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

Building Science

Adventures In Building Science

www.buildingscience.com

Stucco Failures

Stucco Evolved As A Barrier System

Exterior Insulation Finish Systems

EIFS



Exterior Insulation Finish Systems

EIFS

Barrier System

Face-Sealed Not Water Managed

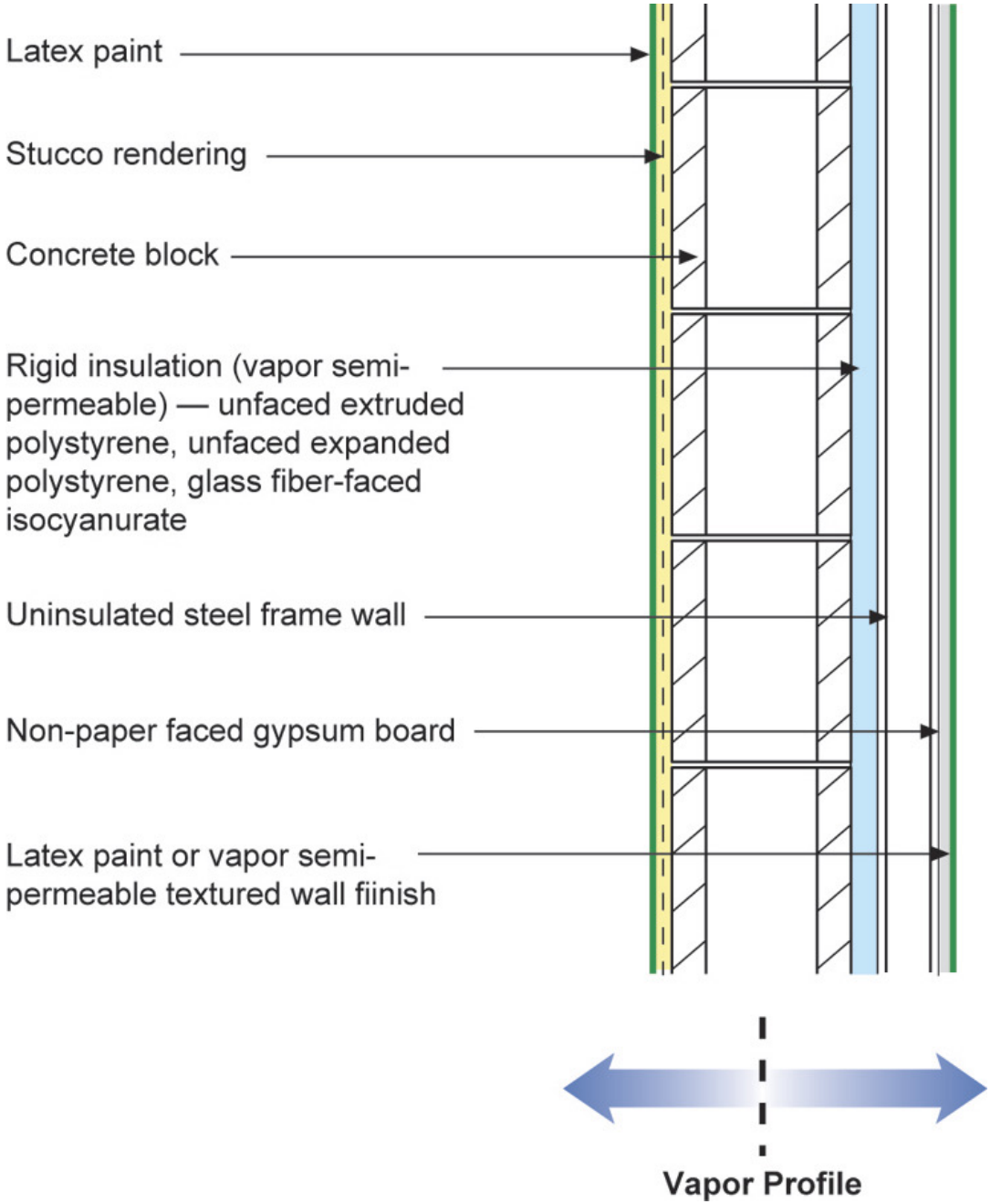


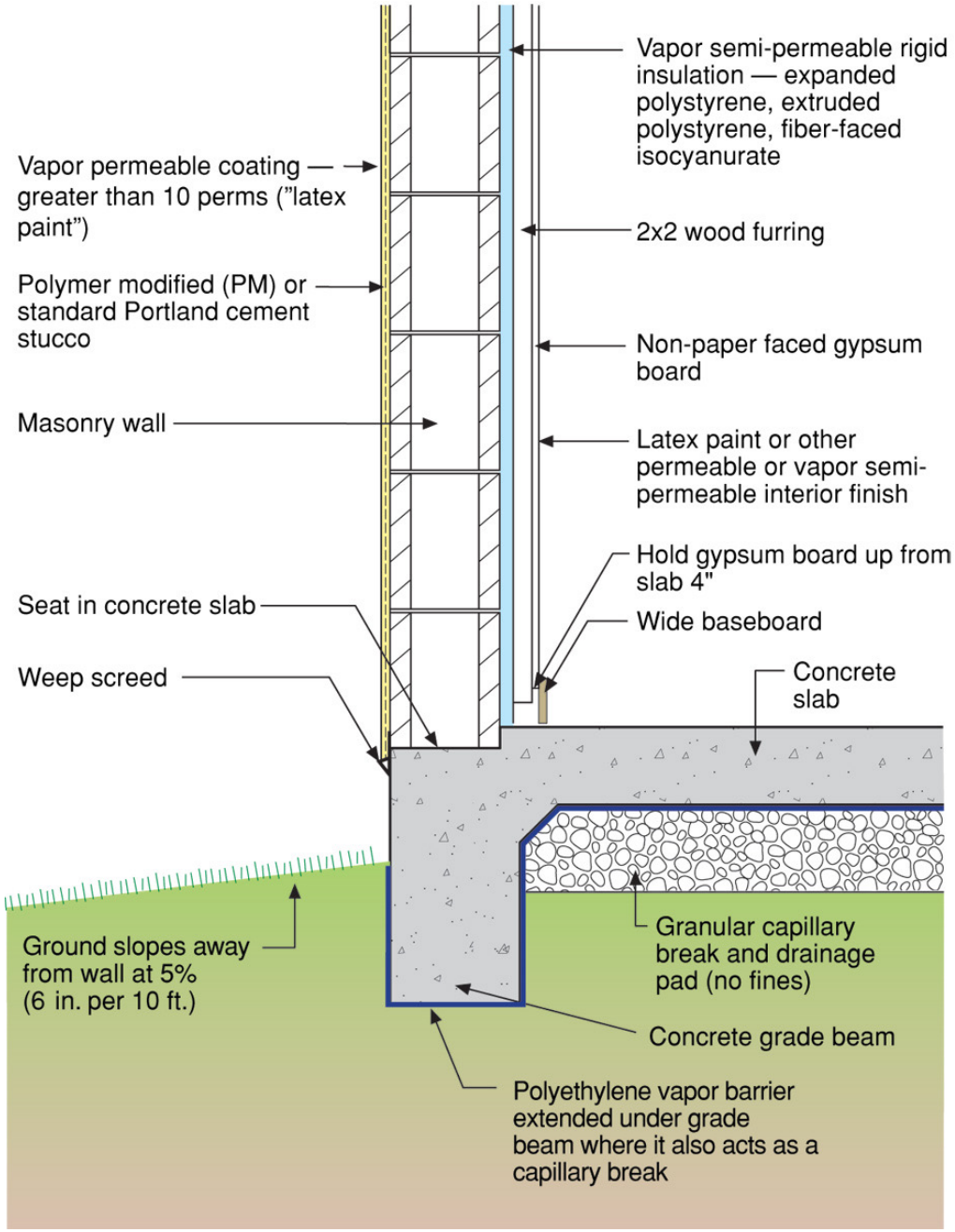



BUILT BY
EDDIE EVANS
CONSTRUCTION
1994



Can Barrier or Face Seal Work?

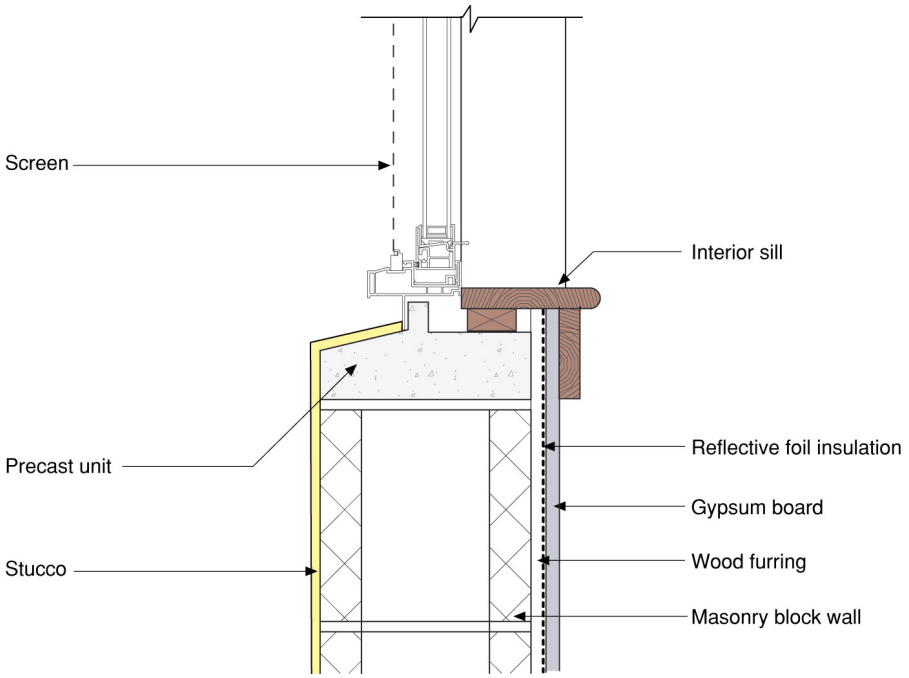

Latex paint
Stucco rendering
Concrete block
Rigid insulation (vapor semi-permeable) — unfaced extruded polystyrene, unfaced expanded polystyrene, glass fiber-faced isocyanurate
Uninsulated steel frame wall
Non-paper faced gypsum board
Latex paint or vapor semi-permeable textured wall fiinish
Vapor Profile

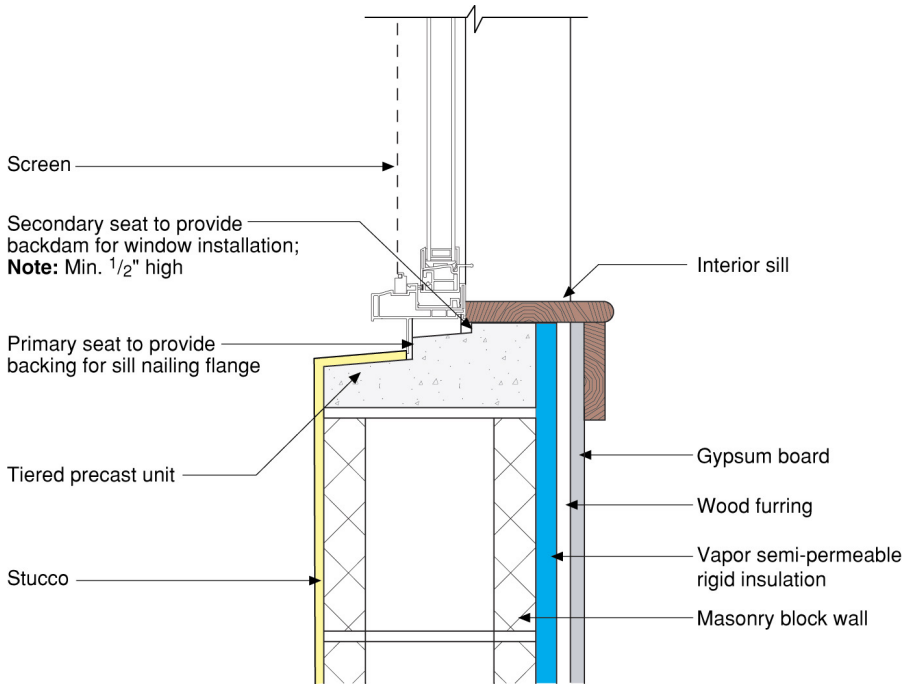

Vapor semi-permeable rigid insulation — expanded polystyrene, extruded polystyrene, fiber-faced isocyanurate
Vapor permeable coating — greater than 10 perms ("latex paint")
2x2 wood furring
Polymer modified (PM) or standard Portland cement stucco
Non-paper faced gypsum board
Masonry wall
Latex paint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




DOW
Styrofoam
SCOREBOARD
EXTRUDED FOAM INSULATION
DOW
Styrofoam
SCOREBOARD
EXTRUDED FOAM INSULATION




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


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

Reminder…

Don’t Do Stupid Things


CertainTeed
R19 6
AL FOL



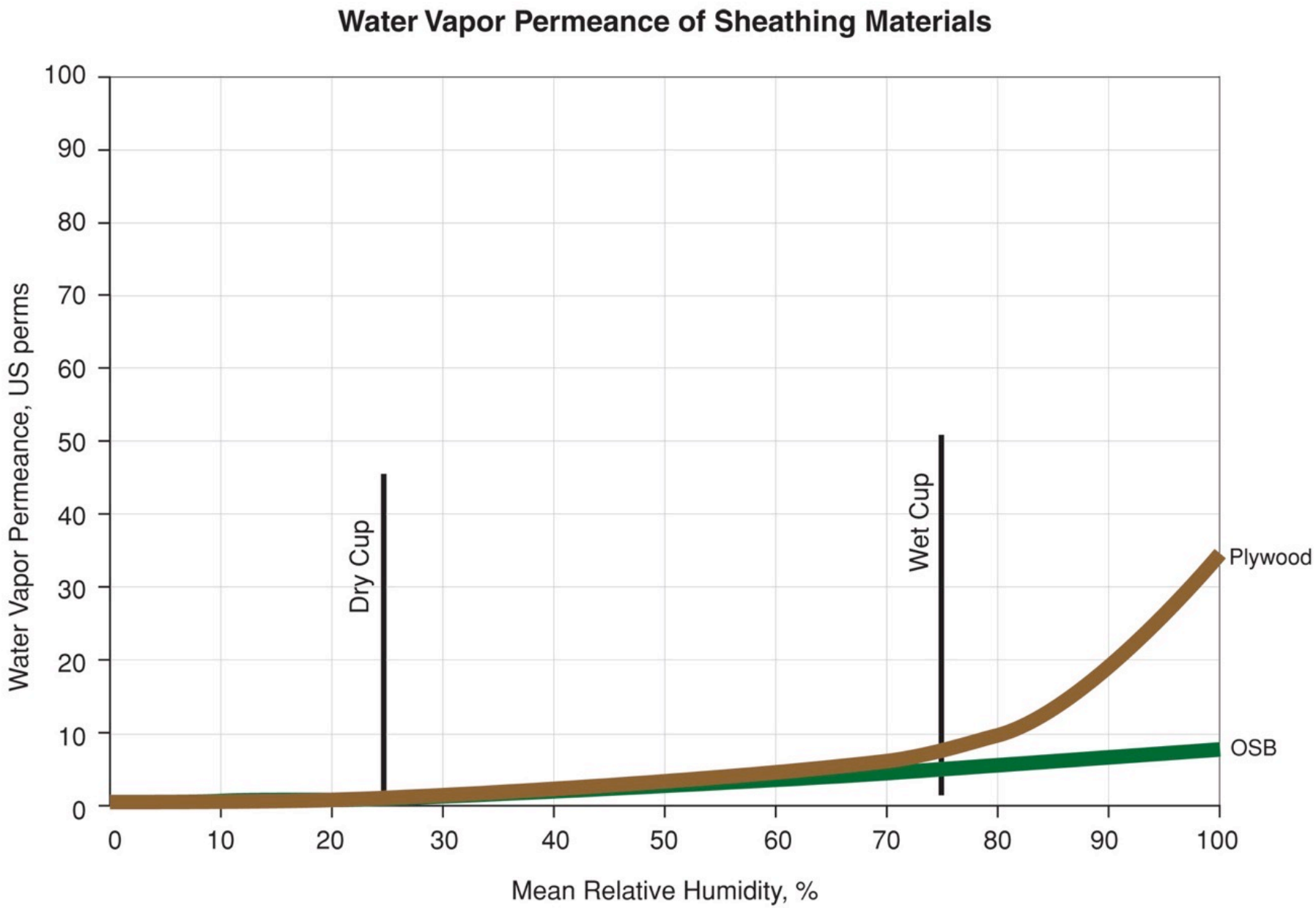
What Is Going On With Stucco?

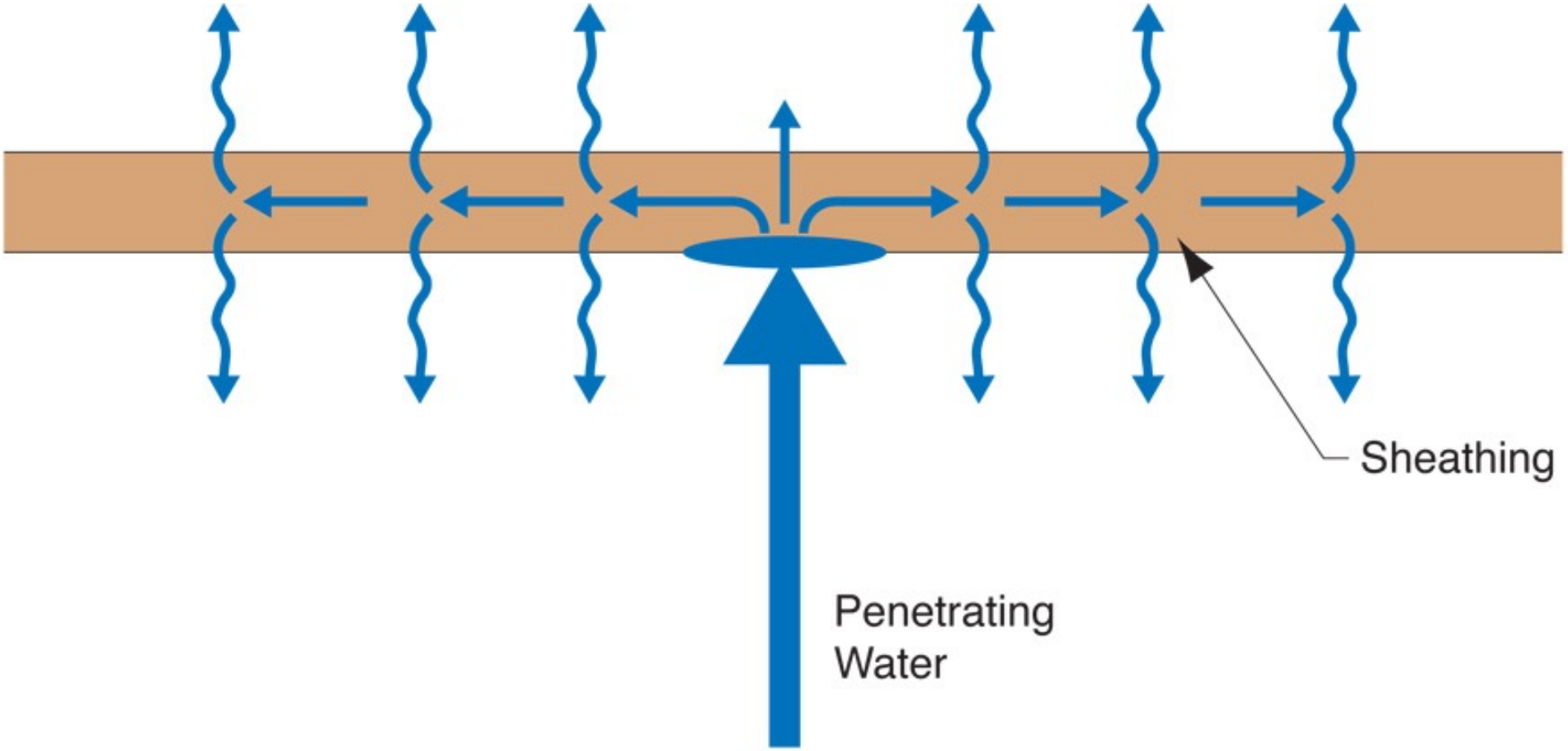
Materials

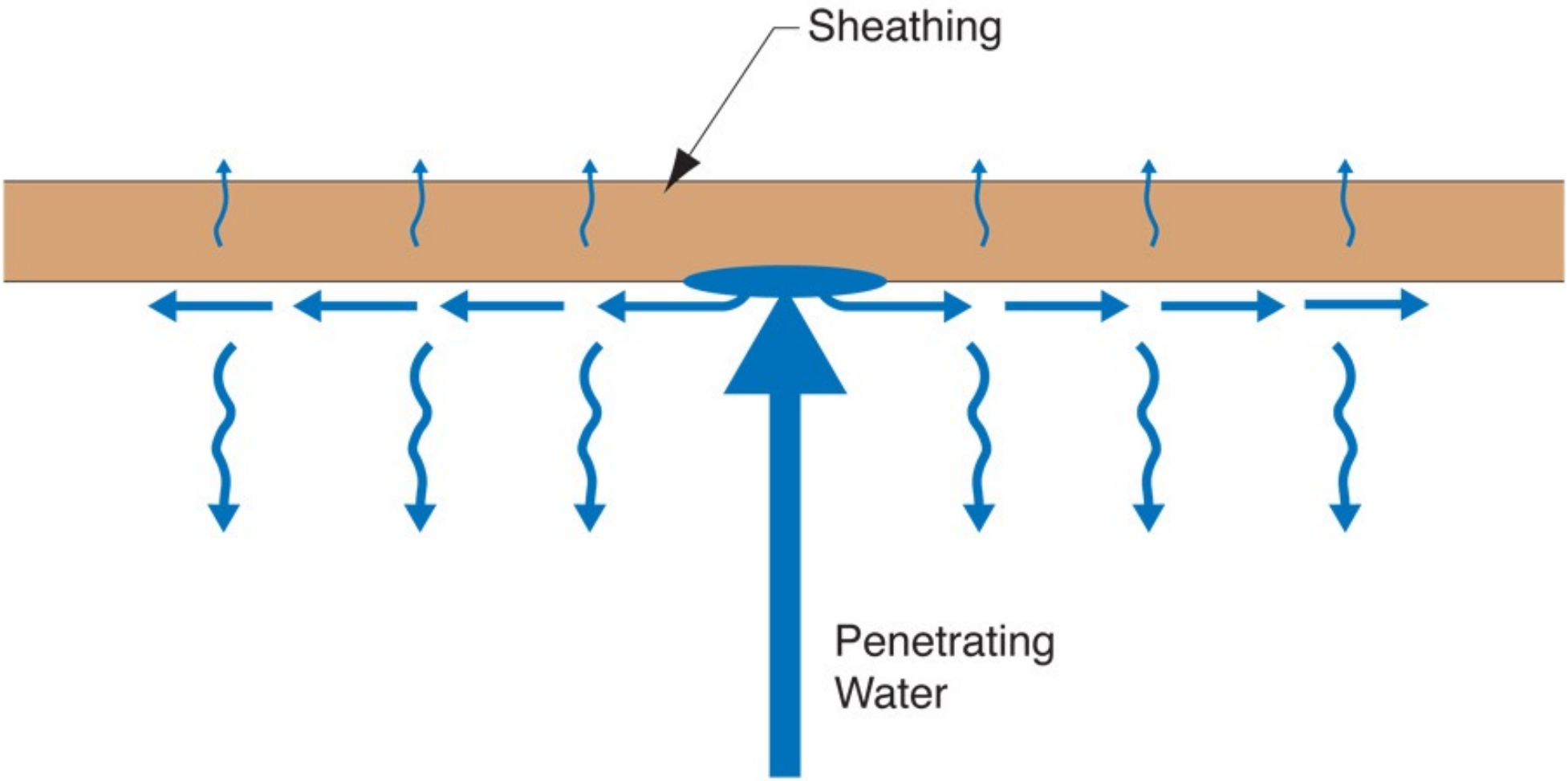
Inward Vapor Drive

Energy




Water Vapor Permeance of Sheathing Materials
Water Vapor Permeance, US perms
100
90
80
70
60
50
40
30
20
10
0
Dry Cup
Wet Cup
Plywood
OSB
0
10
20
30
40
50
60
70
80
90
100
Mean Relative Humidity, %

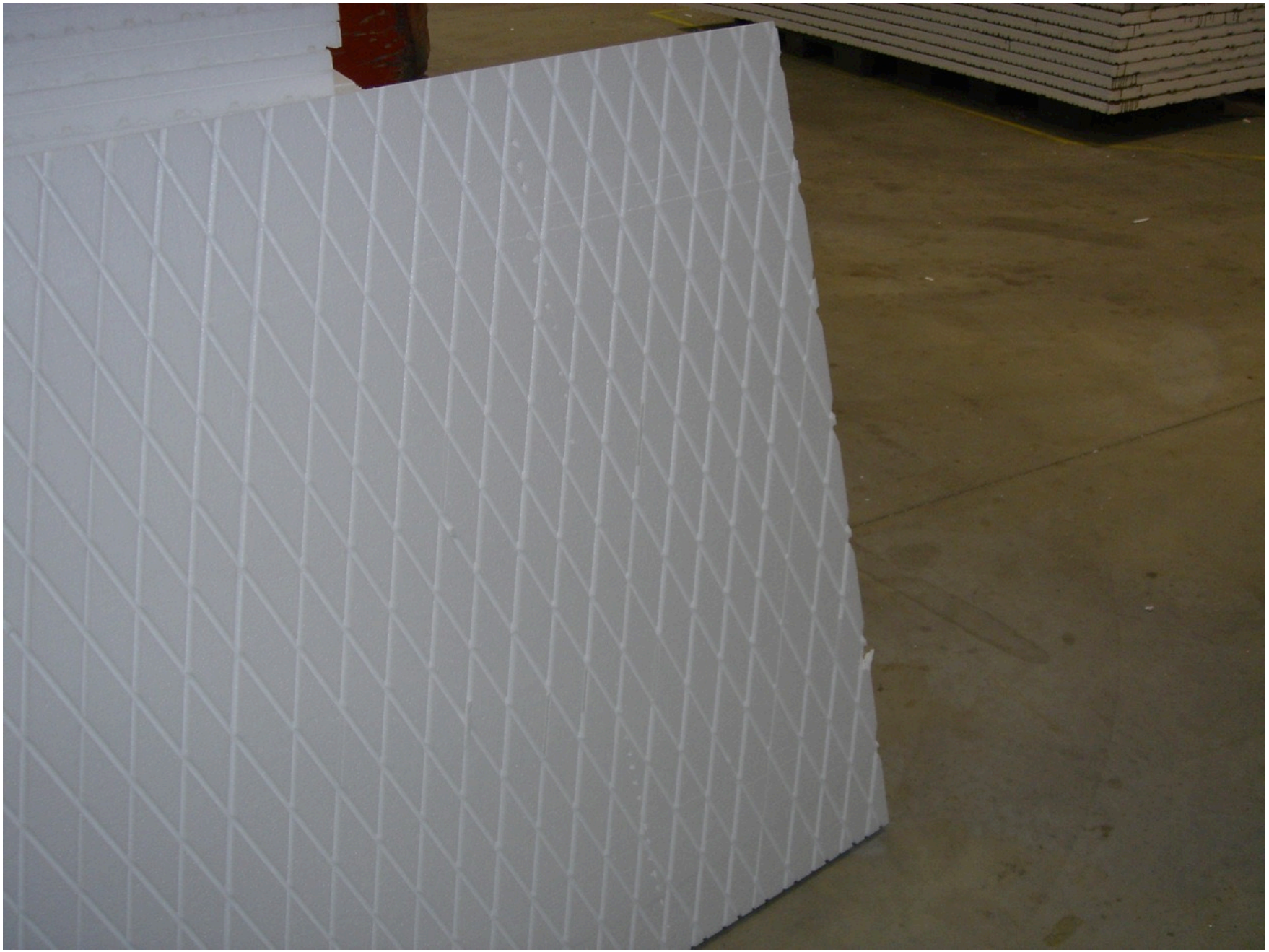

Sheathing
Penetrating
Water


Sheathing
Penetrating
Water

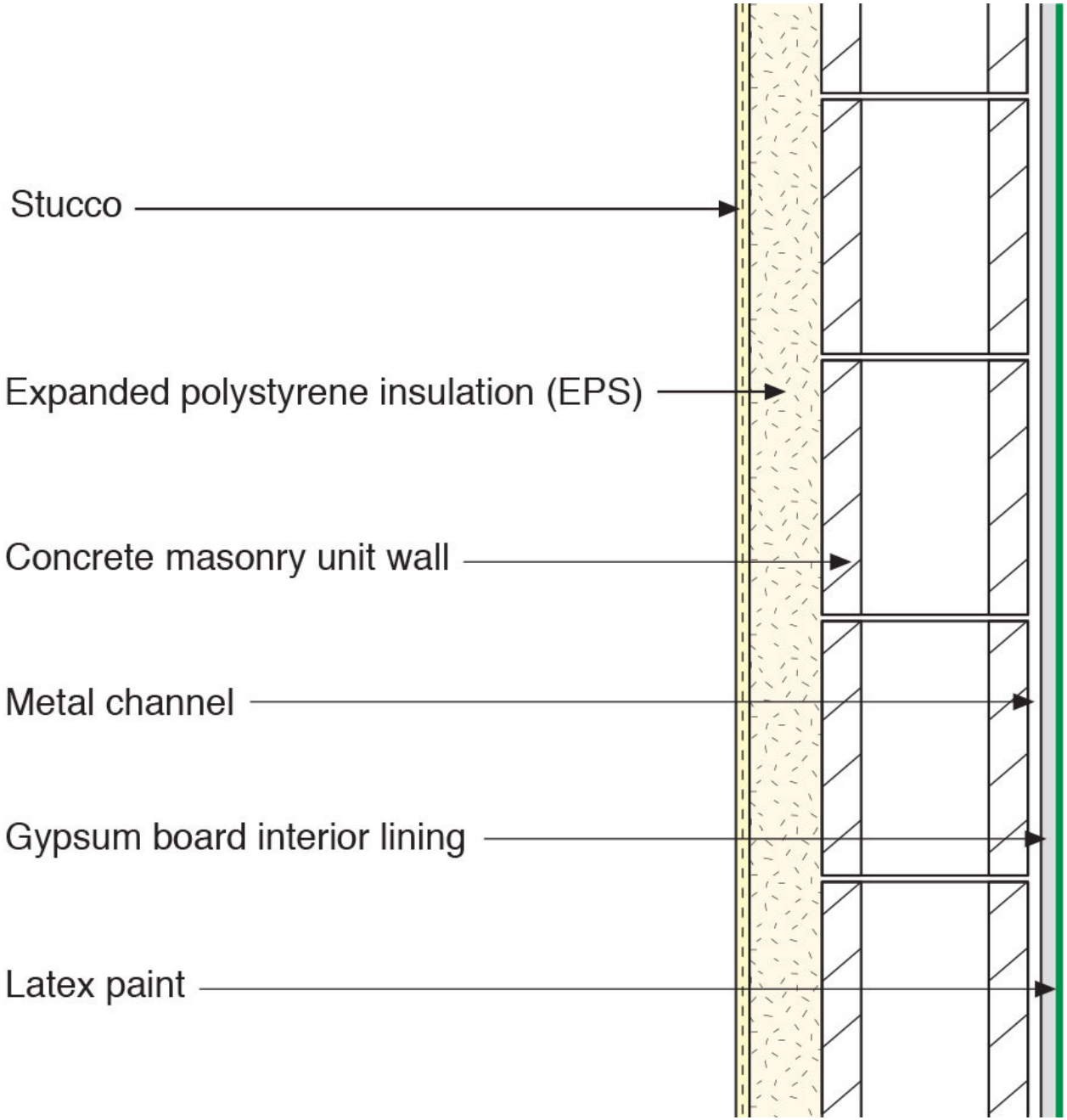
Rain Screen

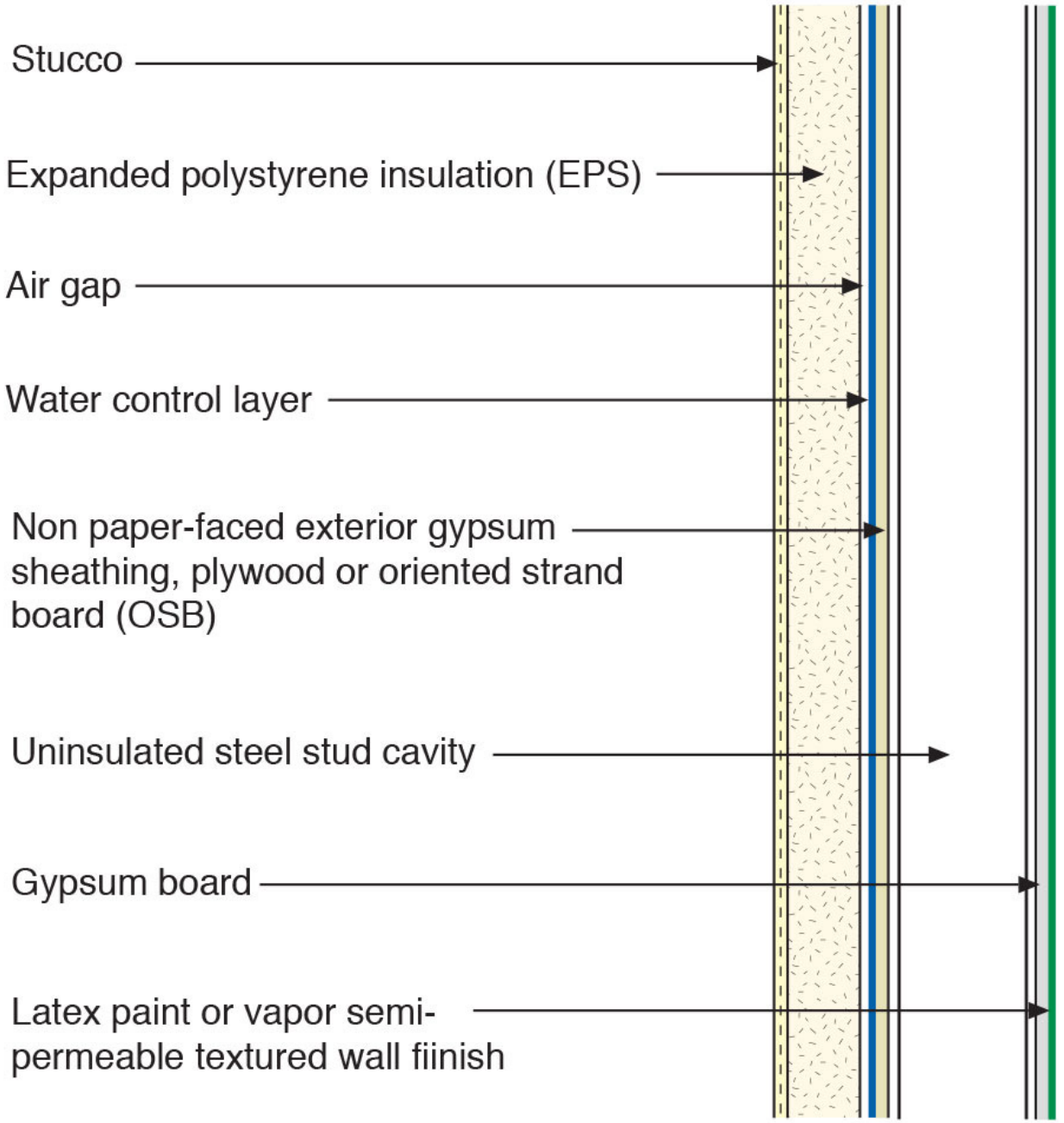

yvek
omeWrap
Tyvek
HomeWrap

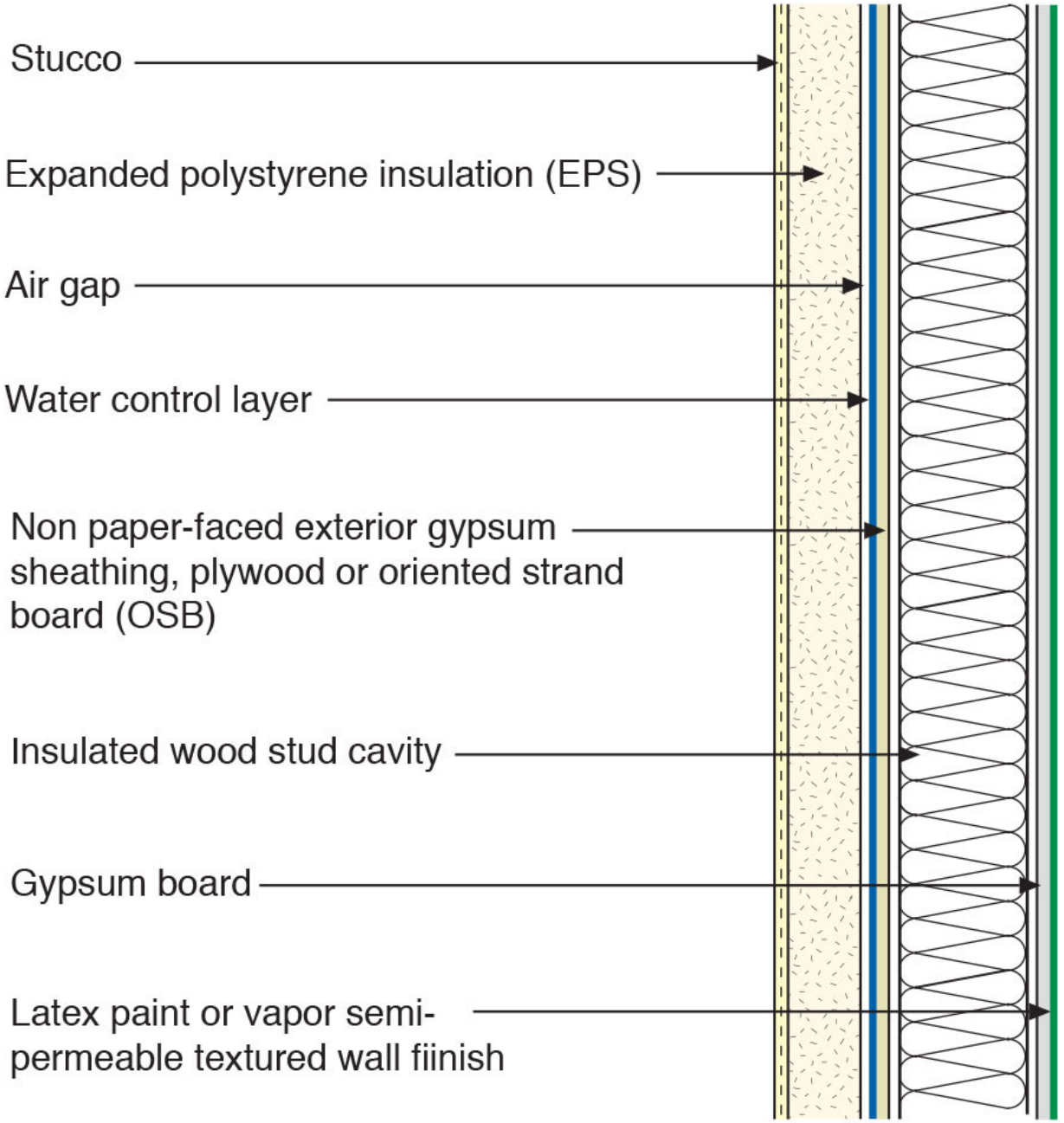

DuPont
Tyvek
Tape

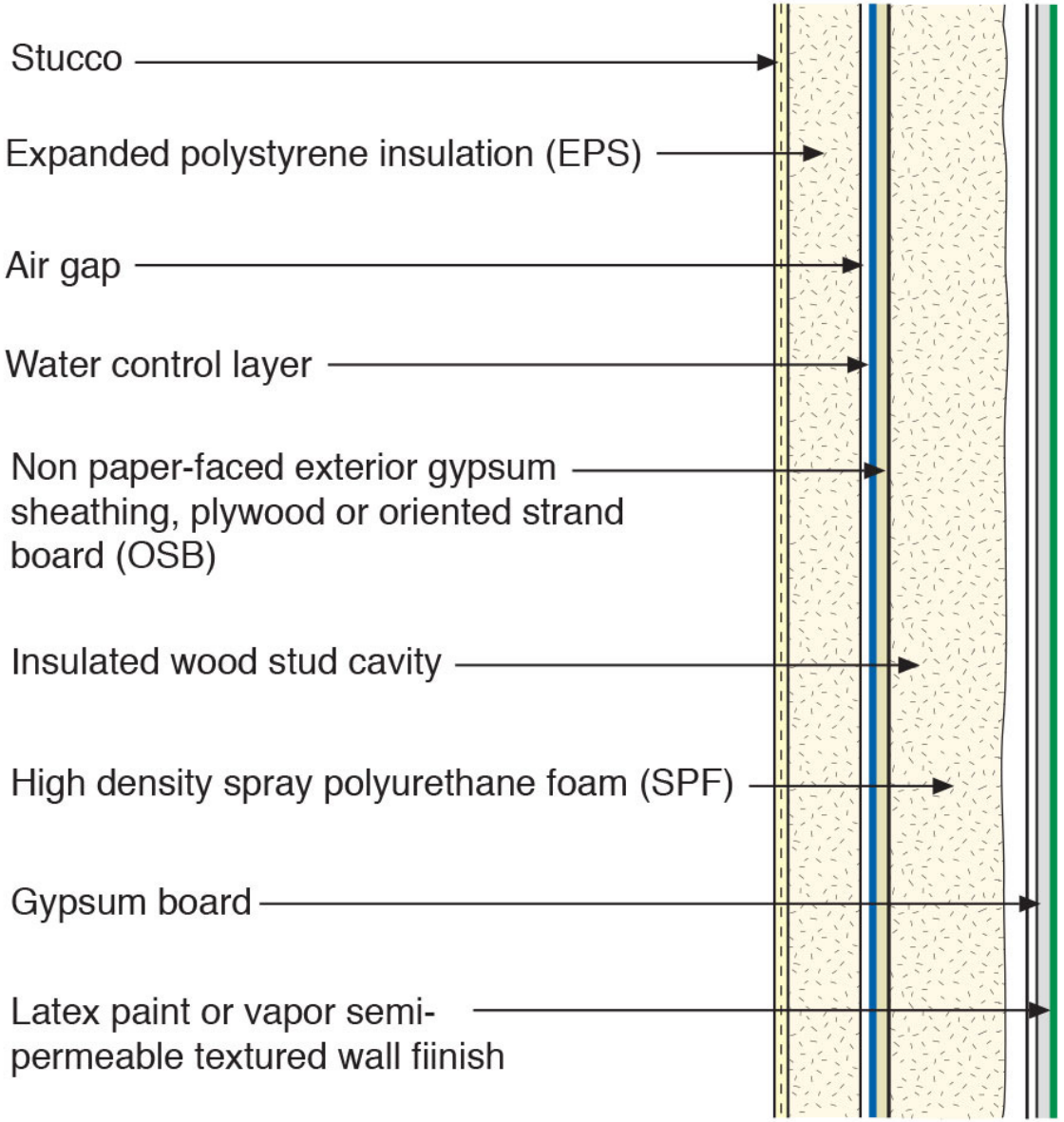


EIFS No Longer Has Issues


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


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


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


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

Back To Stucco….





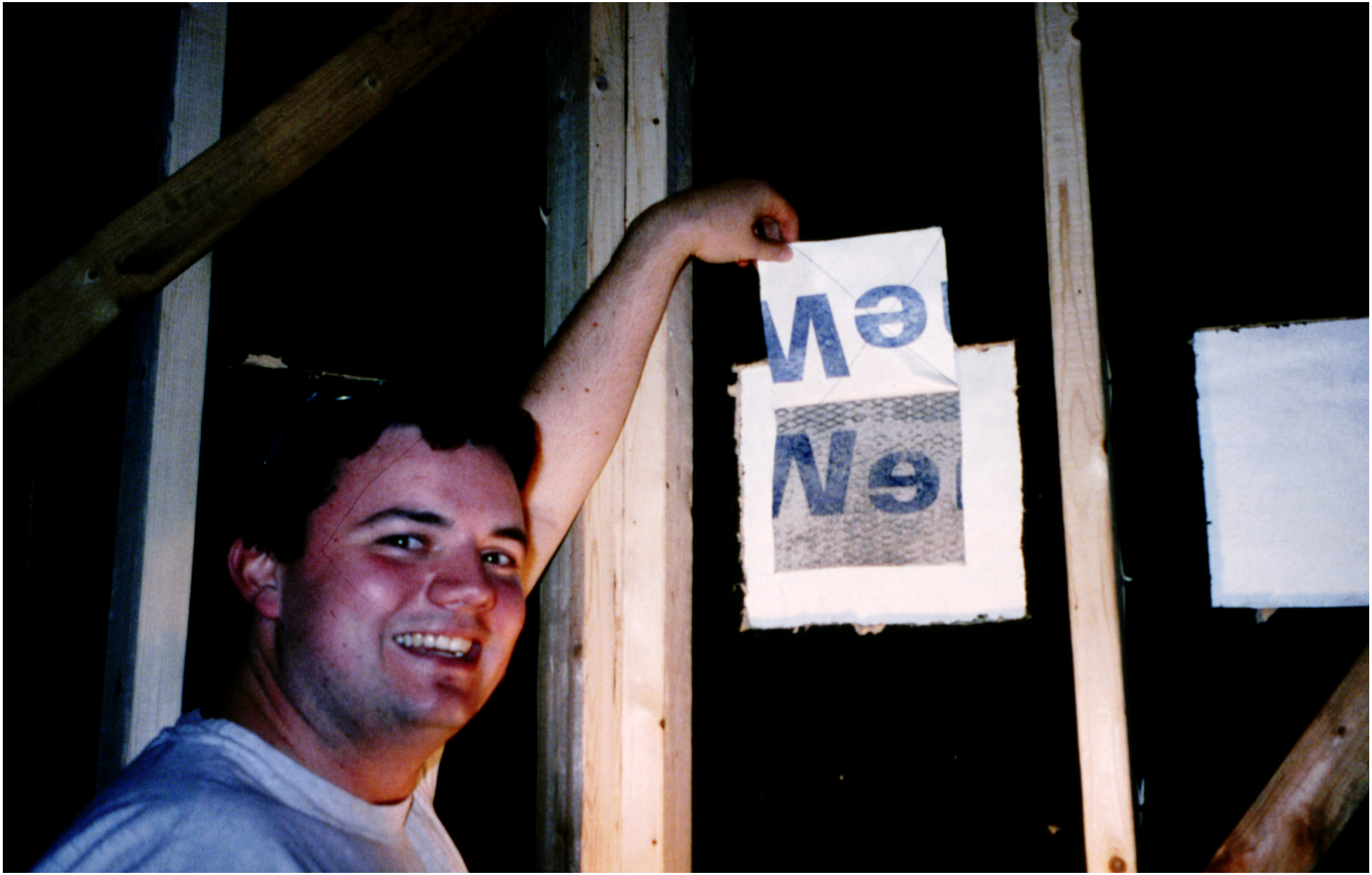


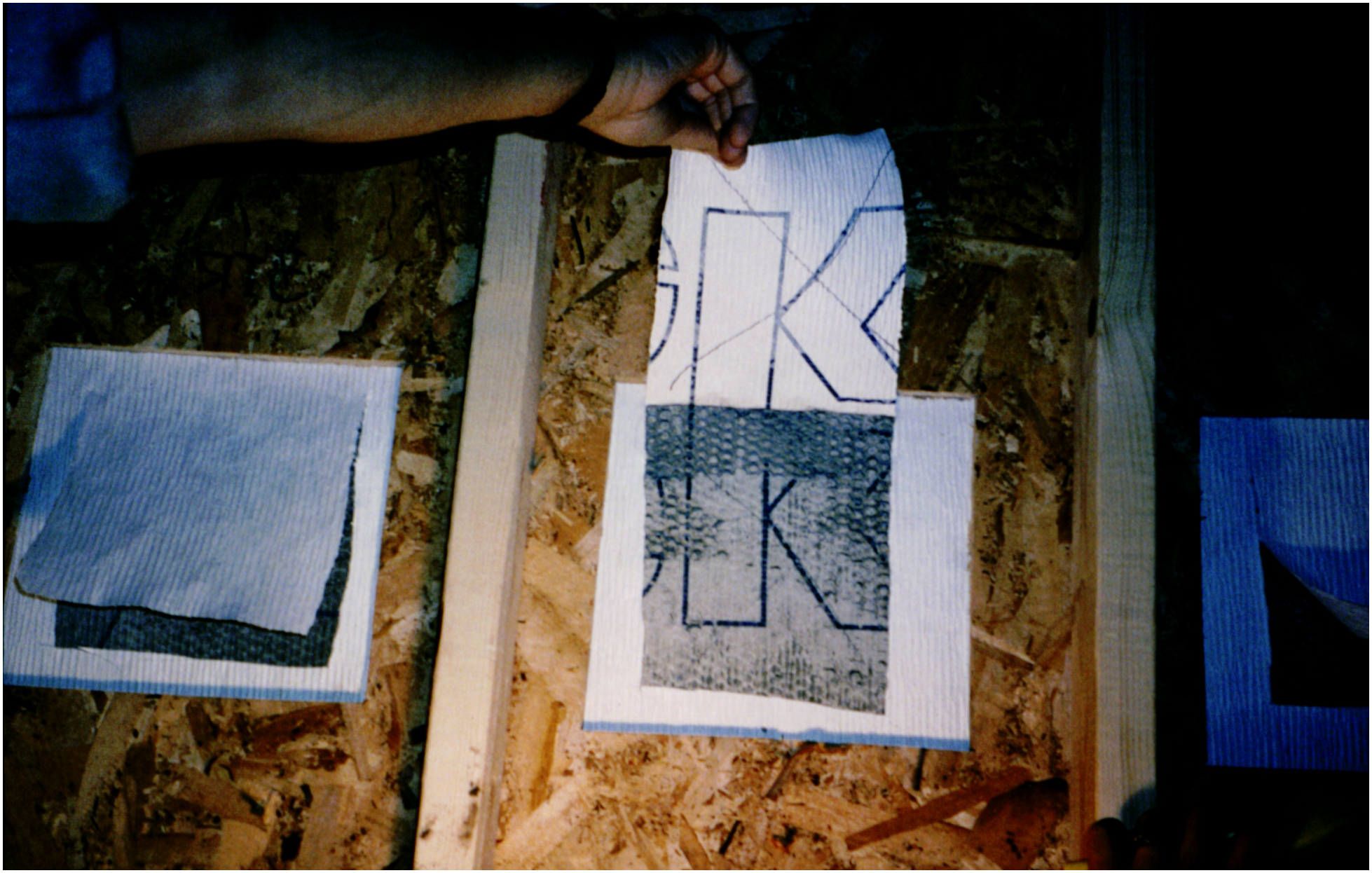



3514
DUPONT
Finish

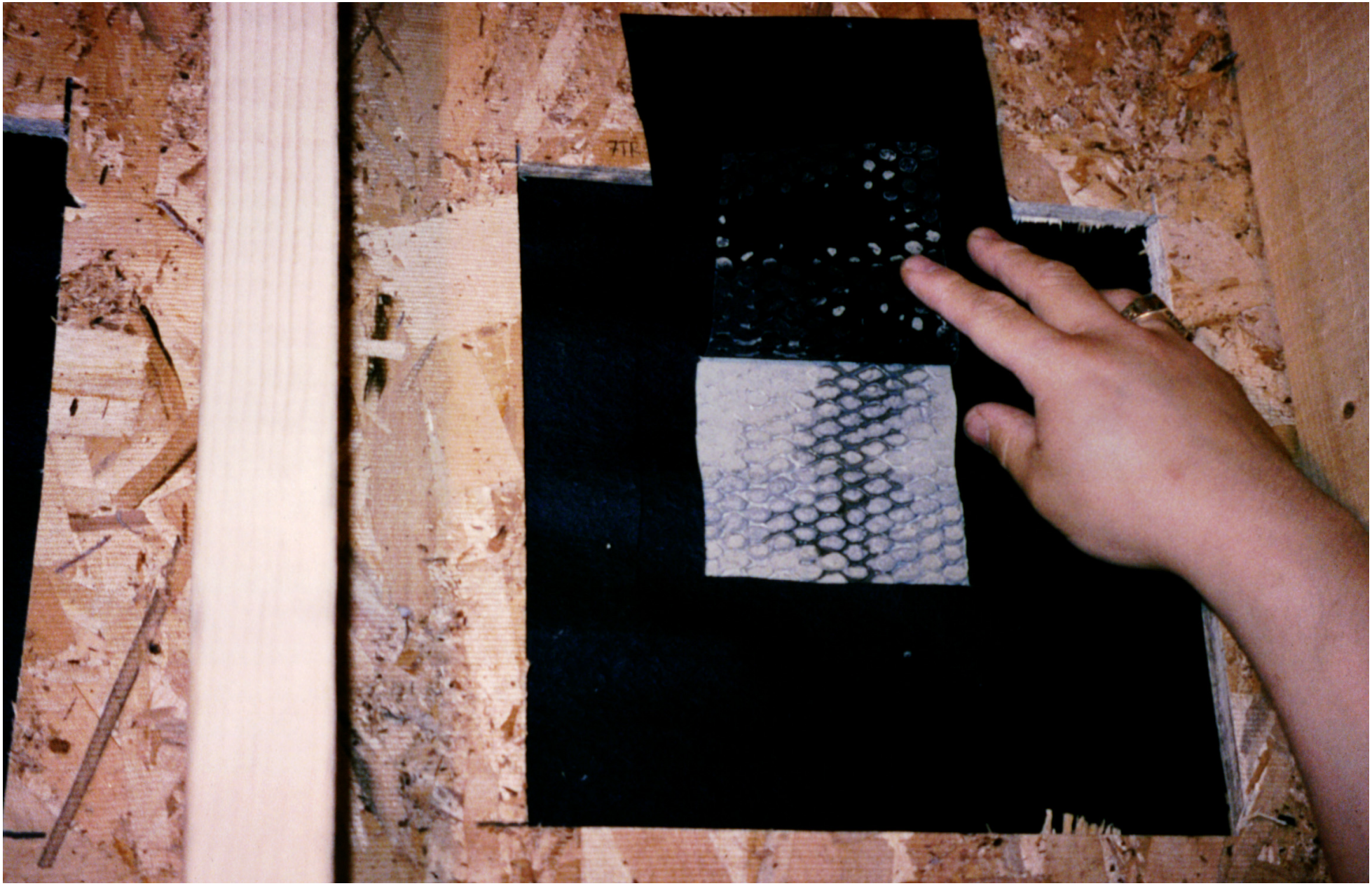
Side Trip To My Backyard….



