Smart Home IAQ: Looking to the Future

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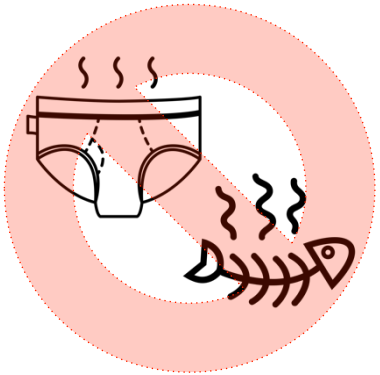
ENERGY STAR Certified Homes Stakeholder Meeting

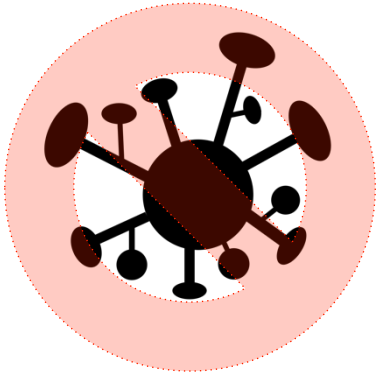
Sep 6, 2018 - Phoenix AZ

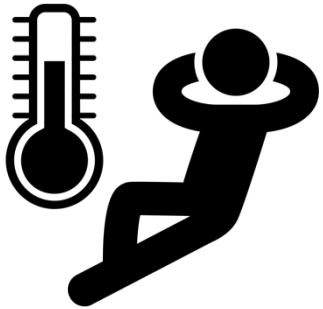
Outline

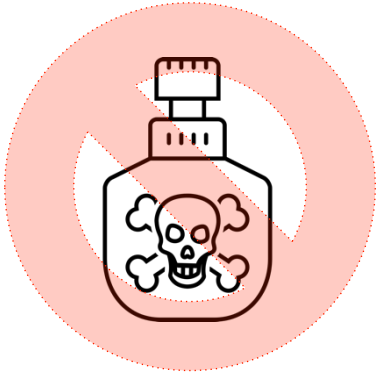
- Pollutant hazards and sources
- Guidance informed by research
- Ventilation and IAQ in California new homes
- IAQ sensors and monitors
- New home IAQ survey

What is Indoor Air Quality?









Good IAQ = Low-Risk of Bad IAQ

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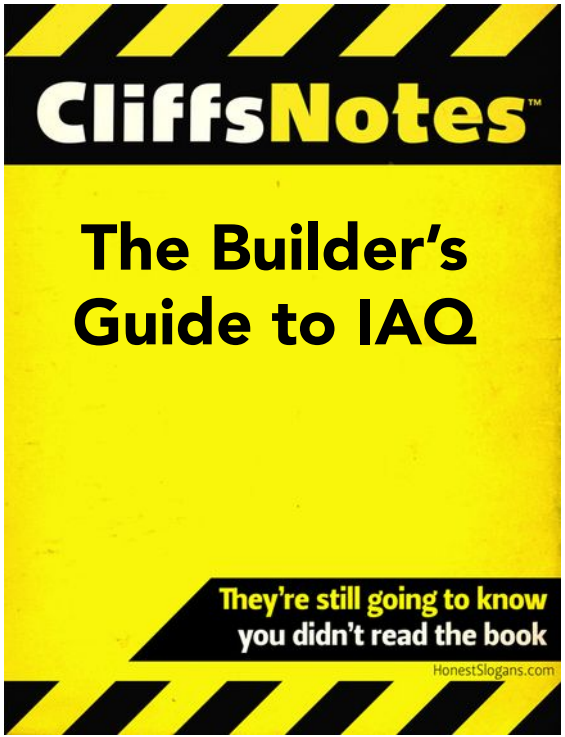
How to Reduce IAQ Risk

- **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**



What pollutants do we have to worry about?

From Inside **From Inside + Outside** **From Outside**

Particulate matter:

- **PM_{10}, $PM_{2.5}$, Ultrafine particles**
- **Metals; Acids; Condensed organics**

Nitrogen dioxide: NO_2

Carbon monoxide: CO

Ozone

Gas-phase organics (VOC)

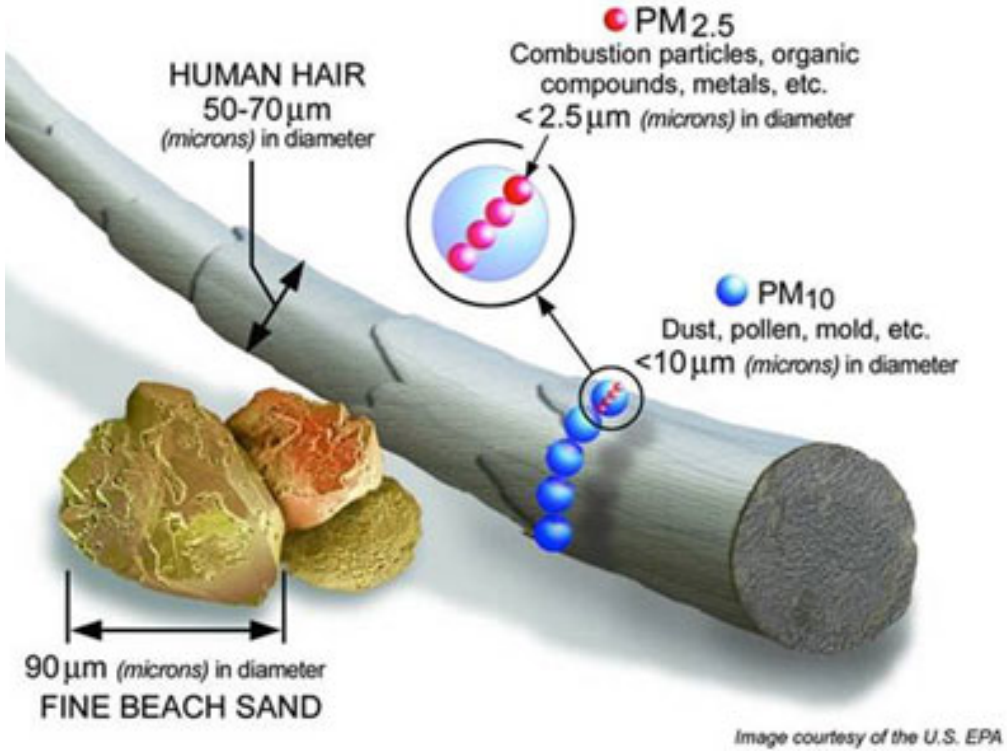
- **Formaldehyde**
- **Other aldehydes**
- Benzene
- **Acrolein**
- Organic acids
- **Semi-volatile organics (SVOC)**

Mold and dampness
Allergens in air and dust

Bioeffluents including CO_2
Viruses (maybe)

Radon

Fine particulate matter ($PM_{2.5}$)



- **Higher $PM_{2.5}$ -> badness**
  - Death, strokes, and other cardiovascular illness
  - Increased respiratory illness
  - Linked to many other outcomes

Sources of $PM_{2.5}$ in homes

Outdoor pollution is largest source overall

Indoor sources more important if used often in your home

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Nitrogen dioxide

- Airway irritant
- Exacerbates asthma and other respiratory diseases
- May cause asthma and increase infections
- Asthmatics, elderly, young children most susceptible

EPA Ambient Standards

100 ppb for 1h*

53 ppb annual

* 98th percentile of daily 1h max, averaged over 3 years

Nitrogen dioxide – high risk sources

Biggest risk is unvented heating
- frequent and long events
- more BTU/h = more NO_2

Francisco et al., Indoor Air 2010

30 homes with unvented fireplaces

4 random days of monitoring

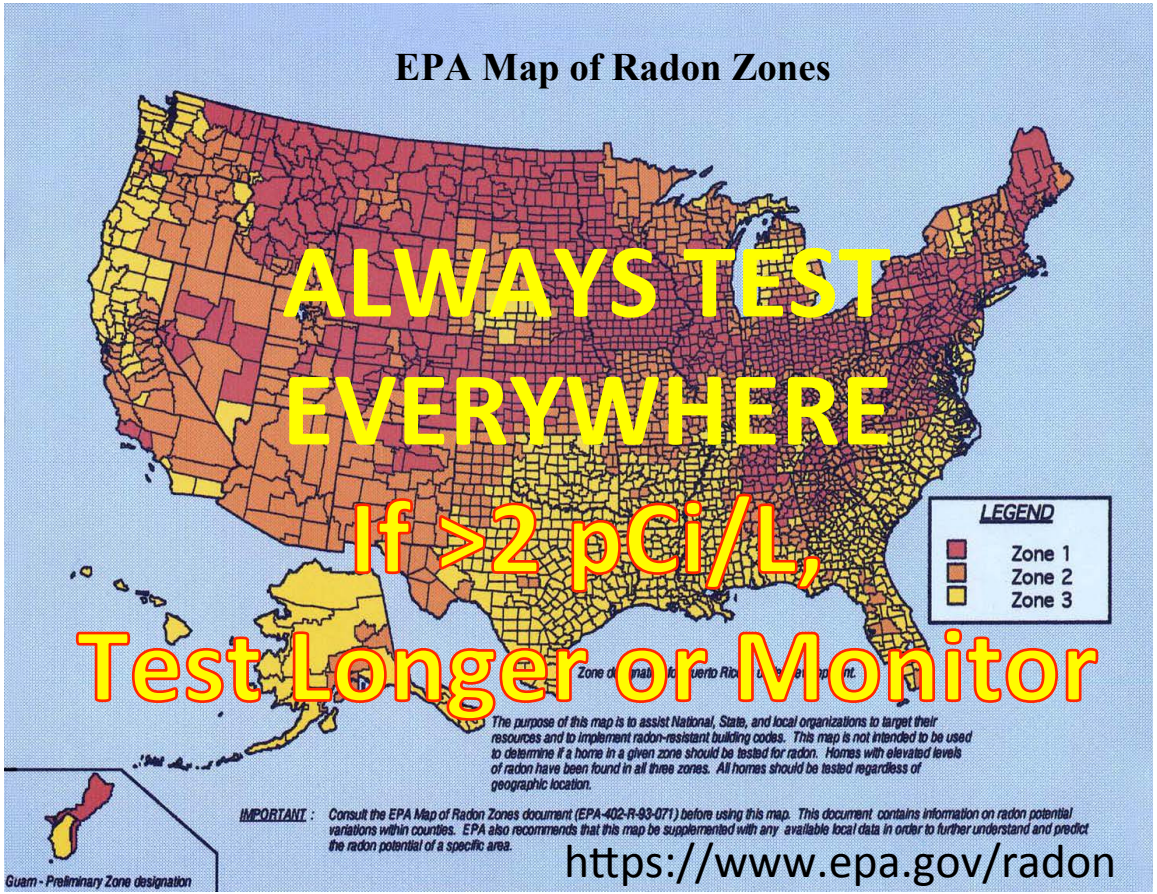
80% had NO_2 above 100 ppb for 1h

Radon

Radon entry varies with soil, season, weather.

