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

Building Science

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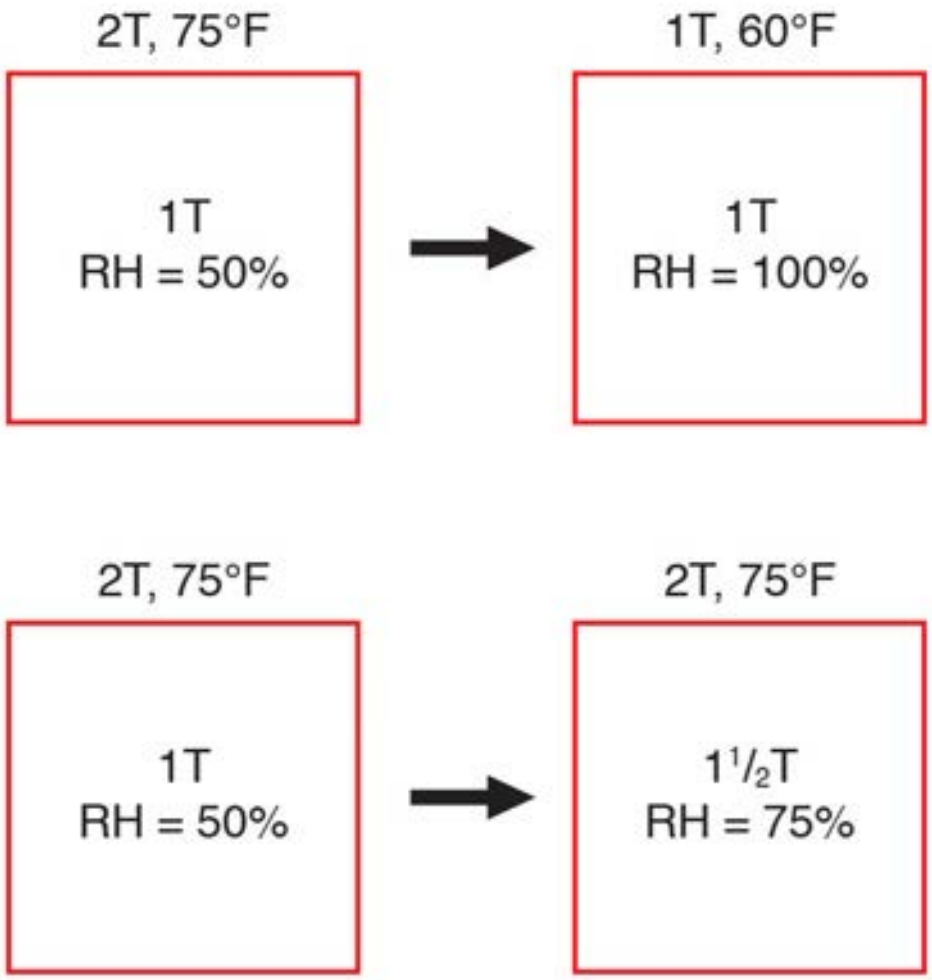
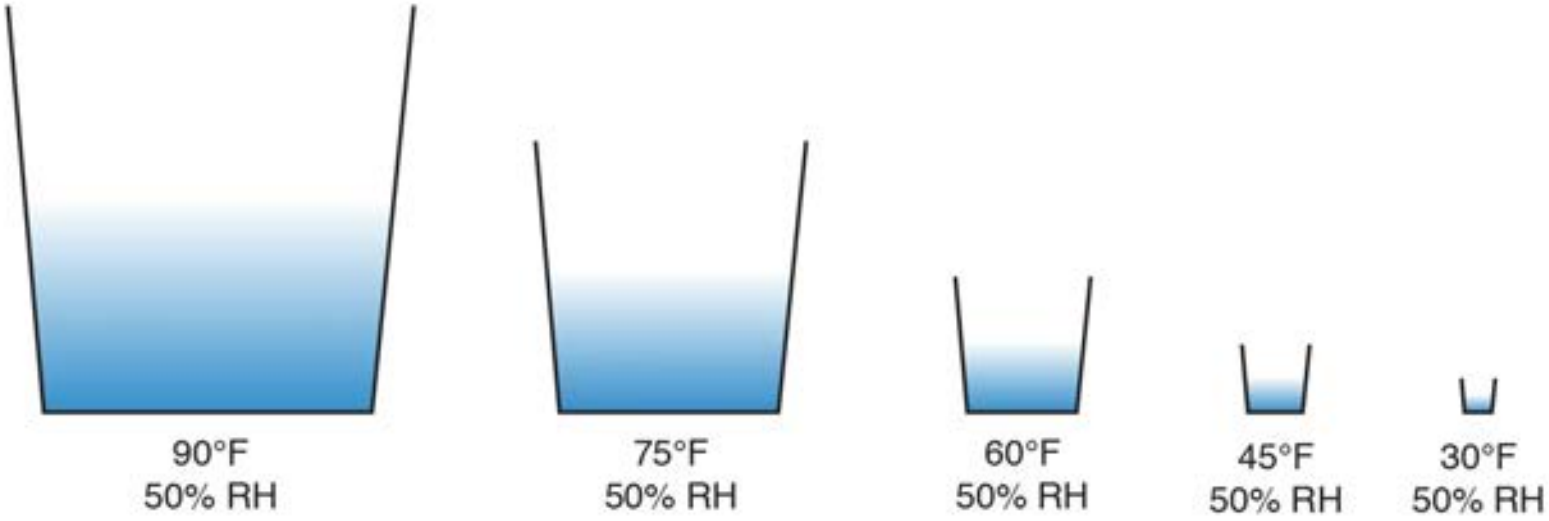
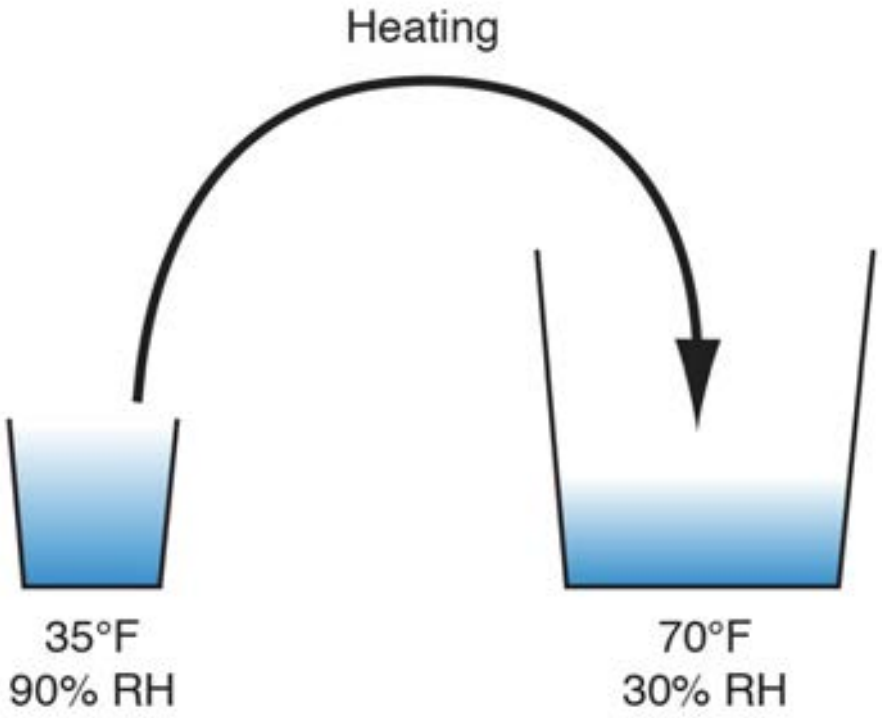
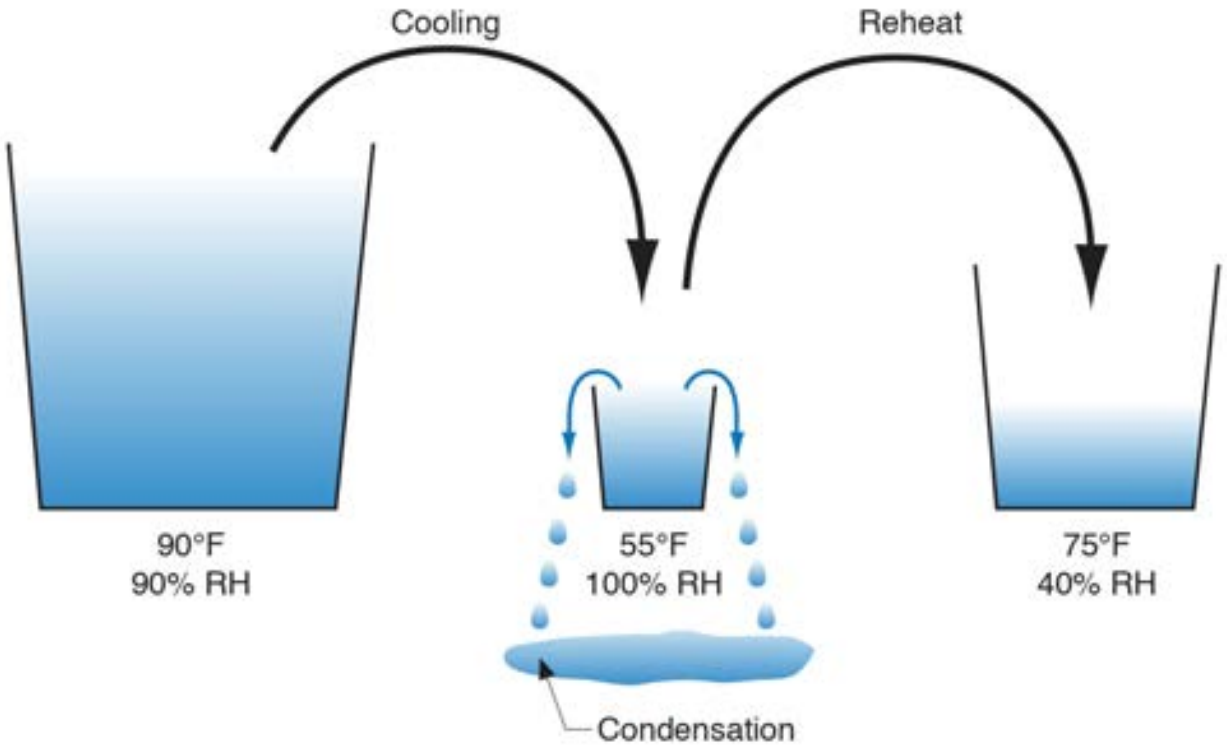
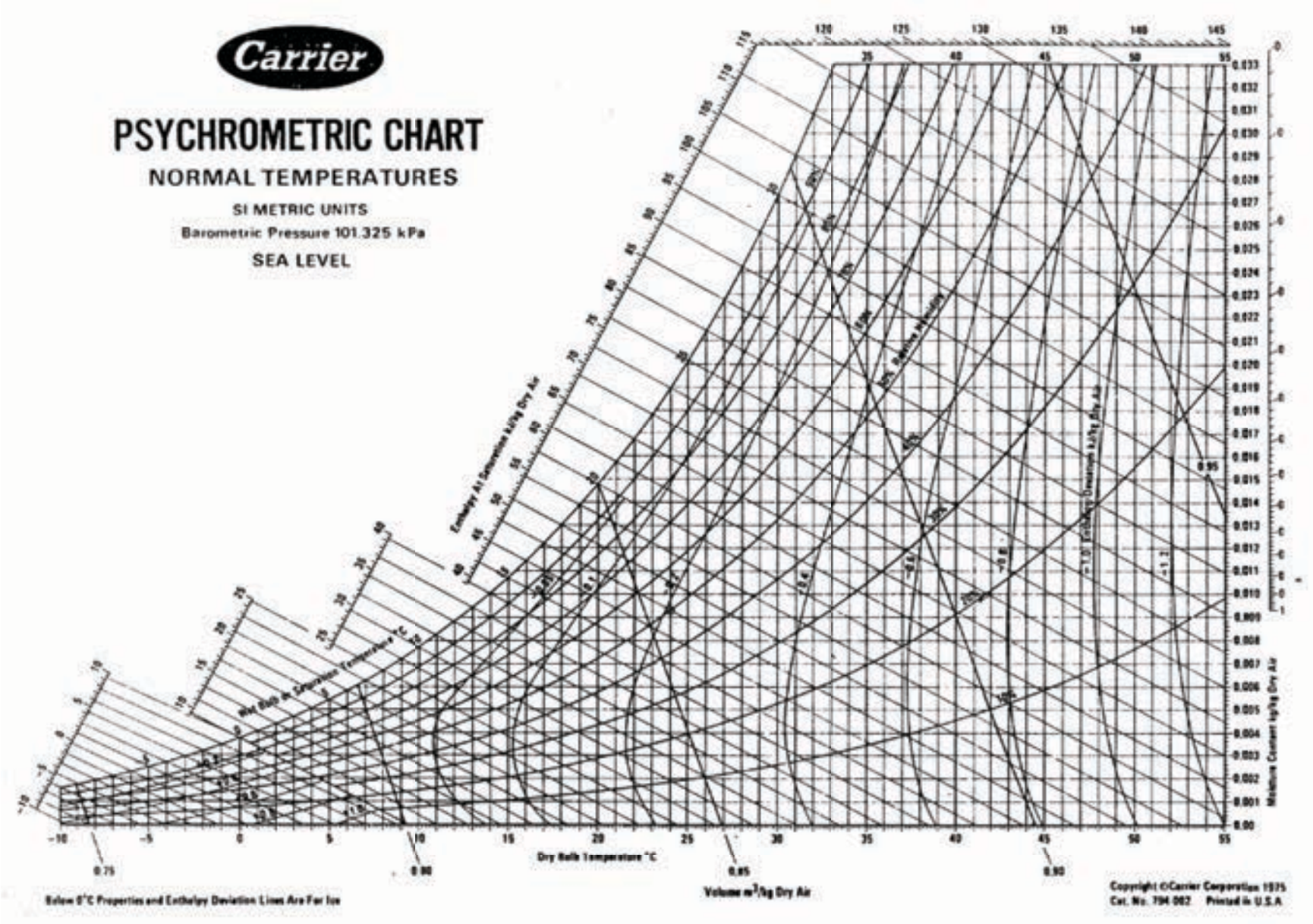
Vapor Pressure and Relative Humidity

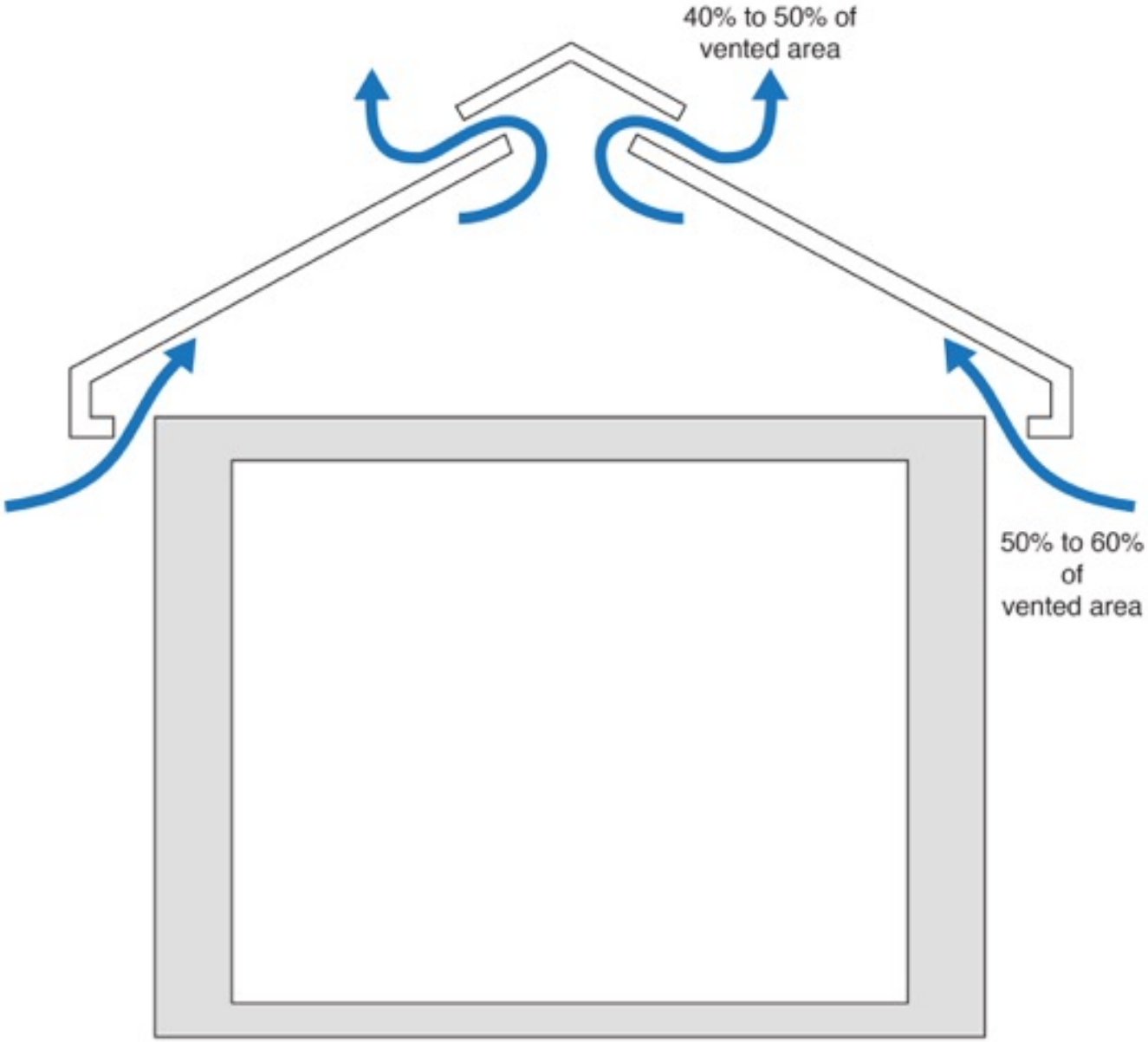

2T, 75°F
1T
RH = 50%
1T, 60°F
1T
RH = 100%
2T, 75°F
1T
RH = 50%
2T, 75°F
1 1/2T
RH = 75%

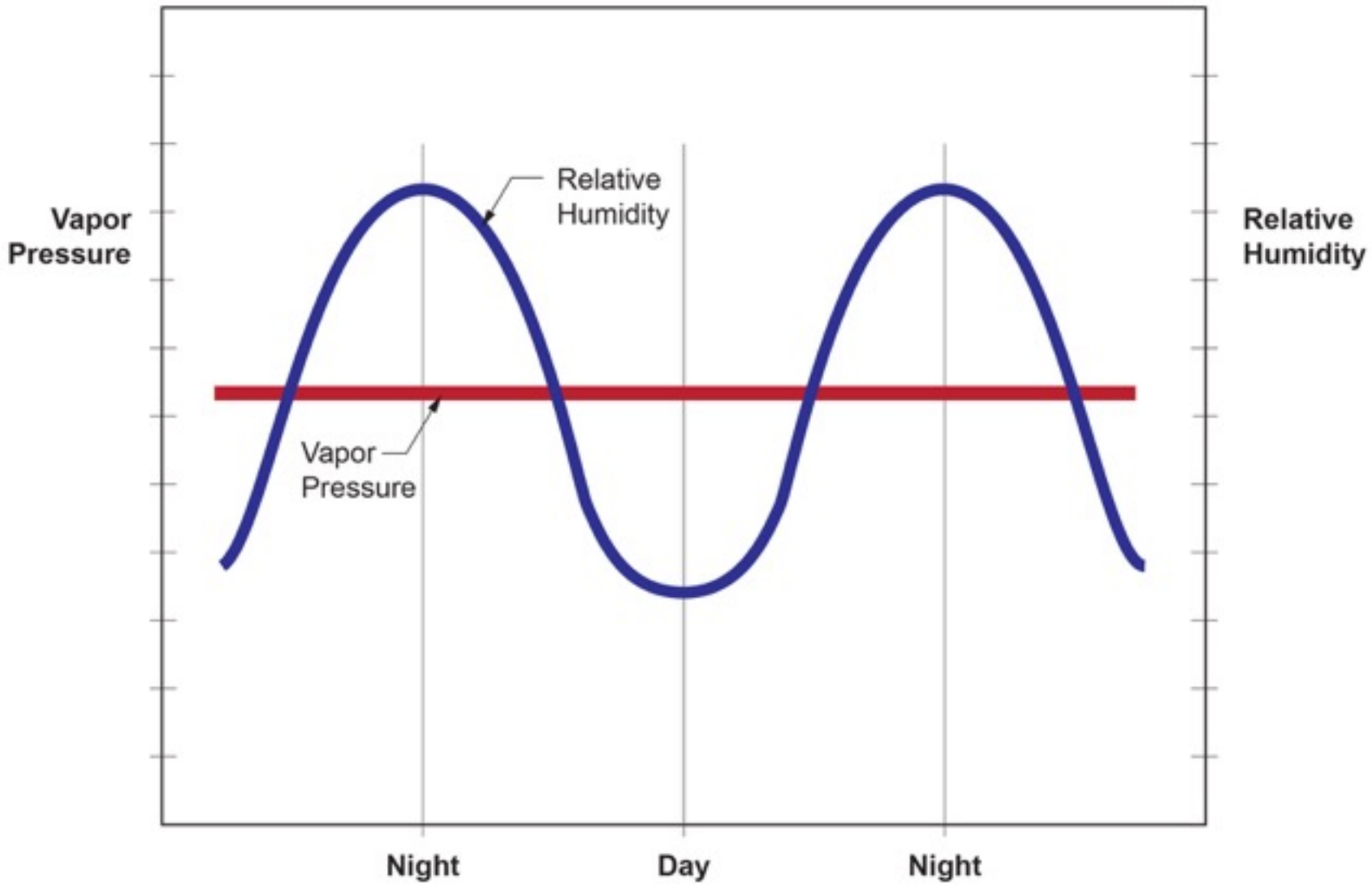

90°F
50% RH
75°F
50% RH
60°F
50% RH
45°F
50% RH
30°F
50% RH


Heating
35°F
90% RH
70°F
30% RH

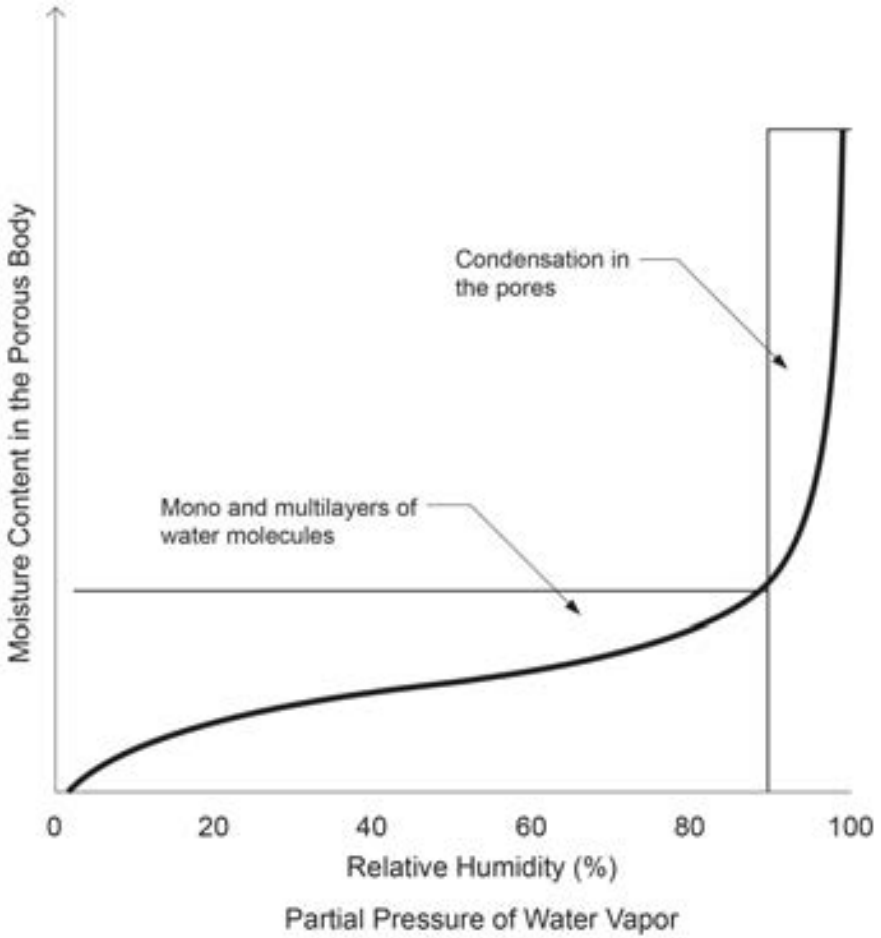

Cooling
Reheat
90°F
90% RH
55°F
100% RH
75°F
40% RH
Condensation


Carrier
PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101.325 kPa
SEA LEVEL
Dry Bulb Temperature °C
Volume m³/kg Dry Air
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice
Copyright © Carrier Corporation 1975
Cat. No. 794 002 Printed in U.S.A.


