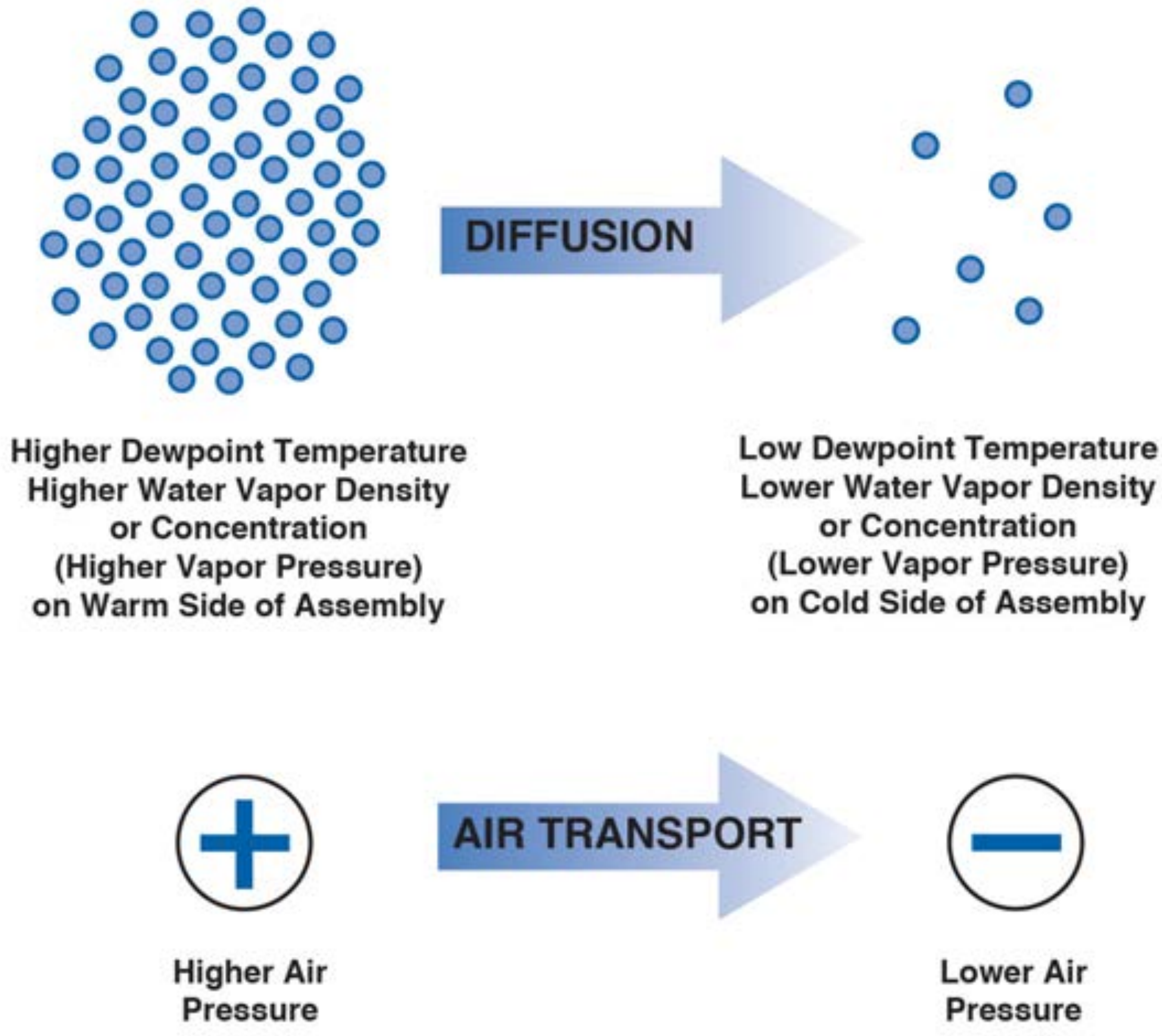
Joseph Lstiburek, Ph.D., P.Eng, ASHRAE Fellow

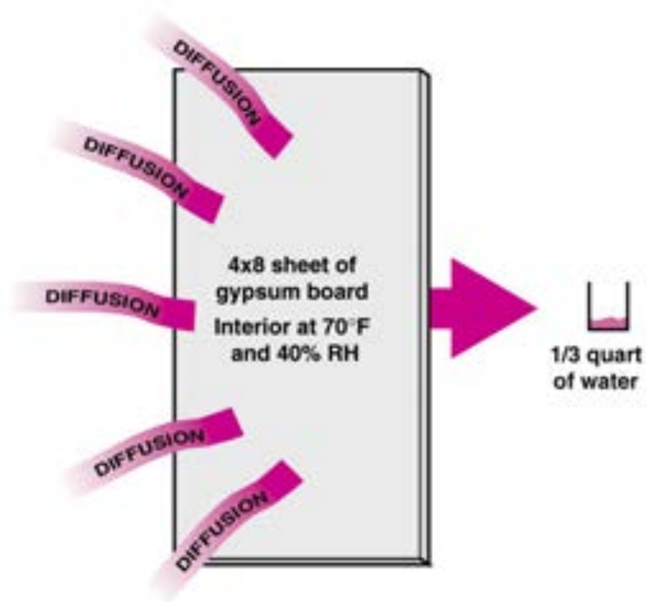
Building Science

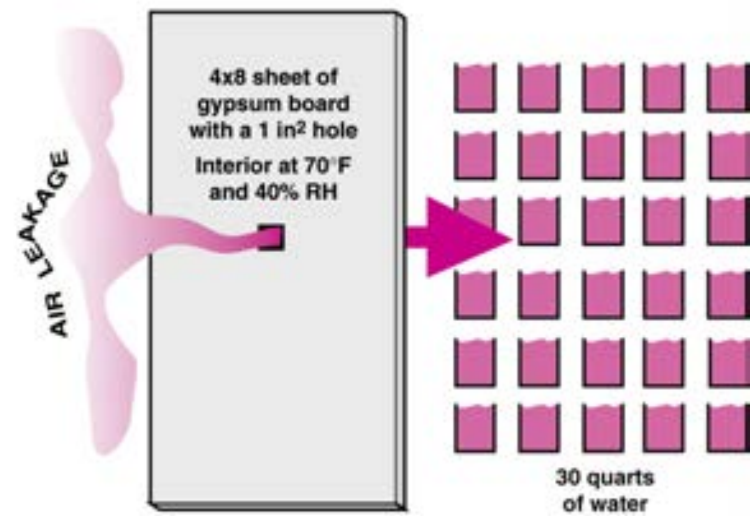
Air Flow Control

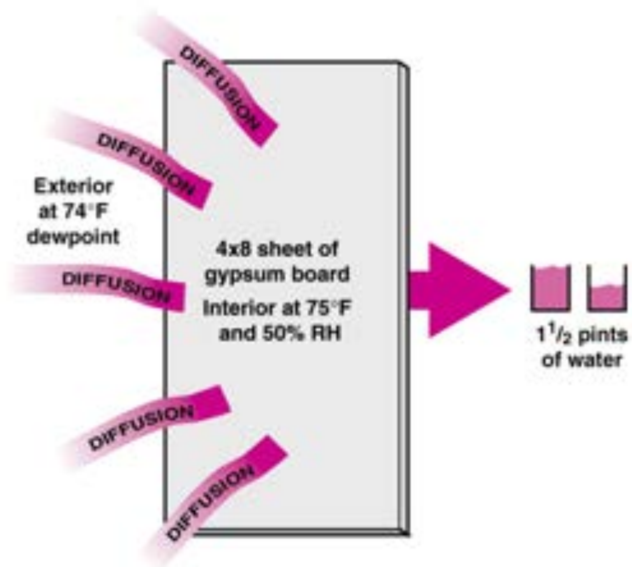
presented by www.buildingscience.com

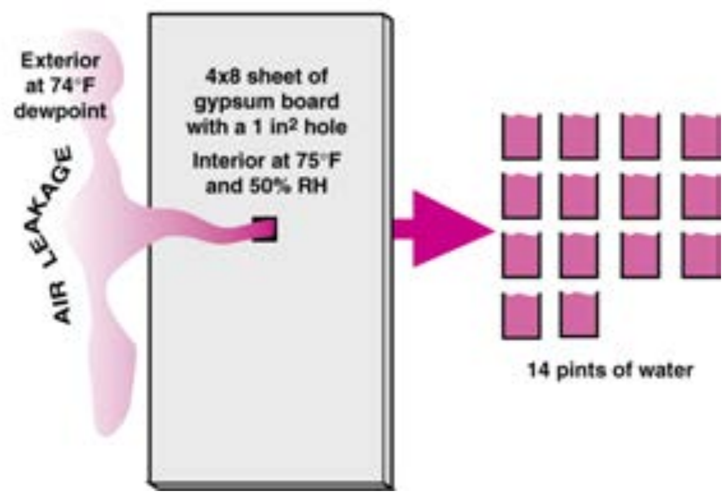
Air Barriers Had Nothing to Do With Energy
….at First


DIFFUSION
Higher Dewpoint Temperature
Higher Water Vapor Density
or Concentration
(Higher Vapor Pressure)
on Warm Side of Assembly
Low Dewpoint Temperature
Lower Water Vapor Density
or Concentration
(Lower Vapor Pressure)
on Cold Side of Assembly
AIR TRANSPORT
Higher Air
Pressure
Lower Air
Pressure


DIFFUSION
DIFFUSION
DIFFUSION
DIFFUSION
DIFFUSION
4x8 sheet of gypsum board
Interior at 70°F and 40% RH
1/3 quart of water


AIR LEAKAGE
4x8 sheet of gypsum board with a 1 in2 hole
Interior at 70°F and 40% RH
30 quarts of water


DIFFUSION
DIFFUSION
Exterior
at 74°F
dewpoint
DIFFUSION
4x8 sheet of
gypsum board
Interior at 75°F
and 50% RH
1 1/2 pints
of water
DIFFUSION
DIFFUSION


Exterior
at 74°F
dewpoint
AIR LEAKAGE
4x8 sheet of
gypsum board
with a 1 in2 hole
Interior at 75°F
and 50% RH
14 pints of water

Air Barriers Had Nothing to Do With Energy

….at First

Became a Big Deal with Attics


021

Air Barriers Had Nothing to Do With Energy

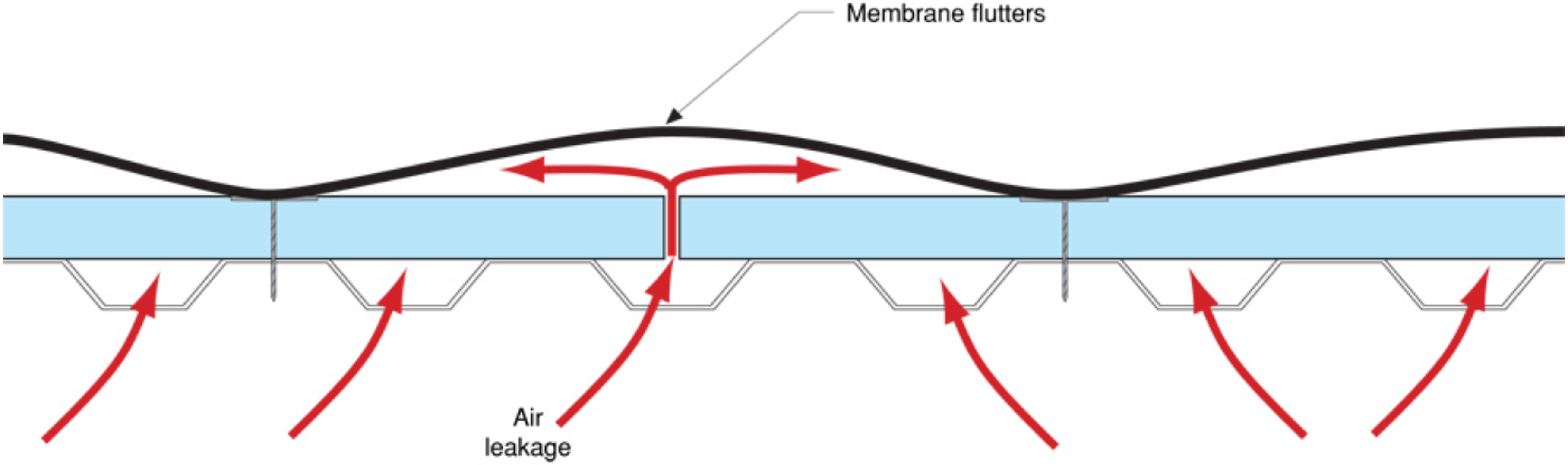
….at First

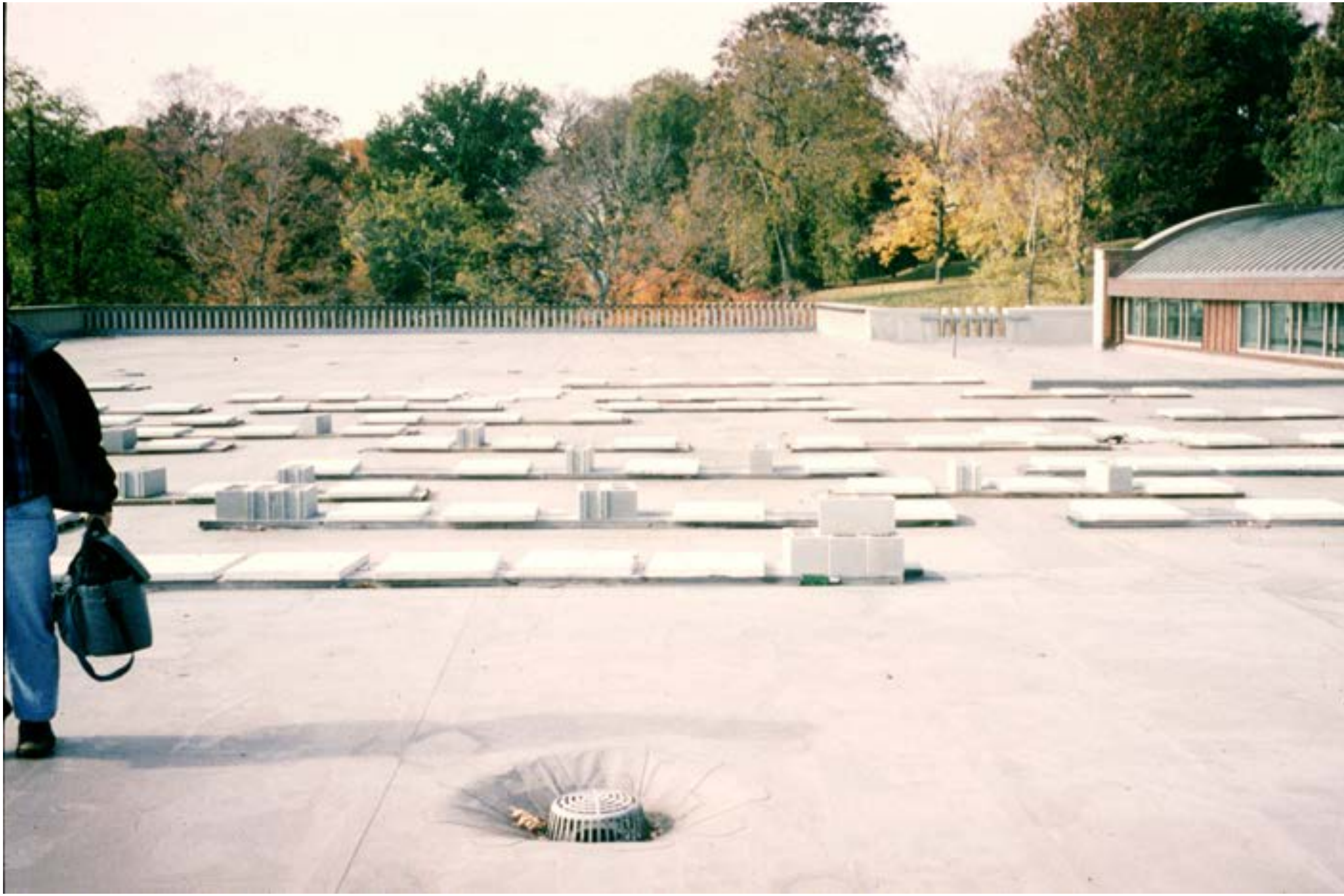
Then Became a Big Deal with Walls

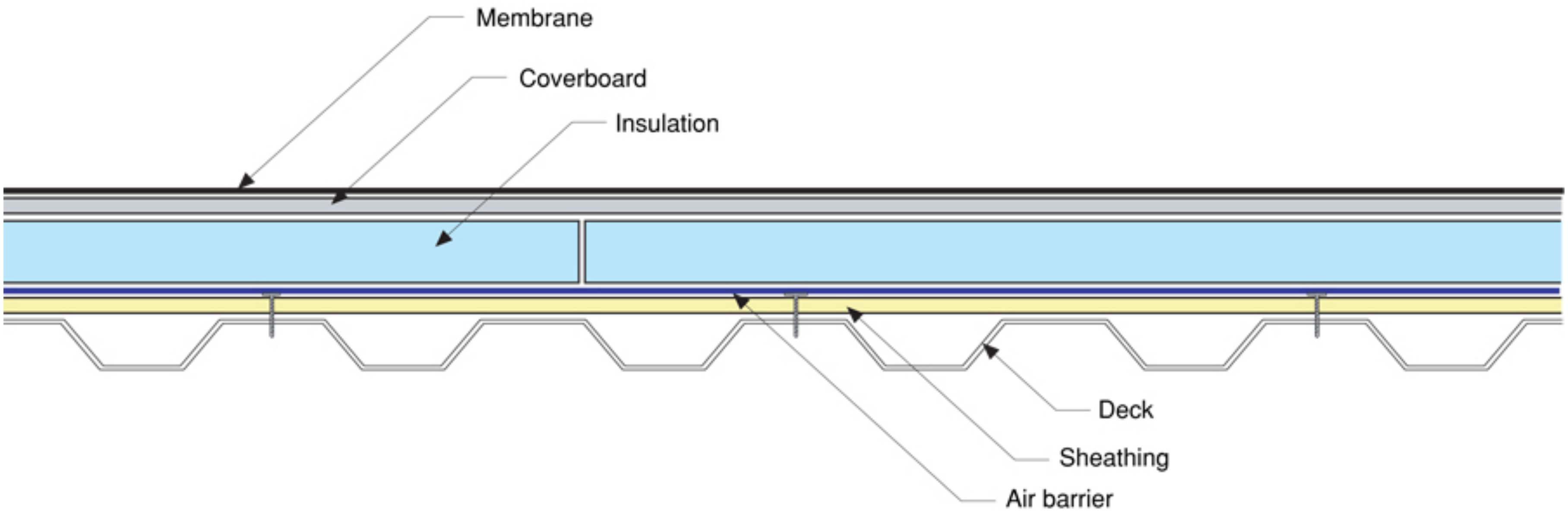
Air Barriers Had Nothing to Do With Energy

….at First

And A Really Big Deal with Compact Roofs…


Membrane flutters
Air
leakage




Membrane
Coverboard
Insulation
Deck
Sheathing
Air barrier

Then Energy…..

