Ventilation and IAQ in New US Homes: Results from the Building America Field Study

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UNIVERSITY OF CENTRAL FLORIDA



Project Team

- Lawrence Berkeley National Laboratory: oversaw study protocol development and provided central oversight
 - Executed related field study in CA
- Pacific Northwest National Laboratory: led field study in marine and cold climates (OR and CO)
- Florida Solar Energy Center: led field study in hot-humid climate (FL SC, and GA)
- University of Illinois: led field study in NE cold climate (IL)



Project Funding

- The U.S. Dept. of Energy's Building America Program provided the vast majority of financial and programmatic support (Eric Werling).
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- The California study was supported by the California Energy Commission, Building America, EPA IED, GTI, PG&E and SoCalGas
- Cost-Share

o Panasonic (PNNL) o University of Central Florida





State of the art

<u>Context</u>

- Air tightness reduces thermal loads & outdoor pollutants, but can increase indoor contaminants
- ASHRAE 62.2 requires MV equipment and airflows; used by Energy Star, other programs
- Since 2012, IECC requires "whole-house" MV
 - o States modify to only require at <3 ACH50
 - o Kitchen exhaust not required in many states

Specific Issues

- Limited data on contaminants in homes
- Ventilation alone not sufficient to maintain IAQ
- Existing data suggest deficiencies:
 - o Equipment not performing to spec
 - o Specs for kitchen exhaust may not be adequate
 - o Equipment not used

Indoor Air Pollutants in Homes

From Inside Ventilation can reduce Particulate matter indoor levels of air Nitrogen dioxide: NO₂ pollutants from inside From Outside Water vapor -> Mold Particulate matter People/pet bioeffluents Allergens Cooking / chemical odors Ventilation can increase Ozone Allergens indoor levels of air Nitrogen dioxide: NO₂ pollutants from outside Formaldehyde Mold Acrolein Odors Other VOCs, CO CO_2 Energy & Environmental Building Alliance

Radon

Indoor Pollutant Exposure and Health

- Americans spend approximately 90% of their lives indoors.
- Indoor pollutant concentrations are not regulated; often, pollutant concentrations inside can be greater than outside.
- High-performance homes with tight envelopes decrease natural infiltration and thus the air change rate.
- Adding WHMV to airtight homes is important to dilute pollutants.... "Build tight, ventilate right!"
- Filtration is important for decreasing pollutants from outdoors, and for recirculating clean air.
 - Especially true when outdoor air is polluted.



Codes and Standards

- ASHRAE Standard 62.2 is the minimum standard specifying airflow, and sound requirements for ventilation in residential buildings.
- WHMV and additional exhaust ventilation in kitchens and bathrooms are part of new home codes (IRC, IECC).
- Above-code programs, such as ENERGY STAR, DOE Zero Energy Ready Home, Indoor AirPLUS and others also require 62.2compliant ventilation but not better than 62.2.
- Homes renovated under DOE's Weatherization Assistance Program also are required to install 62.2-compliant ventilation systems.



Approaches to Home Ventilation

- Continuous exhaust or supply
- Central Fan Integrated Supply (CFIS) (with mechanical damper)
- Balanced supply plus exhaust
- Ventilating dehumidifiers (in hot-humid climates)
- Energy recovery or heat recovery ventilation
- Local exhausts



General ventilation doesn't fully protect against acute hazards



chen exceeds safe level

•Cooking particles and VOCs from consumer products present similar challenges



California Healthy Efficient New Gas Homes Study (HENGH)

- 70 detached homes, built 2011-2017
- Natural gas cooking burners
- Measurements in 2016-2018
- Characterized ventilation equipment
- Measured IAQ, tracked activities for 1 week
- Windows closed; general MV operating





WHMV System Type

System Type	Operation Mode	Fan Location(s)	Number of Homes
Exhaust	Continuous	Laundry Room	43
		Bathroom	9
		Attic	3
	Intermittent	Laundry Room	5
		Bathrooms (multiple)	4
Supply	Continuous	Attic	4
	Intermittent	None*	2
	70		

*These central fan integrated supply (CFIS) systems had a duct with motorized damper that connected the outdoors to the return side of the forced air system, but no supply fan.



