Whole House Ventilation: Better, Stronger, Faster

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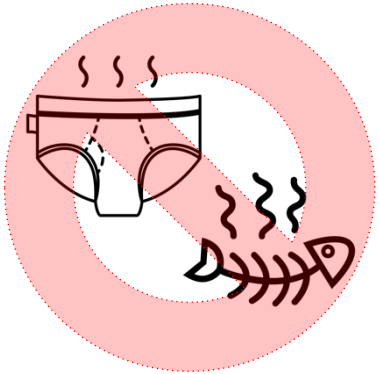
ENERGY STAR Certified Homes Stakeholder Meeting

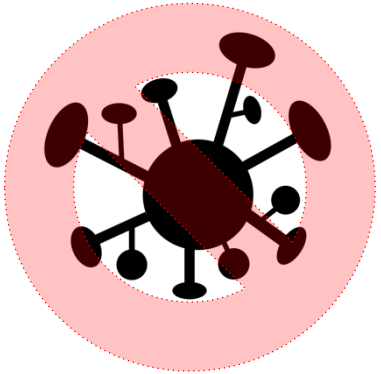
Sep 12, 2019 – Charlotte NC

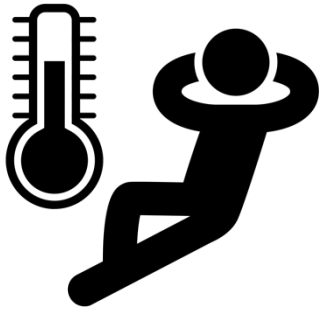
Outline

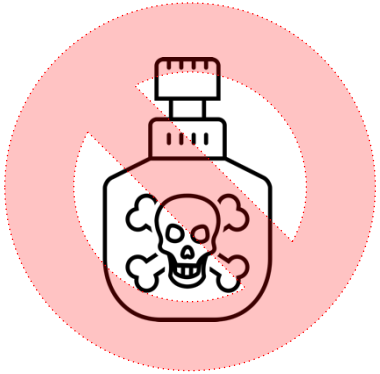
- Mechanical ventilation (MV) as control for IAQ
- Studies of MV performance
- Smart ventilation studies
- Guidance on ventilation

What is Indoor Air Quality?









IAQ Challenges

Ventilation reduces indoor levels

Ventilation can increase indoor levels

From Inside

Particulate matter

Nitrogen dioxide: NO_2

Water vapor –> Mold

People/pet bioeffluents

Cooking / chemical odors

Allergens

Formaldehyde

Acrolein

Other VOCs, CO

Carbon dioxide?

From Outside

Particulate matter

Radon

Allergens

Ozone

Nitrogen dioxide: NO_2

Benzene

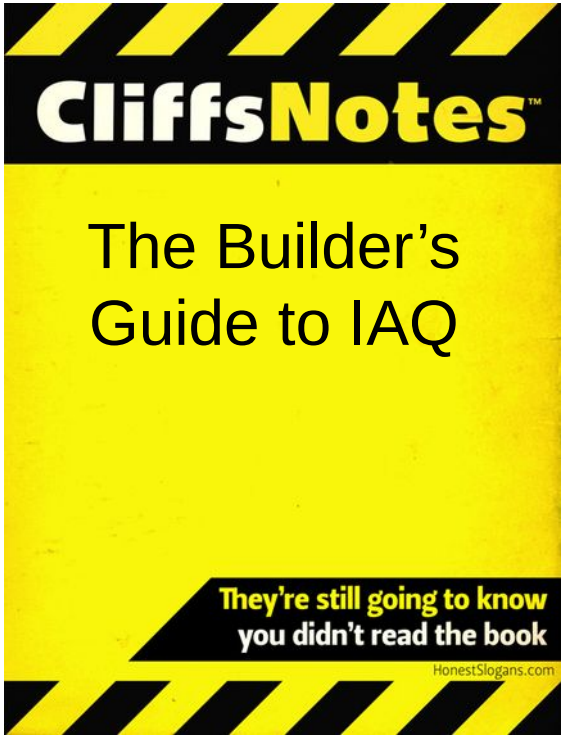
Mold

Odors

Good IAQ = Low-Risk of Bad IAQ

How to Reduce IAQ Risk

- **Reduce hazard entry**
  - **Airtight envelope and ducts**
  - **Radon-resistant construction**
  - Low-emitting materials
  - **Vent combustion & cooking**
  - Vent kitchen, bath, laundry
  - Filter supply air
  - **Keep it dry**
- **Increase hazard removal rate**
  - **General ventilation**
  - **Filtration**



Reducing IAQ Risks

Source reduction / elimination

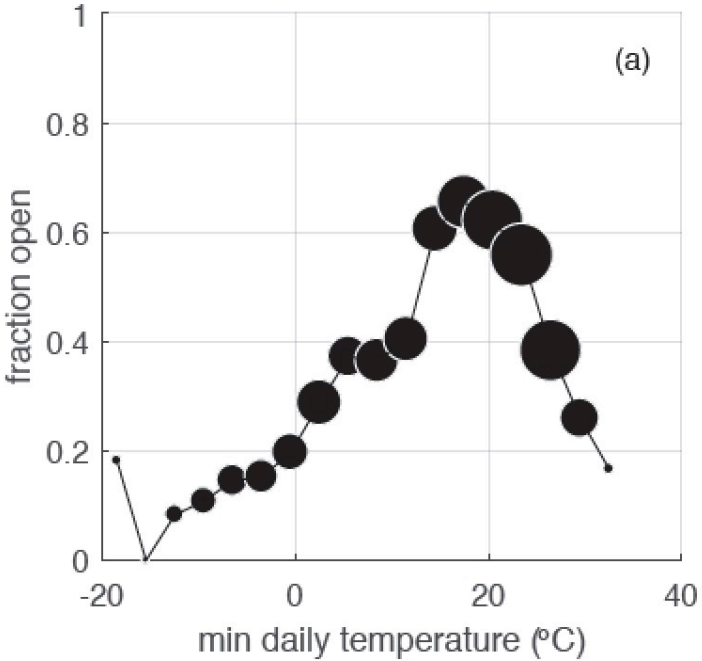
Source ventilation

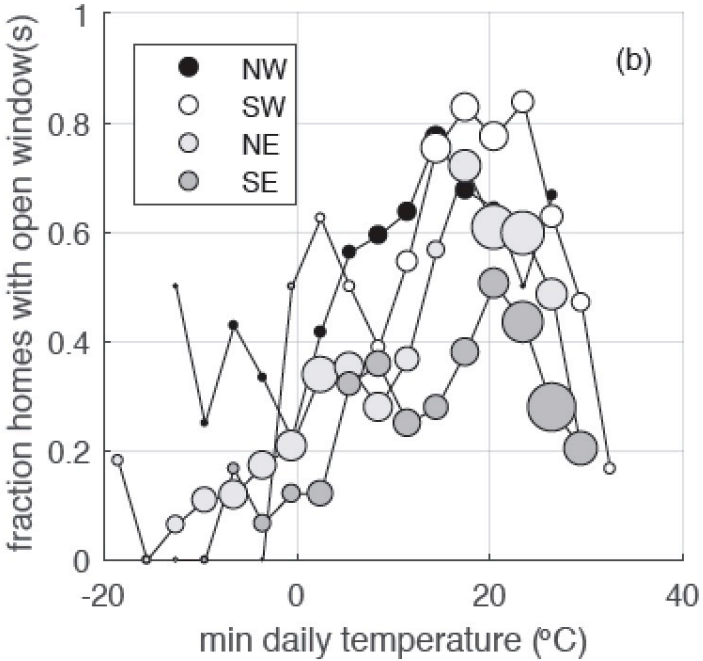
Dwelling unit ventilation

Filtration / air cleaning

Lots of people in US don't use windows

3600 responses to "Were any windows open at all yesterday?" (Amazon Mechanical Turk)





