Residential Ventilation in the Pacific Northwest

Field Study of Mechanical Ventilation Effectiveness in Tightly Constructed Houses

David Hales
Washington State University Extension Energy Program
halesd@energy.wsu.edu
509-443-4355 ext. 2

Research Supported by the Northwest Energy Efficiency Alliance
Charlie Stephens, Project Manager

WSU Contributors: Ken Eklund, David hales, Rich Prill, Luke Howard, Rick Kunkle, Adria Banks, Luke Mattheis, Marla Hacklander, Tanya Beavers, Mike Lubliner, Andy Gordon

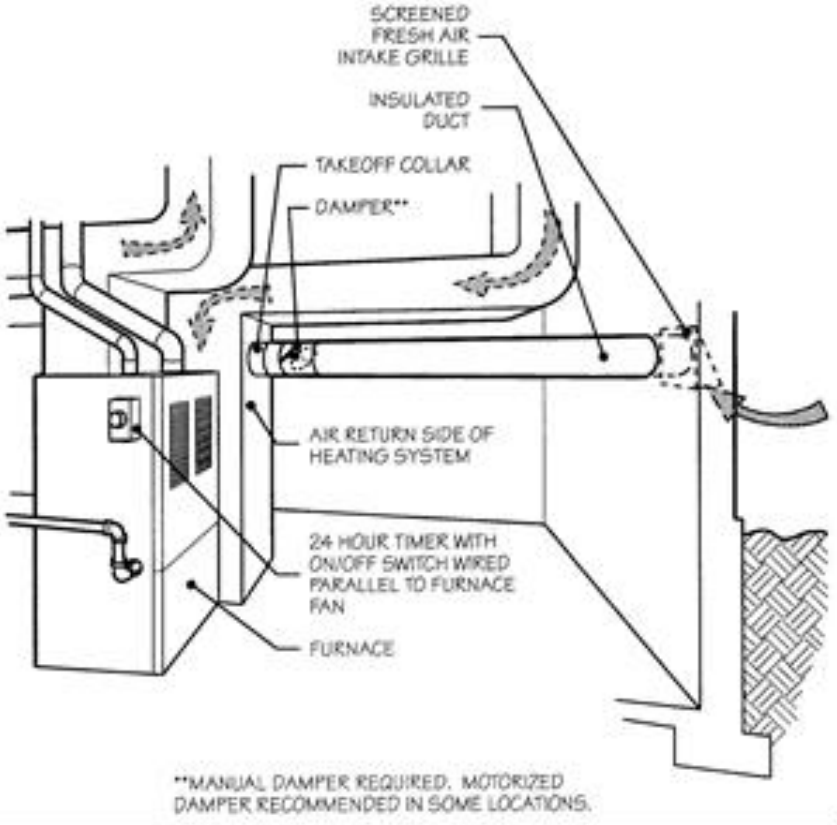
Additional Consultants: Terry Brennan and Dr. Jeff Siegel

History

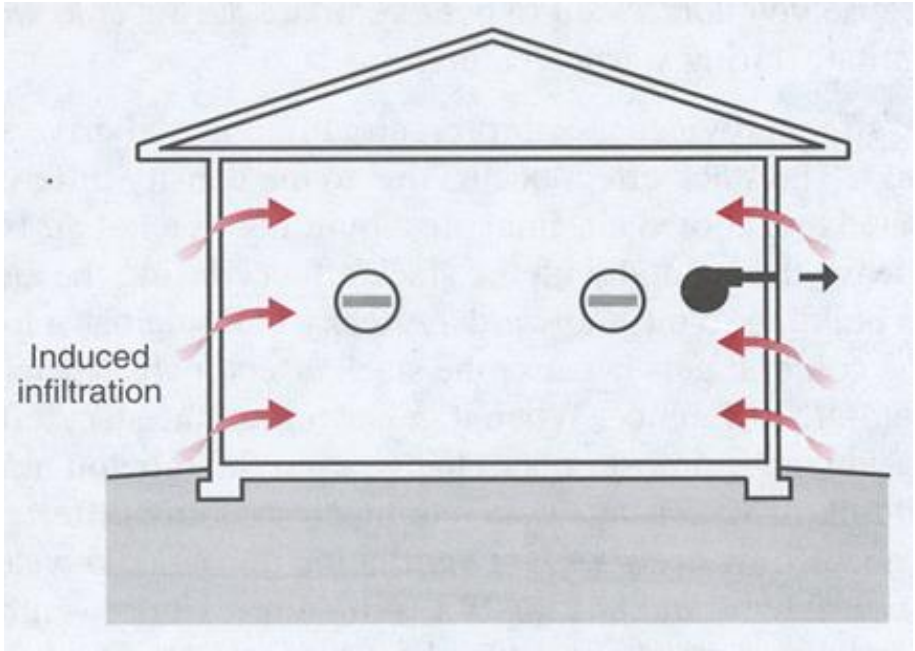
- Mechanical whole house ventilation required in residential construction in Washington State since July 1, 1991. VIAQ Code
- First statewide requirement in US.
- Based on ASHRAE 62.2 1989
  - 15 CFM/occupant or .35 ACH
- In 22 years about 800K homes.
- 1991 WA State Energy Code assumed tight houses < .1 ACH “Seal all penetrations”

Ventilation System Types

Integrated with Central Forced Air



Exhaust Only



What Really Happened

- Houses didn't get as tight as assumed.

  Tested average of WA Code homes since 1991

  .37 ACH.
- Systems often didn't work properly, were turned off or disabled by occupants.
- If operated often over ventilated especially during colder seasons.
- Not a lot of complaints or problems.

What's Happening Now

- WA Code required blower door testing to about .285 ACH since 2009 (tested av. .31).
- 2012 WA Code .25 ACH started 7/1/13.
- 2012 IECC requires tested 3 ACH50 (.15 ACH).

- It may really matter if ventilation systems actually work and are operated!

What's Happening Now

- Most really tight houses (2 ACH50 or less) have HRVs. Conventional wisdom is they work but they are expensive.
- Super tight, high performance homes are moving away from CFA so integrated ventilation is less common option. Conventional wisdom is they work, low up front cost but high operating costs (big fan).
- Single point exhaust only systems are relatively low cost, economical to operate but conventional wisdom questions how well they actually work.

