Ventilation Effectiveness Research at UT-Tyler Lab Houses

Source Of Outside Air, Distribution, Filtration

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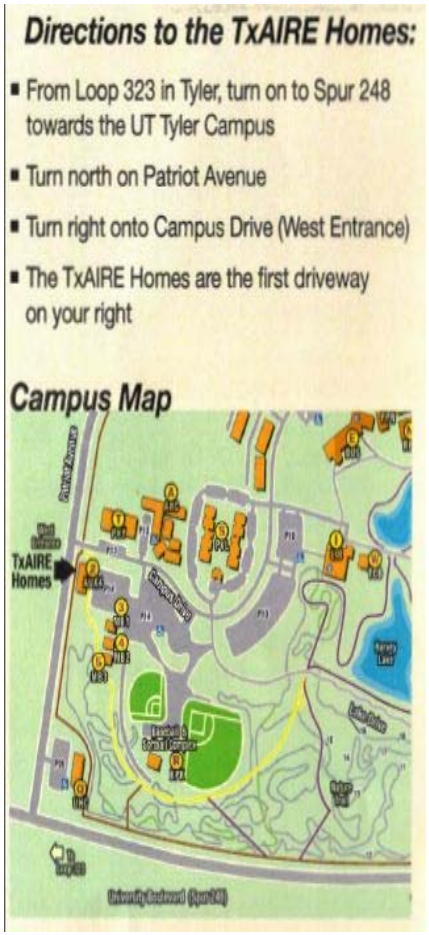
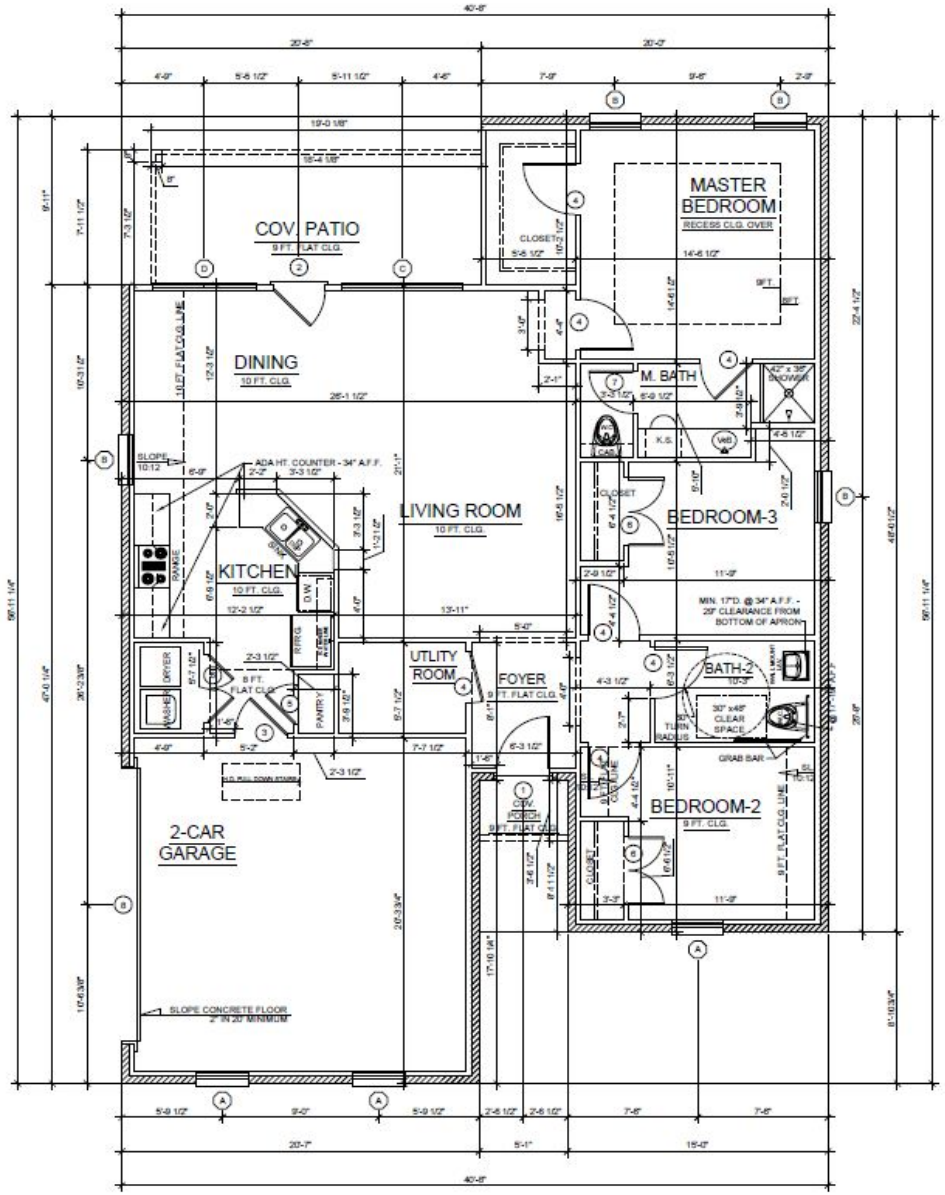
Twin (almost) Lab Houses at UT-Tyler

House 1: Vented attic

House 2: Unvented attic, lower loads + PV



HOUSE 1



- 1475 ft^2, 3-bedroom houses
- House 2 was mirrored plan
- 45 cfm 62.2 ventilation rate
- Garage connected to house on only one wall
- Access to attic via pull-down stairs in garage
- Further access to House 2 unvented attic through gasket sealed door

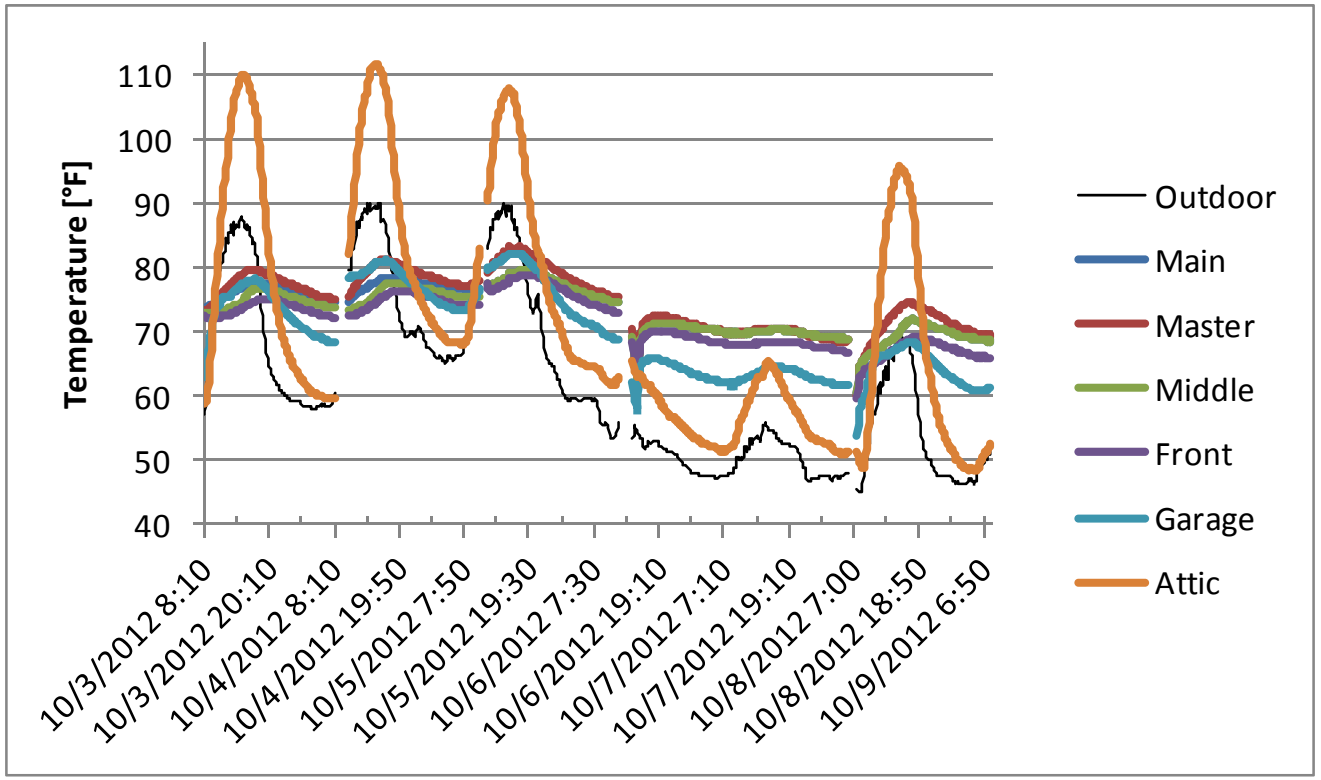
Testing Approach

- Building enclosure and building mechanical systems characterization by measurement of building enclosure air leakage, central air distribution system airflows, and ventilation system airflows.
- Multi-zone tracer gas testing using per-fluorocarbon tracer gases (PFT's) to determine zone air change rates and inter-zonal airflows with different ventilation systems operating.
- Multi-zone sampling of volatile organic compounds (VOC), formaldehyde (HCHO), and airborne particulates to determine indoor air quality impacts as a function ventilation system operation.
- A preliminary CONTAM airflow network simulation model constructed from the detailed building enclosure and building mechanical systems characterization testing.

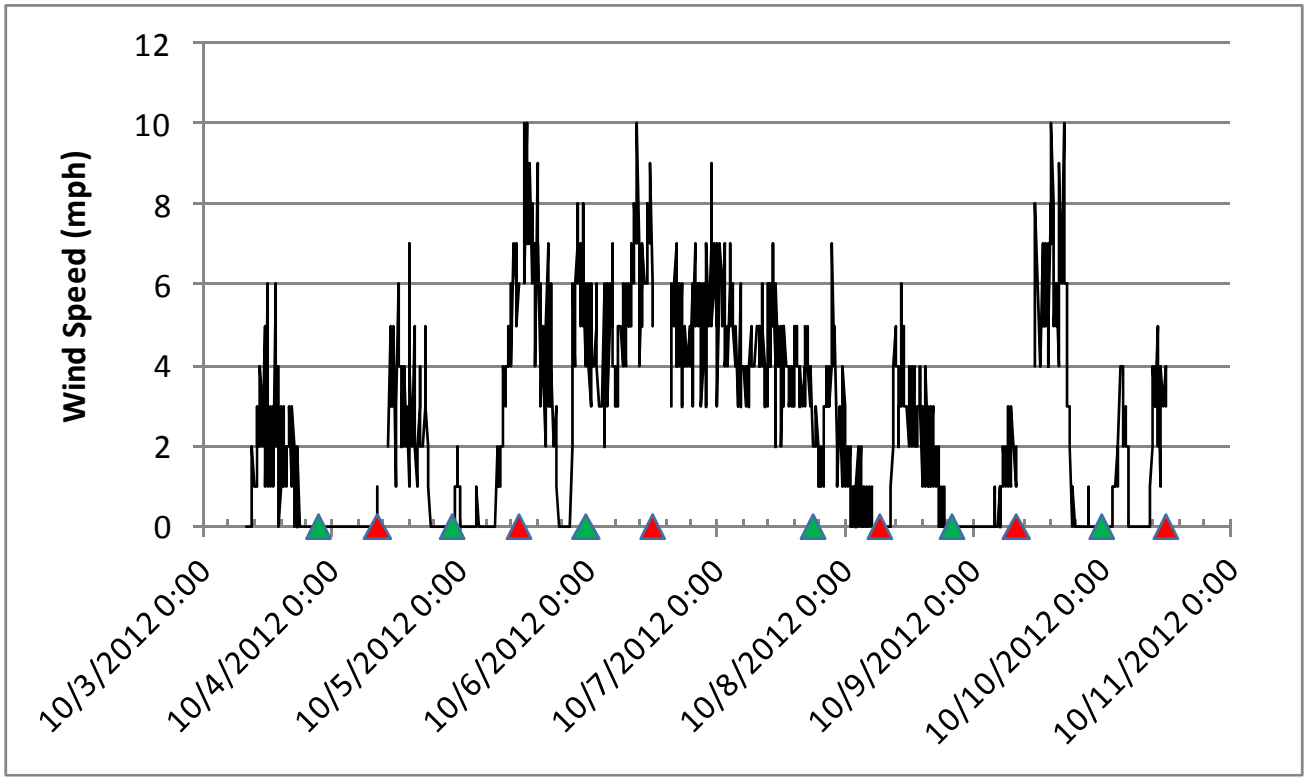
Five Ventilation Tests Conducted in Each House