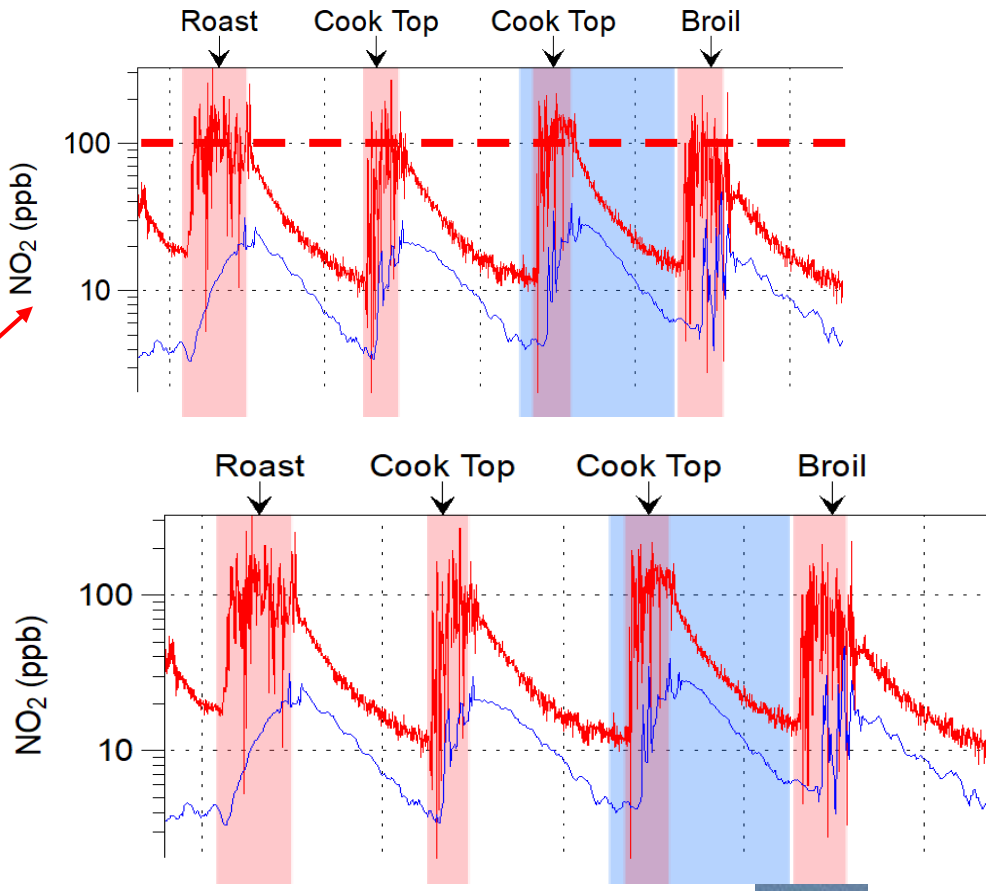
Morrison and Date, Indoor Air 2018 Conference

General ventilation does not fully protect against acute hazards

Example: Gas cooking in 1400 sf house

- Passive House airtightness
- ERV providing 0.5 ach

- NO_2 in kitchen exceeds safe level
- Cooking particles and VOCs from consumer products present similar challenges



Singer et al., 2017, Building Environment

Very limited *data* on general MV impacts on IAQ

Austria – built 2010-2012
- 62 low-energy with MV
- 61 conventional

California
- 108 pre-code; built 2002-5
- 70 code-required MV, built 2011-7

Canada[4] – retrofit existing
- 43 added HRV/ERV
- 40 controls
- Multiple winters

US: OR, CO, IL, Southeast
- ~70 with MV, 70 without
- 30–40 MV homes also with MV off
- Built 2013+, Msd 2018-2020

Installed MV airflows and working condition
- Florida[1]: **21** homes
- Washington[2]: **29** homes
- Netherlands[3]: **299** homes

[1]Sonne; [2]Eklund; [3]Balvers; [4]Lajoie

Project Ventilation 3.0 (Austria)

Does mechanical ventilation provide healthy comfortable interiors?

Do their mechanical ventilation systems convince consumers?

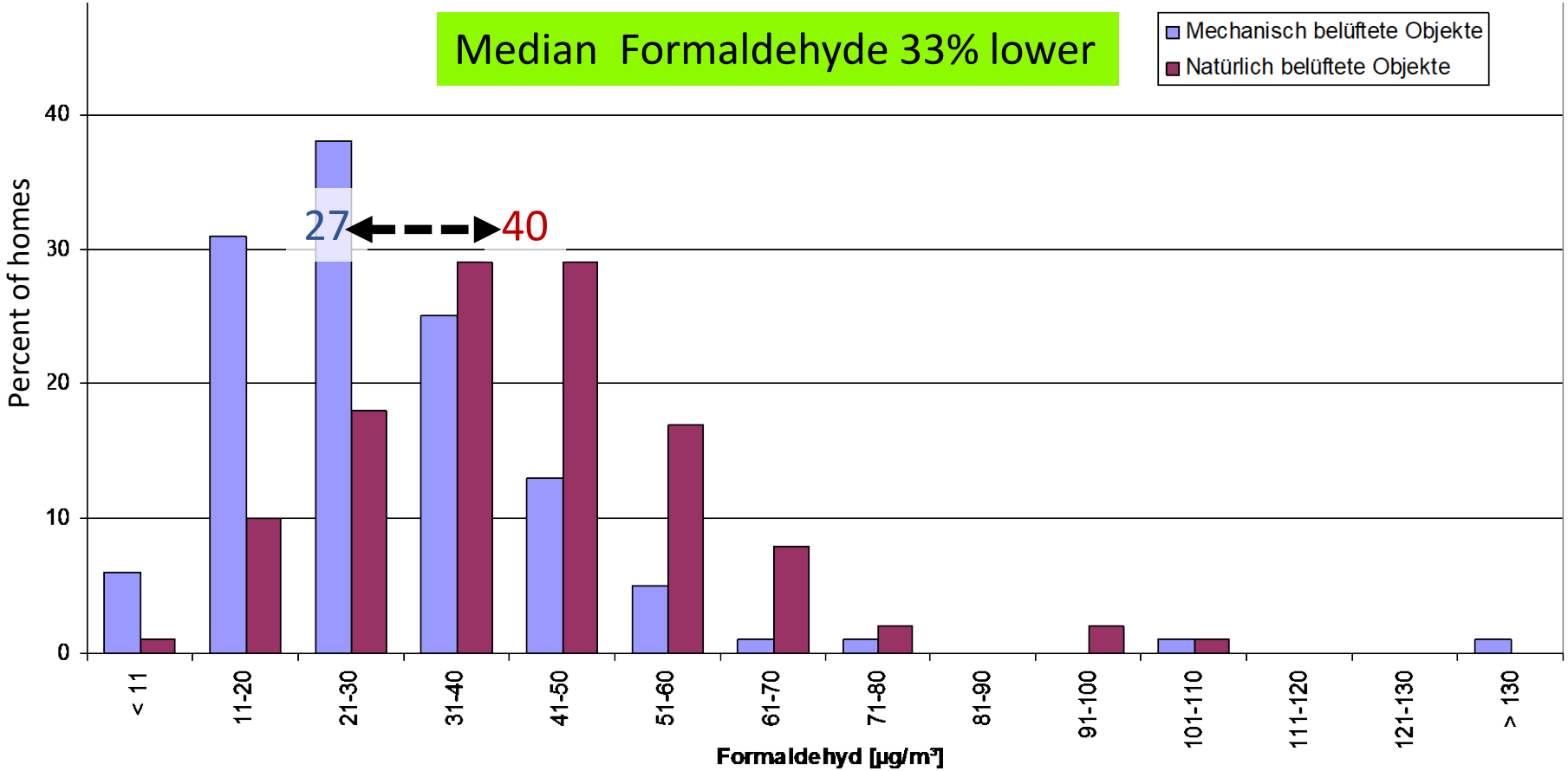
- 62 low-energy or passive std – MV with heat recovery
- 61 conventional – natural ventilation (windows)
- 70% detached, 30% apts. in each group:

Measure IAQ metrics and air change rate at 3 and 15 months:

Survey of perceptions, satisfaction and health status

Adapted from slide provided by Peter Tappler

Austria Results: Formaldehyde @ 3 months



Adapted from slide provided by Peter Tappler

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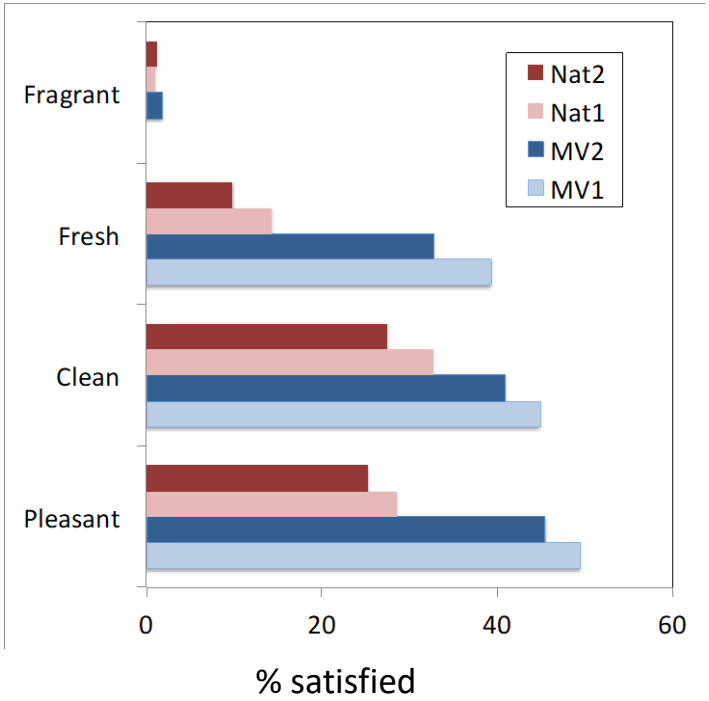
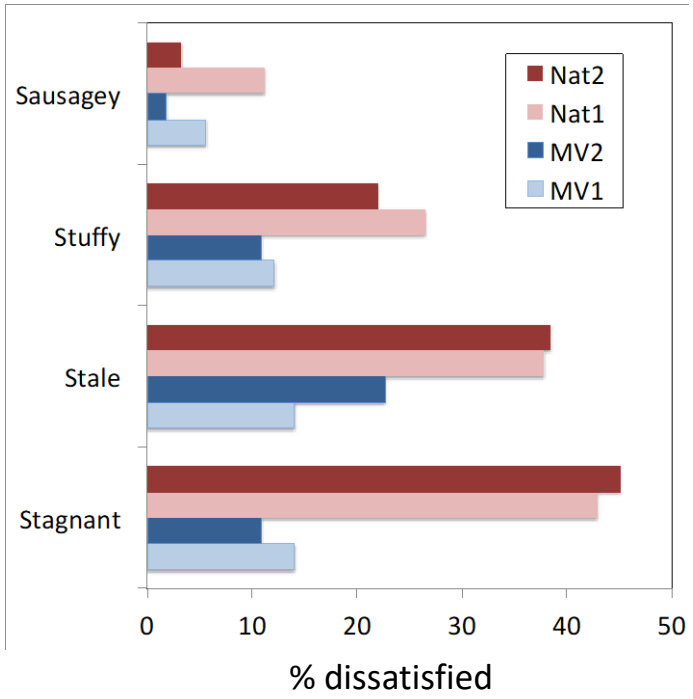
Austria: MV improved IAQ satisfaction

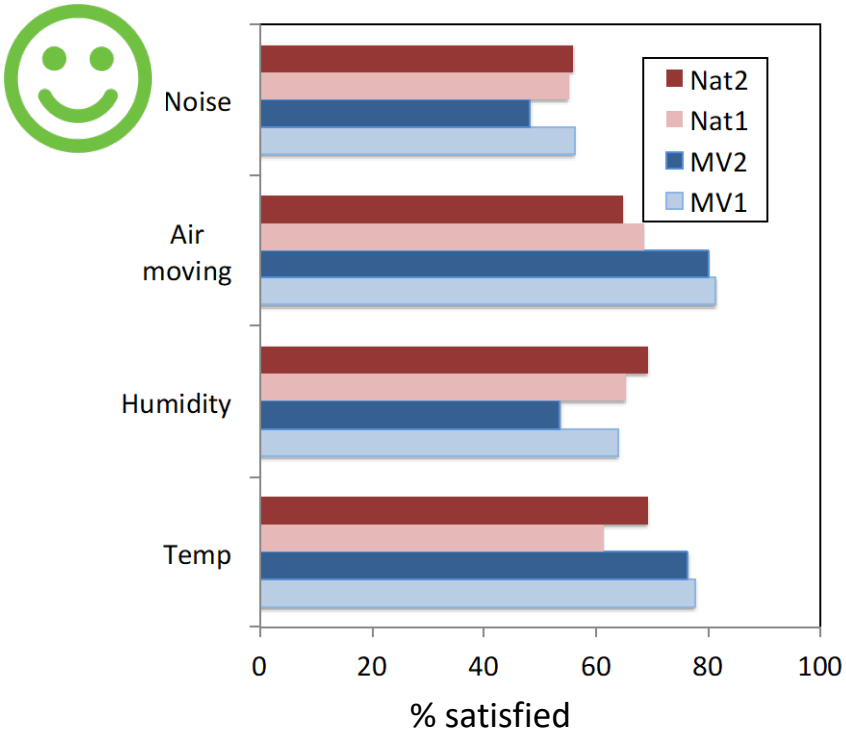


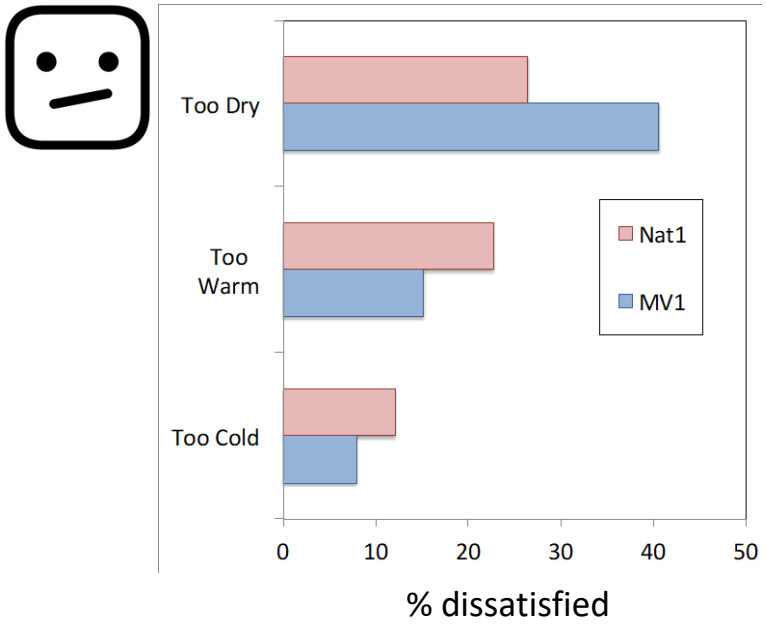


Wallner et al. Health and Wellbeing of Occupants in Highly Energy Efficient Buildings: A Field Study. *Int J Environ Res Public Health.* 2017;14.

Austria: comfort results

Low-energy homes with MV better on most measures, **except dryness**





Wallner et al. Health and Wellbeing of Occupants in Highly Energy Efficient Buildings: A Field Study. *Int J Environ Res Public Health.* 2017;14.

California: Healthy Efficient New Gas Homes Study (HENGH)

Rengie Chan

Yang-Seon Kim

Brett Singer

Iain Walker

BERKELEY LAB

STATE OF CALIFORNIA ENERGY COMMISSION

Building AMERICA U.S. Department of Energy

PG&E

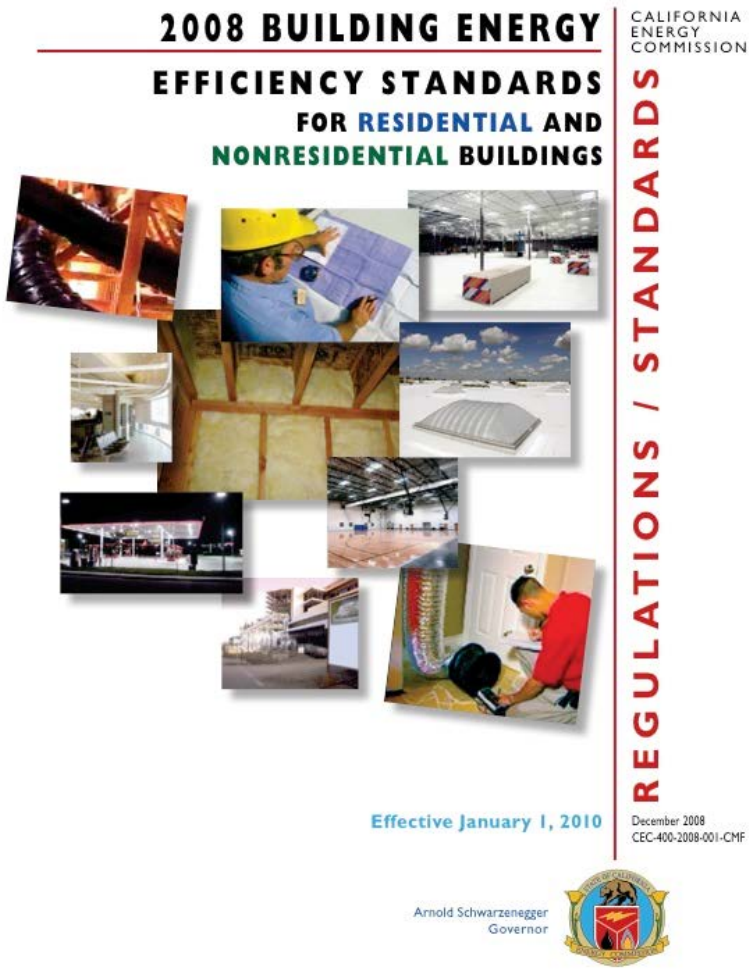
SoCalGas A Sempra Energy utility

gti

California Context

- Since 2008, California code has required MV similar to 62.2
  - Includes general, bath, & kitchen

