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

Building Science

Adventures In Building Science

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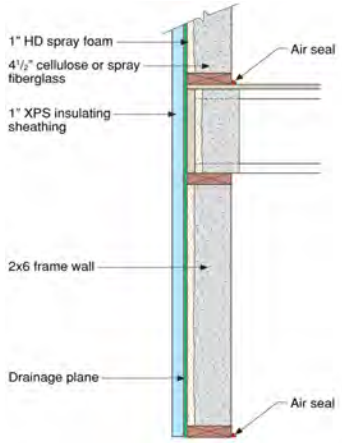

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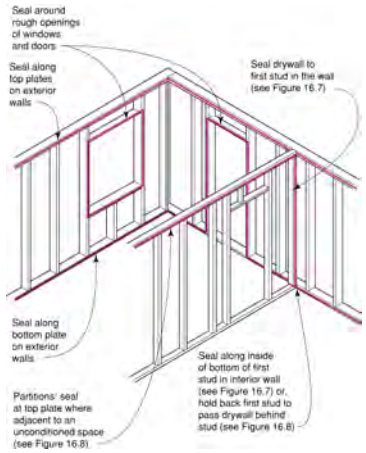

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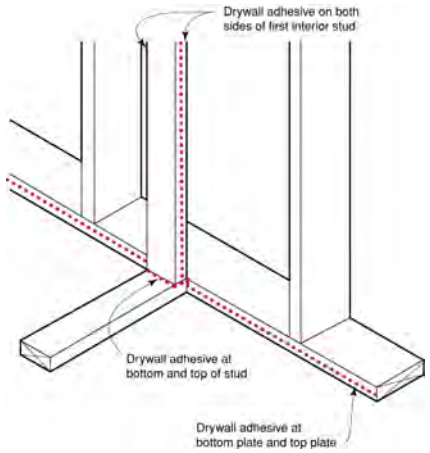

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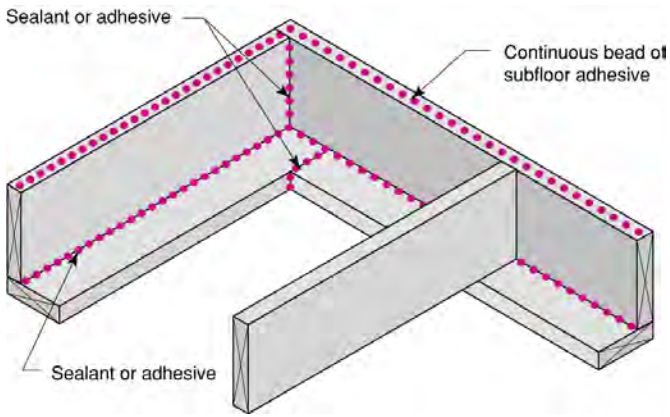

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Build Tight - Ventilate Right

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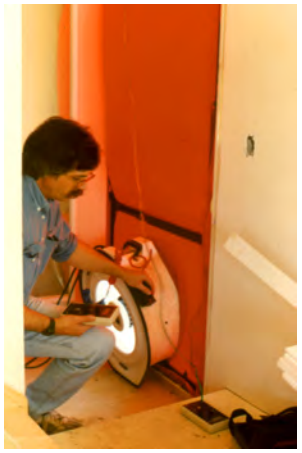

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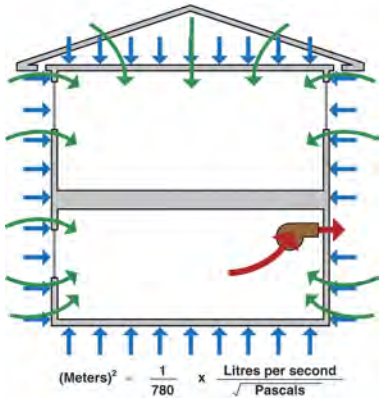
$$ELA = C \times \frac{\text{Rate of flow}}{\sqrt{\text{Pressure difference}}}$$