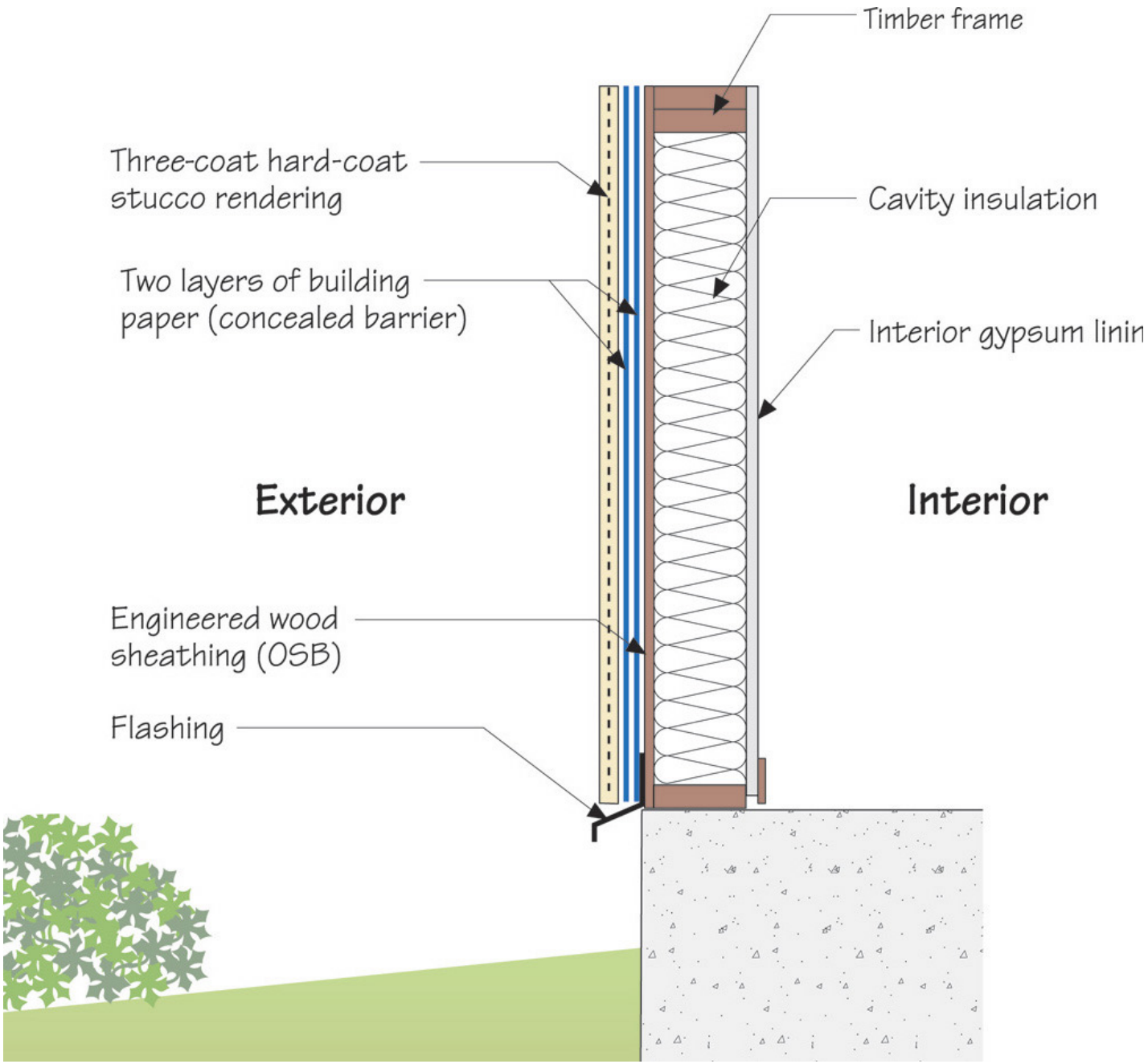









GYPSUM


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

“Lumpy Stucco”….

Should Have Been The Big Warning….







Side Trip To Vancouver….


6'8" CLEARANCE 2.0m








OCT 14 2003


OCT 14 2003

Back To America….Pennslyvania….

And Then Pretty Much Anywhere It Rains…








JLG ULTRA
1250AJP
JLG


LOWE'S











Back To Lumpy Stucco….









Easy Solution….




Genie Z-60/34
4x4


VRAP
TYVEK.COM
USA

Inward Vapor Drive

Exterior Conditions

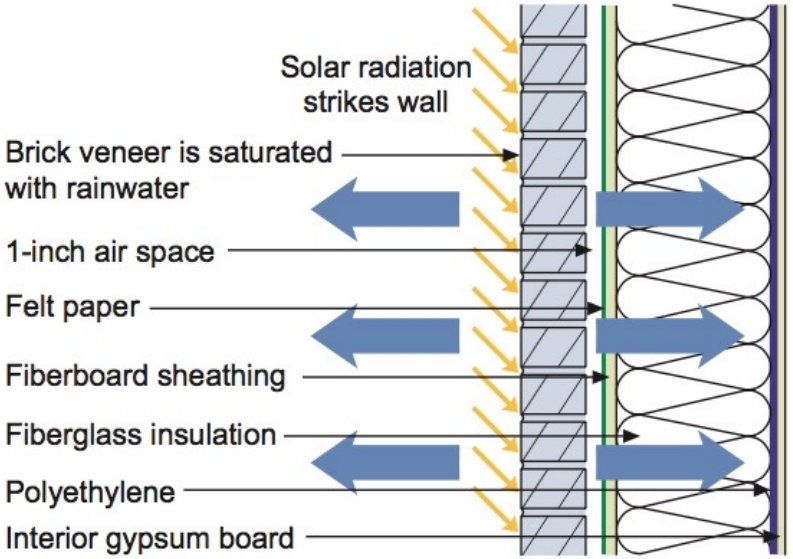
Temperature: 80°F
Relative humidity: 75%
Vapor pressure: 2.49 kPa

Conditions within Cavity:

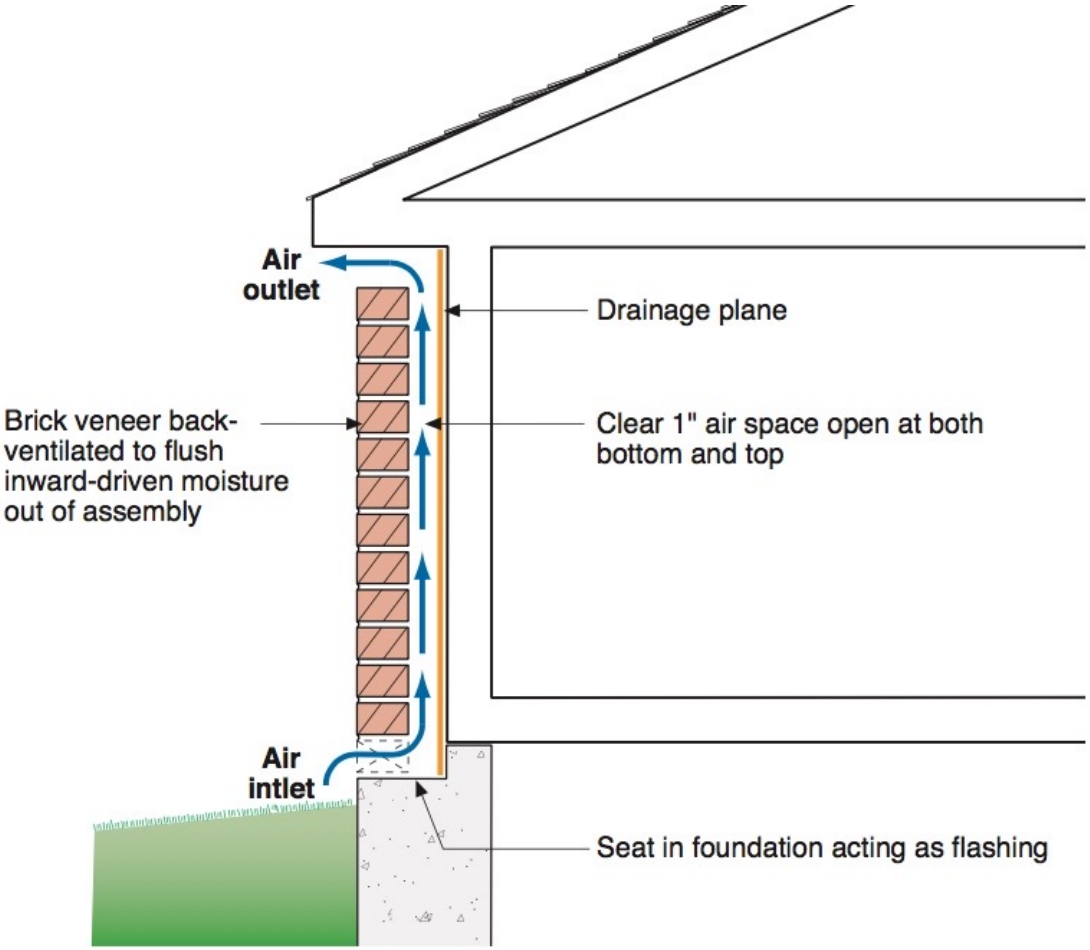
Temperature: 100°F
Relative humidity: 100%
Vapor pressure: 6.45 kPa

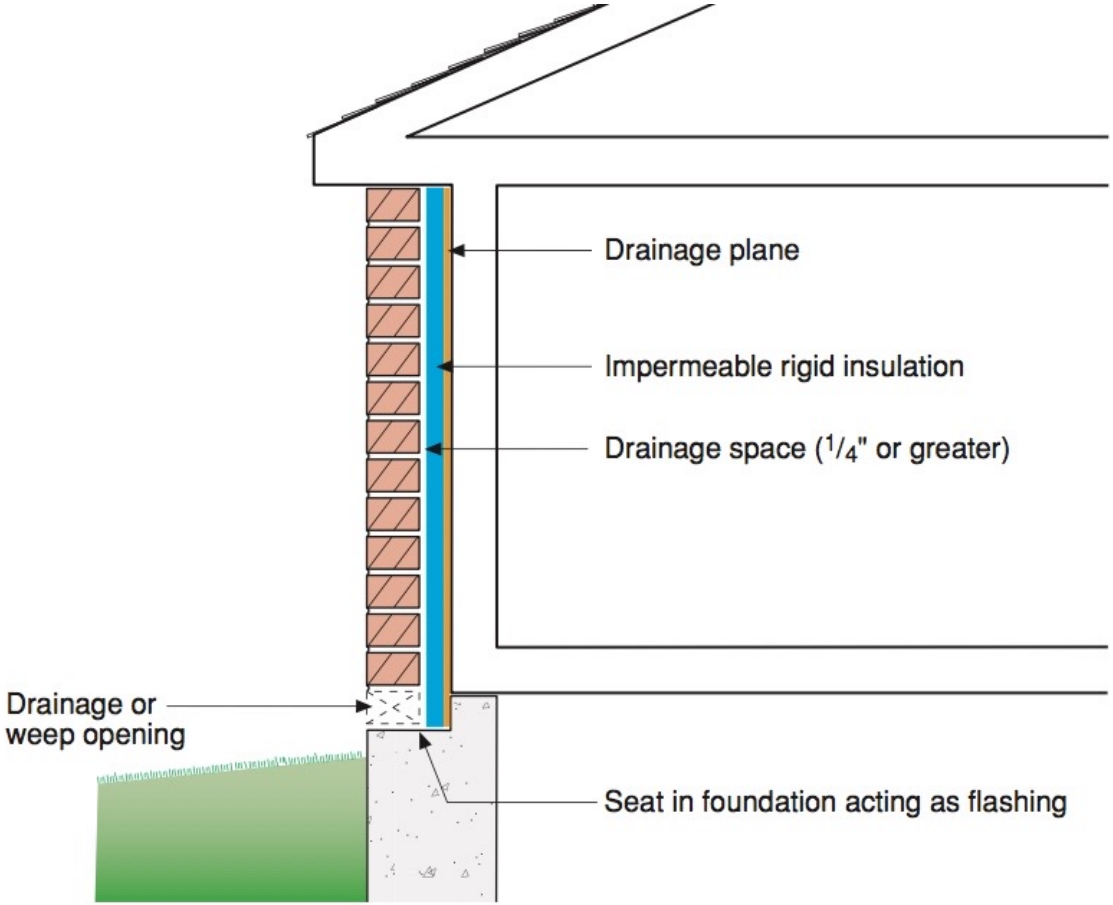
Interior Conditions

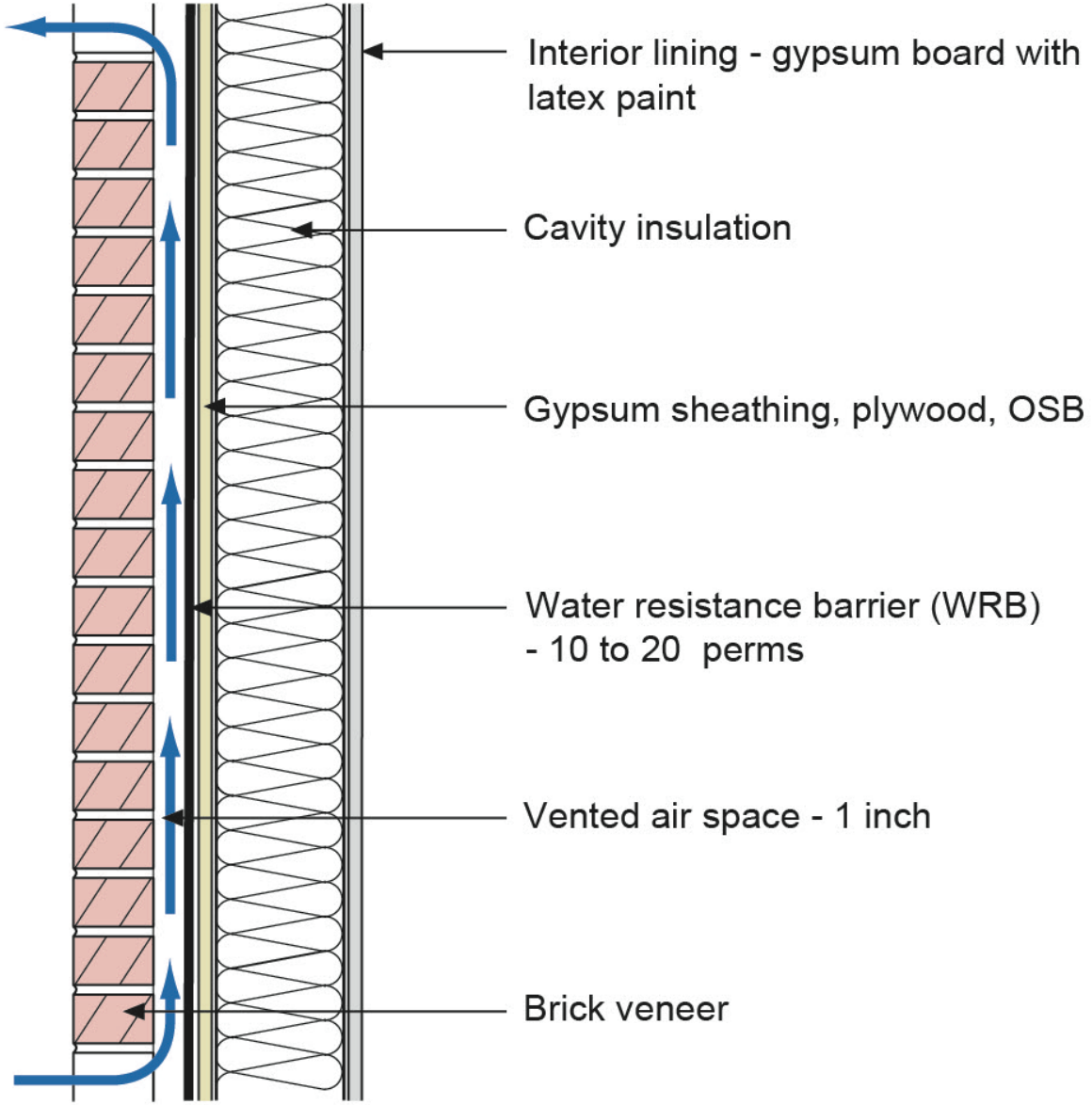
Temperature: 75°F
Relative humidity: 60%
Vapor pressure: 1.82 kPa

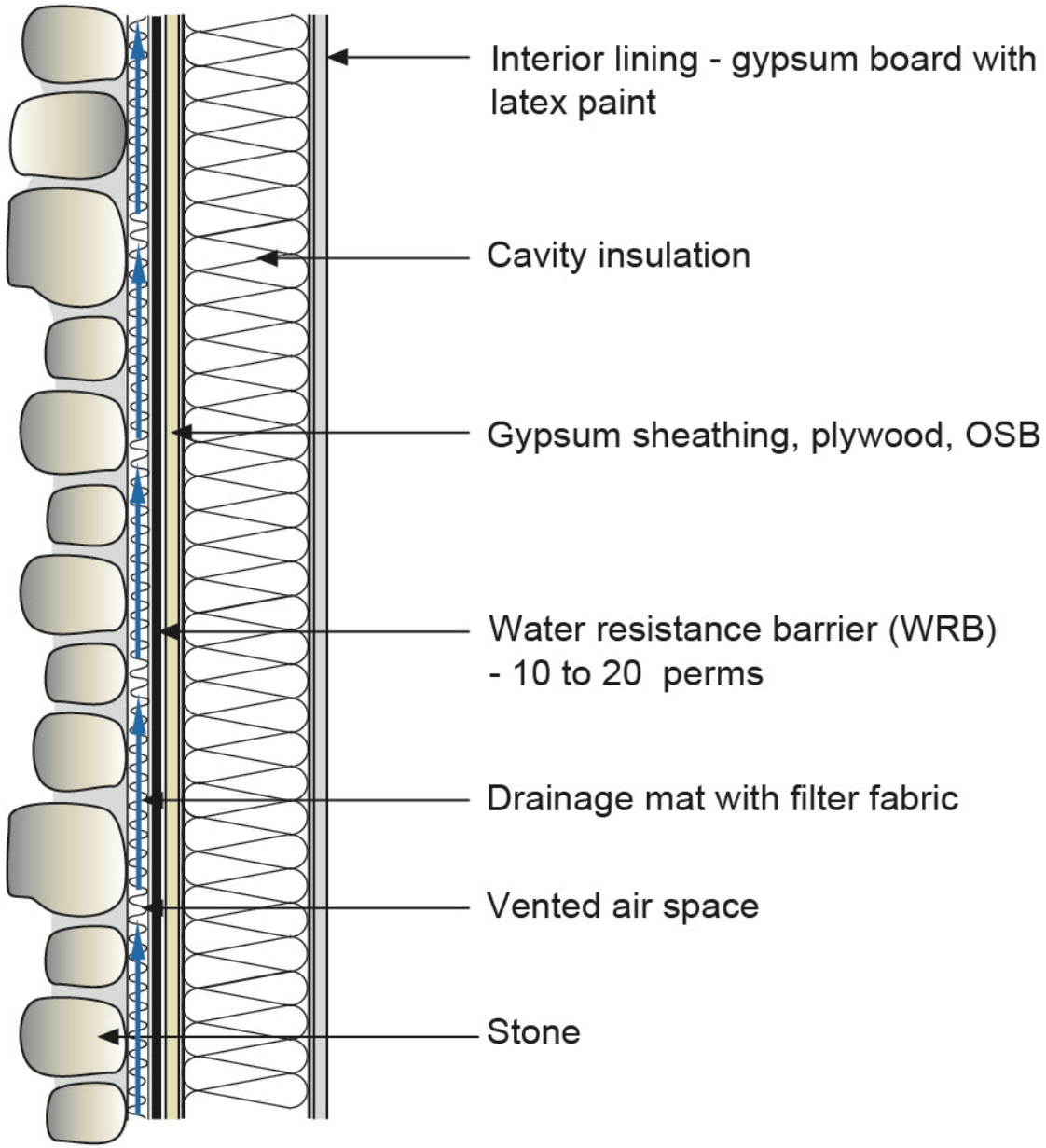


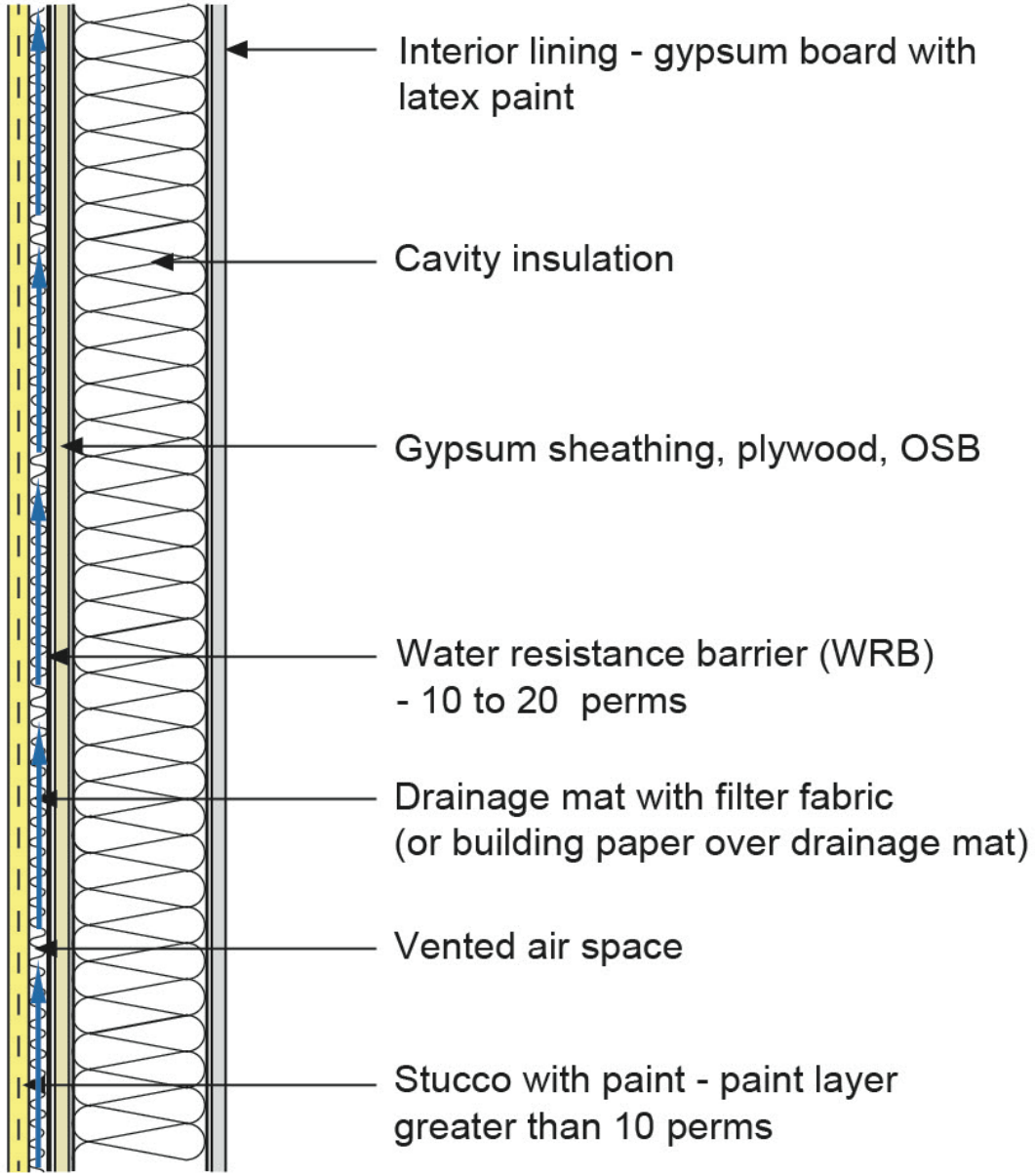
Vapor is driven both inward and outward by a high vapor pressure differential between the brick and the interior and the brick and the exterior.

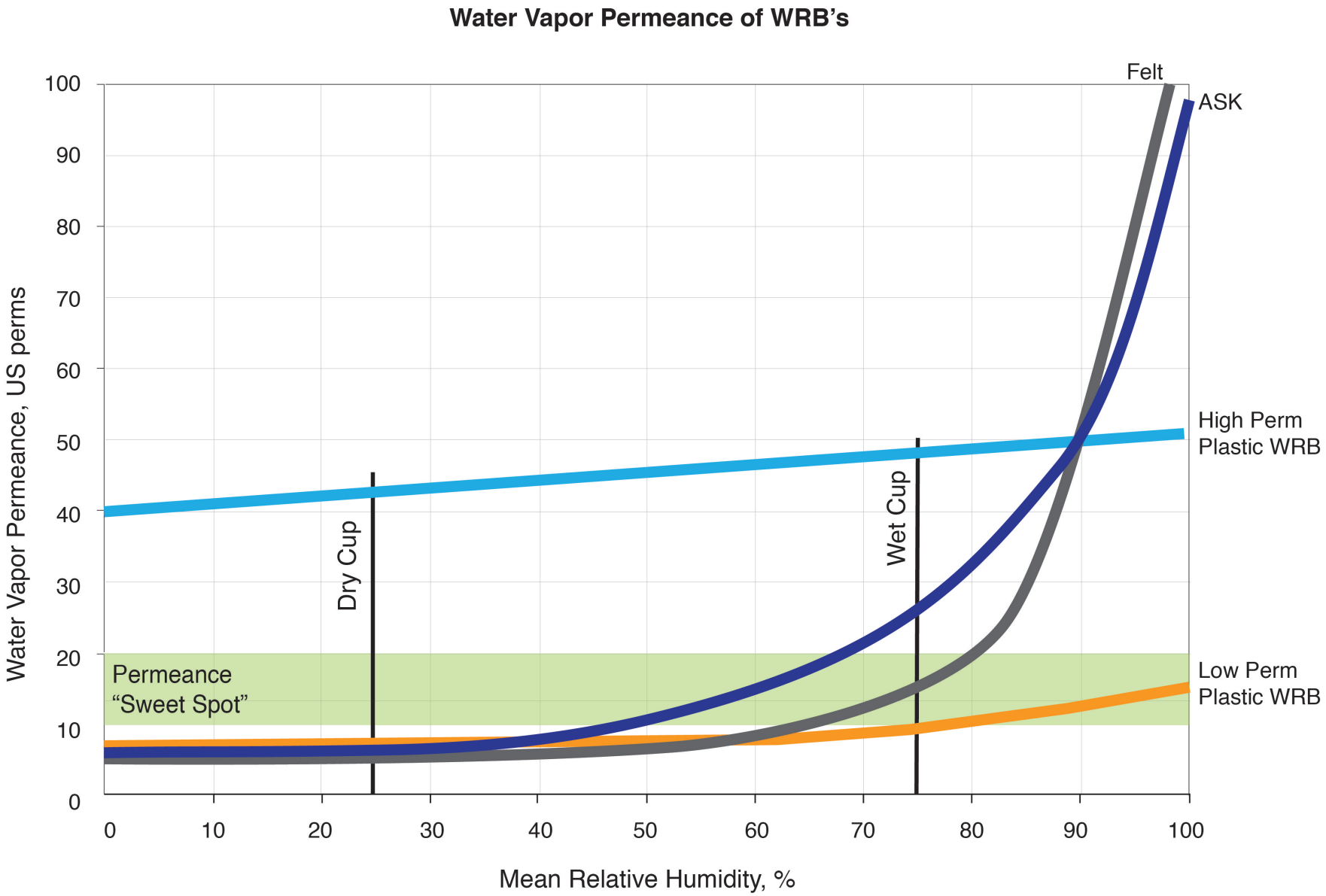

Air outlet
Drainage plane
Brick veneer back-ventilated to flush inward-driven moisture out of assembly
Clear 1" air space open at both bottom and top
Air intlet
Seat in foundation acting as flashing


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

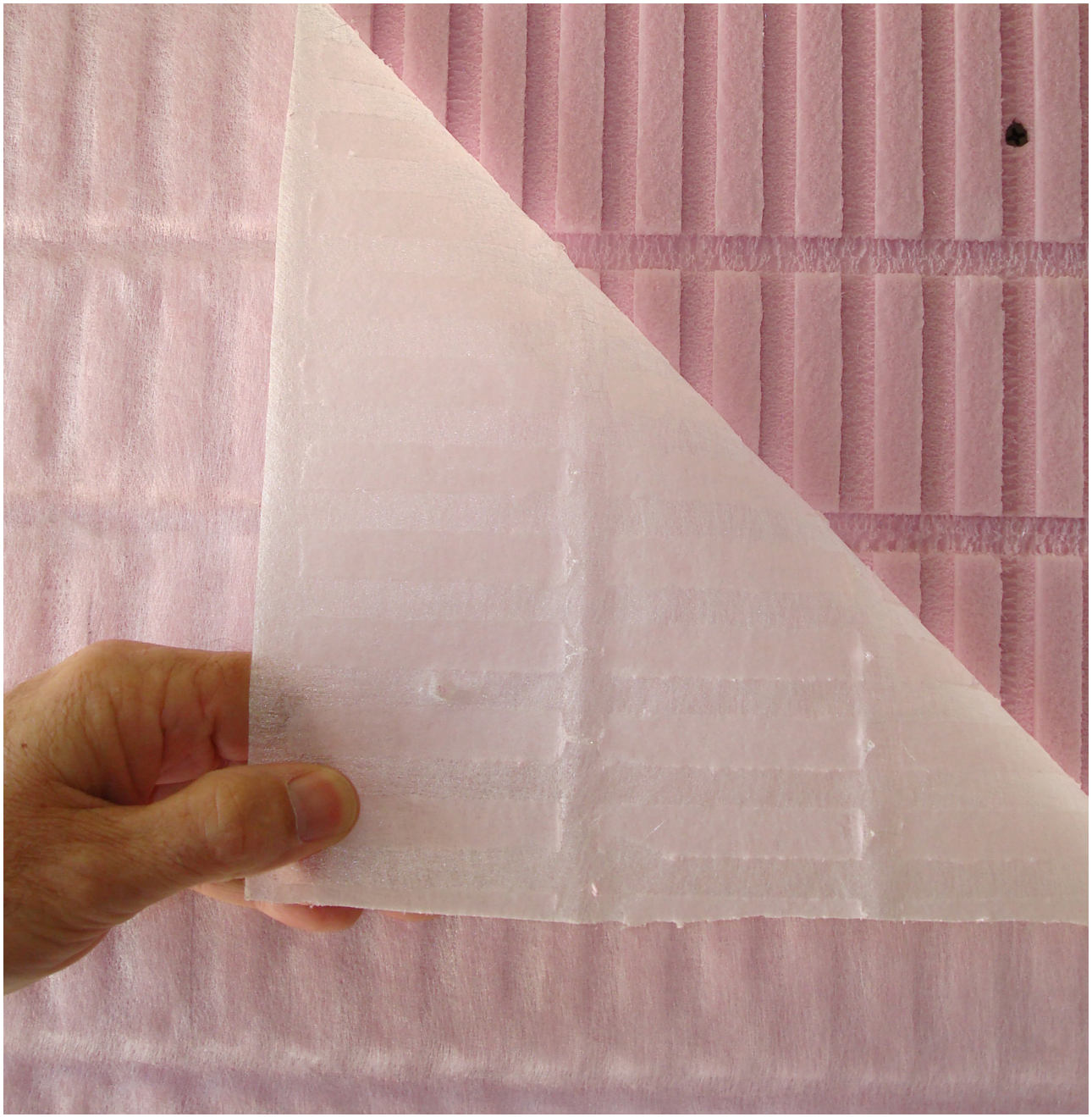

Interior lining - gypsum board with latex paint
Cavity insulation
Gypsum sheathing, plywood, OSB
Water resistance barrier (WRB) - 10 to 20 perms
Vented air space - 1 inch
Brick veneer


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


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

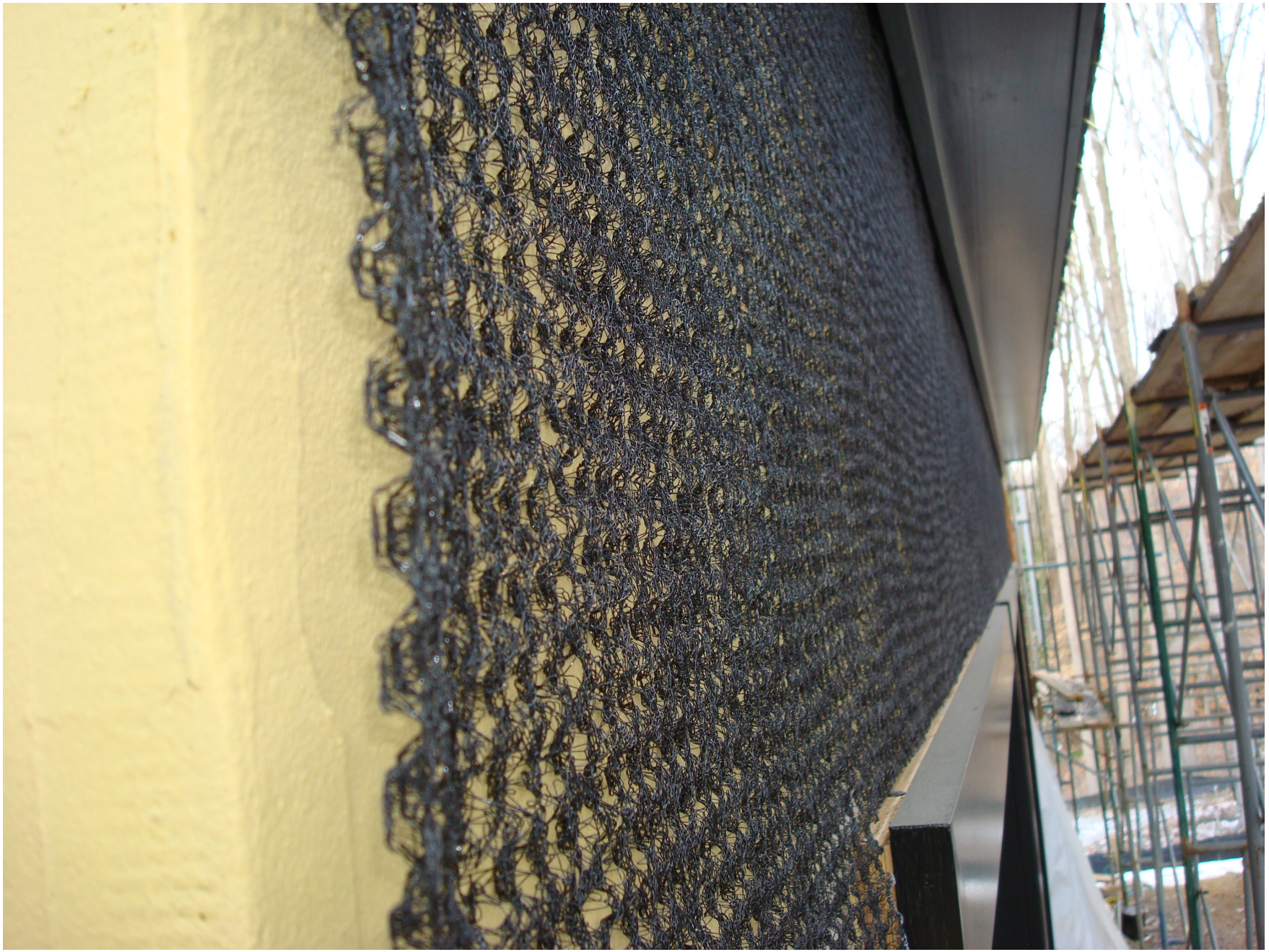

Water Vapor Permeance of WRB's
Water Vapor Permeance, US perms
Mean Relative Humidity, %
0
10
20
30
40
50
60
70
80
90
100
Felt
ASK
High Perm
Plastic WRB
Low Perm
Plastic WRB
Dry Cup
Wet Cup
Permeance
"Sweet Spot"











Recommendations….

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

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

Don’t install interior vapor barriers

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

Recommendations….

Barrier works in Florida over block

Barrier does not work in Florida over OSB

Don’t install interior vapor barriers in Florida

Don’t drain a drained system into a barrier system

Pressures and IAQ

Definition of a Problem

People

Pollutant (hot, wet, UV, ozone)

