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

# Building Science

## Ventilation

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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

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## Lapse Rate

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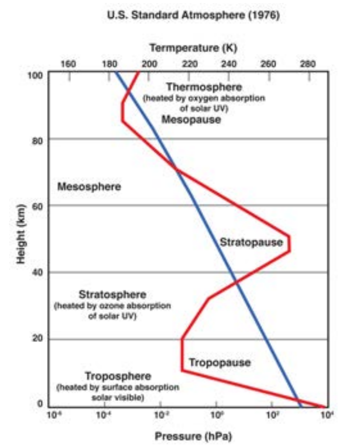


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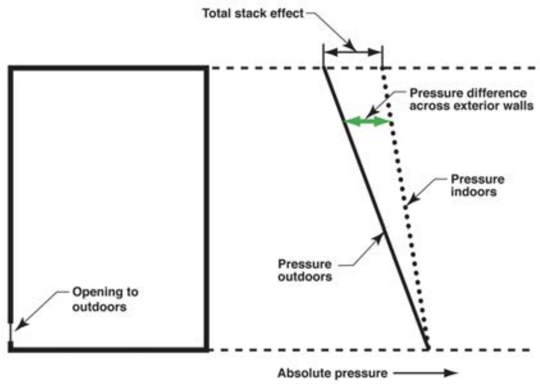


Figure 11.1: Building with no internal separations with opening at the bottom (Adapted from G.O. Handegord, 1998)

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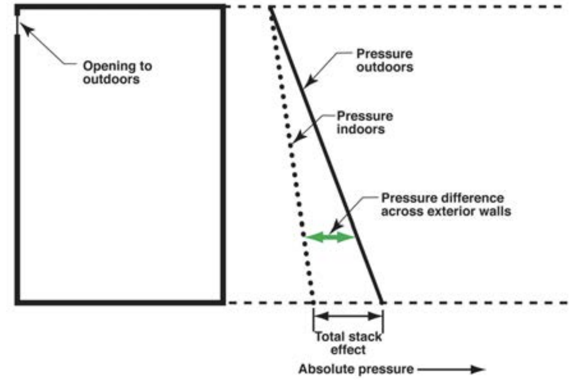


Figure 11.2: Building with no internal separations with opening at the top (Adapted from G.O. Handegord, 1998)

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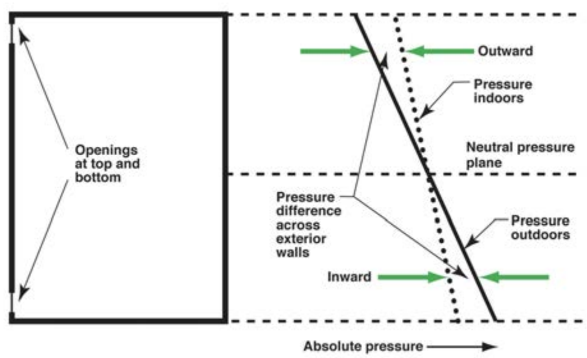


Figure 11.3: Building with no internal separations with openings at top and bottom (Adapted from G.O. Handegord, 1998)

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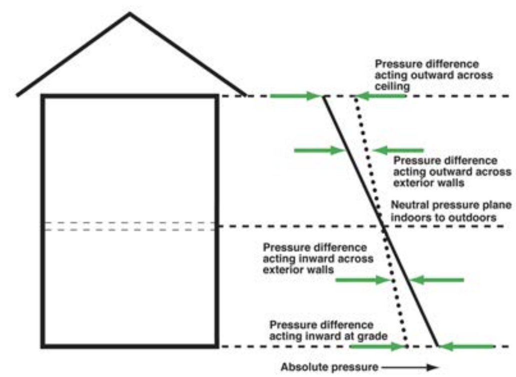


Figure 11.4: Basic two storey house with vented attic (Adapted from G.O. Handegord, 1998)

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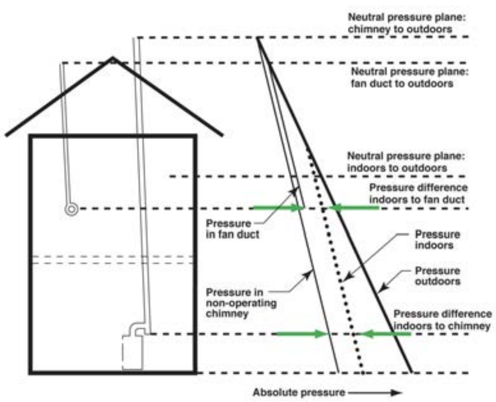


Figure 11.5: Two storey house with non-operating chimney and exhaust fan (Adapted from G.O. Handegord, 1998)

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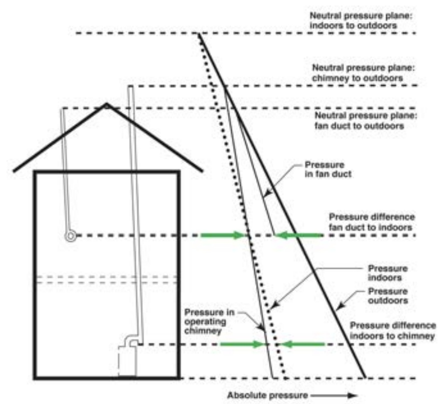


Figure 11.6: Two storey house with operating chimney (Adapted from G.O. Handegord, 1998)

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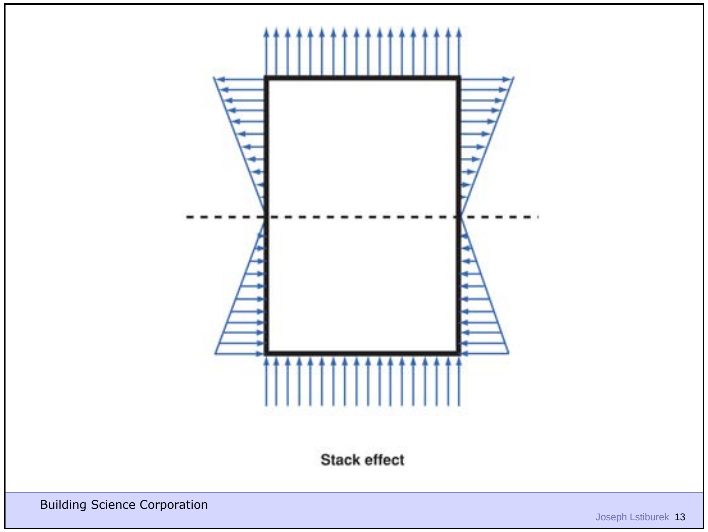
Stack effect
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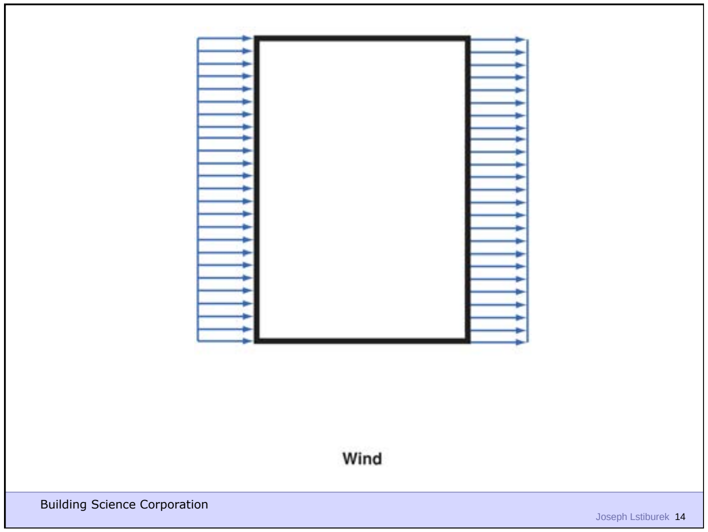
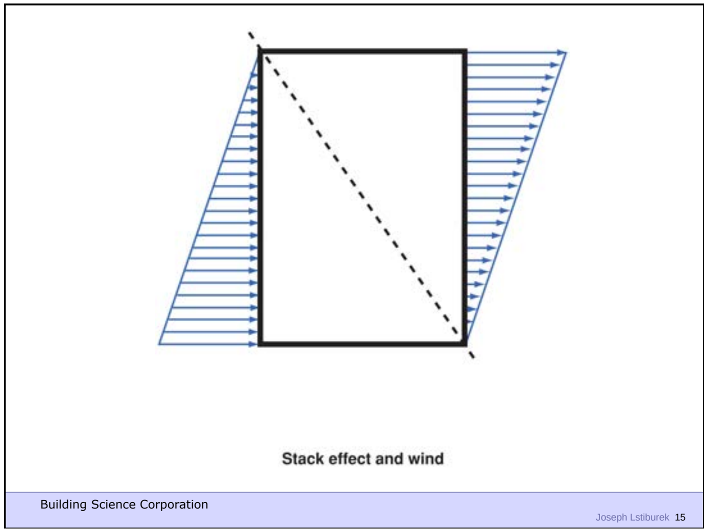

Wind
Building Science Corporation
Joseph Lstiburek 14


Stack effect and wind
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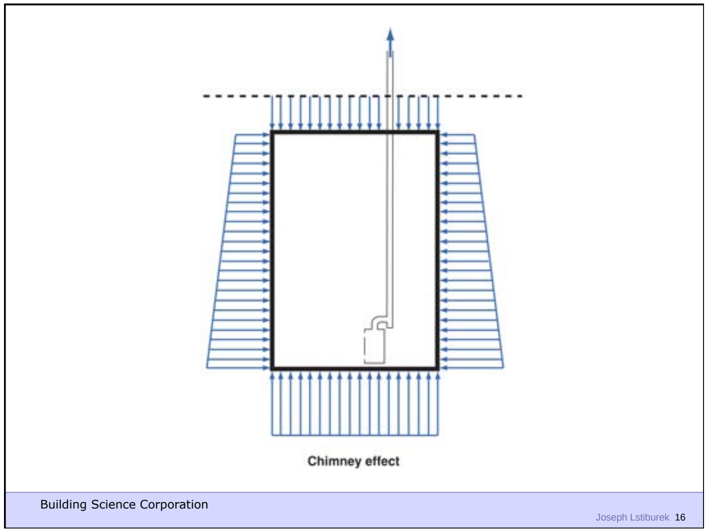
Joseph Lstiburek 15


Chimney effect
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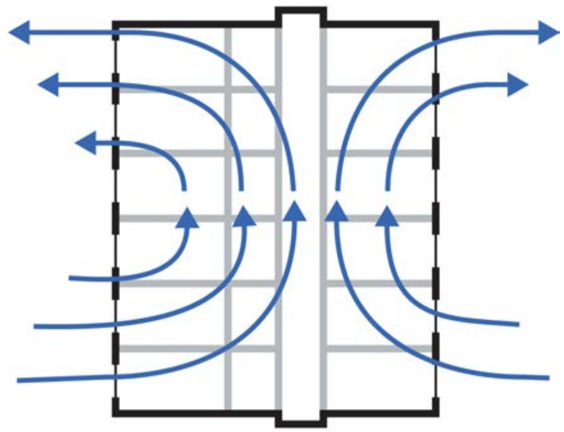

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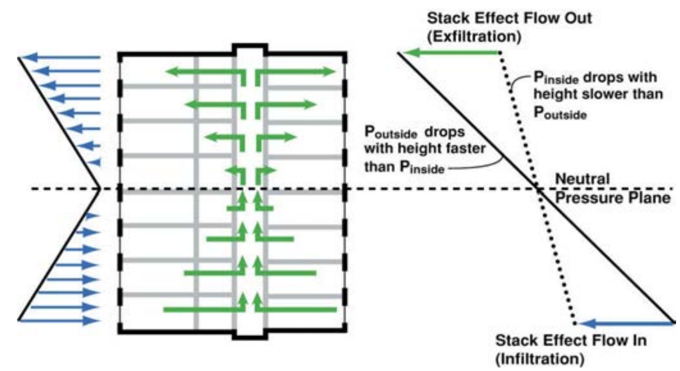
Joseph Lstiburek 17

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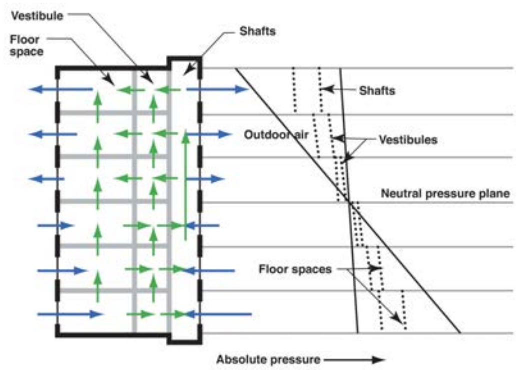


Figure 11.8: Stack effect pressures in high rise office building
(Adapted from G.O. Handegord, 1998)

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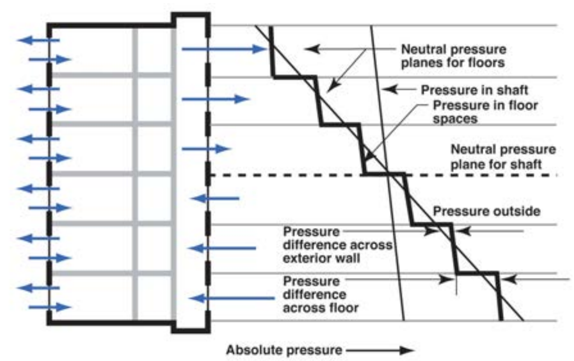


Figure 11.9: Multi-storey building with floor spaces isolated from vertical shafts
(Adapted from G.O. Handegord, 1998)

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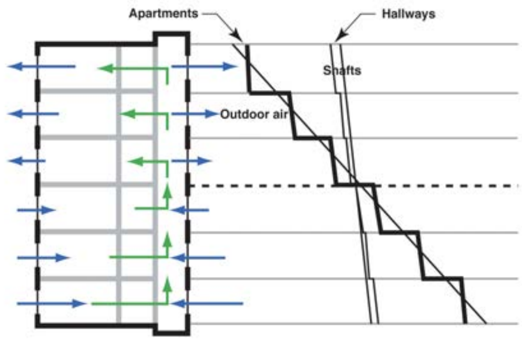


Figure 11.12: Apartment building with tighter apartment entry doors (Adapted from G.O. Handegord, 1998)

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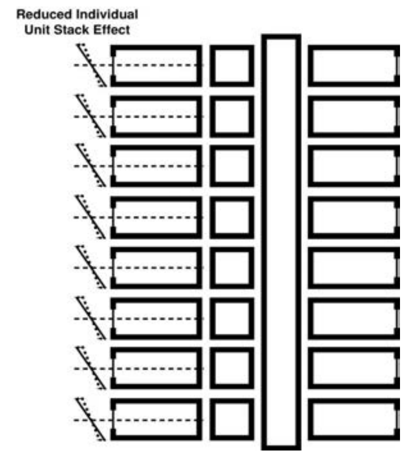


