Welcome

IAQ Challenges and Solutions in Net Zero Homes

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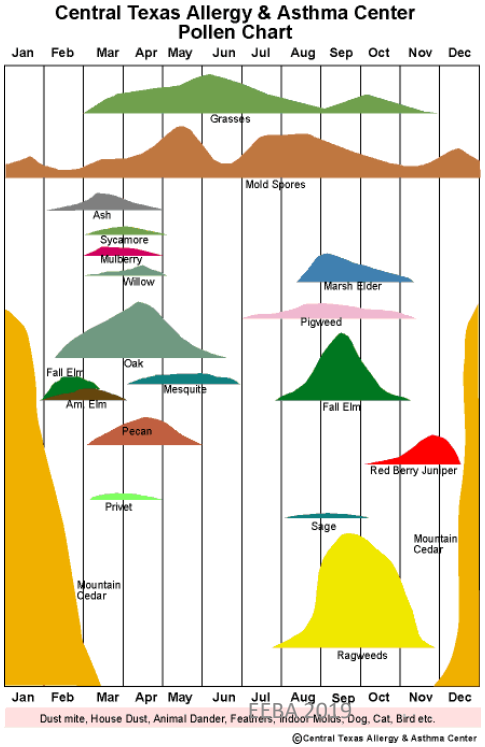
Outline

- Pollutant hazards and sources
- Reducing IAQ risks
- Measured ventilation and IAQ in new homes
- IAQ monitoring
- What to do for IAQ in a ZEH?

Top IAQ Issues

Odors

Pollutants



Moisture

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Which indoor contaminants are most important for Health?

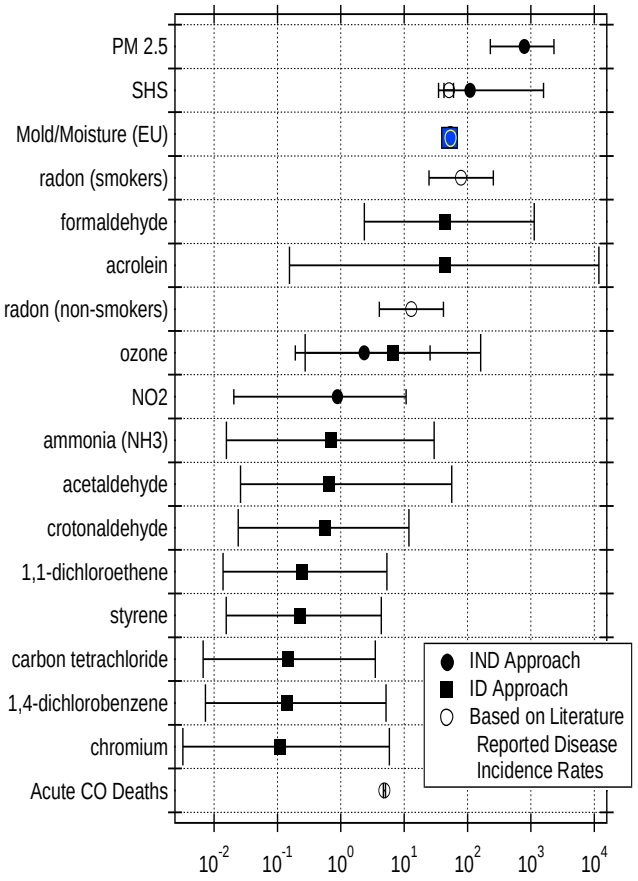
Prioritize based on population harm

Disability Adjusted Life Years =

Years lost to premature death

+ Years lost to disability

$PM_{2.5}$
Secondhand smoke
Mold / moisture
Radon
Formaldehyde
Acrolein, Ozone, NO_2



Logue et al. (2012)

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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

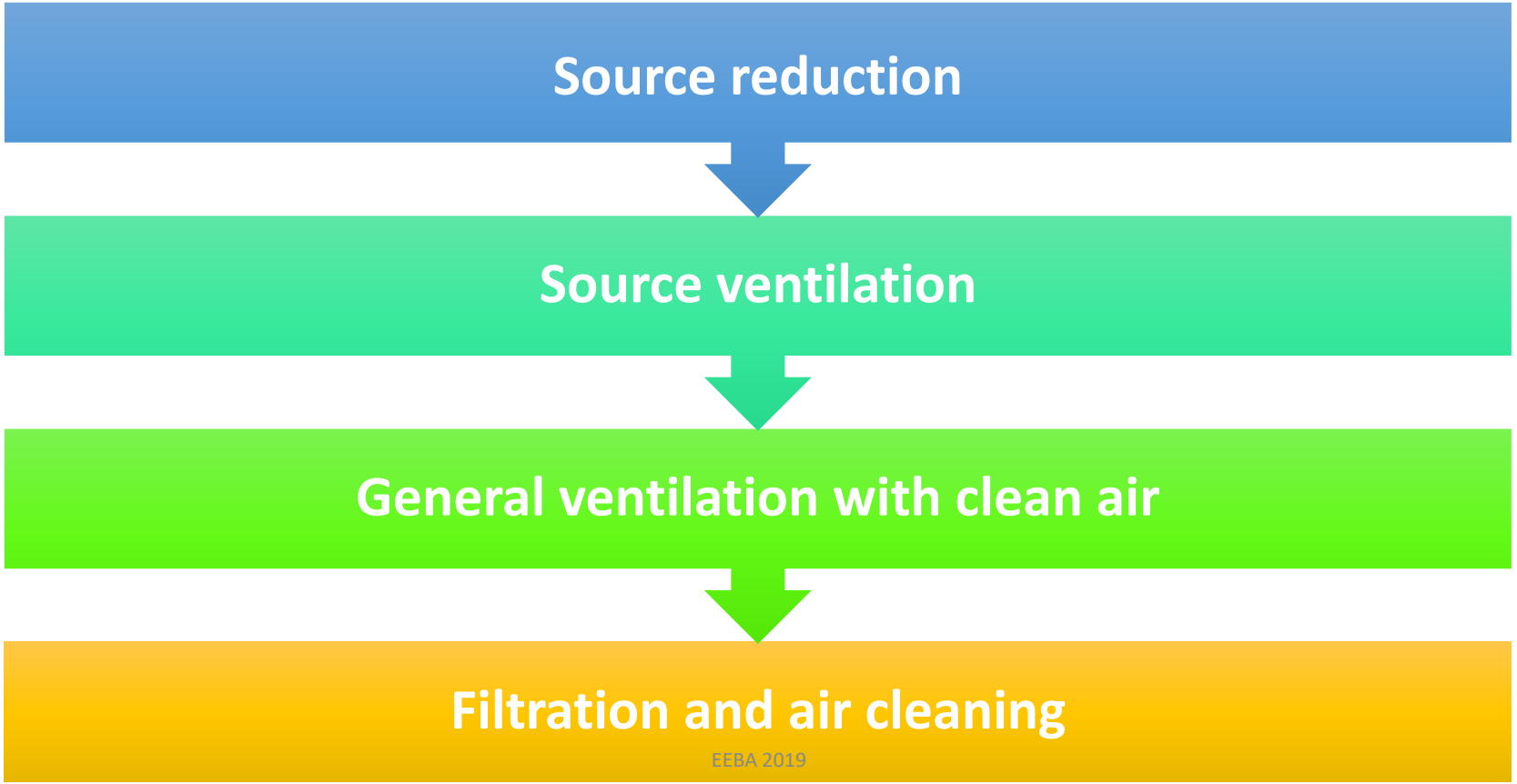
Mold

Odors

Volatile Organic Compounds (VOC)

- Thousands of distinct chemicals
- Vast majority are harmless at concentrations in homes
- Those shown to be harmful mostly removed from products….
- But … often takes a while before we find out a chemical is harmful

Reducing IAQ Risks



Use low emitting materials and finishes

- Formaldehyde & VOCs
  - Building materials
  - Furniture
  - Consumer products

Regulations limit emissions in Comp Wood

California rule effective January 1, 2009

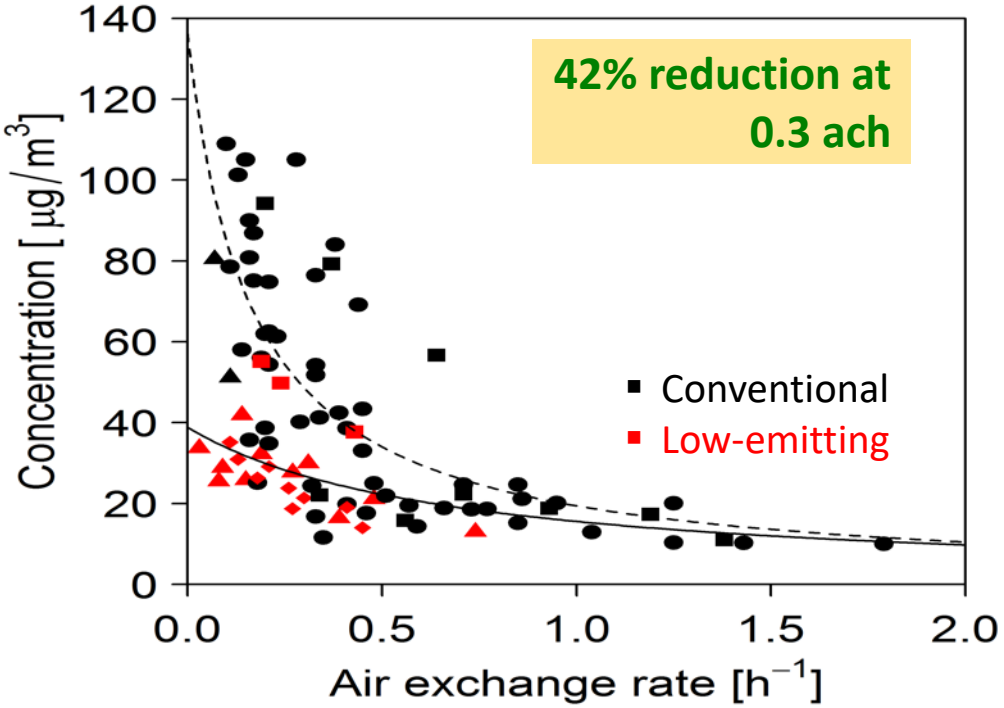
US Formaldehyde Control Act in 2010

Products labeled starting June 1, 2018

- Use certified green building materials
- Prioritize materials with:
  - Most surface area
  - Direct paths of exposure (e.g., flooring over attic insulation)
  - Documented histories of contributing to IAQ issues
- Consider avoiding products with flame retardants