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

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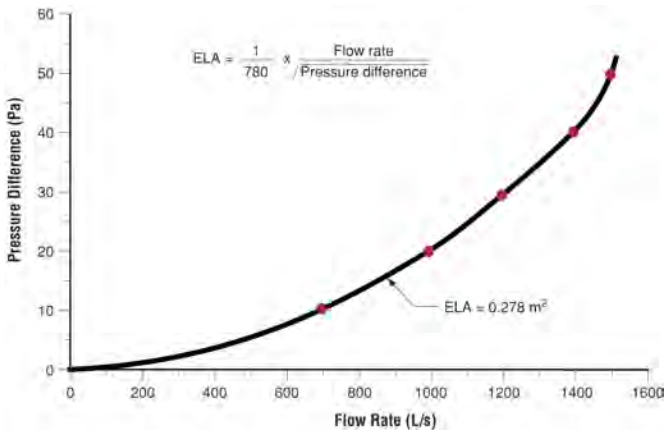

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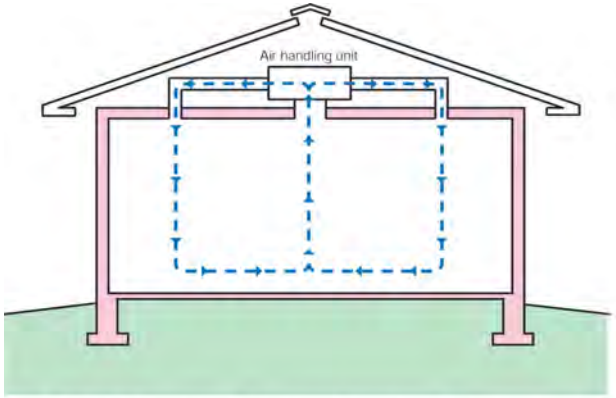
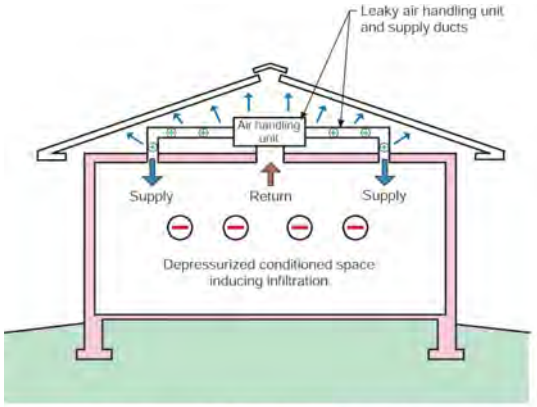
Duct Leakage Should Be Less Than 5% of Rated Flow As Tested by Pressurization To 25 Pascals



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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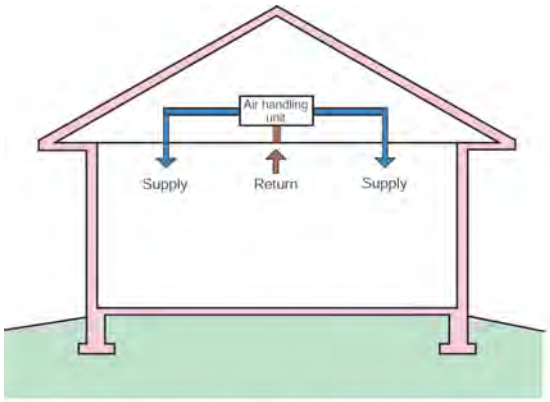

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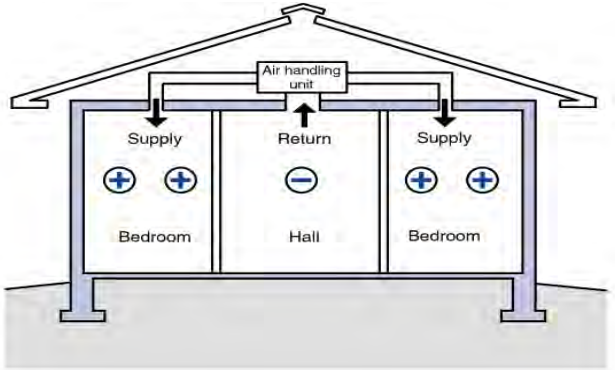

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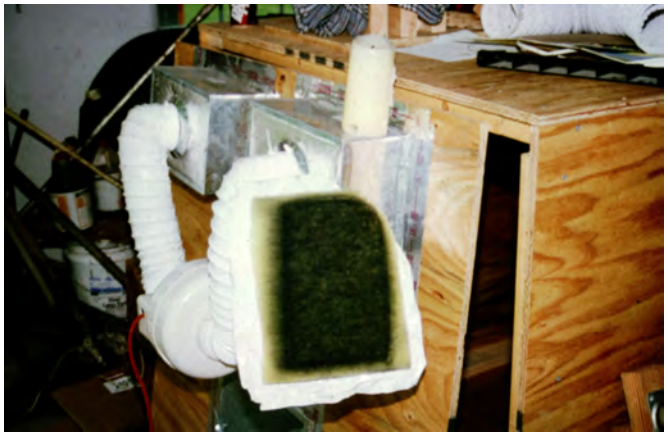

