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

Building Science

Distribution Coefficients

presented by www.buildingscience.com

Build Tight - Ventilate Right

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

Best

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

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

Barriers - Policy	ASHRAE 62.2
	HERS/RESNET
Barriers - Technology	ECM
	Supplemental Dehumid
Barriers - Cost	Exhaust $100
	Exhaust + Dist $150
	Supply + Dist $150
	Spot + Ex/Sup + Dist $450
	Balanced/ER $1,000

ASHRAE Standard 62.2 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) = Ventilation Rate

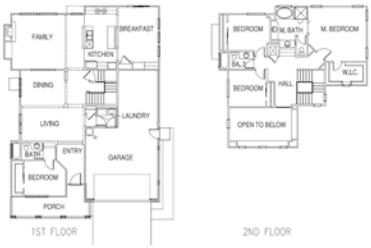
Q(fan) = Q(v) • C(d)

C(d) = Distribution Coefficient

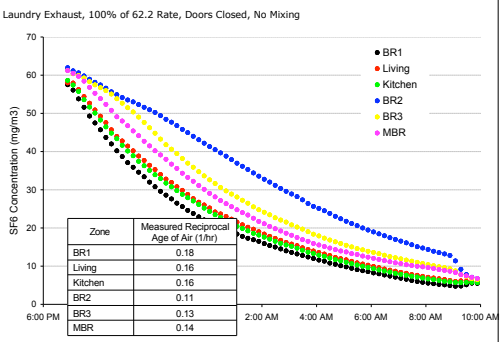
System Type	Distribution Coefficient (C_d)
Balanced ventilation, with central forced air distribution system or a fully ducted ventilation system	1.0
Unbalanced ventilation (Supply or exhaust), with central forced air distribution system having a minimum run time of 10 minutes per hour	1.25
Unbalanced ventilation (Supply or exhaust), with central forced air distribution system or multi-point exhaust or supply	1.5
All other systems	1.75

- 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

Floor Plan - 2 Story House



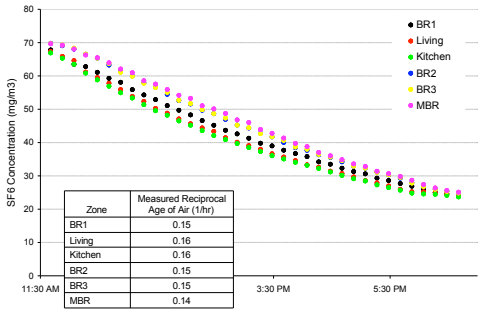
Example Results of Tracer Gas Testing



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

Example Results of Tracer Gas Testing

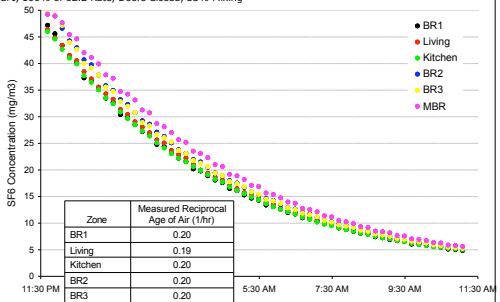
Laundry Exhaust, 100% of 62.2 Rate, Doors Closed, 33% Mixing



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

Example Results of Tracer Gas Testing

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

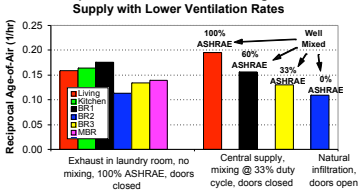


Zone	Measured Reciprocal Age of Air (1/hr)
BR1	0.20
Living	0.19
Kitchen	0.20
BR2	0.20
BR3	0.20
MBR	0.19