Formaldehyde and PM2.5 lower in HENGH homes

	Formaldel	nyde (ppb)	PM2.5 (ug/m3)		NO2 (ppb)		CO2 (ppm)	
	HENGH	CNHS	HENGH	CNHS	HENGH	CNHS	HENGH	CNHS
Indoor: Mean Median 10 th -90 th	19.8 18.2 13-28 N=68	35.0 29.3 11-70 N=105	7.5 4.8 1.6-16 N=67	13.4 10.5 6.0-31 N=28	5.8 4.5 1.1-12 N=66	5.2 1.6 1.4-12 N=29	620 608 481-770 N=69	610 564 405-890 N=107
Outdoor: Mean Median 10 th -90 th	2.2 2.3 1.4-3.1 N=66	1.8 1.7 0.6-2.8 N=39	9.3 6.8 2.7-18 N=67	7.9 8.7 5.0-10 N=11	5.4 3.6 0.1-11 N=65	2.1 1.5 1.4-1.7 N=11	No data	No data







Only 1 in 4 homes had the central ventilation system running as found.

Mean required: 63 cfm Mean provided: 96 cfm





Labels Make a Difference

Whole-House Ventilation Control	Controller Labelled?	% On As-Found
On/Off Switch	No (N=42)	5%
	Yes (N=12)	58%
Programmable Controller	No (N=10)	50%
Thermostat	No (N=2)	0%
Breaker Panel	No (N=1)	100%
No Controller	No (N=3)	100%







BAIAQ Field Study: Scope, Approach & Data Collection



Building America New Home IAQ Study

- 25-30 homes per climate zone (CZ)
- About 50% with mechanical ventilation (MV)



•Characterize home, equipment, household

•Monitor ventilation, IAQ, activities for 1 week in all homes

•Repeat with WHMV on and off in ~8 homes per CZ (except CA)



Key Questions

- What MV equipment is present in homes that meet 62.2-2010 / IECC?
- How do WHMV system designs and performance vary by climate zone?
- What is the working condition of installed WHMV equipment?
- What are the airflows when operating?
- Do people know how to operate their WHMV and is it used?
- How do occupants use kitchen ventilation when present?
- What are air pollutant & IAQ satisfaction levels in recent year homes?
- Are there discernible differences in IAQ in homes with/out WHMV?



Recruitment Strategy Florida example

- Identified regional home characteristics to qualify sample using data from EIA RECS, NREL Restock, RESNET, NAHB, US Census.
- FSEC Energy Rated Home Database used as primary source of recruitment records, with ~50,000 qualifying homes.
- RESNET National Registry used as a secondary source.
 Home Distribution to Date



Recruitment Website

FSEC Energy Research Center	Se	Sarch Search
About Us • Working With Us • Research • Solar Detrification • Education • Consumer Research • Buildings Research • Indoor Air Quality Research Study	UCF Energy Personnel ·	
Indoor Air Quality Research Study	Latest News	
WANTED:		Space Coast Education
Southeastern U.S. homeowners are wanted to participate in an indoor air quality study conducted by the University of Central Florida's FSEC Energy Research Center.		Community Celebrates Its 20th Year Recognizing Exemplar Science Teachers
What is this study about?	$= M \sqrt{11}$	l

FSEC is conducting a study funded by the US Department of Energy to learn about the indeor air quality in new homes. Lawrence Berkeley National Laboratory (LBNL) and Paolfic Northwest National Laboratory (PNNL) are partners in this study.

What does participation involve?