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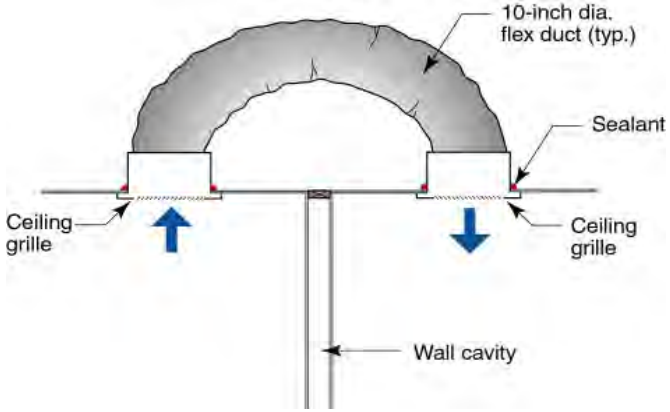

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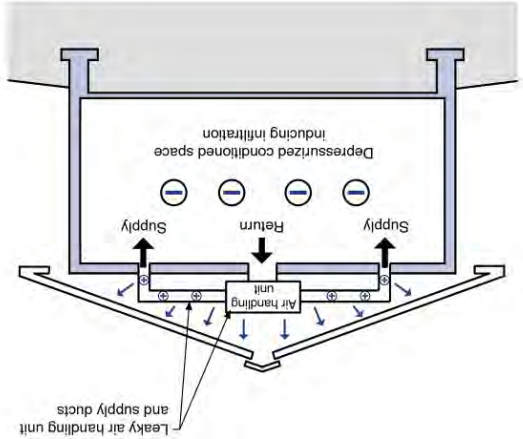

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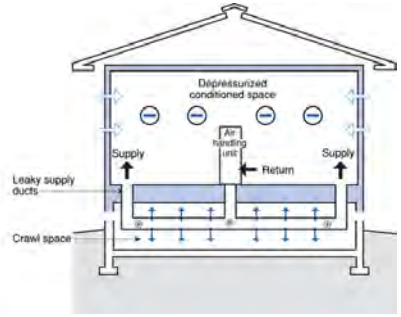

Figure 3.16
Leaky Supply Ductwork in Vented Crawl Space
- Air pressurization pattern with mechanical system ducts in the crawl space

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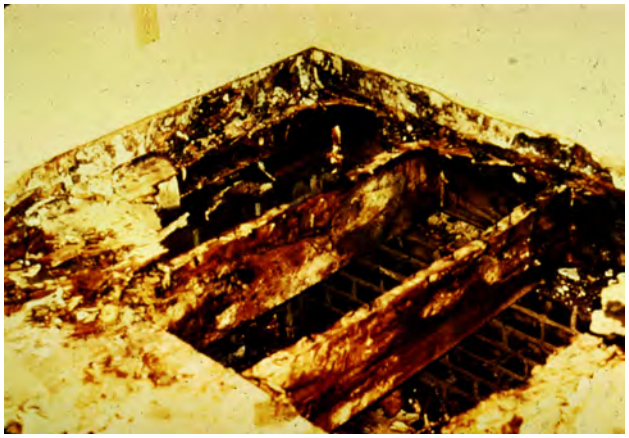

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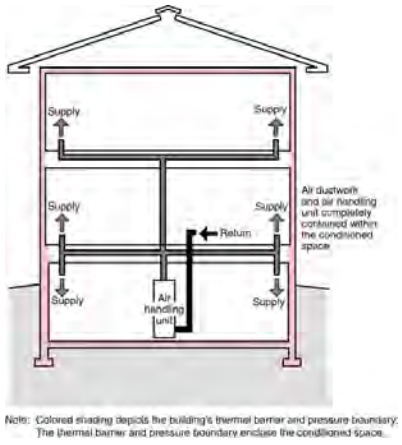