Test Number	Test Name	Test Description
1	Baseline	No ventilation, bedroom doors closed, no central fan operation
2	Exhaust	Exhaust ventilation from master bathroom, bathroom door open to bedroom, bedroom doors closed, no central fan operation
3	Exh w/mixing	Exhaust ventilation from master bathroom, bathroom door open to bedroom, bedroom doors closed, 20% central fan operation (48 off / 12 on)
4	CFIS	Central-fan-integrated supply (CFIS) ventilation, bedrooms closed, 33% central fan duty cycle (20 off / 10 on)
5	ERV	Balanced (ERV) ventilation, bedrooms closed, no central fan operation, 50% runtime (30 on /30 off)

House 1 and outdoor temperatures during the test period



Wind speed throughout the testing period
Green and red markers indicate start and stop of the 12-hour nighttime sampling periods



Physical characteristics of the test houses

Zone Name	Floor Area (ft^2)	Max Height (ft)	Volume (ft^3)	Perimeter (ft)	Exterior Wall Area (ft^2)	House 1 Exterior Surface Area[2] (ft^2)	House 2 Exterior Surface Area[2] (ft^2)
Main	750	10.0	7220	47	472	1972	1222
Master	337	9.0	2766	48	433	1107	770
Middle	159	8	1272	13	100	418	259
Bath	64	8	512	6	50	178	114
Front	165	9	1485	35	315	645	480
House 1 Total	1475	44	13255	149	1370	4320	
Attic (House 2)[1]	1475		13507				2860
House 2 Total	1475	44	26762	149	1370		5705
% diff. H2/H1			102%				32%

[1] Attic volume and roof surface from AutoCAD 3D model

[2] Exterior surface area includes the slab floor, walls and roof

Typically reported blower door test results

	Conditioned Floor Area (ft^2)	Conditioned Volume (ft^3)[1]	Surface Area[2]	C	n	CFM50	ACH50	CFM50 per ft^2 surface area	EqLA[3] (in^2)	ELA[4] (in^2)	SLA[5]
House 1	1,475	13,255	4,320	66.2	0.706	1048	4.74	0.24	99	49.94	2.35
House 2	1,475	26,762	5,705	67.1	0.63	789	1.77	0.14	84	45.56	2.14

[1] For House 2, volume includes the unvented attic which is inside conditioned space but not actively conditioned

[2] Exterior surface area includes the slab floor, walls and roof

[3] Equivalent Leakage Area; EqLA = CFM10 * 0.2939

[4] Effective Leakage Area; ELA = CFM4 * 0.2835

[5] Specific Leakage Area; SLA = ELA / 144 / floor area * 10,000

Room Supply Airflow and Duct Leakage

Central AC Supply		
Room	**House 1 (CFM)**	**House 2 (CFM)**
Living	89	43
	104	44
	122	60
	97	59
	134	82
	98	125
Mechanical Room	69	26
Master Bedroom	187	64
Master Bath	74	20
Master Closet	33	21
Middle Bedroom	63	67
Bath 2	42	21
Front Bedroom	25	75
Supply Total	**1137**	**707**

Duct Leakage				
	House 1 (CFM25)	**House 2 (CFM25)**		
Total	182	217		
To Outside[1]	56	30		

[1] Leakage to outside for House 2 is realistically zero. It is an artifact of the test that shows a non-zero value, due to the unvented attic "buffer zone" not being completely nulled to the duct pressure.

Ventilation system airflow and runtime setup

Exhaust (100% runtime)		
	House 1 (CFM)	House 2 (CFM)
Master bathroom	45	45
CFIS (33% runtime)		
	House 1 (CFM)	House 2 (CFM)
Flow station	135	135
Outside Air Intake	109	100
ERV (50% runtime)		
Room	House 1 (CFM)	House 2 (CFM)
Master Supply	36	47
Middle Supply	27	25
Front Supply	30	24
Supply Total	**93**	**96**
Outside Air Intake	**116**	**96**
Exhaust Foyer	58	48
Exhaust Kitchen	80	75
Exhaust Total	**138**	**123**

Sampling Station in Each Zone for:
PFT, Airborne Particles, Formaldehyde, VOC

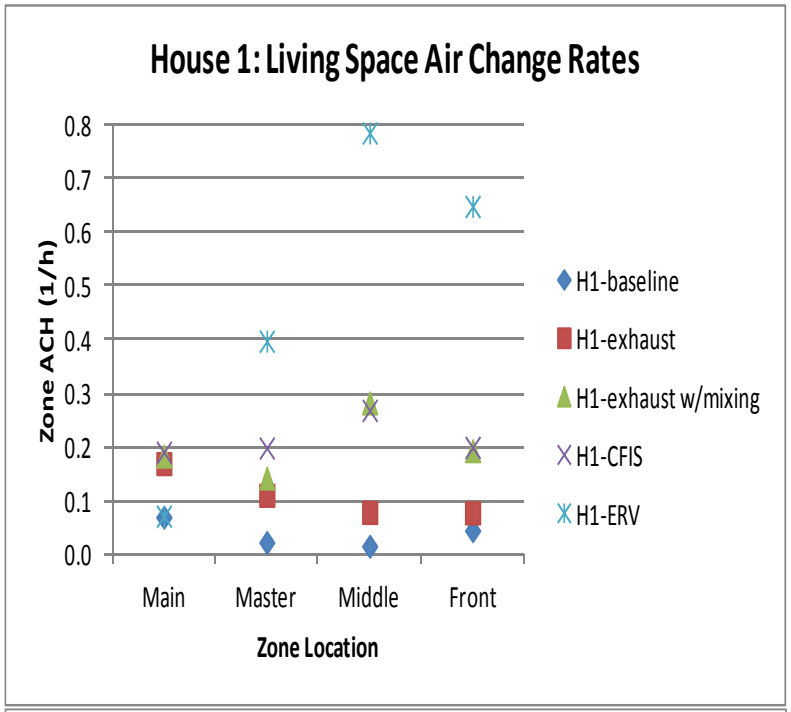
Six PFT Sources

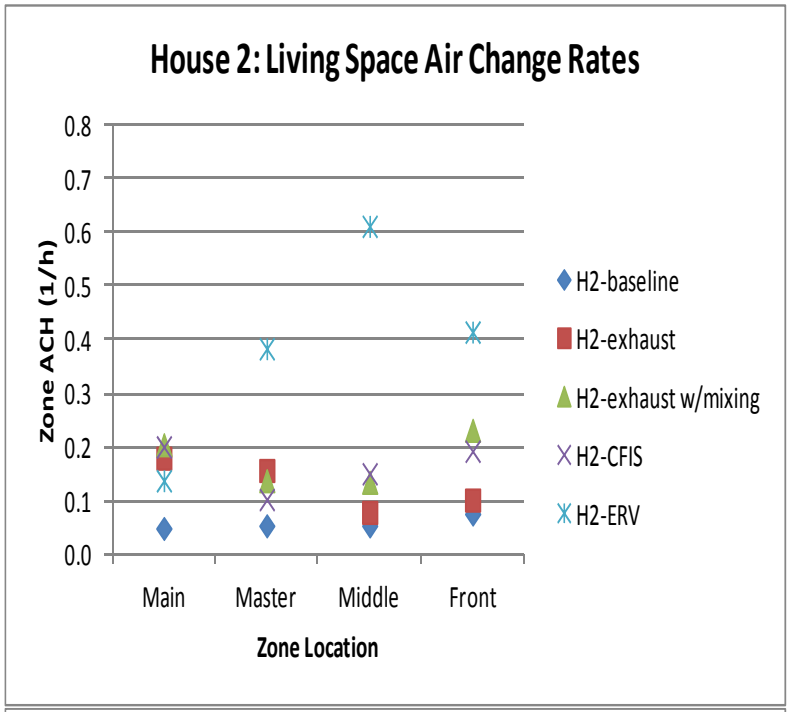
PFT source selection optimized by room volume and resulting relative source strength

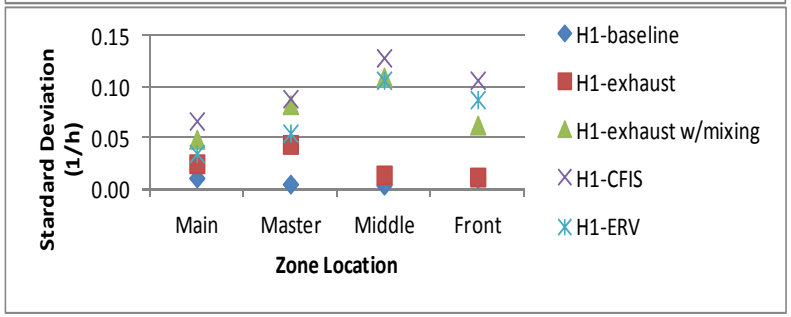
Zone Name	Floor Area (ft^2)	Height (ft)	Volume (ft^3)	PFT	Color	RSS	Qty	Resulting RSS
H1 Attic, vented	1463	9.2	13507	PDCB	brown	1	1	1.00
H2 Attic, unvented	1463	9.2	13507	PDCB	brown	1	1	1.00
Main	738	9.8	7220	PMCH	red	0.93	1	0.93
Garage	419	9	3771	ocPDCH	blue	0.16	5	0.80
Master bed	337	8.2	2766	iPPCH	purple	0.25	3	0.75
Front bed	165	9	1485	1-2PTCH	silver	0.12	6	0.72
Middle bed	159	8	1272	PMCP	gold	0.62	1	0.62
1/2 Bath (open to Main)	64	8	512					

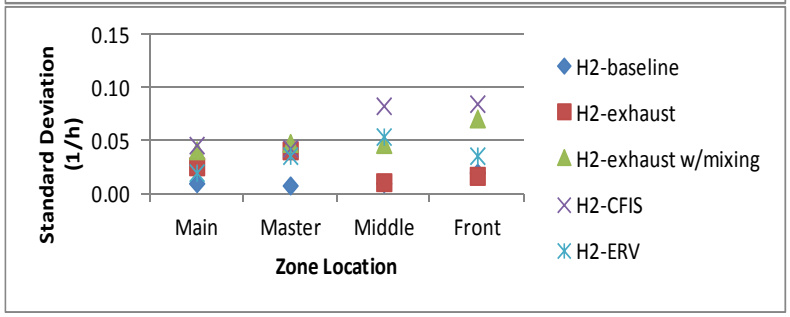
PFT Source and Sampler (CATS) Placement

Air change rates in the living space zones for the Baseline test and four different ventilation systems; both houses show the same trends