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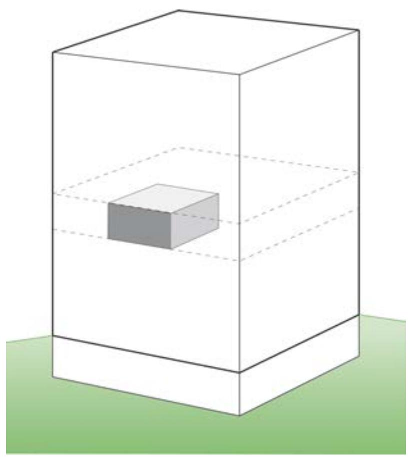

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Figure 3.12
**Ductwork and Air Handlers in Basements**

- No air pressure differences result in a house with an air handler and ductwork located in a basement if there are no leaks in the supply ducts, the return ducts or the air handler and if the amount of air delivered to each room equals the amount removed

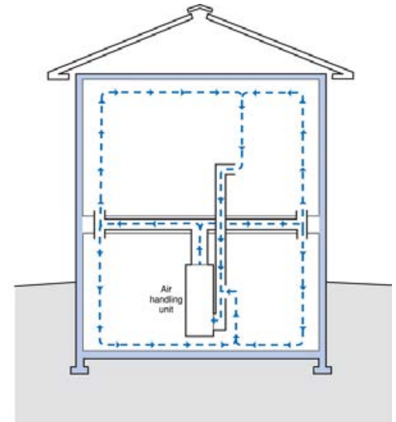


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Figure 3.13
**Ductwork and Air Handlers in Vented Attics**

- No air pressure differences result in a house with an air handler and ductwork located in a vented attic if there are no leaks in the supply ducts, the return ducts or the air handler and if the amount of air delivered to each room equals the amount removed

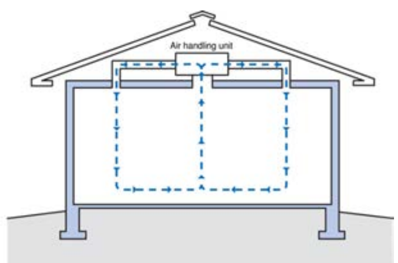


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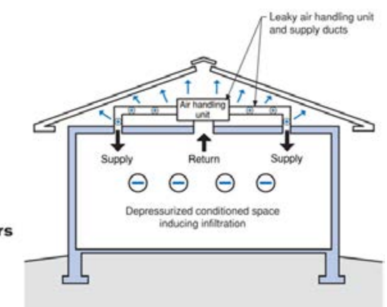
Figure 3.15
**Leaky Ductwork and Air Handlers in Vented Attics**

- Supply ductwork and air handler leakage is typically 20% or more of the flow through the system

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Joseph Lstiburek – Airflow 32

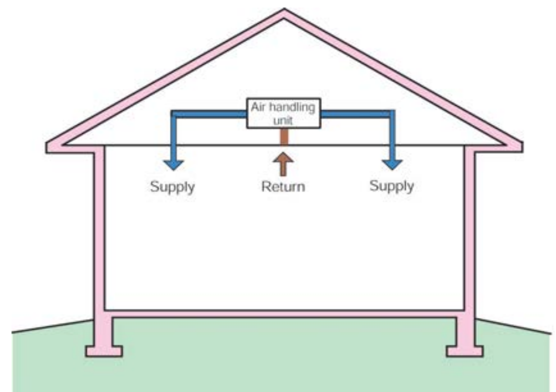




Duct Leakage Should Be Less Than 5% of Rated Flow As

Tested By Pressurization To 25 Pascals






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

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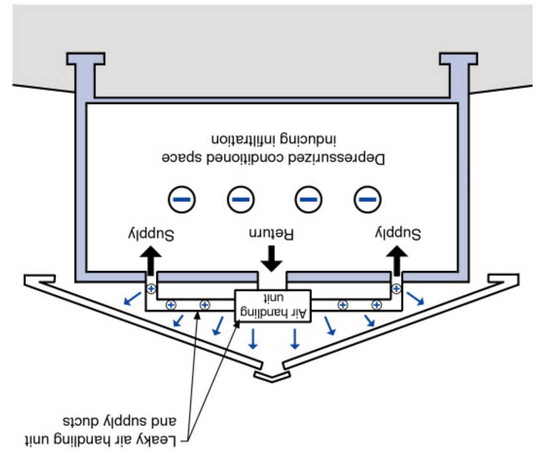


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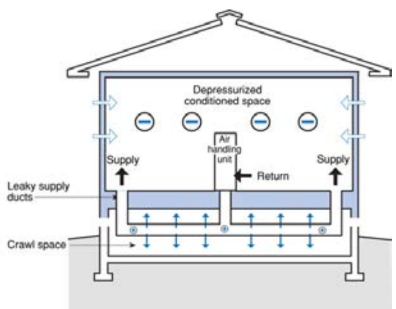
Figure 3.16

**Leaky Supply Ductwork in Vented Crawl Space**

- Air pressurization pattern with mechanical system ducts in the crawl space

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Joseph Lstiburek – Airflow 40

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Joseph Lstiburek – Airflow 41

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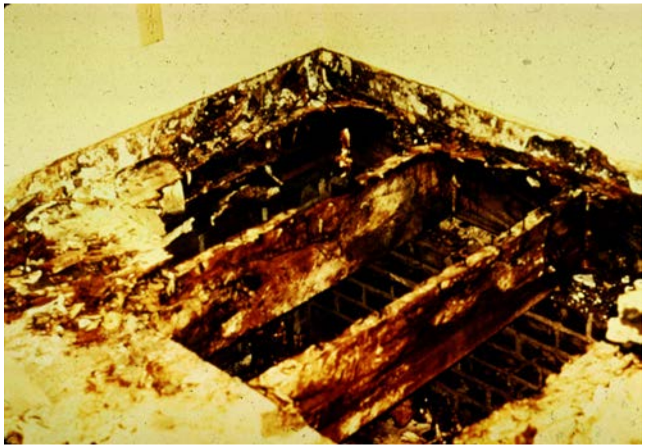
Joseph Lstiburek – Airflow 42



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Joseph Lstiburek – Airflow 44

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Joseph Lstiburek – Airflow 45

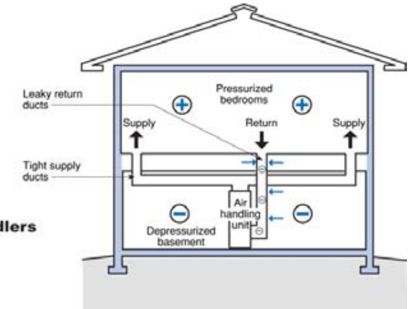


Figure 3.14

**Leaky Ductwork and Air Handlers in Basements**

- Air pressurization patterns in a house with leaky ductwork in the basement

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Joseph Lstiburek – Airflow 50

Building Science Corporation

Joseph Lstiburek – Airflow 51

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Joseph Lstiburek – Airflow 52

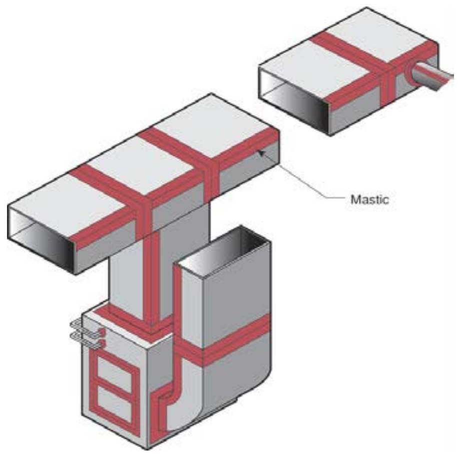


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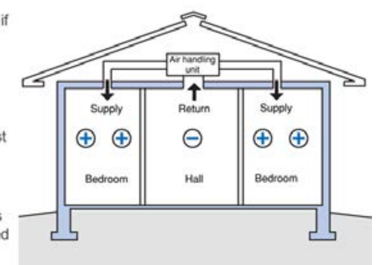
Figure 3.18

**Insufficient Return Air Paths**

- Pressurization of bedrooms often occurs if insufficient return pathways are provided; undercutting bedroom doors is usually insufficient; transfer grilles, jump ducts or fully ducted returns may be necessary to prevent pressurization of bedrooms
- Master bedroom suites are often the most pressurized as they typically receive the most supply air
- When bedrooms pressurized, common areas depressurize; this can have serious consequences when fireplaces are located in common areas and subsequently backdraft

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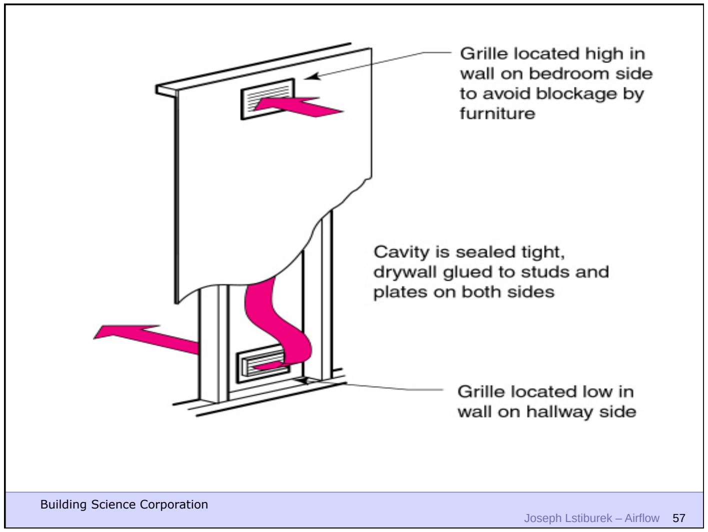
Grille located high in wall on bedroom side to avoid blockage by furniture
Cavity is sealed tight, drywall glued to studs and plates on both sides
Grille located low in wall on hallway side
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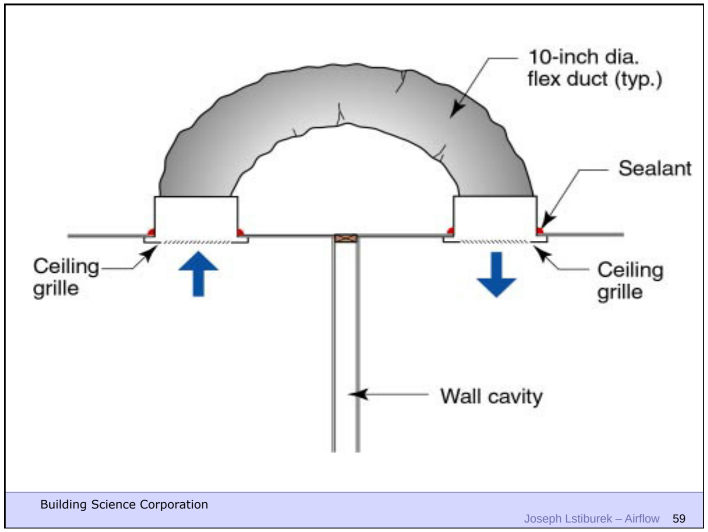
10-inch dia. flex duct (typ.)
Sealant
Ceiling grille
Ceiling grille
Wall cavity
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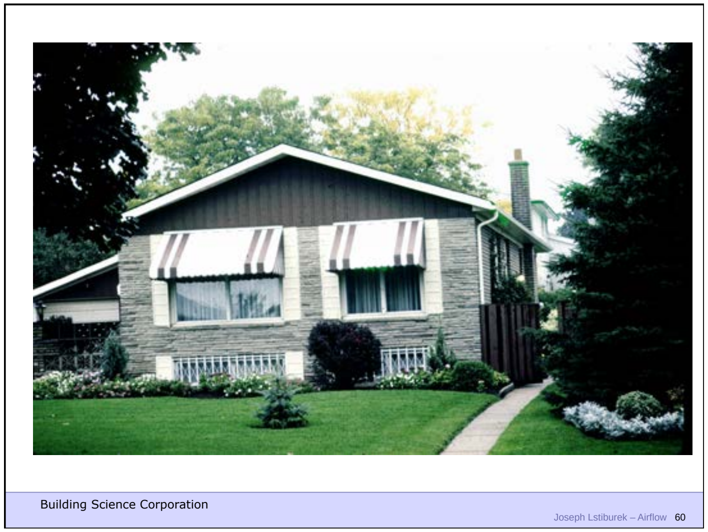
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Joseph Lstiburek – Airflow 61


Building Science Corporation
Joseph Lstiburek – Airflow 62

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Joseph Lstiburek – Airflow 63

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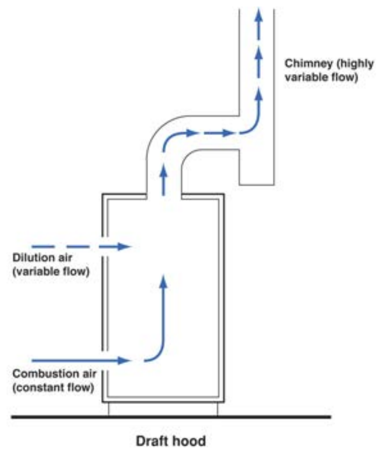
Joseph Lstiburek – Airflow 64

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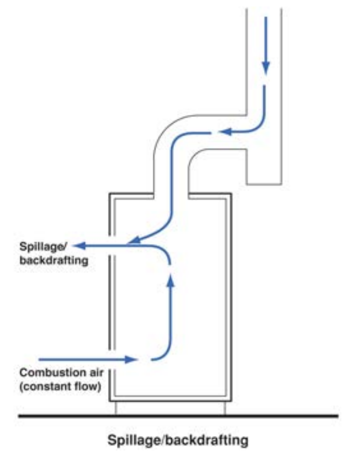


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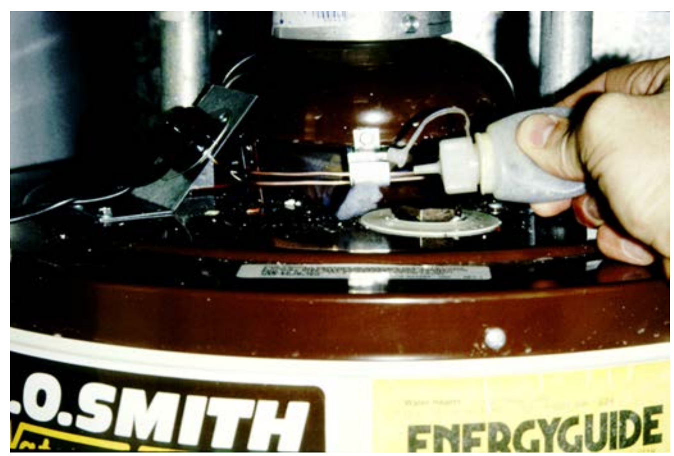
Joseph Lstiburek – Airflow 67

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Joseph Lstiburek – Airflow 70

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

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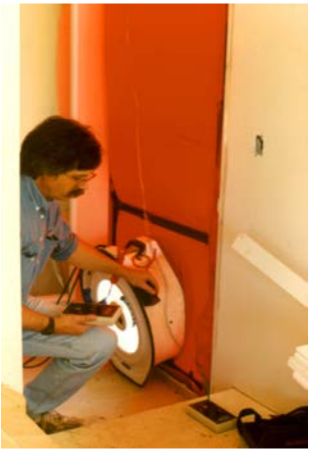