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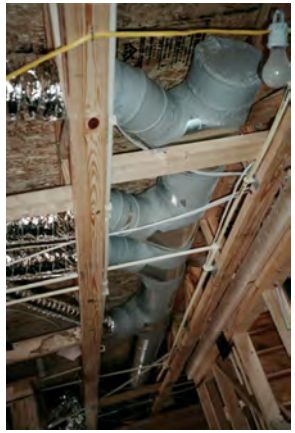

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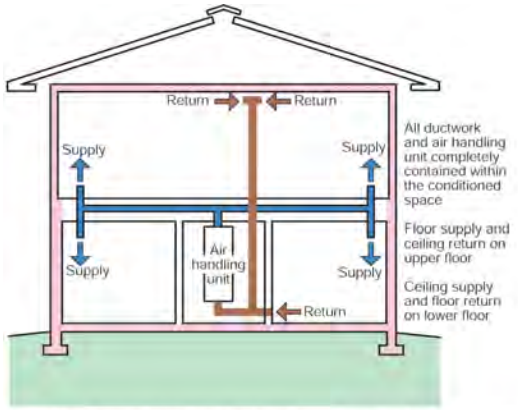

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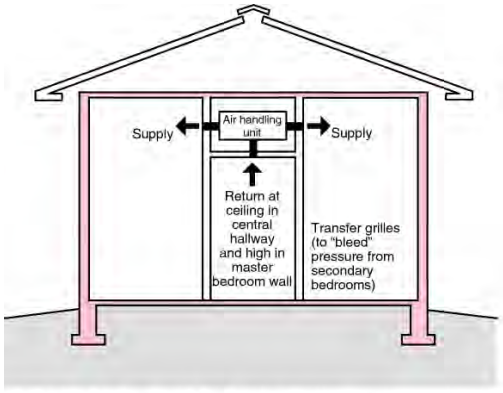

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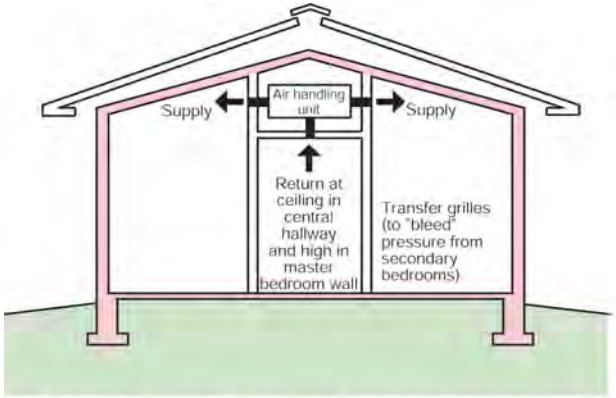

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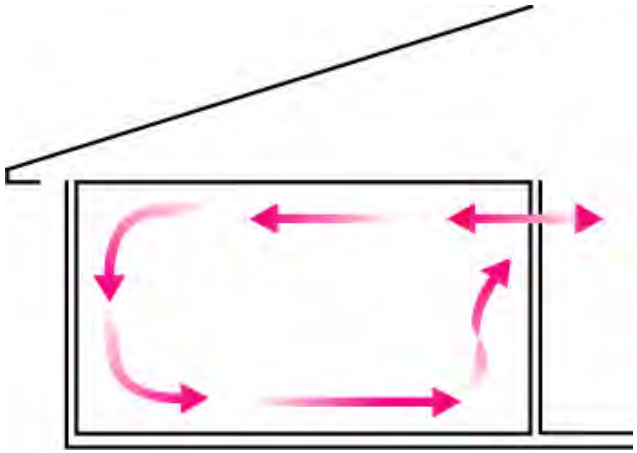

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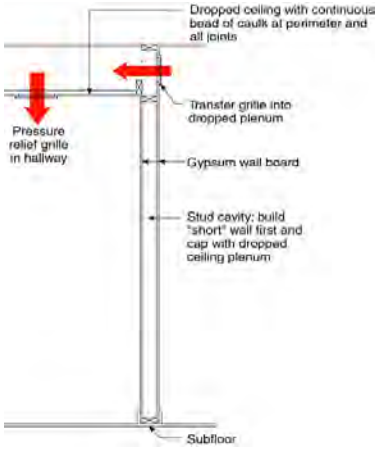

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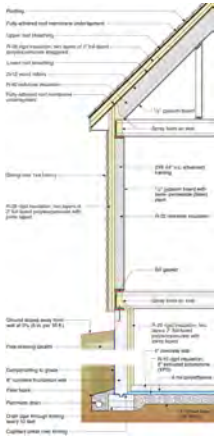

