

IAQ @Home: How are we doing?



Brett C. Singer

Lawrence Berkeley National Lab

bcsinger@lbl.gov

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The Corsi Code



Indoors

69

In bed

26

Outside

6

79

Average life expectancy

54

At home

4.3

In vehicles

My first home



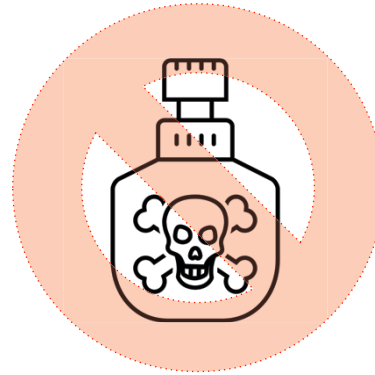
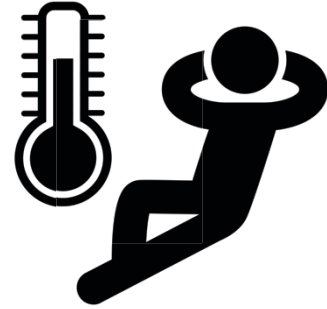
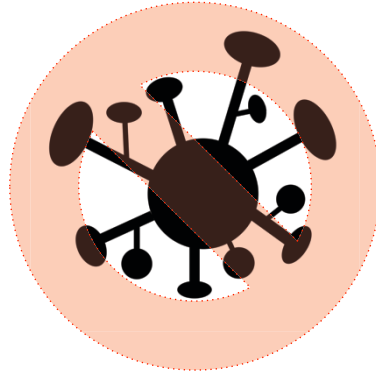
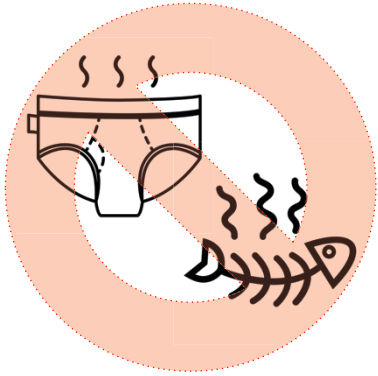
The indoor environment of my youth



cigarettezoom.com

What is Indoor Air Quality?

Indoor air quality is...



What do we have to worry about?

Particulate matter:

- PM₁₀, PM_{2.5}, Ultrafine particles
- Metals; PAH
- Acids

Nitrogen dioxide: NO₂

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 CO₂

Viruses (maybe)

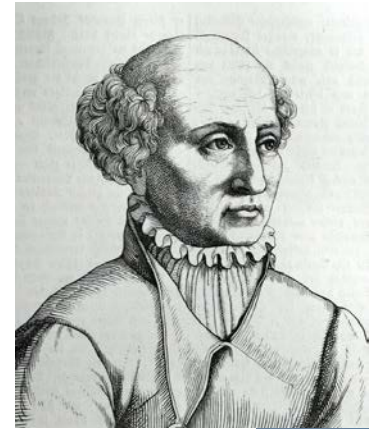
Radon

The Dose Makes the Poison

“Alle Ding sind Gift und nichts ohn Gift; allein die Dosis macht das ein Ding kein Gift ist”

All things are poison and not without poison; only the dose makes a thing not a poison.

- Paracelsus, 1493-1541



The risks of air pollution are not evenly distributed

Concentrations and exposures vary

Susceptibility varies

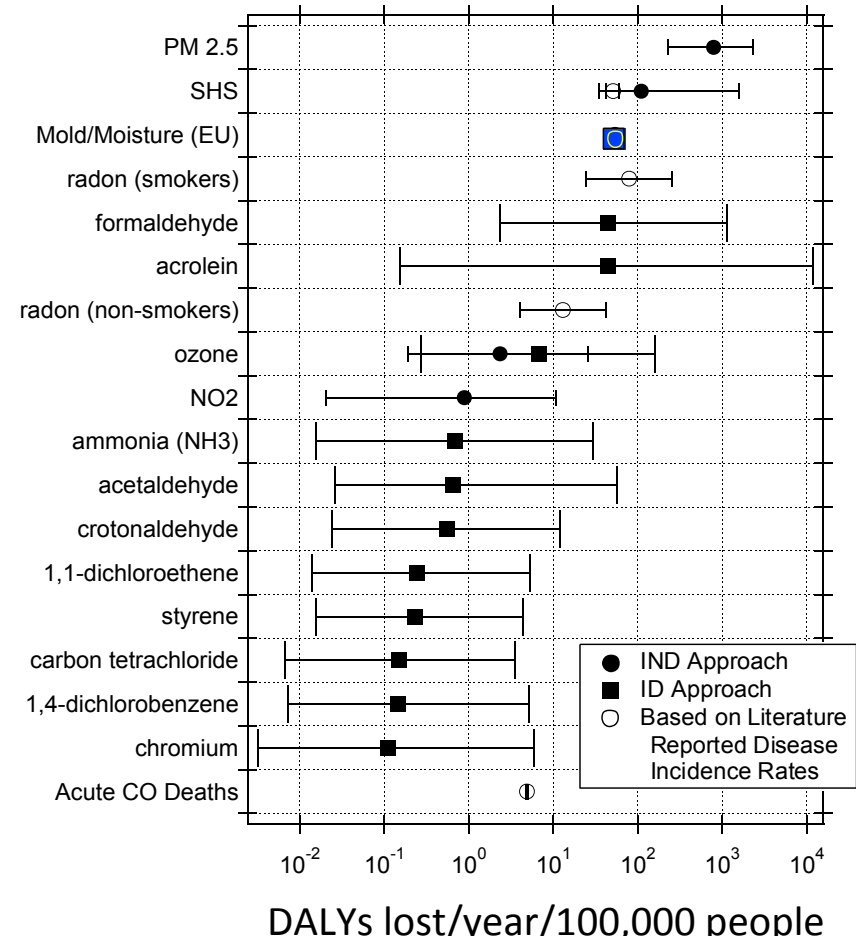
Which indoor air pollutants most impact health?

Estimate **Disability Adjusted Life Years**

DALYs consider severity of health outcomes

4-11 DALYs per 1000 people per year

PM_{2.5}
 Secondhand smoke
 Mold / moisture
 Radon
 Formaldehyde
 Acrolein, Ozone, NO₂



Fine particulate matter (PM_{2.5})

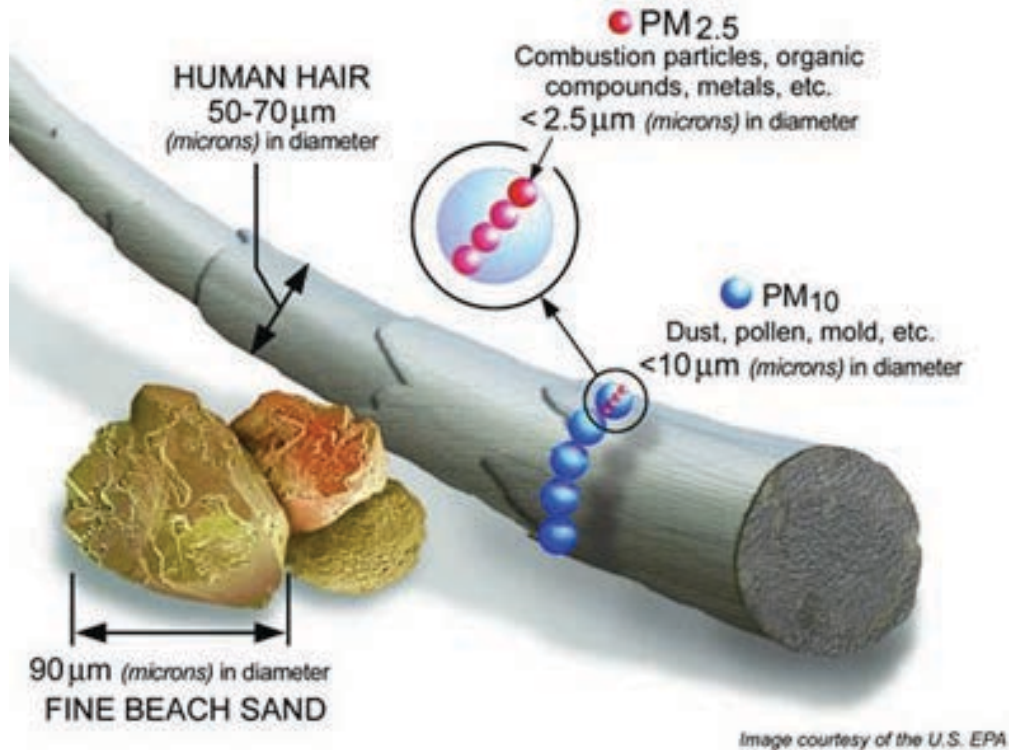


Image courtesy of the U.S. EPA

- **Higher PM_{2.5} outdoors = badness**
 - Death, strokes, and other cardiovascular illness
 - Hospital admissions for respiratory distress
 - Severity of chronic lung disease
- **Mechanisms explain many effects**
 - Lung irritation leading to more permeable lung tissue
 - Inflammation of lung tissue releases chemicals that impact heart
 - Changes in blood chemistry increase risk of clots

Sources of PM_{2.5} in homes

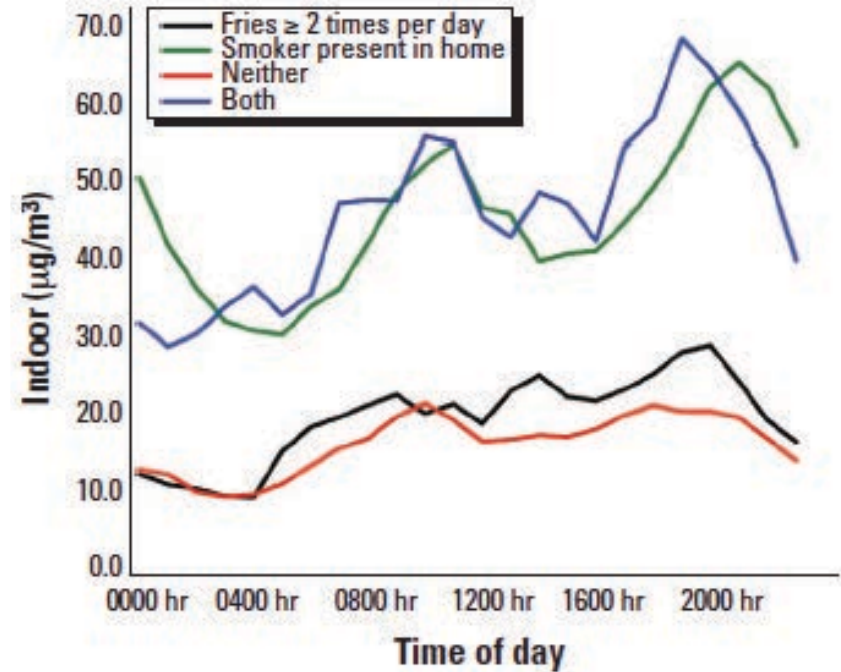


Figure 4. Diurnal variation of hourly average concentrations in homes with smokers, homes reporting frequent frying (twice a day or more), homes with both characteristics, and homes with neither characteristic.

Wallace et al., EHP, 2003, 111, 1265

Particulate matter is really complicated

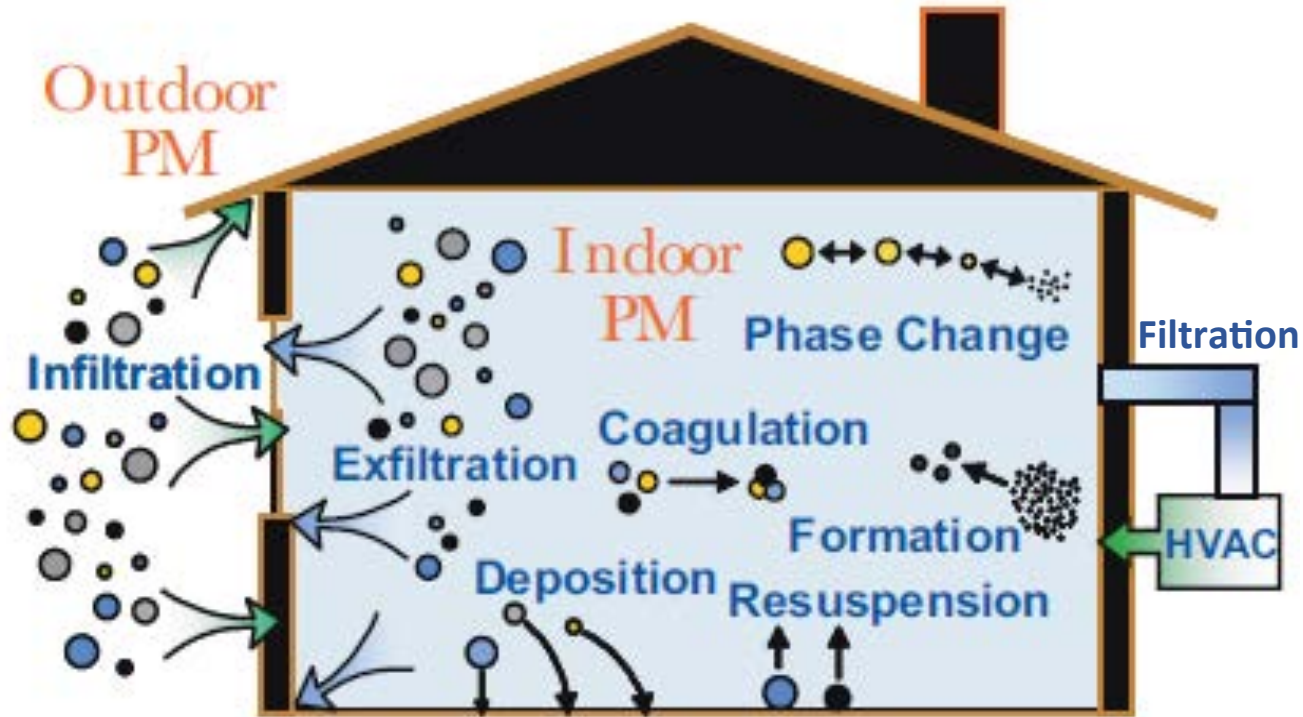


Image Ref: <http://eetd.lbl.gov/newsletter/nl14/>

Nitrogen dioxide

- Airway irritant
- Exacerbates asthma and other respiratory diseases
- Leads to cough, wheeze, etc.
- May cause asthma and increase infections
- Asthmatics, elderly and children most susceptible

Nitrogen dioxide – just a few key sources

Greatest risk from unvented heaters – from frequent and long emission events

Francisco et al., Indoor Air 2010
30 homes with unvented fireplaces
4 random days of monitoring
80% had NO₂ above ambient std

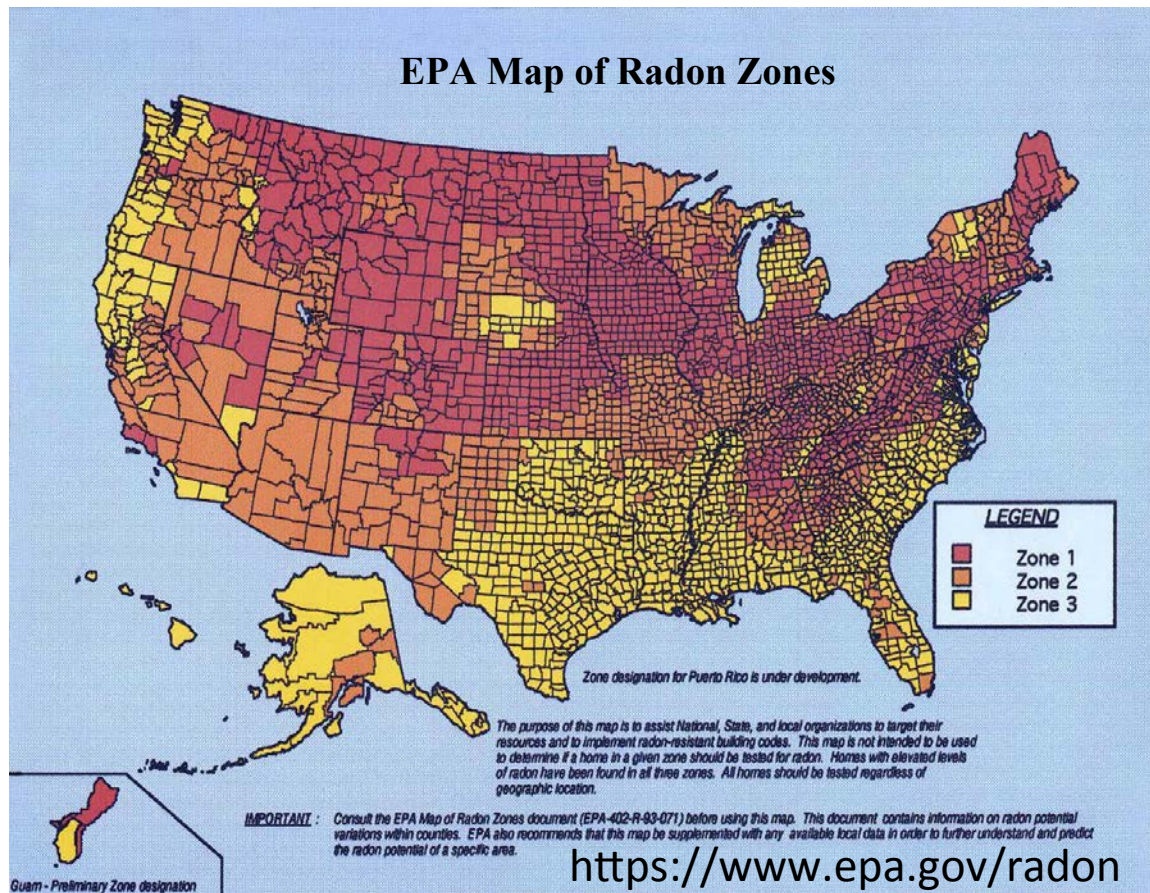


Radon will remain a hazard

Lung Cancer Risk, per 1000
Lifetime Exposure,

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

Radon entry to homes
varies with soil, season,
and weather



<https://www.epa.gov/radon>

Formaldehyde



Photo: Wikipedia

Urea-formaldehyde foam insulation, used 1930-1970s. Banned in 1980 in Canada and in 1983 in US.



