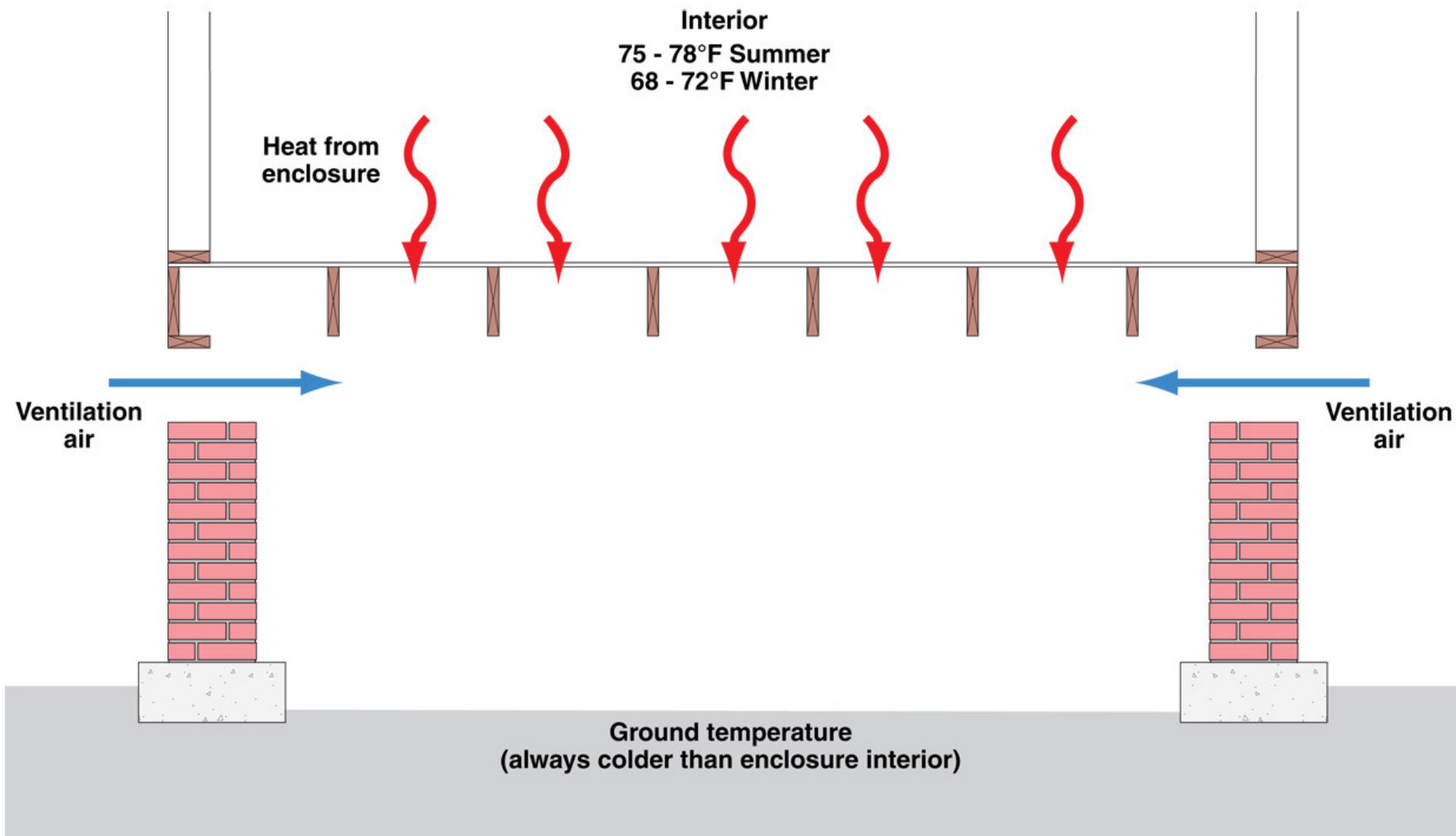


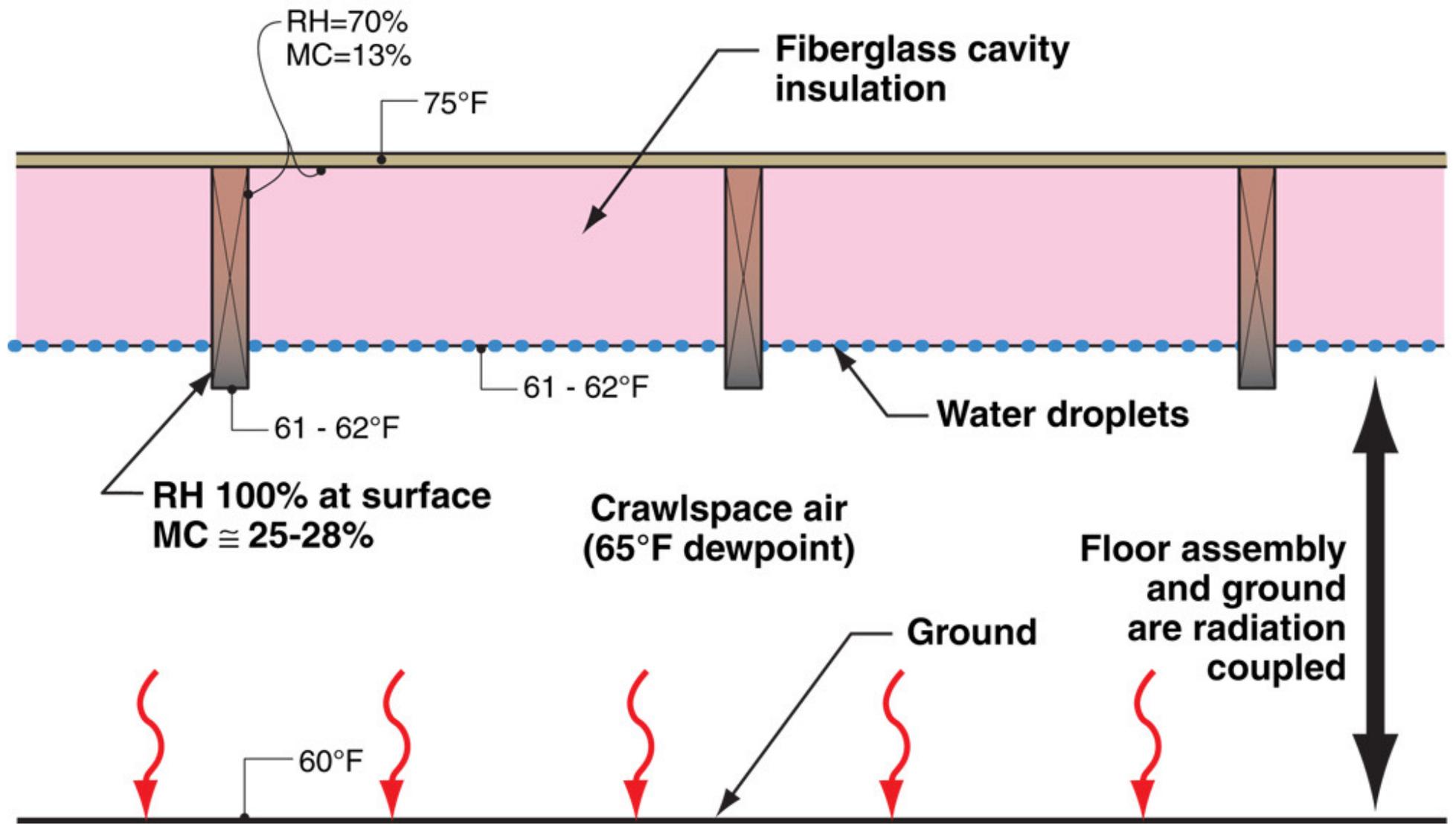