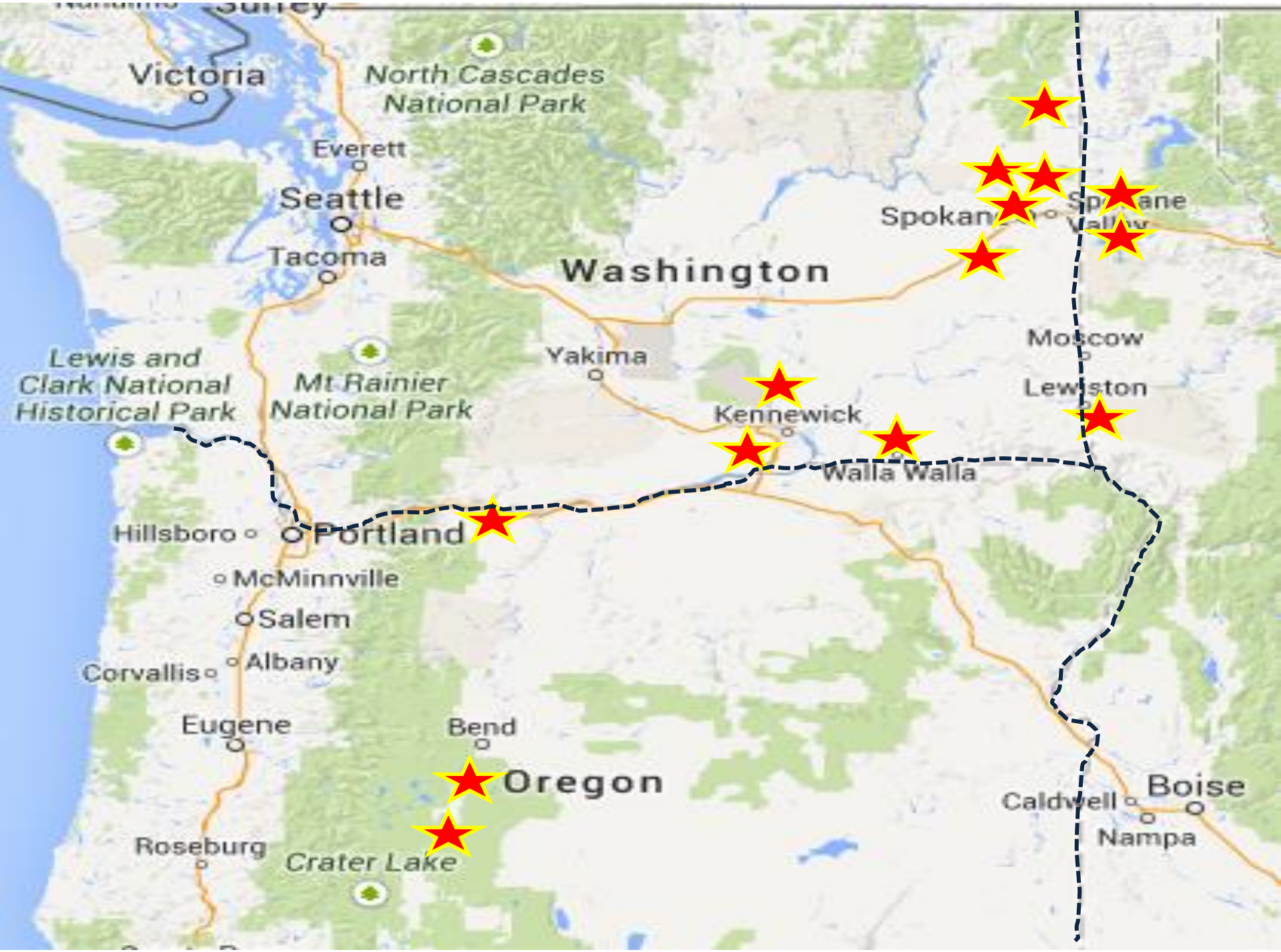
The Plan

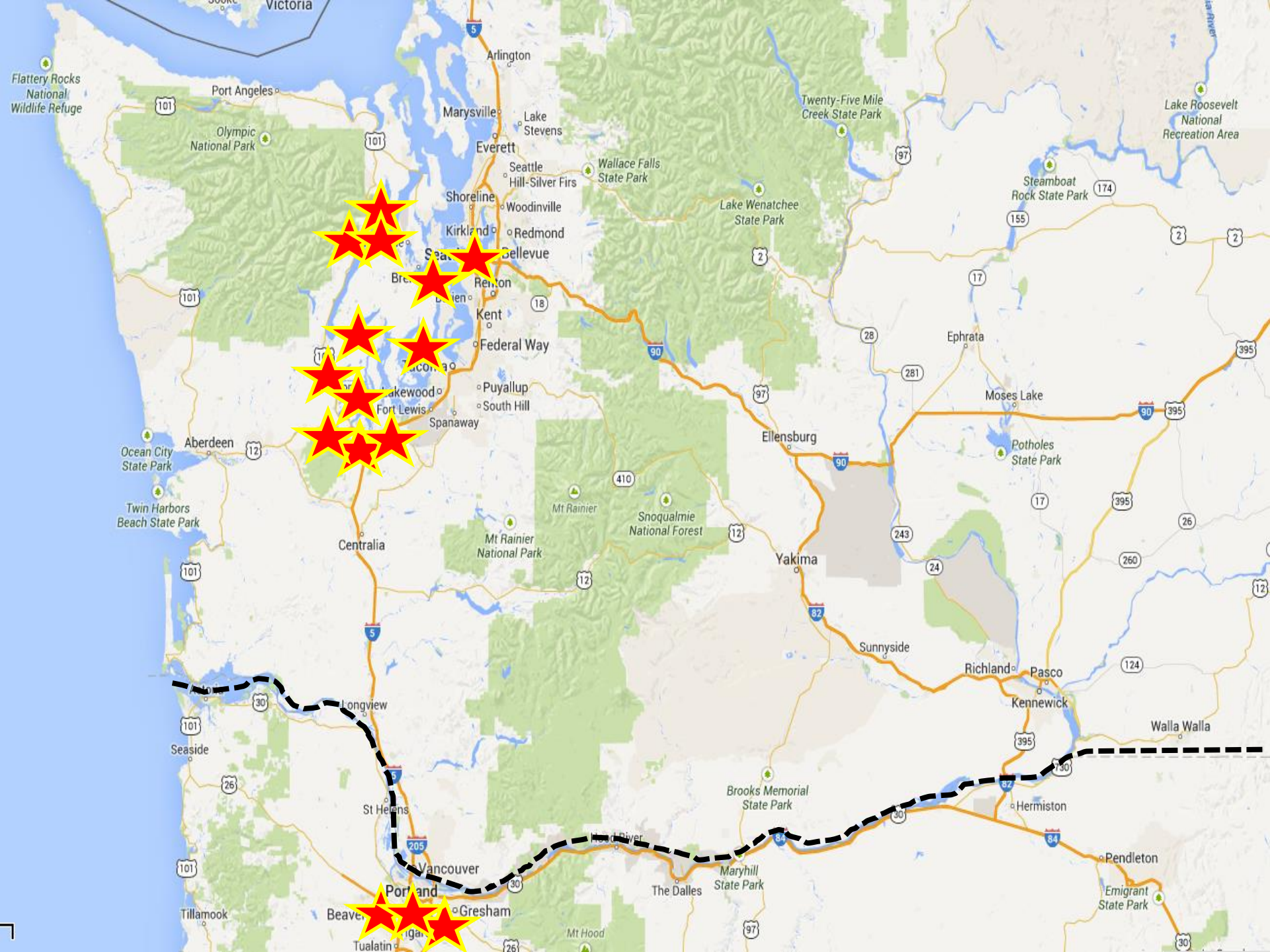
Let’s ask some questions and try to answer them by measuring some stuff!

Ventilation Effectiveness Field Study

What questions did we want to try and answer?

1. How well do different types of ventilation systems work in really tight houses (<3ACH50) in terms of compliance with ASHRAE 62.2 2010?
2. What is the efficacy of different systems in terms of watts / CFM as operated?
3. How does door closure (especially in bedrooms) affect the performance of different types of systems?
4. Do trickle vents improve the performance of exhaust only systems?


Victoria
North Cascades National Park
Everett
Seattle
Tacoma
Washington
Spokane
Moscow
Lewiston
Yakima
Lewis and Clark National Historical Park
Mt Rainier National Park
Kennewick
Walla Walla
Hillsboro
Portland
McMinnville
Salem
Albany
Corvallis
Eugene
Bend
Oregon
Boise
Caldwell
Nampa
Roseburg
Crater Lake


Victoria
Flattery Rocks National Wildlife Refuge
Port Angeles
Olympic National Park
Arlington
Marysville
Lake Stevens
Everett
Seattle
Hill-Silver Firs
Wallace Falls State Park
Shoreline
Woodinville
Kirkland
Redmond
Bellevue
Renton
Kent
Federal Way
Lakewood
Puyallup
South Hill
Fort Lewis
Spanaway
Aberdeen
Ocean City State Park
Twin Harbors Beach State Park
Centralia
Mt Rainier
Mt Rainier National Forest
Snoqualmie National Forest
Ellensburg
Yakima
Twenty-Five Mile Creek State Park
Lake Wenatchee State Park
Steamboat Rock State Park
Lake Roosevelt National Recreation Area
Ephrata
Moses Lake
Potholes State Park
Sunnyside
Richland
Pasco
Kennewick
Walla Walla
Hermiston
Pendleton
Emigrant State Park
Brooks Memorial State Park
Maryhill State Park
The Dalles
Longview
Seaside
St Helens
Vancouver
Portland
Gresham
Tillamook
Mt Hood

Matrix of ACH_{50} and Vent Systems

System Type	House < 1 ACH50	House < 2 ACH50	House < 3 ACH50
Exhaust Only	1	4	2
Exhaust Only with Trickle Vents	1	3	4
Integrated with CFA*			2
HRV	6	3	1
HRV Integrated with CFA*			2

1. Sample selected from ~ 900 homes built 2006 or newer (final sample 29 sites).
2. Screened out occupants with respiratory problems.
3. Single family detached or multi-family with no more than 1 common wall.
4. Roughly ½ sites marine climate zone 4 and ½ cold climate zone 5.
5. Occupants agreed not to open windows during test cycles.

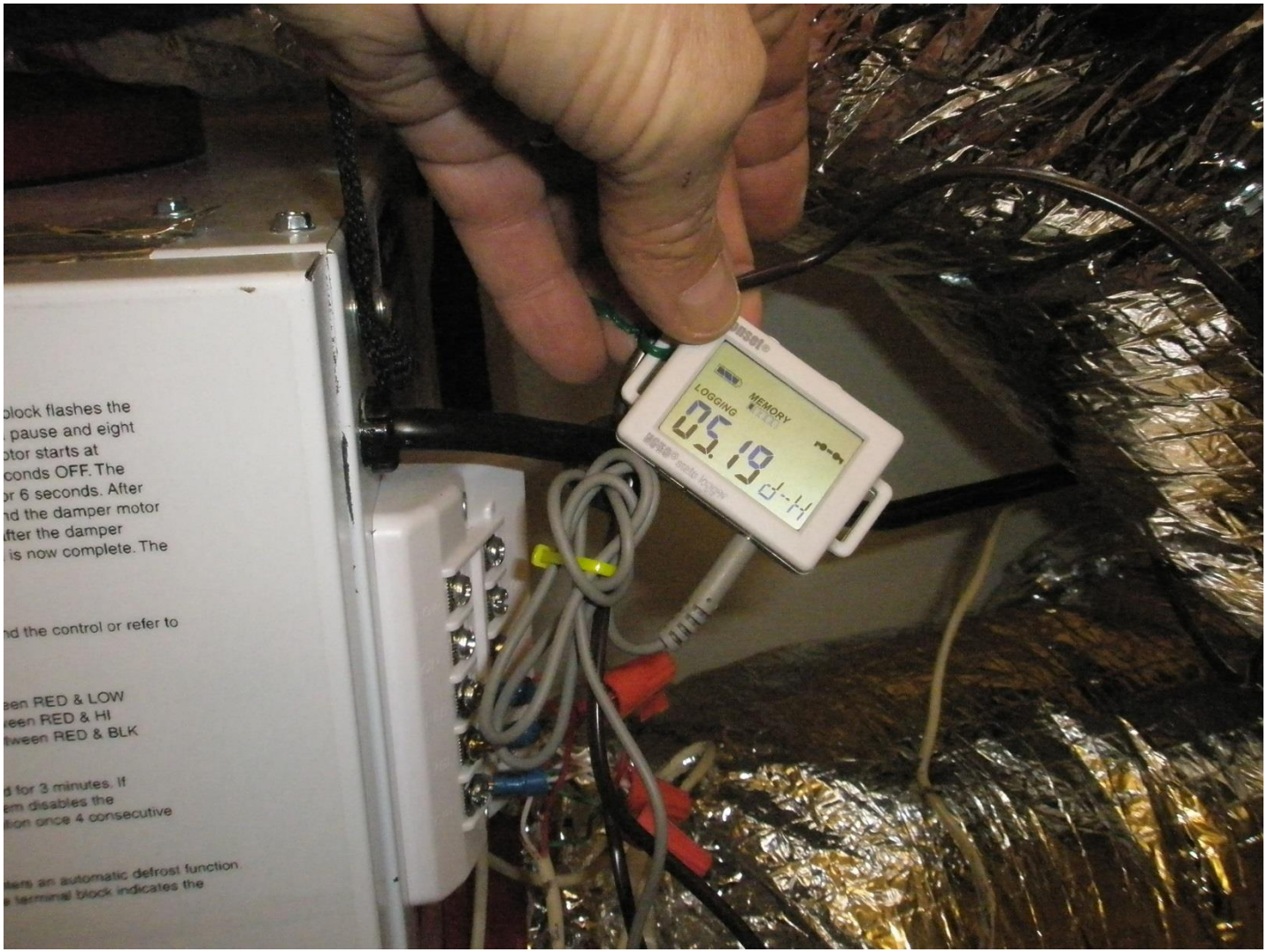
**Central Forced Air*

House Characterization

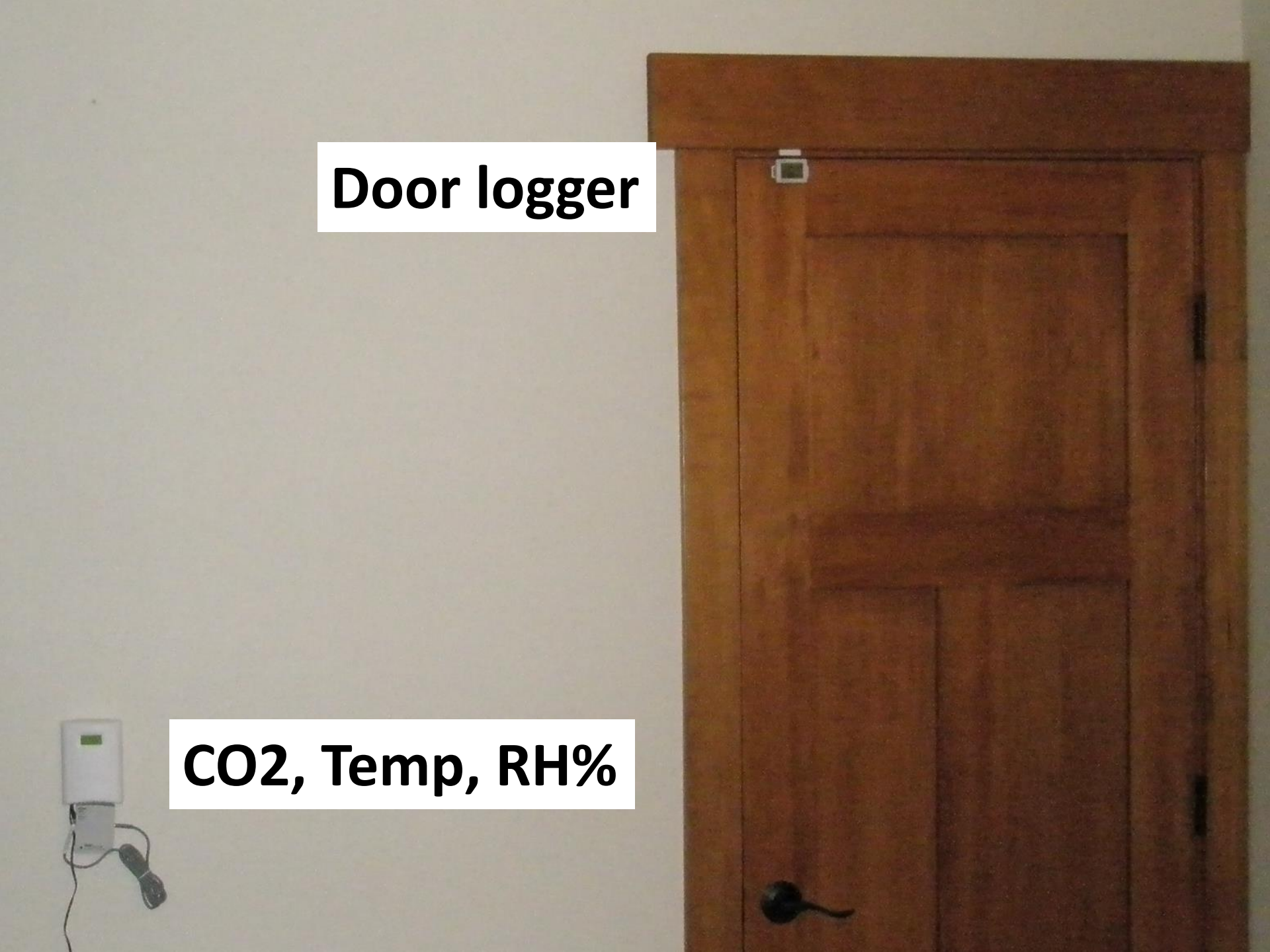
- General: size; volume; bedrooms, occupancy; stories; type heating/cooling; type ventilation; ventilation operation; foundation type; garage.
- Inventory of all exhaust appliances: type; location; flow (cfm); power draw of ventilation equipment.
- House tightness; duct leakage to exterior.
- Pressure mapping: incremental depressurization induced by exhaust air flows and CFA operation.
- Pressure induced across closed bedroom doors when whole house ventilation operated.
- Tracer gas decay on 90% of sites; ventilation off/on; bdrm doors open/closed.