Lo Cal House - USA - 1976

Lo Cal House - USA – 1976

Wayne Shick and Bud Konzo

R-30 double stud walls

R-30 vented roof

Triple glazed windows

Air to air heat exchanger

Saskatchewan Conservation House - 1977

Saskatchewan Conservation House – 1977

R-40 double stud walls

R-60 ceiling

Triple glazed windows

Air to air heat exchanger

0.8 ach@50 Pa

Leger House - USA - 1977

Leger House - USA – 1977

Double wall – R 40 walls R 60 ceiling

Airtight construction

Air to air heat exchanger

Parade of Homes - Saskatoon - 1980

Parade of Homes - Saskatoon – 1980

10 homes that were all less than

1.0 ach@50 Pa

R-2000 Program – 1982

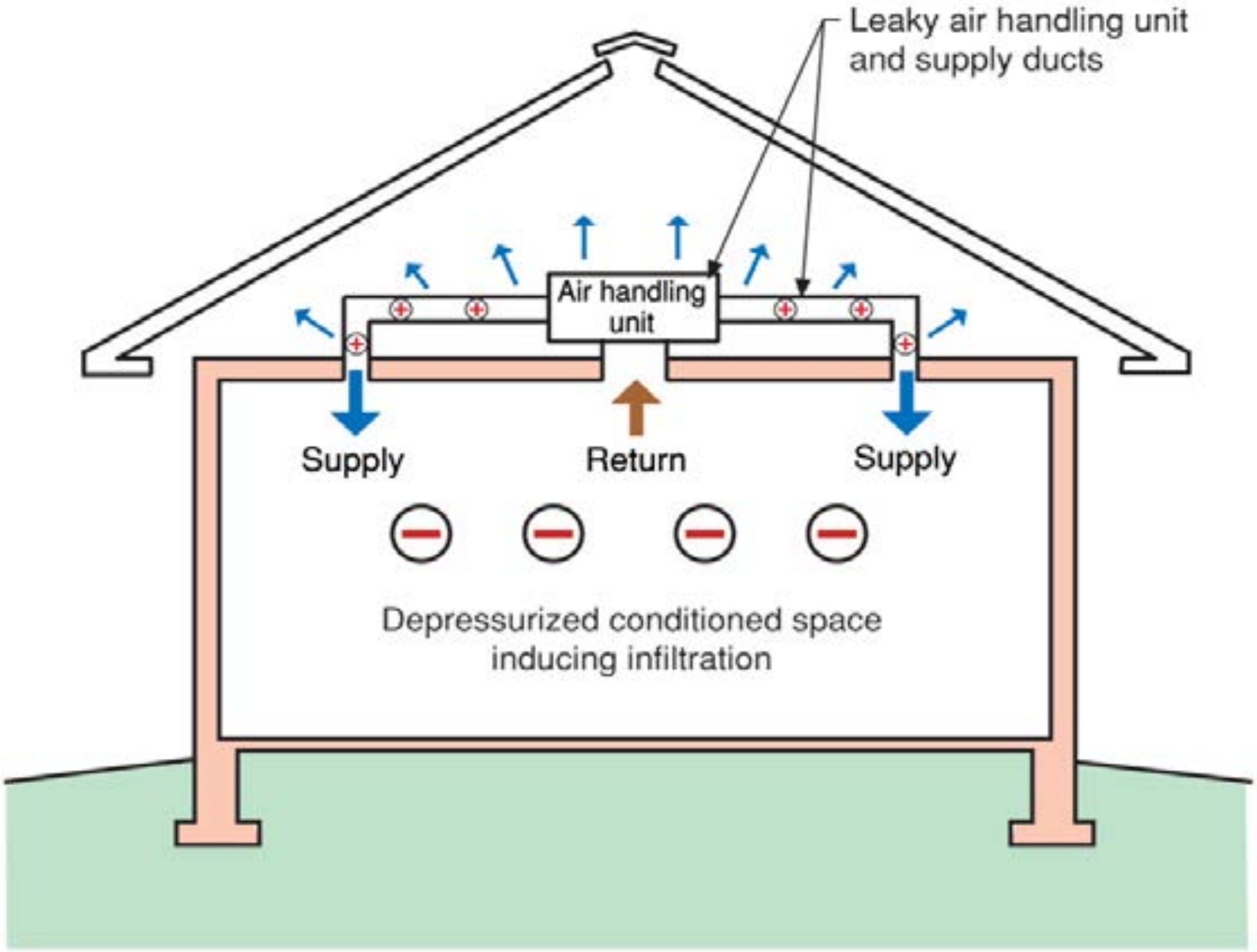
1.5 ach@50 Pa

Chicago – 1990 to 1995

3.0 ach@50 Pa


Thermo
ply

- Chicago – 1990 to 1995
- 3.0 ach@50 Pa
- Became the EEBA metric
- Became the Building America metric
- Focus on big holes….EPA “Thermal Bypass Checklist”
- Became the IECC code…



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

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

Air Barrier Metrics

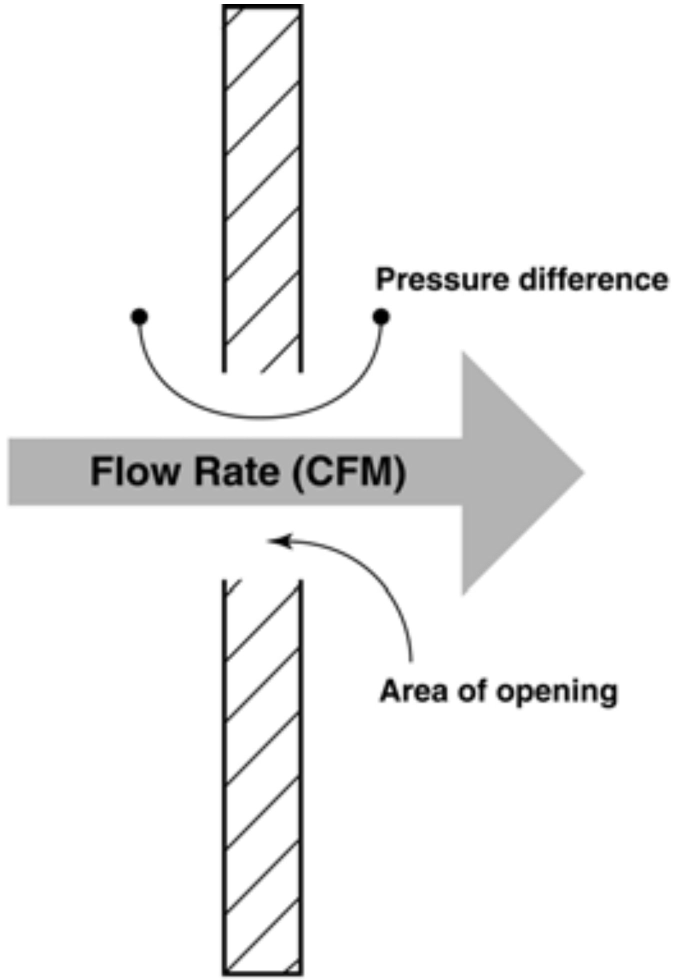
Material	0.004	ft3/(min-ft2) @ 75 Pa
Assembly	0.04	ft3/(min-ft2) @ 75 Pa
Enclosure	0.4	ft3/(min-ft2) @ 75 Pa

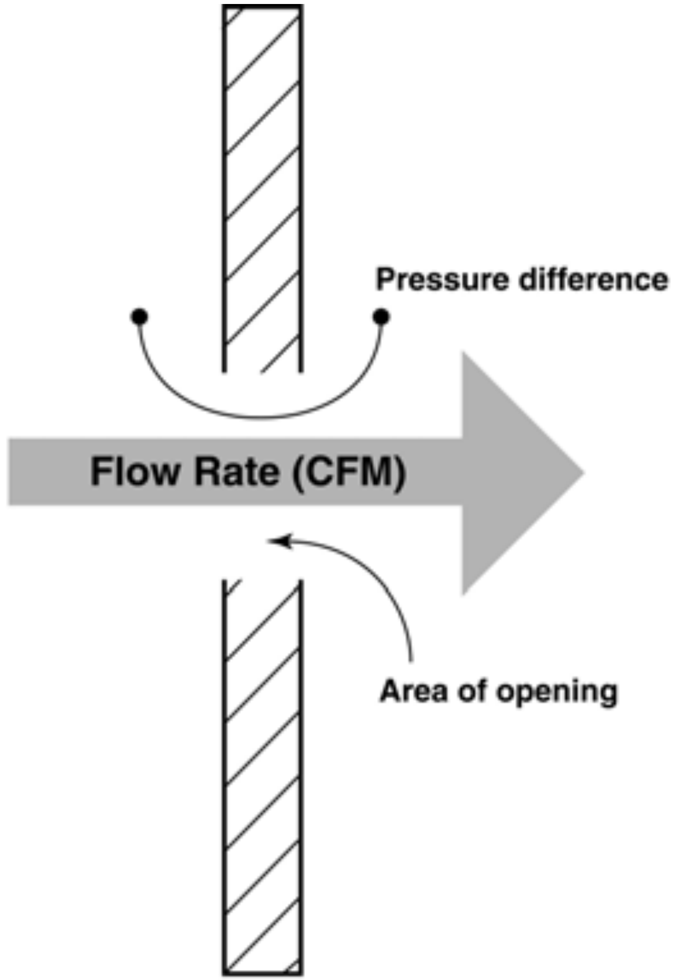
Air Barrier Metrics

Enclosure 2.00 l/(s-m2) @ 75 Pa
0.3 cfm/ft2 @ 50 Pa
(3 ach@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

Getting rid of big holes	3 ach@50 (0.4 cfm/ft2@75)
Getting rid of smaller holes	1.5 ach@50 (0.25 cfm/ft2@75)
Getting German	0.6 ach@50 (0.08 cfm/ft2@75)


Pressure difference
Flow Rate (CFM)
Area of opening



"this is a lie"

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”

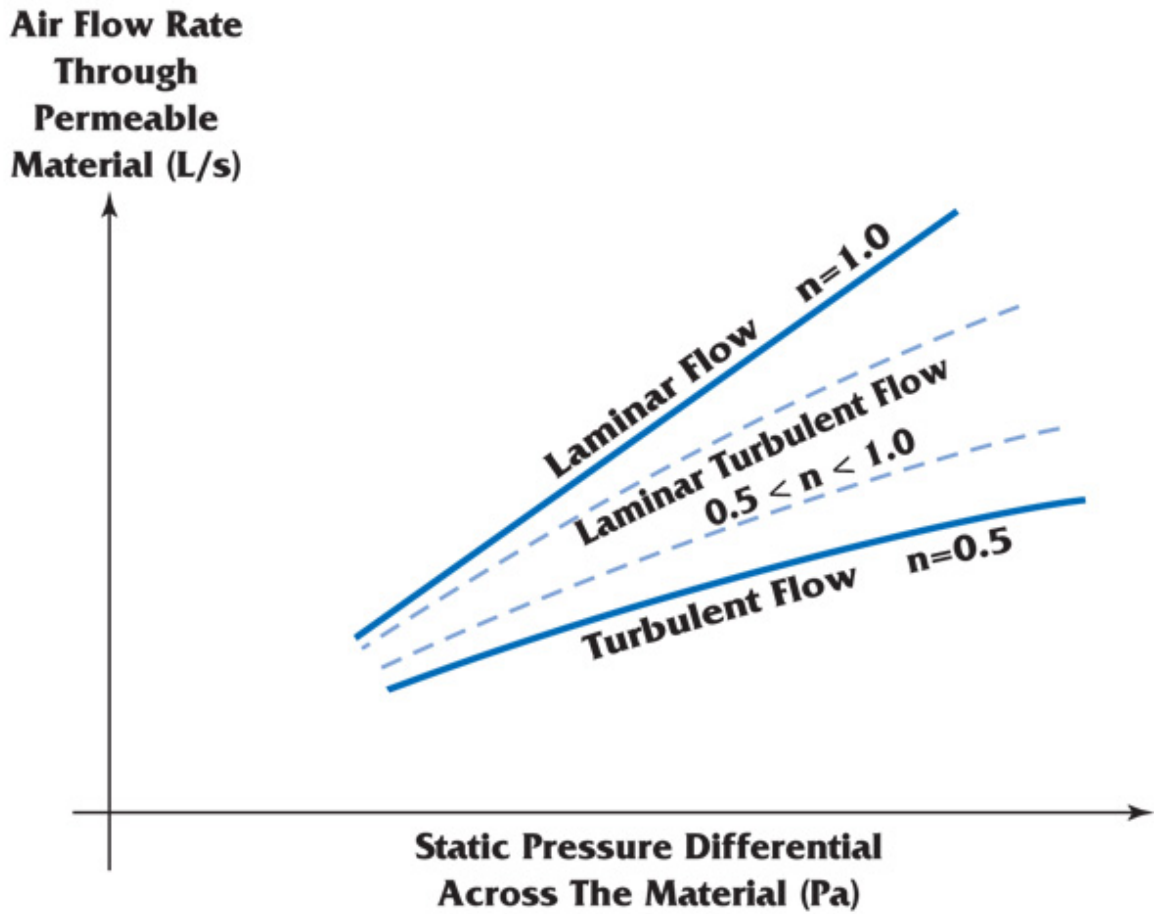


Figure 2.5

Modes of Air Flow

(from Bumbaru, Jutras and Patenaude, 1988)

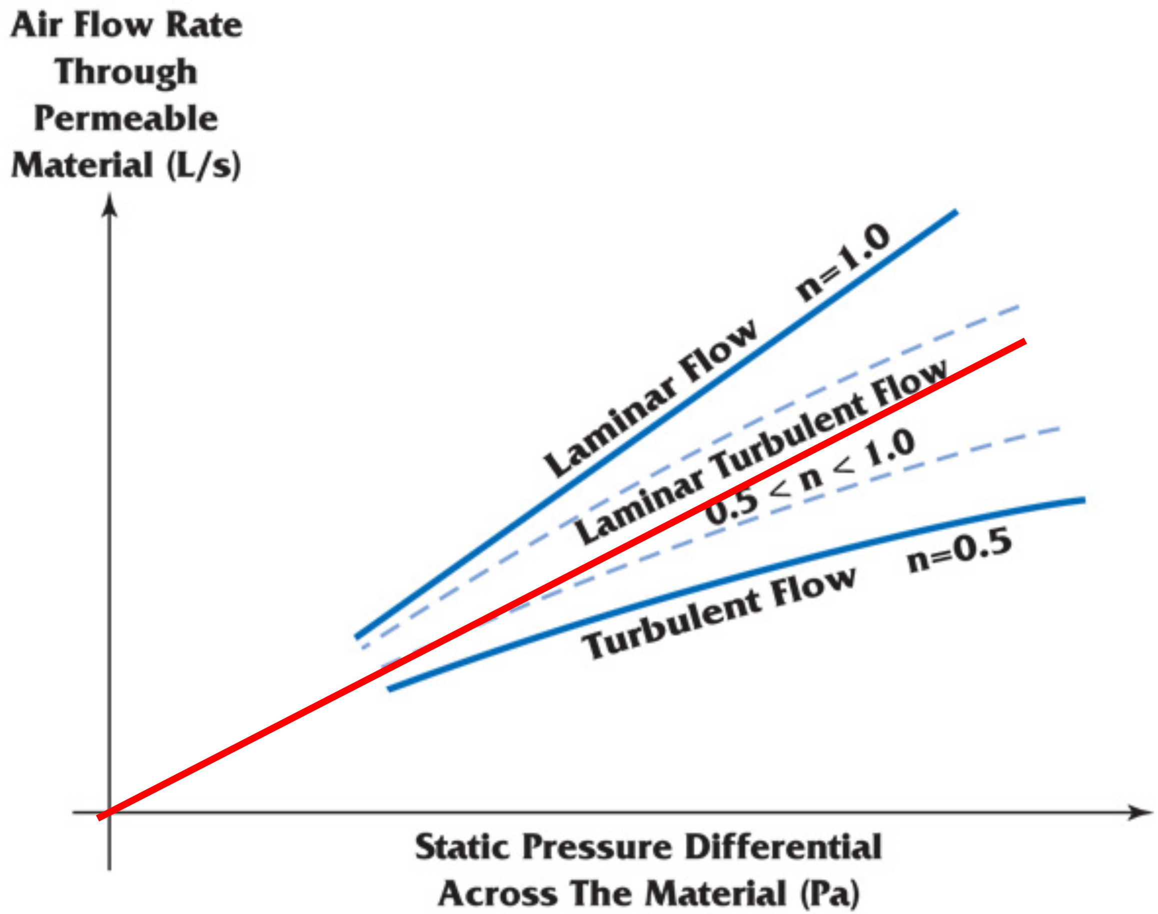


Figure 2.5
Modes of Air Flow
(from Bumbaru, Jutras and Patenaude, 1988)

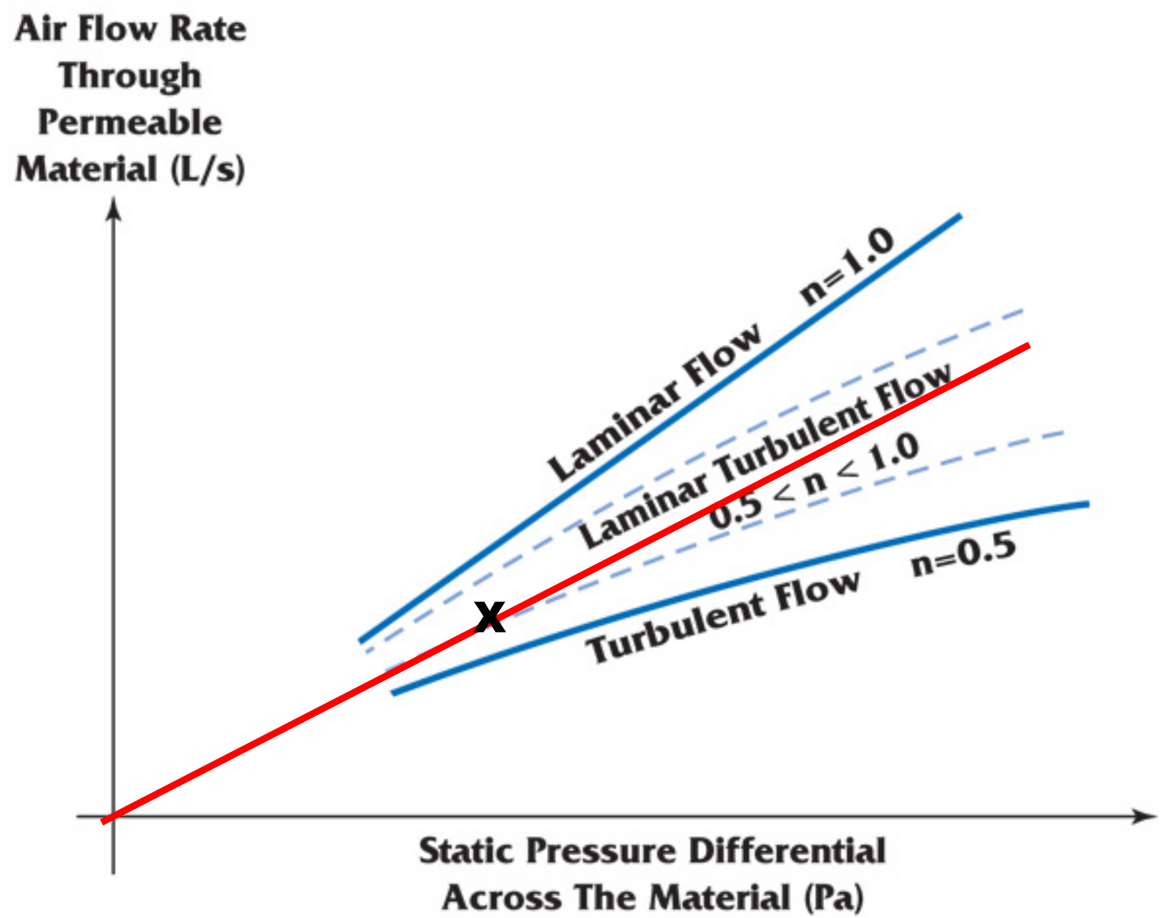


Figure 2.5
Modes of Air Flow
(from Bumbaru, Jutras and Patenaude, 1988)

$$Q = f\,(Dp) \text{ » } k\,(Dp)^{b}$$

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

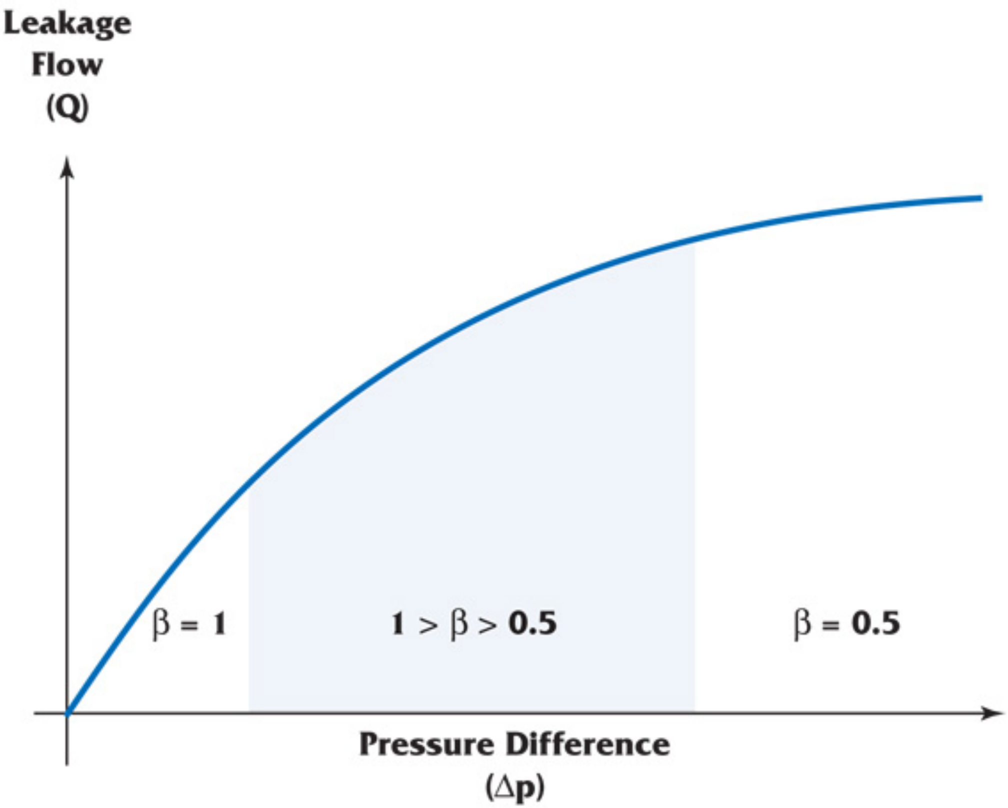


Figure 2.6
Characteristic Curve of Leakage Flow as a Function of Pressure Difference
(from Nylund, 1980)