- Starting in ~2010, manufactured wood products with low formaldehyde



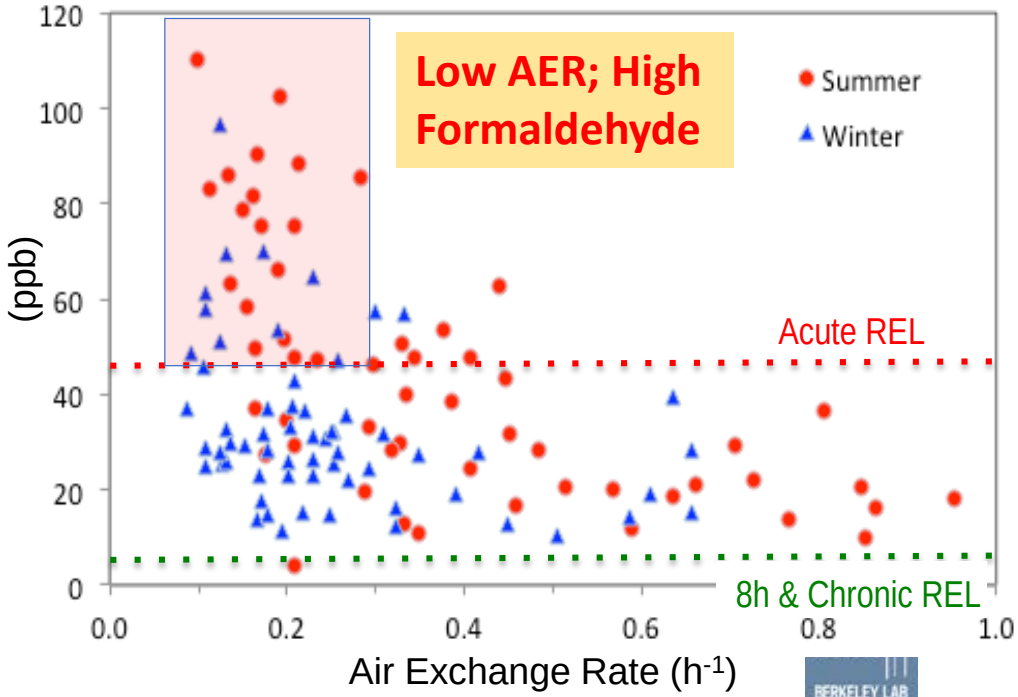
Past California Studies

New Home Survey: 2004-5

- 1500 responses by mail
- Homes built 2002-3
- Self-reported window use
  - 50% didn't use in winter
  - 20% didn't use in spring & fall
- Kitchen & bath fans not used routinely

Field study: 2006-7 (CNHS)

- 108 homes, built 2002-05, 98% electric

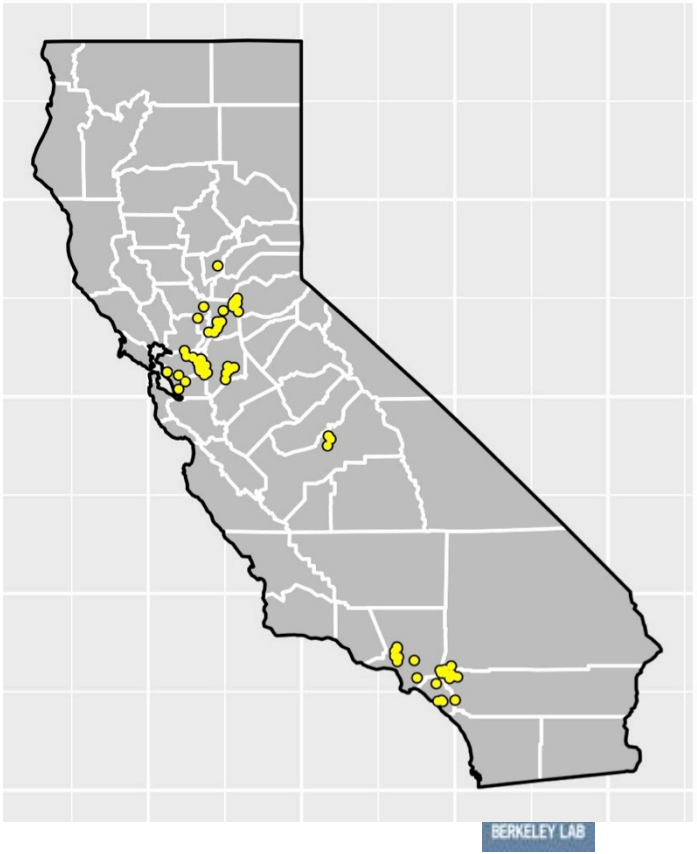


Price & Sherman, 2006, LBNL-59620;
Offermann, 2009, CEC-500-2009-085

HENGH Field Study

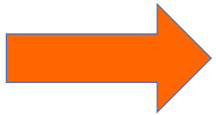
- 70 detached homes, built 2011-17
- Natural gas cooking burners

- Measurements in 2016-2018
- Characterized ventilation equipment
- Measured IAQ, tracked activities for 1 week
- Windows closed; general MV operating



General MV systems exceeded required airflow

Mean required: 63 cfm
Mean provided: 96 cfm



~50% above code

- Continuous exhaust (N=55)
- Intermittent exhaust (N=9)
- Continuous inline fan connected to central forced air system (N=4)
- Central fan integrated supply with motorized damper (N=2)

CA: $PM_{2.5}$ and formaldehyde lower with MV

Median Indoor Concentration	CNHS* – 98% Electric 2006–07	HENGH - Gas Homes 2016–18
Formaldehyde	29 ppb	18 ppb
$PM_{2.5}$	11 μg/m^3	5.0 μg/m^3
NO_2	1.6 ppb	4.5 ppb

*Offermann (2009).

