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Building Science

Adventures In Building Science

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"It isn't what we don't know that gives us trouble, it's what we know that ain't so"

Will Rogers

"There are known knowns. These are things we know. There are known unknowns. There are things that we know we don't know. But there are also unknown unknowns. There are things we don't know we don't know.

Donald Rumsfeld

Faking the Physics…..

Flow Through Orifices

Turbulent Flow - “inertial effects”

Flow Through Porous Media

Laminar Flow - “viscosity effects”

Flow Through Orifices

Turbulent Flow - “inertial effects”

Flow Through Porous Media

Laminar Flow - “viscosity effects”

“true but not useful”

$$Q = A \cdot C_D \left[\frac{2}{\rho} (\Delta P) \right]^{\frac{1}{2}}$$

Bernoulli

$$Q = C_K \frac{\rho}{\mu} (\Delta P)$$

Darcy

$$Q = A \cdot C_D \left[\frac{2}{\rho} (\Delta P) \right]^{\frac{1}{2}}$$

Bernoulli

$$Q = C_K \frac{\rho}{\mu} (\Delta P)$$

Darcy

$$Q = A \cdot C (\Delta P)^{\frac{1}{2}}$$

$$Q = C (\Delta P)$$

$$Q = A \cdot C_D \left[\frac{2}{\rho} (\Delta P) \right]^{\frac{1}{2}}$$

Bernoulli

$$Q = C_K \frac{\rho}{\mu} (\Delta P)$$

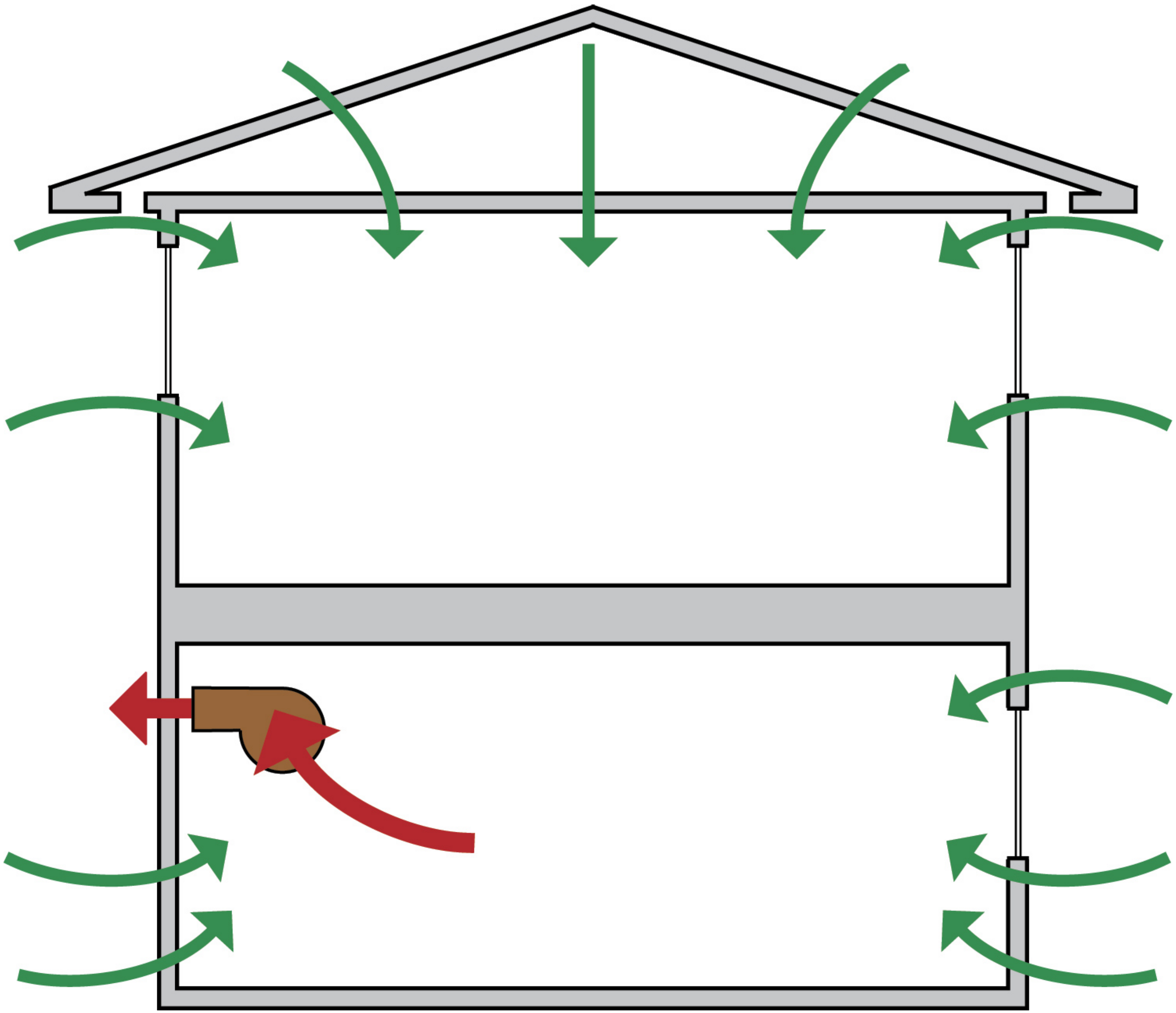
Darcy

$$Q = A \cdot C (\Delta P)^{\frac{1}{2}}$$

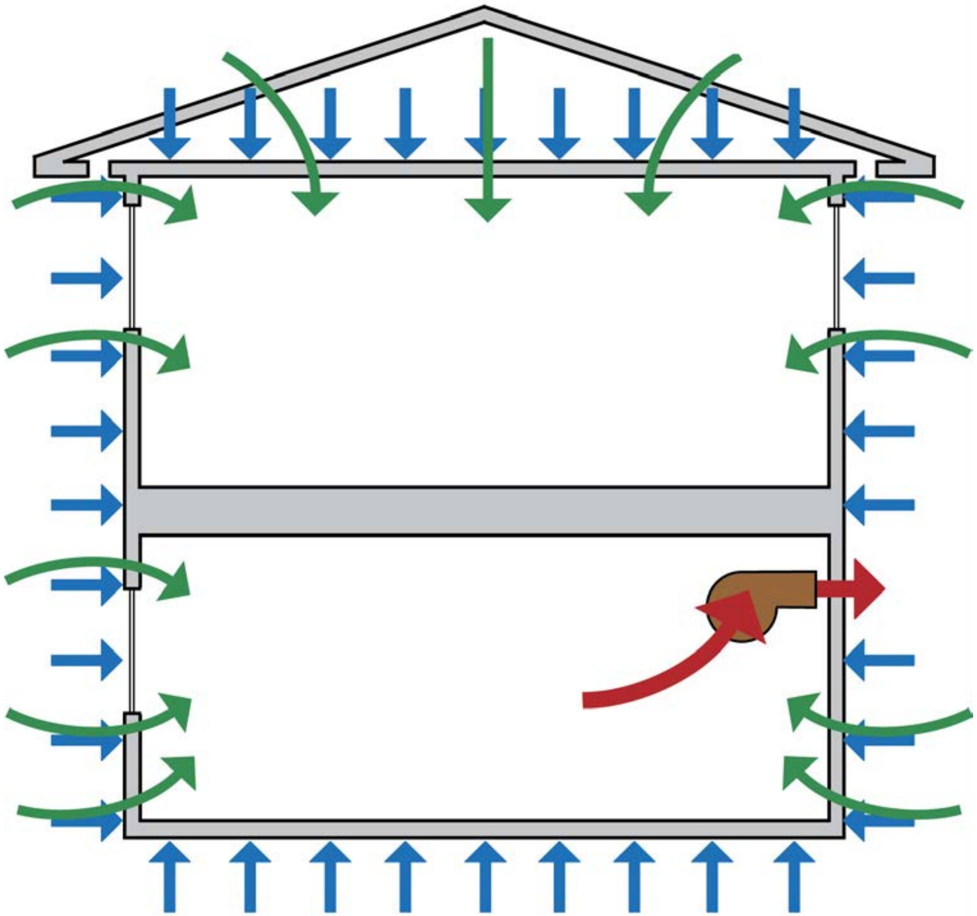
$$Q = C (\Delta P)$$

$$Q = A \cdot C (\Delta P)^n$$

Kronval "an engineer"

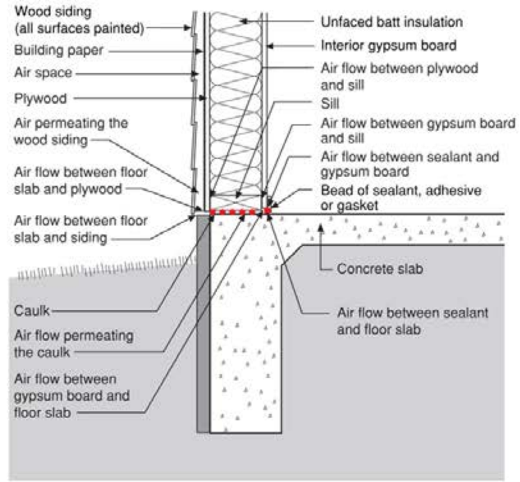


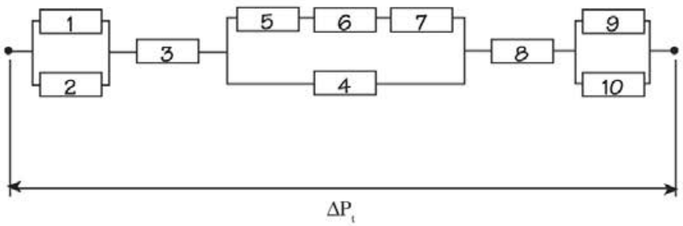
$$\text{ELA} \approx C \times \frac{\text{Rate of flow}}{\sqrt{\text{Pressure difference}}}$$



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

Possible air flows around sill of a wood-framed house modelled as a resistance network





1. Air permeating the wood-panel cladding
2. Air flow between floor slab and panel
3. Air flow between floor slab and wind protection
4. Air permeating the caulking
5. Air flow between wind protection and sill
6. Air flow bewteen insulation material and sill
7. Air flow between inner lining and sill
8. Air flow between inner lining and floor slab
9. Air flow between fillet and inner lining
10. Air flow between fillet and floor slab

Figure 2.10
Resistance Network
(from Kronvall, 1980)

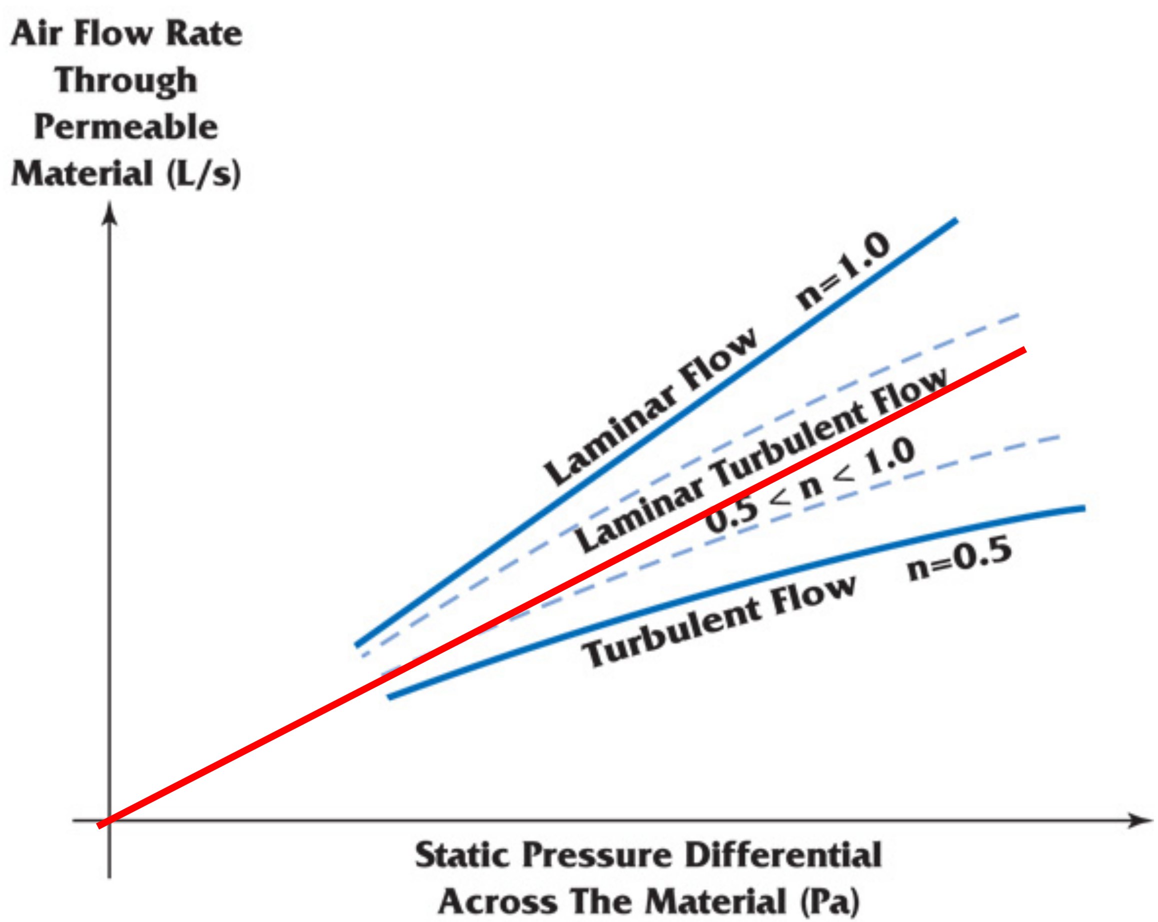


Figure 2.5

Modes of Air Flow

(from Bumbaru, Jutras and Patenaude, 1988)

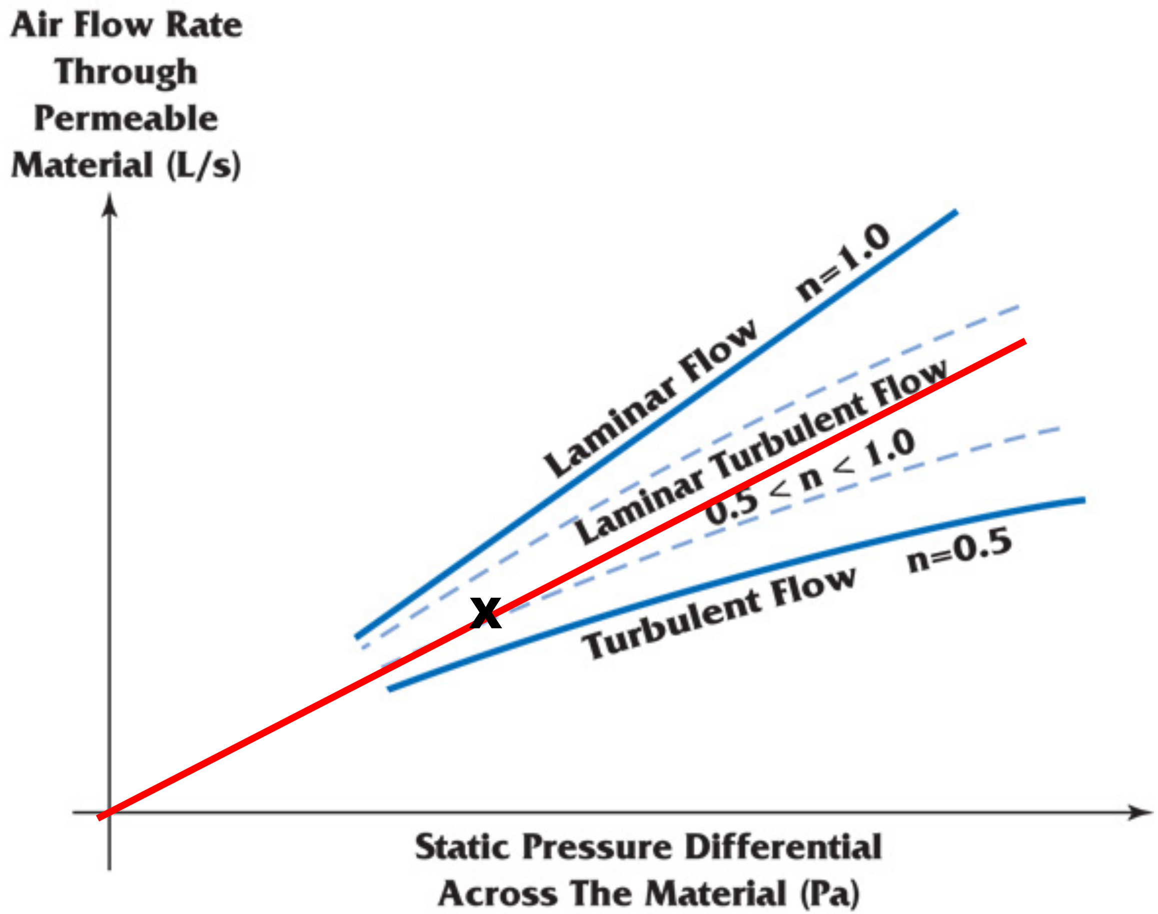


Figure 2.5

Modes of Air Flow

(from Bumbaru, Jutras and Patenaude, 1988)

Q = f (Dp) » k (Dp)^{b}

Q = air flow, volume/unit of time

D**p** = pressure difference

k = coefficient

b = exponent in approximate leakage function

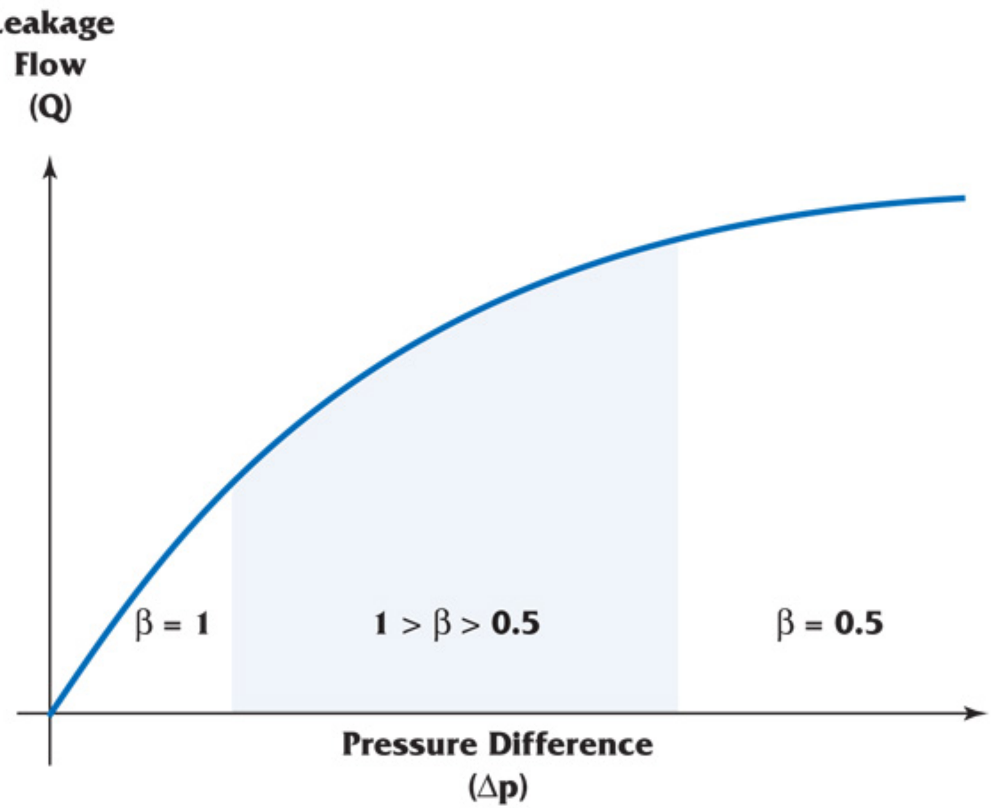


Figure 2.6

Characteristic Curve of Leakage Flow as a Function of Pressure Difference

(from Nylund, 1980)

$$Q = f\,(Dp) \;»\; k\,(Dp)^b$$

Q = air flow, volume/unit of time
D**p** = pressure difference
k = coefficient
b = exponent in approximate leakage function

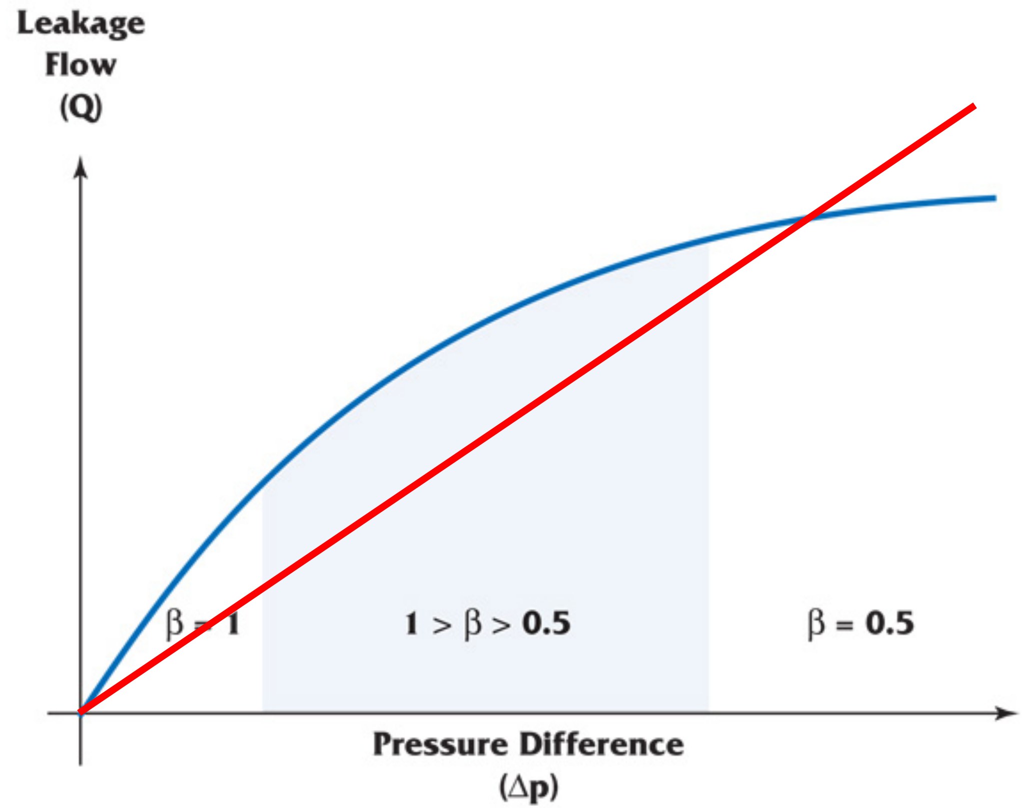


Figure 2.6
Characteristic Curve of Leakage Flow as a Function of Pressure Difference
(from Nylund, 1980)

Q = f (Dp) » k (Dp)^{b}

Q = air flow, volume/unit of time

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b = exponent in approximate leakage function

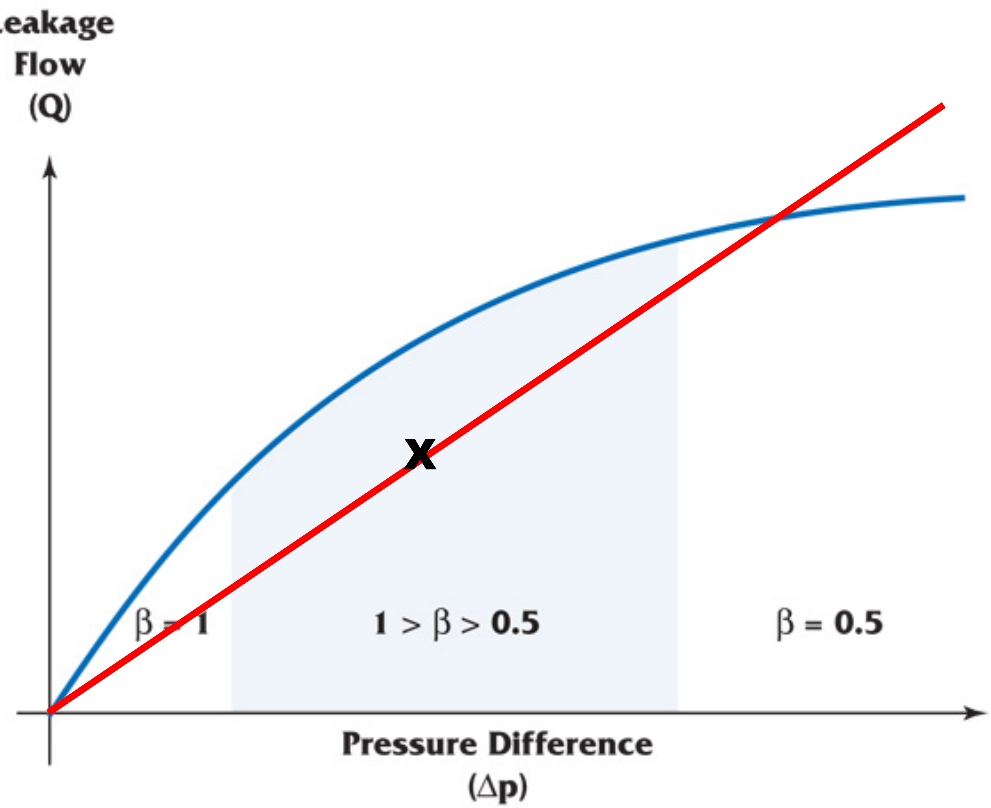
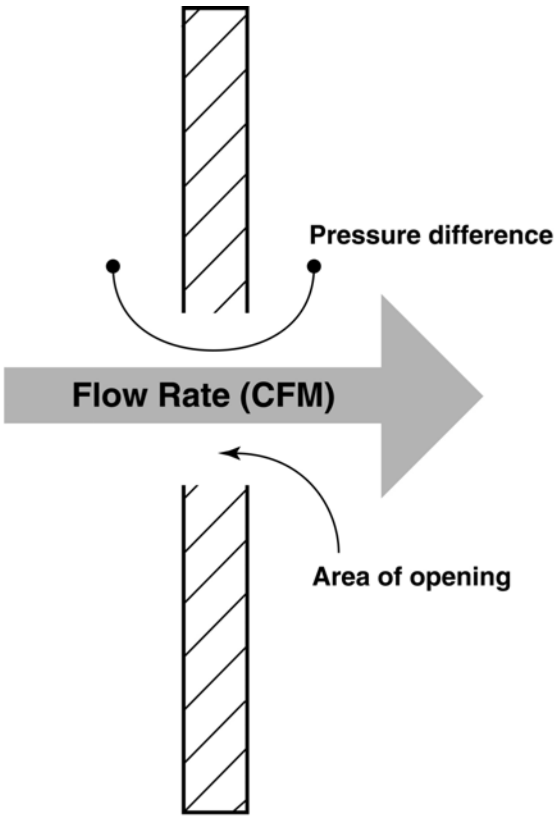


Figure 2.6

Characteristic Curve of Leakage Flow as a Function of Pressure Difference

(from Nylund, 1980)



Air Flow

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

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

The Cult of The Blower Door

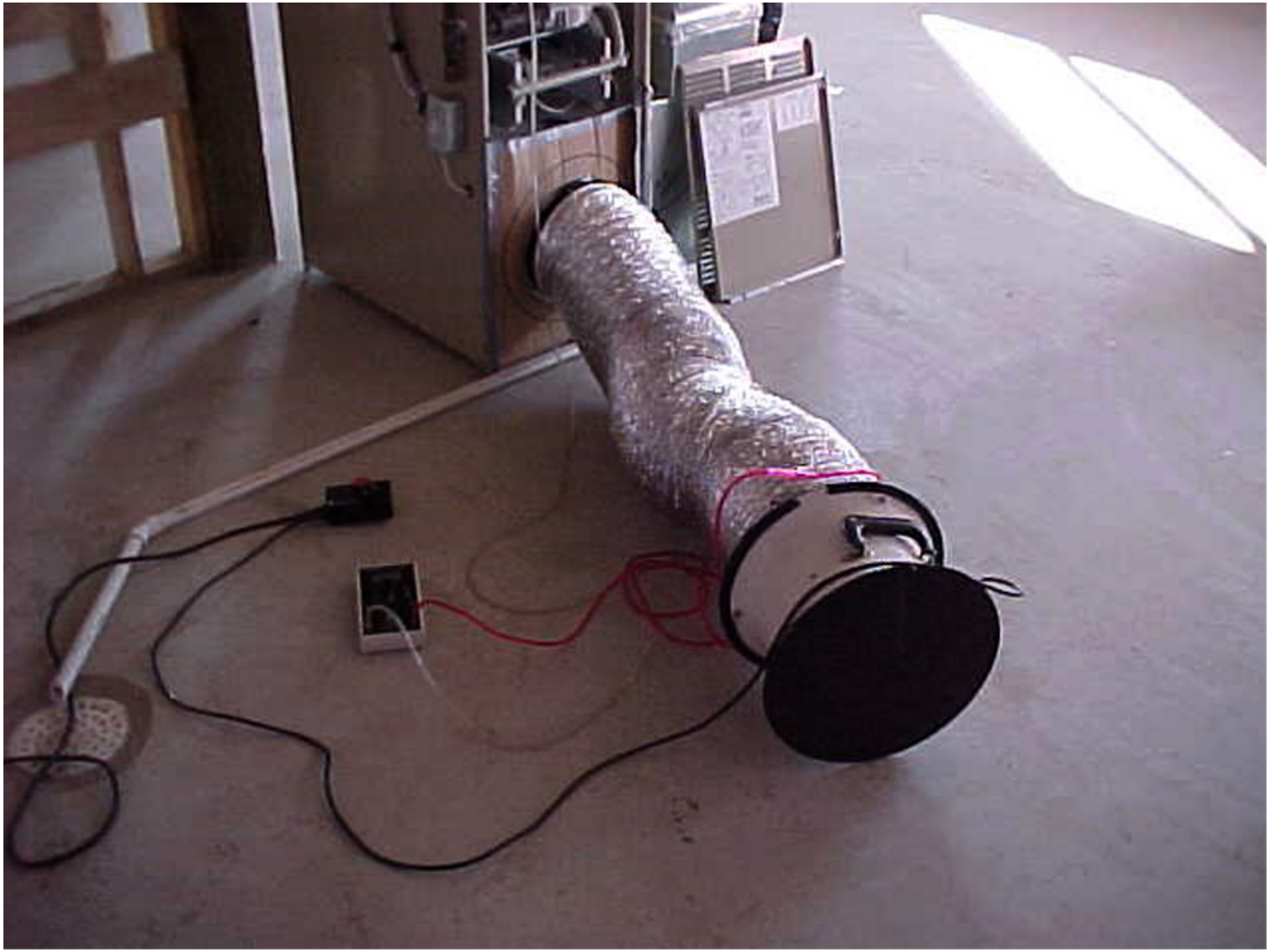
Blower Door Can't Get You The True ACH On A Short Term Basis – Hour, Day, Week

Don’t Know Where The Holes Are

Don’t Know The Type of Holes

Don’t Know The Pressure Across The Holes

Why Do We Suck and Not Blow?