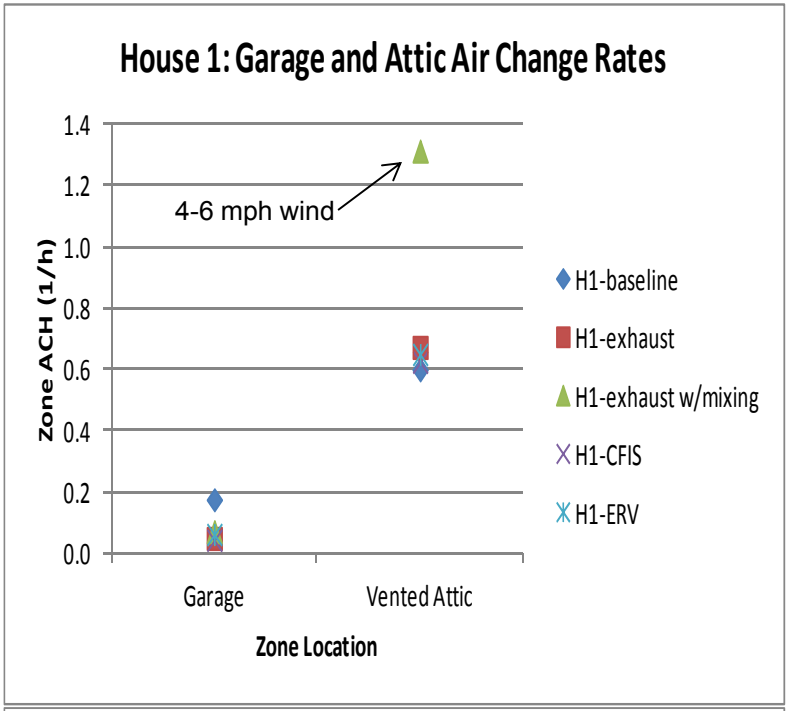


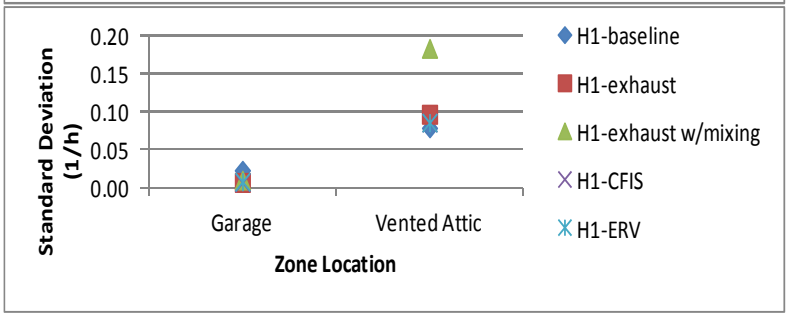


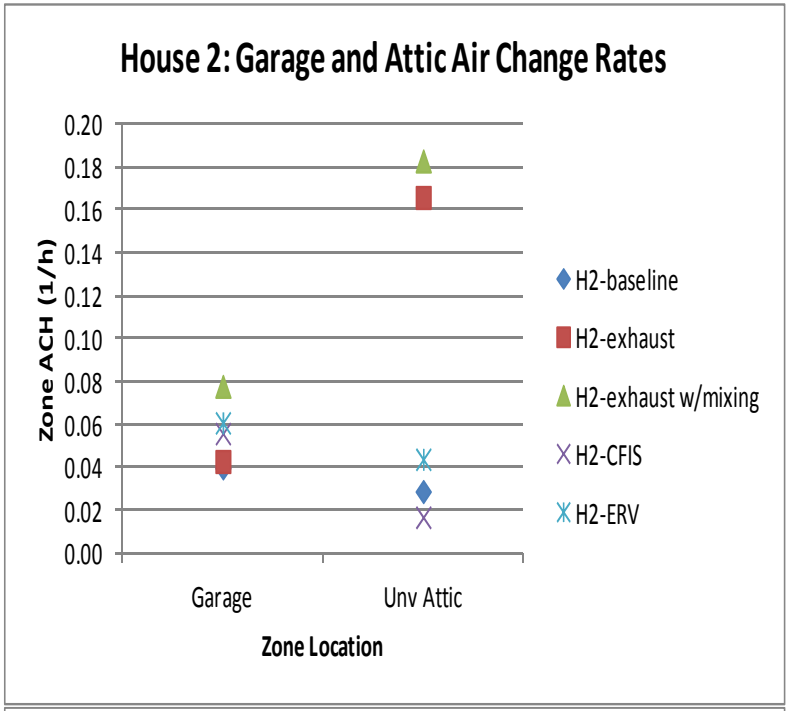


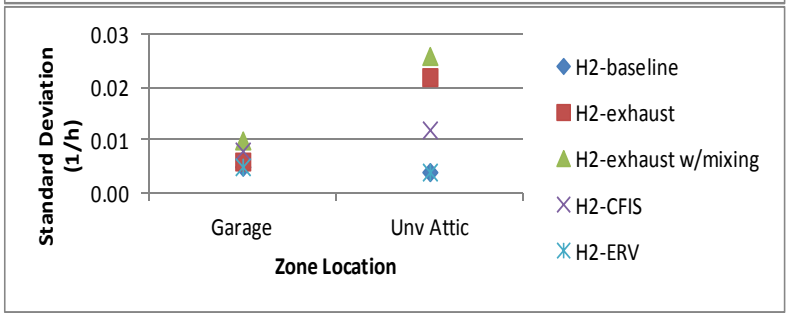
The AIMS error analysis uses a 5% error in the estimate of the volume of the room, a 7% error in the source emission rate, and a 10% error in the CATS PFT concentration when there is only a single CATS in the zone. A full description of the error analysis is in Leadererr et al. 1995.

Air change rates in the Garage and Attic zones for the Baseline test and four different ventilation systems





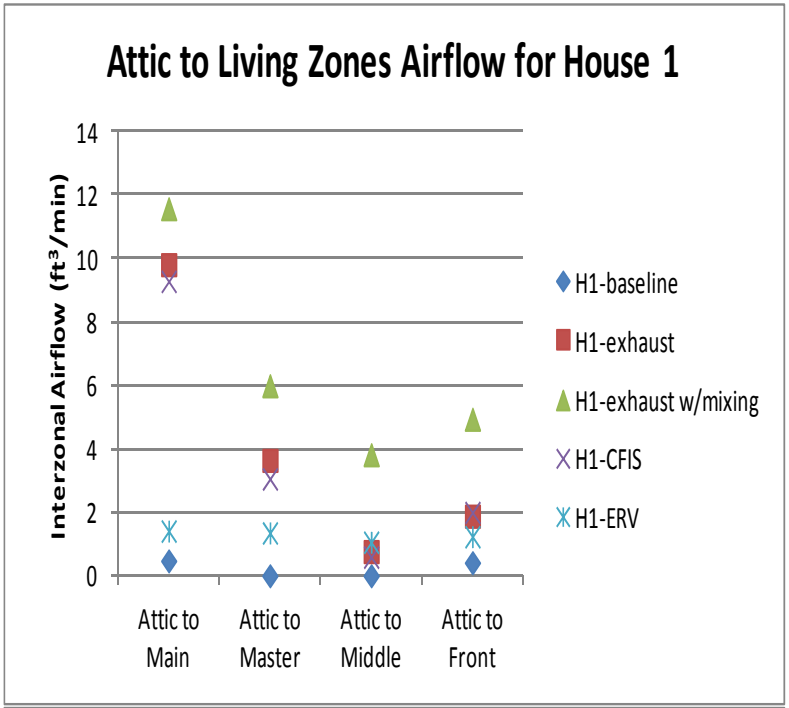


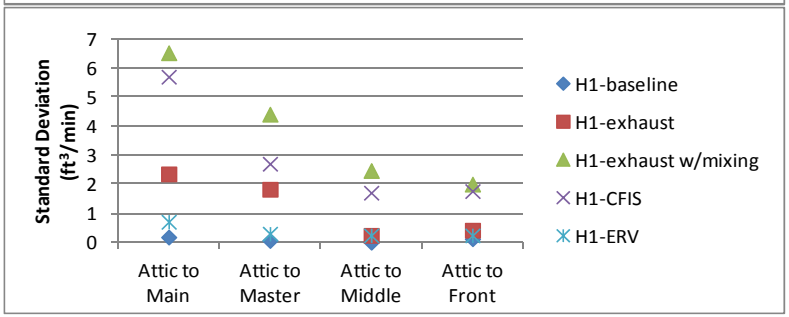


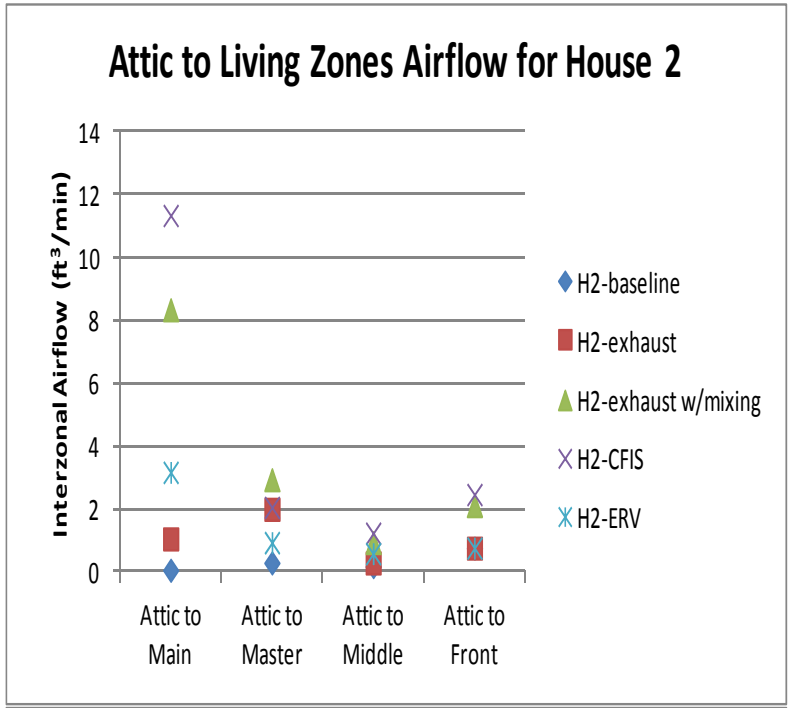
Source of Outside Air (Exhaust Makeup Air)

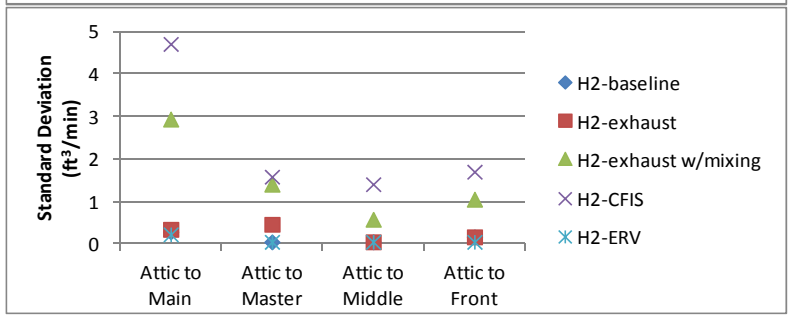
- The Exhaust system was moving 20% of its ventilation air (10 cfm) from the vented attic in House 1 to the Main zone.
- About 7 cfm or another 14% of the Exhaust ventilation air in House 1 was moving from the Attic to the bedroom zones.
- A total of 34% (17 cfm out of 50) of the ventilation air for the Exhaust system in House 1 was coming from the vented attic.
- In the unvented attic of House 2, the Exhaust system moved only 2% of its ventilation air from the Attic to the Main zone.
  - Spray-foamed roof in House 2 was tighter than drywall ceiling with recessed lights in House 1.
- Airflow from the Garage to the living space zones was low in all cases, but it was highest for Exhaust (negative house pressure) and lowest for CFIS (positive house pressure).