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

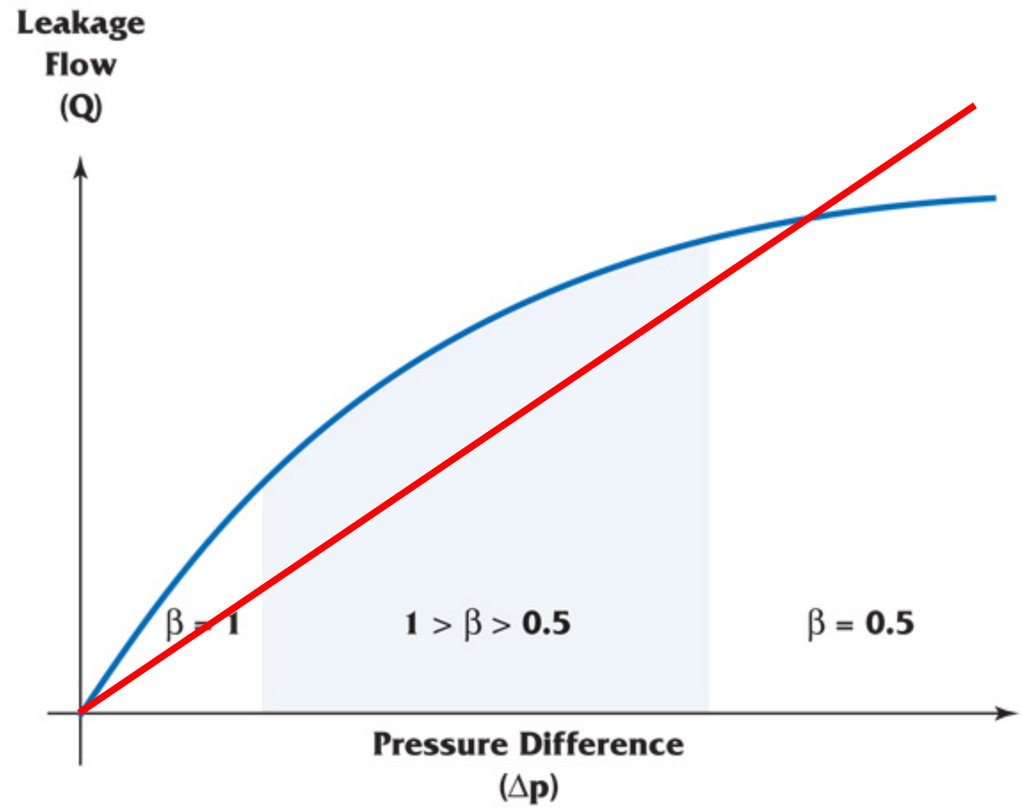


Figure 2.6

Characteristic Curve of Leakage Flow as a Function of Pressure Difference

(from Nylund, 1980)

$$\mathbf{Q = f\ (Dp)\ »\ k\ (Dp)^{b}}$$

Q = air flow, volume/unit of time

D**p** = pressure difference

k = coefficient

b = exponent in approximate leakage function

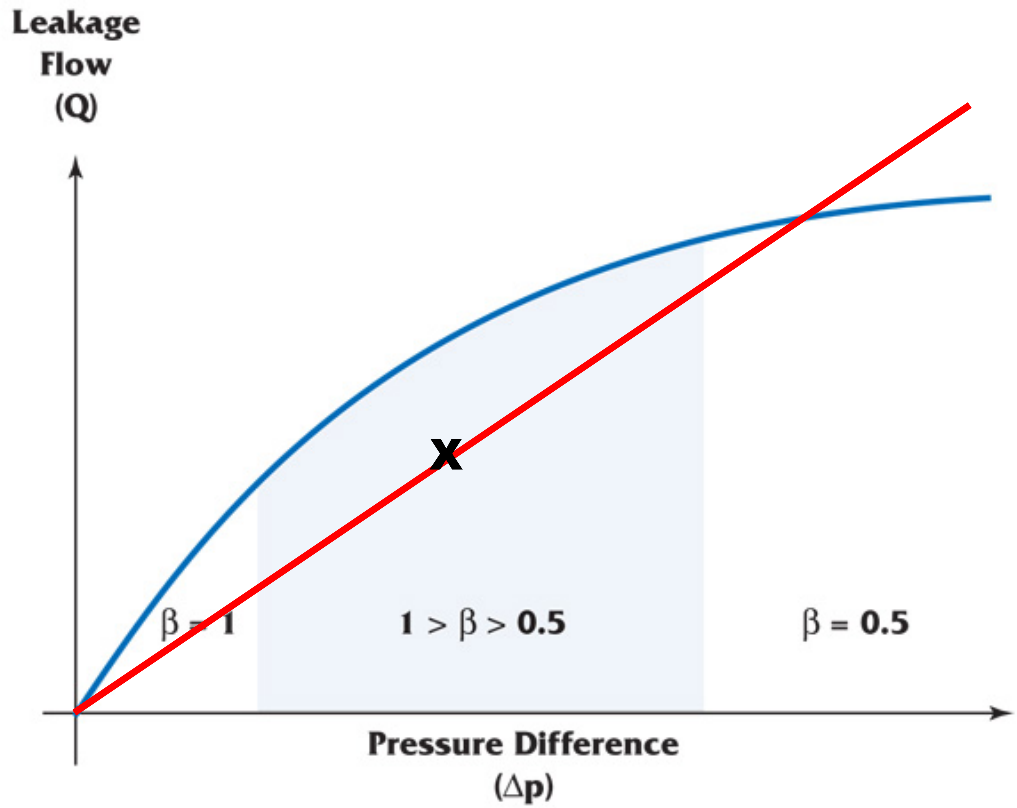
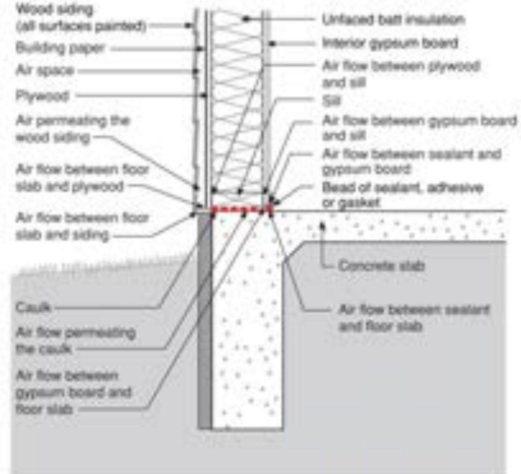


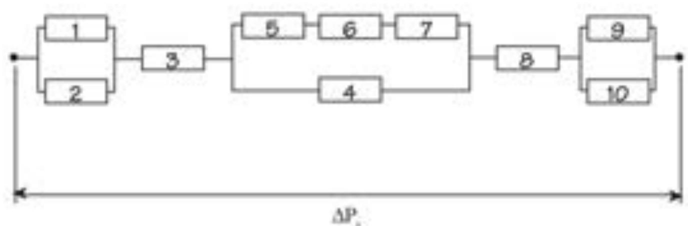
Figure 2.6

Characteristic Curve of Leakage Flow as a Function of Pressure Difference

(from Nylund, 1980)

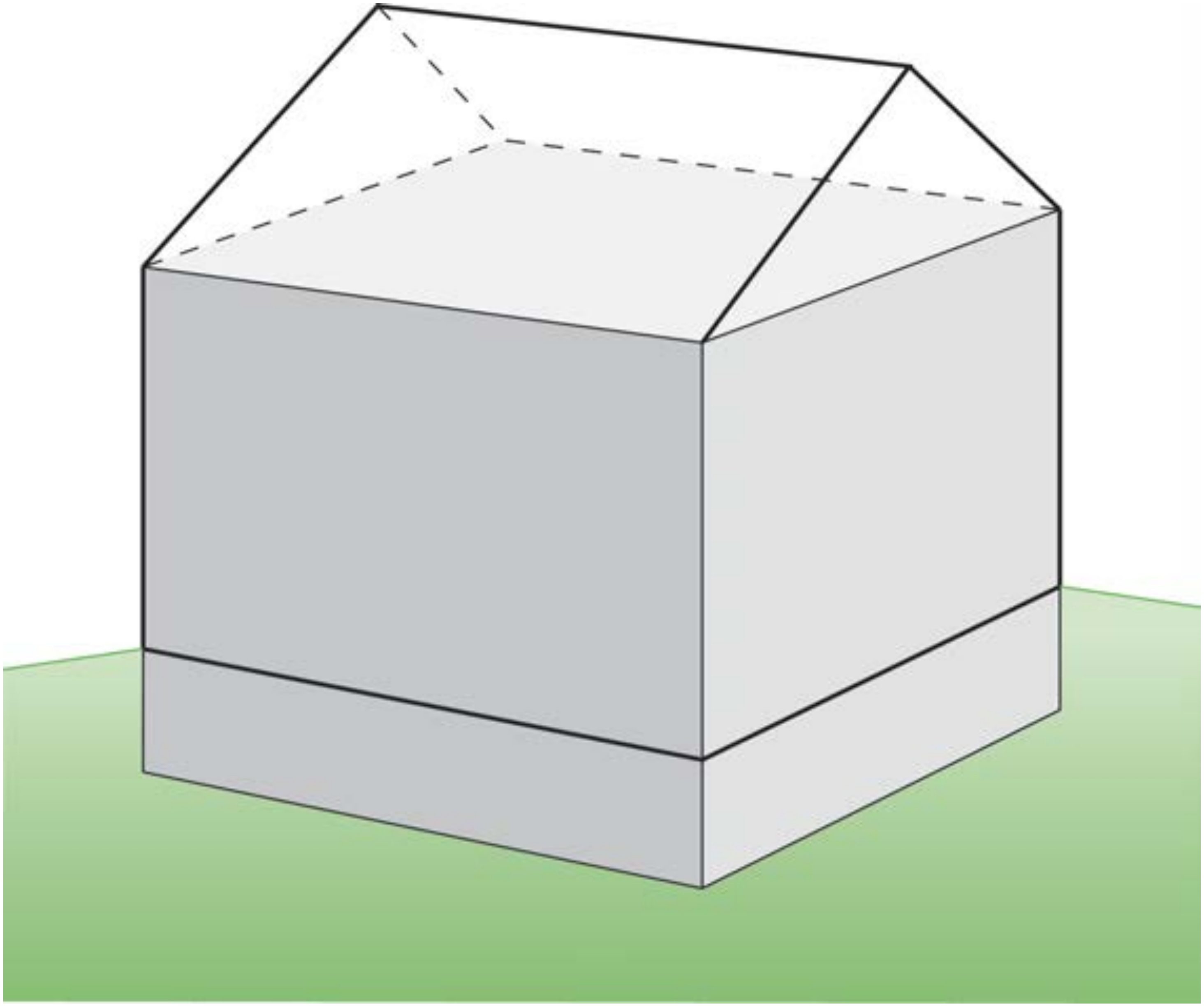


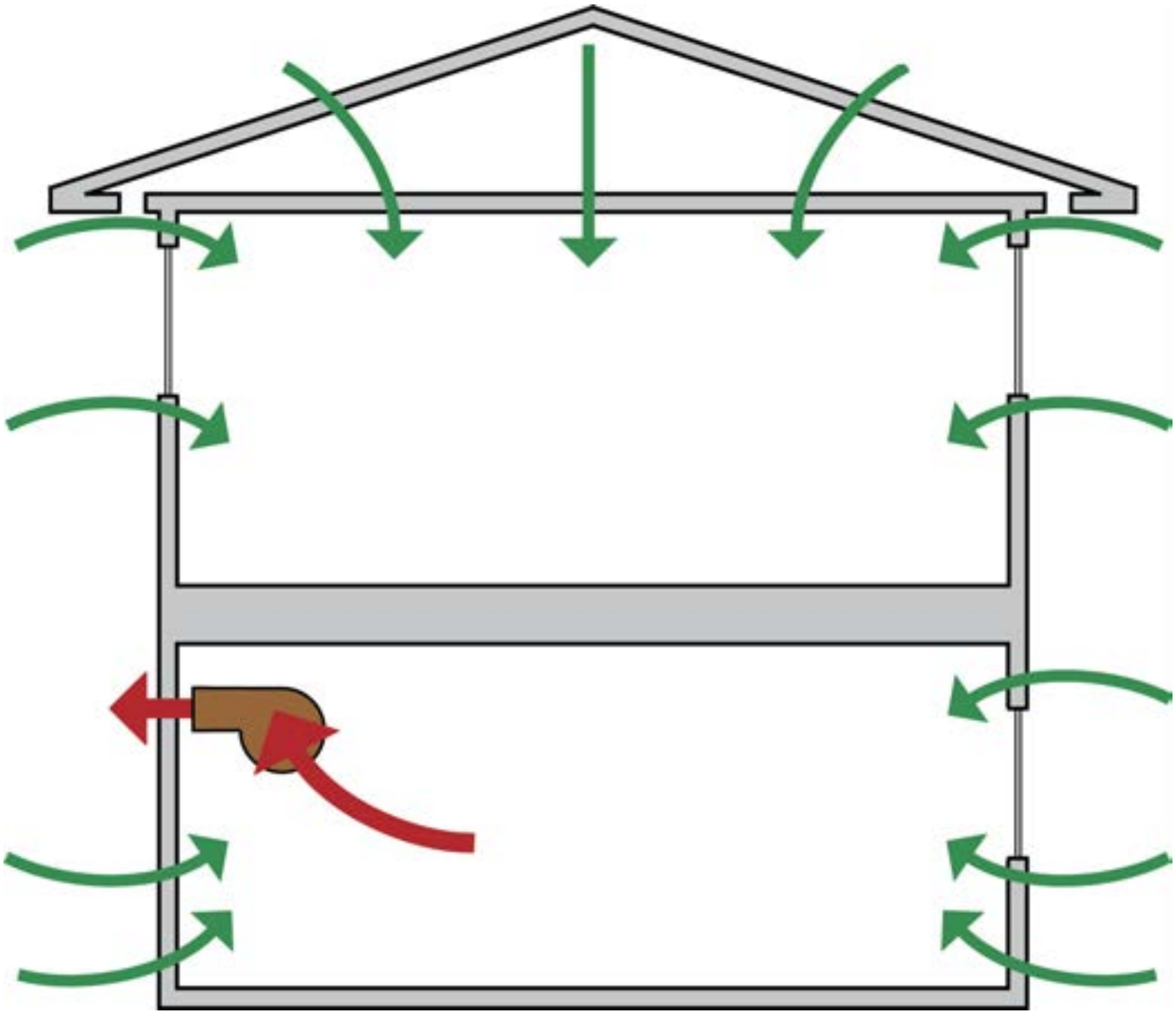
Possible air flows around sill of a wood-framed house modelled as a resistance network



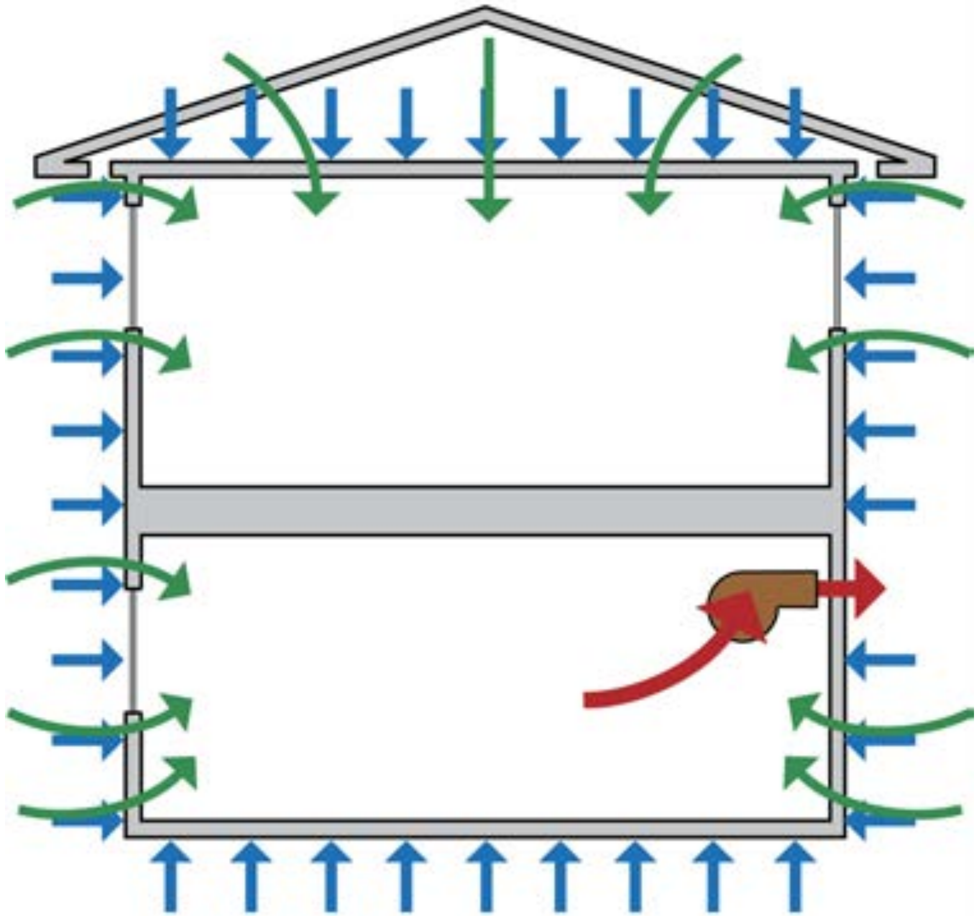
1. Air permeating the wood-panel cladding
2. Air flow between floor slab and panel
3. Air flow between floor slab and wind protection
4. Air permeating the caulking
5. Air flow between wind protection and sill
6. Air flow bewteen insulation material and sill
7. Air flow between inner lining and sill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