https://greensciencepolicy.org/topics/six-classes/

Homes built with low-emitting materials have lower formaldehyde concentrations



Data adjusted for temperature, RH, house age

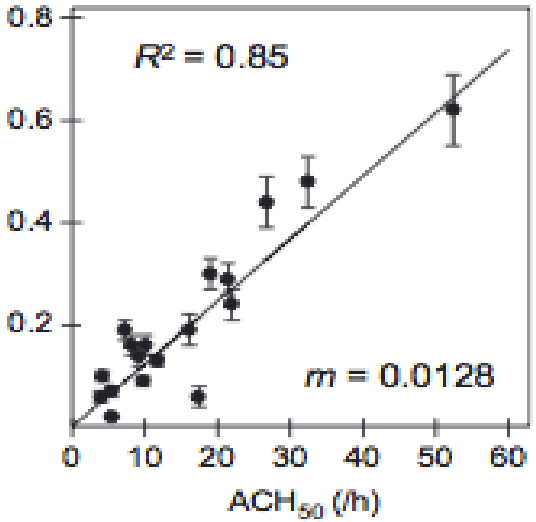
Hult et al., Indoor Air, 2015 – Compares Indoor Air Plus to Conventional New Homes in US

Particles - reduce entry from outdoors

Much of the $PM_{2.5}$ in our homes comes from outdoors

This fraction varies, and increases as indoor sources are mitigated.

A tighter envelope is better filter



Stephens, B., & Siegel, J. A. (2012).

5 ACH50; Sealed ducts; 62.2 Exhaust

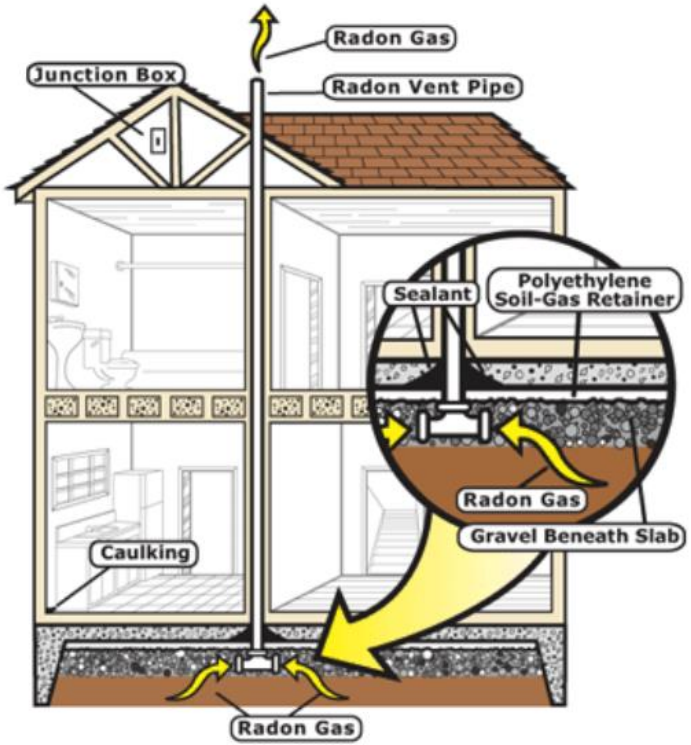
$PM_{2.5}$ inside 66-73% lower than outside

Same as MERV13 supply system

Singer et al. (2016)

Radon Resistant Construction / Mitigation

- For new homes in Zone 1
- 4” gravel + 6 mil polyethylene
- Caulk and seal all joints
- PVC pipe from subsurface to roof, through house – passive vent
- Install power to enable adding fan
- Test post-construction; add fan if needed



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Dealing with Combustion in ZNE homes

Option 1:
No combustion – go electric

Option 2:
Vent everything robustly:

- Furnaces, boilers and water heaters outside conditioned space or sealed combustion
- Fires/woodstoves use outside air for combustion
- Gas cooking only if range hood exhausts to outside
- Always test for low CO

Cooking makes pollutants

CO_2 & H_2O

NO,NO_2, HONO, Formaldehyde

Ultrafine particles

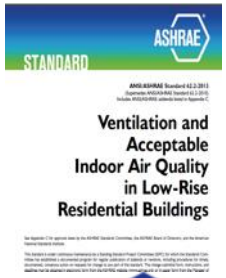
Ultrafine particles, $PM_{2.5}$

Formaldehyde, Acetaldehyde

Acrolein, PAH

Ultrafine particles

Standards and Codes for Kitchen Ventilation



HVI
HOME VENTILATING INSTITUTE

- Range hood: ≥100 cfm, ≤3 sone
- Other fan: ≥300, ≤3 sone
- Airflow must be verified as installed or hood must be HVI certified with prescribed ducting

Guidelines:
- Minimum 40 cfm / ft = 100 cfm for 30” range
- Recommend 100 cfm / ft = 250 cfm for 30”

ENERGY STAR

ENERGY STAR Certified Homes, Version 3

- Similar to ASHRAE 62.2
- “Microwave compliance pathway” allows unrated hood with 6” smooth, straight duct

International Residential Code

- Installed kitchen ventilation should be ≥100 cfm on demand or **≥25 cfm continuous**, or… recirculating hood!
- Make-up air required for >400 cfm exhaust

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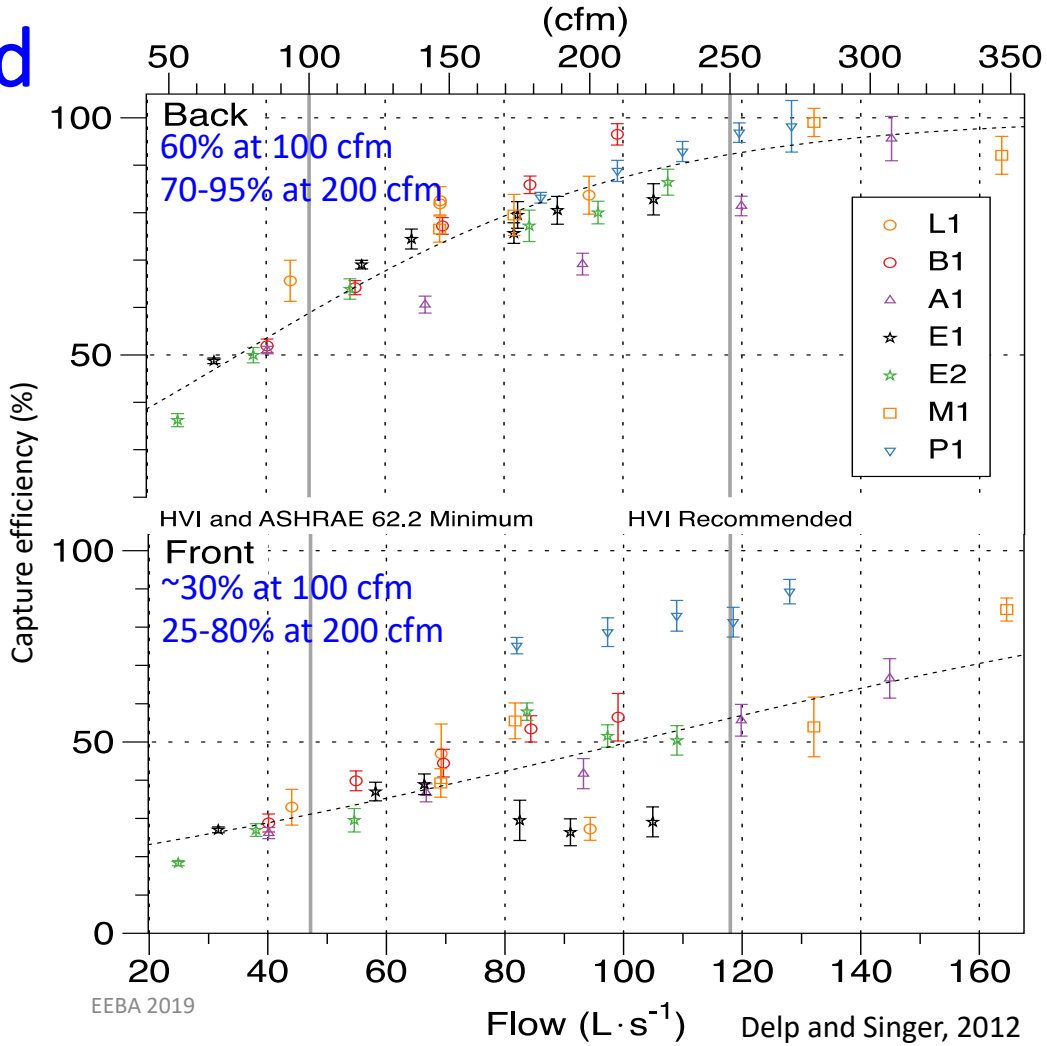
Lab study of range hood performance