40% to 50% of
vented area
50% to 60%
of
vented area


Vapor Pressure
Relative Humidity
Relative Humidity
Vapor Pressure
Night
Day
Night

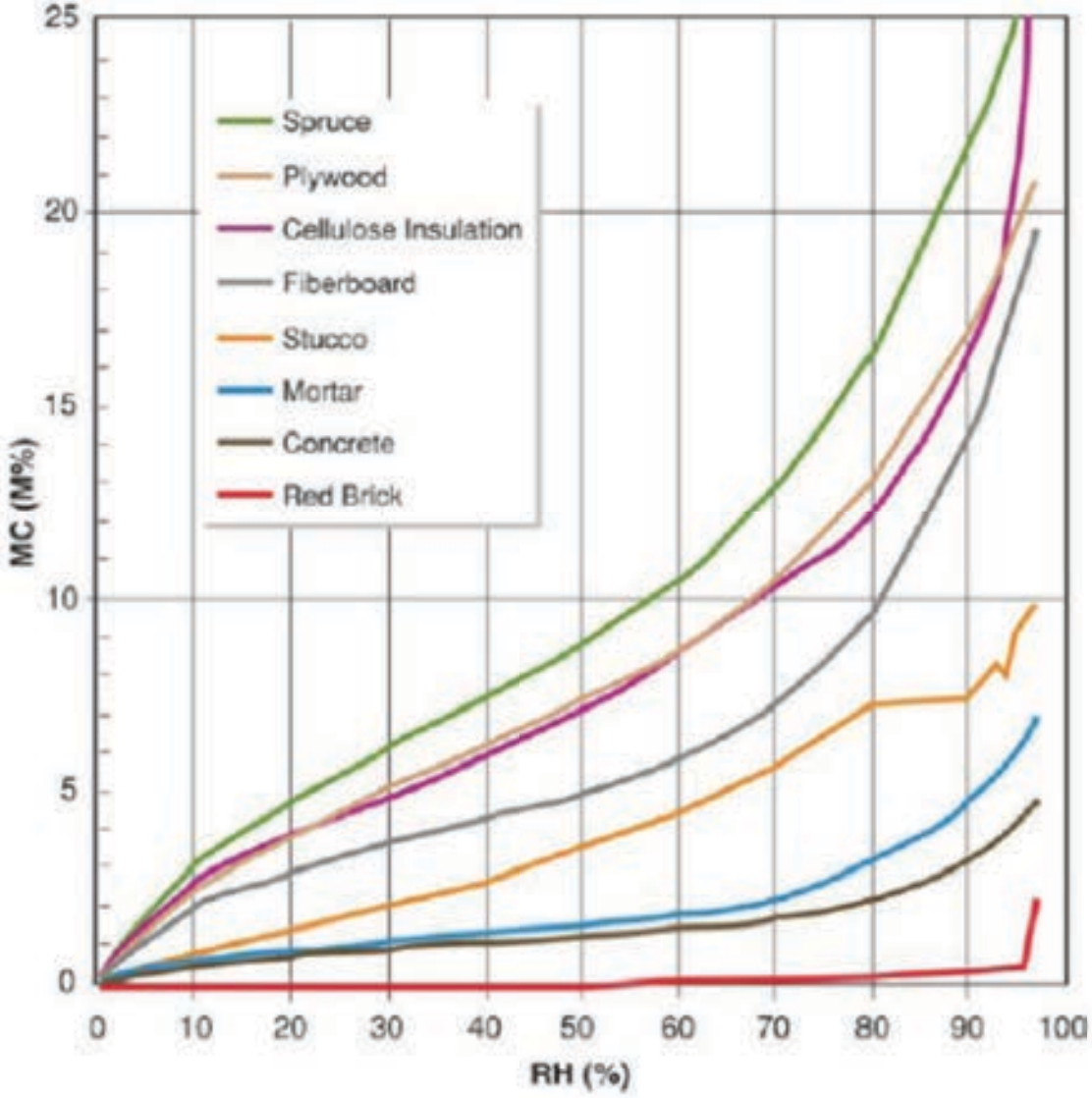
Sorption Isotherms

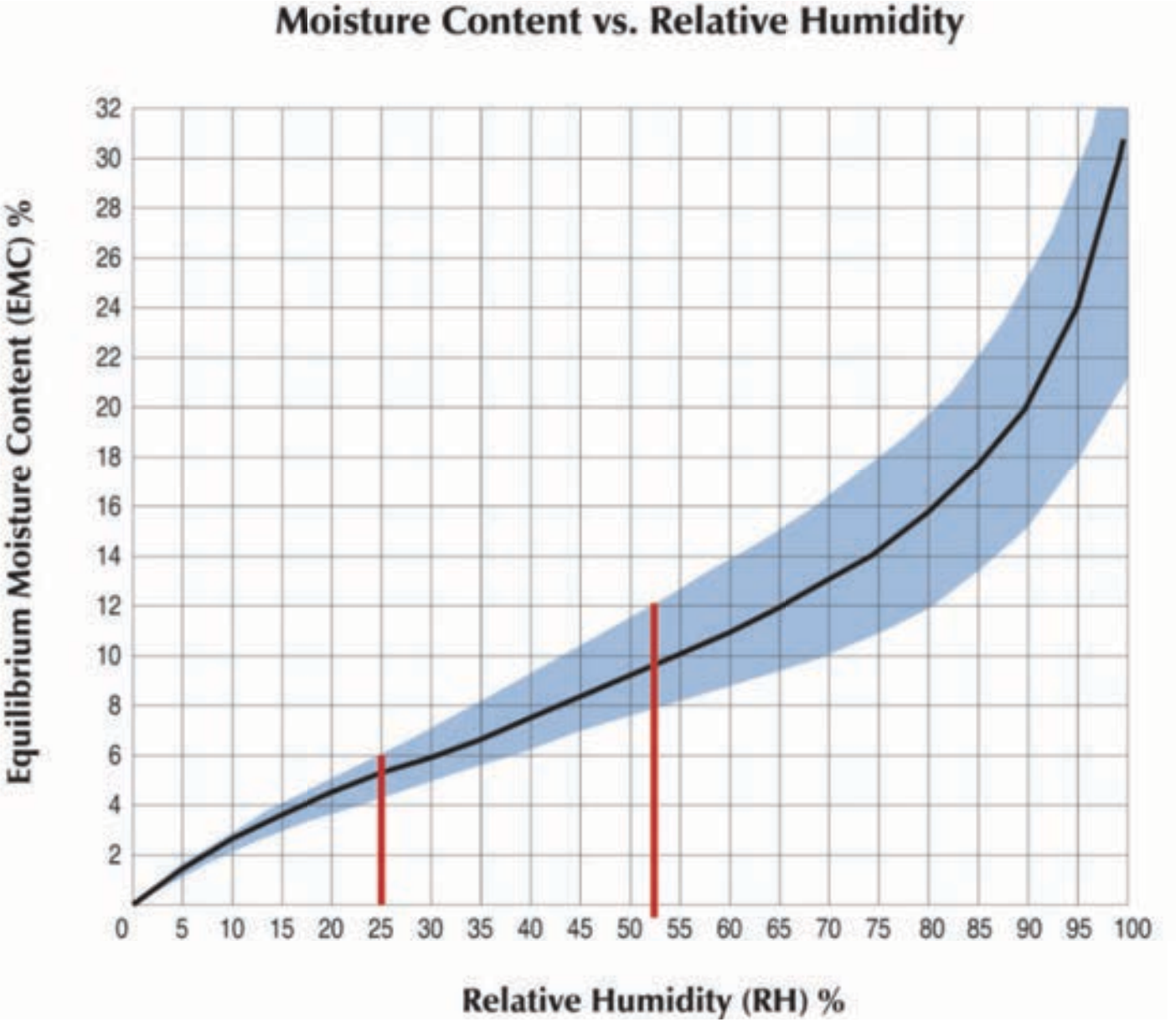


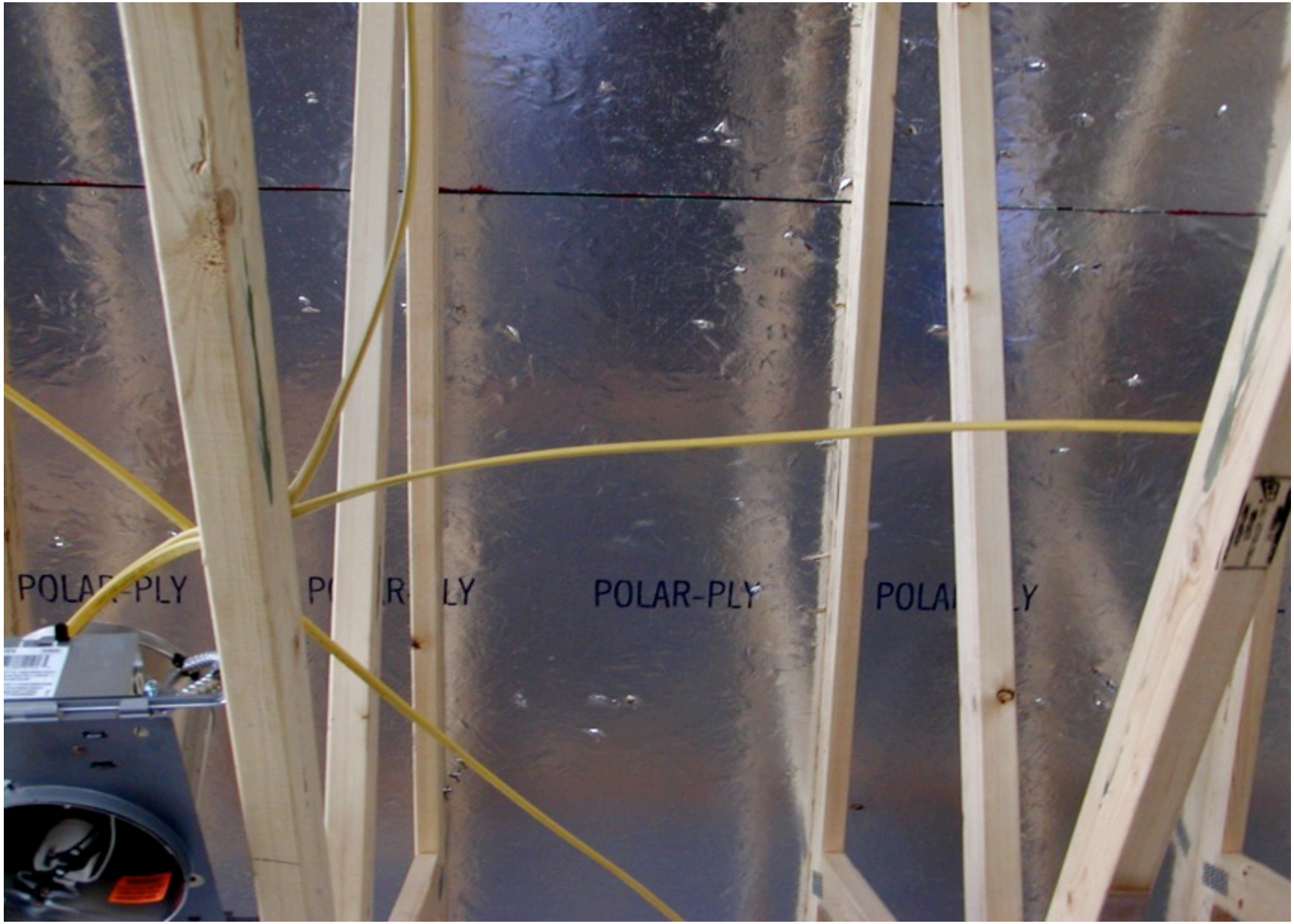
Change in the storage of moisture in a porous building material as the partial pressure of water vapor in the ambient air increases from zero to full saturation value at a given temperature.

Sorption Curve

From M.K. Kumaran, ASTM MNL 18-2nd Edition, Moisture Control in Buildings, 2009

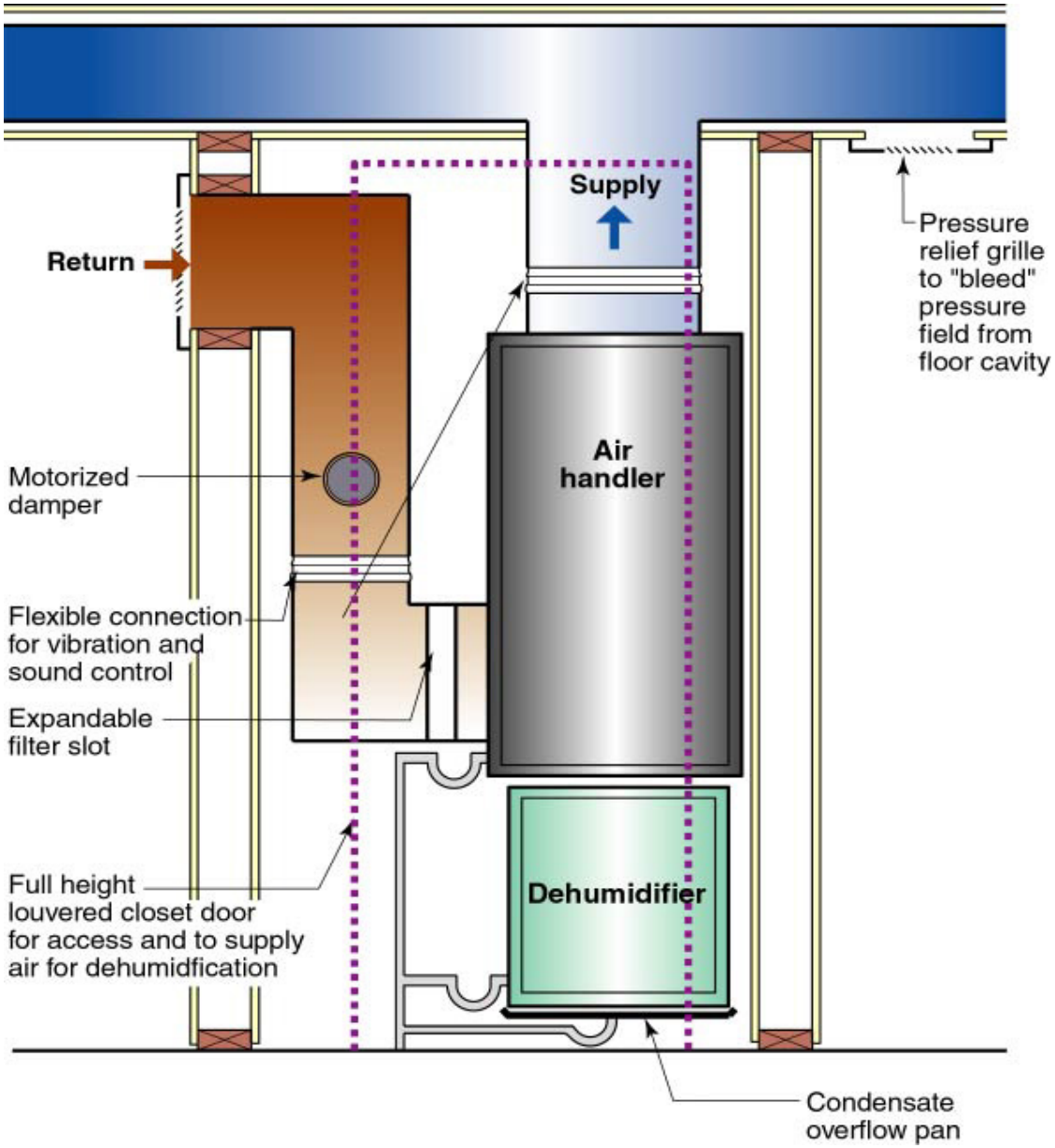

Spruce
Plywood
Cellulose Insulation
Fiberboard
Stucco
Mortar
Concrete
Red Brick
MC (M%)
RH (%)
0
5
10
15
20
25
0
10
20
30
40
50
60
70
80
90
100

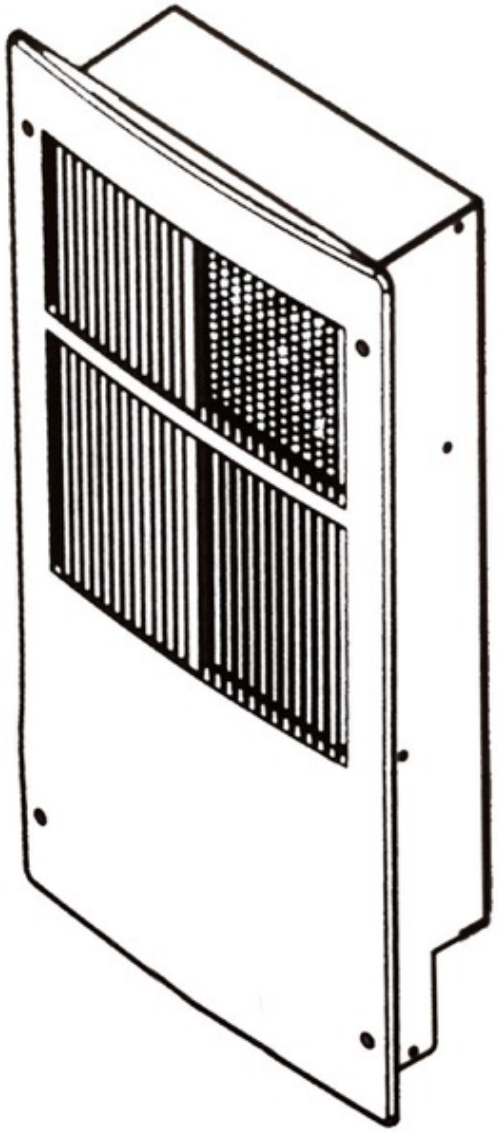

Moisture Content vs. Relative Humidity
Equilibrium Moisture Content (EMC) %
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
Relative Humidity (RH) %


POLAR-PLY
POLAR-PLY


09/14
AF 100
1818-FX

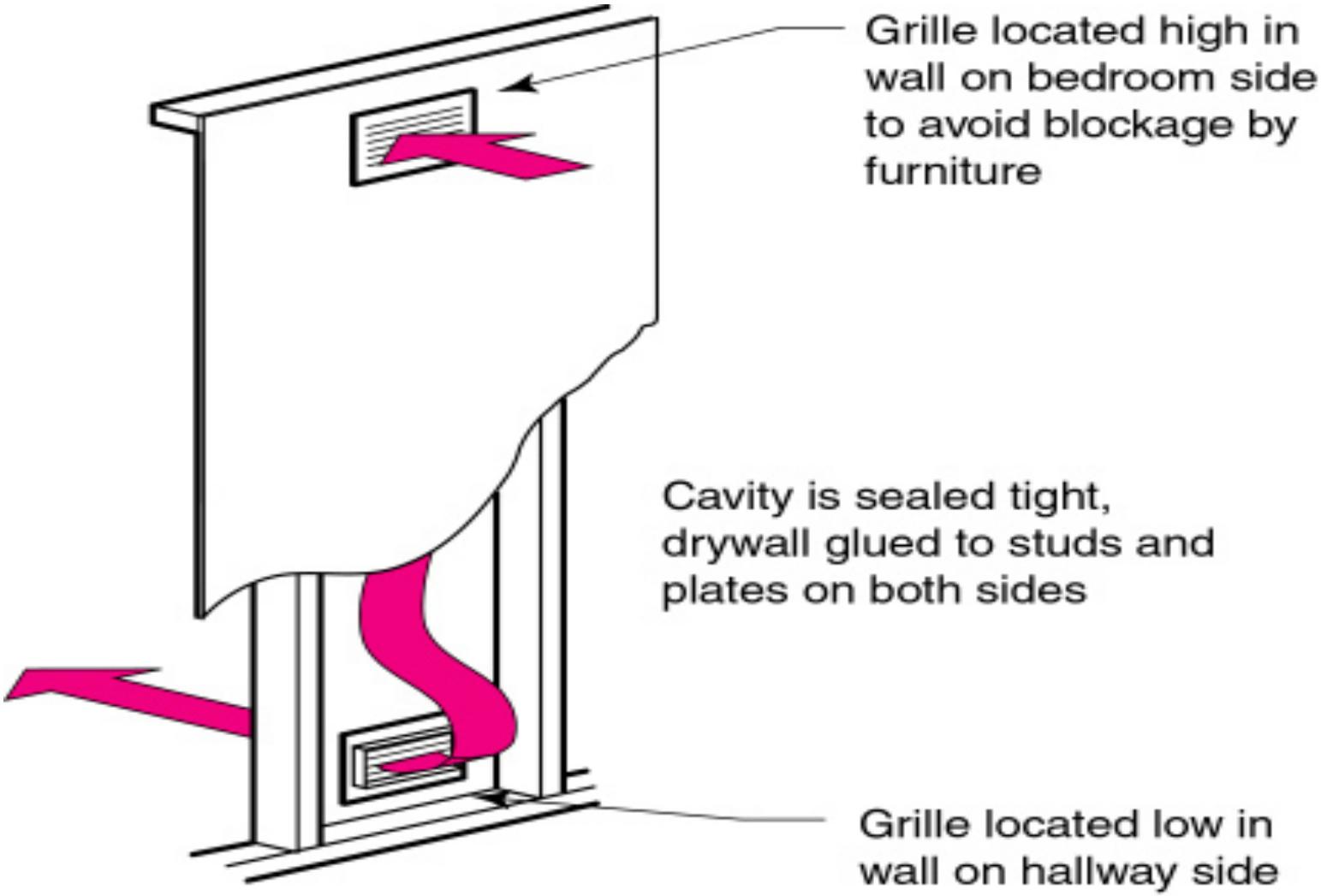

Dual In-Duct
Psychrometer
Fieldpiece
SDP2

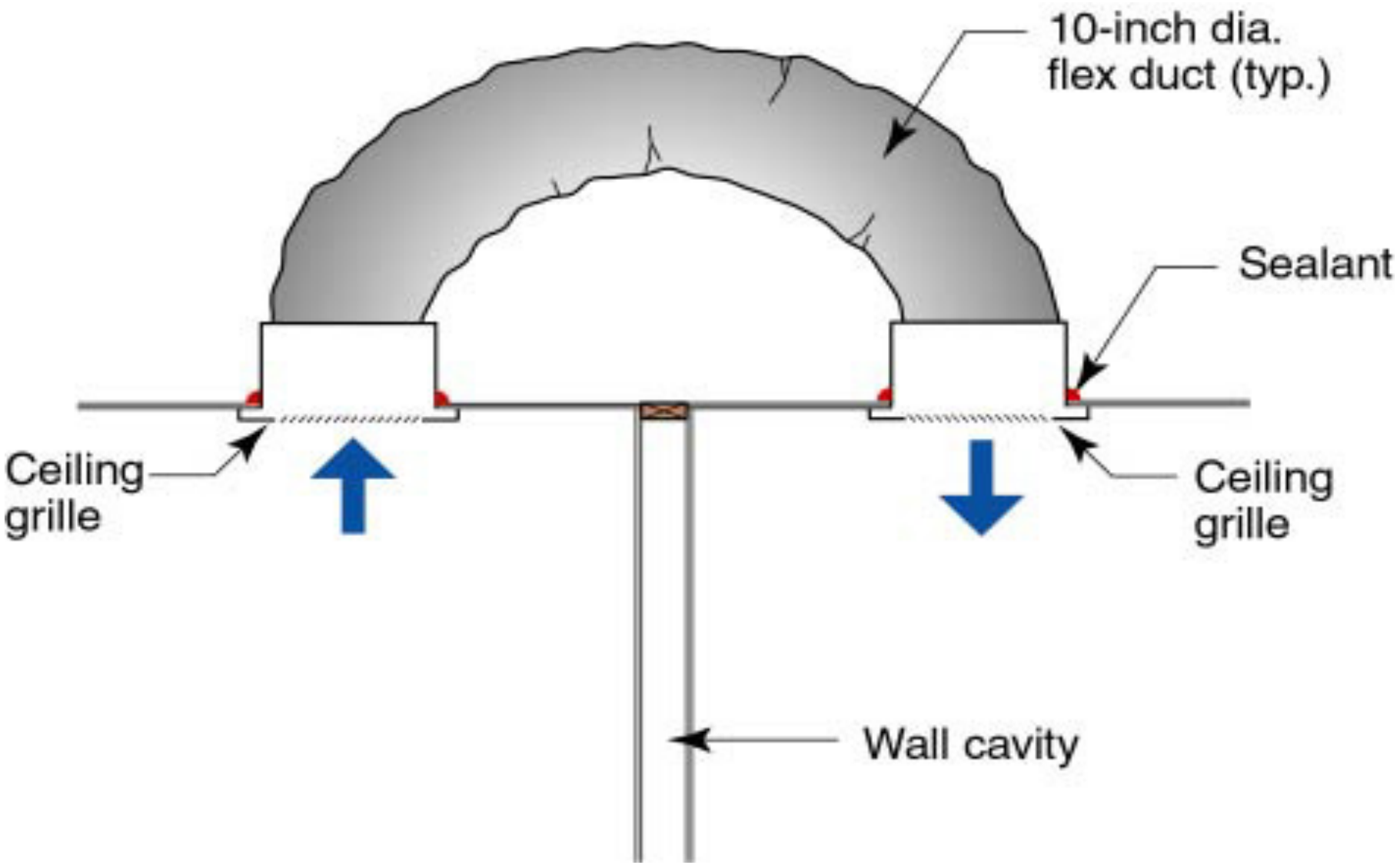

Supply
Return
Pressure relief grille to "bleed" pressure field from floor cavity
Air handler
Motorized damper
Flexible connection for vibration and sound control
Expandable filter slot
Dehumidifier
Full height louvered closet door for access and to supply air for dehumidfication
Condensate overflow pan