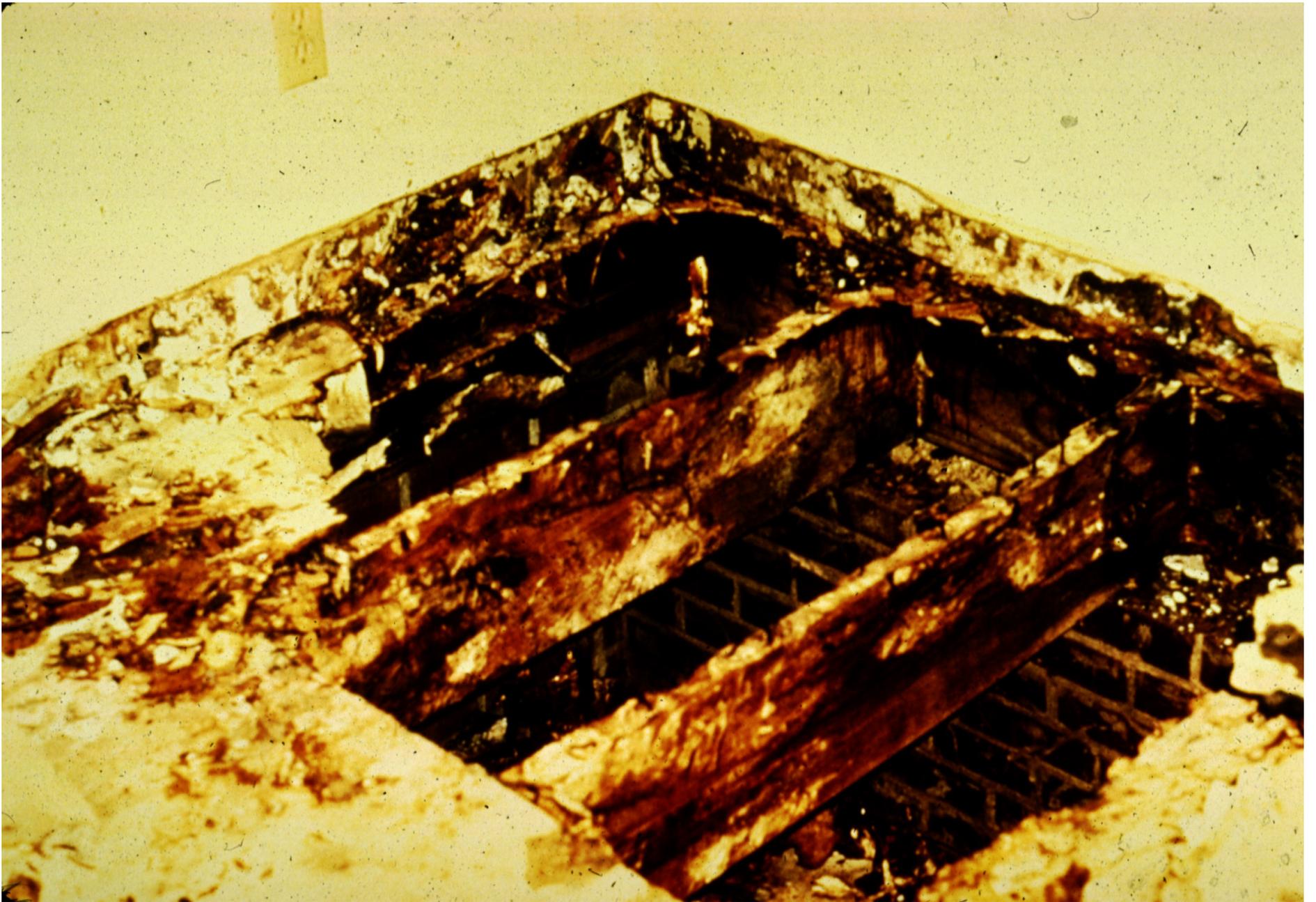








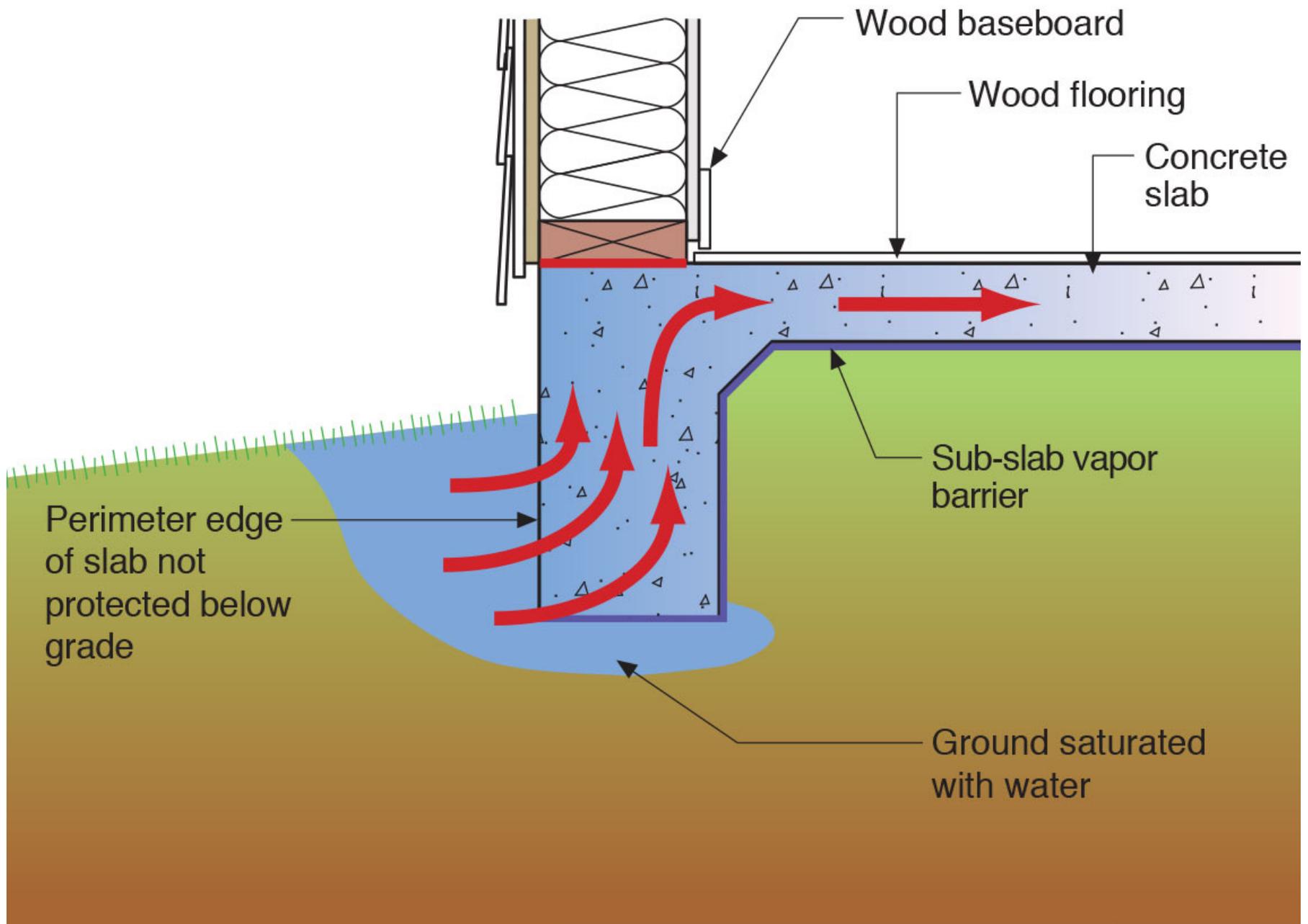








Slabs