Lung Cancer Risk, per 1000 people Lifetime Exposure

Radon pCi/L	Non-smokers	Smokers
2	4	32
4	7	62
8	15	120
20	36	260



Formaldehyde

Urea-formaldehyde foam insulation
Used 1930-1970s
Banned in Canada 1980, in U.S. 1983

Used as binder in plywood, MDF, and particle board; in many finished products

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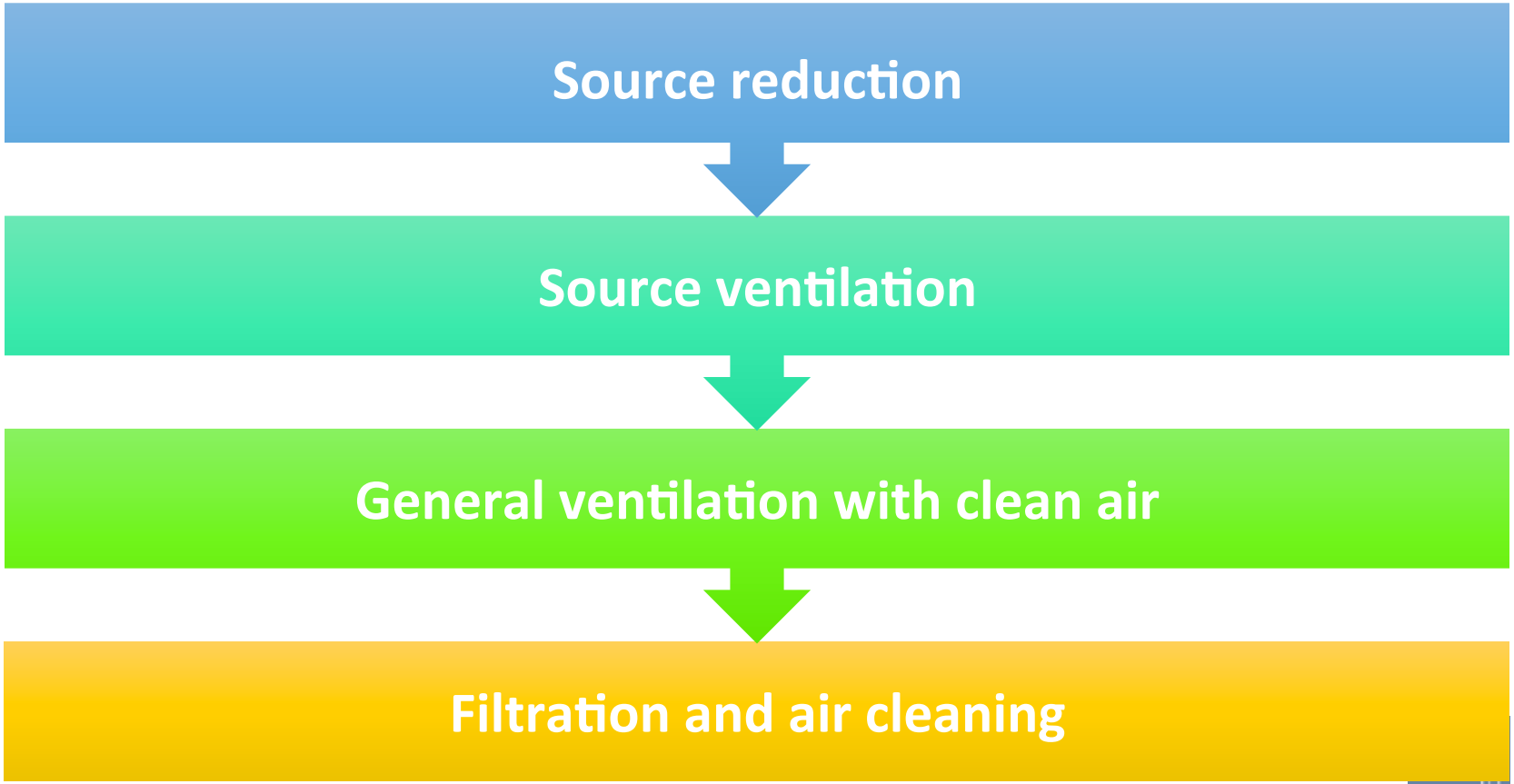
Reducing IAQ Risks

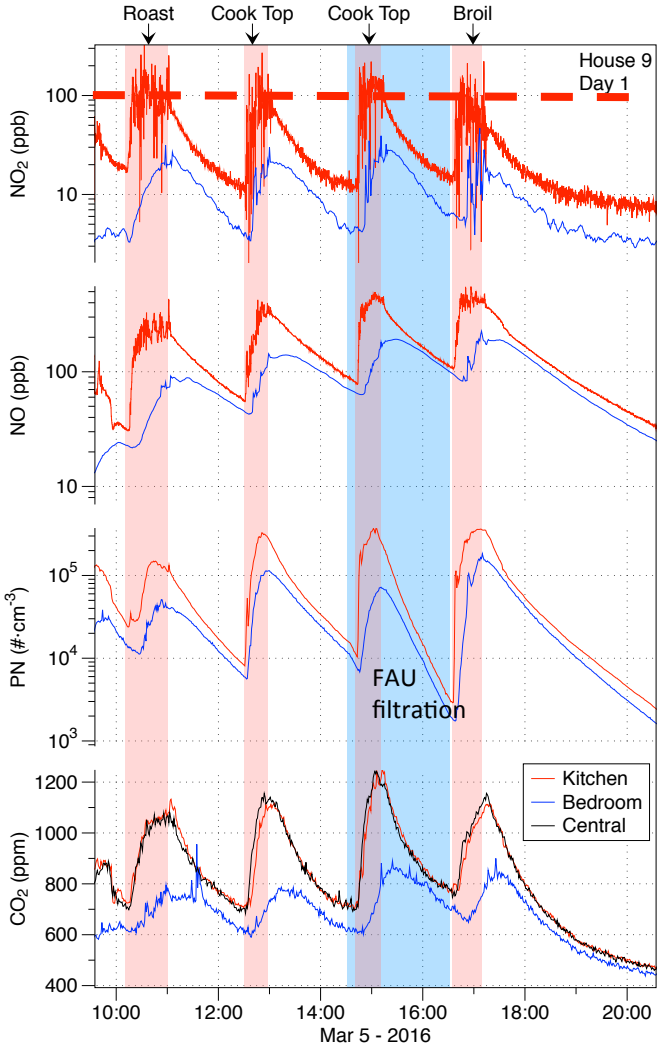

Source reduction
Source ventilation
General ventilation with clean air
Filtration and air cleaning

General ventilation does not protect against acute hazards

Pollutants from gas burner use

- 1400 sf, super efficient house
- ERV providing 0.5 ach
- FAU with MERV16 filter

Cooking particles and VOCs from consumer products present similar challenges



NO_2 >100 ppb in kitchen

 Singer et al., 2017, Building Environment

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Pollutant Source Reduction

Formaldehyde Emission Standards

California Environmental Protection Agency | AIR RESOURCES BOARD

FREQUENTLY ASKED QUESTIONS FOR CONSUMERS

REDUCING FORMALDEHYDE EMISSIONS FROM

Composite Wood Products

California rule effective January 1, 2009

US Formaldehyde Control Act in 2010

Products labeled starting June 1, 2018

https://www.arb.ca.gov/toxics/compwood/compwood.htm

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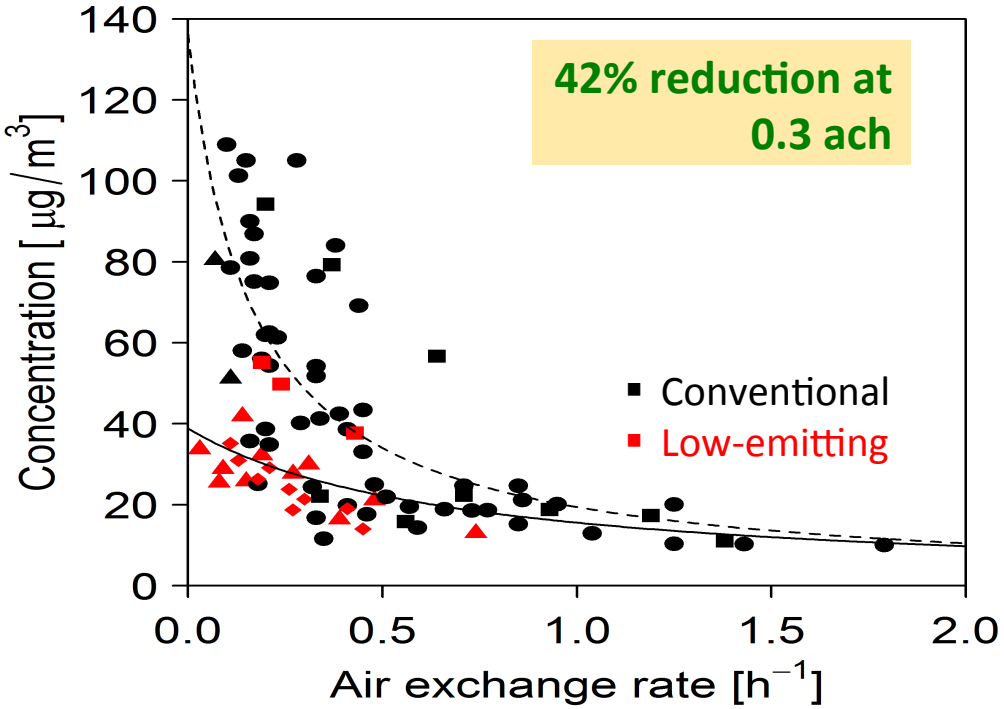
Homes built with low-emitting materials have lower formaldehyde concentrations