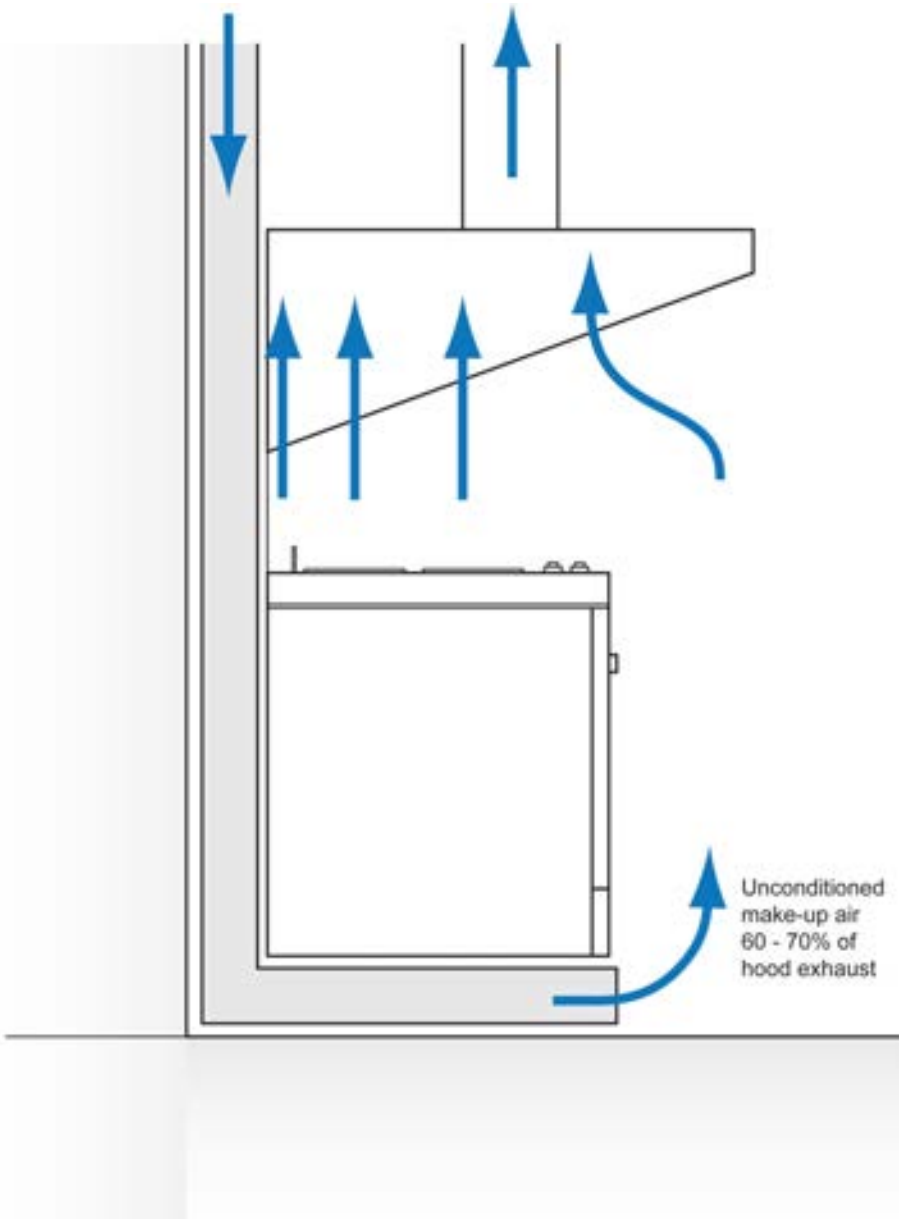


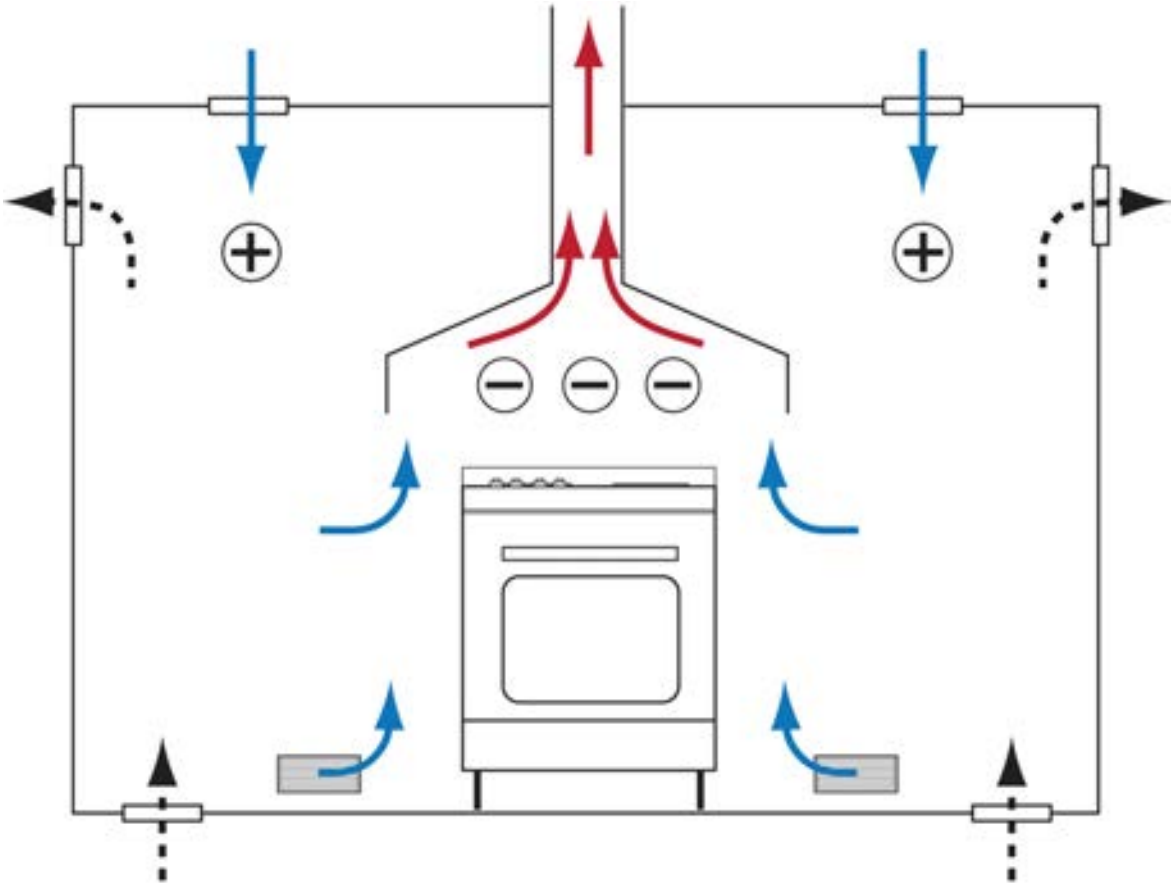

A.O. Smith

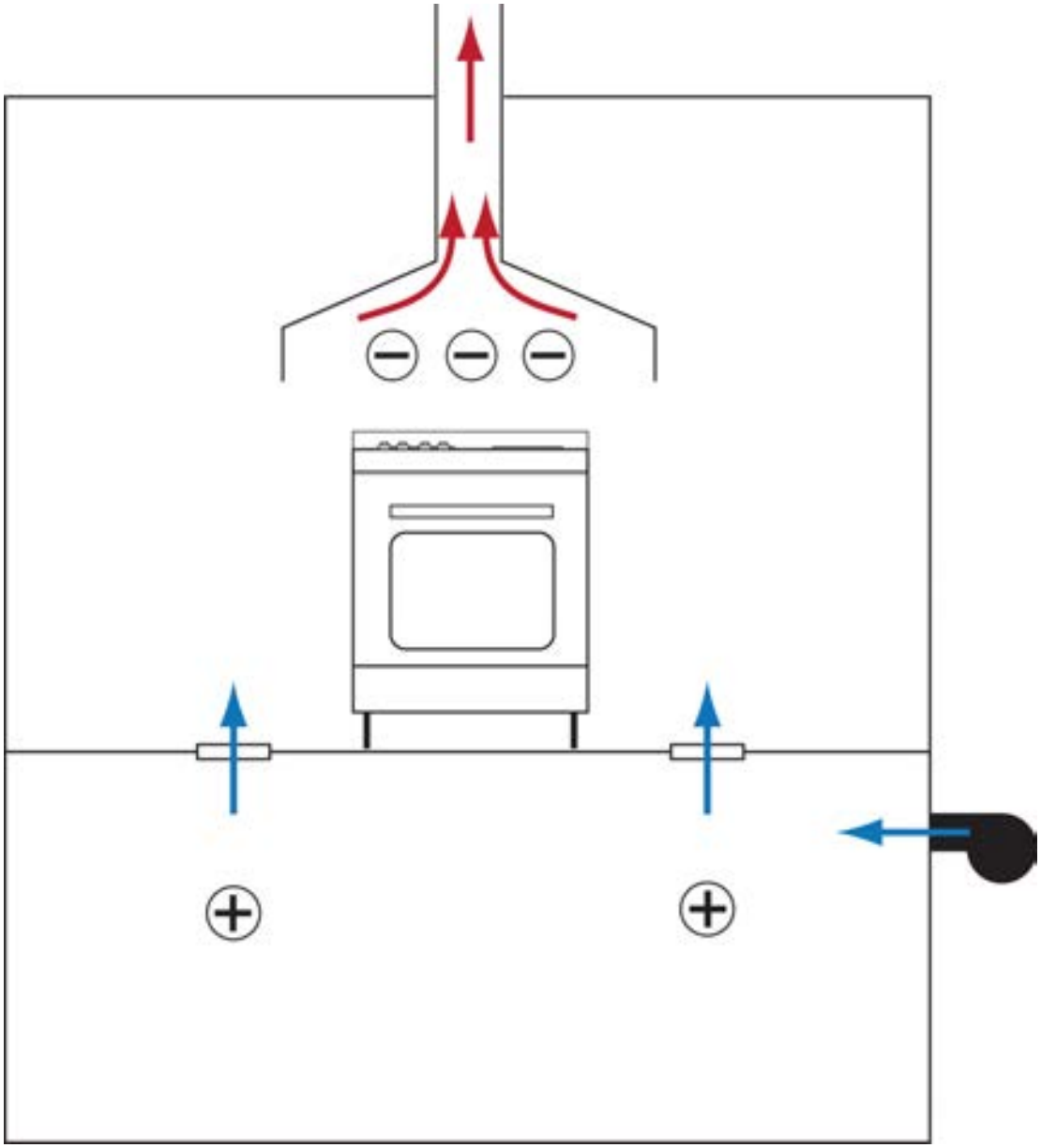

Carrier
Carrier

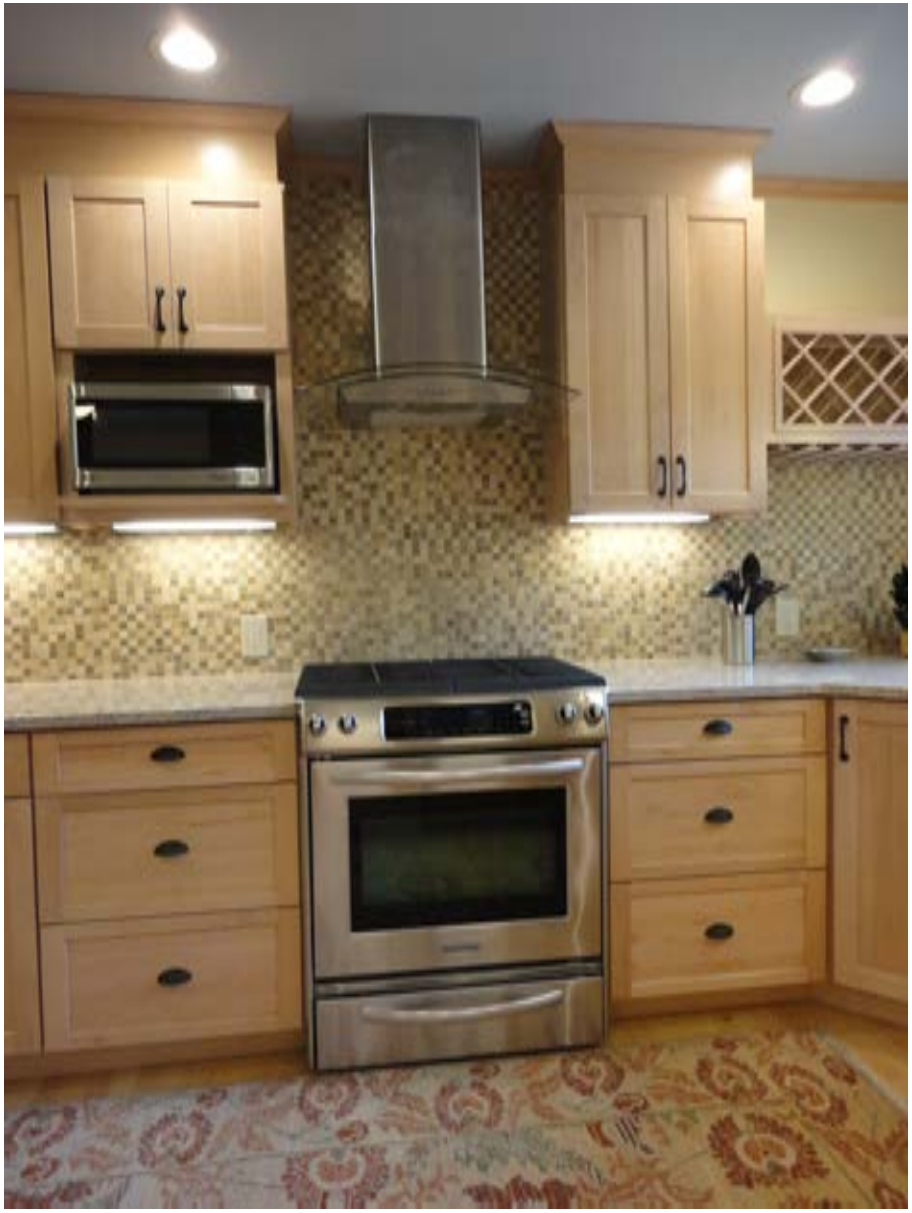

Grille located high in wall on bedroom side to avoid blockage by furniture
Cavity is sealed tight, drywall glued to studs and plates on both sides
Grille located low in wall on hallway side