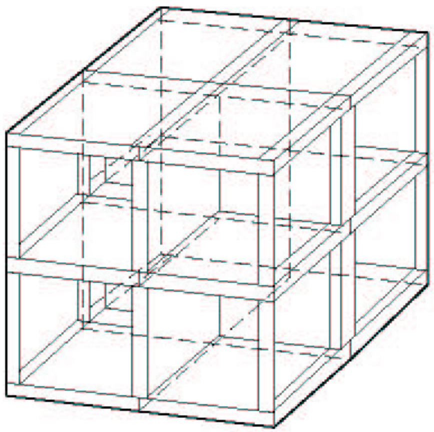


Figure 2.11
Three Dimensional Multi-Layer Multi-Cell Analogue

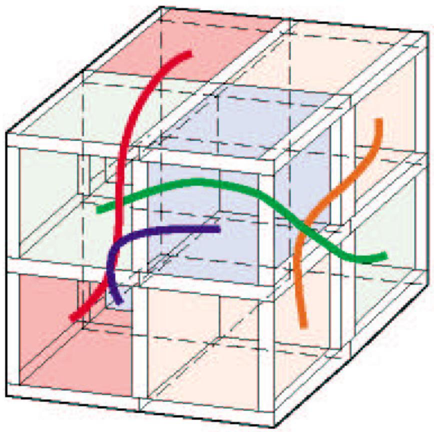
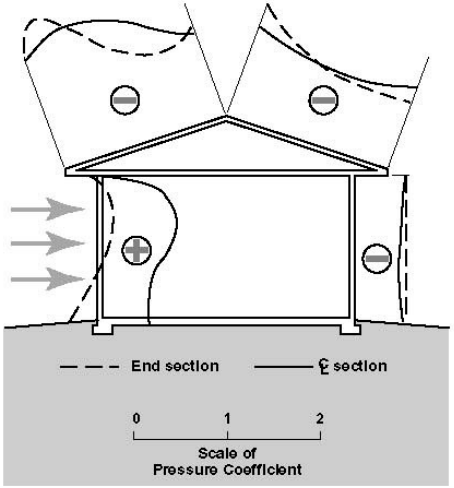


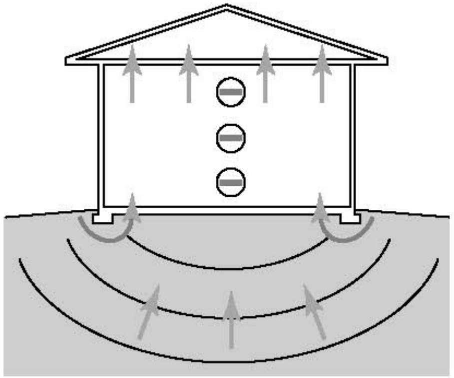
Figure 2.12
Three Dimensional Multi-Layer Multi-Cell Non-Contiguous Analogue

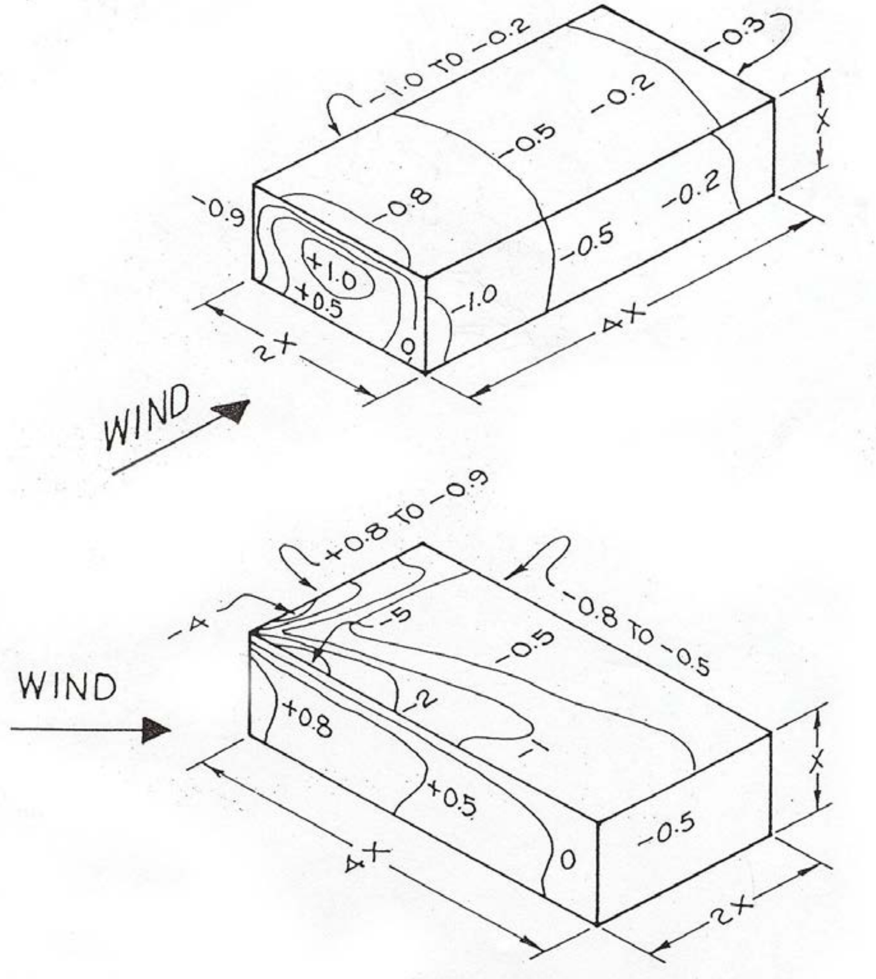
Figure 3.1
Exterior Air Pressure Field
(from Hutcheon & Handegord, 1983)



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.

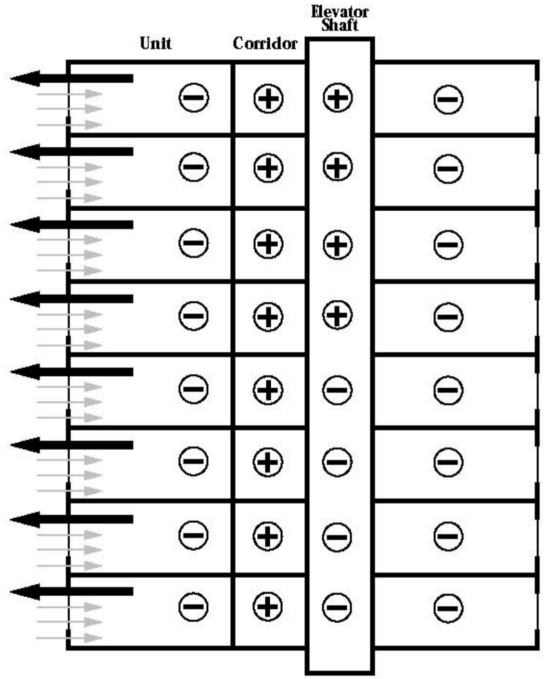


Figure 3.3
Interior Air Pressure Field

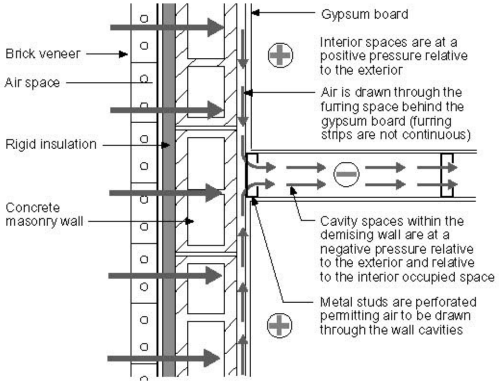


Figure 3.4
Interstitial Air Pressure Field

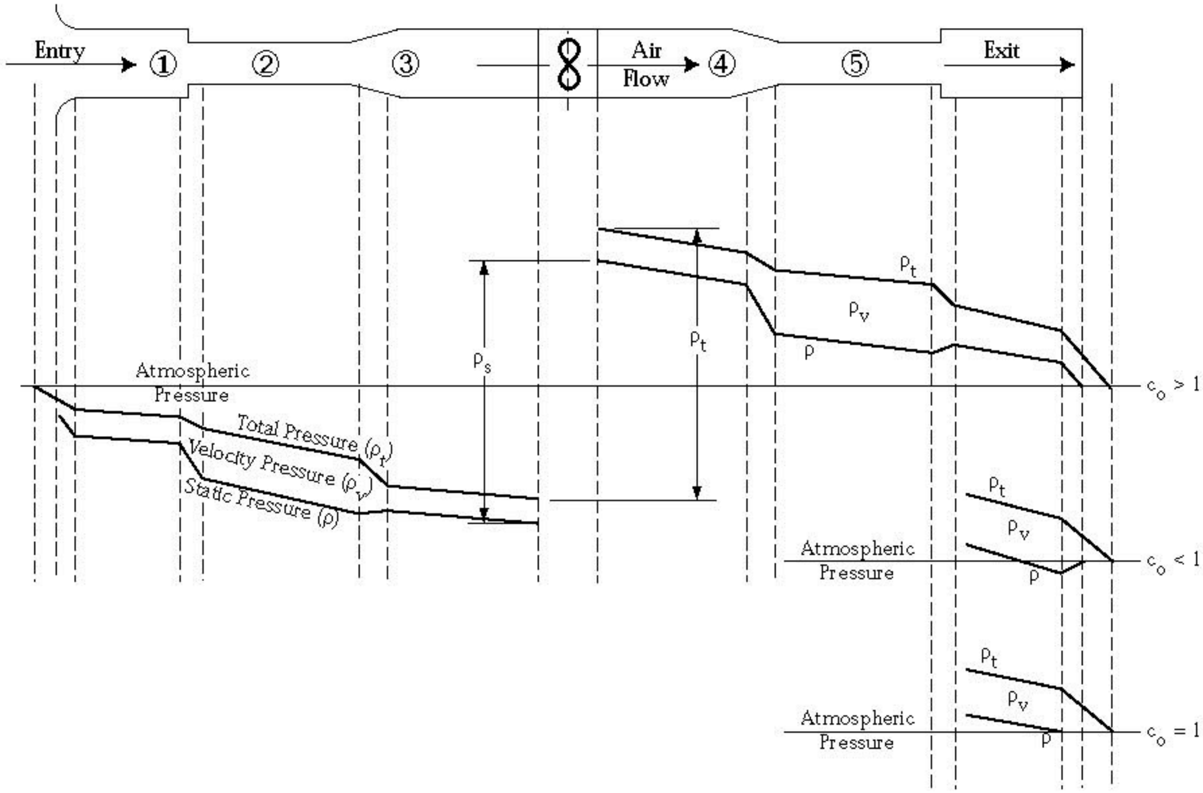


Figure 3.5

Air Conveyance System Air Pressure Field

(from Sauer & Howell, 1990)

People

Pollutant (hot, wet, UV, ozone)

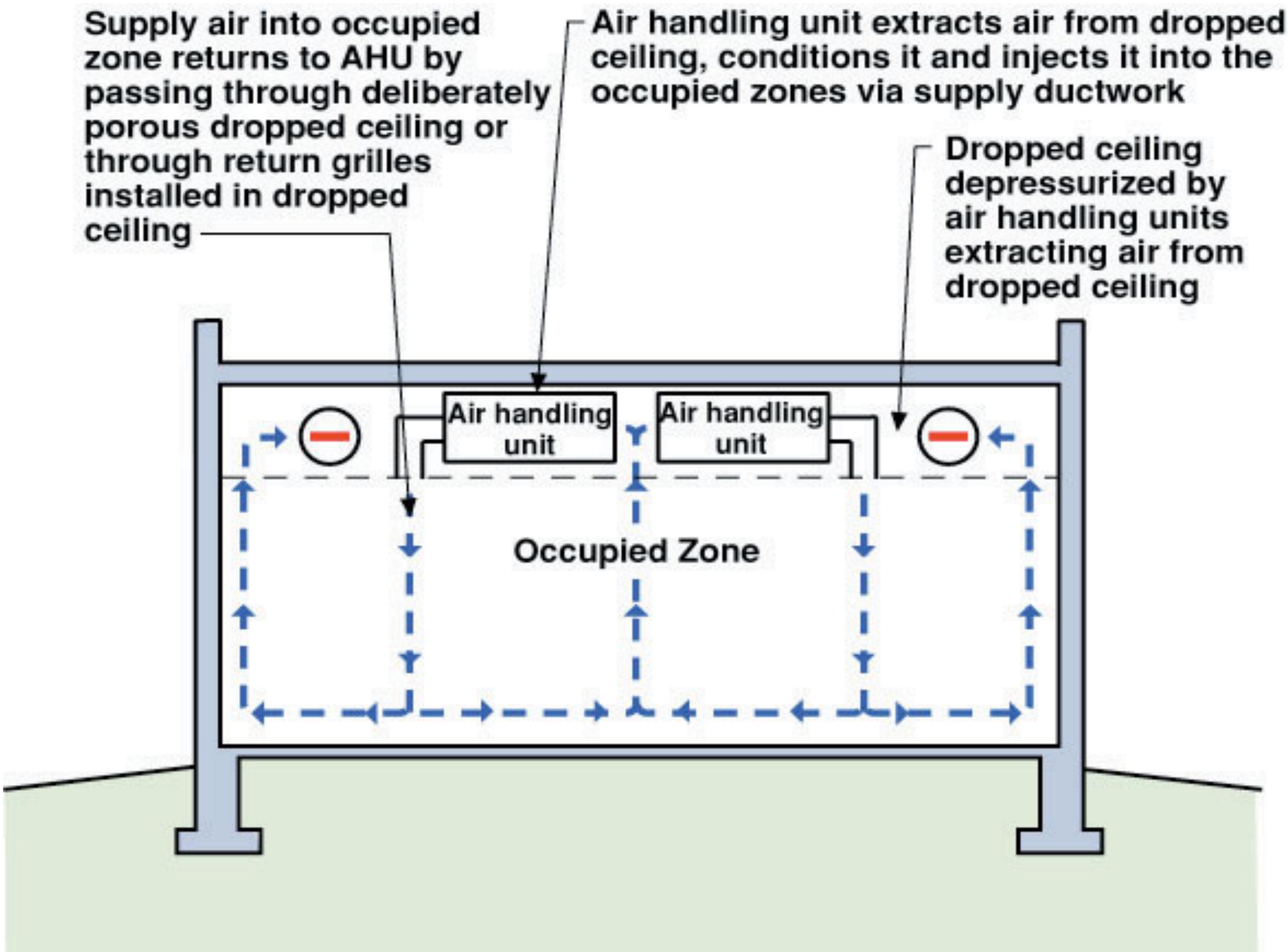
Path

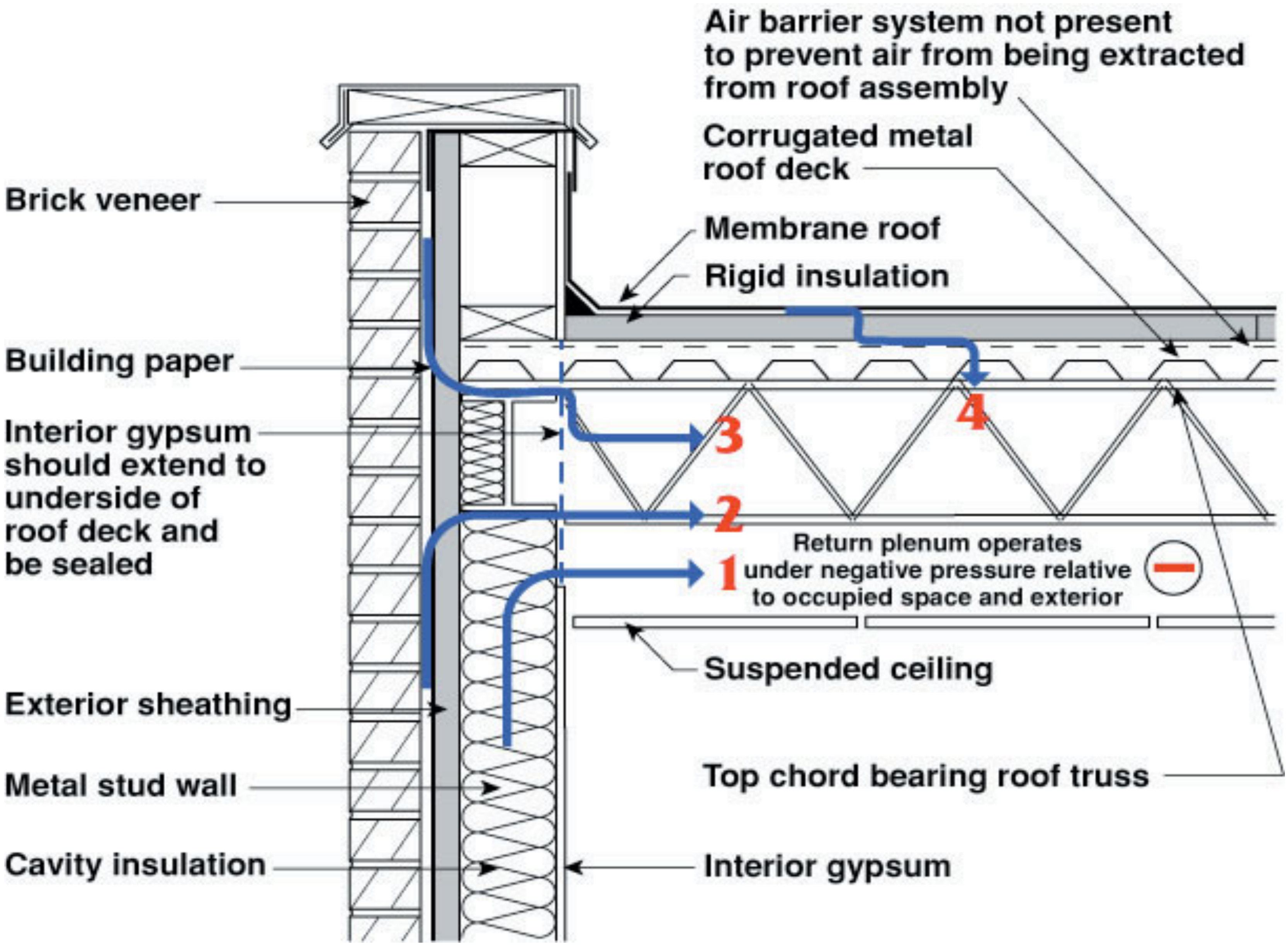
Pressure

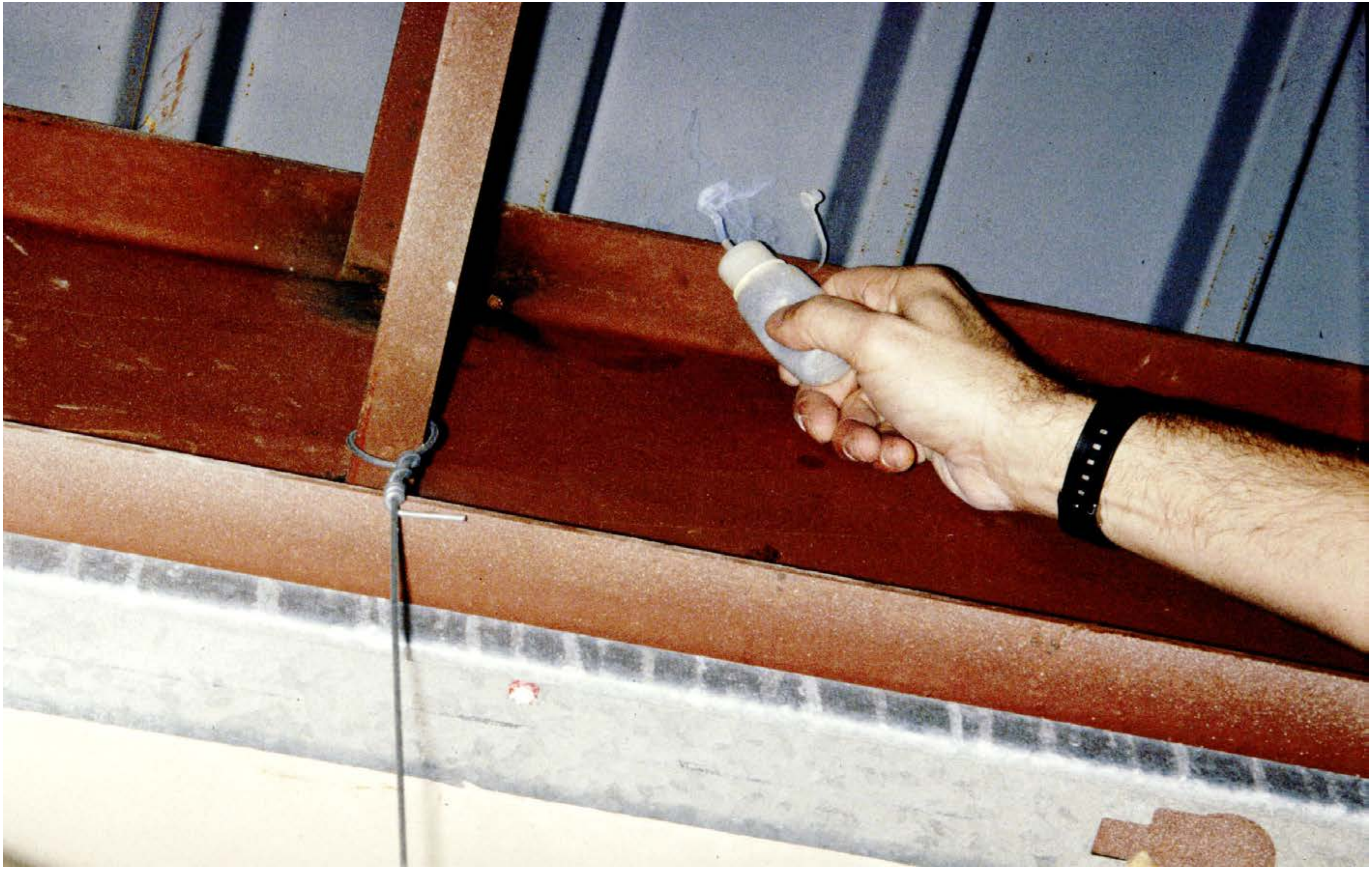

PUBLIC SERVICES

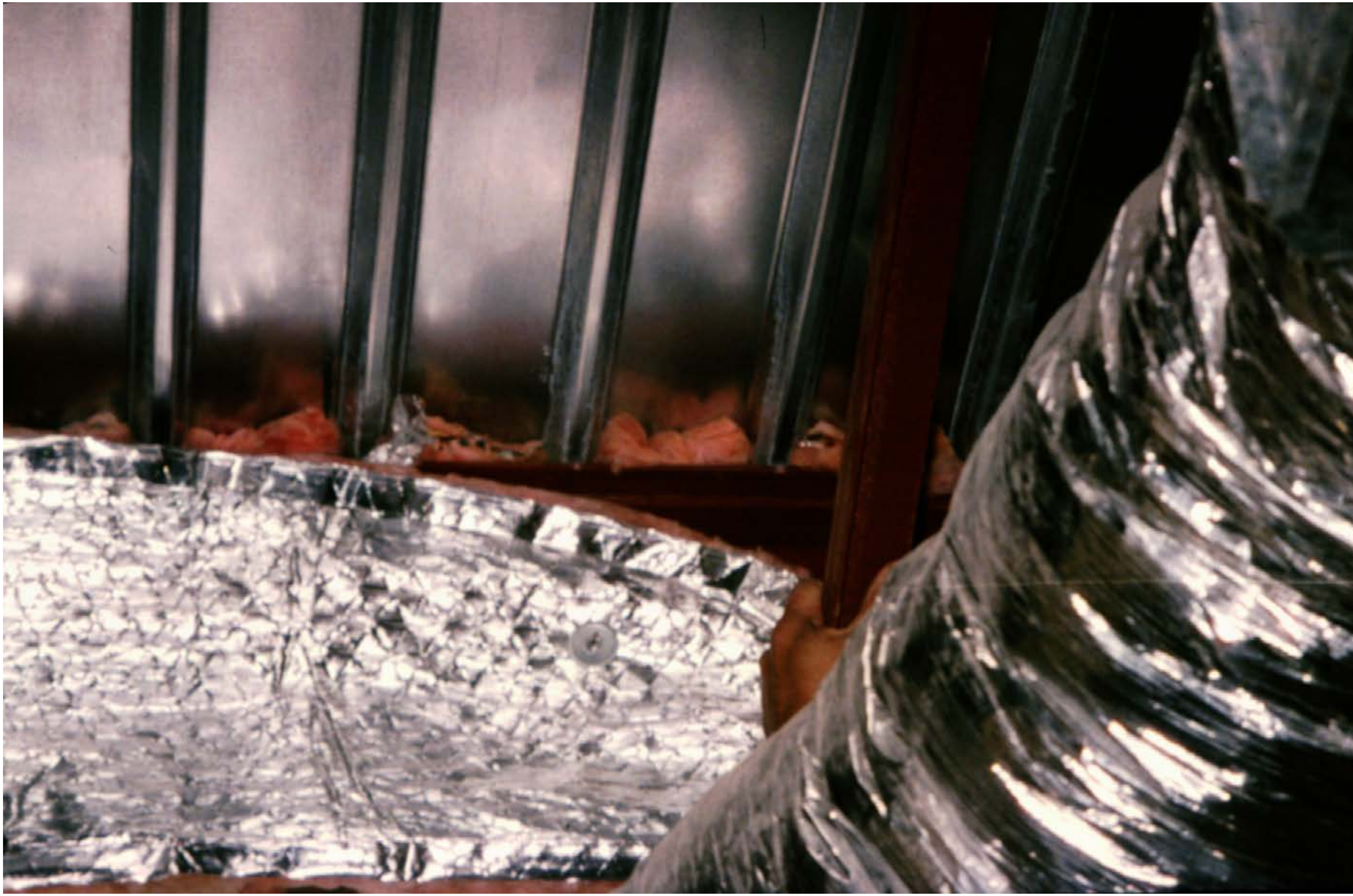

STOP


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

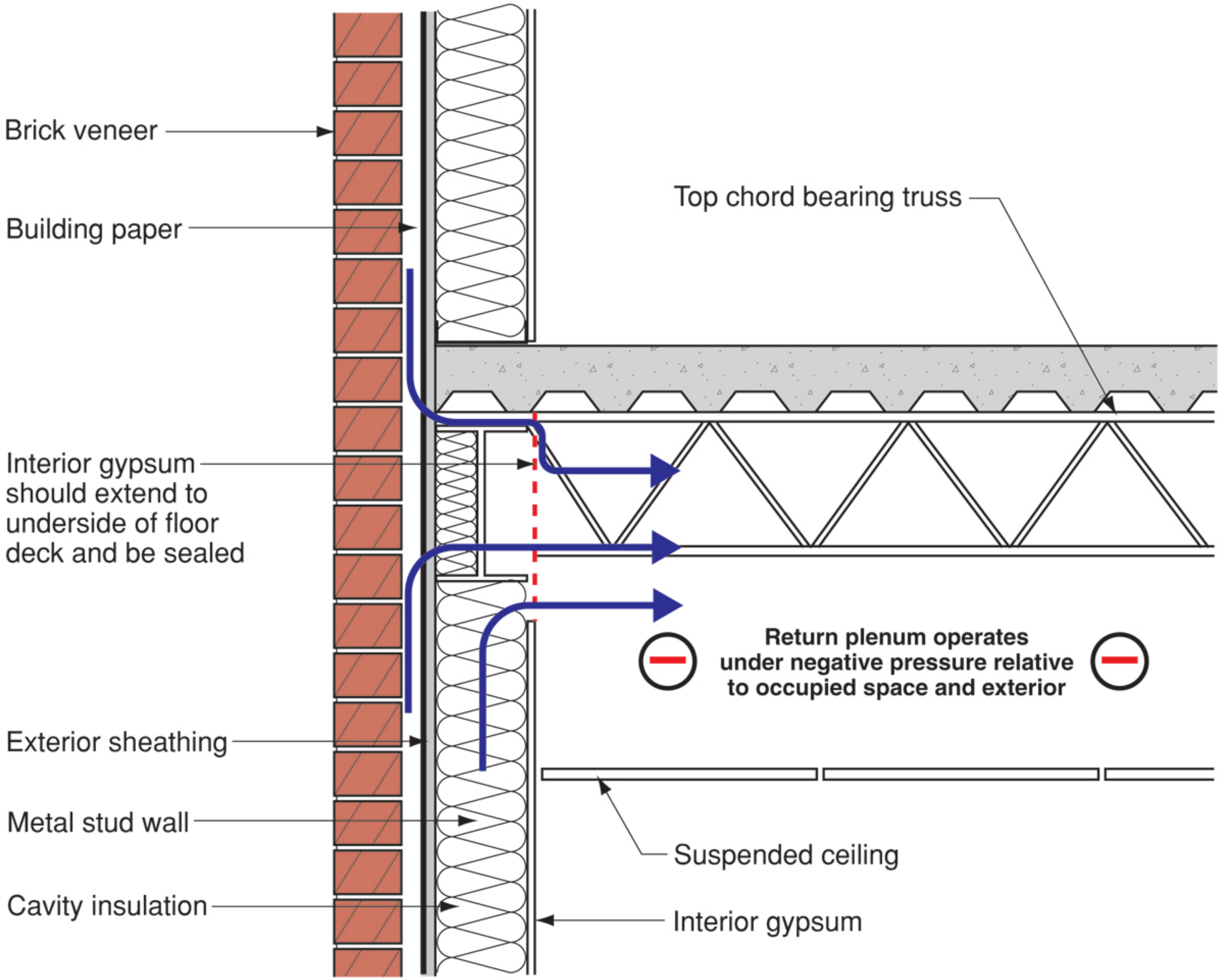

Air barrier system not present to prevent air from being extracted from roof assembly
Corrugated metal roof deck
Membrane roof
Rigid insulation
Brick veneer
Building paper
Interior gypsum should extend to underside of roof deck and be sealed
Exterior sheathing
Metal stud wall
Cavity insulation
3
4
2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