Data adjusted for temperature, RH, house age

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

For PM, very helpful to reduce entry from outdoors

A large fraction of indoor $PM_{2.5}$ comes from outdoors

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

RIOPA Study[1]

- Los Angeles (n=112) – 63%
- Elizabeth, NJ (n=80) – 52%
- Houston, TX (n=76) – 33%

MESA Air[2] (n=353 homes) – 80%

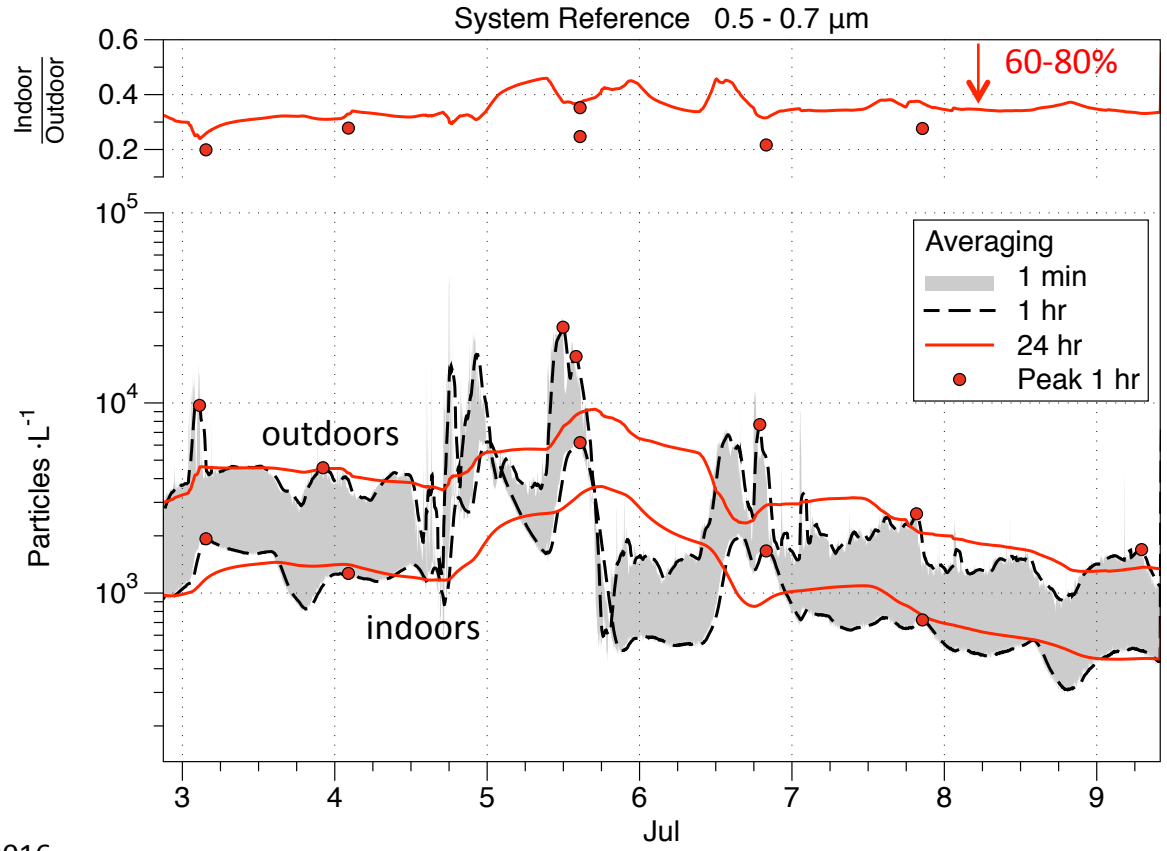
- Baltimore,
- Chicago,
- Los Angeles,
- New York,
- Rockland,
- St. Paul,
- Winston-Salem

[1]Meng, JEAEE, 2005, 15:17-28; [2]Allen, EHP, 2012, 120: 824-830

Air tightness helps reduce outdoor particles

Built 2006, 1200 sf, 5 ach50
Sealed ducts, MERV4 filter
Exhaust at Title 24 rate

$PM_{2.5}$ inside ~50% lower than outdoors



Singer et al., Indoor Air, 2016

Kitchen Ventilation

Cooking & burners are important sources

CO_2 & H_2O

NO,NO_2, HONO, Formaldehyde

Ultrafine particles

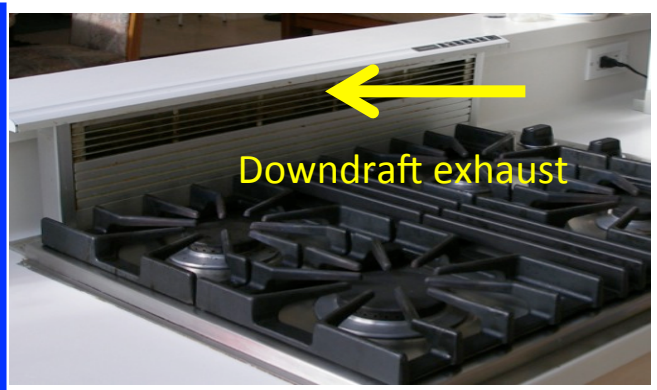
Ultrafine particles, $PM_{2.5}$

Formaldehyde, Acetaldehyde

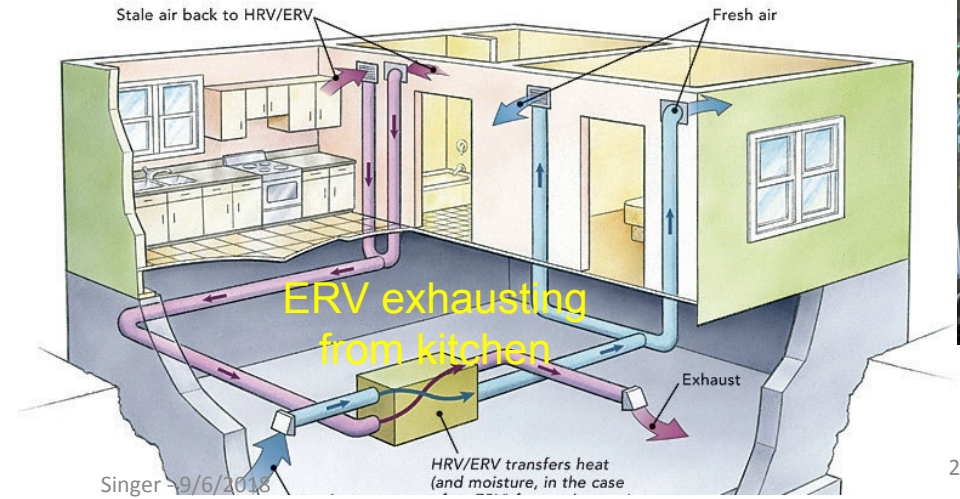
Acrolein, PAH

Ultrafine particles

Kitchen ventilation options



Exhaust fan on wall



Ceiling exhaust fan

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Lab study of range hood performance

Capture efficiency is the fraction of emitted pollutants removed by the range hood.