Monitoring

- Monitored CO2, temp. & %RH in master bdrm, secondary bdrm and core living area (15 min data).
- Monitored door closure of master and secondary bdrms.
- Monitored run times of whole house ventilation systems.


block flashes the
pause and eight
otor starts at
conds OFF. The
r 6 seconds. After
nd the damper motor
fter the damper
is now complete. The
nd the control or refer to
een RED & LOW
ween RED & HI
tween RED & BLK
d for 3 minutes. If
em disables the
ion once 4 consecutive
ers an automatic defrost function.
e terminal block indicates the
LOGGING
MEMORY
05.19


Vent Fan
system
96308
20A~
HOLD
200A~
400A~
300V~
300V⎓
2000Ω
200kΩ
OFF
CEN-TECH
3129923
00.7
Digital Clamp Meter
COM
V/Ω/⇔
MAX 300V
CAT II


Door logger
CO2, Temp, RH%


Extra

Test Cycles

7 day test cycle periods (included weekends)

Occupants provided with detailed test calendar and Journal* WSU weekly reminders via phone/email

Test configurations:

- **Whole house ventilation on/off**
- **Bedroom doors open/closed**
- **Trickle vents open/closed (as applicable)**

Heating and Spring season The test cycles at each house performed in cold winter conditions and repeated during mild spring

*Occupants logged system and house & exhaust appliance operation, activities, changes in occupancy

Data and Analysis

What is Effective Ventilation?

- Really complex
- Dynamic interaction of:
  - Structural characteristics of the house
  - Different mechanical systems & operation
  - Outside environment
  - Occupants & occupancy patterns
  - Pollutant sources & strengths

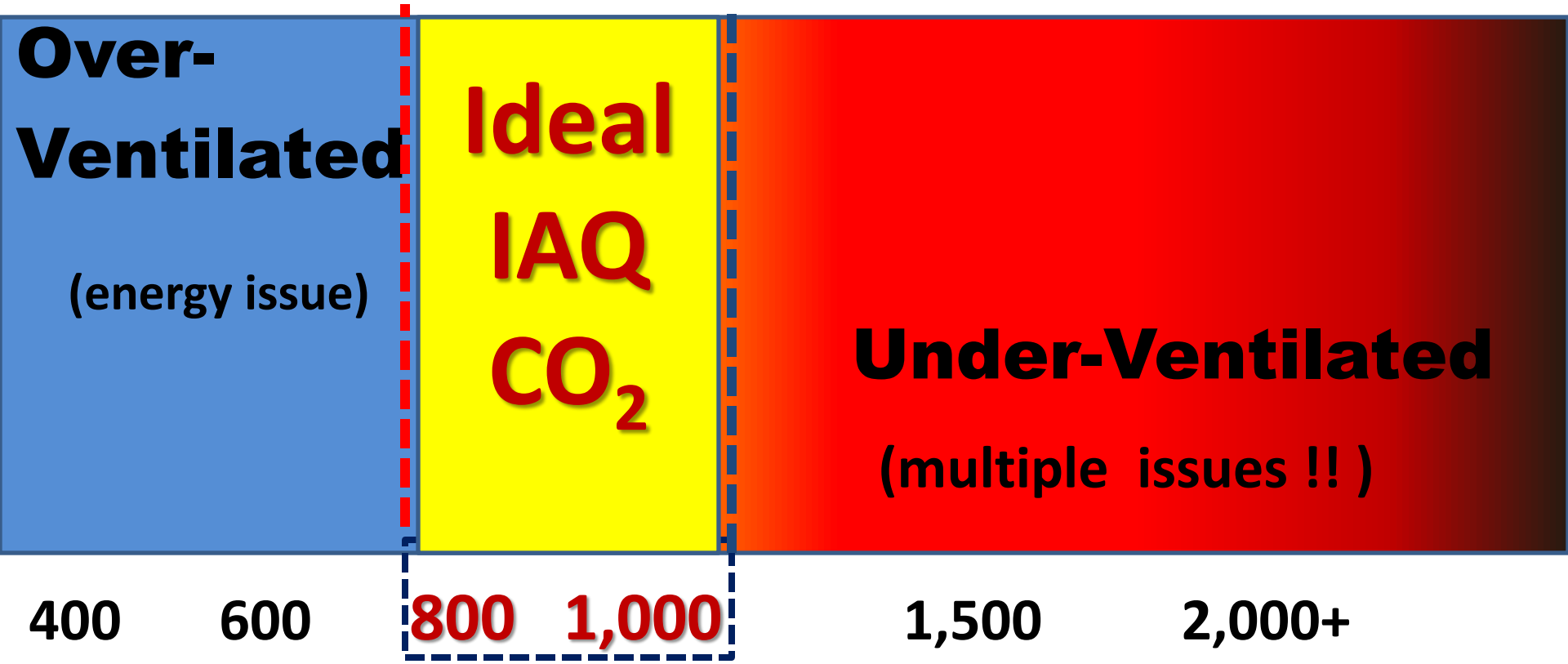
Our Analysis

- Assumed that ventilating to ASHRAE 62.2 2010 was the goal.
- Used C02 levels generated by occupants as a tracer gas to estimate CFM/occupant at steady state.
- Focused on occupied bedrooms at night

Carbon Dioxide vs. Ventilation Rate

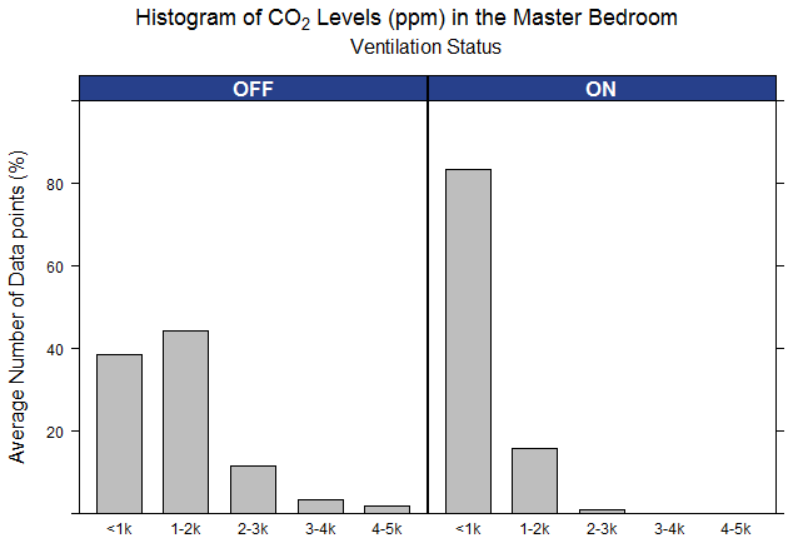
Carbon Dioxide (ppm)	Outside Air	
2,400	----- 5 cfm/p	Unacceptable
1,400	----- 10 cfm/p	Poor
1,000	----- 15 cfm/p	ASHRAE Standard 62
800	----- 20 cfm/p	
600	----- 25 cfm/p	
400 (and above)		Outdoor