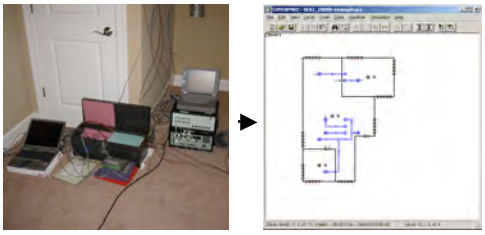
Conclusions From Tracer Gas Testing

- 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

Simple Exhaust vs Central Fan Integrated Supply with Lower Ventilation Rates



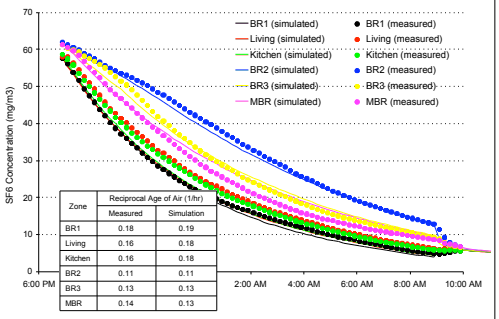
Tuned CONTAM Model



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

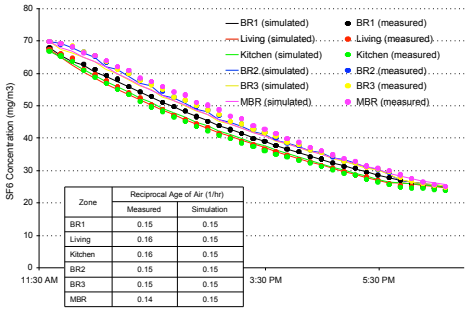
Laundry Exhaust, 100% of 62.2 Rate, Doors Closed, No Mixing



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

Example Results of Tuned CONTAM Model

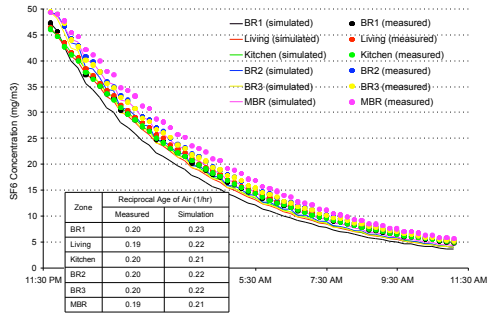
Laundry Exhaust, 100% of 62.2 Rate, Doors Closed, 33% Mixing



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



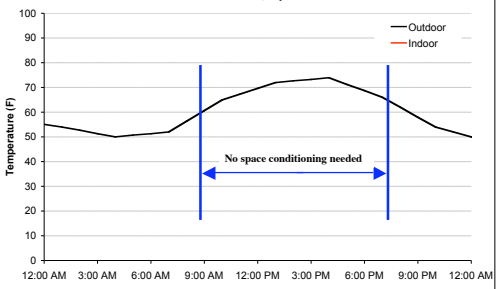
Zone	Reciprocal Age of Air (1/hr)	
	Measured	Simulation
BR1	0.20	0.23
Living	0.19	0.22
Kitchen	0.20	0.21
BR2	0.20	0.22
BR3	0.20	0.22
MBR	0.19	0.21

Tuned CONTAM Model Applied to Other Systems

Six 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

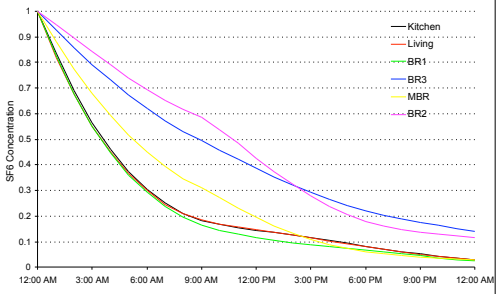
Indoor and Outdoor Temperature
Sacramento, April 13



Simulation allows identical weather conditions for each system (generally not possible in field tests).