Participation involves allowing 2-3 FSEC staff members to visit your home and place temporary monitors to measure air quality indoors and outdoors, and monitor appliance operation. The visit may last 6-8 hours, and the monitors will remain for one week. A second visit of 6-8 hours will take place at the end of the week to collect monitors and conduct air flow testing. We ask that participants keep their windows closed during the week, and to log



Cloudy Skies Add to Real-World Learning Challenges at

EnergyWhiz

Posing as Florida Sola

Energy Center



Data Collected in Each Home

- Homeowner IAQ and comfort perceptions
- Ventilation practices and activities that impact IAQ
- Household characteristics
- House and mechanical equipment
- Envelope and duct leakage
- Airflows of ventilation equipment

Monitor

Measure

- Ventilation use & activities that affect IAQ
- Air pollutant concentrations & weather
- Inside and outside



Survey

Occupant Survey

	I am unhappy with it (1)	I feel it could be improved (2)	I feel it's fine (3)	I am happy with it (4)
Overall quality of home (1)	0	0	0	0
Air quality inside home (2)	\bigcirc	\bigcirc	\bigcirc	\bigcirc
Air quality outside within neighborhood (3)	\bigcirc	\bigcirc	\bigcirc	\bigcirc
Ability to control temperature inside home (4)	\bigcirc	\bigcirc	\bigcirc	\bigcirc
Ability to control humidity inside home (5)	\bigcirc	\bigcirc	\bigcirc	\bigcirc
Natural lighting (daylight) inside home (6)	\bigcirc	\bigcirc	\bigcirc	\bigcirc
Noise from heating & cooling system (7)	\bigcirc	\bigcirc	\bigcirc	\bigcirc
Privacy (8)	0	0	\bigcirc	\bigcirc
Security (9)	\bigcirc	\bigcirc	\bigcirc	\bigcirc

ling Alliance

Q5 When thinking about your home, how do you feel about the ... ?

Air Flow Testing









Whole House Ventilation, Dryer: Powered Flow Hood.

Bathroom Exhaust: Exhaust fan flow box.

Kitchen range hood: Custom flow box/duct blaster.

Enclosure and duct leakage: Delta Q.



Whole House Air Exchange: SF6 Tracer Gas (FSEC only)



Air handler flow: Flow plate.

Equipment Monitoring



Clothes Dryer Use



Bath Fan Use



Range Hood Use



Heating/Cooling Runtime



Door Use: Garage, Master Bedroom, Patio

Activity Log

 night
 am
 am

3

4

5

6

7

Night

2

1

Mid-

Completed daily by occupants

Helps to identify occupant activities that lead to contaminant emissions

												-
	Mid- night	1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	
Bad outdoor air ¹												
BBQ/outdoor grill												
Exterior door open												
Window open												
Standard cooking ²												
Microwave												
Spray cleaner												
Vacuuming												
Candle												
Other event ³												
Other event mins.												
							Frances		montal D		llonco	

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Morning

8

9

10



Air Quality Measurements







Photometric Outdoor PM_{2.5}

Photometric Indoor PM_{2.5} Gravimetric Indoor PM_{2.5} CO₂, PM_{2.5} In multiple rooms

Subset of Homes



Real-time NO₂



30-min resolved Formaldehyde



1-week avg. Formaldehyde



1-week NO₂, NO_X 1 week of hourly Radon

Raderar



6-month integrated Radon



Ultrafine particles

Outdoor & Indoor Equipment Set-Up



<u>Master Bedroom:</u> T/RH, PM_{2.5}, HCHO, CO₂ <u>Master Bathroom and 2nd Bathroom:</u> T/RH <u>Secondary Central Indoor Location:</u> T/RH, PM_{2.5}, CO₂



Slide credit: FSEC

Field Study Results



Home Characteristics

Values are median (10th–90th) unless specified

	California (70)	Oregon (29)	Colorado (26)	Illinois (32)	FL/GA/SC (51)
Year built, Median (range)	2014 (2011–2017)	2016 (2013–2018)	2015.5 (2013–2018)	2016 (2013–2020)	2017 (2013–2020)
Floor area, sf	2616 (1572–3649)	2164 (1594–3289)	2825 (1850–4139)	2721 (1492–3846)	2146 (1425–3397)
1 / >1 stories (#)	27 / 43	1/28	6 / 20	14 / 16	33 / 17
Residents	3 (2–5)	3 (2–4)	2 (2–4)	4 (2–5)	3 (2–5)
Density, sf/person	828 (484–1539)	900 (589–1519)	1225 (751–2175)	758 (456–1380)	847 (500–1686)
Envelope leakage, ach50	4.4 (3.4–6.0)	2.9 (1.9–5.0)	2.8 (2.0–4.3)	3.5 (1.7-5.3)	3.8 (1.9–5.7)
Gas cooktop / oven (%)	100% / 43%	90% / 40%	88% / 38%	70% / 70 %	47% / 25%
Kitchen exhaust vented (%)	100%	100%	100%	60%	84%