7 devices
L1: Low-cost $40
B1: Basic, quiet $150
A1: 62.2-compliant, $250
E1: Energy Star, $300
E2: Energy Star, $350
M1: Microwave, $350
P1: Performance, $650

Lab performance: Delp and Singer, 2014

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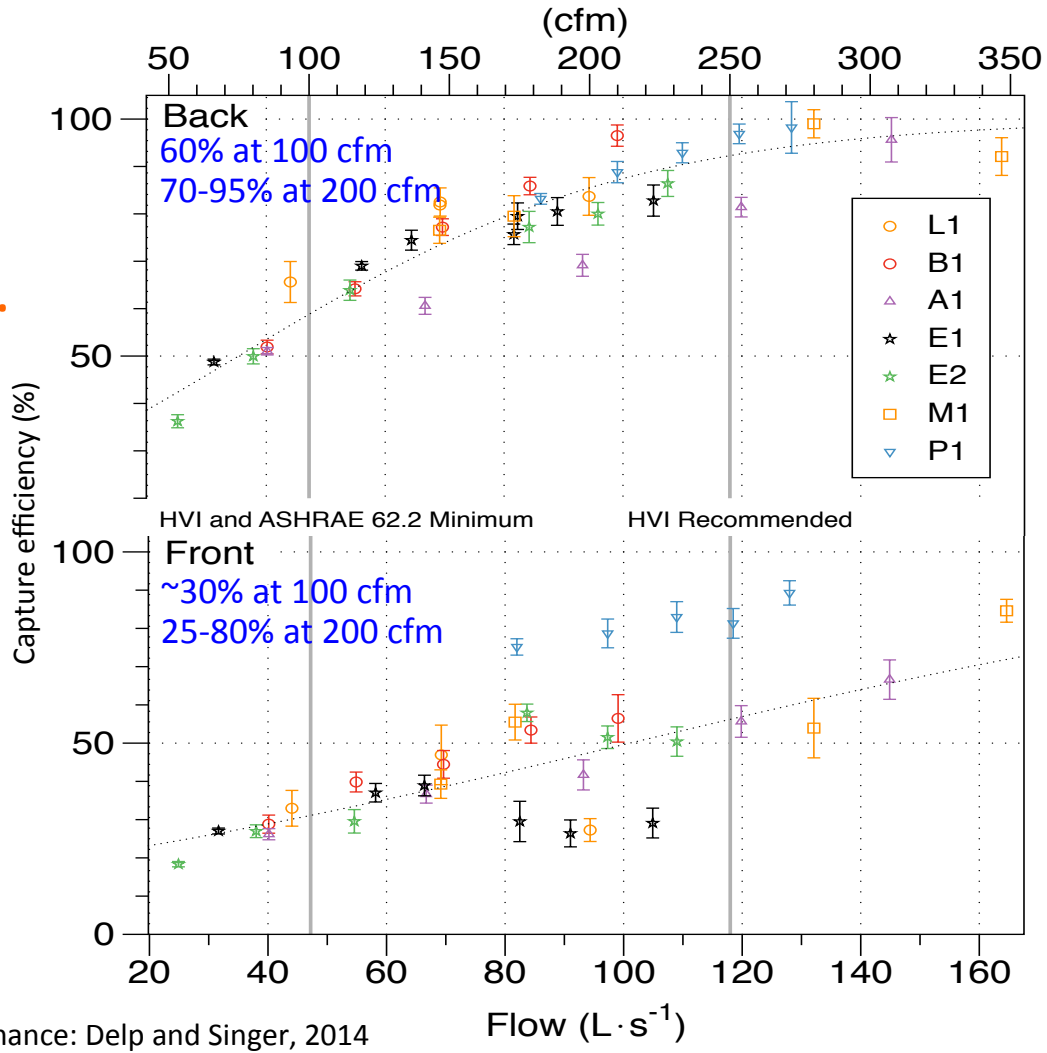
Lab study of range hood performance

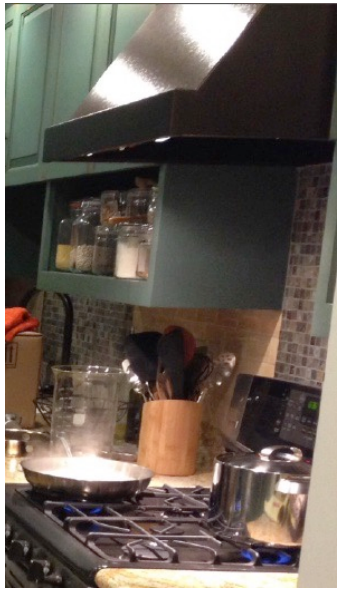
Capture increases with airflow.
Much better for back burners!

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



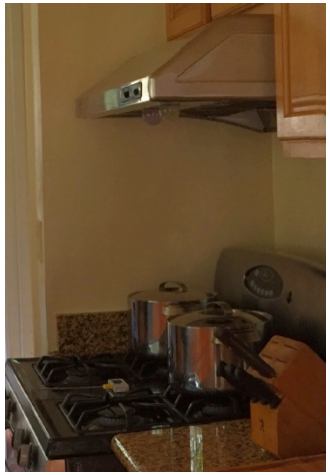
Lab performance: Delp and Singer, 2014

Field study of range hood benefits



H1

H2



H5

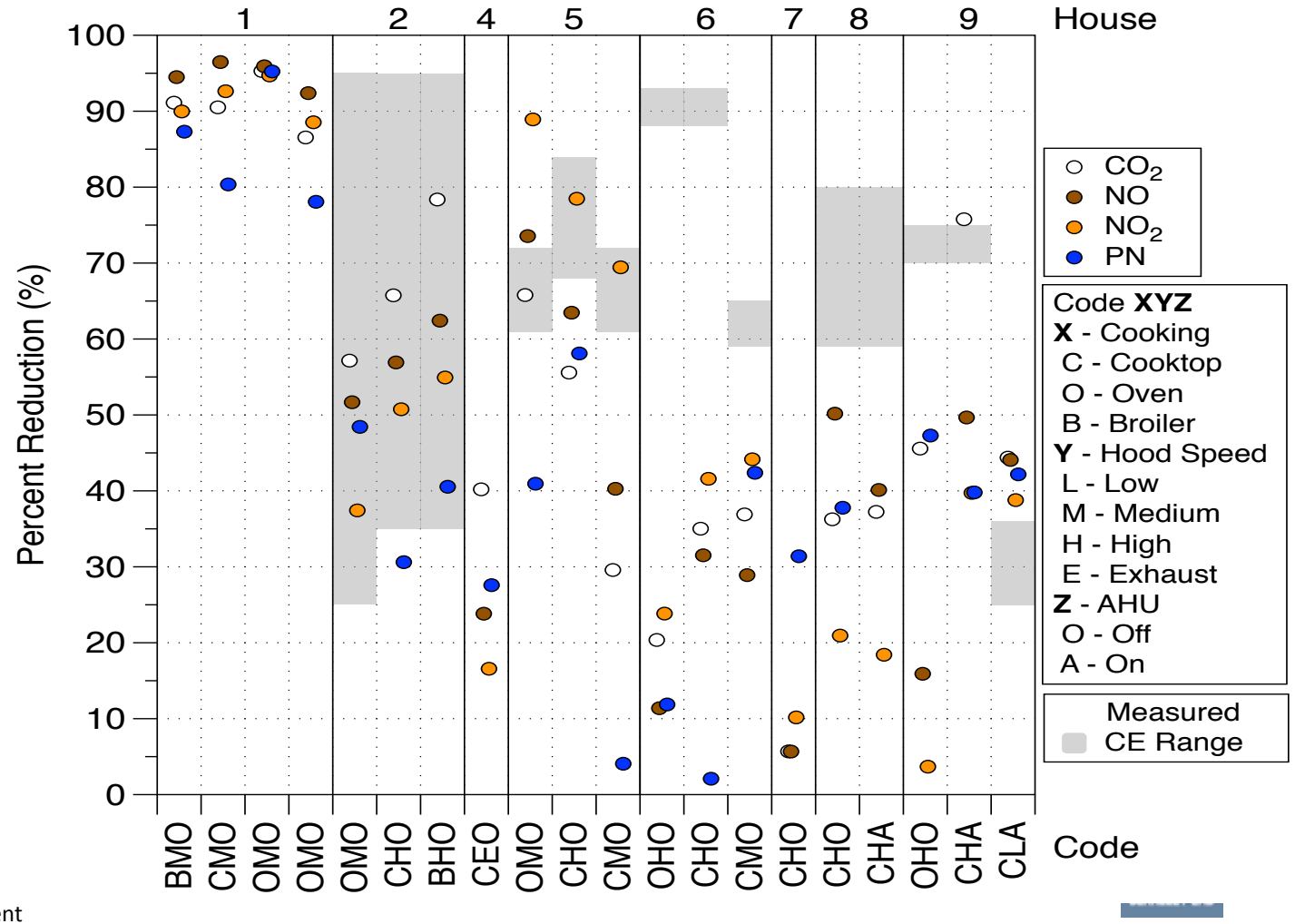
H6

H9

H8

Singer et al., 2017, Building Environment

Installed range hoods provide varying benefits



Singer et al., 2017, Building Environment

Range Hood Guidance

Builder / Contractor

- Low-resistance ducting
- Hood that covers all burners
- Quiet at 200 cfm

User

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

Roofer

- Don't drop debris down the vent

Materials (287 g) extracted from RH vent.
Photo & arrangement: M. Lunden

Many use kitchen exhaust only “as needed”

Self-reported usage	Number	Percent
Most times (>75%) when cooktop or oven used	44	13%
Most times when cooktop used, but not oven	39	11%
About half the time	45	13%
Infrequently, only when needed	**113**	**32%**
Never	35	10%
No exhaust fan	73	21%

