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

Building Science

Adventures In Building Science

presented by www.buildingscience.com

Definition of a Problem

People
Pollutant (hot, wet, UV, ozone)
Path
Pressure

Building Science

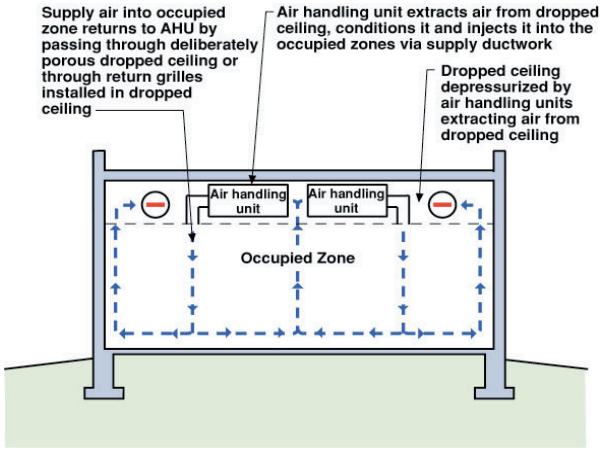
Joseph Lstiburek 5

Building Science

Joseph Lstiburek 6

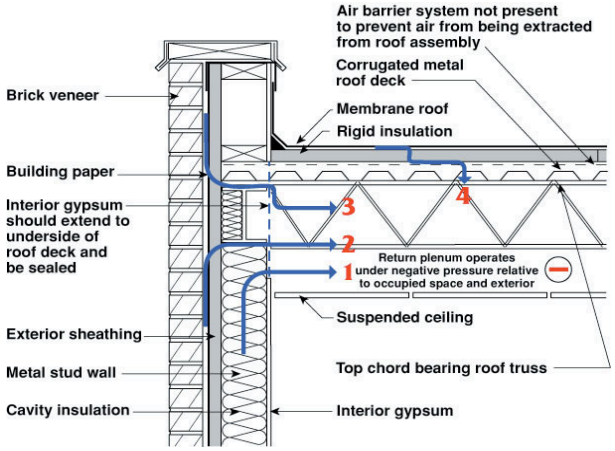
Building Science

Joseph Lstiburek 7



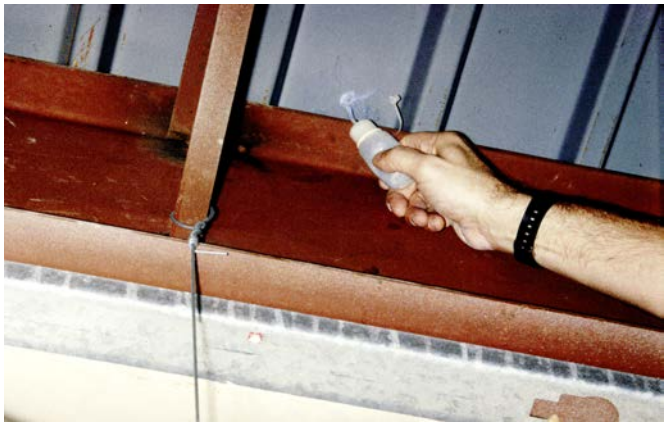
Building Science Corporation

Joseph Lstiburek 8



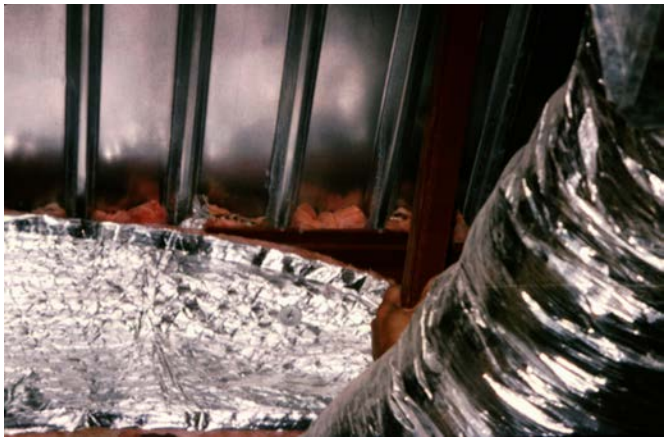
Building Science Corporation

Joseph Lstiburek 9



Building Science Corporation

Joseph Lstiburek 10



Building Science Corporation

Joseph Lstiburek 11

Building Science Corporation

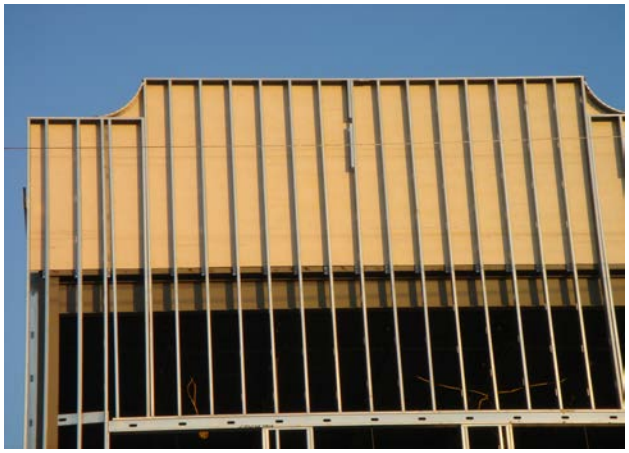
Joseph Lstiburek 12

Building Science Corporation
Joseph Lstiburek 13

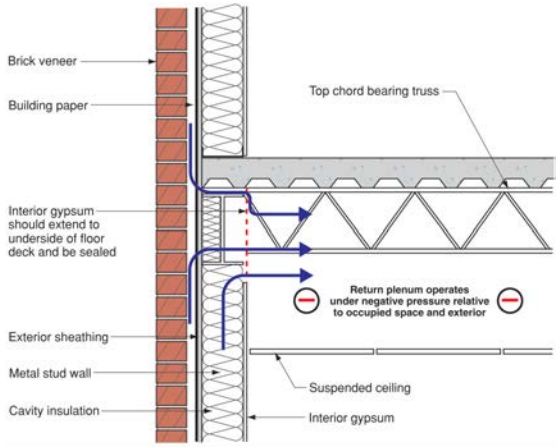
Building Science 2009
Joseph Lstiburek – Pressures and IAQ 14

Building Science Corporation
Joseph Lstiburek 15

Building Science Corporation
Joseph Lstiburek 16



Building Science Corporation Joseph Lstiburek 17



Building Science Corporation Joseph Lstiburek 18

Building Science Corporation Joseph Lstiburek 19

Building Science Corporation Joseph Lstiburek 20

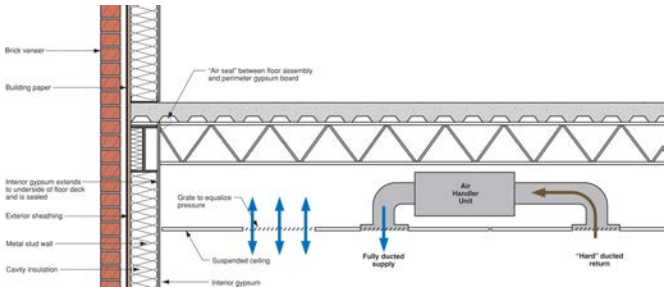
Building Science Corporation Joseph Lstiburek 21

Building Science Corporation Joseph Lstiburek 22