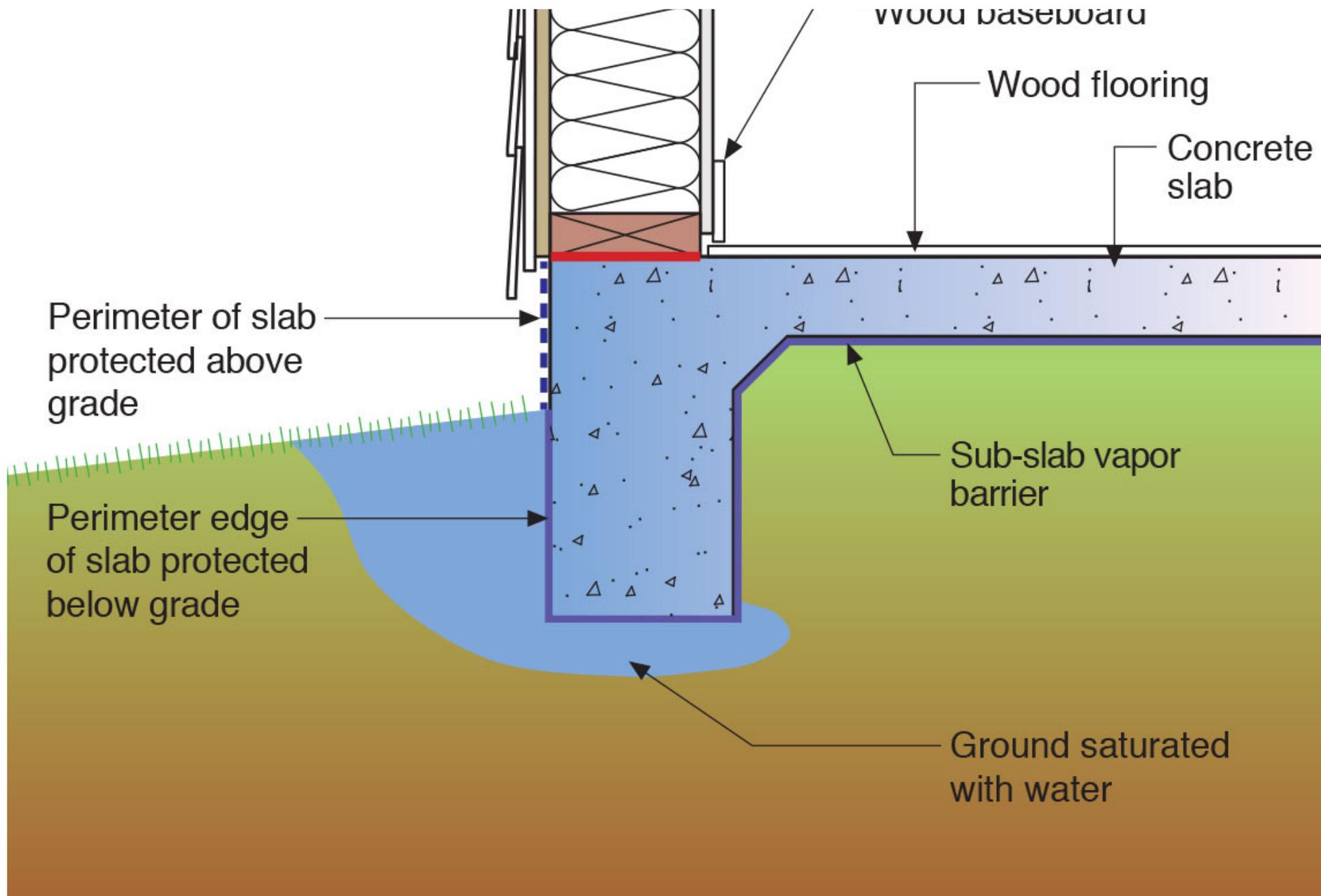


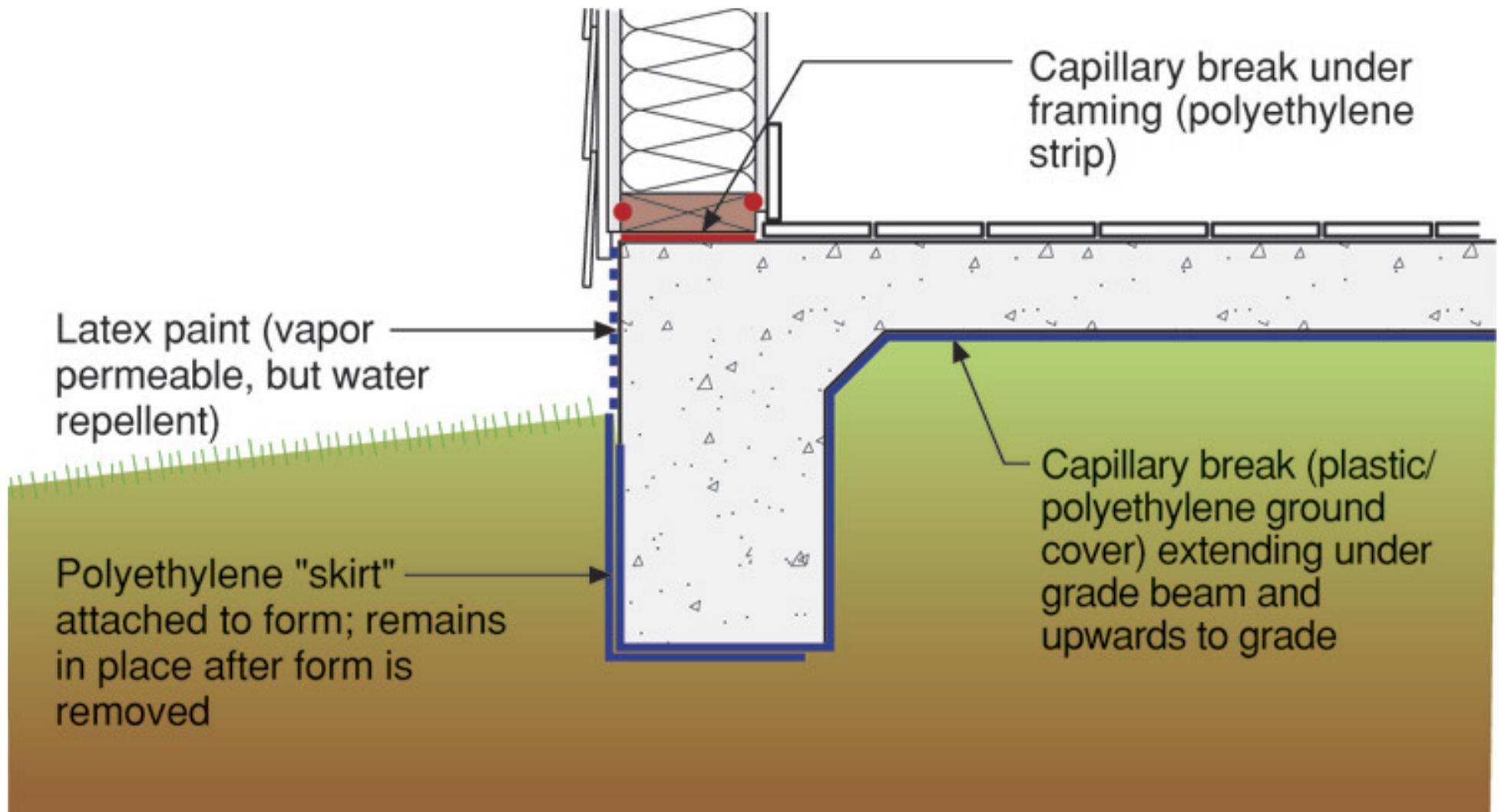










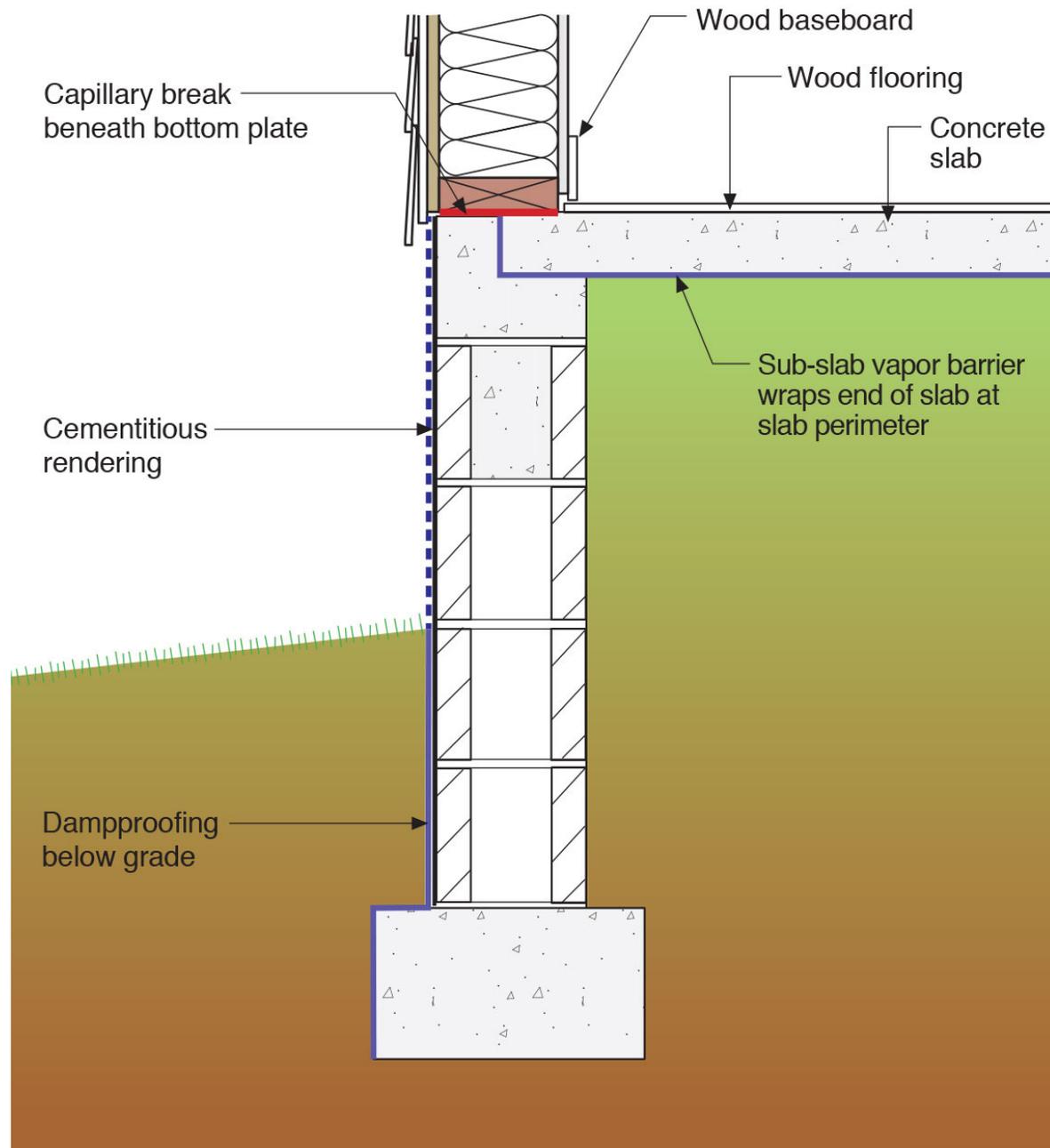