Path

Pressure

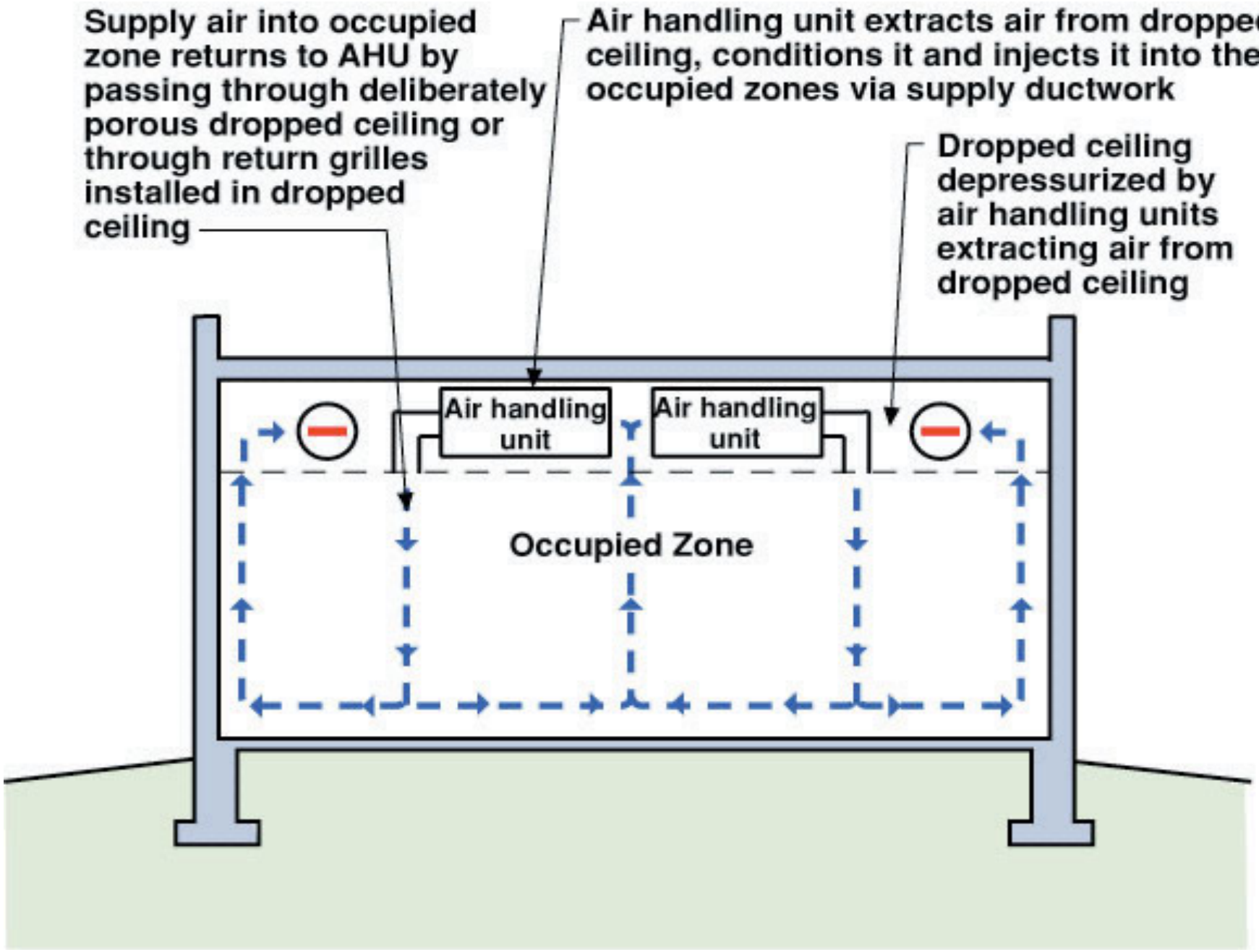


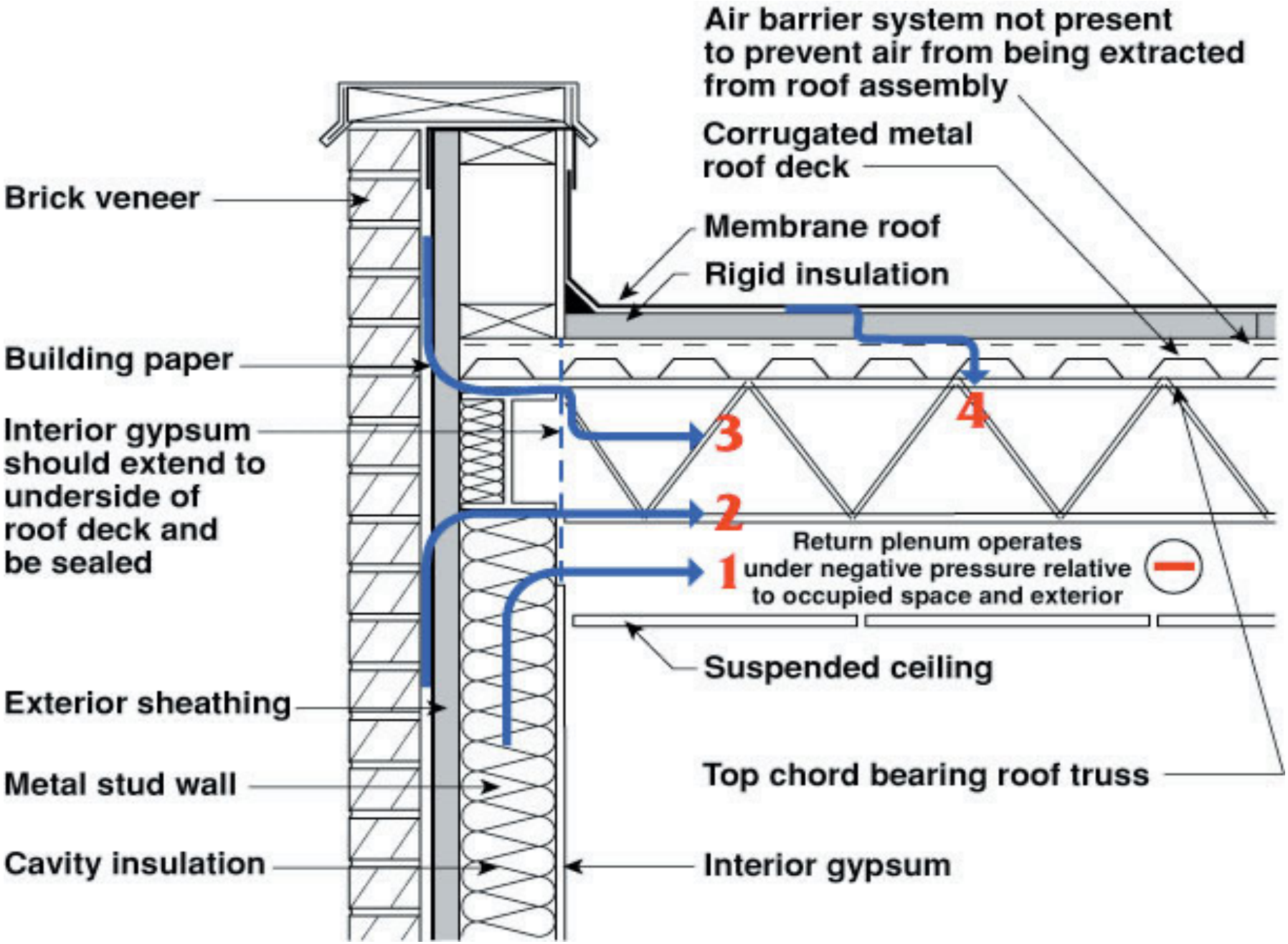

PUBLIC SERVICES
PUBLIC SERVICES

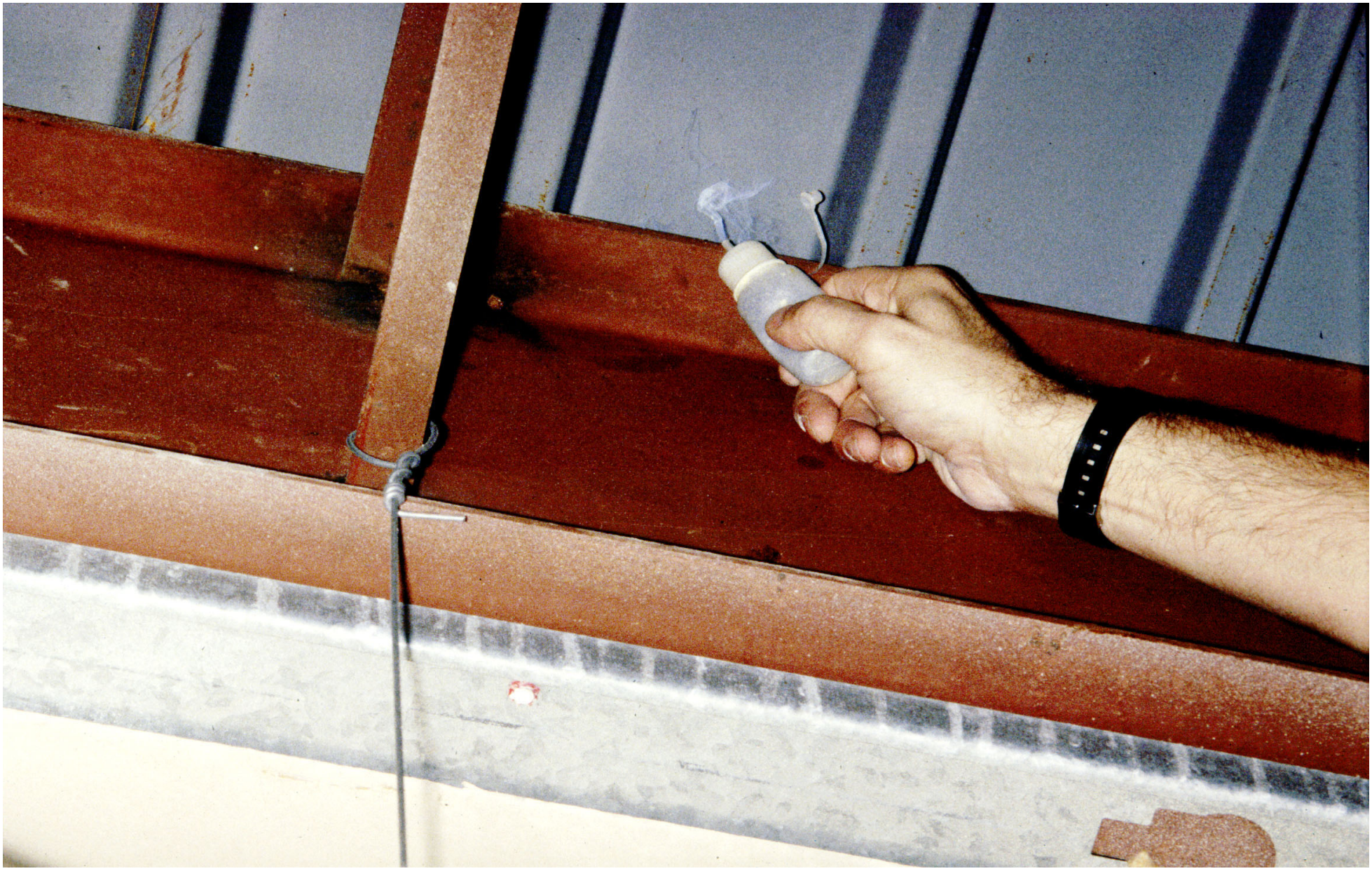

STOP

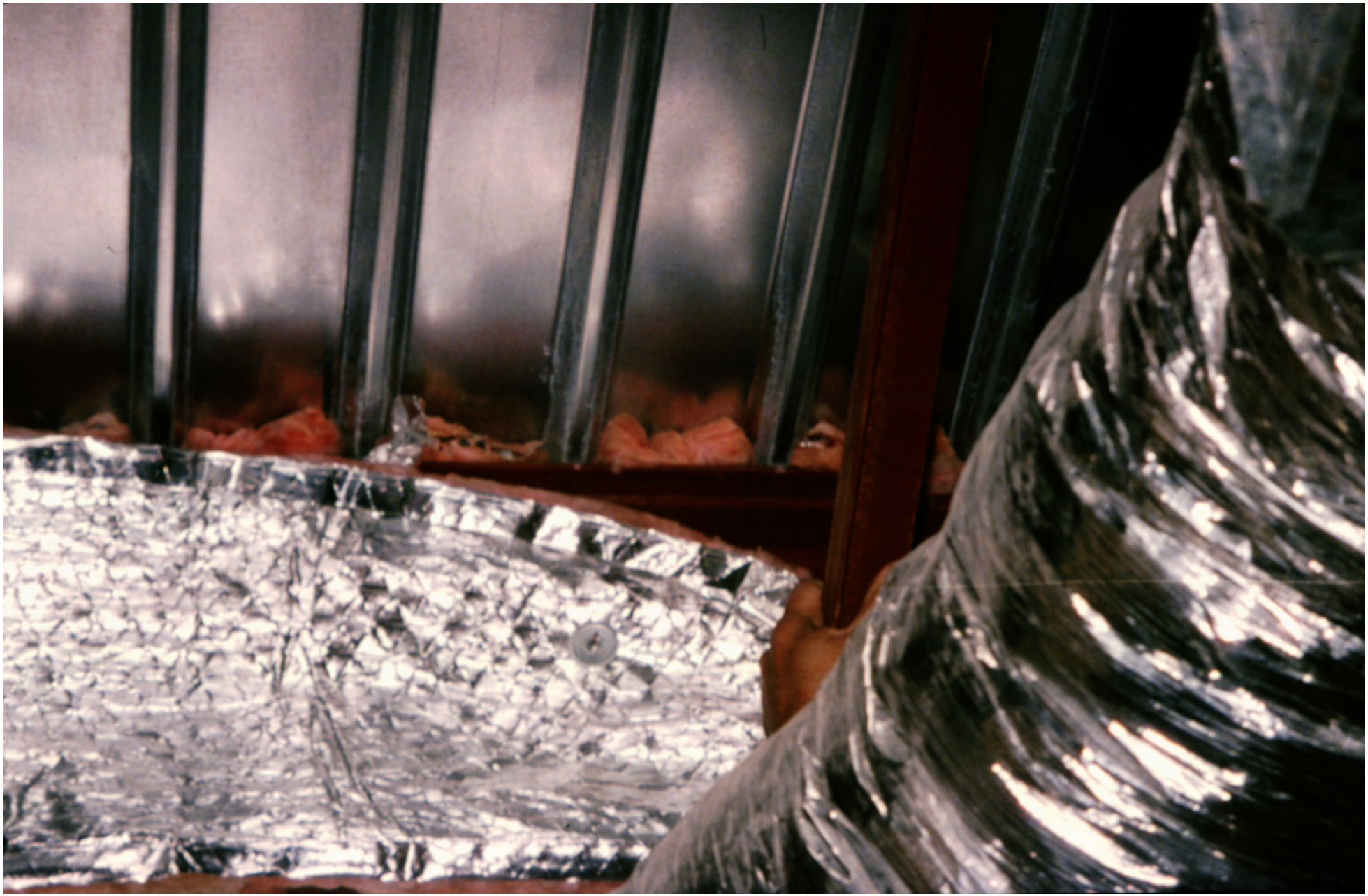



EXIT


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


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







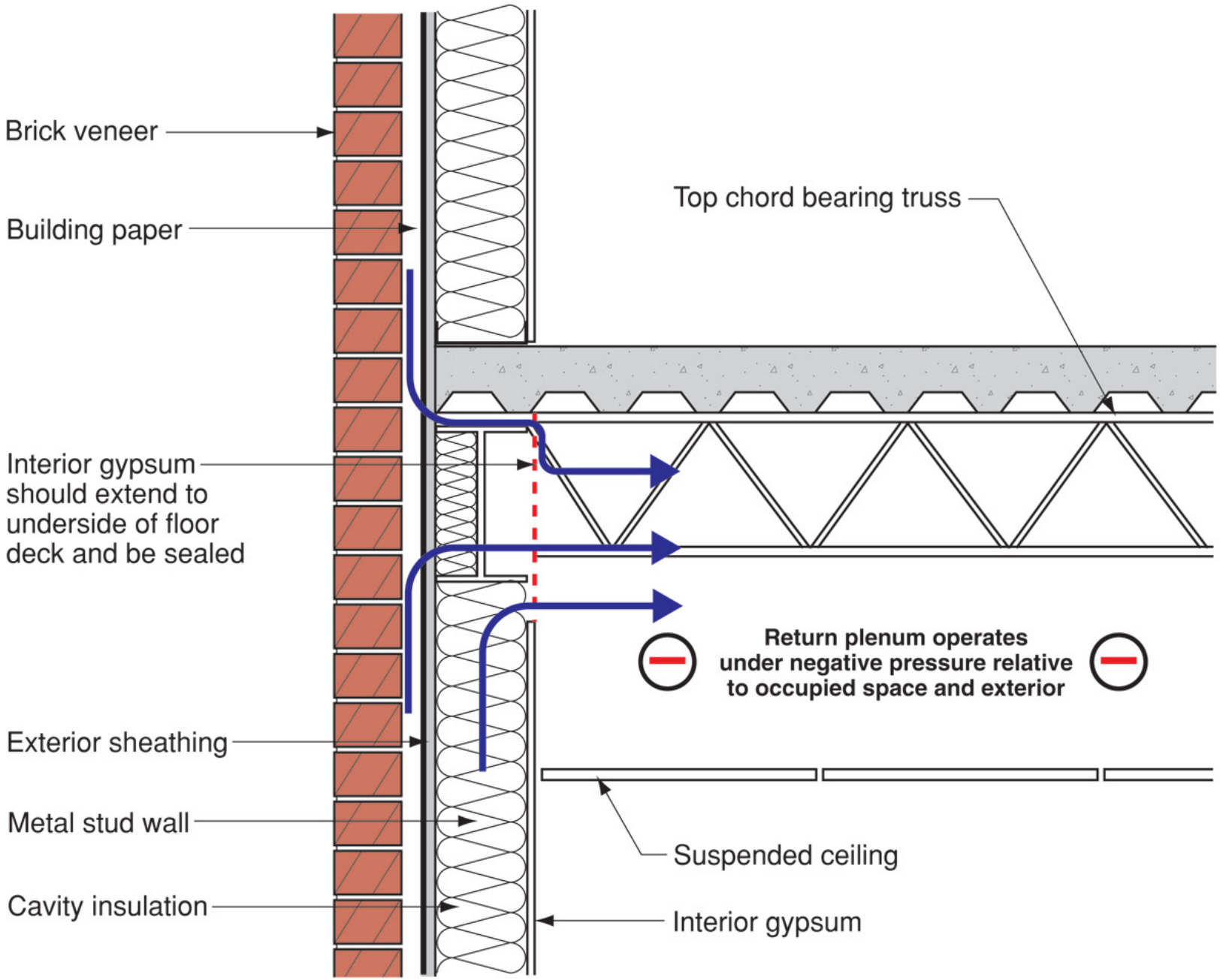





Tyvek


RE COMPANY




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



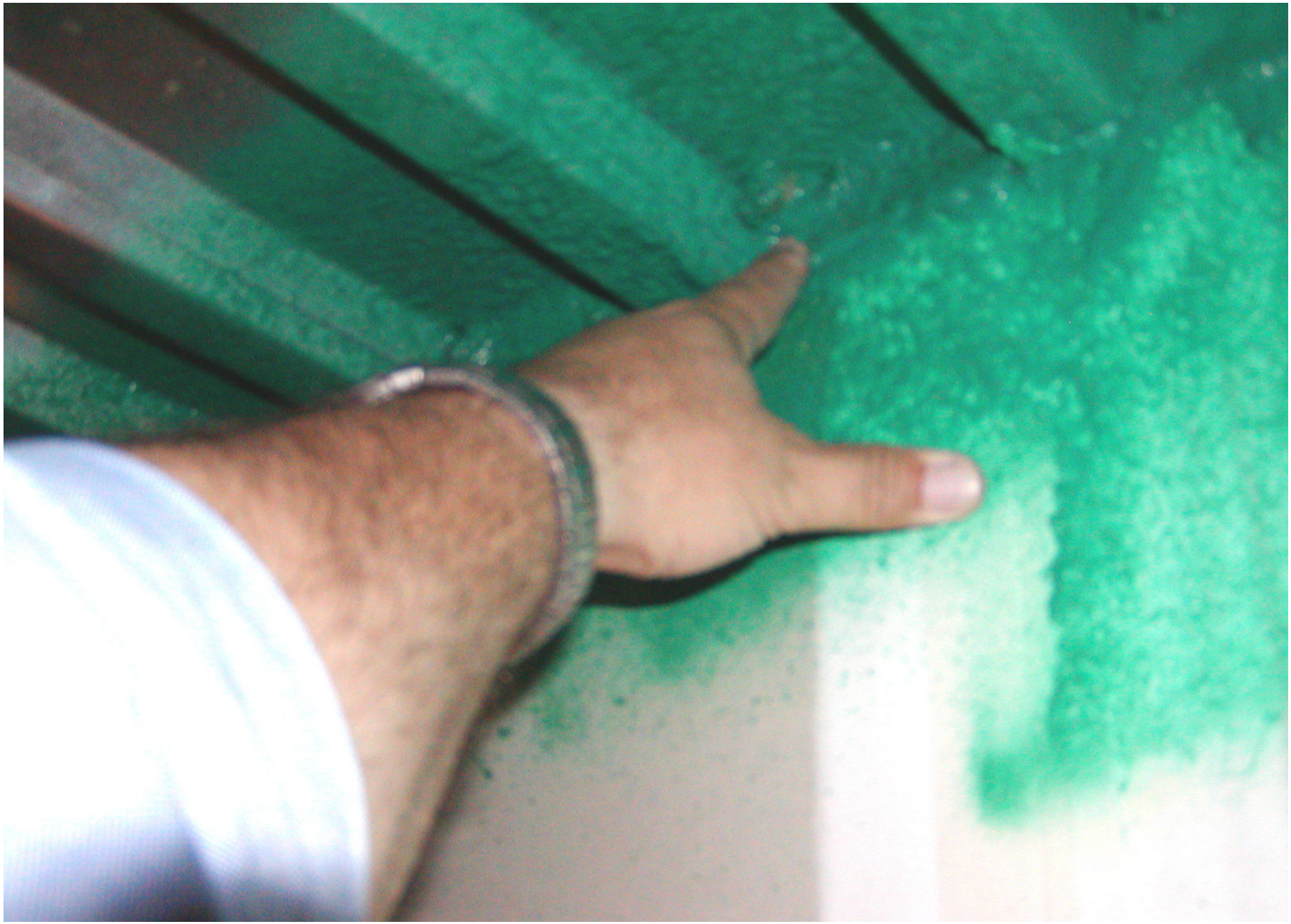


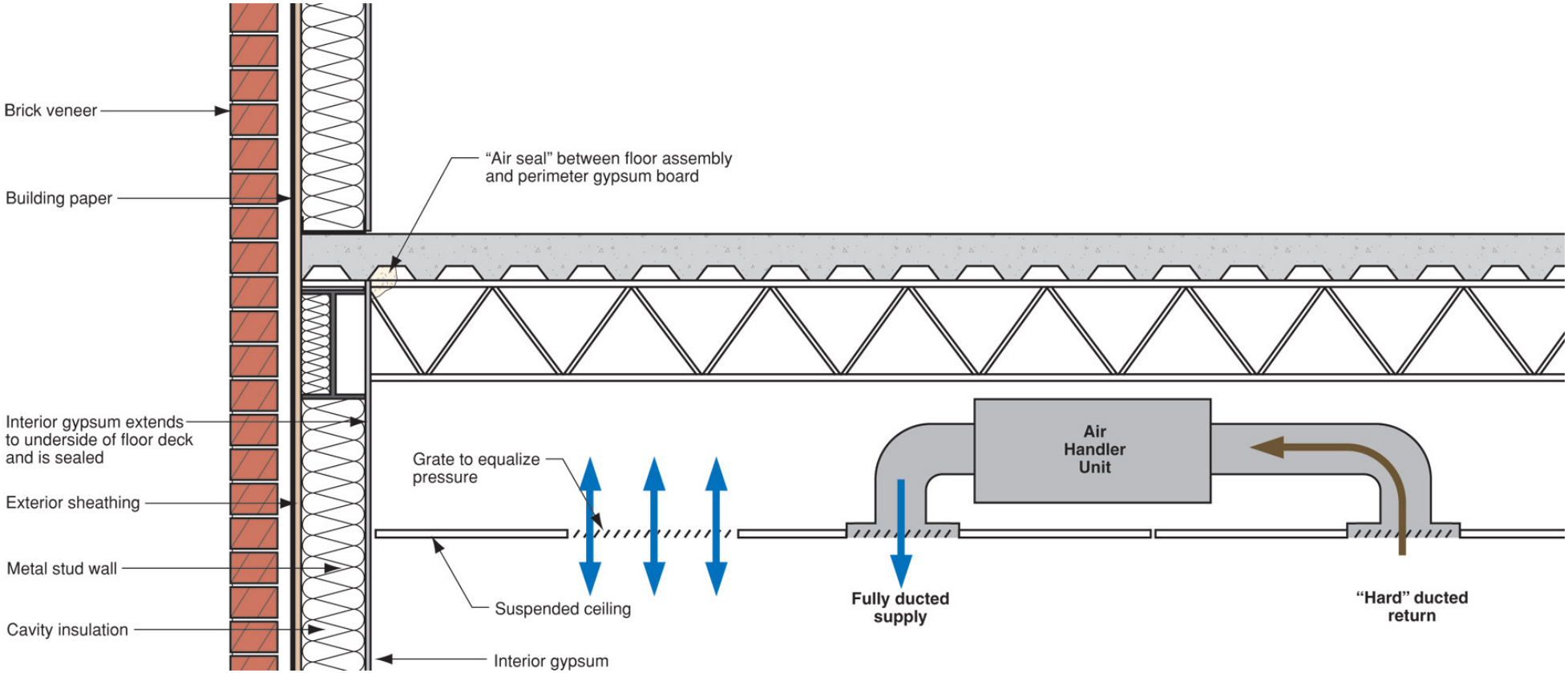


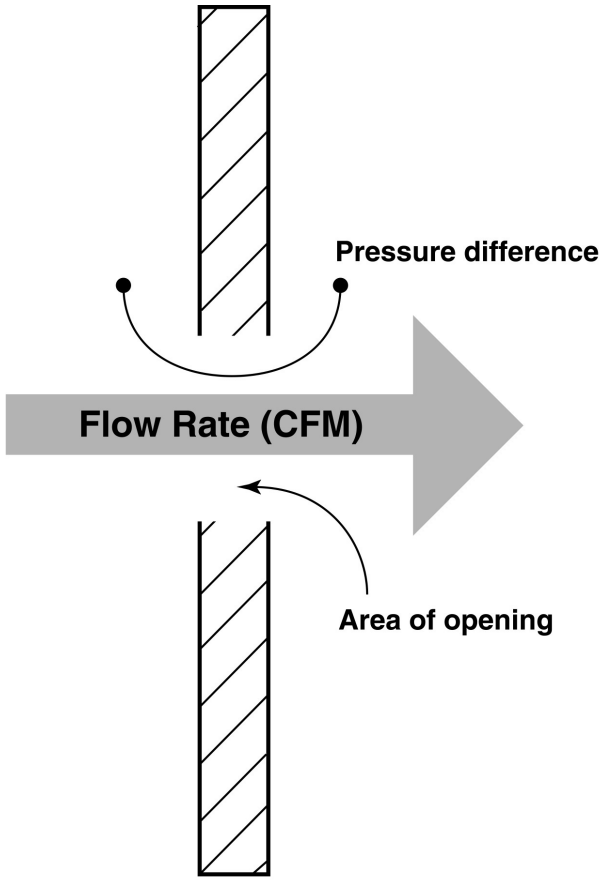









Brick veneer
Building paper
"Air seal" between floor assembly and perimeter gypsum board
Interior gypsum extends to underside of floor deck and is sealed
Exterior sheathing
Metal stud wall
Cavity insulation
Grate to equalize pressure
Suspended ceiling
Interior gypsum
Air Handler Unit
Fully ducted supply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



Air Flow

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

  Flow ≅ Area x $\sqrt{\Delta P}$ x Coefficient
- Air flows from higher pressure to lower pressure

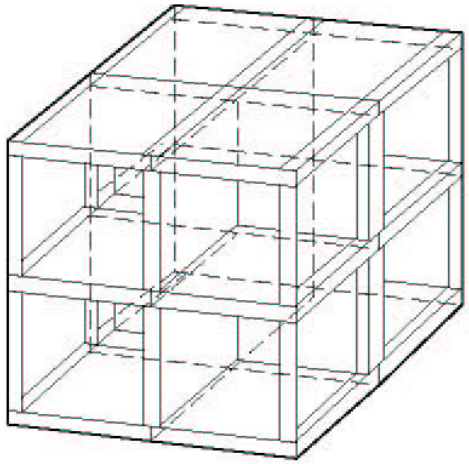


Figure 2.11
Three Dimensional Multi-Layer Multi-Cell Analogue

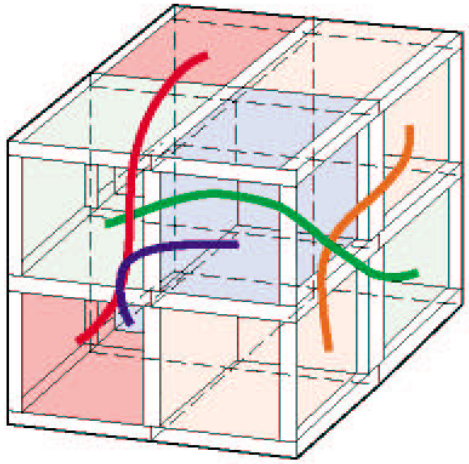
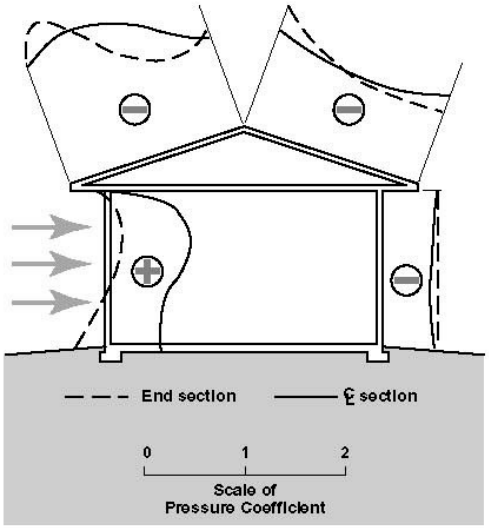


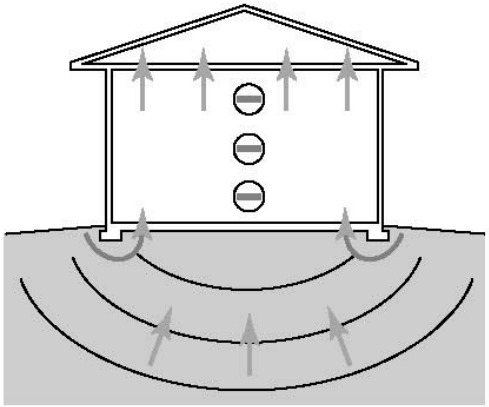
Figure 2.12
Three Dimensional Multi-Layer Multi-Cell Non-Contiguous Analogue

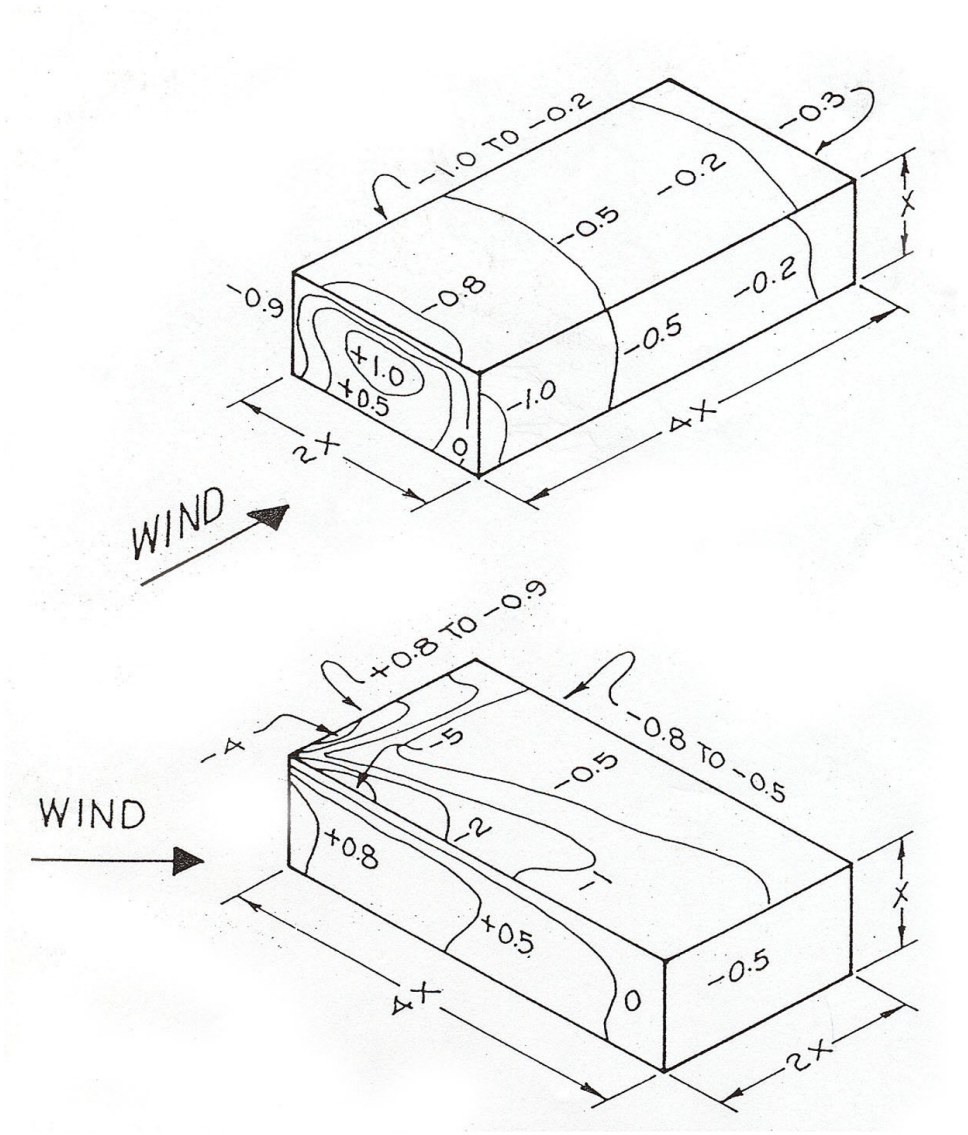
Figure 3.1
Exterior Air Pressure Field
(from Hutcheon & Handegord, 1983)



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

Figure 3.2
Exterior Air Pressure Field Extending Below Grade





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

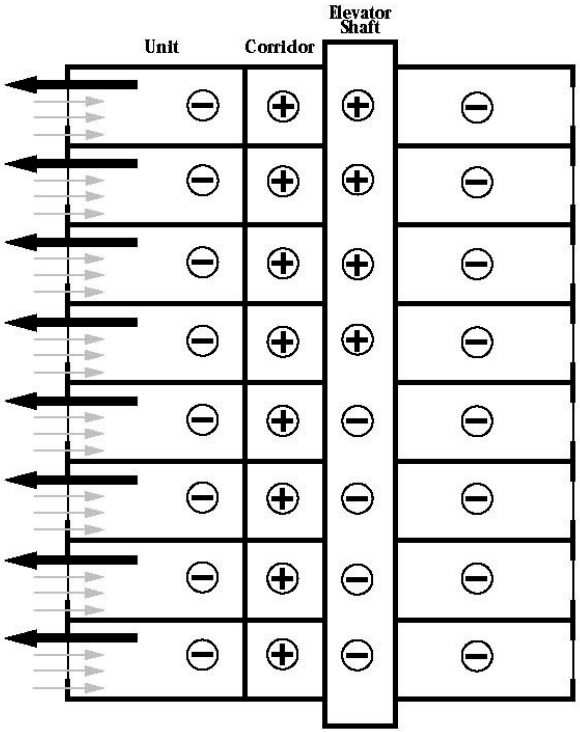


Figure 3.3
Interior Air Pressure Field

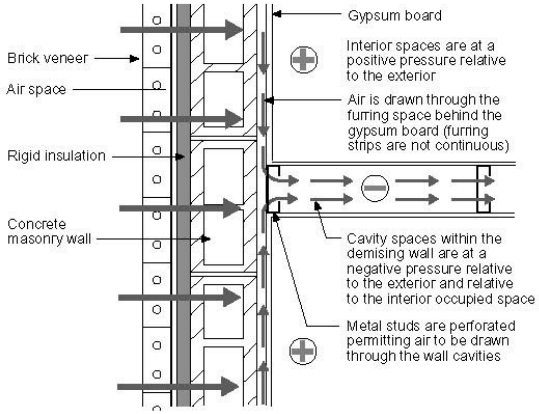


Figure 3.4
Interstitial Air Pressure Field

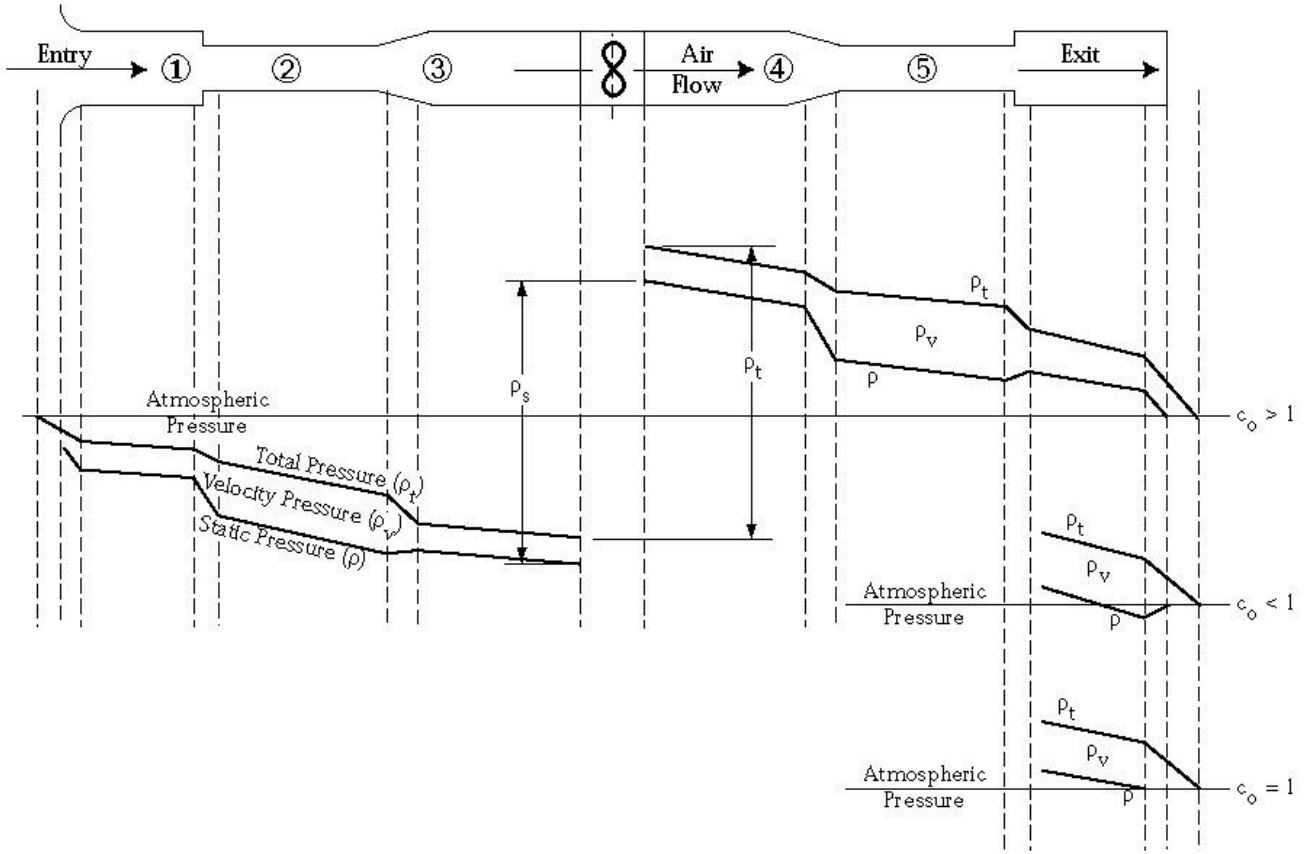


Figure 3.5
Air Conveyance System Air Pressure Field
(from Sauer & Howell, 1990)



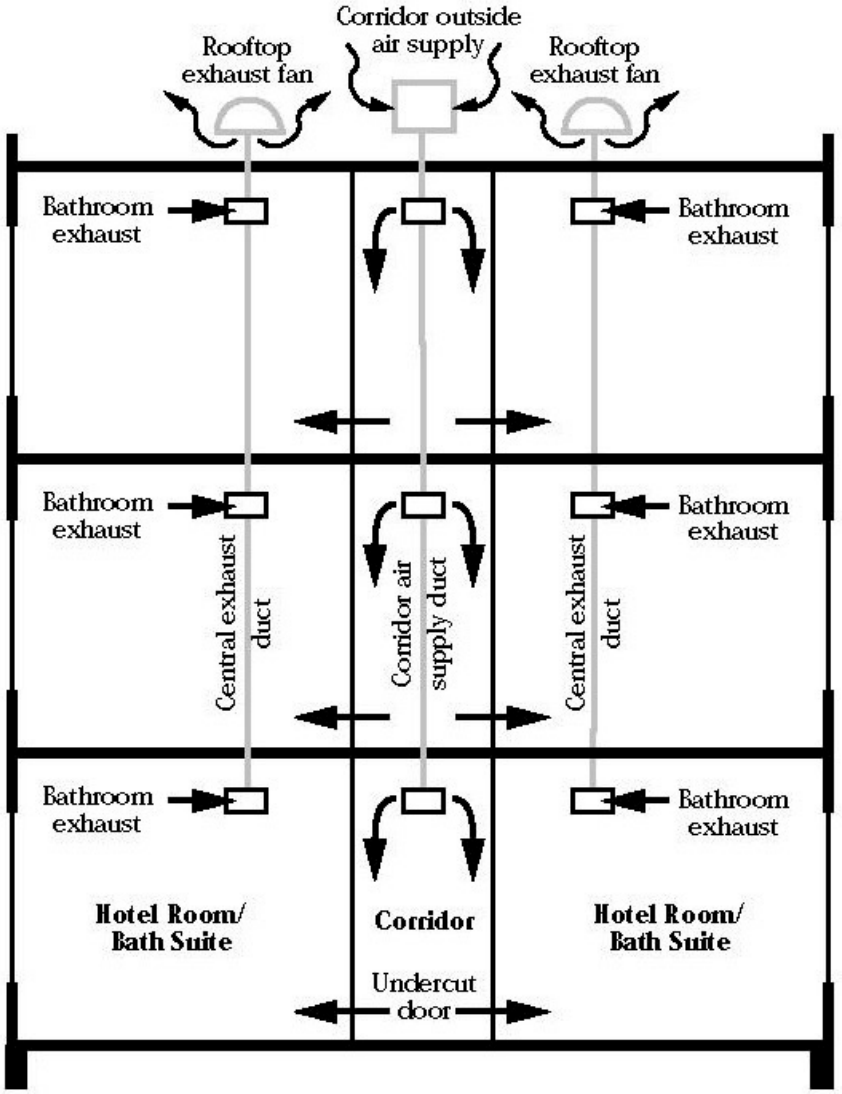


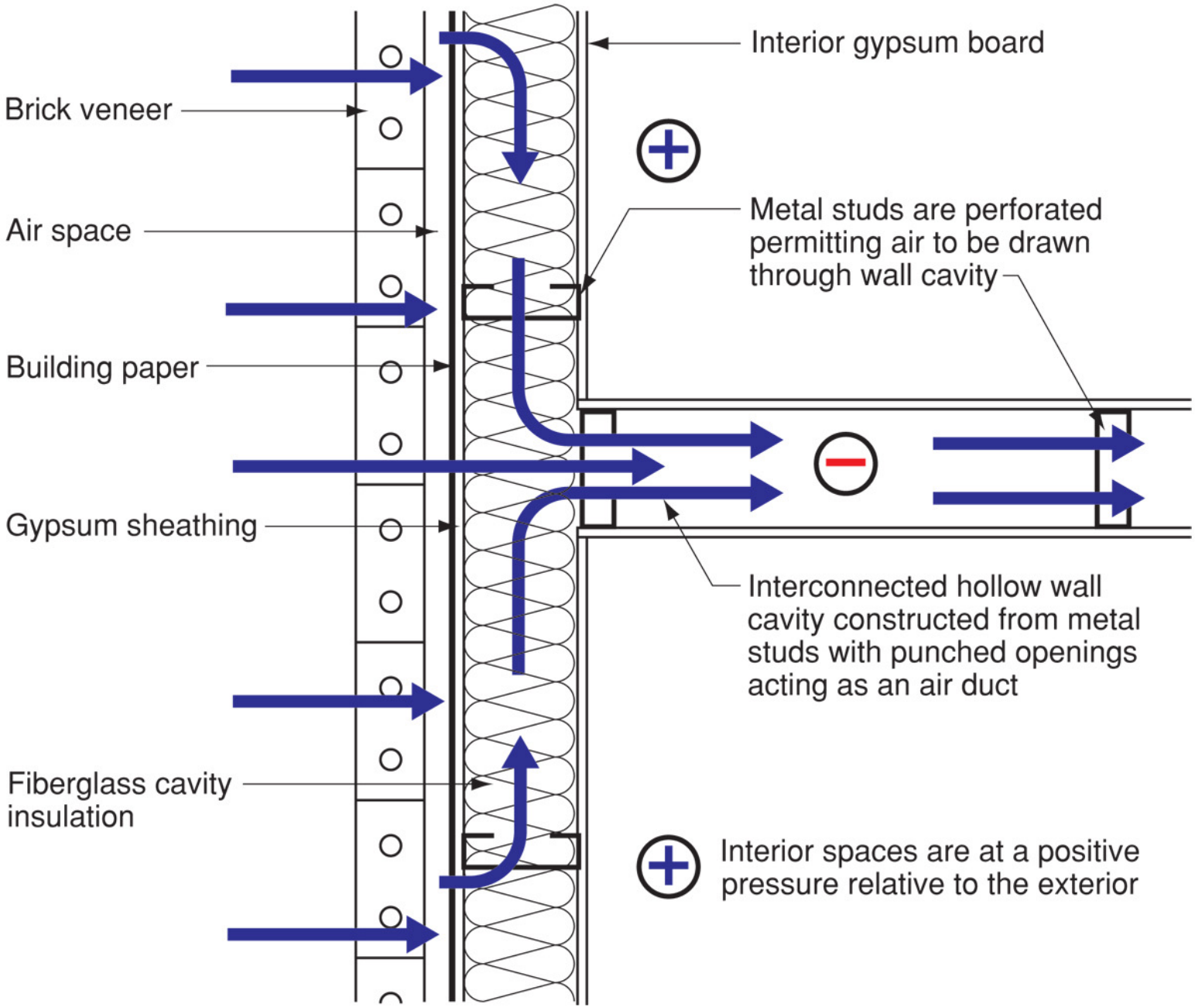
Figure 3.8

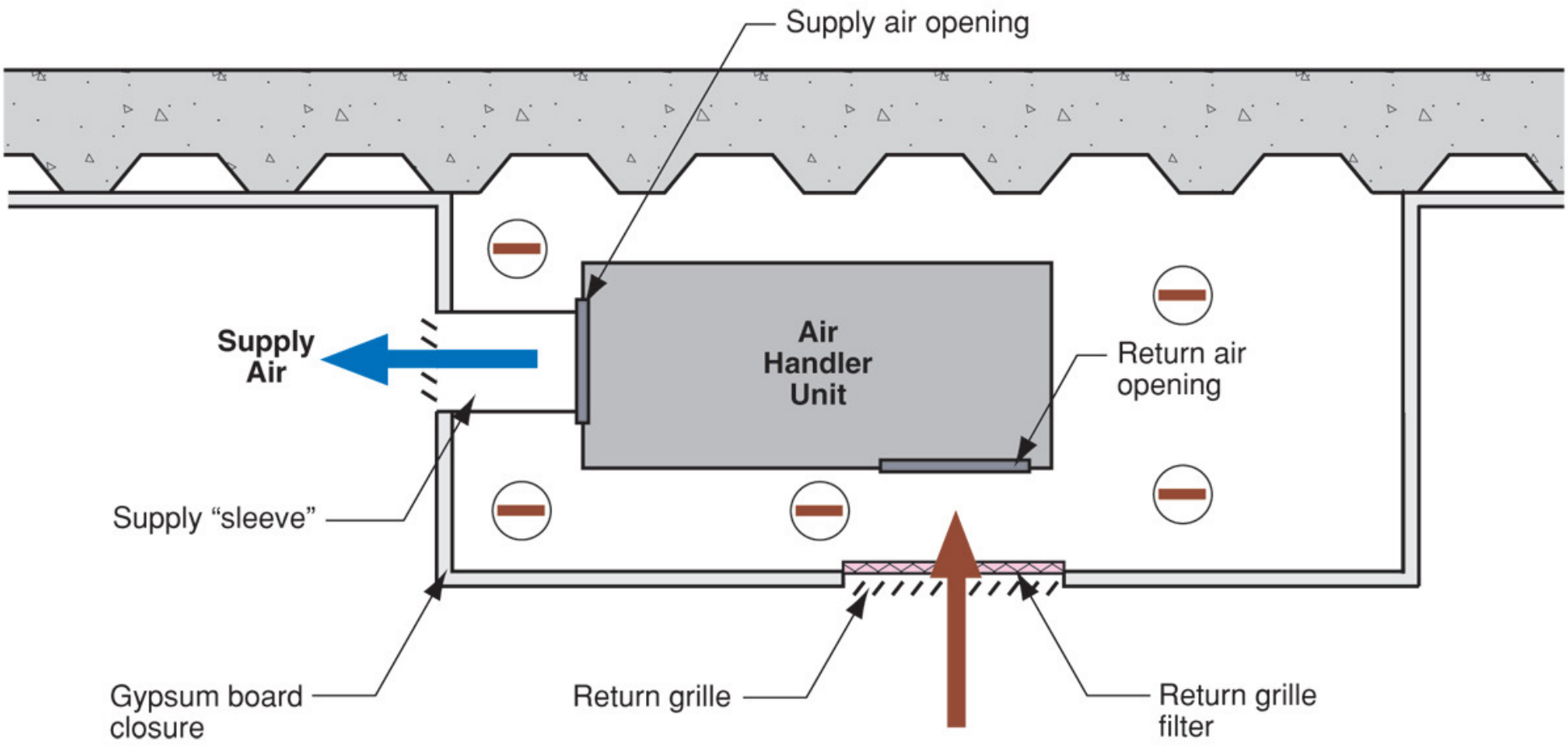
Hotel HVAC System

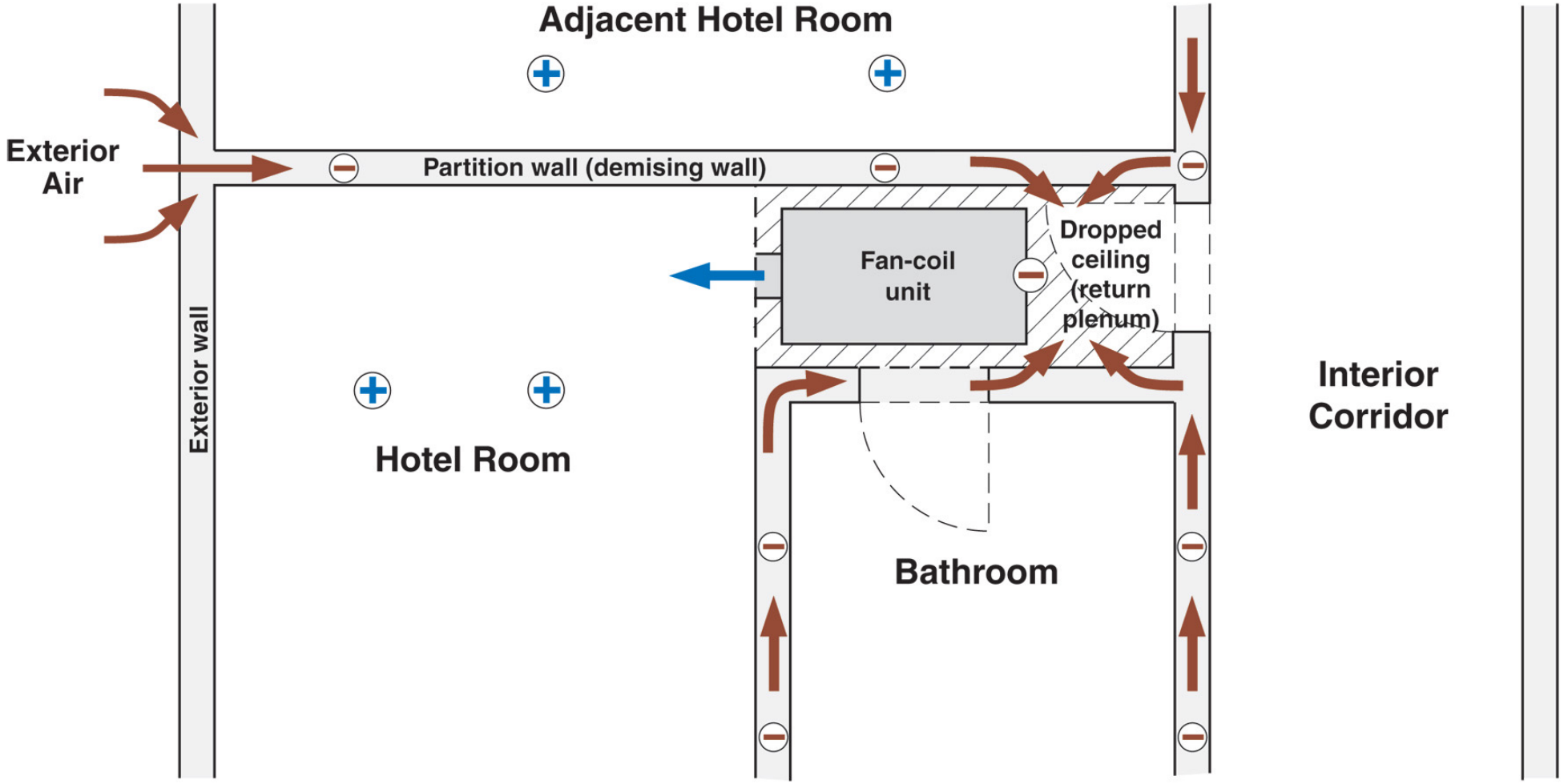
- Air exhausted from bathrooms via central rooftop exhaust fans
- Air supplied from corridors via undercut doors




zenith


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


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


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

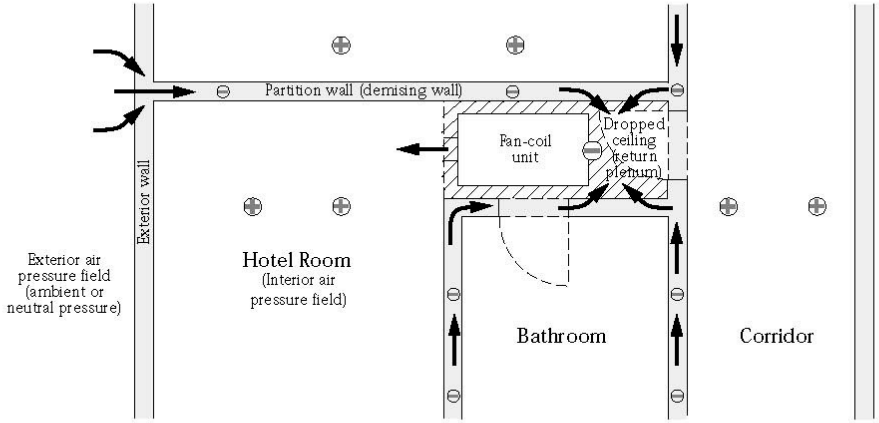


Figure 3.10
Pressure Field Due to Fan-Coil Unit
Plan View

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

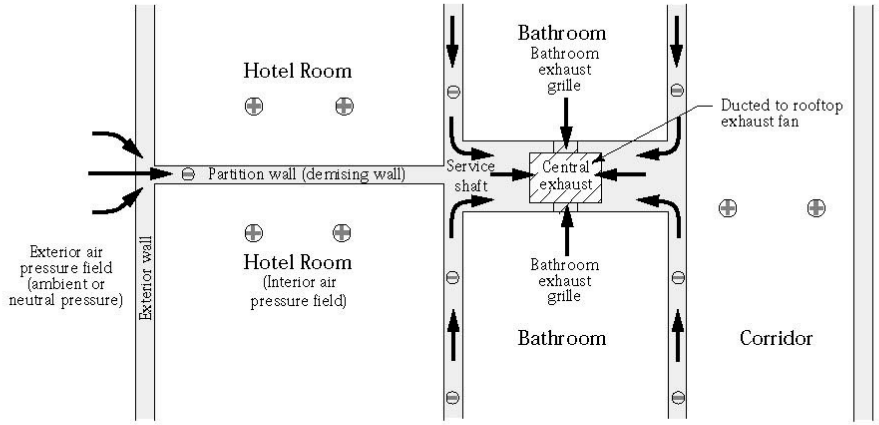


Figure 3.11
Pressure Field Due to Central Exhaust
Plan View

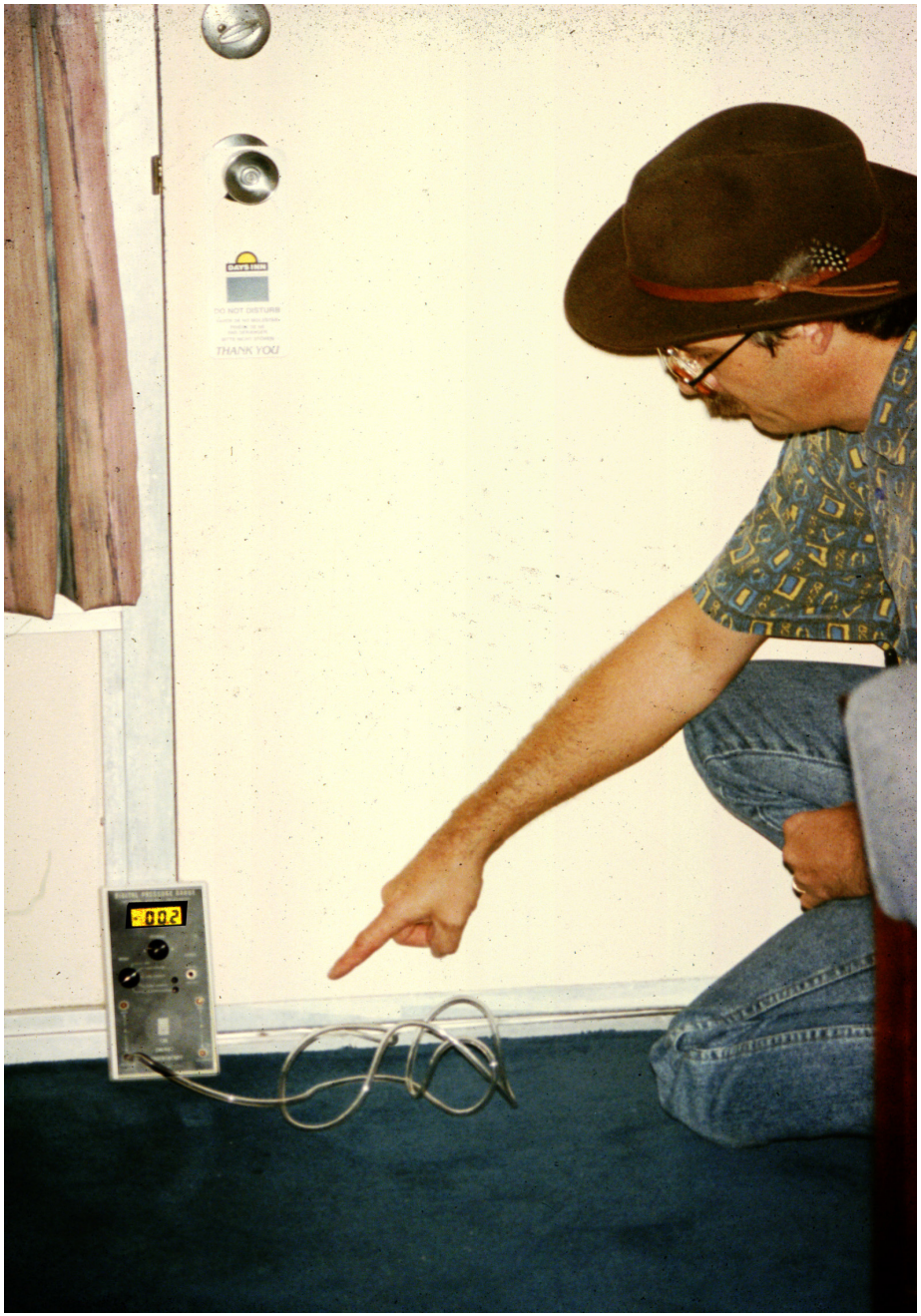
- Leakage of central exhaust duct pulls air out of service shaft depressurizing shaft and demising walls


DAYS INN








DO NOT DISTURB
THANK YOU
-.002



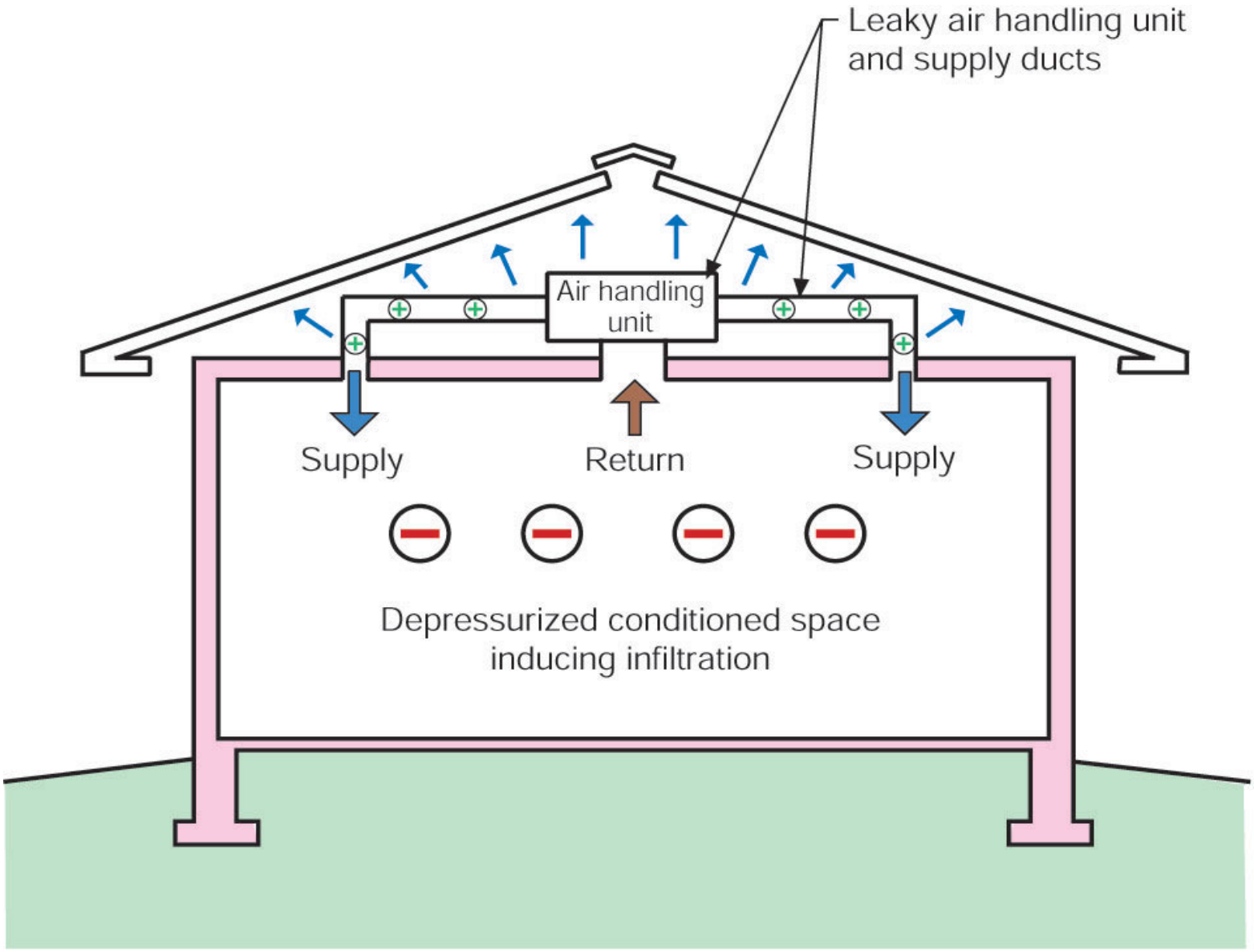




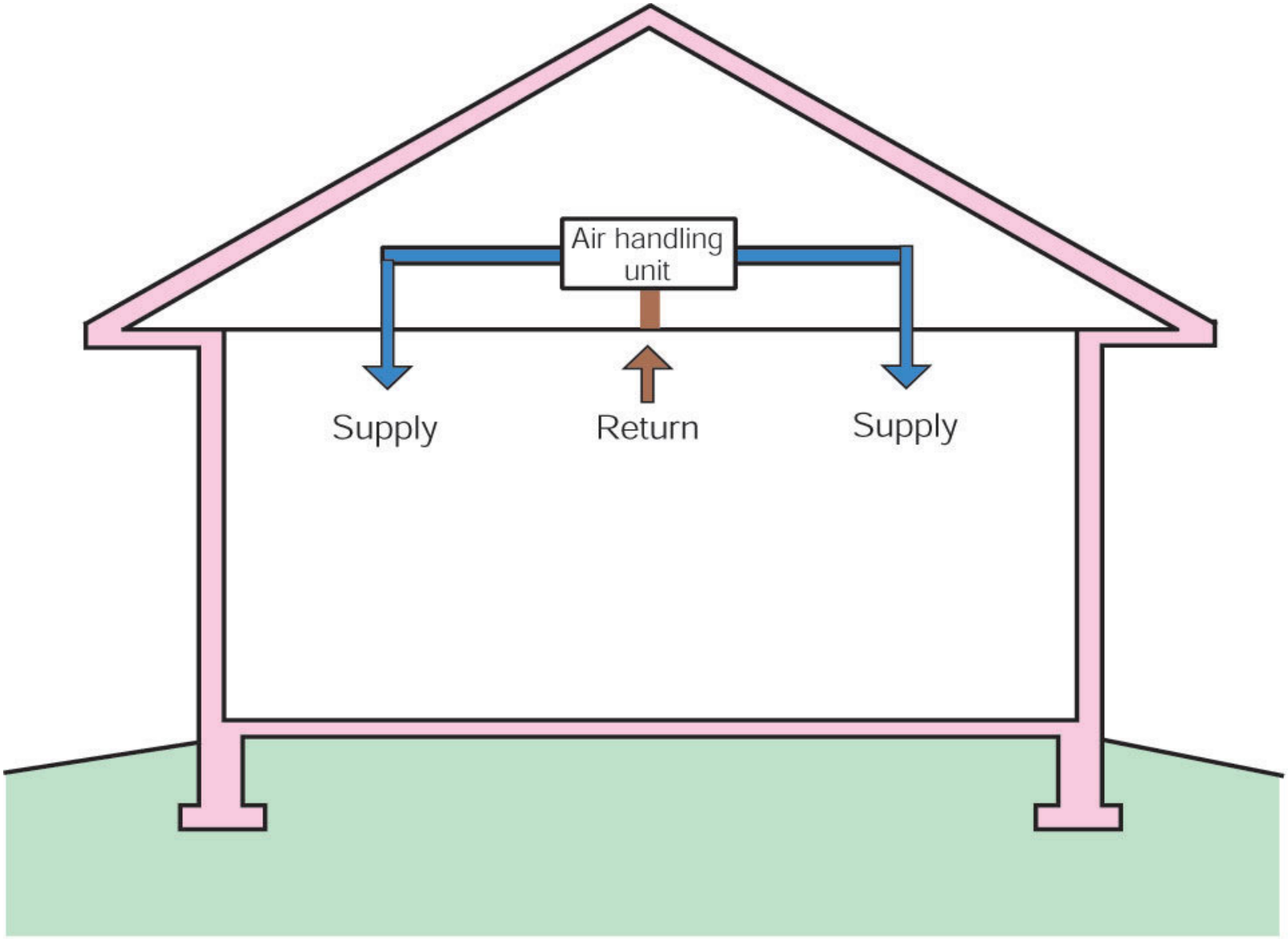






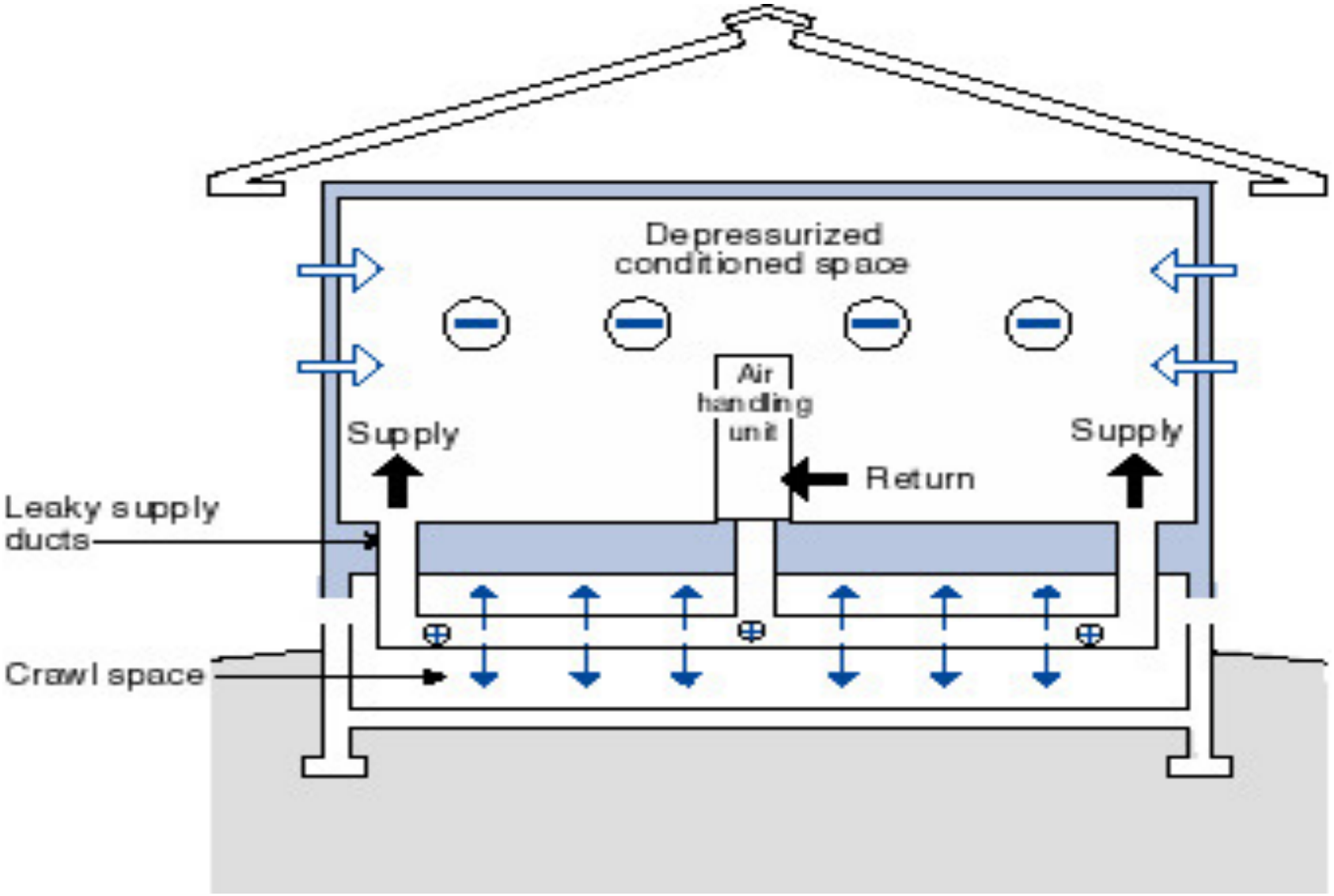


Note: Colored shading depicts the building's thermal barrier and pressure boundary.
The thermal barrier and pressure boundary enclose the conditioned space.