Airflow from Attic to living zones

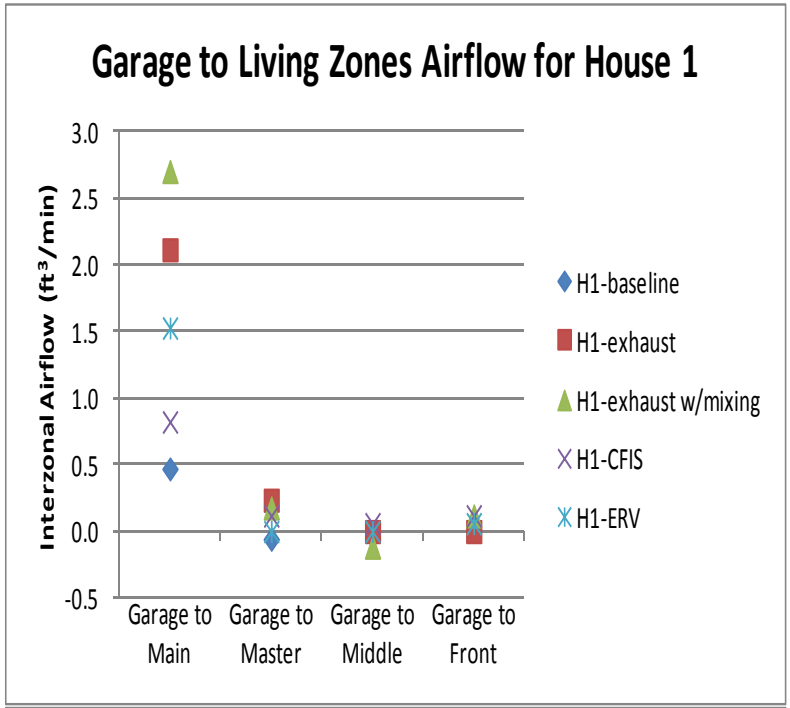


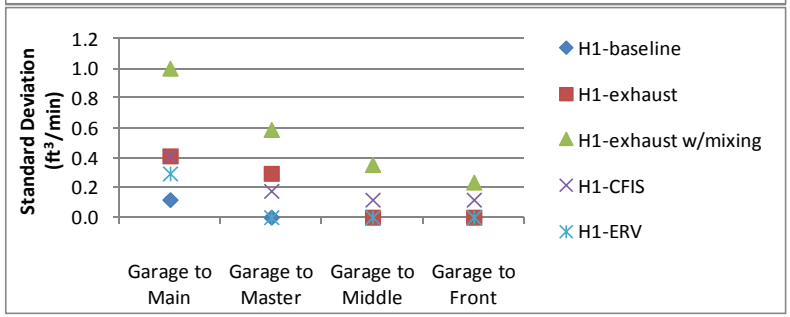


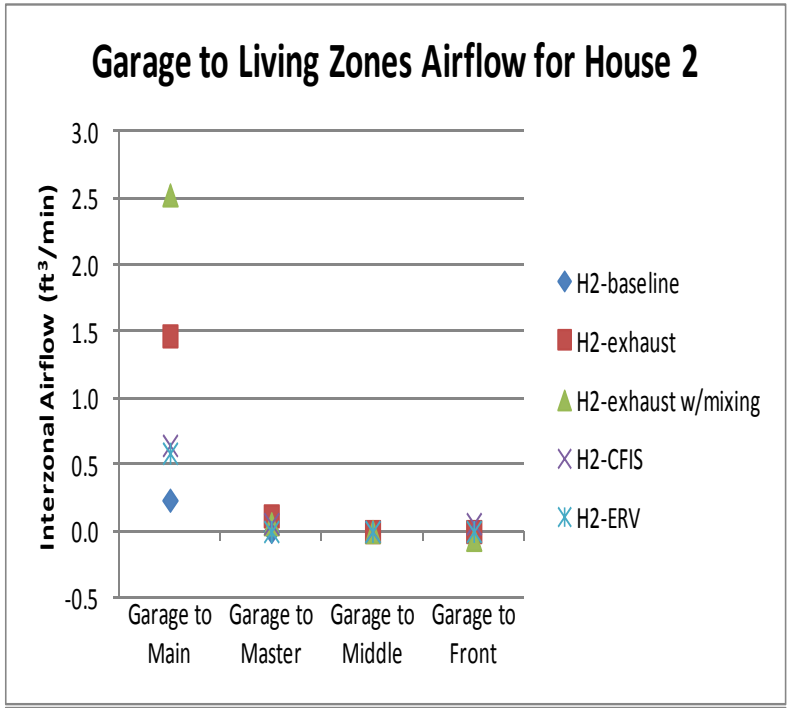


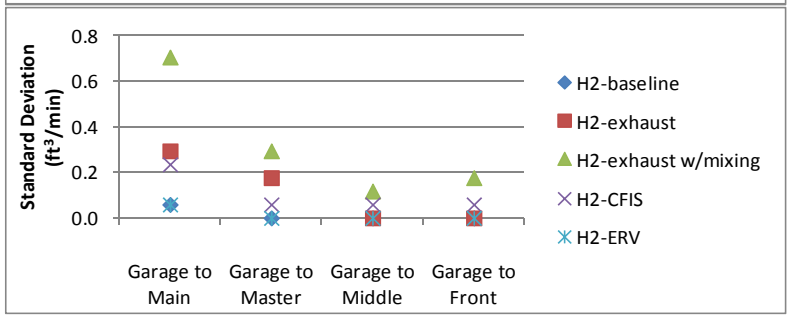


Airflow from Garage to living zones

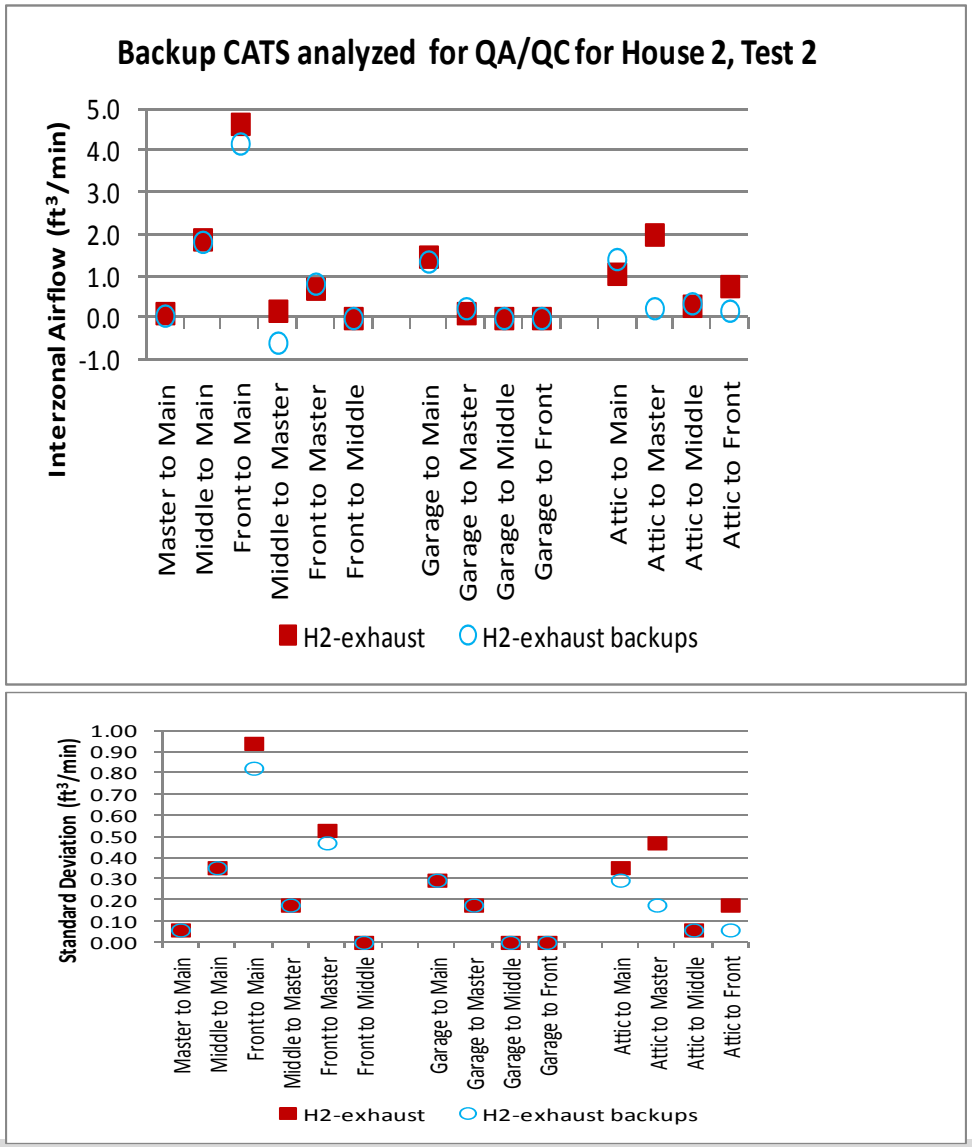




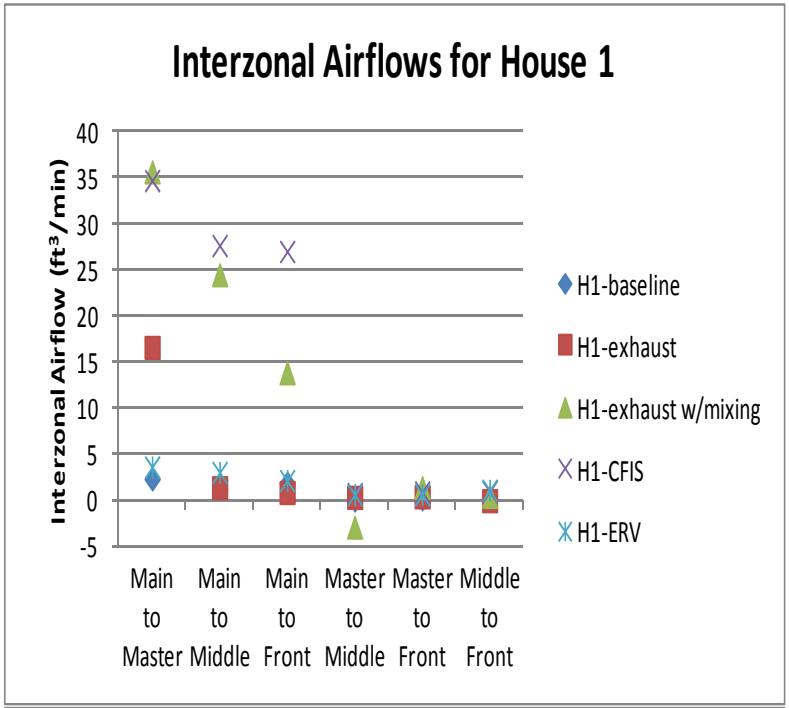


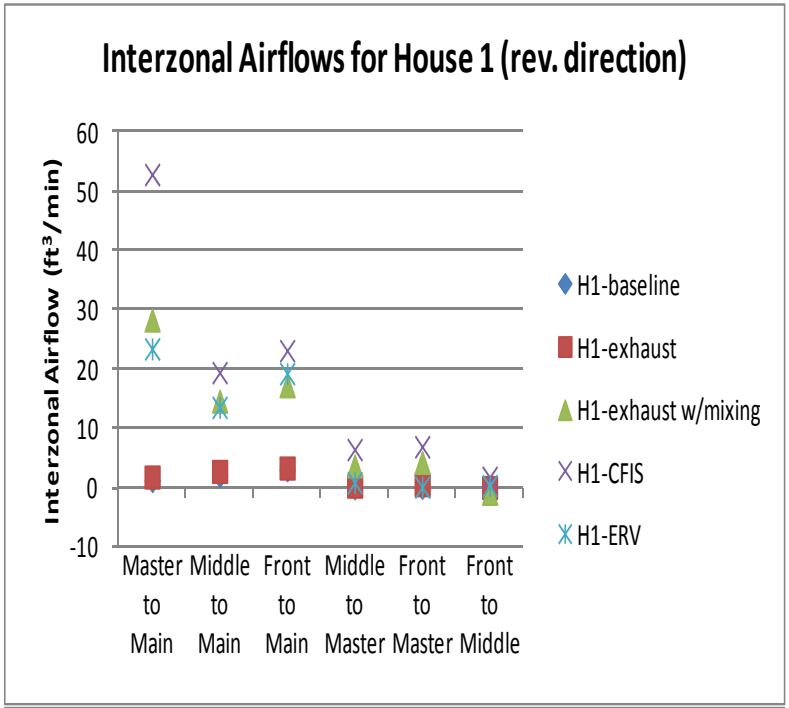


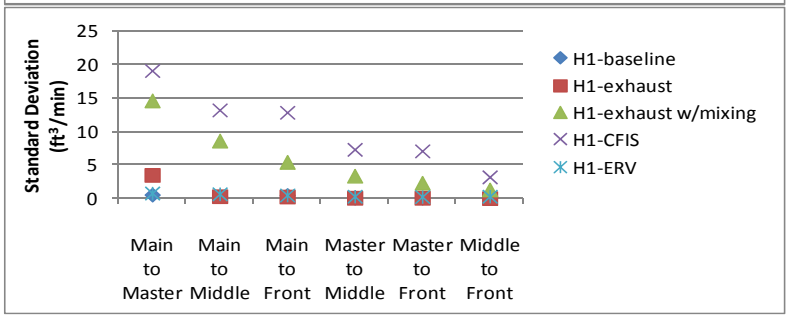
QA/QC Check on PFT Sample Accuracy and Analysis Accuracy