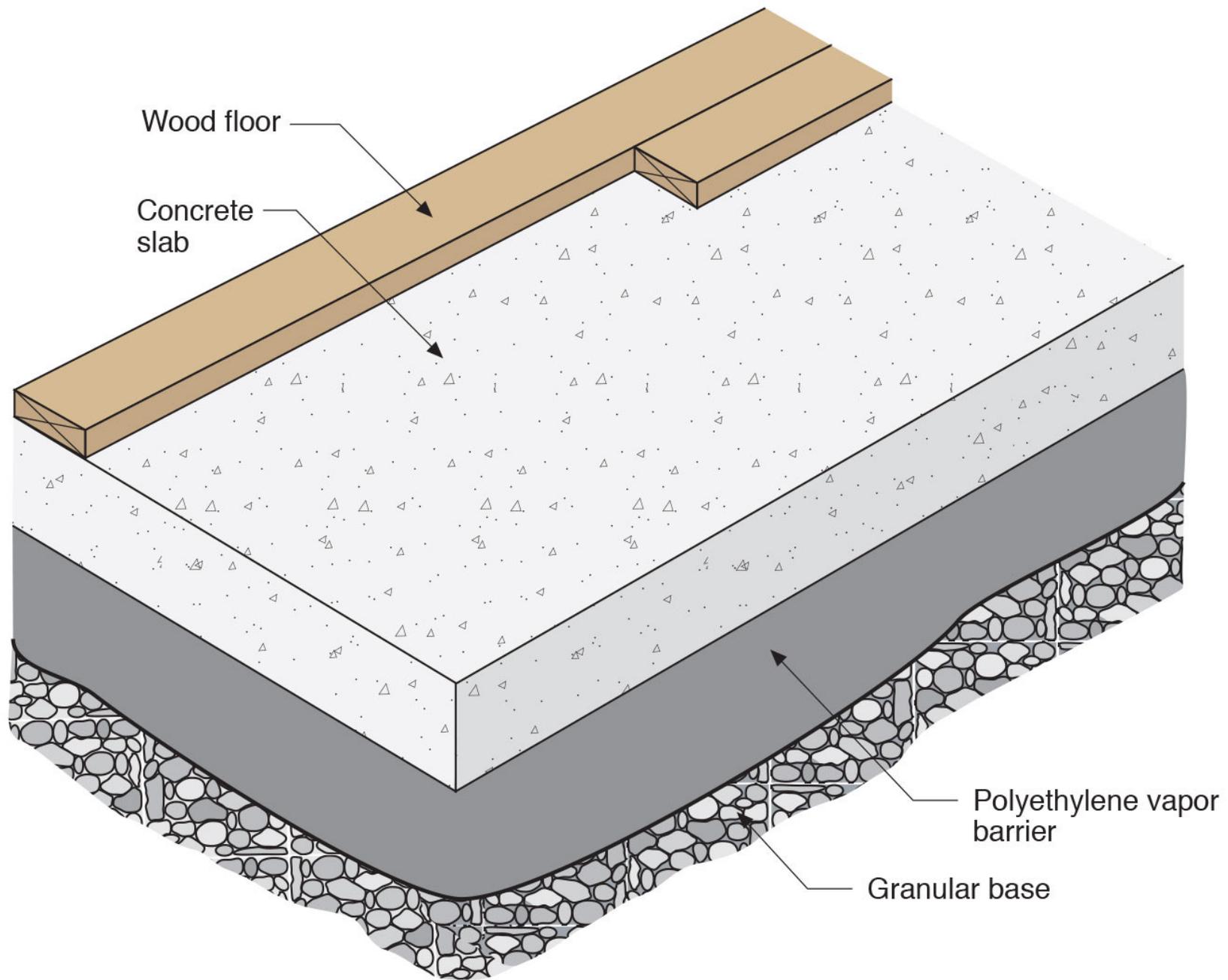


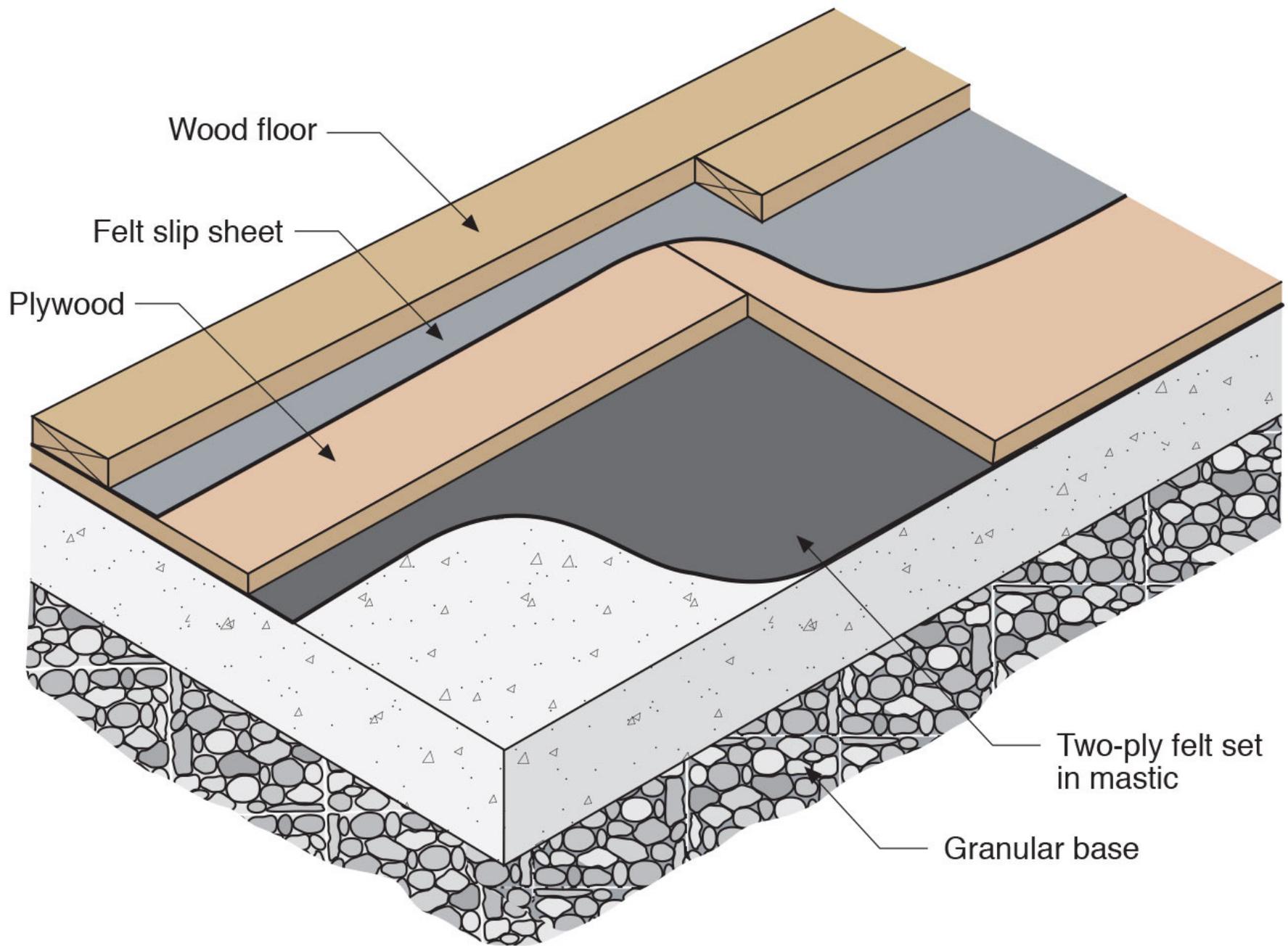