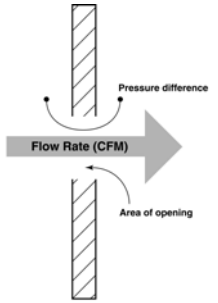
Building Science Corporation Joseph Lstiburek 23

Building Science Corporation Joseph Lstiburek 24

Building Science Corporation Joseph Lstiburek 25



Building Science Corporation Joseph Lstiburek 26



Air Flow

- Air flow depends on size of hole
- Air flow depends on pressure difference
  Flow = Area x $\sqrt{\Delta P}$ x Coefficient
- Air flows from higher pressure to lower pressure

Building Science Corporation Joseph Lstiburek 27

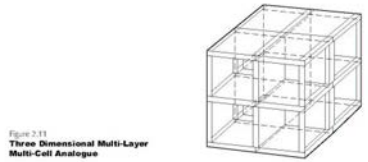


Figure 2.11
Three Dimensional Multi-Layer Multi-Cell Analogue

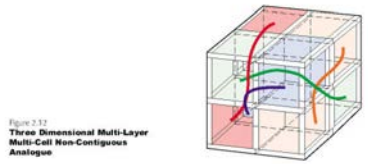


Figure 2.12
Three Dimensional Multi-Layer Multi-Cell Non-Contiguous Analogue

Building Science Corporation Joseph Lstiburek 28

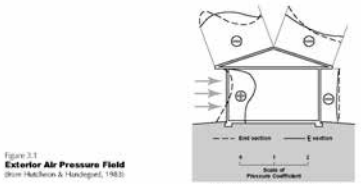


Figure 3.1
Exterior Air Pressure Field
(from Hutcheon & Handegord, 1983)

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

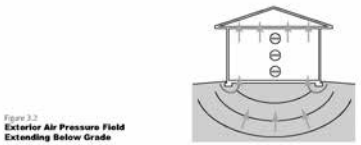
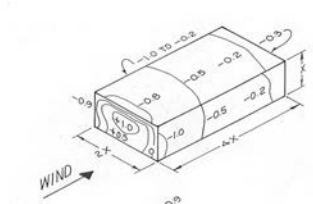
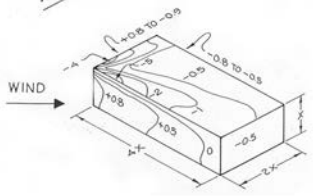


Figure 3.2
Exterior Air Pressure Field Extending Below Grade





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

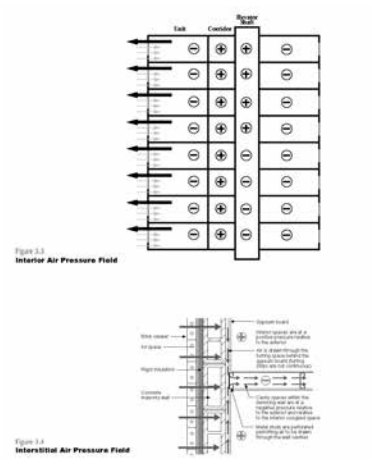


Figure 3.3
Interior Air Pressure Field

Figure 3.4
Interstitial Air Pressure Field

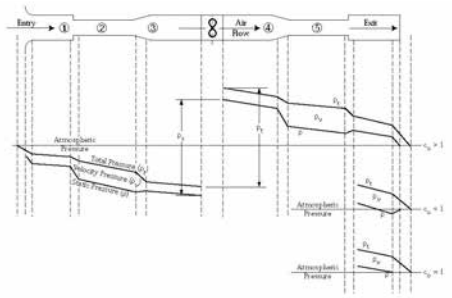


Figure 3.5
Air Conveyance System Air Pressure Field
(from Sauer & Howell, 1990)