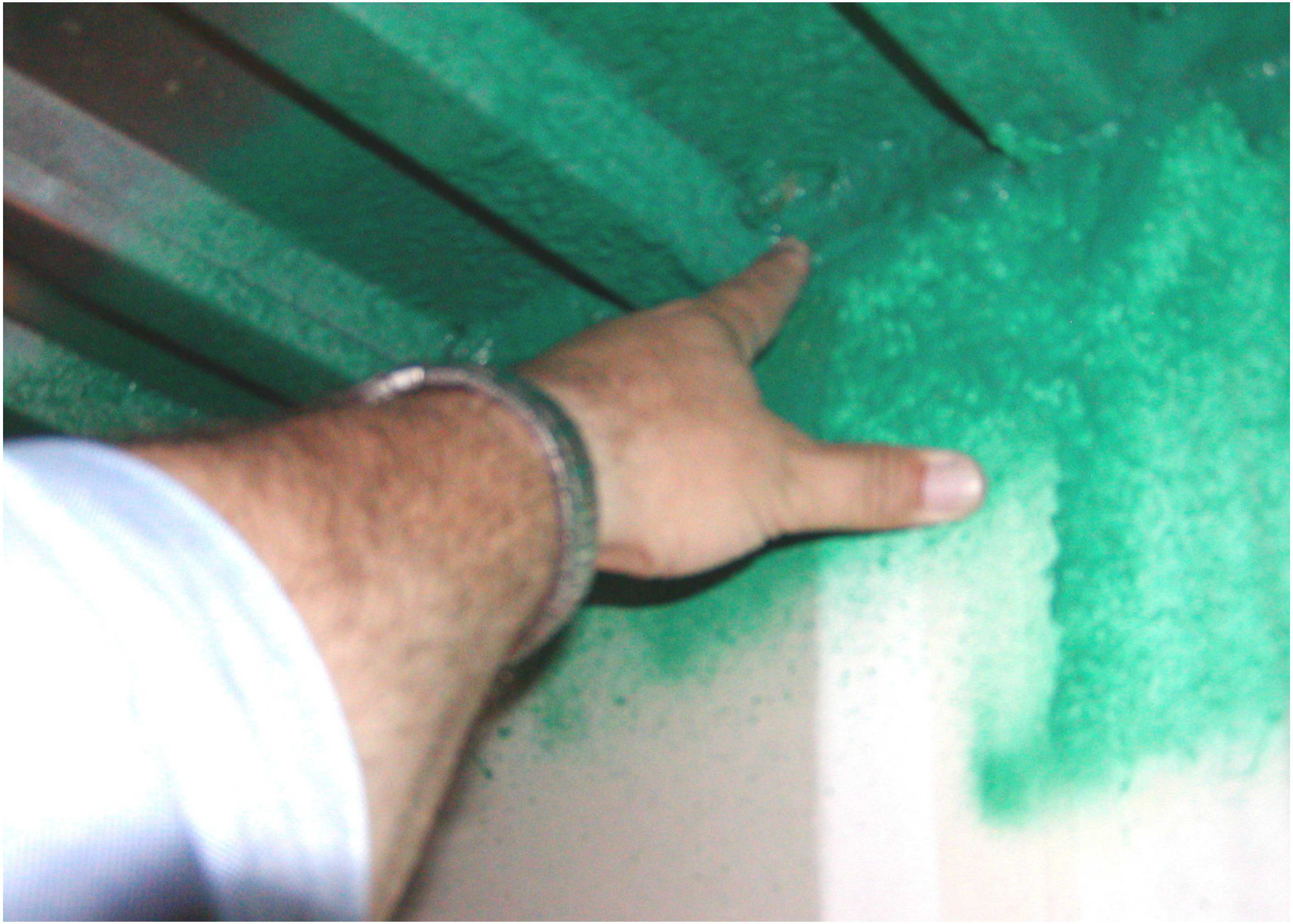


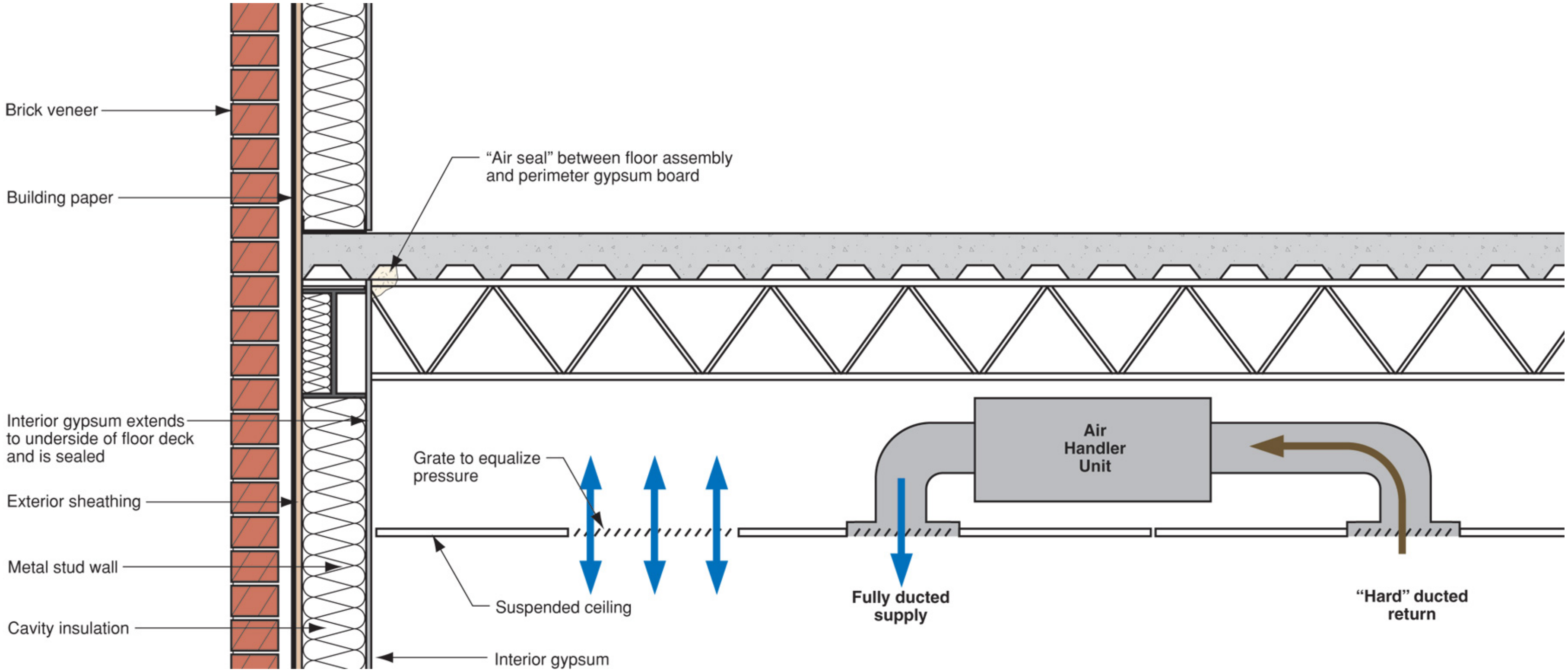



Tyvek


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
Suspended ceiling
Cavity insulation
Interior gypsum




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

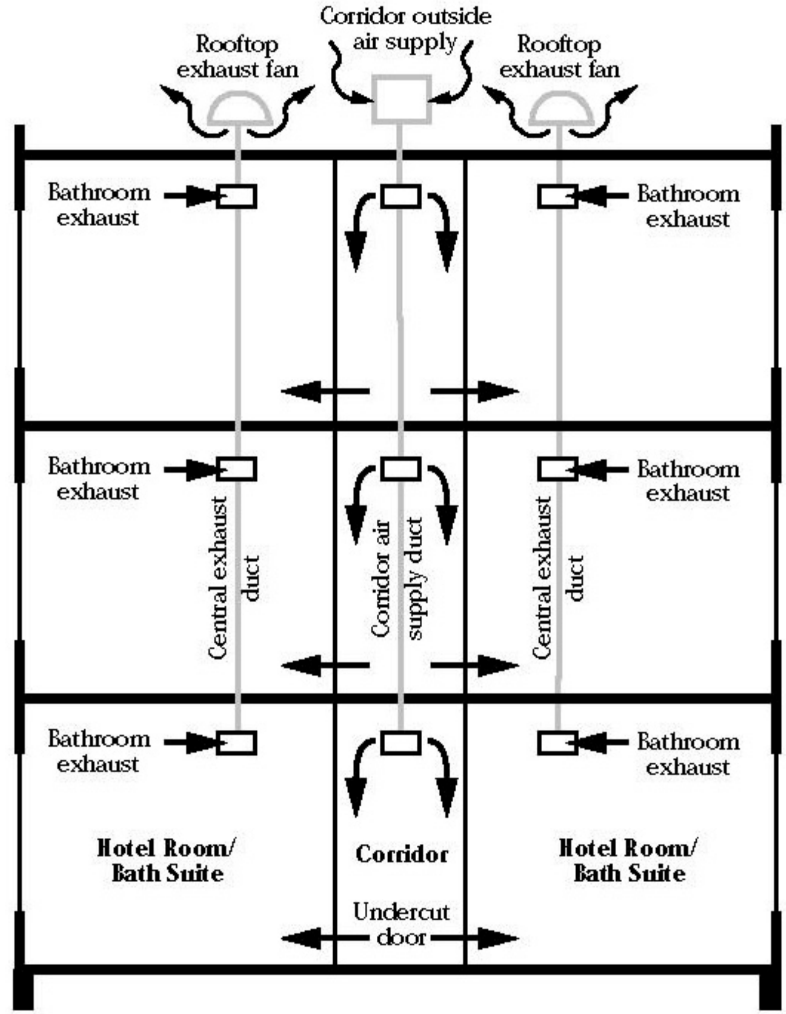
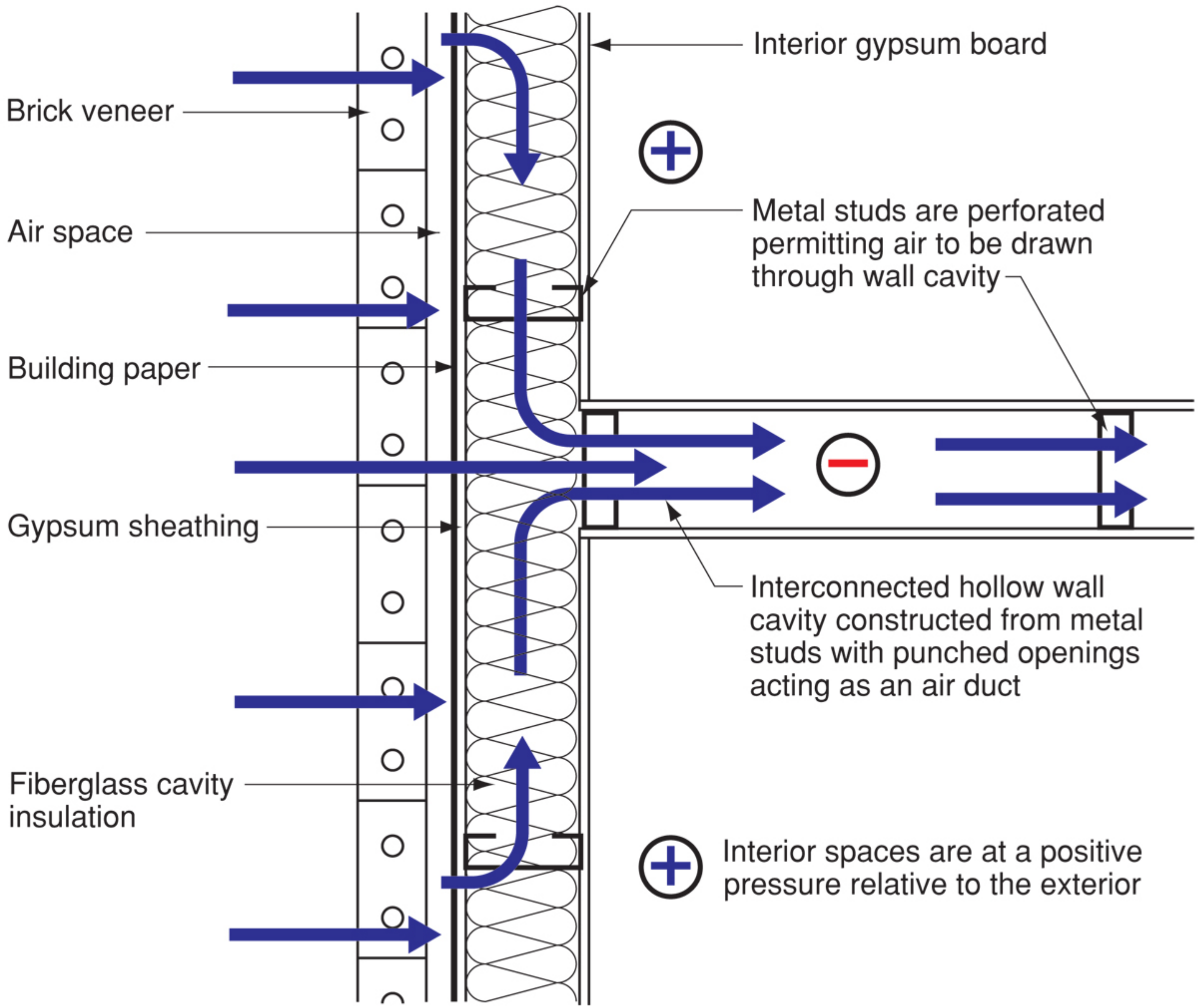


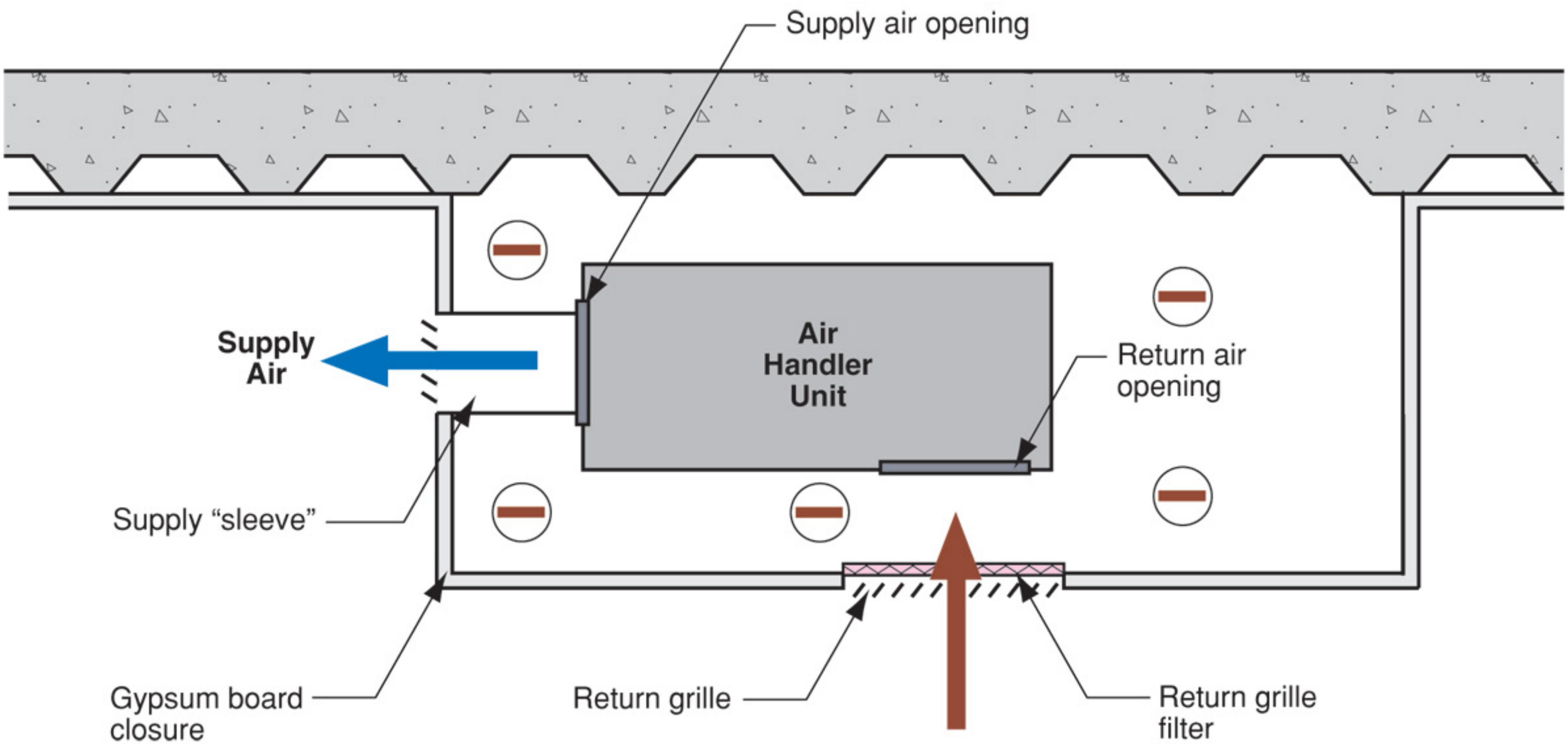
Figure 3.8

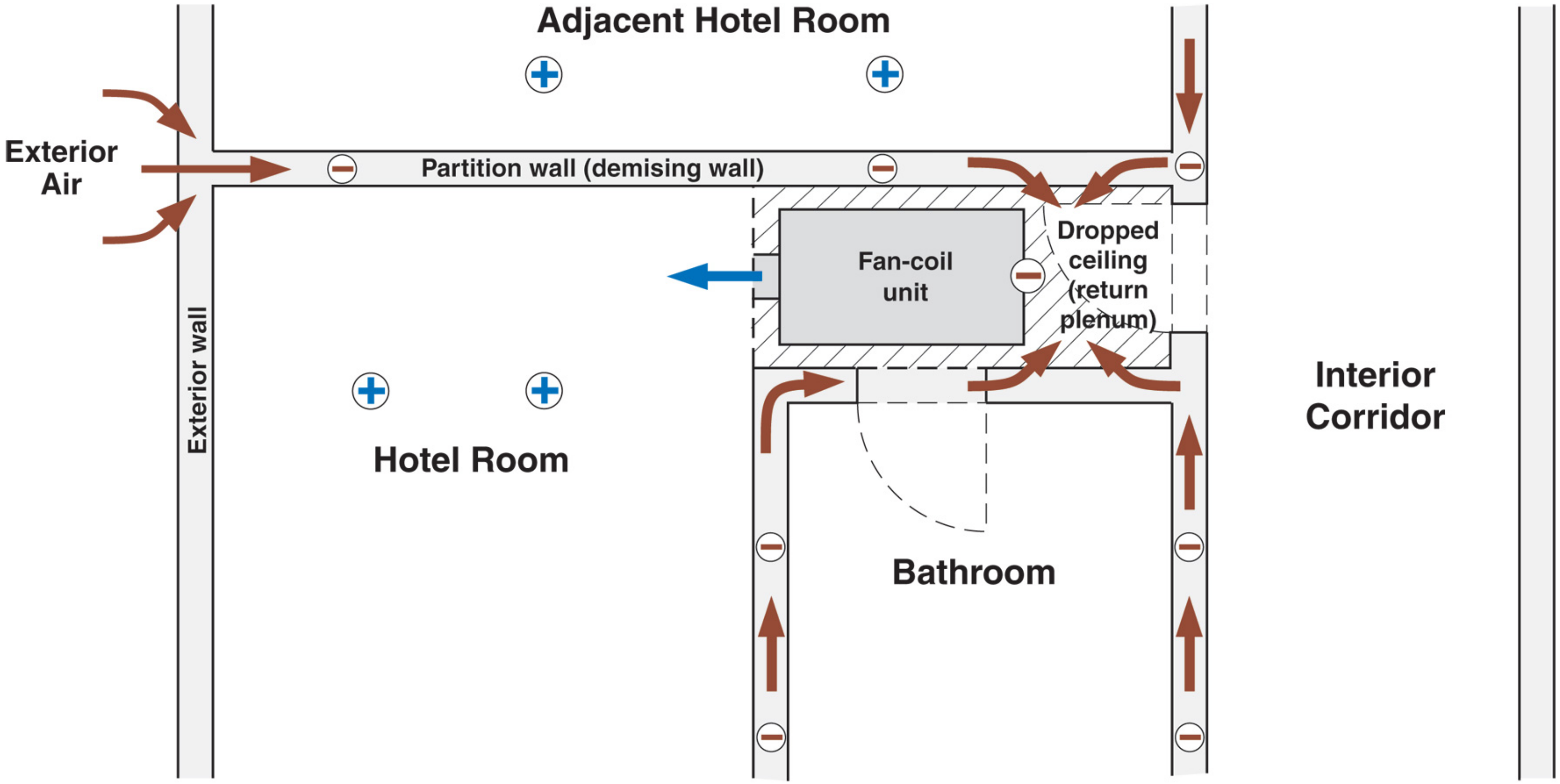
Hotel HVAC System

- 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

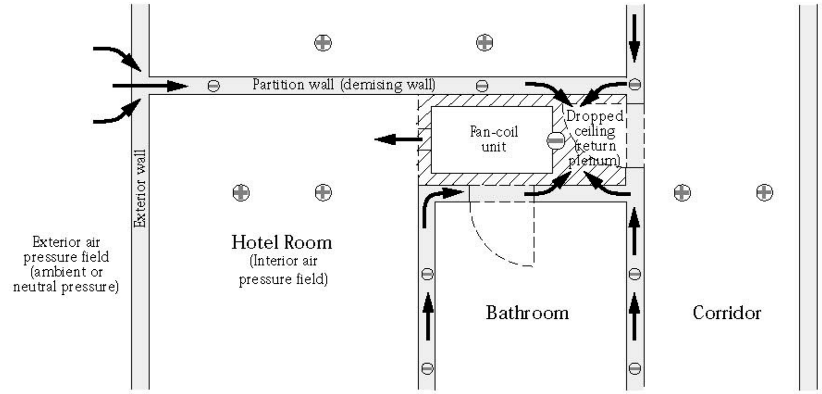


Figure 3.10
Pressure Field Due to Fan-Coil Unit
Plan View

- 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

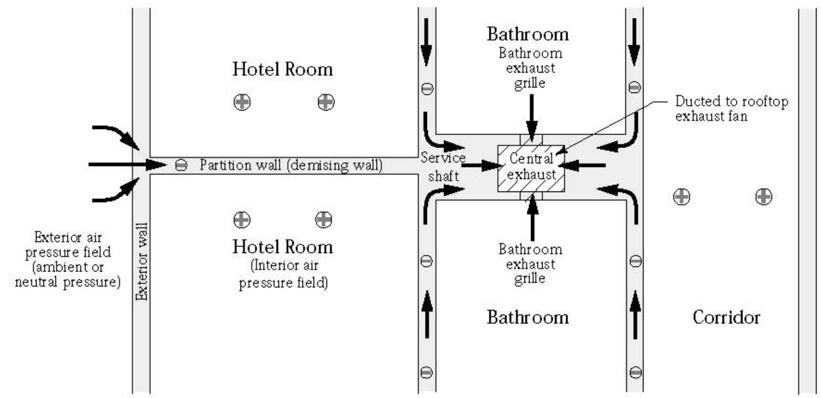
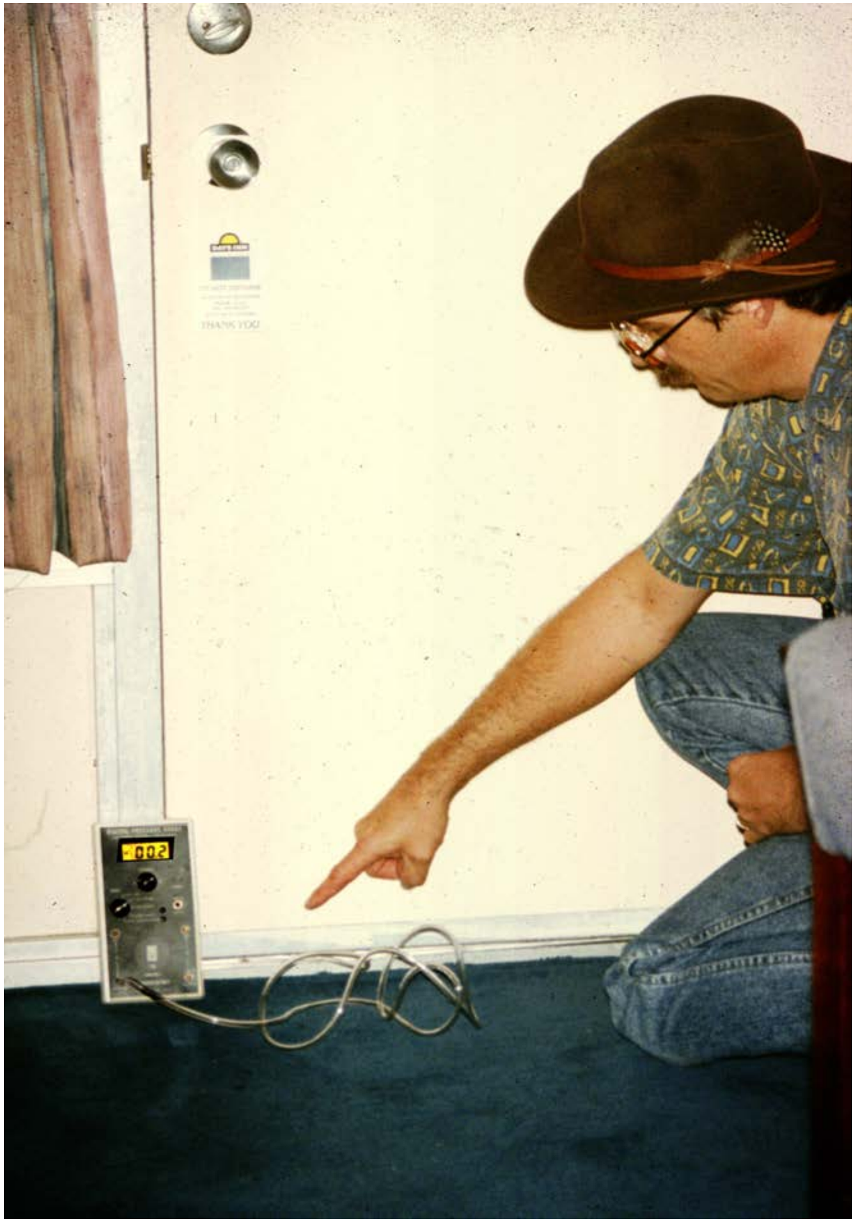