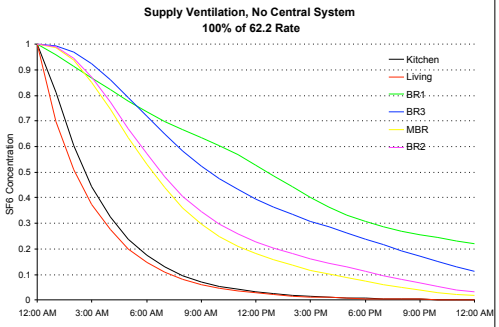
Results of Tuned CONTAM Model

Exhaust Ventilation, No Central System
100% of 62.2 Rate



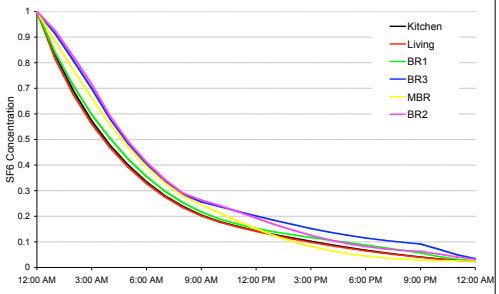
Results of Tuned CONTAM Model

Supply Ventilation, No Central System
100% of 62.2 Rate



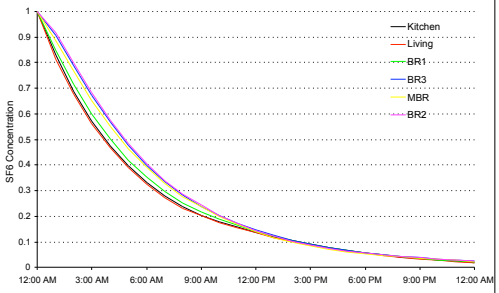
Results of Tuned CONTAM Model

Exhaust Ventilation, Central AHU w/ Standard Tstat
100% of 62.2 Rate



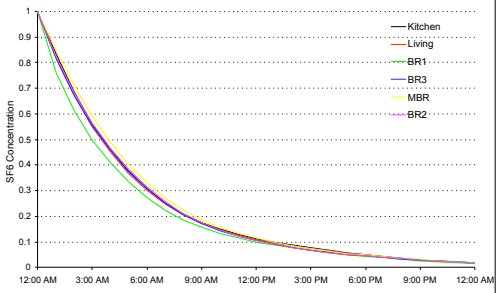
Results of Tuned CONTAM Model

Exhaust Ventilation, Central AHU w/ Tstat and Timer
100% of 62.2 Rate



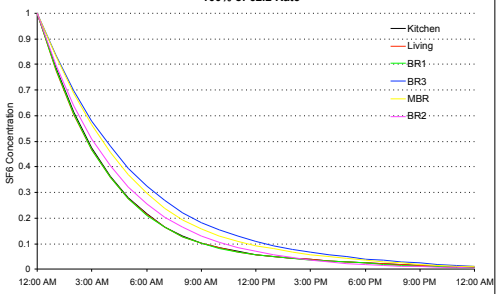
Results of Tuned CONTAM Model

Supply Ventilation (CFI), Central AHU w/ Tstat and Timer
100% of 62.2 Rate



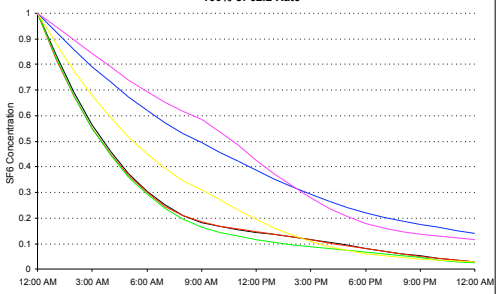
Results of Tuned CONTAM Model

Balanced Ventilation, No Central System
100% of 62.2 Rate



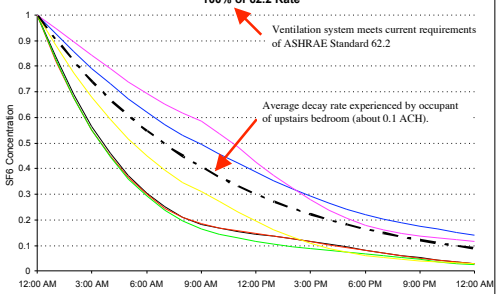
Adjusting Ventilation Rate to Achieve Equivalent Performance