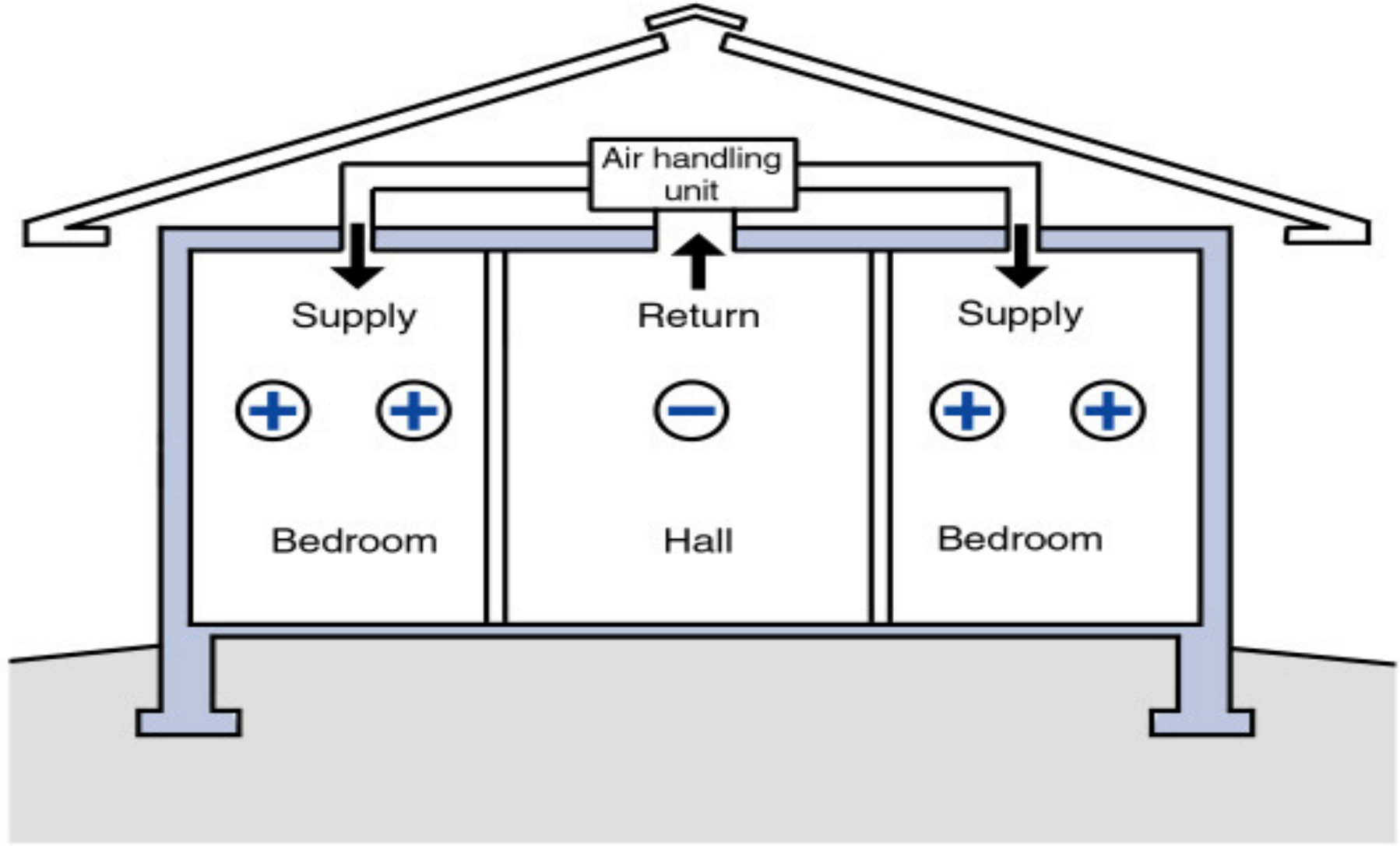


Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

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


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




Air handling unit
Supply
Return
Supply
Bedroom
Hall
Bedroom




PULTE
Richly
Scented Candle
Trim the wick to 1/4" before burning. Keep
the wick centered and trimmed at all times
to avoid blackening the container. Never
leave a burning candle unattended or
EMPIRE
Kansas City, MO
$1099
Net Wt. 23 oz. (651g)



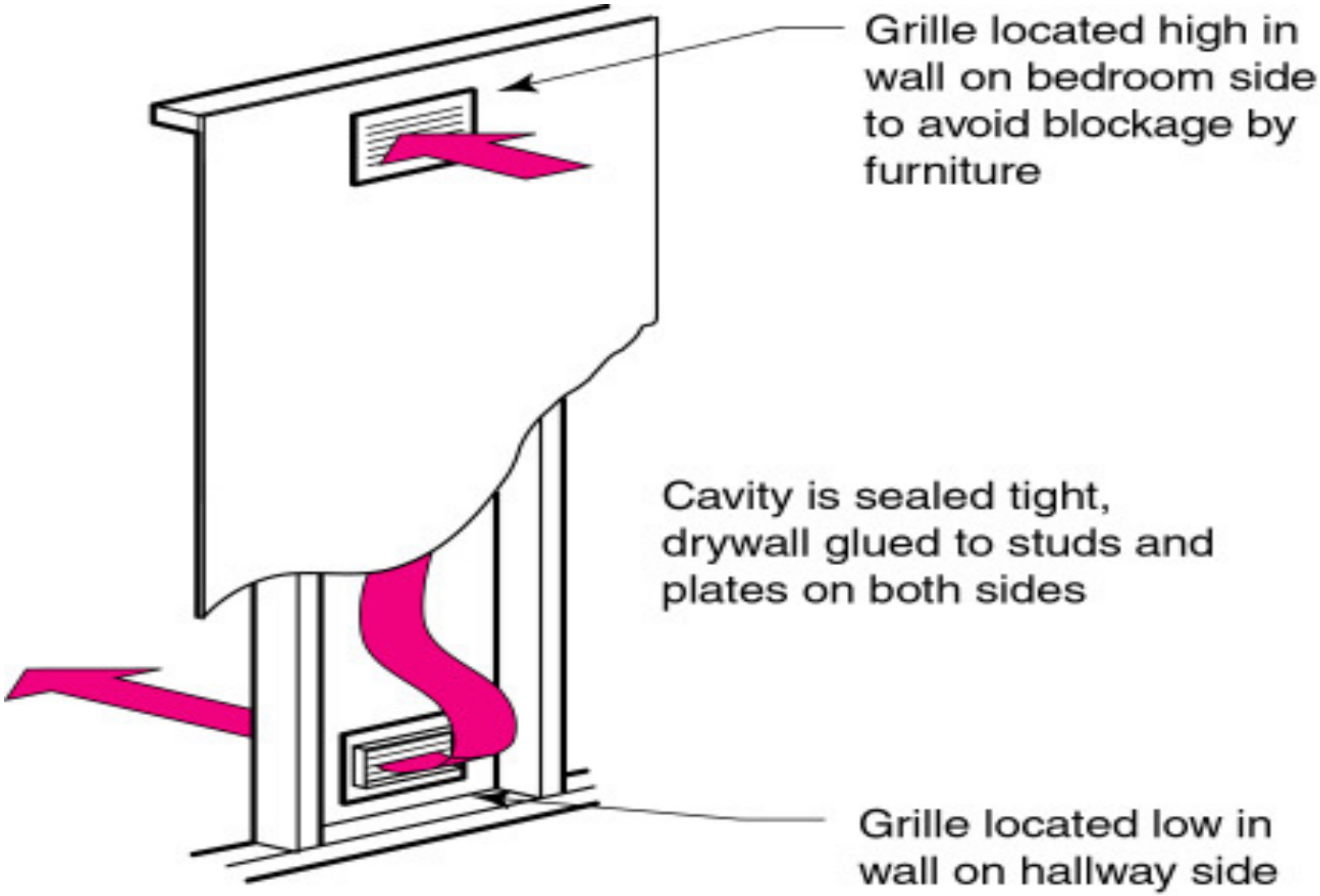

YANKEE



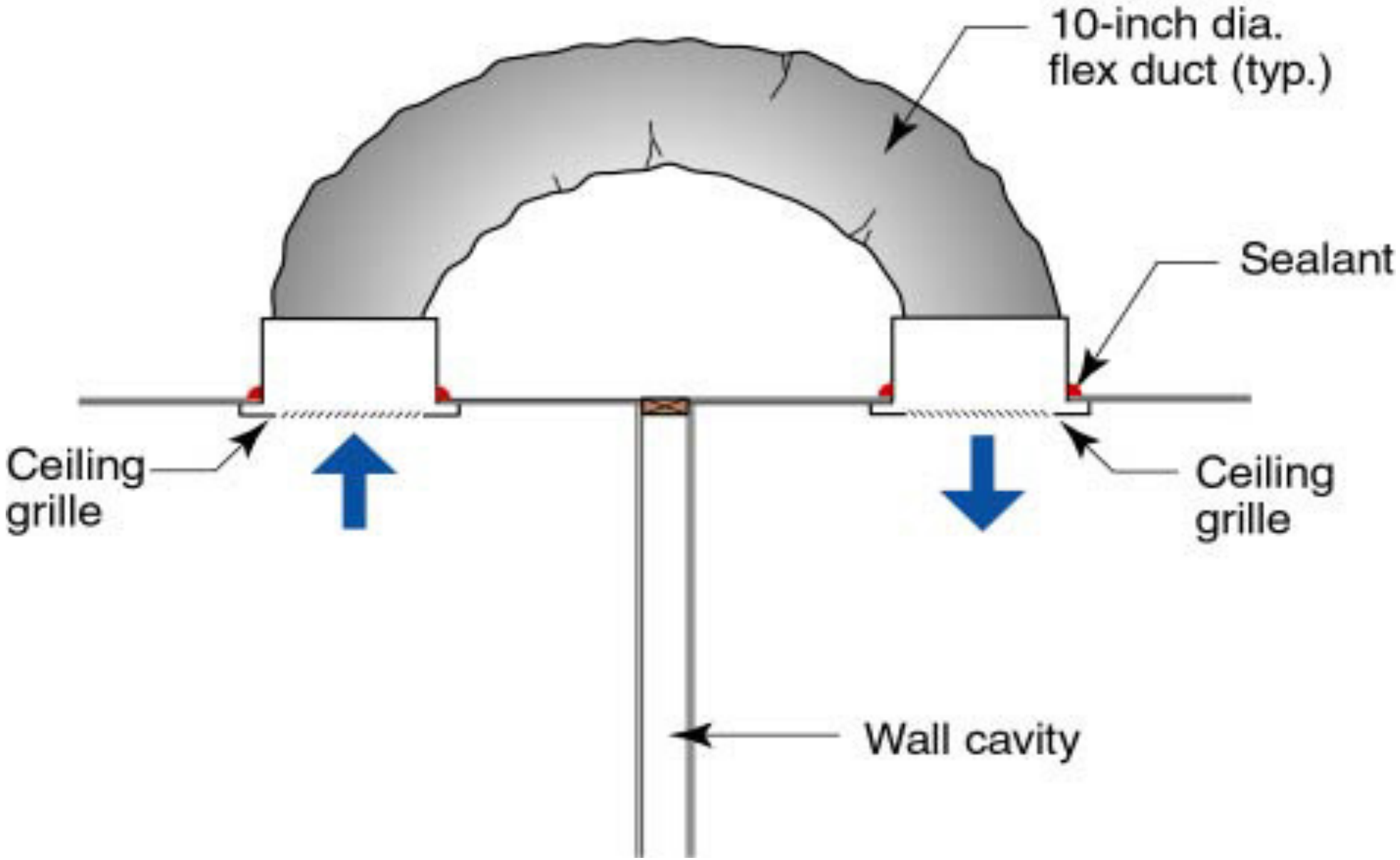







Grille located high in wall on bedroom side to avoid blockage by furniture
Cavity is sealed tight, drywall glued to studs and plates on both sides
Grille located low in wall on hallway side




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



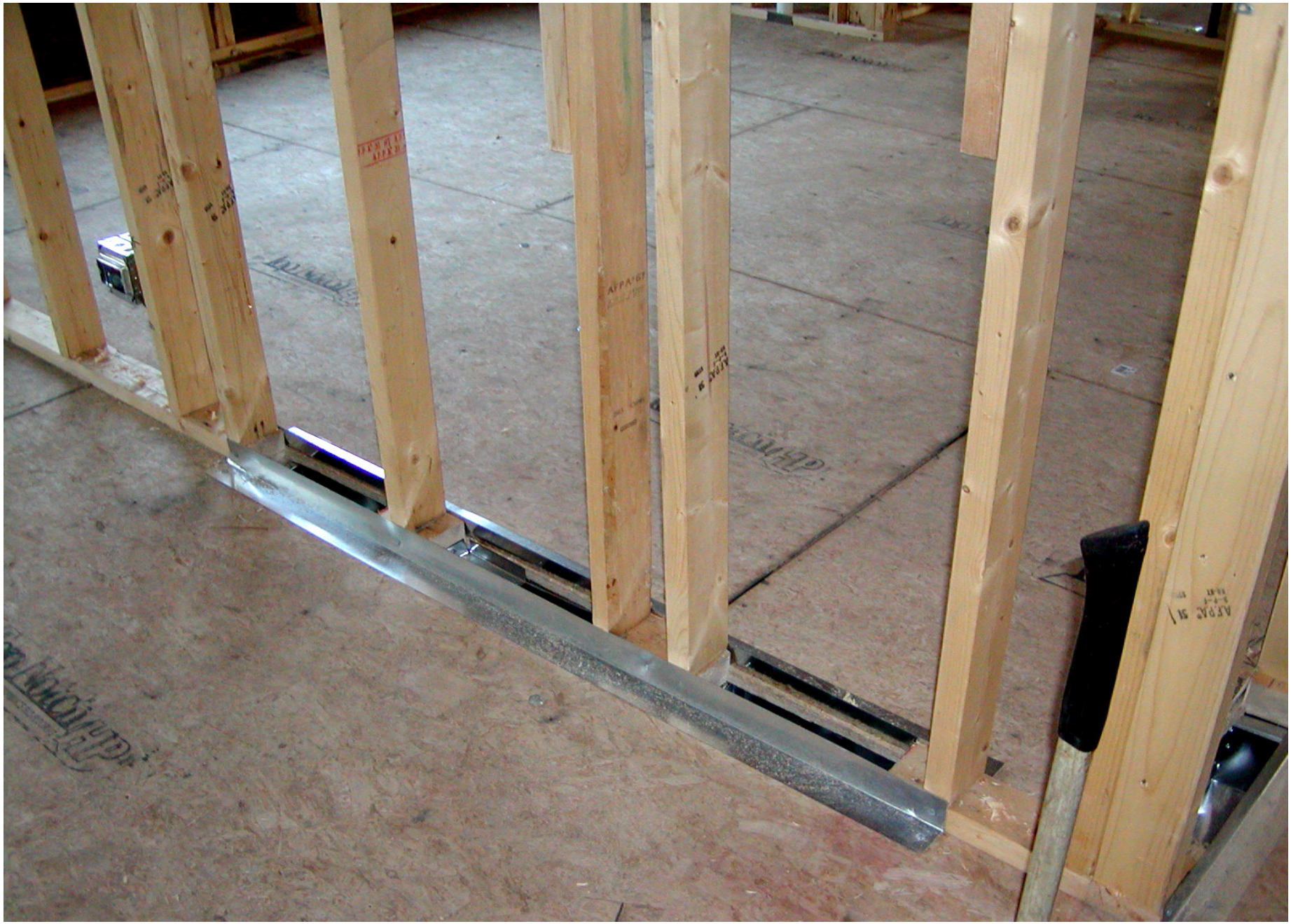




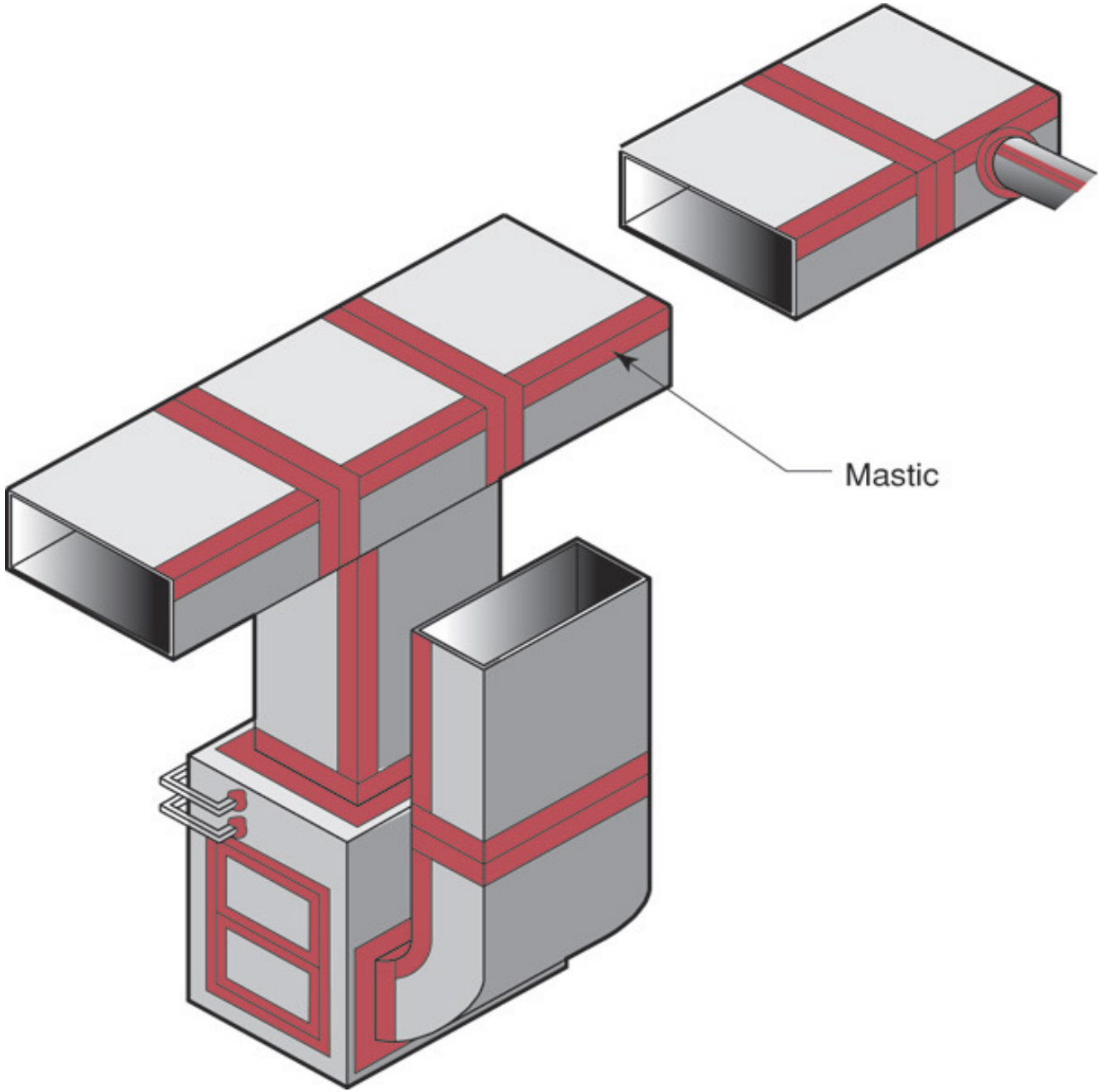


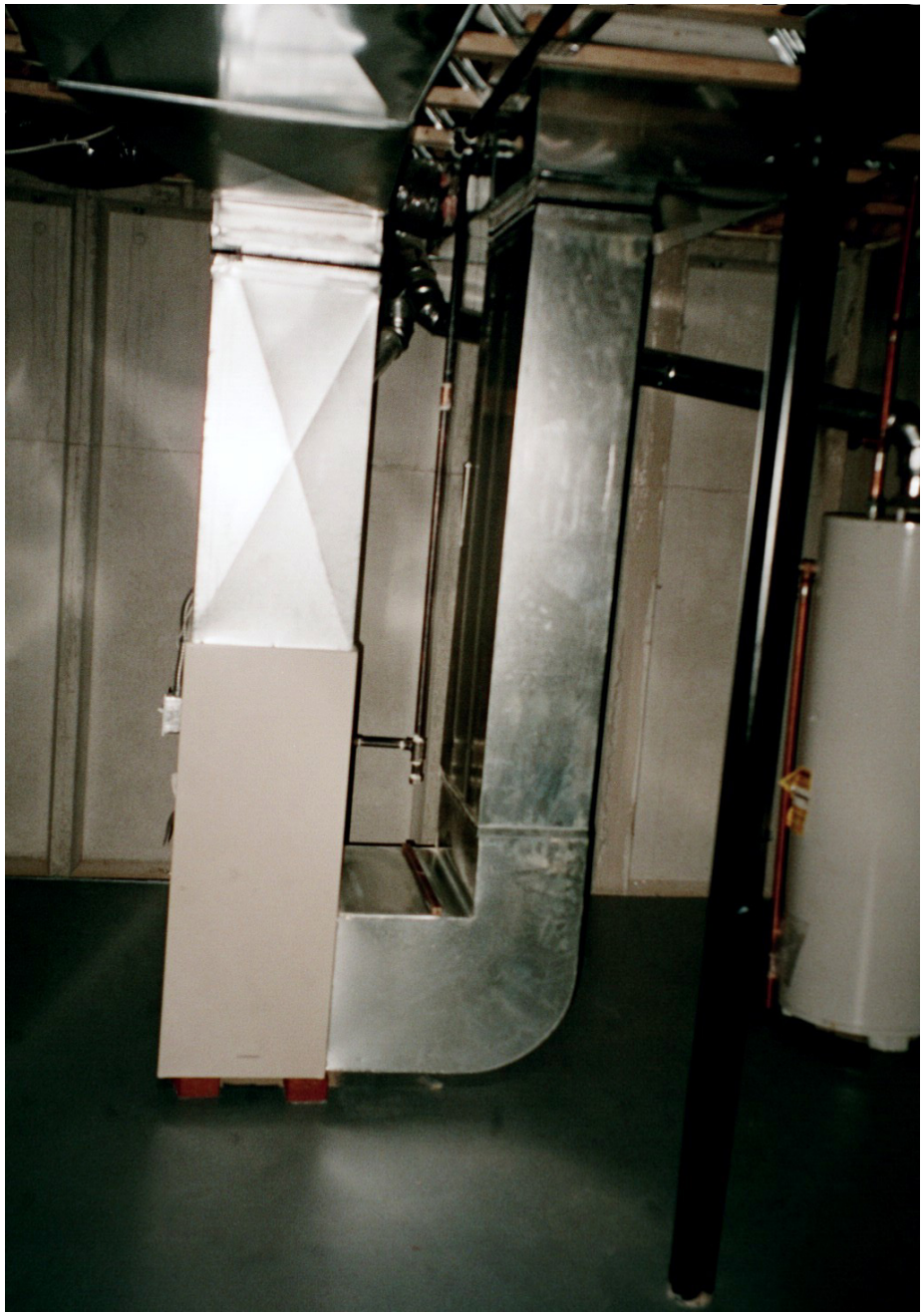









Mastic







Mechanical Systems

Mechanical Systems

Cooling System To Make It Cold

Mechanical Systems

Cooling System To Make It Cold

Dehumidification System To Make It Dry

Mechanical Systems

Cooling System To Make It Cold

Dehumidification System To Make It Dry

Heating System To Make It Warm

Mechanical Systems

Cooling System To Make It Cold

Dehumidification System To Make It Dry

Heating System To Make It Warm

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

Mechanical Systems

Cooling System To Make It Cold

Dehumidification System To Make It Dry

Heating System To Make It Warm

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

Distribution System To Make It Uniform

Mechanical Systems

Cooling System To Make It Cold

Dehumidification System To Make It Dry

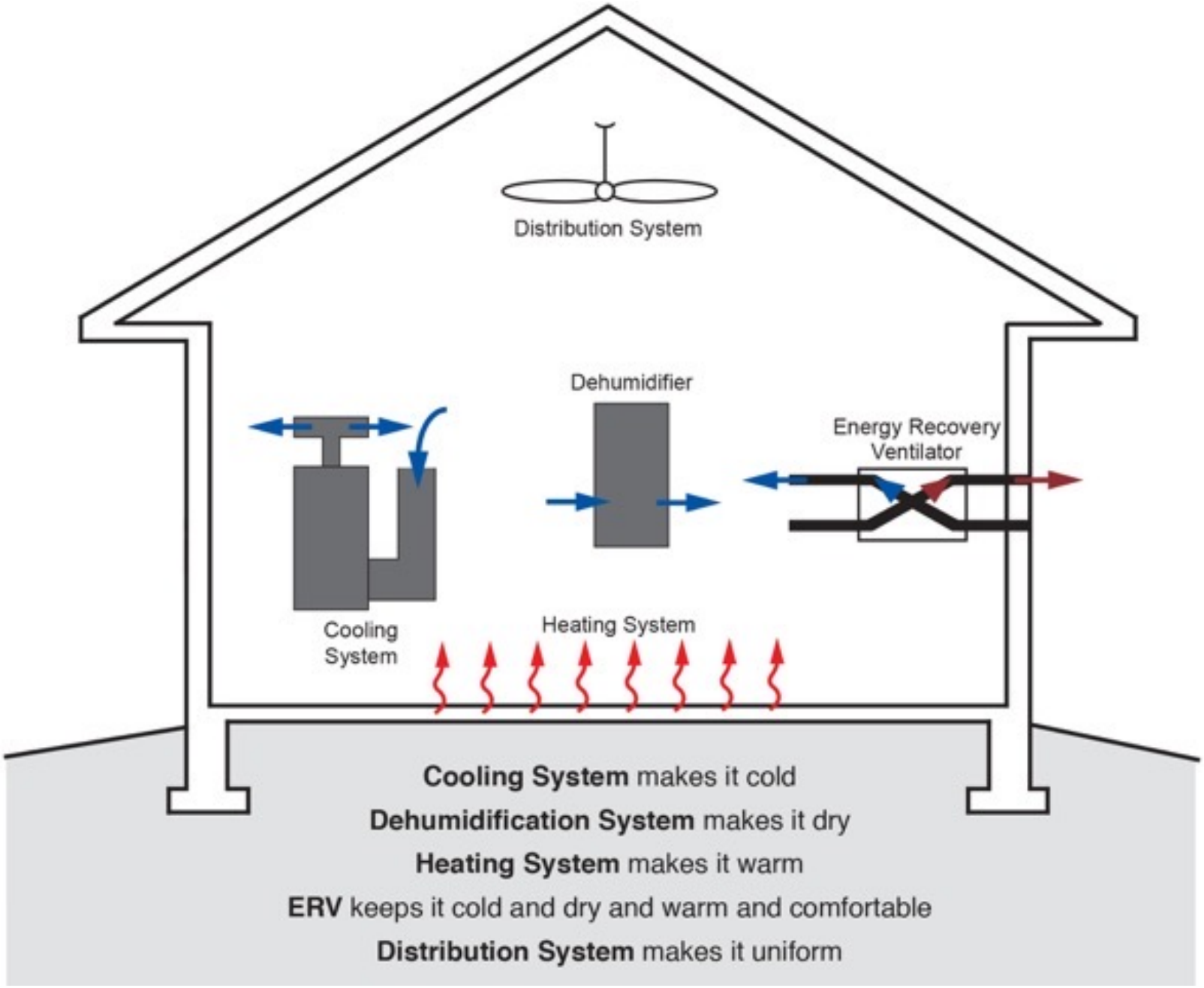
Heating System To Make It Warm

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

Distribution System To Make It Uniform

Range Hoods Are A Special Kind of Hell

Don’t Try to Combine Them…...


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

Build Tight - Ventilate Right

Build Tight - Ventilate Right

How Tight?

What's Right?

Air Barrier Metrics

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

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

Best

As Tight as Possible - with -

Balanced Ventilation

Energy Recovery

Distribution and Mixing

Source Control - Spot exhaust ventilation

Filtration

Material selection

Worst

Leaky - with – Nothing

Spot Ventilation in Bathroom/Kitchen

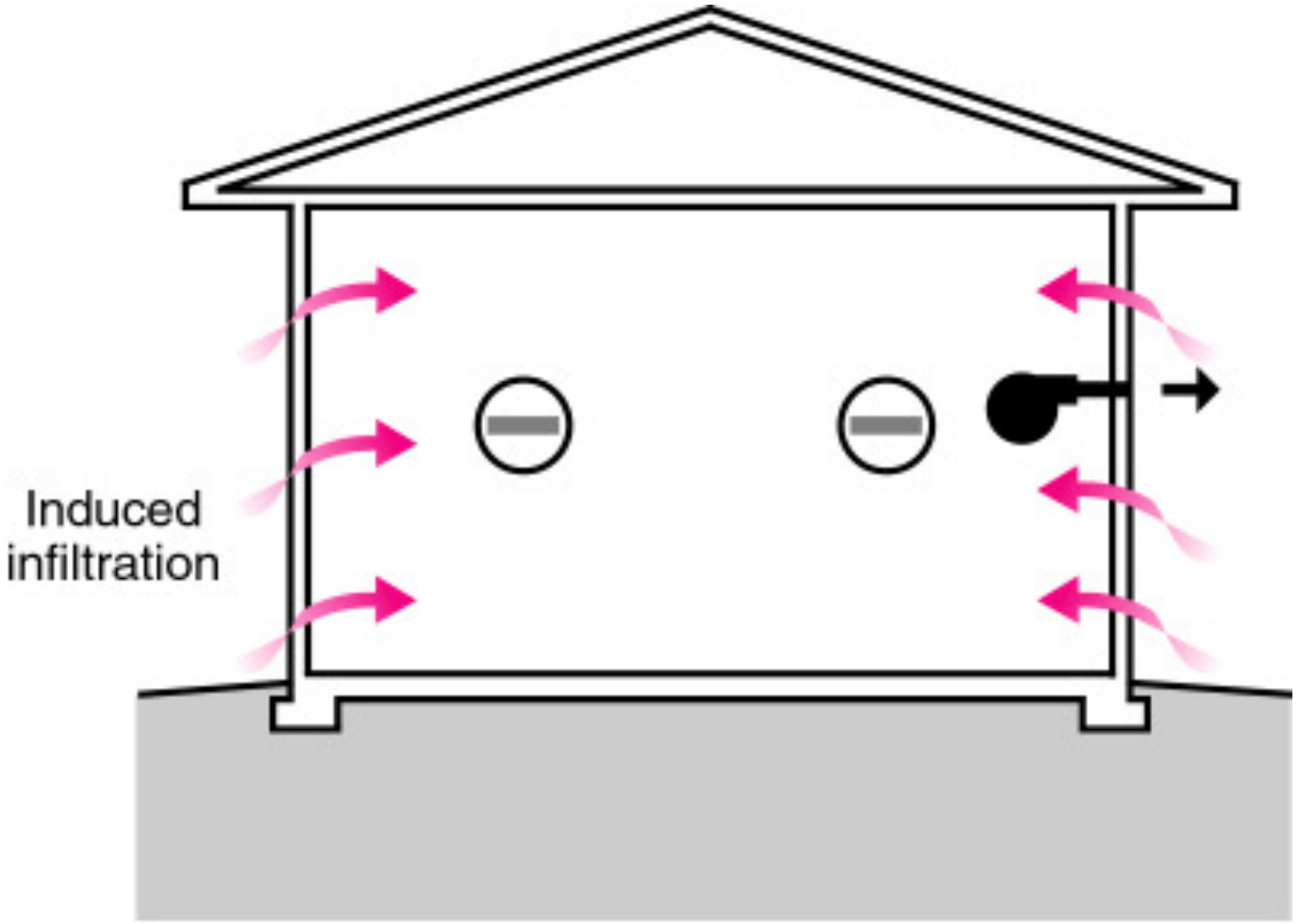
Exhaust Ventilation – with – No Distribution and No Mixing

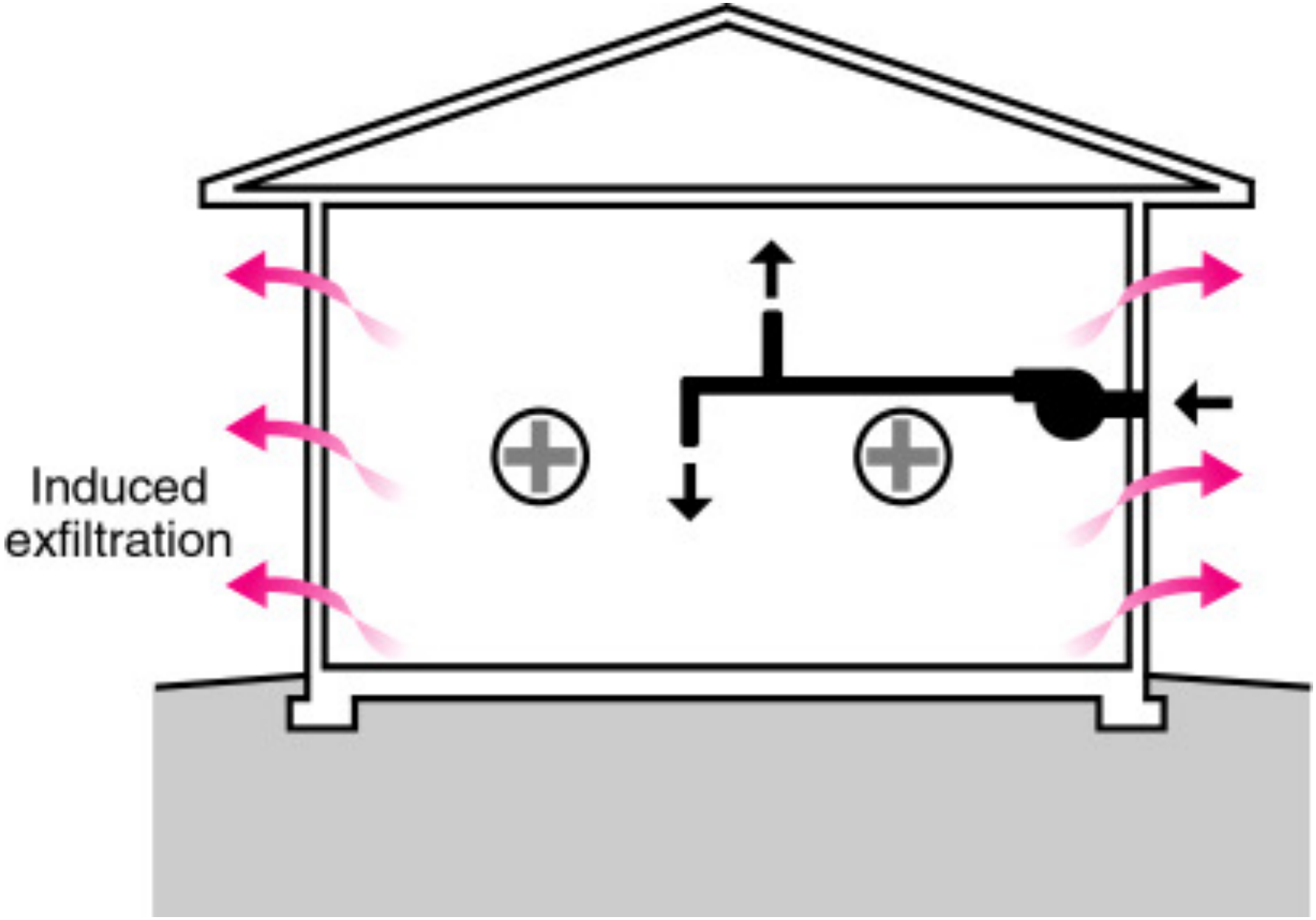
Three Types of Controlled Ventilation Systems