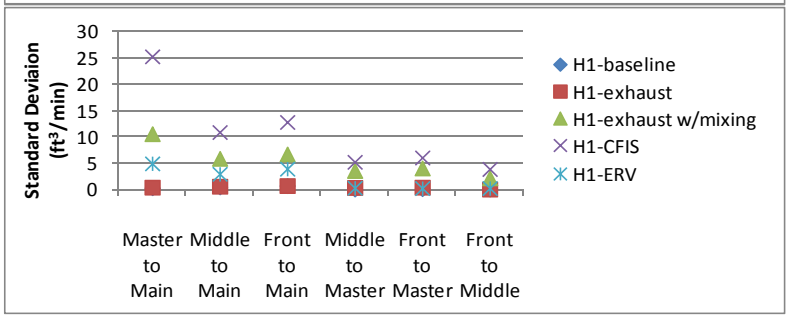


Interzonal Airflow for House 1

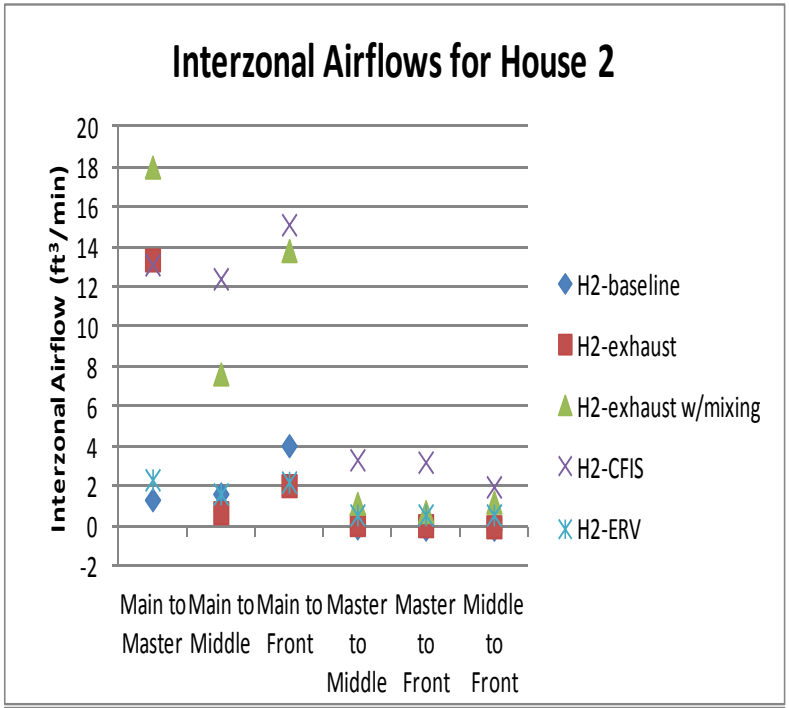


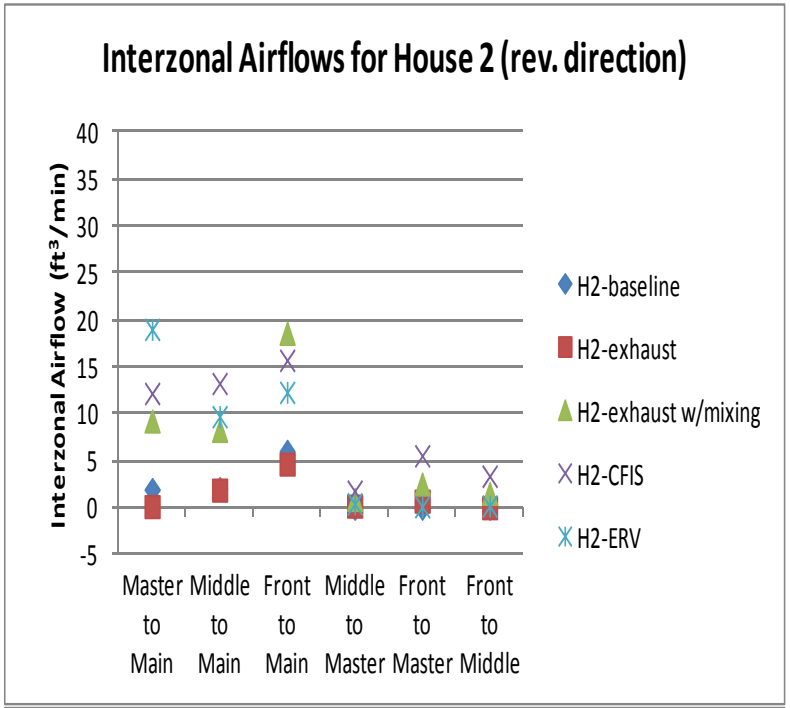


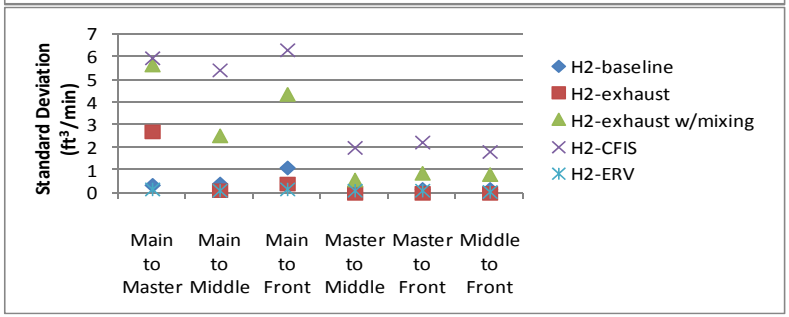


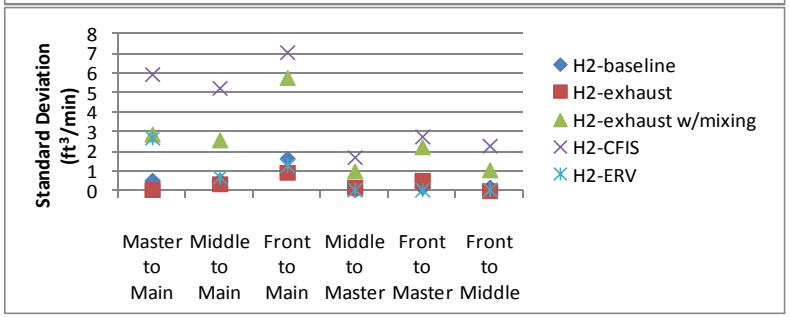


Interzonal Airflow for House 2



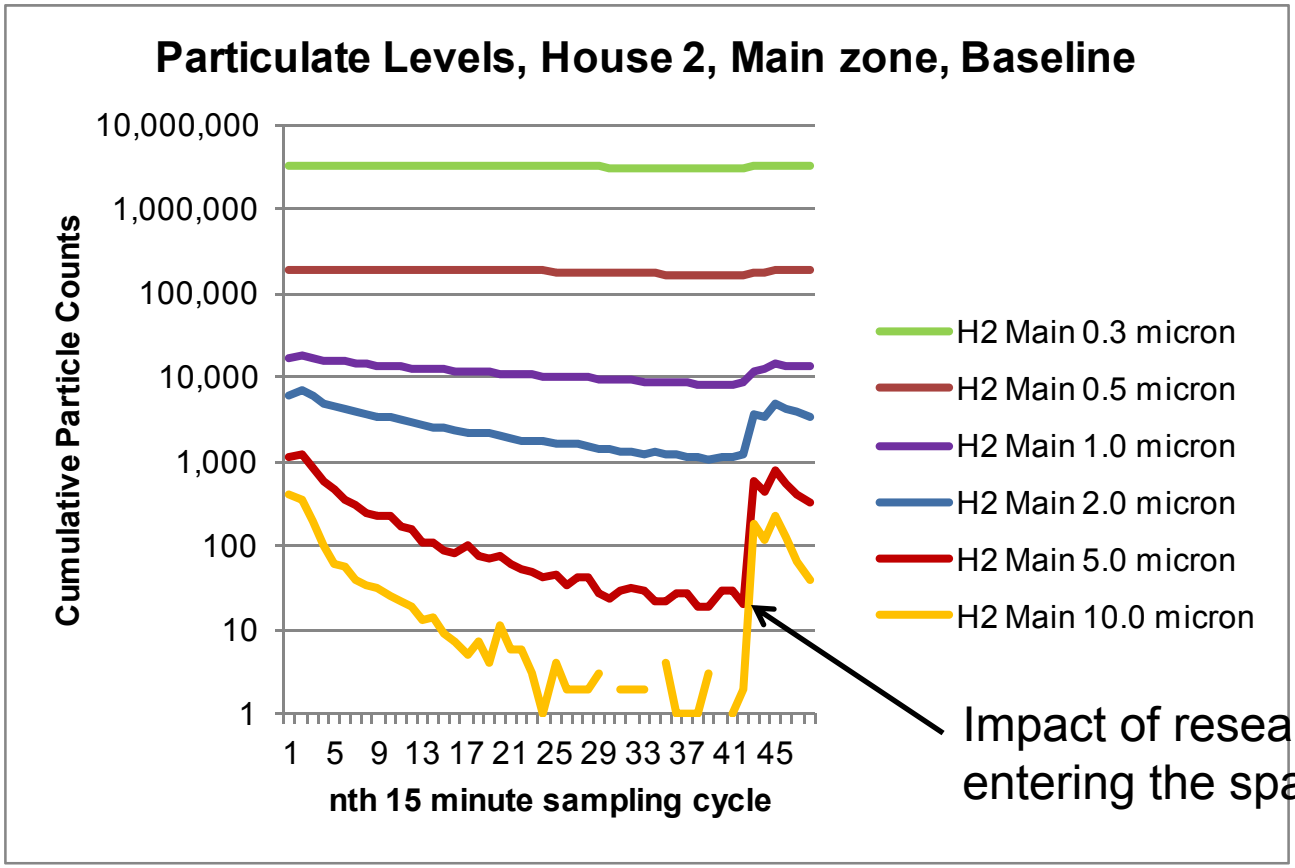




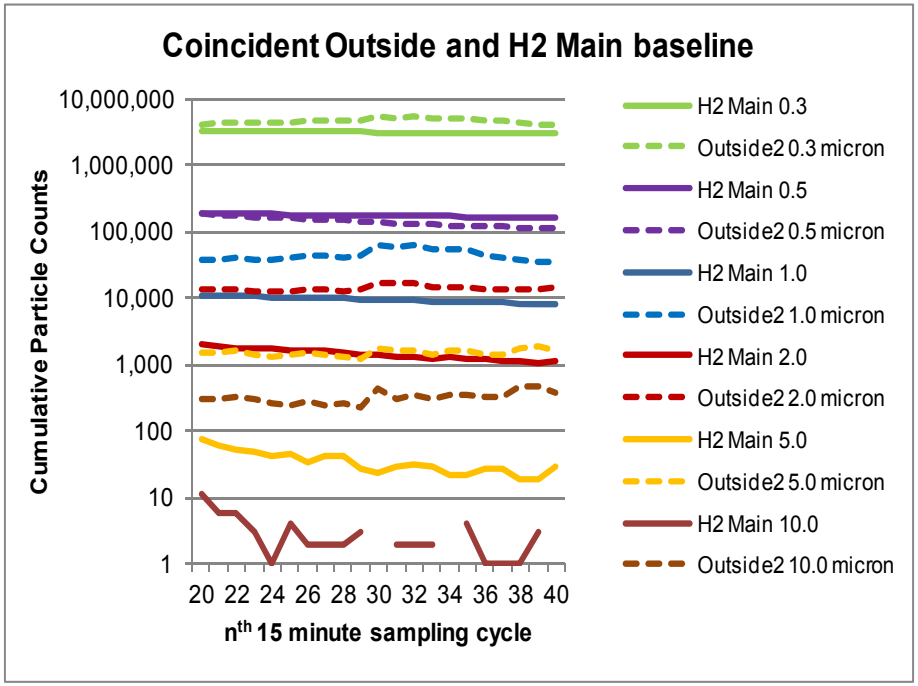


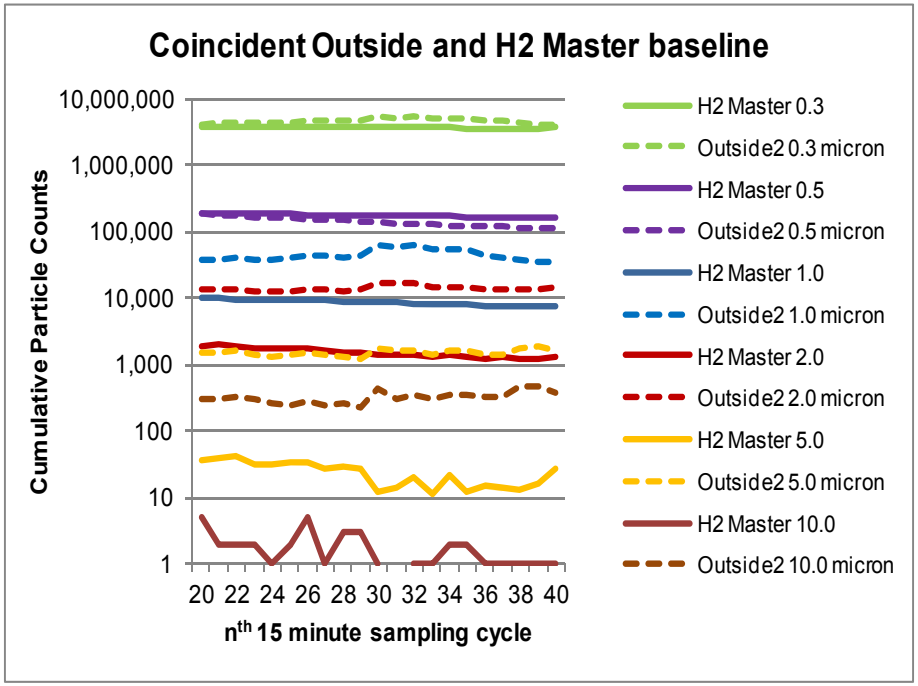
Airborne Particle Monitoring

Particulate Analyzed for 5.25 hour period *before* researchers entered the buildings to start the VOC and formaldehyde testing



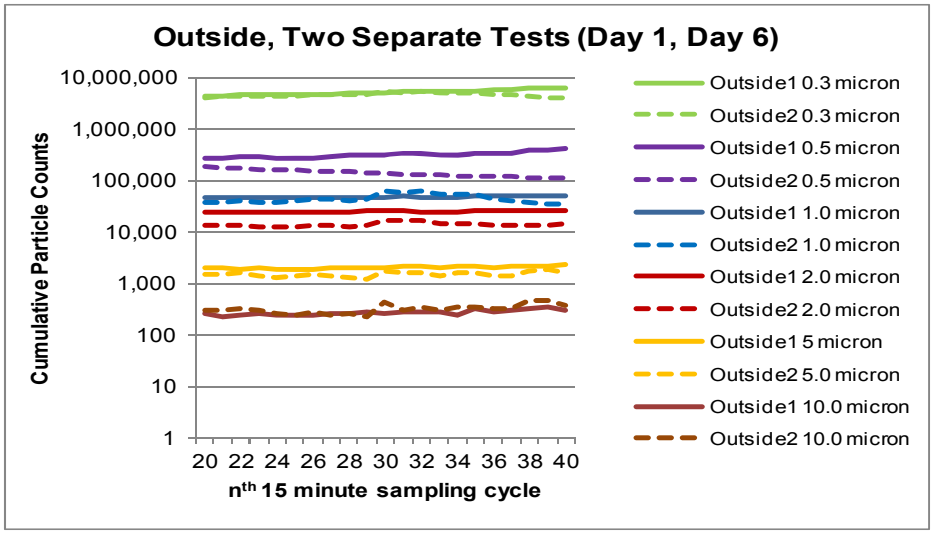
Outside Particulate Levels Compared to House 2 Baseline Test



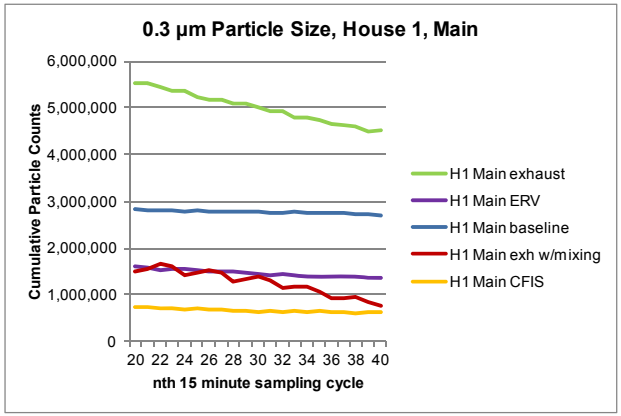


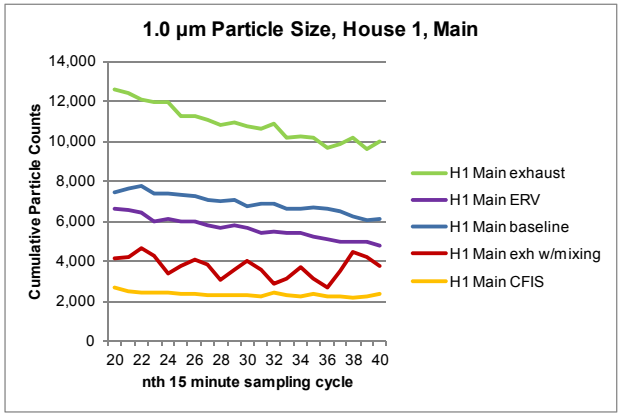