Mullen et al. LBNL-5970E

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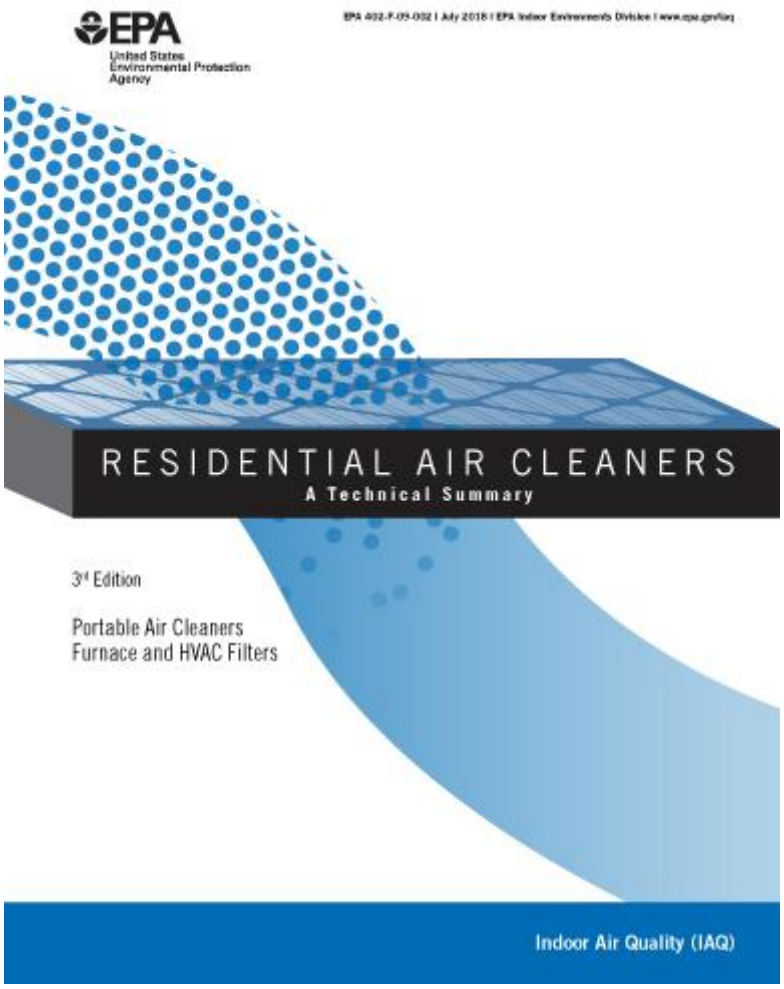
Filtration and Air Cleaning

- Potential to drive PM to very low levels
- Field studies find that actual benefits are smaller than theoretical
- Key issues:
  - **People turn them off**
  - FAU doesn't run consistently
  - Thermostat controls confusing
  - Noise
  - Energy



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

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

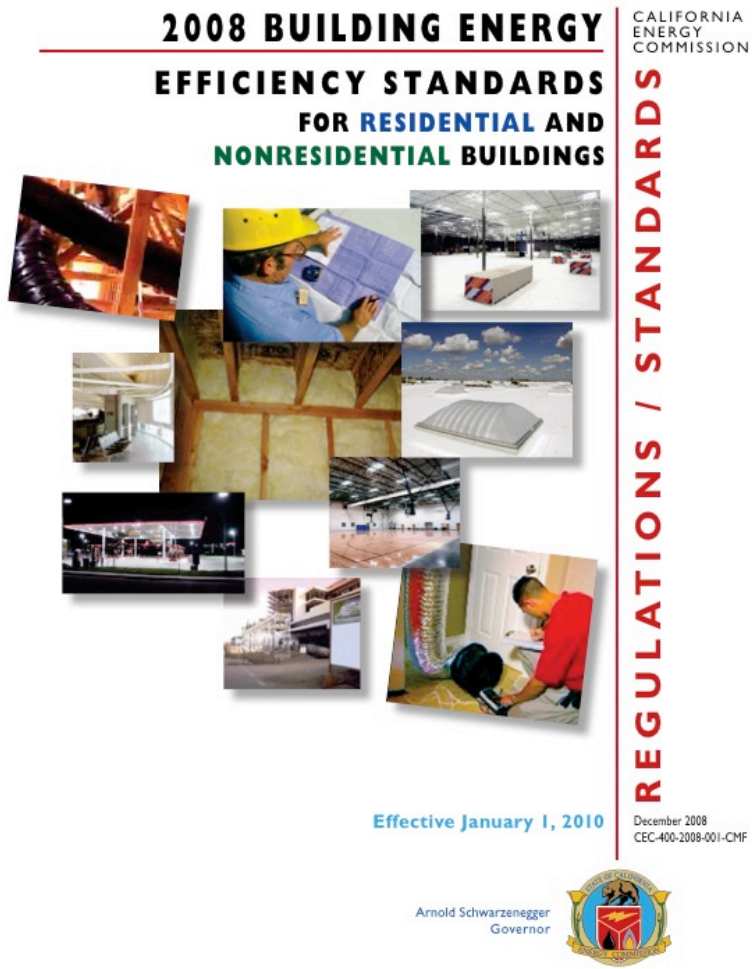
PG&E

SoCalGas A Sempra Energy utility

gti

Context

- Air sealing key strategy for residential energy efficiency
- Prior studies raised IAQ concerns
- Since 2008, California code has required mechanical ventilation (MV)



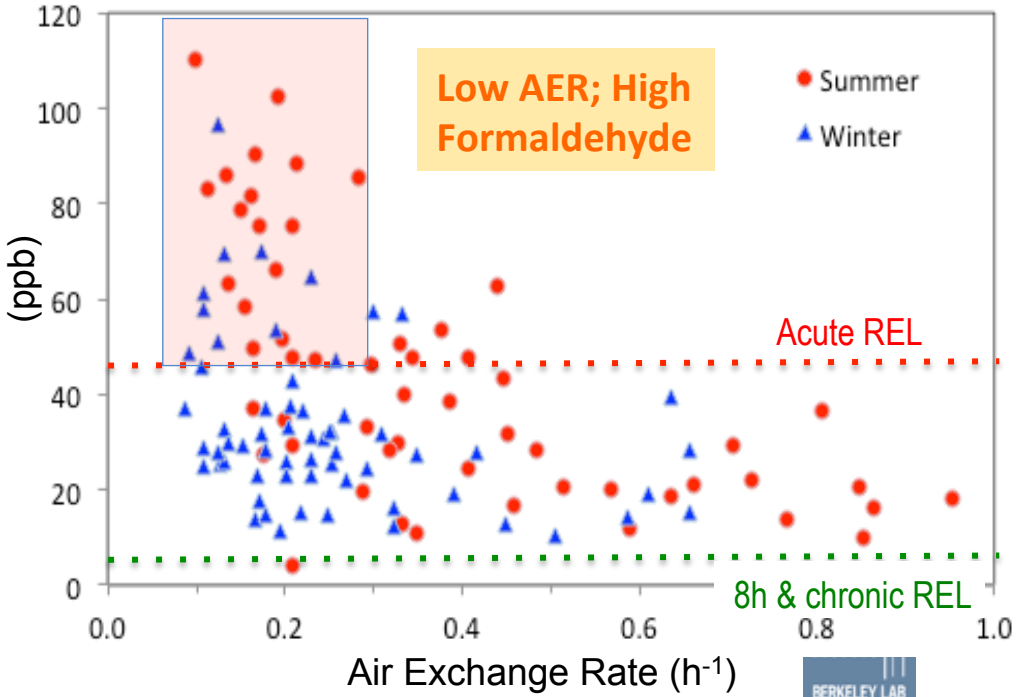
Prior California Studies

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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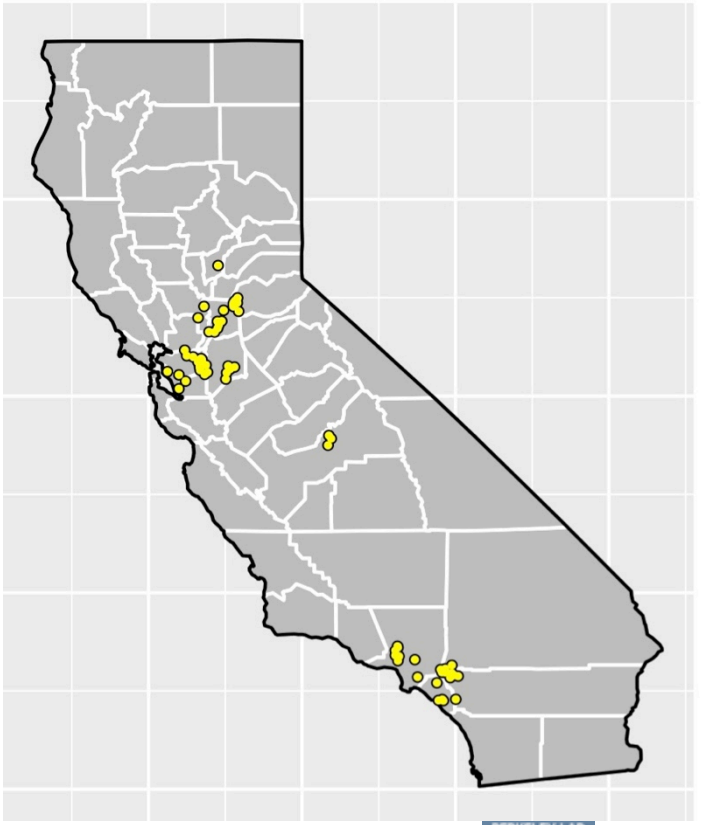
HENGH Field Study

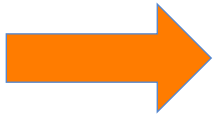
- 70 detached homes, built 2011-17
- Natural gas cooking burners