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



Guidelines vary by 10x

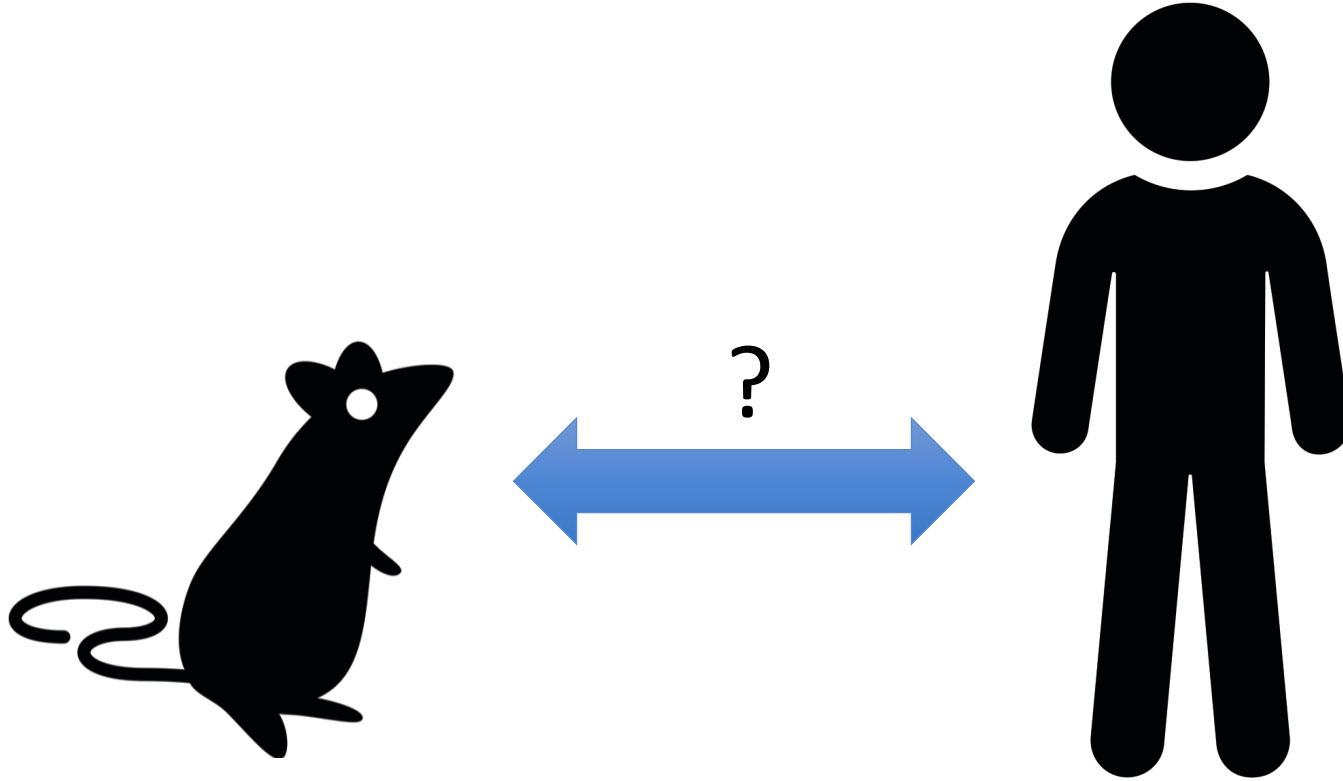
California: 7 ppb

Canada: 40 ppb

Germany, UK,

China & WHO: 80 ppb

Uncertainty in formaldehyde guidelines



Reducing IAQ Risks

The Healthy Home Code

1. Dry
2. Clean
3. Safe from hazards
4. Well-Ventilated
5. Pest-free
6. Contaminant-free
7. Well-Maintained

Source: www.hud.gov/healthyhomes



The graphic features a dark blue header with the U.S. Department of Housing and Urban Development logo on the left and the text 'Healthy Homes' in large white font on the right. Below the header, a black and white photograph of a young child's face is shown on the left side. To the right of the photo is a yellow box containing the title 'Seven Tips for Keeping a Healthy Home' and a numbered list of seven tips. At the bottom of the graphic, the website address 'www.hud.gov/healthyhomes' is displayed in white text on a dark blue background.

Healthy Homes
U.S. Department of Housing and Urban Development • Office of Healthy Homes and Lead Hazard Control

Seven Tips for Keeping a Healthy Home

- 1. Keep it Dry**
Prevent water from entering your home through leaks in roofing systems, rain water from entering the home due to poor drainage, and check your interior plumbing for any leaking.
- 2. Keep it Clean**
Control the source of dust and contaminants, creating smooth and cleanable surfaces, reducing clutter, and using effective wet-cleaning methods.
- 3. Keep it Safe**
Store poisons out of the reach of children and properly label. Secure loose rugs and keep children's play areas free from hard or sharp surfaces. Install smoke and carbon monoxide detectors and keep fire extinguishers on hand.
- 4. Keep it Well-Ventilated**
Ventilate bathrooms and kitchens and use whole house ventilation for supplying fresh air to reduce the concentration of contaminants in the home.
- 5. Keep it Pest-free**
All pests look for food, water and shelter. Seal cracks and openings throughout the home; store food in pest-resistant containers. If needed, use sticky-traps and baits in closed containers, along with least toxic pesticides such as boric acid powder.
- 6. Keep it Contaminant-free**
Reduce lead-related hazards in pre-1978 homes by fixing deteriorated paint, and keeping floors and window areas clean using a wet-cleaning approach. Test your home for radon, a naturally occurring dangerous gas that enters homes through soil, crawlspaces, and foundation cracks. Install a radon removal system if levels above the EPA action-level are detected.
- 7. Keep it Well-Maintained**
Inspect, clean and repair your home routinely. Take care of minor repairs and problems before they become large repairs and problems.

www.hud.gov/healthyhomes

How do we reduce our risk?

Source reduction



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graph TD; A[Source reduction] --> B[Source ventilation]; B --> C[Filtration and air cleaning]; C --> D[General ventilation (with clean air)]
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Source ventilation

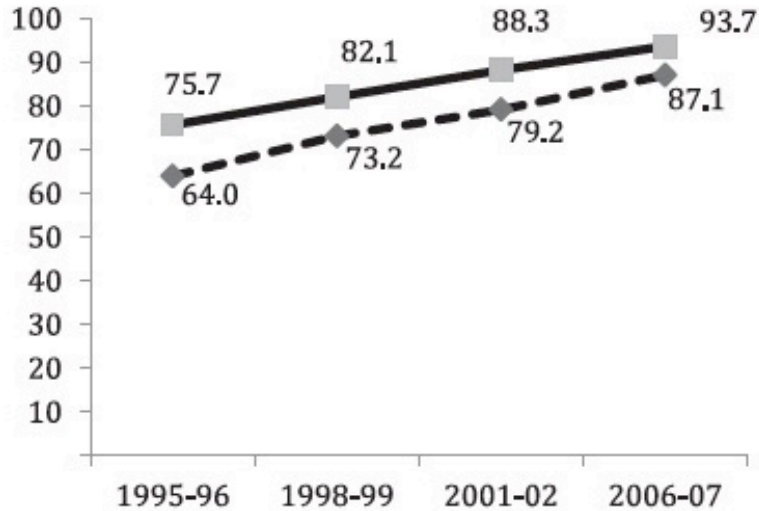
Filtration and air cleaning

General ventilation (with clean air)