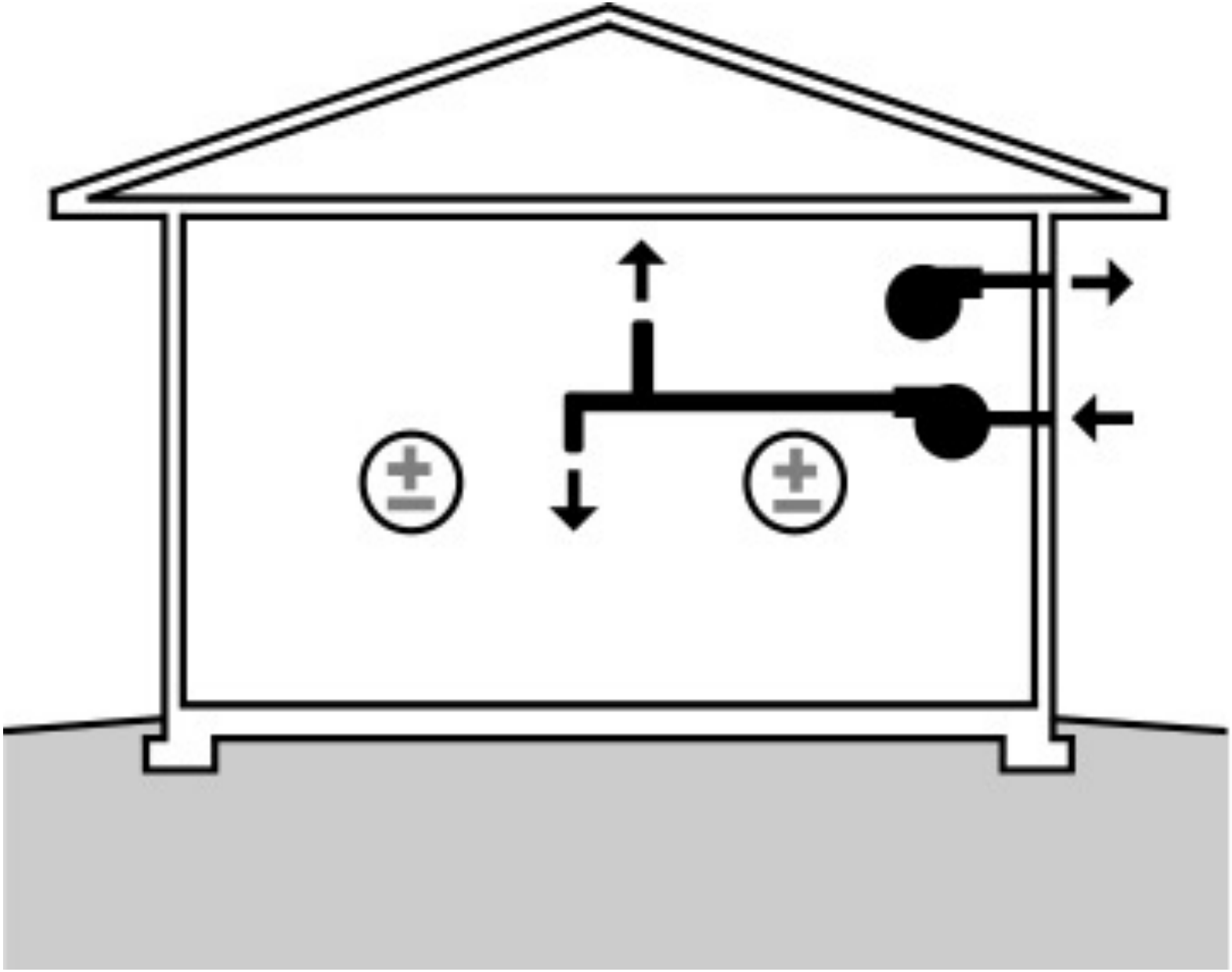
Exhaust Ventilation

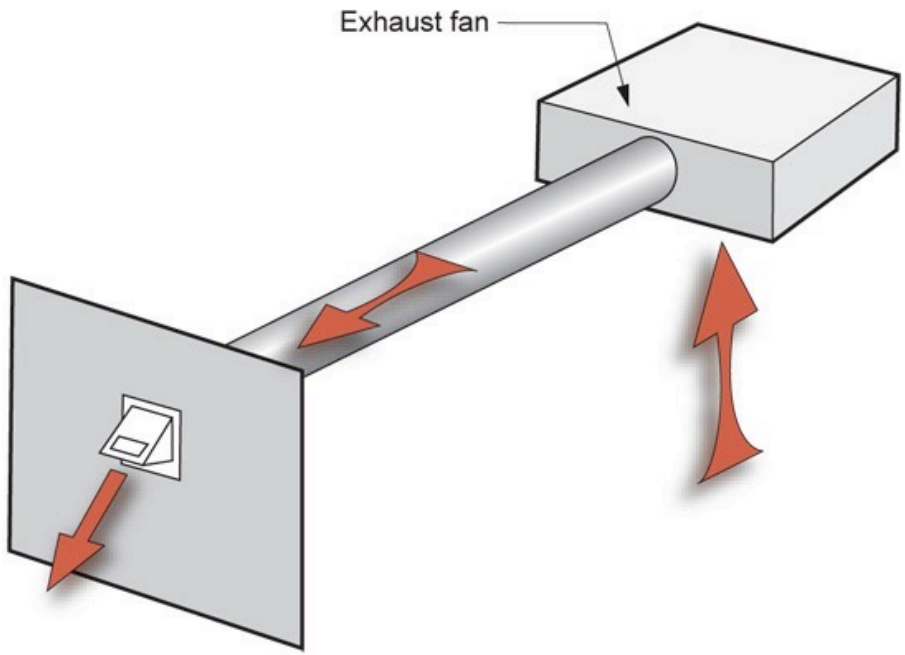
Supply Ventilation

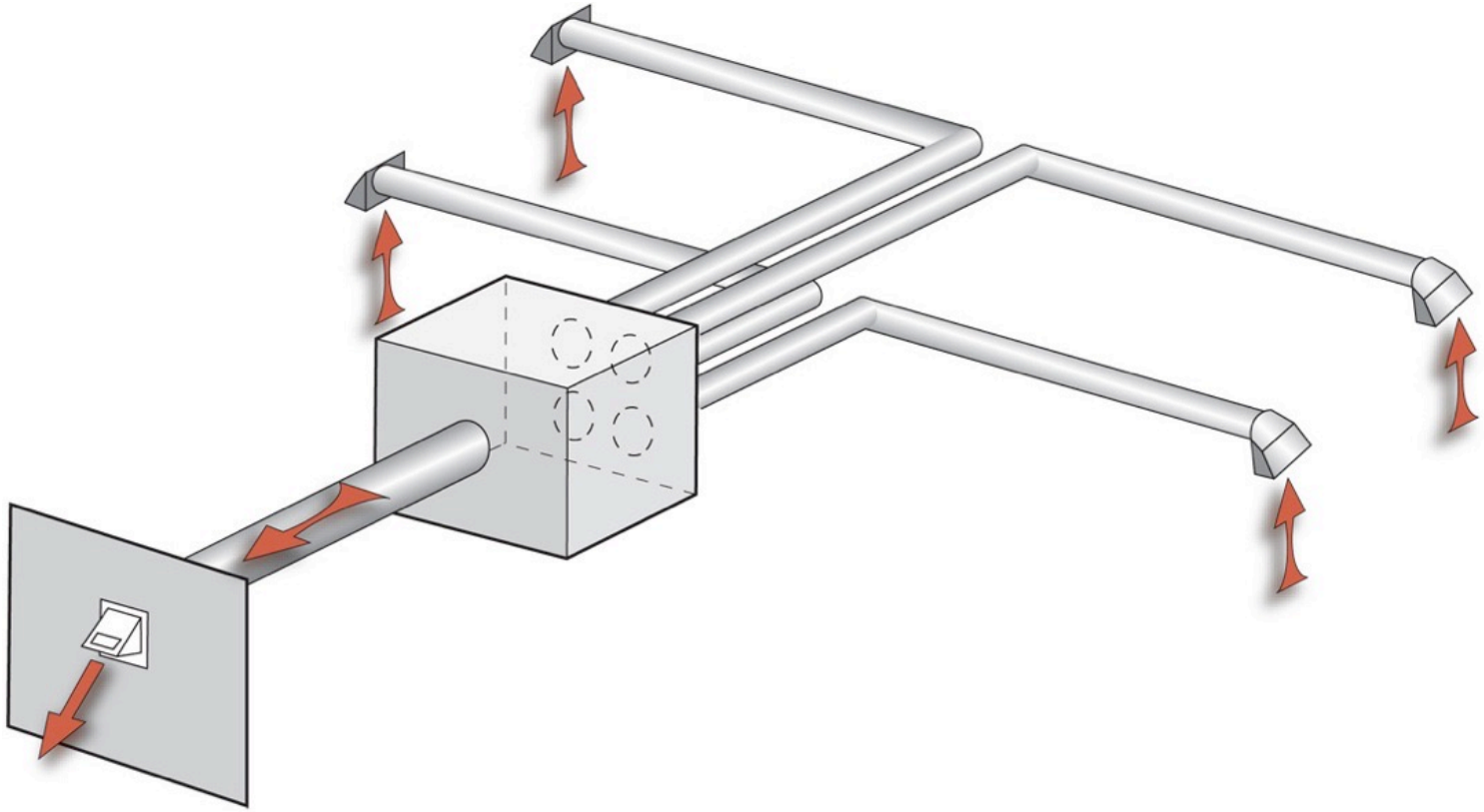
Balanced Ventilation

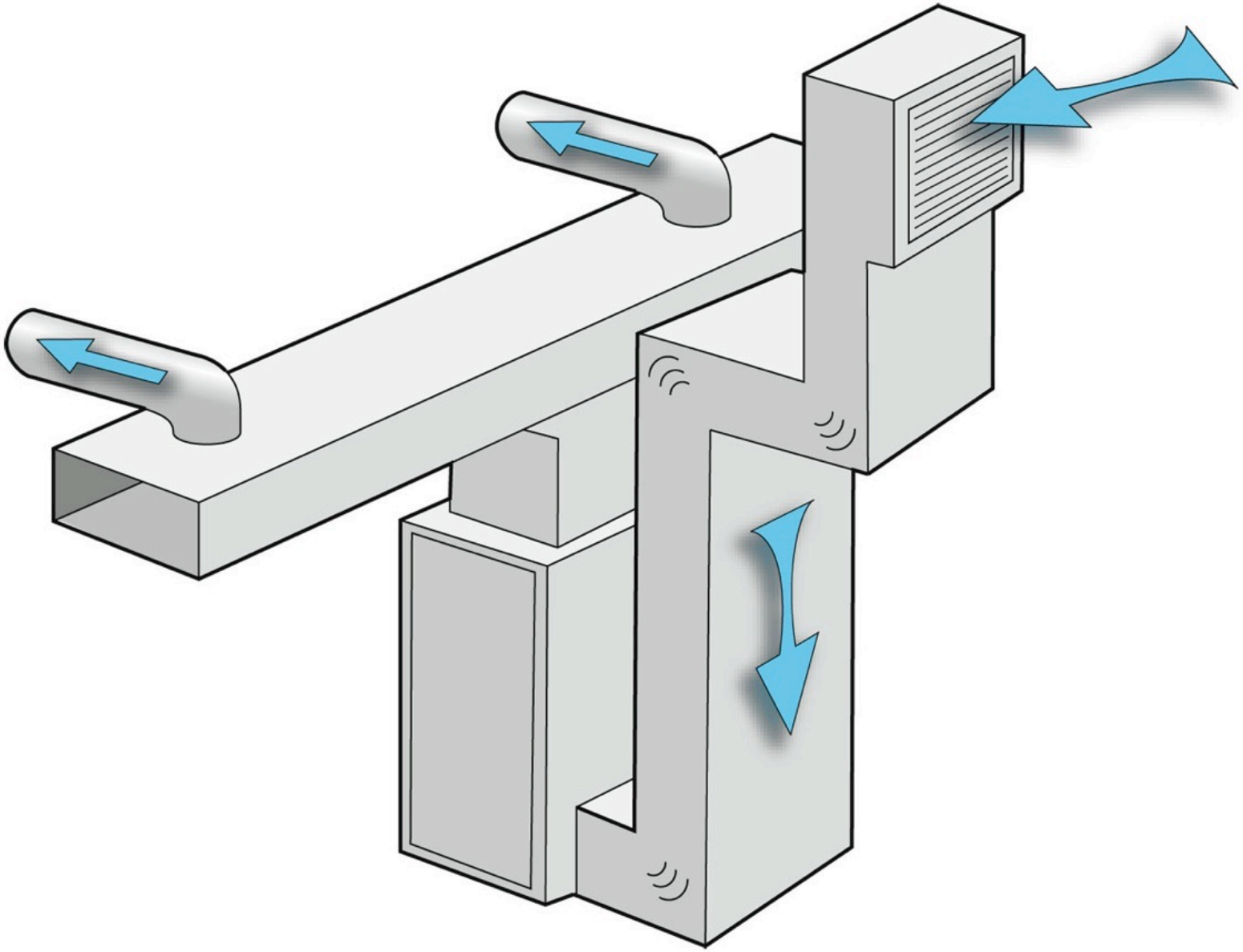

Induced
infiltration

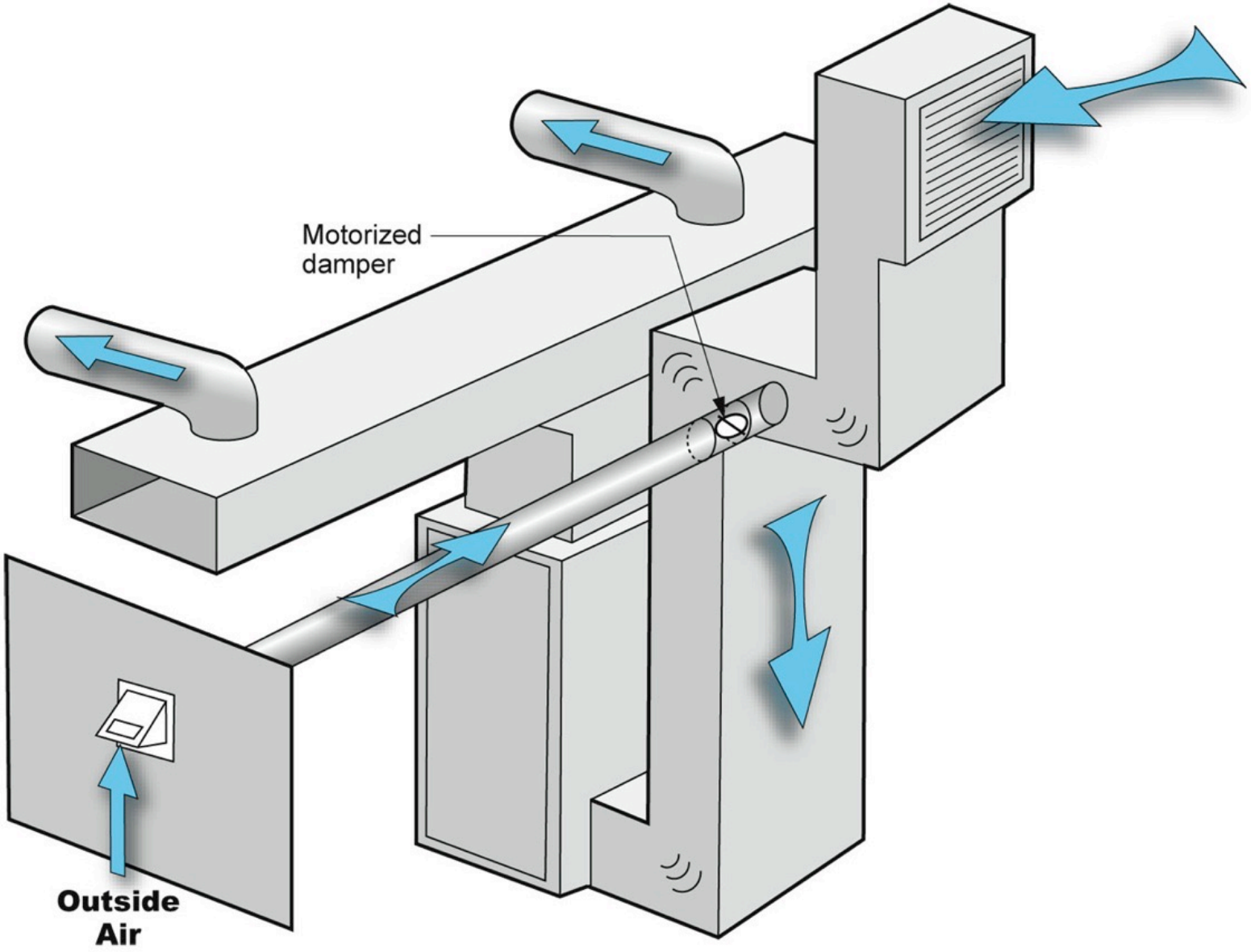

Induced
exfiltration

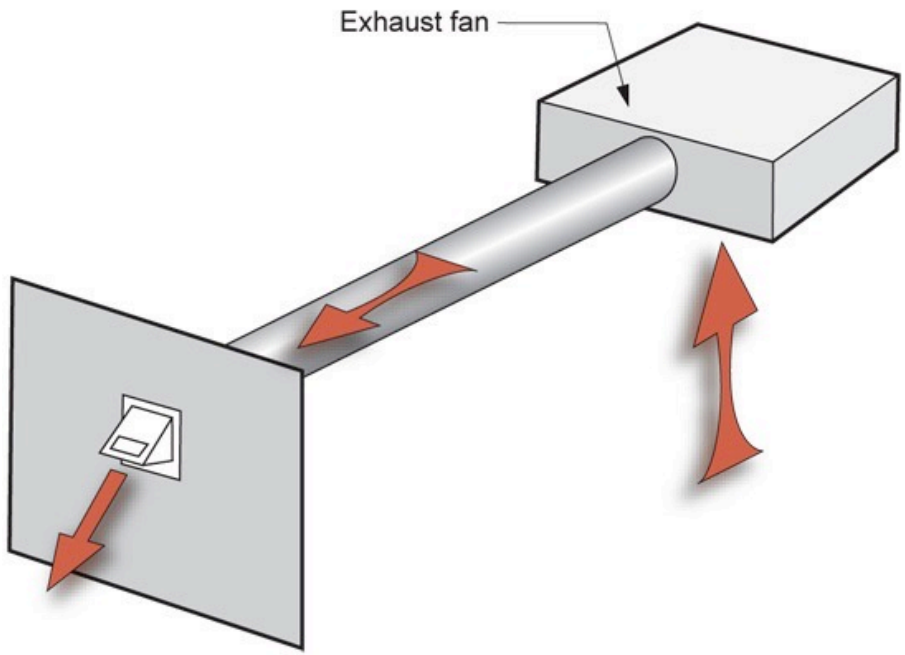


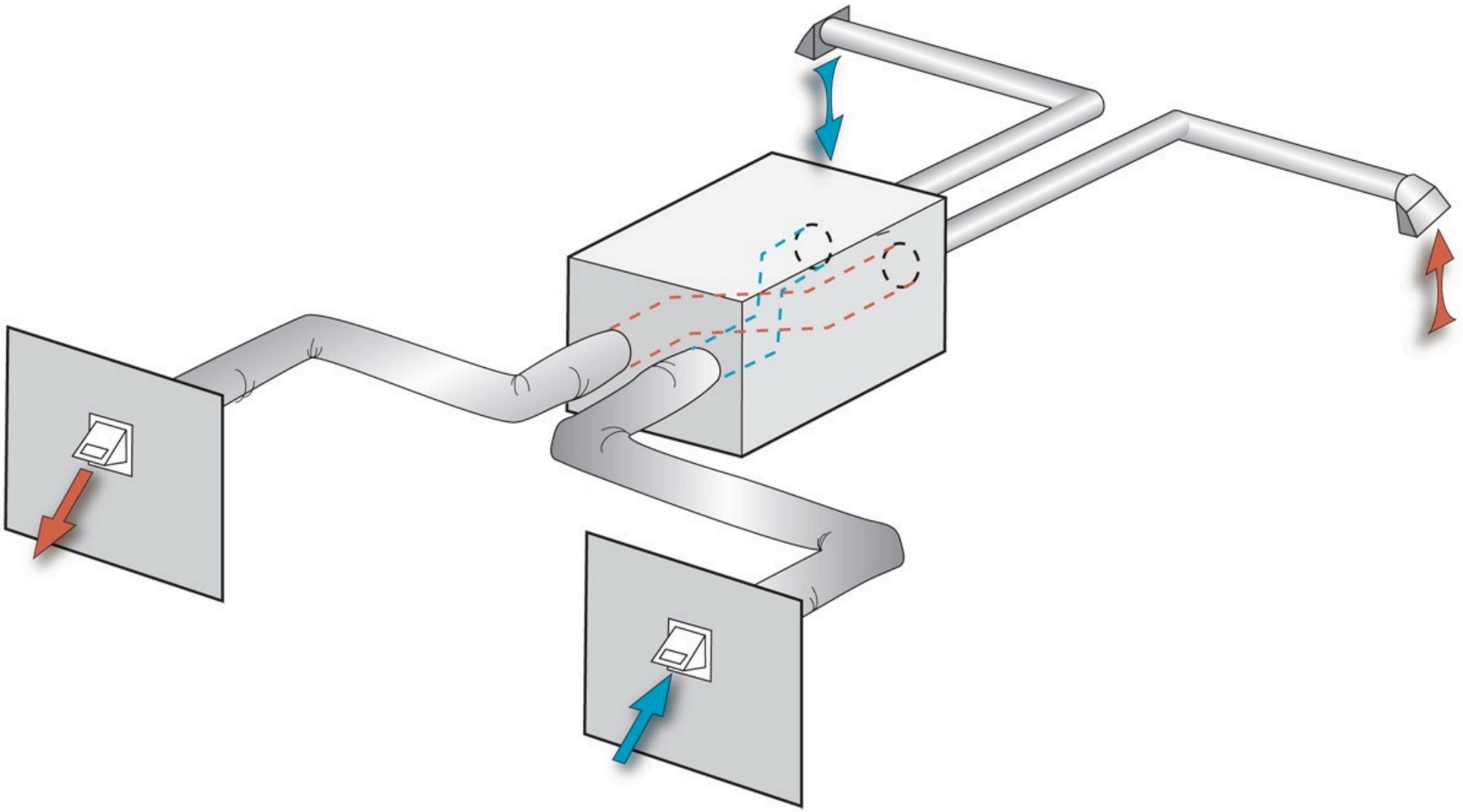

Exhaust fan






Motorized
damper
Outside
Air


Exhaust fan



Ventilation Rates Are Based on Odor Control

- Ventilation Rates Are Based on Odor Control
- Health Science Basis for Ventilation Rates is Extremely Limited

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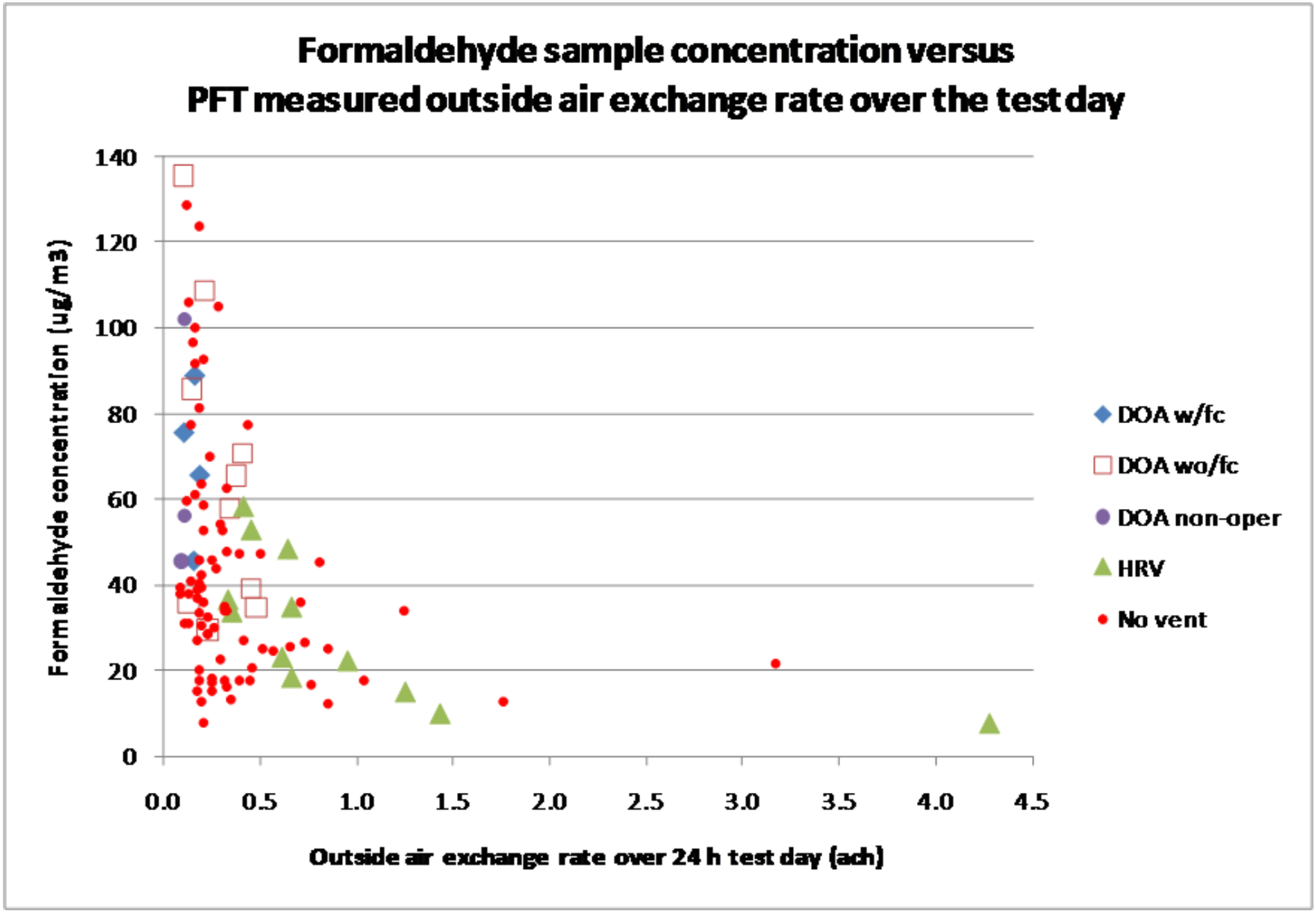
- Almost Nothing Cited Applies to Housing

- Ventilation Rates Are Based on Odor Control
- Health Science Basis for Ventilation Rates is Extremely Limited
- Almost Nothing Cited Applies to Housing
- The Applicable Studies Focus on Dampness

House

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

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


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

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

Occupancy is deemed to be the number of bedrooms plus one

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

Occupancy is deemed to be the number of bedrooms plus one

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

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

Occupancy is deemed to be the number of bedrooms plus one

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

3 Bedroom House – 2,500 ft2

30 cfm plus 75 cfm

105 cfm

3 Bedroom House – 2,500 ft2

30 cfm plus 25 cfm

55 cfm

3 Bedroom House – 2,500 ft2

30 cfm plus 25 cfm

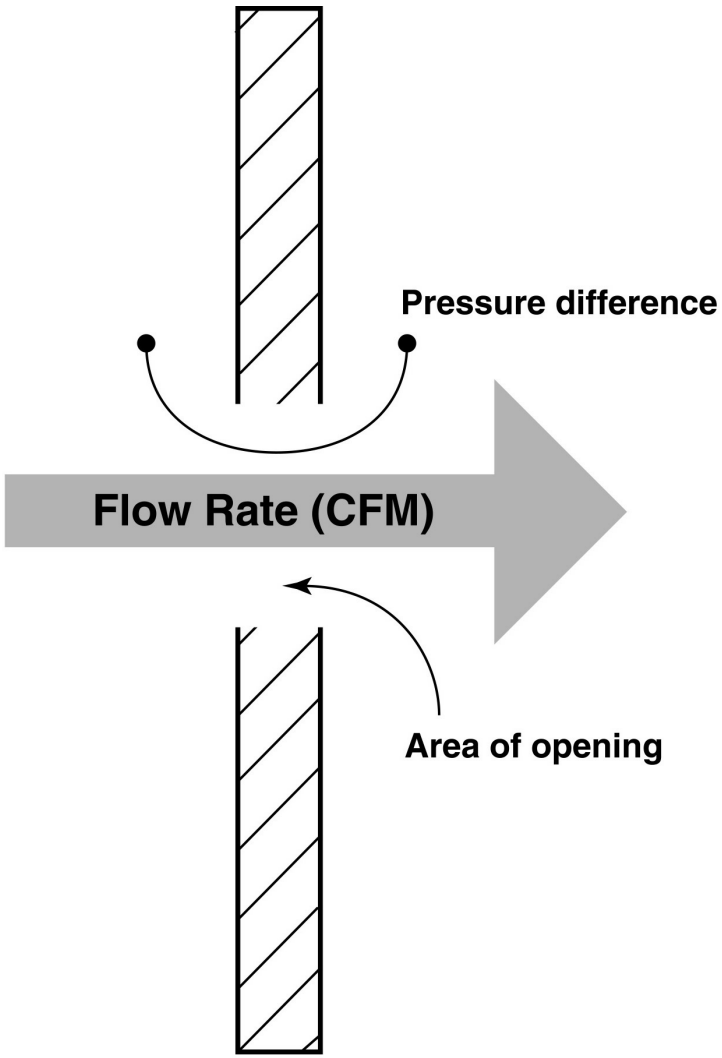
55 cfm

With Balanced and Distributed 30 percent credit

38.5 cfm

The Cult of The Blower Door



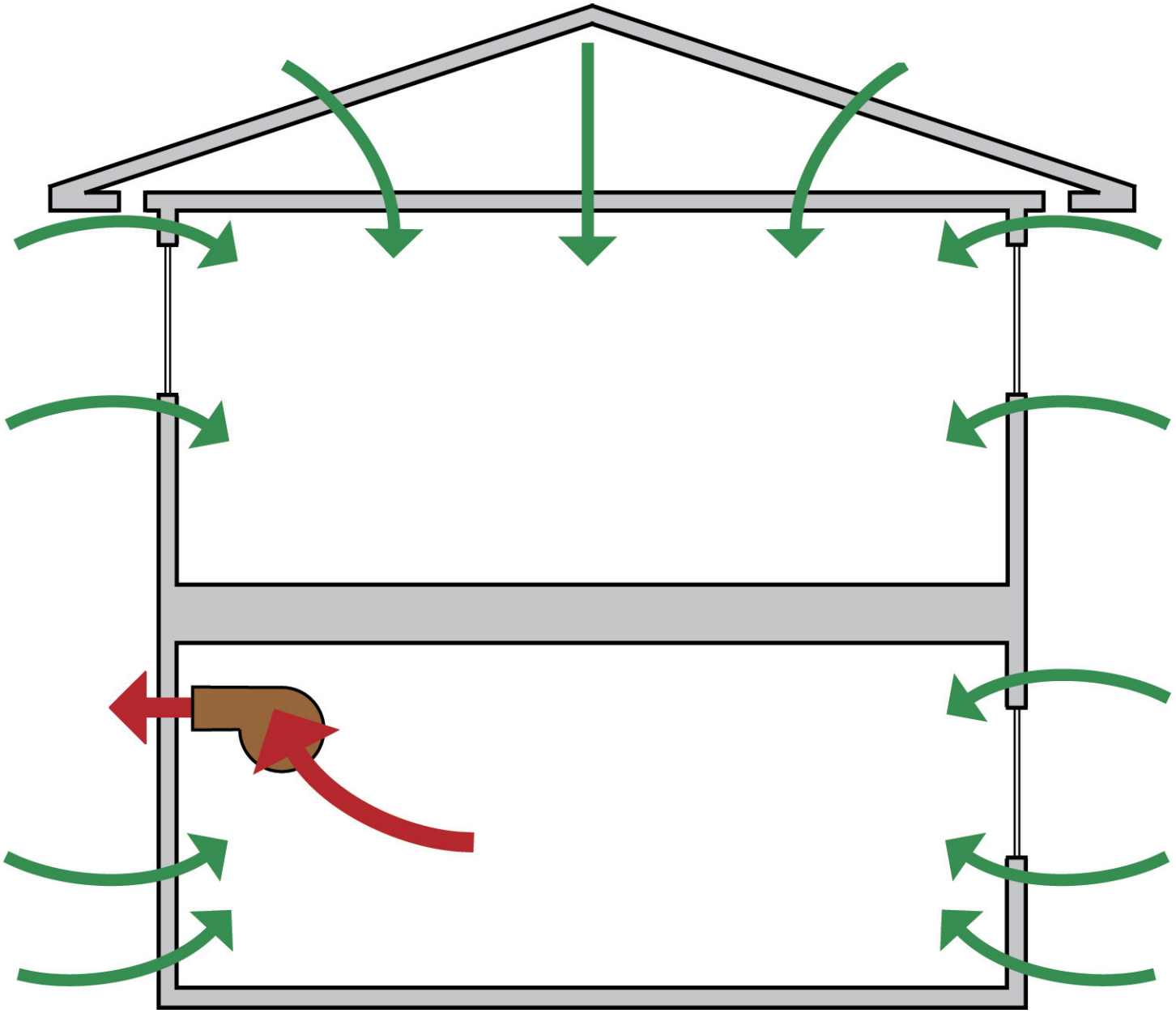

Pressure difference
Flow Rate (CFM)
Area of opening

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

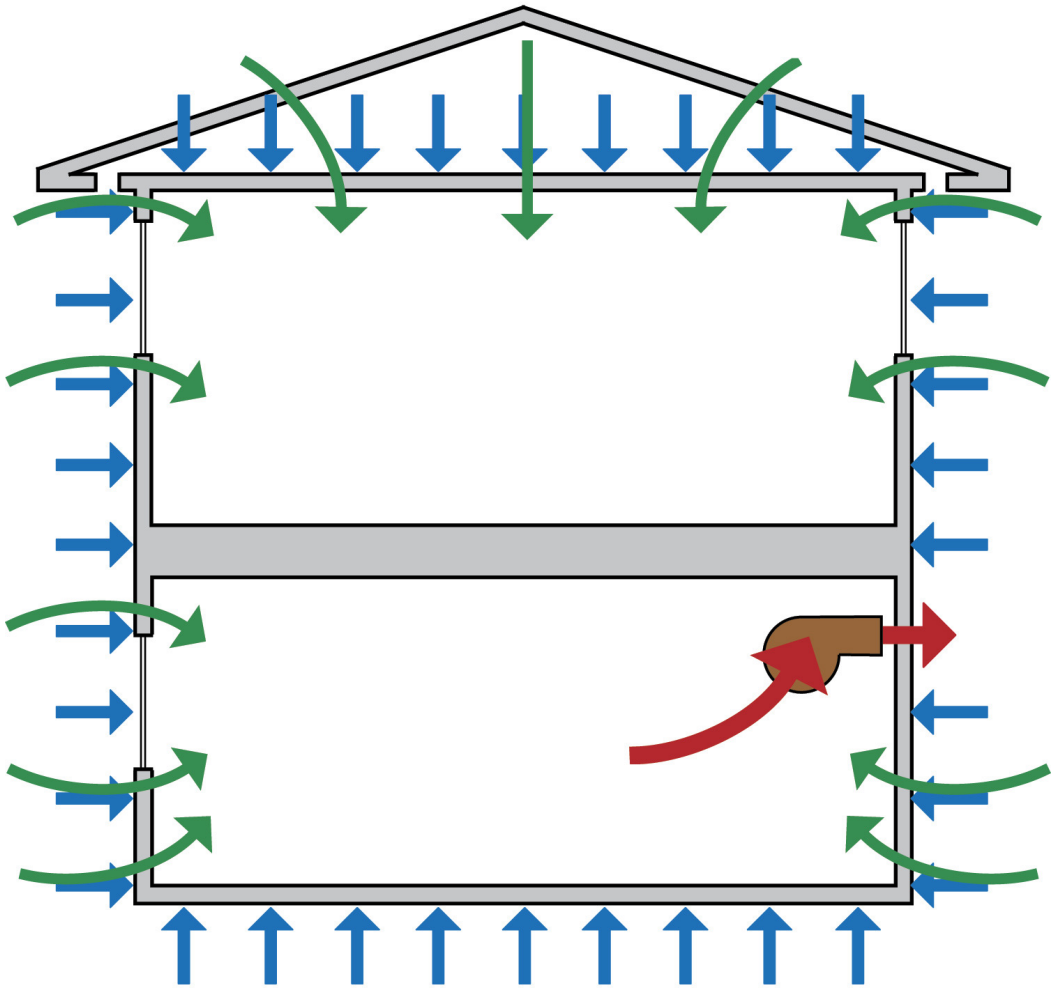
Don’t Know Where The Holes Are

Don’t Know The Type of Holes

Don’t Know The Pressure Across The Holes



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



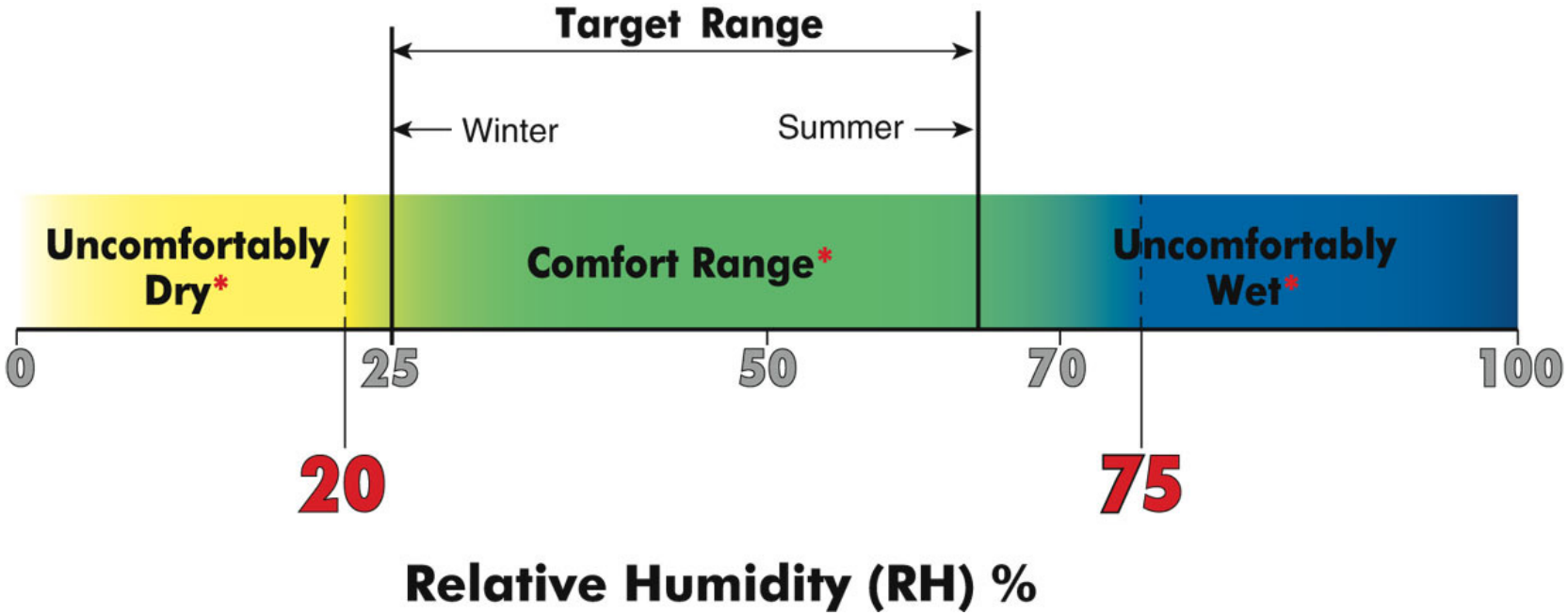
$$(\text{Meters})^2 \approx \frac{1}{780} \times \frac{\text{Litres per second}}{\sqrt{\text{Pascals}}}$$

Dilution Is Not The Solution To Indoor Pollution

Source Control

Dilution For People

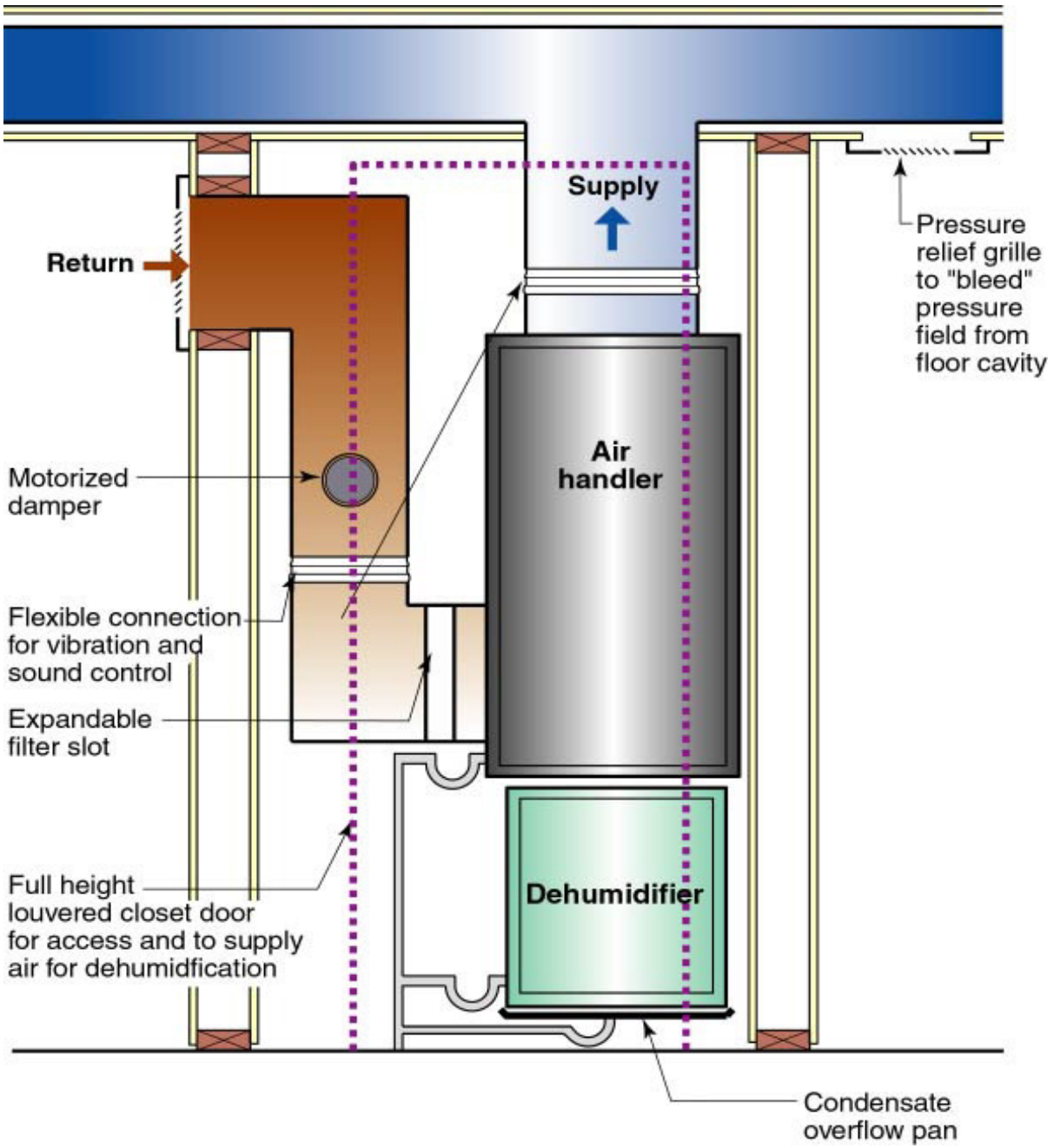
Source Control For The Building


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

Recommended Range of Relative Humidity

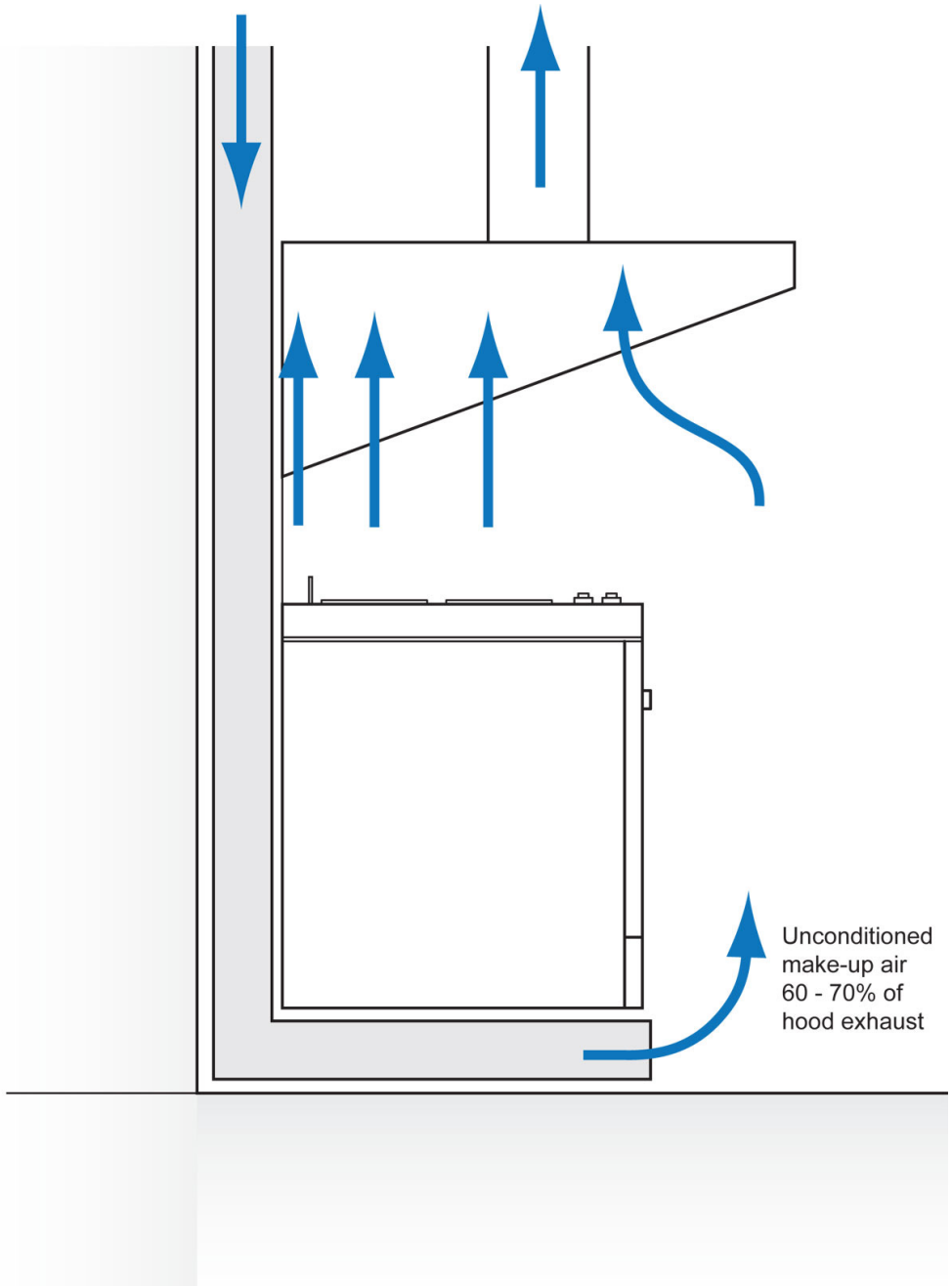
Above 25 percent during winter

Below 70 percent during summer

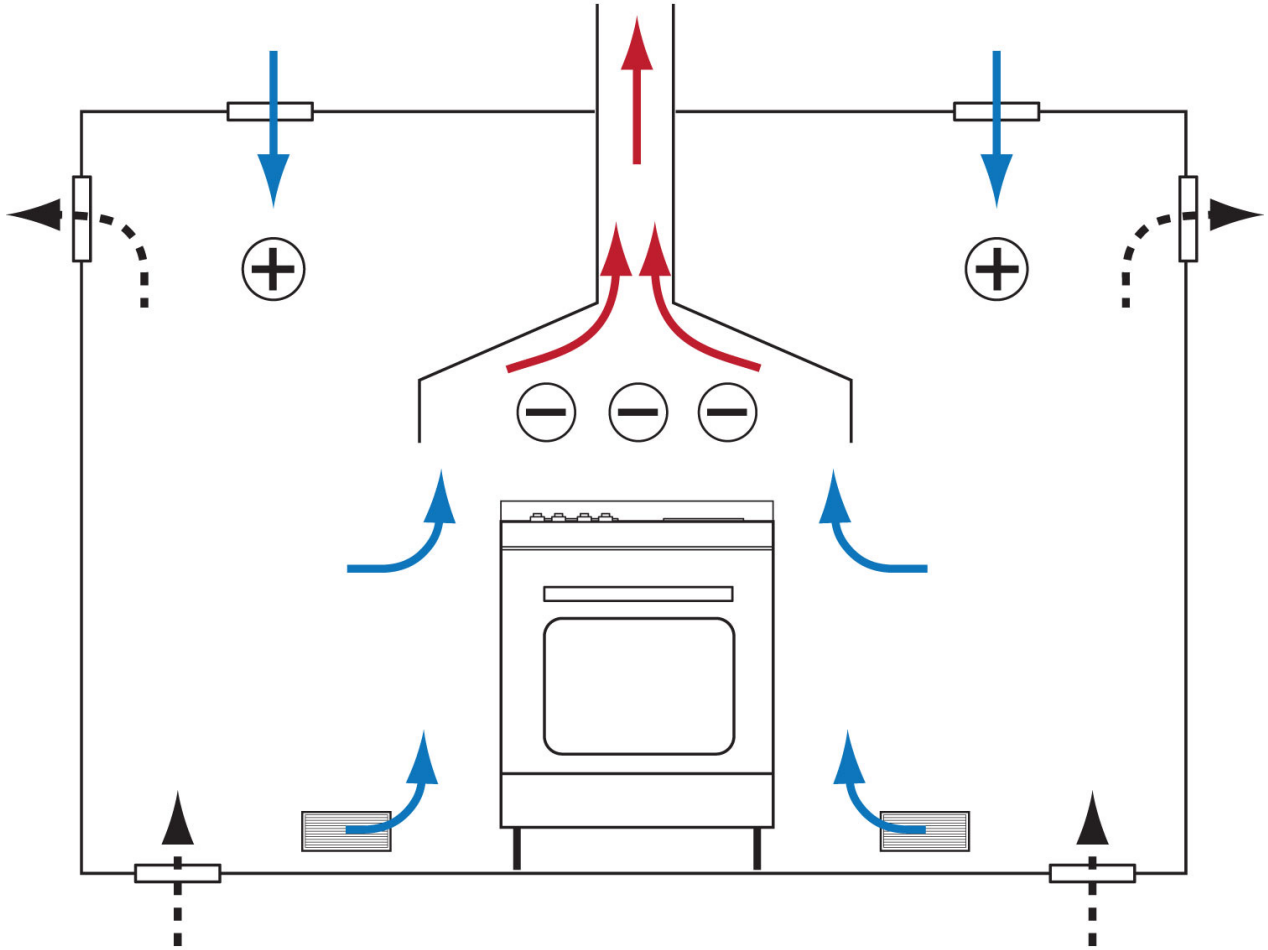

Supply
Return
Pressure relief grille to "bleed" pressure field from floor cavity
Air handler
Motorized damper
Flexible connection for vibration and sound control
Expandable filter slot
Dehumidifier
Full height louvered closet door for access and to supply air for dehumidfication
Condensate overflow pan

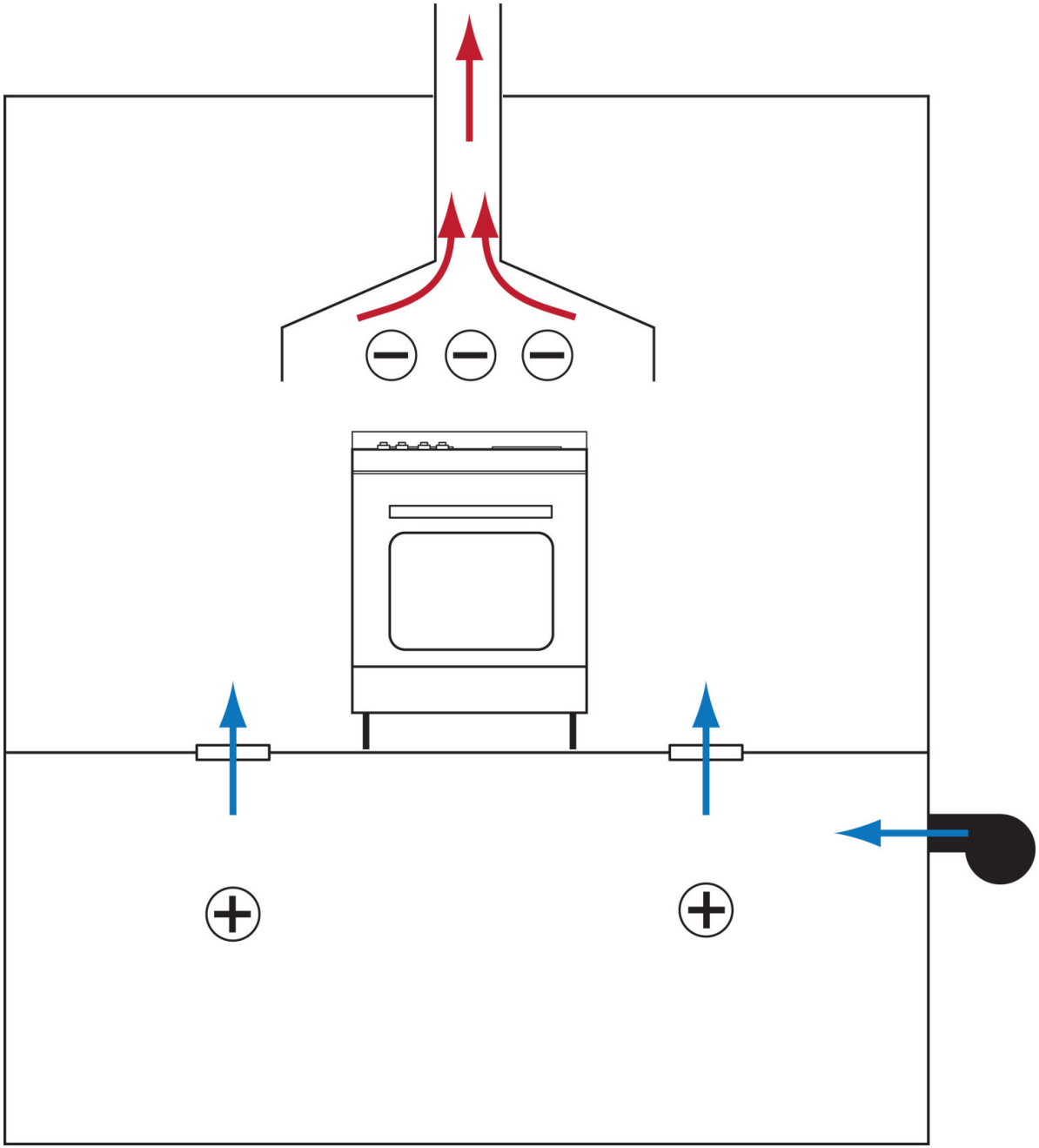

WARNING
MAXIMUM
Florida HVAC Efficiency Card
Wood's
25

Kitchen Exhaust Hoods


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







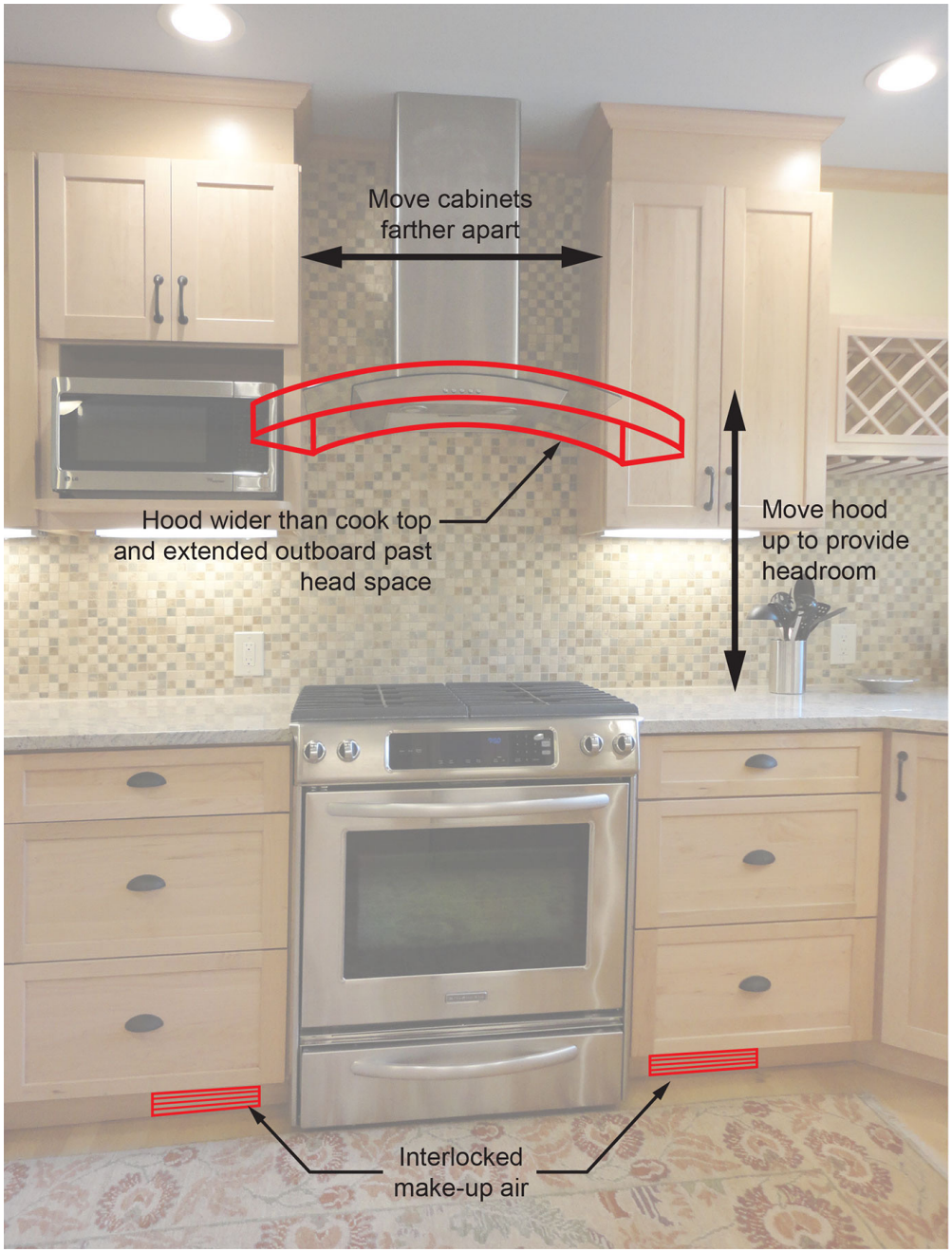











Move cabinets
farther apart
Hood wider than cook top
and extended outboard past
head space
Move hood
up to provide
headroom
Interlocked
make-up air