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



Central MV systems exceeded required airflow

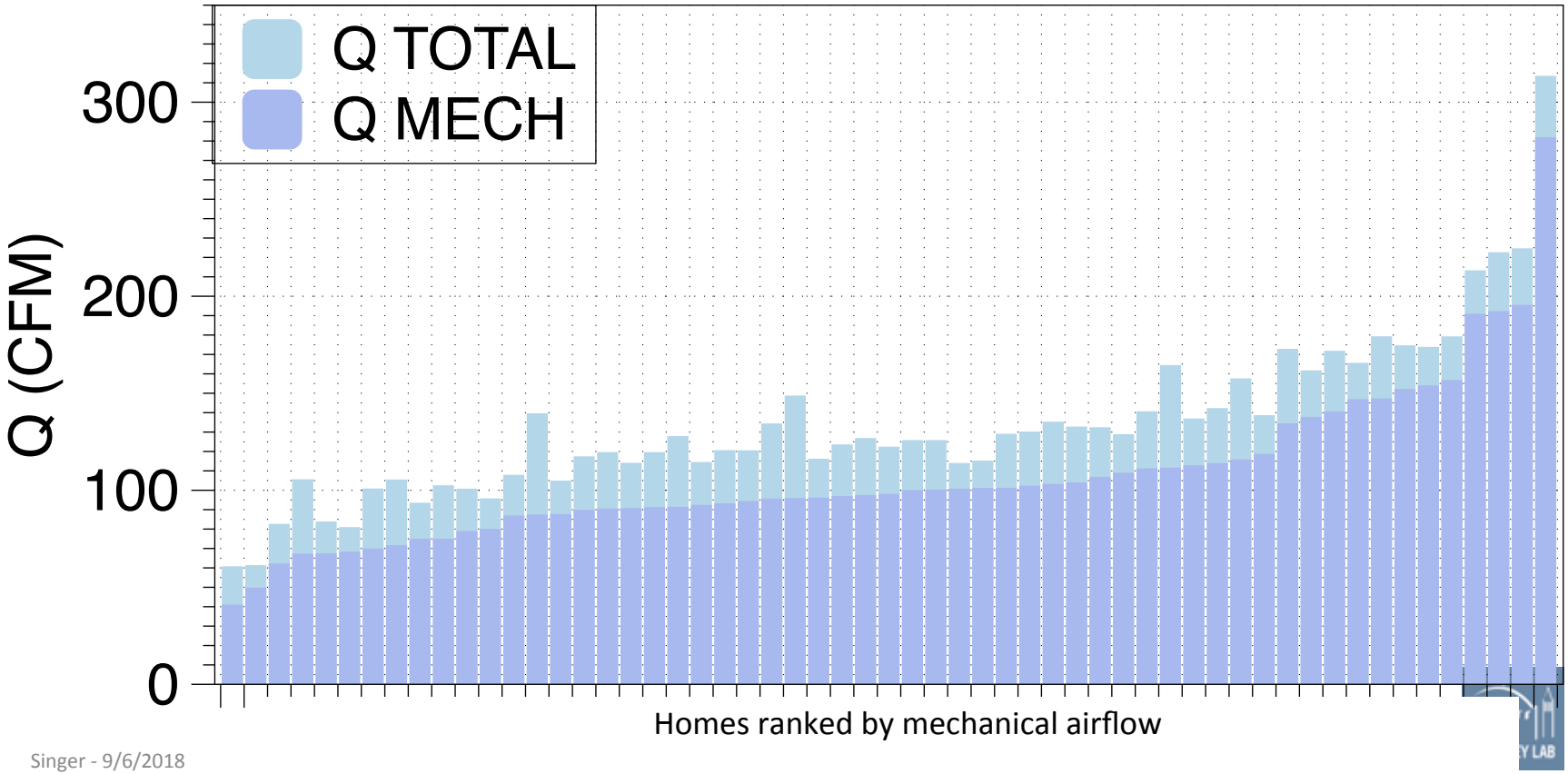
Mean required: 63 cfm
Mean provided: 96 cfm



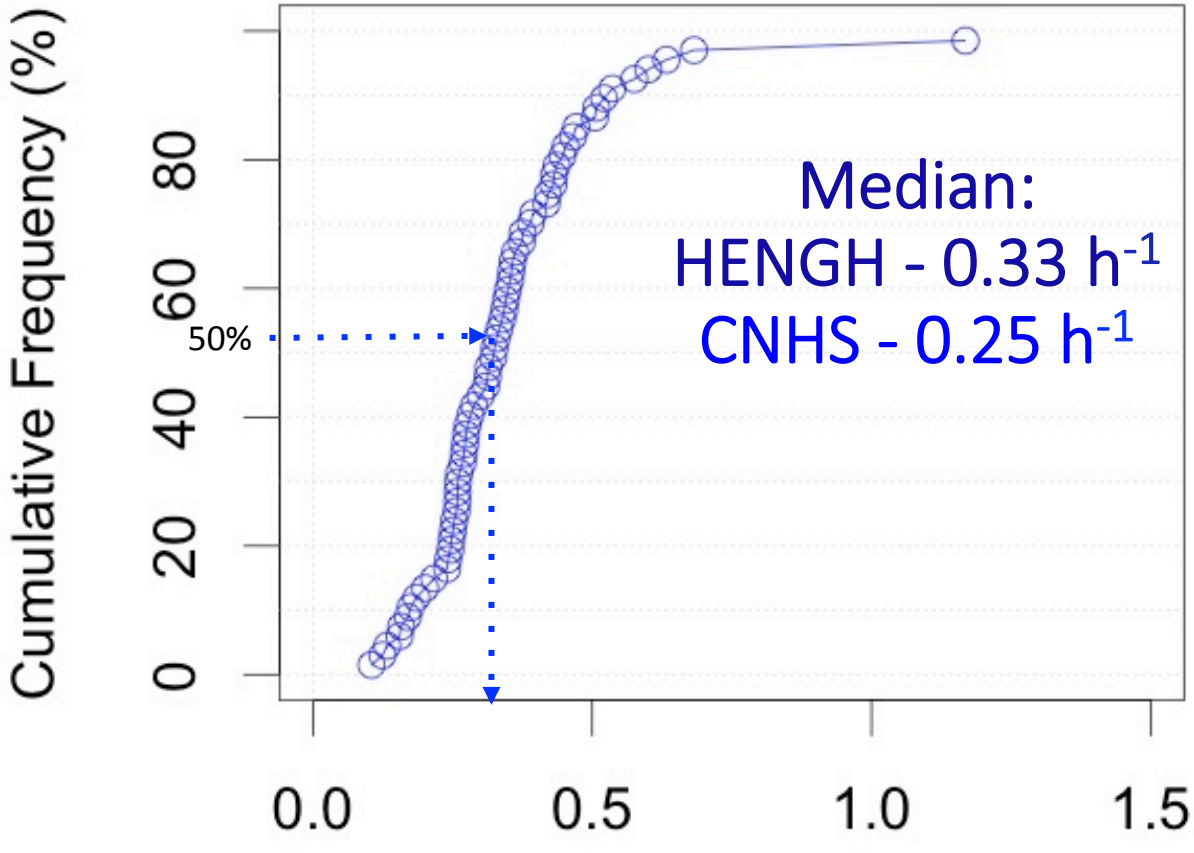
~50% above code

- 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)

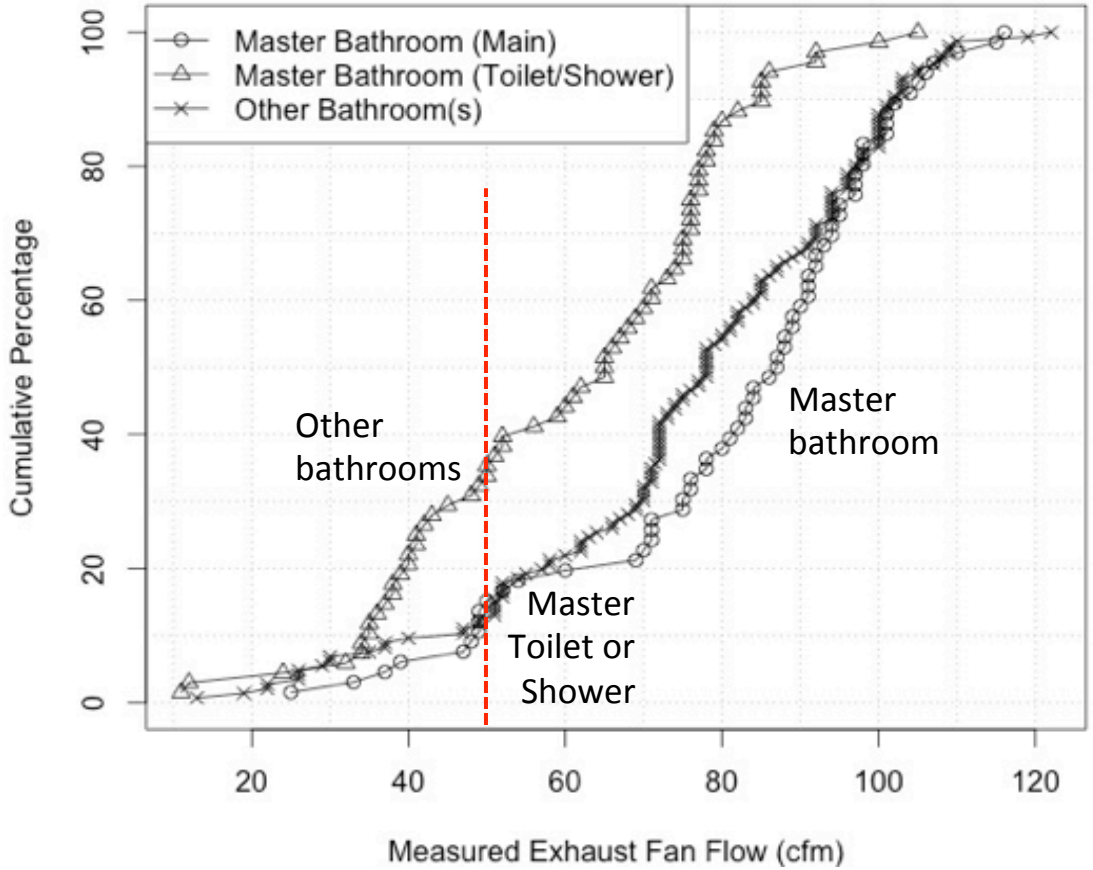
MV provided 78% of total estimated outdoor air