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

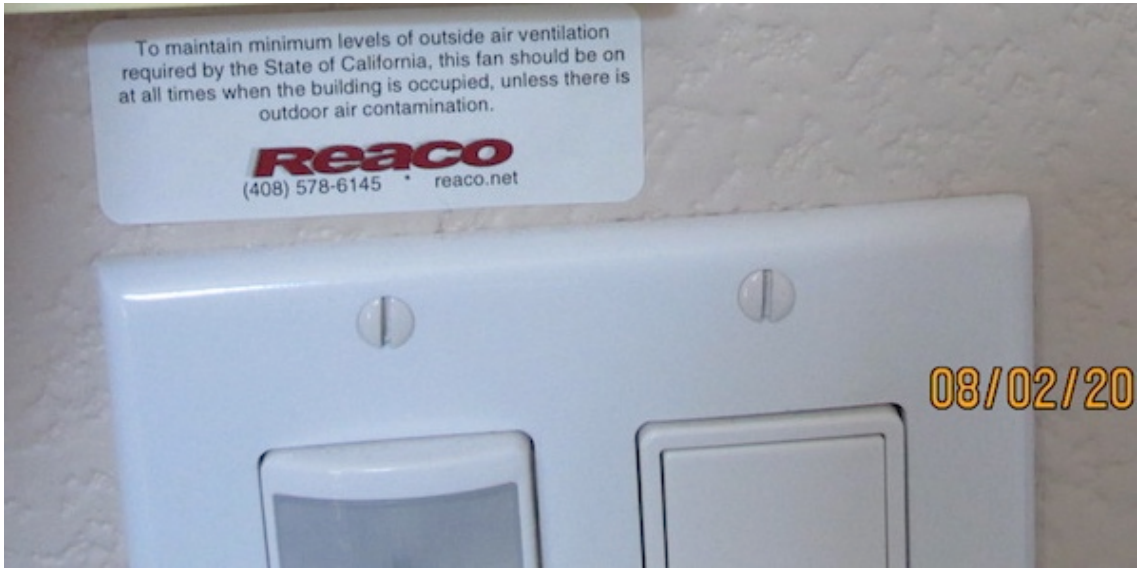
Labels make a difference

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%

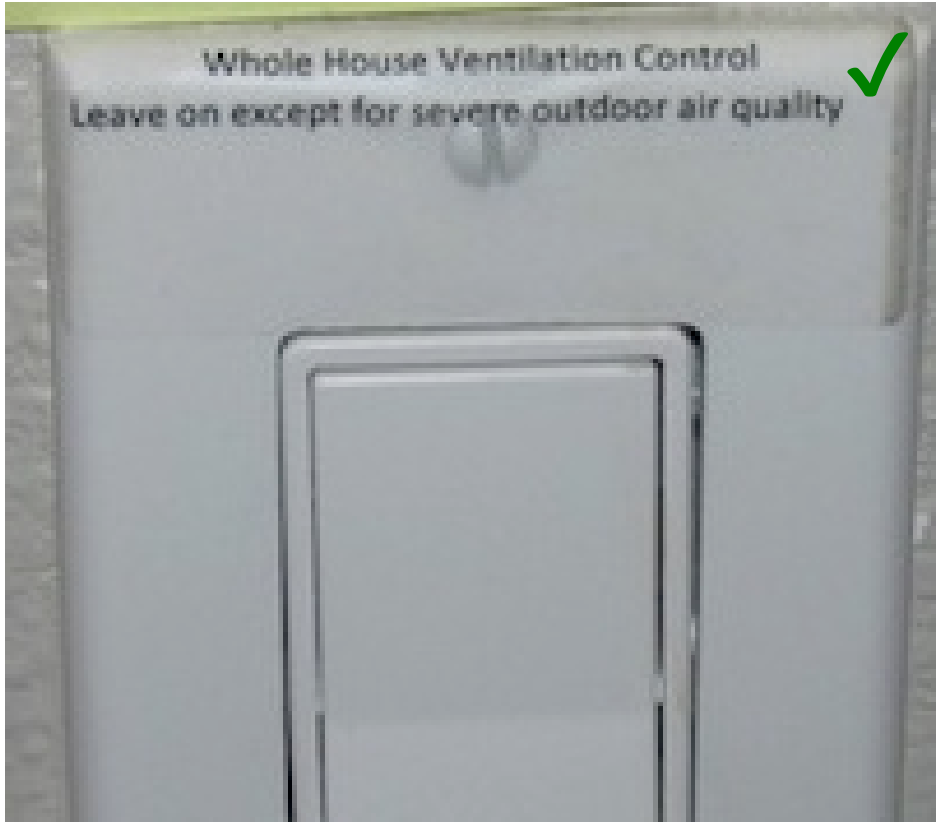
Labels not always clear

✗ CONTINUOUS DUTY

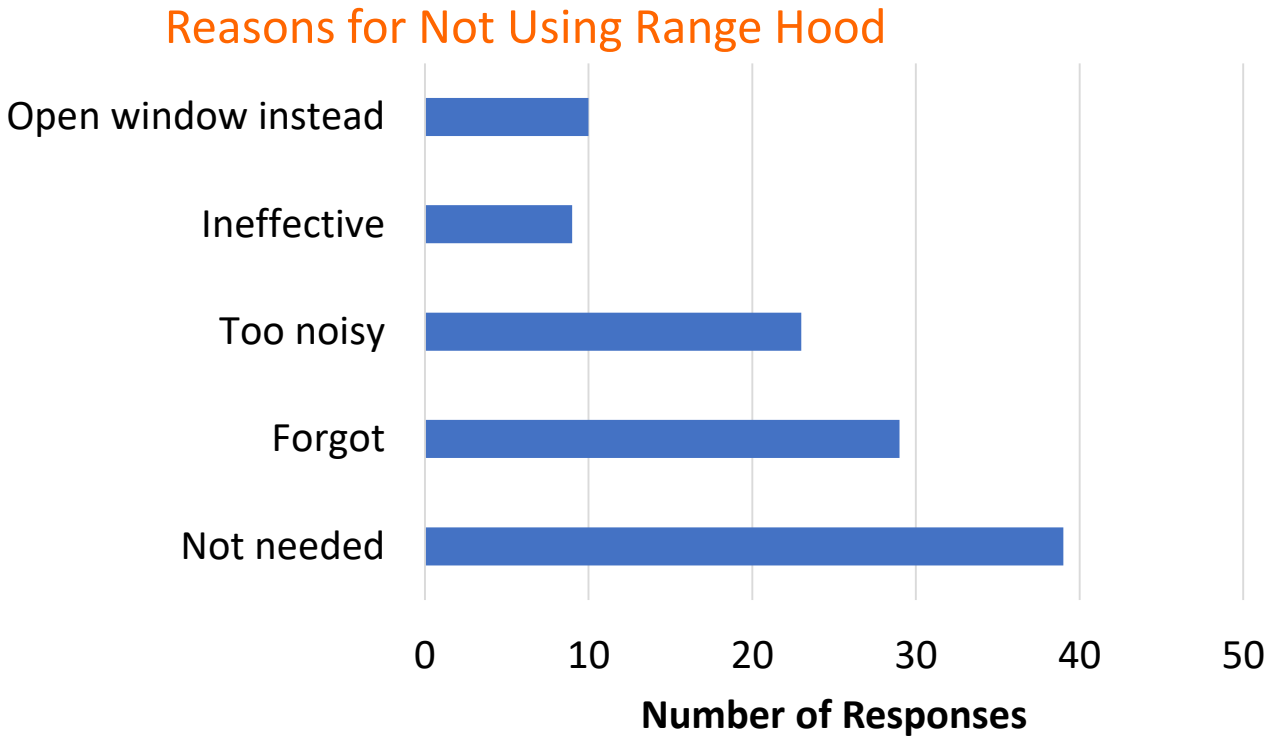
✓ To maintain minimum levels of outside air ventilation required by the State of California, this fan should be on at all times when the building is occupied, unless there is outdoor air contamination.




Keep fan
"ON" at
all times
except in
case of
outdoor air
contamination
or if home
is vacant
for more
than 7 days


Whole House Ventilation Control
Leave on except for severe outdoor air quality

Half of the HENGH households reported using range hood sometimes or less frequently



Building America New Home IAQ Study

Context

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

Specific Issues

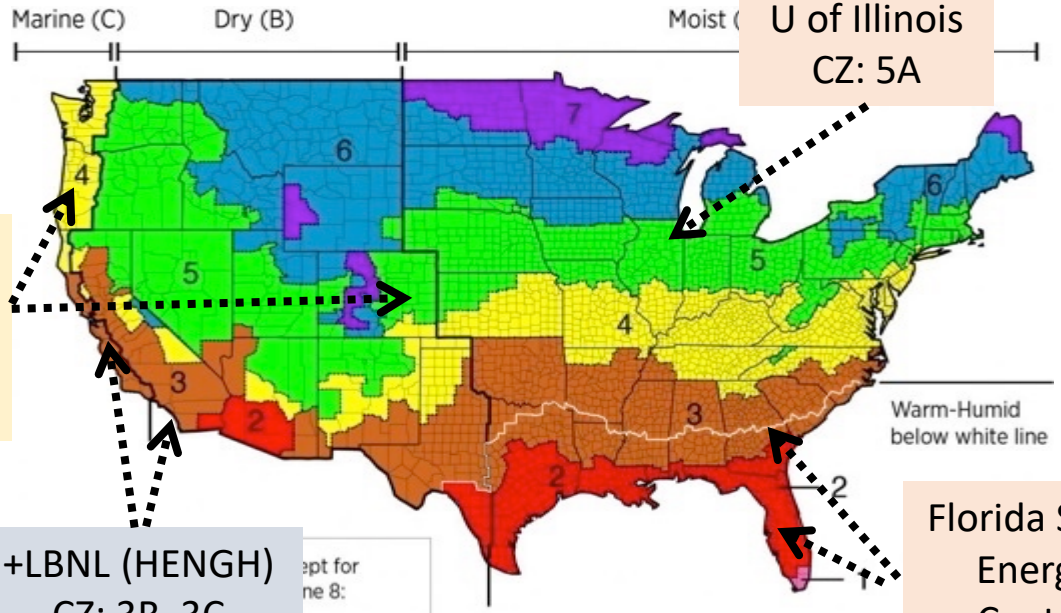
- Questions about necessity, value of MV
- Ventilation alone not sufficient to maintain IAQ
- Limited data on installed performance
- Existing data suggest deficiencies
  - Equipment not performing to spec
  - Specs for kitchen exhaust may not be adequate
  - Equipment not used