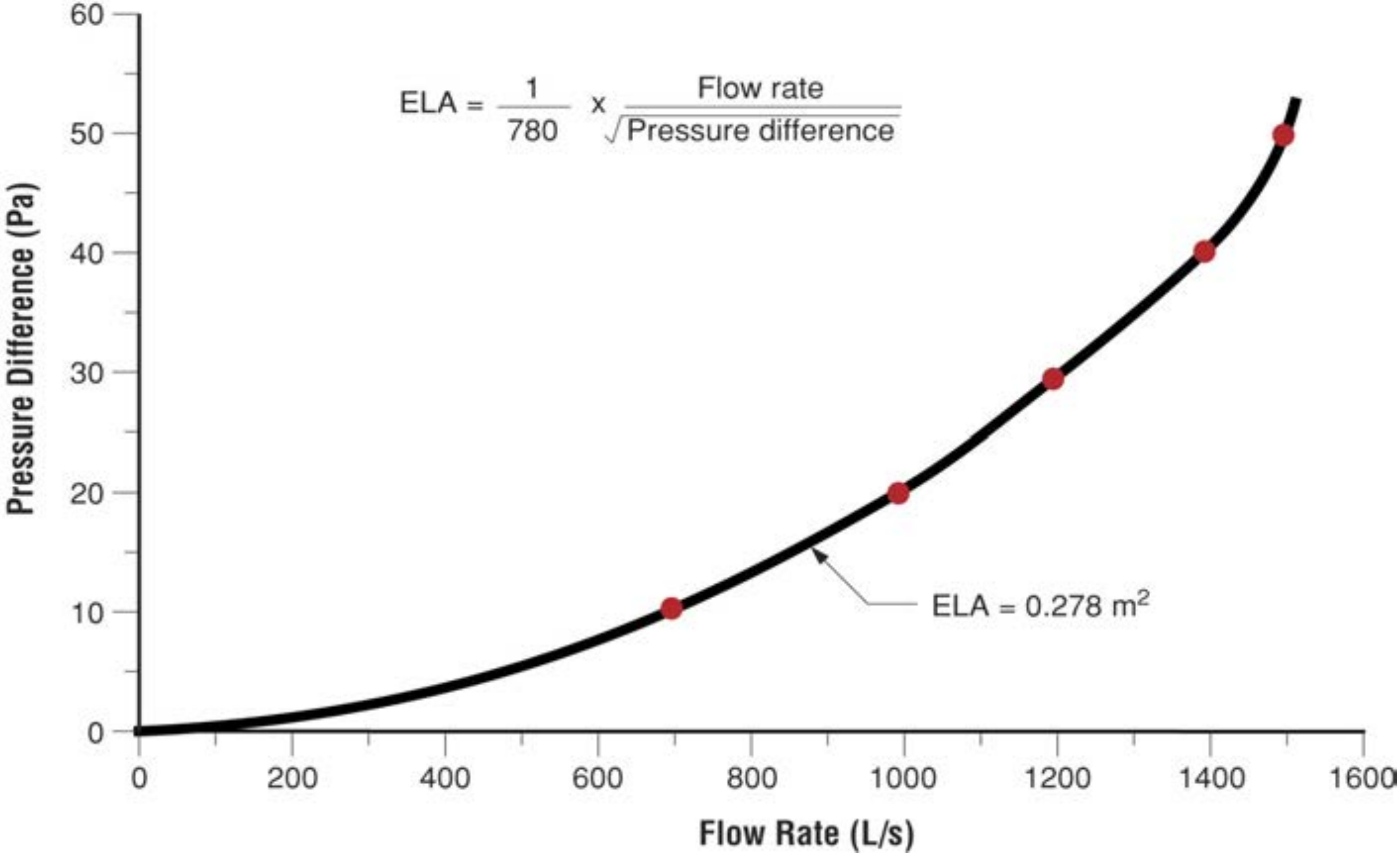




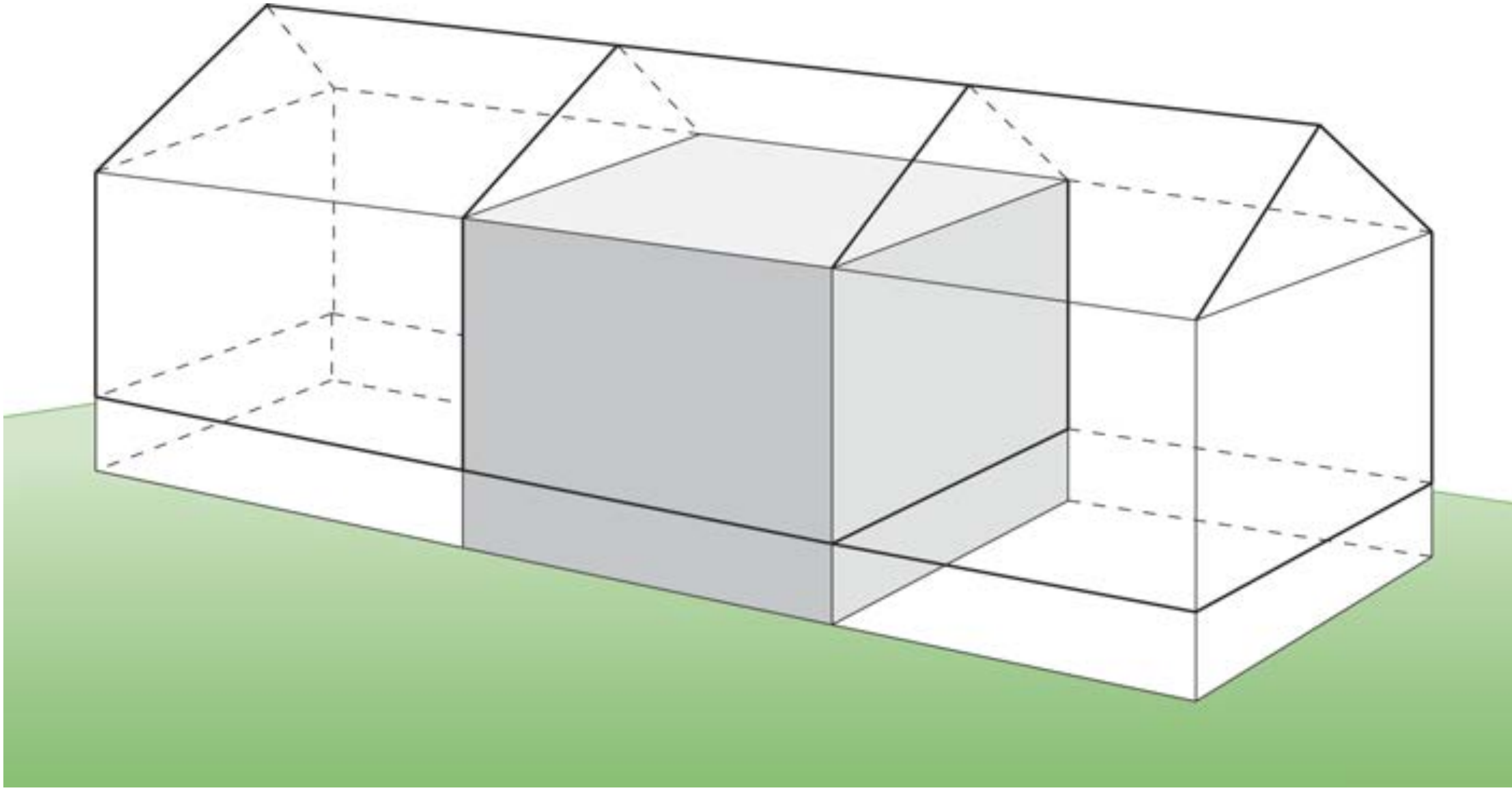
$$\text{ELA} \approx C \times \frac{\text{Rate of flow}}{\sqrt{\text{Pressure difference}}}$$



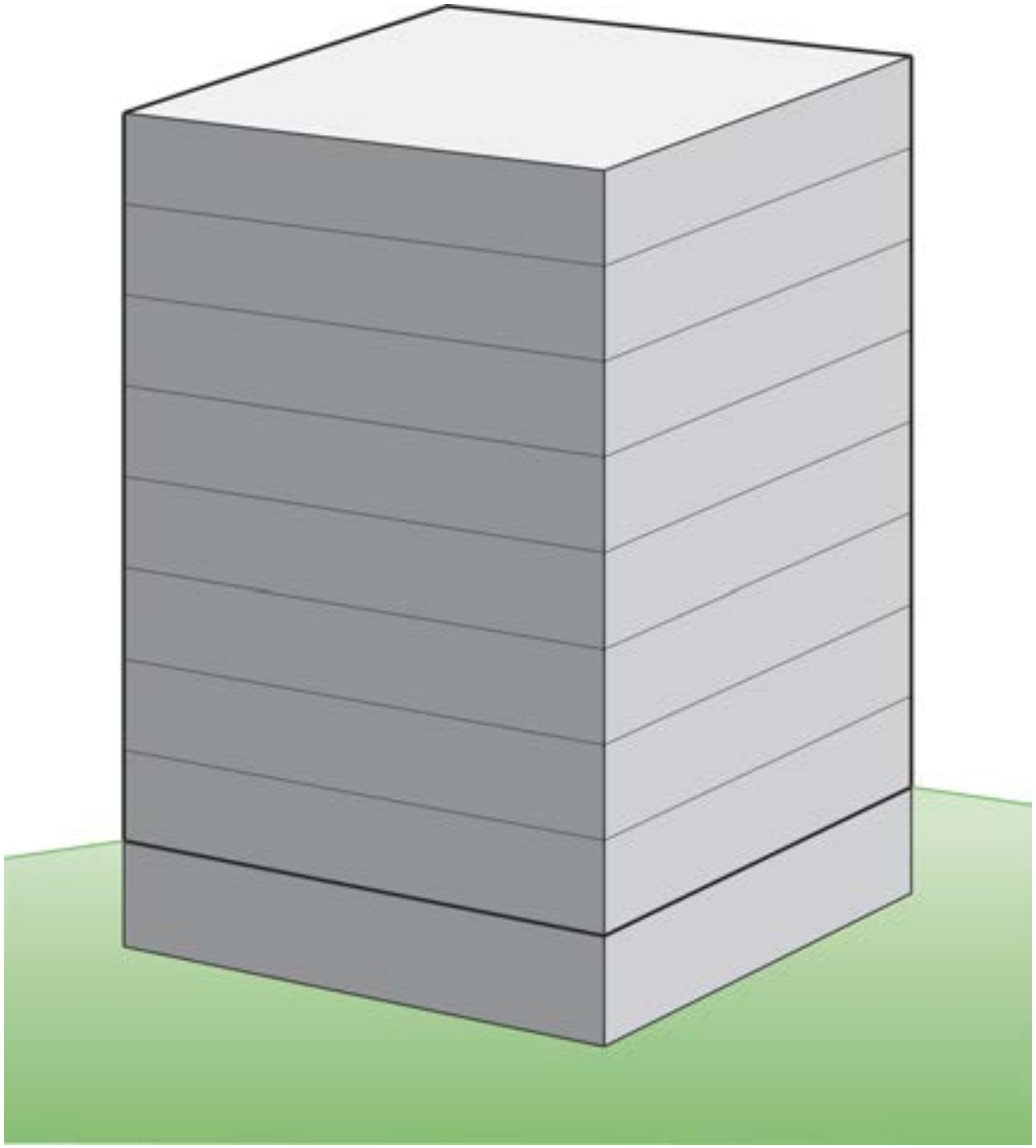
$$(\text{Meters})^2 \approx \frac{1}{780} \times \frac{\text{Litres per second}}{\sqrt{\text{Pascals}}}$$



ELA = 1/780 x Flow rate / √Pressure difference
ELA = 0.278 m²
Pressure Difference (Pa)
Flow Rate (L/s)
0
10
20
30
40
50
60
0
200
400
600
800
1000
1200
1400
1600