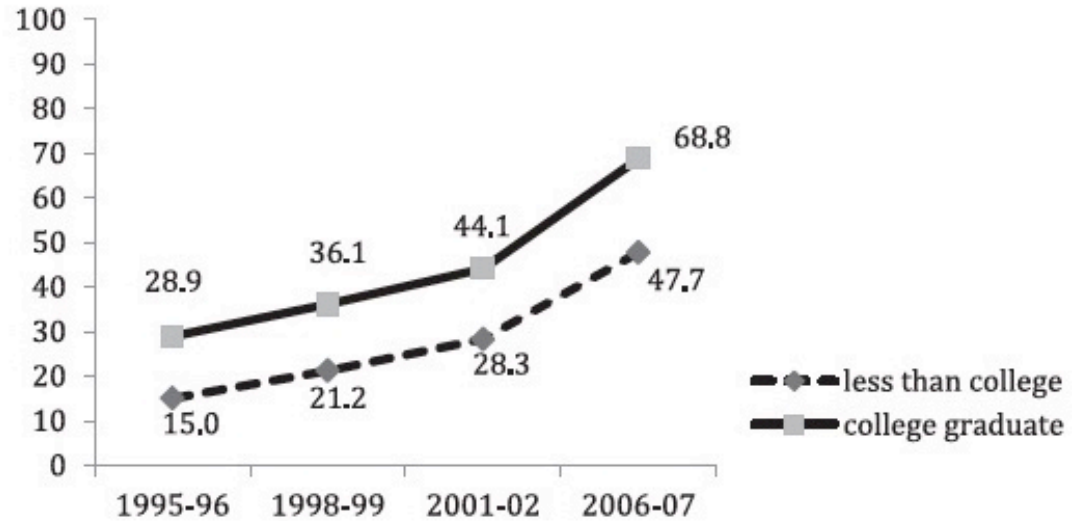
Pollutant Source Reduction

Progress: Smoking now banned in most US homes

% of **non-smoker** households
with smoking bans



% of **smoker** households
with smoking bans



Zhang et al., Nicotine and Tobacco Research, V15, 1978-1987, 2013,



Smoking banned in public housing

U.S. Imposes Nationwide Ban On Smoking In All Public Housing

November 30, 2016 · 5:49 PM ET



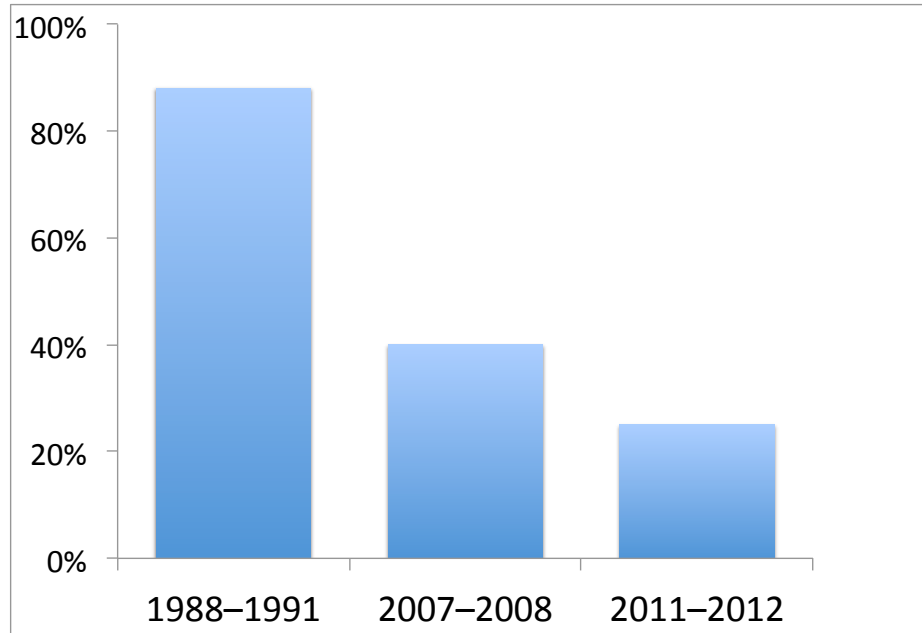
Implemented 8/1/2018



Source: NPR's The Two Way, Accessed 8/4/18

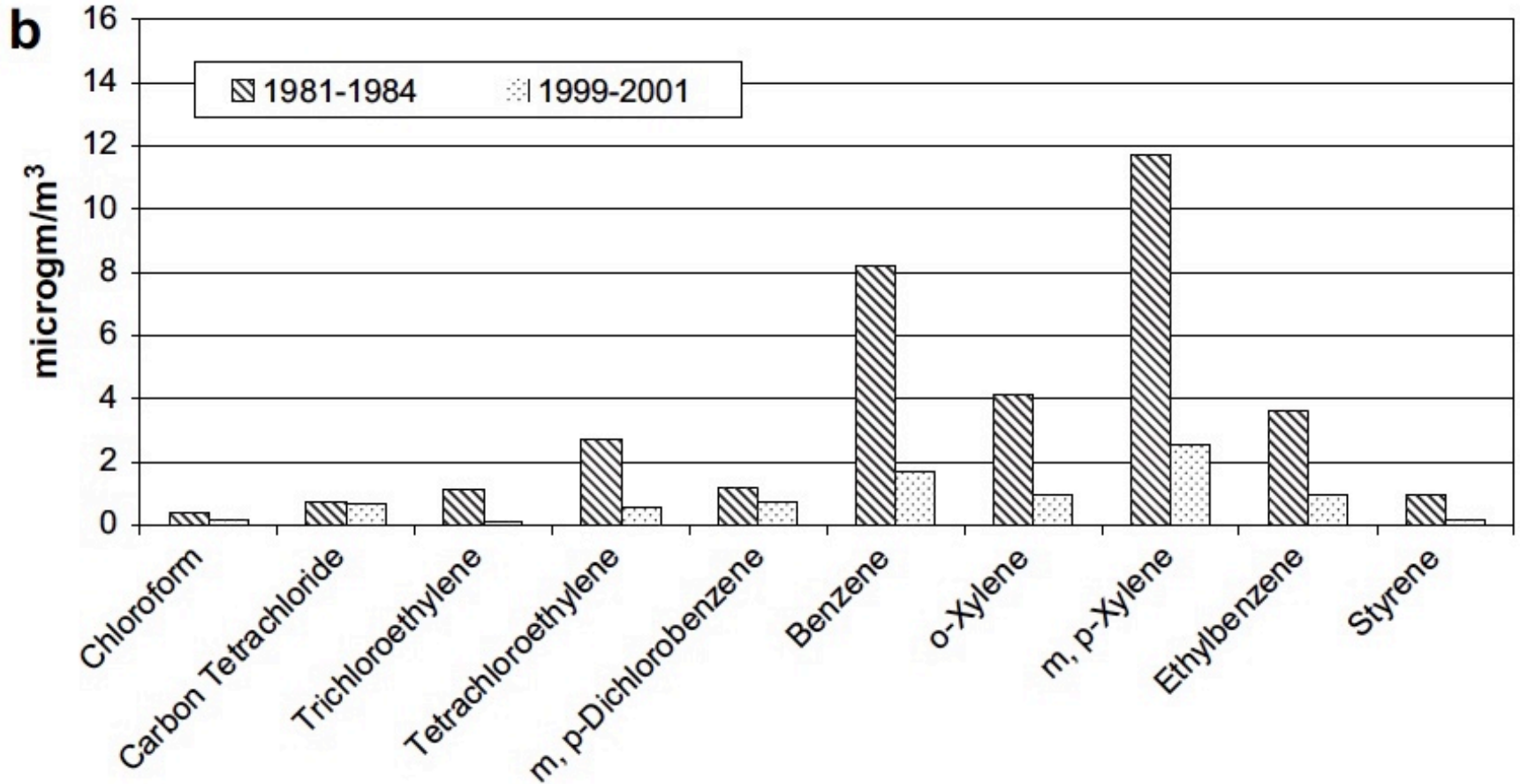
Smoking bans reduce exposure

Non-smokers with measurable cotinine

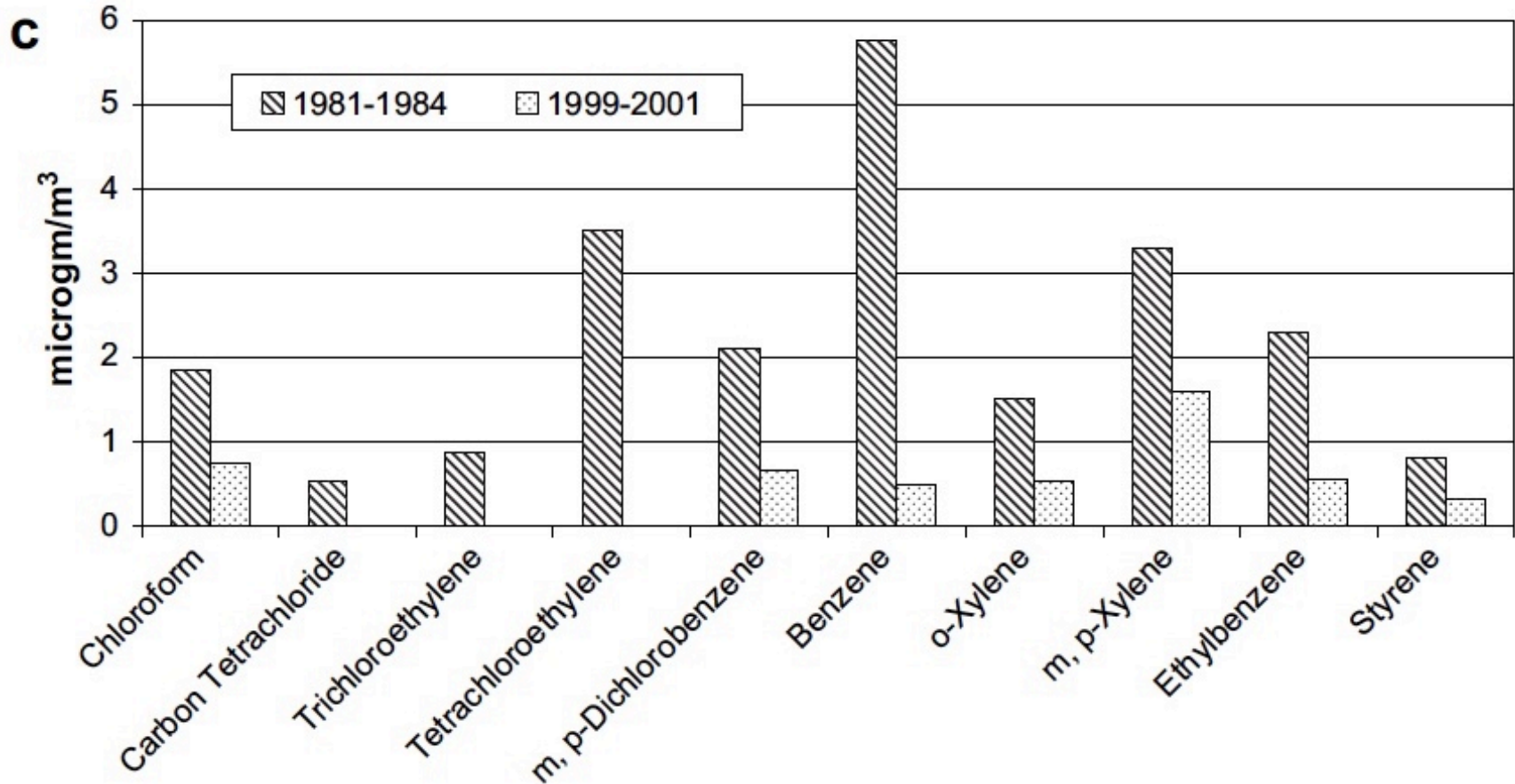


Data from https://www.cdc.gov/tobacco/data_statistics/fact_sheets/secondhand_smoke/general_facts/index.htm
Accessed 8/4/18

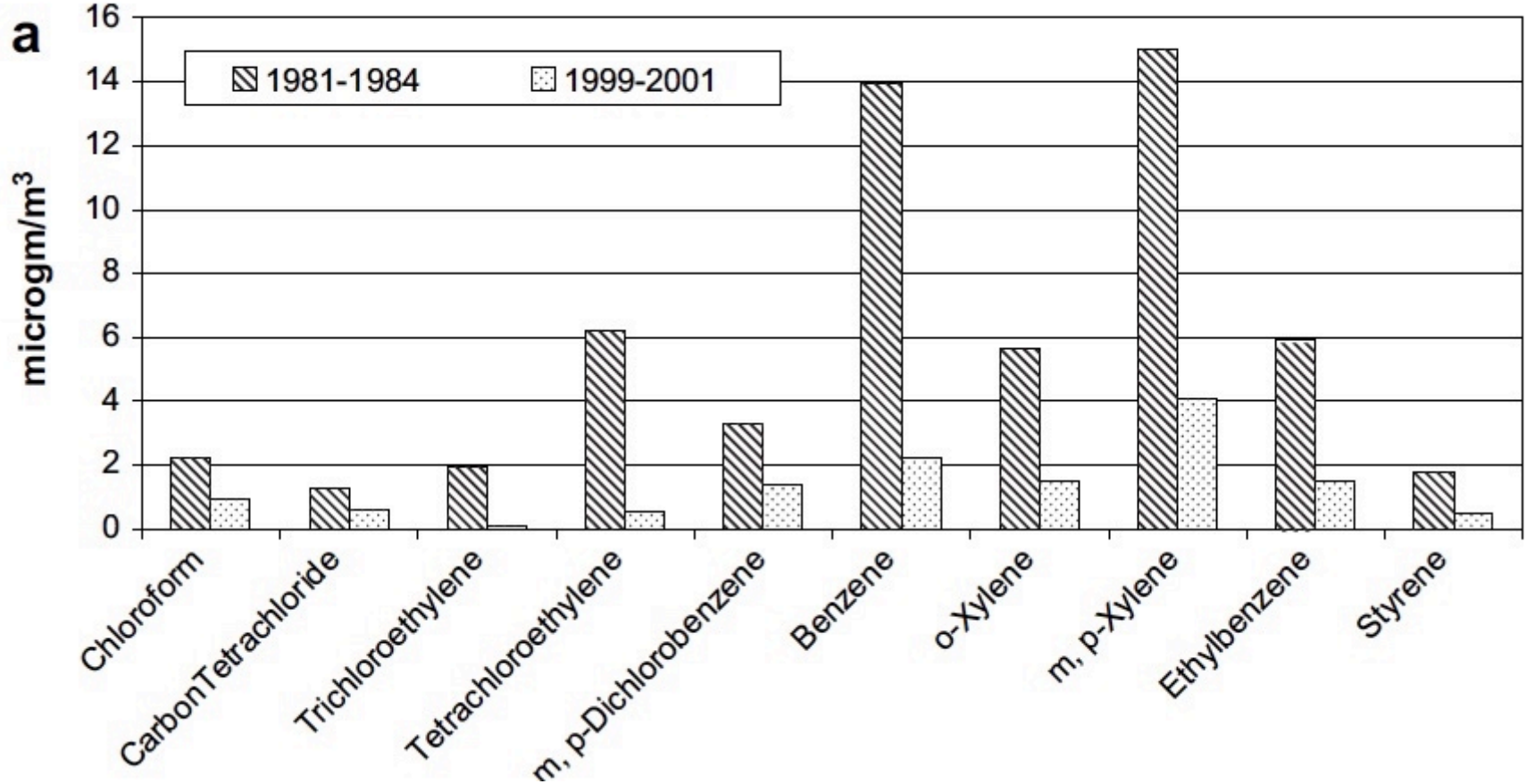
VOCs have decreased *outside*



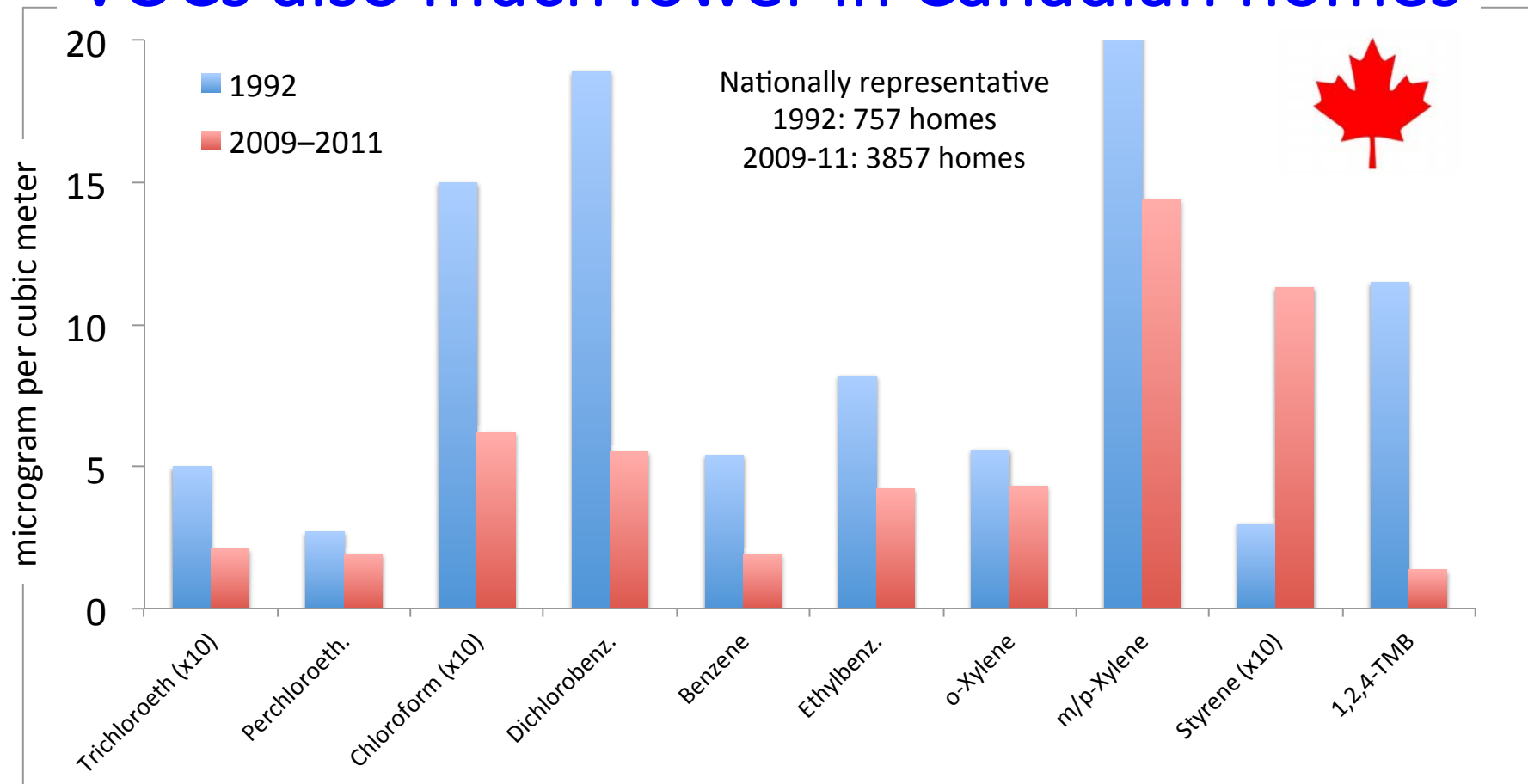
Emissions have decreased inside



...leading to VOC reductions inside homes



VOCs also much lower in Canadian homes



Formaldehyde Emission Standards

California Environmental Protection Agency | AIR RESOURCES BOARD

FREQUENTLY ASKED QUESTIONS FOR CONSUMERS

REDUCING FORMALDEHYDE EMISSIONS FROM

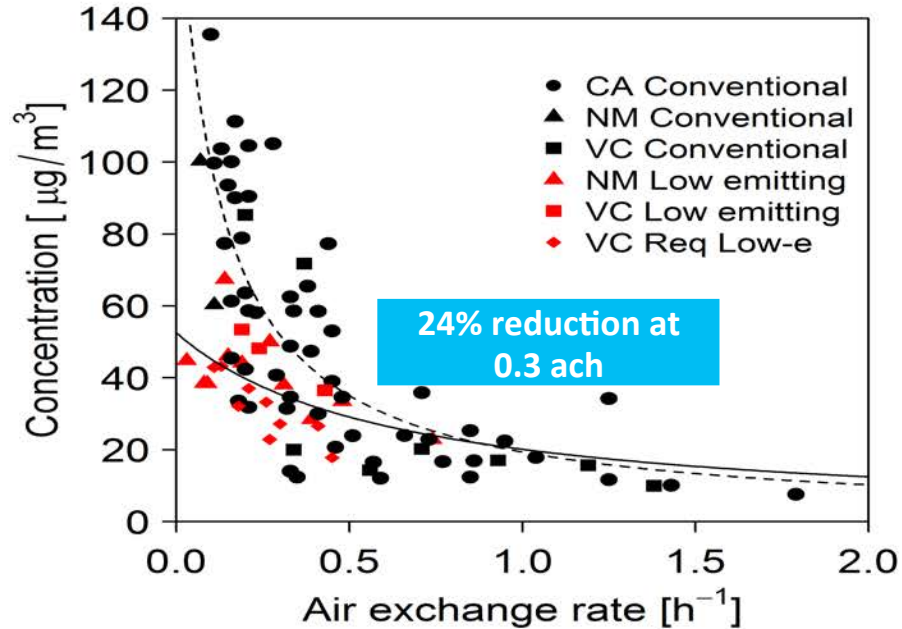
Composite Wood Products

California rule effective January 1, 2009
US Formaldehyde Control Act in 2010
Products labeled starting June 1, 2018



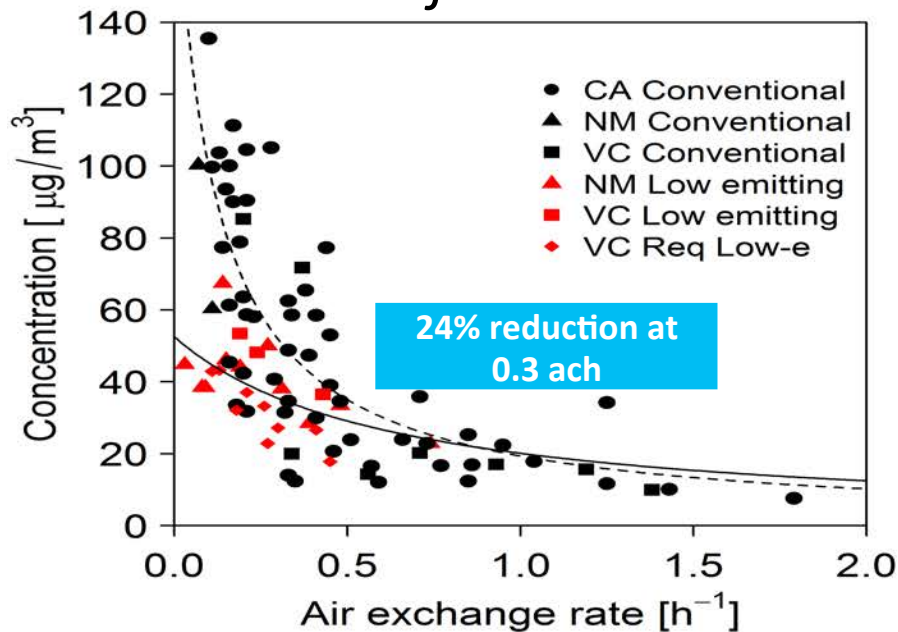
Homes built with low-emitting materials have lower formaldehyde concentrations