Most homes between 0.2 and 0.6 ach

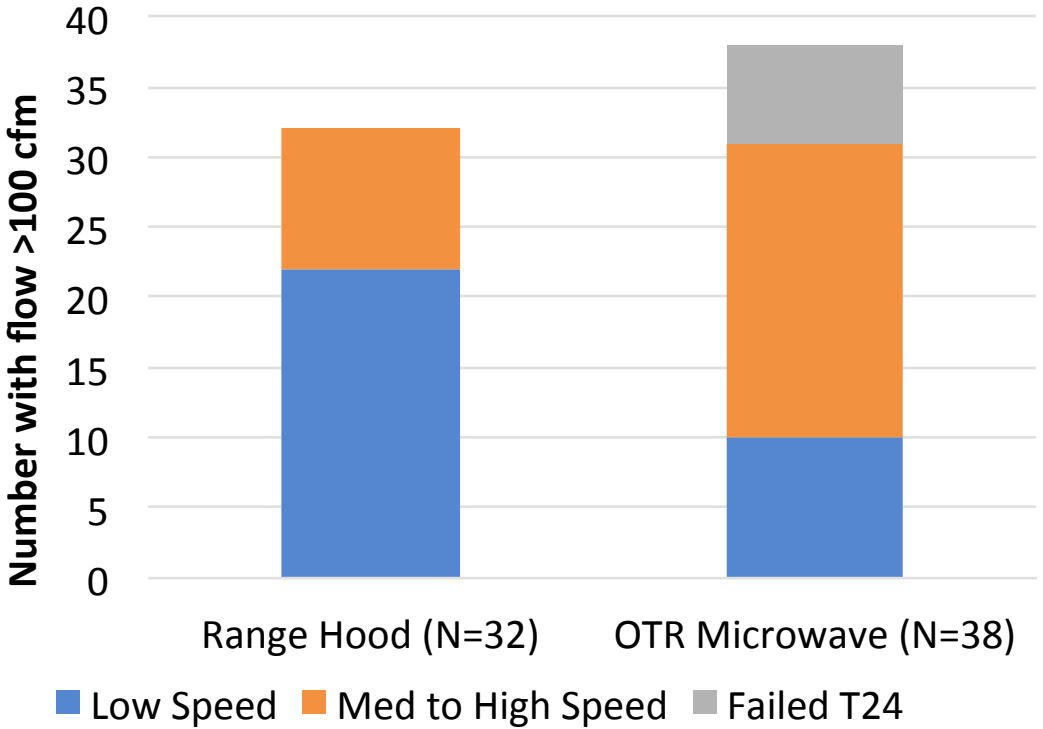


Code-compliant ventilation in 85% of master baths 1/3 of other bathrooms below code



Chan et al., Data from 70 California homes

Most range hoods met minimum airflow
Many OTR microwaves did not



$PM_{2.5}$ and formaldehyde lower in HENGH

Median Indoor Concentration	CNHS* – 98% Electric 2006–07	HENGH - Gas Homes 2016–18
Formaldehyde	30 ppb	18 ppb
$PM_{2.5}$	10.4 microg/m^3	5.0 microg/m^3
NO_2	3.1 ppb	4.4 ppb

*Offermann (2009).

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Problems Affecting Occupant Comfort a Few Times per Week or More Frequently	Online Survey Built 2002-8 SoCal (N=2271)	Field Study Built 2011-7 California (N=70)
Too hot in summer	41%	31%
Too cold in winter	20%	29%
Not enough air movement	18%	21%
Too hot in winter	10%	14%
Indoor air too dry	11%	9%
Too cold in summer	9%	4%
Too much air movement	5%	1%
Musty odor	3%	1%
Indoor air too damp	2%	1%

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

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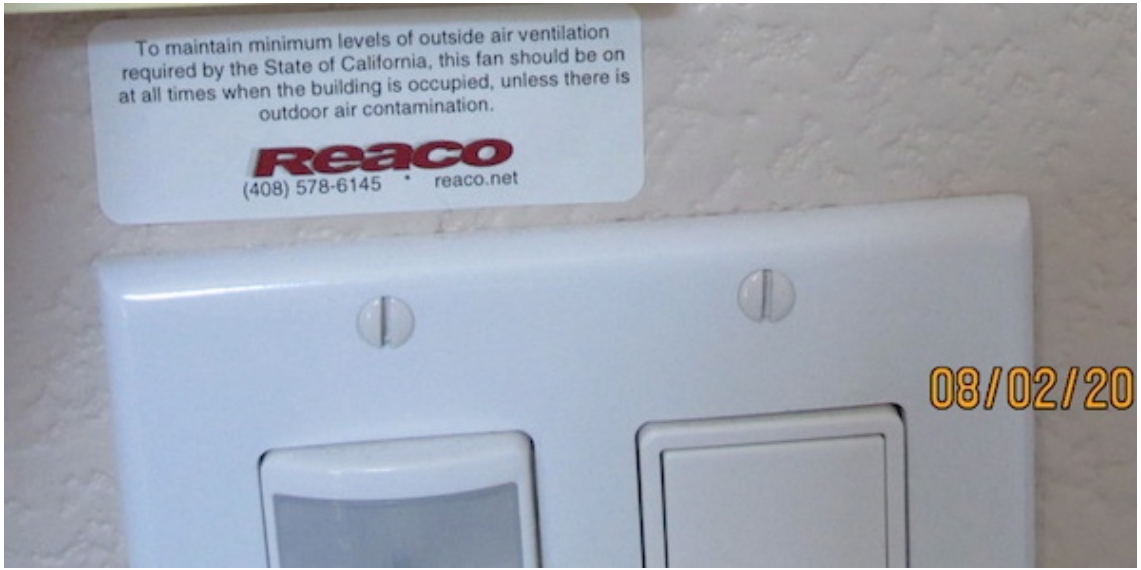
Labels made a difference