Attic Particulate Levels Compared to Outdoors

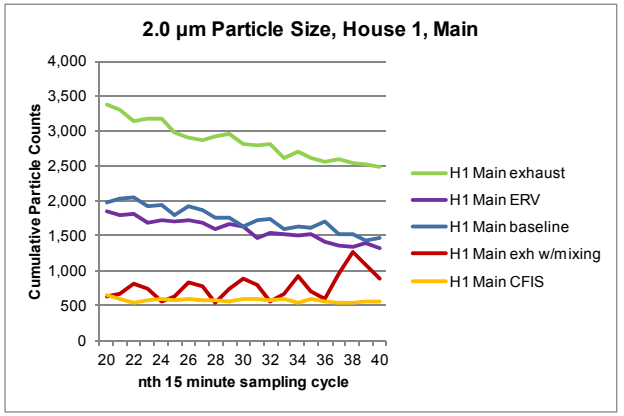
	Cumulative Particle Counts							
Particle Size (µm)	Outdoor Day 1	Outdoor Day 6	Outdoor Average	H1 Attic	H1 Attic % Diff from Outdoor Average	H2 Attic	H2 Attic % Diff from Outdoor Average	H2 Attic % Diff from H1 Attic
0.3	4,995,436	4,432,017	4,713,727	1,051,088	-78%	3,322,588	-30%	216%
0.5	316,595	363,054	339,824	55,715	-84%	179,863	-47%	223%
1.0	47,818	39,839	43,829	8,898	-80%	5,550	-87%	-38%
2.0	24,710	13,569	19,140	2,871	-85%	797	-96%	-72%
5.0	2,063	1,409	1,736	121	-93%	41	-98%	-66%
10.0	294	291	292	15	-95%	8	-97%	-49%

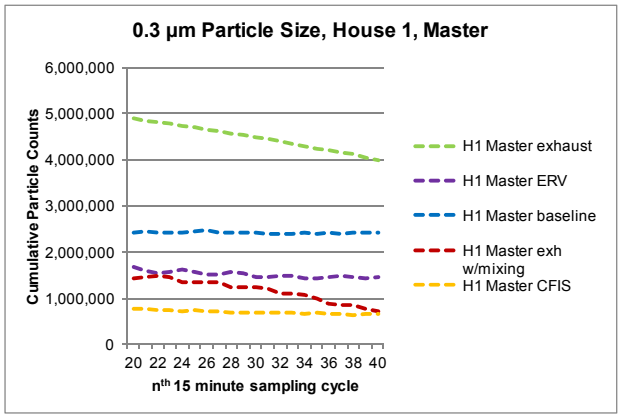


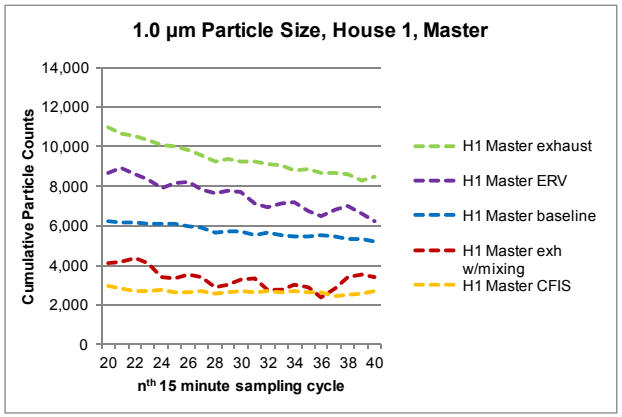
Airborne Particle Sampling in Main and Master Zones of House1