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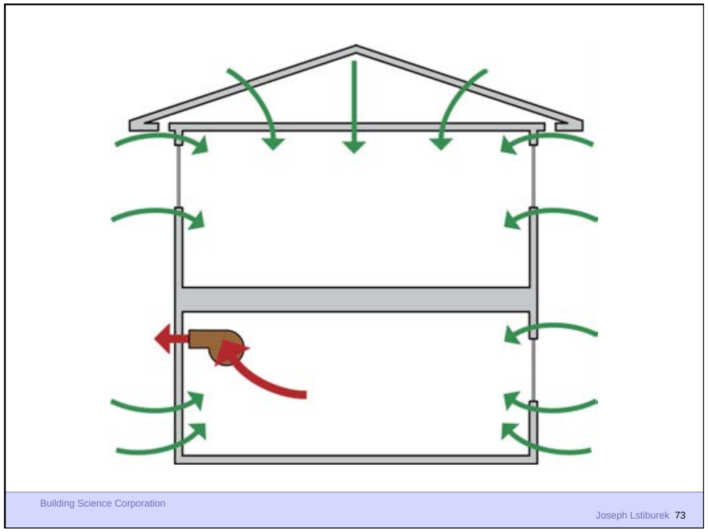
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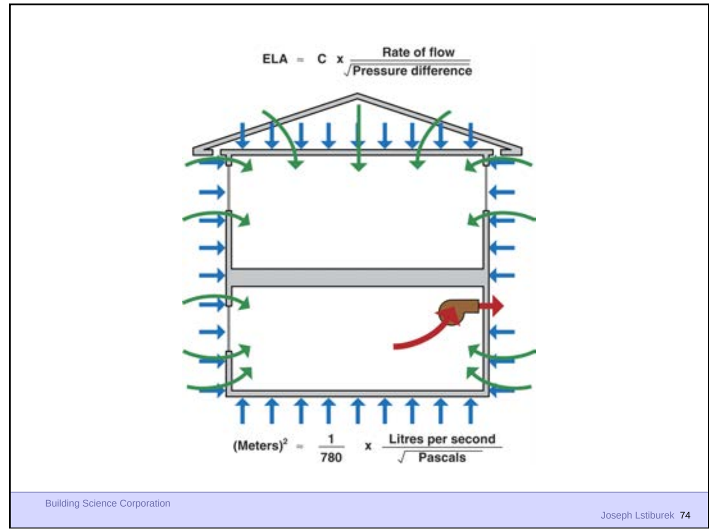
ELA = C x Rate of flow / √Pressure difference
(Meters)² = 1/780 x Litres per second / √ Pascals
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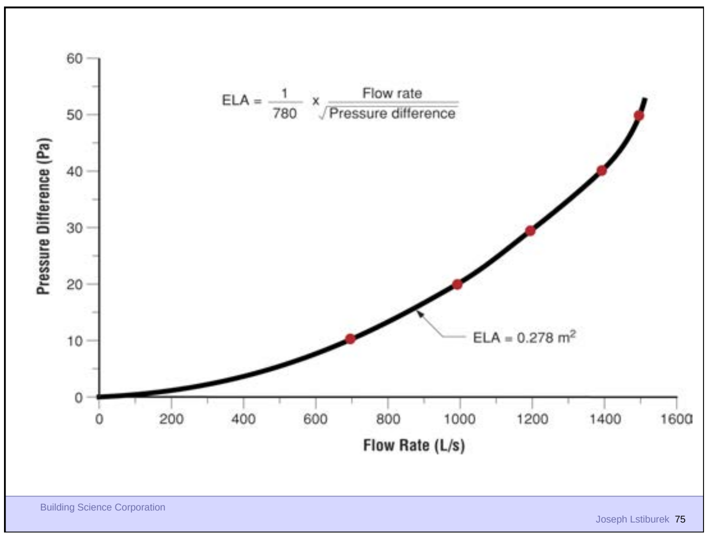
ELA = 1/780 x Flow rate / √Pressure difference
ELA = 0.278 m²
Pressure Difference (Pa)
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
1400
1600
Flow Rate (L/s)
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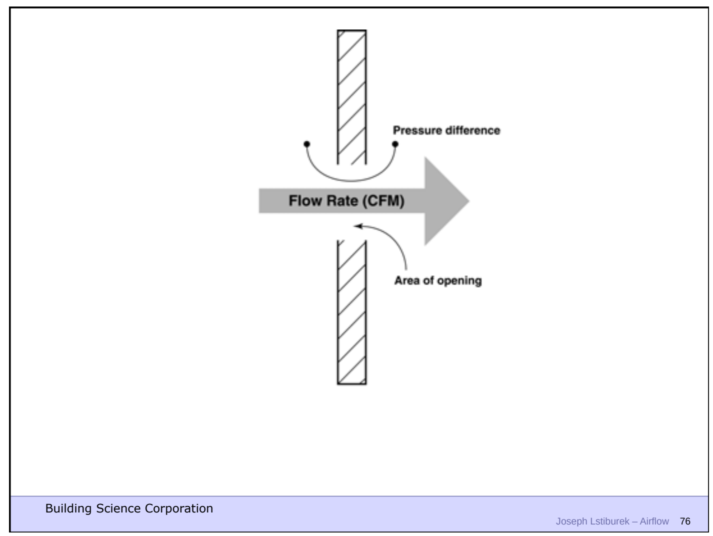
Pressure difference
Flow Rate (CFM)
Area of opening
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Flow Through Orifices

Turbulent Flow - "inertial effects"

Flow Through Porous Media

Laminar Flow - "viscosity effects"

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Flow Through Orifices

Turbulent Flow - "inertial effects"

Flow Through Porous Media

Laminar Flow - "viscosity effects"

"true but not useful"

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

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

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

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

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

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

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



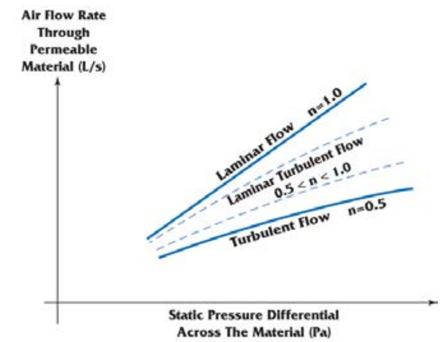
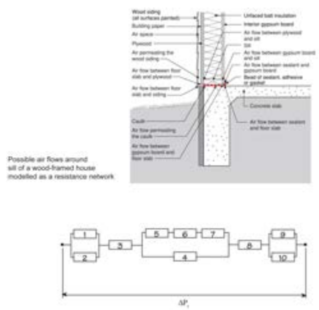



Figure 2.5
**Modes of Air Flow**
(from Bumbaru, Jutras and Patenaude, 1988)



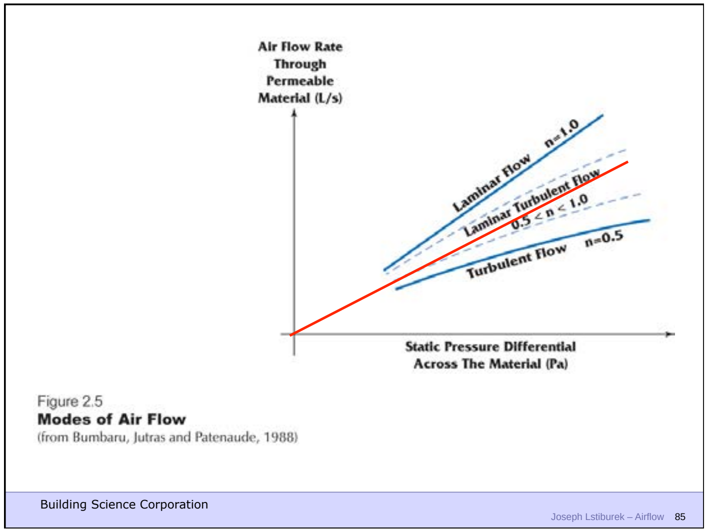



1. Air permeating the wood-panel cladding
2. Air flow between floor slab and panel
3. Air flow between floor slab and wind protection
4. Air permeating the caulking
5. Air flow between wind protection and sill
6. Air flow bewteen insulation material and sill
7. Air flow between inner lining and sill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



Figure 2.11
**Three Dimensional Multi-Layer Multi-Cell Analogue**


Air Flow Rate Through Permeable Material (L/s)
Laminar Flow n=1.0
Laminar Turbulent Flow 0.5 < n < 1.0
Turbulent Flow n=0.5
Static Pressure Differential Across The Material (Pa)
Figure 2.5
Modes of Air Flow
(from Bumbaru, Jutras and Patenaude, 1988)
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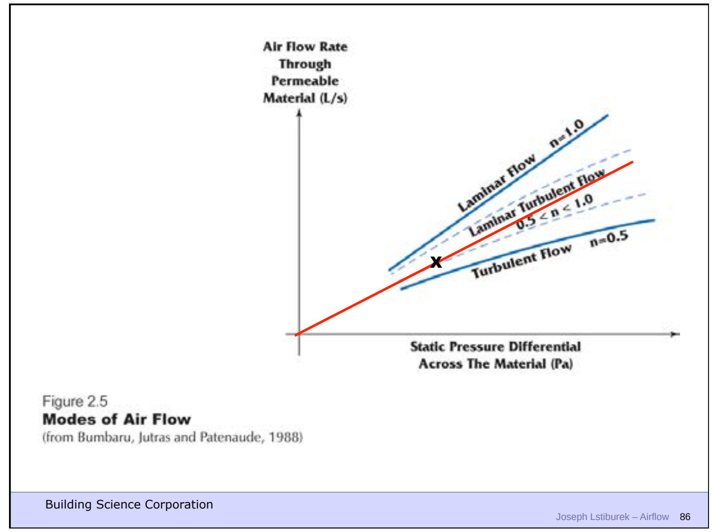
Air Flow Rate Through Permeable Material (L/s)
Laminar Flow n=1.0
Laminar Turbulent Flow 0.5 < n < 1.0
Turbulent Flow n=0.5
X
Static Pressure Differential Across The Material (Pa)
Figure 2.5
Modes of Air Flow
(from Bumbaru, Jutras and Patenaude, 1988)
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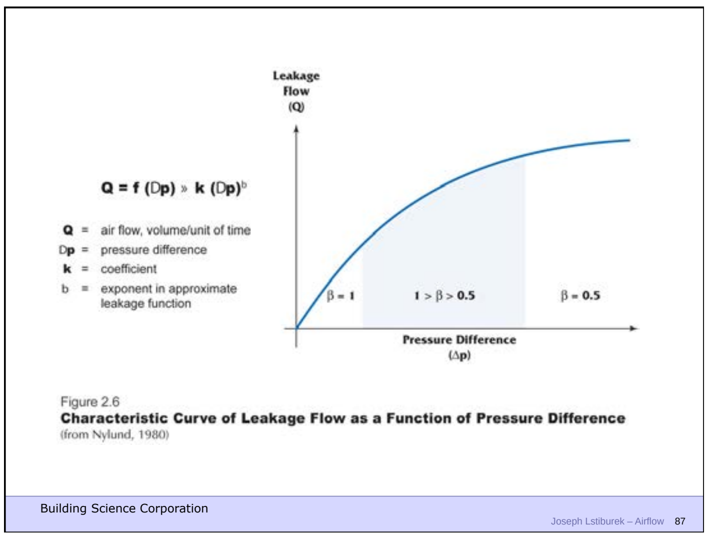
Leakage Flow (Q)
Q = f (Dp) » k (Dp)b
Q = air flow, volume/unit of time
Dp = pressure difference
k = coefficient
b = exponent in approximate leakage function
β = 1
1 > β > 0.5
β = 0.5
Pressure Difference (Δp)
Figure 2.6
Characteristic Curve of Leakage Flow as a Function of Pressure Difference
(from Nylund, 1980)
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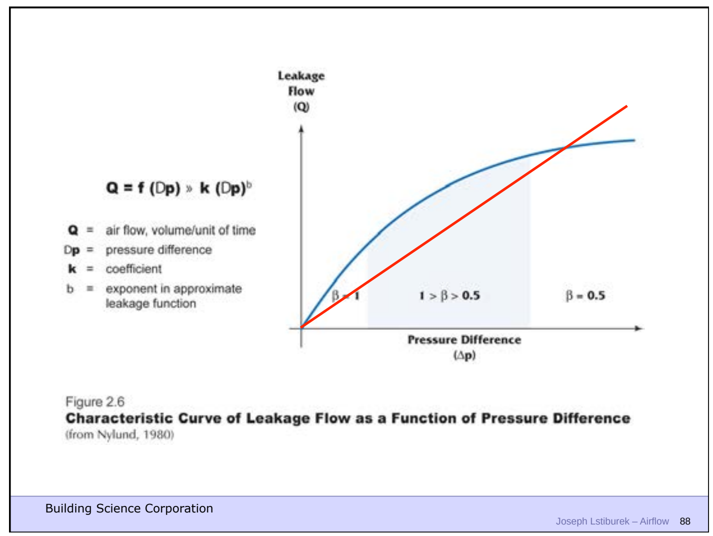
Leakage Flow (Q)
Q = f (Dp) » k (Dp)b
Q = air flow, volume/unit of time
Dp = pressure difference
k = coefficient
b = exponent in approximate leakage function
1 > β > 0.5
β = 0.5
Pressure Difference (Δp)
Figure 2.6
Characteristic Curve of Leakage Flow as a Function of Pressure Difference
(from Nylund, 1980)
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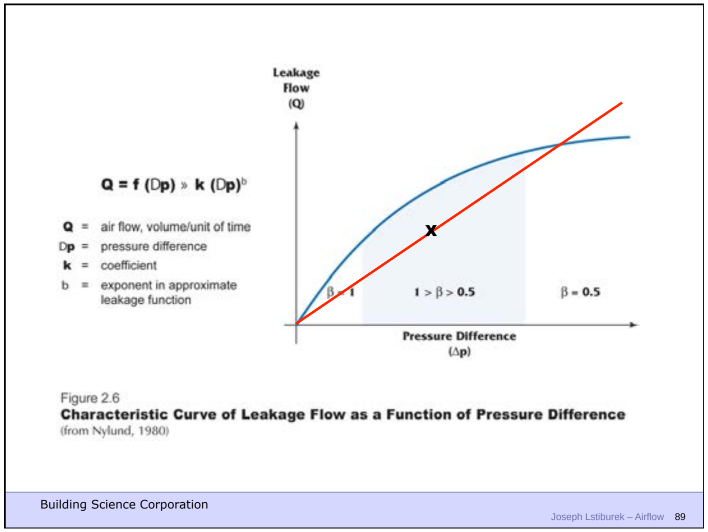
Joseph Lstiburek – Airflow 88