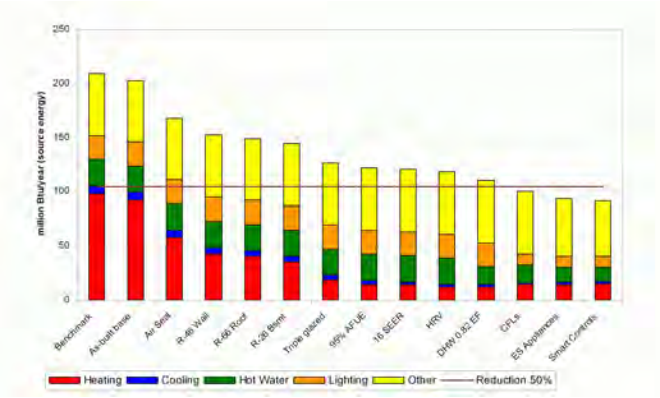

Ventilation Rates Are Based on Odor Control

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Health Science Basis for Ventilation Rates is Extremely Limited

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Almost Nothing Cited Applies to Housing

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Almost Nothing Cited Applies to Housing

The Applicable Studies Focus on Dampness

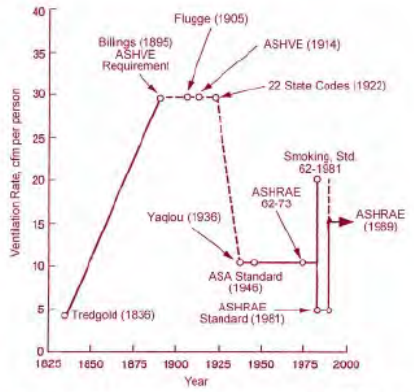

Figure 1: Minimum ventilating rate history.

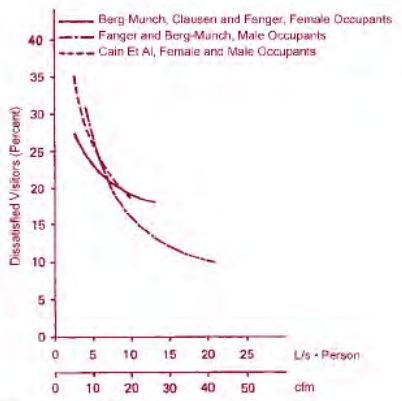

Figure 2: Odor acceptance.

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

Correctional Facility Cell

Occupant Density

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

C.P. Yaglou

Harvard School of Public Health
1936
1955

150 ft³ → 20 cfm/person

300 ft³ → 12 cfm/person

C.P. Yaglou

Harvard School of Public Health
1936
1955

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

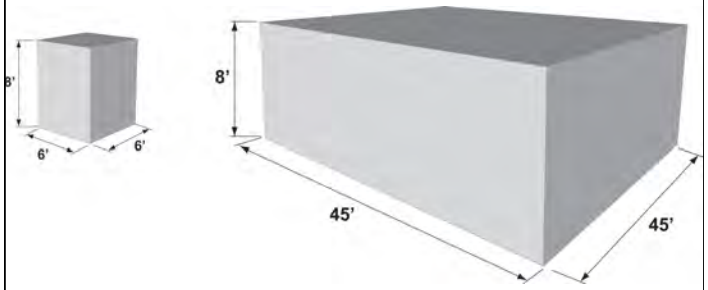
300 ft^3 → 12 cfm/person 37.5 ft^2 53 occupants

Experiment

470 ft^3 → 59 ft^2

200 ft^3 → 25 ft^2

100 ft^3 → 12 ft^2



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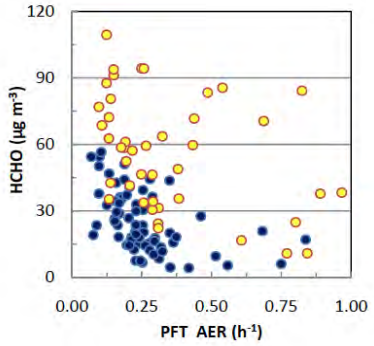