Unadjusted

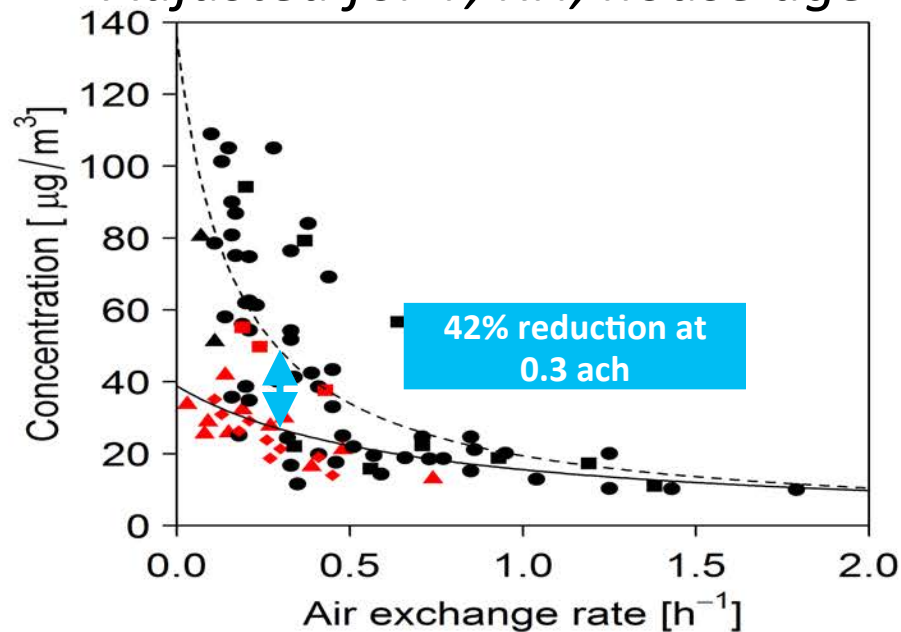


Homes built with low-emitting materials have lower formaldehyde concentrations

Unadjusted



Adjusted for T, RH, house age



Benefits of exposure reduction vary

<u>Reducing</u>	<u>by</u>	<u>Saves how many cancers?</u>
Benzene	10 microg/m ³	20-80 per million people
Formaldehyde	10 microg/m ³	120 per million people
Radon	10 pCi/L	18,000 per million <i>non-smokers</i>

These are *lifetime* benefits.

Indoor pollutants overall: 4,000-11,000 DALYs per year per 1M

For PM, very helpful to reduce entry from outdoors

A large fraction of indoor PM comes from outdoors

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

RIOPA Study¹

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

MESA Air² (n=353 homes) – **80%**

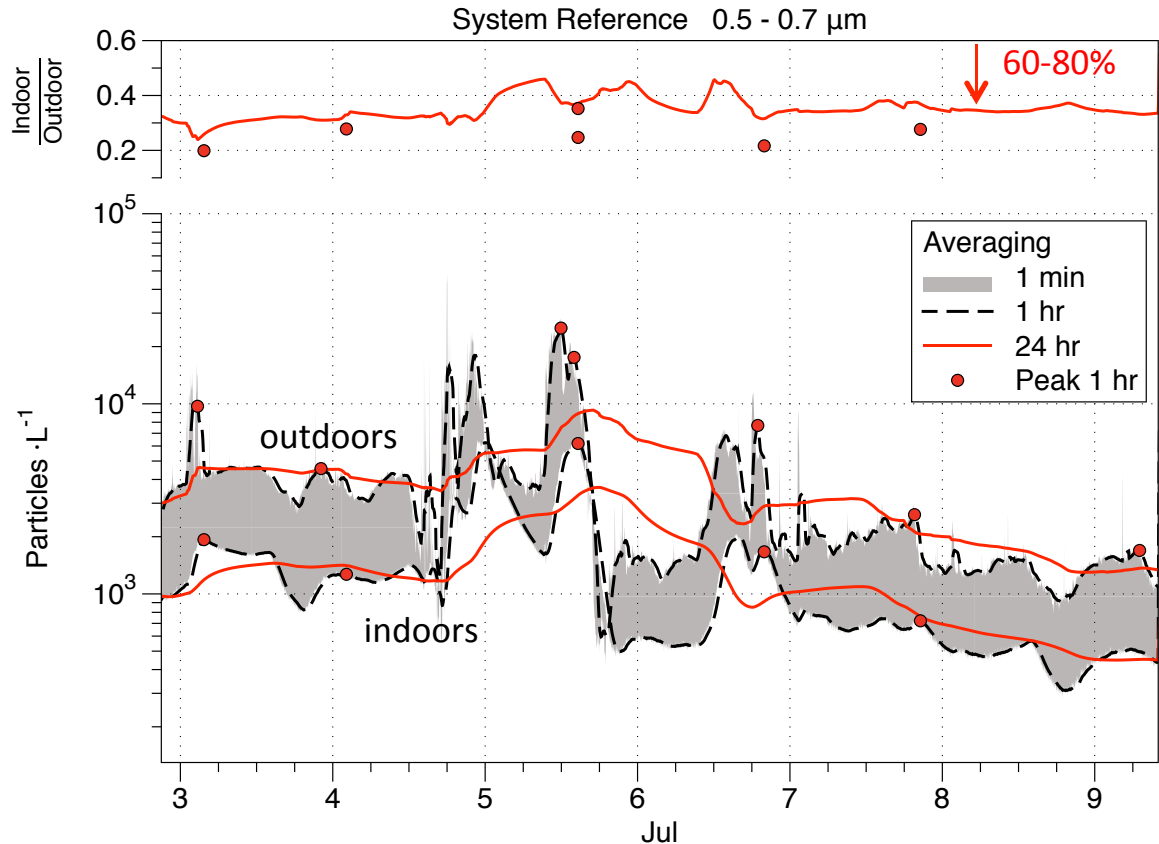
- Baltimore,
- Chicago,
- Los Angeles,
- New York,
- Rockland,
- St. Paul,
- Winston-Salem

Air tightness helps reduce outdoor particles

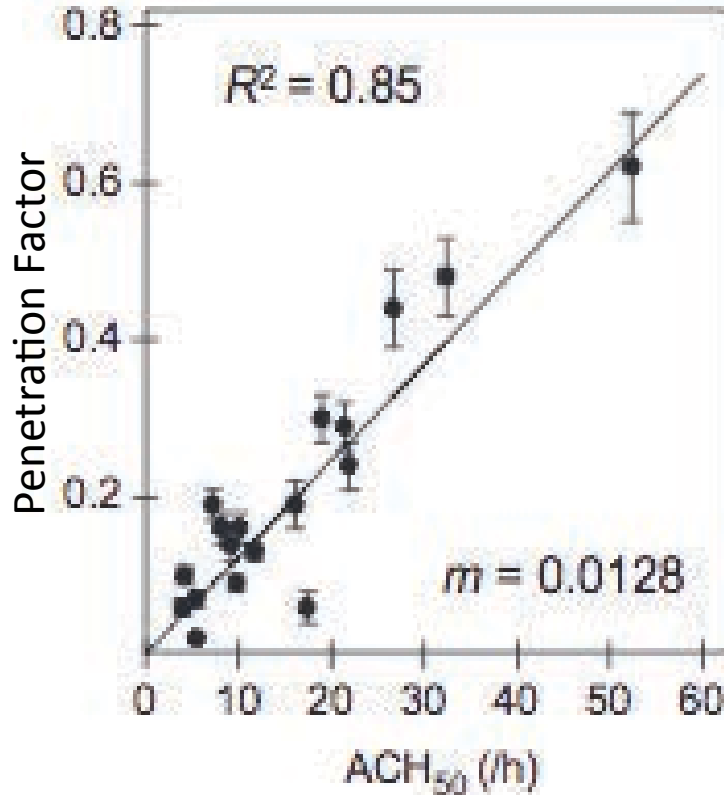


Built 2006, 1200 sf, 5 ach50,
Sealed ducts, 0.22 ach natural
Exhaust ventilation, MERV4 filter

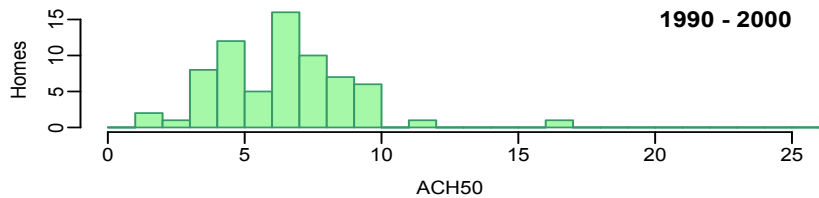
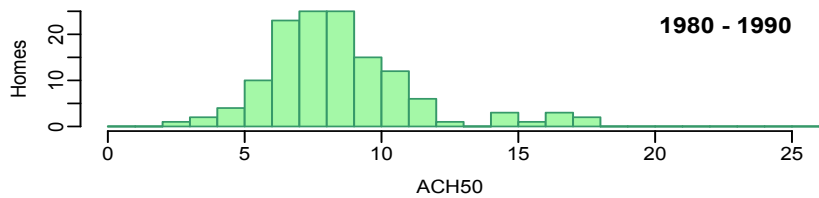
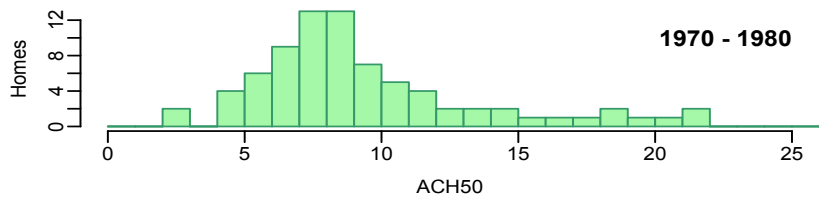
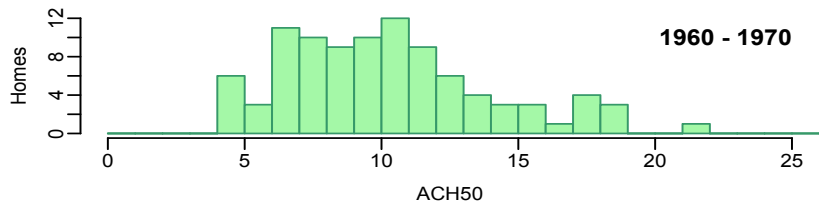
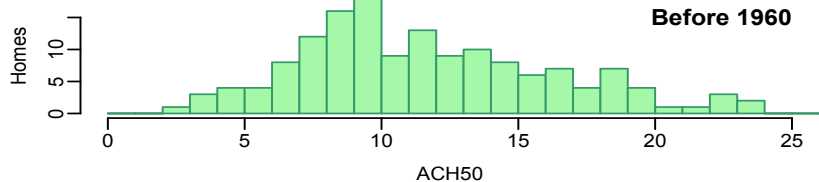
PM_{2.5} inside was
**~50% lower than
outdoors**



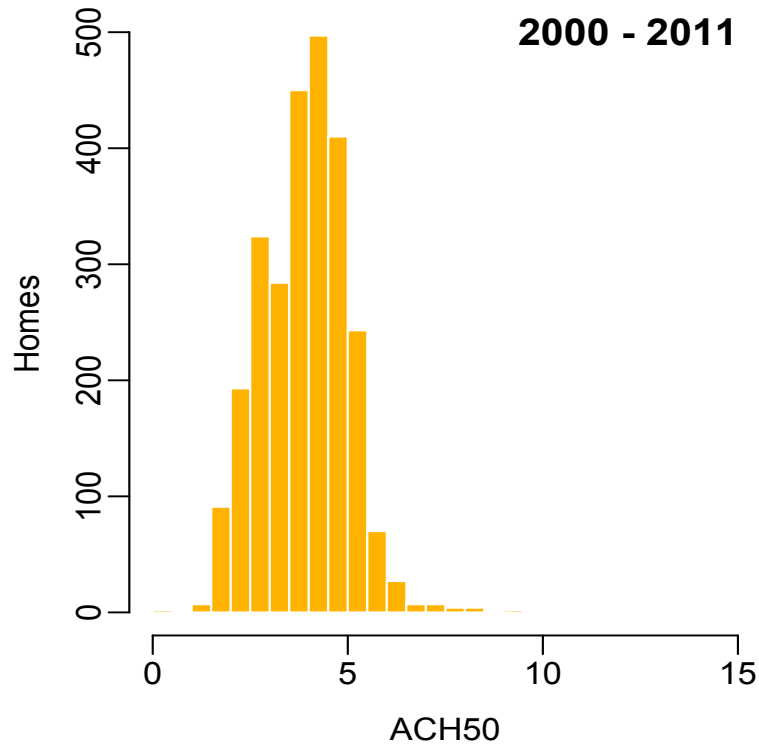
More airtight homes have lower particle penetration rates



The penetration factor is the fraction of outdoor particles that make it into the house with infiltrating air



Homes are much tighter than they used to be



Source: resdb.lbl.gov, Chan et al. 2013, California data

What to do for Radon? **Always Test!**

Existing Homes:

Test for as long as feasible

If short test is 2-8 pCi/L,
test for longer.

If >8 pCi/L, test for longer
or mitigate, then test

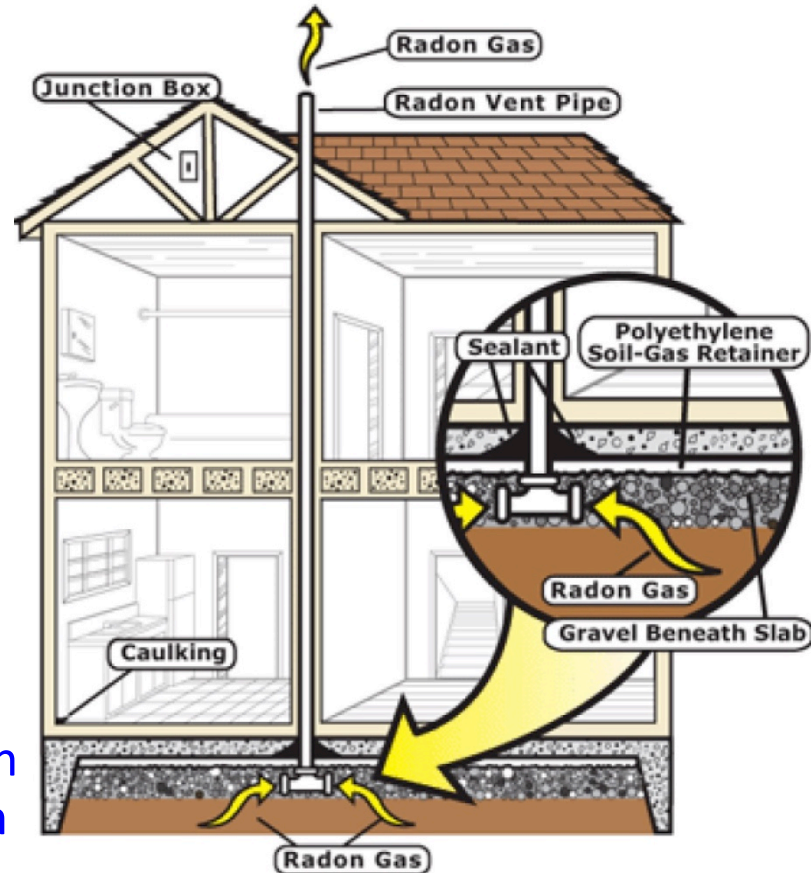
EPA guidance is to retest if
first test is >4 pCi/L.