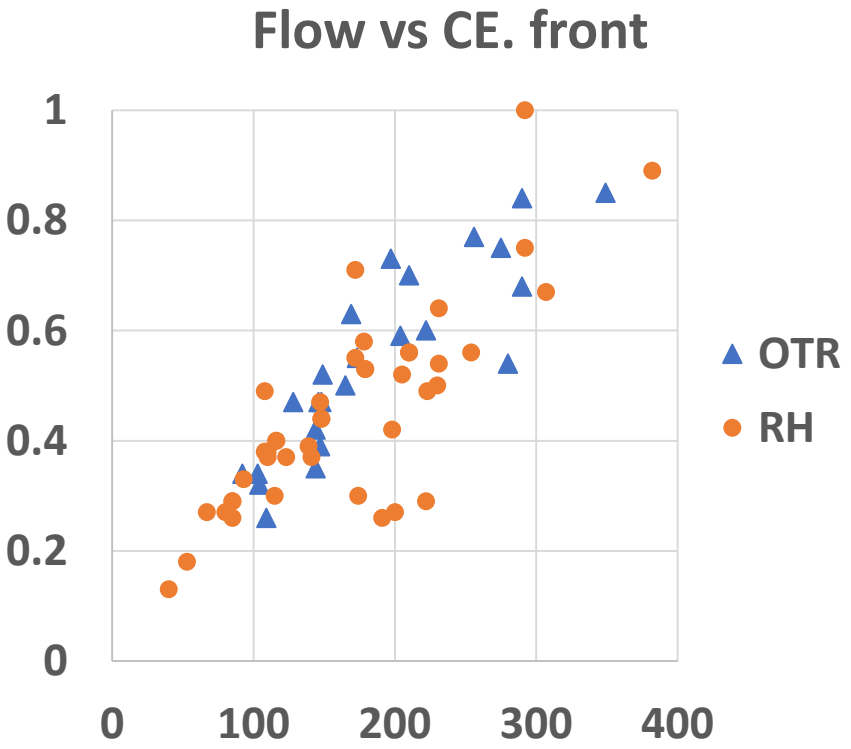
Capture increases with airflow.
Much better for back burners!

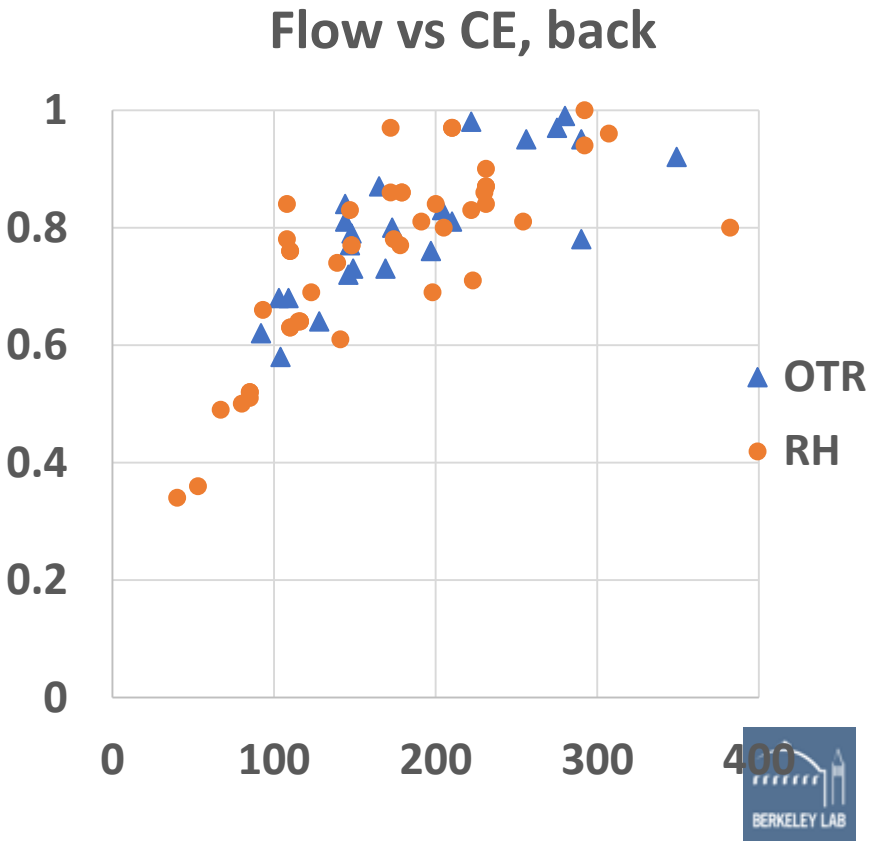
For front burners, range hood at 100 cfm captures ~30%



Delp and Singer, 2012

CE as function of airflow, including previous tests (lab/field) with range hoods (2 burners)





Good coverage

So-so coverage

Bad coverage

Range Hood Guidance

Builder / Contractor

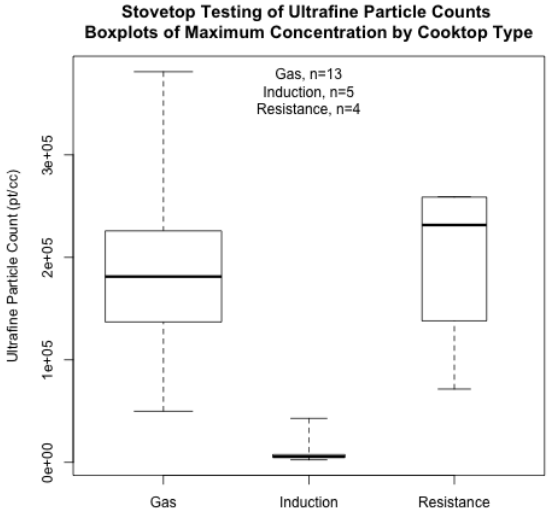
- Low-resistance ducting
- Hood that covers all burners
- Quiet at 200 cfm
- Install make up air
  - If > 400 cfm
  - If <2 ACH50*

User

- Operate the hood
- Cook on back burner
- Higher setting when cooking more

Induction Cooking

More efficient and lower emissions



* - for a 2500 sq.ft. home with a 10 Pa depress limit (door slamming)

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What's New for Range Hoods

Automation

- Turn on and off automatically
- Detecting cooking events

Capture Efficiency Ratings

- Using standard test method
- HVI listing next to air flow, watts and sound

CERTIFIED HOME VENTILATING PRODUCTS DIRECTORY

HVI
HOME VENTILATING INSTITUTE

This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: E3087 – 17

Standard Test Method for
Measuring Capture Efficiency of Domestic Range Hoods[1]

This standard is issued under the fixed designation E3087; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ertified Ratings in Air Delivery, Sound and Energy for Accurate Specifications and Comparisons

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Bathroom/Laundry Exhaust Removes Moisture, Odors, Cleaning Product Emissions

- Continuous (20 cfm) or intermittent (50 cfm)
- Manually operated our automated
  - Humidistat control
  - Timers
- Energy Star lists energy efficient quiet fans

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Humidity Control

Humidity 101:

Indoor Humidity = Outdoor Humidity (ventilation)
+ Interior Generation (people)
– dehumidification (equipment)

- Without dehumidification its always more humid indoors and ventilation always helps (even in Miami!)