Figure 3.11
Pressure Field Due to Central Exhaust
Plan View

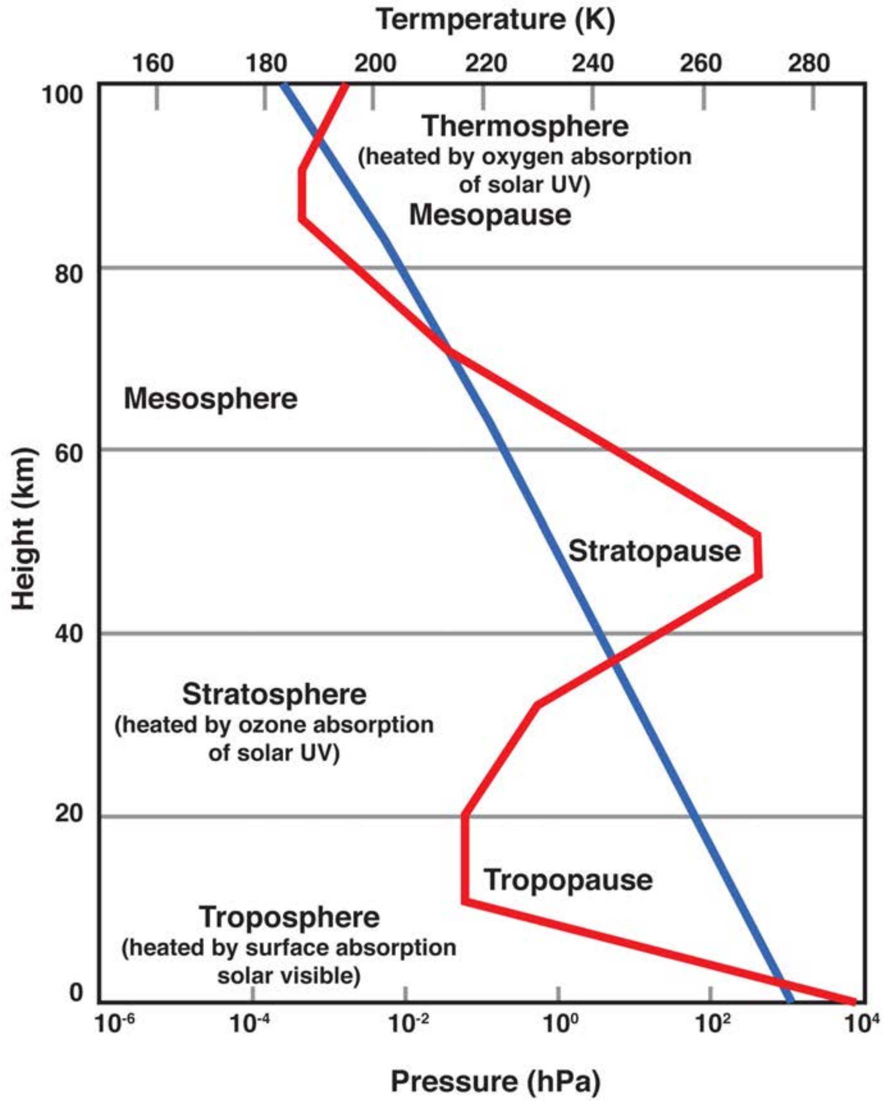
- Leakage of central exhaust duct pulls air out of service shaft depressurizing shaft and demising walls


DAYS INN



Lapse Rate

U.S. Standard Atmosphere (1976)



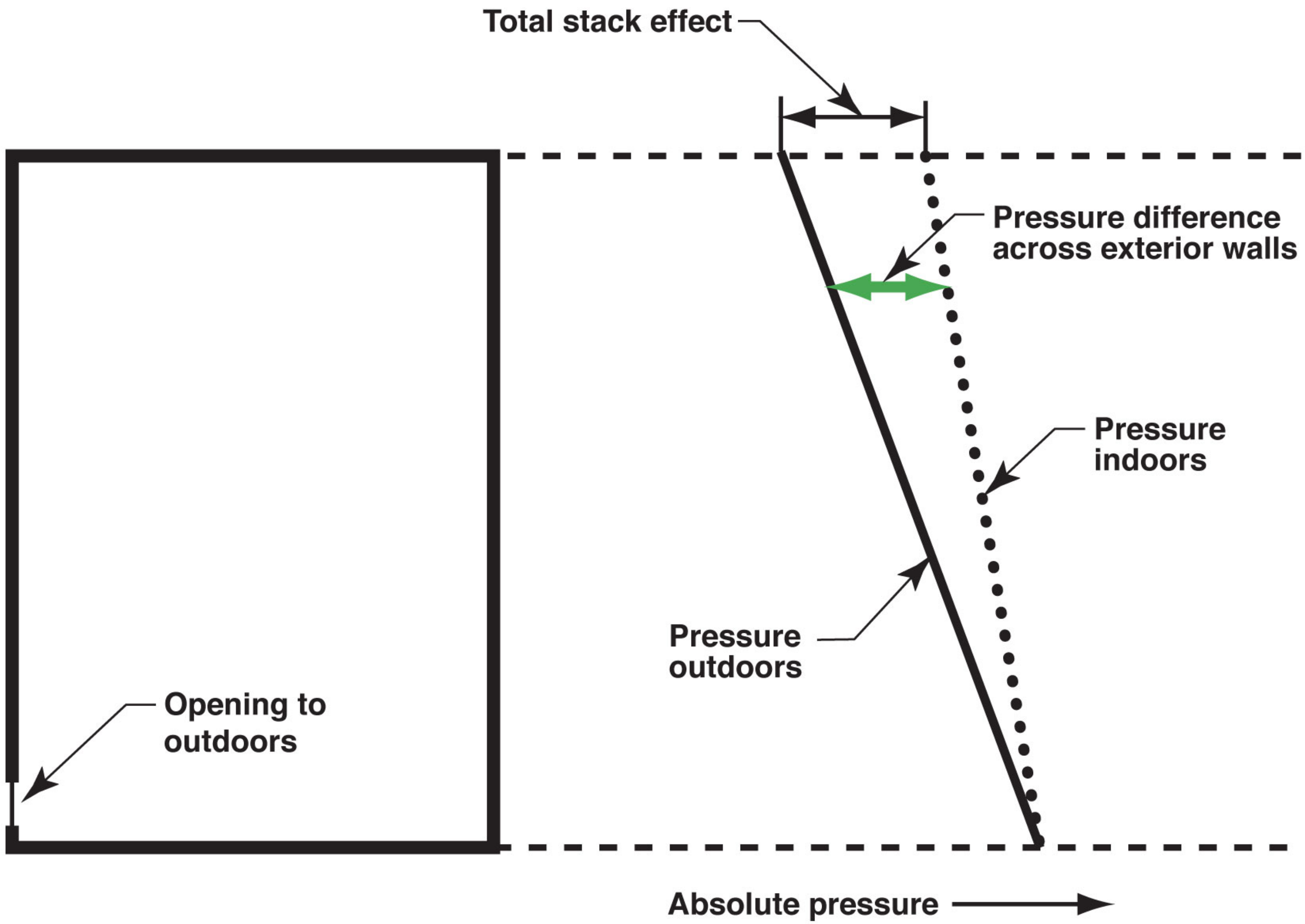


Figure 11.1: Building with no internal separations with opening at the bottom (Adapted from G.O. Handegord, 1998)

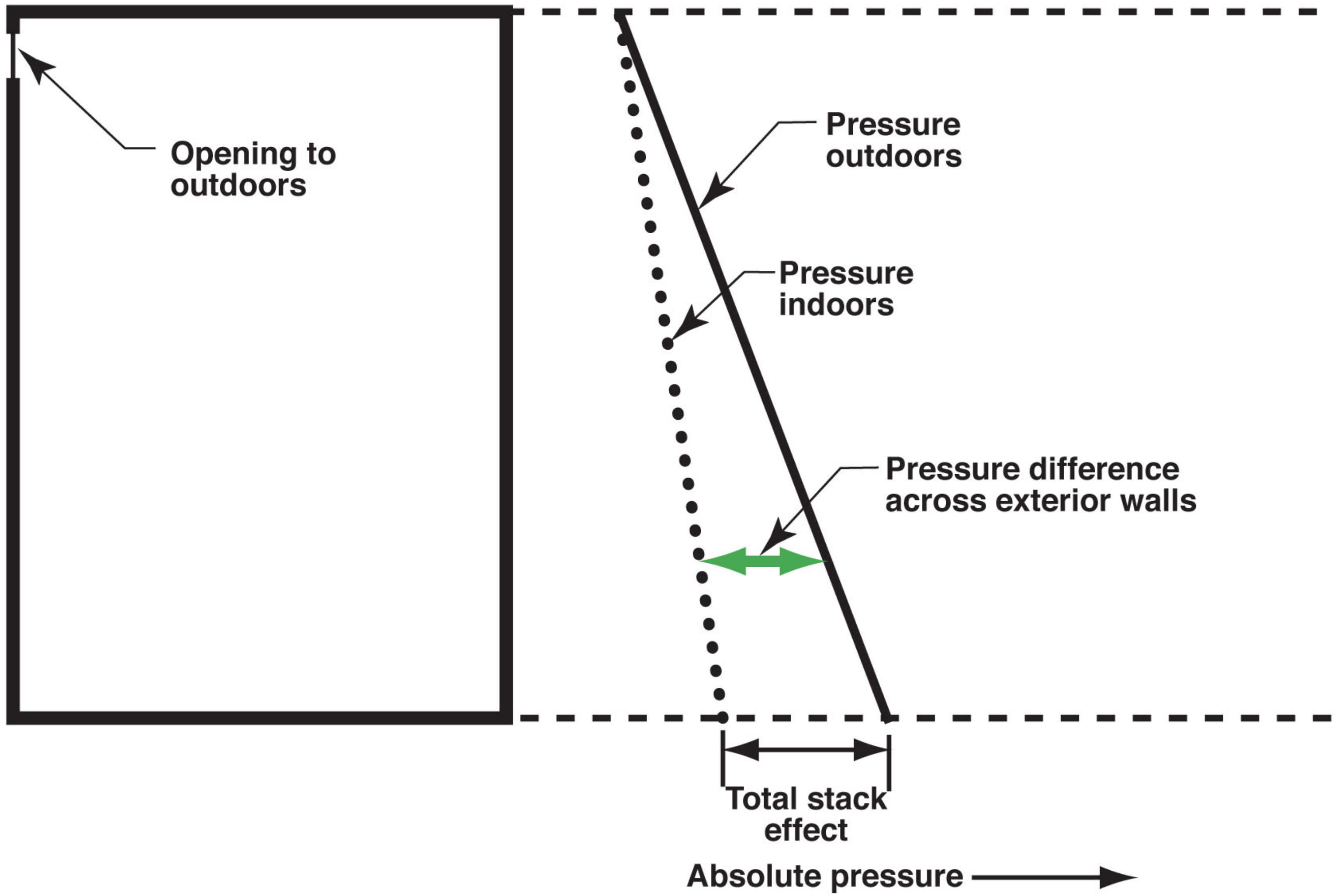


Figure 11.2: Building with no internal separations with opening at the top (Adapted from G.O. Handegord, 1998)

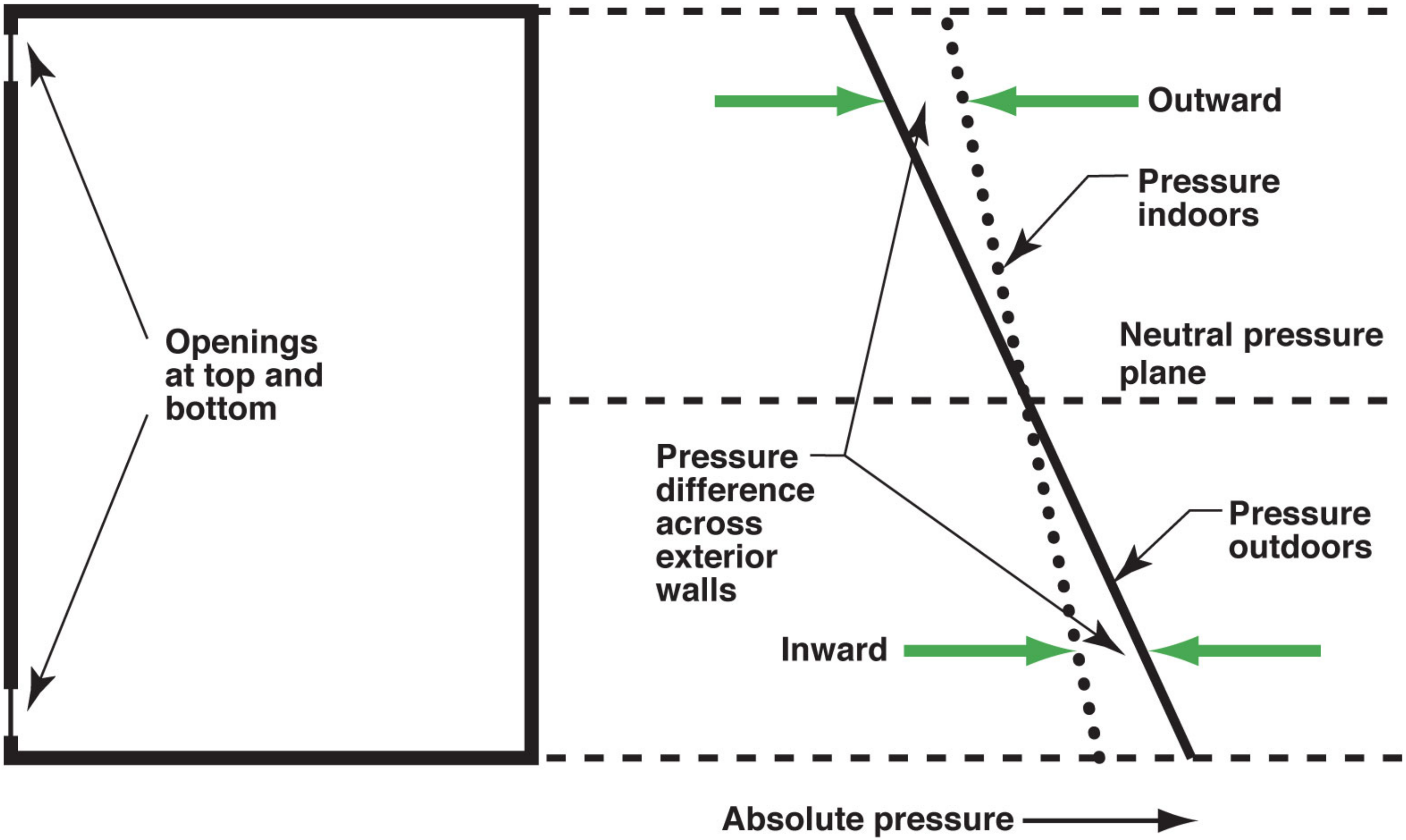


Figure 11.3: Building with no internal separations with openings at top and bottom (Adapted from G.O. Handegord, 1998)

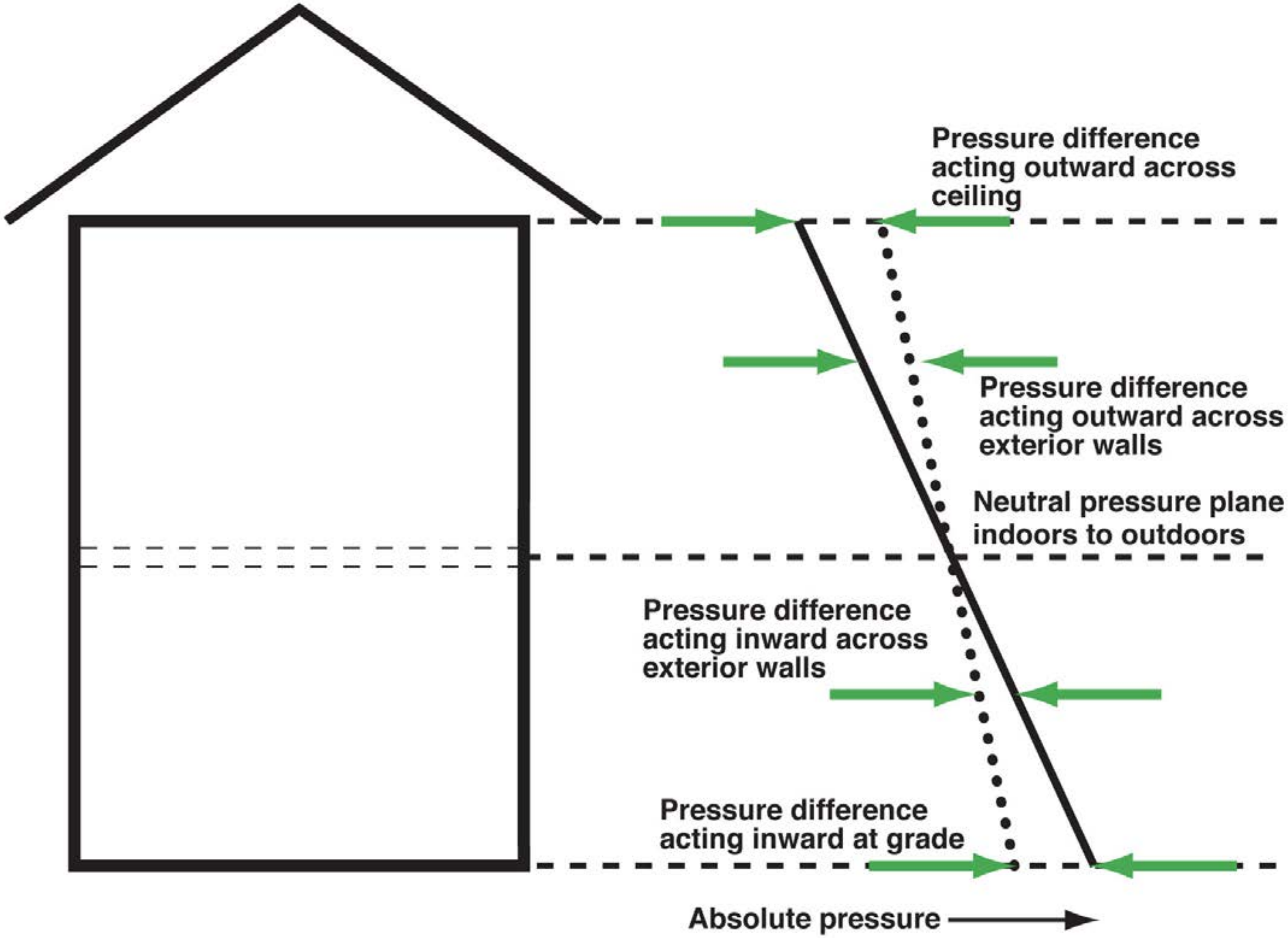


Figure 11.4: Basic two storey house with vented attic (Adapted from G.O. Handegord, 1998)


POMPIERS NO. 3

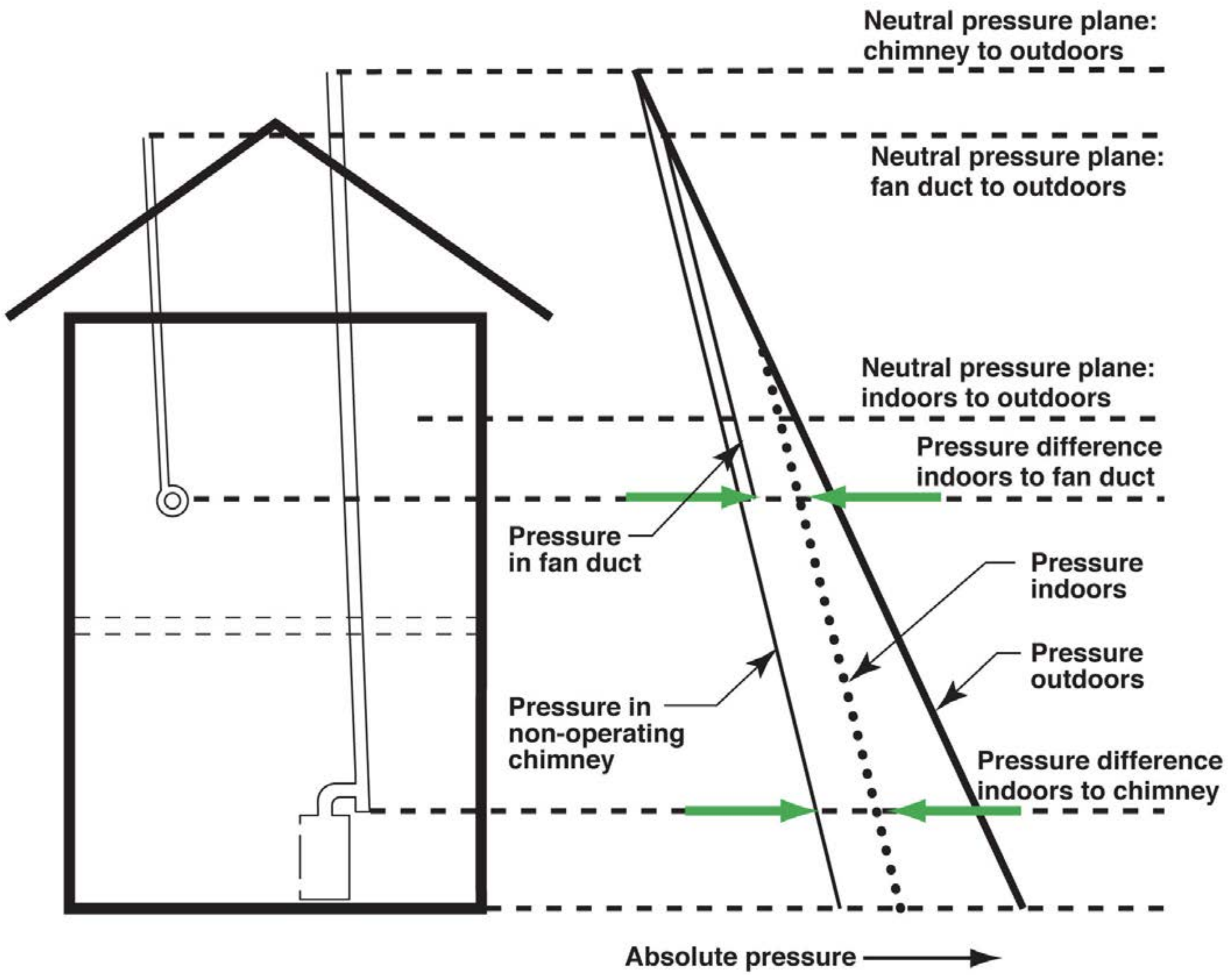


Figure 11.5: Two storey house with non-operating chimney and exhaust fan (Adapted from G.O. Handegord, 1998)

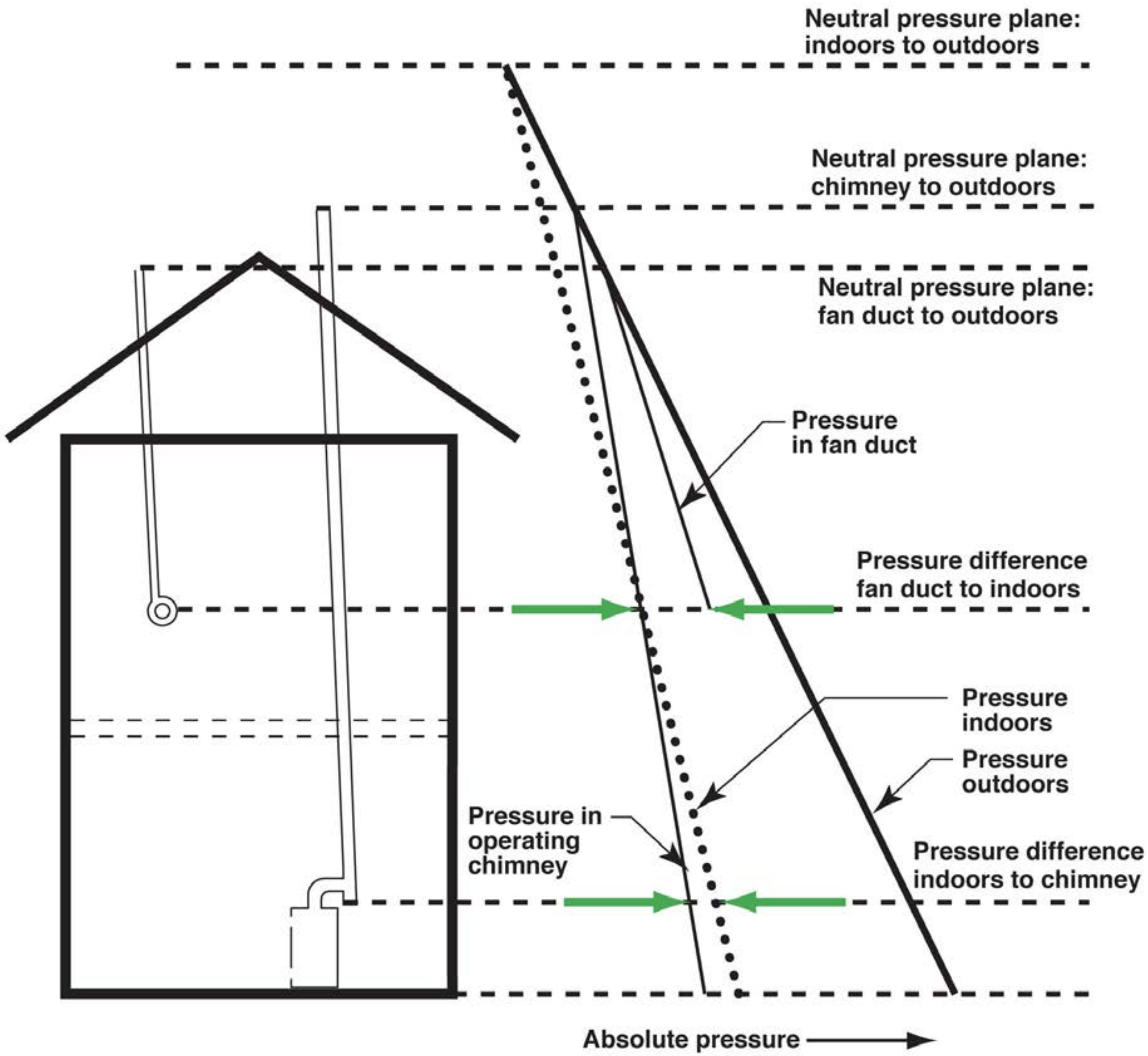
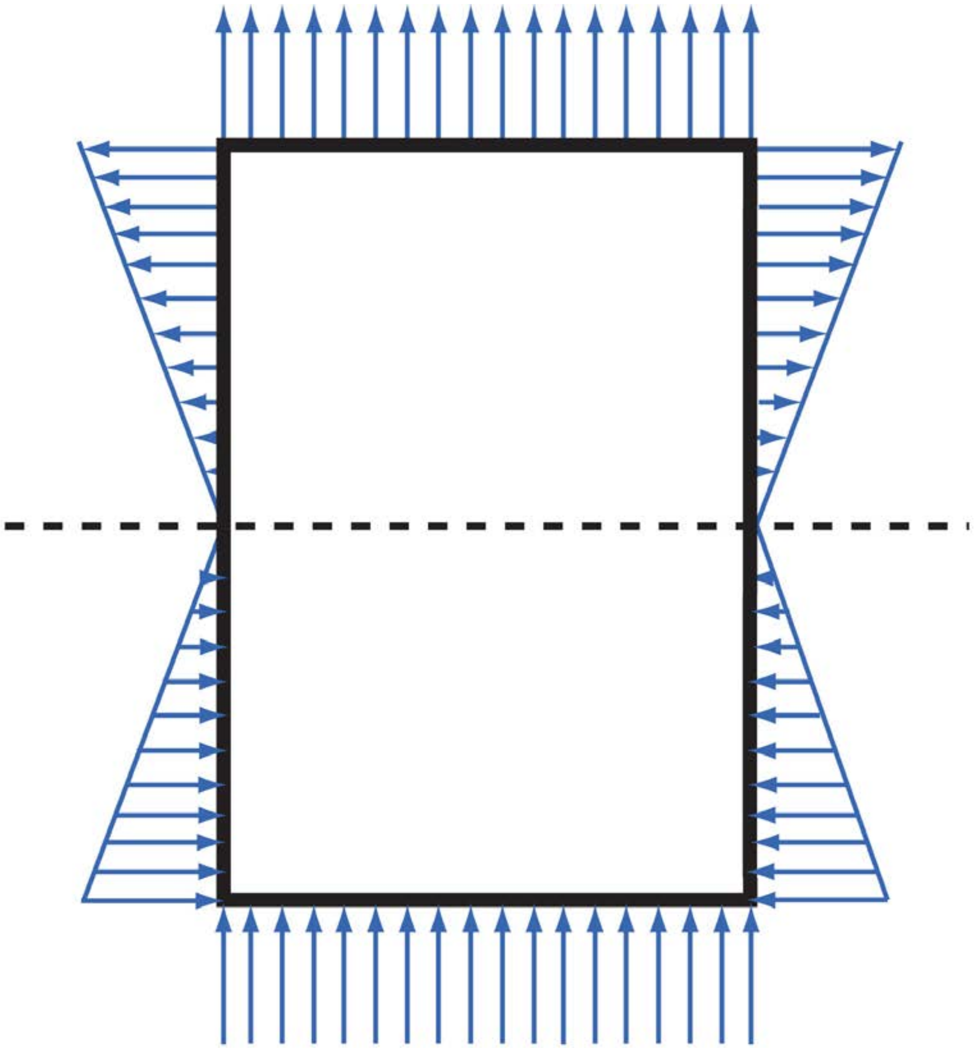
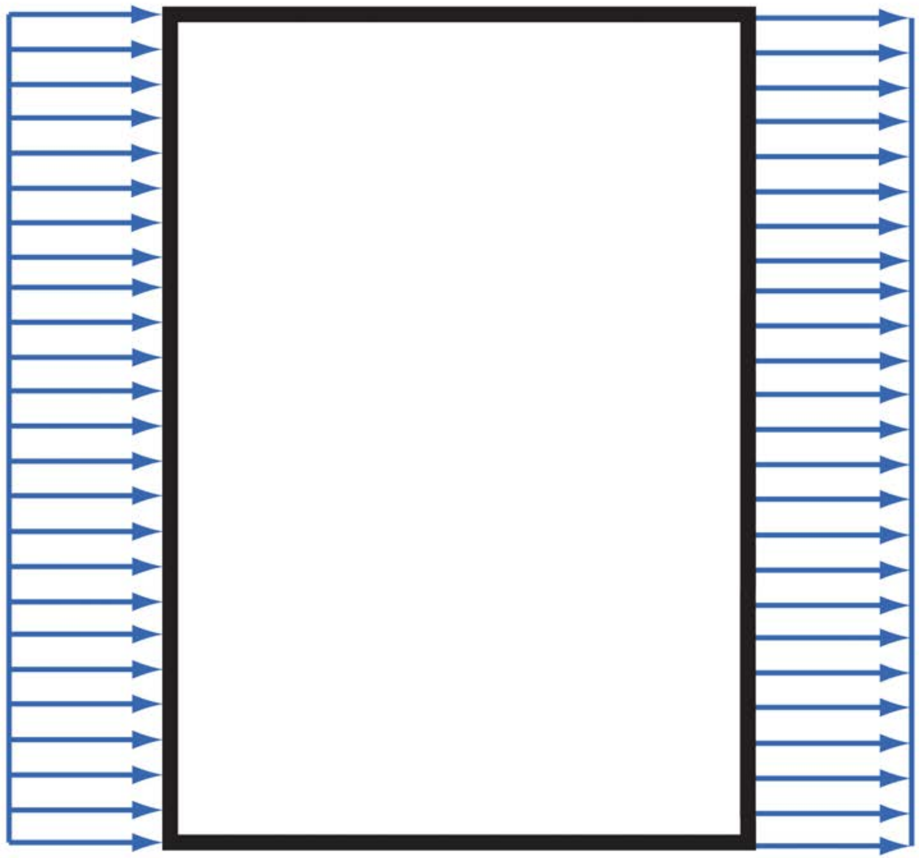