New Homes:

If in Zone 1,
install passive
system & test

Passive Soil Depressurization

- Reduces driving force for entry through slab
- Enables easy installation of fan for active system



Source (Kitchen) Ventilation

Cooking & burners are important sources



CO₂ & H₂O

NO, NO₂, HONO,
Formaldehyde

Ultrafine particles



Ultrafine particles, PM_{2.5}

Formaldehyde, Acetaldehyde

Acrolein, PAH



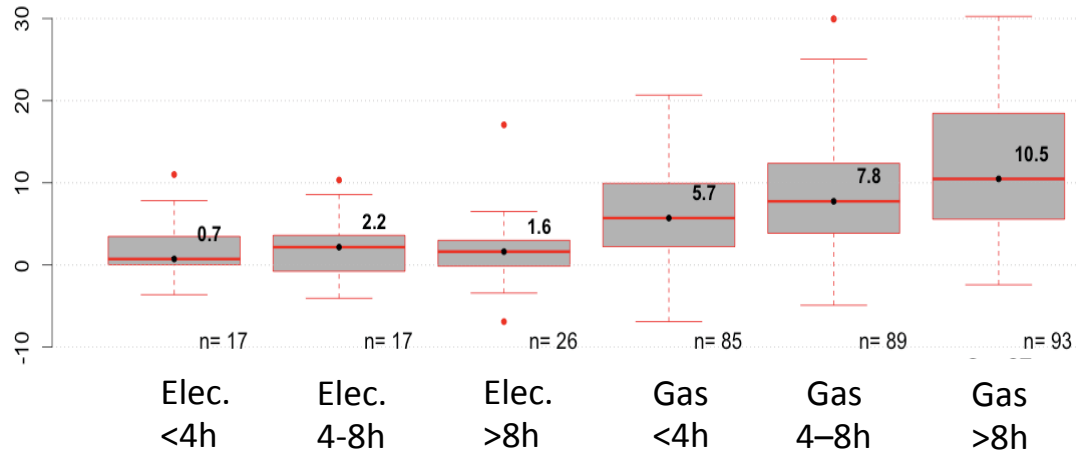
Ultrafine
particles



Gas cooking burners can have big impact

Measurements in 350 California homes;
1-week integrated, winter season

Indoor source contribution to Bedroom NO_2

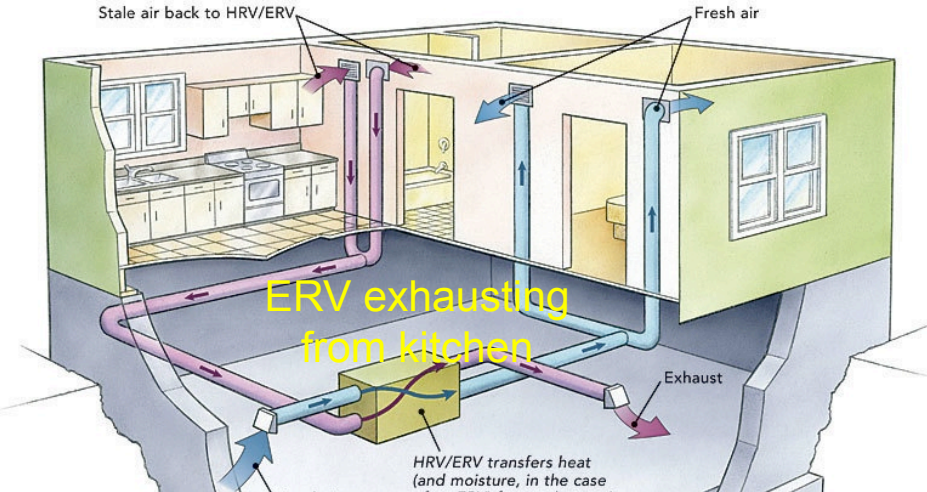


Burner fuel and total amount of cooking in a week

Kitchen ventilation options



Exhaust fan on wall



Ceiling exhaust fan



Studies of range hood performance



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



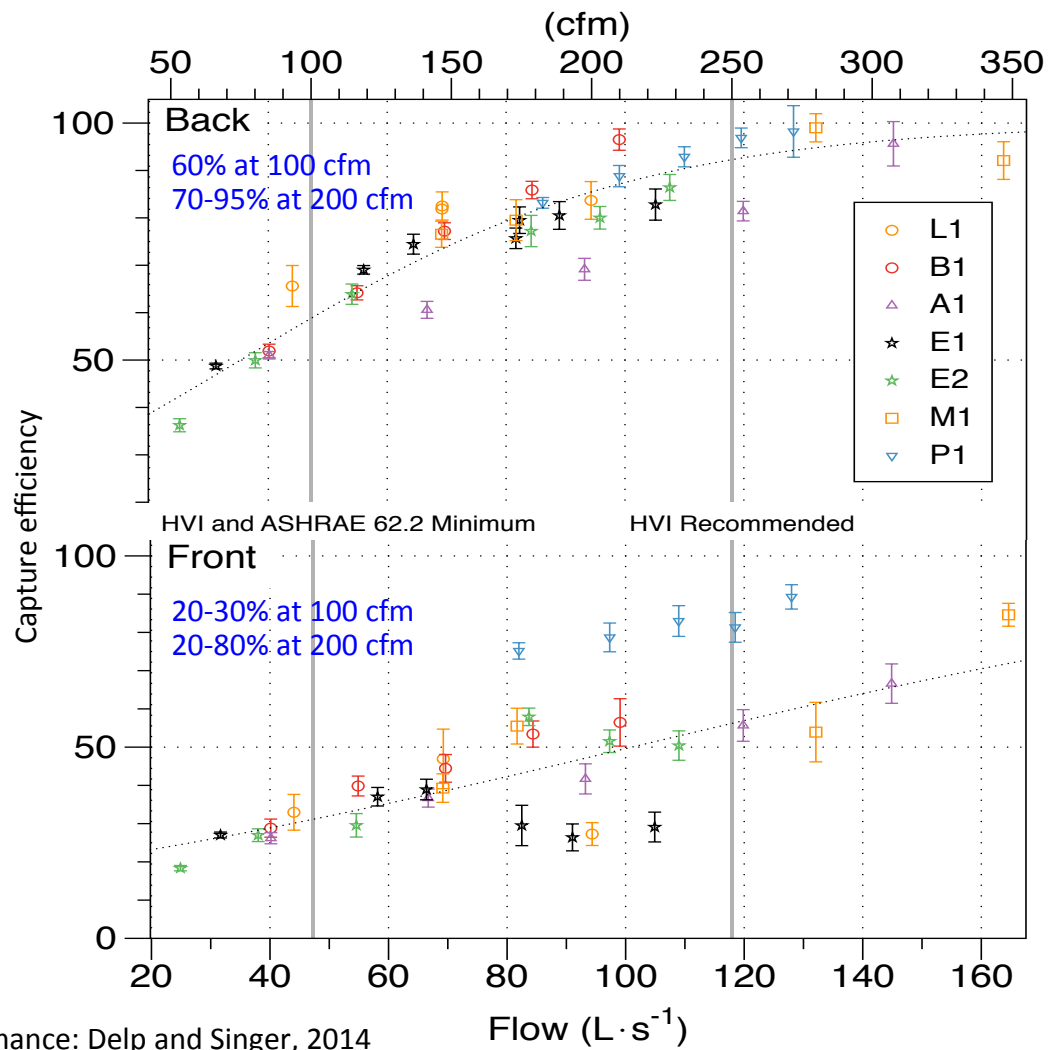
7 devices

- 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

Studies of range hood performance



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



As installed range hood performance varies

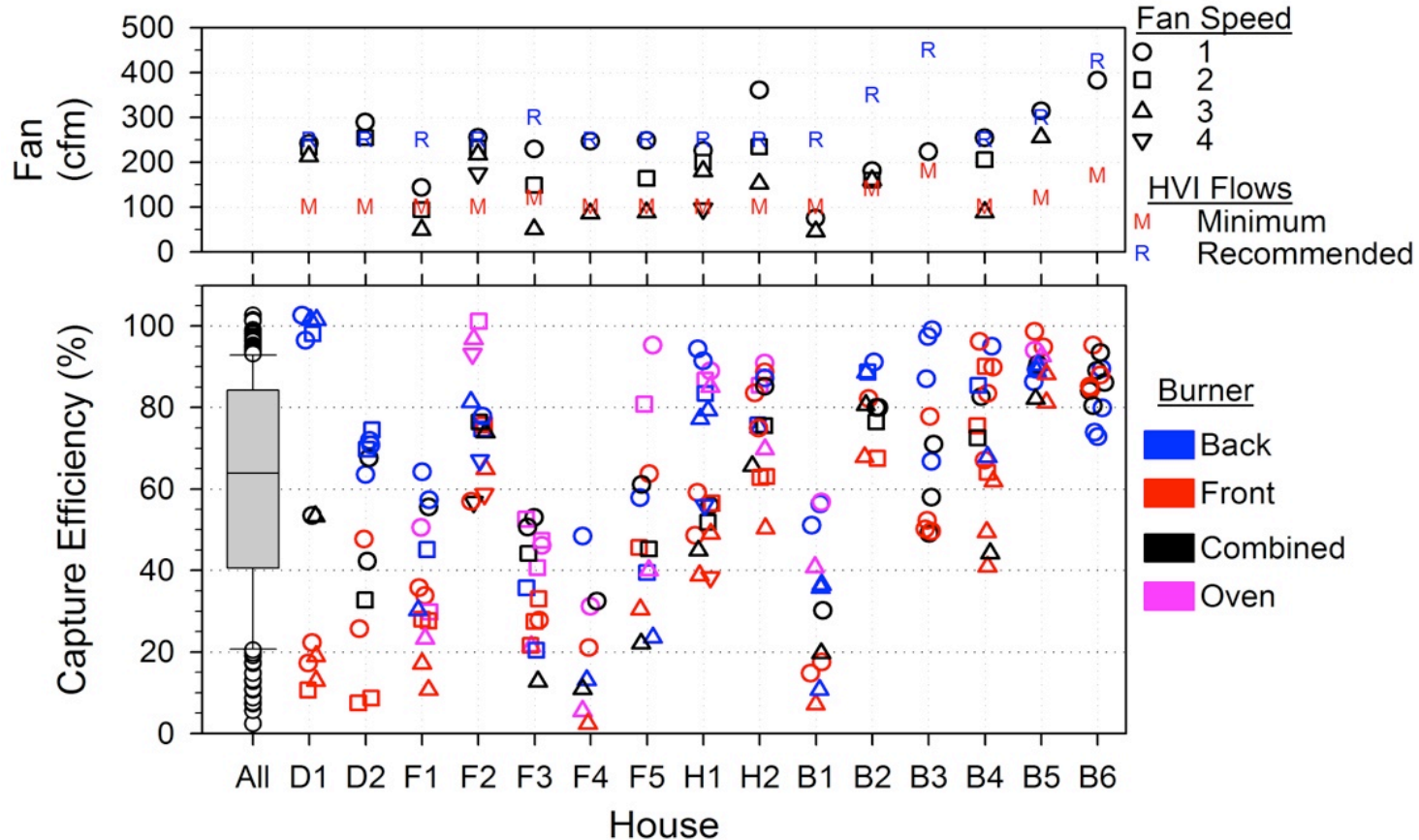
Singer et al., 2012,
Indoor air

Key features:

>150 cfm

“Sump” or hood

Cover front
burners



Field experiments of burners and range hoods

- **Controlled experiments with cooking burners**
 - Cooktop: boil/simmer pot (4L water) and heat/simmer pan (1L water)
 - Oven: preheat to 425°F + 30 min (pot w/1L water)
 - Broiler: preheat 20 min, 15 min (pot w/1L water)
 - No food preparation
- **9 homes in Northern California**
 - 8 houses/flats 108–226 m² + 26 m² apt; 1-2 stories; Built 1904–1991
 - 6 with venting hood, 1 bath fan, 1 recirc hood



Pollutant measurements

CO₂, NO_x, NO, NO₂, Particles ≥ 6 nm, PM_{2.5} by scattering, CO, T, RH



Kitchen



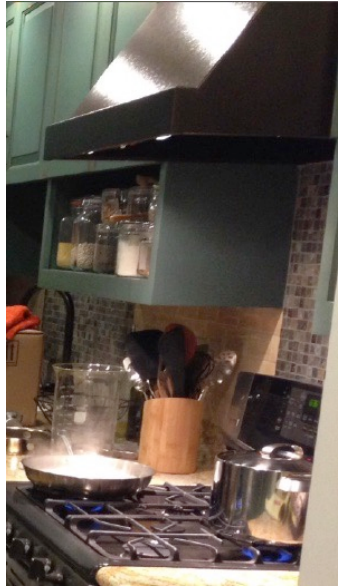
Bedroom area





How we used
to do it.
(circa 2007)

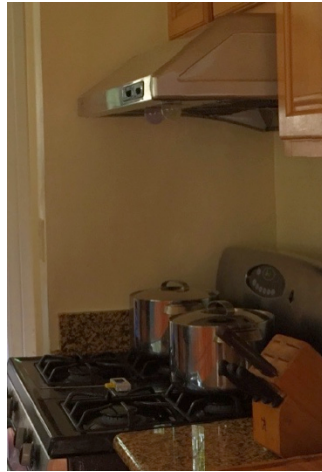
Range hoods in study homes



H1



H2



H5



H9

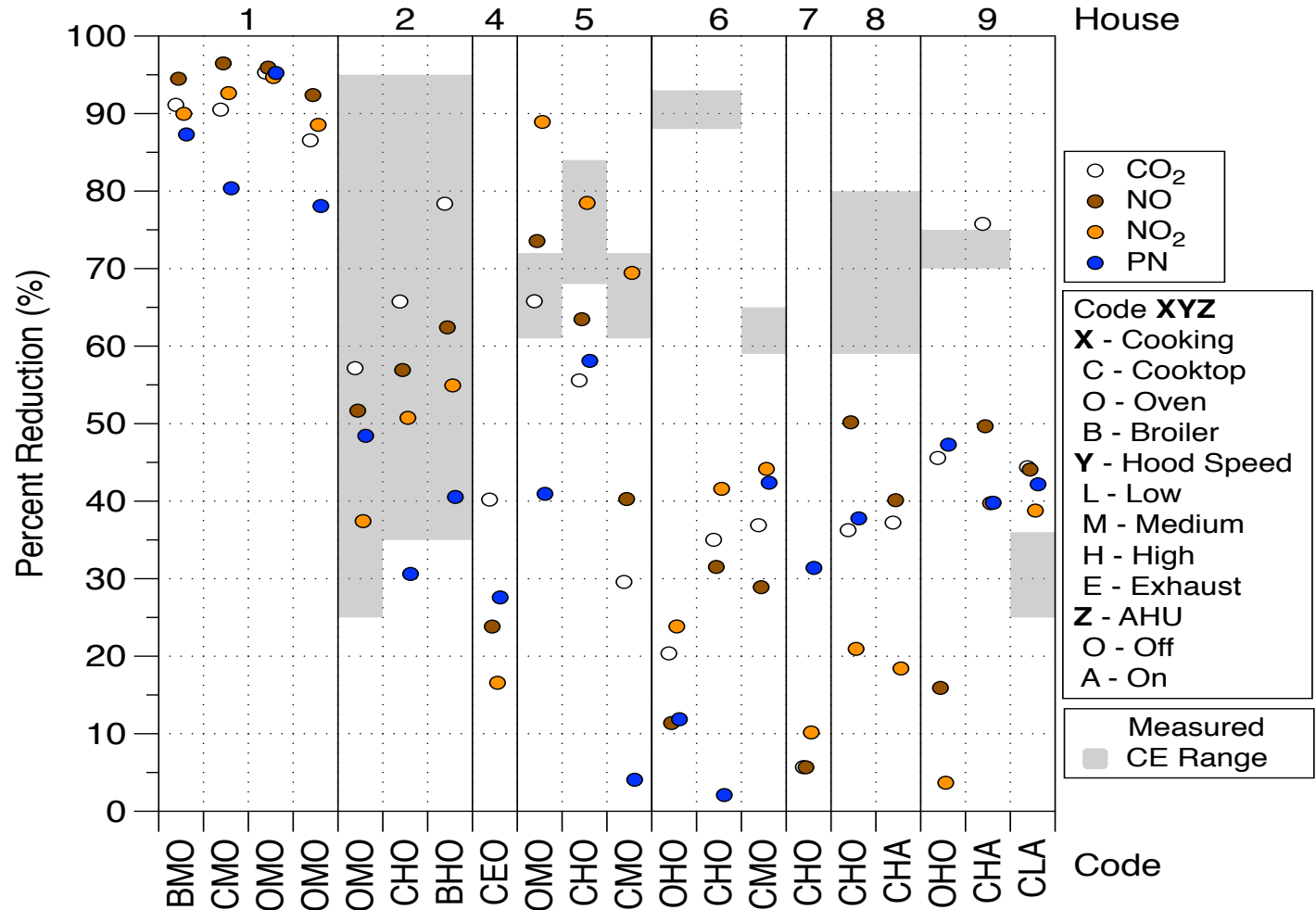


H6



H8

Reductions in pollutant levels with range hood use



Range Hood Guidance

Builder / Contractor

- Venting with low-resistance duct
- Hood that covers all burners
- Quiet at 200 cfm