100% RECYCLED PAPER

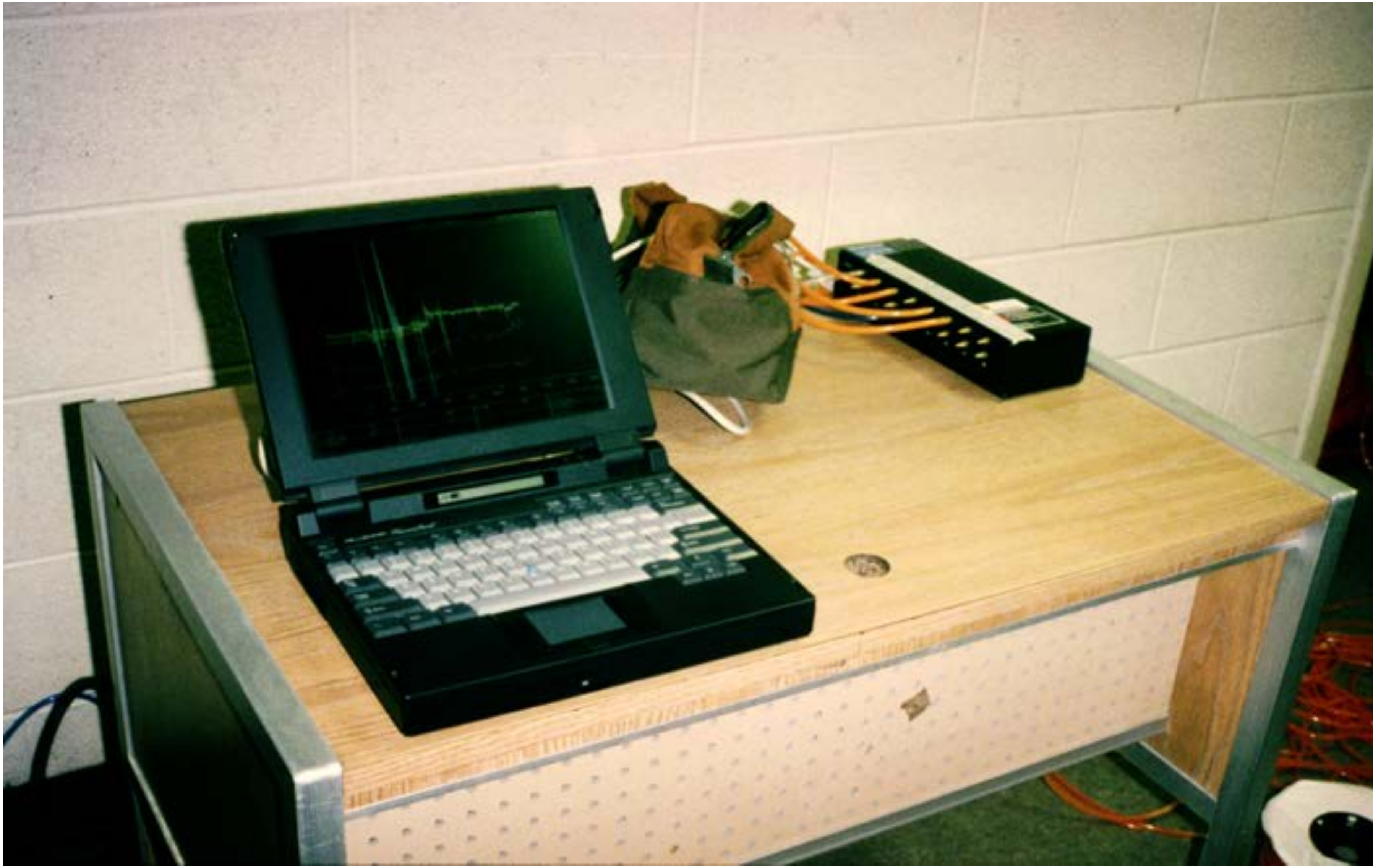


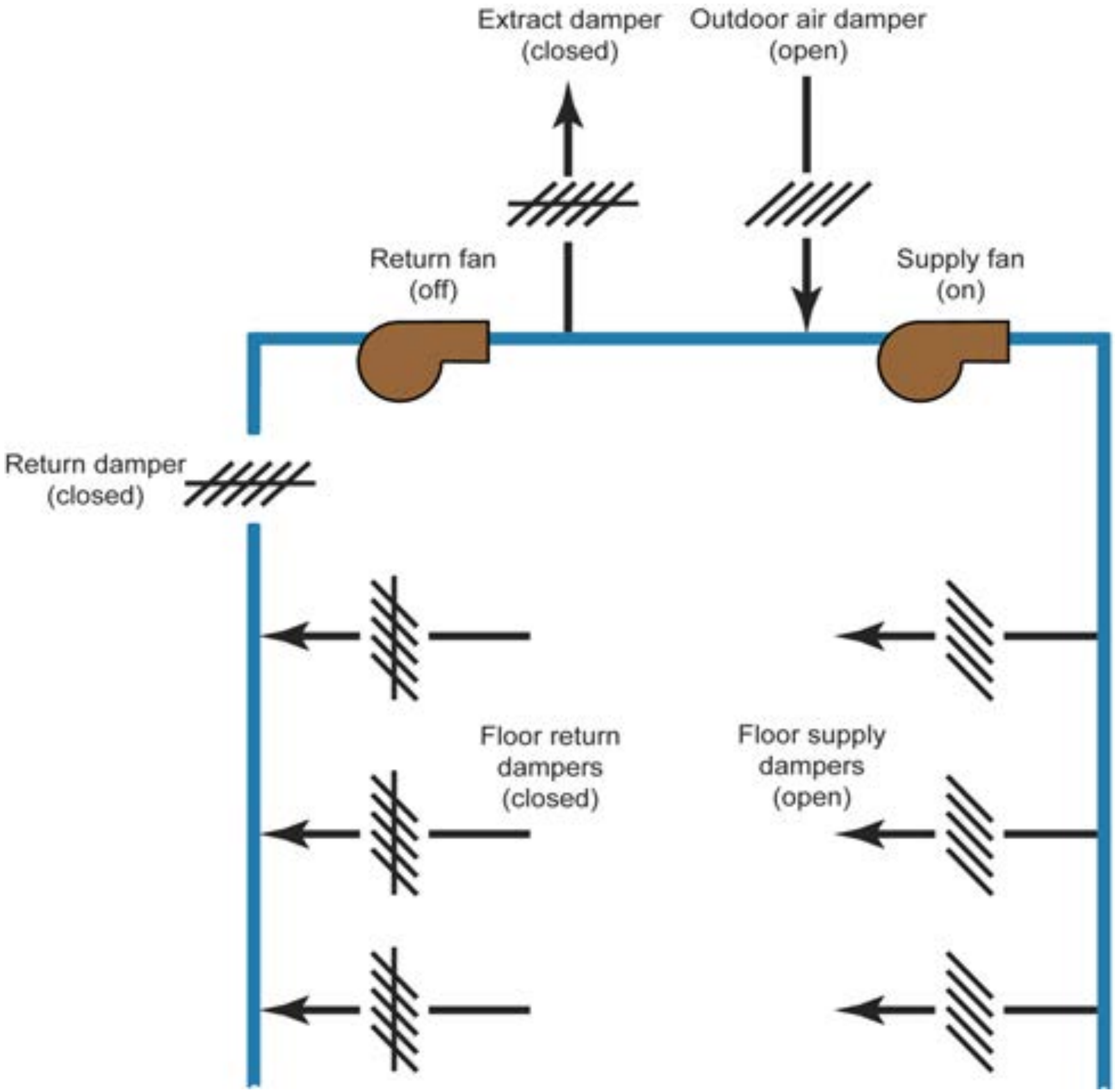

WESTFORD
ACADEMY

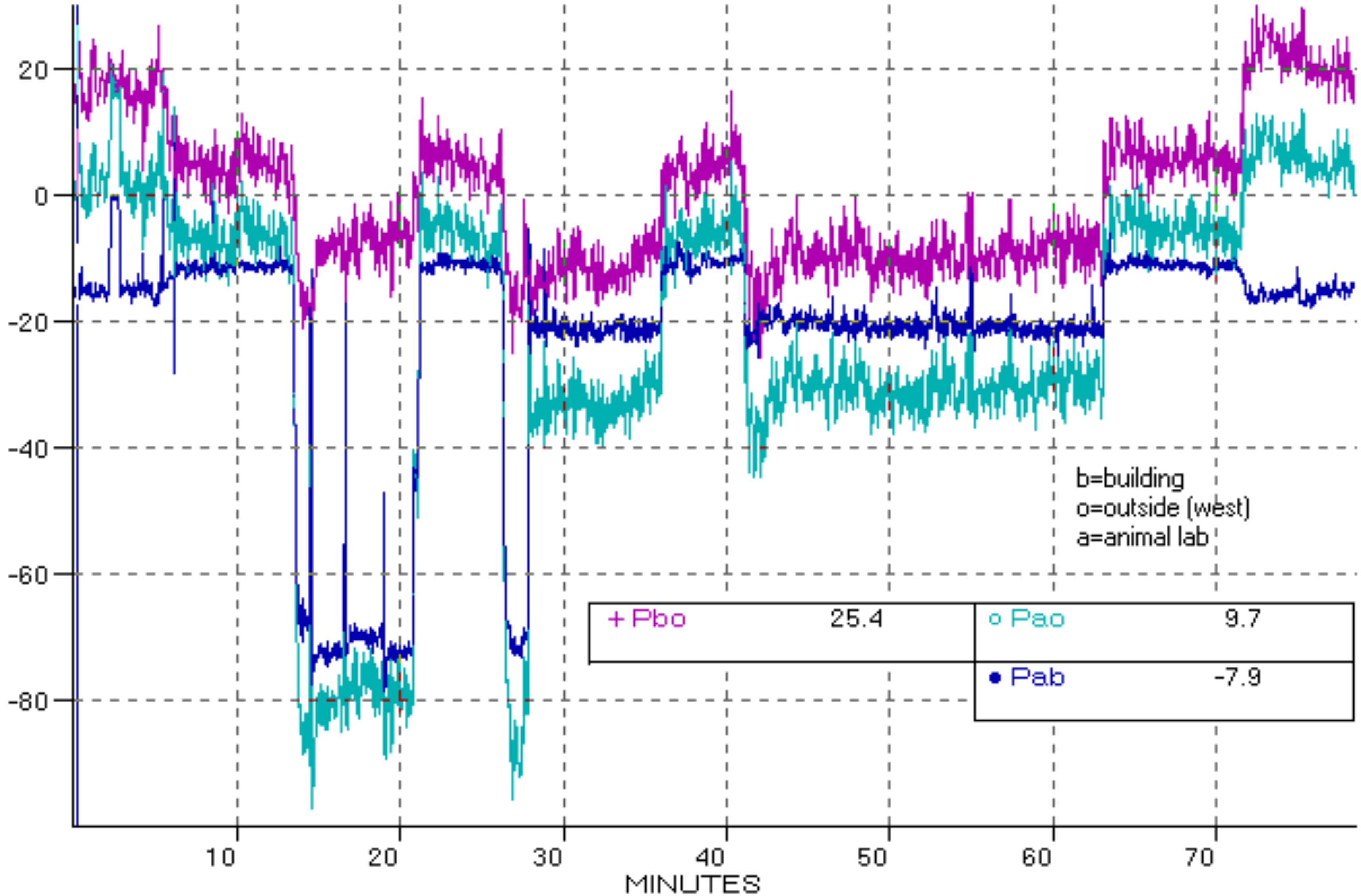

EXIT

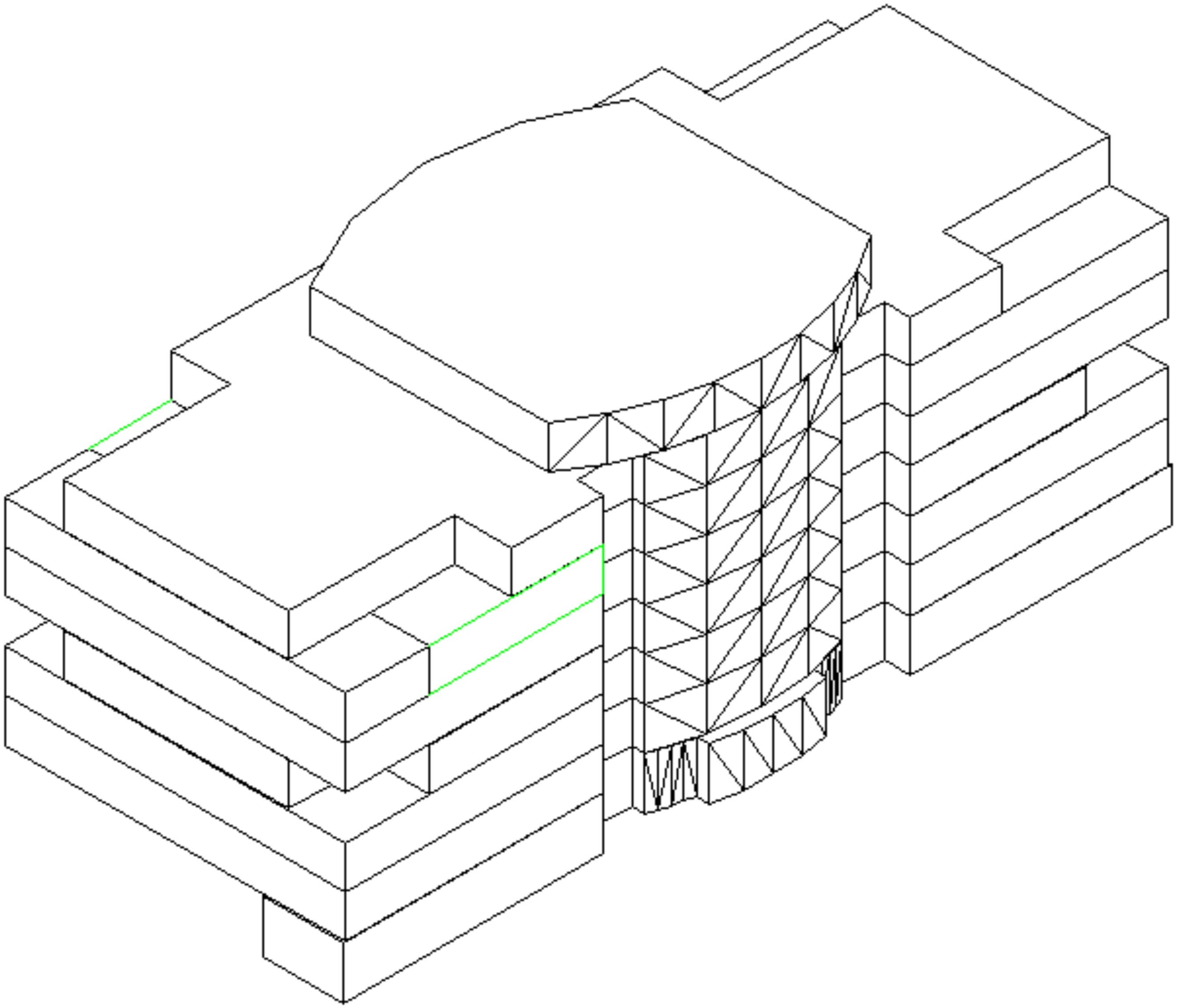

EXIT

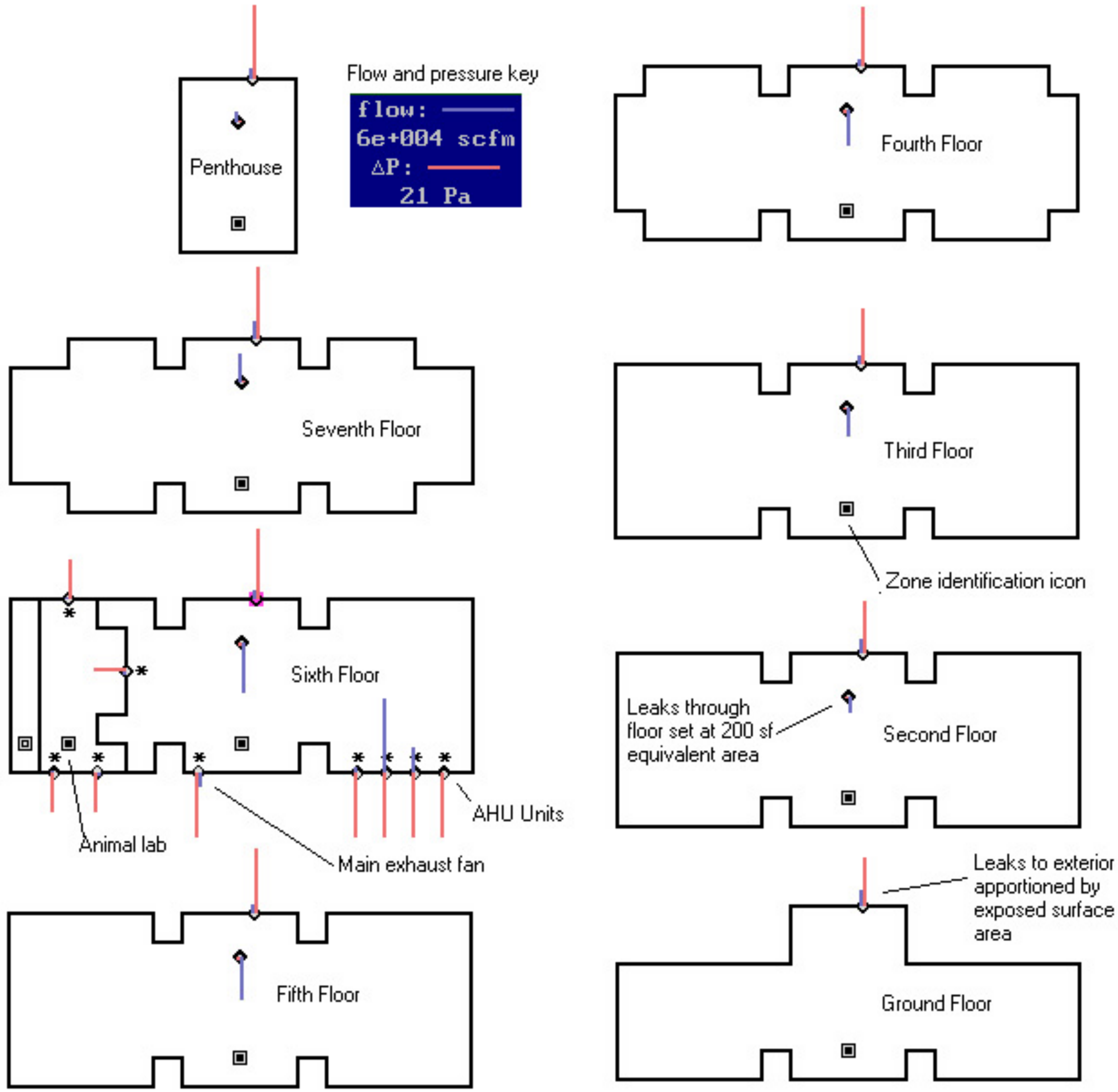

Shriners Hospitals for Crippled Children
Galveston Burns Institute
STOP

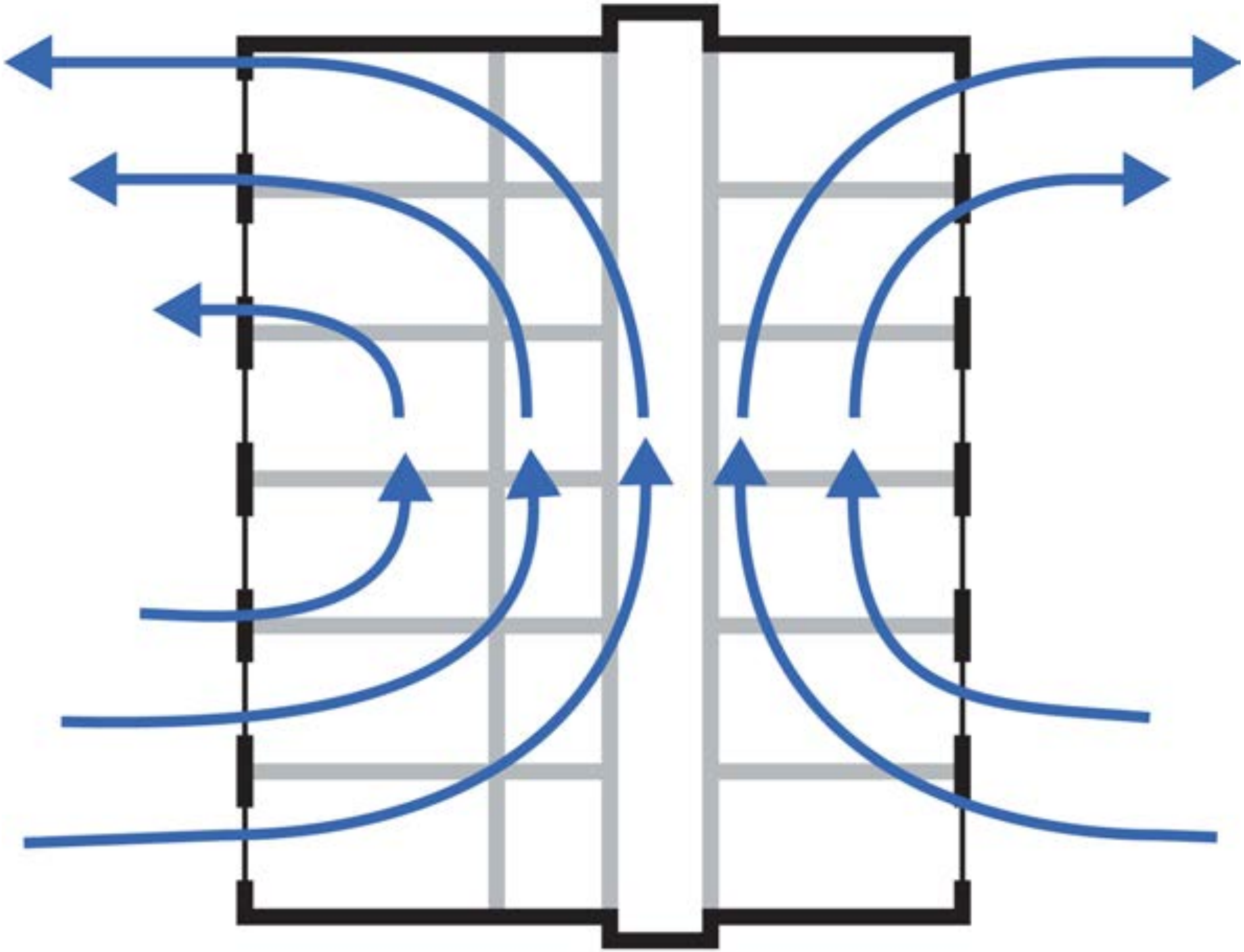


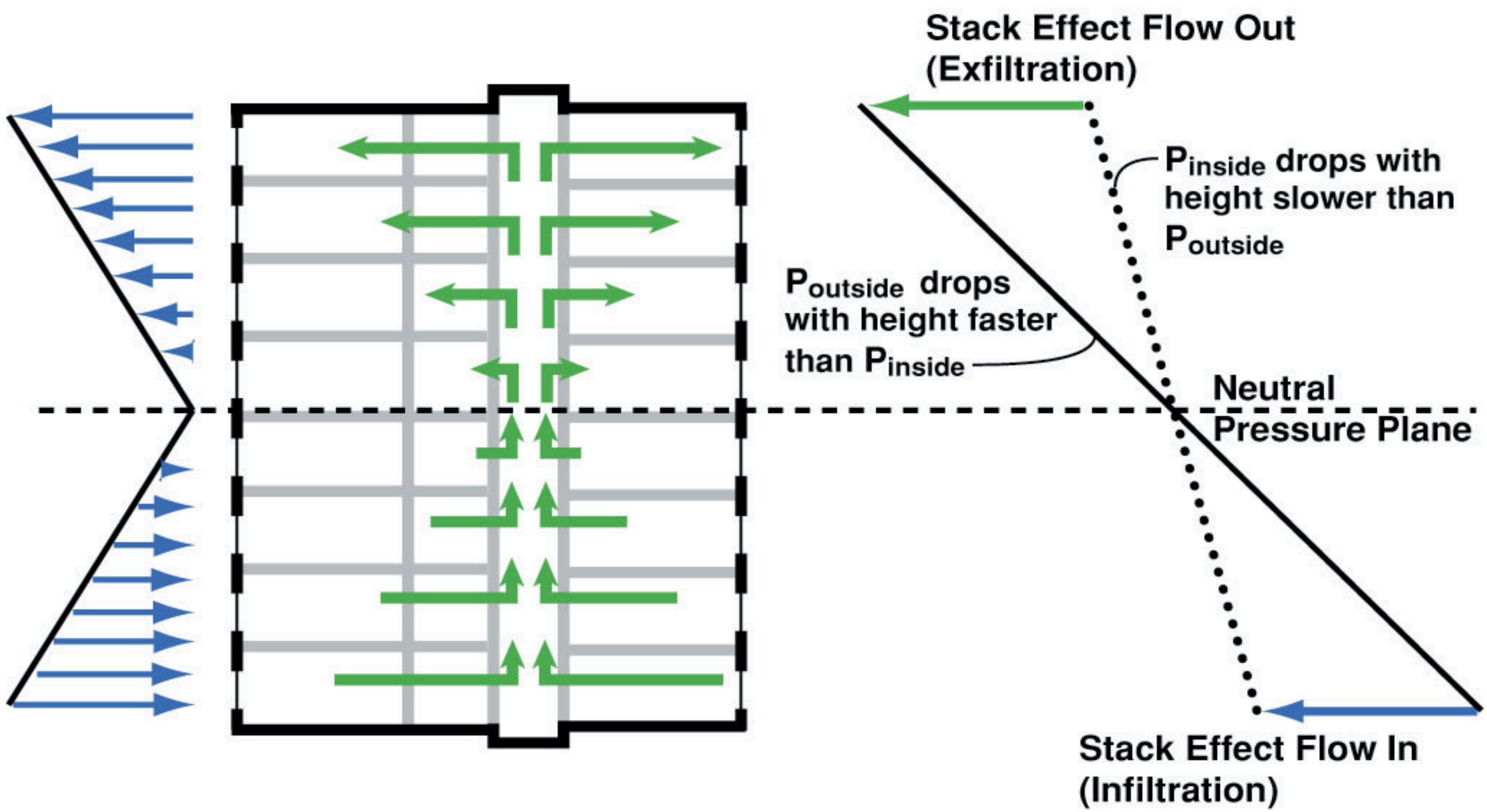

Extract damper
(closed)
Outdoor air damper
(open)
Return fan
(off)
Supply fan
(on)
Return damper
(closed)
Floor return
dampers
(closed)
Floor supply
dampers
(open)

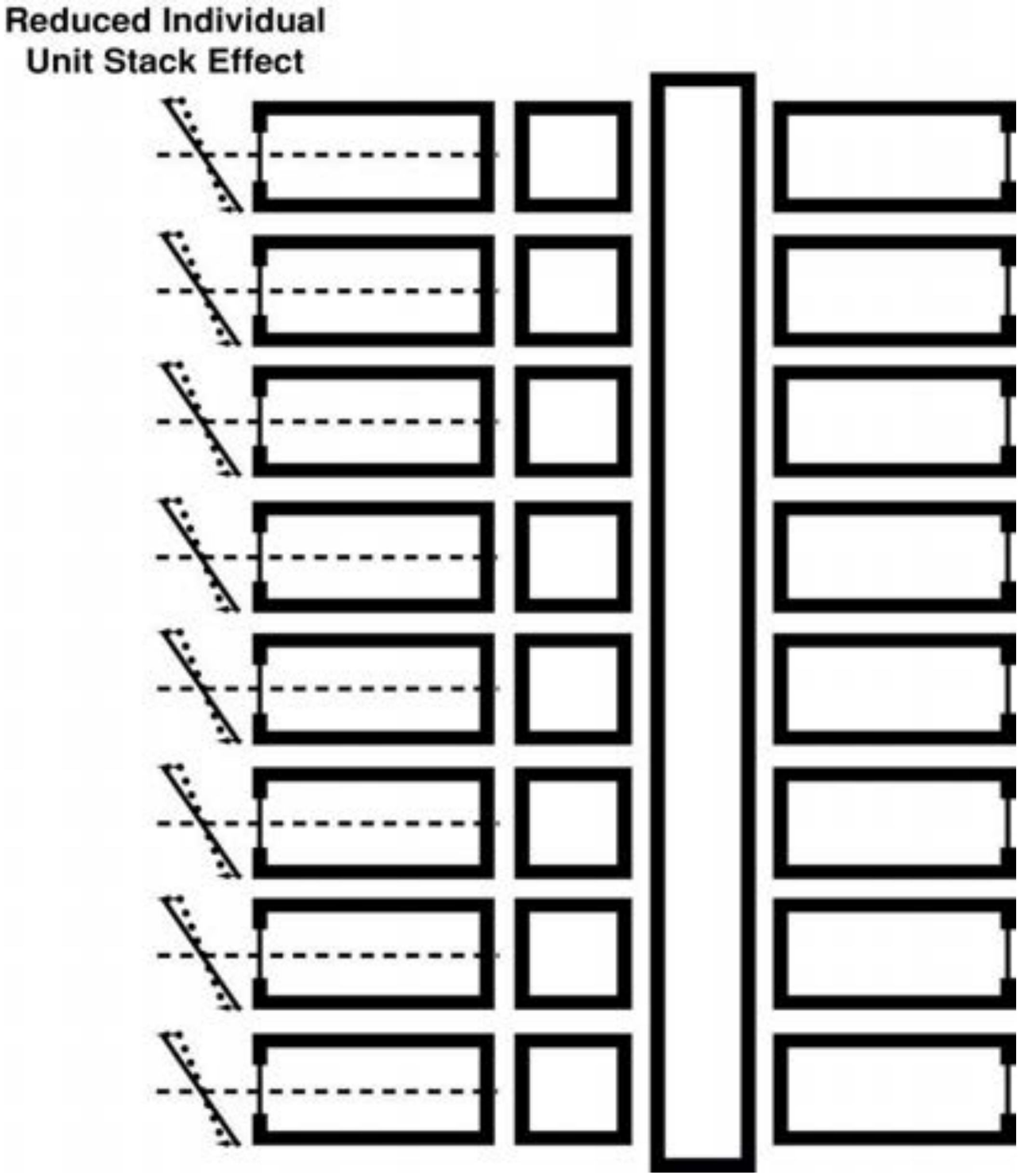

20
0
-20
-40
-60
-80
10
20
30
40
50
60
70
MINUTES
b=building
o=outside (west)
a=animal lab
+ Pbo 25.4
o Pao 9.7
• Pab -7.9