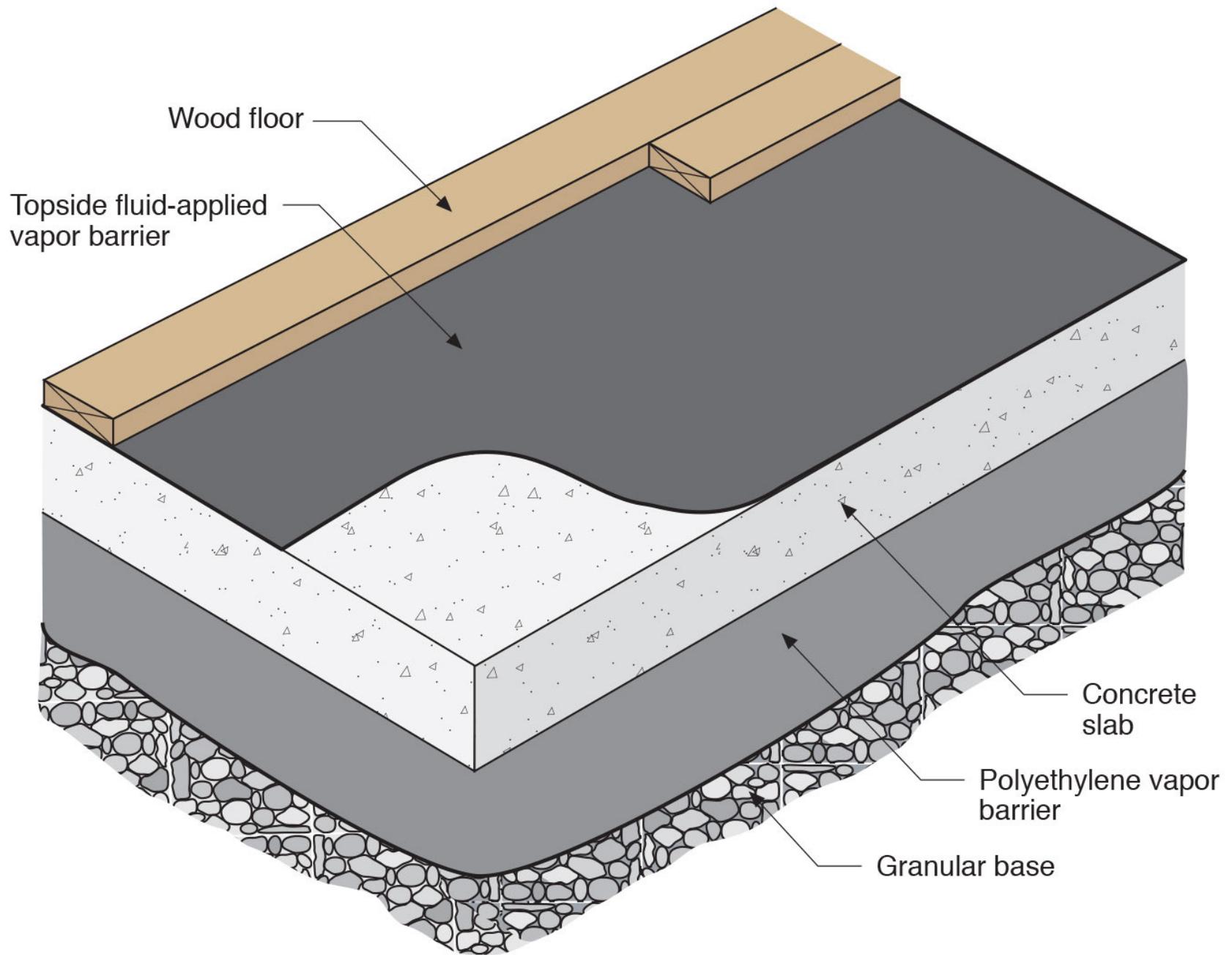






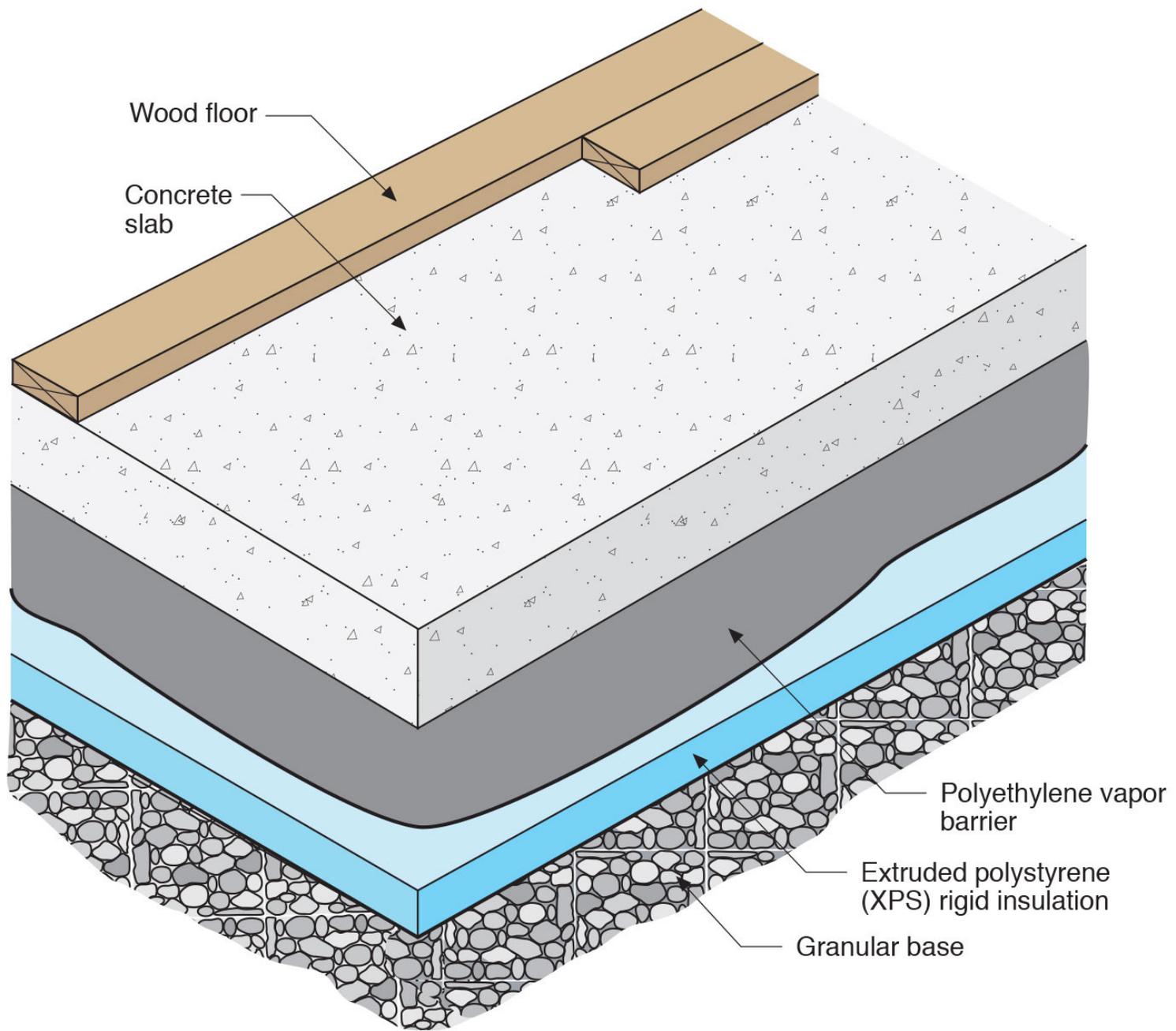