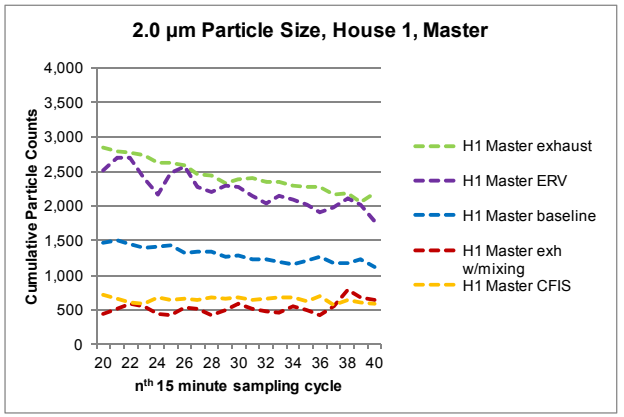




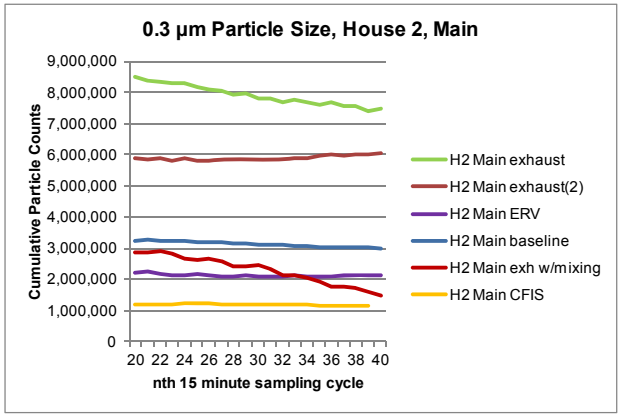


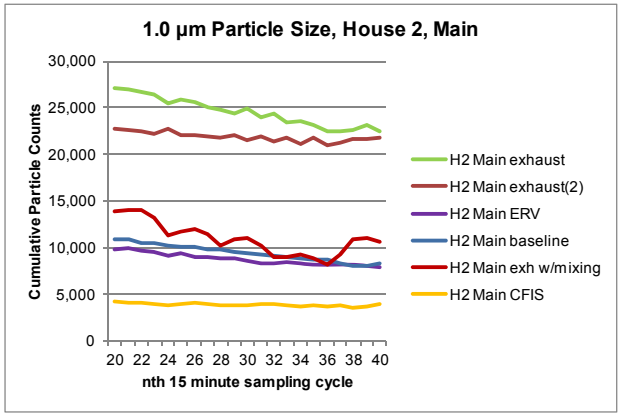


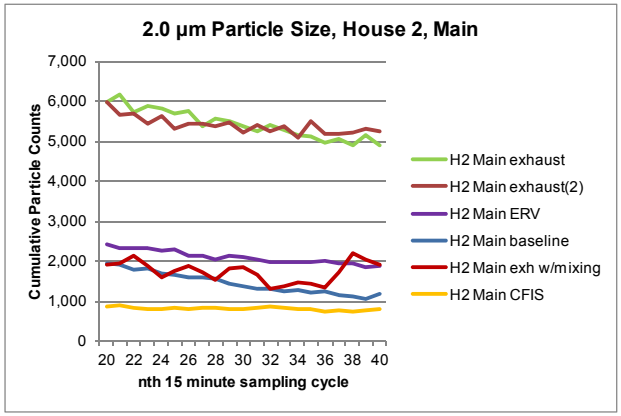


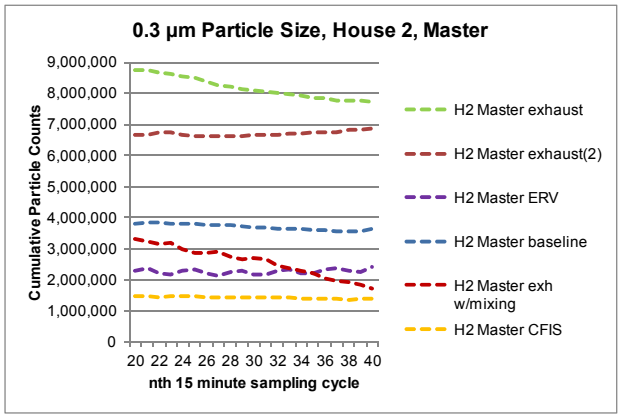


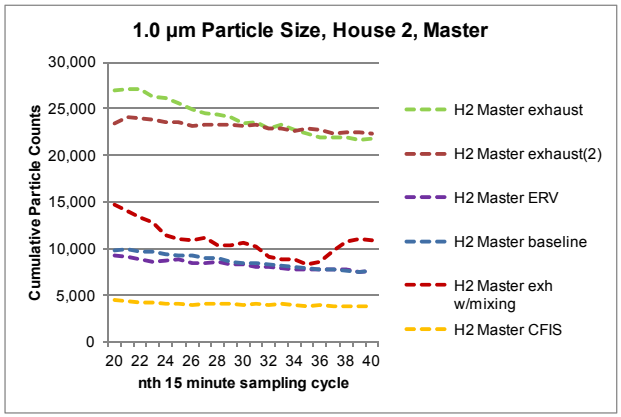
Airborne Particle Sampling in Main and Master Zones of House 2

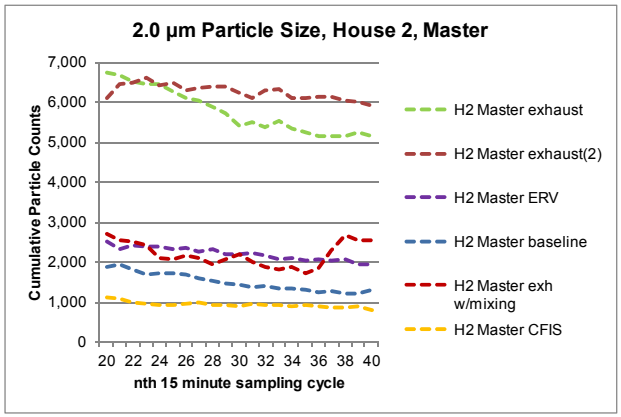












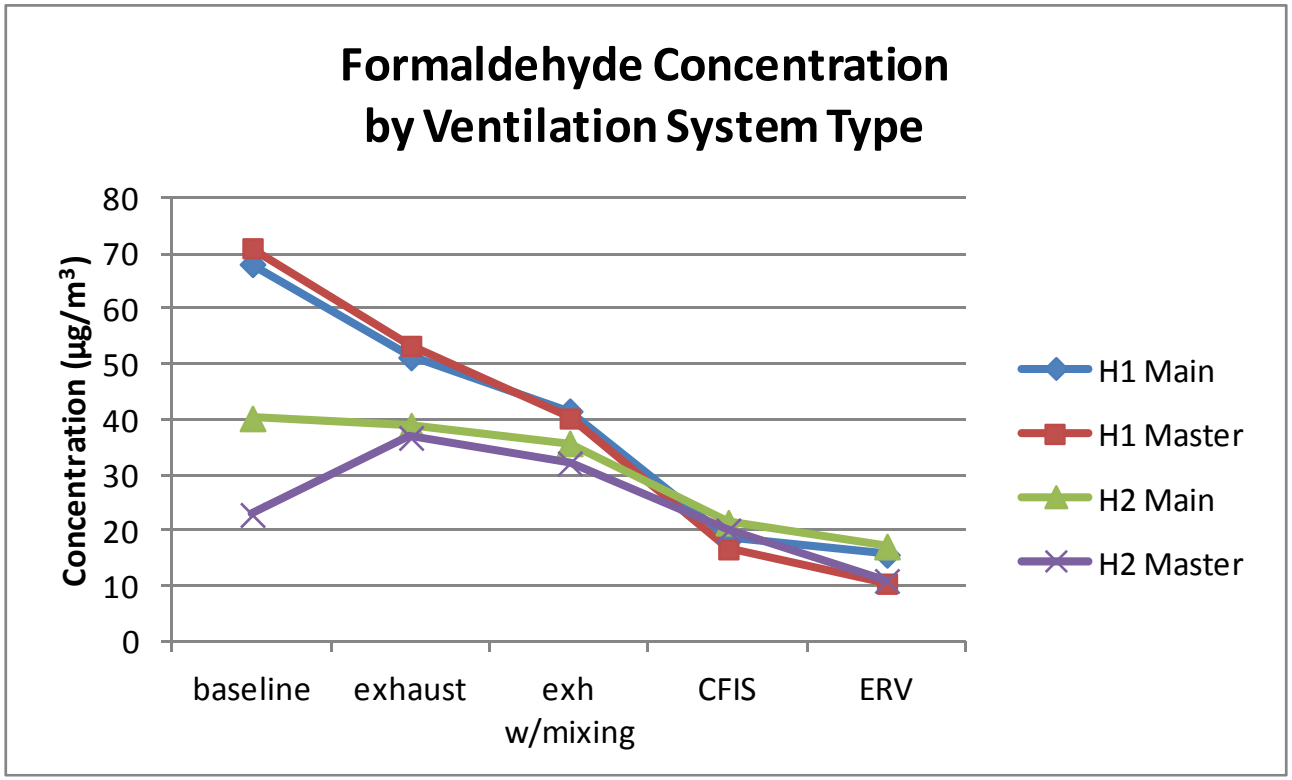
Exhaust Ventilation Showed Highest Level of Particulates (0.3 – 2.0 micron)

		Main zone				Master zone				
Test #	Ventilation System	Cumulative Counts[1] at 0.3 µm	Cumulative Counts[1] at 2.0 µm	Differential Counts 0.3- 2.0 µm	% diff. from Exhaust	Cumulative Counts[1] at 0.3 µm	Cumulative Counts[1] at 2.0 µm	Differential Counts 0.3- 2.0 µm	% diff. from Exhaust	Average % diff.
	House 1									
1	Baseline	2,764,437	2,992	2,761,446	-47%	2,453,086	1,871	2,451,215	-47%	-47%
2	Exhaust	5,223,259	3,917	5,219,341	--	4,654,361	3,087	4,651,275	--	--
3	Exhaust w/mixing	1,407,415	1,557	1,405,858	-73%	1,299,948	1,066	1,298,882	-72%	-73%
4	CFIS	730,706	1,209	729,497	-86%	774,120	942	773,178	-83%	-85%
5	ERV	1,522,578	2,120	1,520,458	-71%	1,572,288	2,652	1,569,636	-66%	-69%
	House 2									
1(6)	Baseline	3,171,002	2,611	3,168,391	-39%	3,745,584	2,061	3,743,523	-20%	-29%
2	Exhaust	8,009,169	7,086	8,002,084	--	8,279,091	7,795	8,271,296	--	--
3	Exhaust w/mixing	2,582,948	4,536	2,578,411	-51%	2,887,309	4,900	2,882,409	-38%	-44%
4	CFIS	1,221,080	2,258	1,218,822	-77%	1,445,509	2,130	1,443,379	-69%	-73%
5	ERV	2,277,061	2,882	2,274,178	-56%	2,396,952	2,935	2,394,018	-49%	-52%