Exhaust Ventilation, No Central System
100% of 62.2 Rate



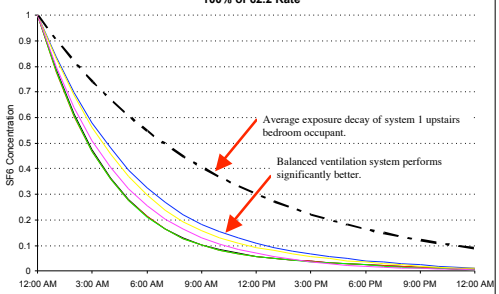
Adjusting Ventilation Rate to Achieve Equivalent Performance

Exhaust Ventilation, No Central System
100% of 62.2 Rate

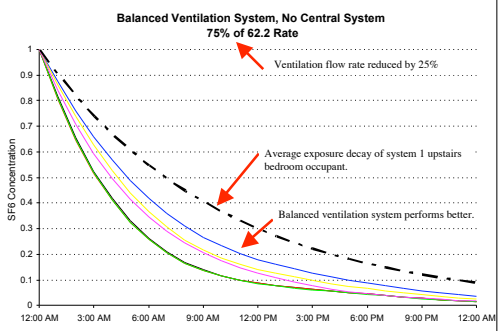


Adjusting Ventilation Rate to Achieve Equivalent Performance

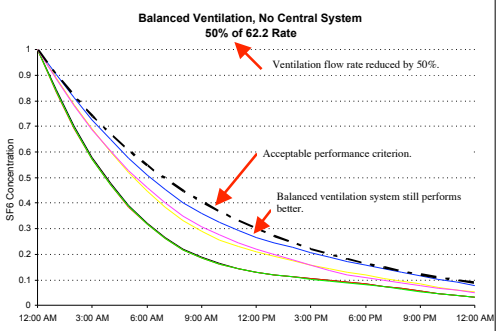
Balanced Ventilation, No Central System
100% of 62.2 Rate



Adjusting Ventilation Rate to Achieve Equivalent Performance



Adjusting Ventilation Rate to Achieve Equivalent Performance



Conclusions from Tuned CONTAM Model

1. Ventilation systems do not perform equally just because they have equal nominal airflow
2. Airflow requirements can be adjusted based on performance of each system

Extending the Modeling

1. Comparison of 1 day in 1 house in 1 climate is useful but needs to be expanded before establishing general guidelines.
2. Expand modeling from 1 day in 1 house in 1 climate to:
   1. Full-year
   2. Various house characteristics (envelope leakage, mechanical systems, etc)
   3. Different climates
3. Methodology of simulations changed from decay to exposure
   1. Uniform generation of pollutant within house
   2. Assumed occupancy schedule
   3. Calculated occupant exposure based on concentration in the zone where they are each hour

Modeling Assumptions: Weather

1. Temperature
   1. Outdoor temperature from TMY2 data
   2. Indoor temperature constant at 72 C (with minor variation between rooms)
2. Wind
   1. Wind speed and direction from TMY2 data
   2. Wind shielding model and modifiers as described in ASHRAE Fundamentals 2005 Chapters 16 and 27 for typical suburban surroundings

Model Assumptions: Air Handler

1. Sizing per Manual J for each climate
2. Duty cycle each hour based on temperature and design temperature for the climate
   1. Maximum 80% runtime at design conditions
   2. Heating balance point = 65 F
   3. Cooling balance point = 75 F
3. Two cycles per hour
   1. Cycles rounded to nearest 5 minute increment (simulation time step = 5 minutes)

Model Assumptions: Envelope Leakage

1. Distribution
   1. Leakage distribution per ASHRAE Fundamentals Chapter 27
      1. Walls, windows, doors: 62%
      2. Ceilings & nonoperating exhaust vents: 23%
      3. Ducts: 15%
2. Total leakage varied as described later