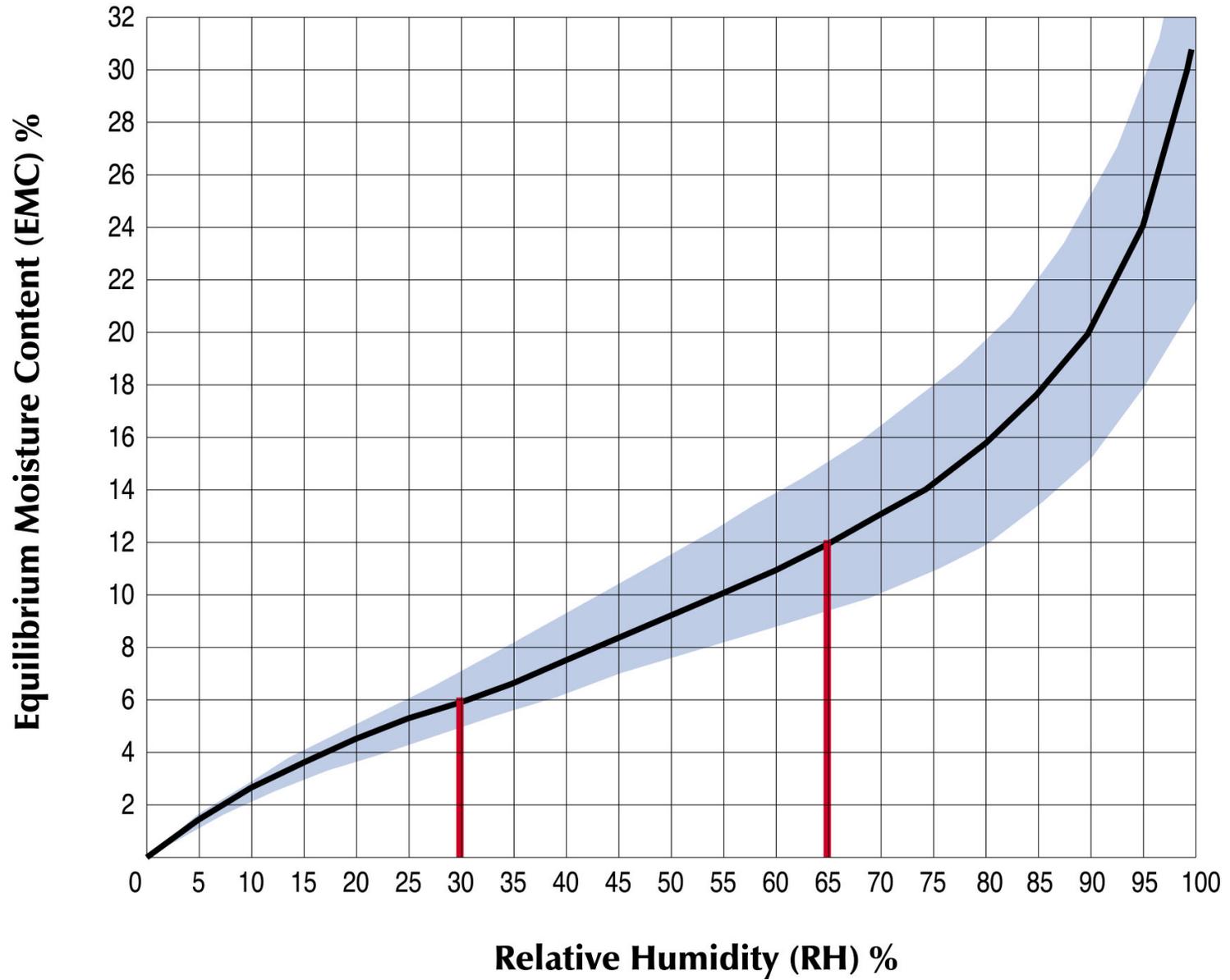


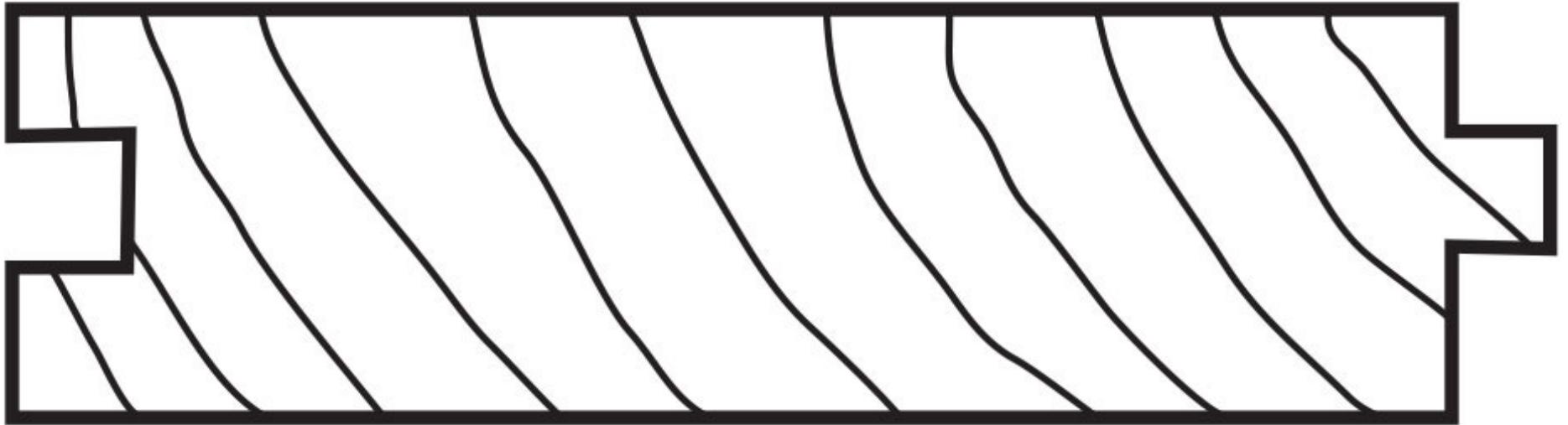




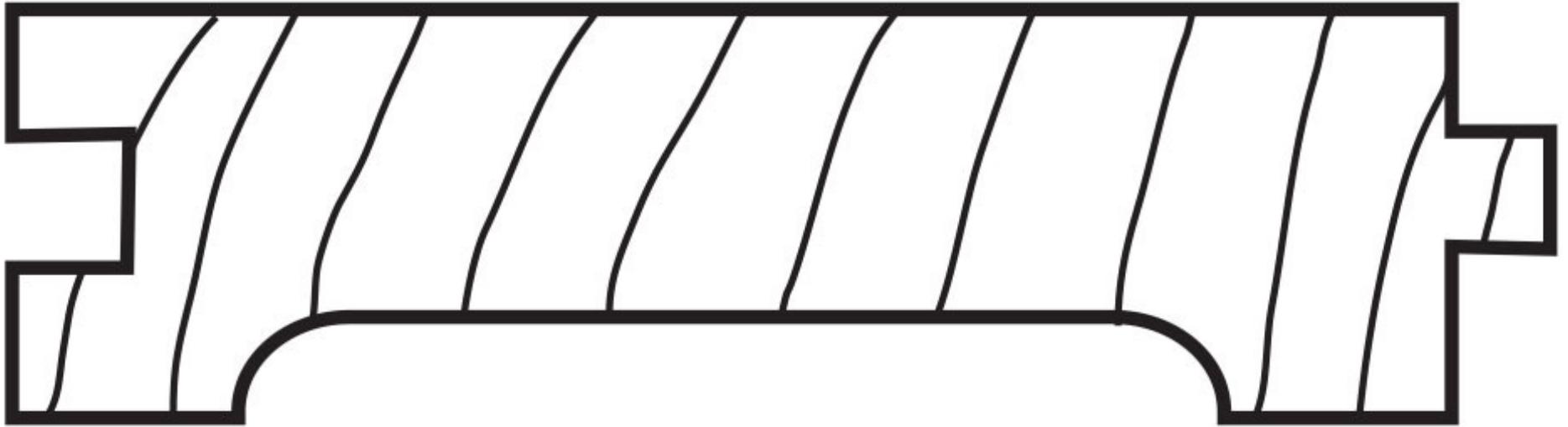