Leakage Flow (Q)
Q = f (Dp) » k (Dp)b
Q = air flow, volume/unit of time
Dp = pressure difference
k = coefficient
b = exponent in approximate leakage function
β = 1
1 > β > 0.5
β = 0.5
Pressure Difference (Δp)
Figure 2.6
Characteristic Curve of Leakage Flow as a Function of Pressure Difference
(from Nylund, 1980)
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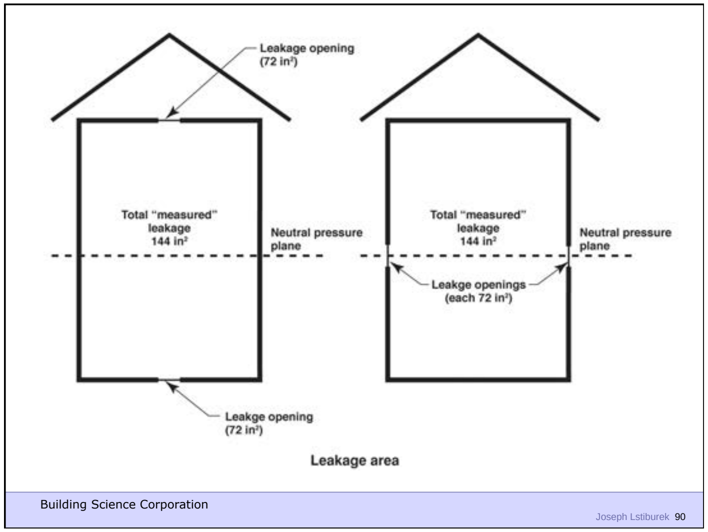
Joseph Lstiburek – Airflow 89


Leakage opening (72 in²)
Total "measured" leakage 144 in²
Neutral pressure plane
Total "measured" leakage 144 in²
Neutral pressure plane
Leakge openings (each 72 in²)
Leakge opening (72 in²)
Leakage area
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Joseph Lstiburek 1


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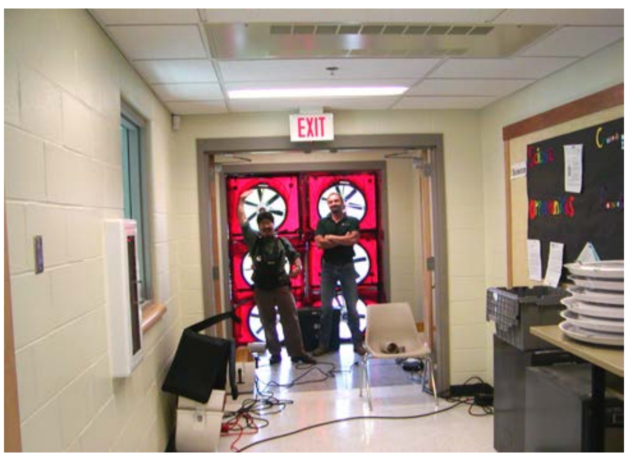
Joseph Lstiburek 2

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Joseph Lstiburek 3

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Joseph Lstiburek 4


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Joseph Lstiburek 5

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Joseph Lstiburek 6

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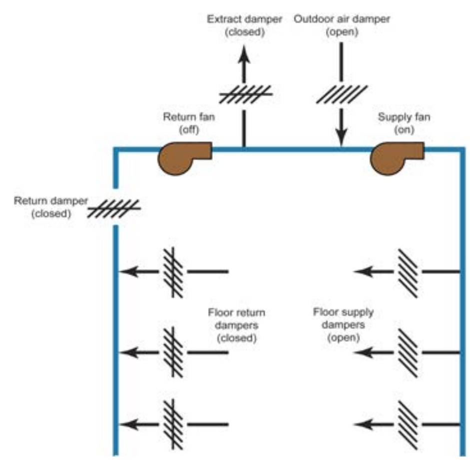
Joseph Lstiburek 7

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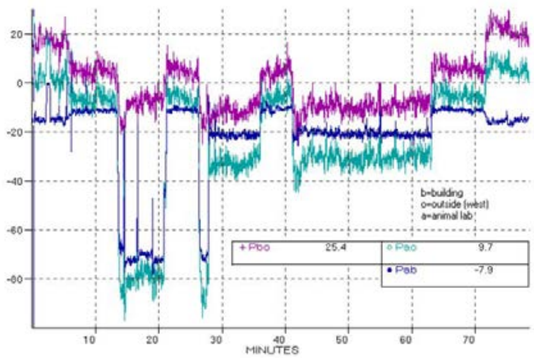


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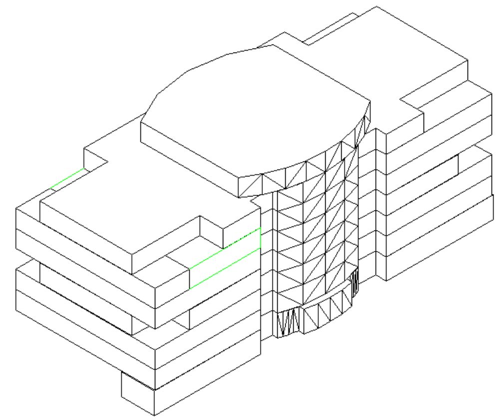
Joseph Lstiburek 9



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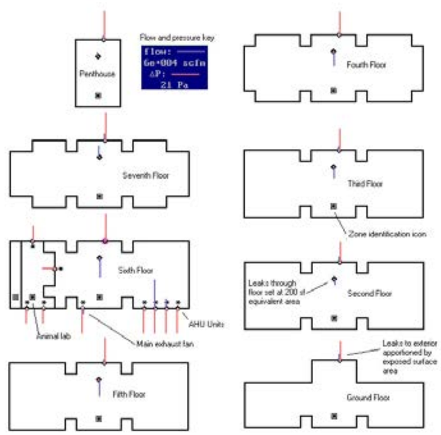
Joseph Lstiburek 10

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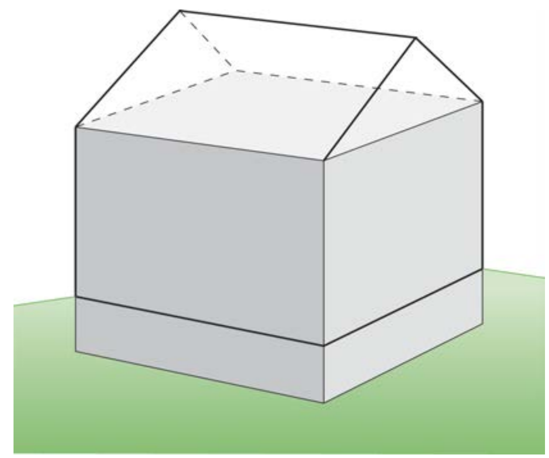
Joseph Lstiburek 11



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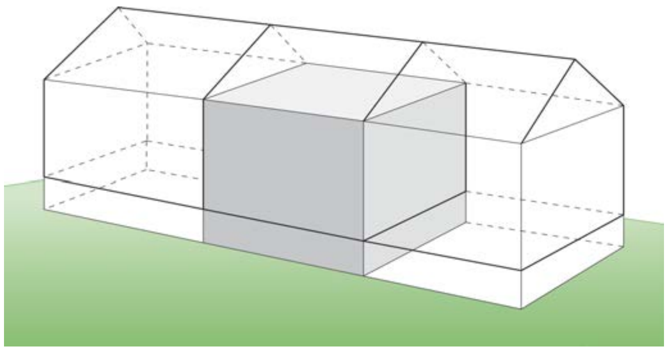
Joseph Lstiburek 12



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Joseph Lstiburek 14

Building Science Corporation

Joseph Lstiburek 15

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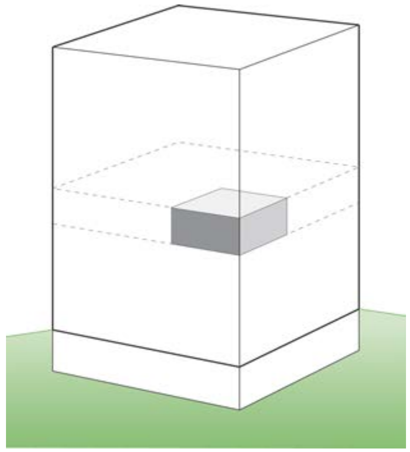
Joseph Lstiburek 16



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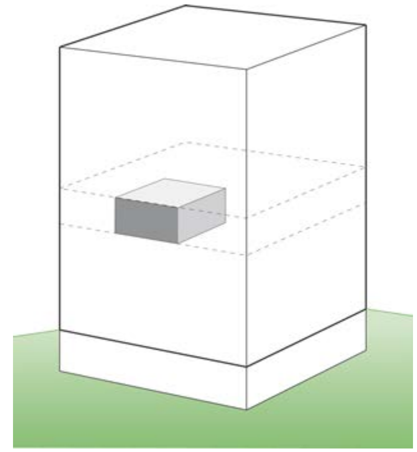
Joseph Lstiburek 17



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Build Tight - Ventilate Right

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Joseph Lstiburek 19

Build Tight - Ventilate Right

How Tight?

What's Right?

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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 |
| | 0.35 cfm/ft2 @ 50 Pa |
| | 0.25 cfm/ft2 @ 50 Pa |
| | 0.15 cfm/ft2 @ 50 Pa |

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

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Best

As Tight as Possible - with -
Balanced Ventilation
Energy Recovery
Distribution
Source Control - Spot exhaust ventilation
Filtration
Material selection

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Worst

Leaky - with – Nothing
Spot Ventilation in Bathroom/Kitchen
Exhaust Ventilation – with – No Distribution

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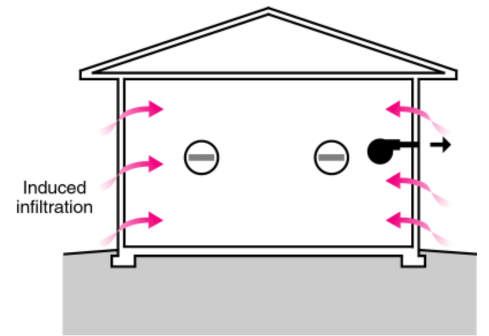
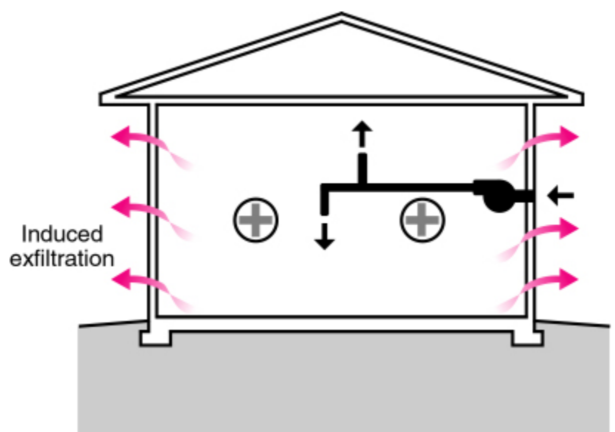
Three Types of Controlled Ventilation
Systems

Exhaust Ventilation
Supply Ventilation
Balanced Ventilation

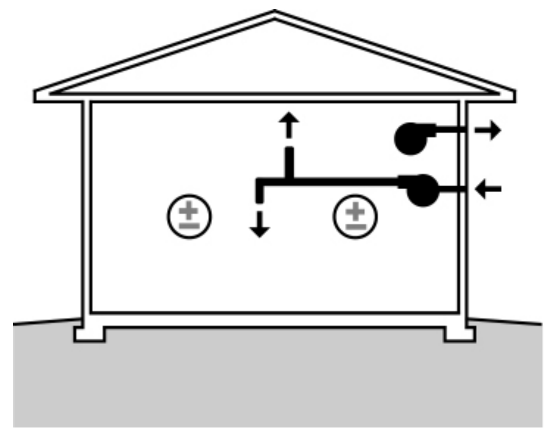


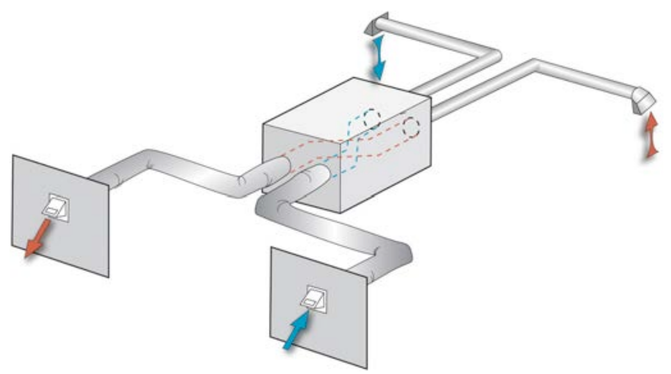








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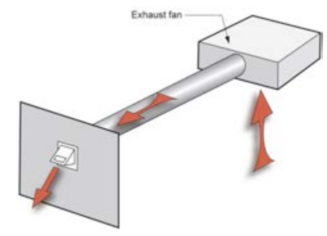


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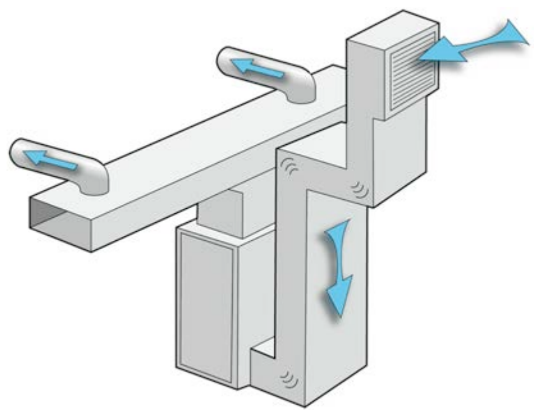

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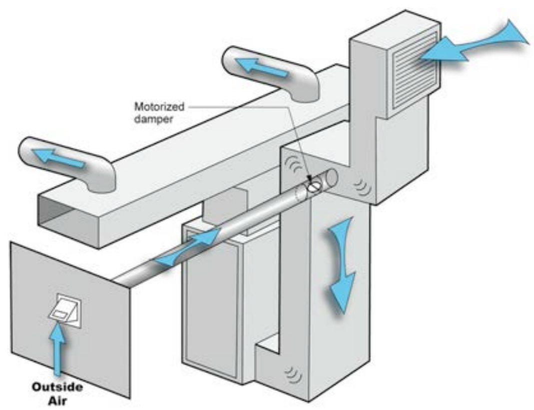
Joseph Lstiburek 31

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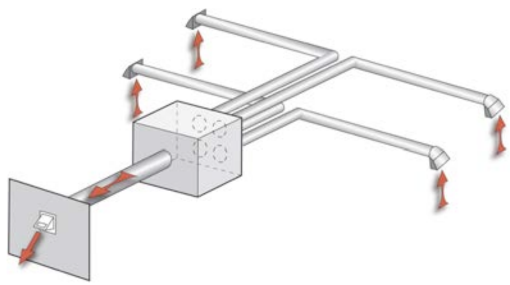
Joseph Lstiburek 32





| | | |
|---|---|---|
| Cost | Exhaust | $150 |
| | Exhaust + Dist | $200 |
| | Supply + Dist | $200 |
| | Spot + Ex/Sup + Dist | $500 |
| | Balanced/HRV | $1,250 |



The Cult of The Blower Door



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

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Don't Know Where The Holes Are
Don't Know The Type of Holes
Don't Know The Pressure Across The Holes

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Good For Long Term Average If No Big Pressures

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Good For Long Term Average If No Big Pressures
Good For Average Annual Energy Prediction

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Joseph Lstiburek 40

Good For Long Term Average If No Big Pressures

Good For Average Annual Energy Prediction

Not Good For IAQ Unless You Accept Average Annual Exposure As A Metric

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Cost of Addressing the Problems Are Less Than The Cost of Testing To See If You Have Problems