Clothes Dryers


ENERGYGUIDE


ASKO
ASKO
ENERGUIDE
209

Fireplaces









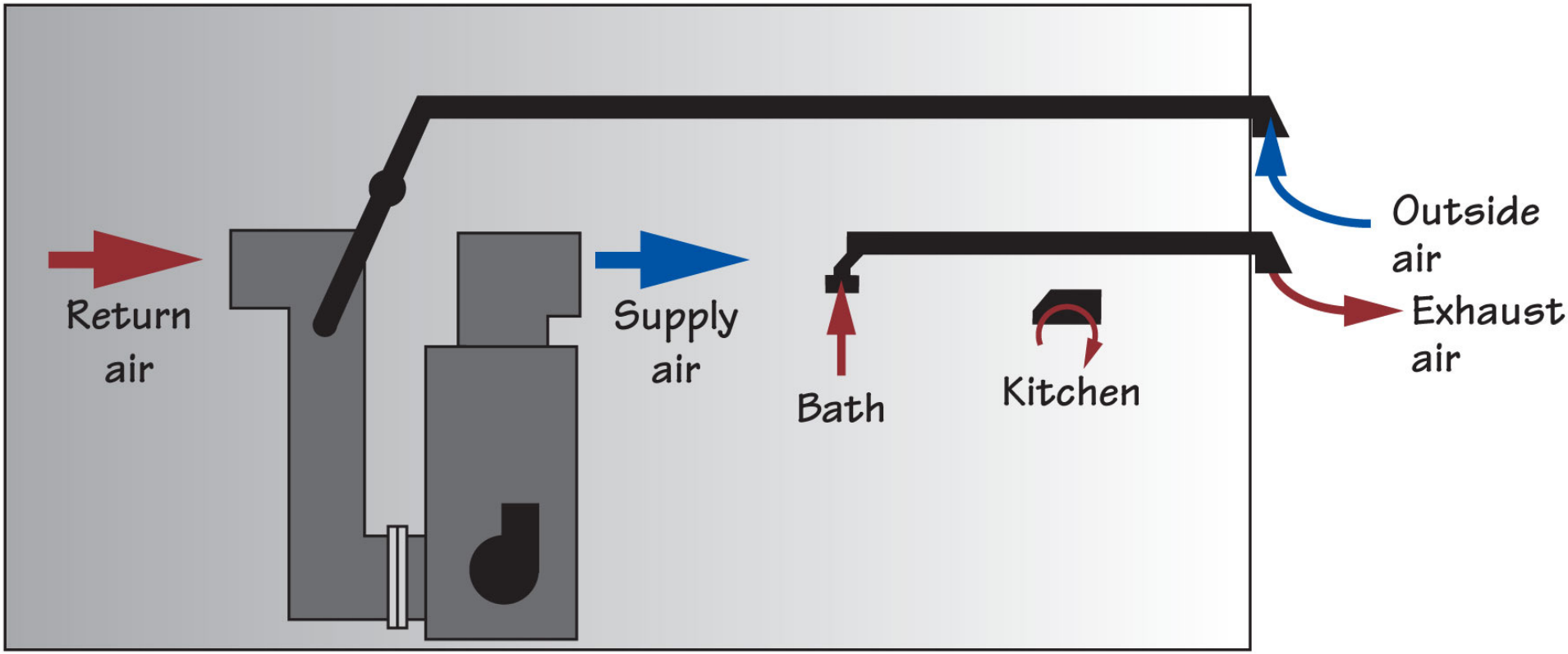


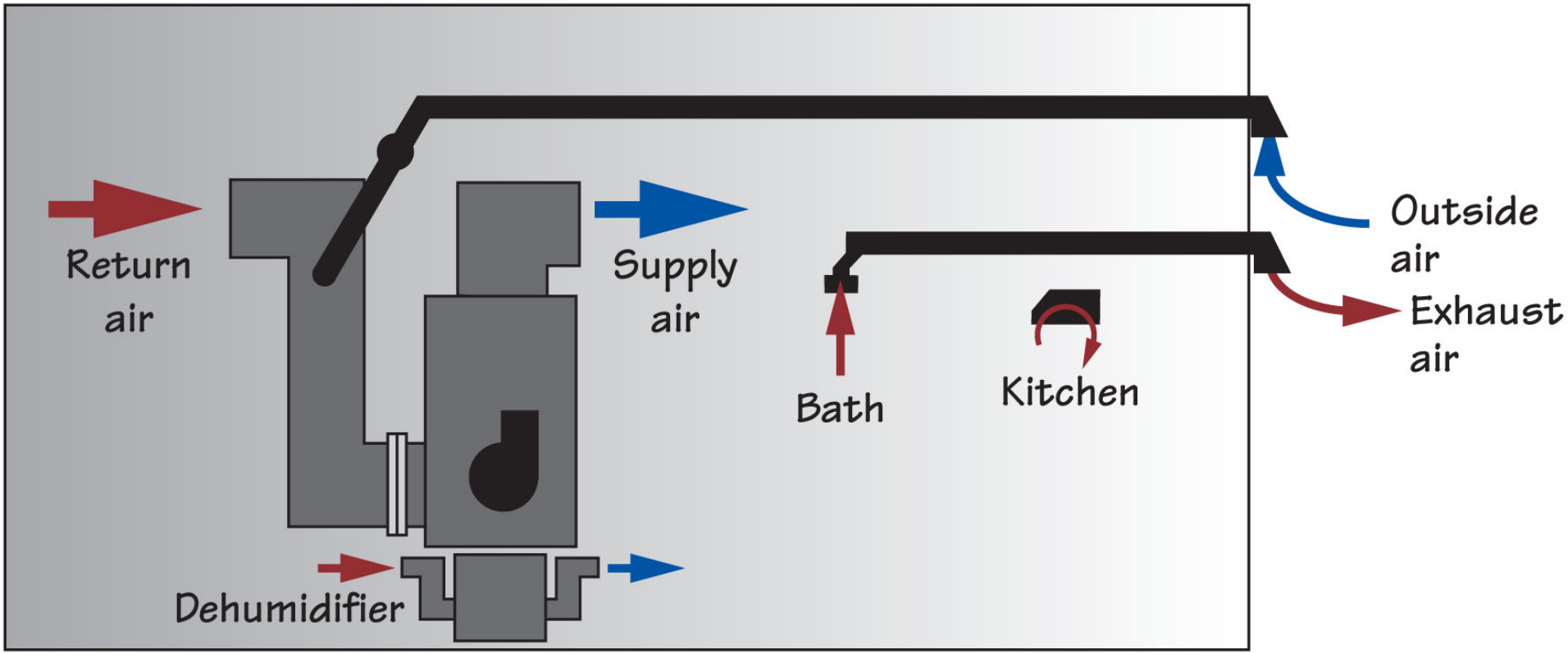


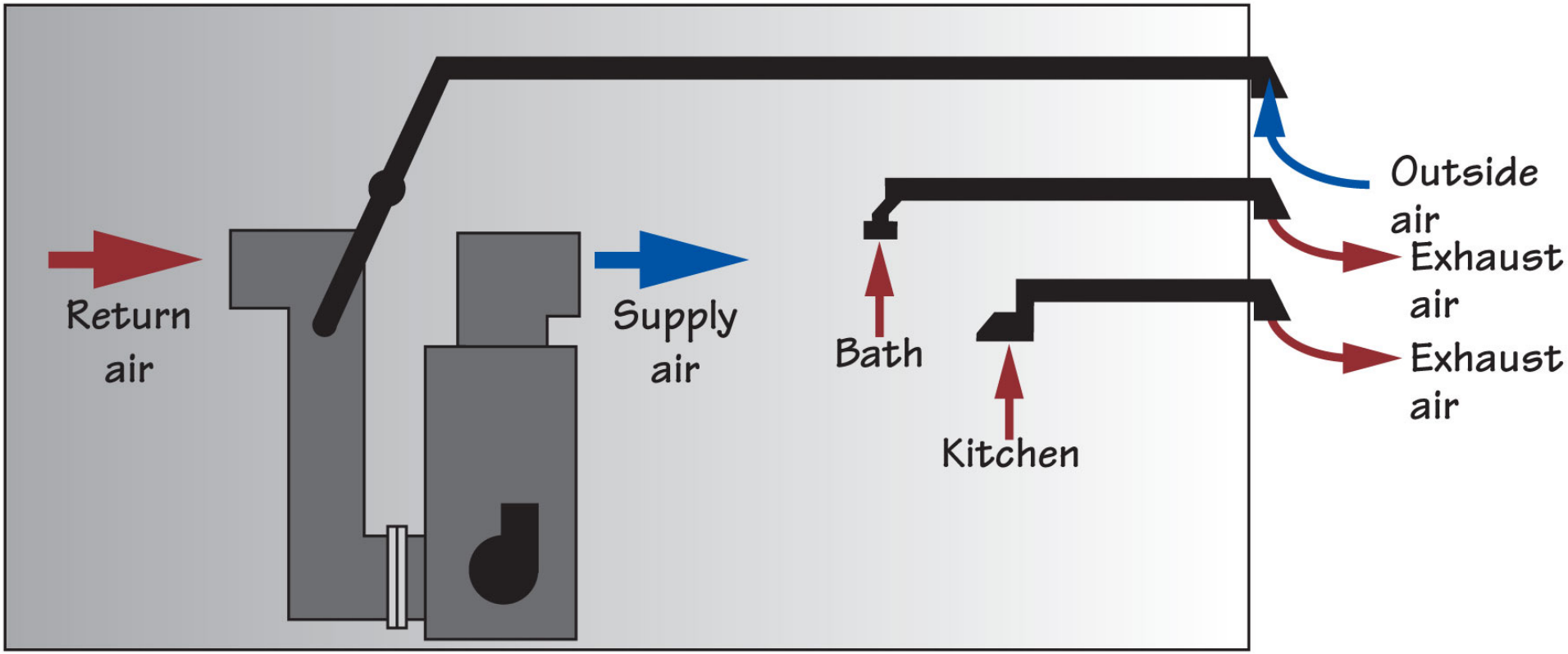


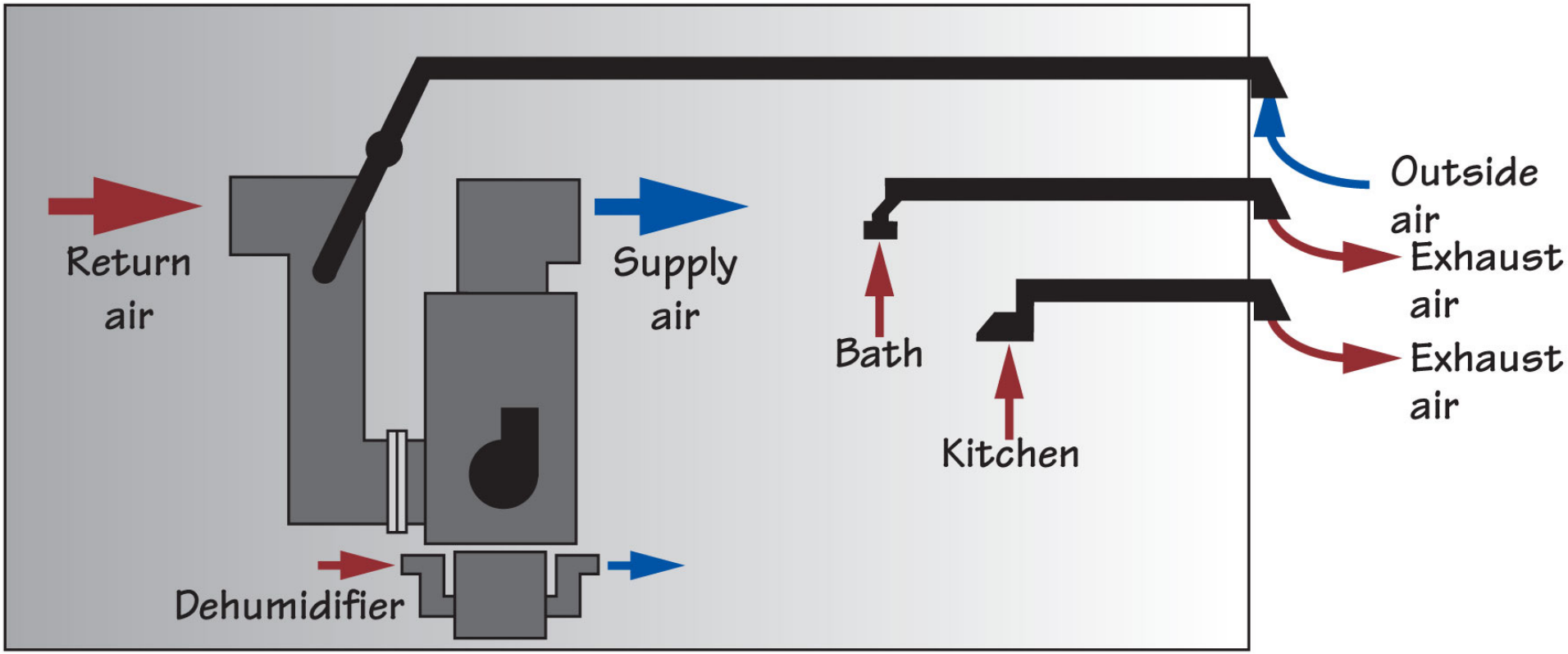


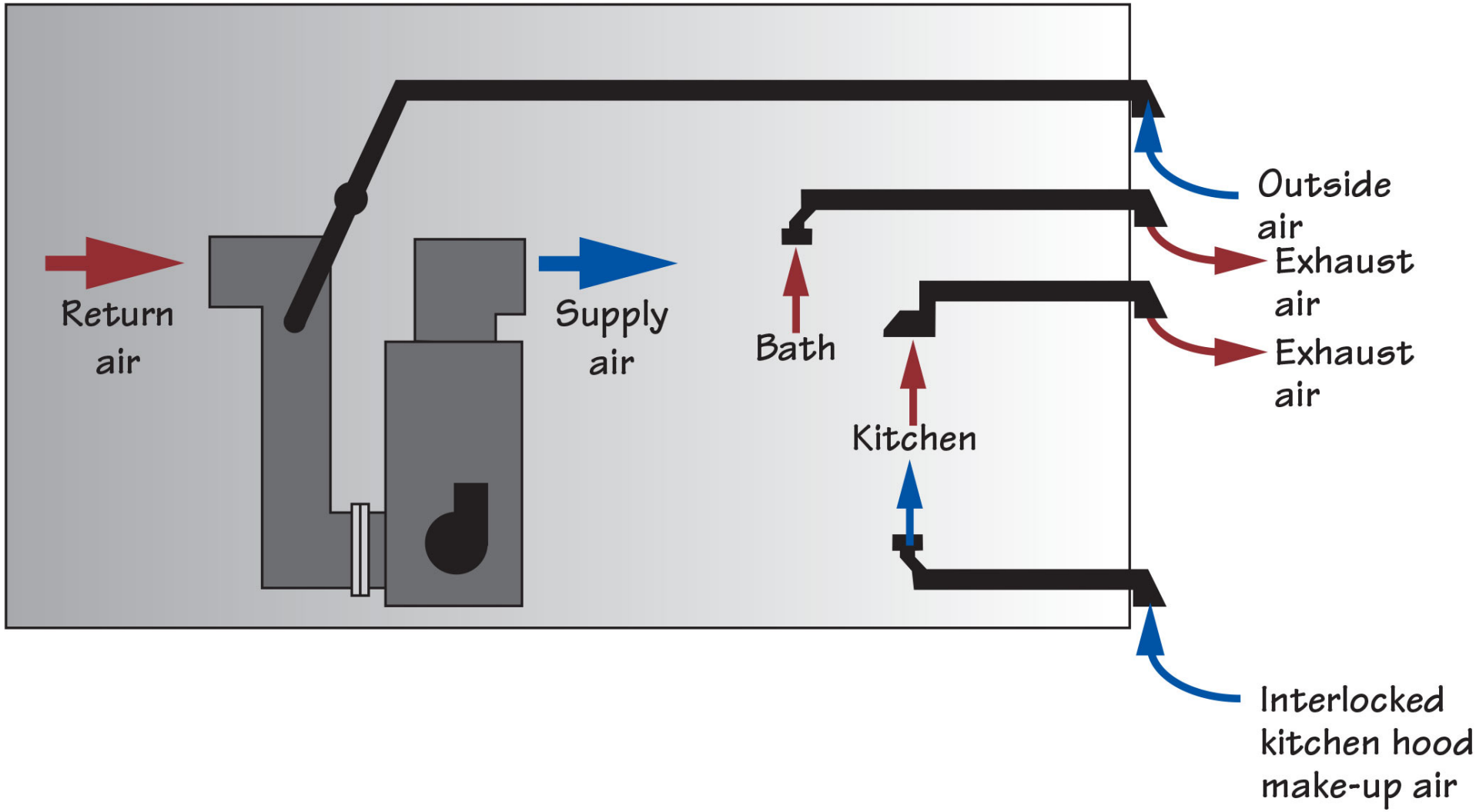
Approaches

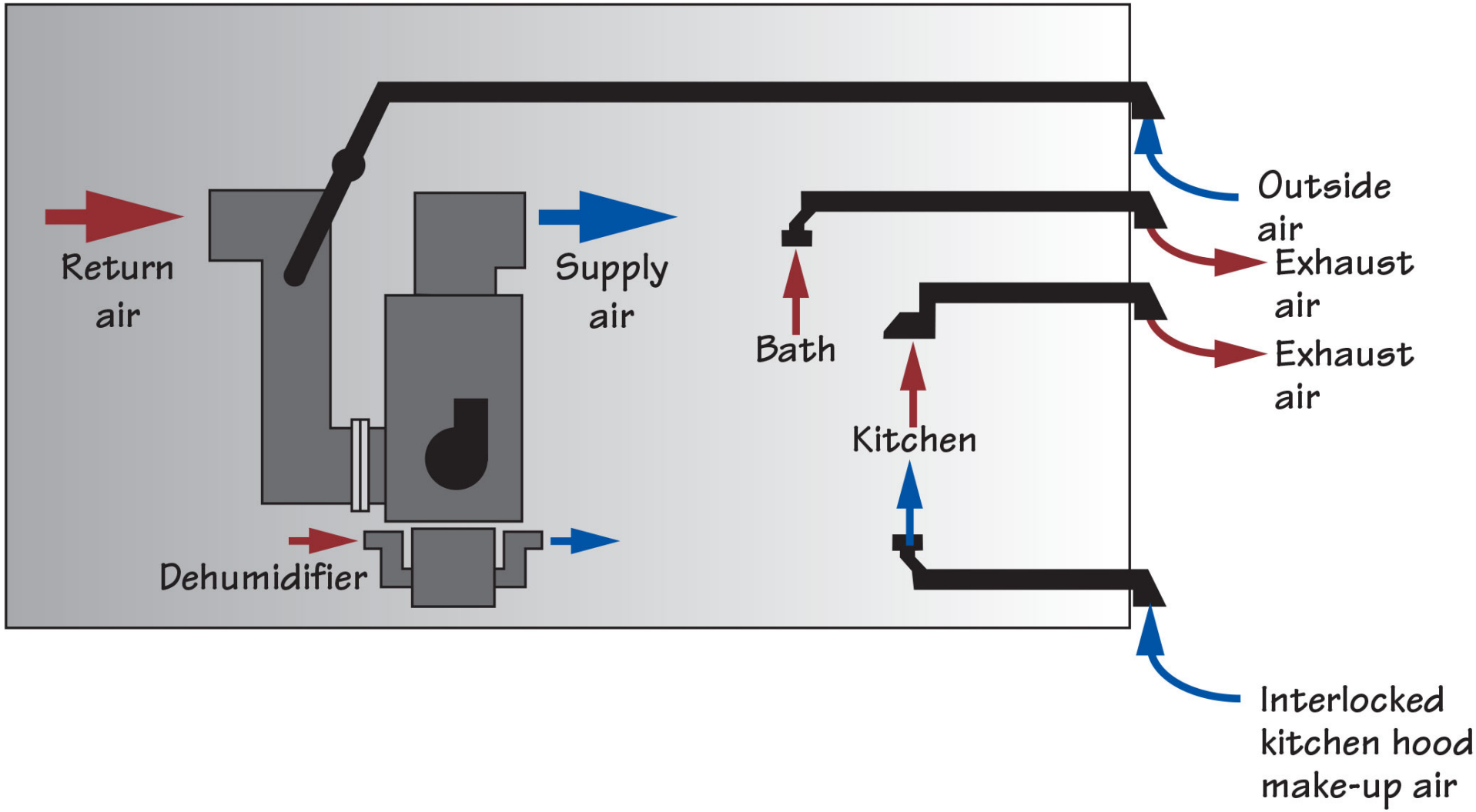

Return
air
Supply
air
Bath
Kitchen
Outside
air
Exhaust
air

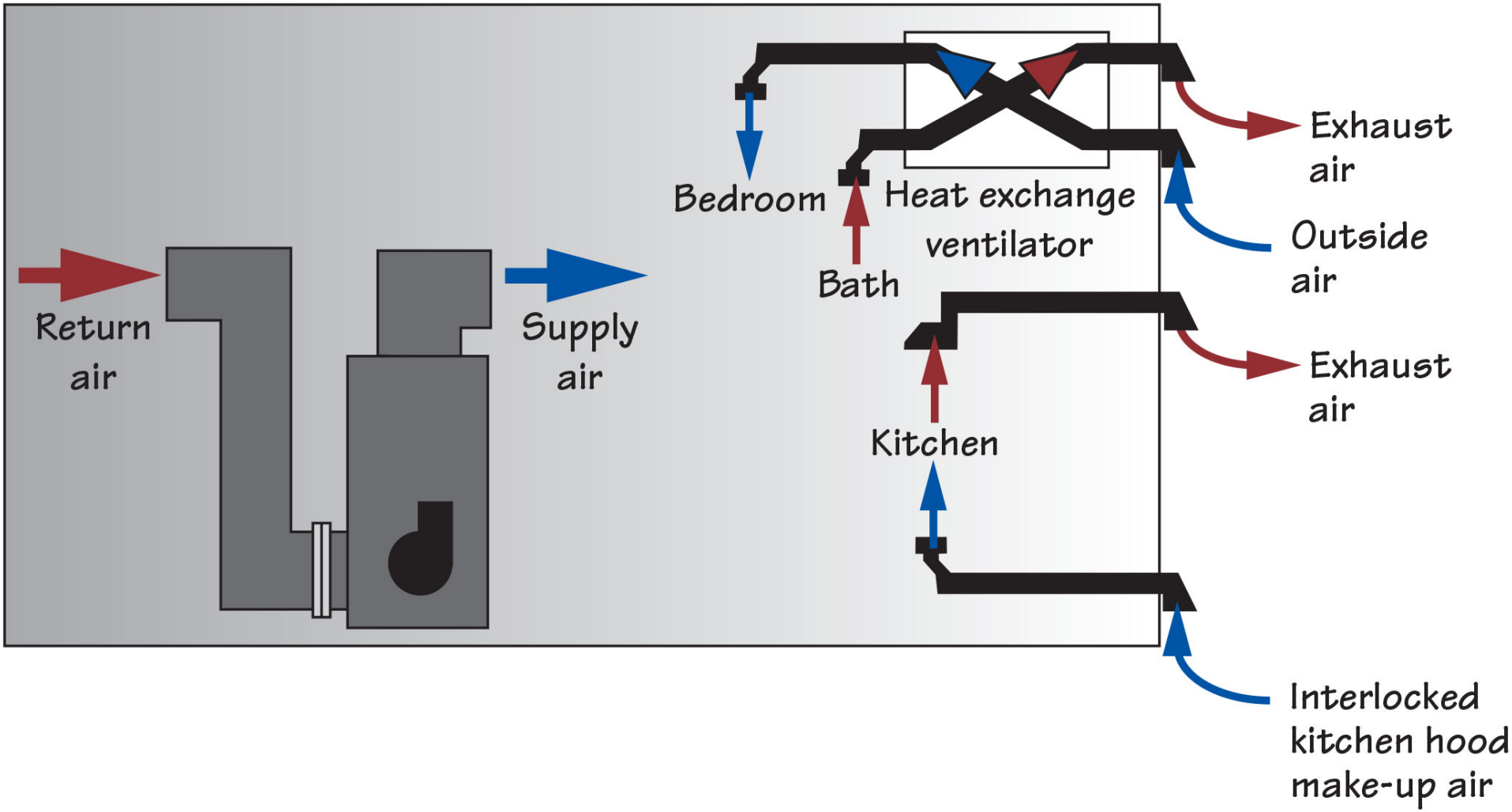

Return
air
Supply
air
Outside
air
Exhaust
air
Bath
Kitchen
Dehumidifier

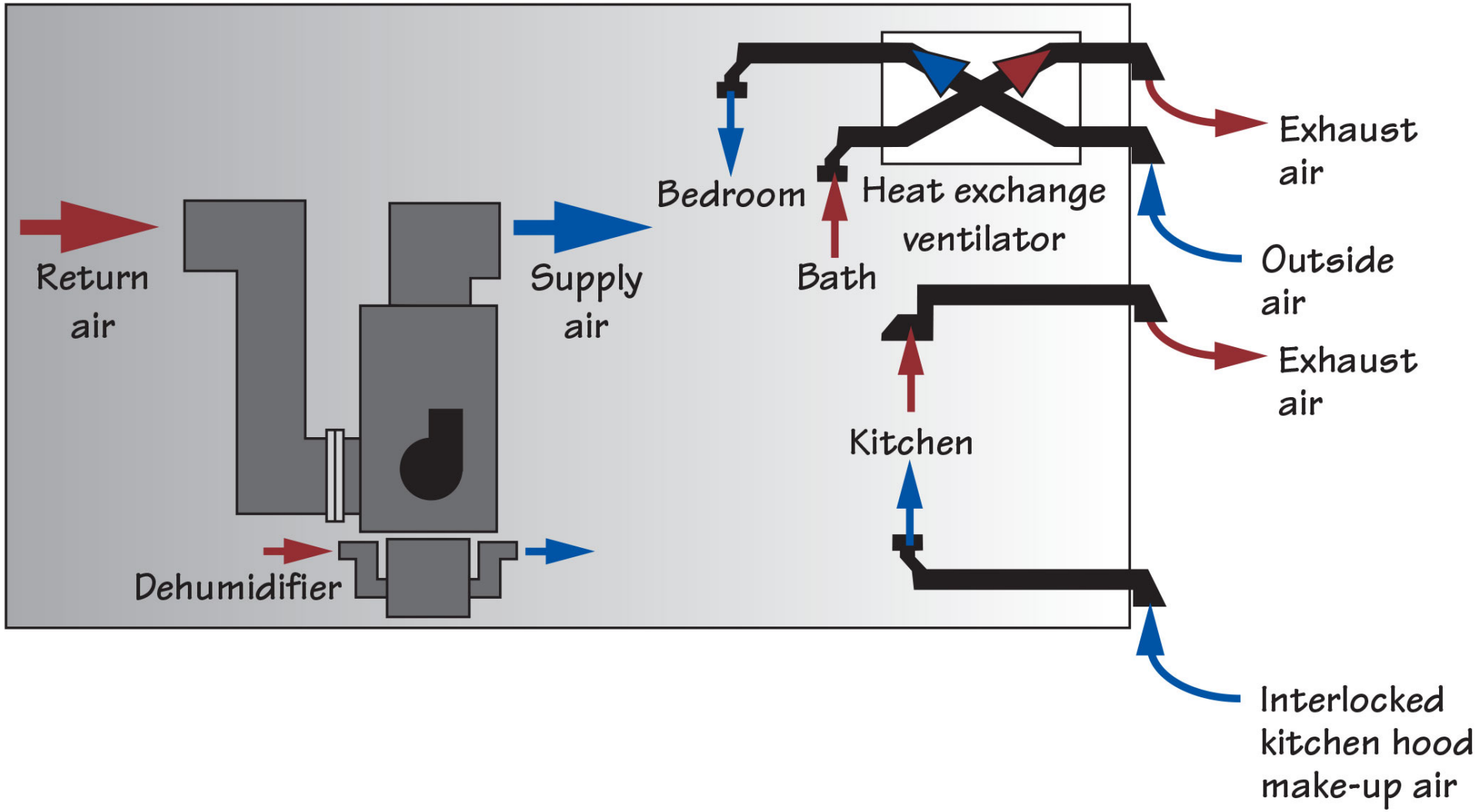

Return air
Supply air
Bath
Kitchen
Outside air
Exhaust air
Exhaust air

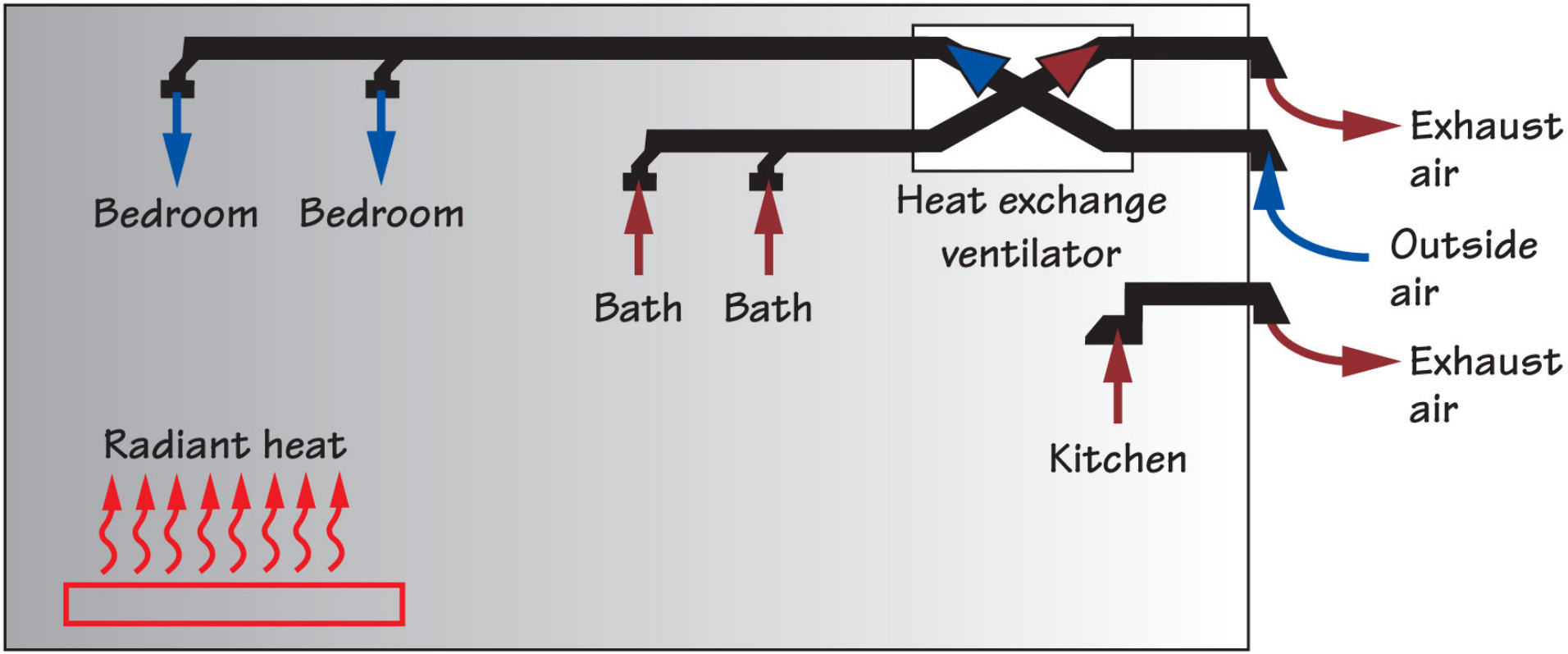

Return
air
Supply
air
Outside
air
Exhaust
air
Bath
Exhaust
air
Kitchen
Dehumidifier

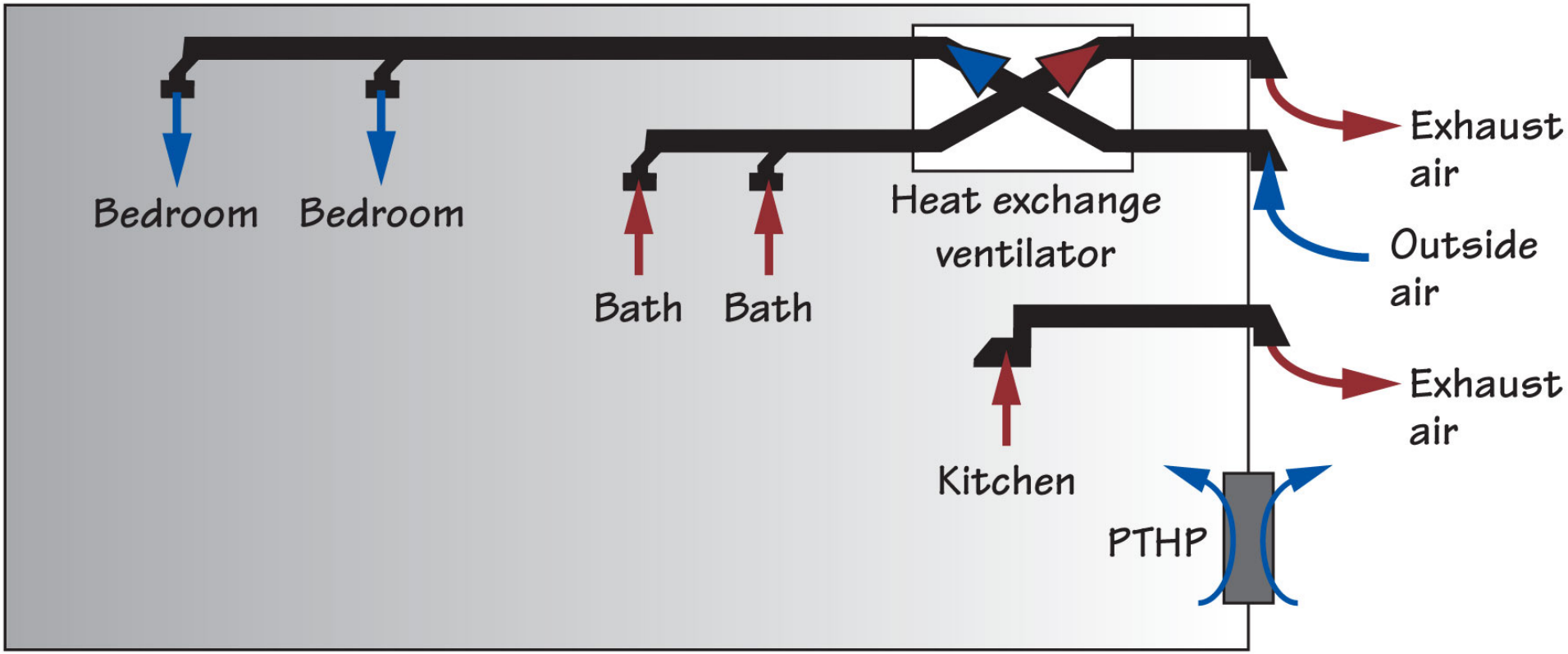

Return air
Supply air
Bath
Kitchen
Outside air
Exhaust air
Exhaust air
Interlocked kitchen hood make-up air

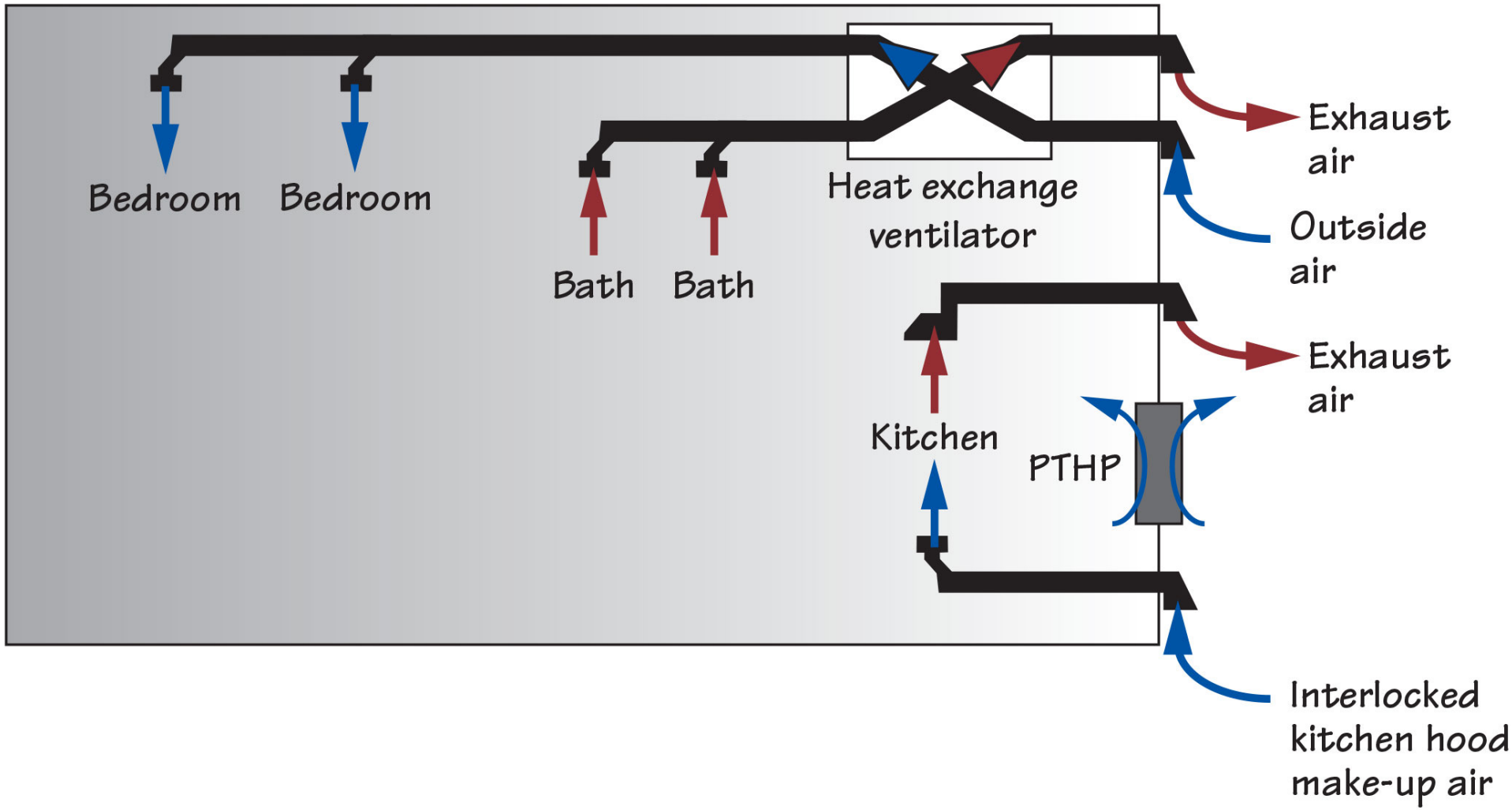

Return air
Supply air
Dehumidifier
Bath
Kitchen
Outside air
Exhaust air
Exhaust air
Interlocked kitchen hood make-up air

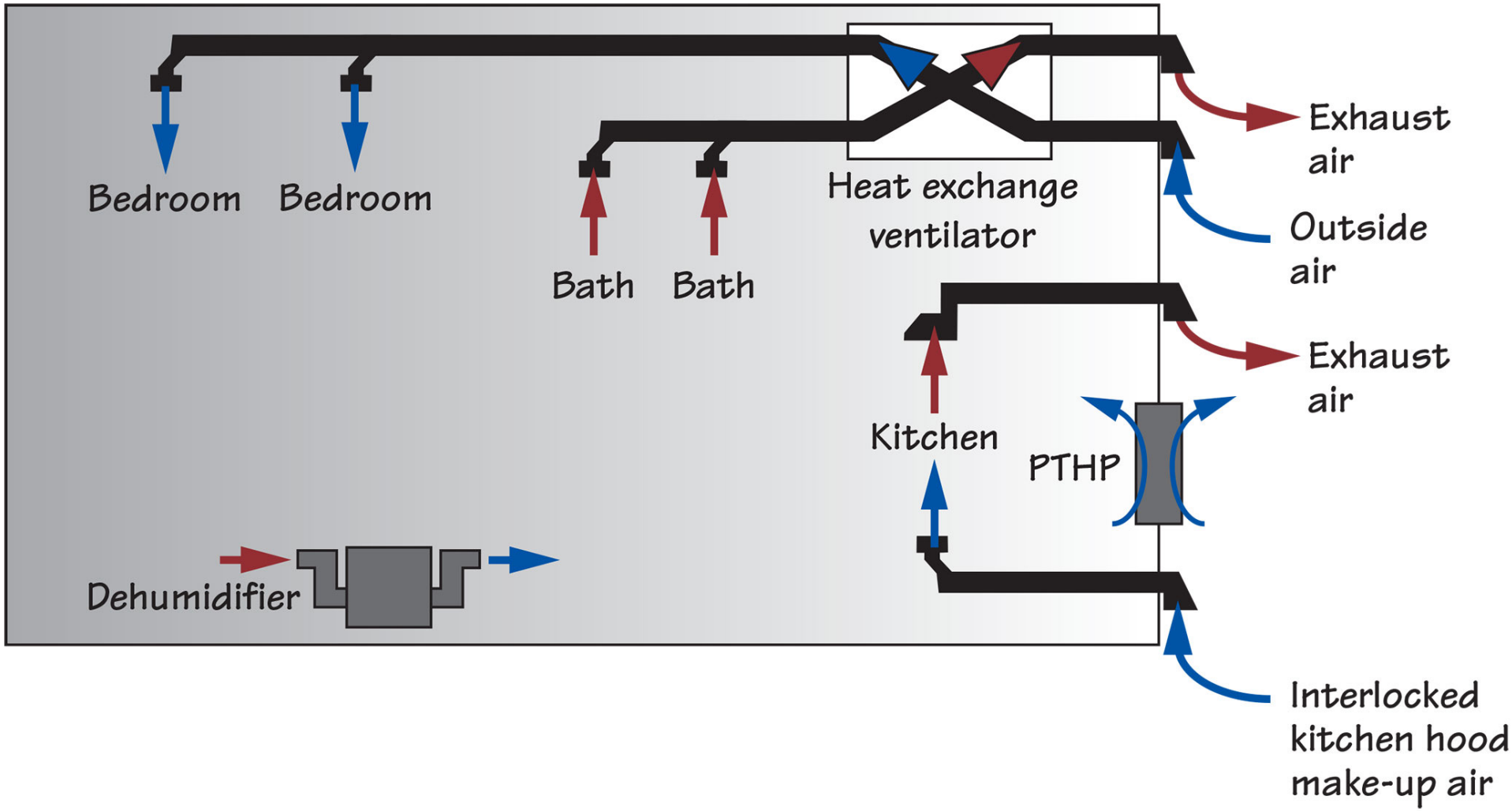

Return
air
Supply
air
Bedroom
Heat exchange
ventilator
Bath
Exhaust
air
Outside
air
Kitchen
Exhaust
air
Interlocked
kitchen hood
make-up air

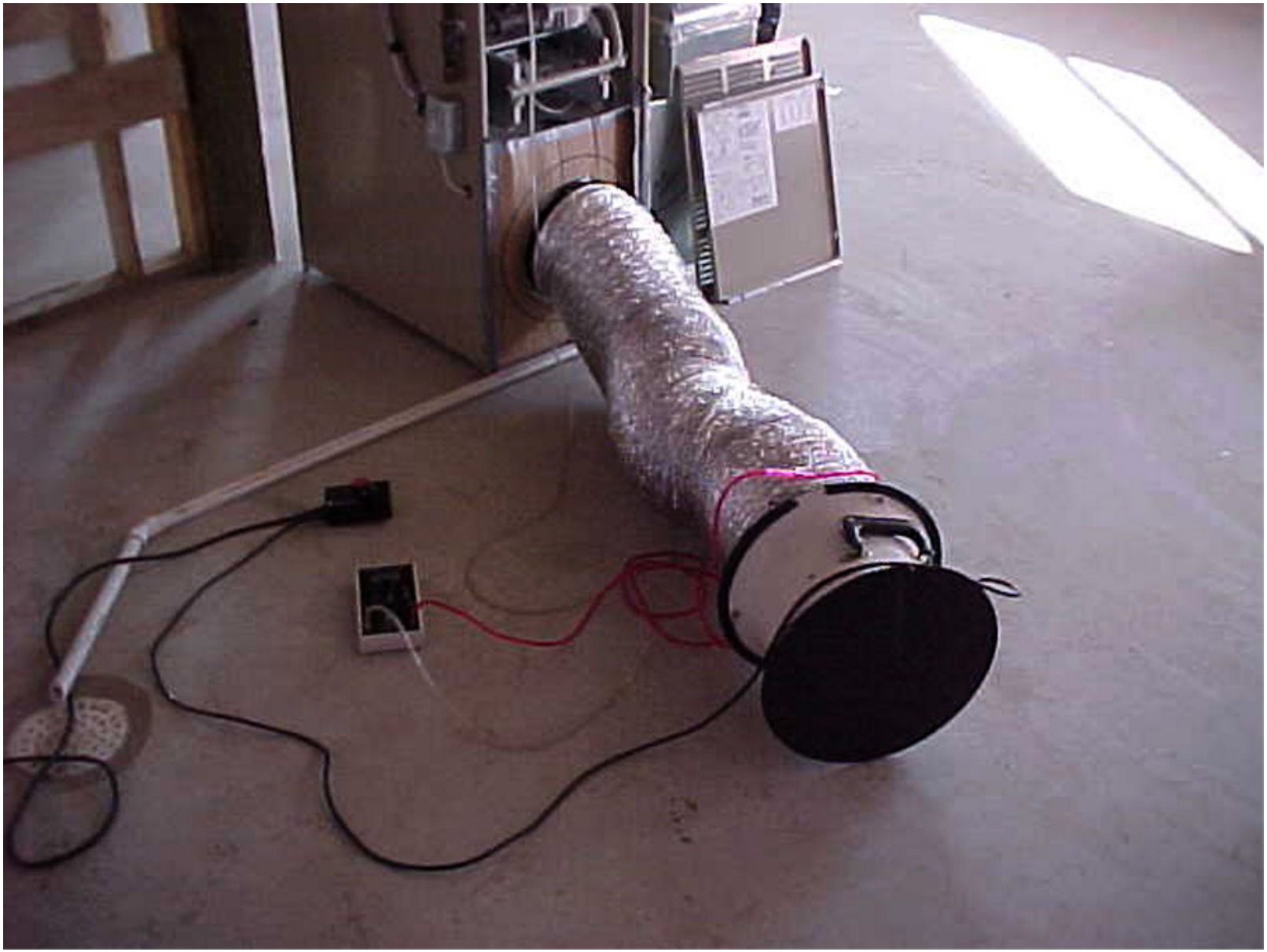

Return air
Supply air
Dehumidifier
Bedroom
Bath
Heat exchange ventilator
Exhaust air
Outside air
Exhaust air
Kitchen
Interlocked kitchen hood make-up air


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

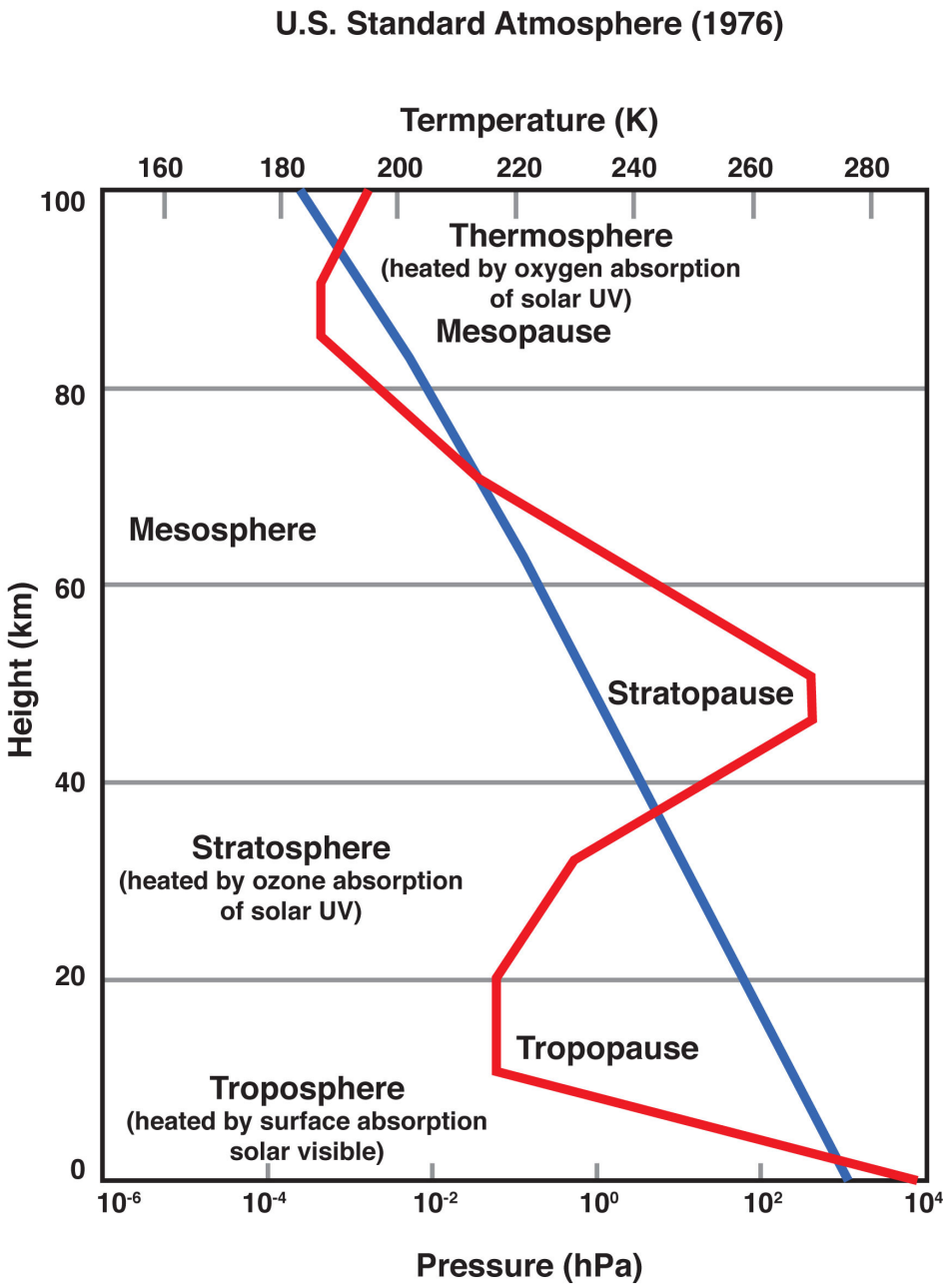

Bedroom
Bedroom
Bath
Bath
Heat exchange ventilator
Exhaust air
Outside air
Exhaust air
Kitchen
PTHP


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


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



Lapse Rate


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

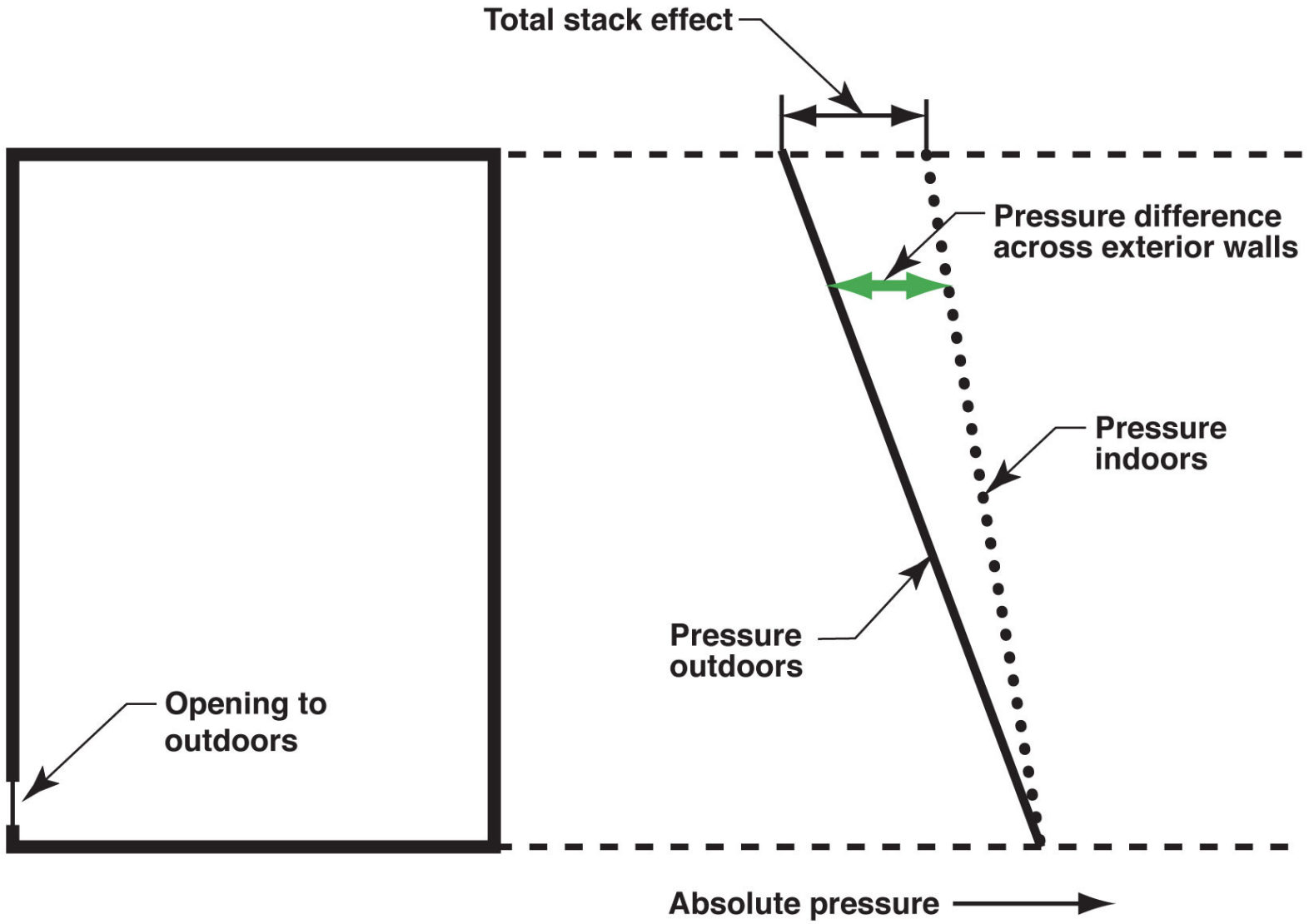


Figure 11.1: Building with no internal separations with opening at the bottom (Adapted from G.O. Handegord, 1998)

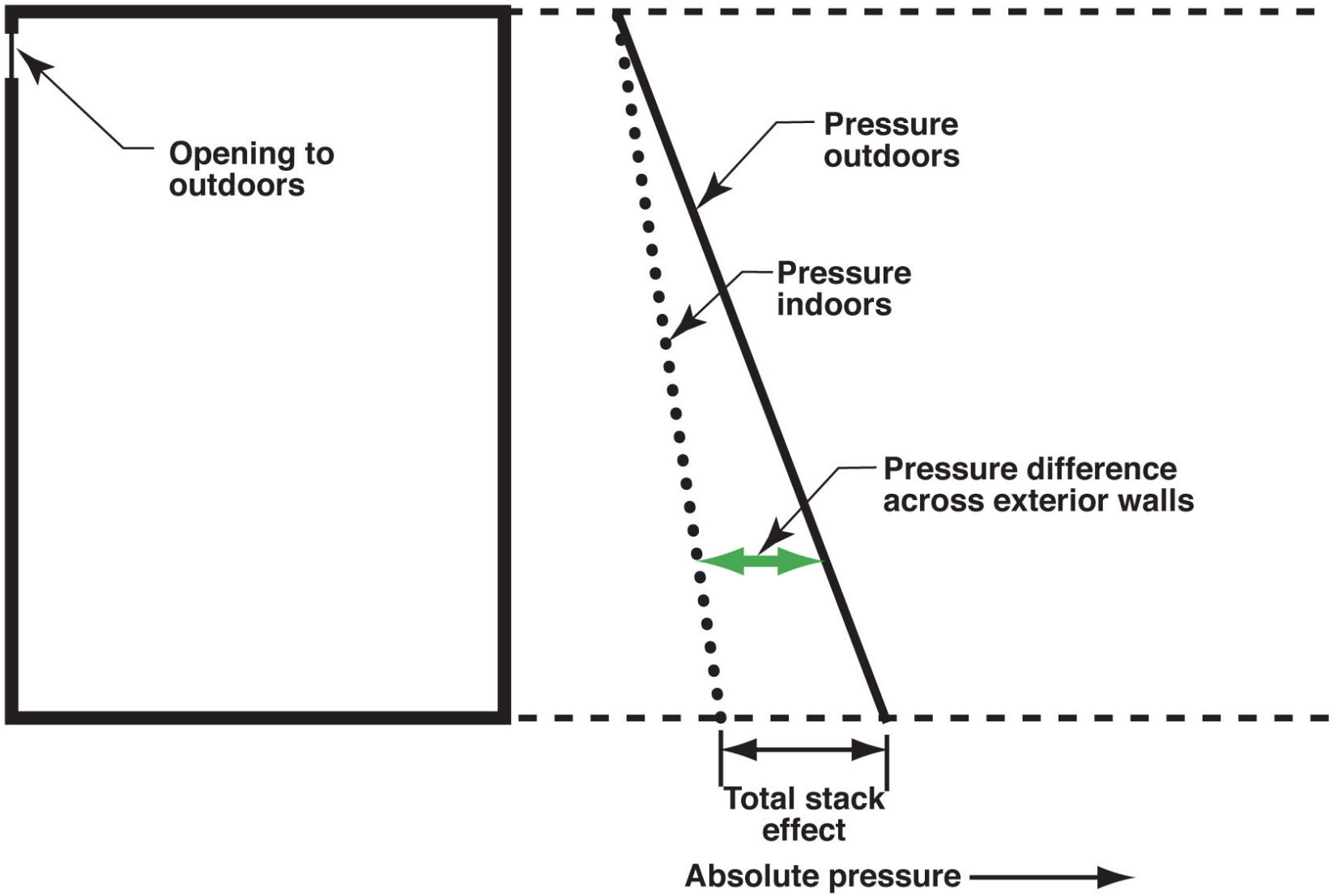


Figure 11.2: Building with no internal separations with opening at the top (Adapted from G.O. Handegord, 1998)