Moisture Content vs. Relative Humidity

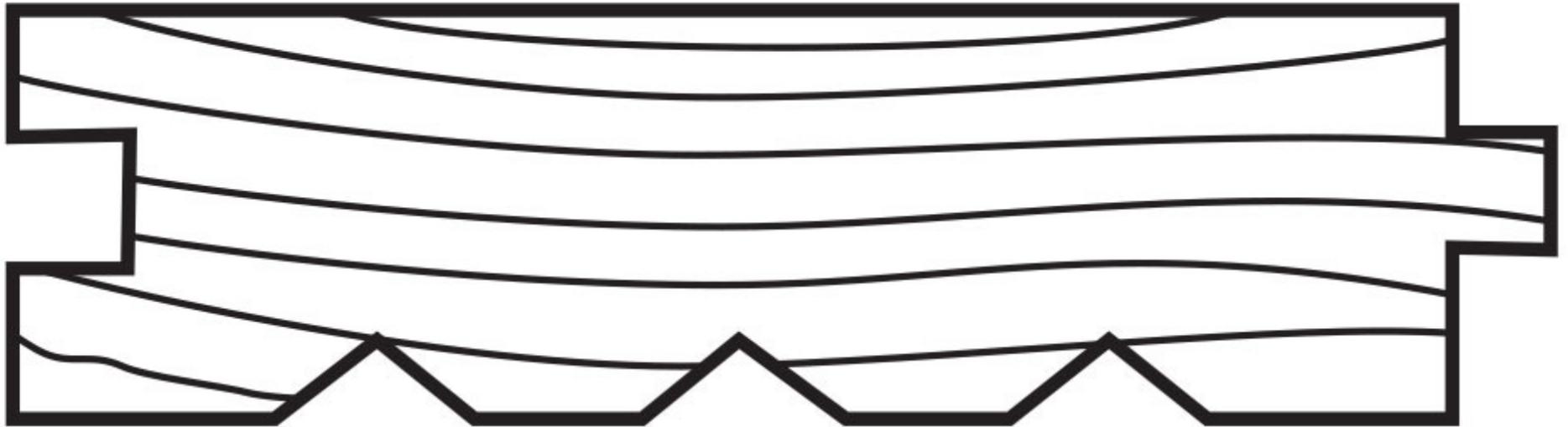