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

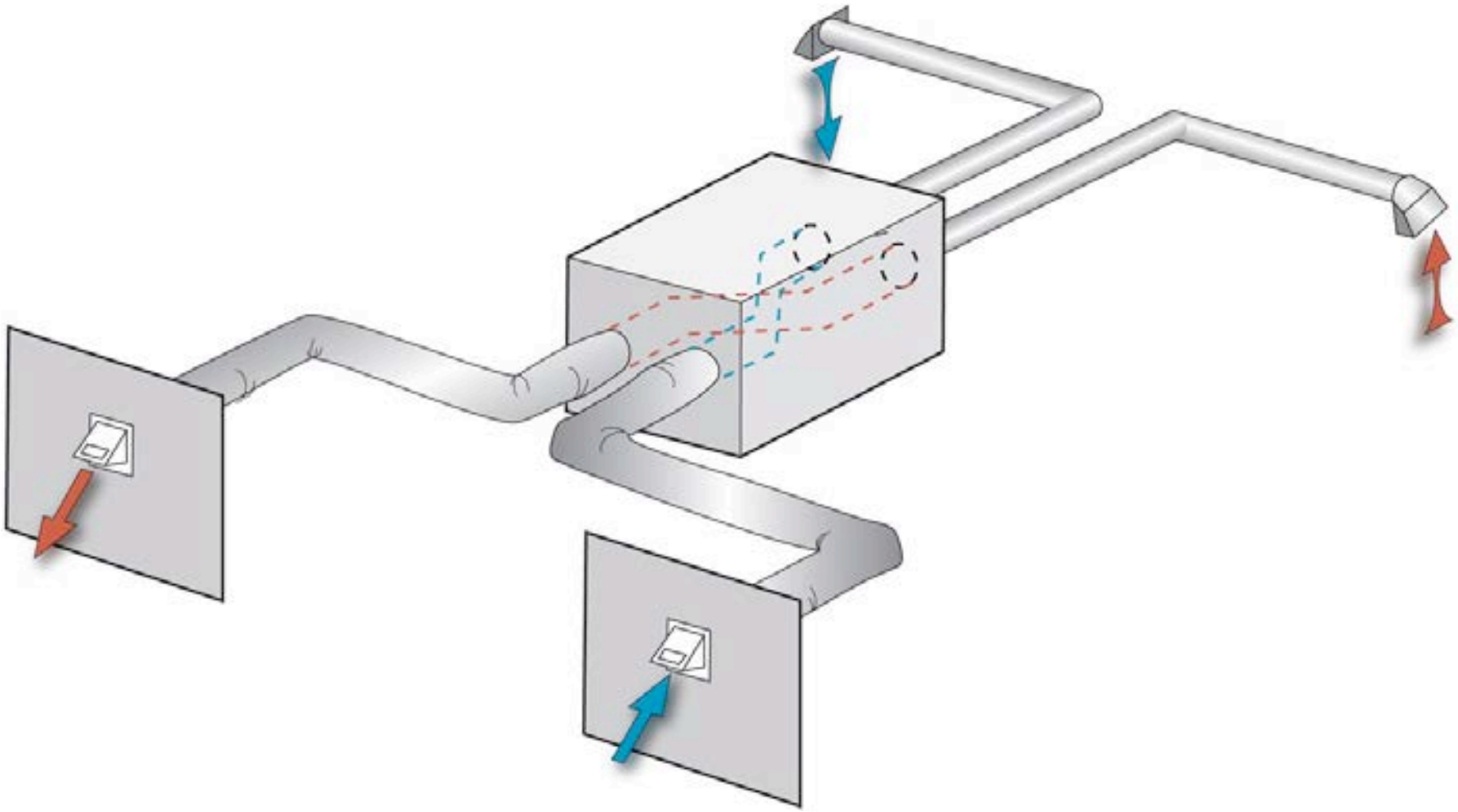

Unconditioned
make-up air
60 - 70% of
hood exhaust

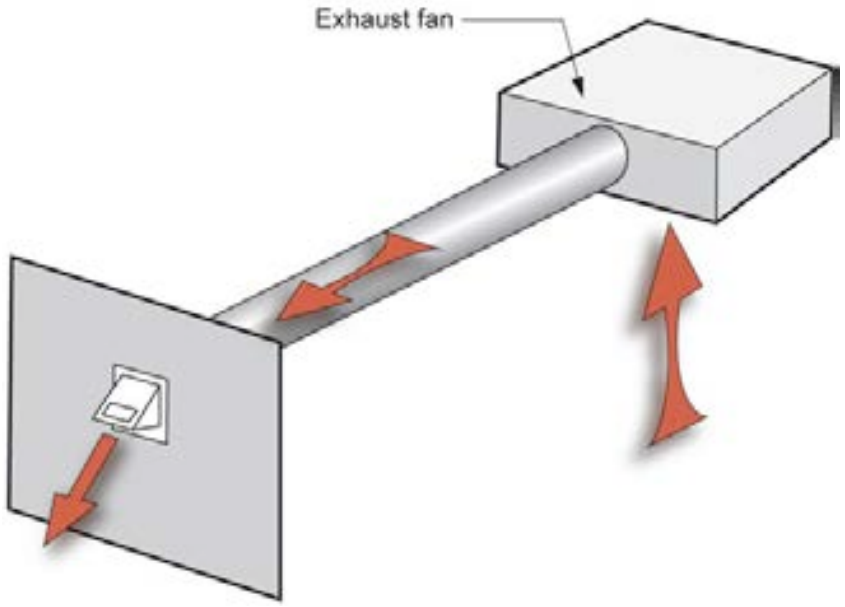


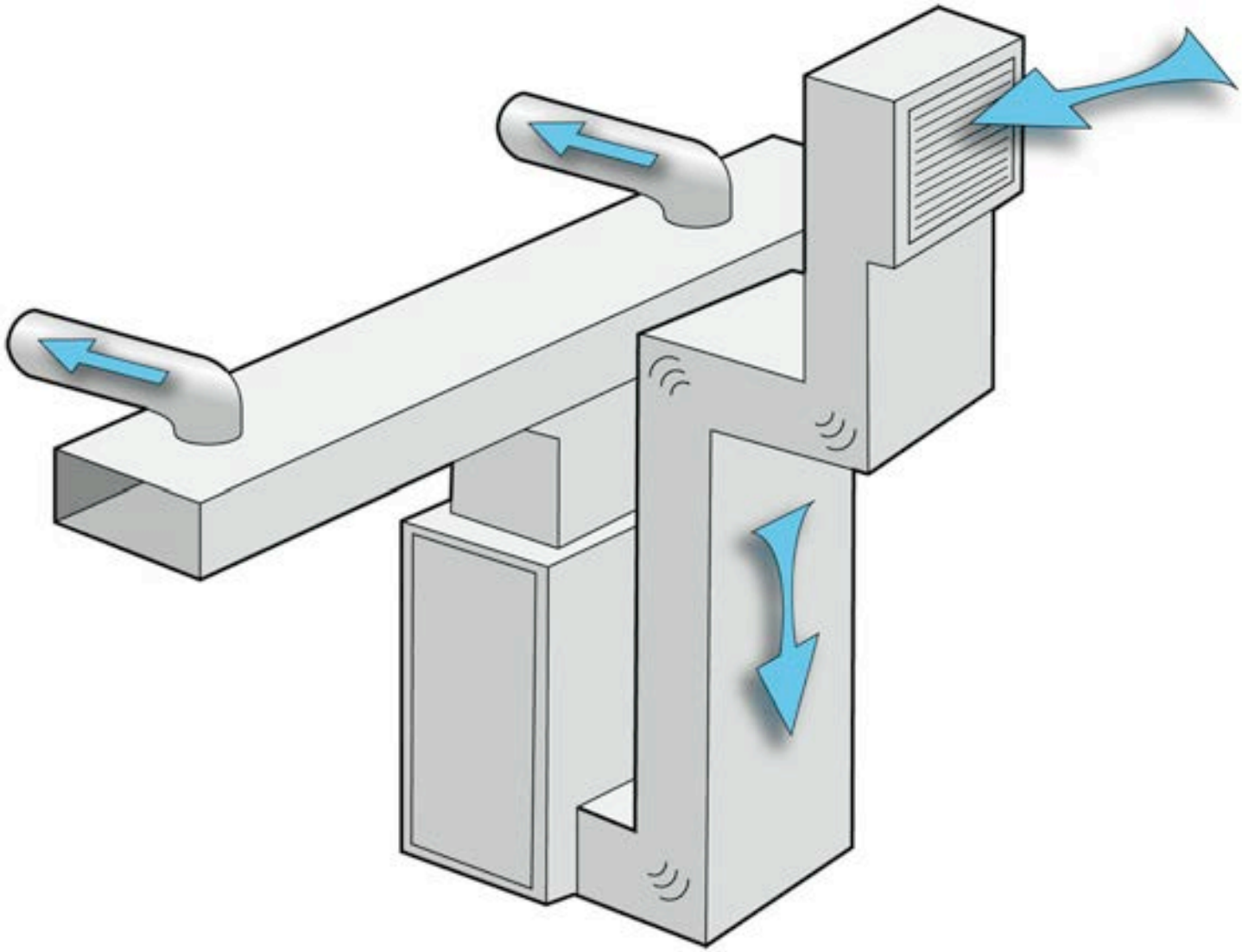


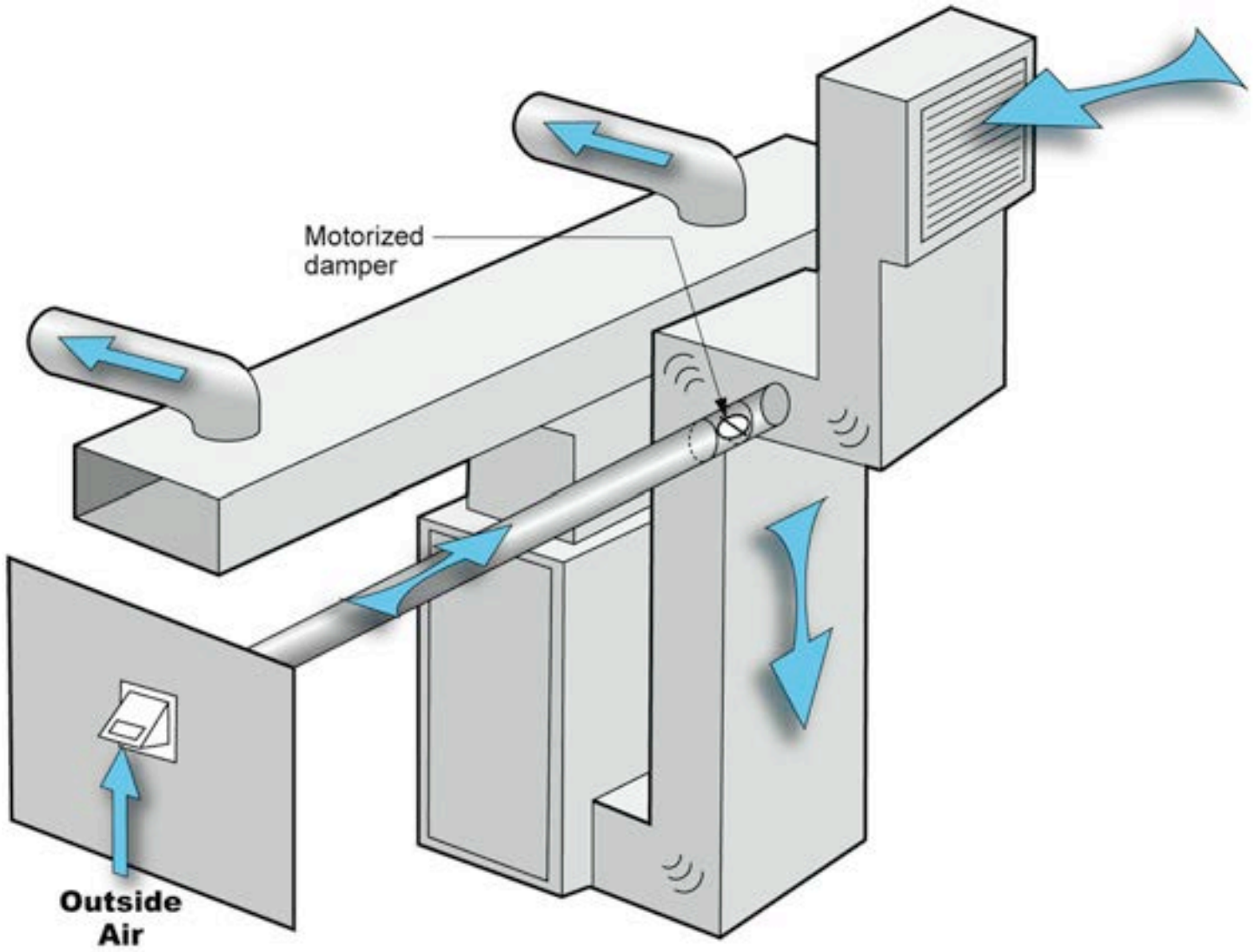


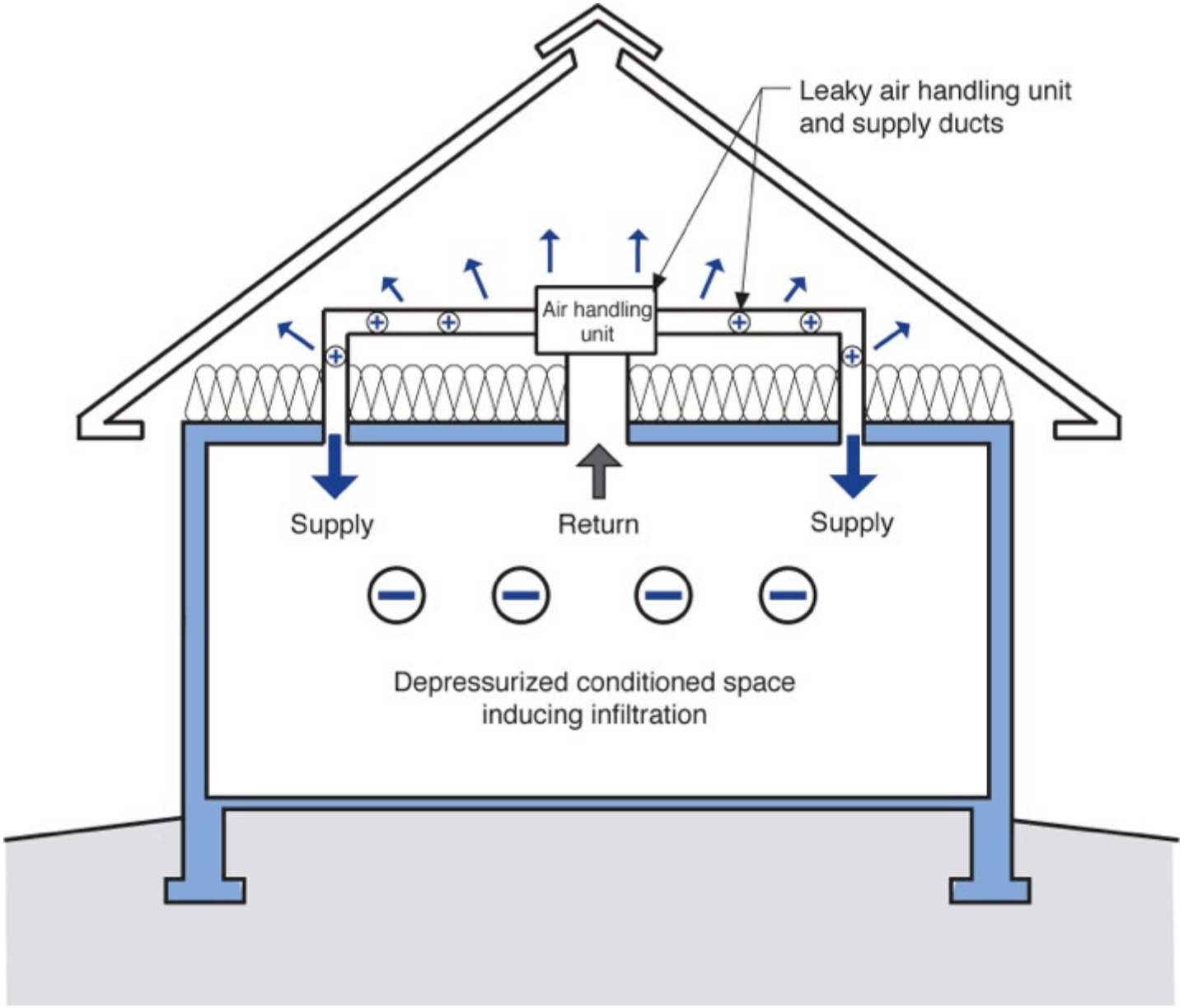

Move cabinets
farther apart
Hood wider than cook top
and extended outboard past
head space
Move hood
up to provide
headroom
Interlocked
make-up air

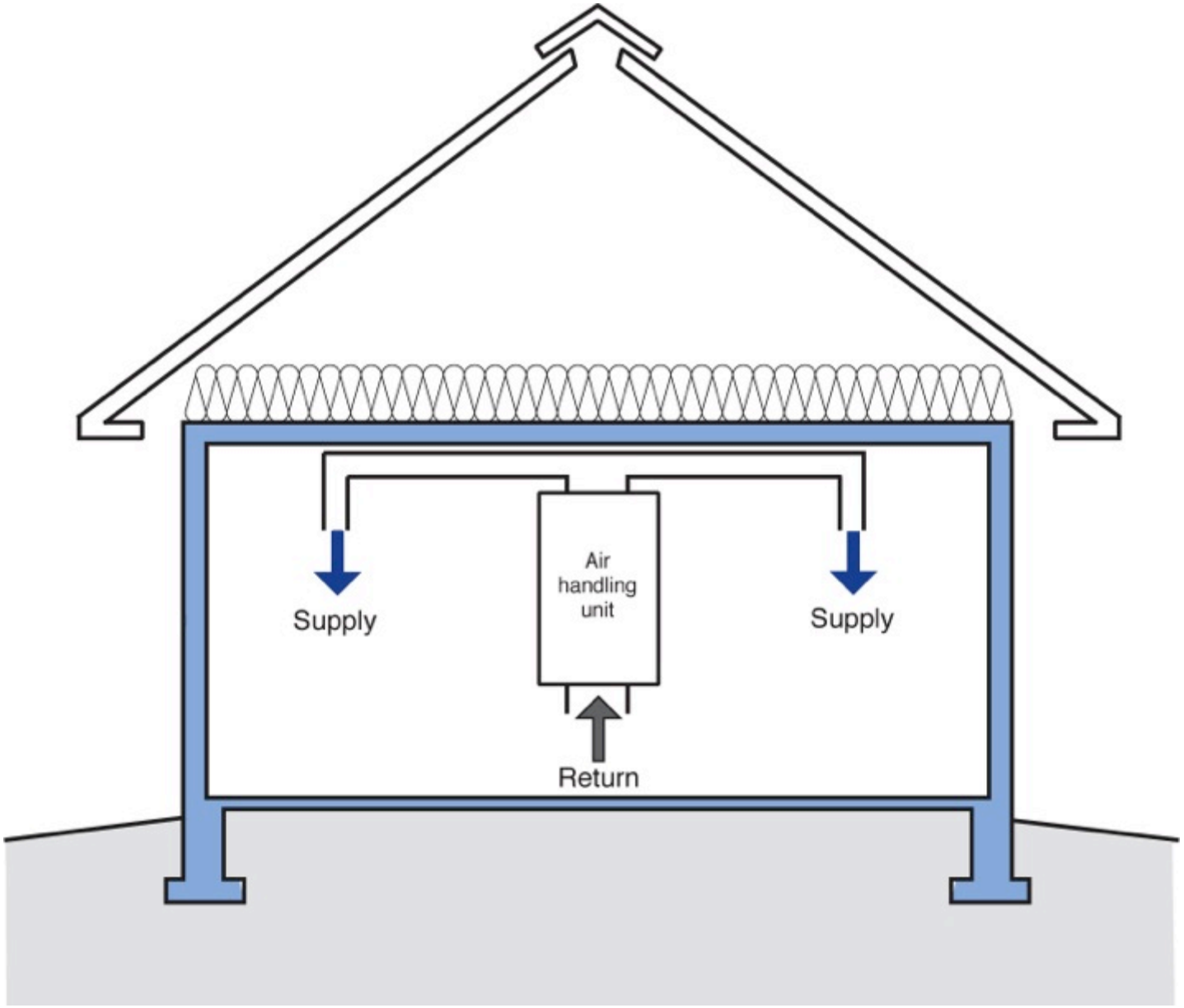


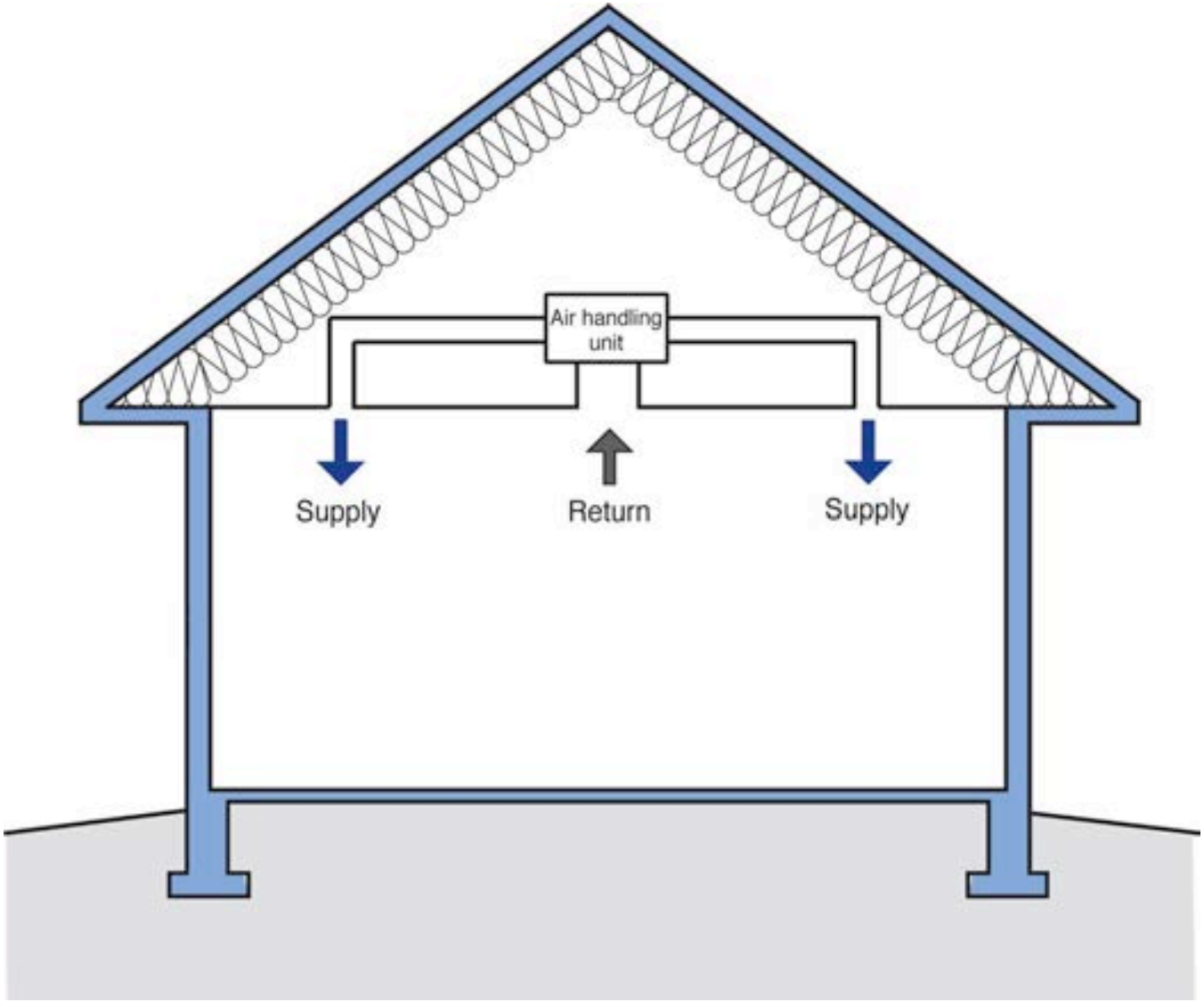

Exhaust fan

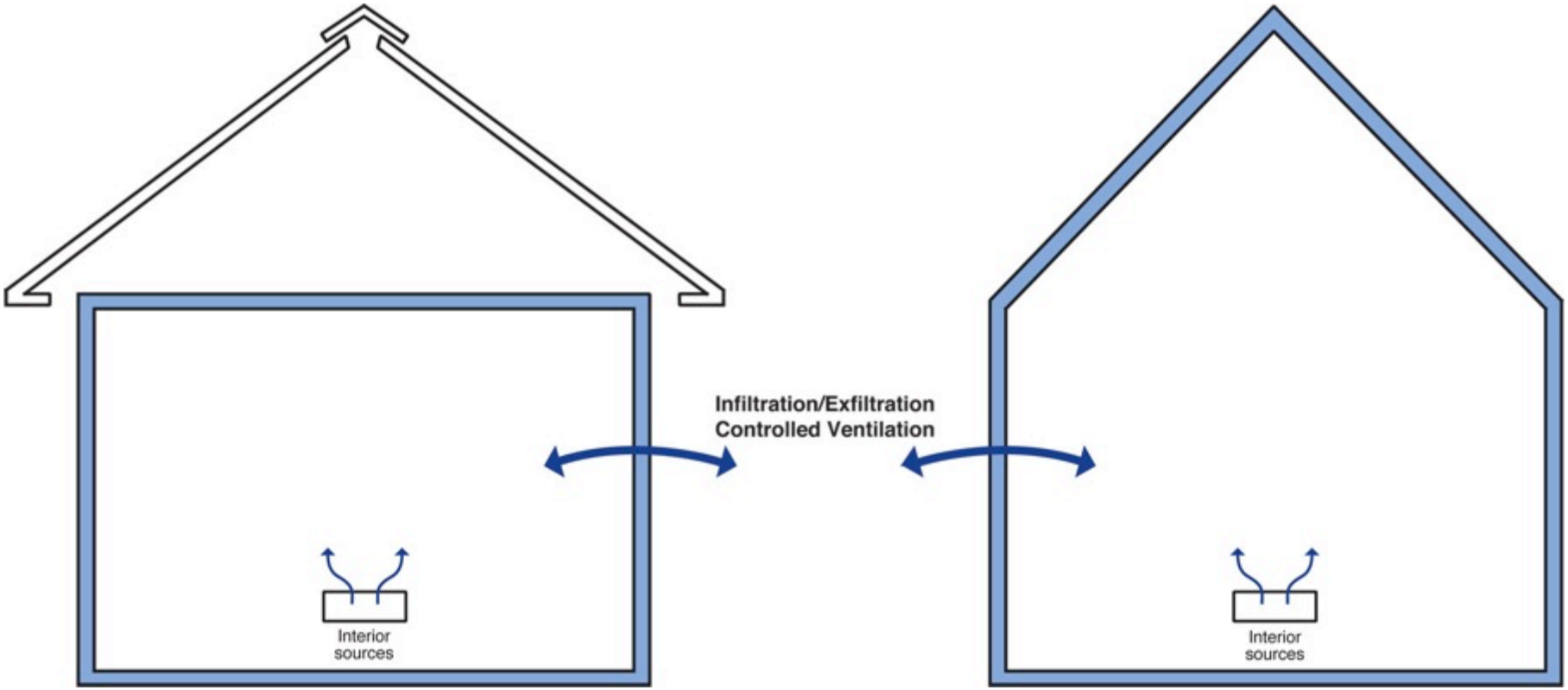


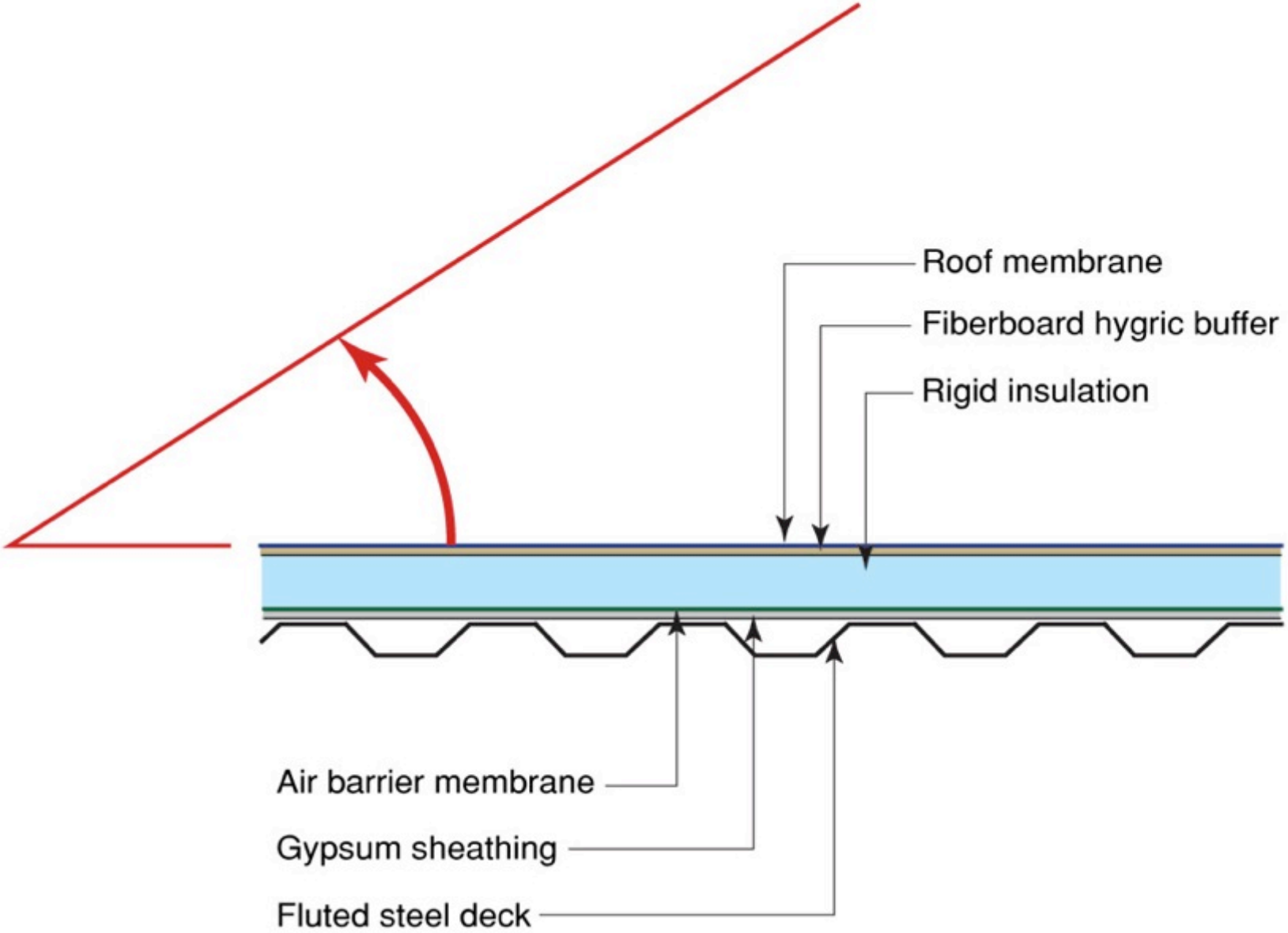

Motorized
damper
Outside
Air

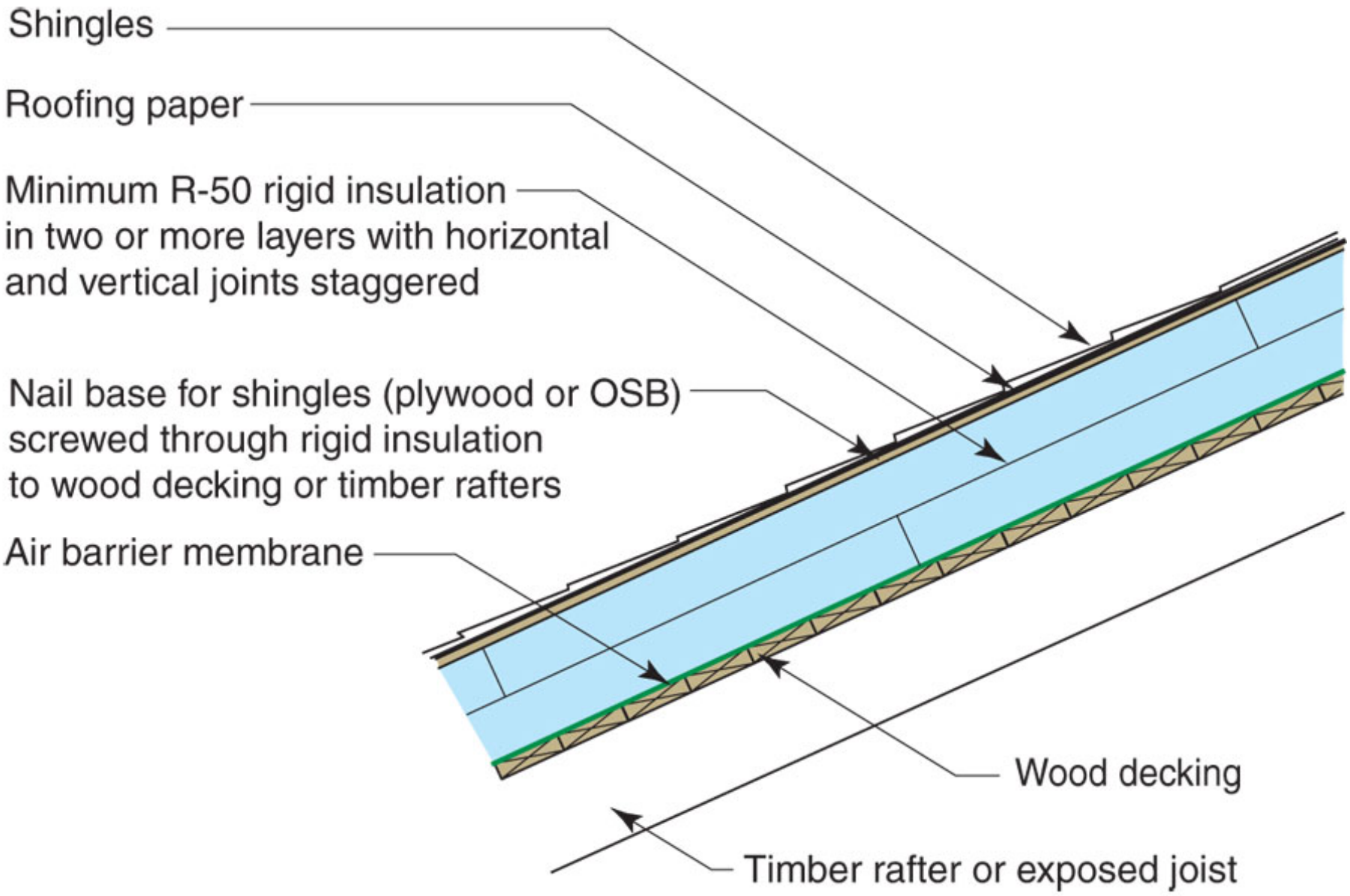

Leaky air handling unit
and supply ducts
Air handling
unit
Supply
Return
Supply
Depressurized conditioned space
inducing infiltration