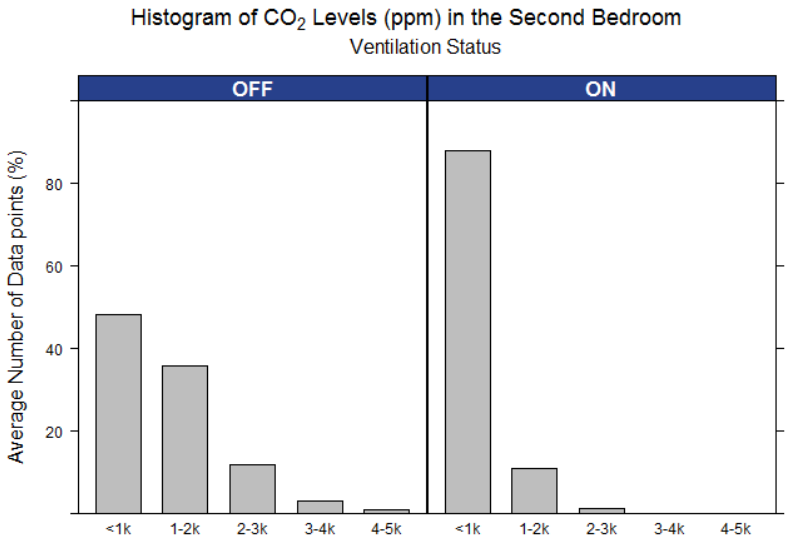
CO_2 Estimate of Ventilation

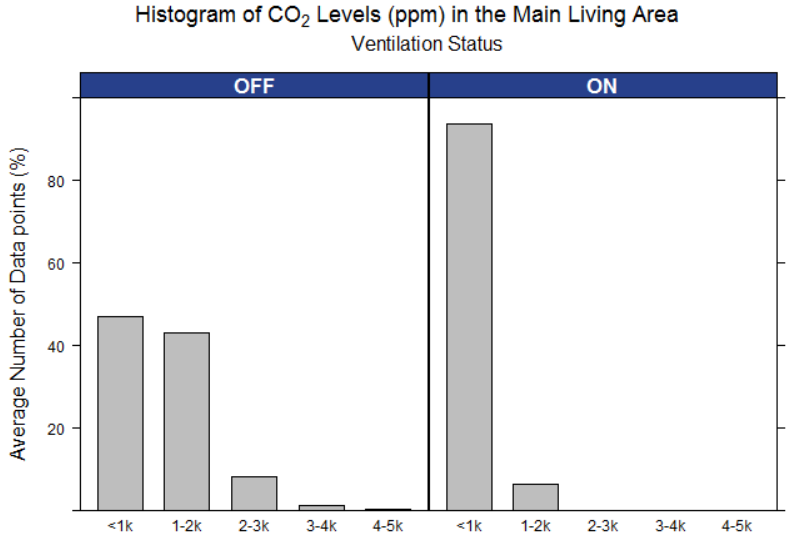


LONG TERM CO2 TESTING

CO2 Level Distribution with Ventilation On or Off

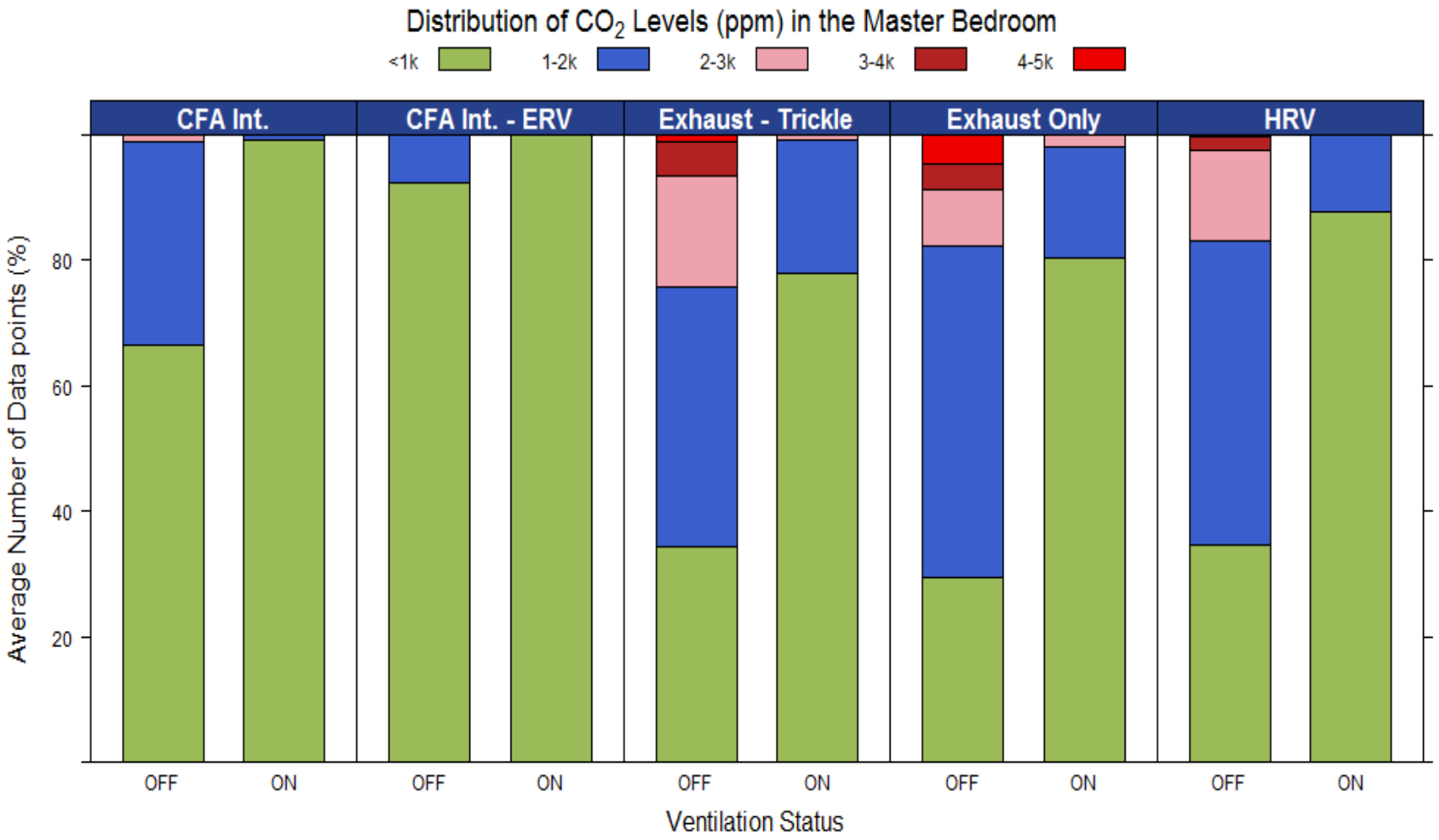


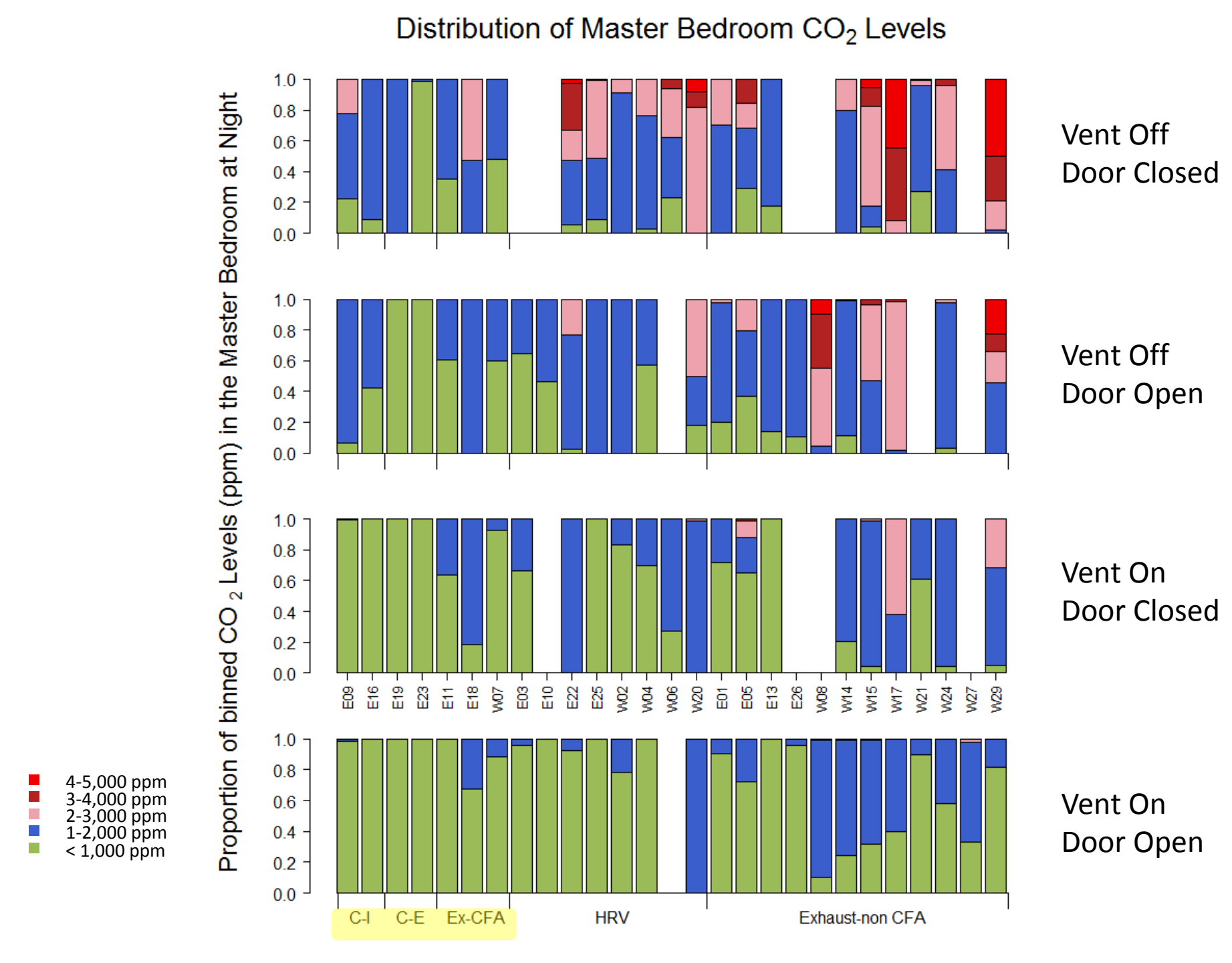




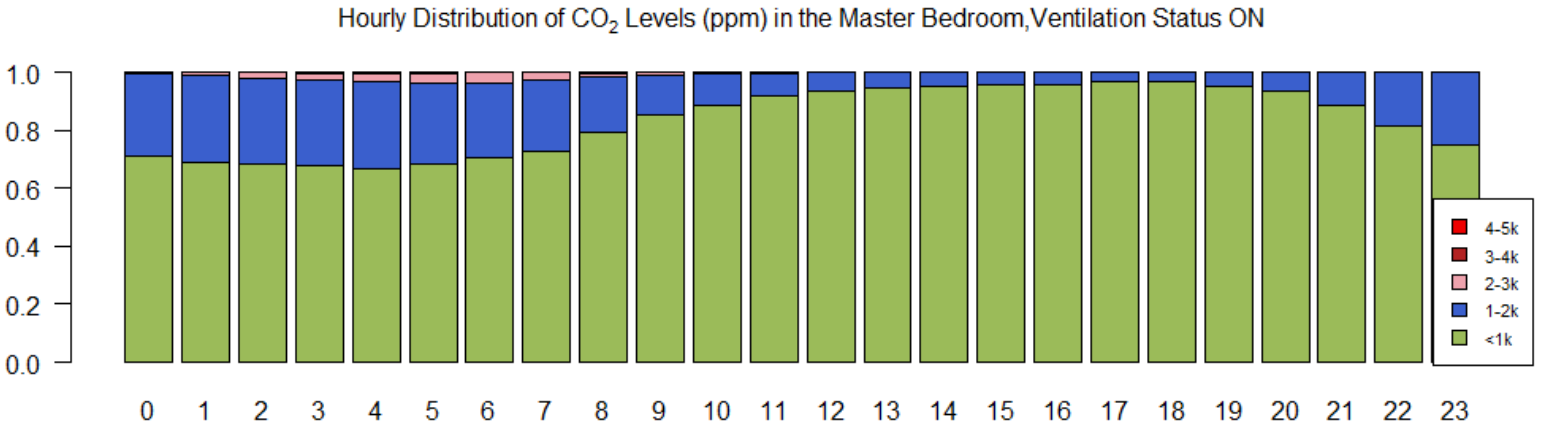
Ventilation Works

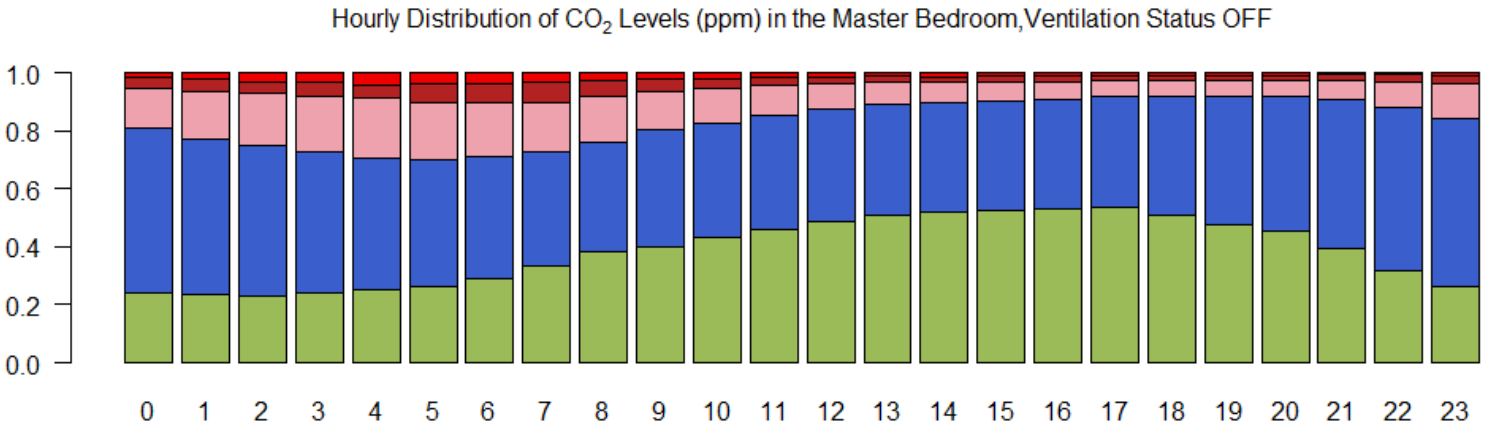
CO_2 Level Distribution by Ventilation Type with Ventilation On or Off