Humidity Control

- Tight homes have higher indoor humidity
- Efficient homes have low sensible loads and little dehumidification from AC
- ZEH needs separate humidity control in humid climates
- Integrate with Smart Ventilation to use indoor-outdoor humidity differences

High indoor RH in winter

FSEC Study: Variable Speed Heat Pumps + Smart Ventilation

Martin et al. 2017

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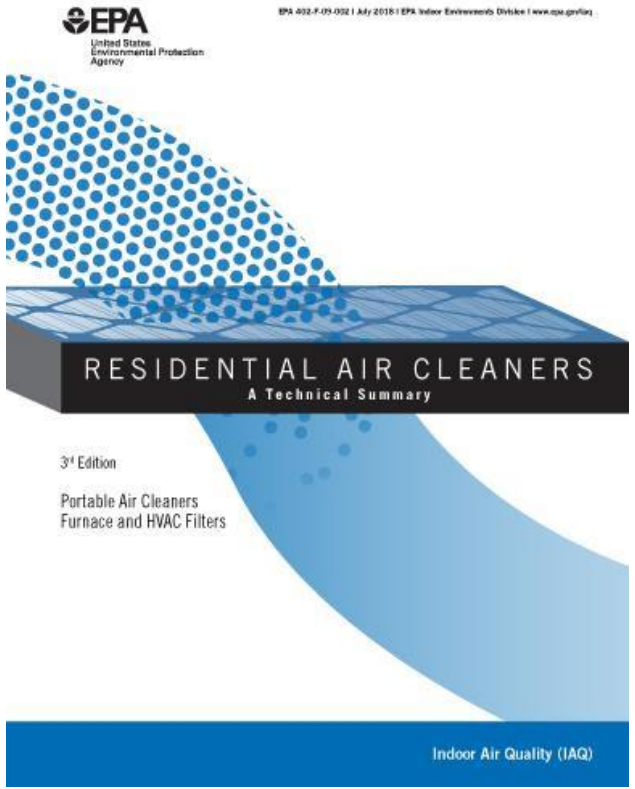
Filtration and Air Cleaning

Potential to drive PM to very low levels

- Diminishing returns after MERV13
- Standalone air cleaners can be much more energy efficient, but may need several for multiple rooms.
- Key issues:
  - **People turn them off**
  - Confusing controls
  - Noise
  - Energy
- What if no central forced air?
  - Filter incoming ventilation air
  - Use stand-alone devices



https://www.epa.gov/indoor-air-quality-iaq/air-cleaners-and-air-filters-home

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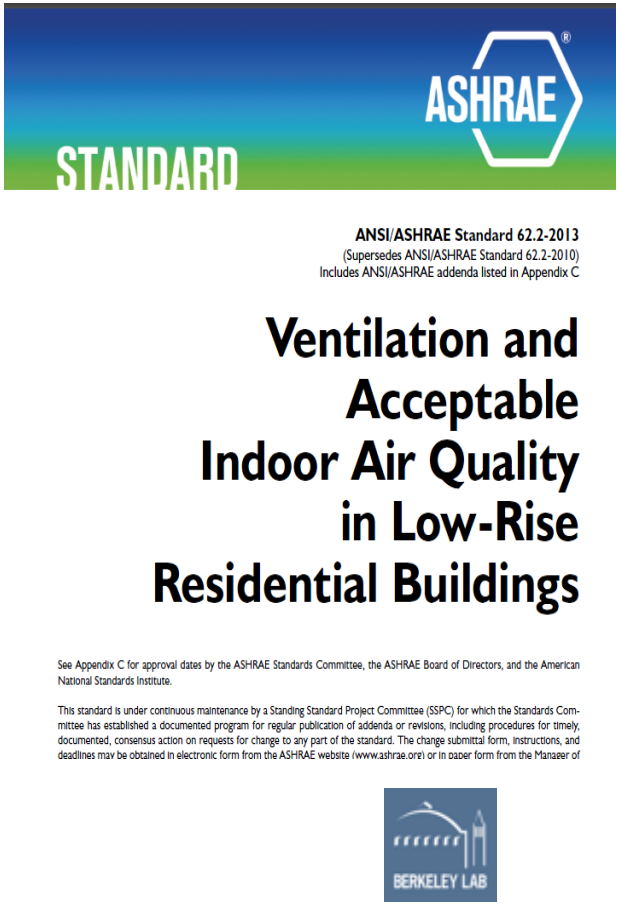
Home Ventilation Requirements

- Minimum requirement: ASHRAE 62.2-2016
  - **Whole house flow—with blower door credit (not in MF)**
  - **Local exhaust in kitchens and bathrooms**
  - Duct leak limits, minimum filtration
  - Existing home allowances for local exhaust
  - Requires CO alarm
  - Filtration credit
  - **Measure air flows**
  - **Allows for "smart" energy efficient ventilation controls**
- "Good" = anything "better" than this minimum



Exhaust, supply or balanced?

Exhaust

- Cheapest & easiest to install
- Easiest to commission
- No tempering needed
- Tight envelopes filter outdoor PM and ozone – typical new home about MERV13
- Air entry distributed – not controlled to specific locations

Balanced

- Can exhaust from bath & kitchen, supply to BR
- Air direct from outdoors
- Best for very tight homes
- Heat recovery improves efficiency
- Most expensive
- Filter required
- Hard to commission & maintain

Supply

- Air direct from outdoors
- Hard to commission & maintain
- Tempering needed in cold or hot climates
- Filter required
- Uses most energy if integrated into central fan

Does home ventilation work?

Healthy Efficient New Gas Homes Study (HENGH)

Rengie Chan

Yang-Seon Kim

Brett Singer

Iain Walker

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STATE OF CALIFORNIA ENERGY COMMISSION

Building AMERICA U.S. Department of Energy

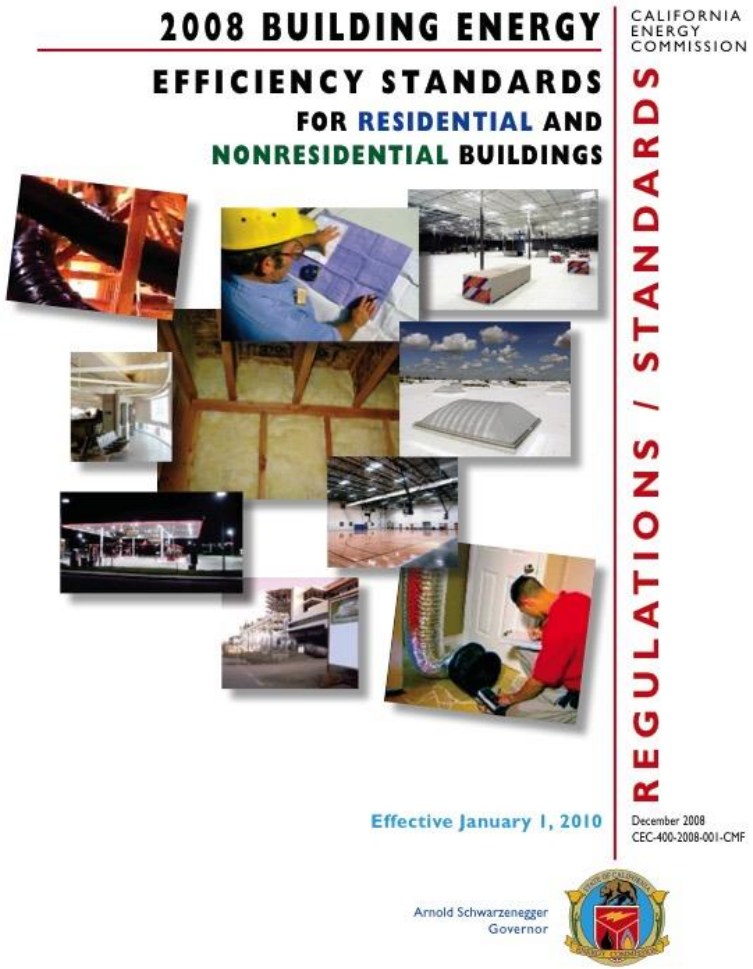
PG&E

SoCalGas A Sempra Energy utility

gti

Context

- Since 2008, California code has required mechanical ventilation (MV) based on ASHRAE 62.2
- Are these requirements working?
- Are homes compliant?