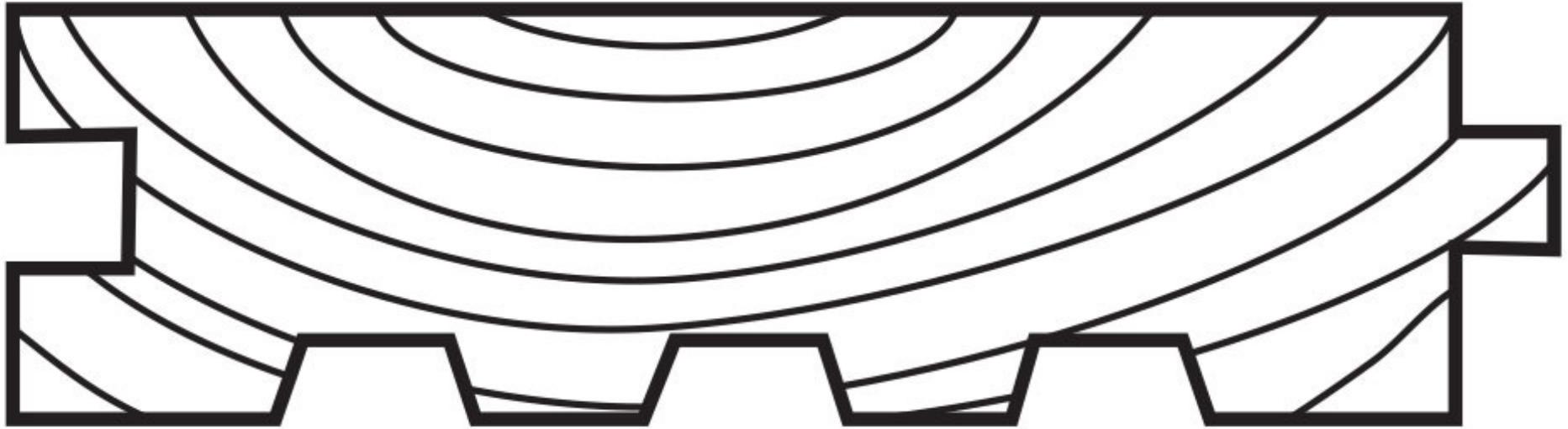
Plain



Hollow Back



Scratch Back



Hollow or Scratch Back