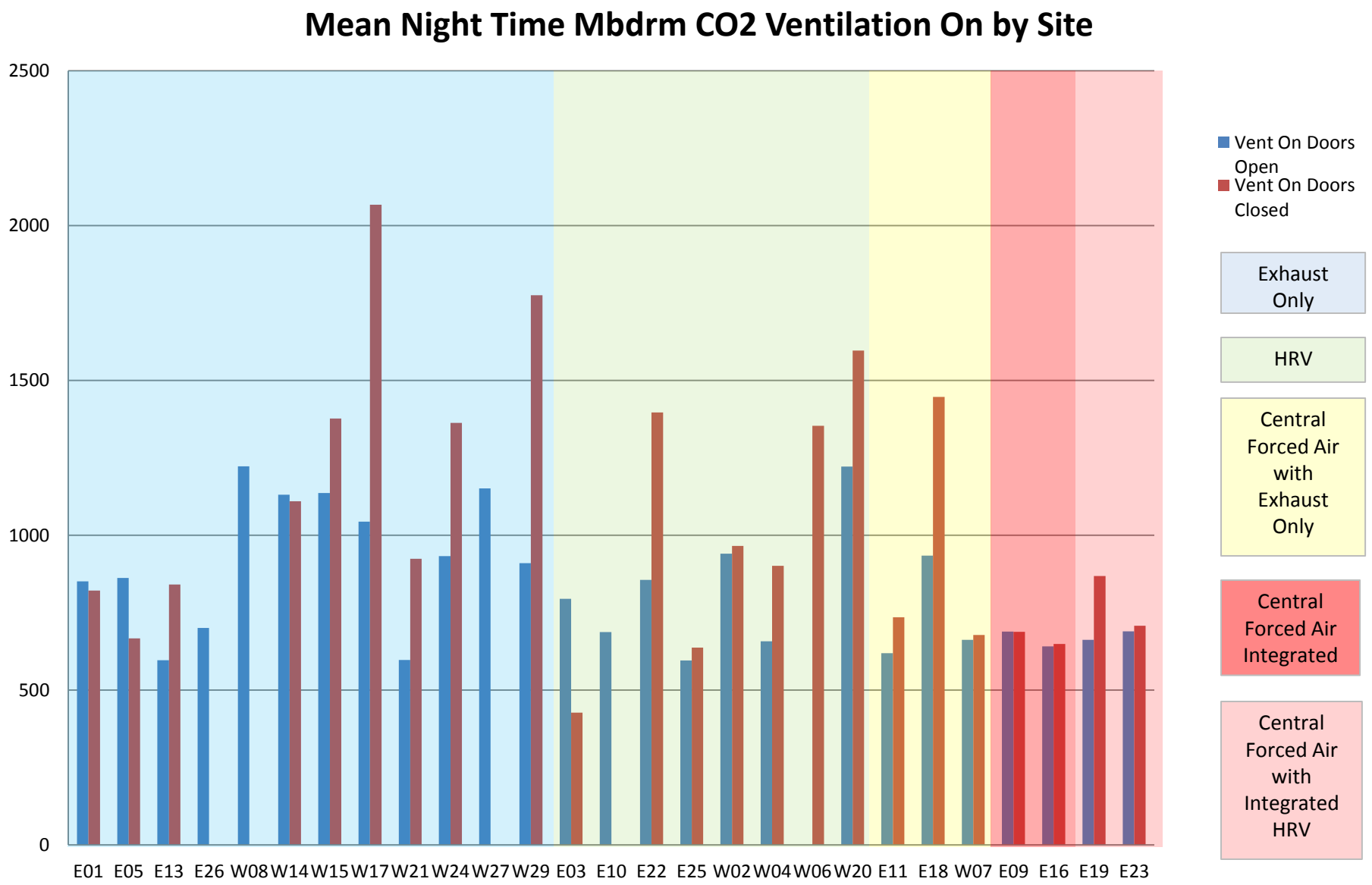



Distribution of Master Bedroom CO_2 Levels
Proportion of binned CO_2 Levels (ppm) in the Master Bedroom at Night
1.0
0.8
0.6
0.4
0.2
0.0
E09 E16 E19 E23 E11 E18 W07 E03 E10 E22 E25 W02 W04 W06 W20 E01 E05 E13 E26 W08 W14 W15 W17 W21 W24 W27 W29
C-I
C-E
Ex-CFA
HRV
Exhaust-non CFA
Vent Off
Door Closed
Vent Off
Door Open
Vent On
Door Closed
Vent On
Door Open
4-5,000 ppm
3-4,000 ppm
2-3,000 ppm
1-2,000 ppm
< 1,000 ppm

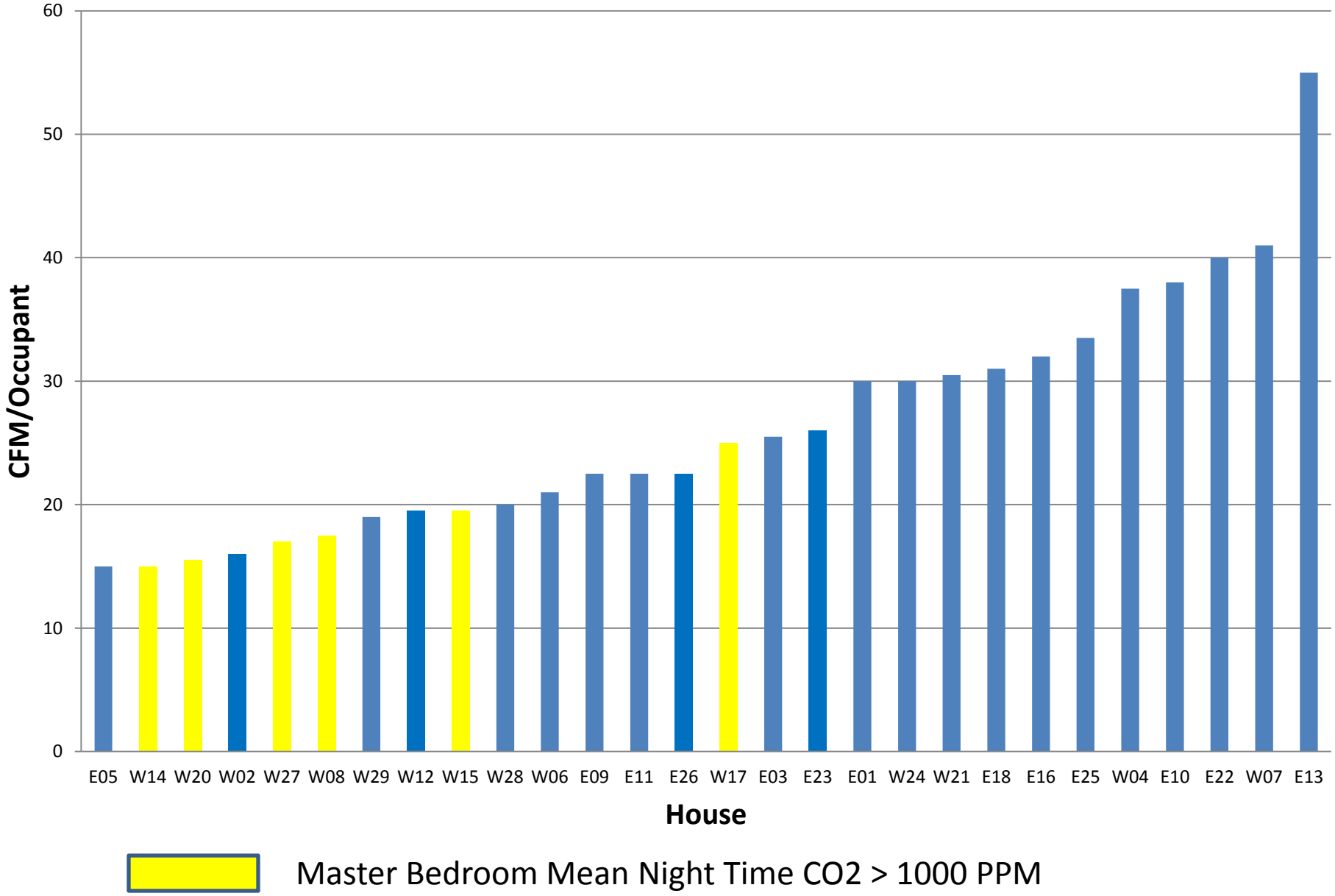
Hourly CO2 Level Distribution with Ventilation On or Off

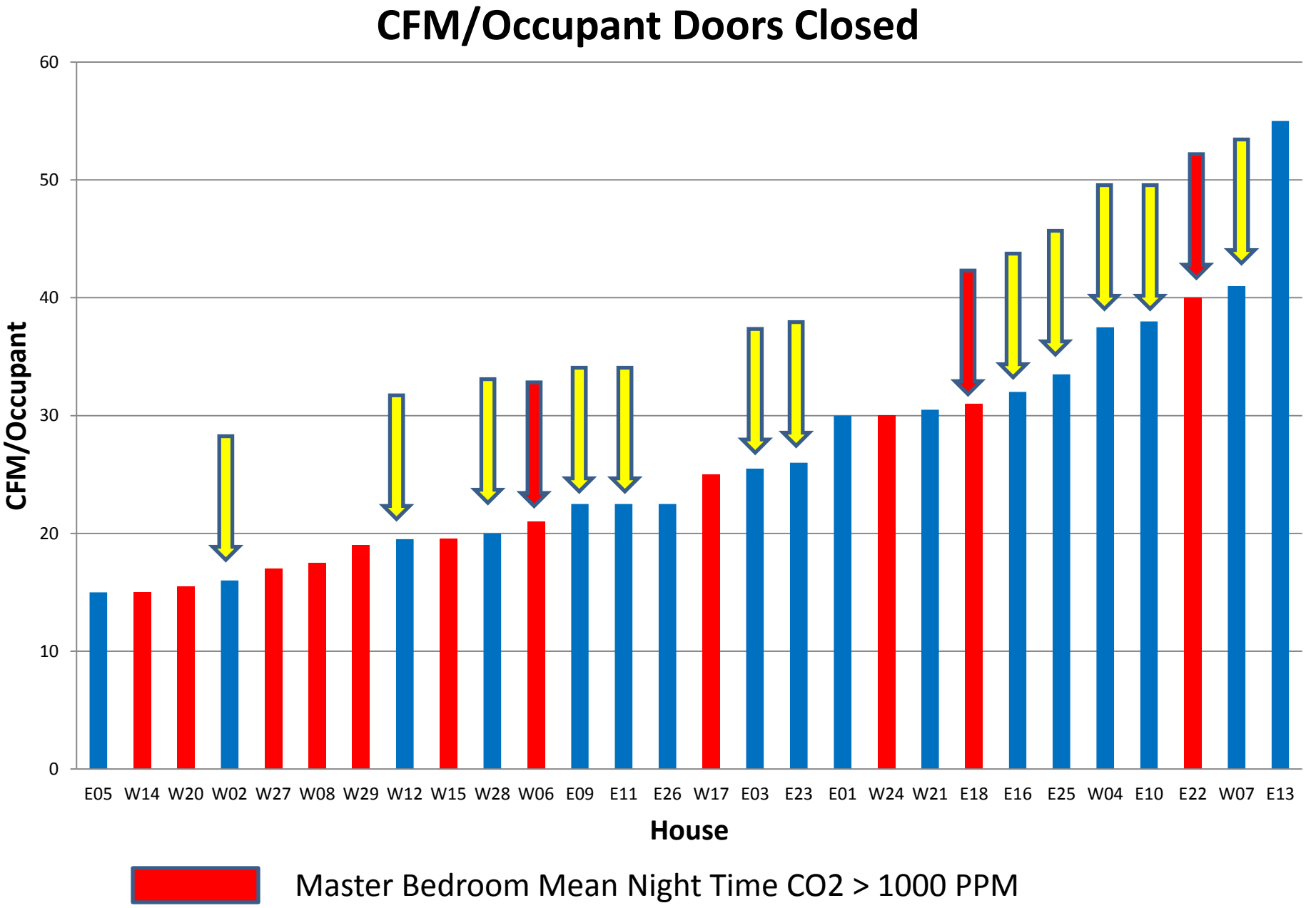





Mean Night Time Mbdrm CO2 Ventilation On by Site
2500
2000
1500
1000
500
0
E01 E05 E13 E26 W08 W14 W15 W17 W21 W24 W27 W29 E03 E10 E22 E25 W02 W04 W06 W20 E11 E18 W07 E09 E16 E19 E23
Vent On Doors Open
Vent On Doors Closed
Exhaust Only
HRV
Central Forced Air with Exhaust Only
Central Forced Air Integrated
Central Forced Air with Integrated HRV