OR/CO WHMV Observations

- CFIS systems more common in OR
- CO had more exhaust systems
- 21 homes had exhaust systems \leq 1 sone:
 - Six homes also had uncontrolled CFIS that operated when the CFA was on.
 - Three systems were set to operate continuously with no override switch.
 - Many homeowners did not know how to operate their WHMV.
- System functionality summary:
 - Most exhaust systems were operating as-found, 5 of 21 could not meet 62.2 airflow capacity.
 - Most CFIS systems were operating, but many were not operating with sufficient airflows.
 - All HRV/ERV systems were operating, and 6 of 7 had airflows ≥ 80% of 62.2-2010.

Southeast WHMV Observations

- Of 26 homes rated with an exhaust system, all were bathroom fans,
 - 6 also had a CFIS system with controller and 5 had uncontrolled CFIS.
 - 7 exhaust fan had timer and/or flow control.
- System functionality summary:
 - ERVs and Ventilating Dehumidifiers most likely to be operating; 2 had clogged filters.
 - No exhaust fans were operating as found (except under RH/occupancy control); but generally capable.
 - CFIS systems often not capable of functioning (disconnected damper, non-functioning damper, or no measurable flow).

Illinois WHMV Observations

• Only 9 of 32 measured homes have WHMV

• Most of them are CFIS, none of them meet 62.2 as found

• None of the exhaust fan in No WHMV homes are <1 sone (i.e. cannot serve as a qualified WHMV fan)

Homeowner Awareness of WHMV System

- In OR/CO, <u>all</u> reported that they had WHMV. In FL/GA/SC, only those with ERVs and Ventilating Dehumidifiers knew at a high rate.
- In FL/GA/SC, homeowners rarely aware of the existence or purpose of a CFIS system (4/11) or exhaust fan acting as WHMV (1/24).
- In CO/OR, all 21 with exhaust knew they had WHMV, but only 3 knew how to operate the system.
- Very few homes had easy-to-understand labels on their WHMV systems.

WHMV label issues

Group	Home with correct label on WHMV	WHMV running as found	Home w/o correct label on WHMV	w/o label WHMV running as found
CO+OR	26	19 (yes) +3(unclear)	21	17 (yes) +1(unclear)
FL+GA+SC	20	8	23	5
IL	10	6 (yes)+1(unclear)	0	0
Total (out of 138)	56	33	44	22

Label status does not indicate if systems are running or not

Poor Controls

Unlabeled timer at AHU and tstat. No accessible override for CFIS system



Better Controls

Clear label at HW controller with accessible override

for CFIS system





Label/Control Issues

Exhaust Fan labeled



Exhaust Fan labeled "WHOLE HOUSE VENTILATION"

WHOLE HOUSE

1

Exhaust Fan NOT labeled



IAQ Results for Formaldehyde, PM2.5 and Radon

WHMV resulted in lower CO₂ in OR/CO homes



Hour of Day



Hour of Day

Summary Findings: WHMV Systems

- Many WHMV systems not operating or turned off upon arrival.
- Some WHMV systems were not capable of operating due to component failures.
- Very few central fan integrated supply (CFIS) designed and operating to provide airflows required by 62.2-2010.
- Improving effectiveness of WHMV systems requires:
 - homeowner and contractor education
 - better commissioning
 - proper labeling
 - fault detection systems

Summary Findings: IAQ

- WHMV had a large and discernible impact on CO₂, an indicator of bio-effluents and people-associated emissions
- WHMV had minimal or no impact on formaldehyde.
- Radon was lower in homes operating with WHMV.
- PM_{2.5} levels generally low and impacted by outdoors.

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THANK YOU!