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Joseph Lstiburek 42

Combustion Safety

Indoor Contaminants

Comfort

Energy

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Joseph Lstiburek 43

Bring Combustion Appliances Up To Code

Control Pressures

Install Controlled Ventilation

Get Rid of Big Holes

Insulate

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Joseph Lstiburek 44

## Code Compliant Combustion Air

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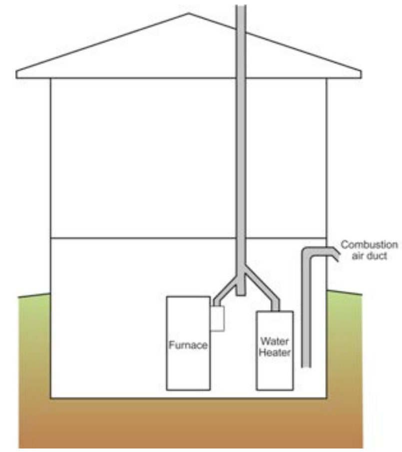


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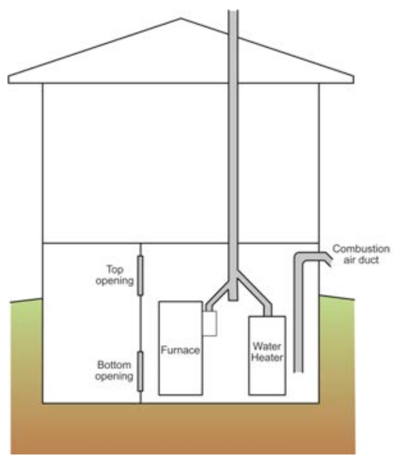
Joseph Lstiburek 46

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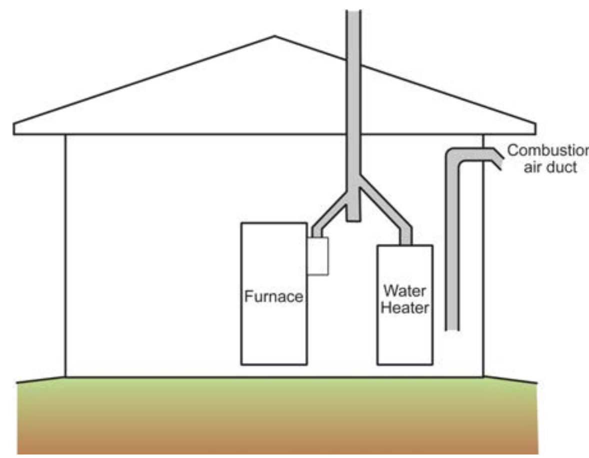
Joseph Lstiburek 47

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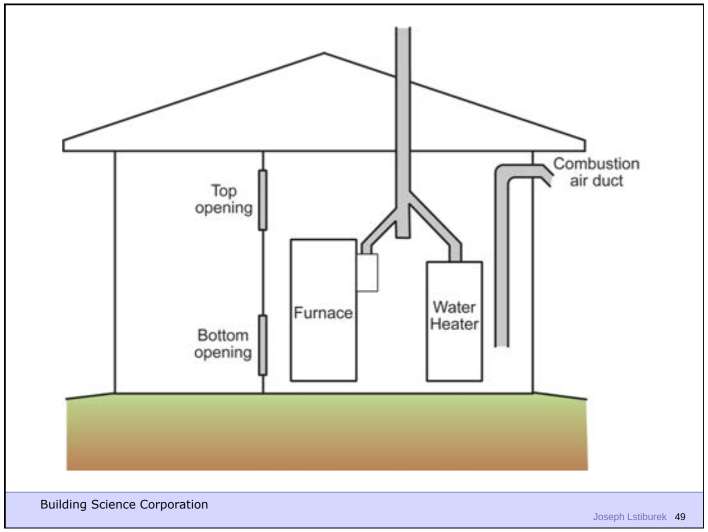
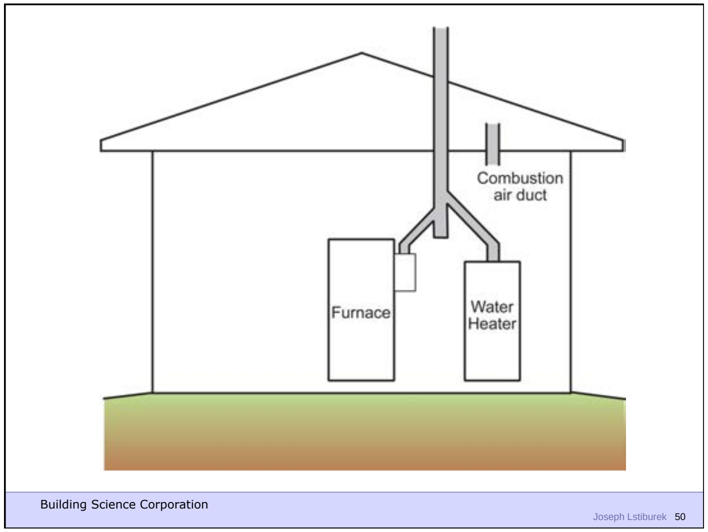
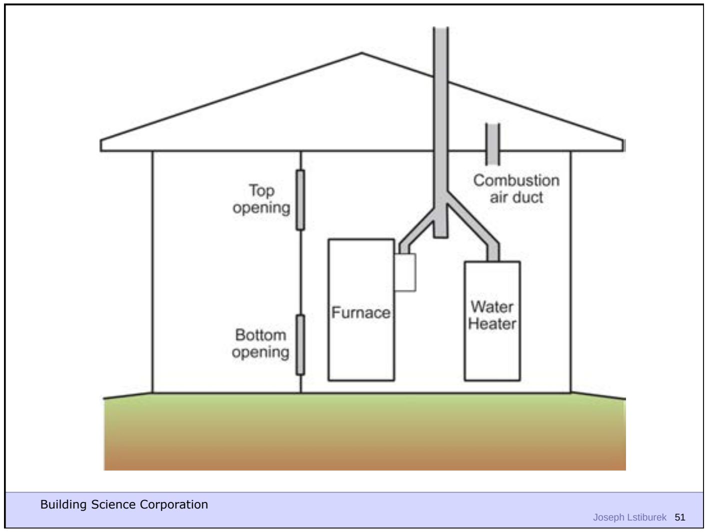
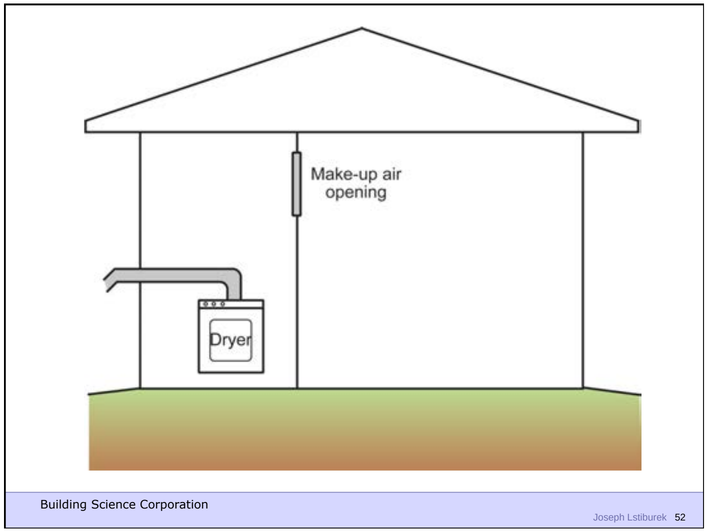
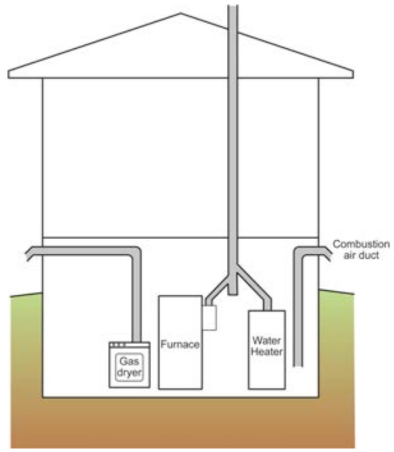
Joseph Lstiburek 48


Top opening
Bottom opening
Furnace
Water Heater
Combustion air duct
Building Science Corporation
Joseph Lstiburek 49


Combustion air duct
Furnace
Water Heater
Building Science Corporation
Joseph Lstiburek 50


Top opening
Bottom opening
Furnace
Water Heater
Combustion air duct
Building Science Corporation
Joseph Lstiburek 51


Make-up air opening
Dryer
Building Science Corporation
Joseph Lstiburek 52

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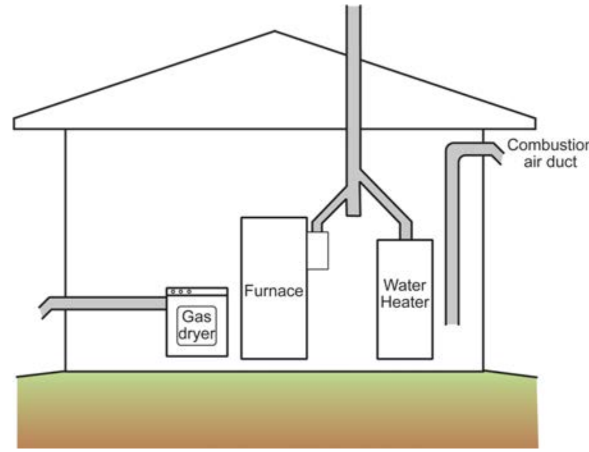
Joseph Lstiburek 53

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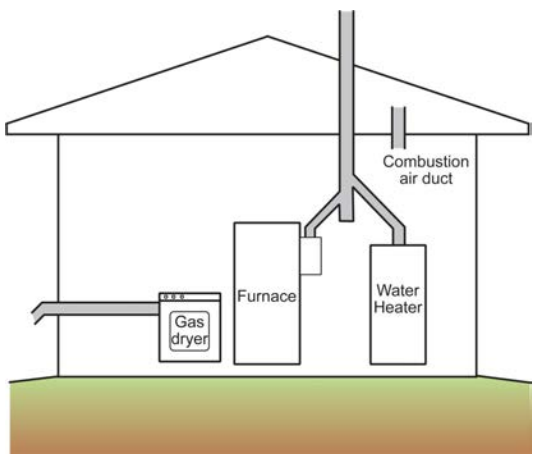
Joseph Lstiburek 54

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## Sealed Combustion Appliances

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Joseph Lstiburek 57

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Joseph Lstiburek 58

Control Pressures

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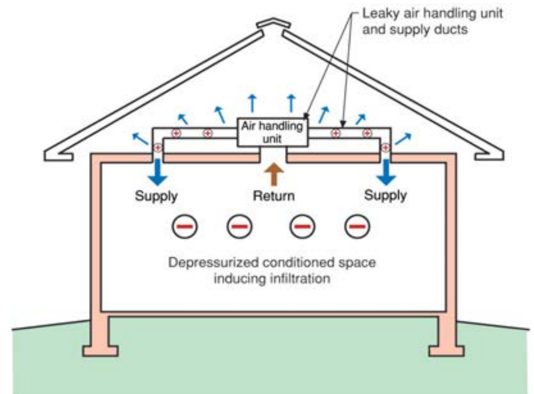
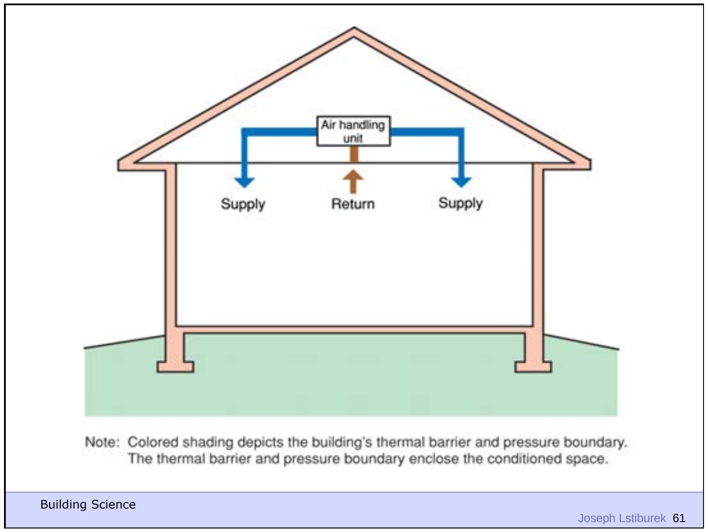
Joseph Lstiburek 59

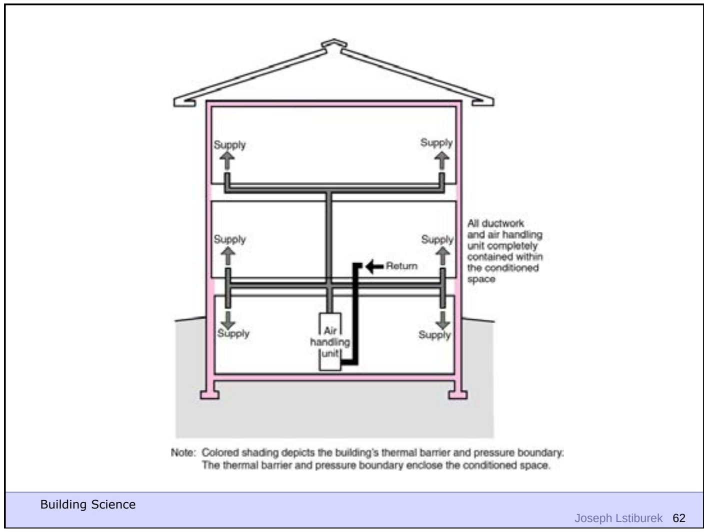


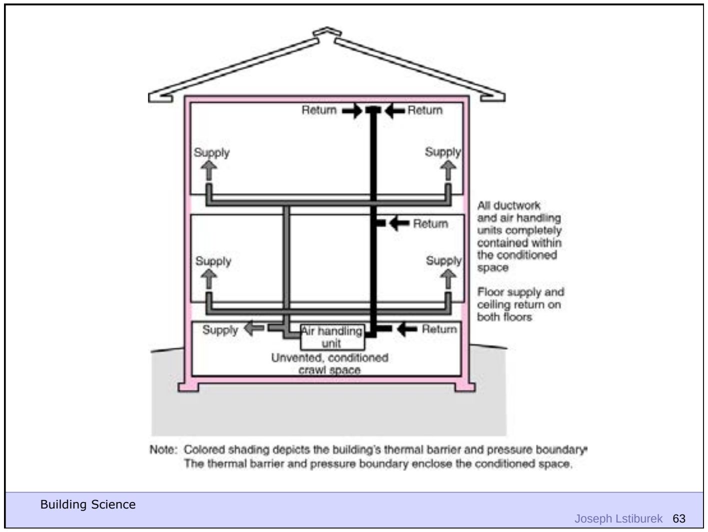

Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

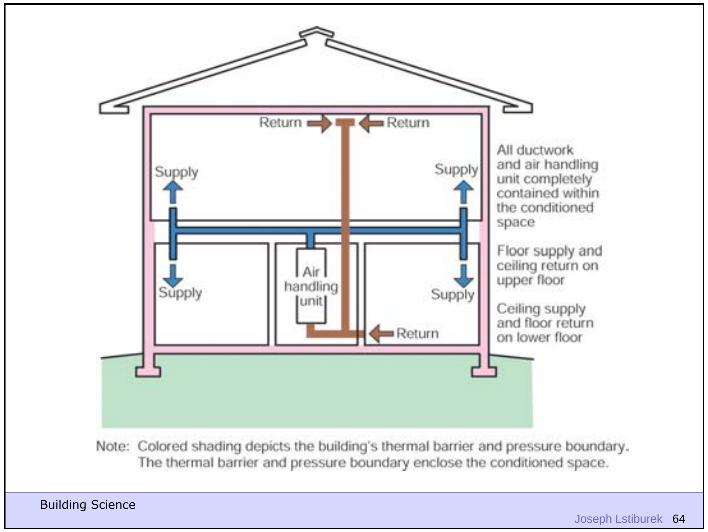
Building Science

Joseph Lstiburek 60


Air handling unit
Supply
Return
Supply
Note: Colored shading depicts the building's thermal barrier and pressure boundary.
The thermal barrier and pressure boundary enclose the conditioned space.
Building Science
Joseph Lstiburek 61