Aubin, D., Won, D.Y., Schleibinger, H., 2010

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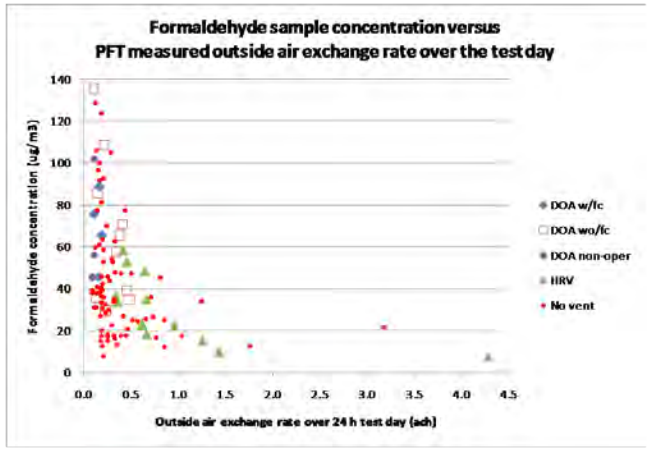

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Table 1. Summary of the air changes rates measured during the winter 2009-10 season in Quebec City

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

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

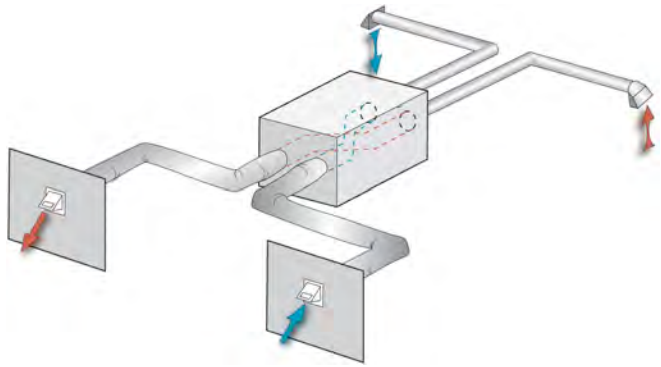
Getting rid of big holes 3 ach@50
Getting rid of smaller holes 1.5 ach@50
Getting German 0.6 ach@50

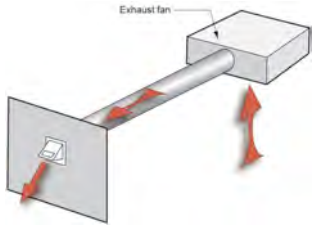
Best

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

Worst

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





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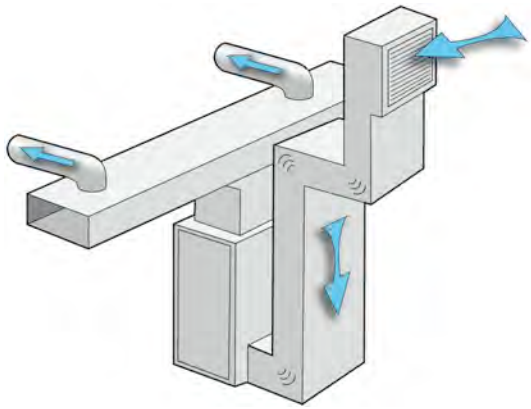

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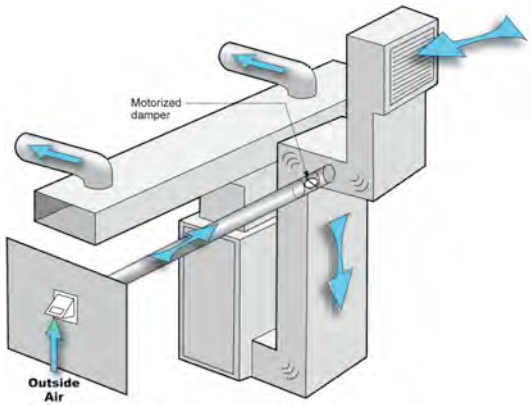

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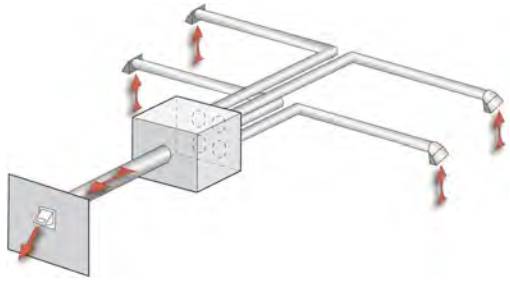