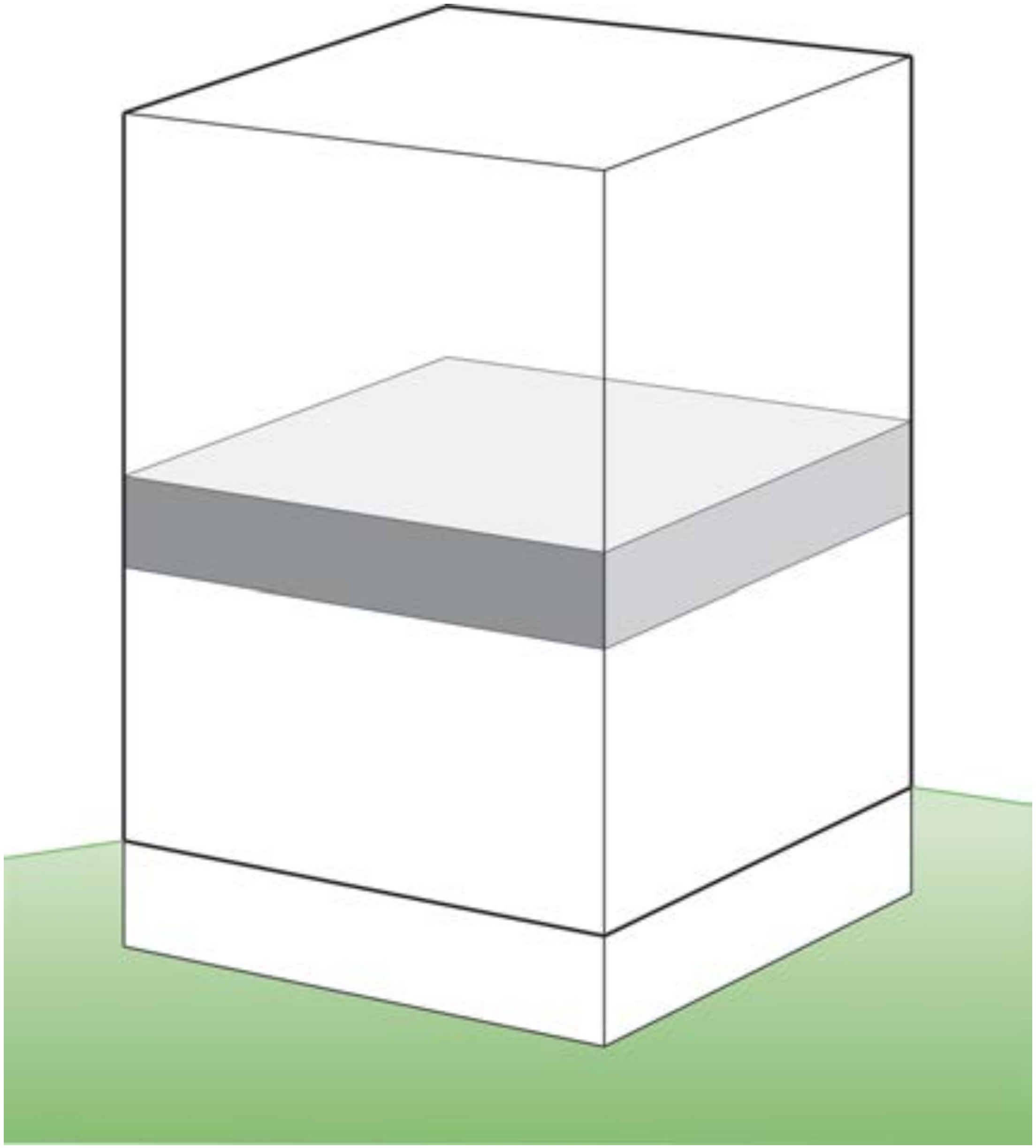


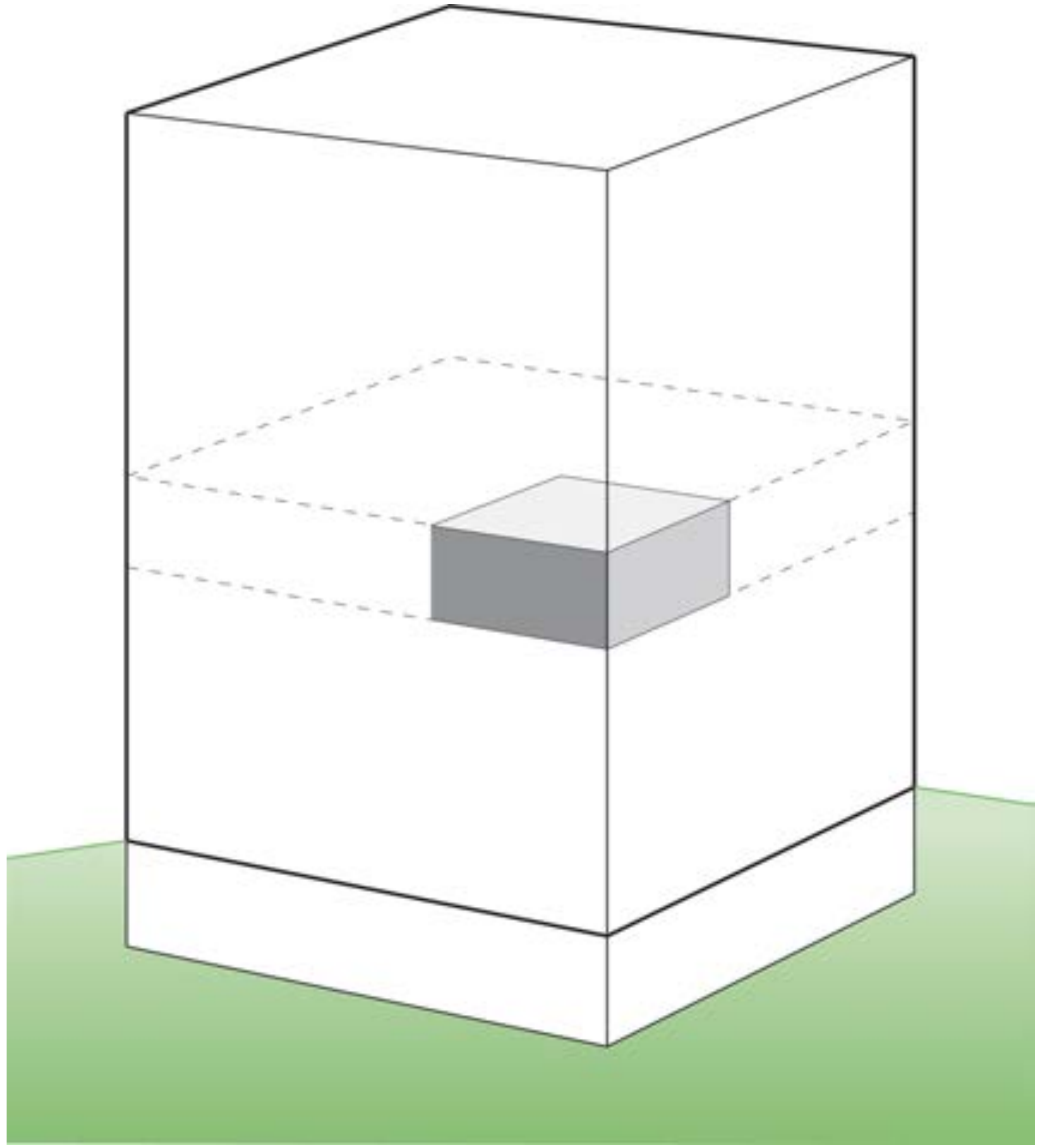

Flow and pressure key
flow:
6e+004 scfm
ΔP:
21 Pa
Penthouse
Fourth Floor
Seventh Floor
Third Floor
Zone identification icon
Sixth Floor
Leaks through floor set at 200 sf equivalent area
Second Floor
AHU Units
Animal lab
Main exhaust fan
Leaks to exterior apportioned by exposed surface area
Fifth Floor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

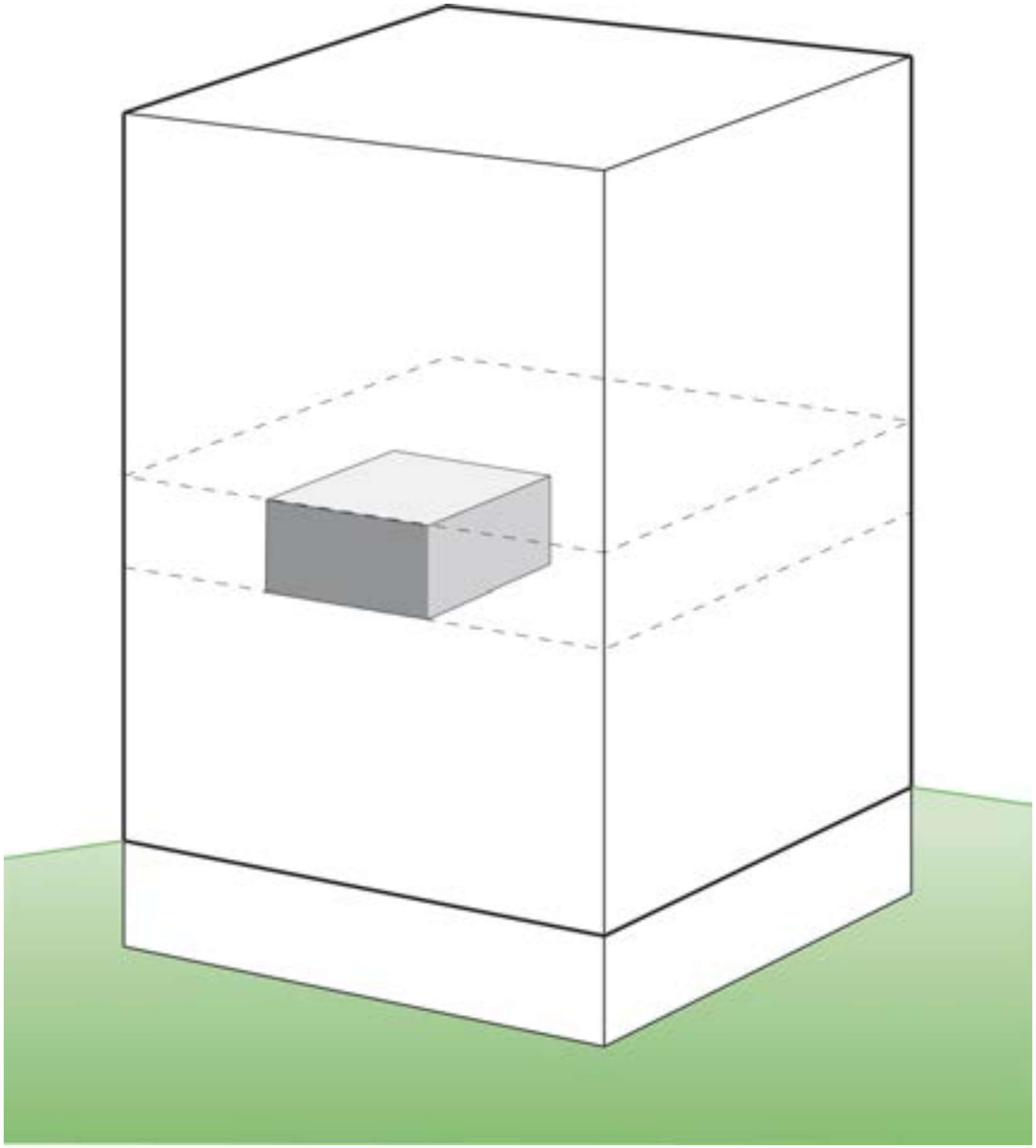


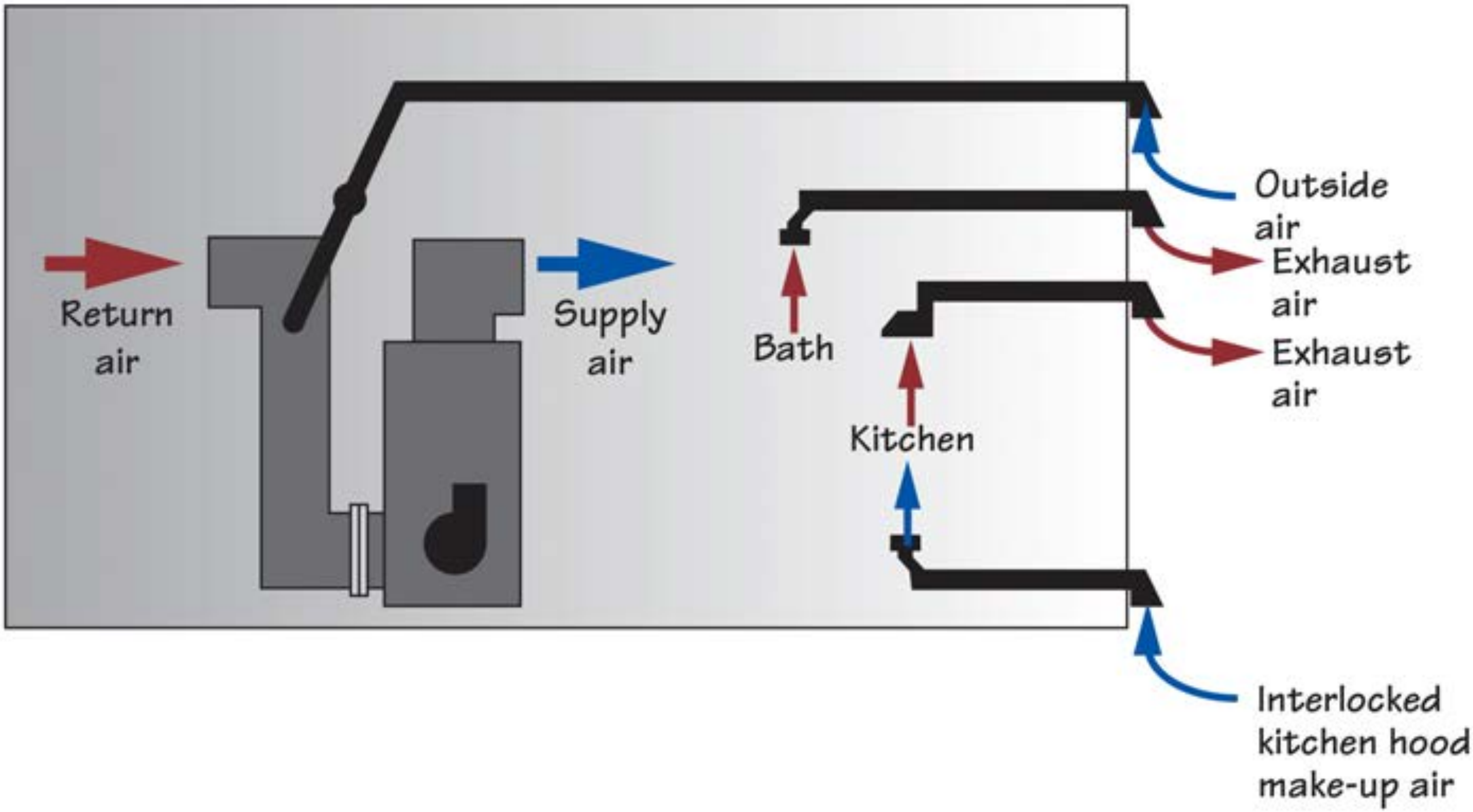

Stack Effect Flow Out
(Exfiltration)
P_{inside} drops with
height slower than
$P_{outside}$
$P_{outside}$ drops
with height faster
than P_{inside}
Neutral
Pressure Plane
Stack Effect Flow In
(Infiltration)