Supply
Supply
Supply
Supply
Return
All ductwork and air handling unit completely contained within the conditioned space
Supply
Air handling unit
Supply
Note: Colored shading depicts the building's thermal barrier and pressure boundary.
The thermal barrier and pressure boundary enclose the conditioned space.
Building Science
Joseph Lstiburek 62


Return
Return
Supply
Supply
Return
Supply
Supply
All ductwork and air handling units completely contained within the conditioned space
Floor supply and ceiling return on both floors
Supply
Air handling unit
Return
Unvented, conditioned crawl space
Note: Colored shading depicts the building's thermal barrier and pressure boundary.
The thermal barrier and pressure boundary enclose the conditioned space.
Building Science
Joseph Lstiburek 63


Return
Return
Supply
Supply
All ductwork and air handling unit completely contained within the conditioned space
Floor supply and ceiling return on upper floor
Ceiling supply and floor return on lower floor
Air handling unit
Supply
Supply
Return
Note: Colored shading depicts the building's thermal barrier and pressure boundary.
The thermal barrier and pressure boundary enclose the conditioned space.
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Joseph Lstiburek 64

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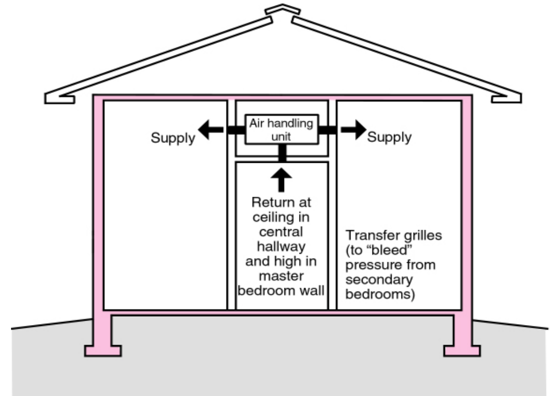
Joseph Lstiburek 65




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

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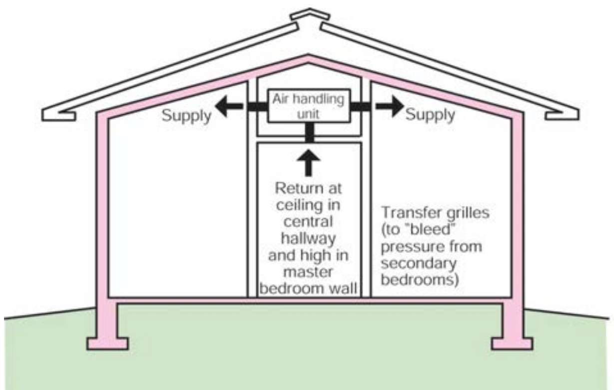
Joseph Lstiburek 66




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

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Joseph Lstiburek 68

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Joseph Lstiburek 69

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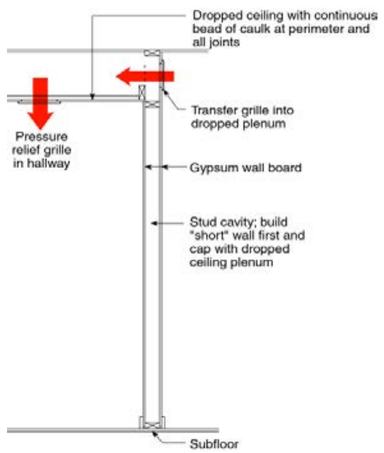
Joseph Lstiburek 70

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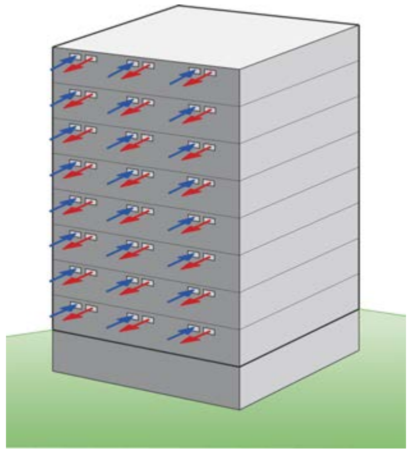
Joseph Lstiburek 71



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Joseph Lstiburek – HVAC 2

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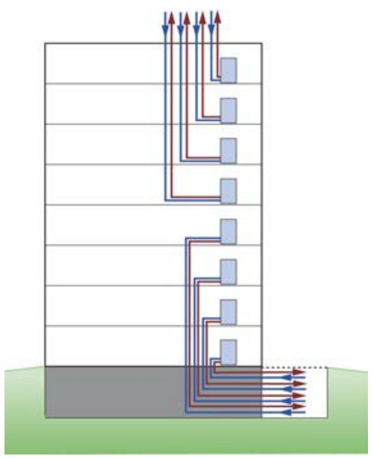
Joseph Lstiburek 3



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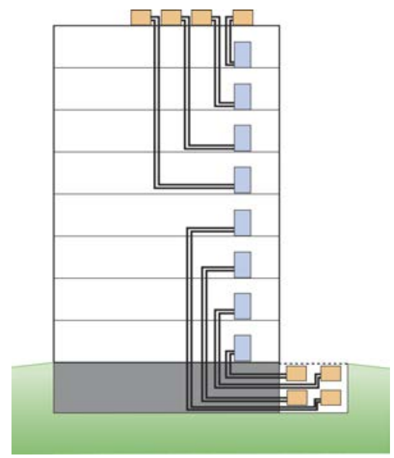
Joseph Lstiburek – HVAC 4



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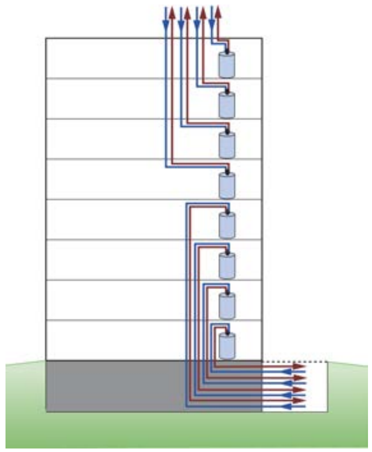
Joseph Lstiburek – HVAC 5



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Joseph Lstiburek – HVAC 6

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Joseph Lstiburek – HVAC 7

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Joseph Lstiburek – HVAC 8

Building Science Corporation

Joseph Lstiburek – HVAC 9

Building Science Corporation

Joseph Lstiburek – HVAC 10

Building Science Corporation

Joseph Lstiburek – HVAC 11

Building Science Corporation

Joseph Lstiburek – HVAC 12

Building Science Corporation

Joseph Lstiburek 13

Building Science Corporation

Joseph Lstiburek – HVAC 14

Building Science Corporation

Joseph Lstiburek – HVAC 15

Building Science Corporation

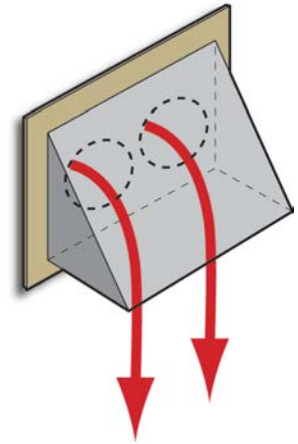
Joseph Lstiburek – HVAC 16

Building Science Corporation

Joseph Lstiburek – HVAC 17

Building Science Corporation

Joseph Lstiburek – HVAC 18



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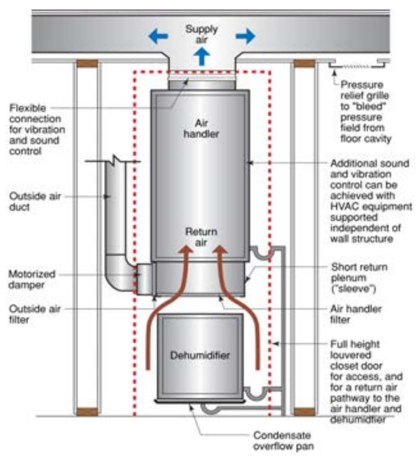
Joseph Lstiburek – HVAC 19

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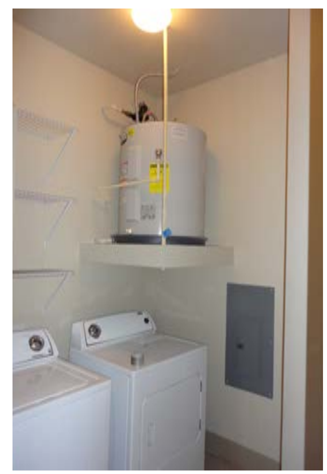
Joseph Lstiburek – HVAC 20



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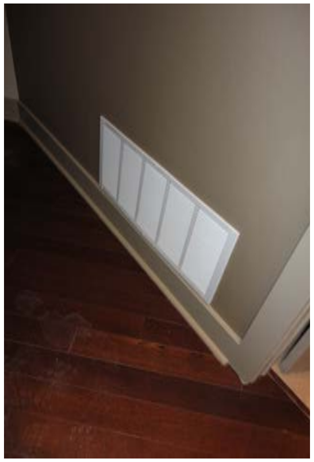
Joseph Lstiburek 21



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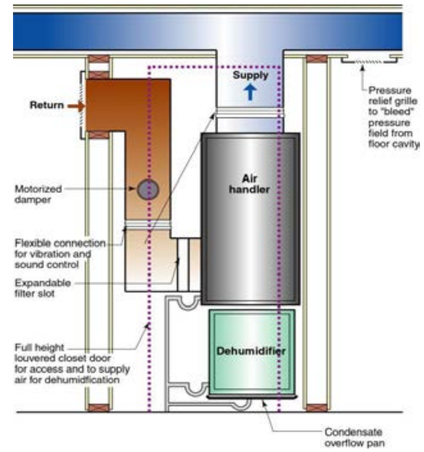
Joseph Lstiburek 22

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Joseph Lstiburek – HVAC 23

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Joseph Lstiburek – HVAC 24


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Joseph Lstiburek – HVAC 25

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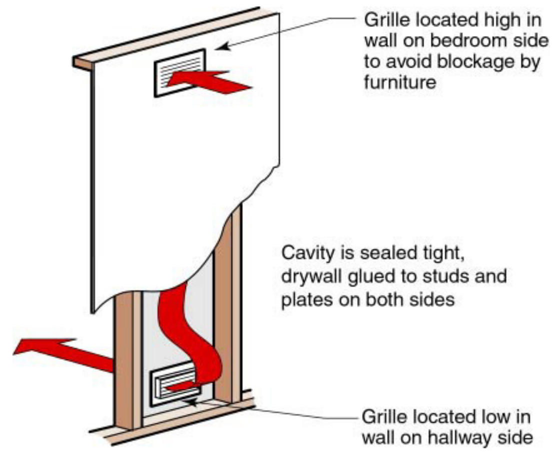
Joseph Lstiburek – HVAC 26

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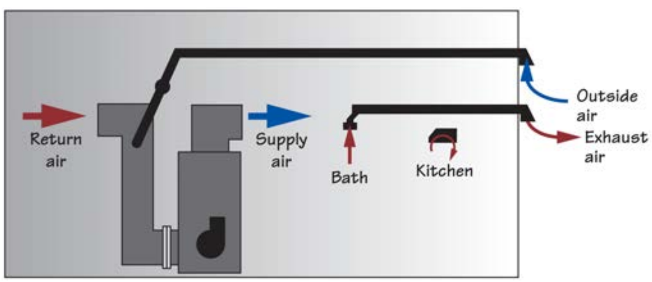
Joseph Lstiburek – HVAC 27

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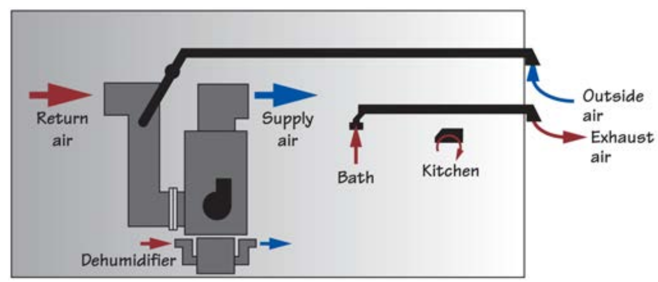
Joseph Lstiburek 28

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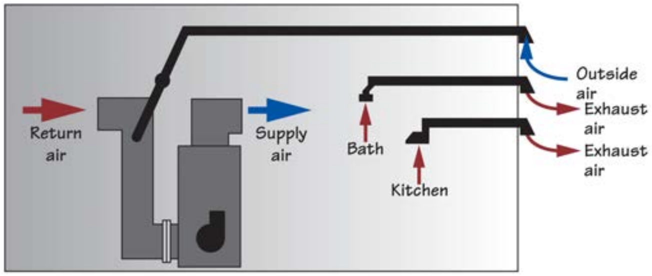
Joseph Lstiburek 29

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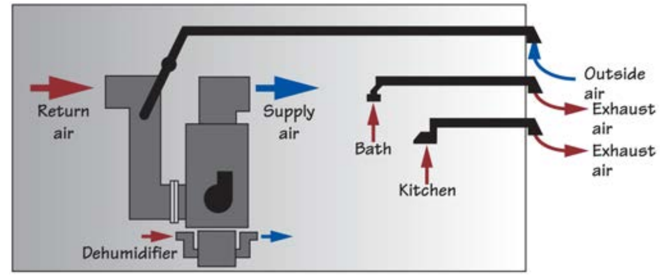
Joseph Lstiburek 30

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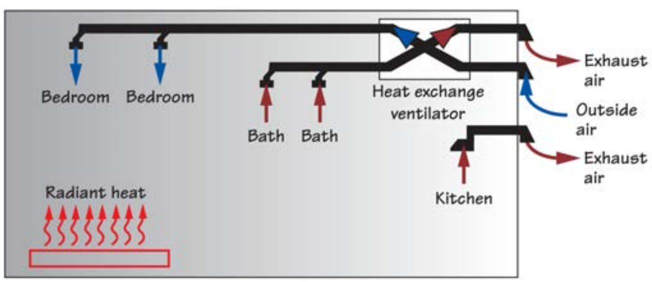
Joseph Lstiburek 31