Key Questions

- What are air pollutant and IAQ satisfaction levels in new homes?
- What MV equipment is present in homes that meet 62.2 / IECC?
- How do MV system designs and performance vary by climate zone?
- What is the working condition of installed MV equipment?
- What are the airflows when operating and how often do they operate?
- How do occupants use kitchen ventilation when present?
- **Are there discernible differences in IAQ in homes with MV?**

Building America New Home IAQ Study

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



- Characterize home, mechanical equipment
- Monitor ventilation, IAQ, activities for 1 week
- Repeat with/out MV operating in 6-8 homes per CZ*

Cold & Marine : Pacific Northwest National Lab

Cheryn Metzger
Manager/Co-PI

Dr. Jian Zhang
Co-PI

Chrissi Antonopoulos

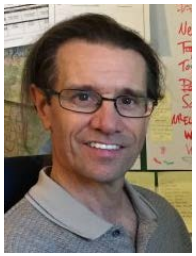
Michael Baechler

PNNL has conducted and managed many field research studies on residential energy and IAQ

Cadmus, WSU, Ecotope are field data collection experts

Technical Advisory Committee

Cadmus, Washington State U. and Ecotope



Mitt Jones/Paul Norton
Field Technicians

Mike Lubliner
QA/QC

Dave Baylon
Senior advisor

Southeast US: Florida Solar Energy Center

Eric Martin

Tanvir Khan, PhD

Chuck Withers

Dave Chasar

Jeff Sonne

- Extensive field experience
- Conducted prior studies of MV:
  - Investigating failure rates
  - Quantifying energy impacts
  - Reducing moisture impacts
- Train practitioners

Data Collected for Each Home

Survey

- Homeowner IAQ and comfort perceptions
- Ventilation practices and activities that impact IAQ
- Household characteristics

Measure

- House and mechanical equipment
- Envelope and duct leakage
- Airflows of ventilation equipment

Monitor

- Ventilation use & activities that affect IAQ
- Air pollutant concentrations & met data

Survey

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

	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)	○	○	○	○
Air quality inside home (2)	○	○	○	○
Air quality outside within neighborhood (3)	○	○	○	○
Ability to control temperature inside home (4)	○	○	○	○
Ability to control humidity inside home (5)	○	○	○	○
Natural lighting (daylight) inside home (6)	○	○	○	○
Noise from heating & cooling system (7)	○	○	○	○
Privacy (8)	○	○	○	○
Security (9)	○	○	○	○

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.

Air handler flow: Flow plate.

Slide credit: FSEC

Air Quality Measurements

Photometric
Outdoor $PM_{2.5}$

Photometric
Indoor $PM_{2.5}$

Gravimetric
Indoor $PM_{2.5}$

CO_2, $PM_{2.5}$
In multiple rooms

Subset of Homes

Real-time NO_2

30-min resolved
Formaldehyde

1-week avg.
Formaldehyde

1-week
NO_2, NO_X

1 week of
hourly Radon

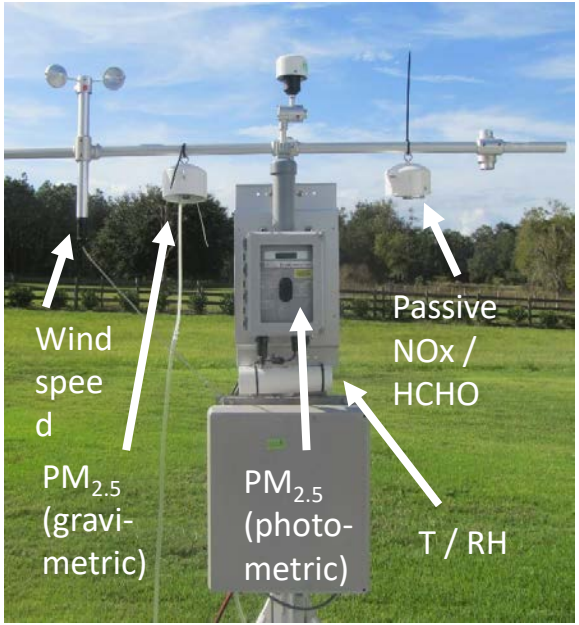
6-month
integrated
Radon

Ultrafine
particles

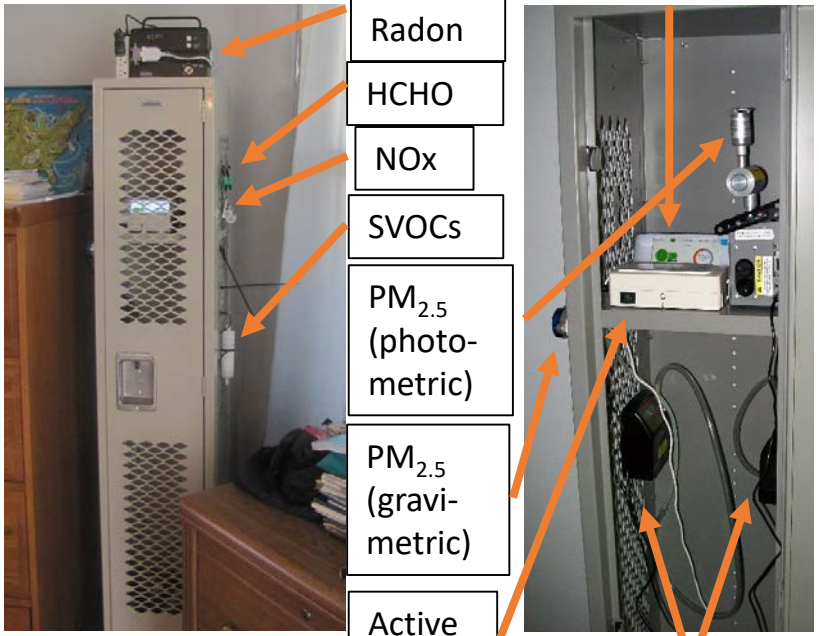
Slide credit: FSEC

Air Quality Measurements (FSEC)

Outdoor Location:



Primary Central Indoor Location:



Master Bedroom: T/RH, $PM_{2.5}$, HCHO, CO_2

Master Bathroom and 2nd Bathroom: T/RH

Secondary Central Indoor Location: T/RH, $PM_{2.5}$, CO_2

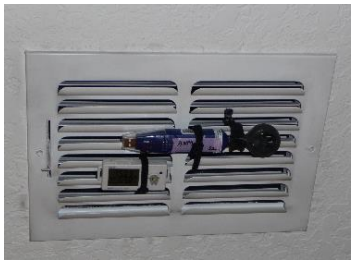
Slide credit: FSEC

Equipment Monitoring

Clothes Dryer Use

Bath Fan Use

Range Hood Use



Heating/Cooling Runtime

Door Use: Garage, Master Bedroom, Patio

Cooking

WH Ventilation Runtime

Condensate Production

Slide credit: FSEC

Activity Log

Instructions: Please fill out this activity log each day. If you are unsure, please provide your best guess. *Do not list the names of any people.*

	Night						Morning					
	Mid-night	1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	
# People in home												
Please add checkmark or X to any hour in which the activity occurred. If several ho												
	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.												