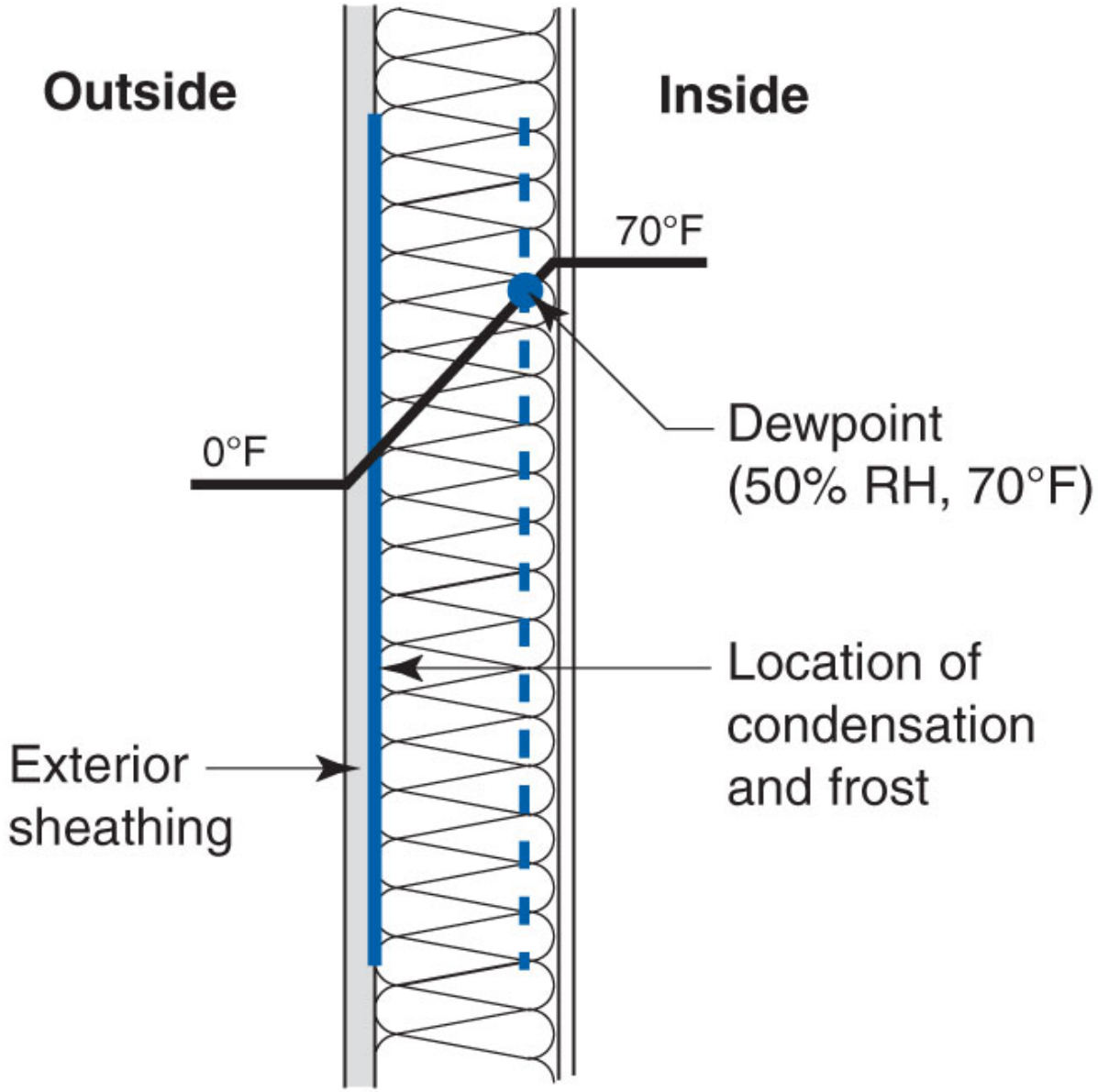

Supply
Air handling unit
Supply
Return

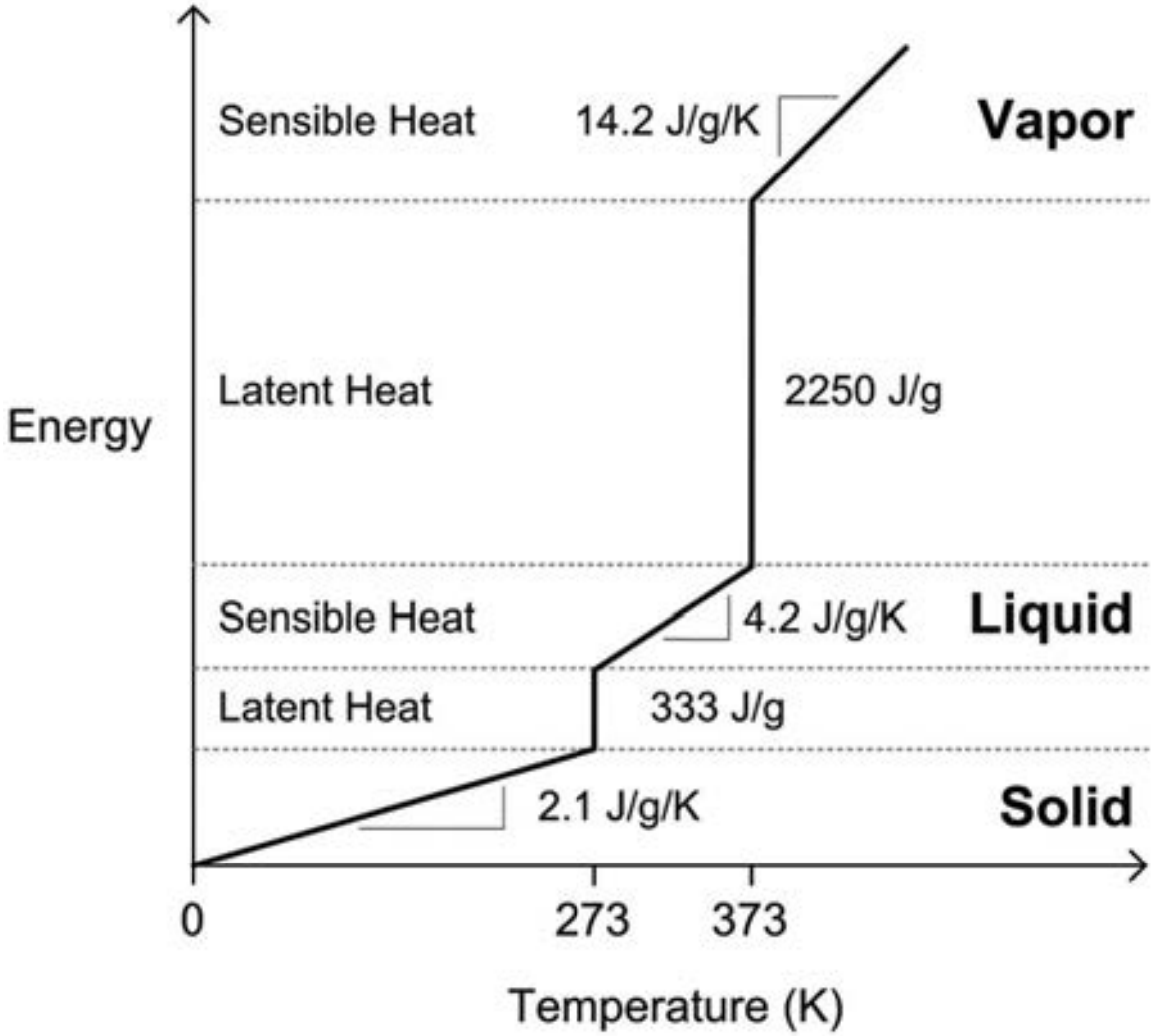

Air handling unit
Supply
Return
Supply


Infiltration/Exfiltration
Controlled Ventilation
Interior sources
Interior sources

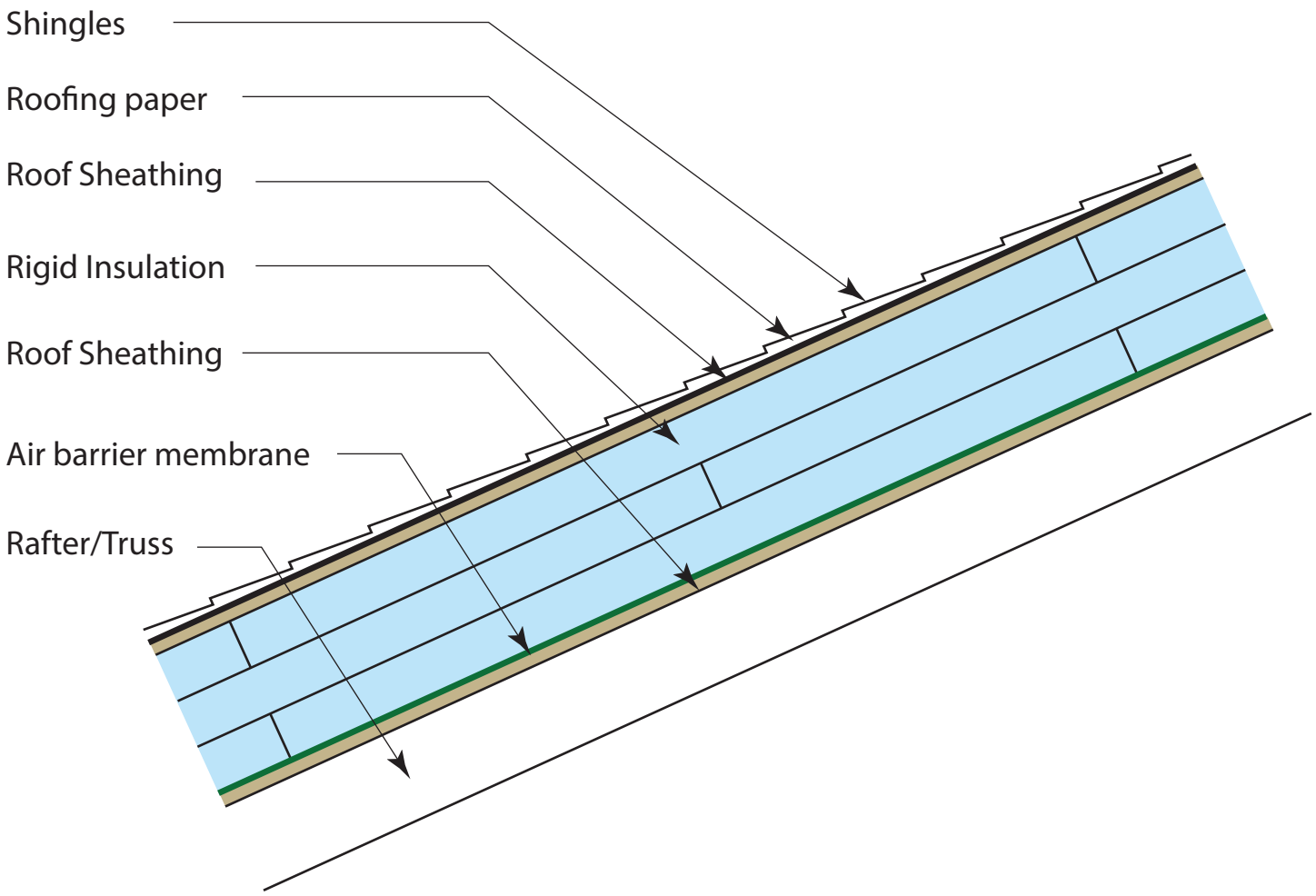

Roof membrane
Fiberboard hygric buffer
Rigid insulation
Air barrier membrane
Gypsum sheathing
Fluted steel deck

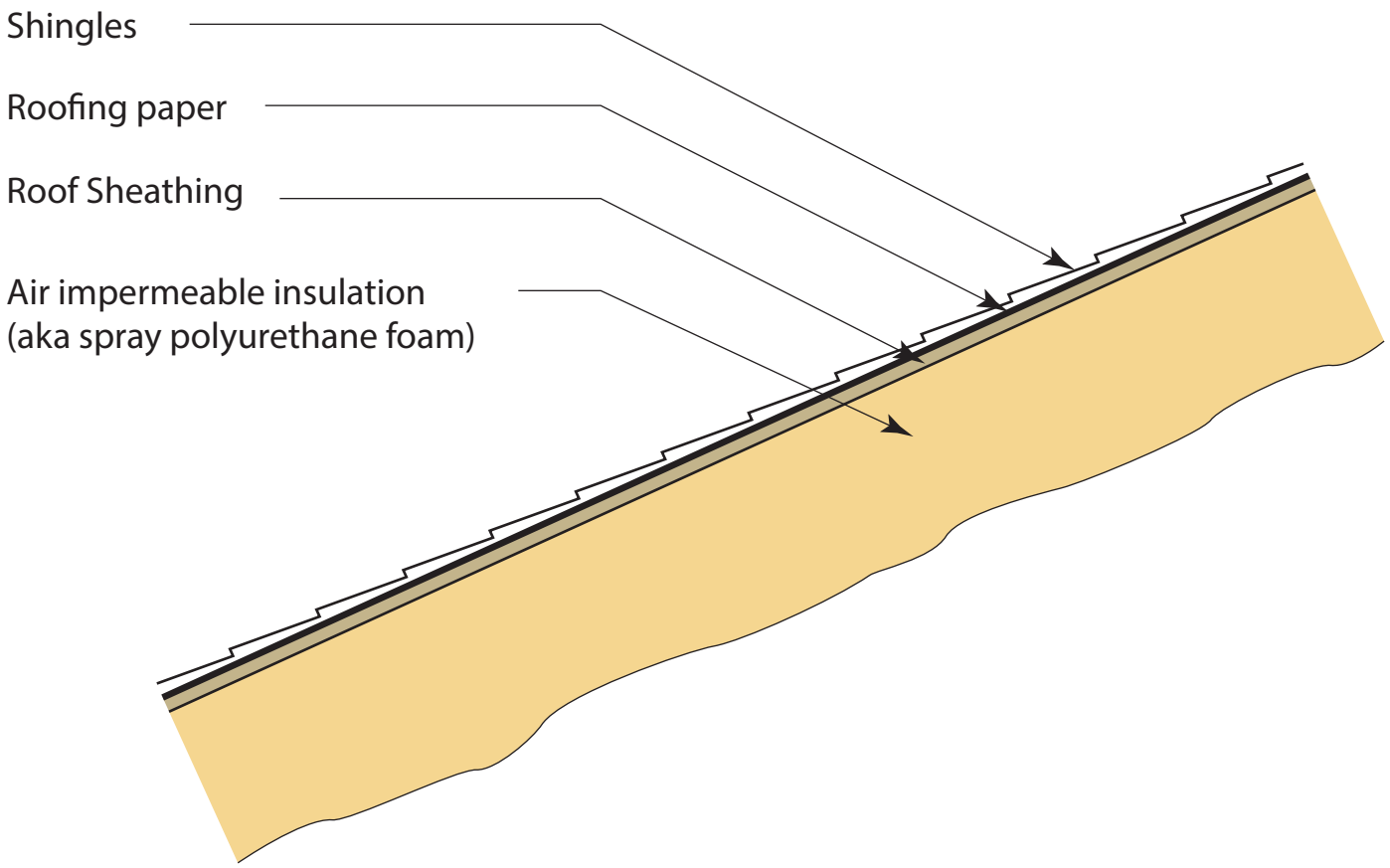

Shingles
Roofing paper
Minimum R-50 rigid insulation
in two or more layers with horizontal
and vertical joints staggered
Nail base for shingles (plywood or OSB)
screwed through rigid insulation
to wood decking or timber rafters
Air barrier membrane
Wood decking
Timber rafter or exposed joist

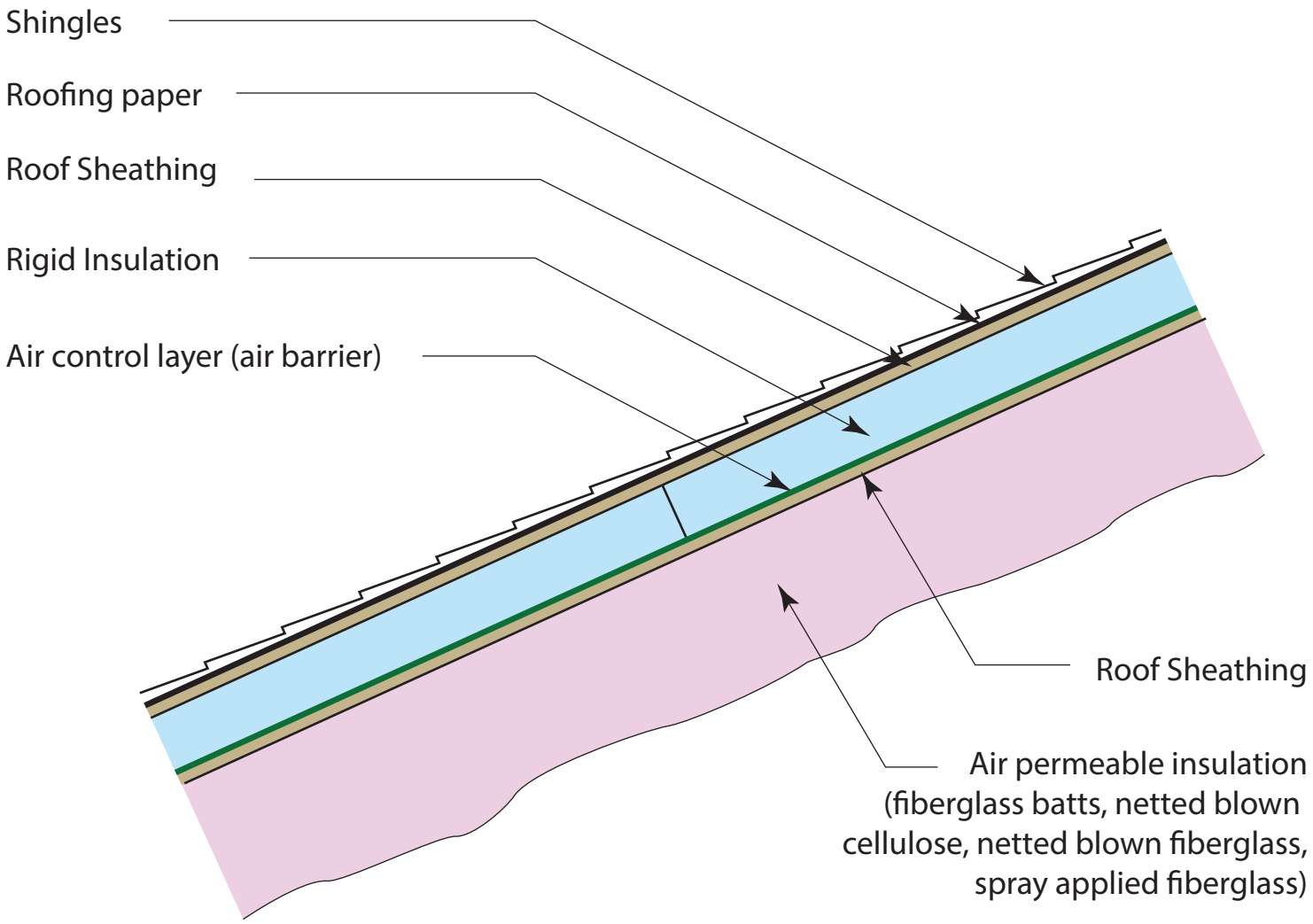

Outside
Inside
70°F
0°F
Dewpoint
(50% RH, 70°F)
Location of
condensation
and frost
Exterior
sheathing

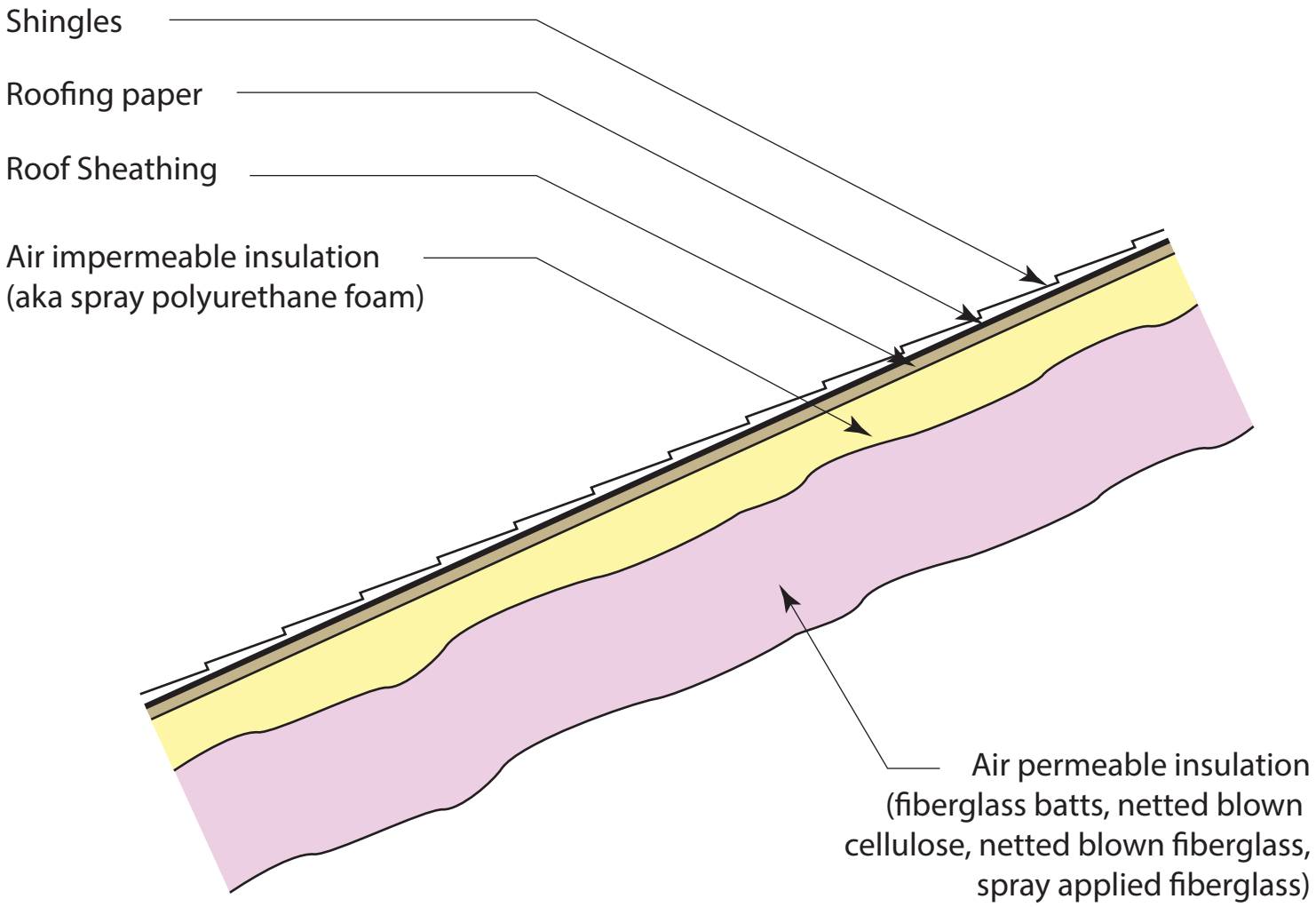


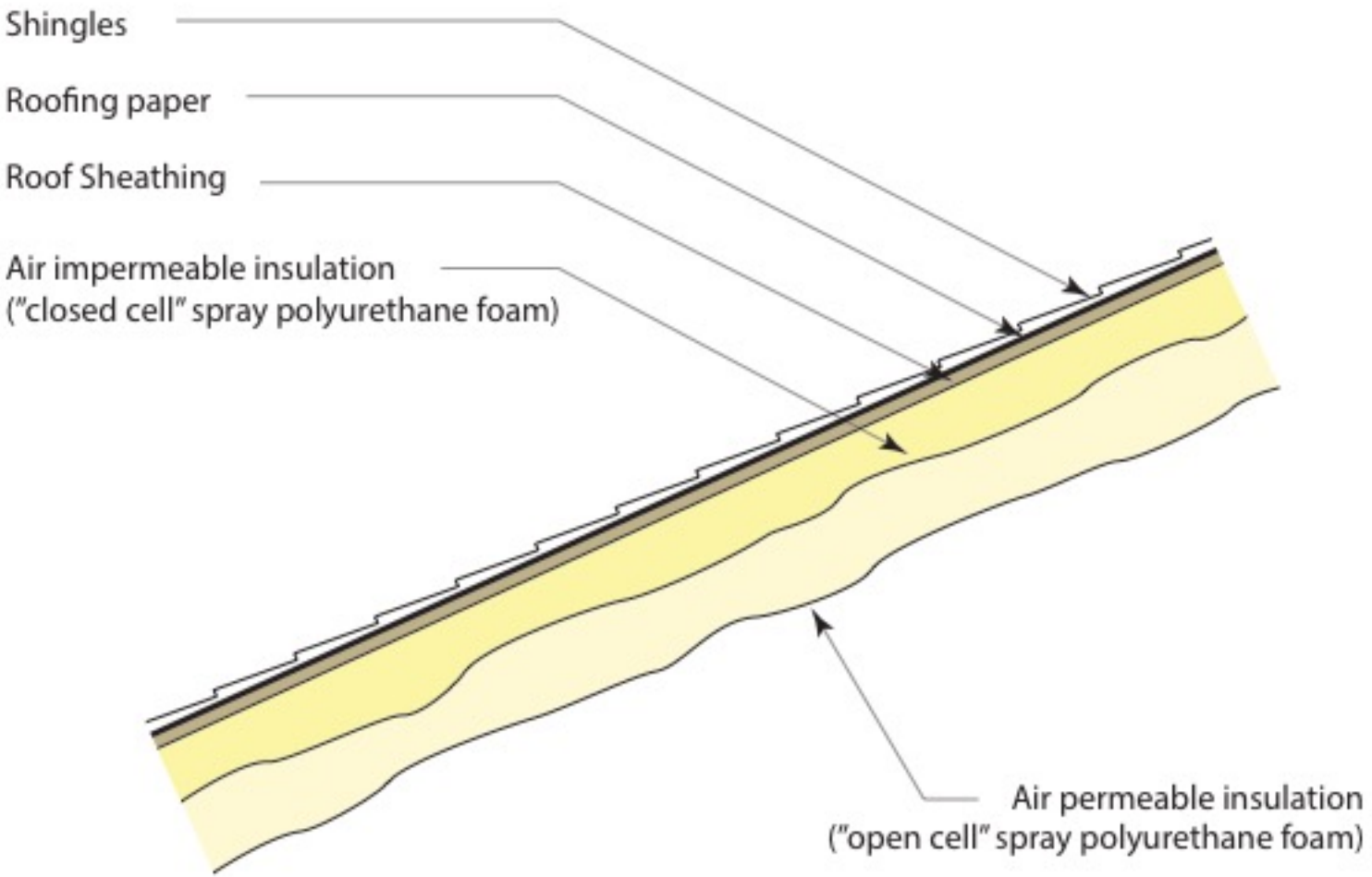
Simple linearized energy-temperature relation for water
From Straube & Burnett, 2005