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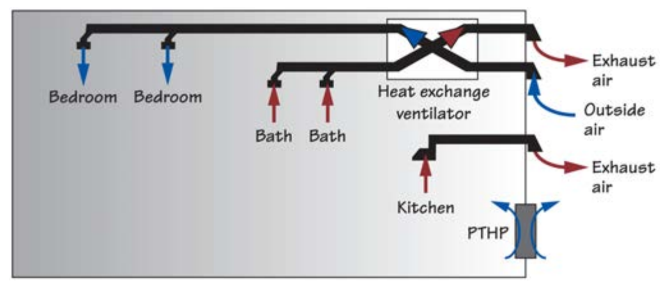


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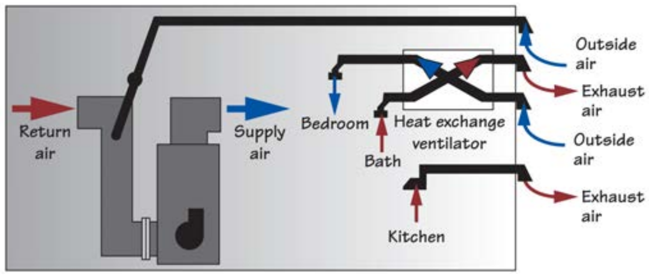


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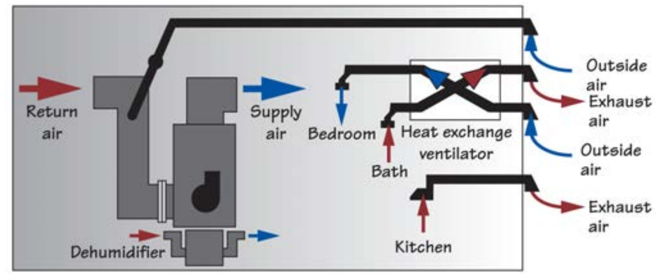


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Joseph Lstiburek 39

Building Science Corporation

Joseph Lstiburek 40

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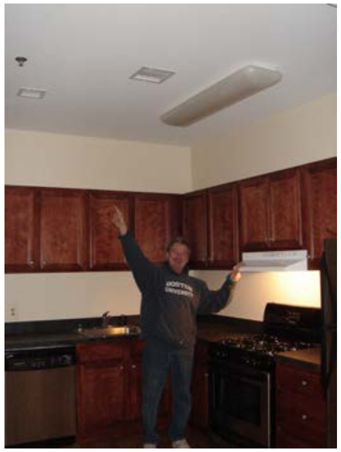
Joseph Lstiburek 41



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Joseph Lstiburek 42

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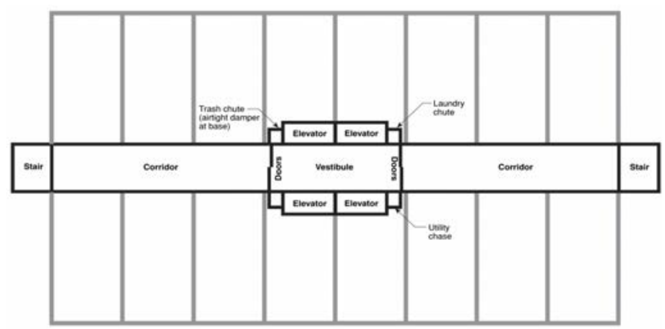
Joseph Lstiburek – HVAC 43

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Joseph Lstiburek – HVAC 44

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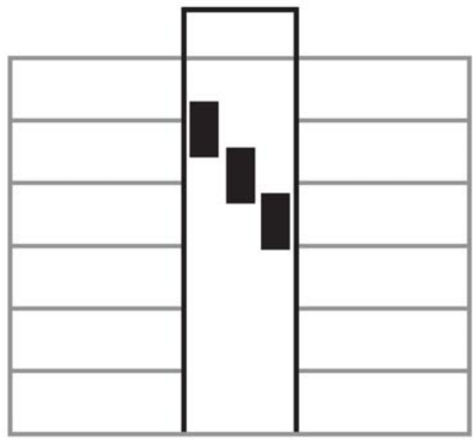
Joseph Lstiburek – HVAC 45



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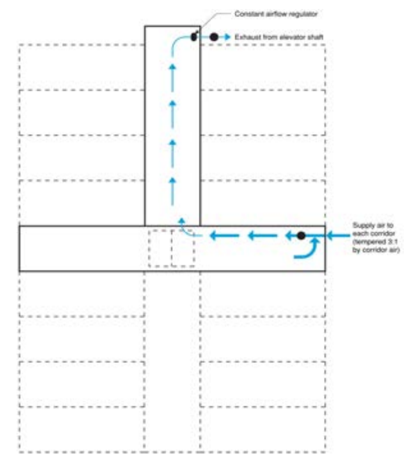
Joseph Lstiburek – HVAC 46

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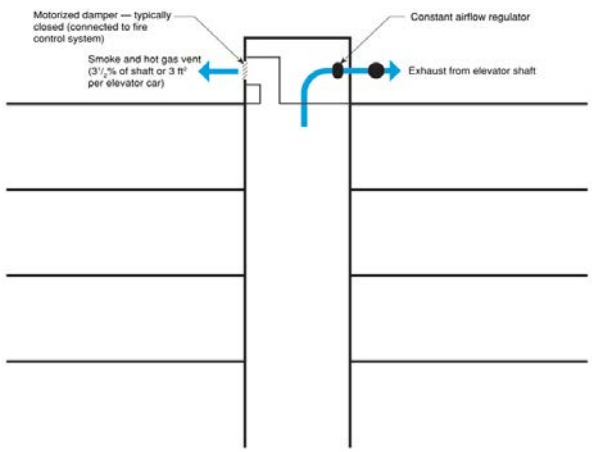
Joseph Lstiburek – HVAC 47

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Joseph Lstiburek – HVAC 48

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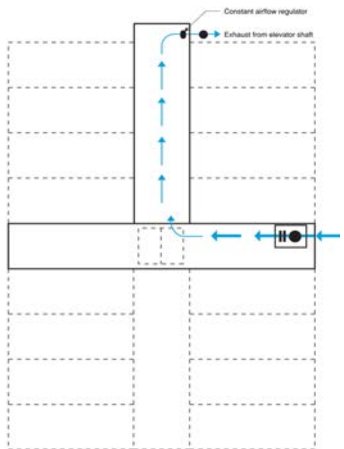
Joseph Lstiburek – HVAC 49

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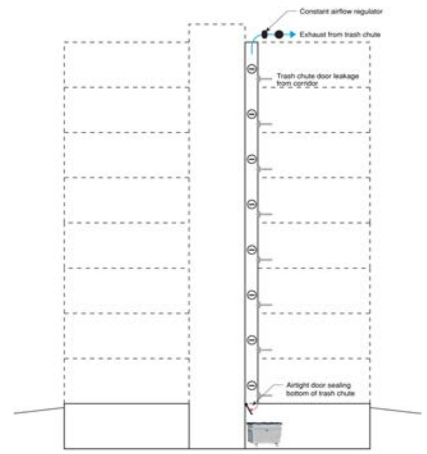
Joseph Lstiburek – HVAC 50

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Joseph Lstiburek – HVAC 51

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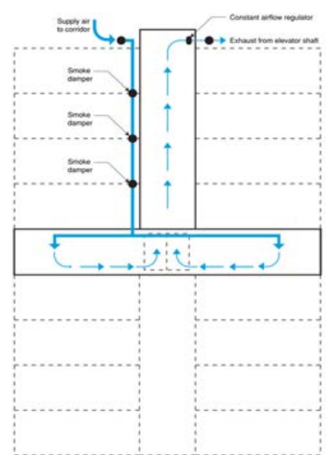
Joseph Lstiburek 52

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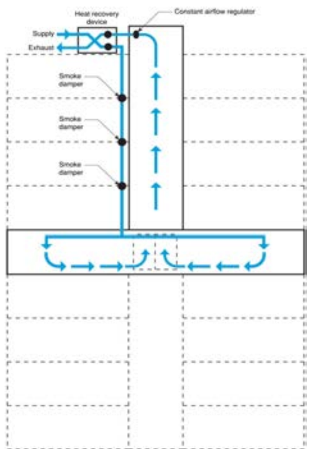


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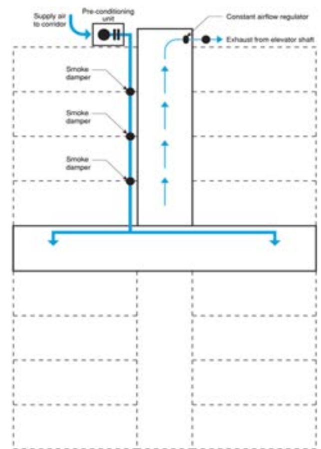


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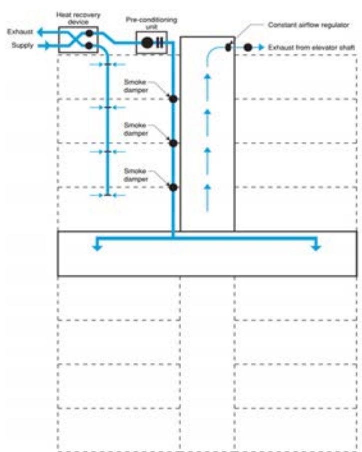
Joseph Lstiburek – HVAC 55

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Joseph Lstiburek – HVAC 56


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Joseph Lstiburek – HVAC 57

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Joseph Lstiburek 58

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Joseph Lstiburek 59

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Joseph Lstiburek 60

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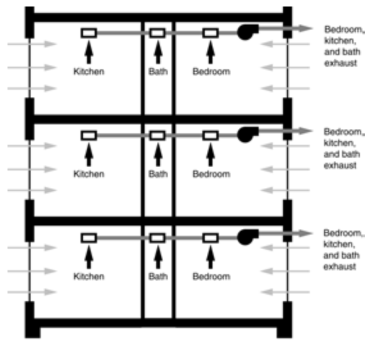
Joseph Lstiburek 61




## Distributed Ventilation

- Individual unit exhaust ventilation fan exhausts (during occupancy) from each bedroom, bathroom, and kitchen
- Operation of system is time of occupancy sensitive — on only when occupied

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Joseph Lstiburek 63

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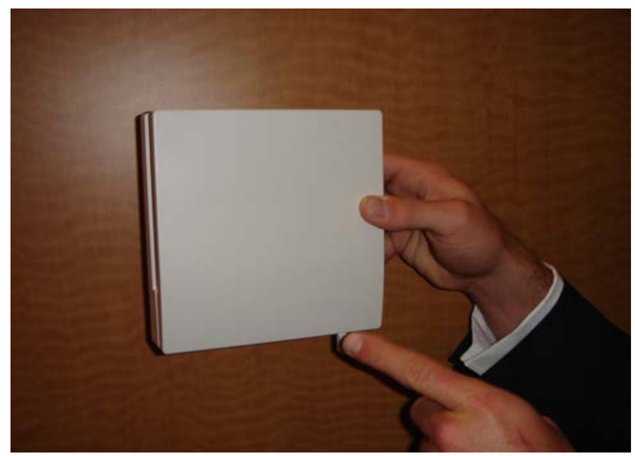
Joseph Lstiburek 64



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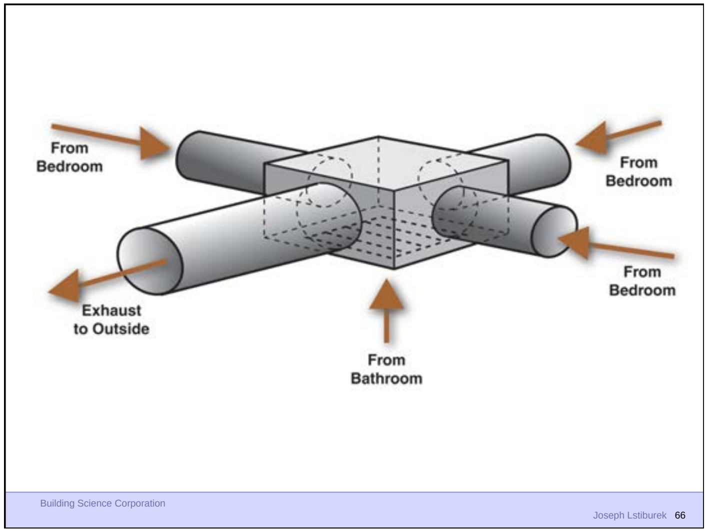
From
Bedroom
From
Bedroom
From
Bedroom
Exhaust
to Outside
From
Bathroom
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Ventilation Rates Are Based on Odor Control

Building Science Corporation Joseph Lstiburek 2

Ventilation Rates Are Based on Odor Control

Health Science Basis for Ventilation Rates is Extremely Limited

Building Science Corporation Joseph Lstiburek 3

Ventilation Rates Are Based on Odor Control

Health Science Basis for Ventilation Rates is Extremely Limited

Almost Nothing Cited Applies to Housing

Building Science Corporation Joseph Lstiburek 4

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

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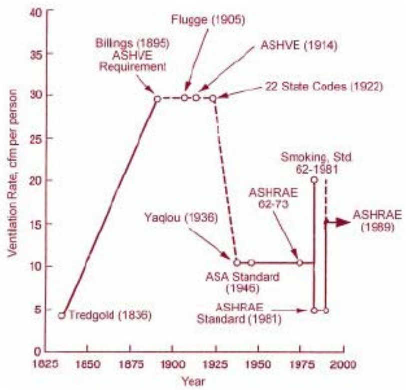



*Figure 1: Minimum ventilating rate history.*



## House

**2,000 ft²**
**3 bedrooms**
**8 ft. ceiling**
**Volume: 16,000 ft³**

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



## House

**2,000 ft²**
**3 bedrooms**
**8 ft. ceiling**
**Volume: 16,000 ft³**

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

**Ventilation Rates**

| | | |
|---|---|---|
| 62 - 73 | 5 cfm/person | 20 cfm |
| | 10 cfm/person | 40 cfm |
| 62 - 89 | 15 cfm/person | 60 cfm |
| | .35 ach | 90 cfm |
| 62.2 - 2010 | 7.5 cfm/person + 0.01 | 50 cfm |
| 62.2 - 2013 | 7.5 cfm/person + 0.03 | 90 cfm |



## Office

**Occupant Density**

| | | |
|---|---|---|
| 15/1000 ft² (67 ft²/person) | 62 - 89 | 15 cfm/person |
| 5/1000 ft² (200 ft²/person) | 62.1 - 2007 | 17 cfm/person |

## Correctional Facility Cell

**Occupant Density**

| | | |
|---|---|---|
| 20/1000 ft² (48 ft²/person) | 62.1 – 2007 | 10 cfm/person |