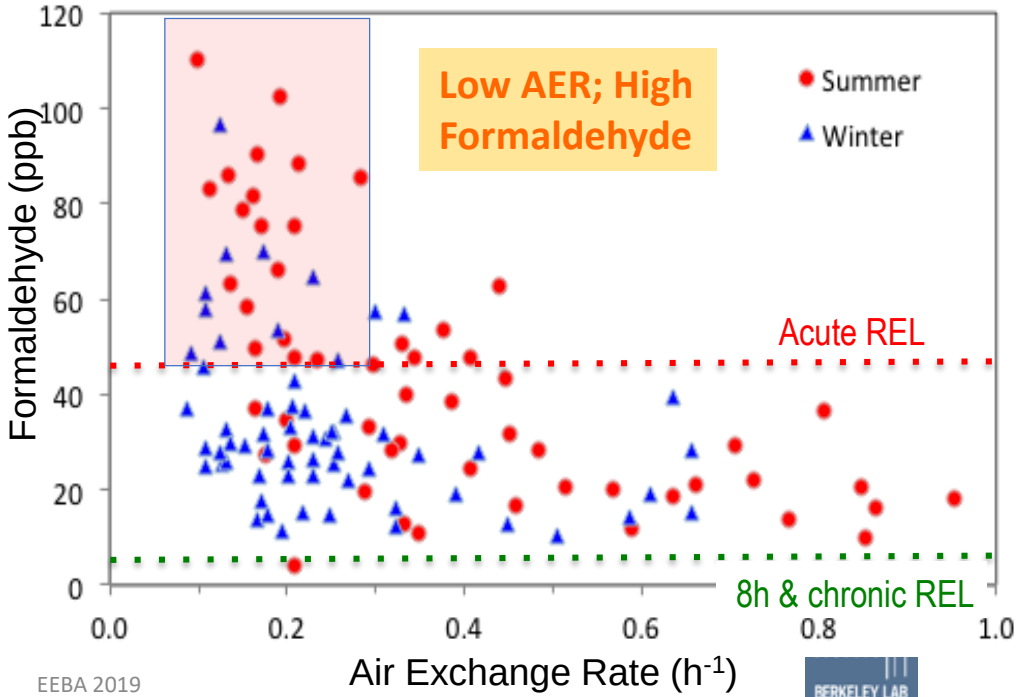
Prior California Studies

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

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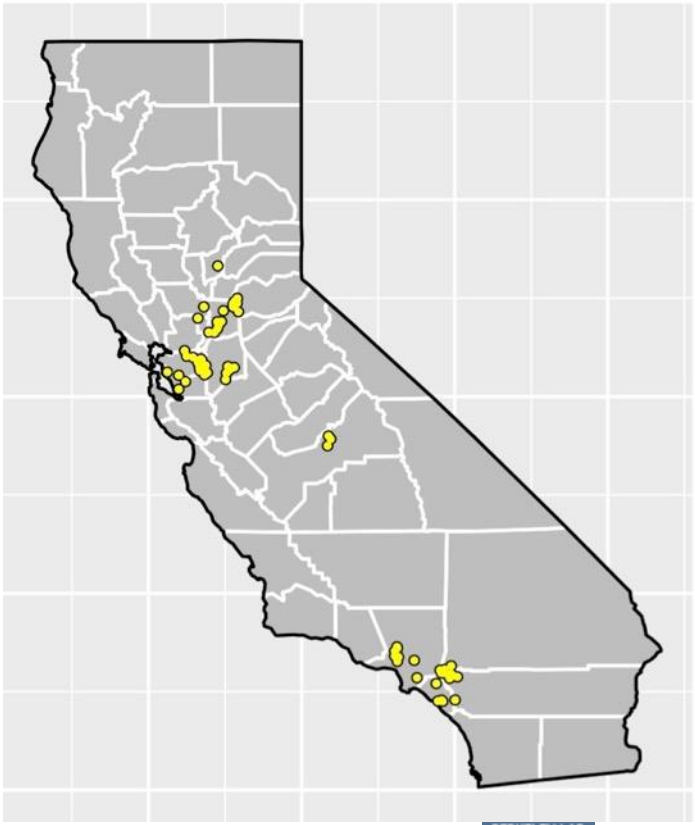
HENGH Field Study

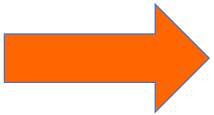
- 70 detached homes, built 2011-17
- Natural gas cooking burners
- Average floor area: 2700 sq.ft.
- Average envelope leakage: 4.5 ACH50
- Average occupant density: 1000 sq.ft. per person
- 90% of homes less than three years old

- Characterized ventilation equipment
- Measured IAQ, tracked activities for 1 week
- Windows closed; Central MV operating



Central MV systems exceeded required airflow

Mean required: 63 cfm
Mean provided: 96 cfm



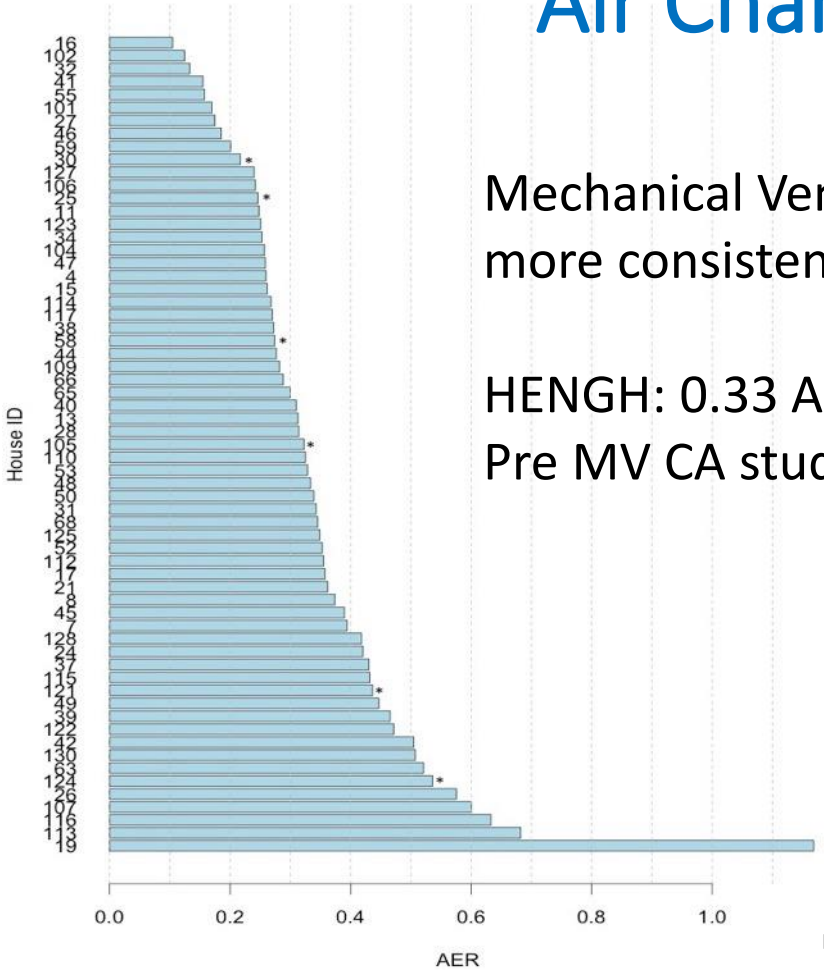
~50% above code

- Easy to verify:
  - Continuous exhaust (N=55)
  - Intermittent exhaust (N=9)
- Hard to verify:
  - Continuous inline fan connected to FAU (N=4)
  - Central fan integrated supply with motorized damper (N=2)

Code-compliant ventilation in 85% of master baths, 1/3 of other bathrooms below code

Most range hoods met minimum airflow
Many only at high speeds that were loud

Air Change Rates



Mechanical Ventilation Requirements leads to more consistent air exchange rates:

HENGH: 0.33 ACH
Pre MV CA study (2009): 0.24 ACH

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$PM_{2.5}$ and formaldehyde lower in HENGH

Mean Indoor Concentration	CNHS – 98% Electric 2006–07	HENGH - Gas Homes 2016–18
Formaldehyde	35 ppb	20 ppb
$PM_{2.5}$	13.4 µg/m^3	10.2 µg/m^3
NO_2	5.2 ppb	6.2 ppb *

* NO2 higher outdoors

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

Labels made 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.

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Labeling Guidance

ASHRAE Guideline 24:

Manual switches associated with a whole-building ventilation system should have a clear label such as,

*"**This controls the ventilation system of the home. Leave on except for severe outdoor contamination.**"*

In addition, guidance on operations and maintenance procedures should be provided to occupants.

Paul Raymer*: Label breaker as "**TV and Ventilation**"*

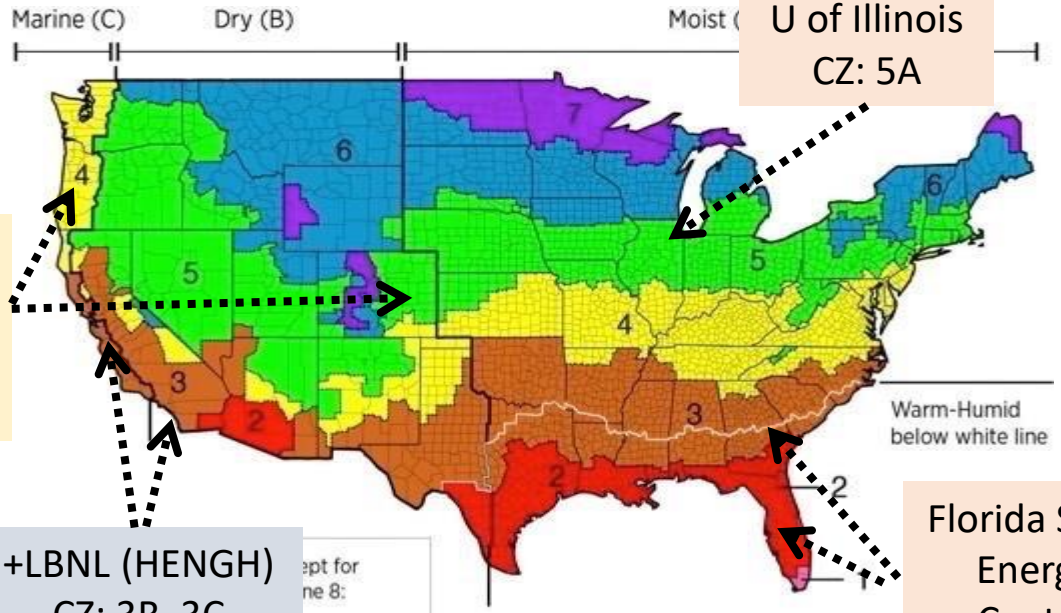
HENGH Conclusions

1. IAQ is acceptable in homes meeting ASHRAE 62.2 (California Title 24) requirements *when systems are operating*
2. Better labeling would have a big impact
3. Encourage the use of commissionable systems*
4. Installed air flows are meeting requirements

More details in Chan et al. 2019

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*

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:

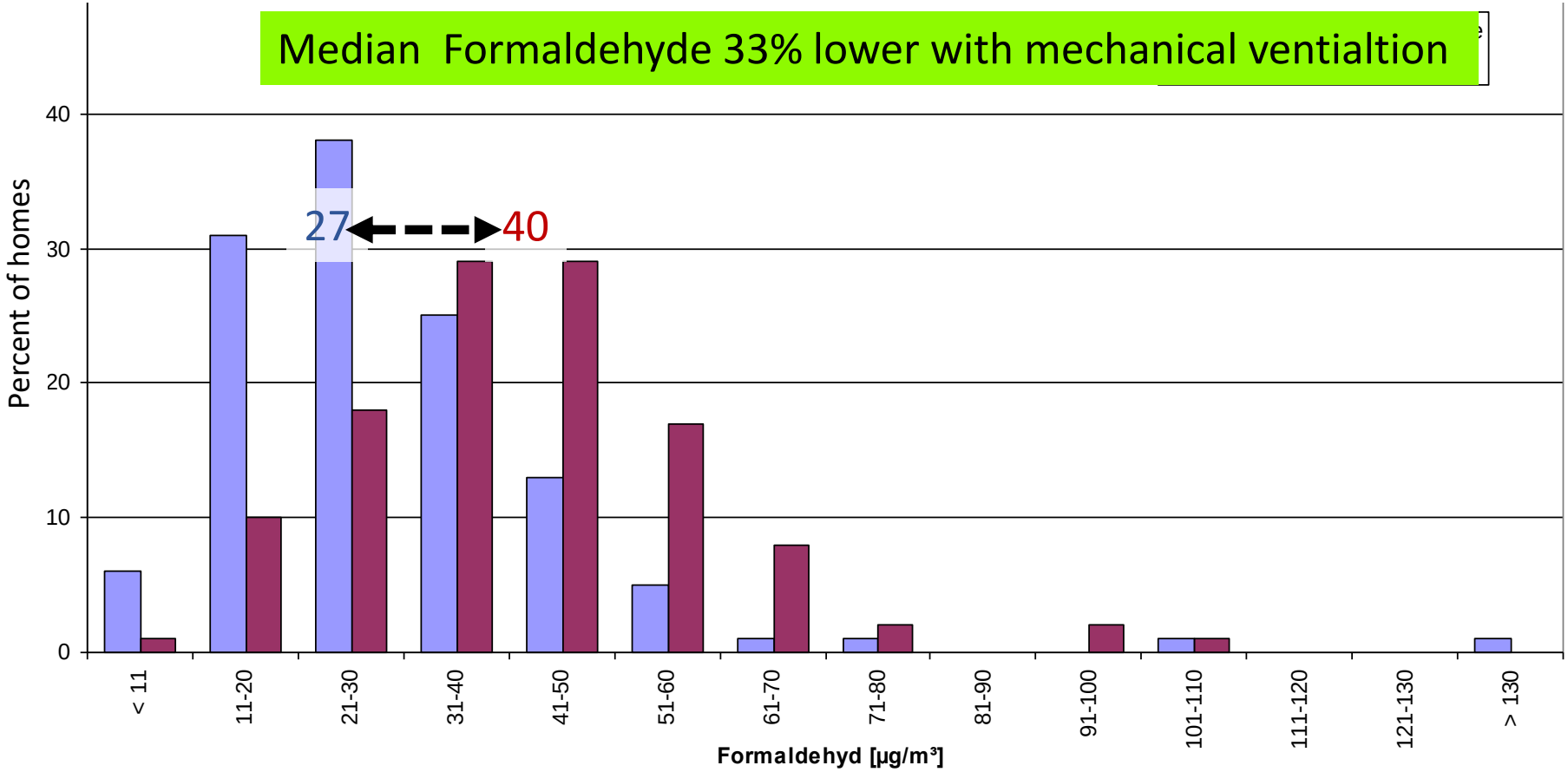
Measure IAQ metrics and air change rate at 3 and 15 months:

Survey of perceptions, satisfaction and health status

Adapted from slide provided by Peter Tappler

Austria Results: Formaldehyde @ 3 months

Median Formaldehyde 33% lower with mechanical ventialtion



Adapted from slide provided by Peter Tappler

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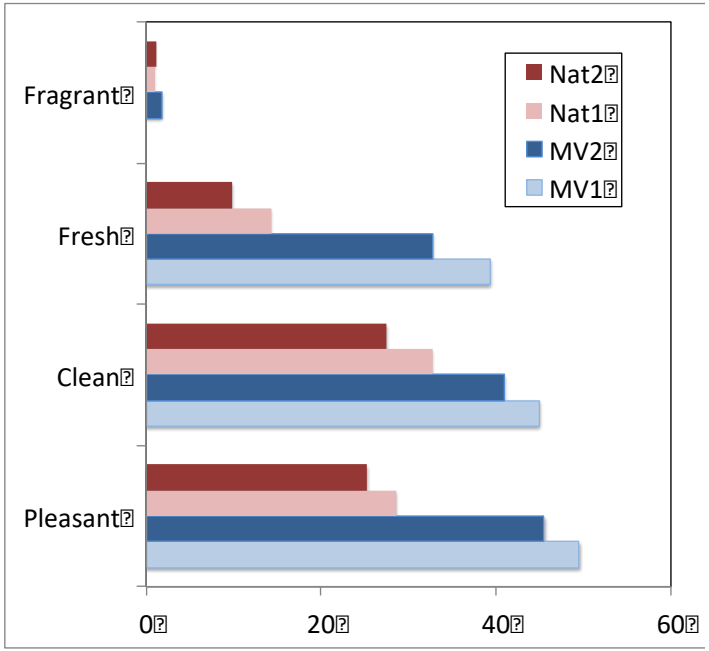
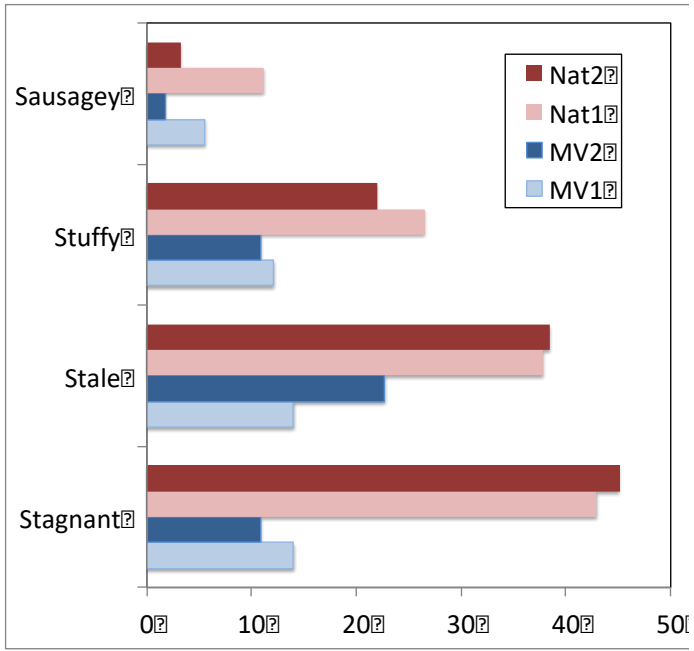
Austria: MV improved IAQ satisfaction





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

Commissioning is essential in airtight homes

If IAQ system fails, there is no natural infiltration backup

Unfortunately, faults are **common** in some system types

TSI/Alnor Balometer® Flow Capture Hood ABT701 (ABT701)

Observator DIFF Automatic Air Volume Flow Meter (DIFF)

TSI/Alnor Balometer® Flow Capture Hood EBT721 (EBT721)

Energy Conservatory - Exhaust Fan Flow Meter (TECEFM)

The Energy Conservatory – FlowBlaster™ (TECFB)

testo 417 Vane Anemometer (testo417)

Figure 1: The six commercially available flow hoods evaluated for this study

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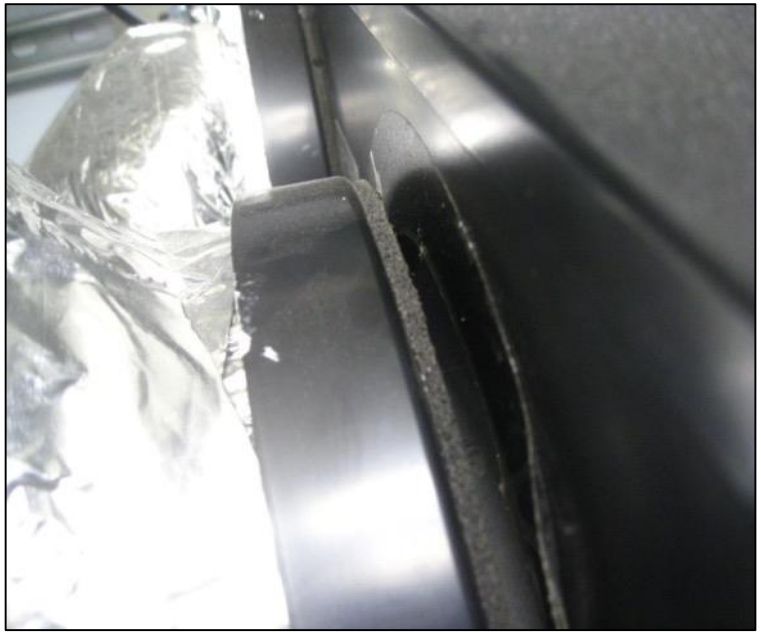
Field Survey of 60 Canadian HRVs

- Cores & filters **“clean” in ~50%** of homes
- 7 **inlets clogged** with debris
- 7% of HRVs **not operational** due to component failure
- Occupant “knowledge” of system largely unrelated to performance, level of maintenance, etc.