Model Assumptions: Pollutant Generation

1. Uniform generation of unique pollutant in each room
   1. Generation rate arbitrarily set at 1 mg/hr/sf
   2. Can be scaled as desired

Model Assumptions: Occupant Schedules

1. Assume similar schedule for each occupant:
   1. 10 PM to 7 AM: in bedroom with door closed
   2. 7 AM to 9 AM: in kitchen
   3. 9 AM to 12 PM: in living room
   4. 12 PM to 1 PM: in kitchen
   5. 1 PM to 6 PM: in living room
   6. 6 PM to 10 PM: in other bedrooms
2. Bedroom doors open except during sleeping period 10 PM to 7 AM

Varied Parameters

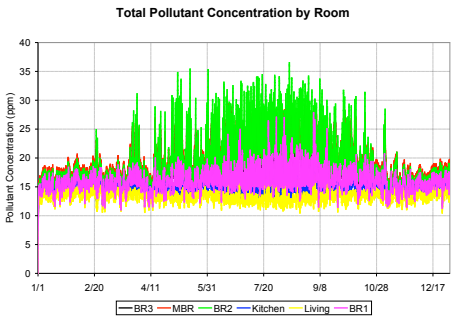
1. Climate
   1. Minneapolis, Seattle, Phoenix
2. Envelope leakage
   1. 1.5, 3.5, 7 ACH50
3. Central AHU System
   1. Not present, in conditioned space, outside of conditioned space
4. AHU Schedule
   1. Standard Tstat, Tstat with minimum runtime (10 minutes per half-hour)
5. Duct Leakage
   1. 6% & 12% of air handler flow

Varied Parameters

6. Ventilation System
   1. Single-point exhaust
   2. Single-point supply
   3. Dual-point balanced
   4. Fully-ducted balanced
7. Ventilation Rate
   1. 0, 50, 100, 150% of current 62.2 rate

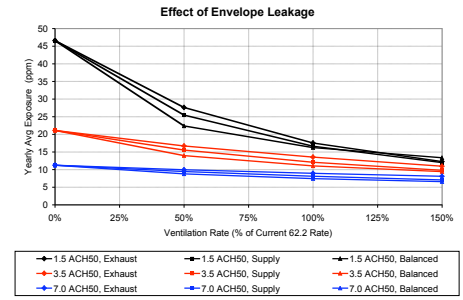
Simulation Tools

- CONTAM Factorial
- CONTAM 2.4b
- CONTAM SimRead



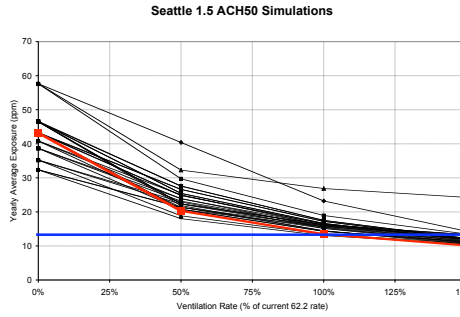
Exposure Calculation

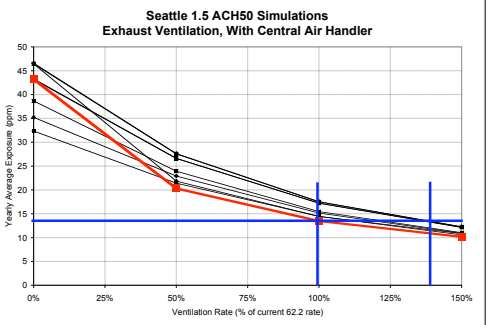
- Yearly average hourly exposure
- Sum of pollutant concentration in the zone occupied by the occupant each hour of the year, divided by 8760 hr/yr



Reference System

- Best available system: fully ducted, balanced ventilation system
- Compare other systems to this system: what ratio of airflows do other systems need to provide equal yearly average exposure?





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

ASHRAE Standard 62.2 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) = Ventilation Rate

Q(fan) = Q(v) • C(d)

C(d) = Distribution Coefficient