BA IAQ Study: Early Data (OR, CO, FL)

Results from 55 homes

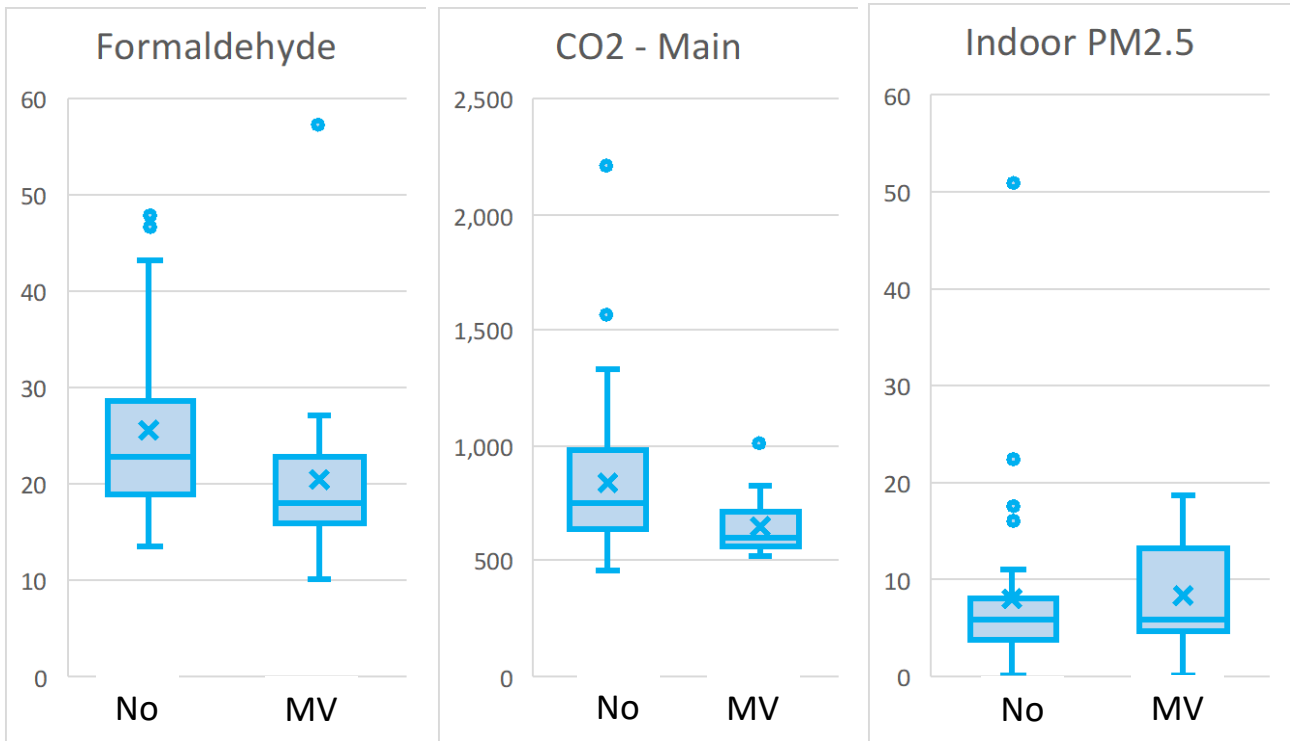
- 26 without MV
- 4 partial MV
- 25 with MV

Means	No MV	Yes MV
# homes	26	25
Formaldehyde	27	20
Average CO_2	850	638
Indoor $PM_{2.5}$	8.2	8.6
Outdoor $PM_{2.5}$	9.0	8.0

BA IAQ Study: Early Data (OR, CO, FL)

Results from 55 homes

- 26 without MV
- 4 partial MV
- 25 with MV



MV Characterization – Early Findings from FSEC

- In first 16 homes constructed with MV systems, only 4 operating upon arrival.
- 12 of 16 systems turned off by homeowners or contractors or could not be made to work due to non-functioning components.
- In most homes, range hood had at least one setting that delivered 100 cfm.
- In more than half of the homes, at least one bath fan did not deliver 50 cfm.

Mechanical Ventilation Design

- ASHRAE 62.2 is minimum, not best practice
- Need good design AND commissioning
- Good design considers use and maintenance
  - Clear documentation
  - Labeled and intuitive controls
  - Convenient access to change filters
- Relying on central AHU for ventilation uses much more energy
- Best to oversize with variable speed –> smart control

Whole-House Ventilation Design

Exhaust

- Lowest first cost
- Easiest to commission
- Ventilation not distributed; can have short-circuiting
- Needs good ceiling and garage wall sealing
- Caution advised in hot, humid climates
- Can impact combustion appliance venting
- Passive vents needed in very tight homes
- Best for mild climates

Supply

- Low first cost
- Can be challenging to commission
- Can be distributed
- Need supply fan or very efficient FAU fan
- Inlet filter must be easily accessible for maintenance
- Tempering essential in cold climates
- If area has high outdoor PM pollution, use good filter*

Balanced

- Most expensive to install and maintain
- Hardest to commission
- Good for distribution: exhaust from wet rooms, supply to living spaces
- Allows for heat and humidity recovery in cold winters
- Can help reduce vapor loads in hot/humid climates
- Best option for Passive and other very air tights homes
- If area has high outdoor PM pollution, use good filter*

*At least MERV11; MERV13 recommended

Smart Ventilation

- Lower cost and lower-maintenance alternative to HRV or ERV
- Install larger fans with efficient, variable speed motors
- Reduce outdoor air when too hot, humid, polluted, or cold & dry
- Increase airflow at other times

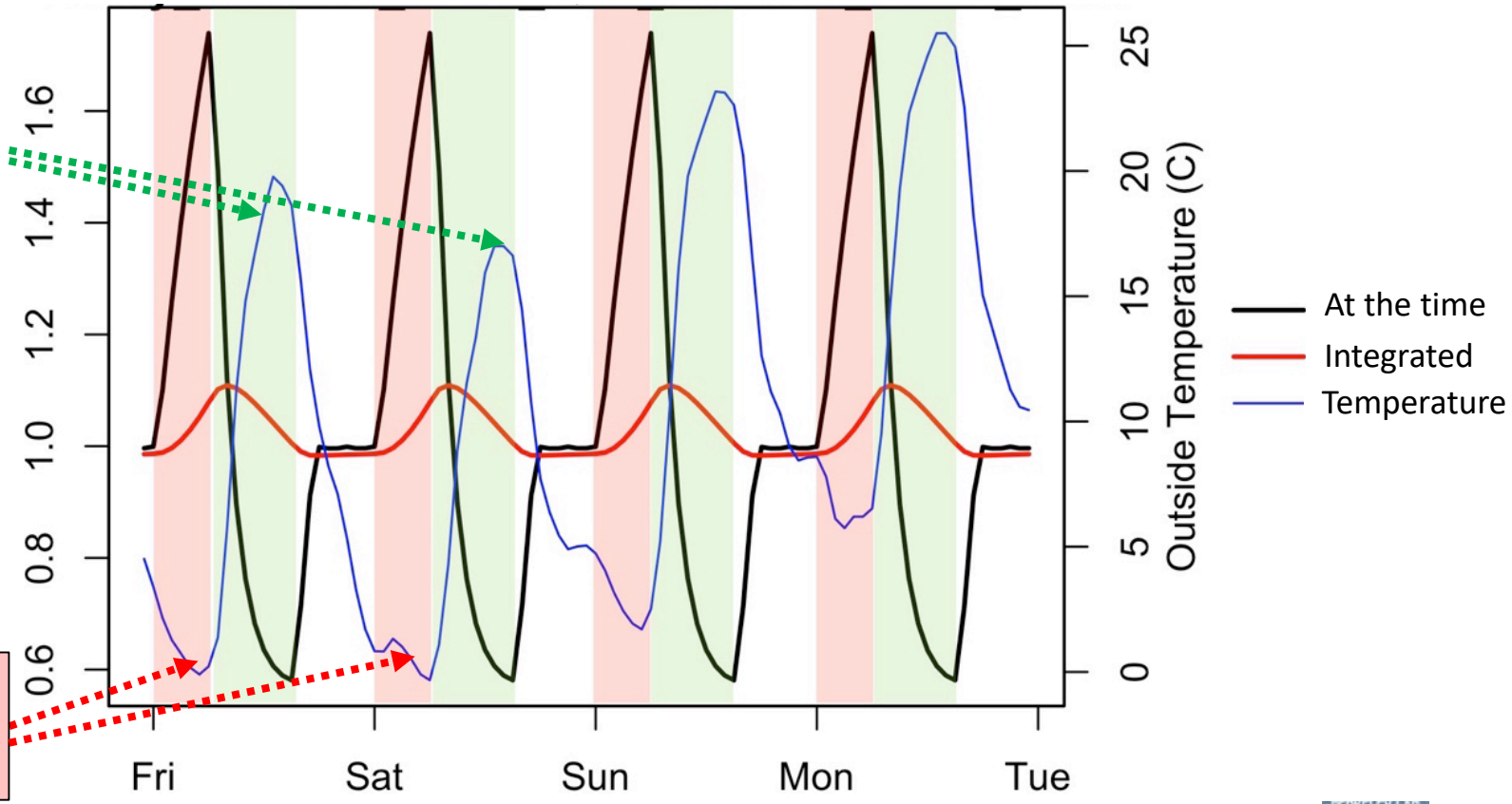
- Can incorporate distribution and mixing