Shingles
Roofing paper
Roof Sheathing
Rigid Insulation
Roof Sheathing
Air barrier membrane
Rafter/Truss


Shingles
Roofing paper
Roof Sheathing
Air impermeable insulation
(aka spray polyurethane foam)


Shingles
Roofing paper
Roof Sheathing
Rigid Insulation
Air control layer (air barrier)
Roof Sheathing
Air permeable insulation
(fiberglass batts, netted blown
cellulose, netted blown fiberglass,
spray applied fiberglass)

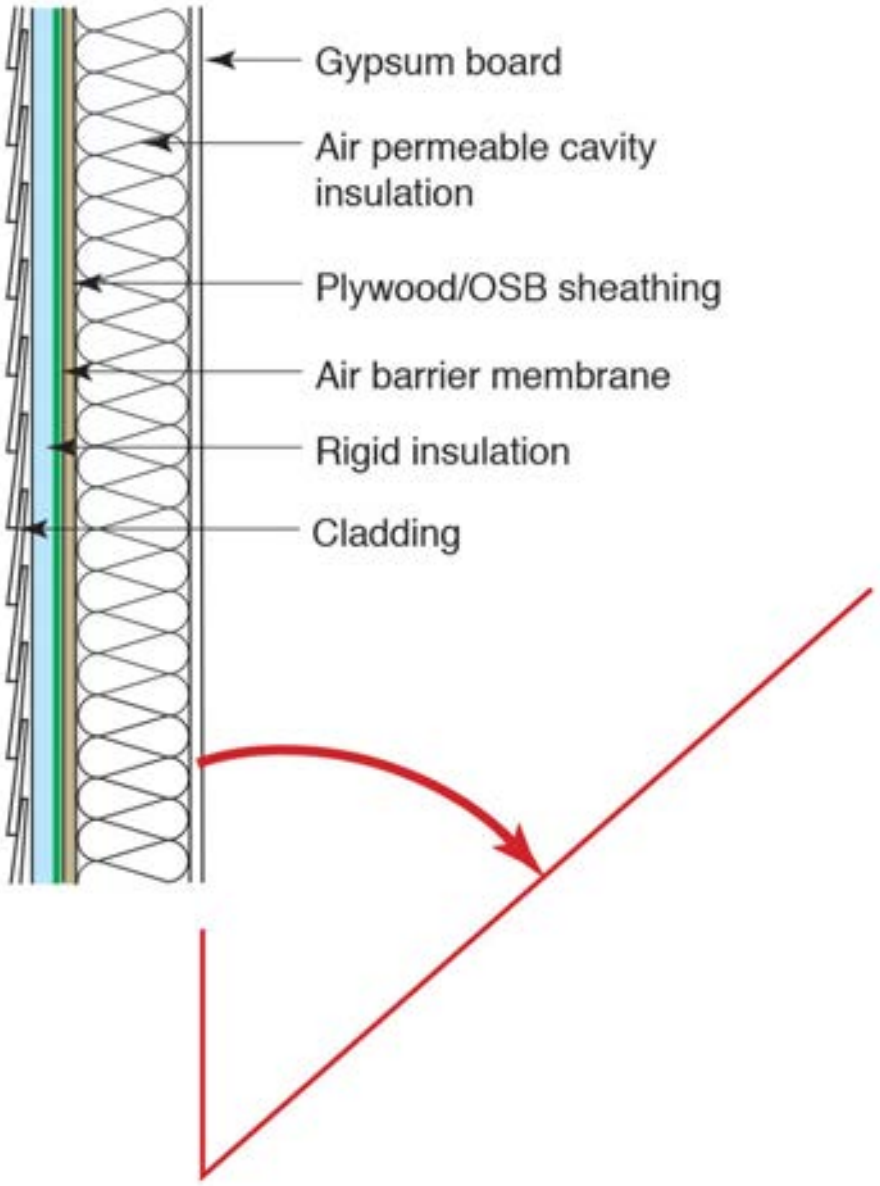

Shingles
Roofing paper
Roof Sheathing
Air impermeable insulation
(aka spray polyurethane foam)
Air permeable insulation
(fiberglass batts, netted blown
cellulose, netted blown fiberglass,
spray applied fiberglass)

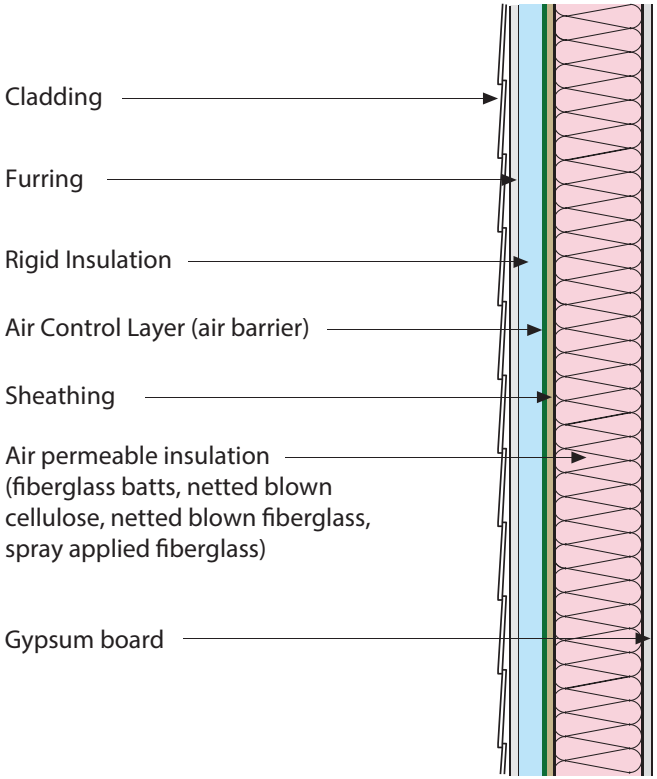

Shingles
Roofing paper
Roof Sheathing
Air impermeable insulation
("closed cell" spray polyurethane foam)
Air permeable insulation
("open cell" spray polyurethane foam)

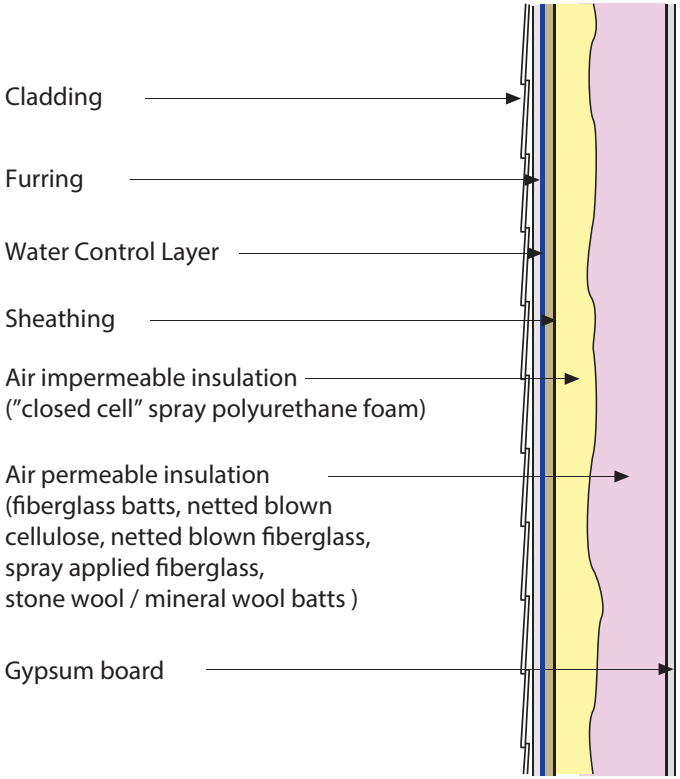
Insulation for Condensation Control*

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


Gypsum board
Air permeable cavity insulation
Plywood/OSB sheathing
Air barrier membrane
Rigid insulation
Cladding


Cladding
Furring
Rigid Insulation
Air Control Layer (air barrier)
Sheathing
Air permeable insulation
(fiberglass batts, netted blown
cellulose, netted blown fiberglass,
spray applied fiberglass)
Gypsum board

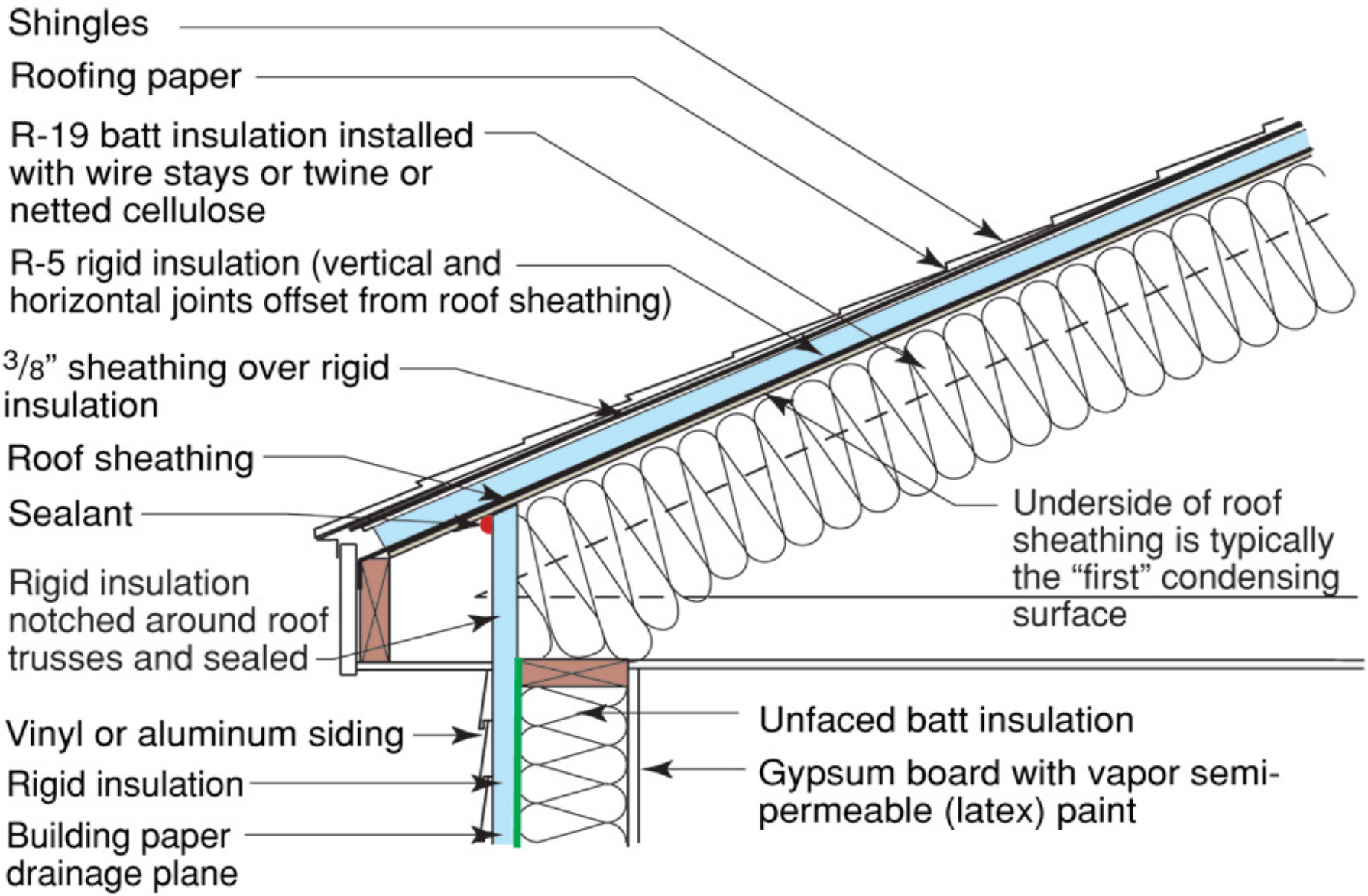

Cladding
Furring
Water Control Layer
Sheathing
Air impermeable insulation
("closed cell" spray polyurethane foam)
Air permeable insulation
(fiberglass batts, netted blown
cellulose, netted blown fiberglass,
spray applied fiberglass,
stone wool / mineral wool batts)
Gypsum board

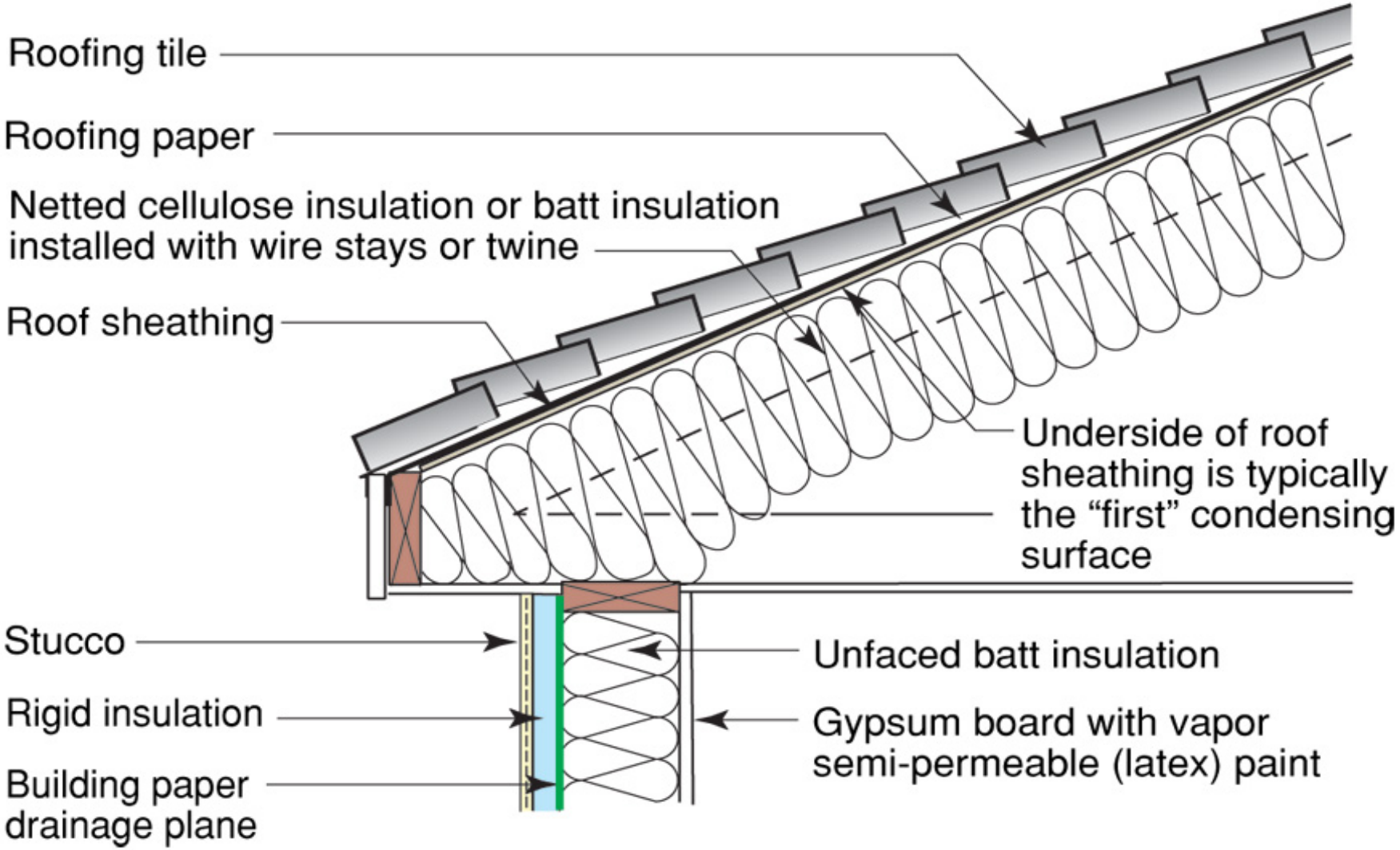
Insulation for Condensation Control*

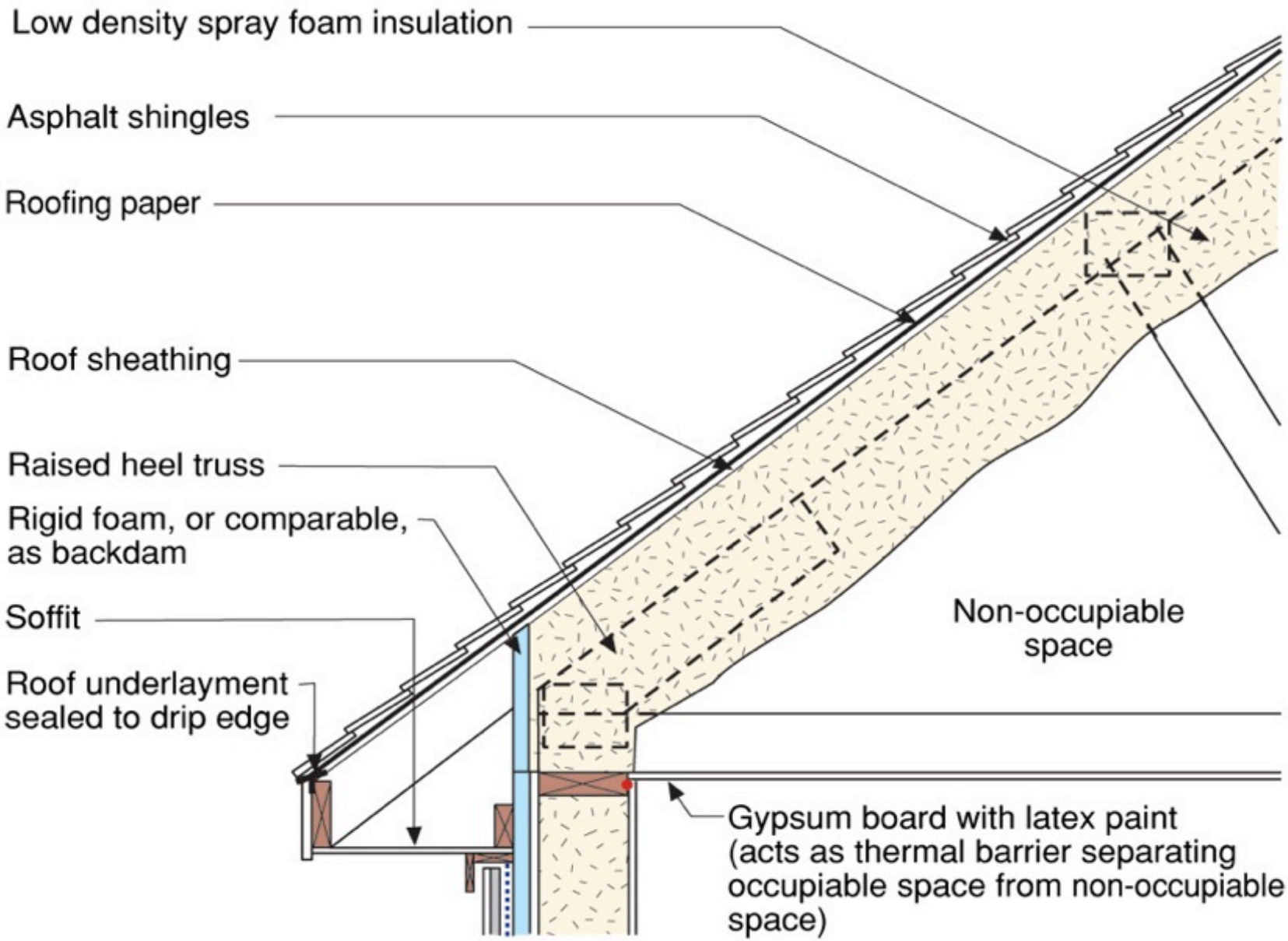
Climate Zone	Rigid Board or Air Impermeable Insulation	Code Required R-Value	Ratio of Rigid Board Insulation or Air Impermeable R-Value to Total Insulation R-Value
1,2,3	R-5	R-38	10%
4C	R-10	R-49	20%
4A, 4B	R-15	R-49	30%
5	R-20	R-49	40%
6	R-25	R-49	50%
7	R-30	R-49	60%
8	R-35	R-49	70%

*Adapted from Table R 806.5 2015 International Residential Code

Table 1


Shingles
Roofing paper
R-19 batt insulation installed with wire stays or twine or netted cellulose
R-5 rigid insulation (vertical and horizontal joints offset from roof sheathing)
3/8" sheathing over rigid insulation
Roof sheathing
Sealant
Rigid insulation notched around roof trusses and sealed
Vinyl or aluminum siding
Rigid insulation
Building paper drainage plane
Underside of roof sheathing is typically the "first" condensing surface
Unfaced batt insulation
Gypsum board with vapor semi-permeable (latex) paint

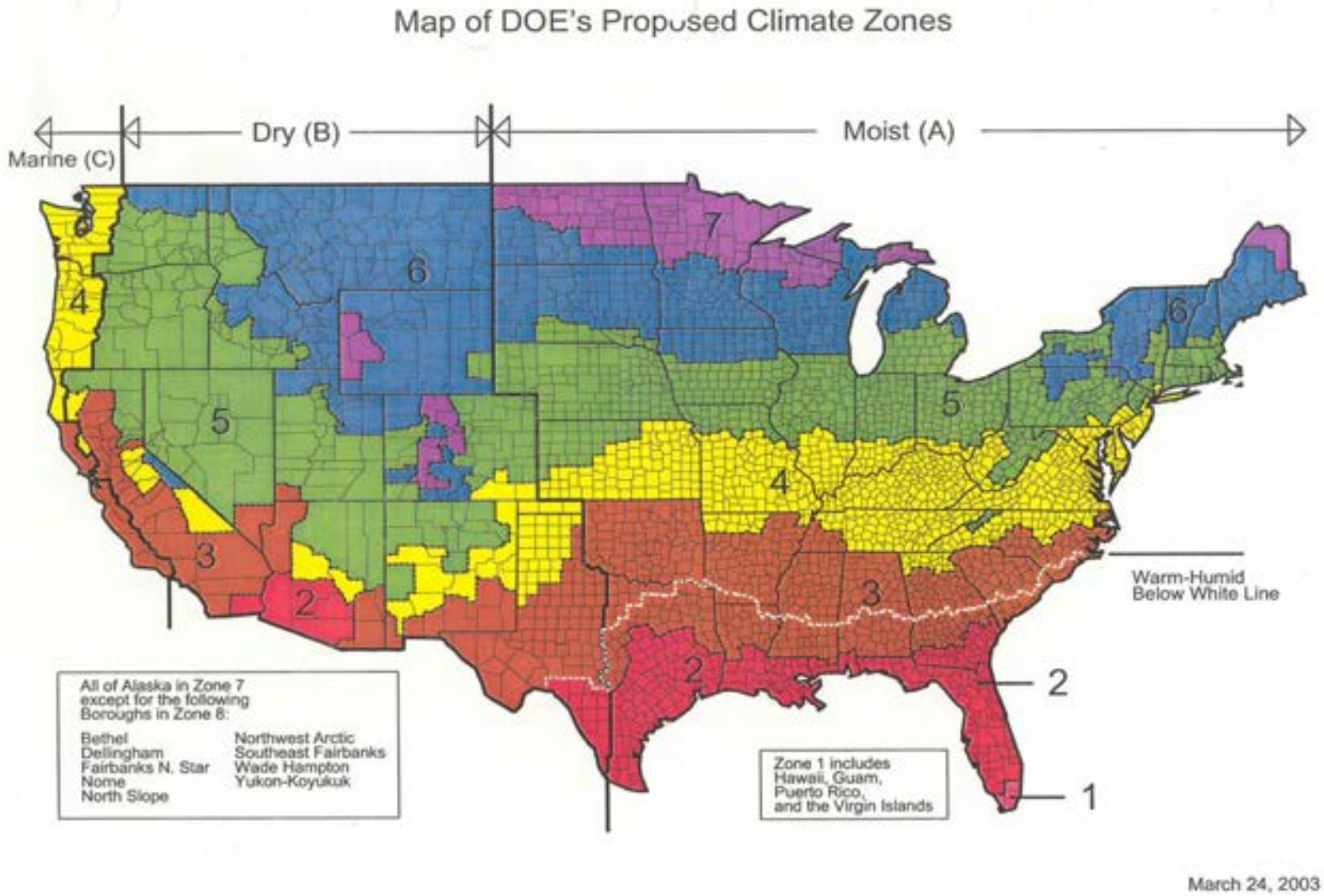

Roofing tile
Roofing paper
Netted cellulose insulation or batt insulation installed with wire stays or twine
Roof sheathing
Underside of roof sheathing is typically the “first” condensing surface
Stucco
Rigid insulation
Building paper drainage plane
Unfaced batt insulation
Gypsum board with vapor semi-permeable (latex) paint