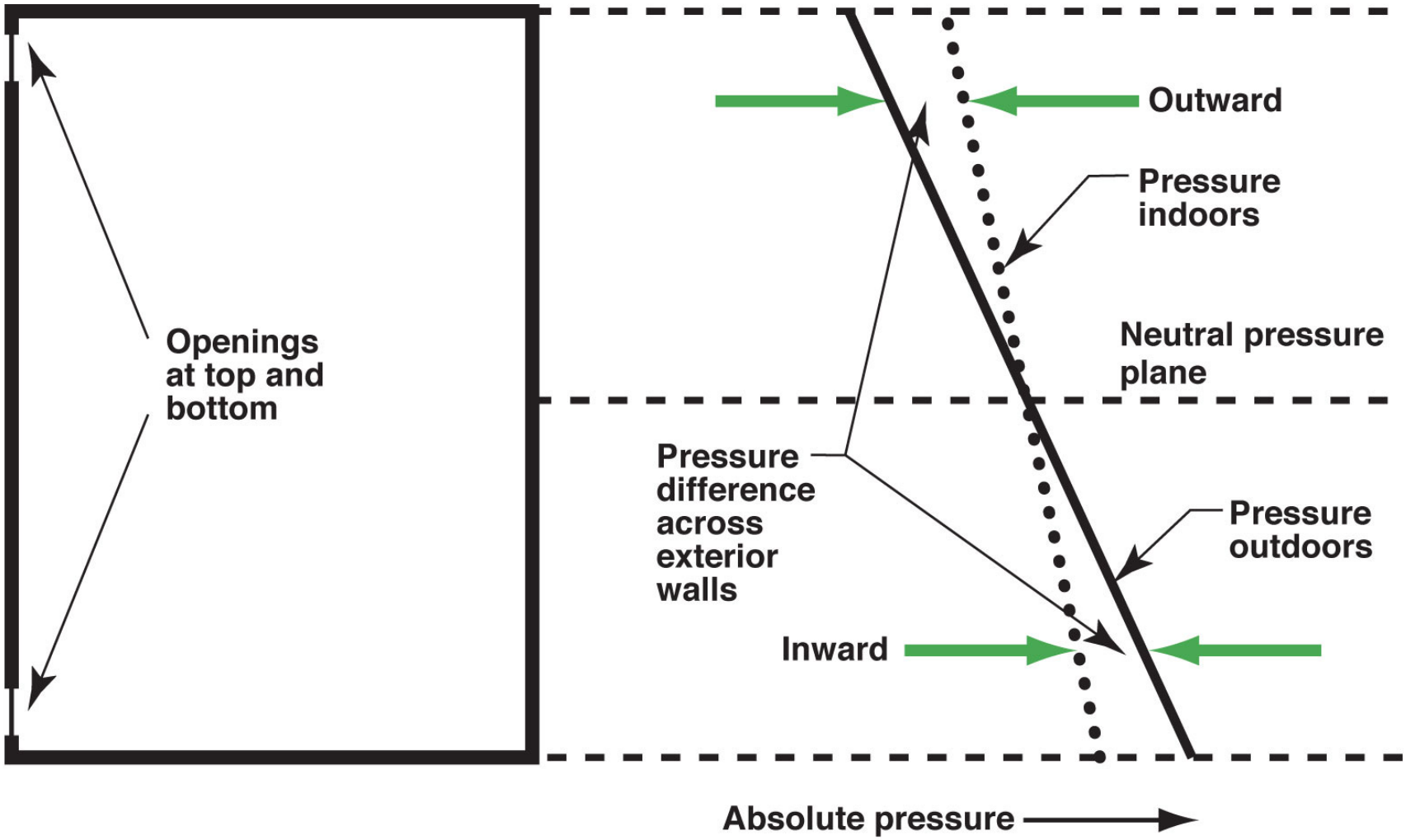


Figure 11.3: Building with no internal separations with openings at top and bottom (Adapted from G.O. Handegord, 1998)

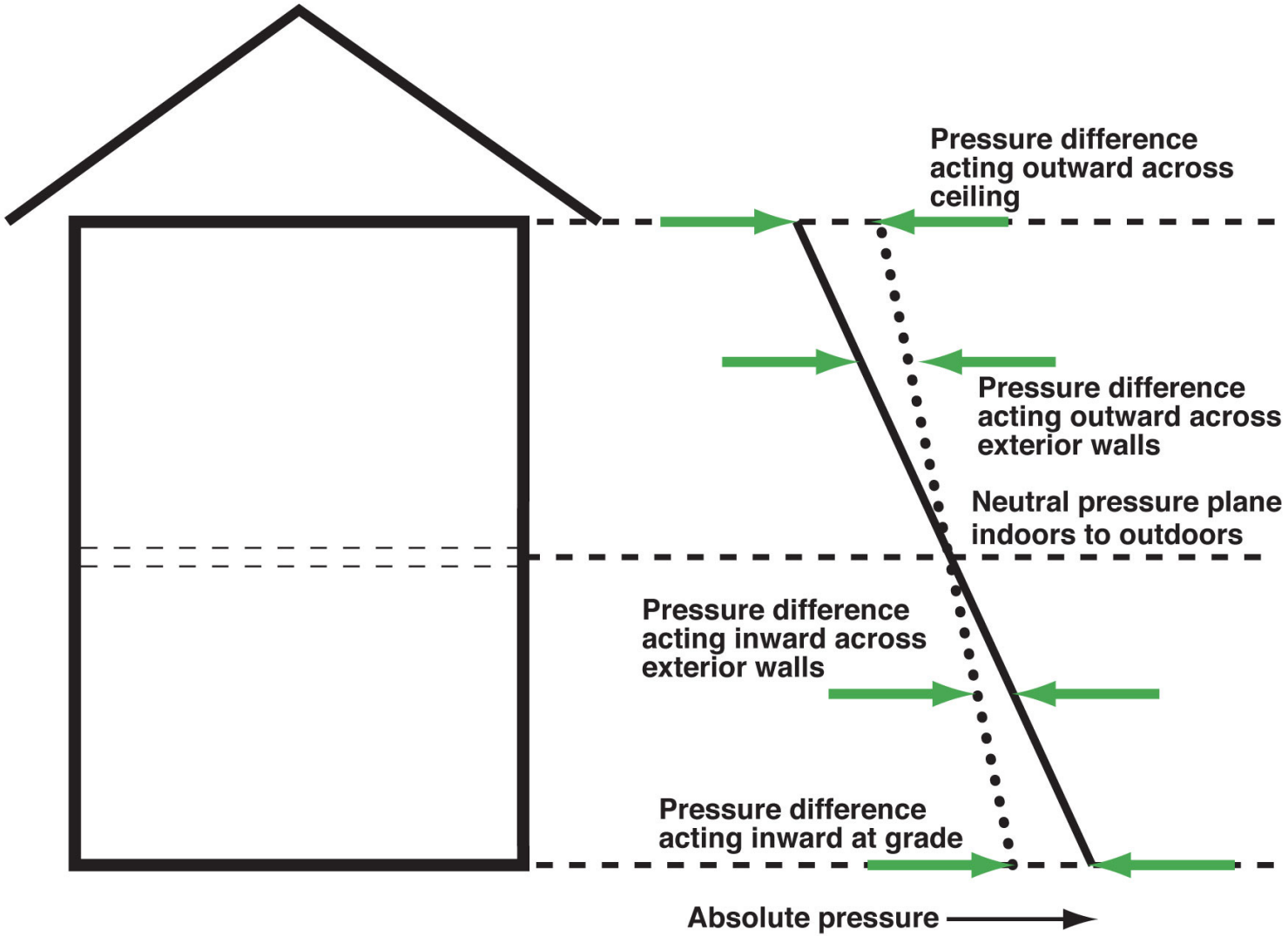


Figure 11.4: Basic two storey house with vented attic (Adapted from G.O. Handegord, 1998)




POMPIERS NO. 3

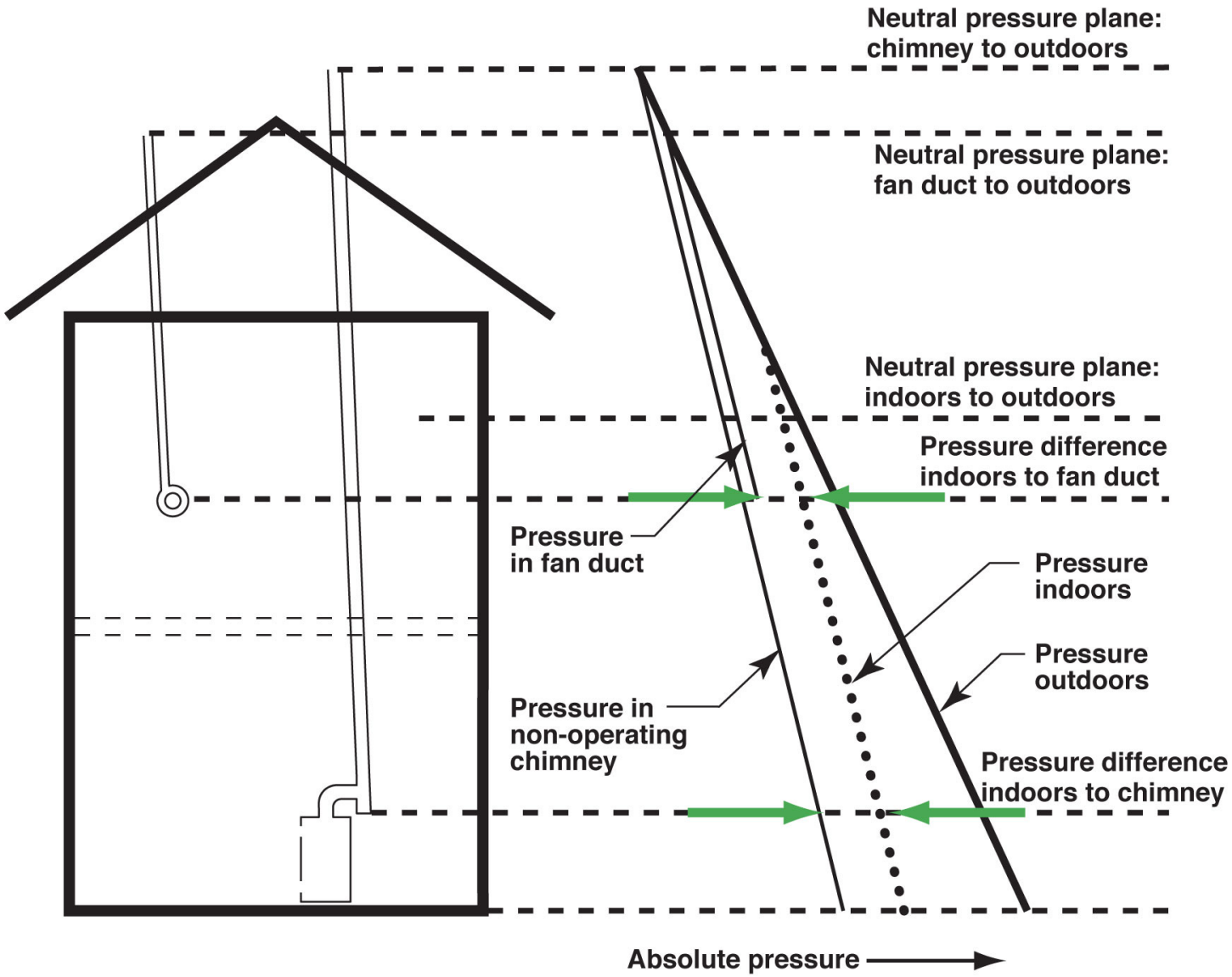


Figure 11.5: Two storey house with non-operating chimney and exhaust fan (Adapted from G.O. Handegord, 1998)

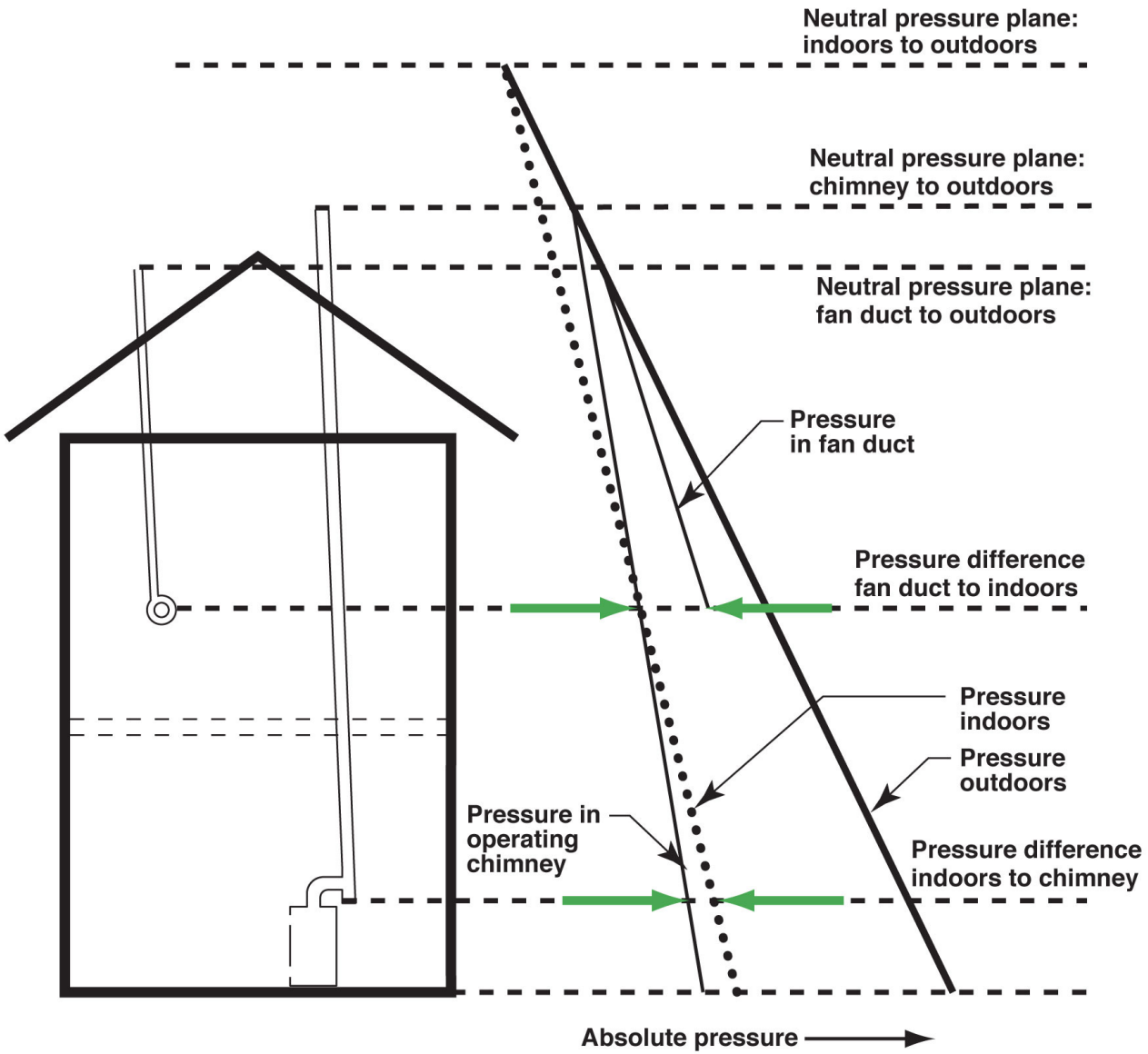
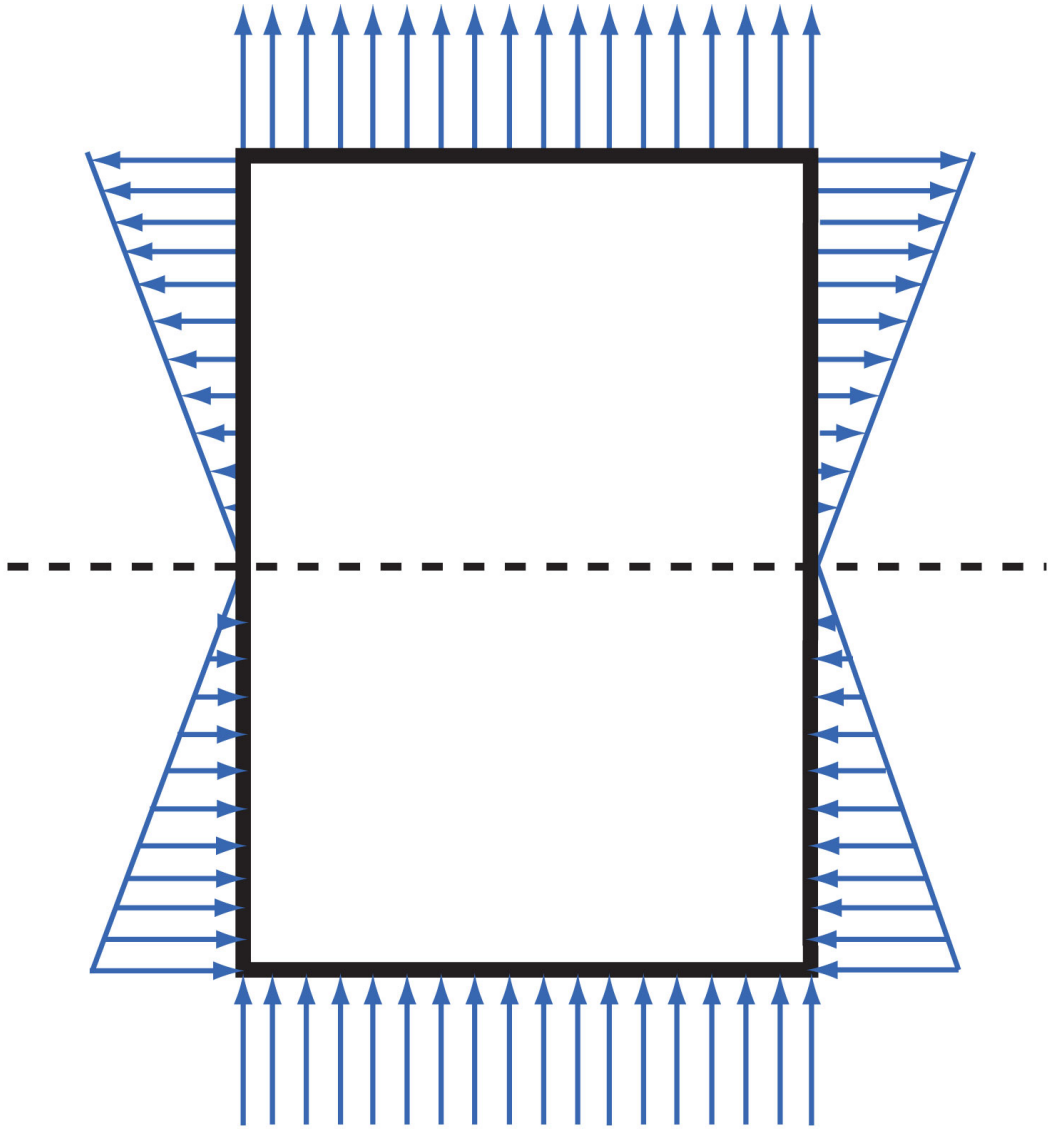
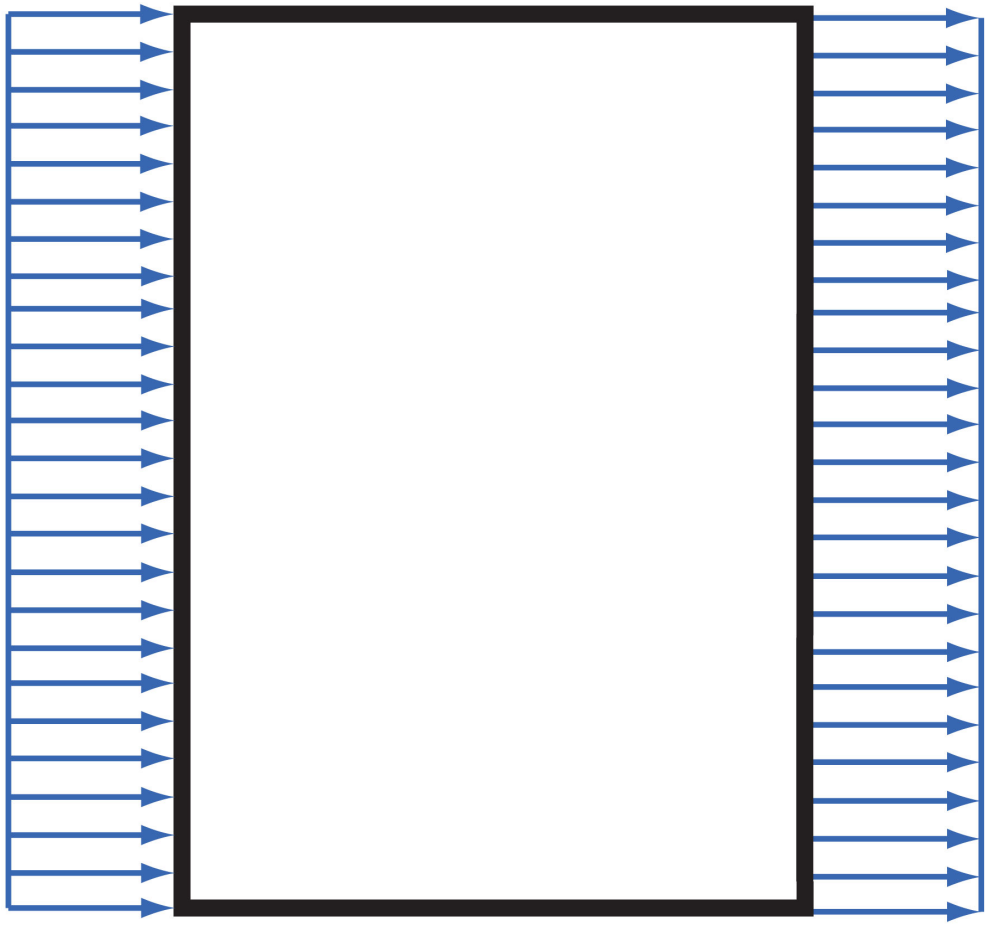


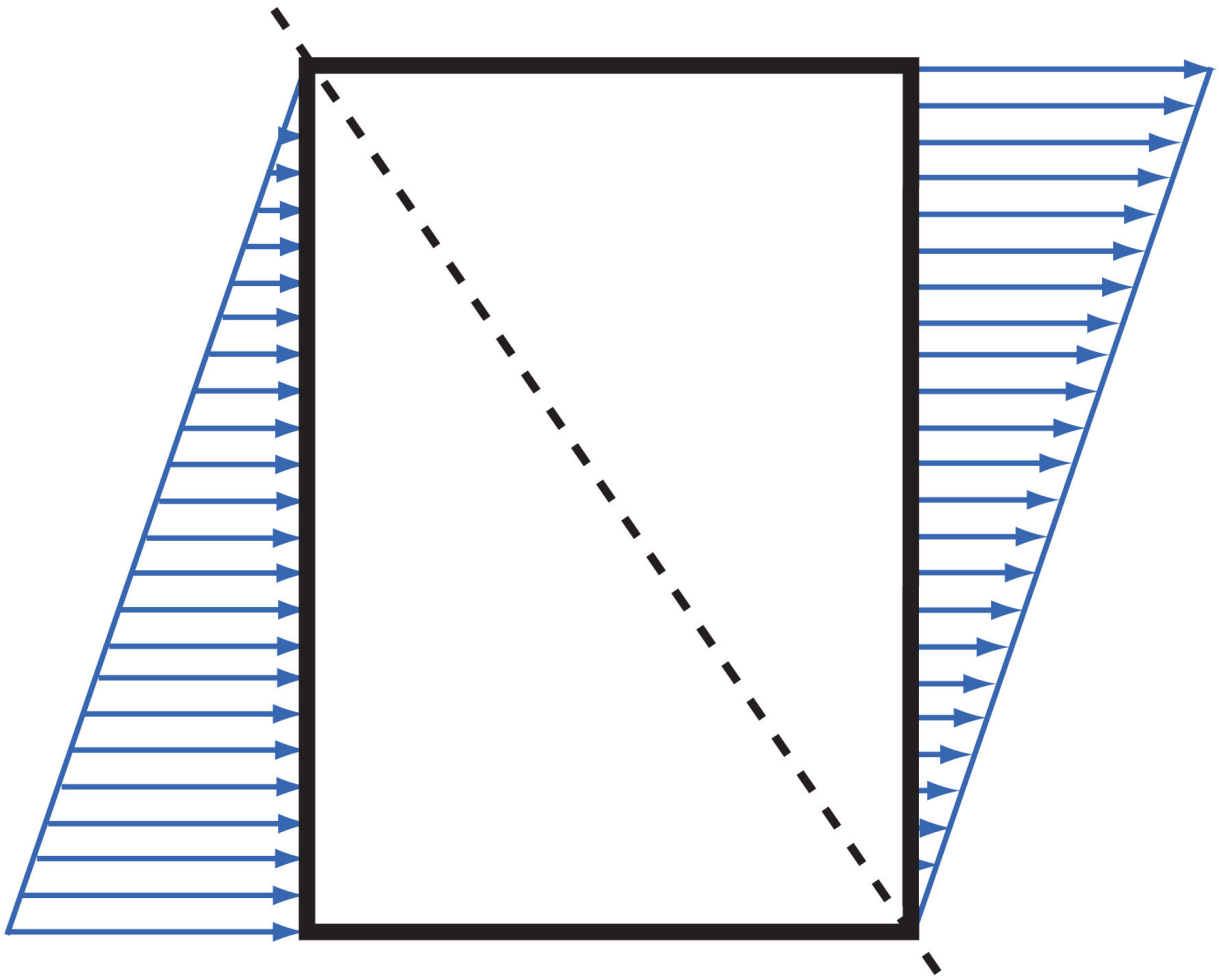
Figure 11.6: Two storey house with operating chimney (Adapted from G.O. Handegord, 1998)



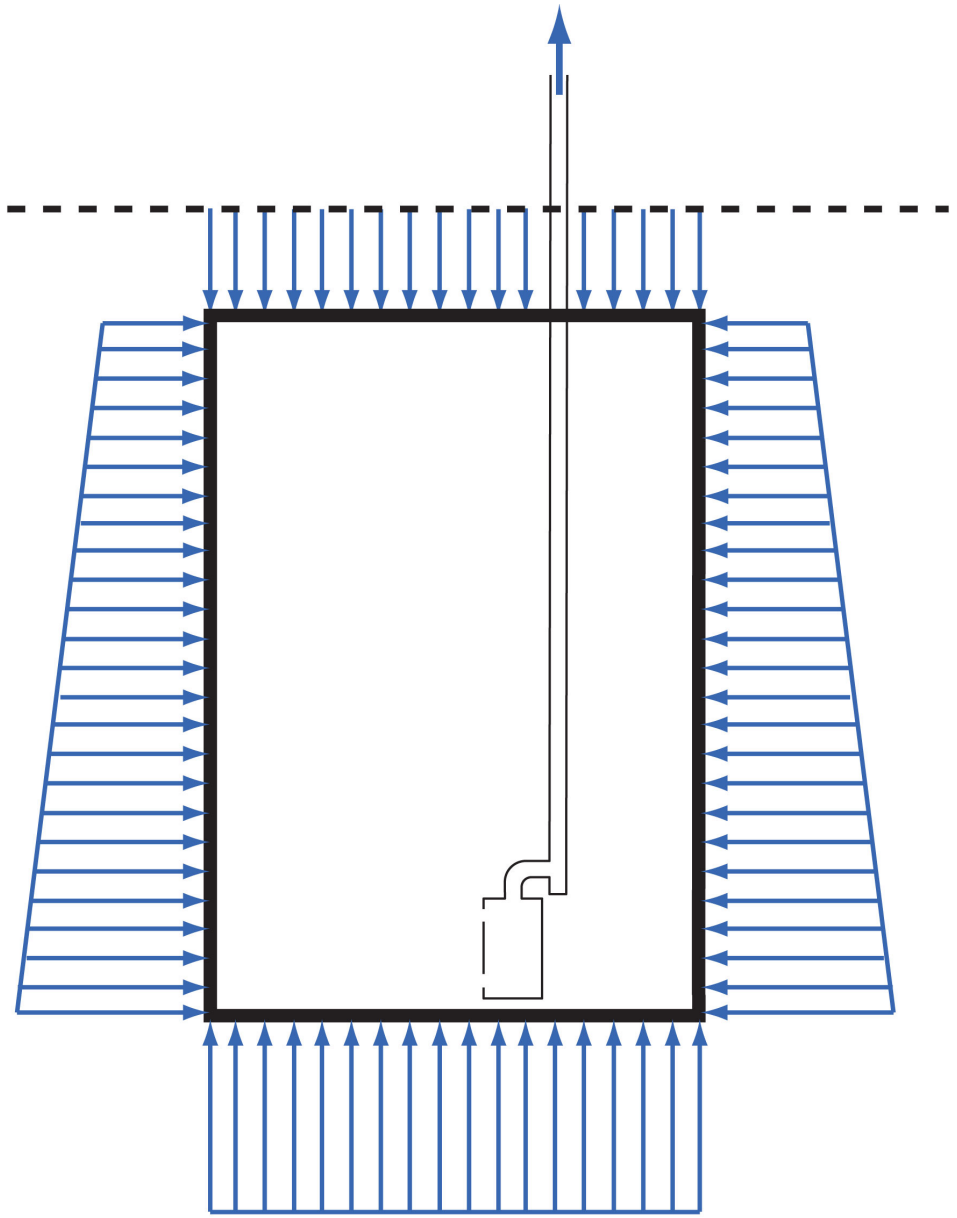
Stack effect



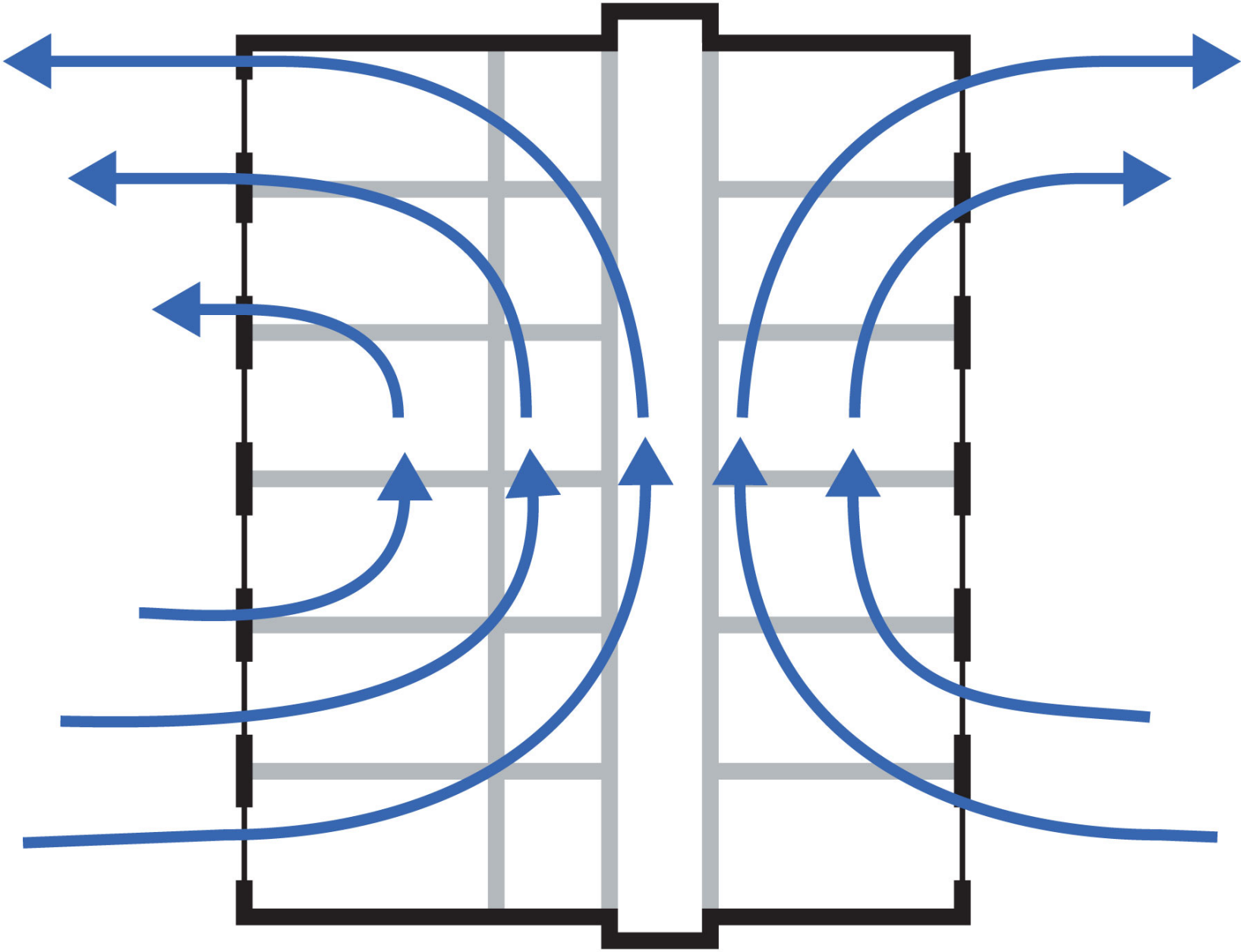
Wind

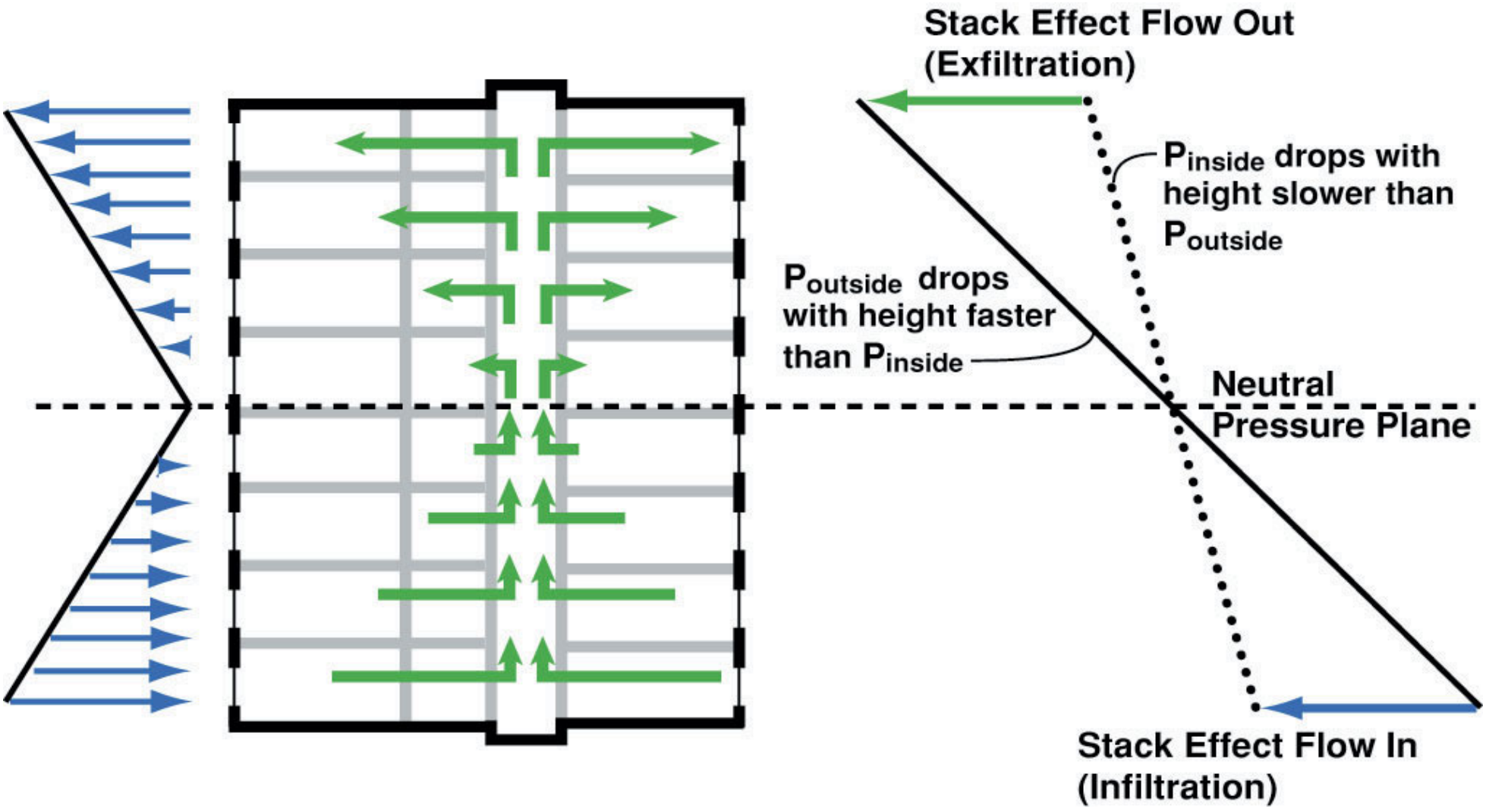


Stack effect and wind



Chimney effect




Stack Effect Flow Out
(Exfiltration)
Pinside drops with
height slower than
Poutside
Poutside drops
with height faster
than Pinside
Neutral
Pressure Plane
Stack Effect Flow In
(Infiltration)

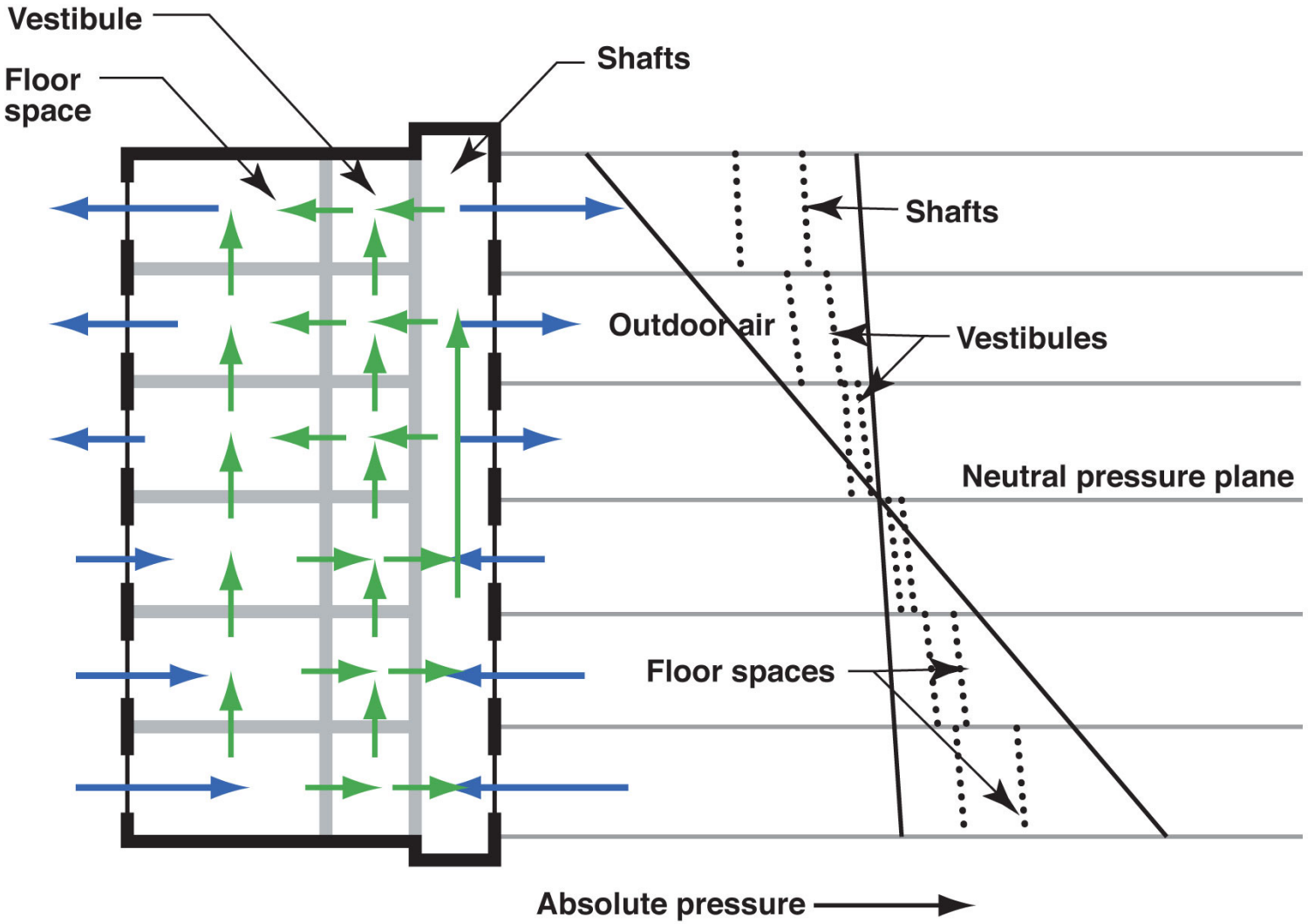


Figure 11.8: Stack effect pressures in high rise office building (Adapted from G.O. Handegord, 1998)

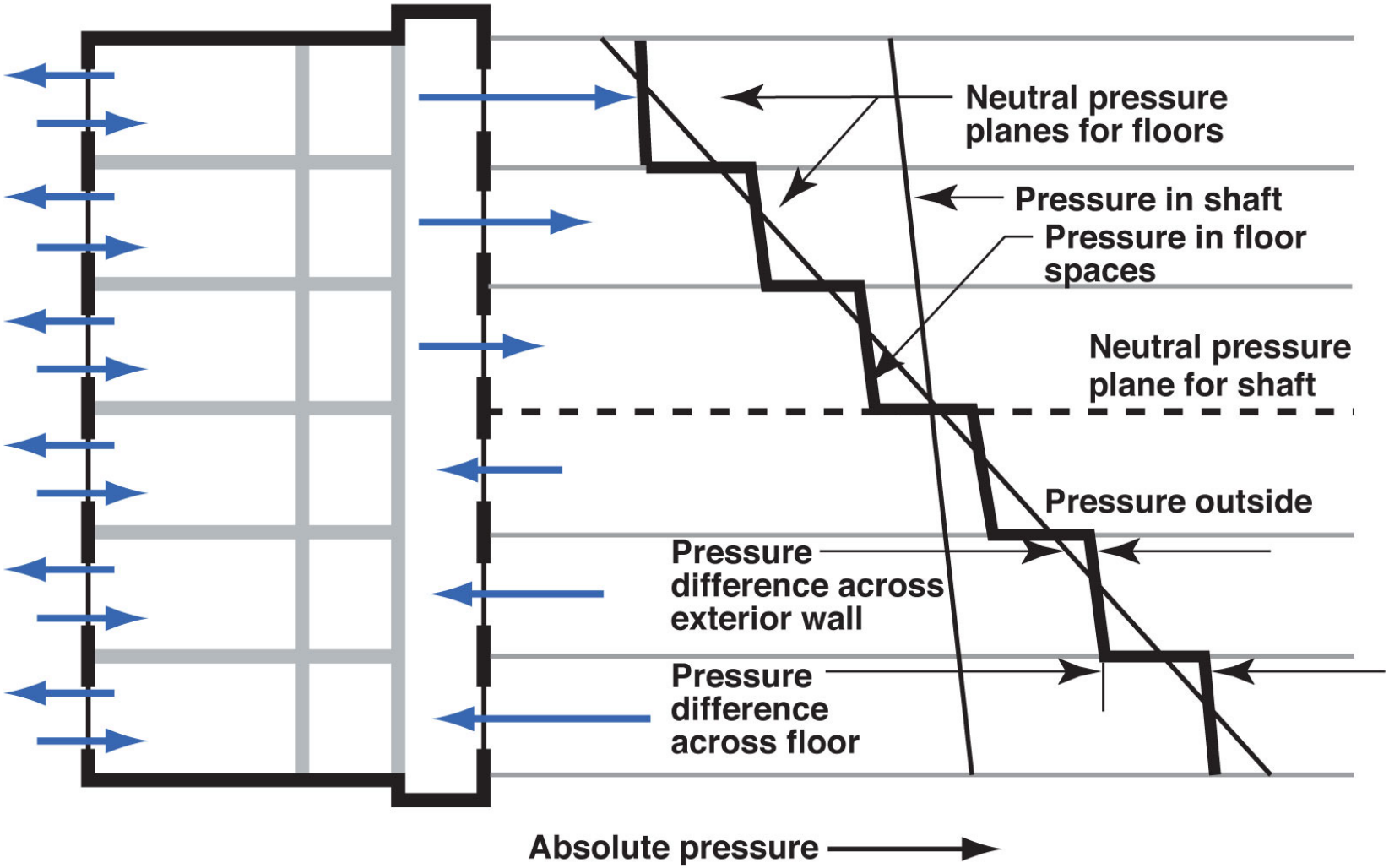


Figure 11.9: Multi-storey building with floor spaces isolated from vertical shafts (Adapted from G.O. Handegord, 1998)

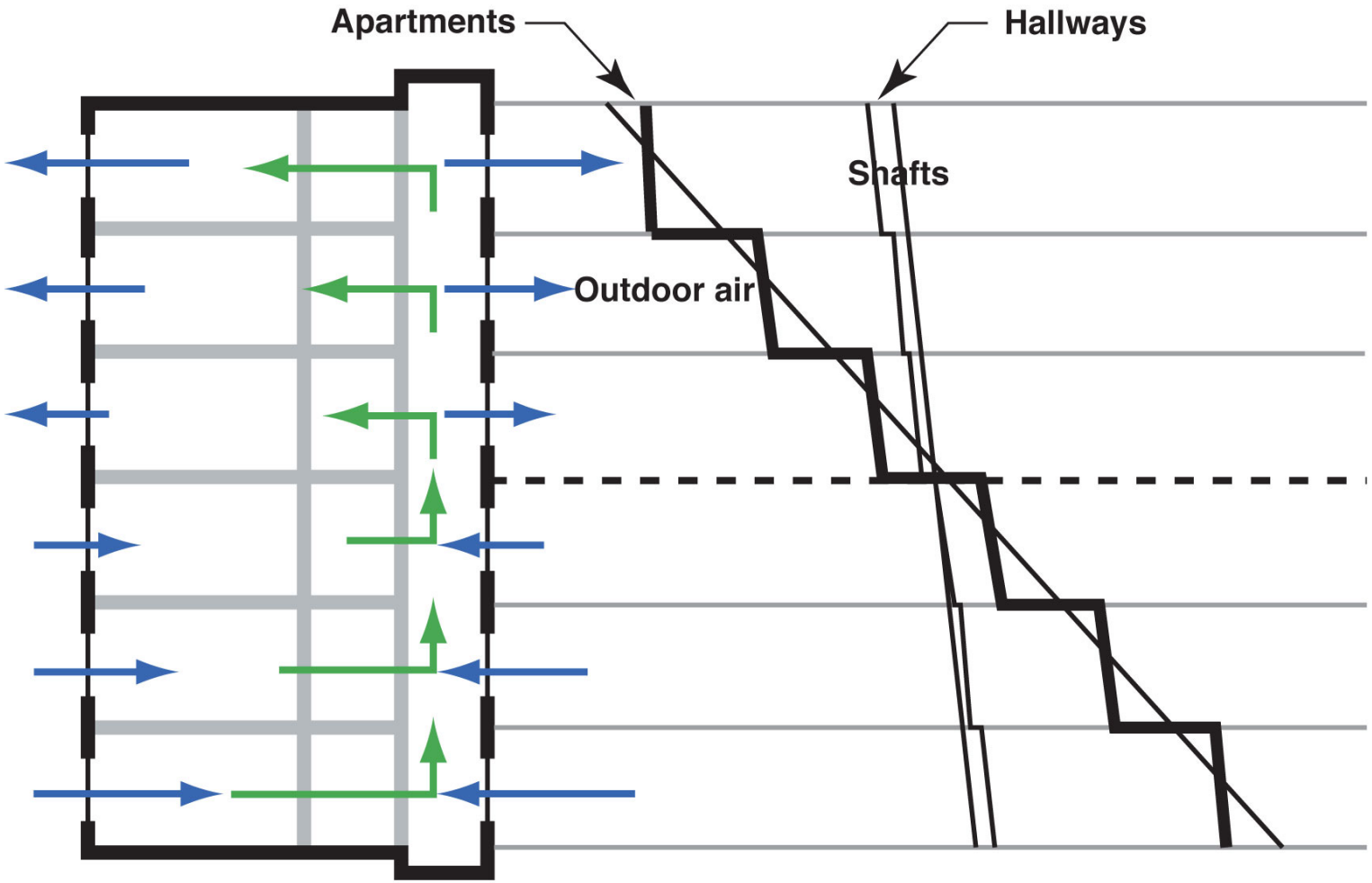
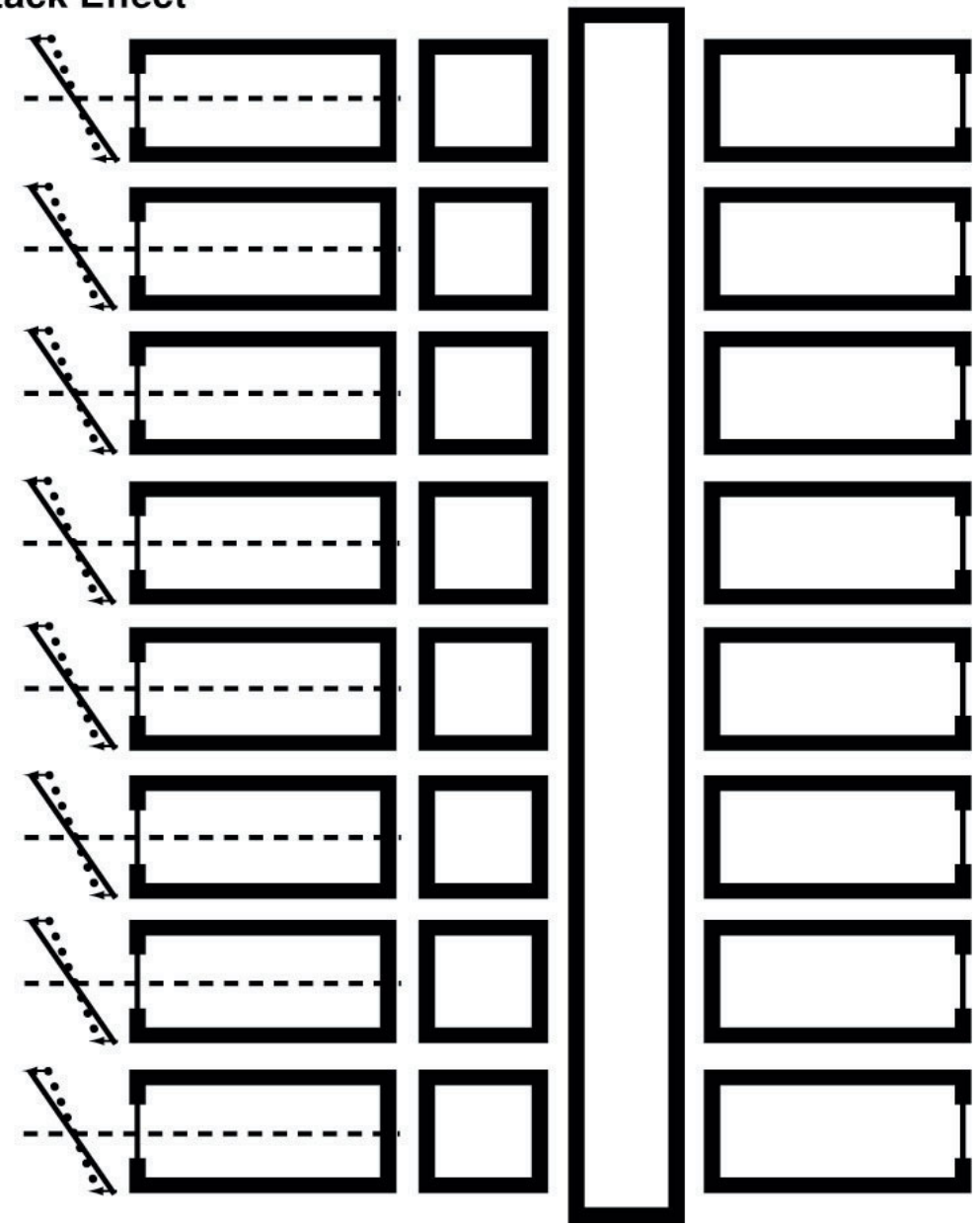
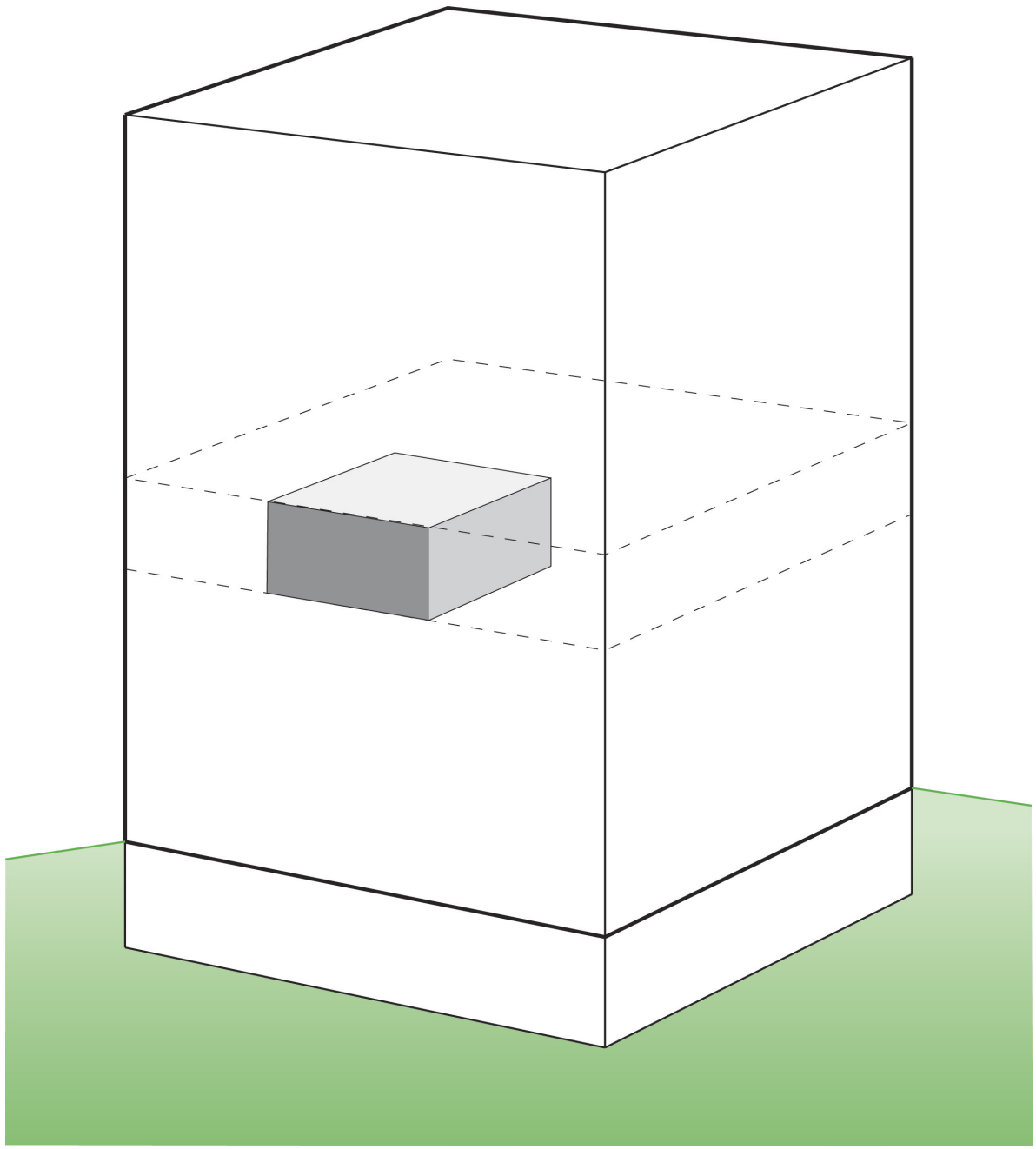