[1] Hill, 1998

Faults Observed in CA High Performance Home Ventilation Systems[1]

- 5 of 9 ERV/HRVs had a problem
  - Low airflows
  - Failed duct connections
  - Improperly installed duct connections
    (recirculating ERV)
  - Erratic control of variable speed
  - Clogged fresh air intake on ERV
  - Not operating, inactive for months



- Similar faults in other studies[2]

[1] Less, 2012
[2] Balvers et al., 2012; Hill, 1998; Offermann, 2009

FSEC 2014 Field Study

- 21 homes with MV, 16 built since 2012
  - I9 of 21 systems not operating
  - 12 of 21 ‘capable of operating’
  - 3 of 21 had airflows close to design
    - 2 of these disabled by occupants
- Faults
  - Failed controllers and dampers
  - Partially disconnected or crushed ducts
  - Dirty filters
  - OA intake directly above exhaust

Dirty outdoor air intake.

Dirty ERV filters.

Sonne et al. 2015

Supply Systems Fail Chronically

- Either supply only or supply side of balanced systems
  - Blocked inlets
  - Fouled filter
- Generally – no occupant access
  - Inlets high on walls, on roofs, under decks
  - Filters in attics at HVAC system – almost no prac
- Very difficult to commission
- Improvements:
  - Install for access
  - Need built-in flow meter – push to test
  - Need low flow alarm

Photo by Joe Nagan

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

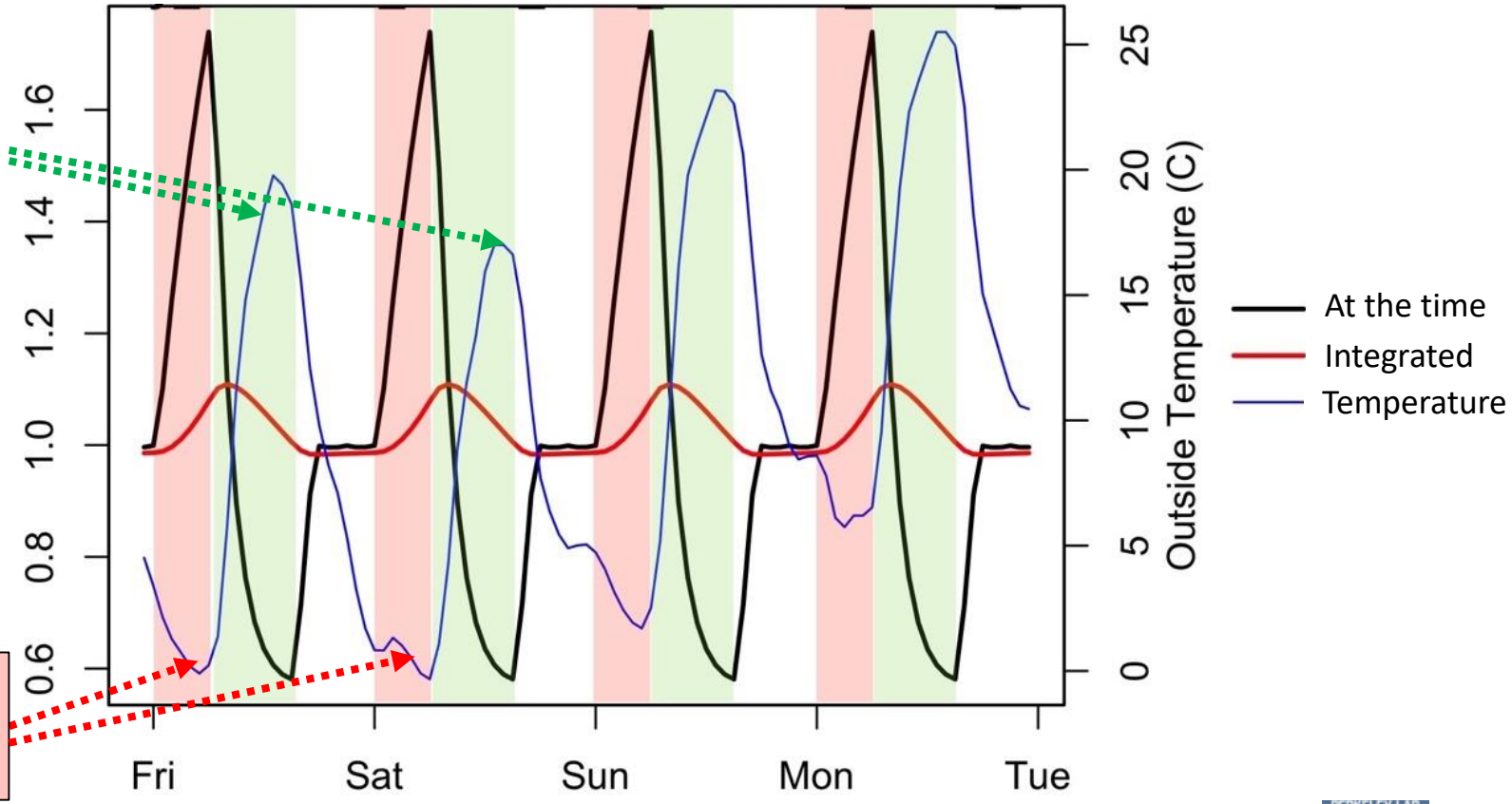
- Can incorporate distribution and mixing

Temperature-Based Control Strategy

Ventilation doubled during warmer hours

Pollutant levels relative to continuous ventilation

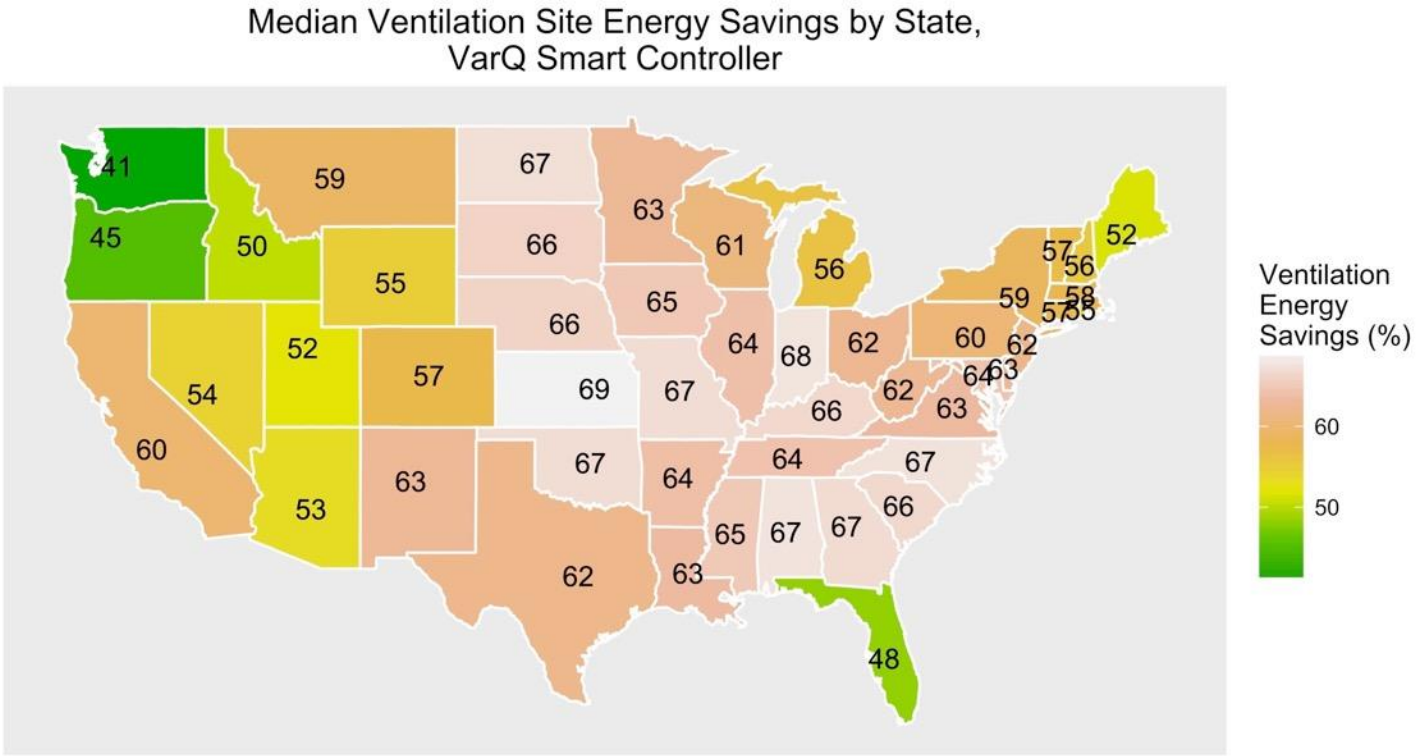
Ventilation off during coldest hours of day



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

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Building AMERICA
U.S. Department of Energy

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Low-cost sensors and air quality monitoring

Sensors generate signals in response to environmental conditions

Calibrations translate signals to data

DATA

Cloud stores data
Dashboards for visuals

Local displays indicate hazards and suggest mitigating actions

Some offer onboard storage

Testing of low-cost monitors for typical PM sources

Burned incense, candles and cigarettes

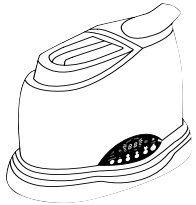





Heated pots of water, an oven, a hair dryer, and an electric burner

Cooked green beans, bacon, pancakes, toast, heated oil



Released AZ test dust, shaked a dust mop, and operated an ultrasonic humidifier using unfiltered tap water

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Results of 2017 LBNL Lab Testing

Within 2x for large $PM_{2.5}$ sources

Detected many sources but very low response.