Building Science Corporation
Joseph Lstiburek 33

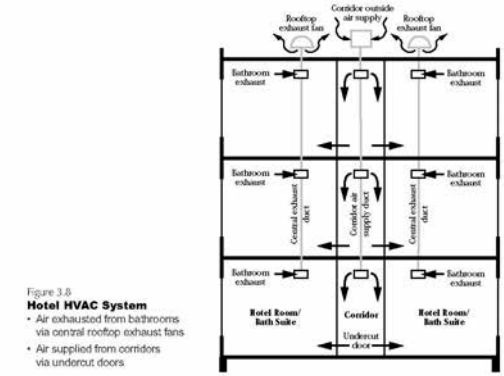
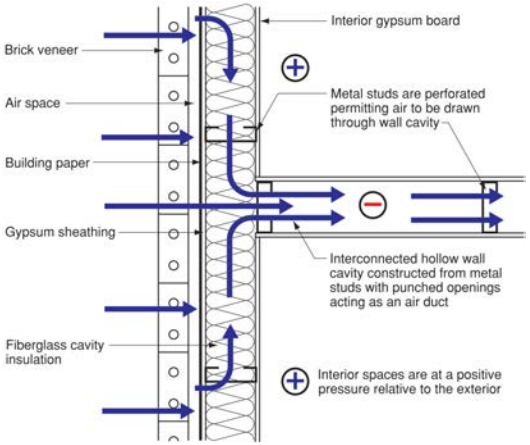


Figure 3.8
Hotel HVAC System
- Air exhausted from bathrooms via central rooftop exhaust fans
- Air supplied from corridors via undercut doors

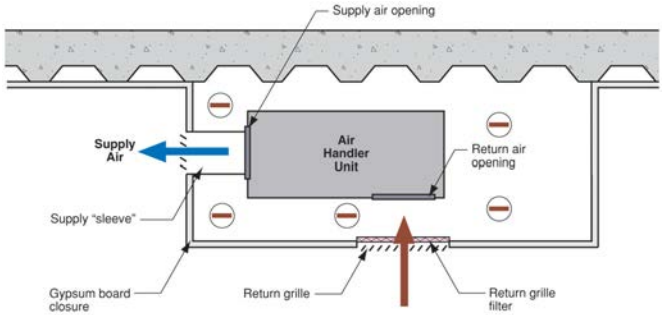
Building Science Corporation
Joseph Lstiburek 34

Building Science Corporation
Joseph Lstiburek 35

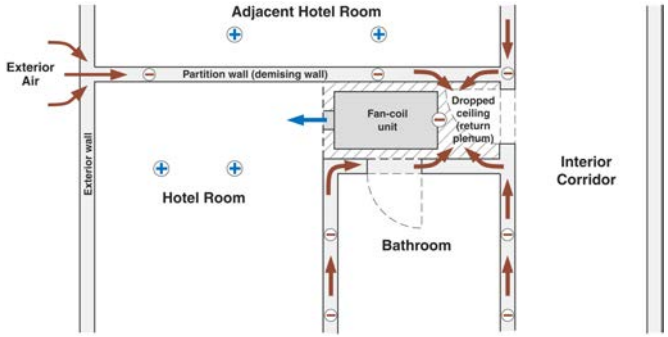
Building Science Corporation
Joseph Lstiburek 36



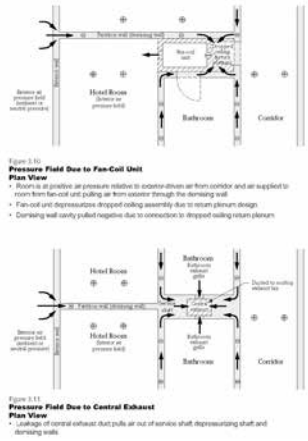
Building Science Corporation Joseph Lstiburek 37