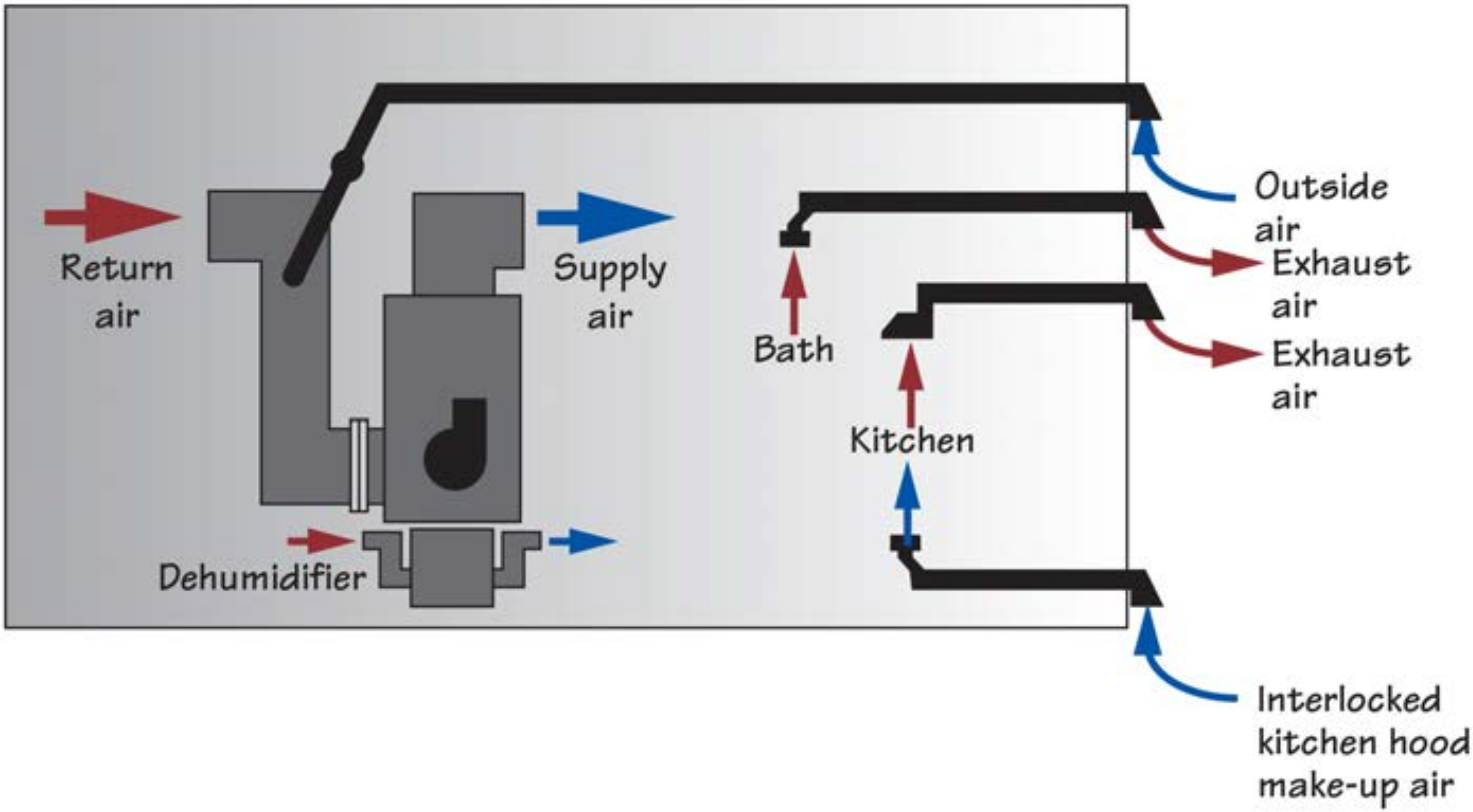

Reduced Individual
Unit Stack Effect

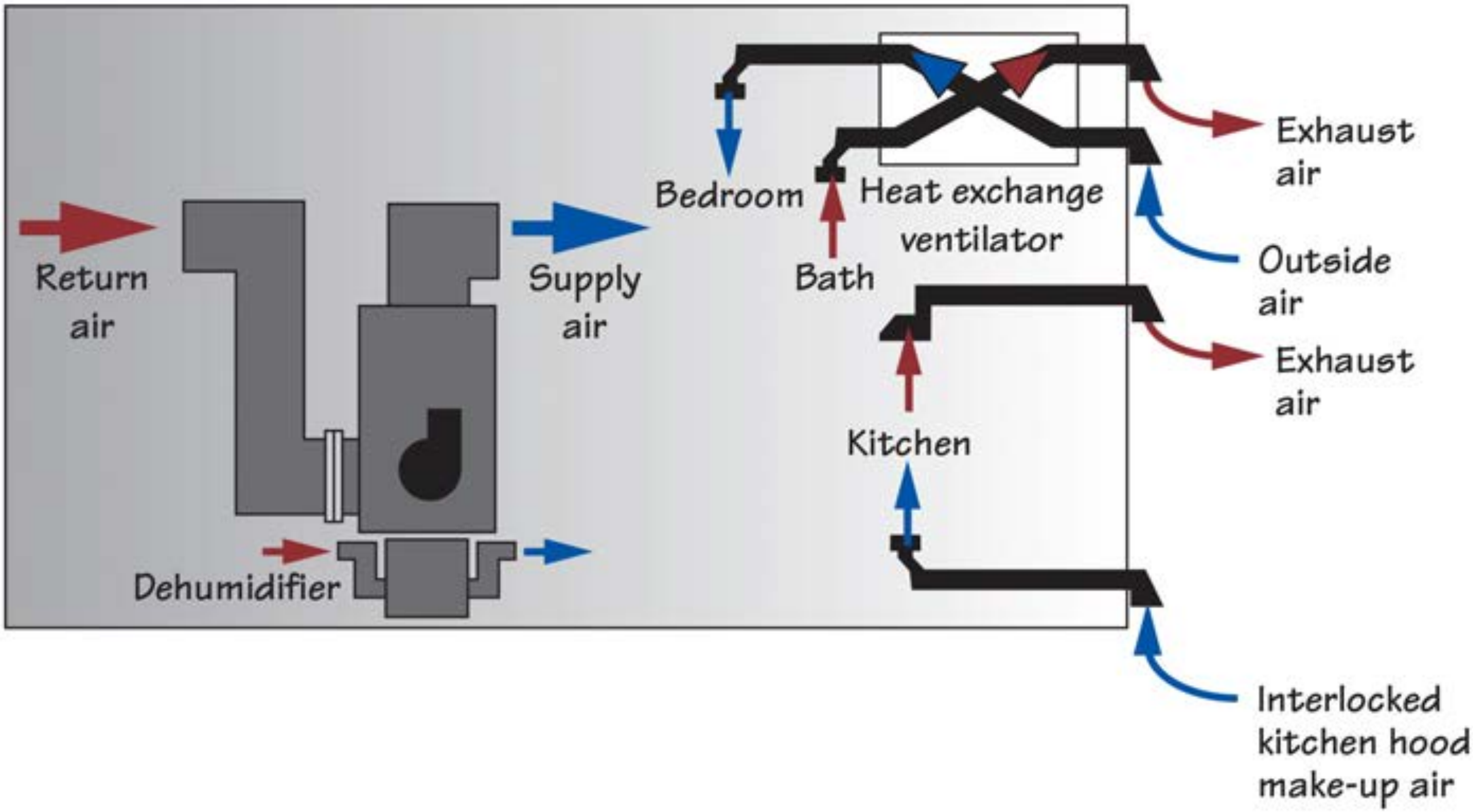


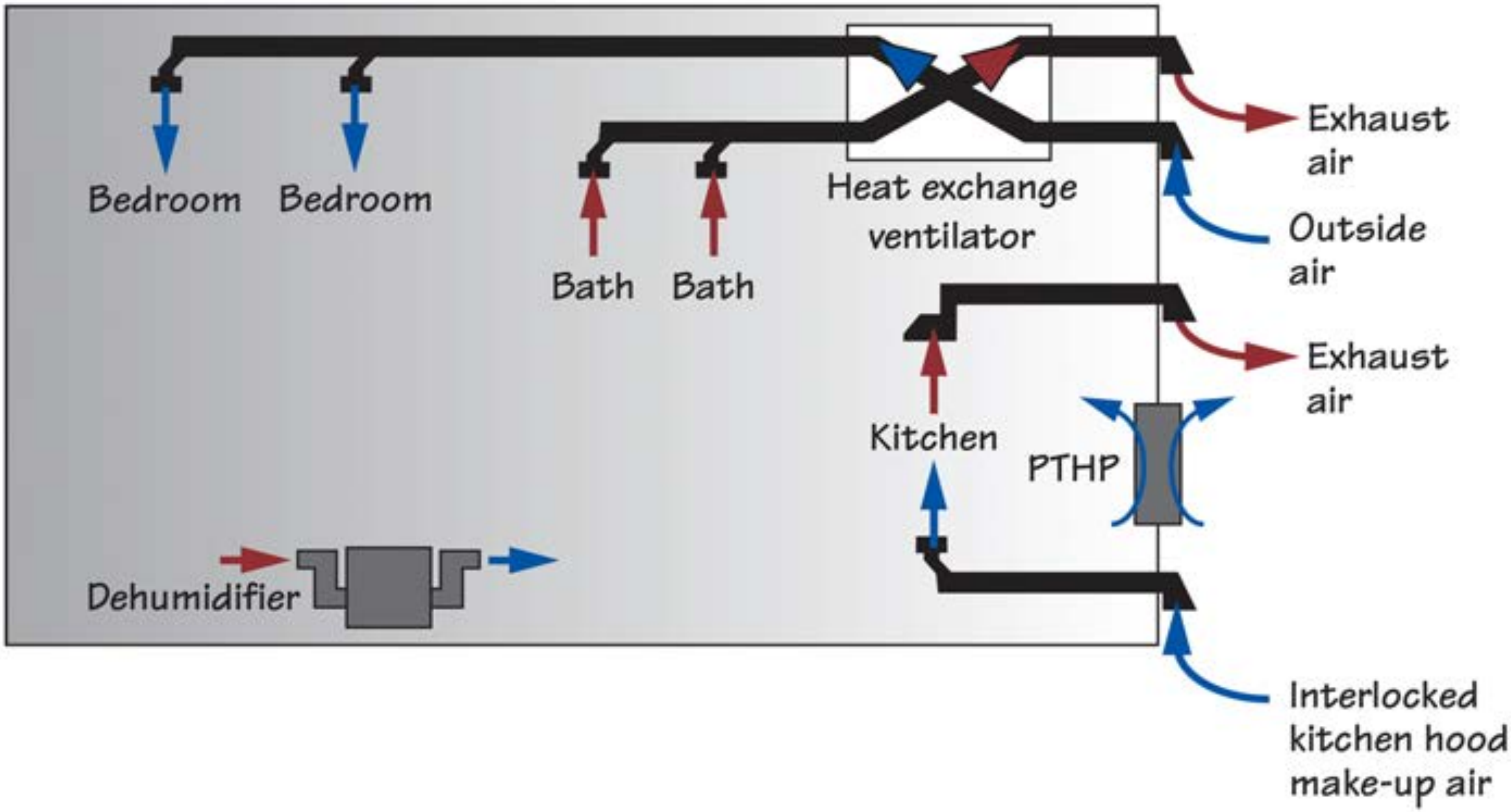


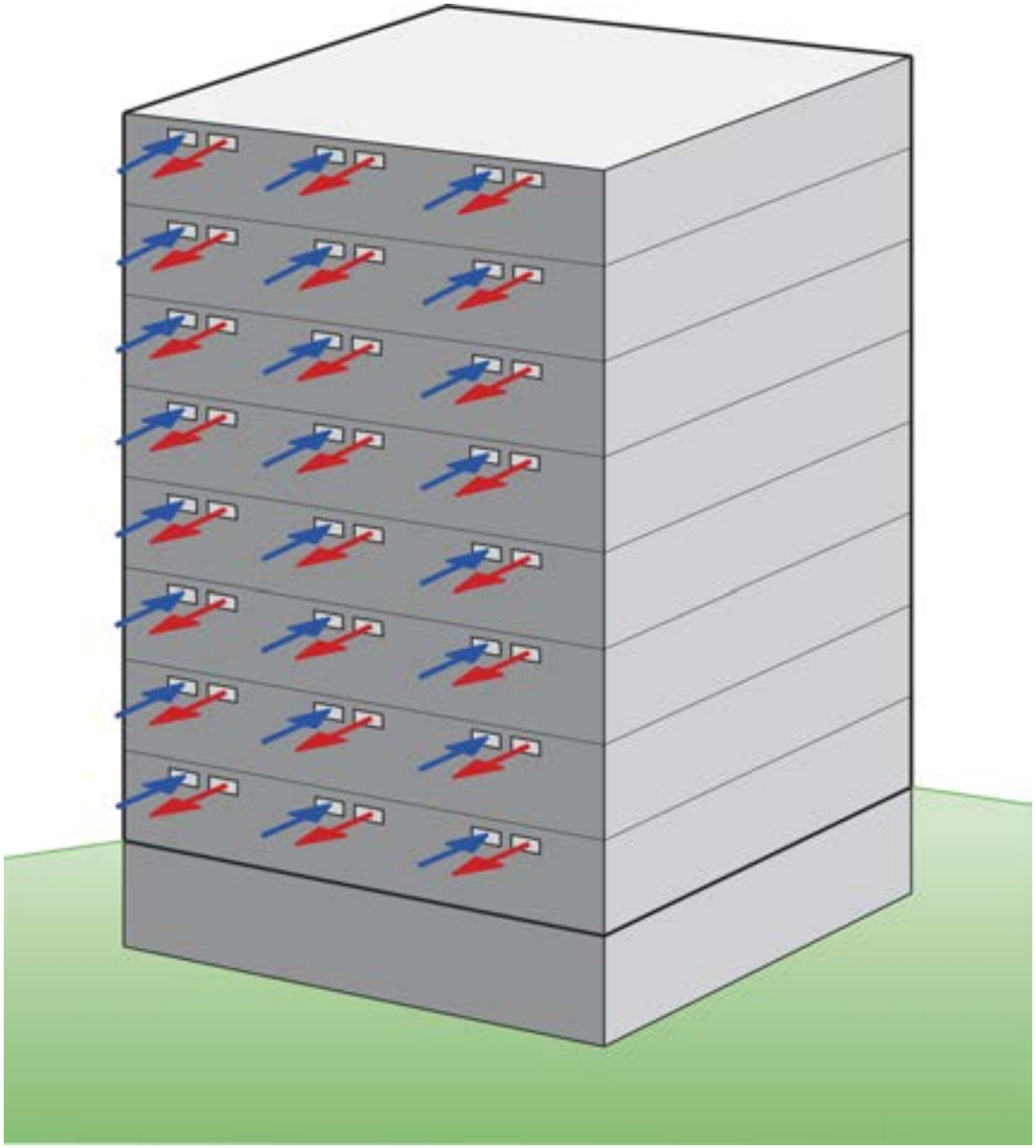


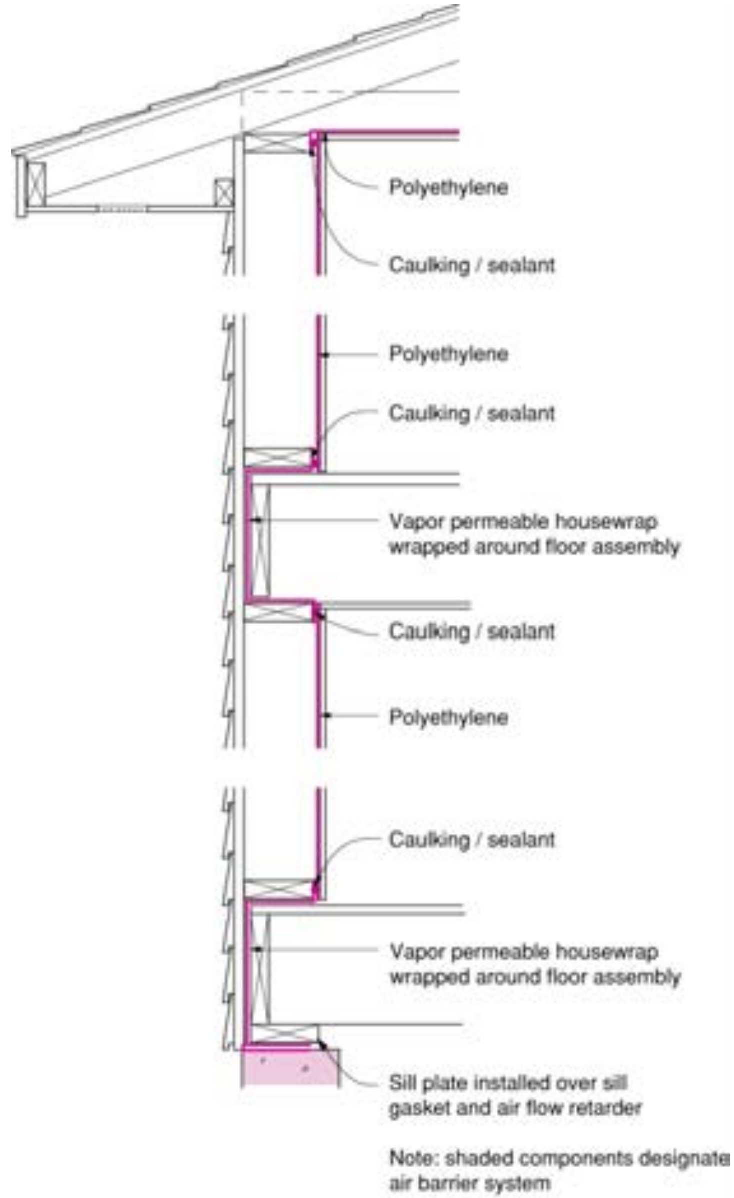

Return
air
Supply
air
Bath
Kitchen
Outside
air
Exhaust
air
Exhaust
air
Interlocked
kitchen hood
make-up air

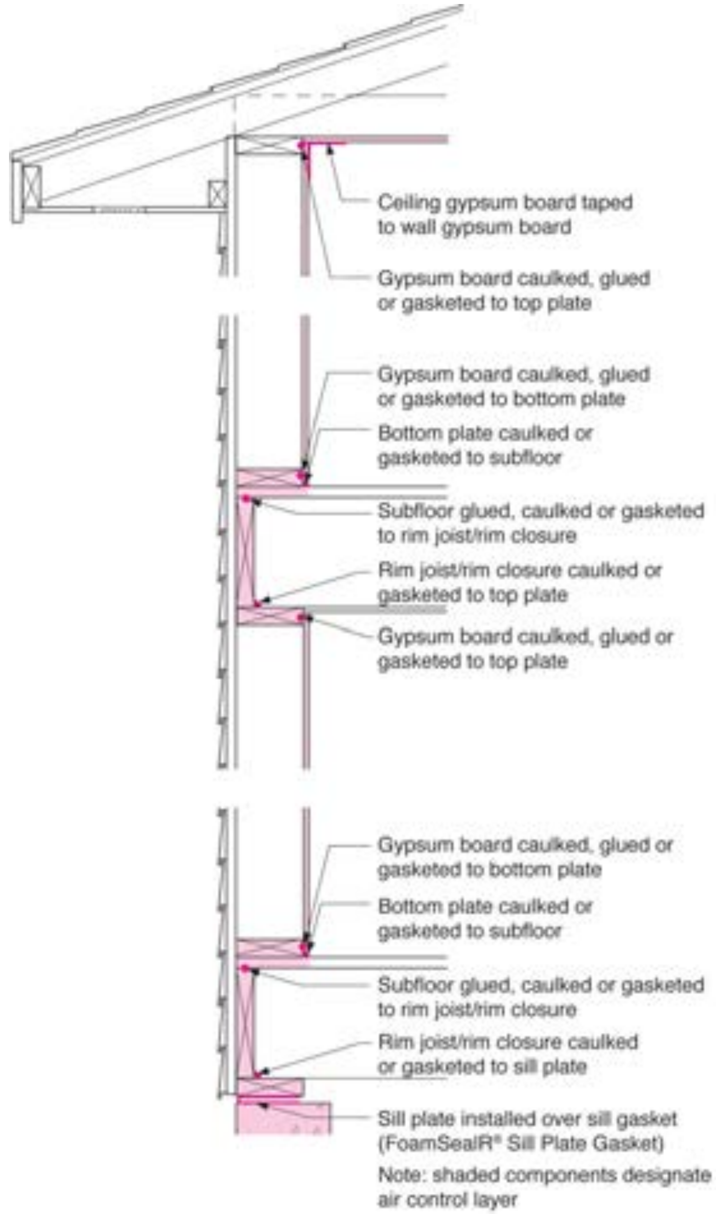

Return
air
Supply
air
Dehumidifier
Bath
Kitchen
Outside
air
Exhaust
air
Exhaust
air
Interlocked
kitchen hood
make-up air

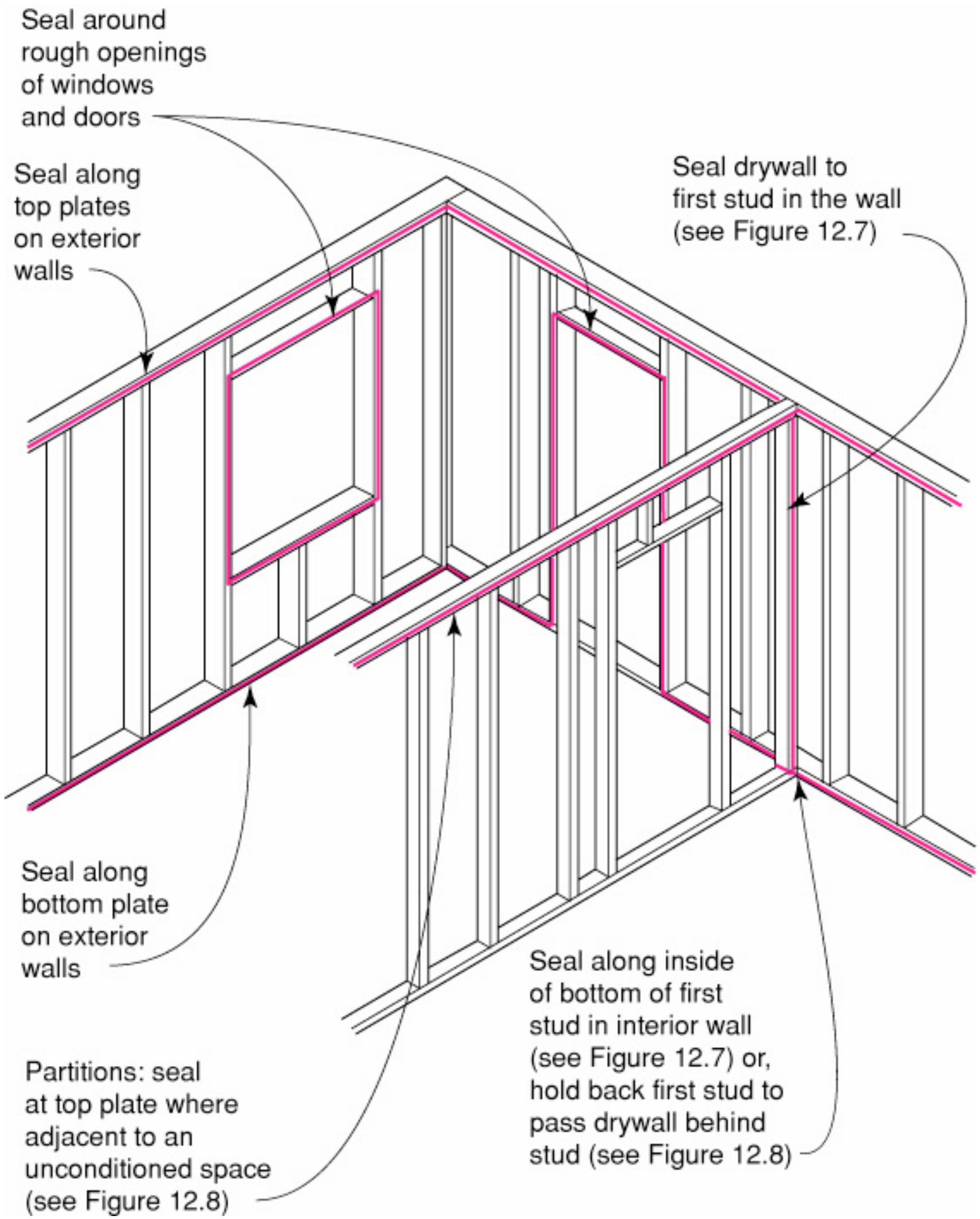

Return air
Dehumidifier
Supply air
Bedroom
Bath
Heat exchange ventilator
Exhaust air
Outside air
Exhaust air
Kitchen
Interlocked kitchen hood make-up air

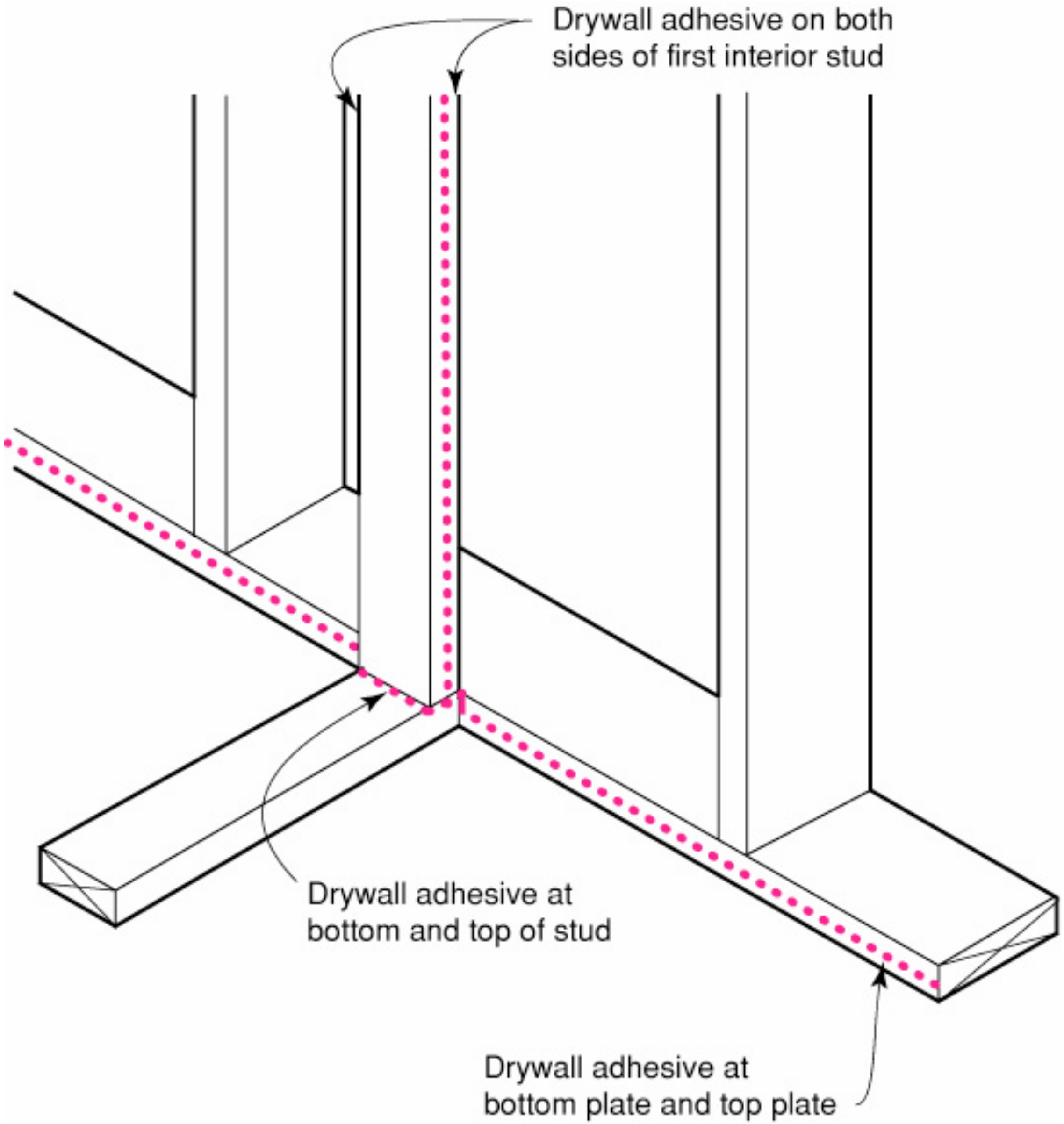

Bedroom
Bedroom
Bath
Bath
Heat exchange ventilator
Exhaust air
Outside air
Exhaust air
Kitchen
PTHP
Dehumidifier
Interlocked kitchen hood make-up air