Figure 11.12: Apartment building with tighter apartment entry doors (Adapted from G.O. Handegord, 1998)

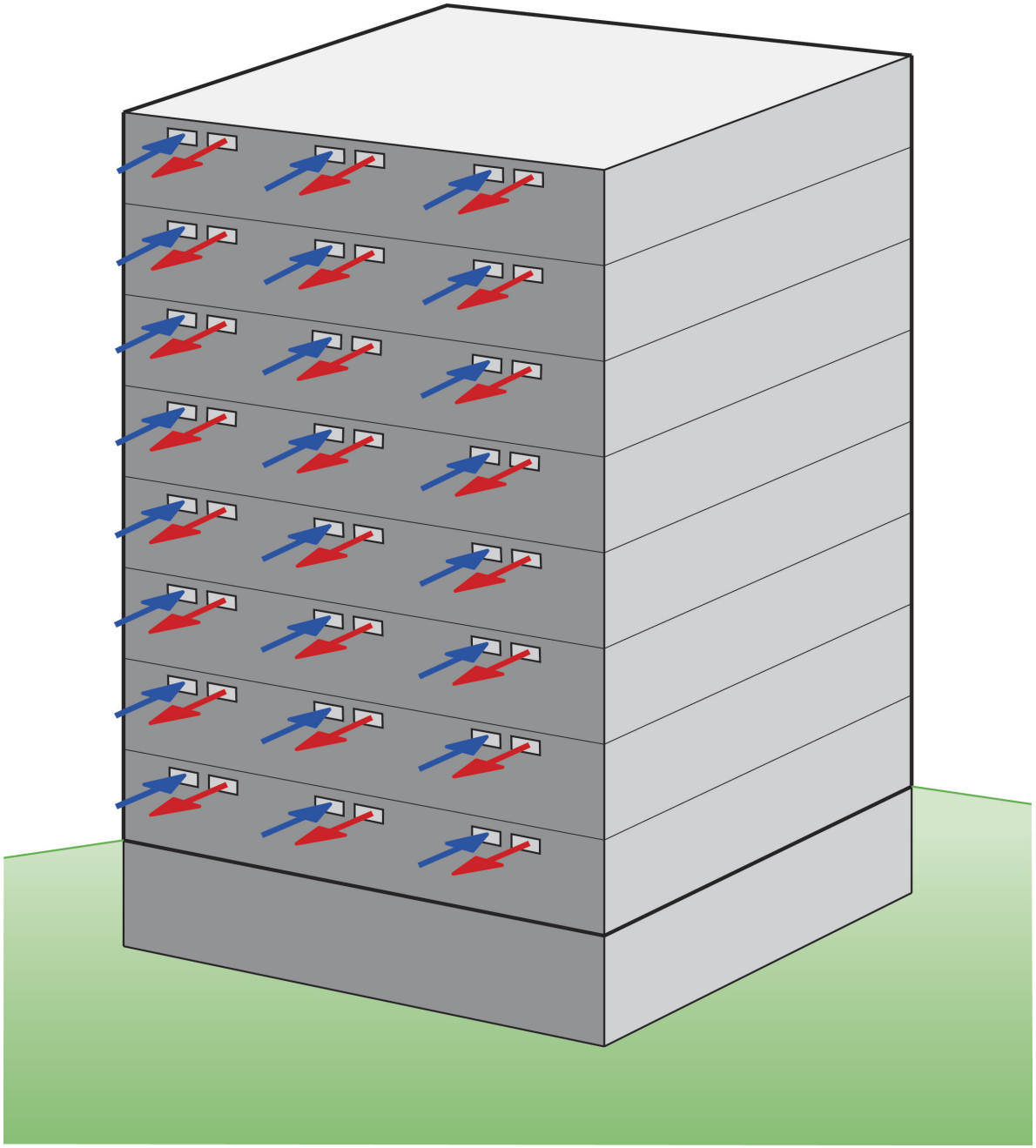
Reduced Individual Unit Stack Effect



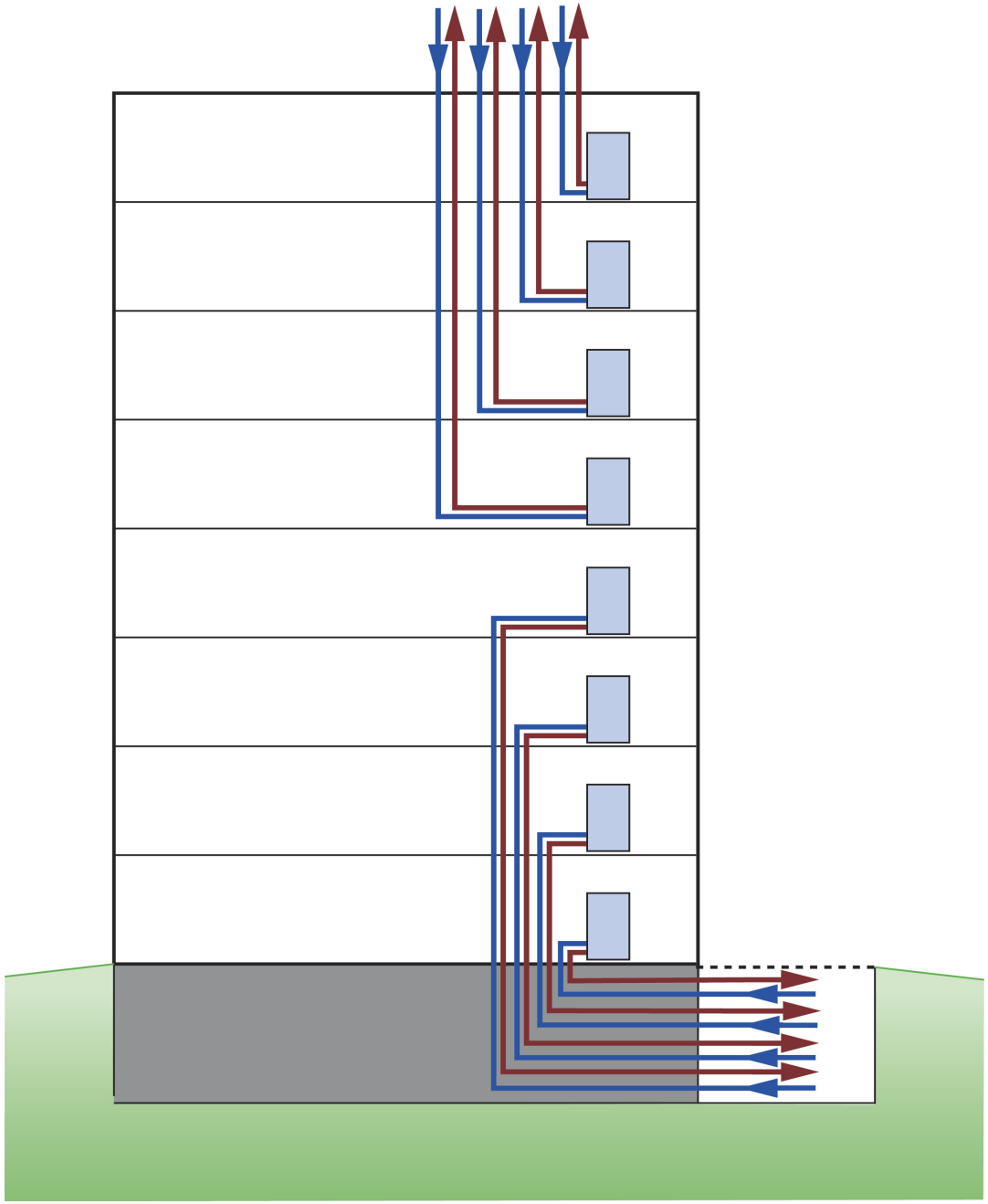


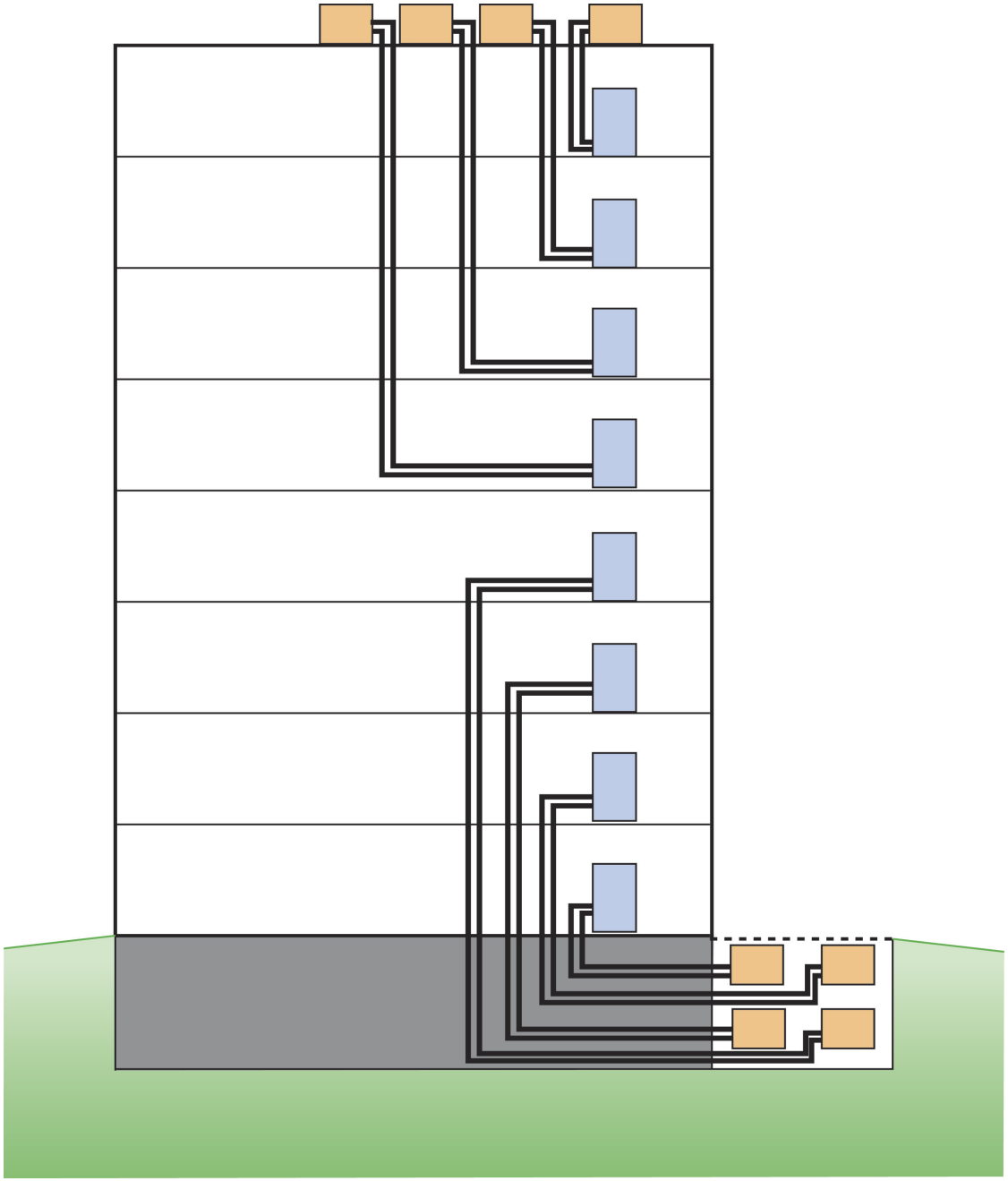


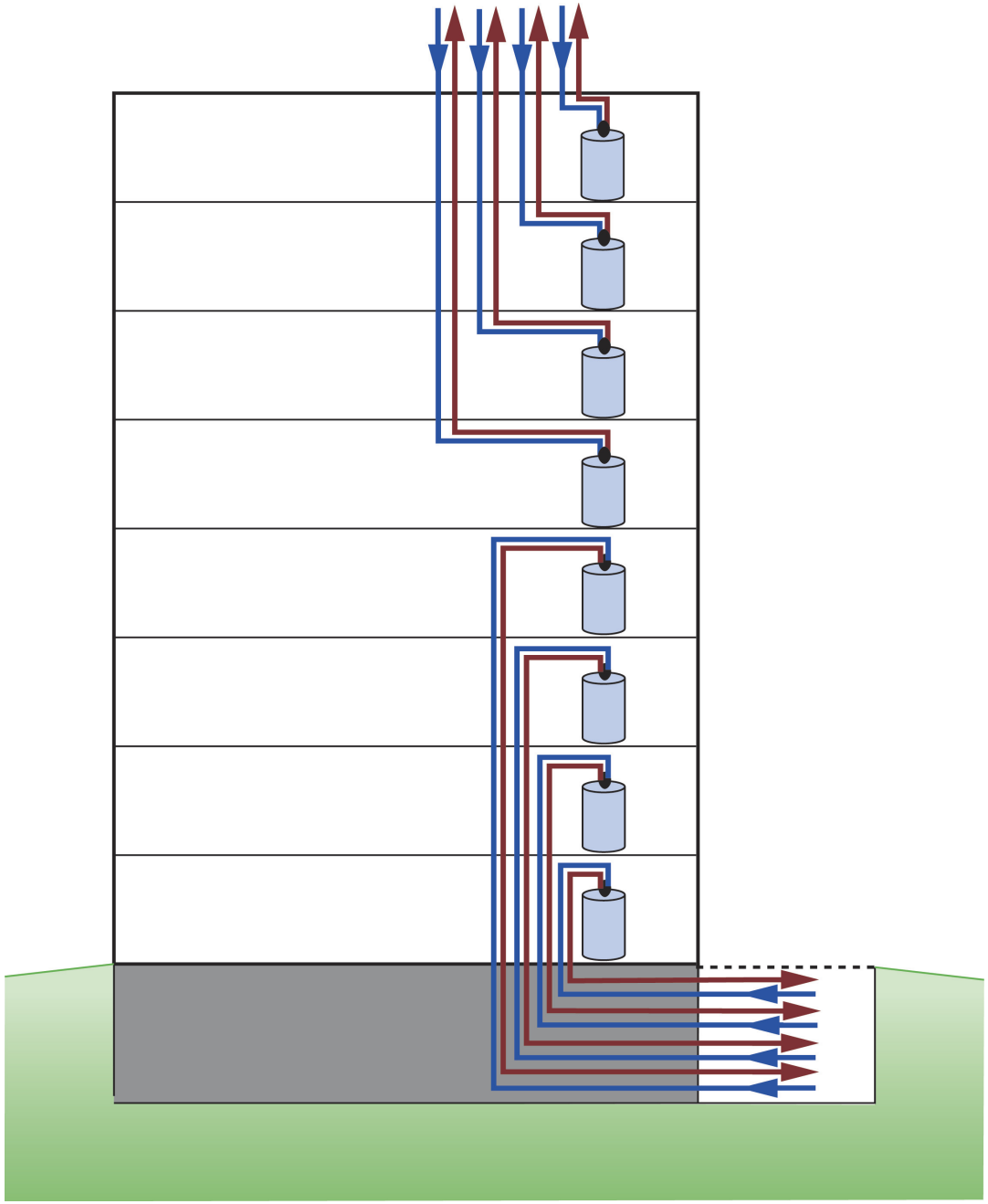















HOT WATER


YORK
YORK








Goodman
Goodman
Goodman
Tyvek


EASTERN
939
ANJAC FASHION BLDG
Carrier








A.O. Smith
EnergySaver
ENERGYGUIDE










ASKO
ASKO
ENERGUIDE
209

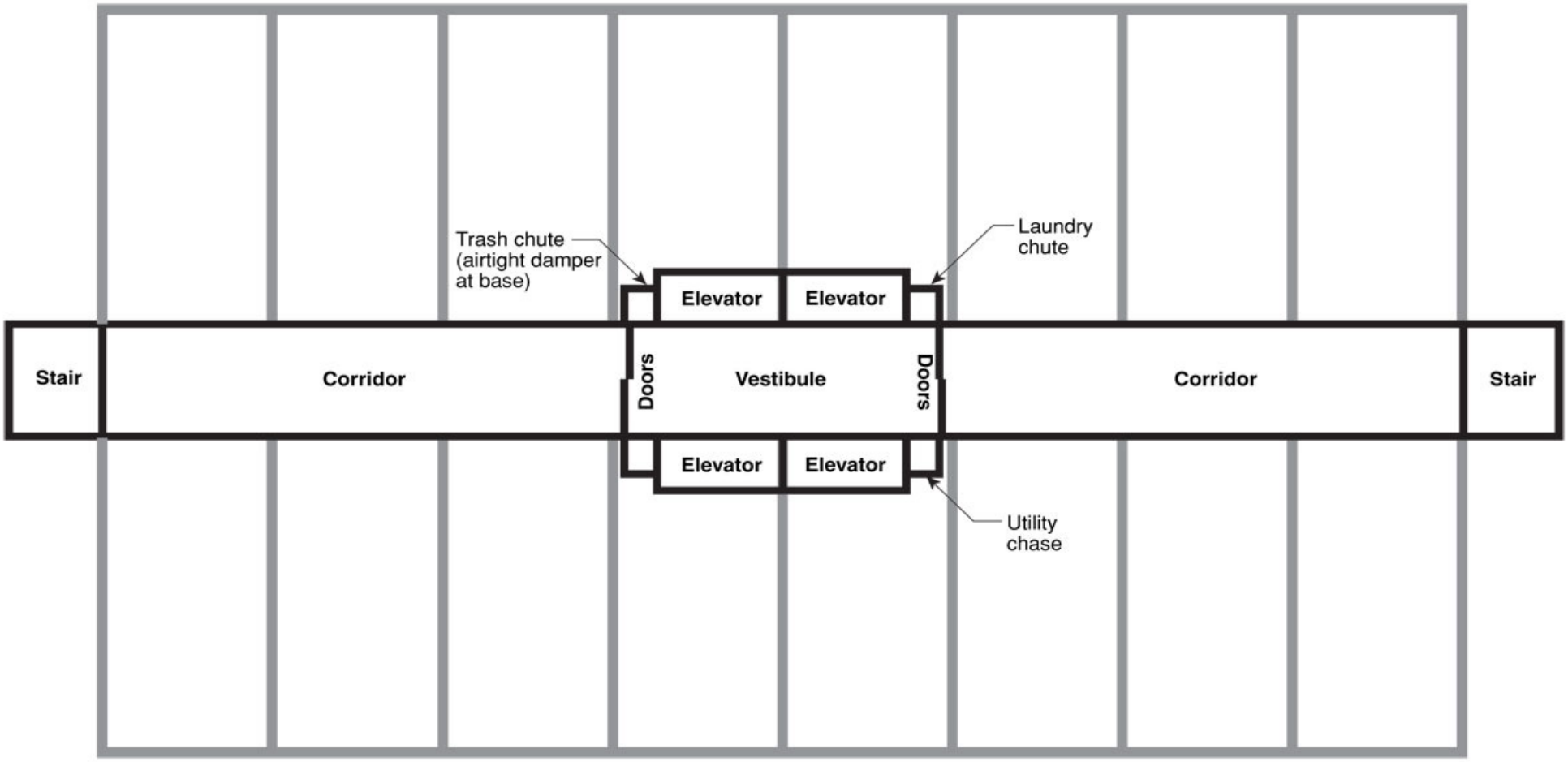

Heating And Air Conditioning


DANGER
DANGER
PELIGRO
ENERGYGUIDE

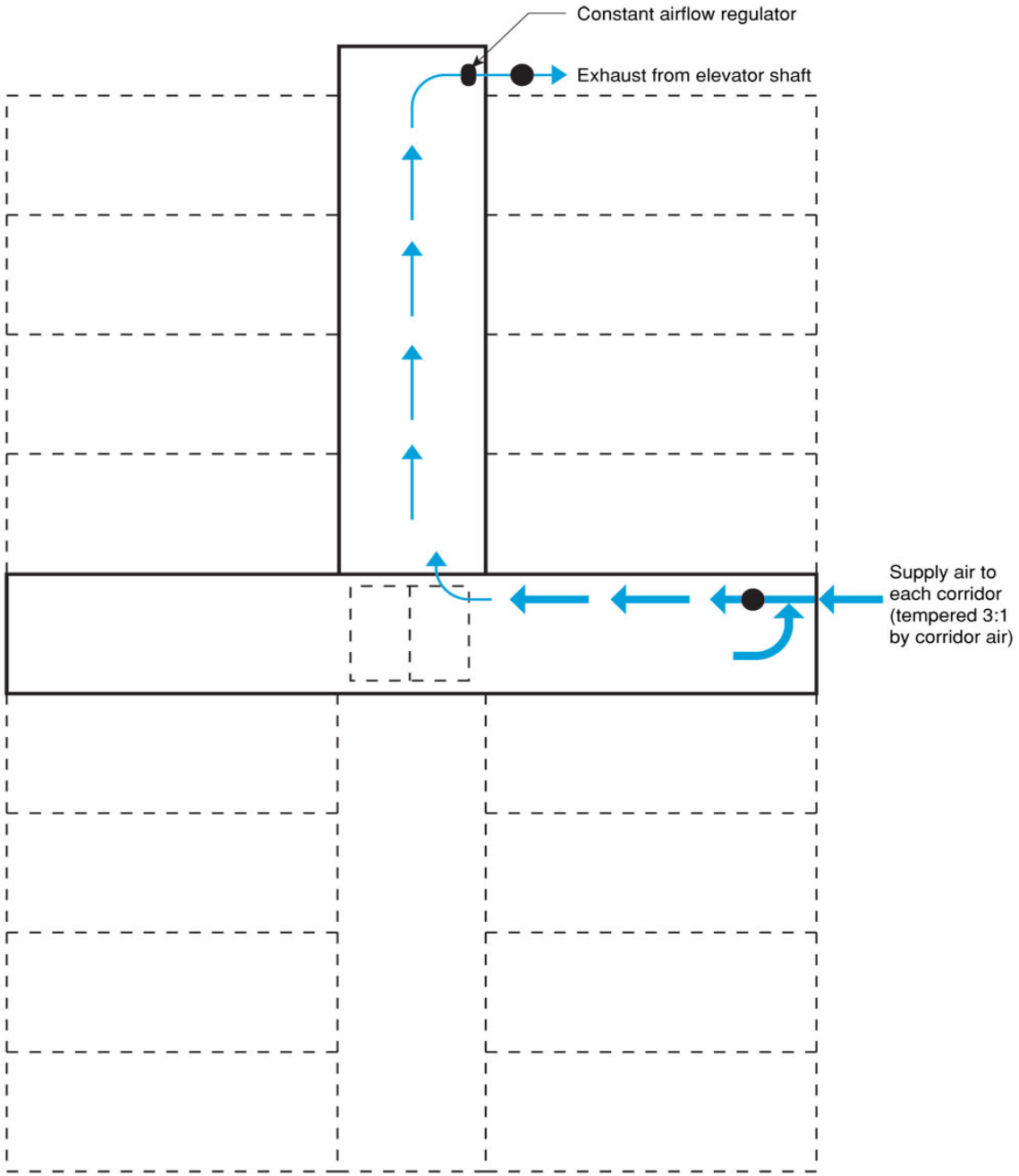

Rheem
RHEEMGLAS
FLBY
EverKleen
Self-Cleaning Water Heaters
ENERGYGUIDE
DANGER

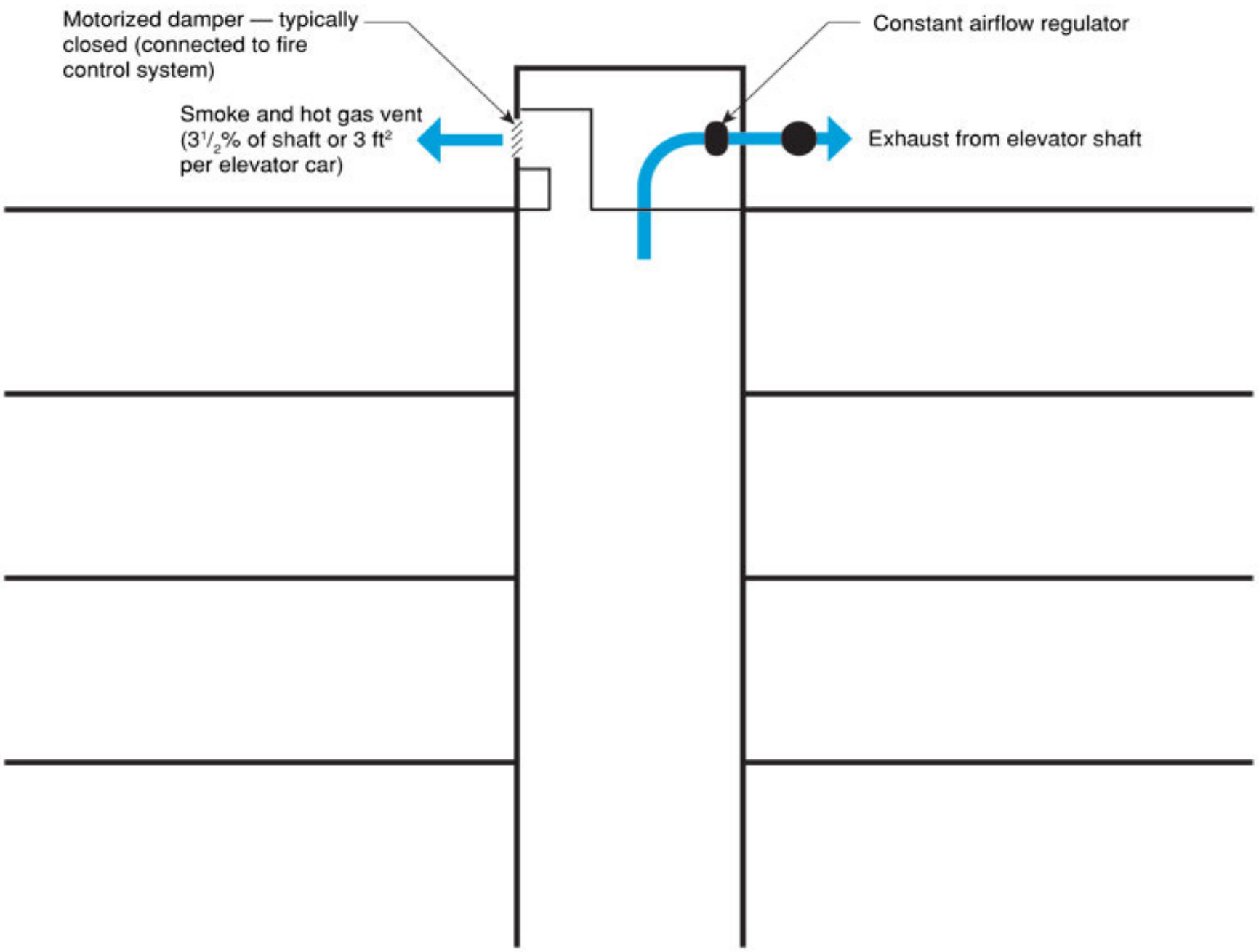

BOSTON
UNIVERSITY



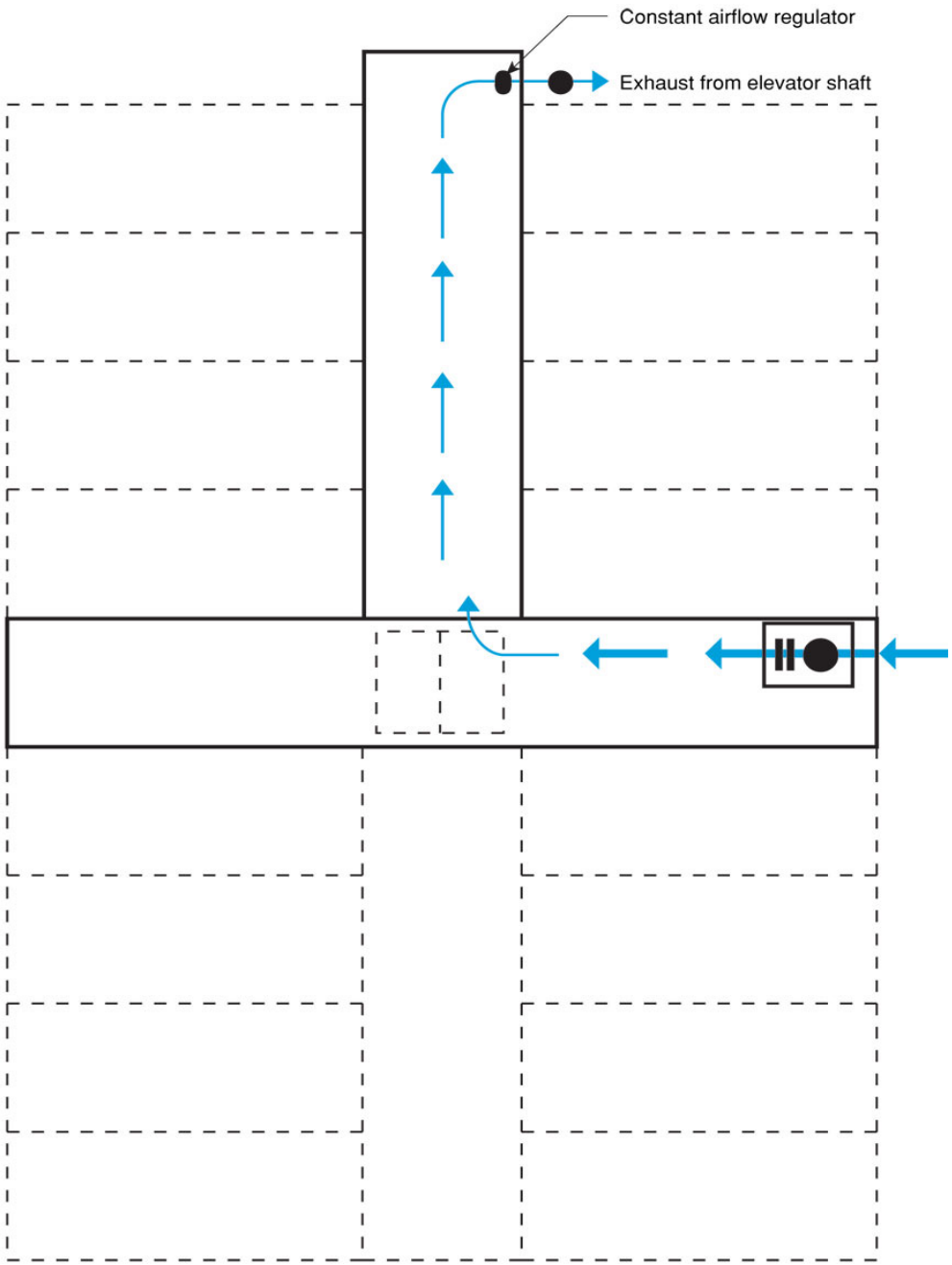

Trash chute
(airtight damper
at base)
Laundry
chute
Elevator
Elevator
Stair
Corridor
Doors
Vestibule
Doors
Corridor
Stair
Elevator
Elevator
Utility
chase

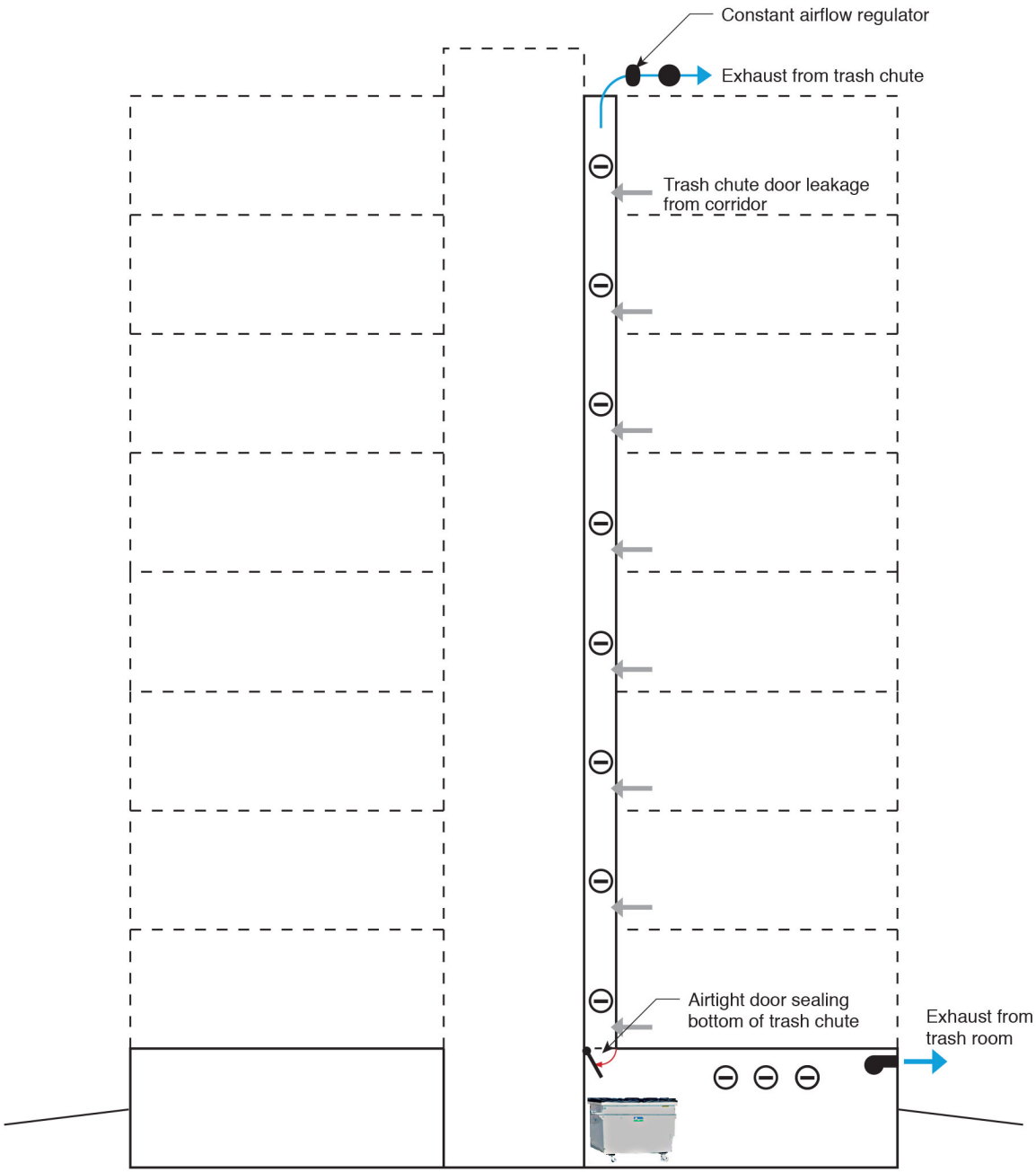



Constant airflow regulator
Exhaust from elevator shaft
Supply air to each corridor (tempered 3:1 by corridor air)

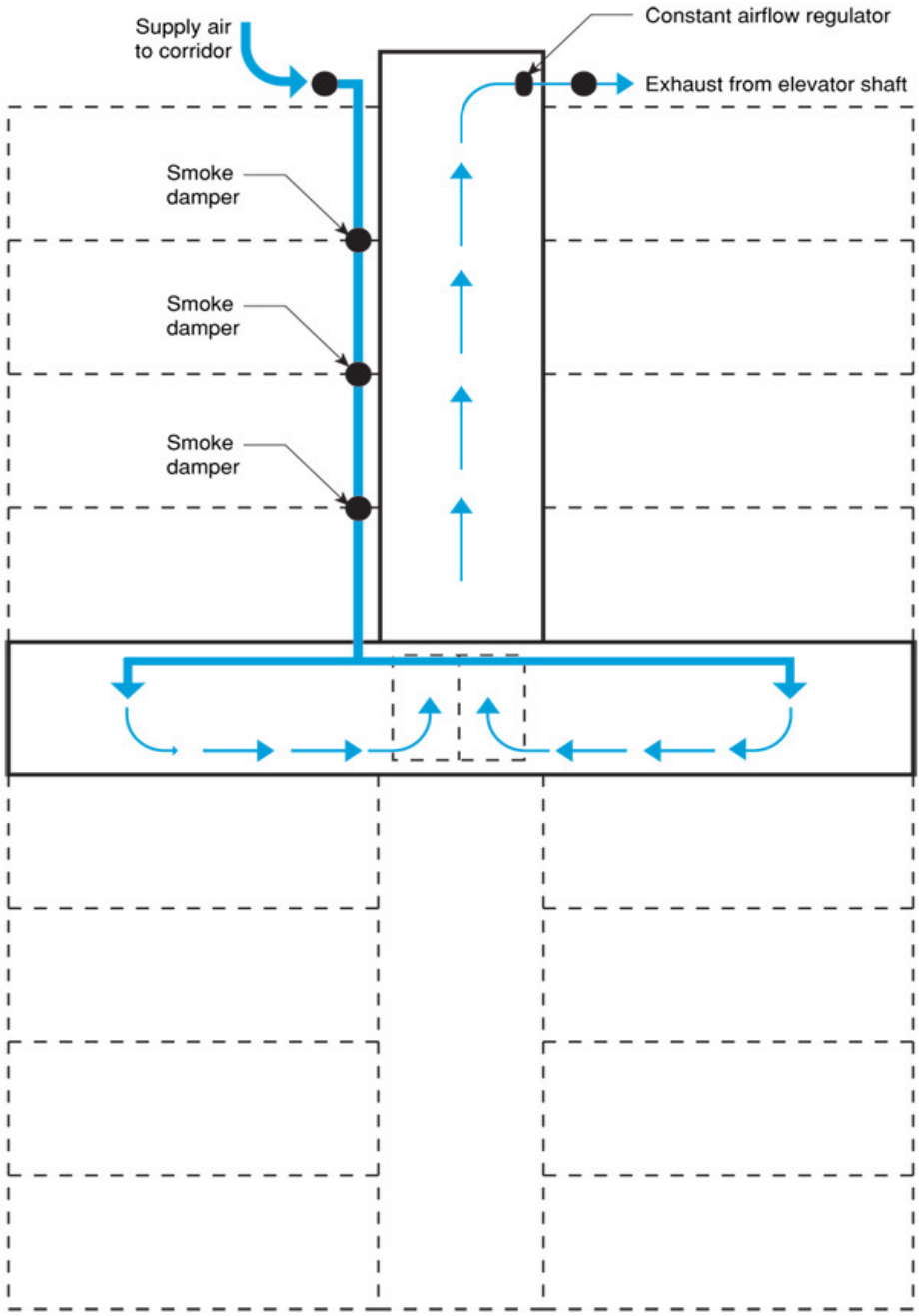

Motorized damper — typically closed (connected to fire control system)
Constant airflow regulator
Smoke and hot gas vent (3 1/2% of shaft or 3 ft² per elevator car)
Exhaust from elevator shaft

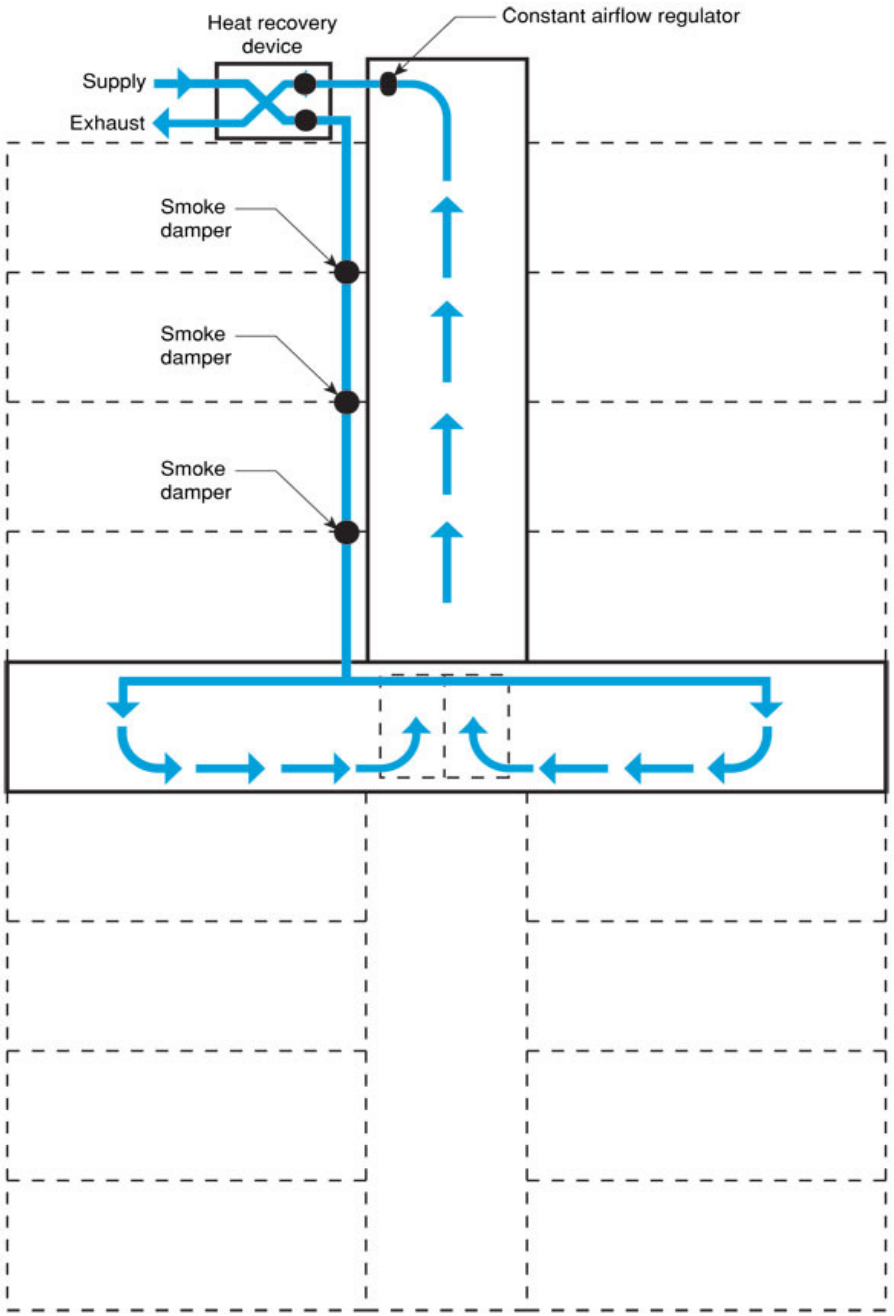


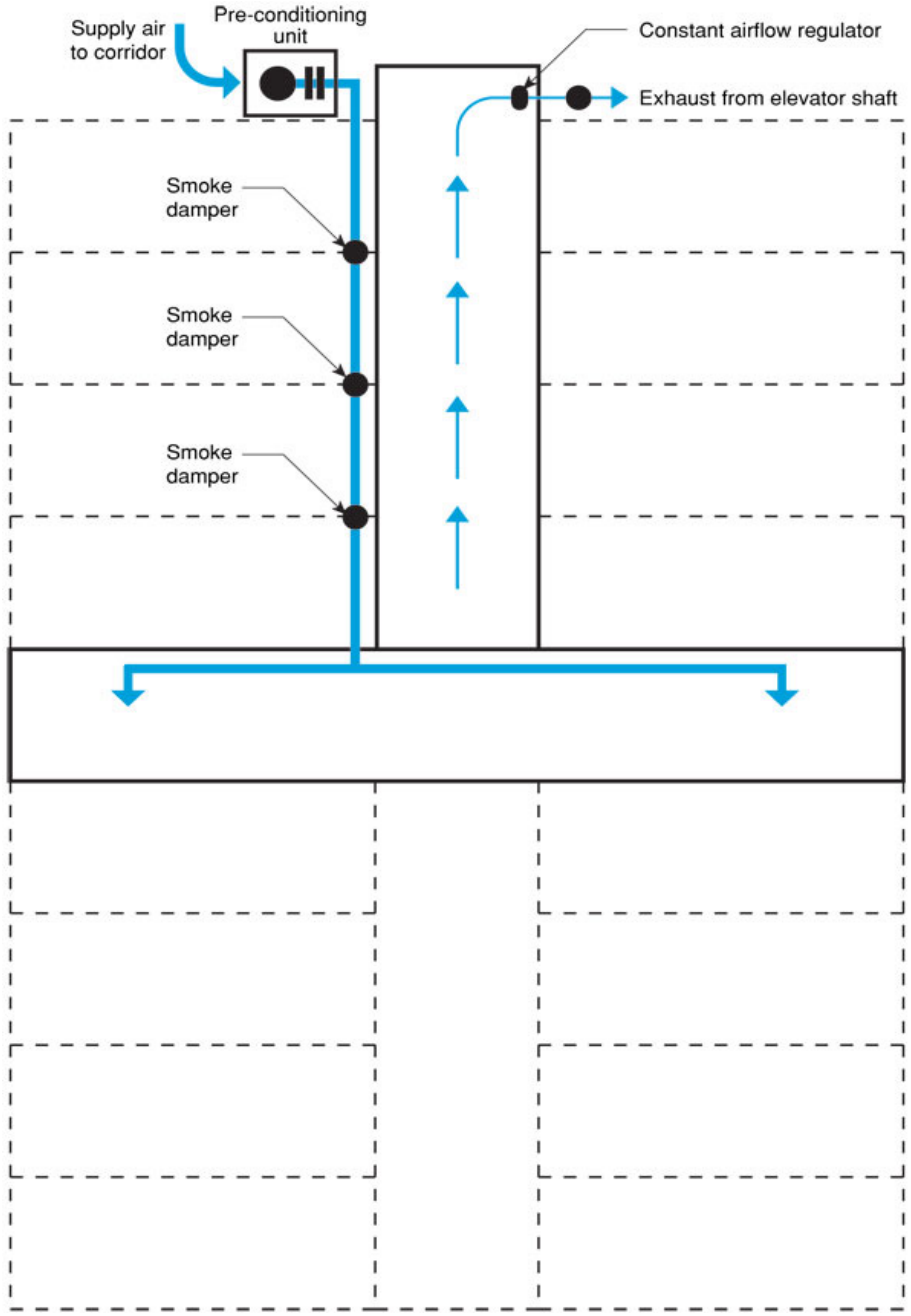

Constant airflow regulator
Exhaust from elevator shaft

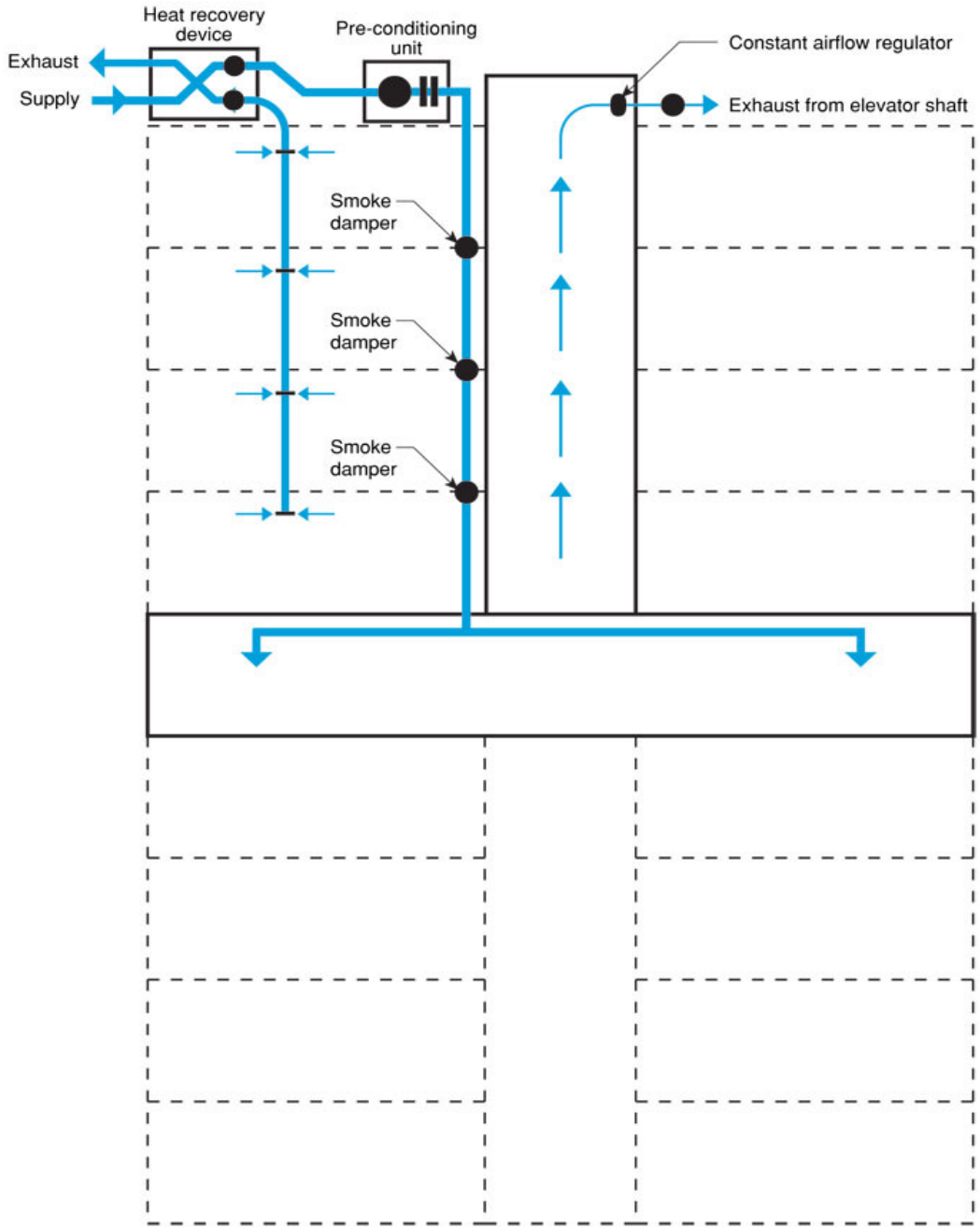

Constant airflow regulator
Exhaust from trash chute
Trash chute door leakage
from corridor
Airtight door sealing
bottom of trash chute
Exhaust from
trash room


PLEASE BAG GARBAGE


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


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


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


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


EXIT










DANGER