Low density spray foam insulation
Asphalt shingles
Roofing paper
Roof sheathing
Raised heel truss
Rigid foam, or comparable, as backdam
Soffit
Roof underlayment sealed to drip edge
Non-occupiable space
Gypsum board with latex paint (acts as thermal barrier separating occupiable space from non-occupiable space)

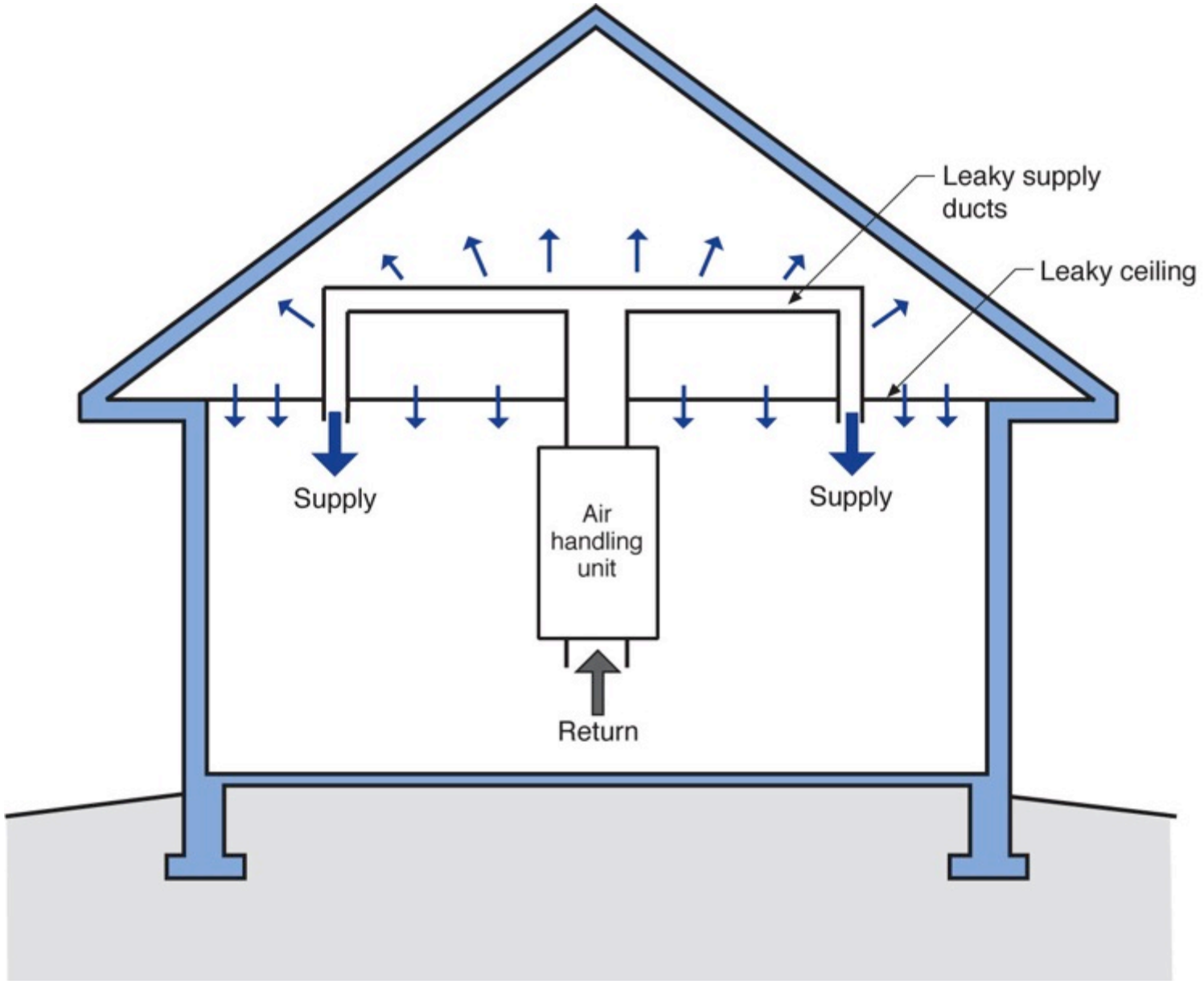

FOAMULAR
OWENS CORNING


GRACE
Ice & Water Shield
TRI-FLEX 30
APR 20 2004


APR 20 2004


Map of DOE's Proposed Climate Zones
Marine (C)
Dry (B)
Moist (A)
Warm-Humid
Below White Line
All of Alaska in Zone 7
except for the following
Boroughs in Zone 8:
Bethel
Dellingham
Fairbanks N. Star
Nome
North Slope
Northwest Arctic
Southeast Fairbanks
Wade Hampton
Yukon-Koyukuk
Zone 1 includes
Hawaii, Guam,
Puerto Rico,
and the Virgin Islands
March 24, 2003

Conditioned Attics Not Unvented Attics


Leaky supply ducts
Leaky ceiling
Supply
Supply
Air handling unit
Return

Conditioned Attics Not Unvented Attics

Need Supply Air

Conditioned Attics Not Unvented Attics

Need Supply Air

50 cfm/1000 ft2 of Attic

Hygric Buoyancy

Components in Dry Air	Volume Ratio compared to Dry Air	Molecular Mass - *M* *(kg/kmol)*	Molecular Mass in Air
Oxygen	0.2095	32.00	6.704
Nitrogen	0.7809	28.02	21.88
Carbon Dioxide	0.0003	44.01	0.013
Hydrogen	0.0000005	2.02	0
Argon	0.00933	39.94	0.373
Neon	0.000018	20.18	0
Helium	0.000005	4.00	0
Krypton	0.000001	83.8	0
Xenon	$0.09\ 10^{-6}$	131.29	0
Total Molecular Mass of Air			28.97

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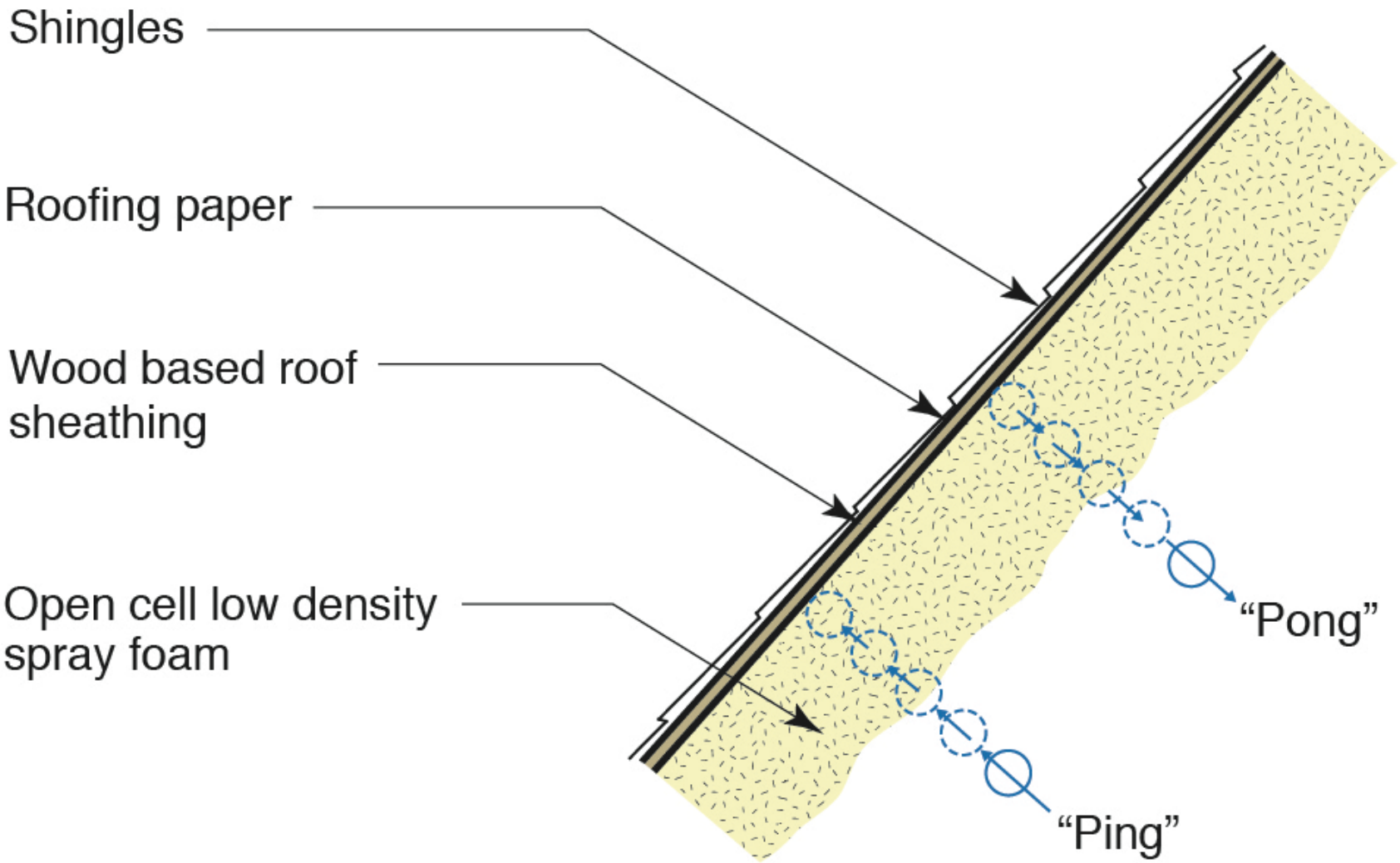
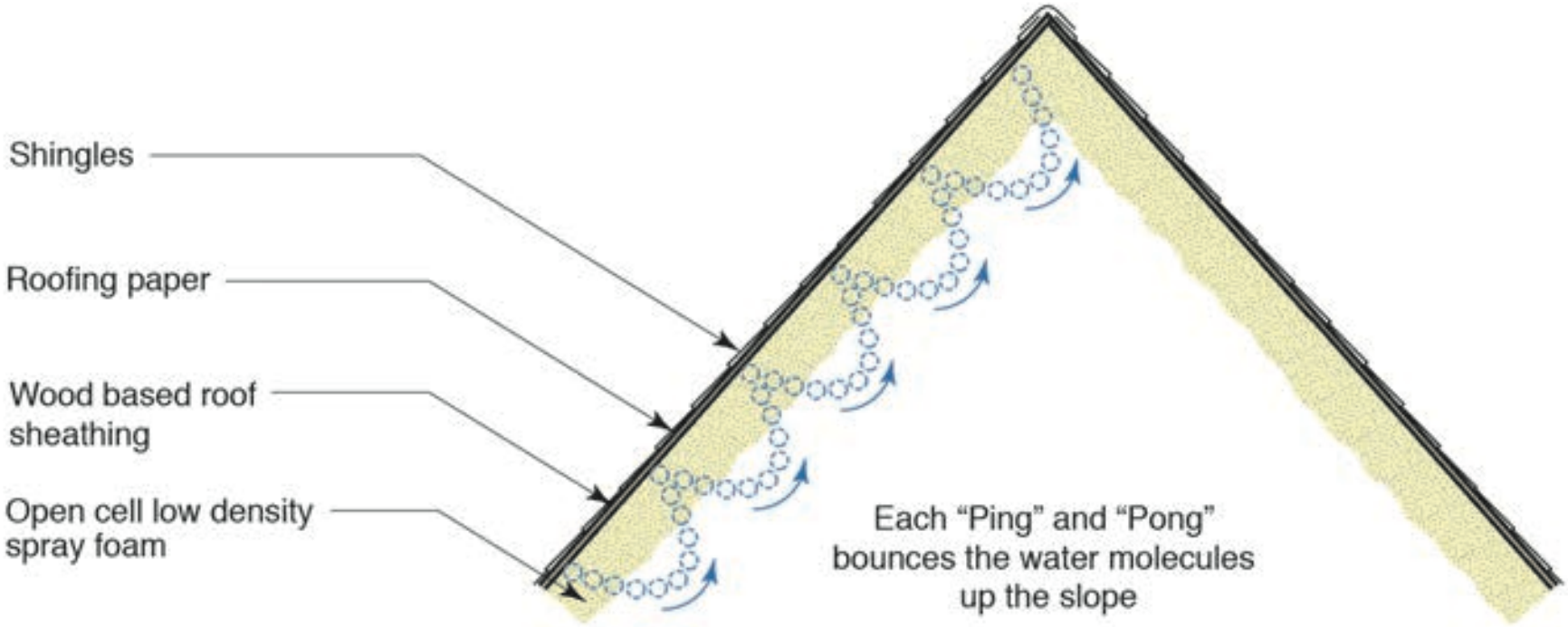
Total Molecular Mass of Air			28.97

Note Water Vapor (H_2O) is 18

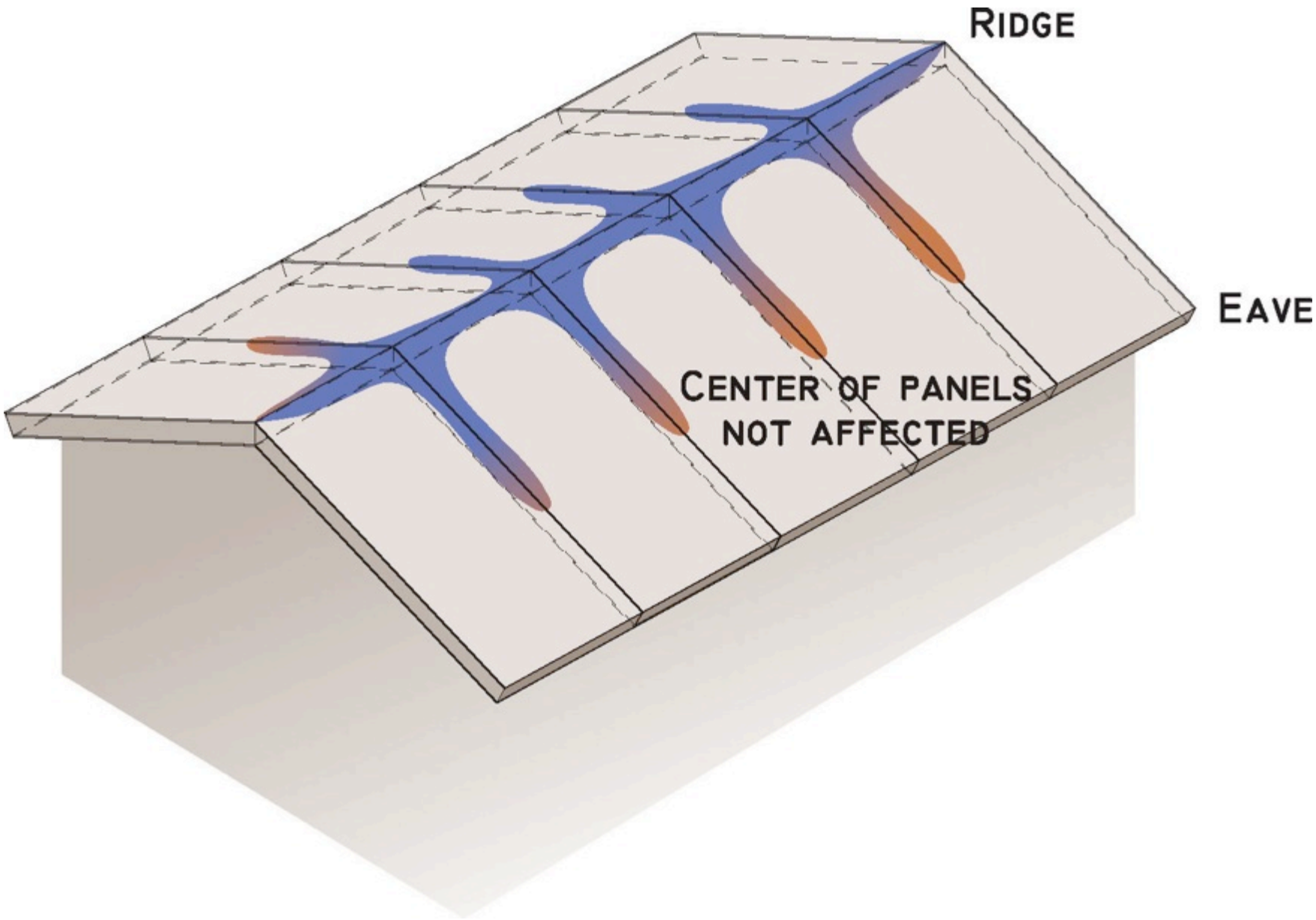
Dry Air is 29


Dual In-Duct
Psychrometer
Fieldpiece
SDP2

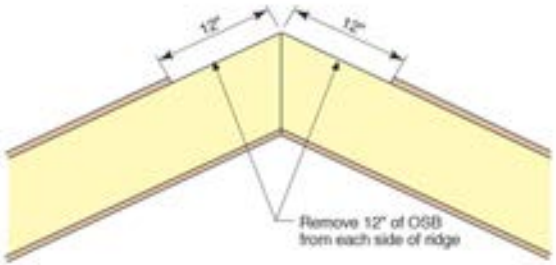

Shingles
Roofing paper
Wood based roof sheathing
Open cell low density spray foam
"Pong"
"Ping"


Shingles
Roofing paper
Wood based roof sheathing
Open cell low density spray foam
Each "Ping" and "Pong" bounces the water molecules up the slope

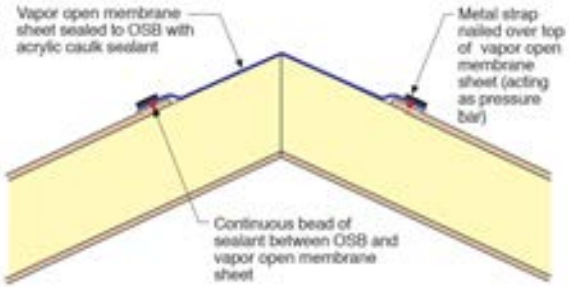

8/22/01 09:32


RIDGE
EAVE
CENTER OF PANELS
NOT AFFECTED

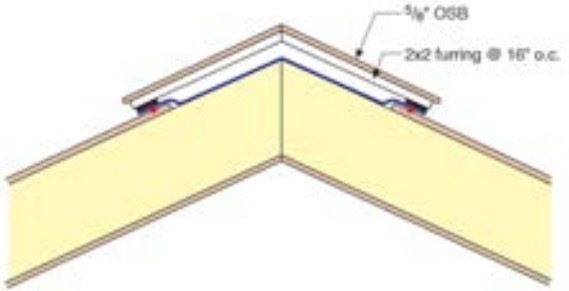
Step 1
- Remove strip of OSB from each side of ridge



Step 2
- Create air seal with strip of vapor open membrane (tape seams)
- Vapor open membrane sheet sealed to OSB with acrylic caulk sealant
- Hold vapor open membrane sheet in place with metal strapping