Building Science Corporation Joseph Lstiburek 38



Building Science Corporation Joseph Lstiburek 39



Building Science Corporation Joseph Lstiburek 40

Building Science Corporation Joseph Lstiburek 41

Building Science Corporation Joseph Lstiburek 42

Building Science Corporation Joseph Lstiburek 43

Building Science Corporation Joseph Lstiburek 44

Building Science Corporation

Joseph Lstiburek 45

Building Science Corporation

Joseph Lstiburek 46

Building Science Corporation

Joseph Lstiburek 47

Building Science Corporation

Joseph Lstiburek 48

Building Science Corporation

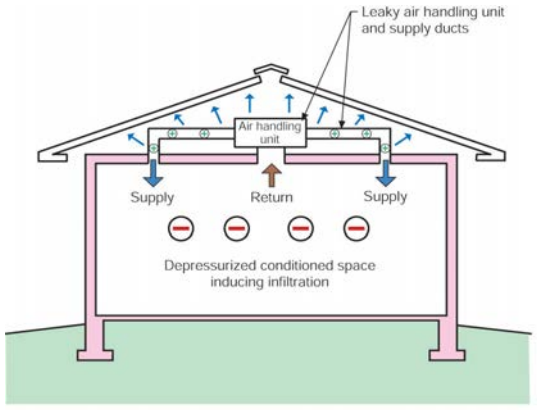
Joseph Lstiburek 49

Building Science Corporation

Joseph Lstiburek 50

Building Science Corporation

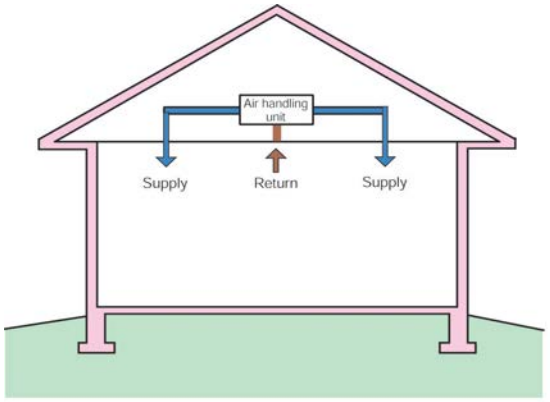
Joseph Lstiburek 51



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

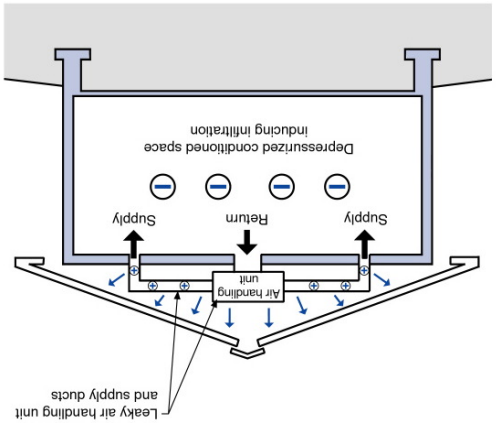
Building Science Corporation

Joseph Lstiburek 52

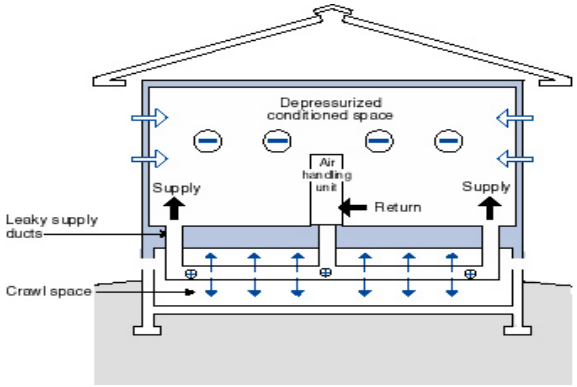


Note: Colored shading depicts the building's thermal barrier and pressure boundary. The thermal barrier and pressure boundary enclose the conditioned space.

Building Science Corporation Joseph Lstiburek 53



Building Science Corporation Joseph Lstiburek 54



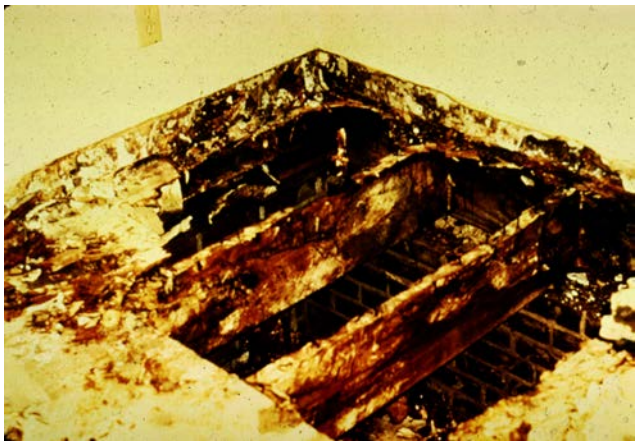
Building Science Corporation Joseph Lstiburek 55