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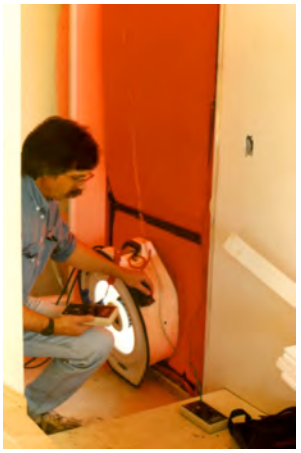
Cost	Exhaust	$150
	Exhaust + Dist + Mix	$200
	Supply + Dist + Mix	$200
	Spot + Ex/Sup + Dist + Mix	$500
	Balanced/HRV	$1,250

- 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

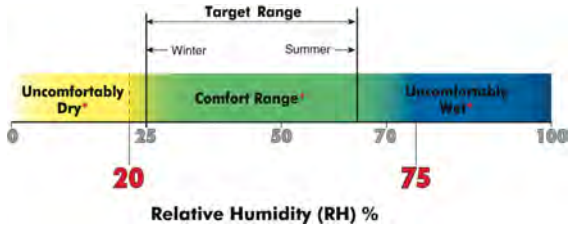
- ASHRAE Standard 62.2 calls for 7.5 cfm per person plus 0.03 cfm per square foot of conditioned area
- Occupancy is deemed to be the number of bedrooms plus one
- Outcome is often bad – part load humidity problems, dryness problems, energy problems

The Cult of The Blower Door

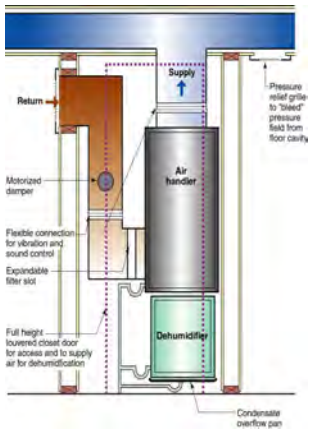


Blower Door Can't Get You The True ACH
On A Short Term Basis – Hour, Day, Week

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



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



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

- 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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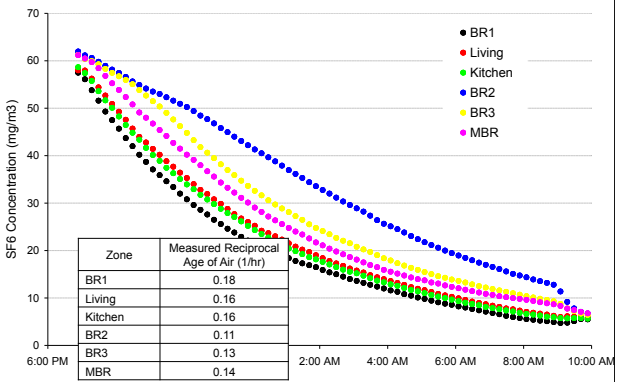
Example Results of Tracer Gas Testing

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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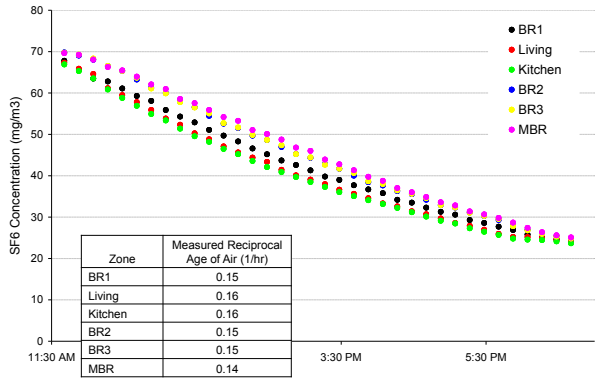
Example Results of Tracer Gas Testing

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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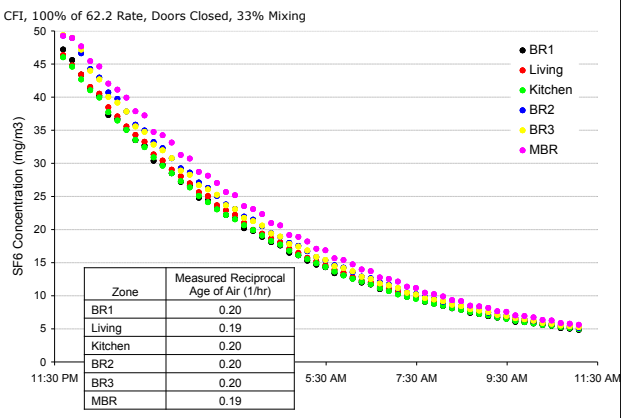
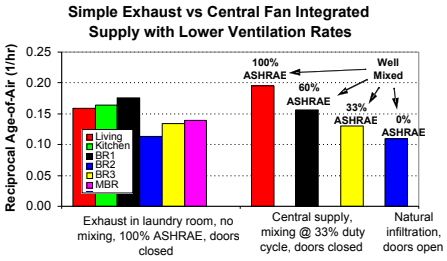
Example Results of Tracer Gas Testing