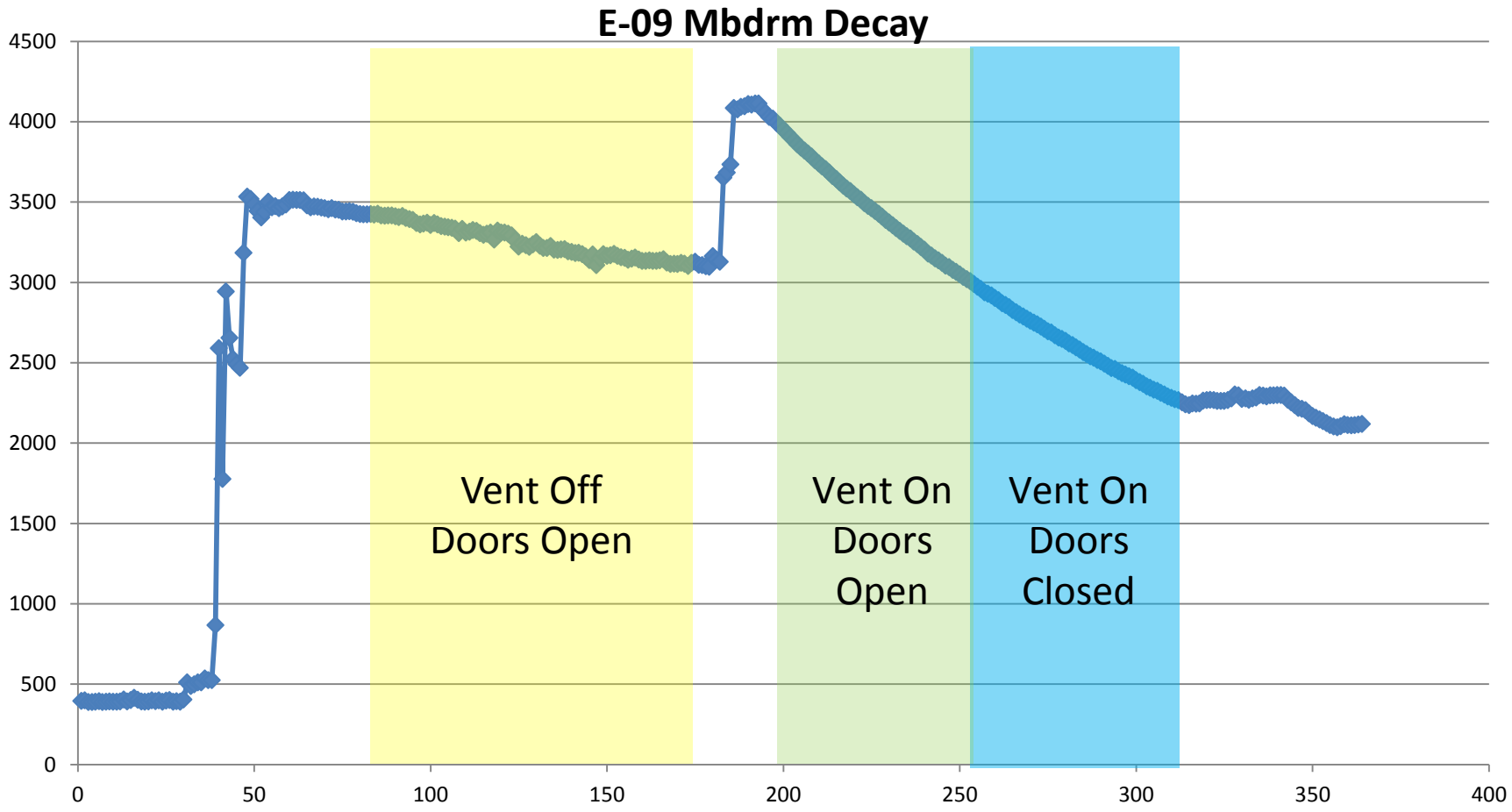
CFM/Occupant Doors Open



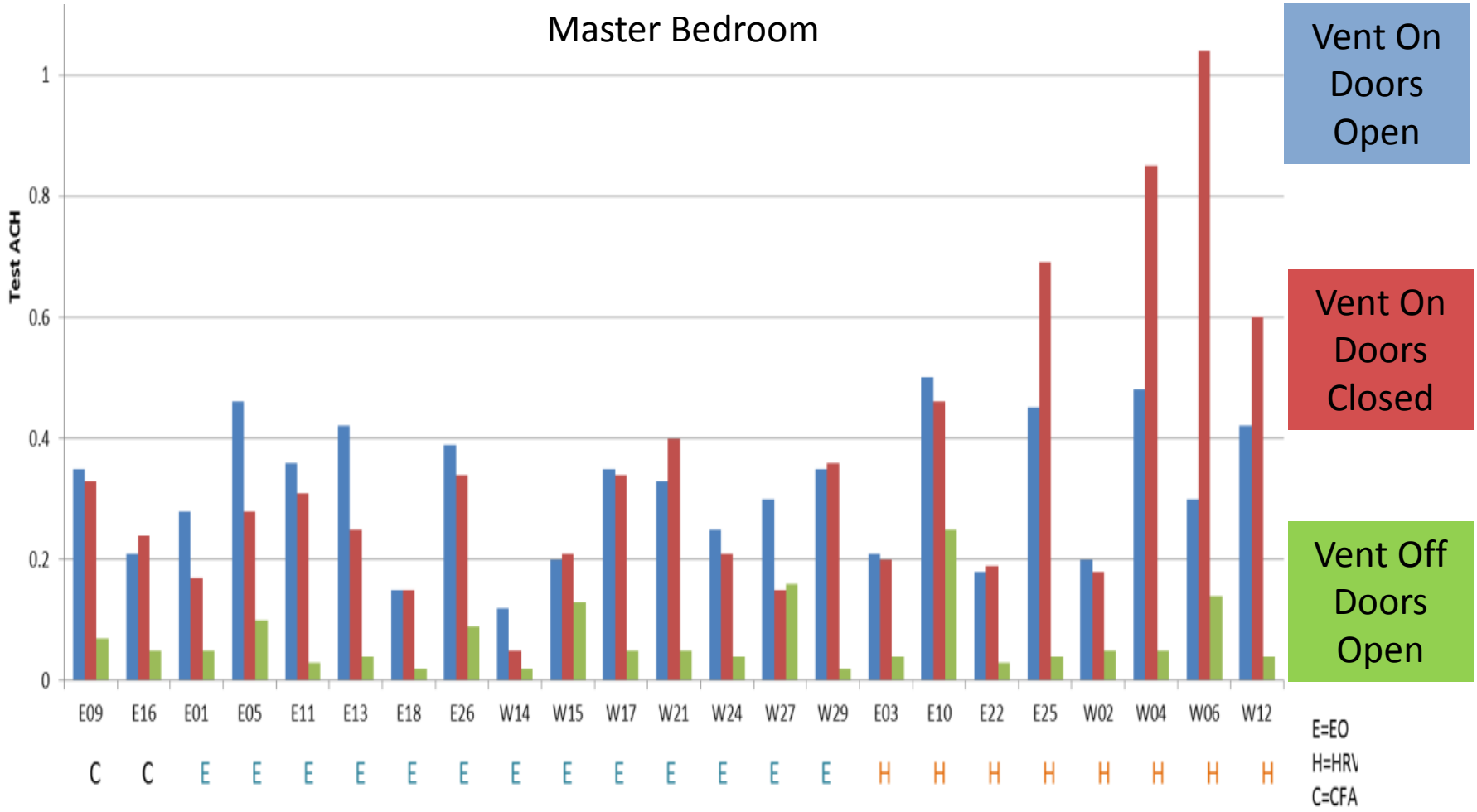

CFM/Occupant Doors Closed
CFM/Occupant
60
50
40
30
20
10
0
E05 W14 W20 W02 W27 W08 W29 W12 W15 W28 W06 E09 E11 E26 W17 E03 E23 E01 W24 W21 E18 E16 E25 W04 E10 E22 W07 E13
House
Master Bedroom Mean Night Time CO2 > 1000 PPM

TRACER DECAY TESTING

CO2 Tracer Decay Integrated CFA System



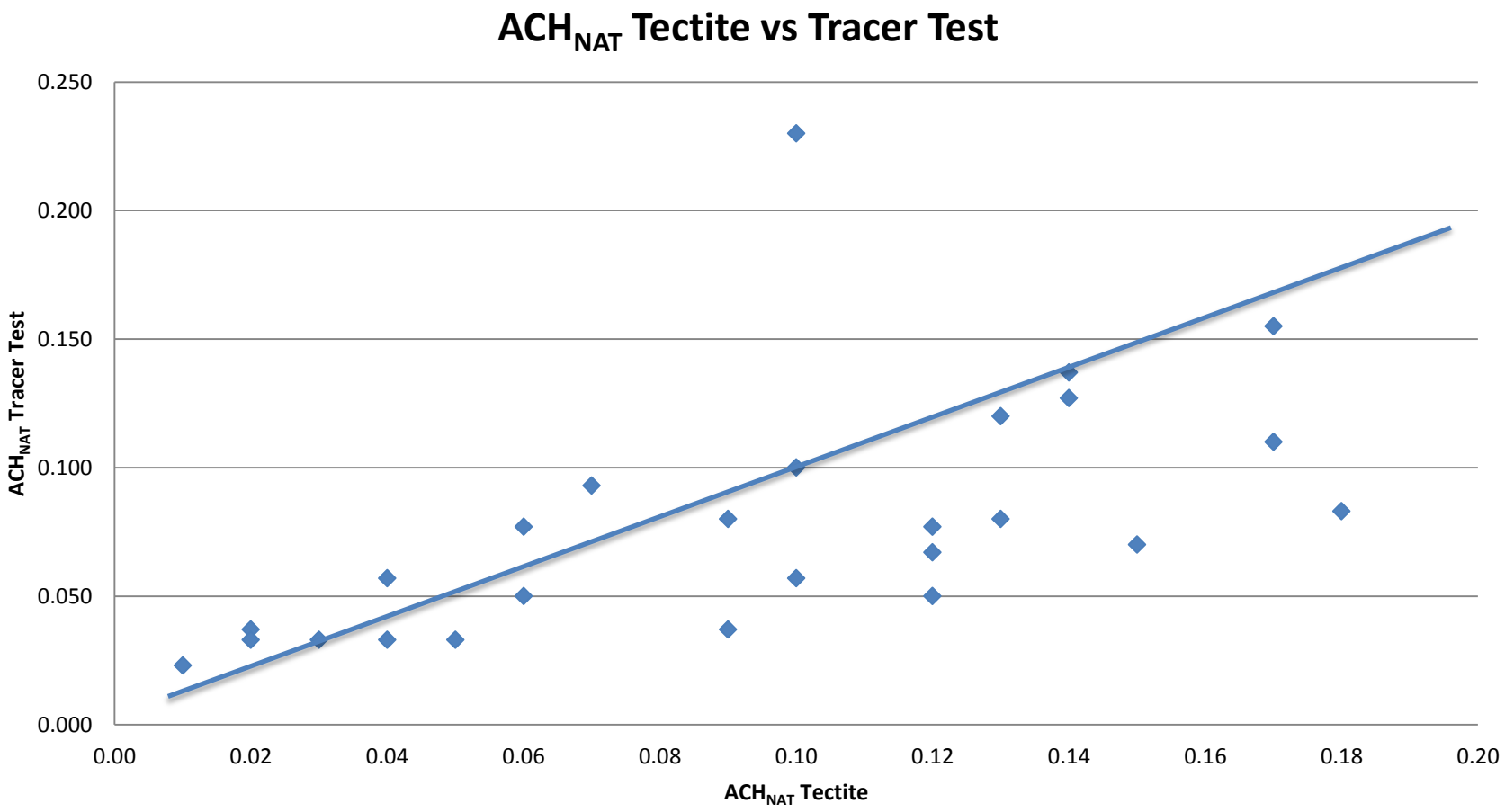
Tracer Decay Test ACH by Test Condition Sorted by Ventilation Type