Building Science Corporation Joseph Lstiburek 56

Building Science Corporation Joseph Lstiburek 57

Building Science Corporation Joseph Lstiburek 58

Building Science Corporation Joseph Lstiburek 59

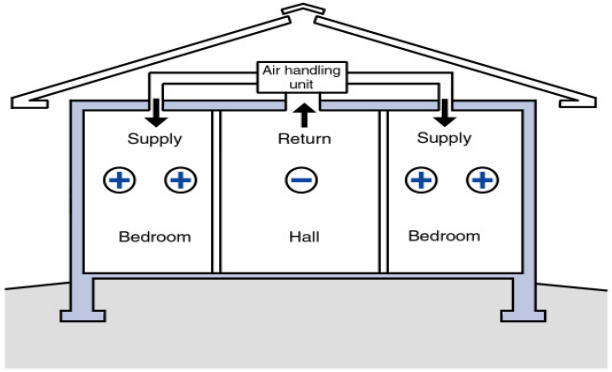


Building Science Corporation Joseph Lstiburek 60

Building Science Corporation Joseph Lstiburek 61

Building Science Corporation Joseph Lstiburek 62

Building Science Corporation Joseph Lstiburek 63



Building Science Corporation Joseph Lstiburek 64

Building Science Corporation
Joseph Lstiburek 65

Building Science Corporation
Joseph Lstiburek 66

Building Science Corporation
Joseph Lstiburek 67

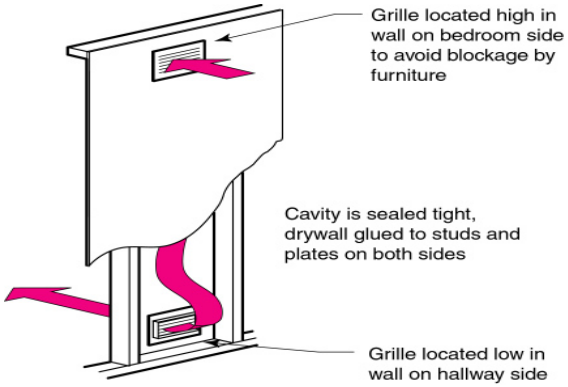
Building Science Corporation
Joseph Lstiburek 68

Building Science Corporation Joseph Lstiburek 69

Building Science Corporation Joseph Lstiburek 70

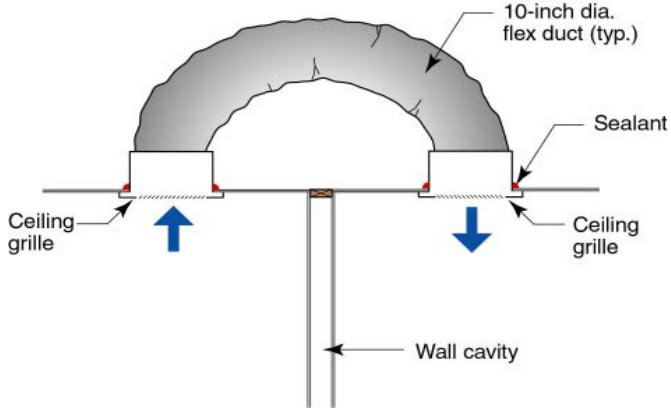
Building Science Corporation Joseph Lstiburek 71

Building Science Corporation Joseph Lstiburek 72

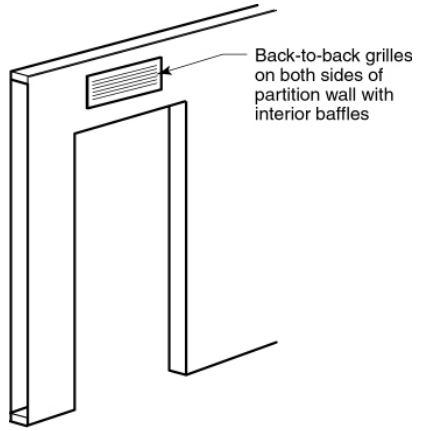


Building Science Corporation Joseph Lstiburek 73

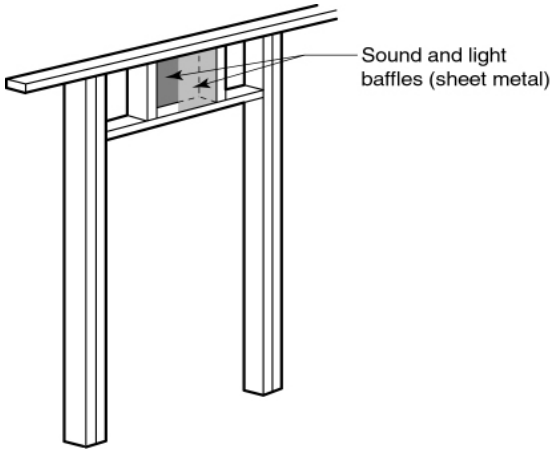
Building Science Corporation Joseph Lstiburek 74



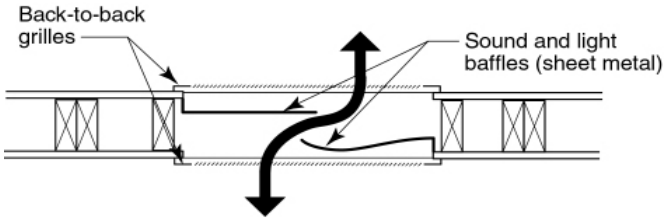
Building Science Corporation Joseph Lstiburek 75



Building Science Corporation Joseph Lstiburek 76



Building Science Corporation
Joseph Lstiburek 77



Building Science Corporation
Joseph Lstiburek 78

Building Science Corporation
Joseph Lstiburek 79

Building Science Corporation
Joseph Lstiburek 80

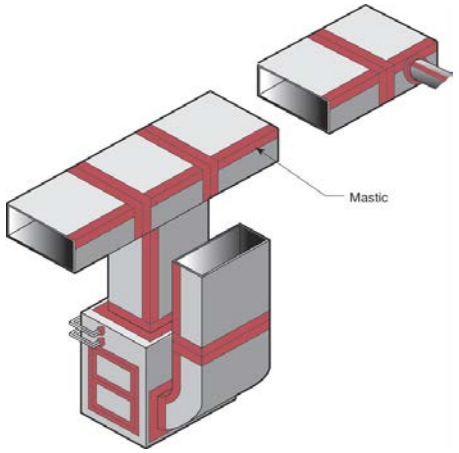
Building Science Corporation Joseph Lstiburek 81

Building Science Corporation Joseph Lstiburek 82

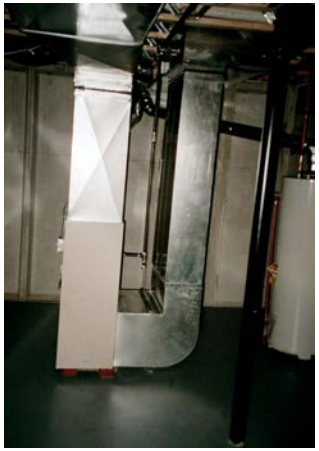
Building Science Corporation Joseph Lstiburek 83

Building Science Corporation Joseph Lstiburek 84

Building Science Corporation Joseph Lstiburek 85



Building Science Corporation Joseph Lstiburek 86



Building Science Corporation Joseph Lstiburek 87

Building Science Corporation Joseph Lstiburek 88

Build Tight - Ventilate Right

Build Tight - Ventilate Right
How Tight?
What's Right?