Temperature-Based Control Strategy

Ventilation doubled during warmer hours

Pollutant levels relative to continuous ventilation

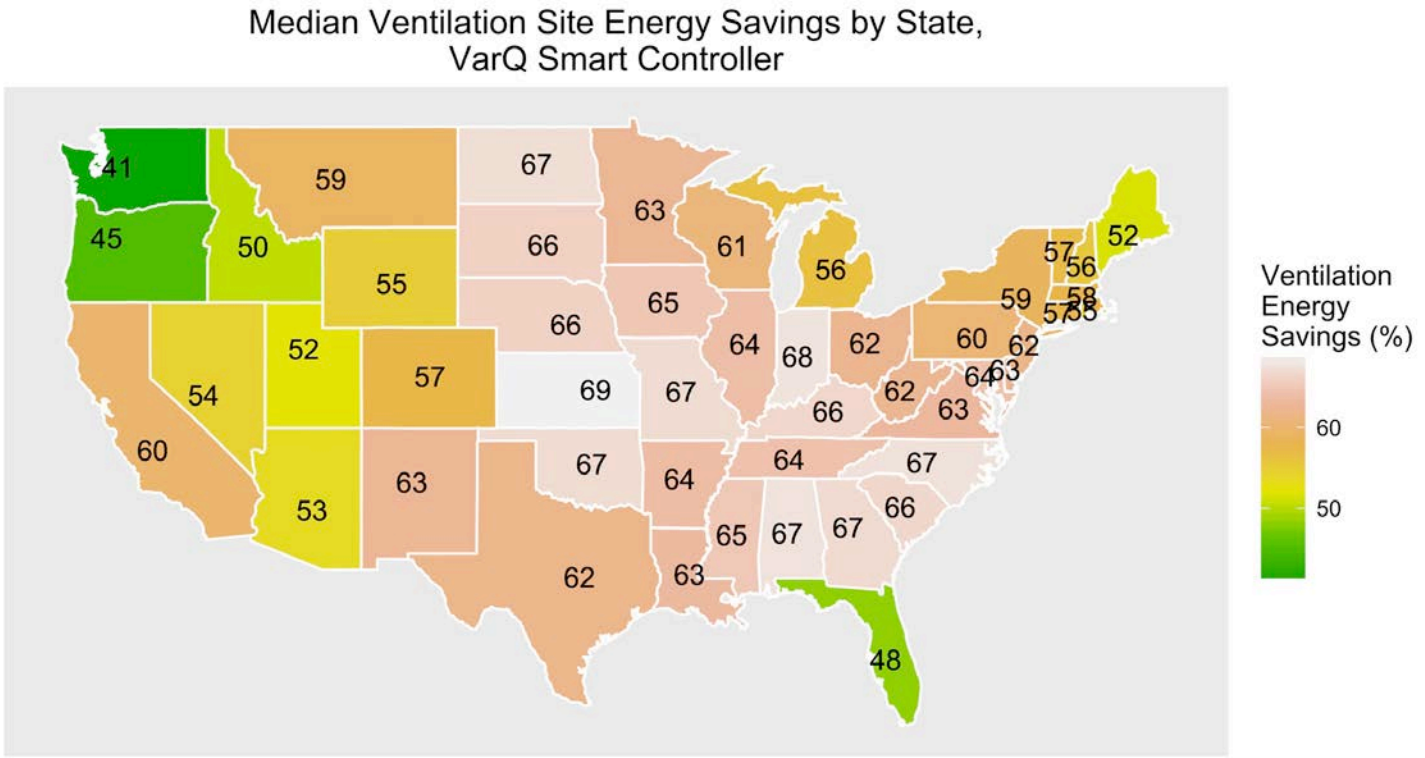
Ventilation off during coldest hours of day



Smart Ventilation – Temperature Control

Seasonal shift saves up to 80% of ventilation load

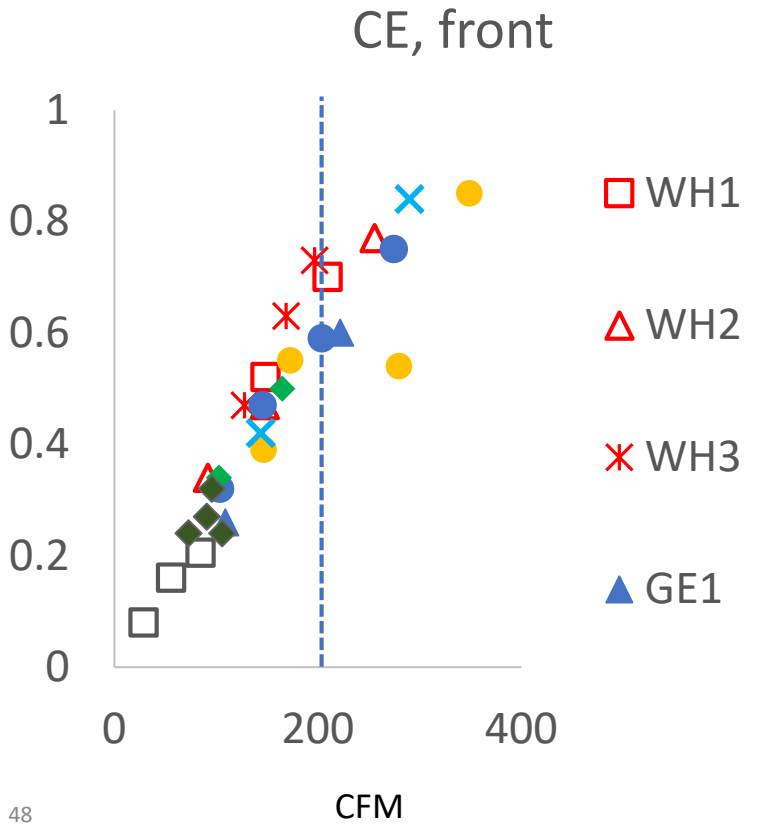
Optimum strategy depends on climate and envelope leakage

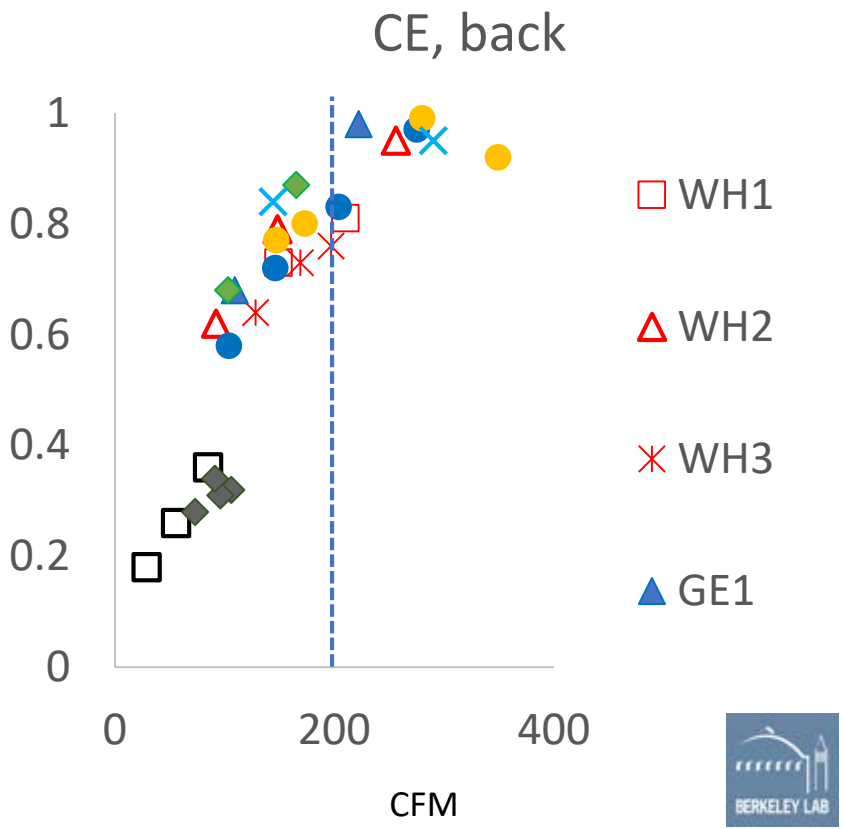


Field Demonstrations of Smart Ventilation

- Compare Smart Controls to continuous (simple)
- Expect to include both supply and exhaust – vary by climate
- Likely based on temperature with seasonal shift
- Goal: 16 homes in 4 climate zones

OTR Microwaves have similar pollutant capture as range hoods, for same airflow





Selected References

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