Induced ACH by Ventilation System

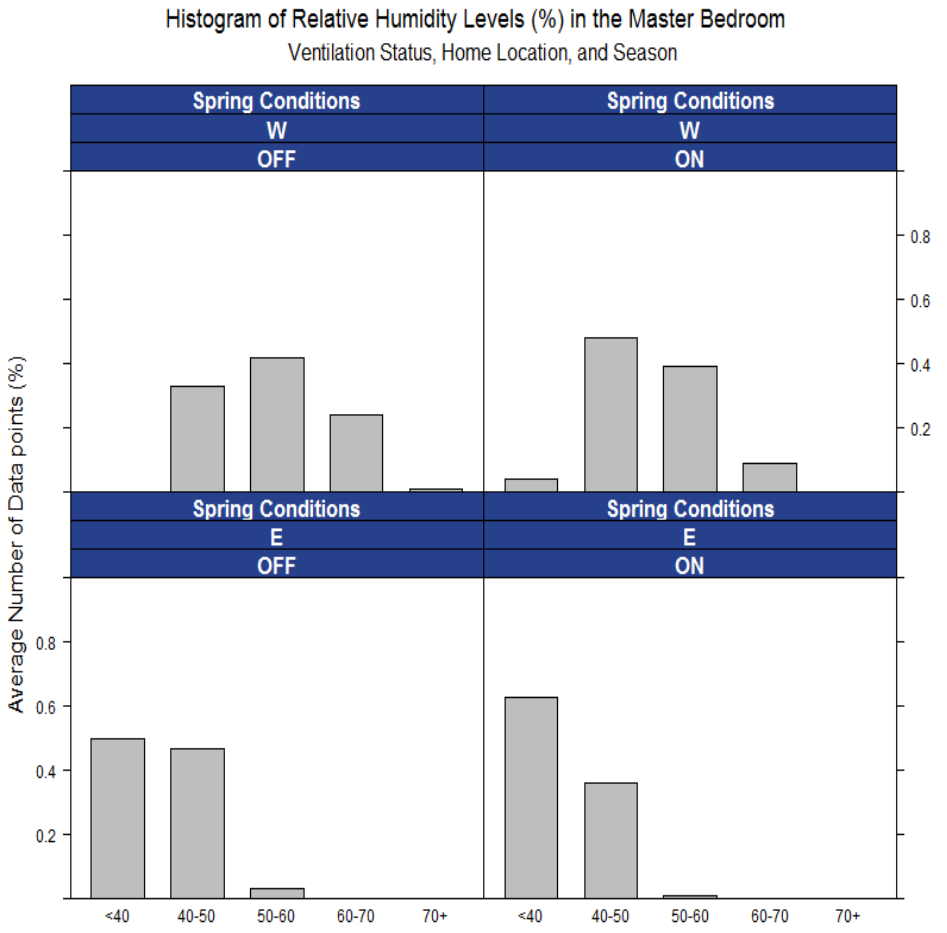
	1	1.3	2.5	Weighting						
	ACH 2B (A-C)	ACH MB (A-C)	ACH ML (A-C)	Weighted Average (A-C)	Measured CFM	Area	Volume	Measured ACH	Difference	Ventilation Type
E01	0.22	0.23	0.19	0.21	60	1656	15499	0.23	0.03	Exhaust
E03	0.22	0.17	0.13	0.16	51	1876	21404	0.14	-0.02	HRV
E05	0.32	0.36	0.27	0.30	59	1310	11135	0.32	0.01	Exhaust
E09	0.31	0.28	0.29	0.29	135	2843	27008	0.30	0.01	CFA
E10	0.39	0.25	0.30	0.31	76	1896	17770	0.26	-0.05	HRV
E11	0.24	0.33	0.25	0.27	90	2364	20094	0.27	0.00	Exhaust
E13	0.21	0.38	0.40	0.36	55	1352	12649	0.26	-0.09	Exhaust
E16	0.16	0.16	0.15	0.15	64	2805	26026	0.15	-0.01	CFA
E18	0.09	0.13	0.05	0.08	62	3150	39525	0.09	0.01	Exhaust
E22	0.53	0.15	0.17	0.24	80	2115	21439	0.22	-0.02	HRV
E25	0.64	0.41	0.33	0.42	67	1496	14178	0.28	-0.13	HRV
E26	0.28	0.30	0.31	0.30	45	1199	9588	0.28	-0.02	Exhaust
W02	0.22	0.15	0.09	0.13	80	3675	35415	0.14	0.00	HRV
W04	0.45	0.43	0.39	0.41	75	3024	25422	0.18	-0.24	HRV
W06	0.60	0.16	0.19	0.27	63	1881	16928	0.22	-0.04	HRV
W12	0.61	0.38	0.29	0.38	78	1904	22000	0.21	-0.17	HRV
W14	0.10	0.10	0.04	0.07	60	3300	30825	0.12	0.05	Exhaust
W15	0.16	0.07	0.25	0.18	39	1176	9408	0.25	0.07	Exhaust
W17	0.30	0.30	0.42	0.36	50	1240	9920	0.30	-0.06	Exhaust
W21	0.14	0.28	0.16	0.19	61	1971	18819	0.19	0.01	Exhaust
W24	0.19	0.21	0.17	0.19	60	1900	20378	0.18	-0.01	Exhaust
W27	0.05	0.14	0.17	0.14	80	1216	10944	0.44	0.30	Exhaust
W29	0.31	0.33	0.19	0.25	38	1764	19839	0.11	-0.14	Exhaust

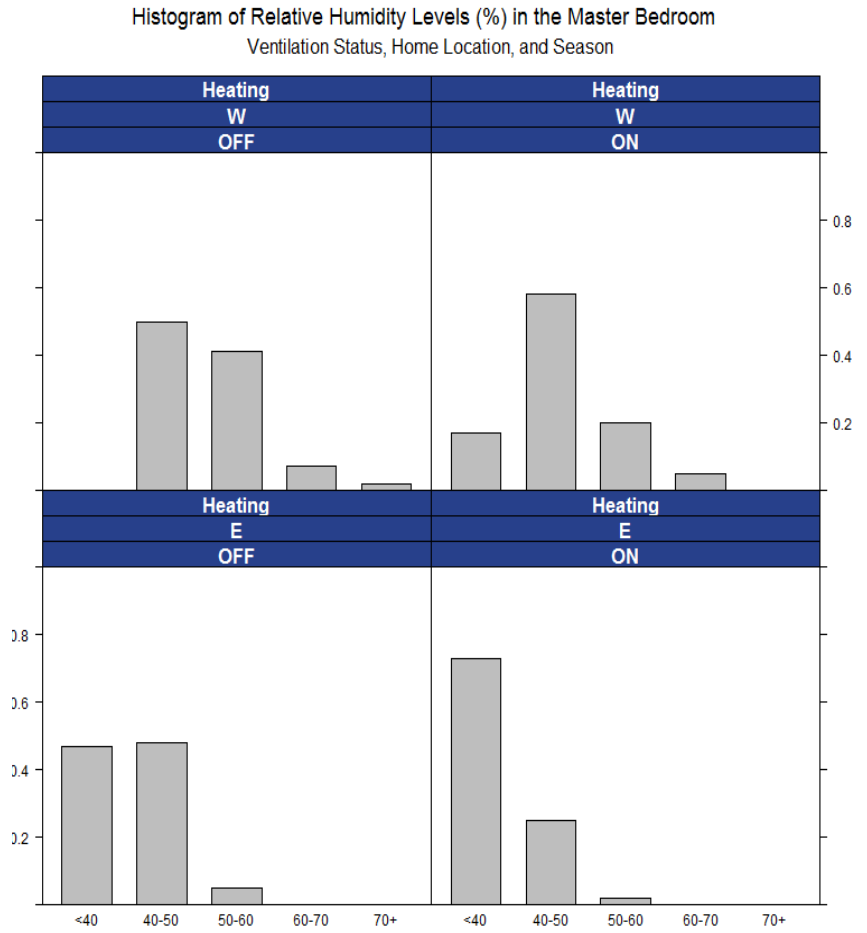
ACH_{NAT}


ACH NAT Tectite vs Tracer Test
0.250
0.200
0.150
0.100
0.050
0.000
ACH NAT Tracer Test
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
ACH NAT Tectite