Step 3
- Construct wood ridge vent with 2x2 furring



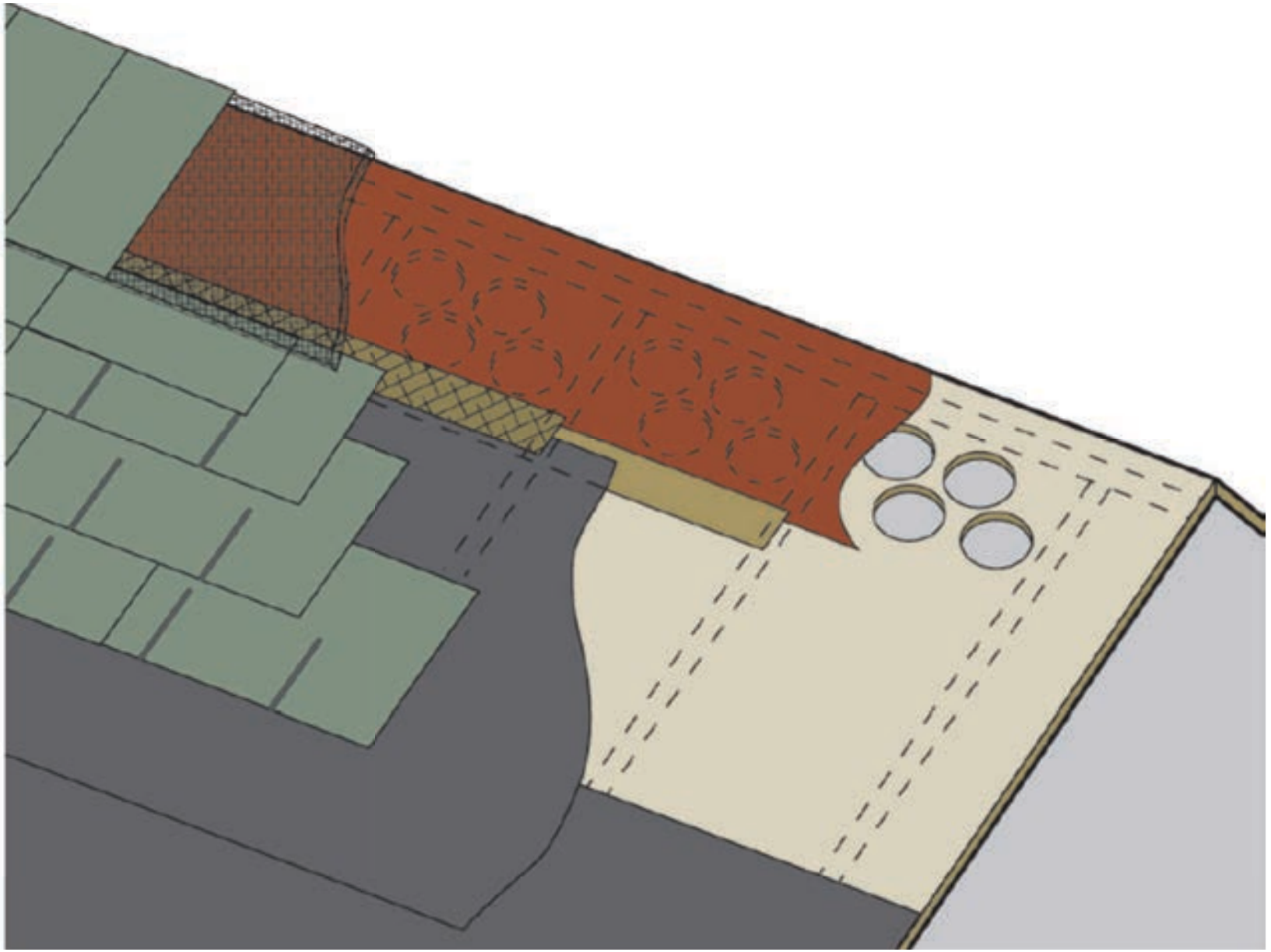

GRACE
Ice & Water Shield
Tyvek
Attic Wrap
DUPONT

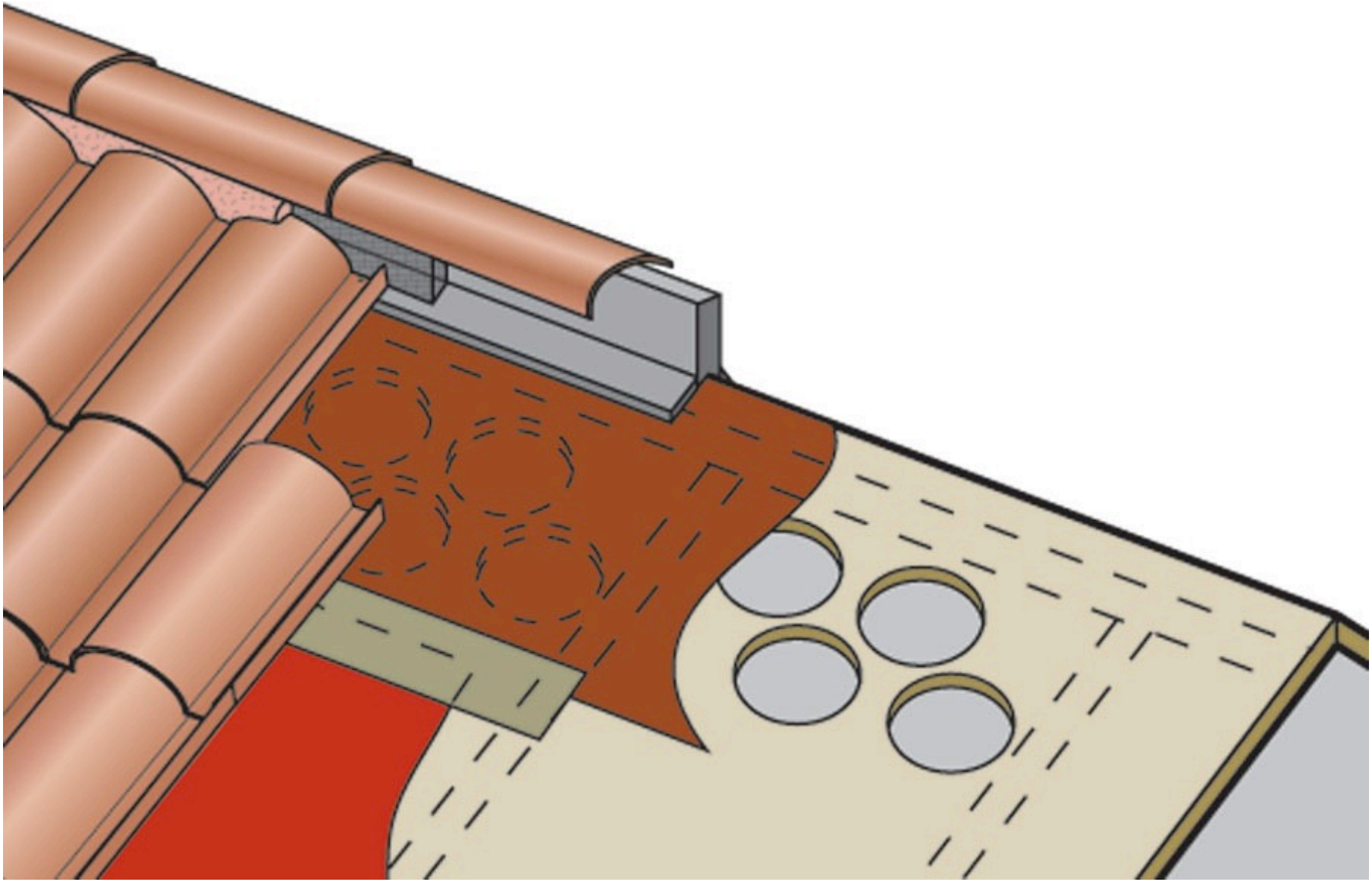

Tyvek
AtticWrap

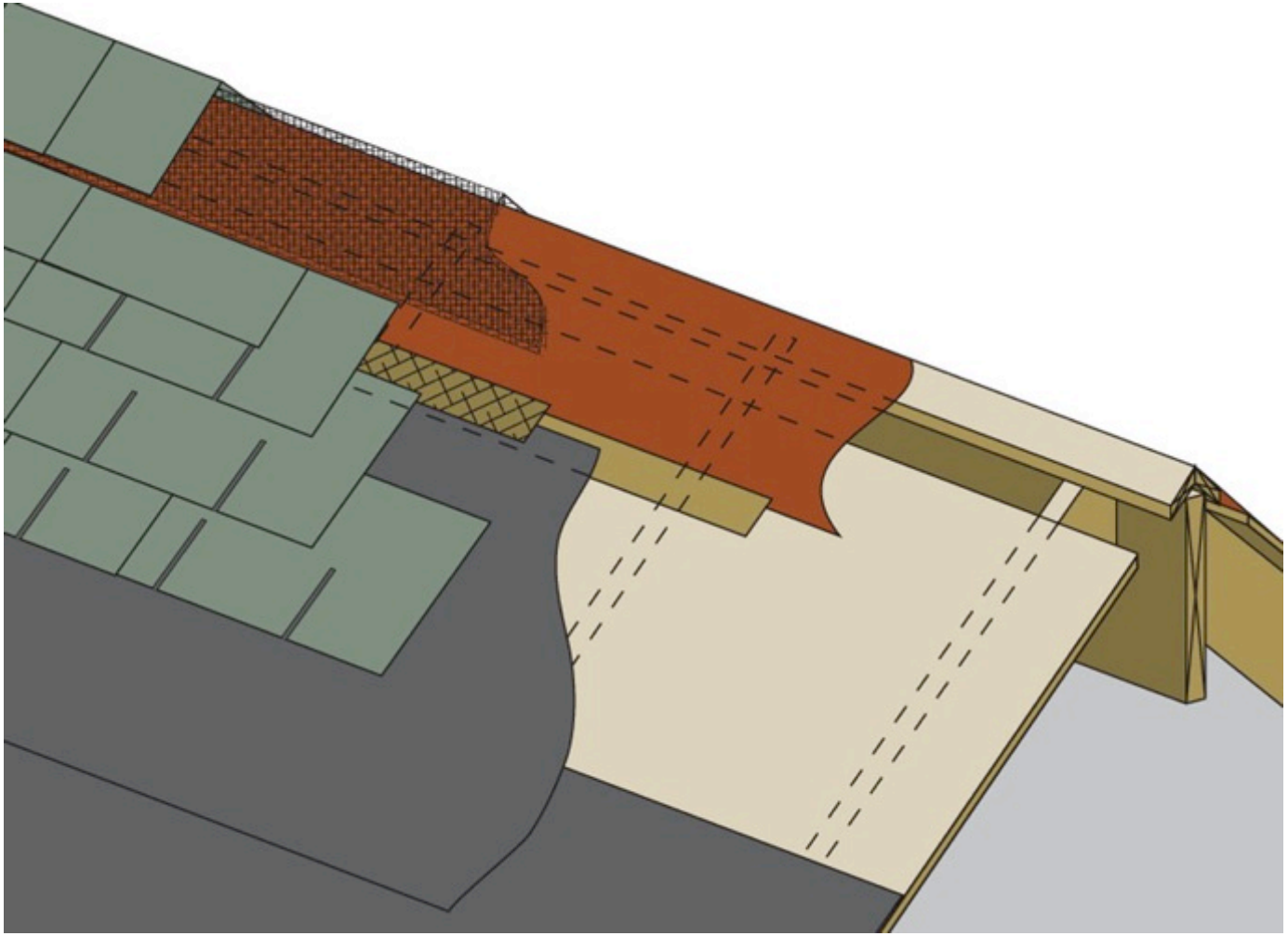

ek
VEK

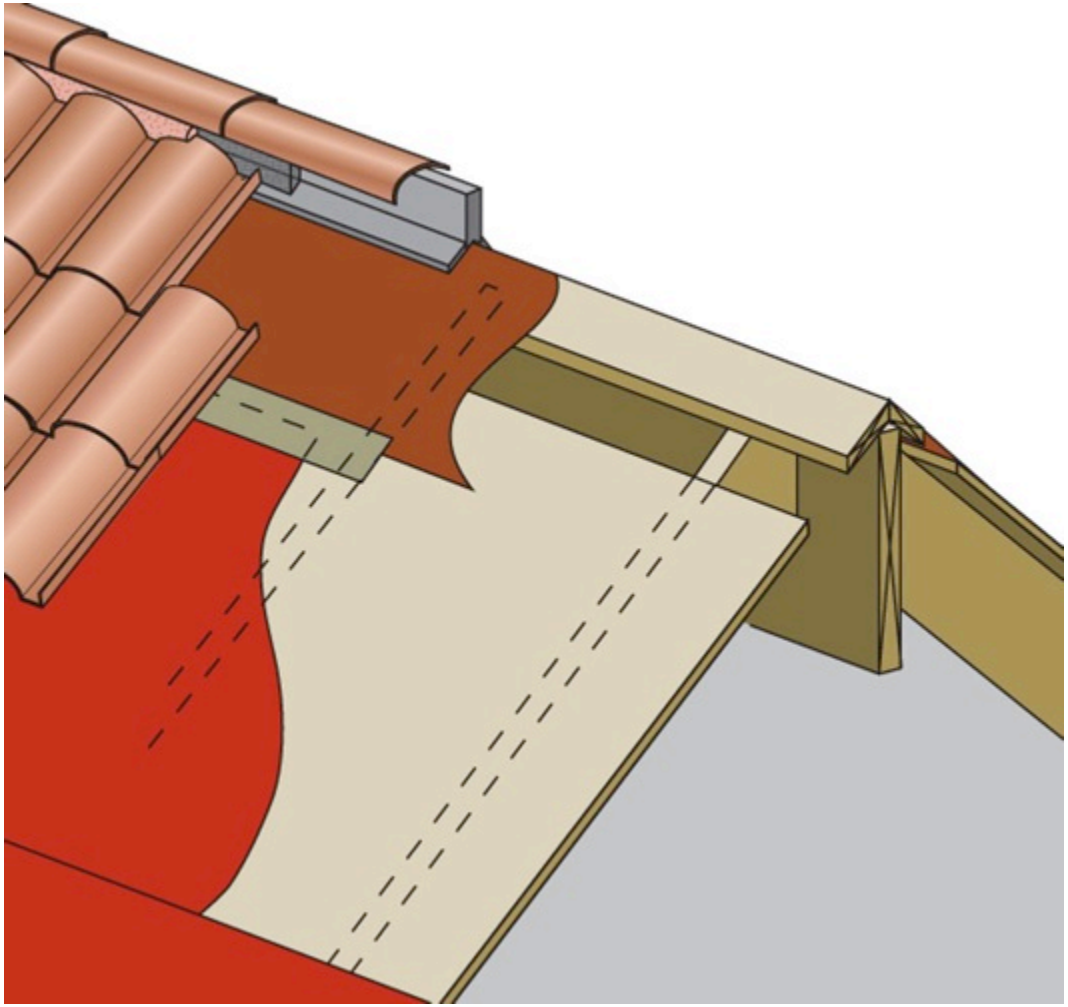

GRACE
Ice & Water Shield®


JUL 9 2006










3M


DELTA
DELTA
DELTA

Sweating Ducts

Sweating Ducts

Light Colored Roofs

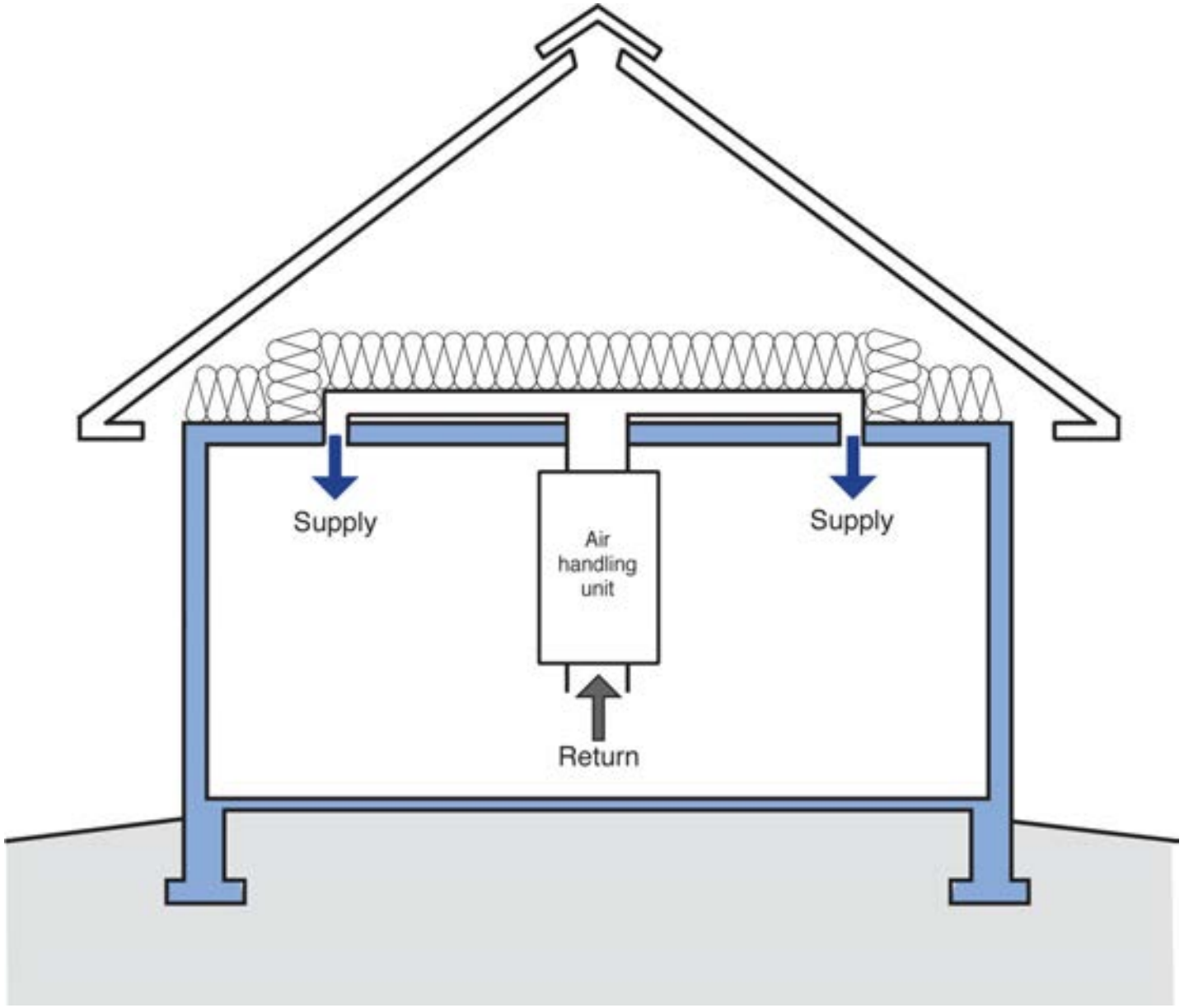
Cool Roofs

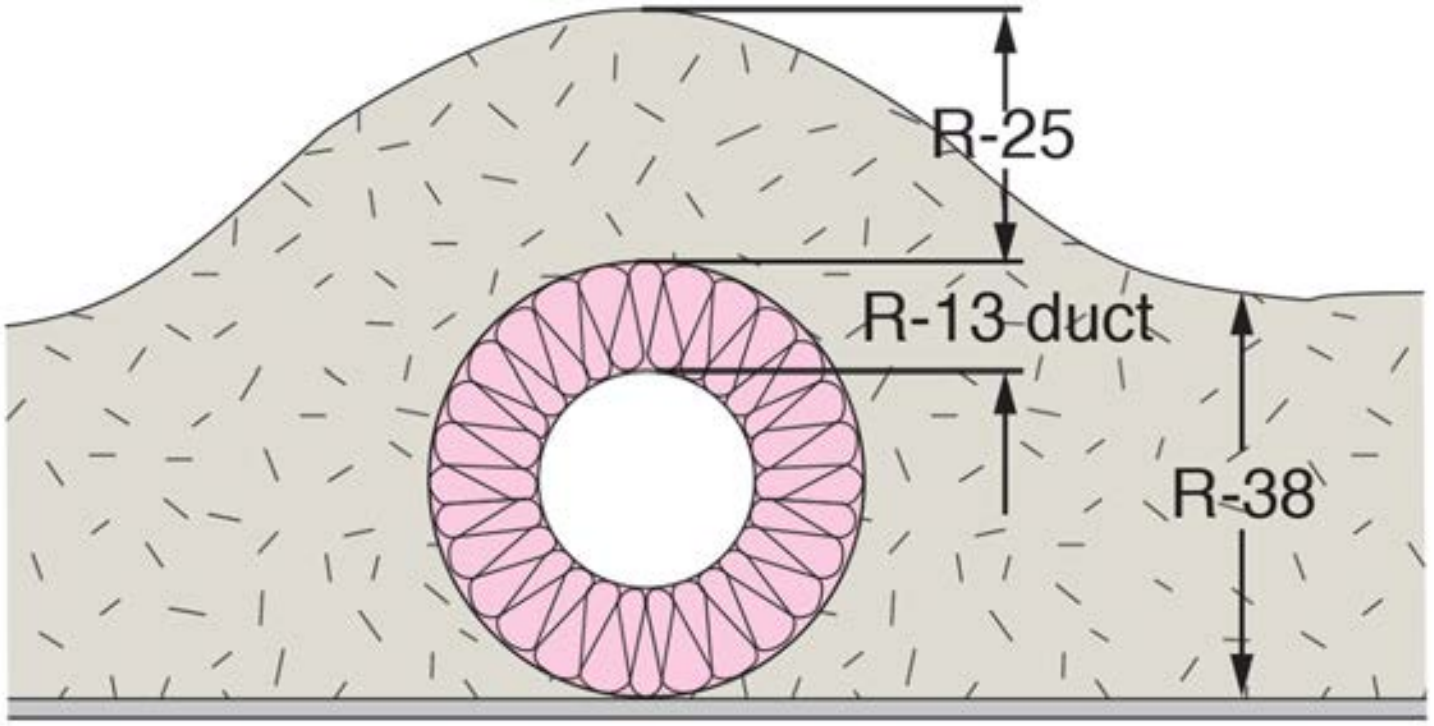
Radiant Barriers

ACCA Manual J, S and D

Ductwork Attic Dehumidification System

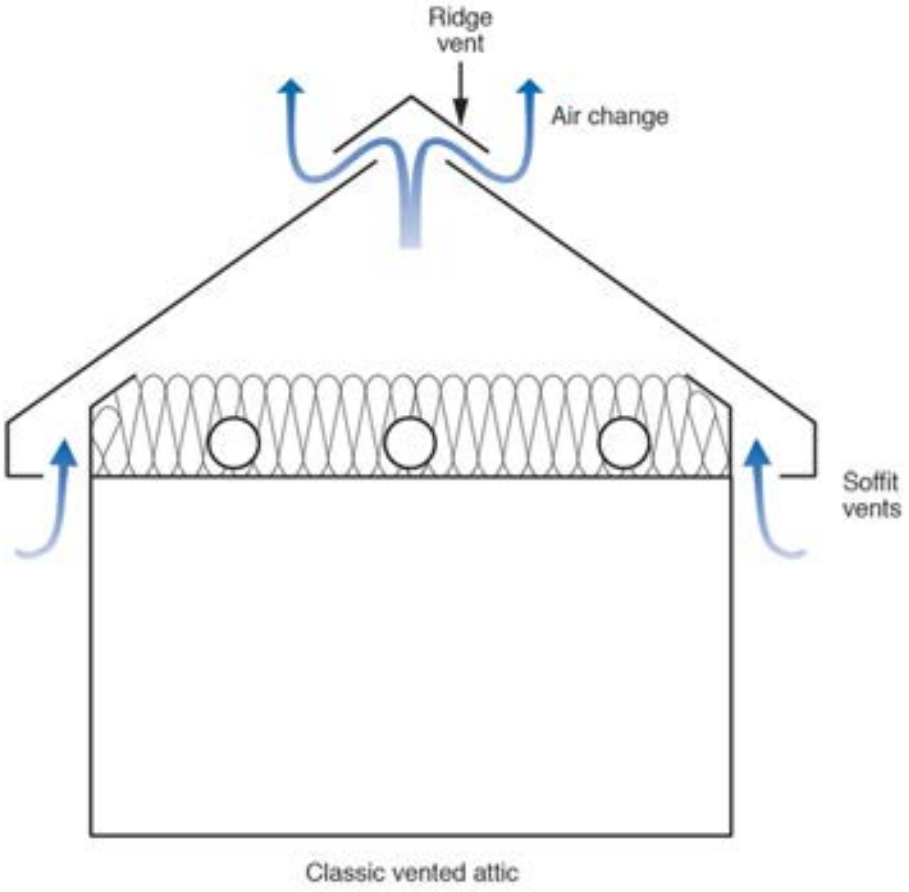
Burying Ducts


Supply
Air handling unit
Supply
Return

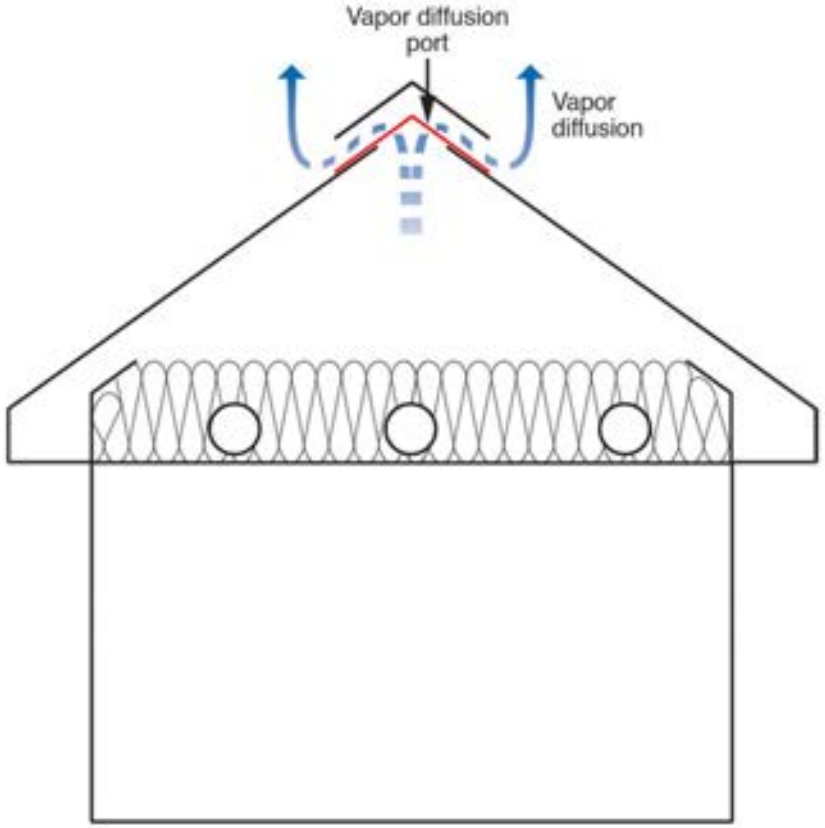

R-25
R-13 duct
R-38


FOAMULAR
FASSON


R-5.0
FOAMULAR
150

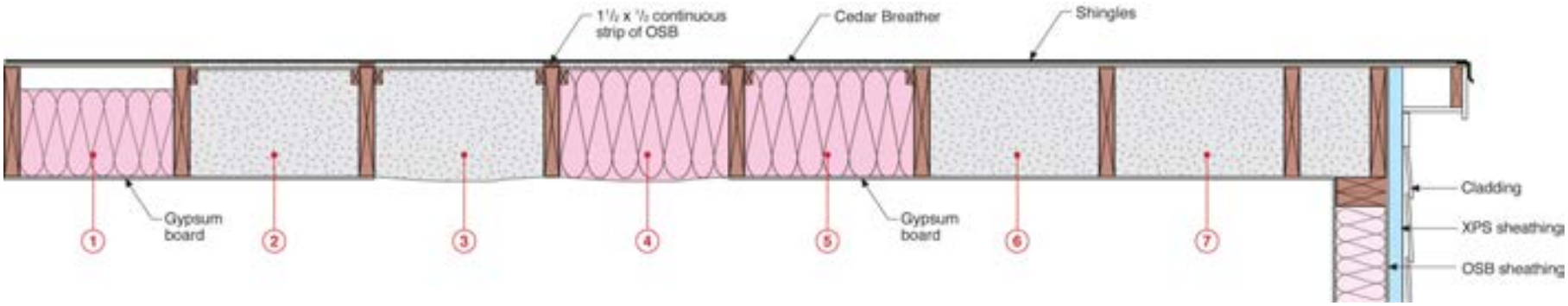


Classic vented attic



Unvented attic with vapor
diffusion port

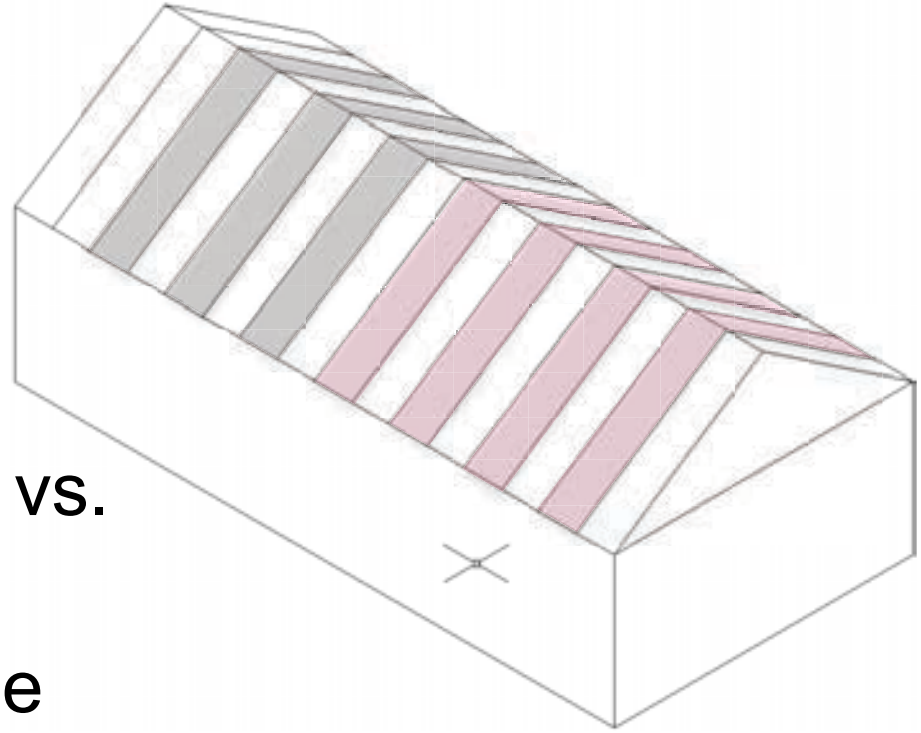
Cold Climates


1½ x ½ continuous strip of OSB
Cedar Breather
Shingles
Gypsum board
Gypsum board
Cladding
XPS sheathing
OSB sheathing
1
2
3
4
5
6
7


FlexWrap


AVAILABLE


R-30
R-30



- Diffusion vent at ridge vs. no diffusion vent
- Fiberglass vs. cellulose
- Vapor retarder: variable perm vs. fixed perm
- “Control” comparison R806.4 spray foam + fibrous


R-30