User

- Operate the hood
- Higher flow for more cooking
- Cook on back burner

Roofer

- Don't drop debris down the vent



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

Infrequent use of kitchen exhaust

Data from Cal. IAQ study; may be biased high

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%

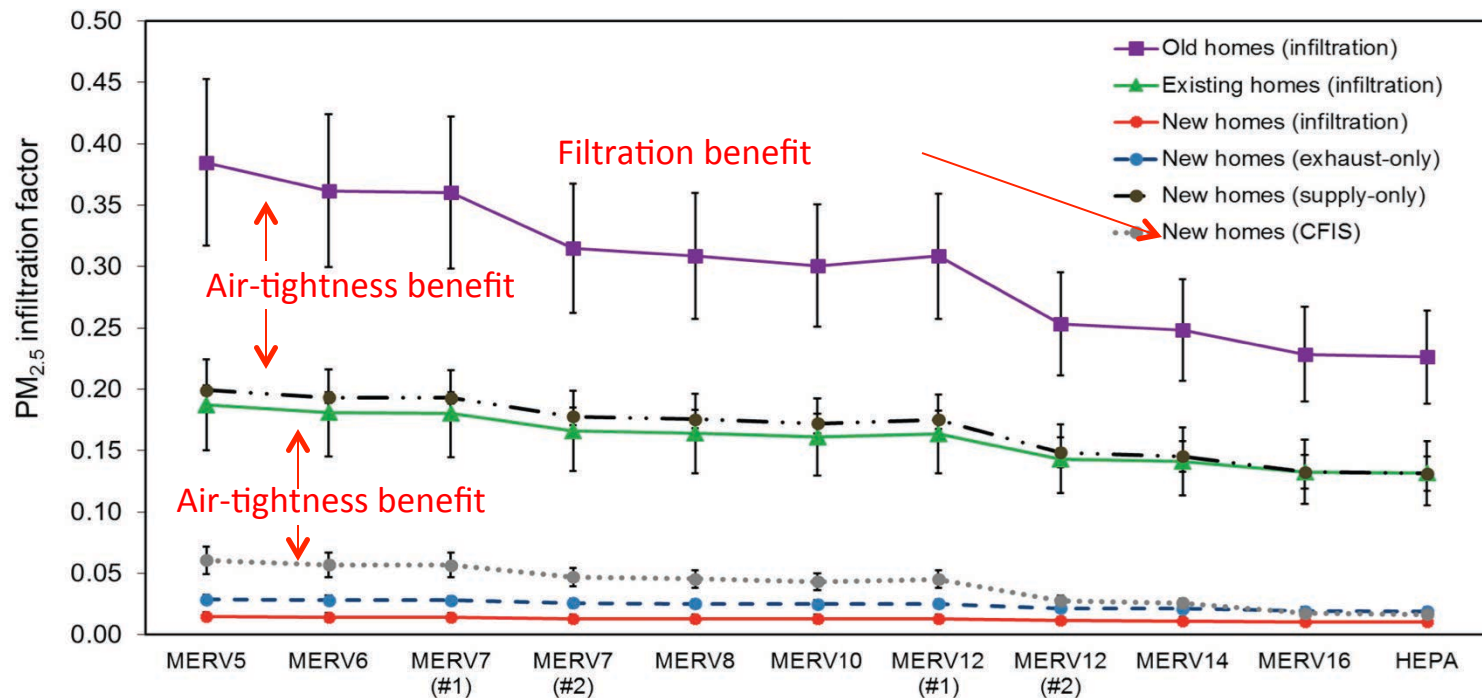
Infrequent use of kitchen exhaust:

Mullen et al. LBNL-5970E Reasons for NOT using exhaust system	Number	% of 193 using <50% of time
Not needed	92	48%
Too noisy	40	21%
Don't think about it	31	16%
Doesn't work	19	10%
Open window instead	17	9%
Other reasons	7	<4%
Wastes energy	3	<2%
No reason selected or don't know	23	12%

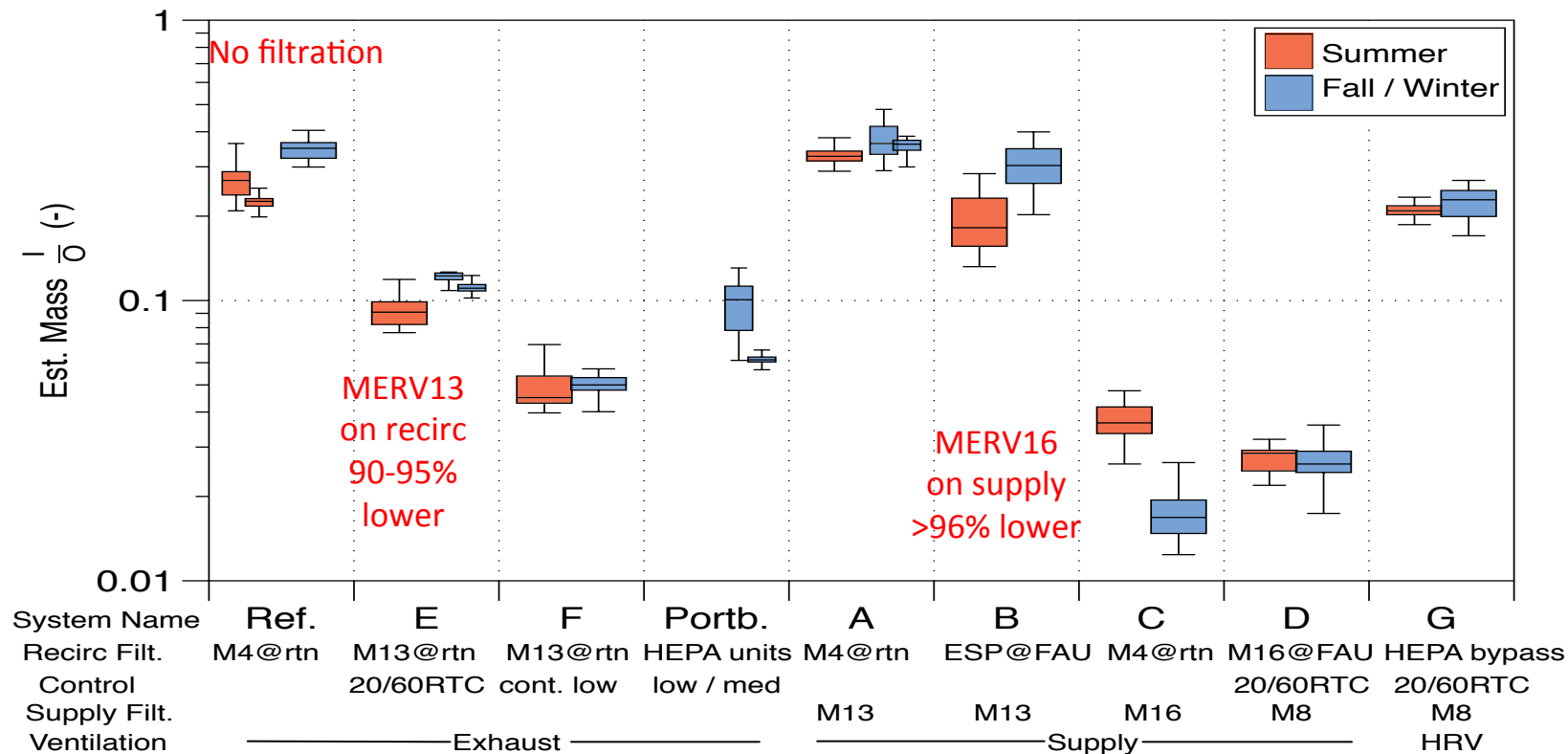
Filtration

Great potential for air-sealing & filtration to reduce in-home exposure to outdoor PM across US

(SIMULATION ANALYSIS USING MEASURED PARAMETERS)



In test house, filtration greatly reduced PM from outdoors



Built 2006, 5.0 ACH50
 Exhaust ventilation
 AER = 0.22 h⁻¹



Example: Filter intervention reduced PM in smoking & non-smoking homes – but lower than theoretical

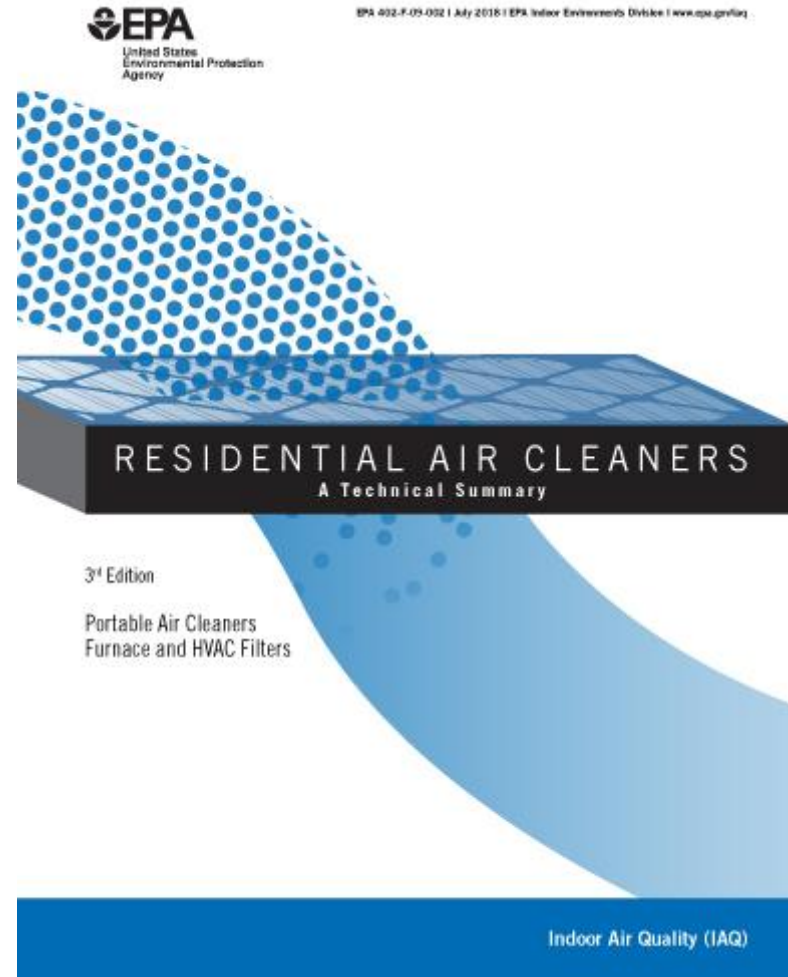
- Intervention study in 126 low-income homes of children with asthma
- Baseline and 3 seasonal follow-up visits
- Some homes had smokers (SHS tracers)

Mean±SD $\mu\text{g m}^{-3}$	No Smoking	Smoking
Without filter use	21.6 ±20.6 (n=62)	42.8 ±32.9 (n=18)
With filter use	11.7 ±11.1 (n=172)	22.1 ±18.5 (n=35)

Filtration and Air Cleaning

- Potential to drive PM to very low levels
- Field studies find that actual benefits much smaller than theoretical
- Key issues:
 - **People turn them off**
 - Thermostat controls confusing
 - Noise
 - Energy (if using FAU)

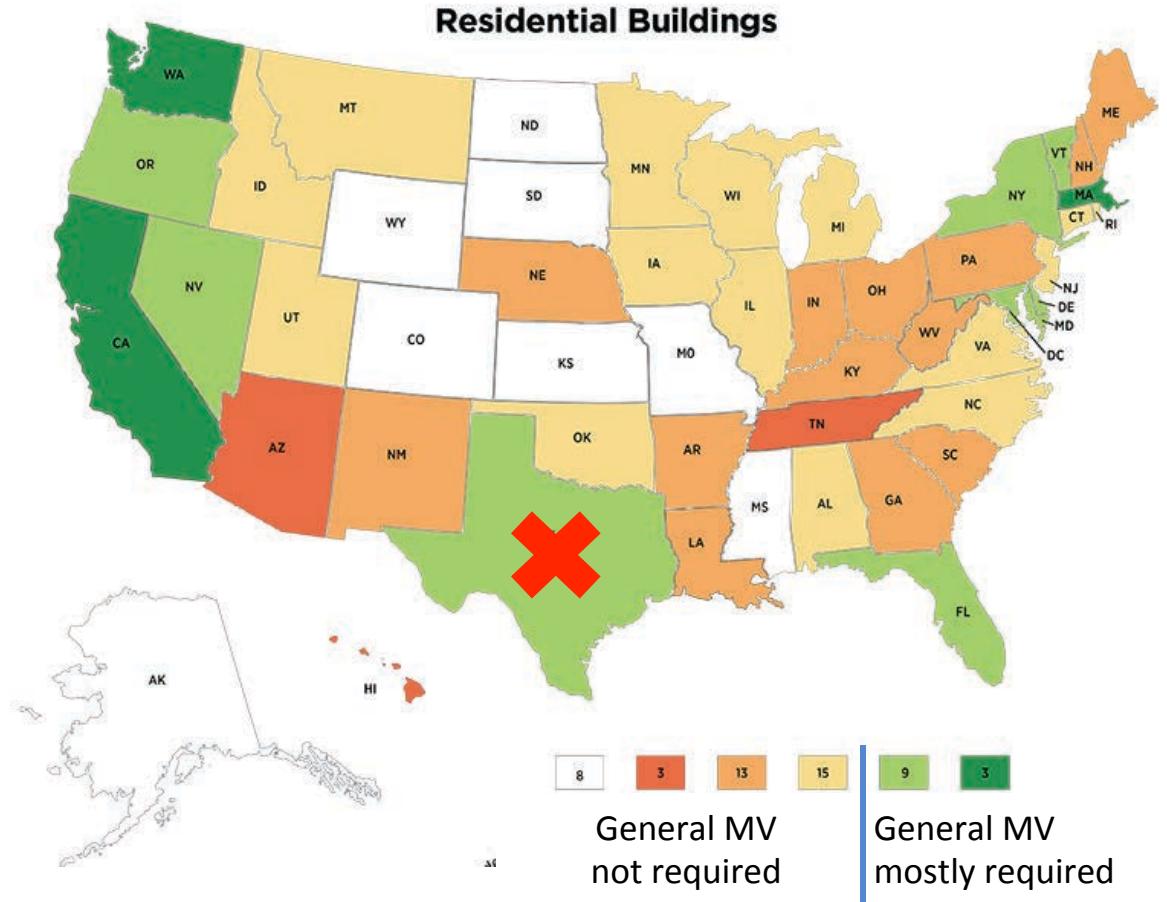
<https://www.epa.gov/indoor-air-quality-iaq/air-cleaners-and-air-filters-home>



General Ventilation

What is required by code?

- Required in states that adopted IECC 2012 / 2015
- Not required in Texas, some local codes
- Kitchen exhaust required in a few states but not by IECC; use varies by region
- Bath exhaust installed in most new homes



Source: US DOE Building Energy Codes Program
<https://www.energycodes.gov/status-state-energy-code-adoption>



Is installed MV meeting the intent?

Field Study of 21 Florida homes

MV installed during prior 15 years
Mostly CFIS; pre-code requirement
20/21 were ≤ 5 ach50

Only 3 had airflows close to required
2 of those turned off!