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%

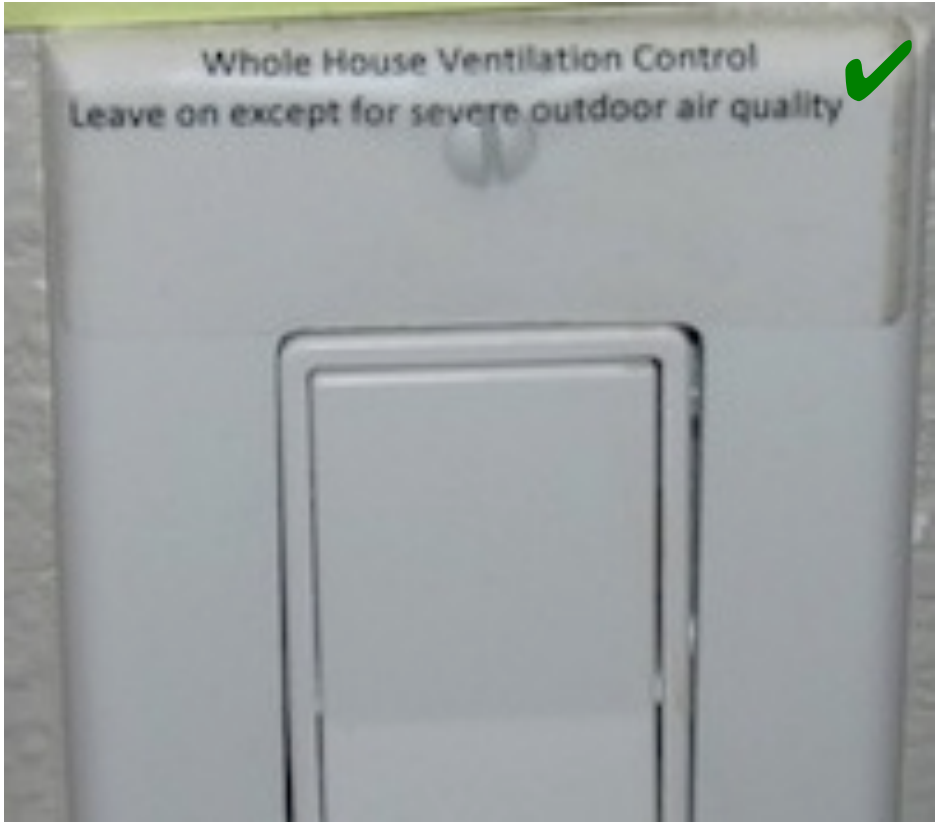
Labels not always clear

✖ CONTINUOUS DUTY

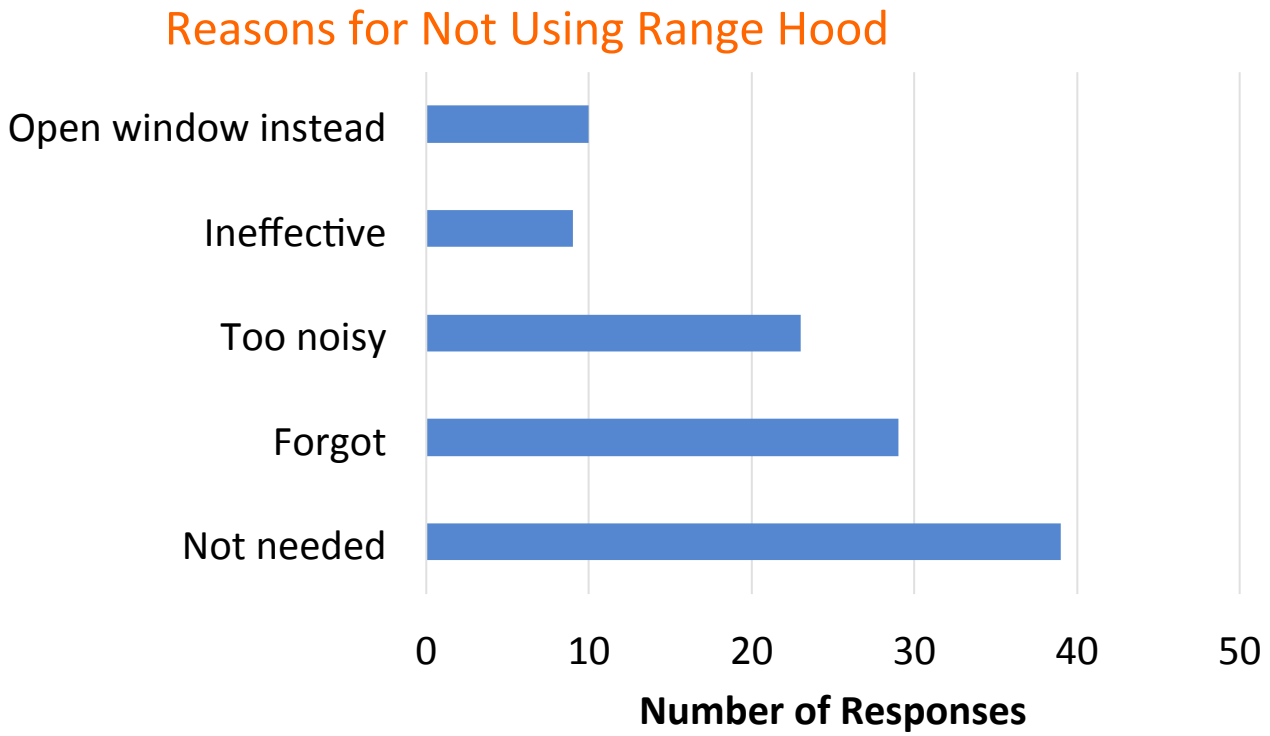
✔ To maintain minimum levels of outside air ventilation required by the State of California, this fan should be on at all times when the building is occupied, unless there is outdoor air contamination.




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

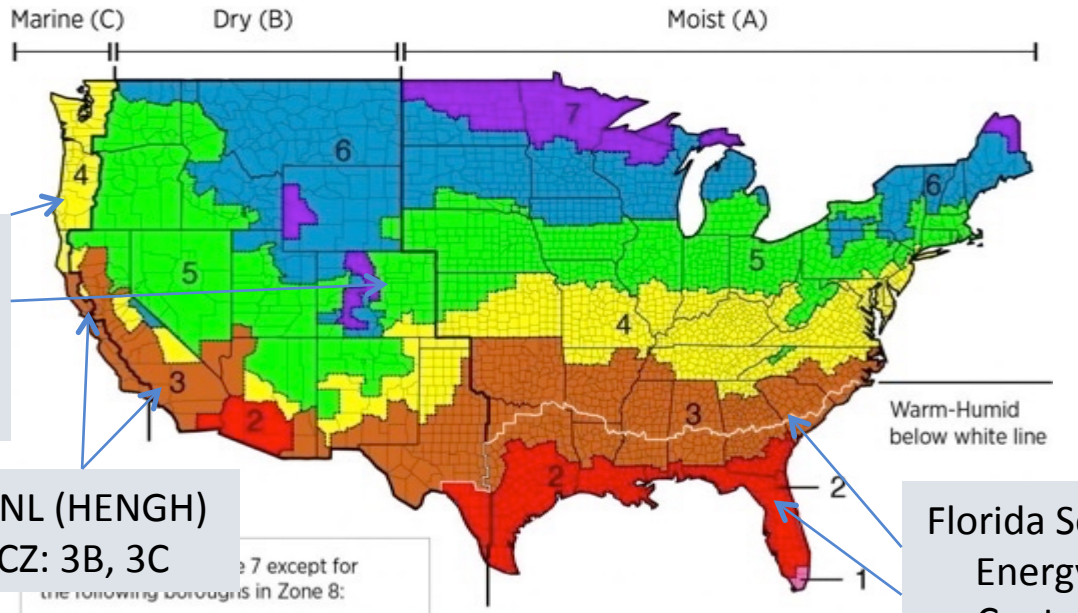

Whole House Ventilation Control
Leave on except for severe outdoor air quality

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



Building America IAQ Study

- Target 32 homes per climate zone (CZ):
  ~50% with mechanical ventilation (MV)



Pacific NW National Lab
CZ: 4C, 5B

LBNL (HENGH)
CZ: 3B, 3C

Florida Solar Energy Center
CZ: 2A, 3A

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

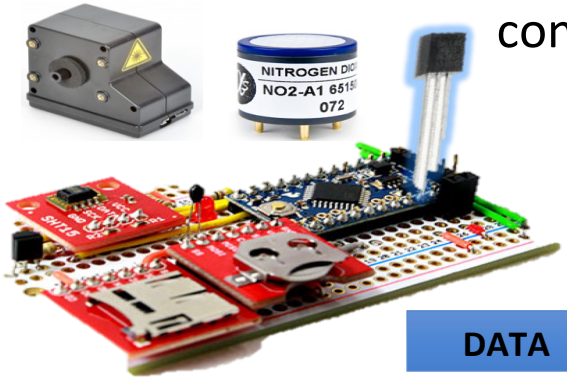
Smart Ventilation

- Larger fans with efficient, variable speed ECM motors
- Reduce outdoor air when too hot, humid, polluted, or very cold & dry
- Increase airflow at other times
- Can save energy and improve comfort

- How valuable is distribution and mixing?

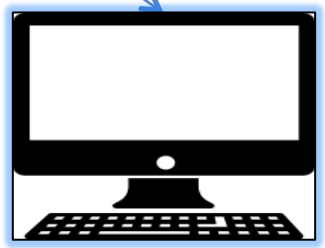
Low-cost sensors for air quality monitoring

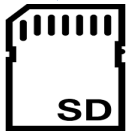
Sensors generate signals in response to environmental conditions



Calibrations translate signals to data

Cloud stores data, presents visualizations





Data sent to cloud & displays; may be stored onboard

Local displays indicate hazards and suggest mitigating actions

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Available info on sensor performance

- EPA has done some work focusing on outdoors

  https://www.epa.gov/air-sensor-toolbox

- Air quality in China

  http://aqicn.org/sensor/

- South Coast AQMD tests outdoor & in chambers

  http://www.aqmd.gov/aq-spec/home

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LBNL Evaluation of Consumer PM Monitors

AB

PM, T, RH

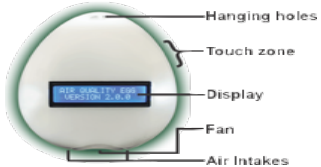
1 sec

AVN

$PM_{2.5}$, PM_{10}, CO_2, T, RH

10 sec – 15 min

AQE



PM, T, RH

1 min

AWA

PM, CO_2, VOC, T, RH,

10 sec – 5 min

FOB

PM, CO_2, VOC, T, RH,

5 min

PA

$PM_{1.0}$, $PM_{2.5}$, PM_{10}, T, RH

80 sec

SPK

PM, # particles, T, RH

1 min

These use mass-produced particle sensors that cost <$10 to $35

Evaluated for typical sources of residential PM

Burned incense, candles and cigarettes



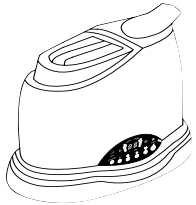



Heated pots of water, an oven, a hair dryer, and an electric burner

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



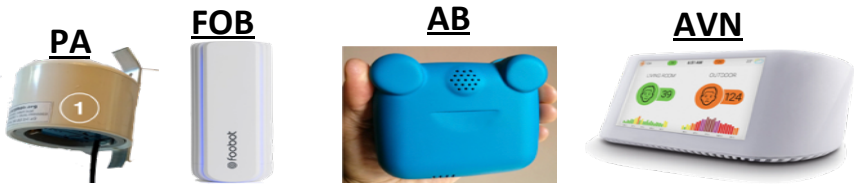




Released AZ test dust, shaked a dust mop, and operated an ultrasonic humidifier using unfiltered tap water

Four monitors detected most sources and quantitatively measured all large sources of $PM_{2.5}$

These 4 should helpful to manage IAQ.



Two consumer monitors detected many sources but not quantitatively.

One monitor was not informative.

Consumer monitors not suitable to detect & control ultrafine particles.

Results should be verified in homes.

- What fraction of $PM_{2.5}$ detected?
- How durable are the devices?

Complete study: Singer et al. 2018, Indoor Air

Which IAQ parameters do we want to measure in homes?

- Temperature and humidity
- CO_2 for demand control ventilation
- VOCs
- Odors

- Indoor pollutants
  - $PM_{2.5}$, PM_{10}, ultrafines
  - Acrolein, NO_2, CO
  - Formaldehyde, radon
  - Irritants
  - Allergens

- Outdoor pollutants
  - Diesel PM / black carbon
  - Ozone
  - $PM_{2.5}$, PM_{10}, ultrafines, NO_2

- Dampness & mold

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Which IAQ parameters do we want to measure in homes?

- Temperature and humidity
- CO_2 for demand control ventilation
- VOCs
- ~~Odors~~

Available & affordable

Available, but costly

Coming soon?

~~X~~ Not needed?

- Indoor pollutants
  - $PM_{2.5}$, PM_{10}, ultrafines
  - ~~Acrolein~~, NO_2, CO
  - Formaldehyde, radon
  - ~~Irritants~~
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- Outdoor pollutants
  - Diesel PM / black carbon
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  - $PM_{2.5}$, PM_{10}, ultrafines, NO_2
- ~~Dampness & mold~~

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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

Take the Berkeley New Home IAQ Survey

https://iaqsurvey.lbl.gov/