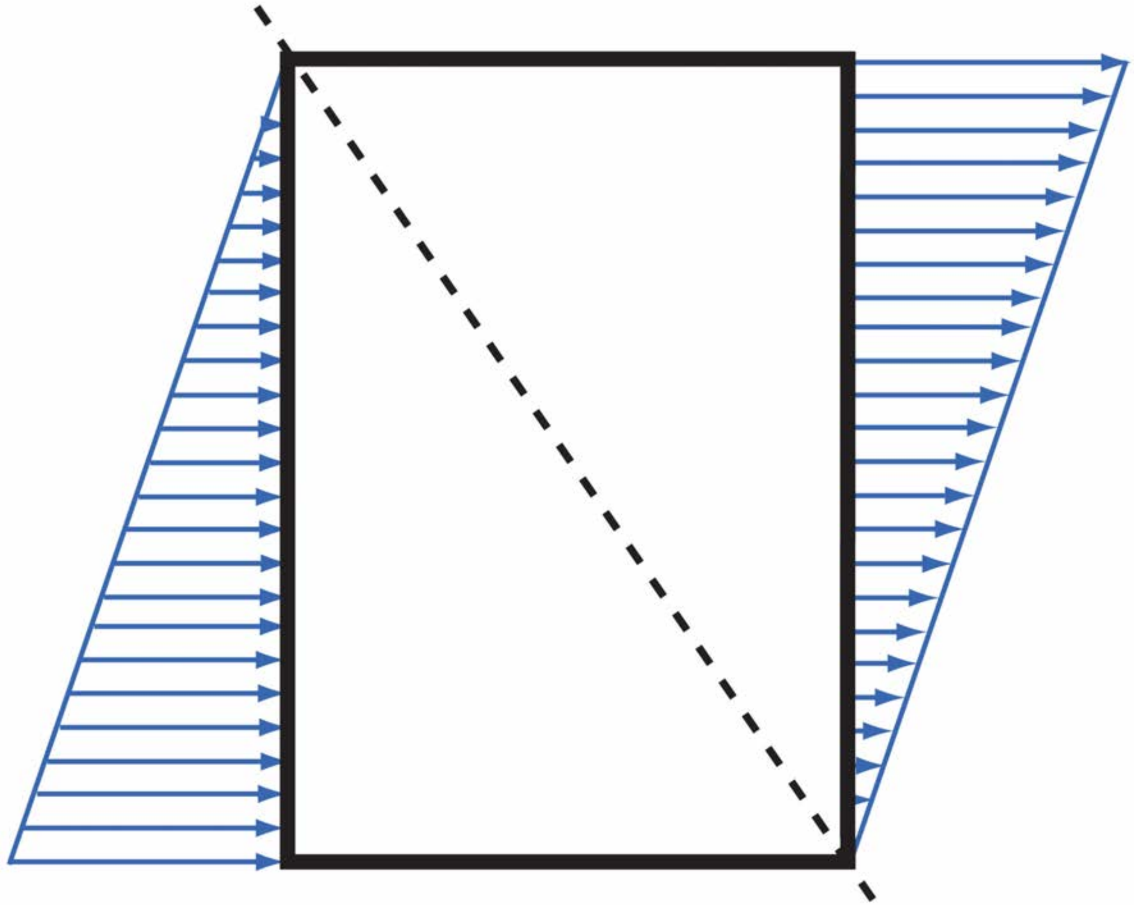
Figure 11.6: Two storey house with operating chimney
(Adapted from G.O. Handegord, 1998)



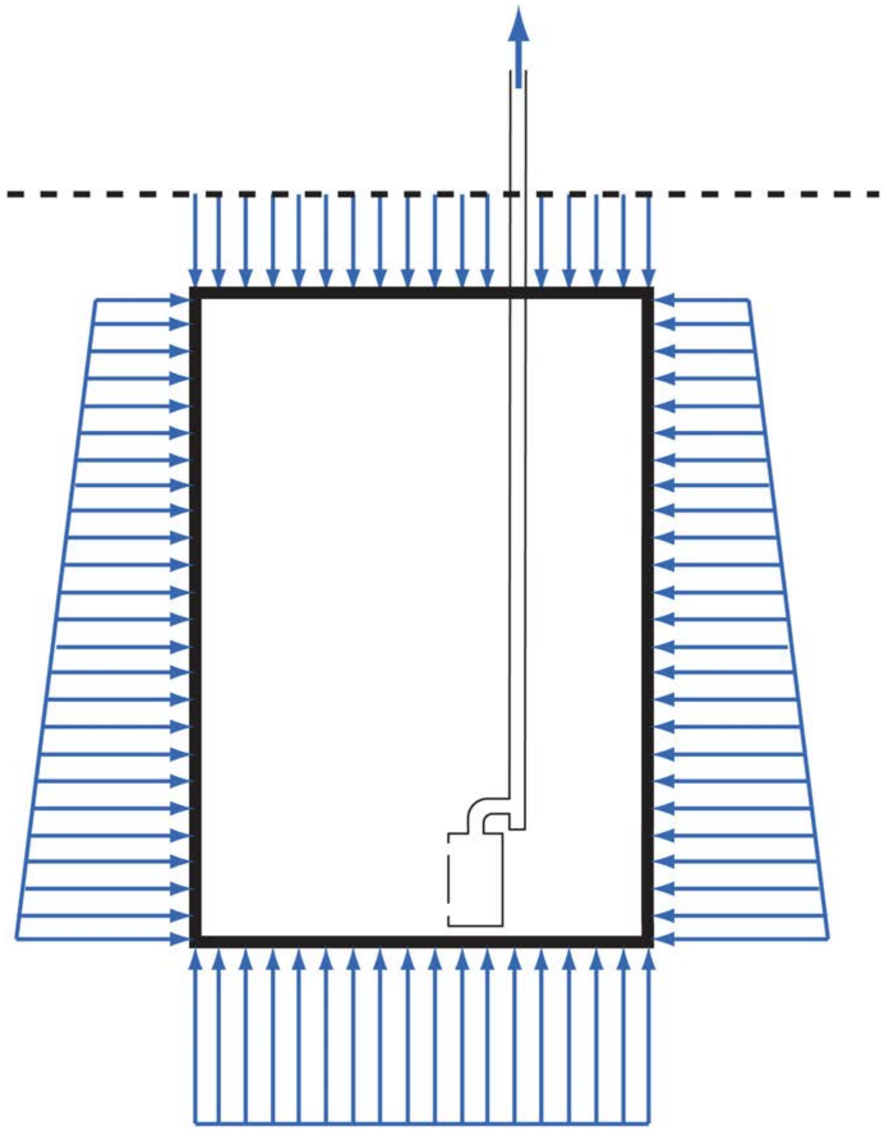
Stack effect



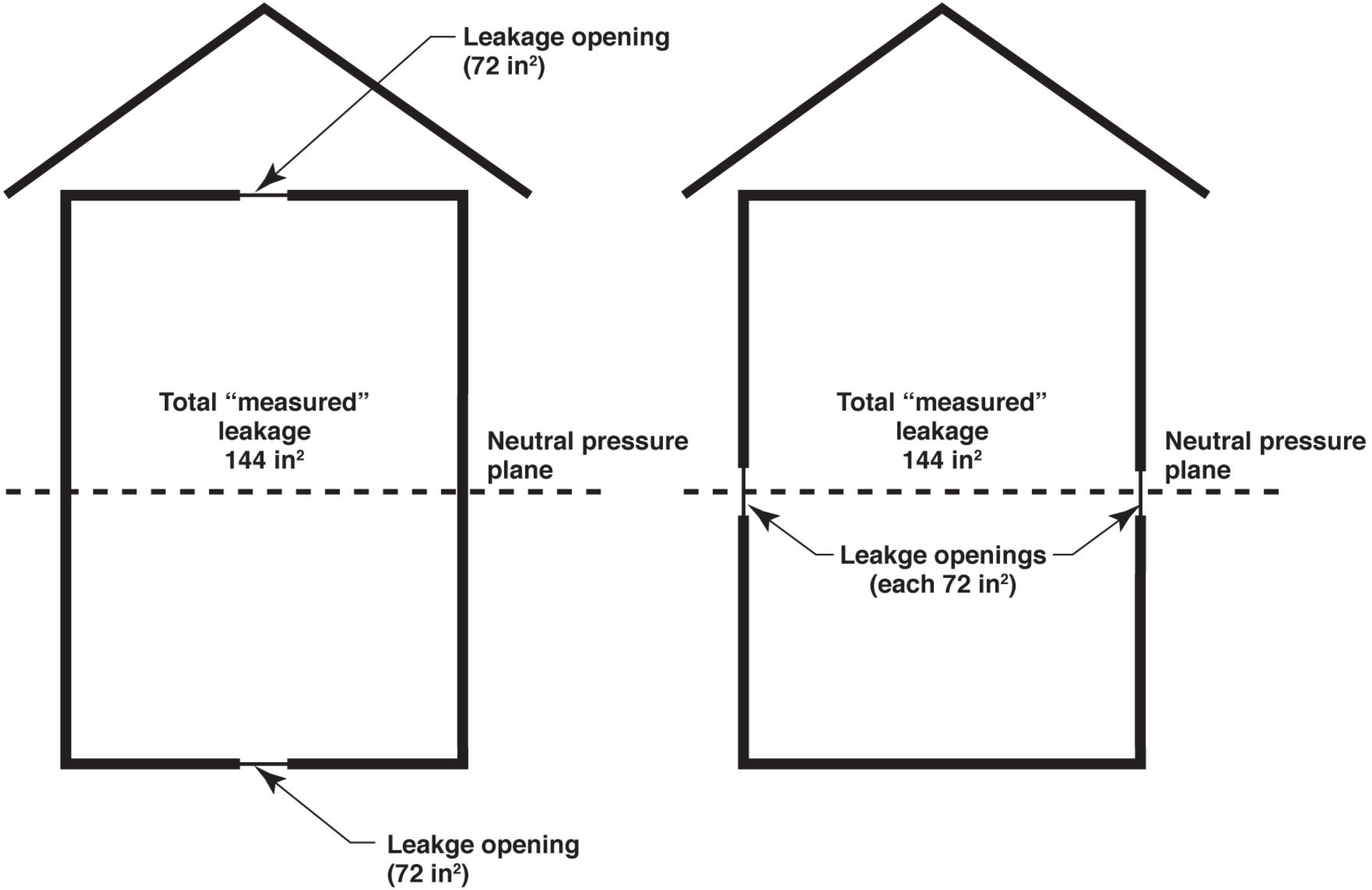
Wind



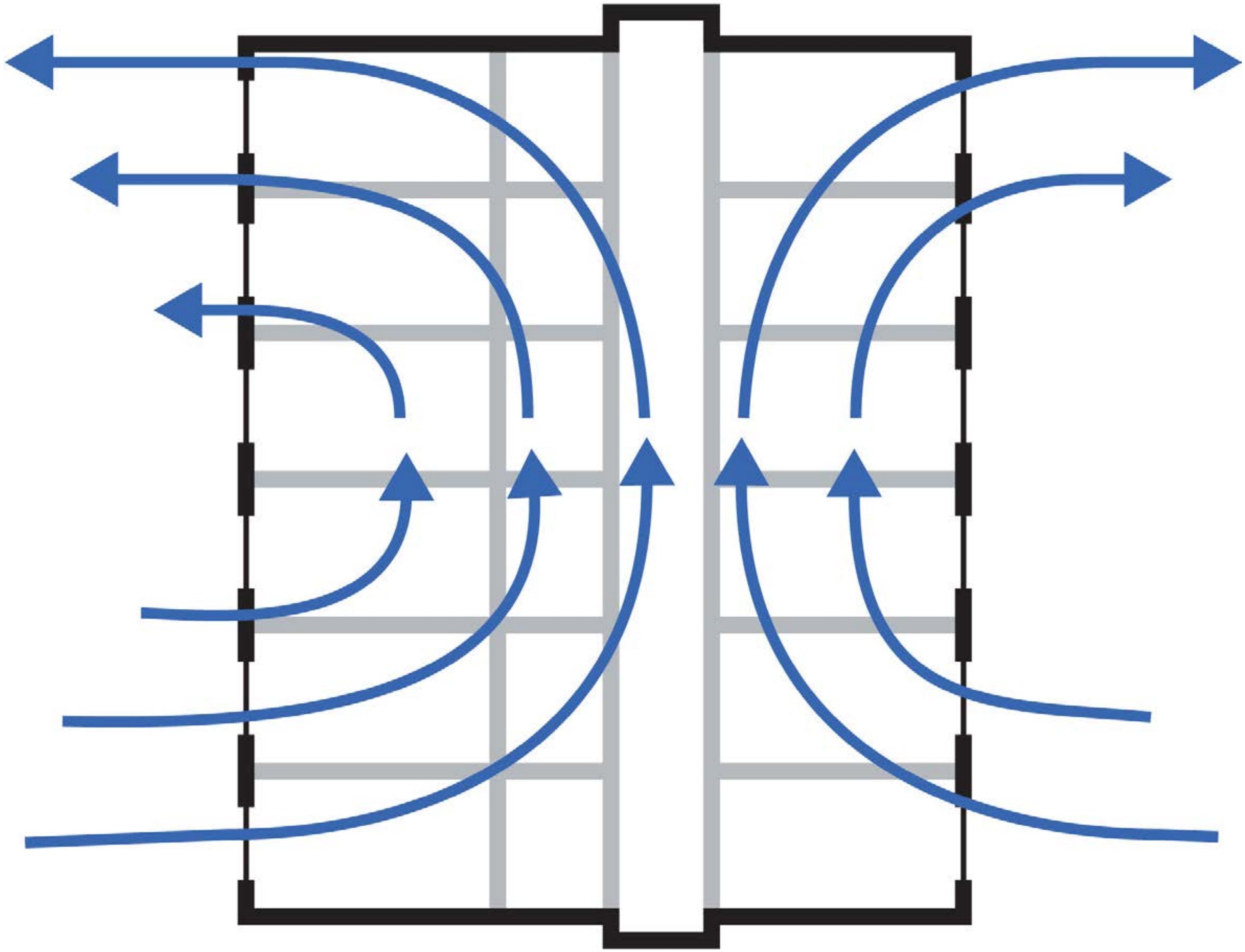
Stack effect and wind

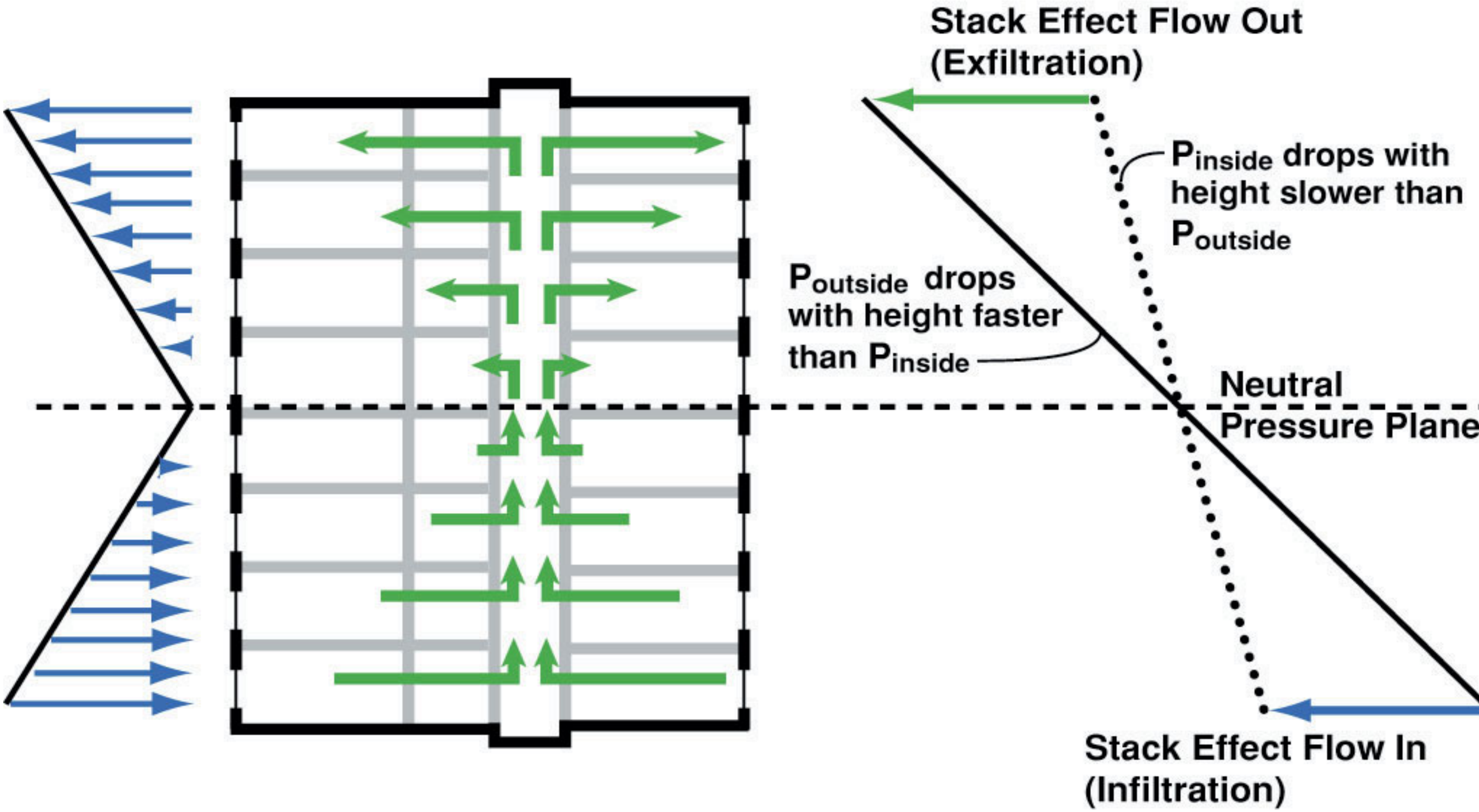


Chimney effect



Leakage area




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

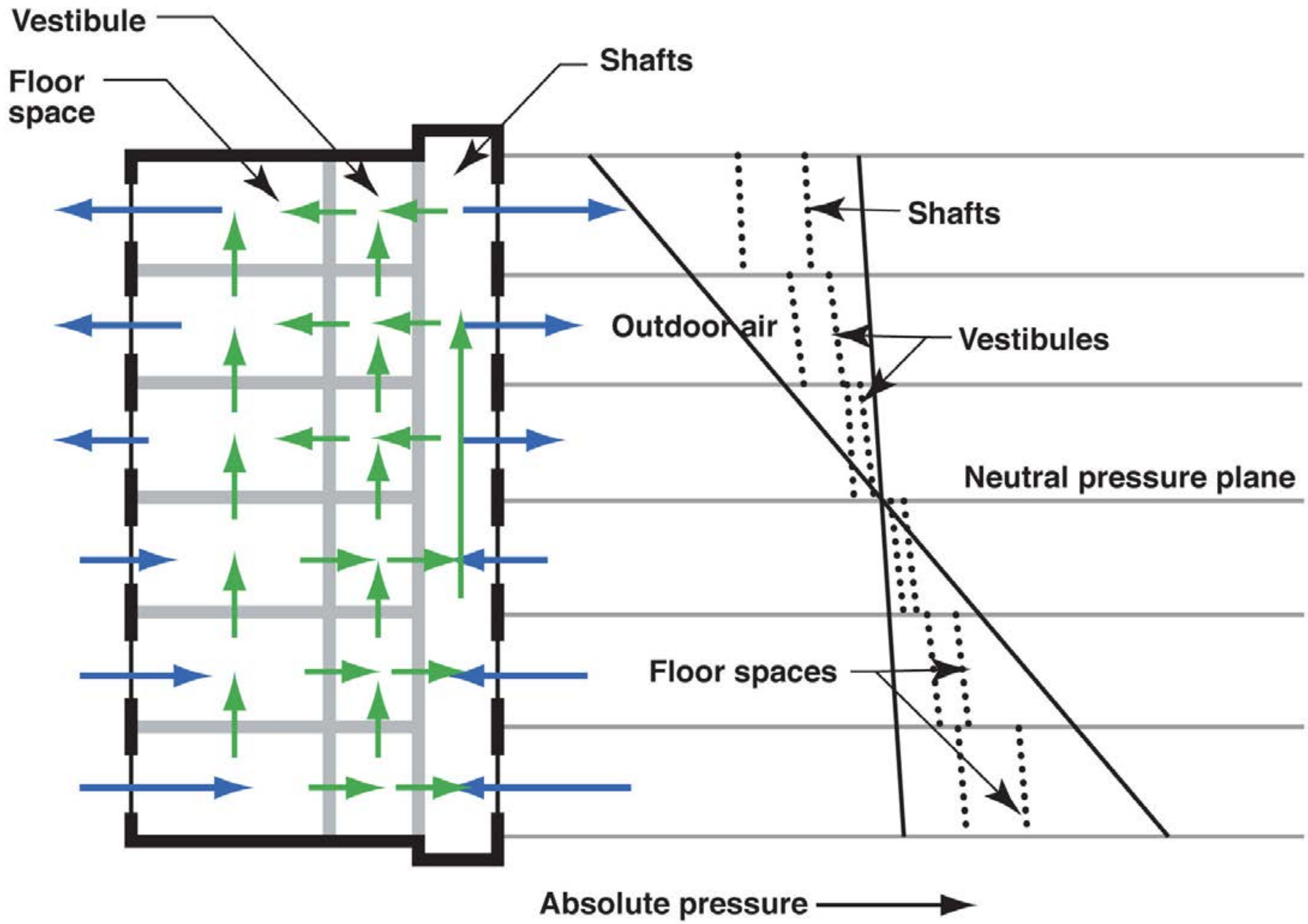


Figure 11.8: Stack effect pressures in high rise office building (Adapted from G.O. Handegord, 1998)

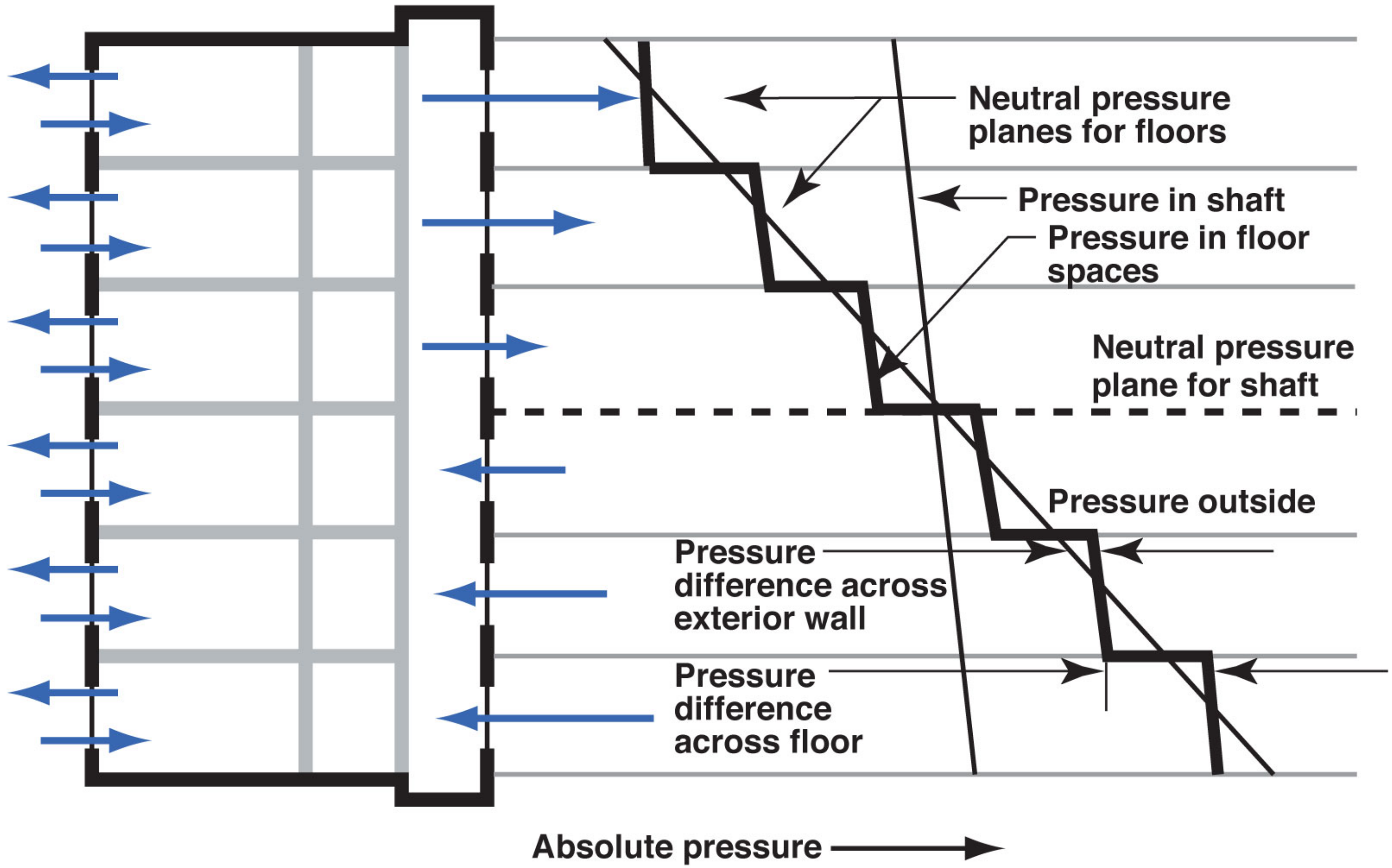


Figure 11.9: Multi-storey building with floor spaces isolated from vertical shafts (Adapted from G.O. Handegord, 1998)