## C.P. Yaglou

**Harvard School of Public Health**
**1936**
**1955**

150 $ft^3$ → 20 cfm/person approx 4x4x8

300 $ft^3$ → 12 cfm/person approx 6x6x8

## C.P. Yaglou

**Harvard School of Public Health**
**1936**
**1955**

150 $ft^3$ → 20 cfm/person 18.75 $ft^2$ 106 occupants

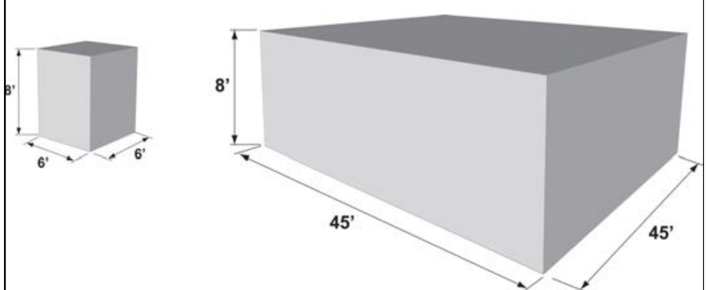
300 $ft^3$ → 12 cfm/person 37.5 $ft^2$ 53 occupants

**Experiment**

470 $ft^3$ → 59 $ft^2$

200 $ft^3$ → 25 $ft^2$

100 $ft^3$ → 12 $ft^2$

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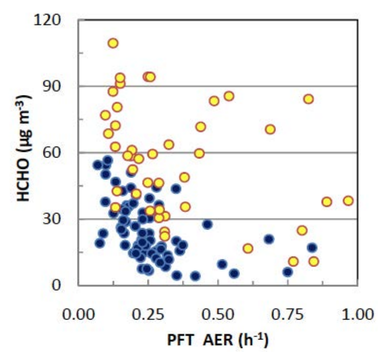


Aubin, D., Won, D.Y., Schleibinger, H., 2010

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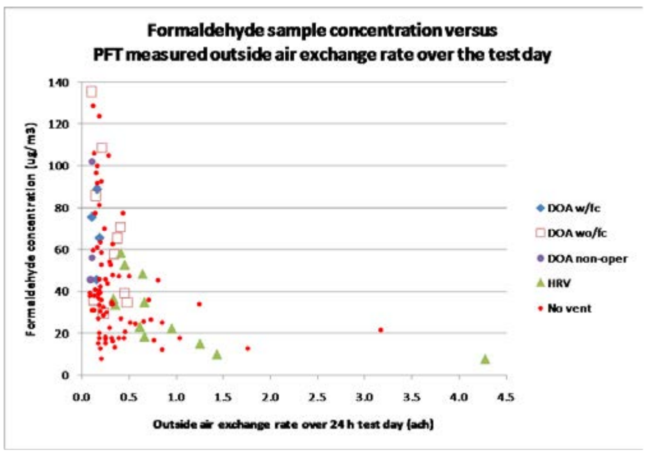




Dilution is Not The Solution To Indoor Pollution



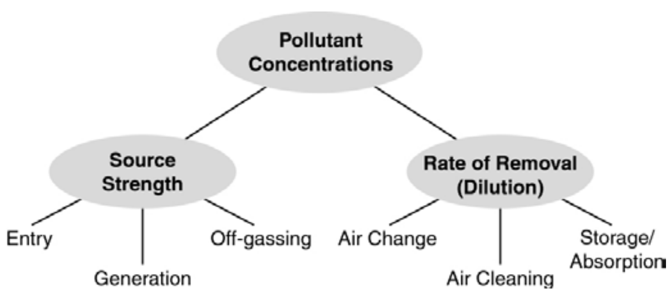




Table 1. Summary of the air changes rates measured during the winter 2009-10 season in Quebec City

| Method | ACH ($h^{-1}$) | ACH standard deviation ($h^{-1}$) | number of measurements |
|---|---|---|---|
| $SF_6$ tracer decay | 0.27 | 0.12 | 77 |
| perflurocarbon tracer | 0.32 | 0.22 | 37 |
| blower door at 50 Pa | 4.16 | 2.64 | 63 |

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

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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

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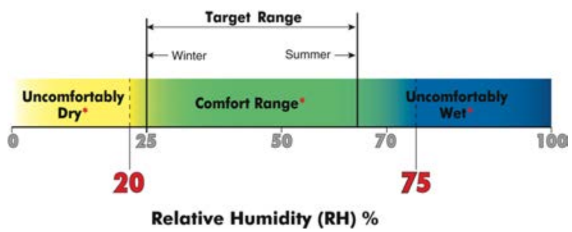


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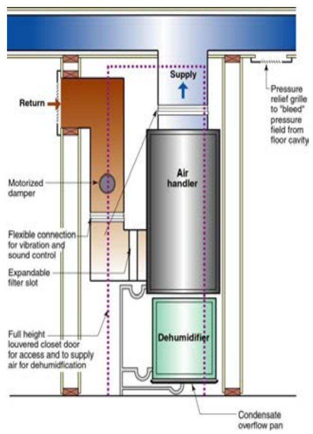
Recommended Range of Relative Humidity

Above 25 percent during winter

Below 70 percent during summer

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Barriers – Technology Dehumidification

Barriers – Cost
- Exhaust $150
- Exhaust + Dist $200
- Supply + Dist $200
- Spot + Ex/Sup + Dist $500
- Balanced/ER $1,250
- Dehumidification $250 to $1,250

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- Tracer gas test of a production house in Sacramento
- 2-story, 4 bedrooms, ~2500 square feet
- Ventilation systems tested: supply and exhaust ventilation, with and without mixing via central air handler

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Floor Plan - 2 Story House


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## Example Results of Tracer Gas Testing

Laundry Exhaust, 100% of 62.2 Rate, Doors Closed, No Mixing

| Zone | Measured Reciprocal Age of Air (1/hr) |
|---|---|
| BR1 | 0.18 |
| Living | 0.16 |
| Kitchen | 0.16 |
| BR2 | 0.11 |
| BR3 | 0.13 |
| MBR | 0.14 |

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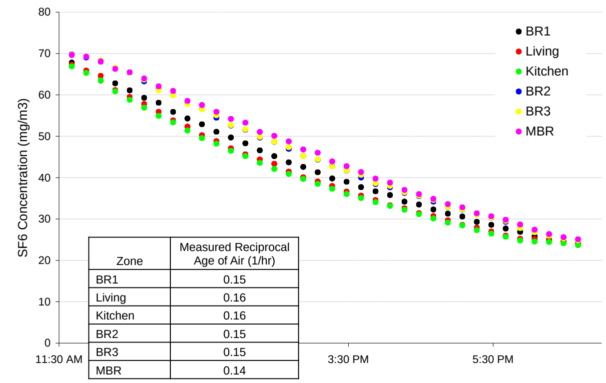
## Example Results of Tracer Gas Testing

Laundry Exhaust, 100% of 62.2 Rate, Doors Closed, 33% Mixing




| Zone | Measured Reciprocal Age of Air (1/hr) |
|---|---|
| BR1 | 0.15 |
| Living | 0.16 |
| Kitchen | 0.16 |
| BR2 | 0.15 |
| BR3 | 0.15 |
| MBR | 0.14 |

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## Example Results of Tracer Gas Testing

CFI, 100% of 62.2 Rate, Doors Closed, 33% Mixing

| Zone | Measured Reciprocal Age of Air (1/hr) |
|---|---|
| BR1 | 0.20 |
| Living | 0.19 |
| Kitchen | 0.20 |
| BR2 | 0.20 |
| BR3 | 0.20 |
| MBR | 0.19 |

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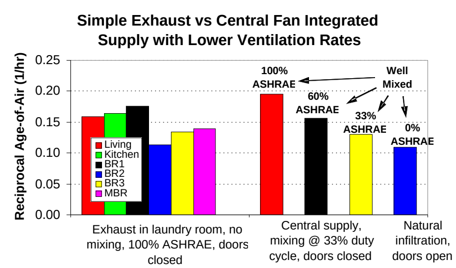
## Conclusions From Tracer Gas Testing

- Mixing is very important to whole-house and individual zone pollutant decay rate
- Supply ventilation is slightly more effective than exhaust ventilation, even with mixing
- The location of a single-point ventilation system affects the performance

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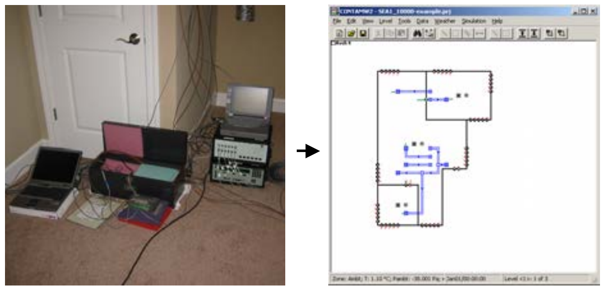
## Tuned CONTAM Model



Computer modeling used to replicate field testing (tune the model) and predict performance of systems not tested in the field

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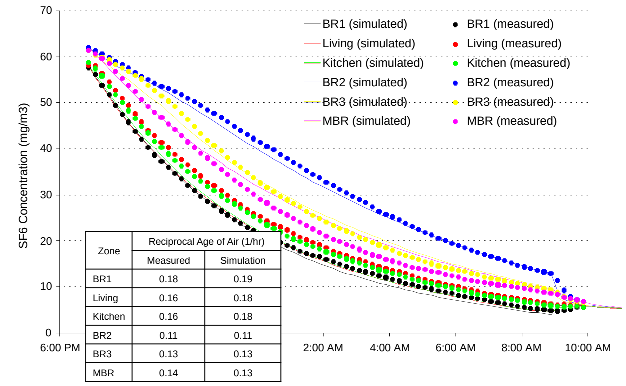
## Example Results of Tuned CONTAM Model

Laundry Exhaust, 100% of 62.2 Rate, Doors Closed, No Mixing




| Zone | Reciprocal Age of Air (1/hr) | |
|---|---|---|
| | Measured | Simulation |
| BR1 | 0.18 | 0.19 |
| Living | 0.16 | 0.18 |
| Kitchen | 0.16 | 0.18 |
| BR2 | 0.11 | 0.11 |
| BR3 | 0.13 | 0.13 |
| MBR | 0.14 | 0.13 |

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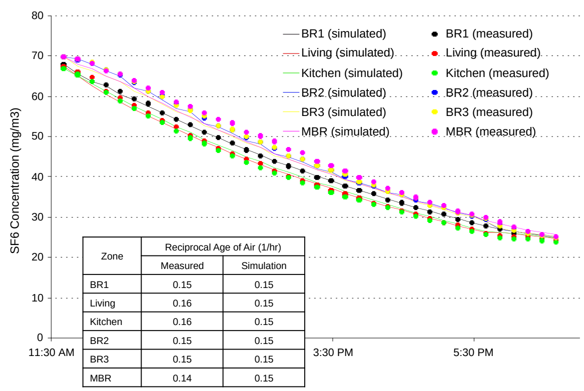
## Example Results of Tuned CONTAM Model

Laundry Exhaust, 100% of 62.2 Rate, Doors Closed, 33% Mixing




| Zone | Reciprocal Age of Air (1/hr) | |
|---|---|---|
| | Measured | Simulation |
| BR1 | 0.15 | 0.15 |
| Living | 0.16 | 0.15 |
| Kitchen | 0.16 | 0.15 |
| BR2 | 0.15 | 0.15 |
| BR3 | 0.15 | 0.15 |
| MBR | 0.14 | 0.15 |

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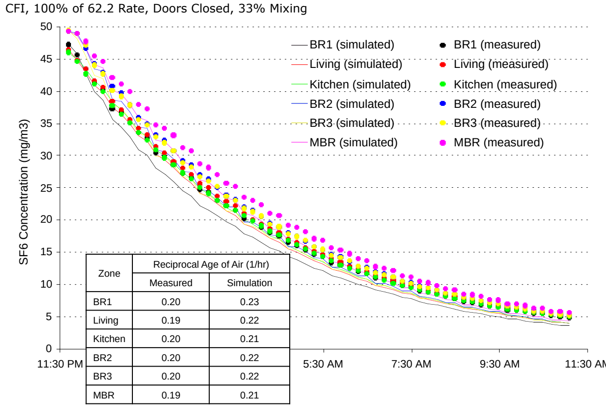
## Example Results of Tuned CONTAM Model

CFI, 100% of 62.2 Rate, Doors Closed, 33% Mixing




| Zone | Reciprocal Age of Air (1/hr) | |
|---|---|---|
| | Measured | Simulation |
| BR1 | 0.20 | 0.23 |
| Living | 0.19 | 0.22 |
| Kitchen | 0.20 | 0.21 |
| BR2 | 0.20 | 0.22 |
| BR3 | 0.20 | 0.22 |
| MBR | 0.19 | 0.21 |

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## Tuned CONTAM Model Applied to Other Systems

Systems Evaluated & Compared:

1. Exhaust ventilation, without central duct system
2. Supply ventilation, without central duct system
3. Exhaust ventilation, with central ducts, standard Tstat
4. Exhaust ventilation, with central ducts, Tstat with timer
5. Supply ventilation, with central ducts, Tstat with timer
6. Fully ducted balanced ventilation system, without central duct system



Q(v) = Ventilation Rate

Q(fan) = Q(v) • C(s)
C(s) = System Coefficient



## Airflow Ratios—All Simulations

| System Type | Range | Approximate Median |
|---|---|---|
| Fully ducted balanced ventilation system, with or without central duct system | 1.0 | 1.0 |
| Non-fully ducted balanced ventilation, with central duct system, and central air handler unit controlled to a minimum runtime of at least 10 minutes per hour | 0.9 to 1.1 | 1.0 |
| Supply ventilation, with central duct system, and central air handler unit controlled to a minimum runtime of at least 10 minutes per hour | 1.1 to 1.7 | 1.25 |
| Exhaust ventilation, with central duct system, and central air handler unit controlled to a minimum runtime of at least 10 minutes per hour | 1.1 to 1.9 | 1.25 |
| Exhaust ventilation, with central duct system, and central air handler unit not controlled to a minimum runtime of at least 10 minutes per hour | 1.0 to 1.8 | 1.5 |
| Supply ventilation, without central duct system | 1.4 to 1.9 | 1.75 |
| Exhaust ventilation, without central duct system | 1.3 to 2.6 | 2.0 |



BSC 01 - 2013 calls 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

Occupant Rate + Building Rate

Q(v) = Fan Flow Rate

Q(fan) = Q(v) • C(s)
C(s) = System Coefficient

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**Table 4.1**

**System Coefficient based on system type**[1]

| System Type | Distributed | Not Distributed |
|---|---|---|
| Balanced | 1.0 | 1.25 |
| Not Balanced | 1.25 | 1.5 |

[1] Where there is whole-building air mixing of at least 70% recirculation turnover each hour, the system coefficient may be reduced by 0.25.

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## BSC 01-2013

**Ventilation for New Low-Rise Residential Building**

**2,000 $ft^2$**
**3 bedrooms**

20 cfm + 30 cfm = 50 cfm

Mixed, Distributed, Balanced (MDB)
37.5 cfm

Not Mixed, Not Distributed, Not Balanced
75 cfm

## 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 |

**Ventilation Rates**

| | | |
|---|---|---|
| 62 - 73 | 5 cfm/person | 20 cfm |
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| 62 - 89 | 15 cfm/person | 60 cfm |
| | .35 ach | 90 cfm |
| 62.2 - 2010 | 7.5 cfm/person + 0.01 | 50 cfm |
| 62.2 - 2013 | 7.5 cfm/person + 0.03 | 90 cfm |
| BSC 01 - 2013 | 7.5 cfm/person + 0.01 (MBD) | 37 cfm |
| | | 75 cfm |

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