Only 12 “capable of operating” as found

Faults

- Failed controllers and dampers
- Partially disconnected or crushed ducts
- Dirty filters; Air intake above exhaust



Dirty outdoor air intake.



Dirty ERV filters.

Healthy Efficient New Gas Homes Study (HENGH)



*Rengie
Chan*



*Yang-
Seon
Kim*



*Brett
Singer*



*Iain
Walker*




Context

- Air sealing key strategy for residential energy efficiency
- Low outdoor air increases indoor air pollutant levels
- Prior studies raised IAQ concerns
- Since 2008, California has required mechanical ventilation (MV) in all new homes

2008 BUILDING ENERGY EFFICIENCY STANDARDS FOR RESIDENTIAL AND NONRESIDENTIAL BUILDINGS

CALIFORNIA ENERGY COMMISSION


REGULATIONS / STANDARDS



Effective January 1, 2010

December 2008
CEC-400-2008-001-CMF

Arnold Schwarzenegger
Governor



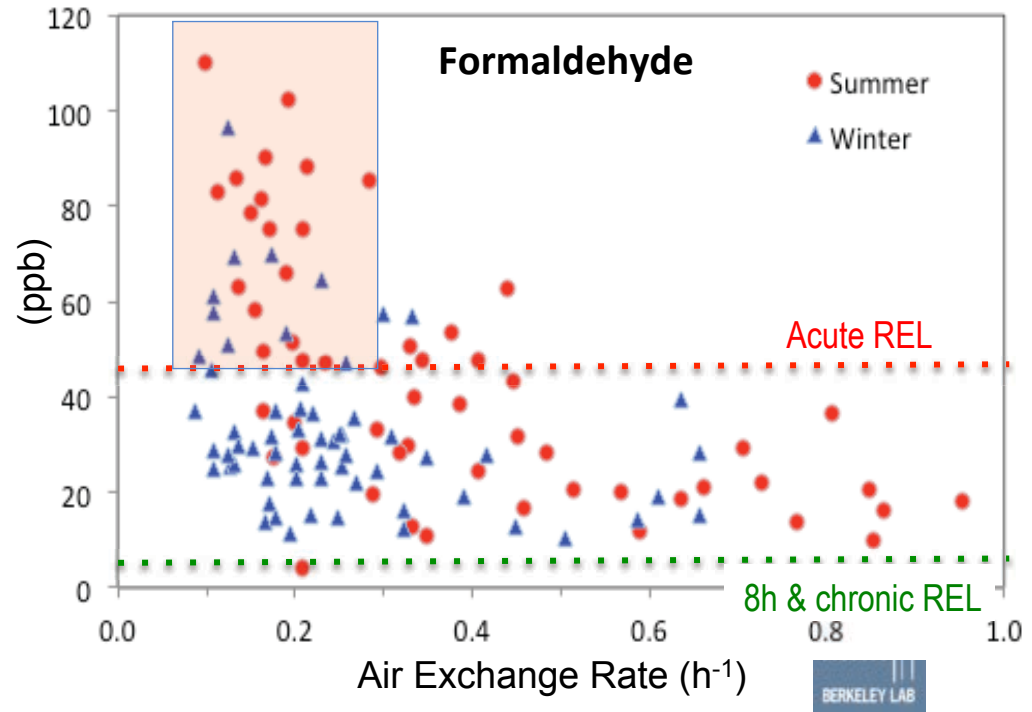
Prior California Studies

New Home Survey: 2004-5

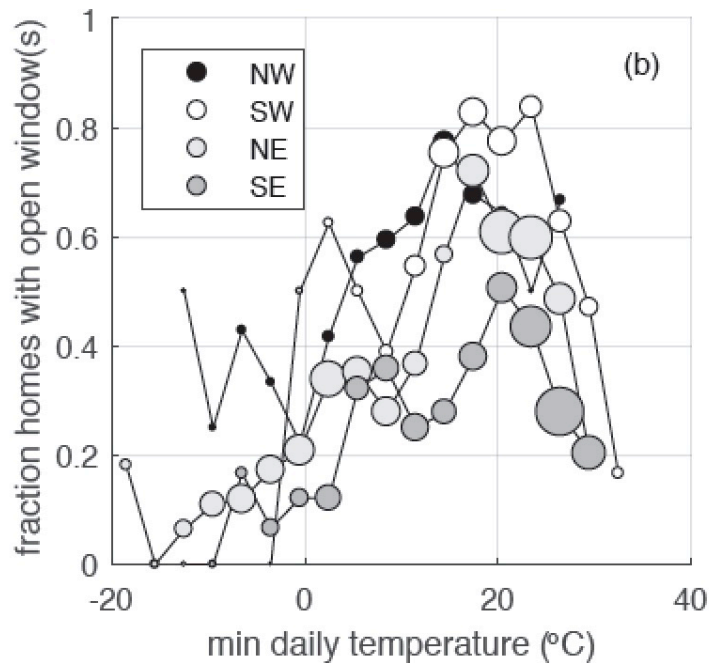
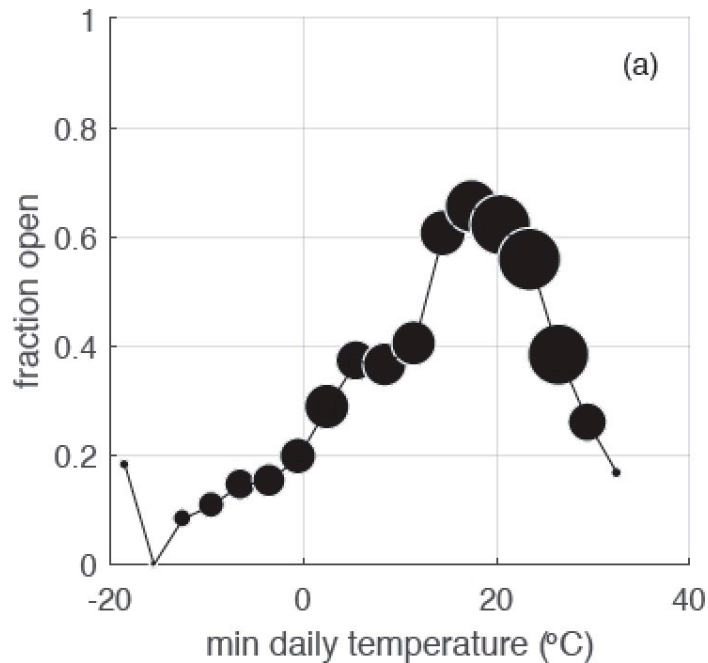
- 1500 responses by mail
- Homes built 2002-3
- Self-reported window use
 - 50% didn't use in winter
 - 20% didn't in spring & fall
- Kitchen & bath fans not used routinely

Field study: 2006-7 (CNHS)

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



Lots of people in US don't use windows

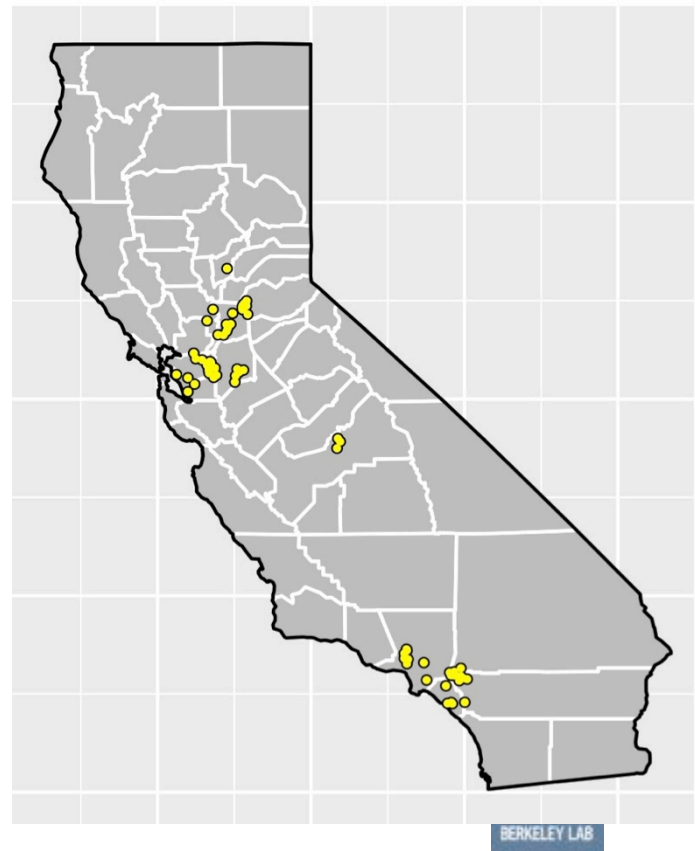


3600 responses to “Were any windows open at all yesterday?”; Amazon Mechanical Turk survey

HENGH: Determine if current ventilation requirements are adequate to protect IAQ

Field study of 70 homes with MV

- Single-family detached, built 2011-17
- Natural gas cooking burners
- Year-round sampling, 2016-2018
- Characterized ventilation equipment
- Measured IAQ, tracked activities 1 week
- **Windows closed; Central MV operating**



Diagnostic Testing

Envelope and Duct Leakage



Exhaust Fan Airflow



Range Hood Airflow



Indoor Air Quality Measurements

PM_{2.5}



CO₂
T,
RH



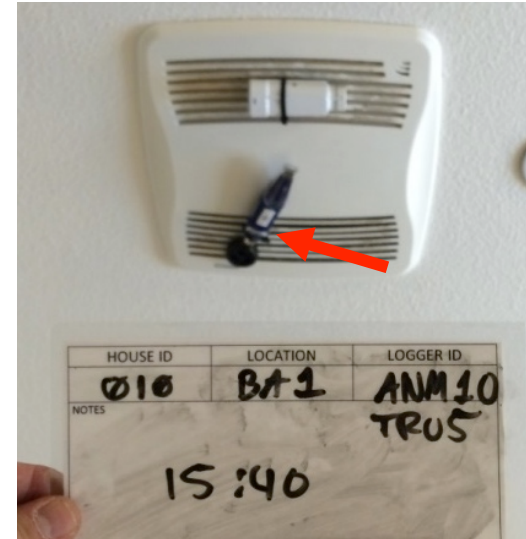
NO₂



Formaldehyde



Activity Monitoring



Range hood use

Exhaust fan use

Cooking (cooktop, oven)

Activity Monitoring

External door use (patio, garage)



Heating/Cooling



Clothes dryer



Occupant Survey and Activity Log

Healthy Efficient New California Homes Study Occupancy and Indoor Activities Data Log

Instructions: Please fill out this data log each day, or on the following day.

Please enter your best estimates. If you are unsure, provide your best guess.
Do not list the names of any people.

House number for home 13

Date 11-30-16

Date completed 11-30-16

	Midnight to 7am	7am to 11am	11am to 1pm	1pm to 5pm	5pm to 9pm	9pm to Midnight
Number of people in home	2	4	4	2	2	2
Stove use Number of minutes	0	30	0	0	.45	0
Refrigerator use Number of minutes	0	0	0	0	0	0
Outdoor grill use Number of minutes	0	0	0	0	0	0
Humidifier use Number of minutes	0	0	0	.25	0	0
Low Use Number of minutes	0	0	0	0	45min 0	0
Other notable indoor/outdoor events	3 air cleaners 24/7		carpet & floor clean			

For example, use of fireplace, candle, air freshener, air cleaner, humidifier, unusual outdoor activity (wood smoke, wildfire), and so on.

B. Air Quality In and Around Your Home

7. To what extent are you satisfied or dissatisfied with the indoor air quality in your home?

Very Dissatisfied						Neutral					Very Satisfied
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

8. How would you rate the outdoor air quality near where you live?

Very Poor						Neutral					Excellent
<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

9. How would you rate your home in protecting you from outdoor air pollution?

Very Ineffective						Neutral					Very Effective
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

C. Comfort Level in Your Home

10. In winter, how often is the temperature in your home uncomfortable to any occupants because some room(s) are too hot or too cold?

	Never	Few times a year	Few times in a month	Few times a week	Every day
Too hot in some room(s).	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Too cold in some room(s).	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

11. In summer, how often is the temperature in your home uncomfortable to any occupants because some room(s) are too hot or too cold?

	Never	Few times a year	Few times in a month	Few times a week	Every day
Too hot in some room(s).	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Too cold in some room(s).	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Central MV systems in 70 California homes

In most cases, the measured airflow of the exhaust fan exceeded the required whole-dwelling ventilation needs.

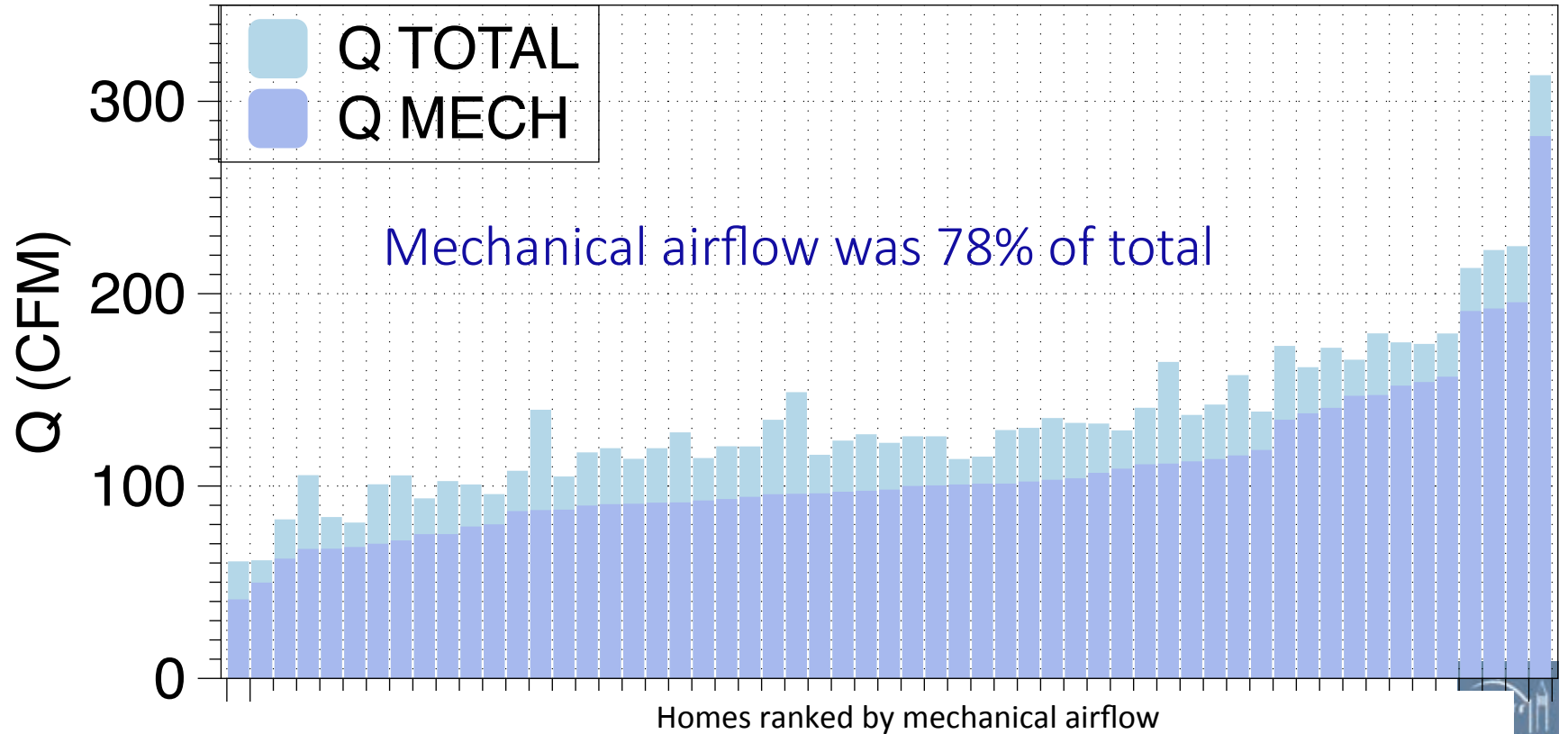
Mean required: 63 cfm
Mean provided: 96 cfm