Air Barrier Metrics

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

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

Best

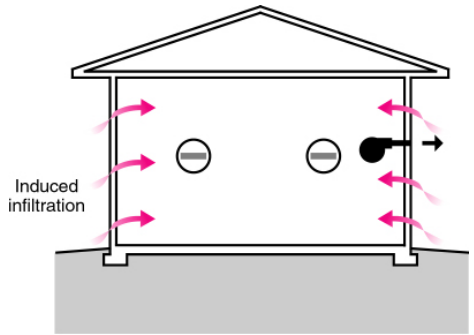
As Tight as Possible - with -
Balanced Ventilation
Energy Recovery
Distribution
Source Control - Spot exhaust ventilation
Filtration
Material selection

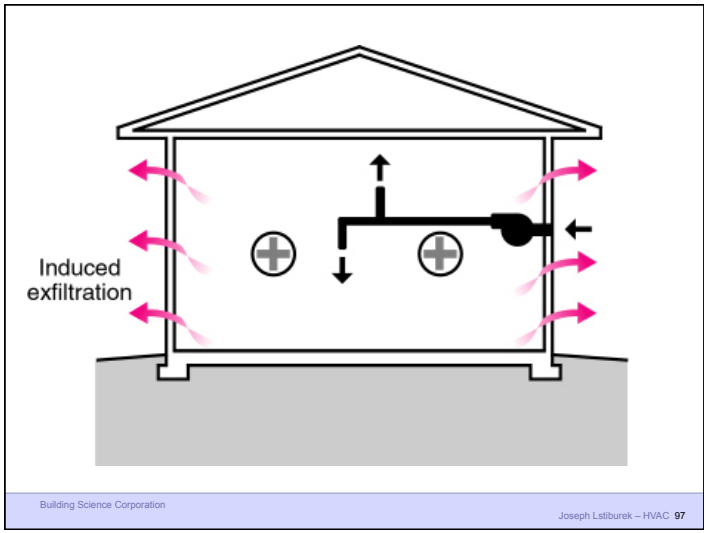
Worst

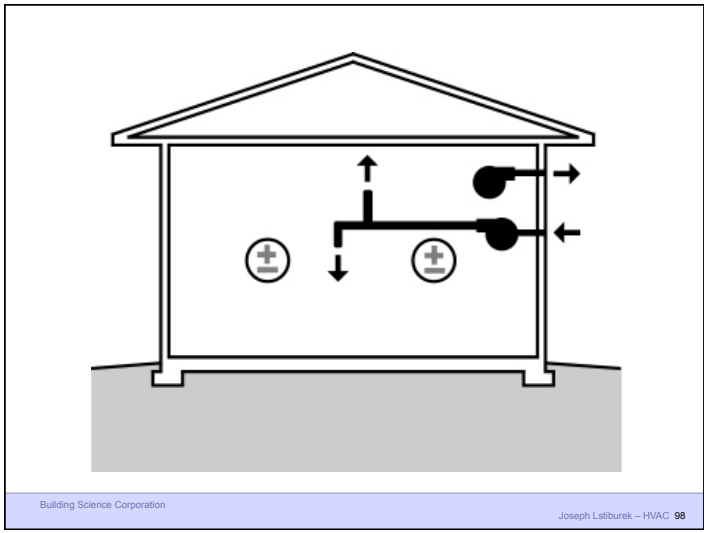
Leaky - with – Nothing
Spot Ventilation in Bathroom/Kitchen
Exhaust Ventilation – with – No Distribution

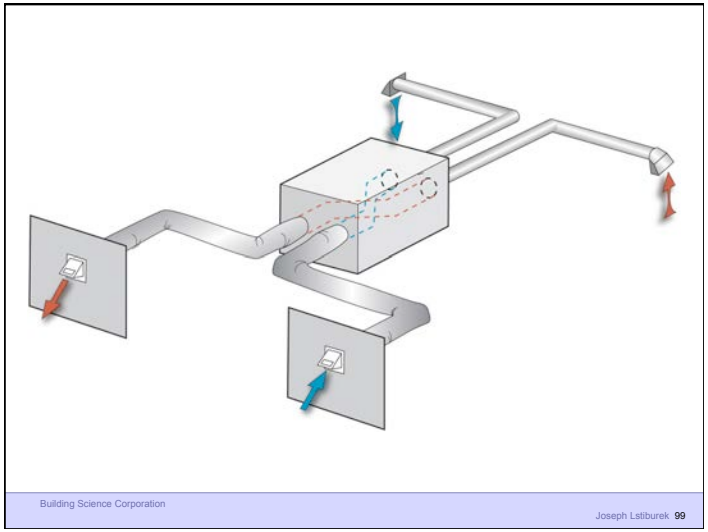
Three Types of Controlled Ventilation Systems