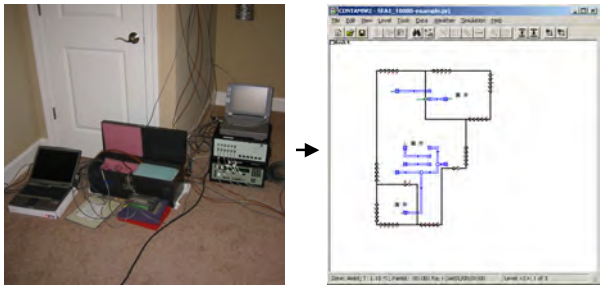
Zone	Measured Reciprocal Age of Air (1/hr)
BR1	0.20
Living	0.19
Kitchen	0.20
BR2	0.20
BR3	0.20
MBR	0.19

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

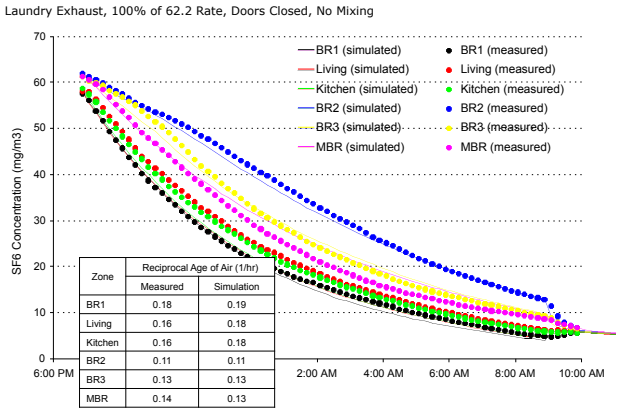


Tuned CONTAM Model



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

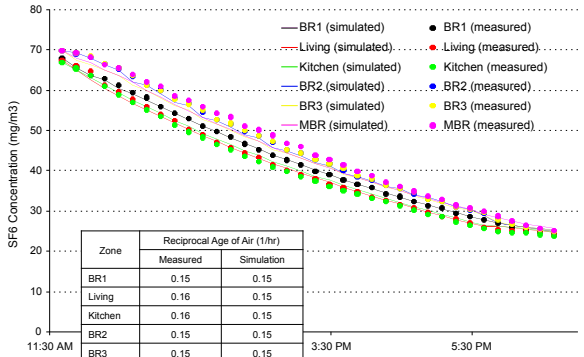
Example Results of Tuned CONTAM Model



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

Example Results of Tuned CONTAM Model

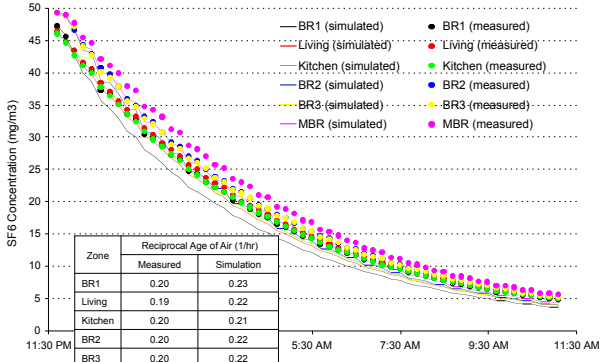
Laundry Exhaust, 100% of 62.2 Rate, Doors Closed, 33% Mixing



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

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

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(d)

C(s) = System Coefficient

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.

BSC 01-2013

Ventilation for New Low-Rise Residential Building

2,000 ft²
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 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	50 cfm
	+ 0.01	
62.2 - 2013	7.5 cfm/person	90 cfm
	+ 0.03	
BSC 01 - 2013	7.5 cfm/person	37 cfm
	+ 0.01 (MBD)	75 cfm

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