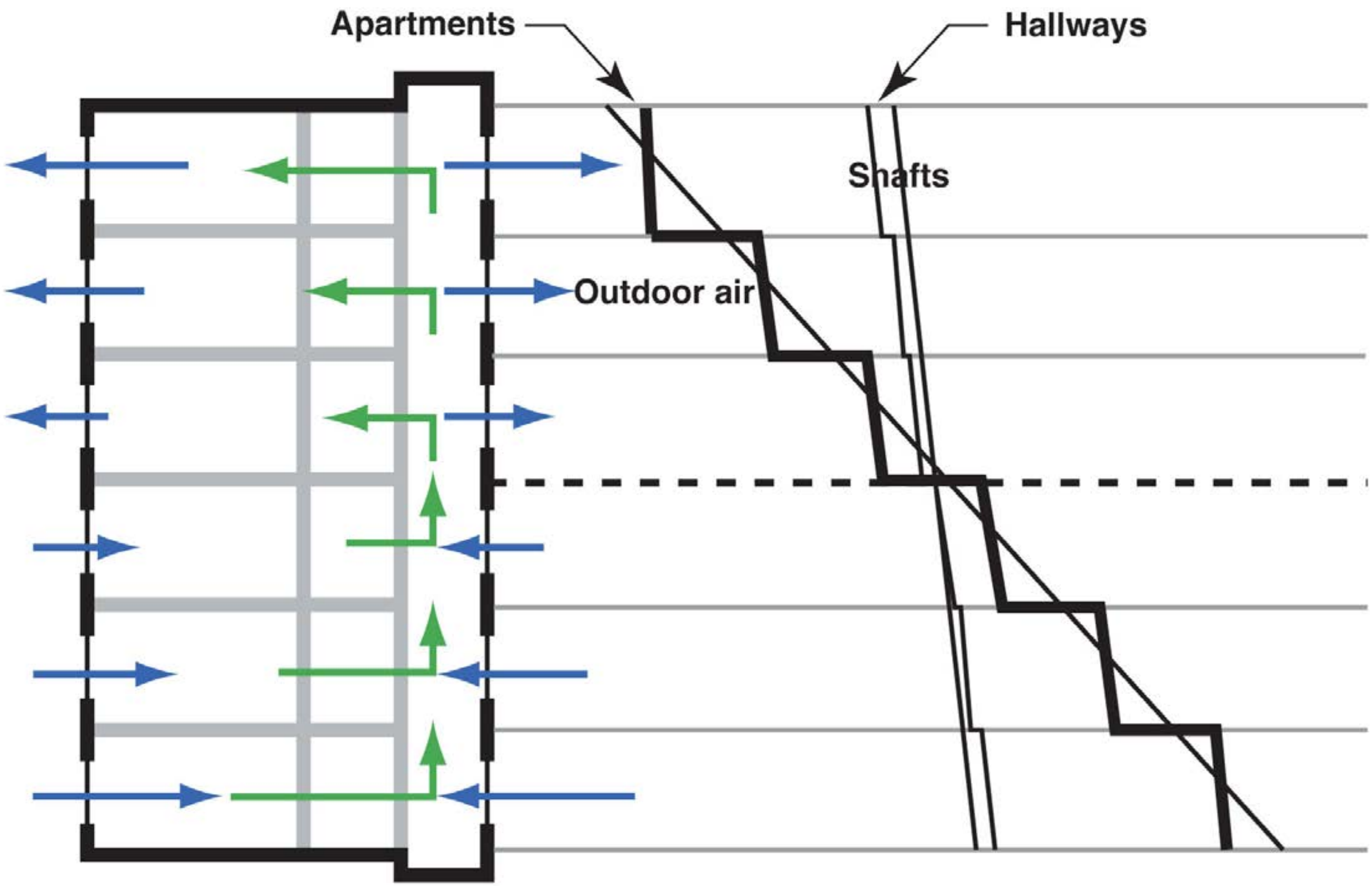
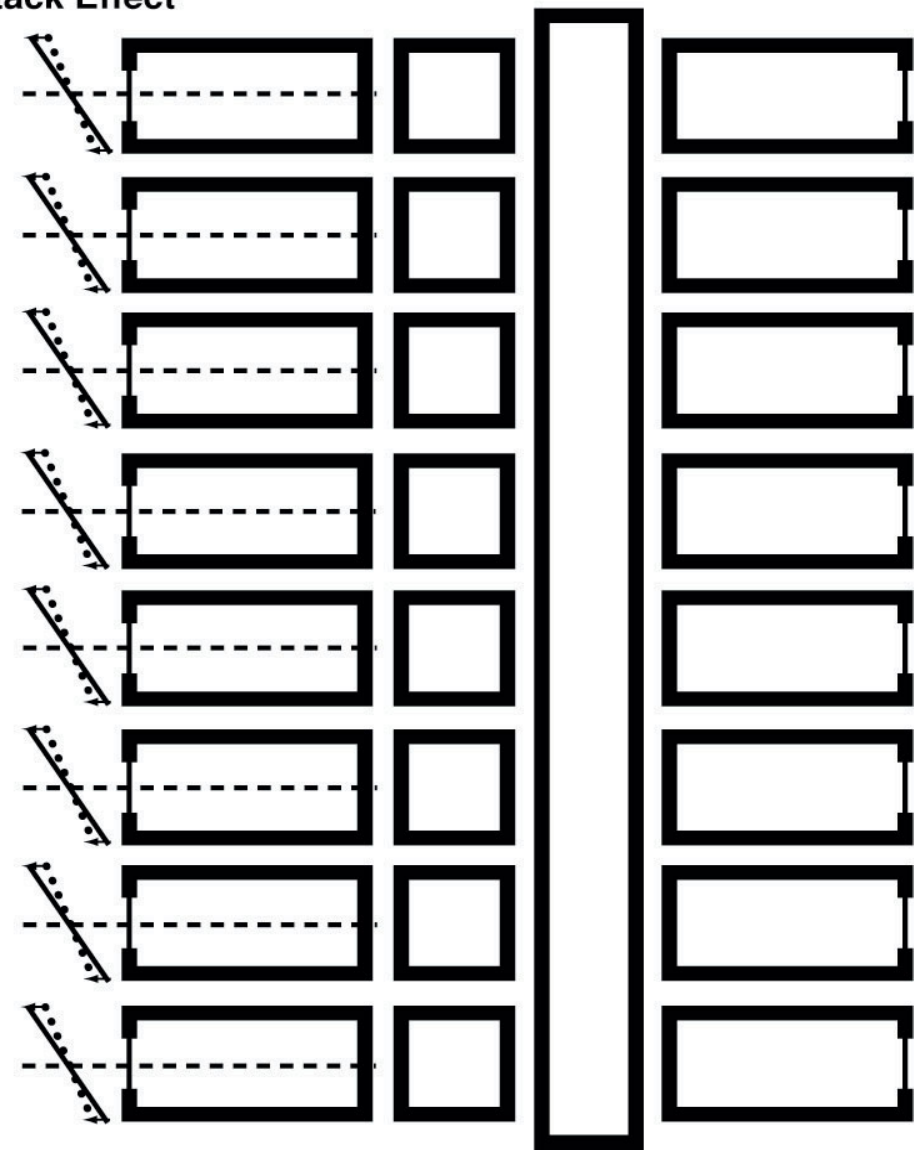
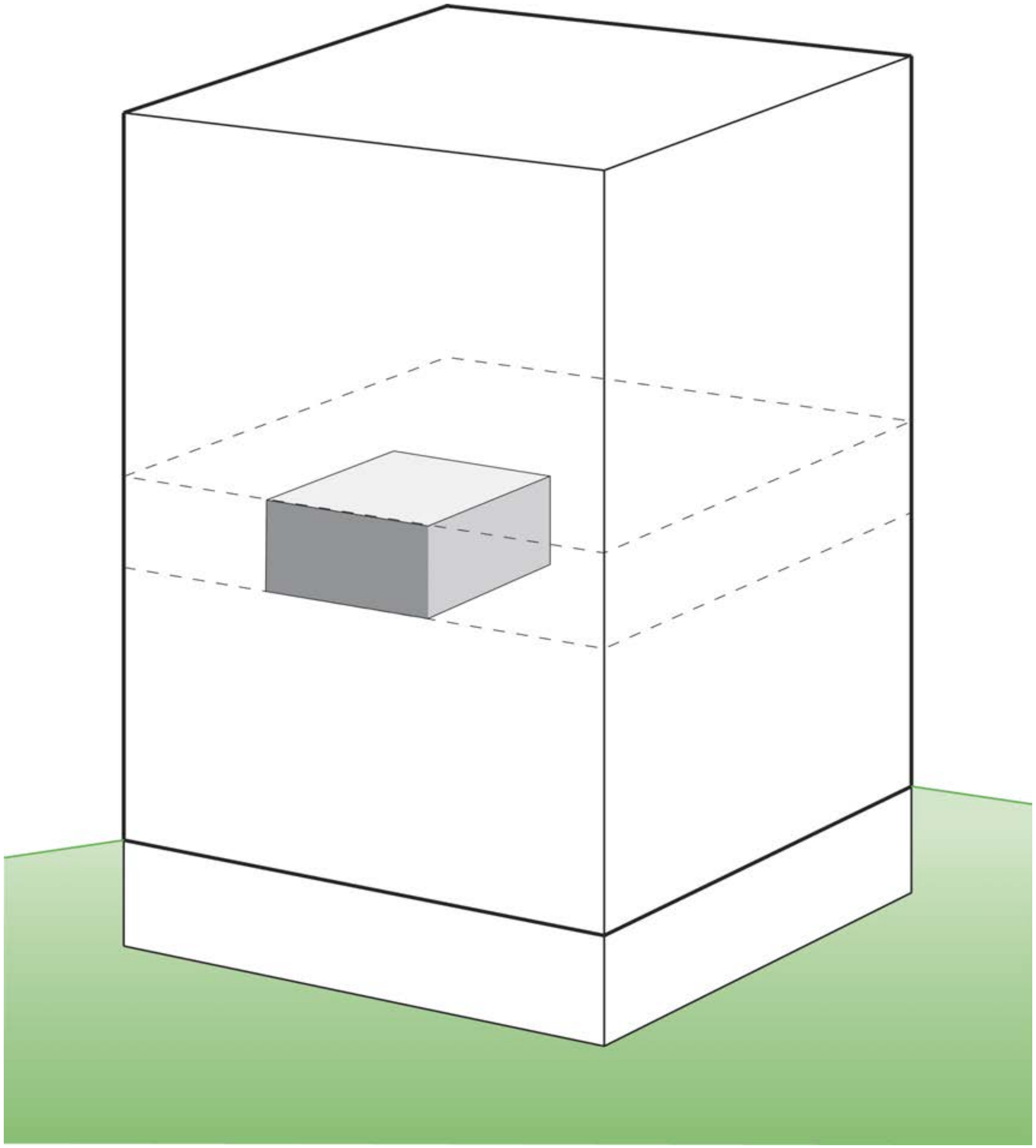
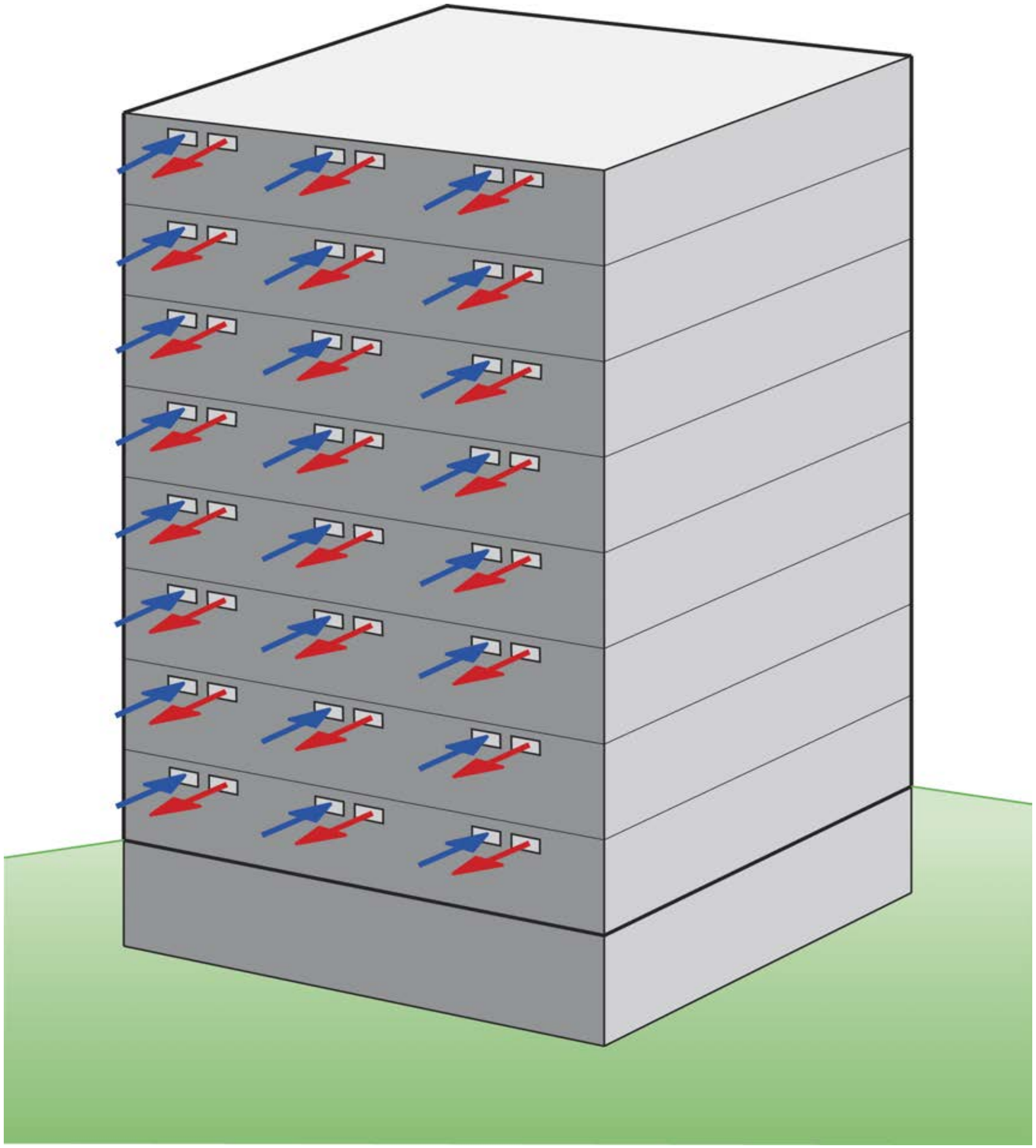


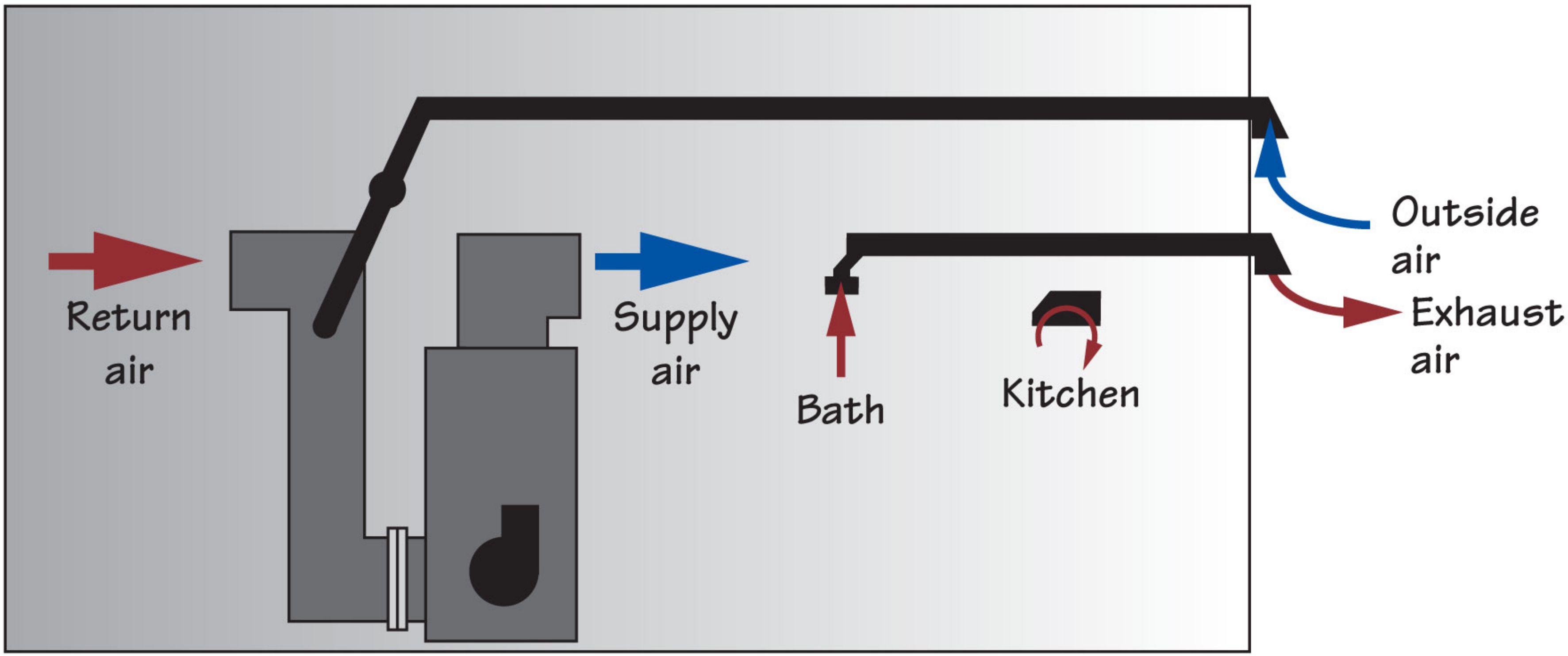
Figure 11.12: Apartment building with tighter apartment entry doors (Adapted from G.O. Handegord, 1998)