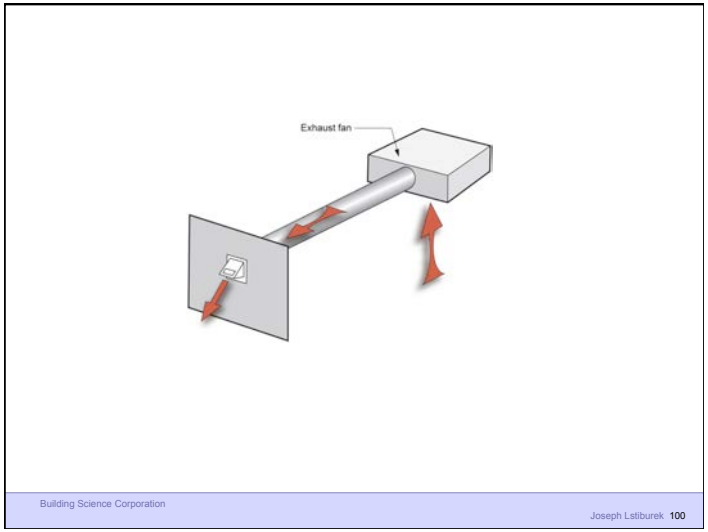
Exhaust Ventilation
Supply Ventilation
Balanced Ventilation

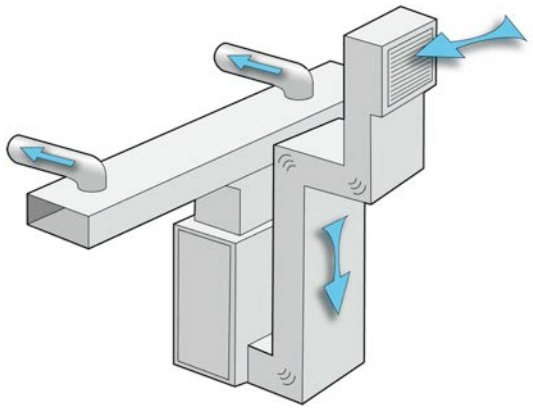


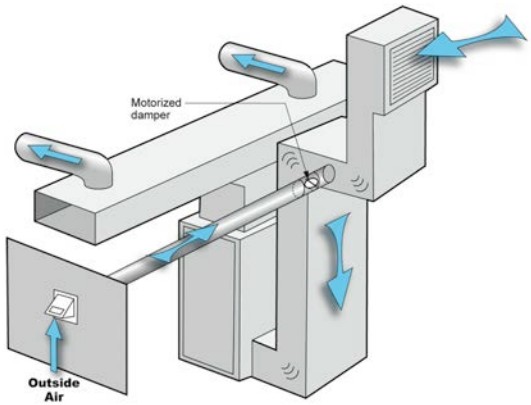

Induced
exfiltration
Building Science Corporation
Joseph Lstiburek – HVAC 97

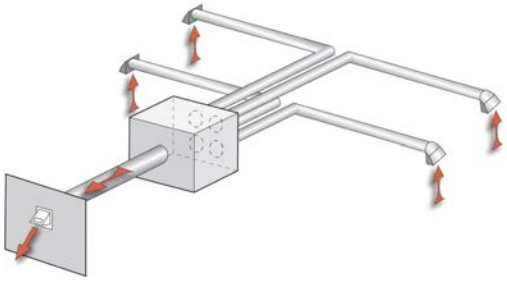

Building Science Corporation
Joseph Lstiburek – HVAC 98


Building Science Corporation
Joseph Lstiburek 99


Exhaust fan
Building Science Corporation
Joseph Lstiburek 100

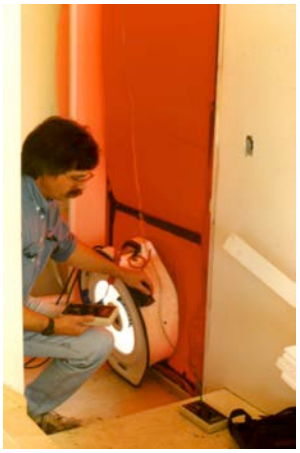






Cost	Exhaust	$150
	Exhaust + Dist	$200
	Supply + Dist	$200
	Spot + Ex/Sup + Dist	$500
	Balanced/HRV	$1,250

The Cult of The Blower Door



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

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

Good For Long Term Average If No Big Pressures

Good For Long Term Average If No Big Pressures

Good For Average Annual Energy Prediction

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

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

Combustion Safety
Indoor Contaminants
Comfort
Energy

Ventilation Rates Are Based on Odor Control

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

Ventilation Rates Are Based on Odor Control
Health Science Basis for Ventilation Rates is Extremely Limited
Almost Nothing Cited Applies to Housing

Ventilation Rates Are Based on Odor Control

Health Science Basis for Ventilation Rates is Extremely Limited

Almost Nothing Cited Applies to Housing

The Applicable Studies Focus on Dampness

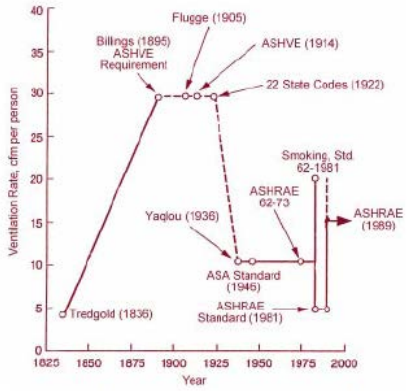


Figure 1: Minimum ventilating rate history.