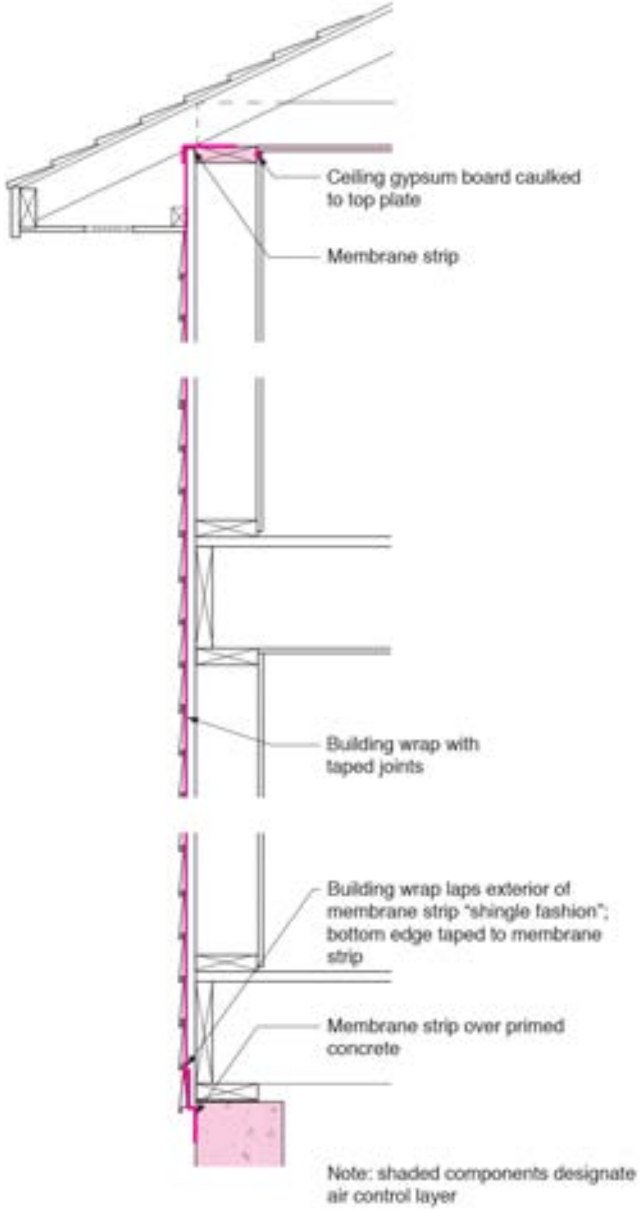



Polyethylene
Caulking / sealant
Polyethylene
Caulking / sealant
Vapor permeable housewrap
wrapped around floor assembly
Caulking / sealant
Polyethylene
Caulking / sealant
Vapor permeable housewrap
wrapped around floor assembly
Sill plate installed over sill
gasket and air flow retarder
Note: shaded components designate
air barrier system


Ceiling gypsum board taped
to wall gypsum board
Gypsum board caulked, glued
or gasketed to top plate
Gypsum board caulked, glued
or gasketed to bottom plate
Bottom plate caulked or
gasketed to subfloor
Subfloor glued, caulked or gasketed
to rim joist/rim closure
Rim joist/rim closure caulked or
gasketed to top plate
Gypsum board caulked, glued or
gasketed to top plate
Gypsum board caulked, glued or
gasketed to bottom plate
Bottom plate caulked or
gasketed to subfloor
Subfloor glued, caulked or gasketed
to rim joist/rim closure
Rim joist/rim closure caulked
or gasketed to sill plate
Sill plate installed over sill gasket
(FoamSealR® Sill Plate Gasket)
Note: shaded components designate
air control layer


Seal around rough openings of windows and doors
Seal along top plates on exterior walls
Seal drywall to first stud in the wall (see Figure 12.7)
Seal along bottom plate on exterior walls
Seal along inside of bottom of first stud in interior wall (see Figure 12.7) or, hold back first stud to pass drywall behind stud (see Figure 12.8)
Partitions: seal at top plate where adjacent to an unconditioned space (see Figure 12.8)


Drywall adhesive on both
sides of first interior stud
Drywall adhesive at
bottom and top of stud
Drywall adhesive at
bottom plate and top plate


Ceiling gypsum board caulked to top plate
Membrane strip
Building wrap with taped joints
Building wrap laps exterior of membrane strip "shingle fashion"; bottom edge taped to membrane strip
Membrane strip over primed concrete
Note: shaded components designate air control layer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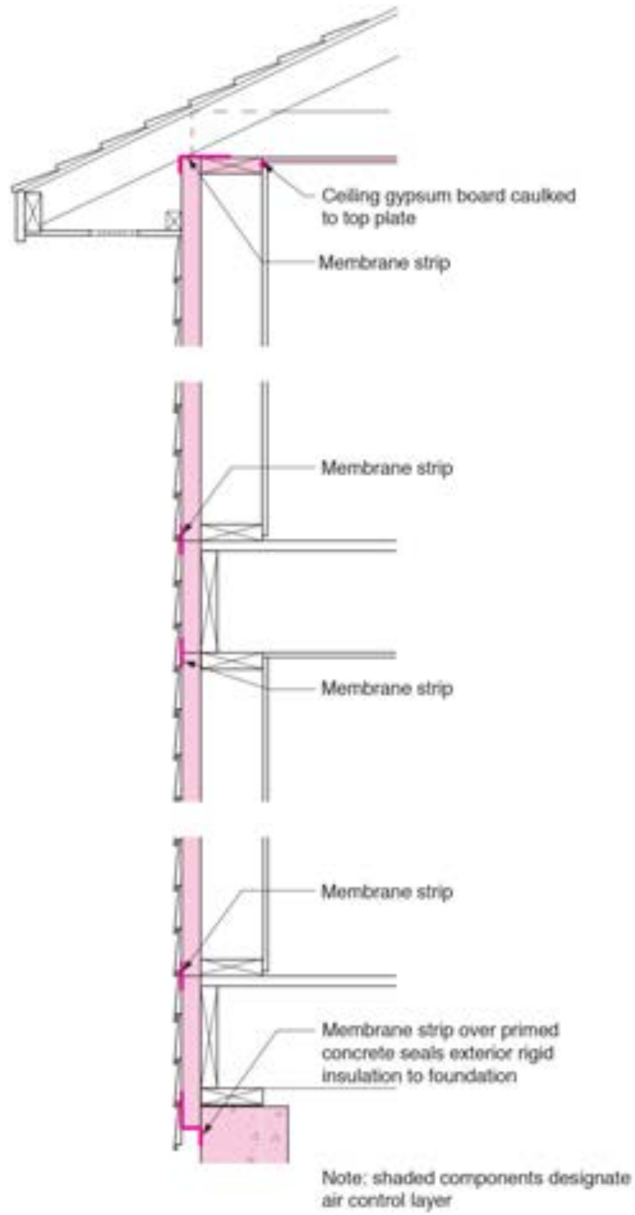
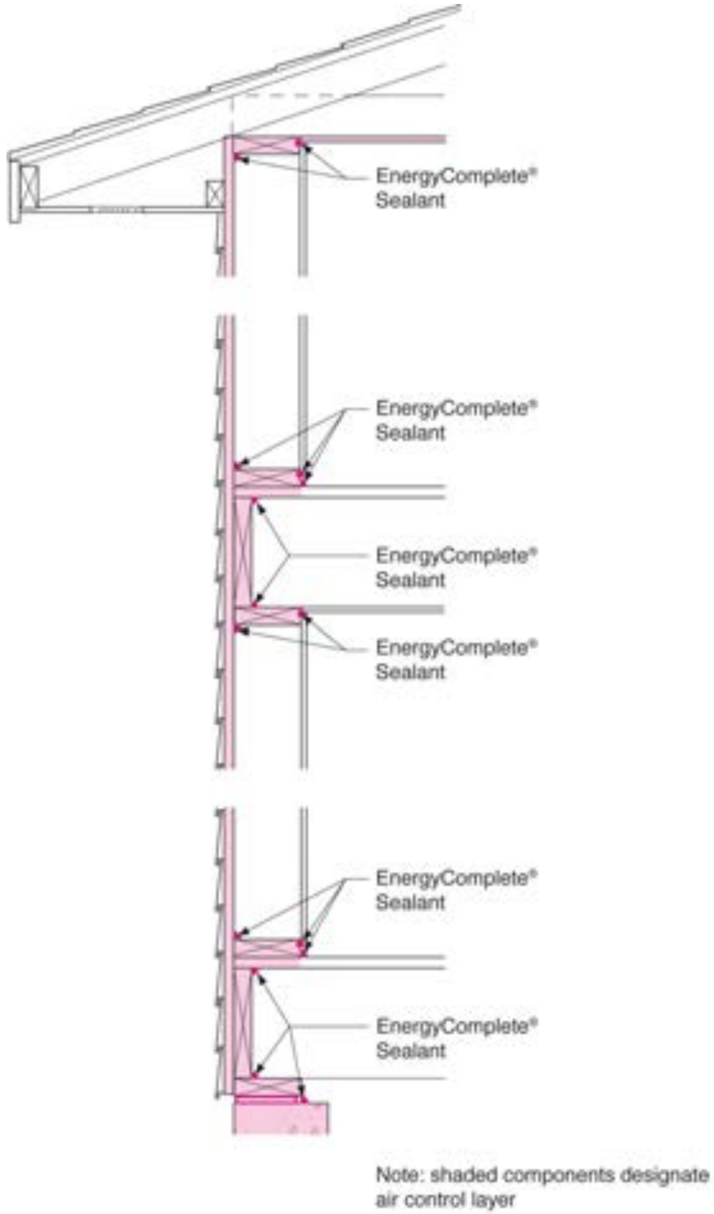

Ceiling gypsum board caulked
to top plate
Membrane strip
Membrane strip
Membrane strip
Membrane strip
Membrane strip over primed
concrete seals exterior rigid
insulation to foundation
Note: shaded components designate
air control layer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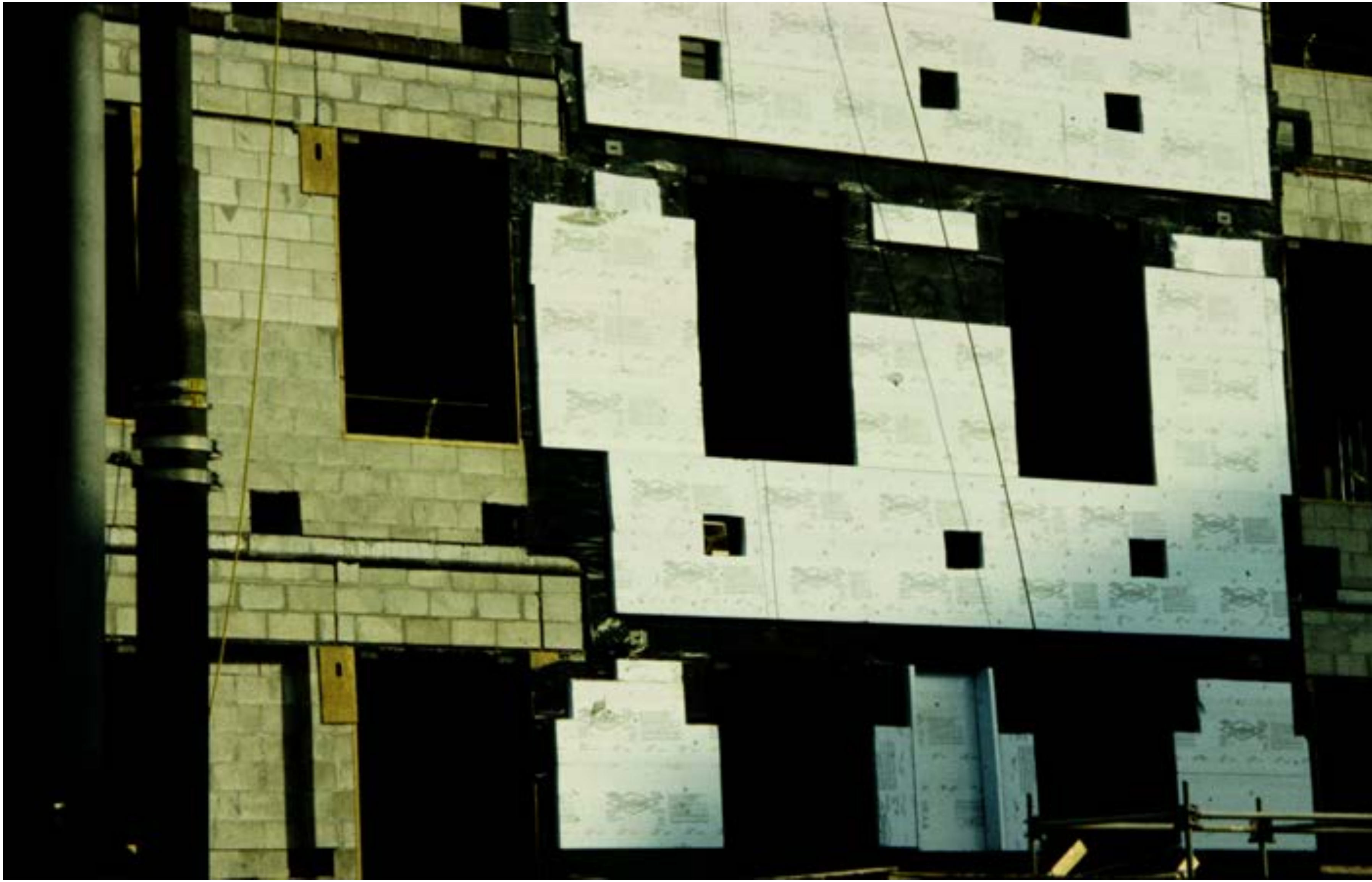
Note: shaded components designate
air control layer


TallWall


GP
DensGlass
Sheathing




HARVARD SCHOOL OF PUBLIC HEALTH


CAUTION
HARD HAT
AREA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DENSGLASS GOLD
Exterior Sheathing


Blueskin


AVAILAB


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DANGER
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LUCIANO


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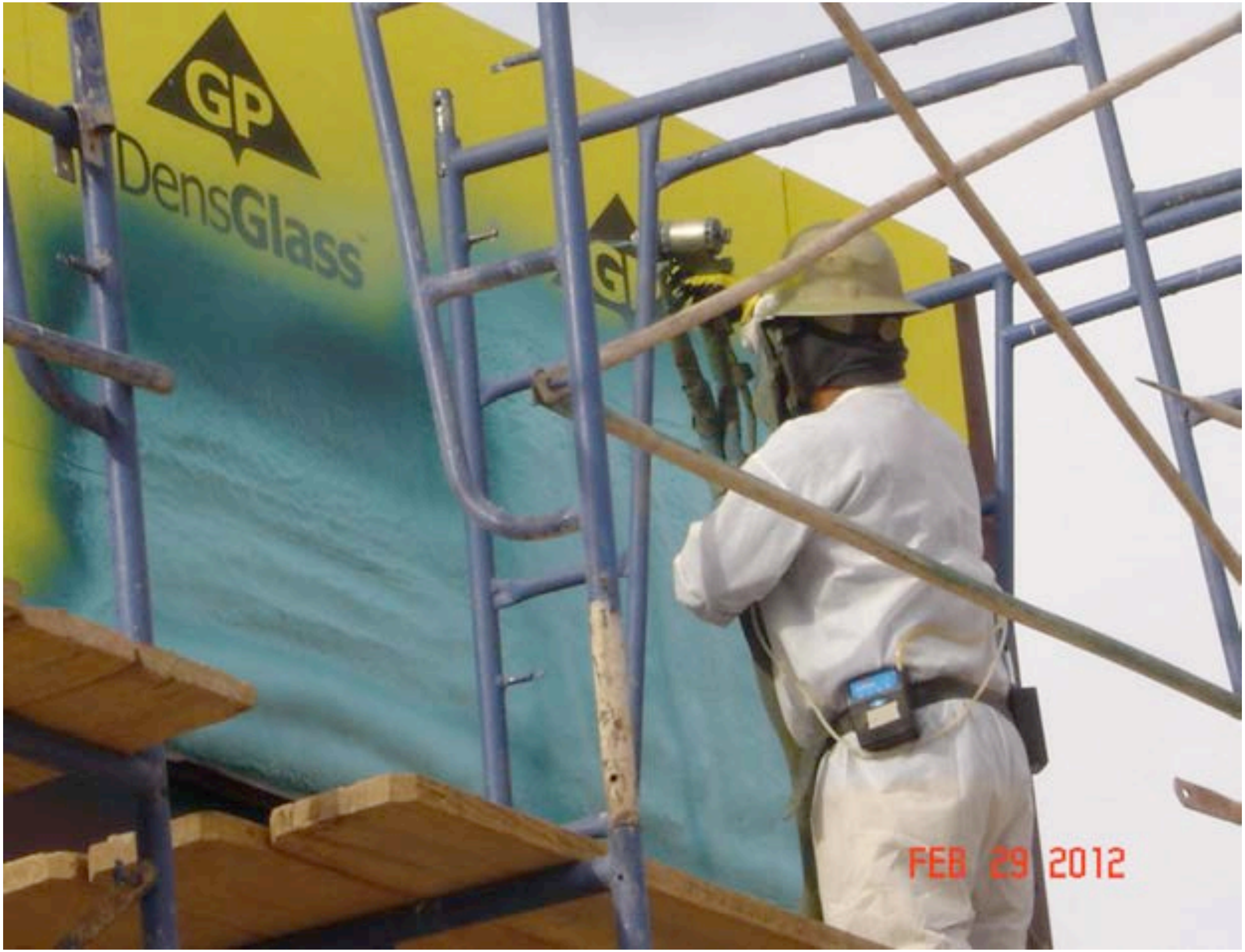
GP
DensGlass
FEB 29 2012


Tribute
Tribute
Tribute

	NORMALIZED AIR FLOW												LEAKAGE AREAS	
	75 Pascals			50 Pascals			10 Pascals			4 Pascals			10 Pascal	4 Pascal
	(l/s-m^2)	ft^3/min-ft^2	(m^3/h-m^2)	(l/s-m^2)	(ft^3/min-ft^2)	(m^3/h-m^2)	(l/s-m^2)	ft^3/min-ft^2	(m^3/h-m^2)	(l/s-m^2)	(ft^3/min-ft^2)	(m^3/h-m^2)	EqLA/100 ft^2	ELA/100 ft^2
enclosure	2.000	0.394	7.200	1.537	0.303	5.532	0.540	0.106	1.943	0.298	0.059	1.071	3.136	1.670
assembly	0.200	0.039	0.720	0.154	0.030	0.553	0.054	0.011	0.194	0.030	0.006	0.107	0.314	0.167
material	0.020	0.004	0.072	0.015	0.003	0.055	0.005	0.001	0.019	0.003	0.001	0.011	0.031	0.017