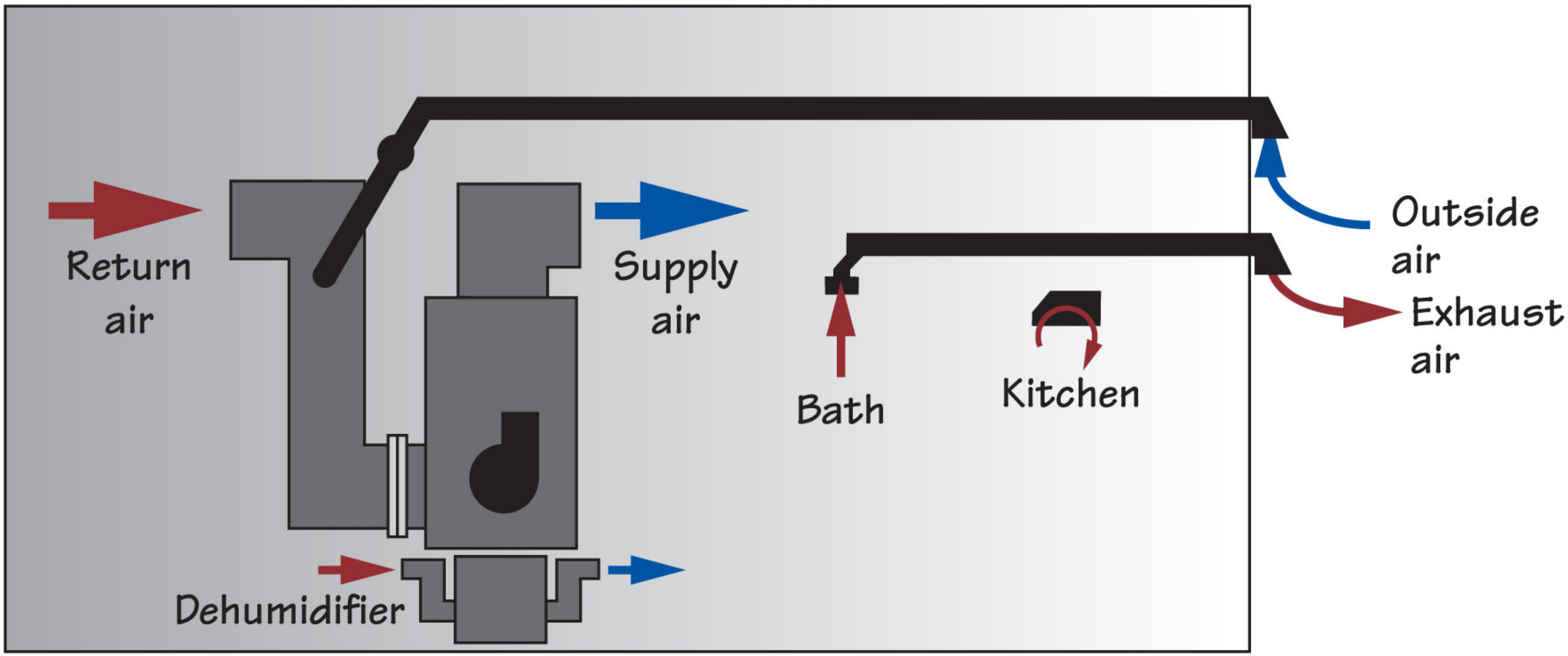
Reduced Individual Unit Stack Effect

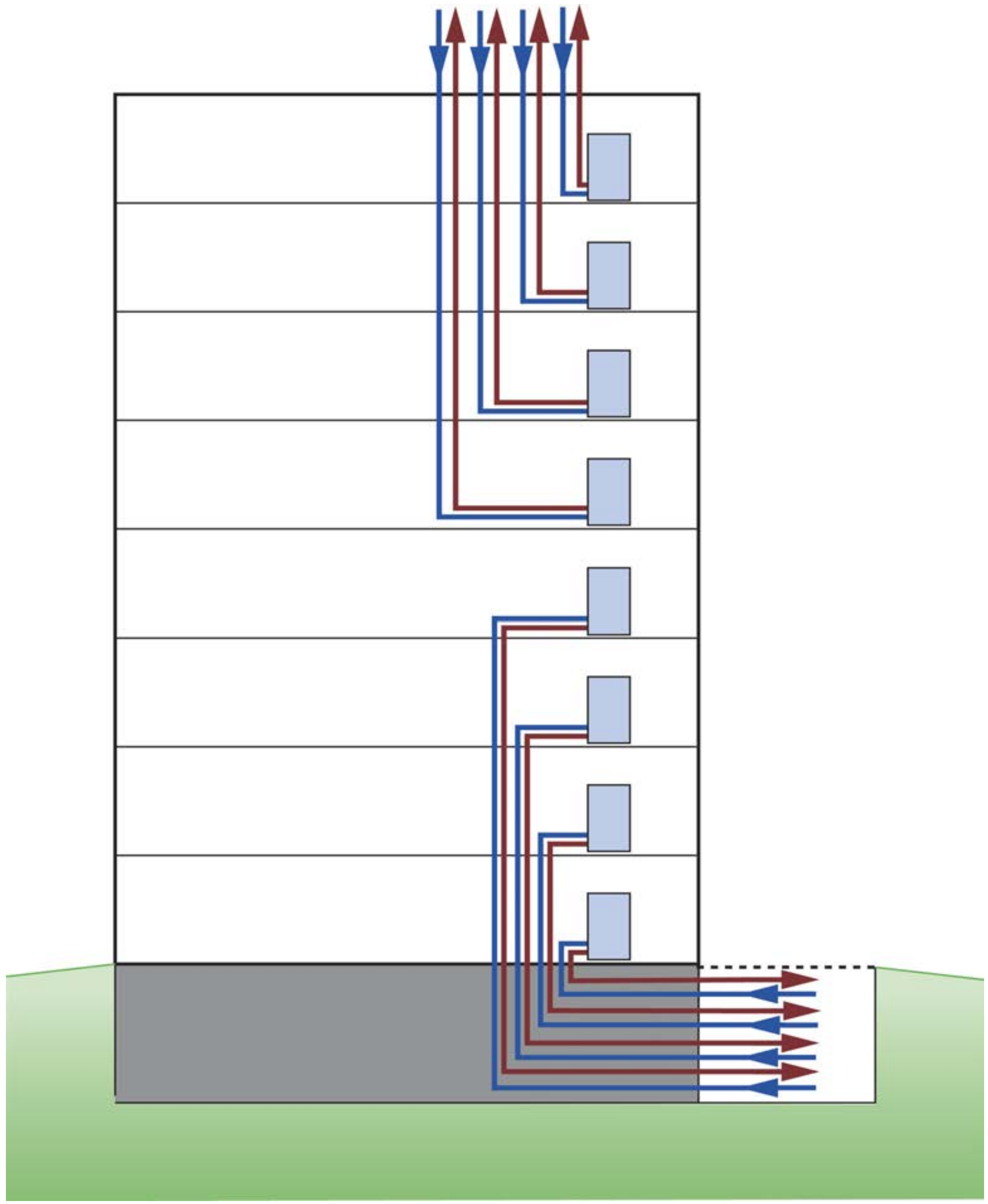


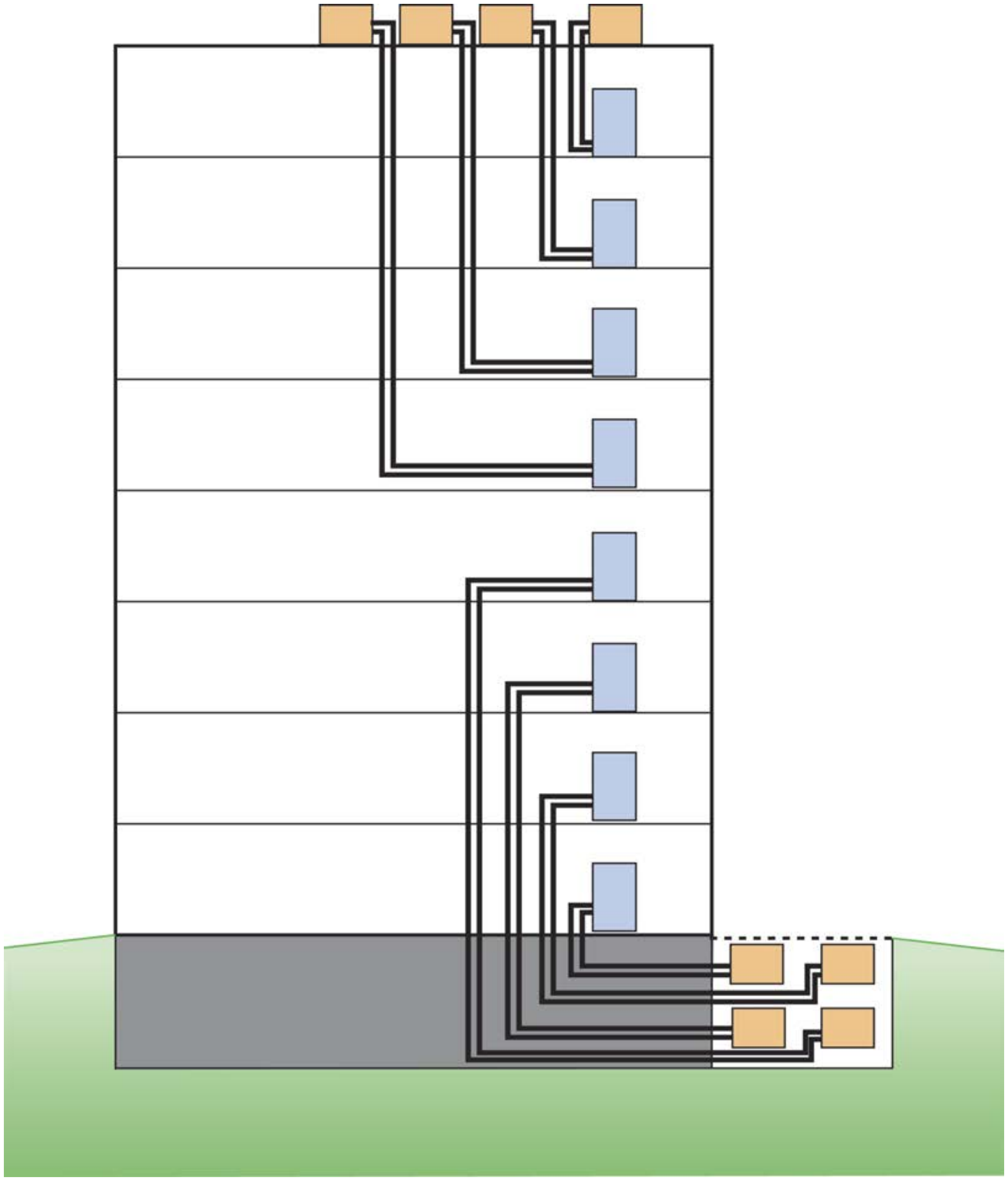


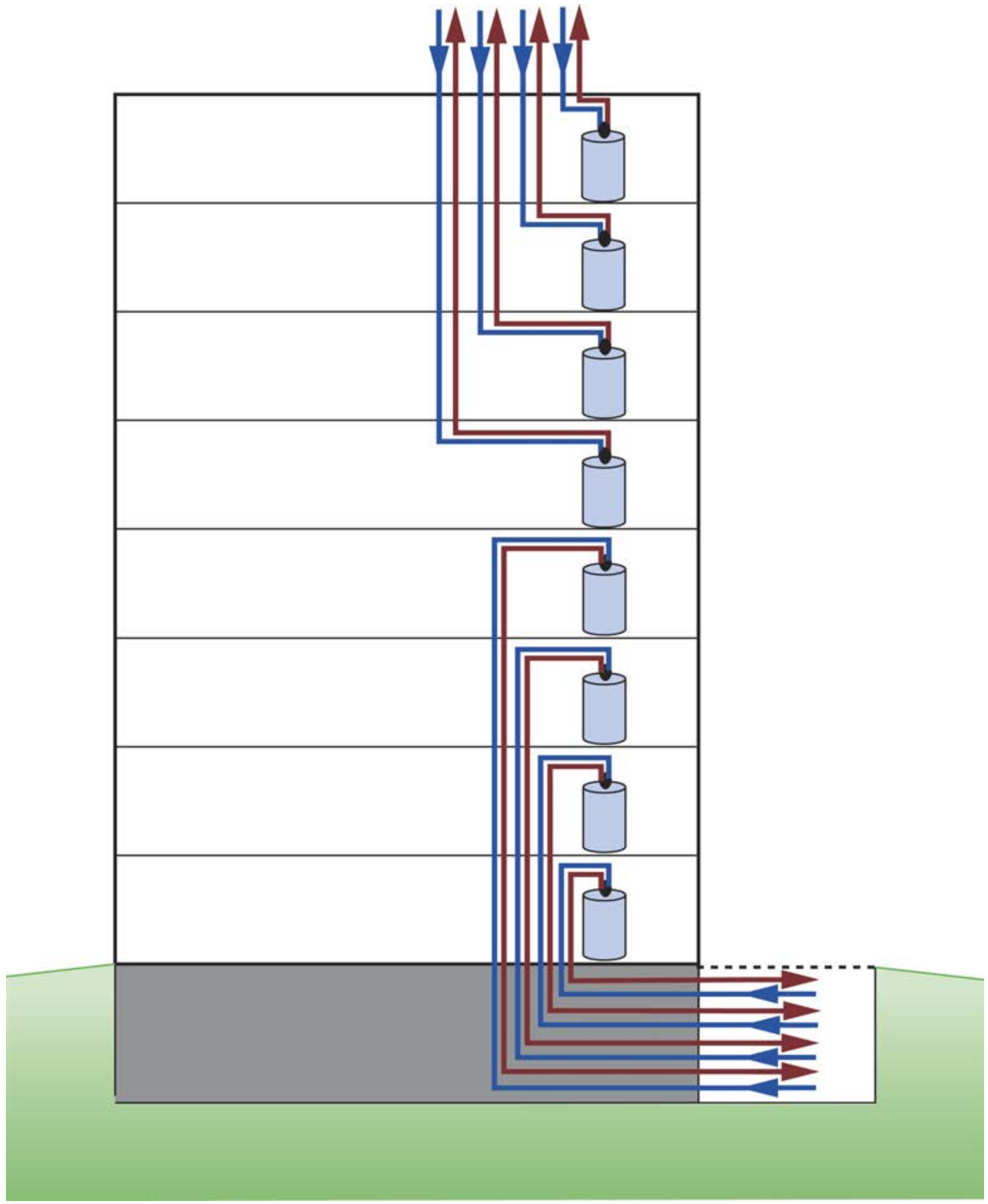



Return air
Supply air
Outside air
Exhaust air
Bath
Kitchen


Return
air
Supply
air
Outside
air
Exhaust
air
Bath
Kitchen
Dehumidifier





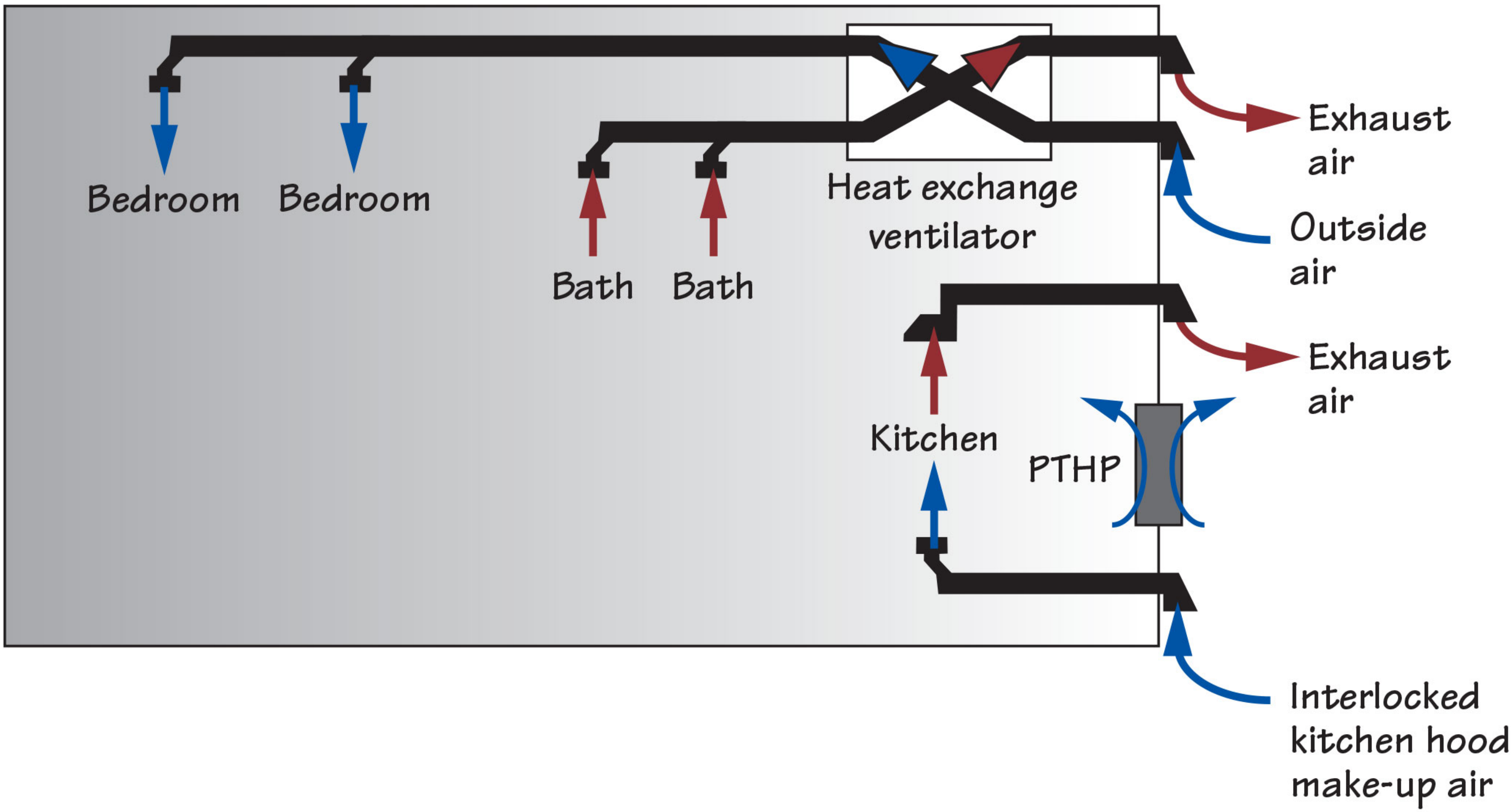


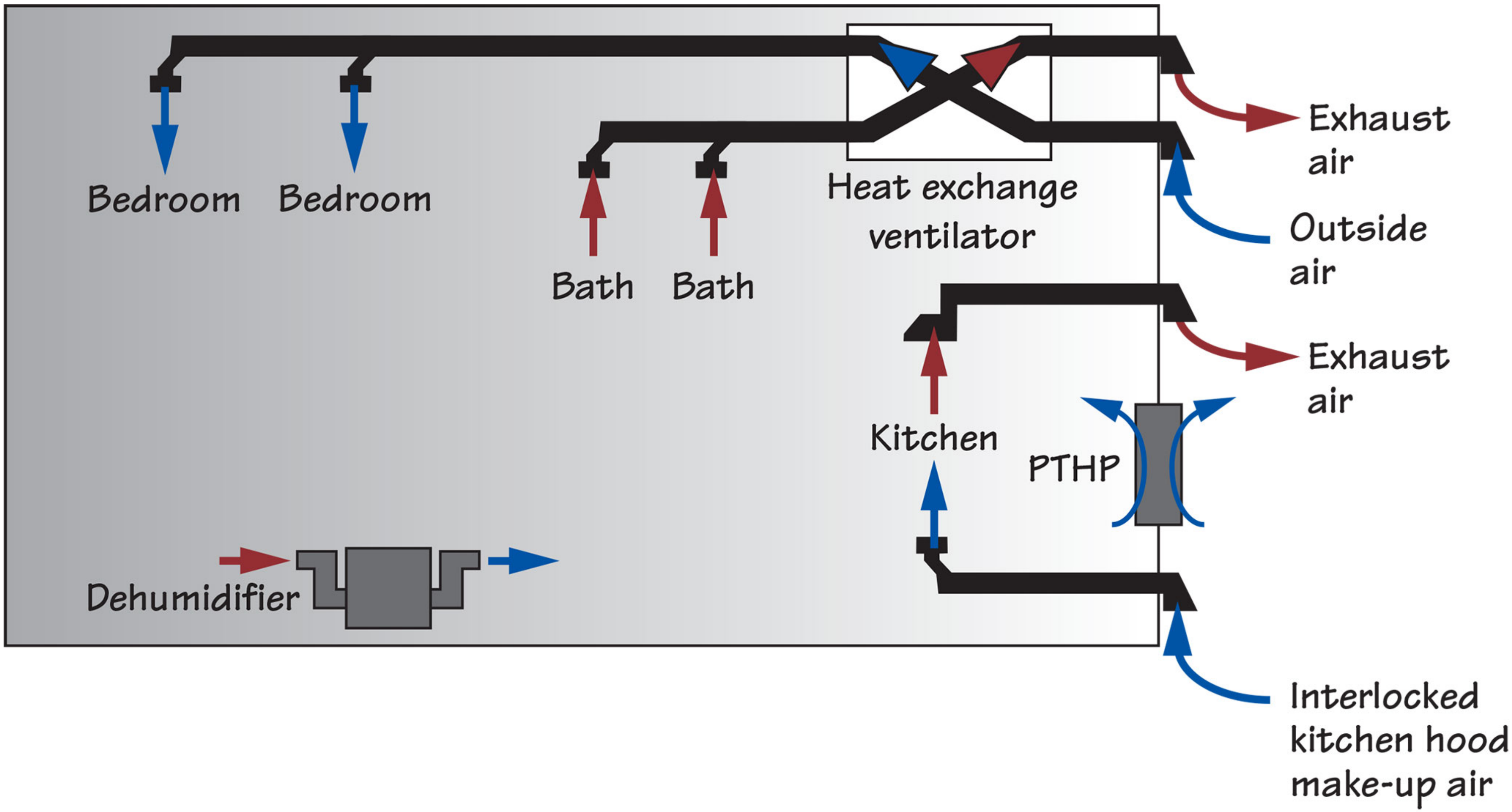

HOT WATER


YORK
YORK


Goodman
Goodman

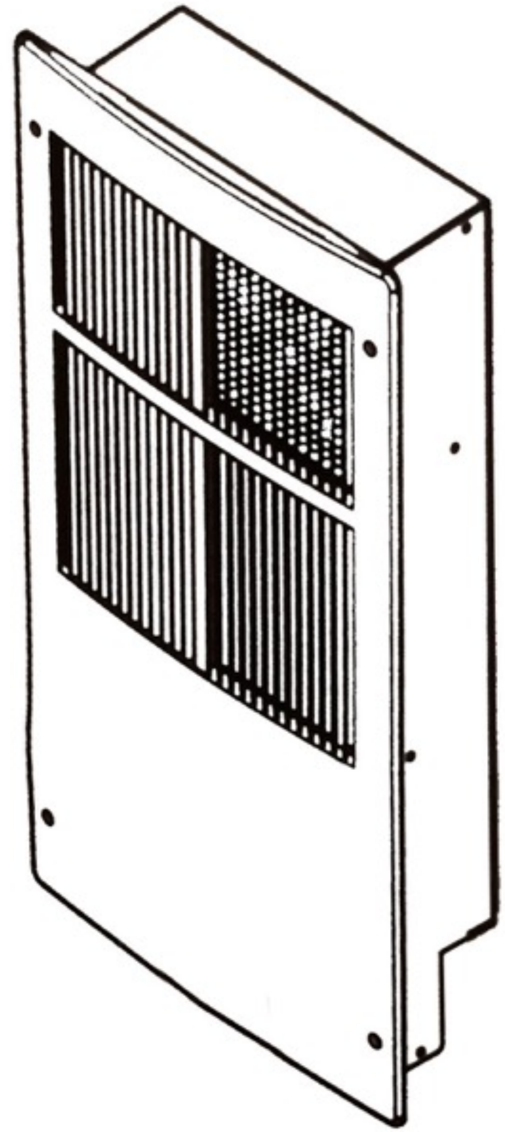

EASTERN
ANJAC FASHION BLDGS
Carrier


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


ASKO
ASKO
ENERGUIDE
209

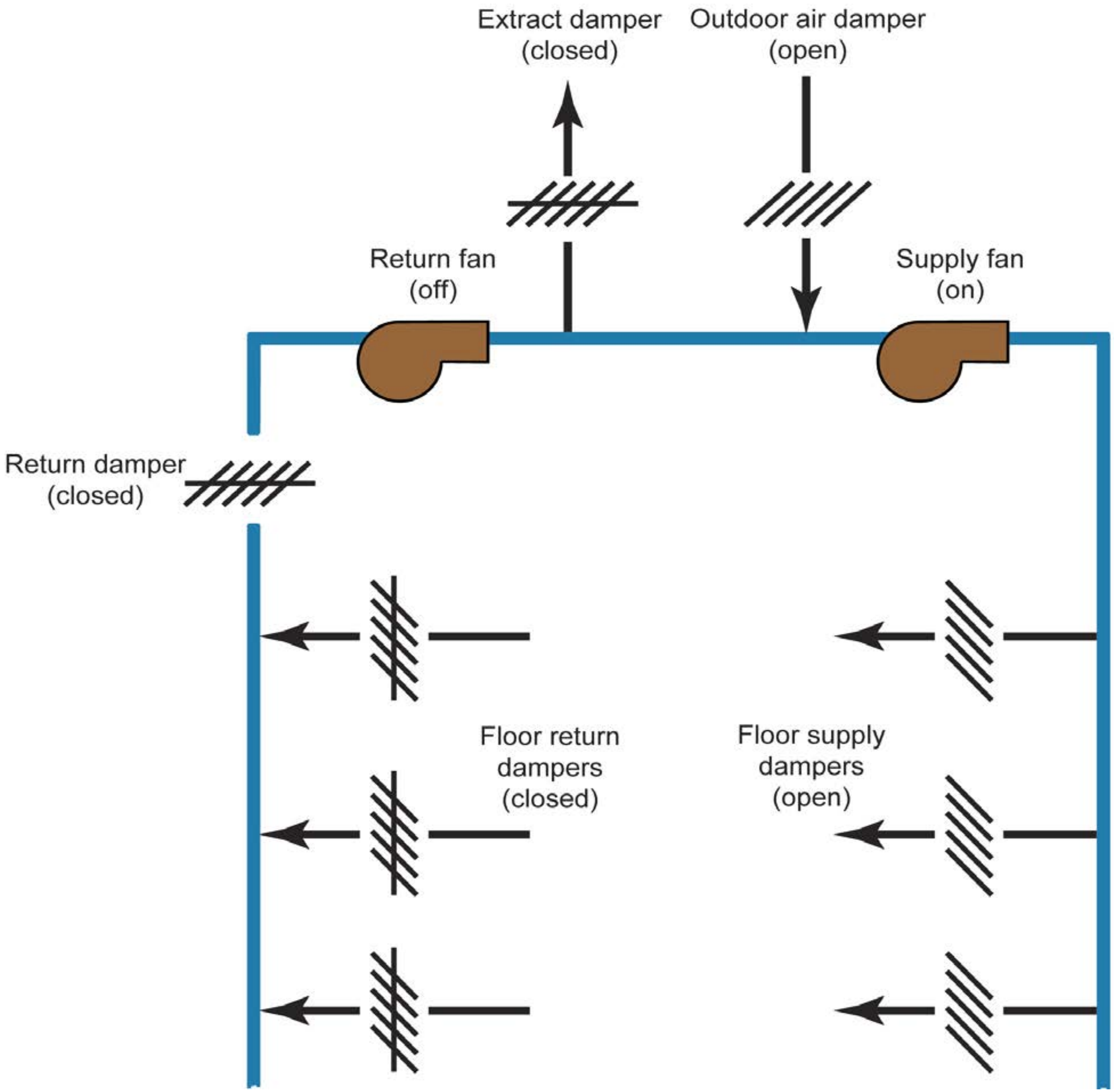


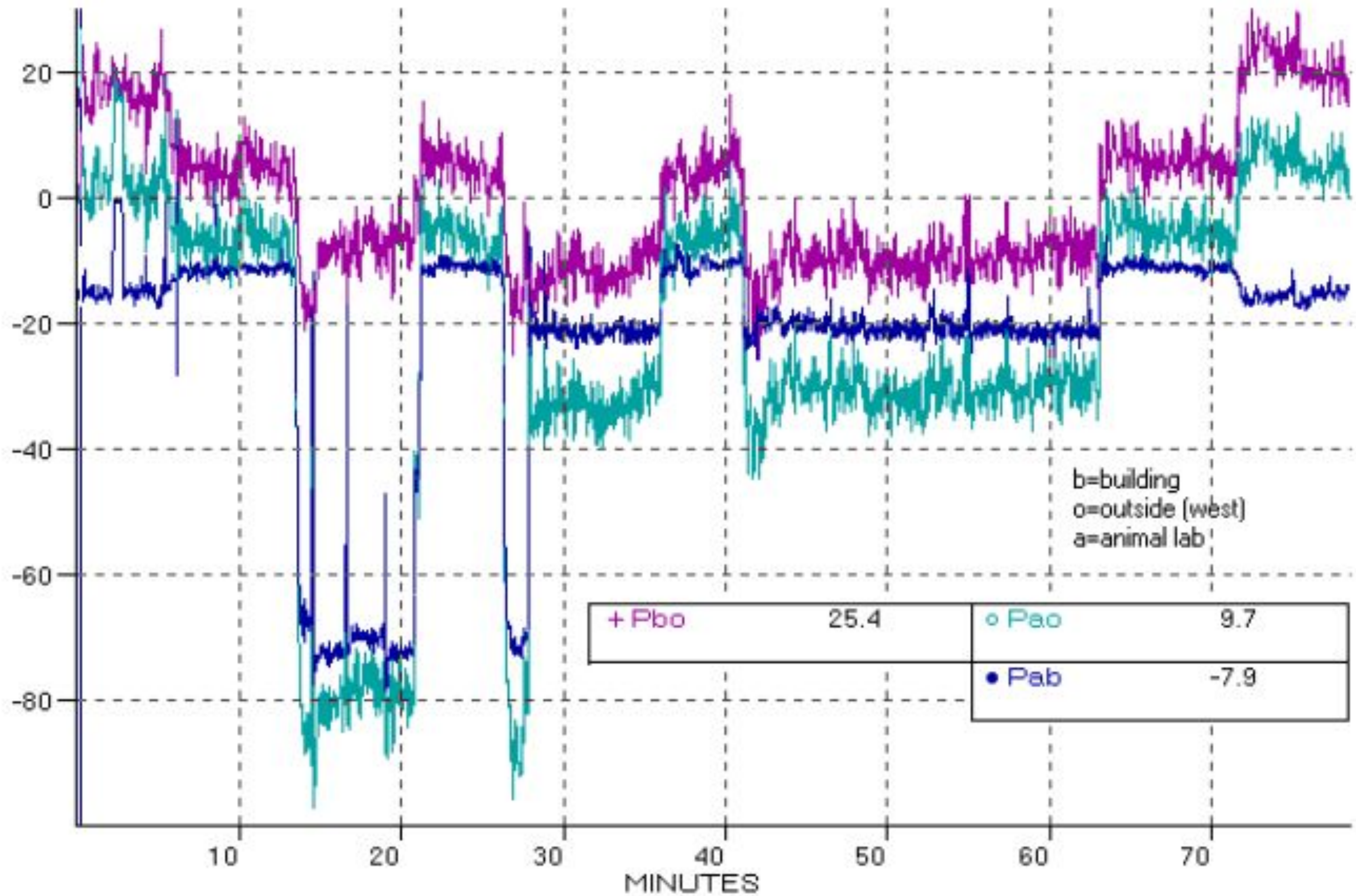

WESTFOR
ACADEMY


EXIT

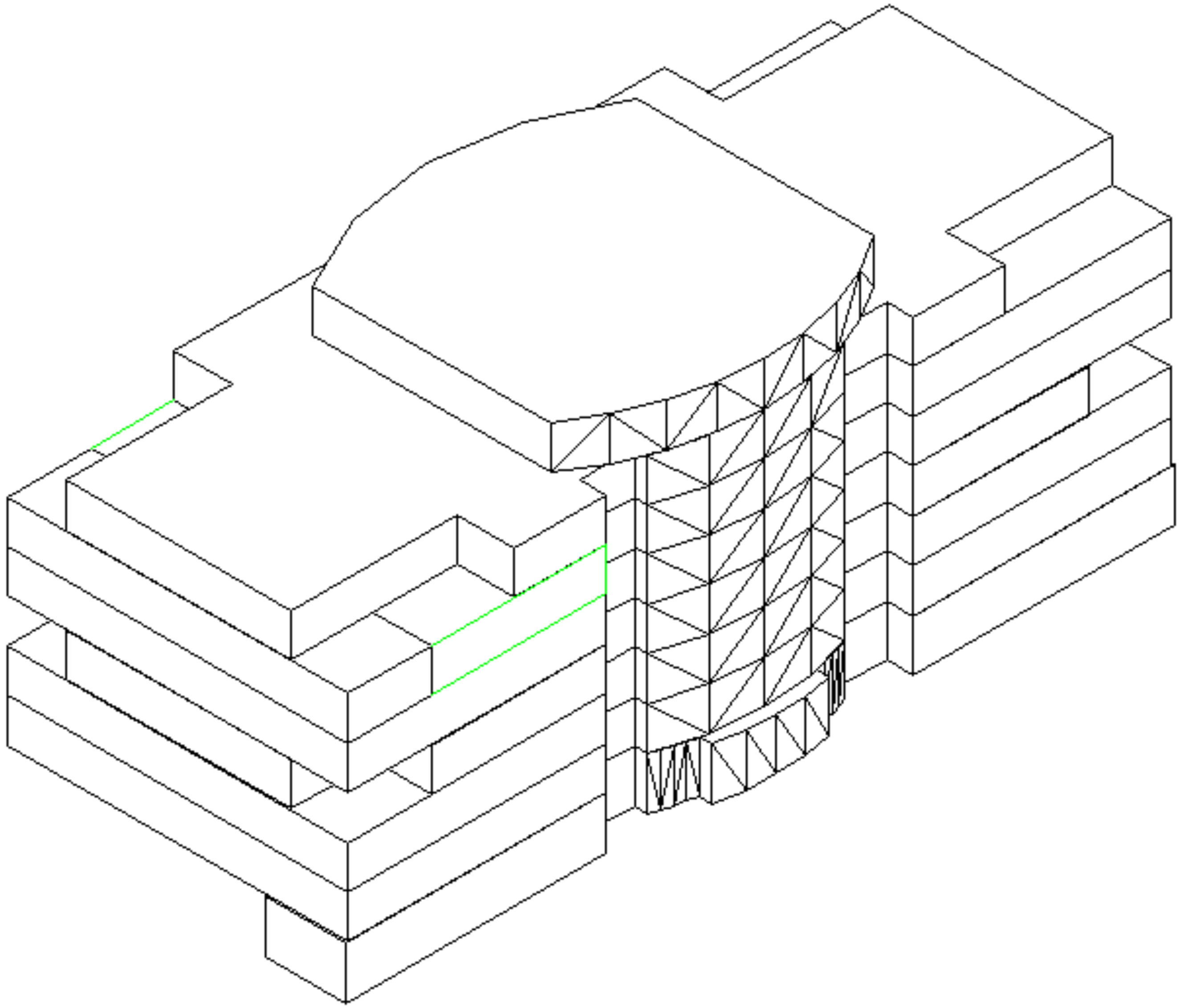

EXIT
Science

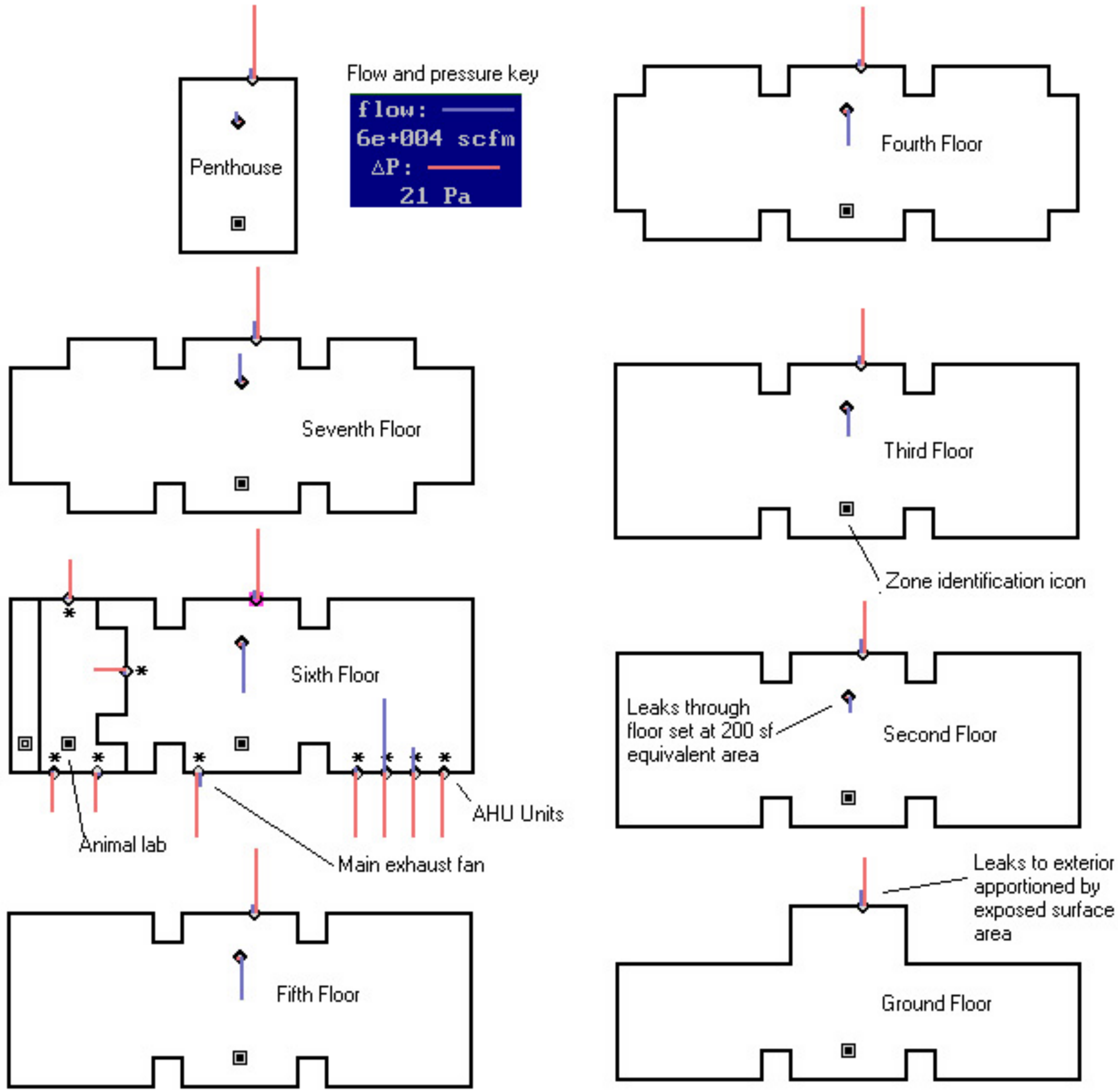

Hospitals for Crippled Children
Galveston Burns Institute
STOP
MAIN ENTRANCE


Extract damper
(closed)
Outdoor air damper
(open)
Return fan
(off)
Supply fan
(on)
Return damper
(closed)
Floor return
dampers
(closed)
Floor supply
dampers
(open)



20
0
-20
-40
-60
-80
10
20
30
40
50
60
70
MINUTES
b=building
o=outside (west)
a=animal lab
+ Pbo 25.4
∘ Pao 9.7
• Pab -7.9




Flow and pressure key
flow:
6e+004 scfm
ΔP:
21 Pa
Penthouse
Fourth Floor
Seventh Floor
Third Floor
Zone identification icon
Sixth Floor
Leaks through
floor set at 200 sf
equivalent area
Second Floor
AHU Units
Animal lab
Main exhaust fan
Leaks to exterior
apportioned by
exposed surface
area
Fifth Floor
Ground Floor