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 ft³ → 20 cfm/person approx 4x4x8

300 ft³ → 12 cfm/person approx 6x6x8

C.P. Yaglou

Harvard School of Public Health
1936
1955

150 ft³ → 20 cfm/person 18.75 ft² 106 occupants

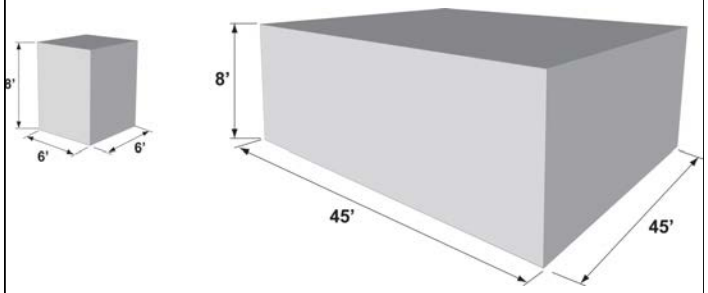
300 ft³ → 12 cfm/person 37.5 ft² 53 occupants

Experiment

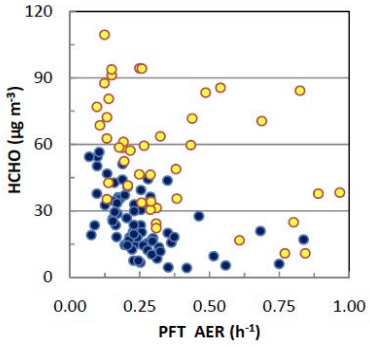
470 ft³ → 59 ft²

200 ft³ → 25 ft²

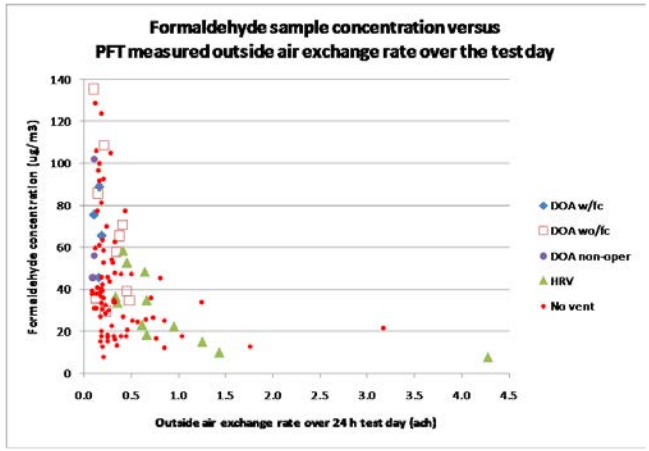
100 ft³ → 12 ft²



Building Science Corporation
Joseph Lstiburek 124



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



Dilution is Not The Solution To Indoor Pollution

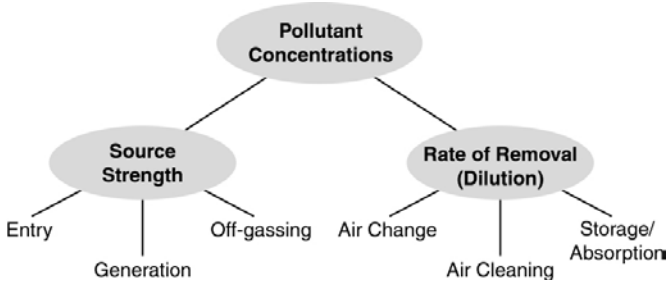
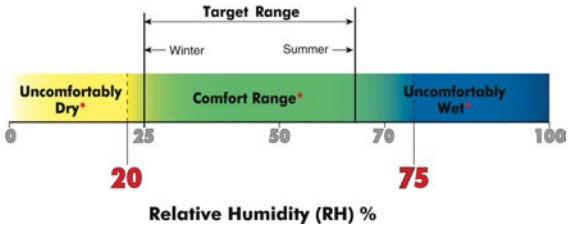


Table 1. Summary of the air changes rates measured during the winter 2009-10 season in Quebec City

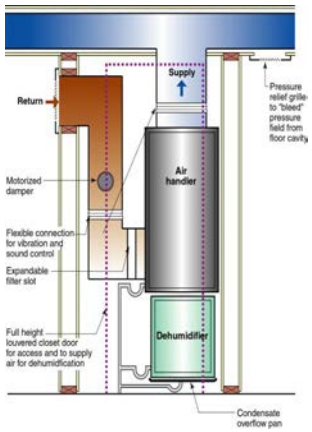
Method	ACH (h^{-1})	ACH standard deviation (h^{-1})	number of measurements
SF_6 tracer decay	0.27	0.12	77
perflurocarbon tracer	0.32	0.22	37
blower door at 50 Pa	4.16	2.64	63

- 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

- 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



Recommended Range of Relative Humidity
Above 25 percent during winter
Below 70 percent during summer



Building Science Corporation
Joseph Lstiburek 134

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

Building Science Corporation
Joseph Lstiburek 135