Not informative.

No detection or control of ultrafine particles.

What fraction of residential $PM_{2.5}$ events are detected?

Can they accurately moderate levels of PM? How durable are they?

Complete study: Singer et al. 2018, Indoor Air

Results of Fall 2018 LBNL Lab Testing

Within 2x for large $PM_{2.5}$ sources.





Many now use Plantower sensors
Calibrations appear to differ

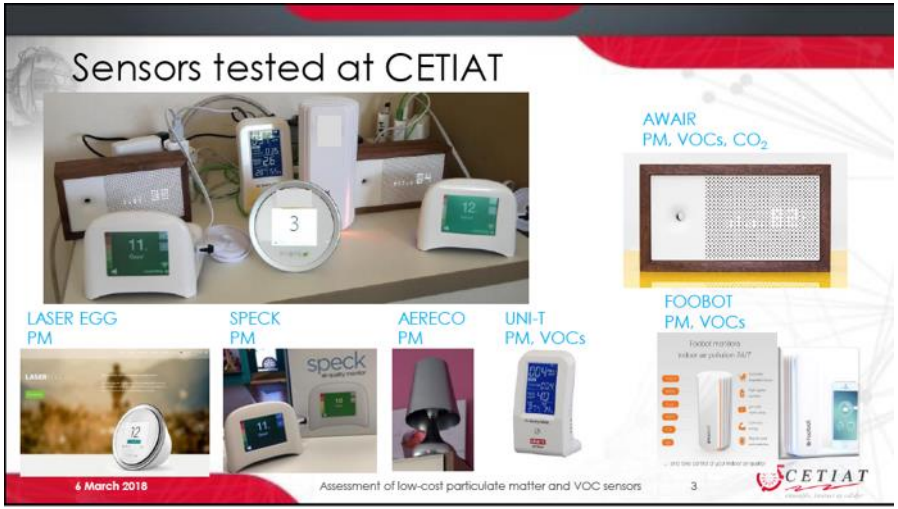
No detection or control of ultrafine particles.

What fraction of residential $PM_{2.5}$ events are detected?

Can they accurately moderate levels of PM? How durable are they?

Ohio State Study

CETIAT Study



Bare sensors: Honeywell HPM, Sharp GP2Y1010AU0F, Plantower PMS5003, Shinyei PPD71

Integrated monitors: Foobot, AirBeam2, Dylos DC1100 PRO, AirThinx, Purple Air II, Tsi Blue Sky, Alphasense OPC-N2

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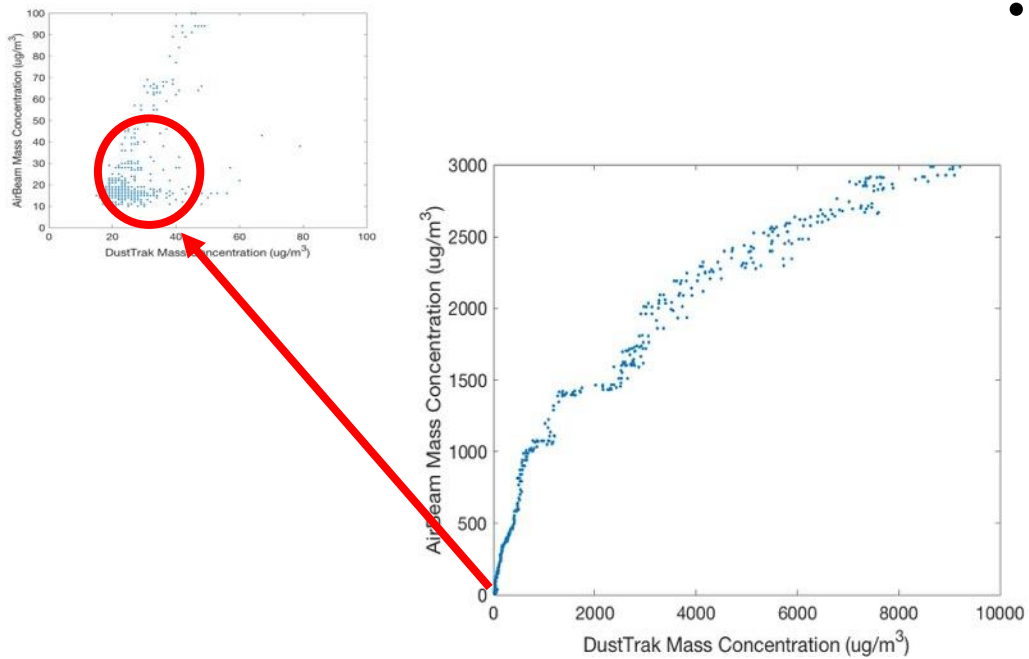
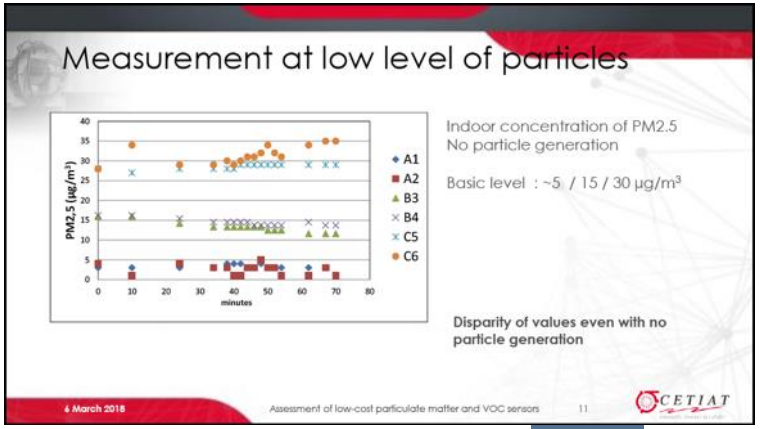
Ohio State Results

- Poor correlation at low concentration – much better at high concentration
- OK for event detection, maybe not for chronic exposure



CETAIT Results

- Most devices can detect events
  - But not quantitatively
- Not good at low concentrations
- OK for events, but not for chronic exposure



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Tips for Best Results

- If possible, buy multiple units and check via side-by-side msts
  - Purple Air outdoor monitor has two sensor units
- When new and intermittently, measure outdoor air and compare
  - Several monitors provide local outdoor data
  - https://www.epa.gov/outdoor-air-quality-data
- If there are sources of concern, check monitor response when sources is used and when controls are in place
- Don’t rely entirely on the monitor; try to always follow best practices for healthy homes

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Top 3 IAQ Challenges in ZEH

1. **Moisture**
   - vent wet rooms + dwelling, dehumidify in humid climates
2. **Cooking**
   - use a good venting hood and induction cooktop
3. **Operation and maintenance**
   - select systems that are easy to install and maintain, use clear labels

Recipe for good IAQ in ZEH

- Take care of water / moisture
  - drainage, vapor barriers, etc.
- No combustion products using house air
  - All electric home
- Select low-emitting materials
- Exhaust ventilation in wet rooms
  - Energy Star quiet & efficient fans
  - Kitchens must vent to outside
  - Induction cooktops
  - Kitchen MUA >400 cfm and < 2ACH50
  - Automate range hoods and bathroom exhaust?
- Test for Radon
- Whole House Ventilation
  - ASHRAE 62.2 minimum
- MERV 13 filters on supply air and central forced air
  - 2 in. filter slot
  - Minimum runtime
- Dedicated dehumidification in humid climates
- Label everything
- Easy access for maintenance and commissioning

Tell Iain about retrofit costs

iswalker@lbl.gov

iaqscience.lbl.gov

- Compiles published studies
- Critical review
- High-level summary
- Periodically updated

Topics

Building Ventilation

Ventilation is the supply of outdoor air to a building. This section discusses how ventilation rates influence indoor air quality and occupant health and performance.

Dampness and Mold

Topics discussed include the causes of excess building dampness, the influence of dampness on indoor biological and organic chemical contaminants, and the effects of dampness and of dampness-related indoor contaminants on people's health.

Volatile Organic Compounds

Indoor volatile organic compounds, or VOCs, are carbon-containing organic chemicals emitted from a variety of sources. The implications of indoor VOCs for health are addressed.

Human Performance

This section discusses how the performance of office and school work is affected by indoor environmental conditions and by the features of buildings that influence indoor environmental conditions.

National-Level Opportunities

This section provides estimates at the national level of some of the benefits and costs of taking practical steps to improve indoor environmental conditions in U.S. buildings.

Air Cleaning

Indoor air cleaning is the process of intentionally removing pollutants from indoor air, or from the outdoor air as it enters a building. This section of the web site addresses the relationship of air cleaning to health and perceived air quality, focusing on application of air cleaning to buildings outside of the health care and industrial sectors.

Climate Change

Climate change will modify outdoor environmental conditions which, in turn, will

IAQ in Schools

This section provides an overview of indoor air quality (IAQ) in schools and its influence

Thank you!

Join the conversation - #EEBASummit2019

Save the dates for next year:

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