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

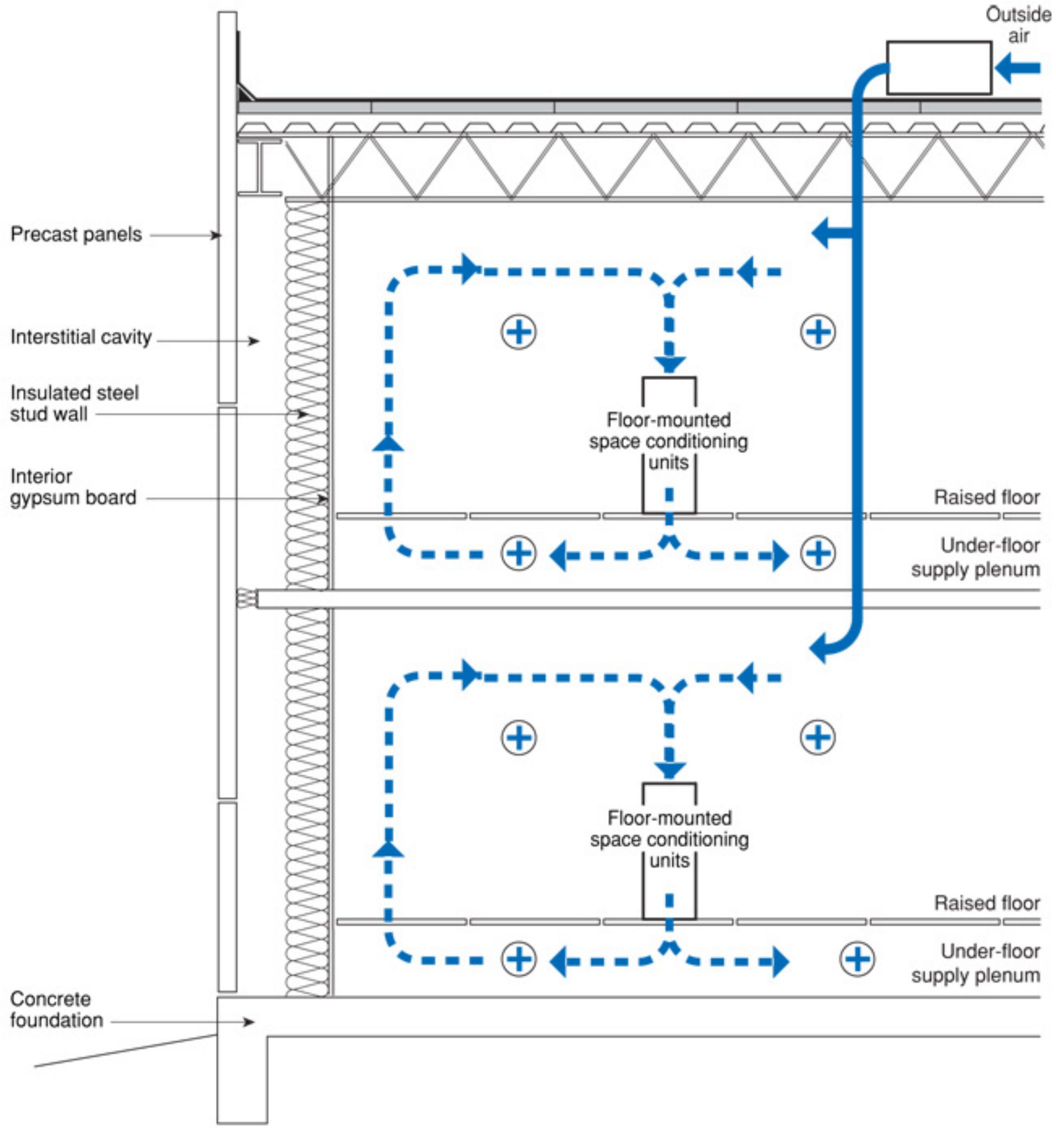


Figure 5.10
HVAC System as Designed

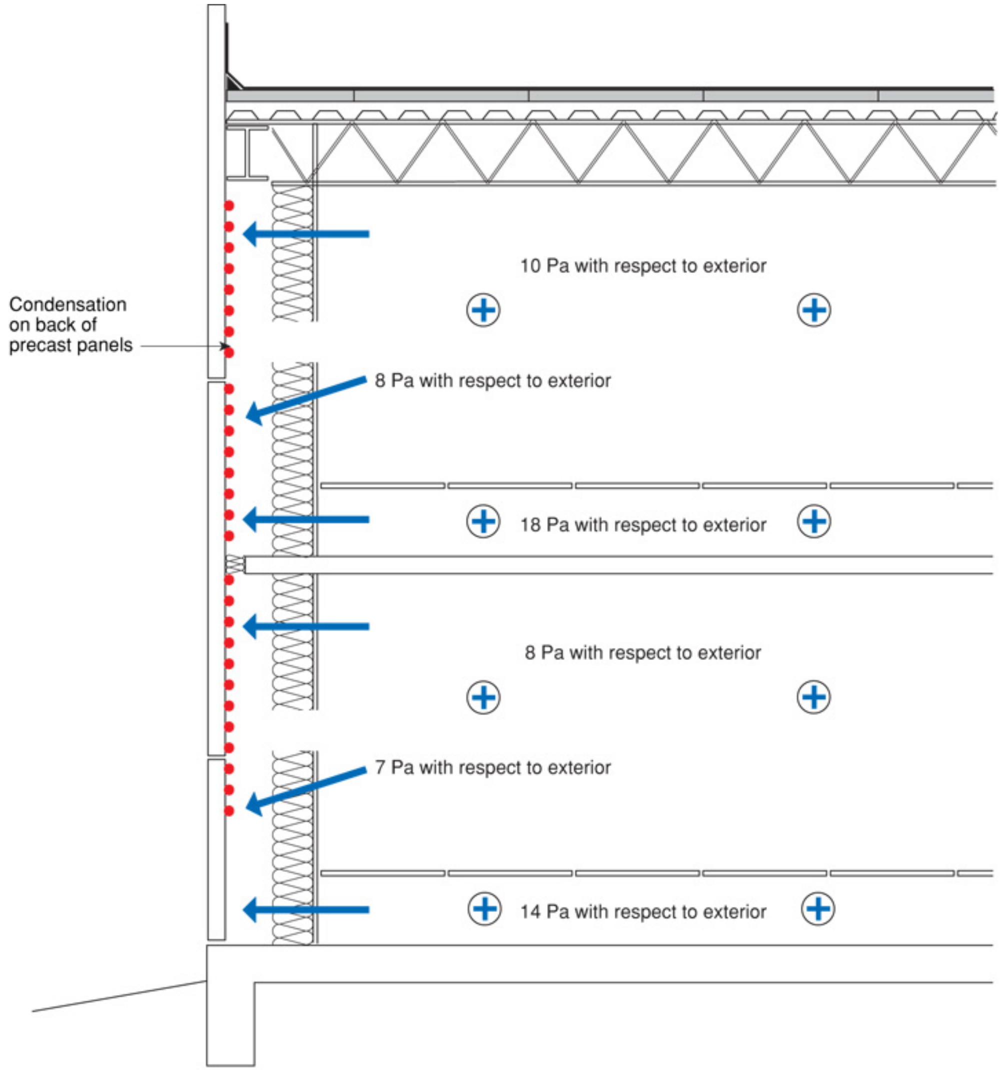


Figure 5.11
Unintended Pressurization of Interstitial Cavity

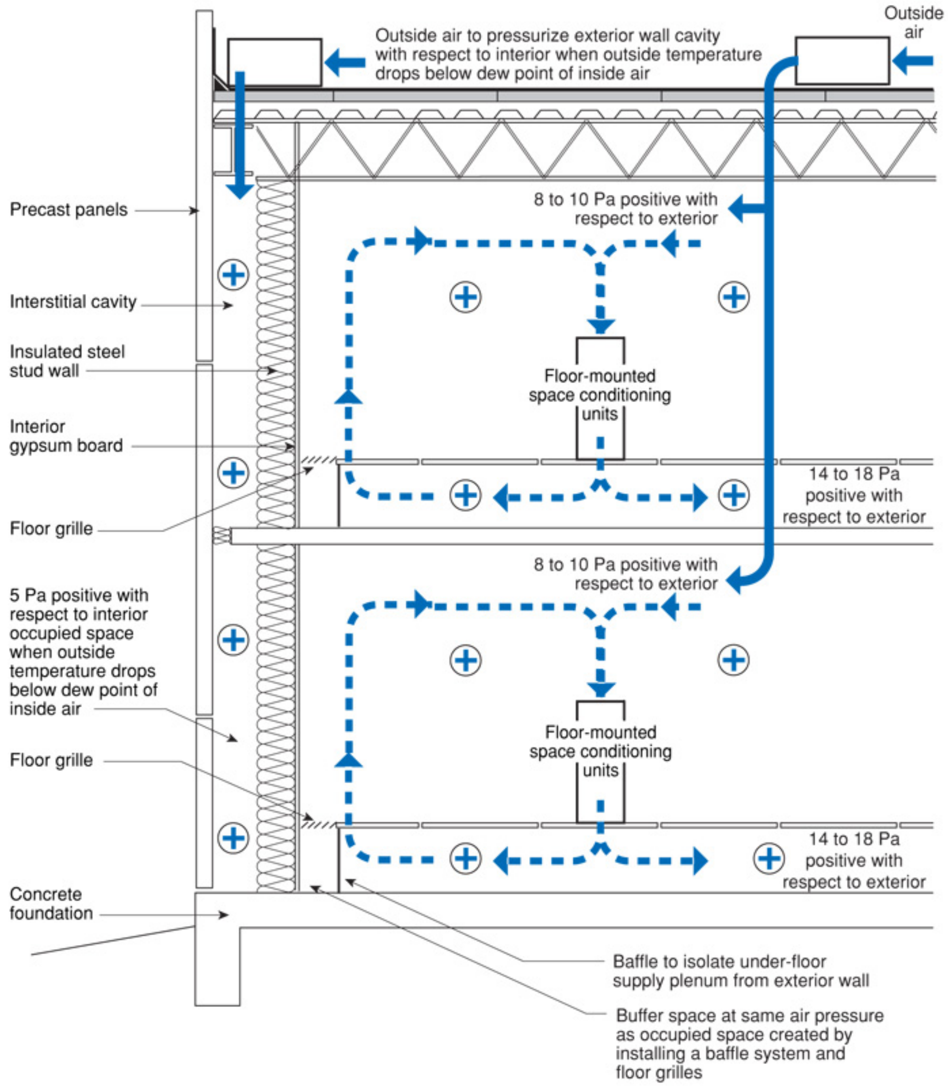
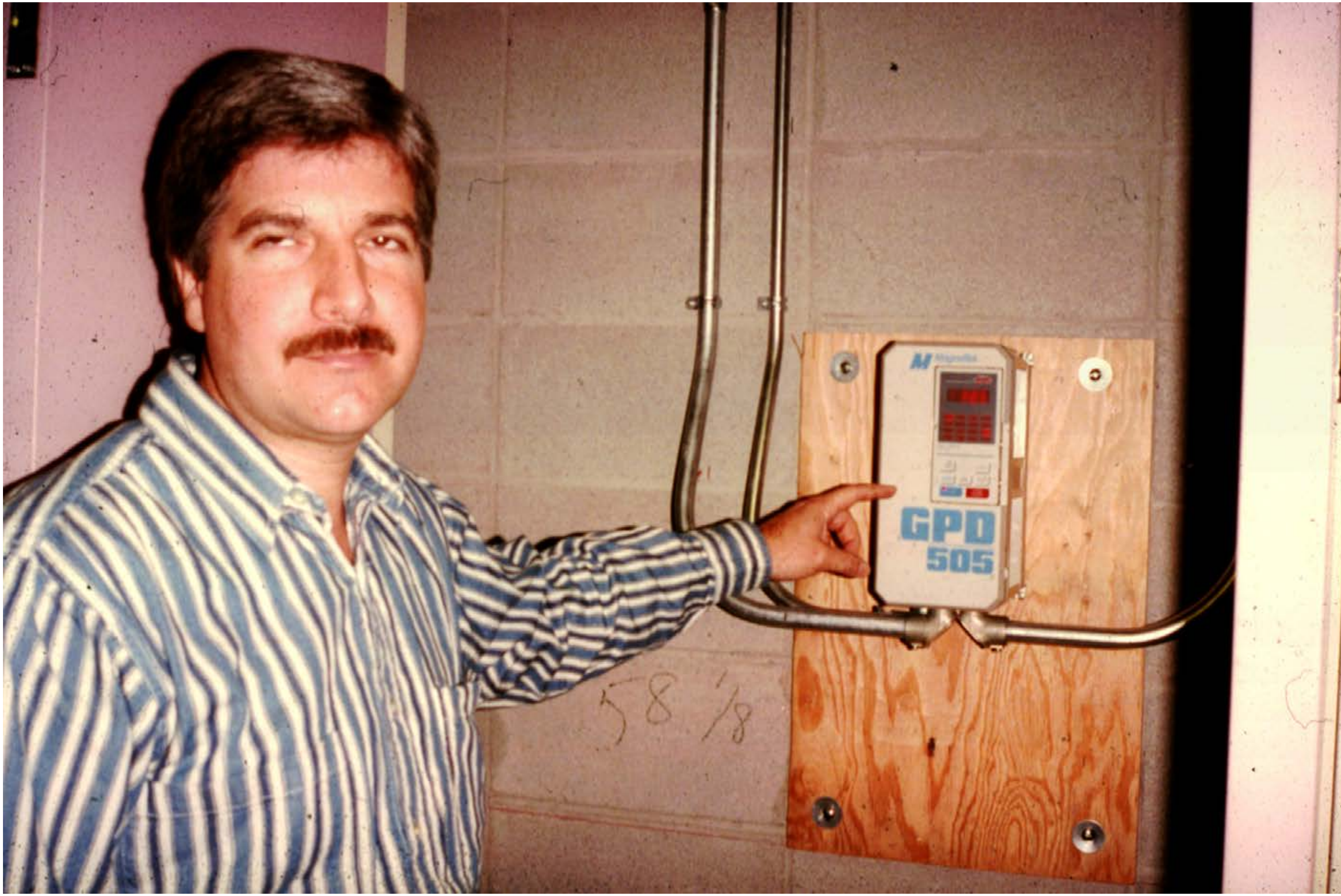


Figure 5.12
Modified Pressure Relationship

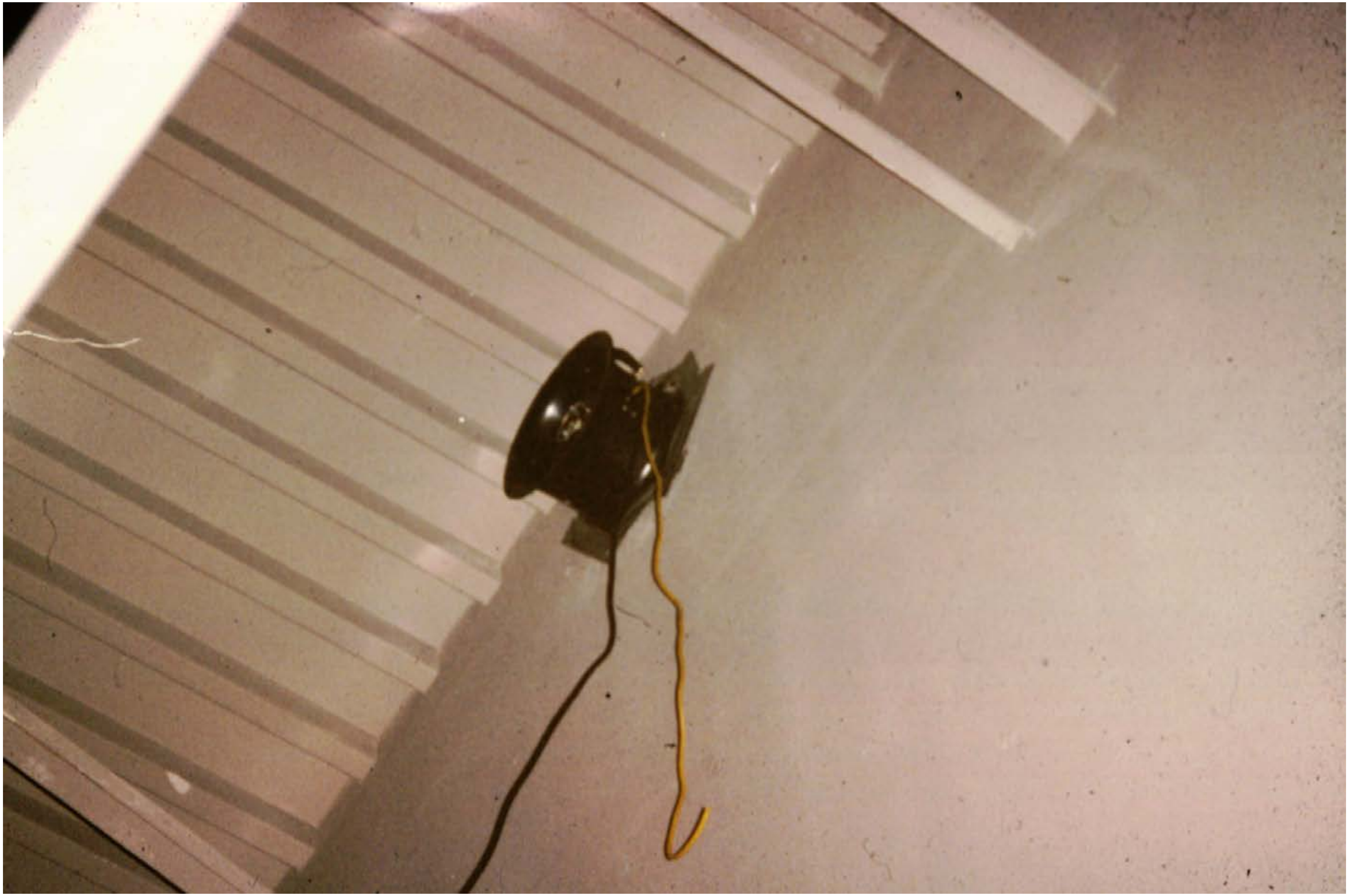

GPD
505

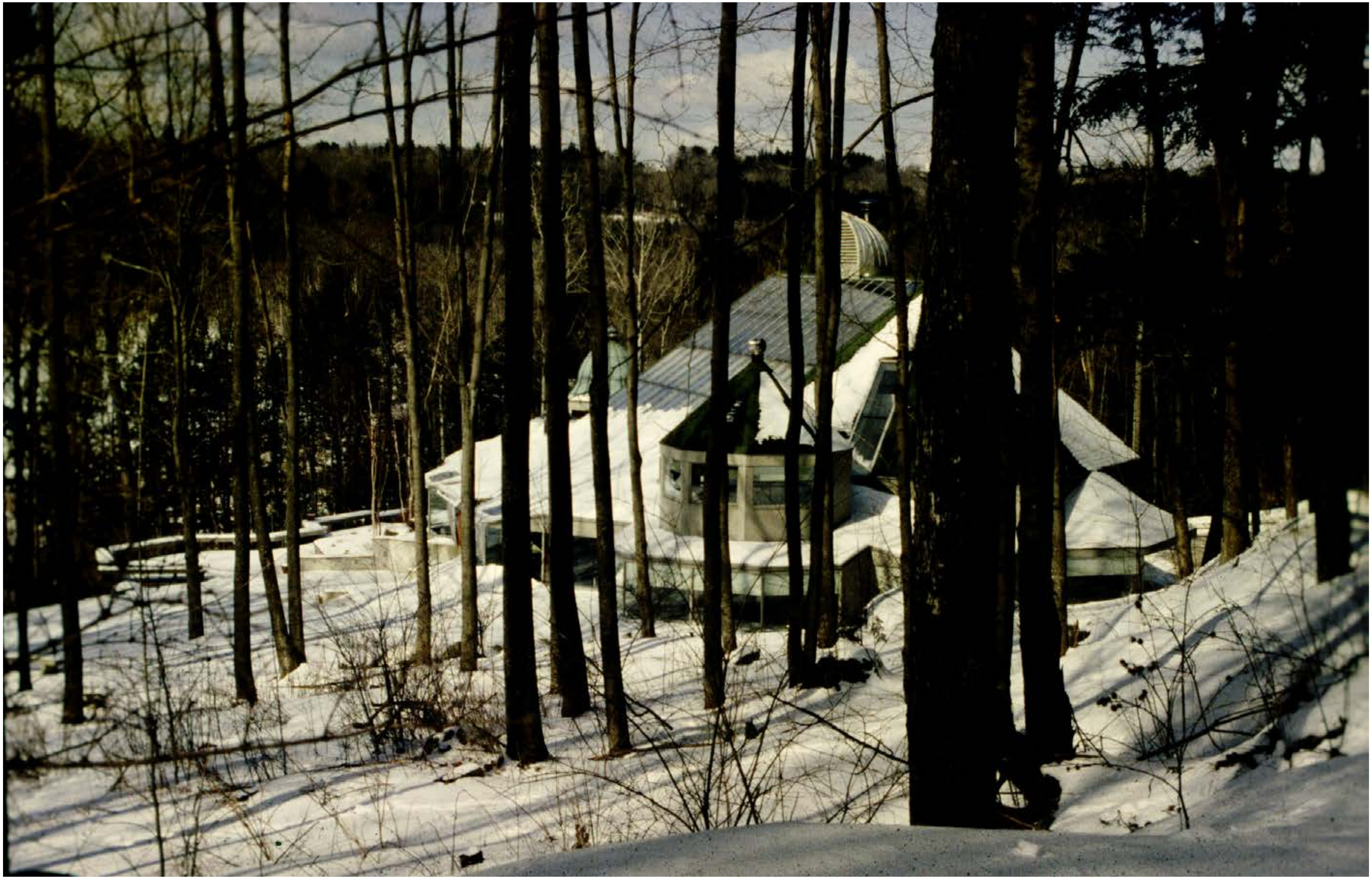

CABINET 32
CDP PRESSURIZATION FANS
EPSON

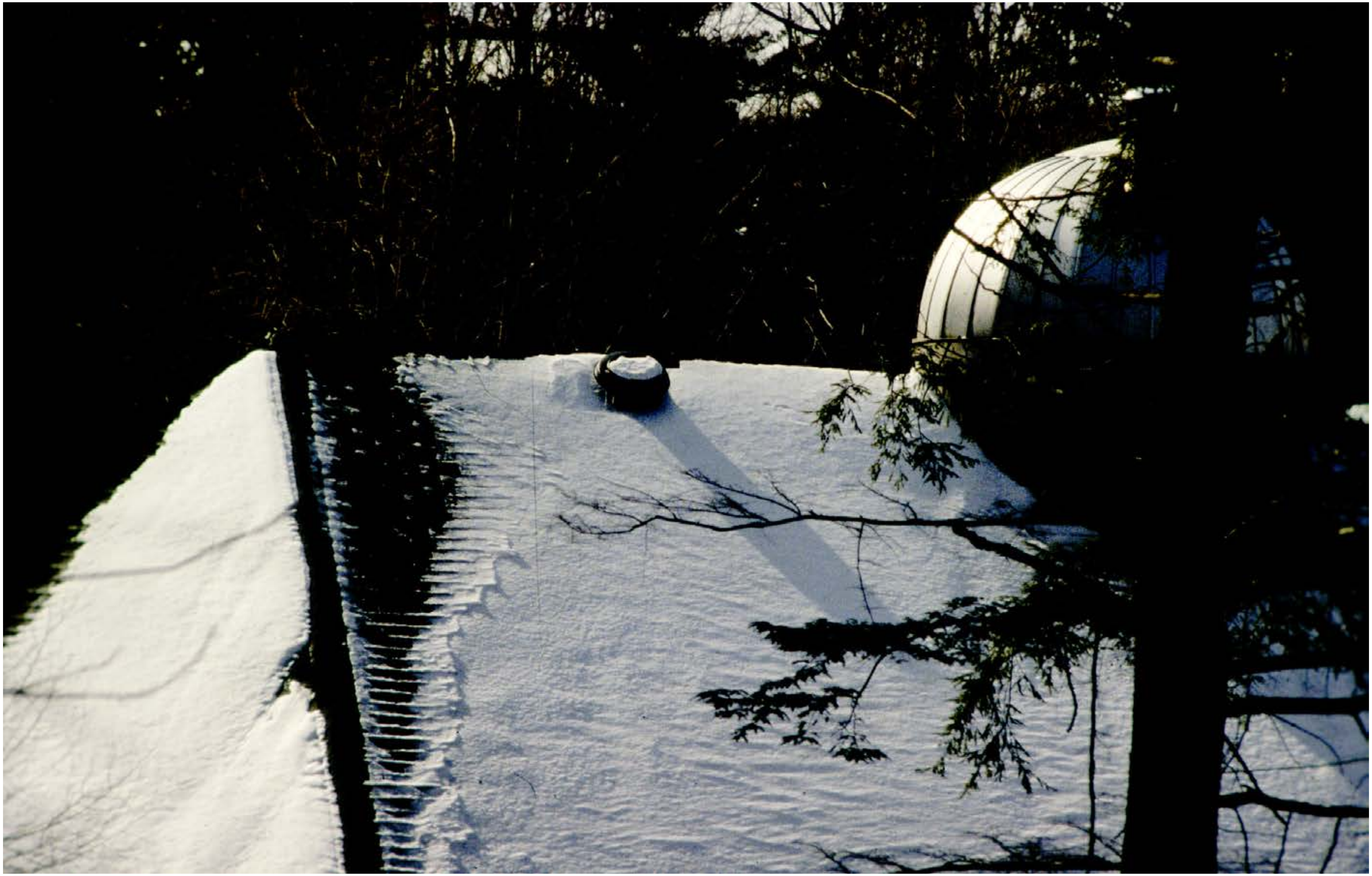

MUSEUM of

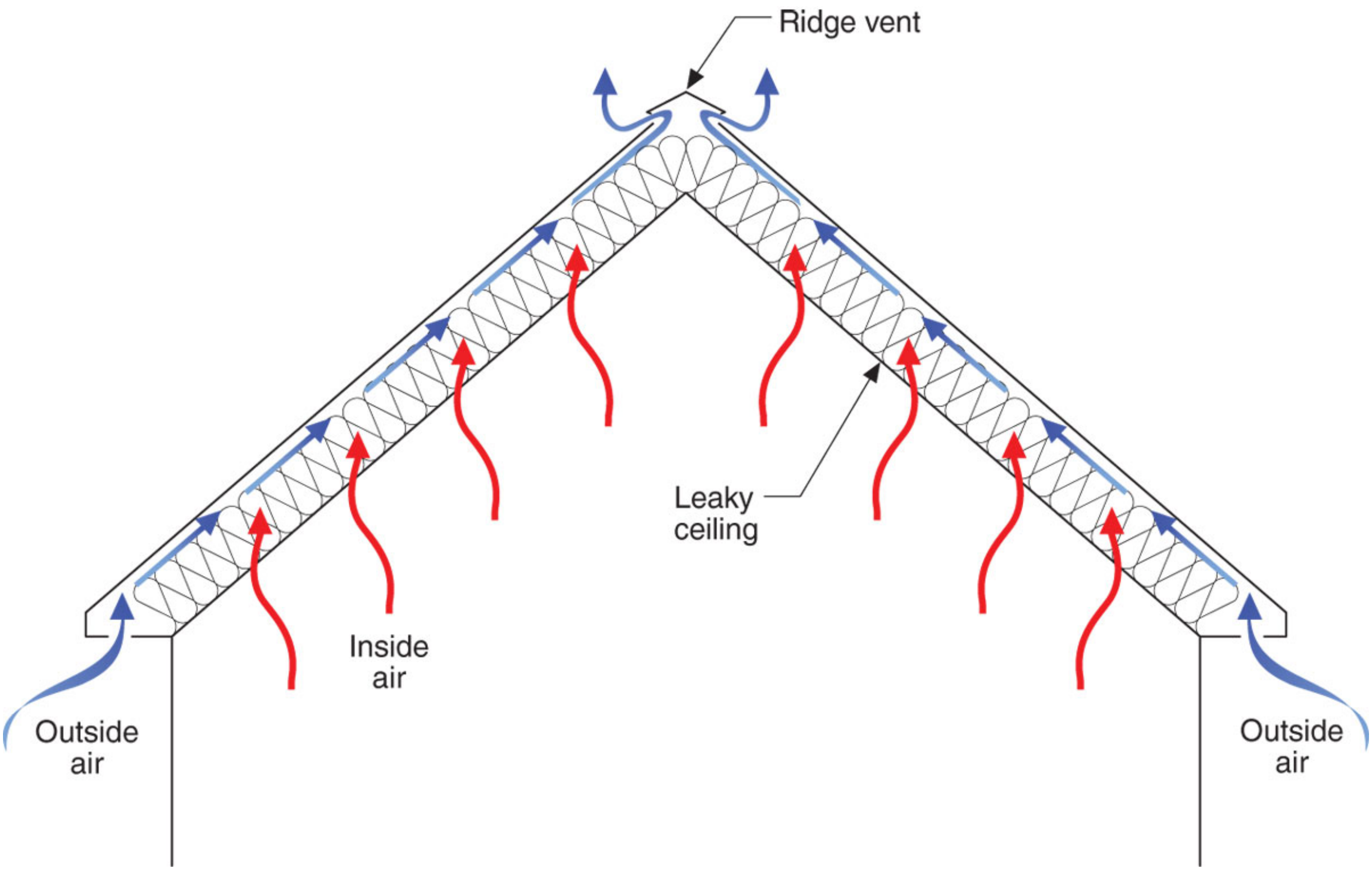

GEORGIA MUS

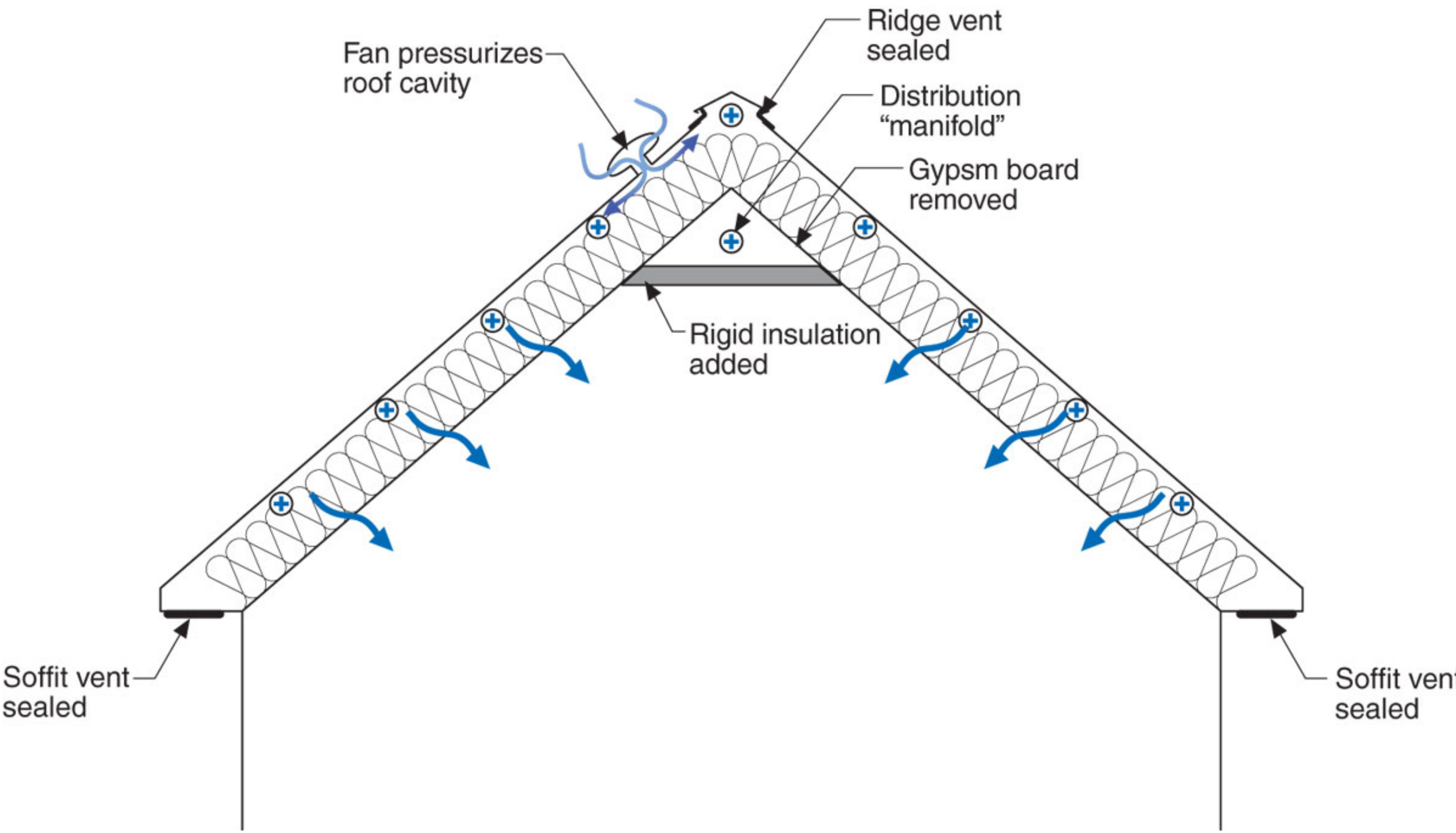

LABELWAGON 2000 XL








Ridge vent
Leaky ceiling
Inside air
Outside air
Outside air


Fan pressurizes roof cavity
Ridge vent sealed
Distribution "manifold"
Gypsm board removed
Rigid insulation added
Soffit vent sealed
Soffit vent sealed