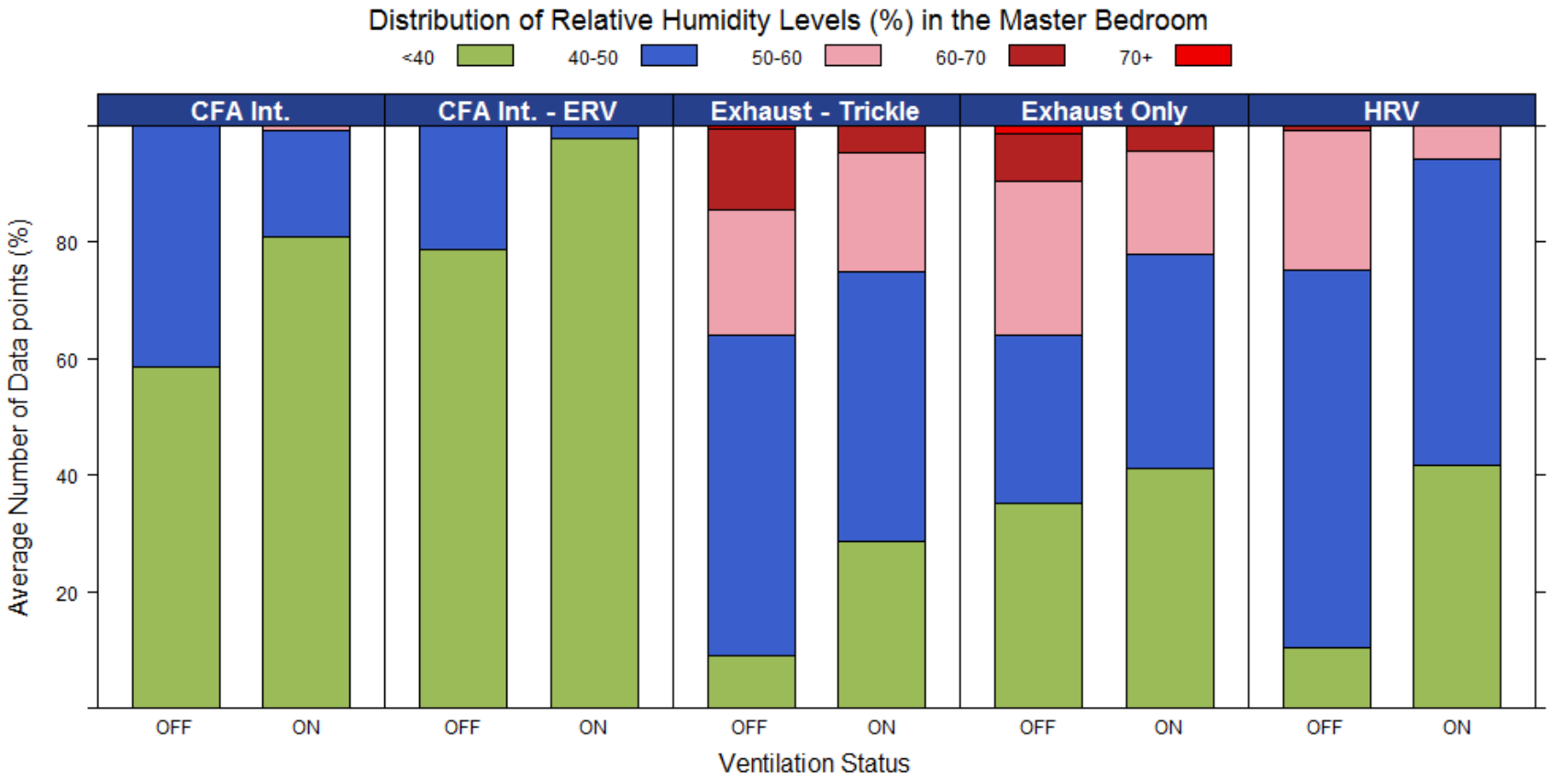
RELATIVE HUMIDITY

Relative Humidity by Room, Eastside (E) or Westside (W), Heating (Winter) or Milder (Spring) Season, and Ventilation System Operation (On or Off)

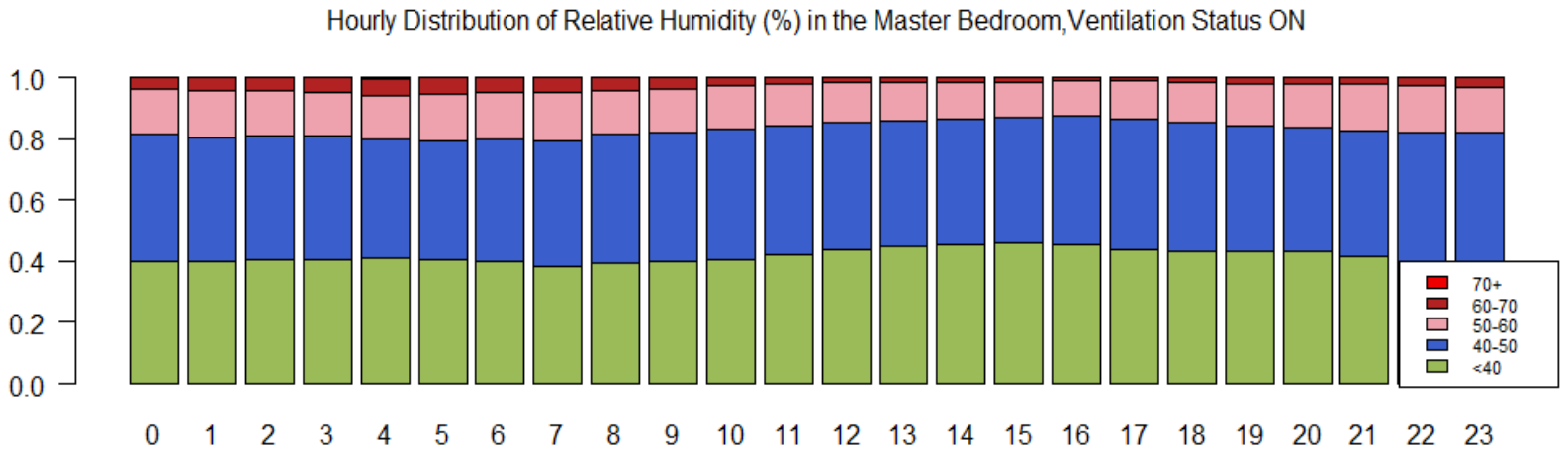


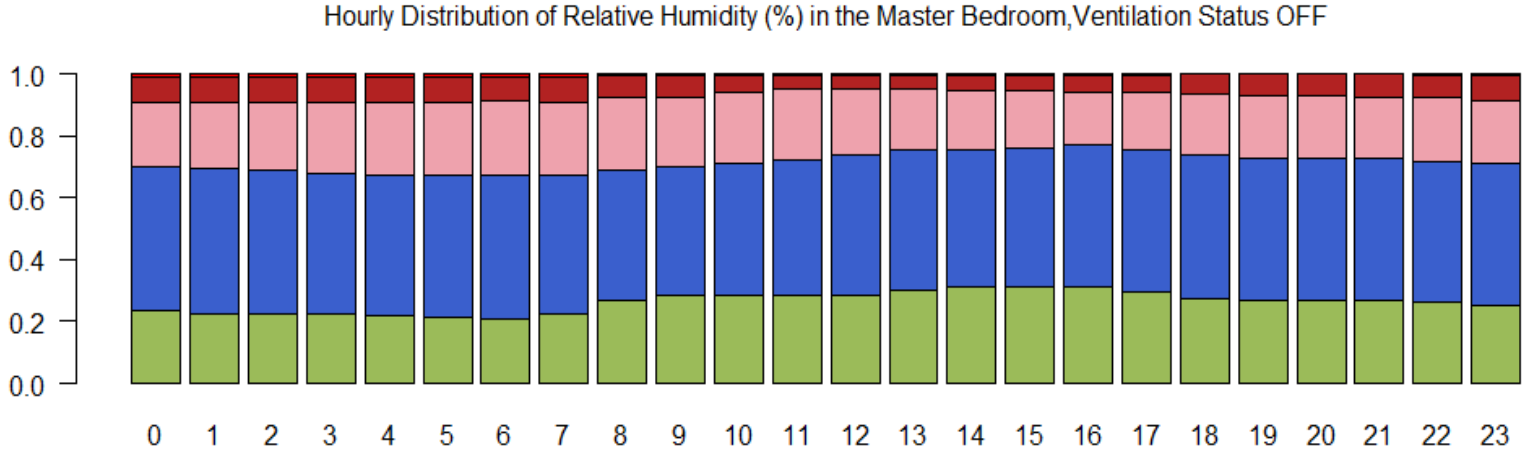


Relative Humidity Levels by Room, Ventilation System, and Ventilation Operation

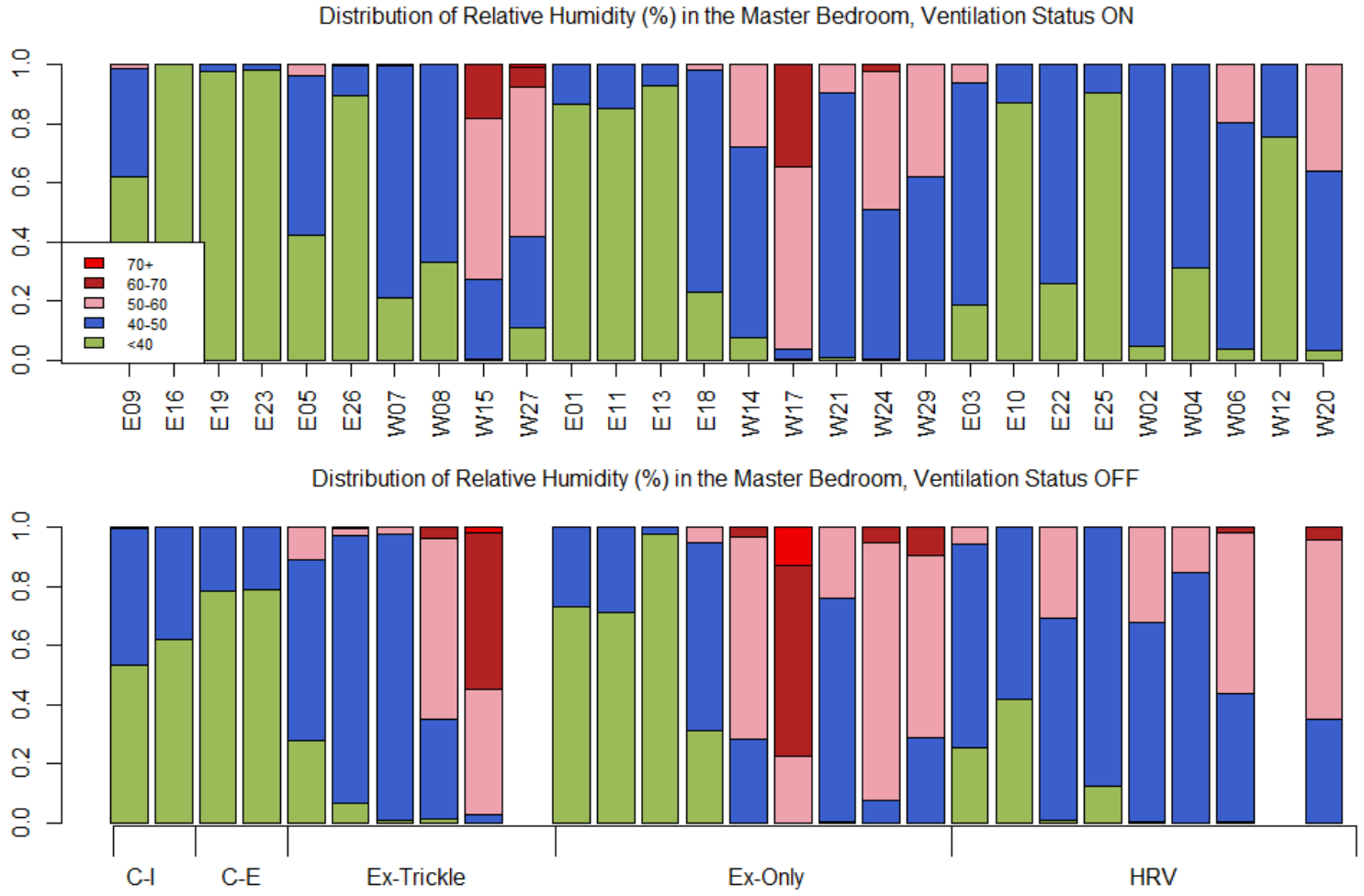


Hourly Distribution of Relative Humidity by Room





Relative Humidity in Individual Houses by Room and Ventilation System Operation



Some Conclusions

- Without ventilation these houses have very low ACH rates (<0.1) potentially allowing significant build up of pollutant concentrations.
- Operation of the ventilation system increased the ACH rate by a factor of 4 on average.
- Door closure has a larger impact on ACH rates in zones without direct distribution or active mixing.

Other Areas of Study Not Discussed Here

- Monitored door closure data
- Fan energy used by ventilation systems
- As found system condition
- Ventilation performance as found
- Occupant knowledge of the ventilation system and its operation and maintenance
- Performance of trickle vents