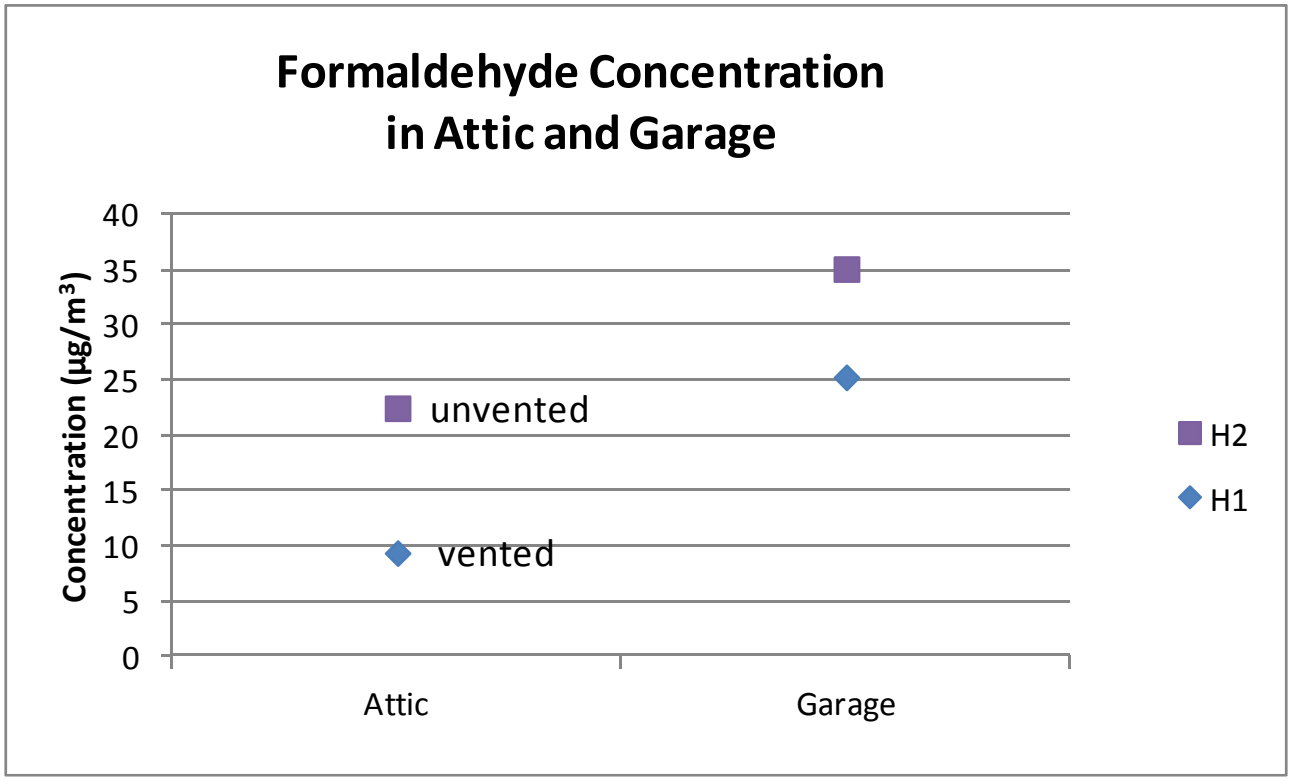
[1] Cumulative counts per 15-minute sample, averaged over 21 samples starting at hour 16.75 and ending at hour 22 of each 24 hour test period

Formaldehyde Sampling (left) and VOC Sampling (right)

Supply and Balanced Ventilation Showed the Lowest Formaldehyde Concentrations



Attic and Garage Formaldehyde Concentrations



~3 µg/m^3 expected outdoors for this region of Texas (EPA 1991)

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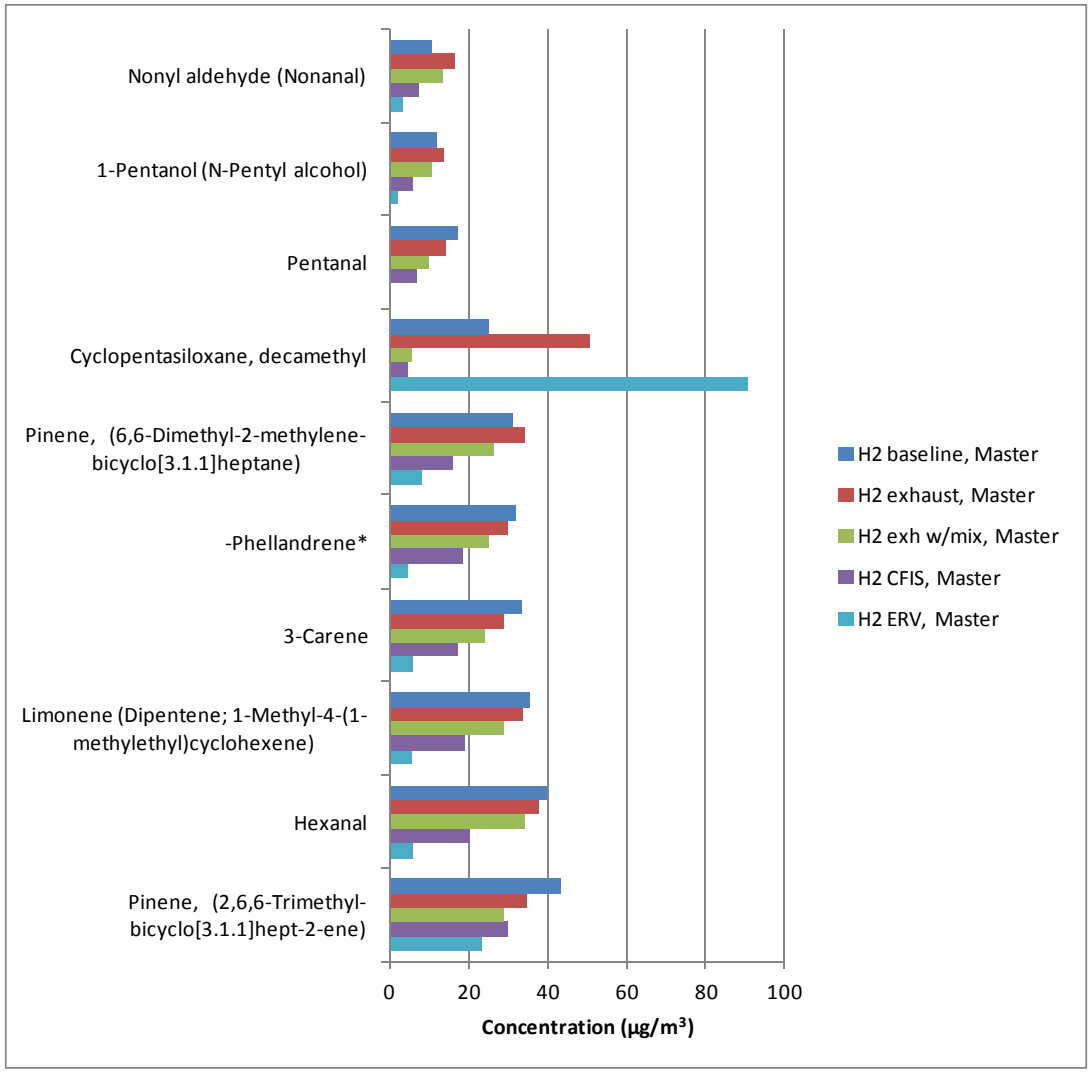
Baseline and Exhaust VOC Concentrations are Highest CFIS and ERV are Lowest



Exhaust Ventilation Showed Highest TVOC Concentration

		Main zone		Master zone		
Test #	Ventilation System	TVOC µg/m³	% diff. from Exhaust	TVOC µg/m³	% diff. from Exhaust	Average % diff.
	House 1					
1	Baseline	690	-37%	1,310	123%	43%
2	Exhaust	1100	--	588	--	--
3	Exhaust w/mixing	820	-25%	865	47%	11%
4	CFIS	459	-58%	458	-22%	-40%
5	ERV	357	-68%	271	-54%	-61%
	House 2					
1(6)	Baseline	519	6%	511	-18%	-6%
2	Exhaust	491	--	622	--	--
3	Exhaust w/mixing	477	-3%	438	-30%	-16%
4	CFIS	264	-46%	252	-59%	-53%
5	ERV	295	-40%	209	-66%	-53%
	Combined					
1	Baseline					18%
2	Exhaust					--
3	Exhaust w/mixing					-3%
4	CFIS					-47%
5	ERV					-57%

Conclusions

- Source of outside air, ventilation air distribution, and air filtration matter
- Compared to the supply and balanced ventilation systems, exhaust ventilation showed:
  - More airflow coming from the attic and garage
  - Higher concentrations of airborne particulate matter
  - Higher concentrations of formaldehyde and other Top 20 VOCs
  - Lower uniformity of outdoor air exchange rate between different living space zones

Recommendations

- System Factors to credit better performing ventilation systems should be considered to allow smaller systems to save cost and energy, and reduce risk in hot-humid climates
- System Factor Table for consideration (factors applied to ASHRAE Standard 62.2-2013 ventilation rate):

Mechanical Ventilation System Type	With central filtration recirculation*	Without central filtration recirculation
Balanced	0.5	0.7
Unbalanced Supply	0.55	0.75
Unbalanced Exhaust	0.7	1.0

* Requires minimum whole-house recirculation turnover of 0.7 ach with minimum MPR 700 or MERV 9 filter. Minimum whole-house recirculation turnover defined as: (AHU cfm)(minimum runtime min/h) / (conditioned floor area*8 ft).

Recommendations, cont,

Numerical basis for the System Factors shown,
given as percent airflow rate reduction for each System Factor Category

	Percent Reduction in 62.2-2013 Ventilation Rate due to listed System Factor Categories									
	With Whole-Building Recirculation Filtration					Without Whole-Building Recirculation Filtration				
	System Factor Categories					System Factor Categories				
Whole-Building Mechanical Ventilation System Type	Balance	Distribution	OA Source	Recirculation Filtration	Total	Balance	Distribution	OA Source	Recirculation Filtration	Total
Balanced	5	10	15	20	50	5	10	15		30
Unbalanced Supply		10	15	20	45		10	15		25
Unbalanced Exhaust		10		20	30					0

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Comparison of ASHRAE Standard 62.2-2013 ventilation fan airflow rates to 62.2-2010, averaged over a range of climates, building archetypes, and building airtightness

			2-story, 62.2-2010 fan cfm=54				1-story, 62.2-2010 fan cfm=50			
			3.0 ach50		1.5 ach50		3.0 ach50		1.5 ach50	
CLIMATE ZONE	LOCATION	ASHRAE WSF*	62.2-2013 fan cfm	% diff from 62.2-2010 fan cfm	62.2-2013 fan cfm	% diff from 62.2-2010 fan cfm	62.2-2013 fan cfm	% diff from 62.2-2010 fan cfm	62.2-2013 fan cfm	% diff from 62.2-2010 fan cfm
Warm-Humid	Orlando, FL	0.39	73	35%	88	62%	71	42%	81	61%
Warm-Humid	Houston, TX	0.40	72	34%	87	61%	71	41%	80	61%
Warm-Humid	Charleston, SC	0.43	70	30%	86	59%	69	38%	80	59%
Mixed-Humid	Baltimore, MD	0.50	65	20%	83	55%	66	31%	78	56%
Mixed-Humid	Kansas City, MO	0.60	58	7%	80	48%	61	22%	75	51%
Mixed-Humid	Charlotte, NC	0.43	70	30%	86	59%	69	38%	80	59%
Cold-Humid	Minneapolis, MN	0.63	55	2%	79	46%	59	19%	75	49%
Cold-Humid	Chicago, IL	0.60	58	7%	80	48%	61	22%	75	51%
Dry	Phoenix, AZ	0.43	70	30%	86	59%	69	38%	80	59%
Dry	Denver, CO	0.61	57	5%	79	47%	60	21%	75	50%
Marine	Los Angeles, CA	0.42	71	31%	86	60%	70	39%	80	60%
Marine	Seattle, WA	0.56	61	12%	81	50%	63	26%	76	53%
	average of climates:		65	20%	83	55%	66	31%	78	56%

	62.2-2013 fan cfm	% diff from 62.2-2010 fan cfm
Avg of climate, archetype, and tightness:	73	40%

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