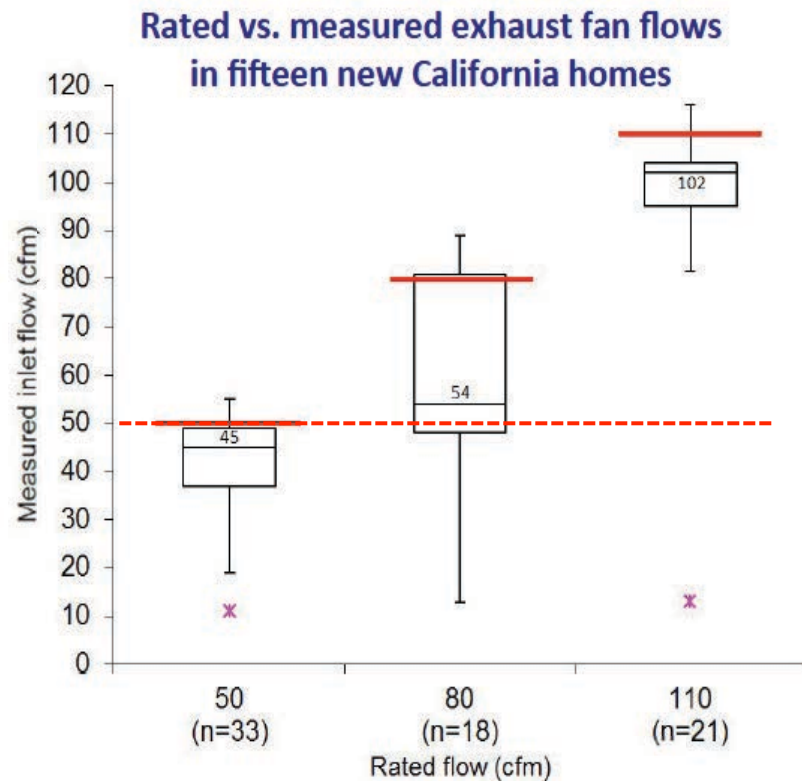
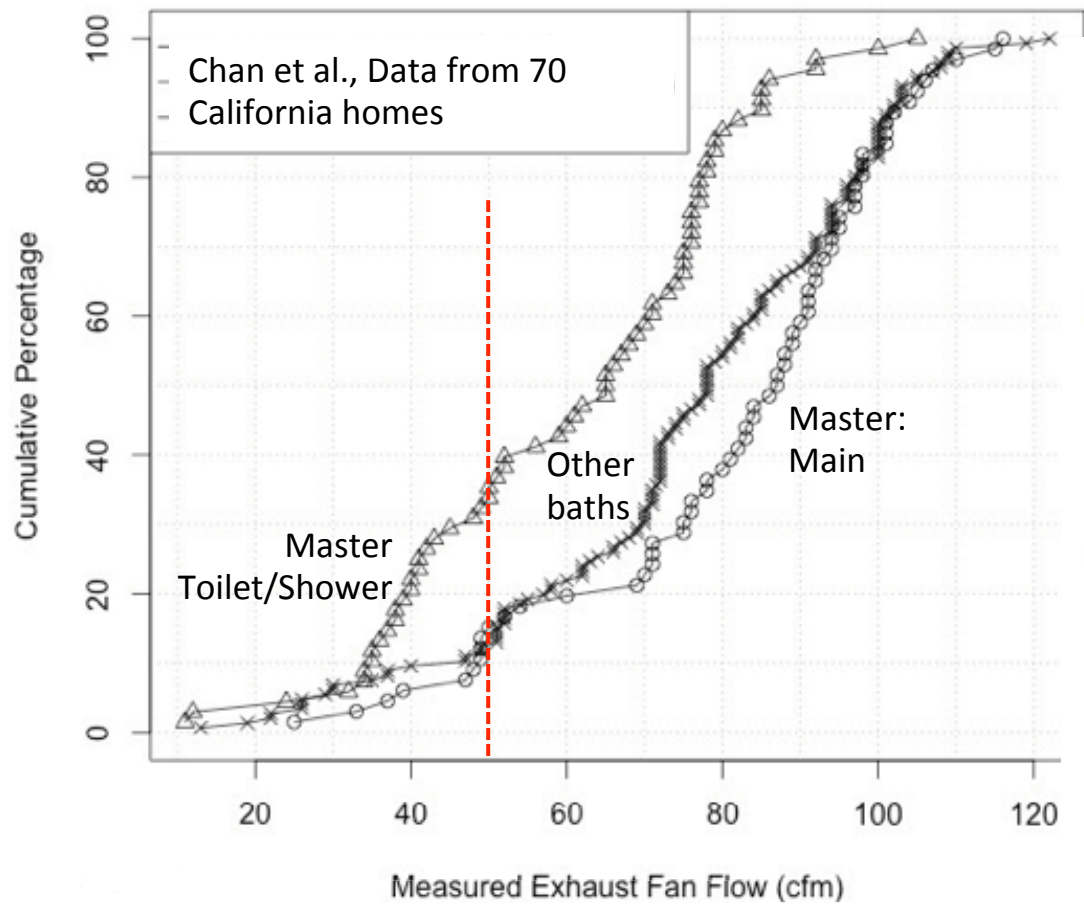
~50% above code

- Continuous exhaust (N=55)
- Intermittent exhaust (N=9)
- Continuous inline fan connected to central forced air system (N=4)
- Supply ventilation provided by central fan integrated system with a motorized damper (N=2)

Outdoor Airflow: Mechanical and Total



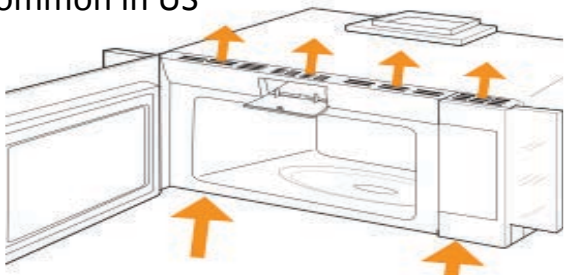
California bathrooms: Most above code, below rated



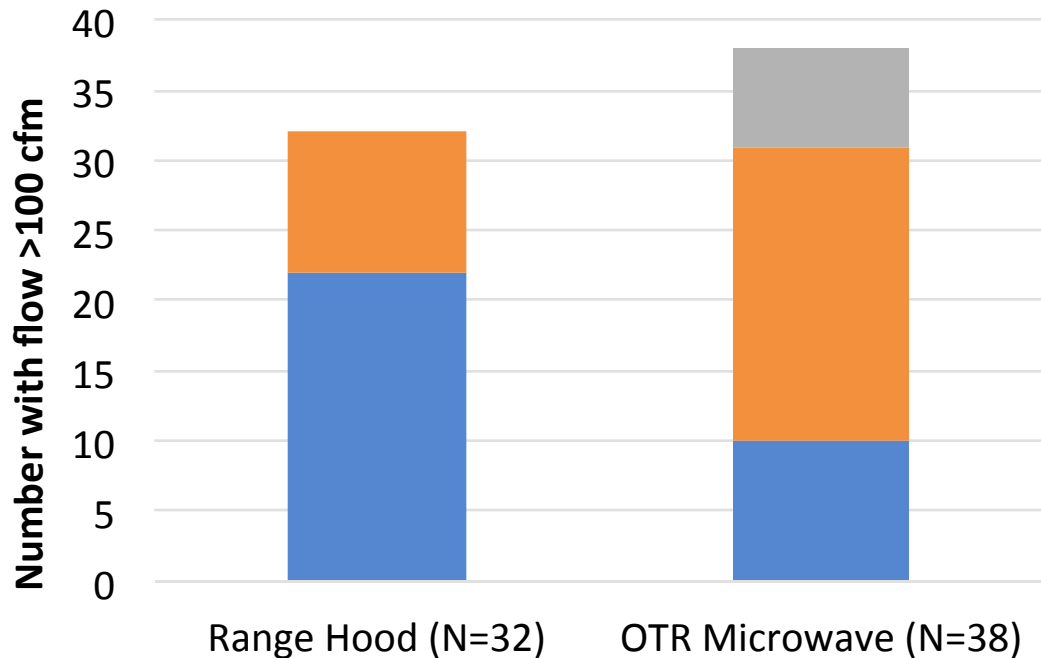
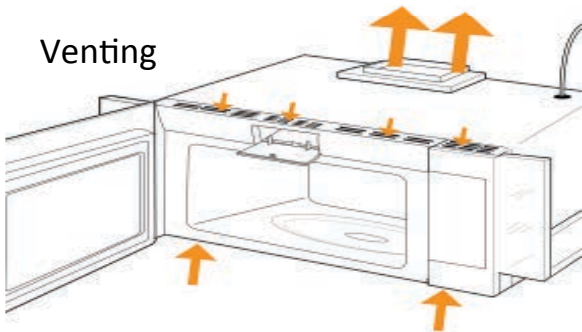
Stratton et al., 2012

Kitchens: Most range hoods meet minimum airflow requirement; but many microwaves don't

Non-venting;
Common in US



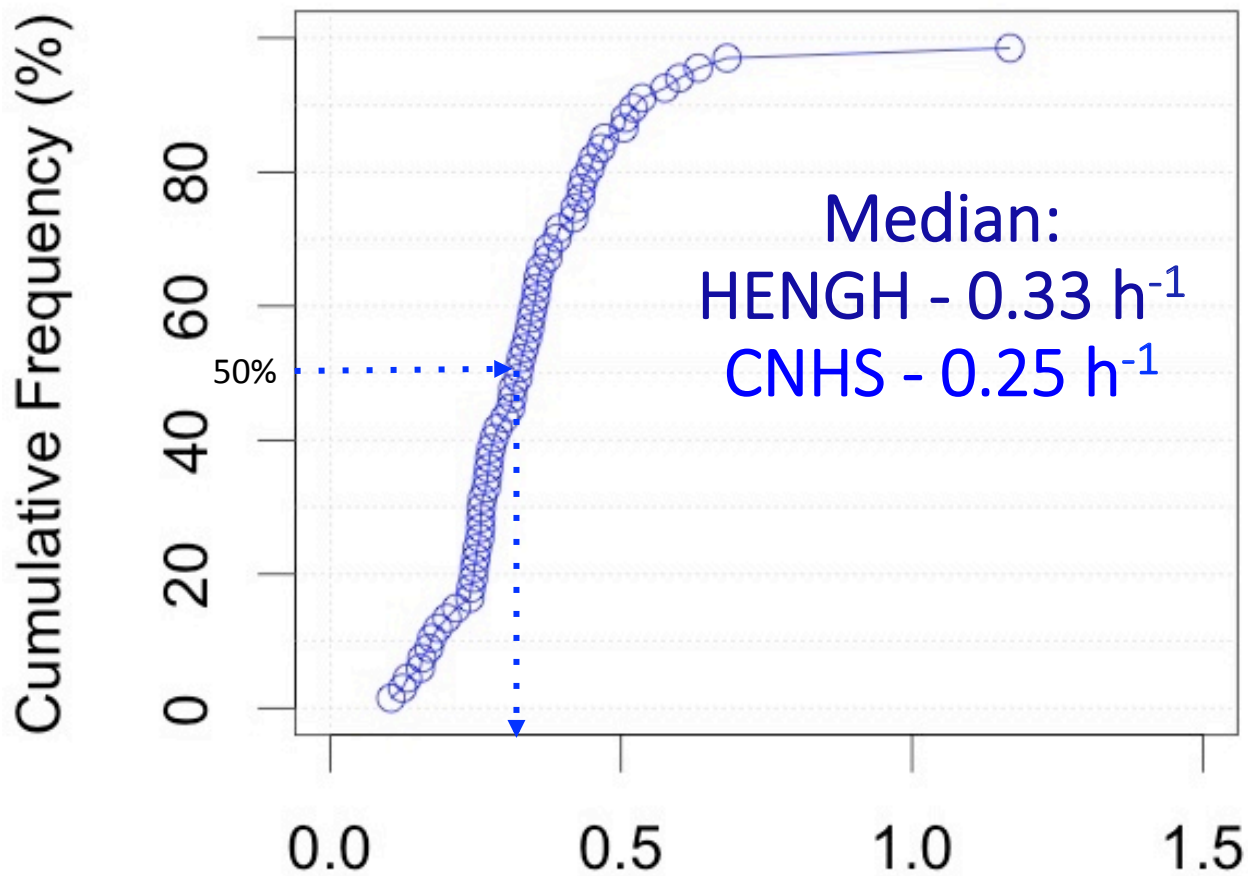
Venting



■ Low Speed ■ Med to High Speed ■ Failed T24



Calculated air change rate (per hour)

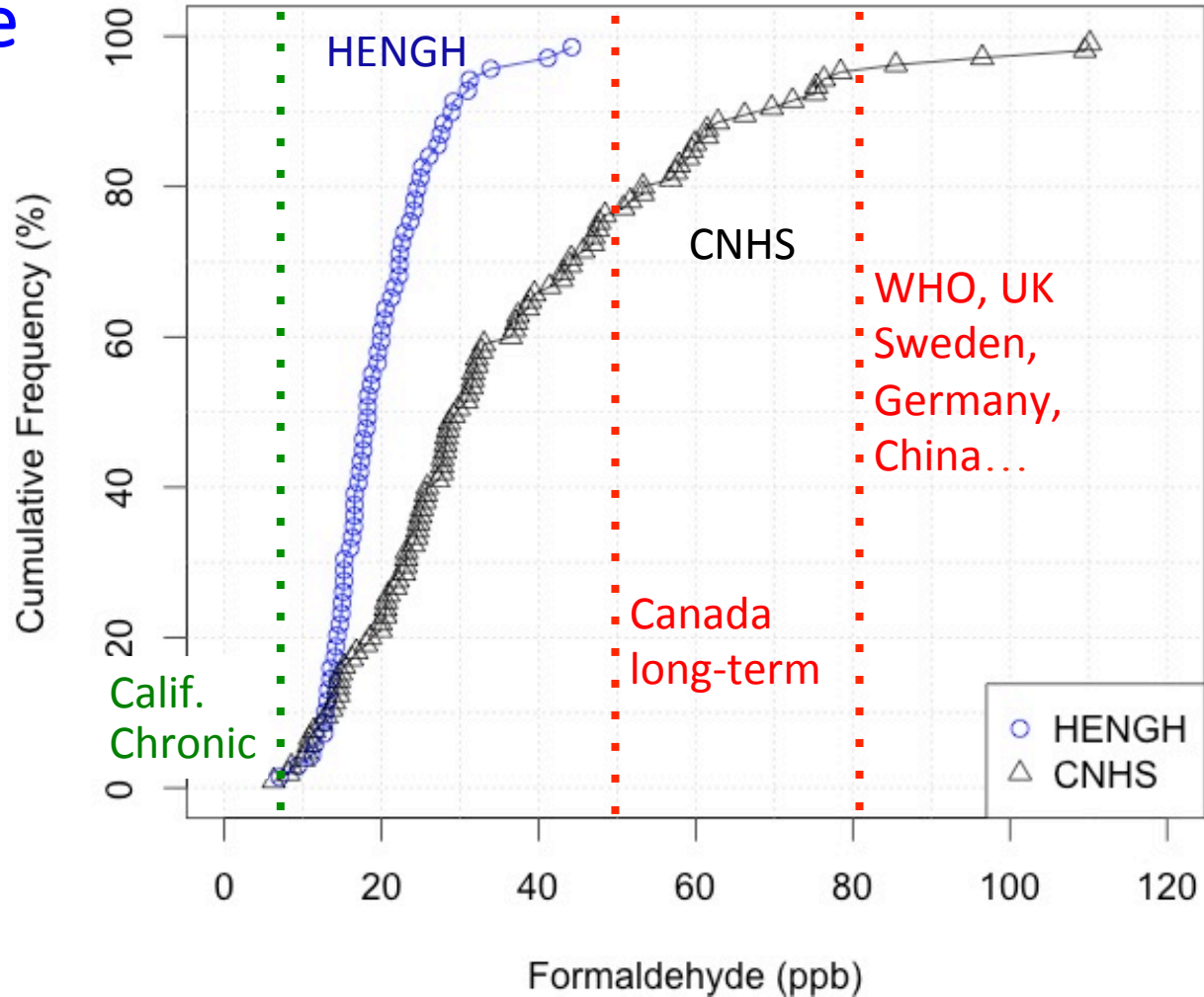


PM_{2.5} and formaldehyde lower

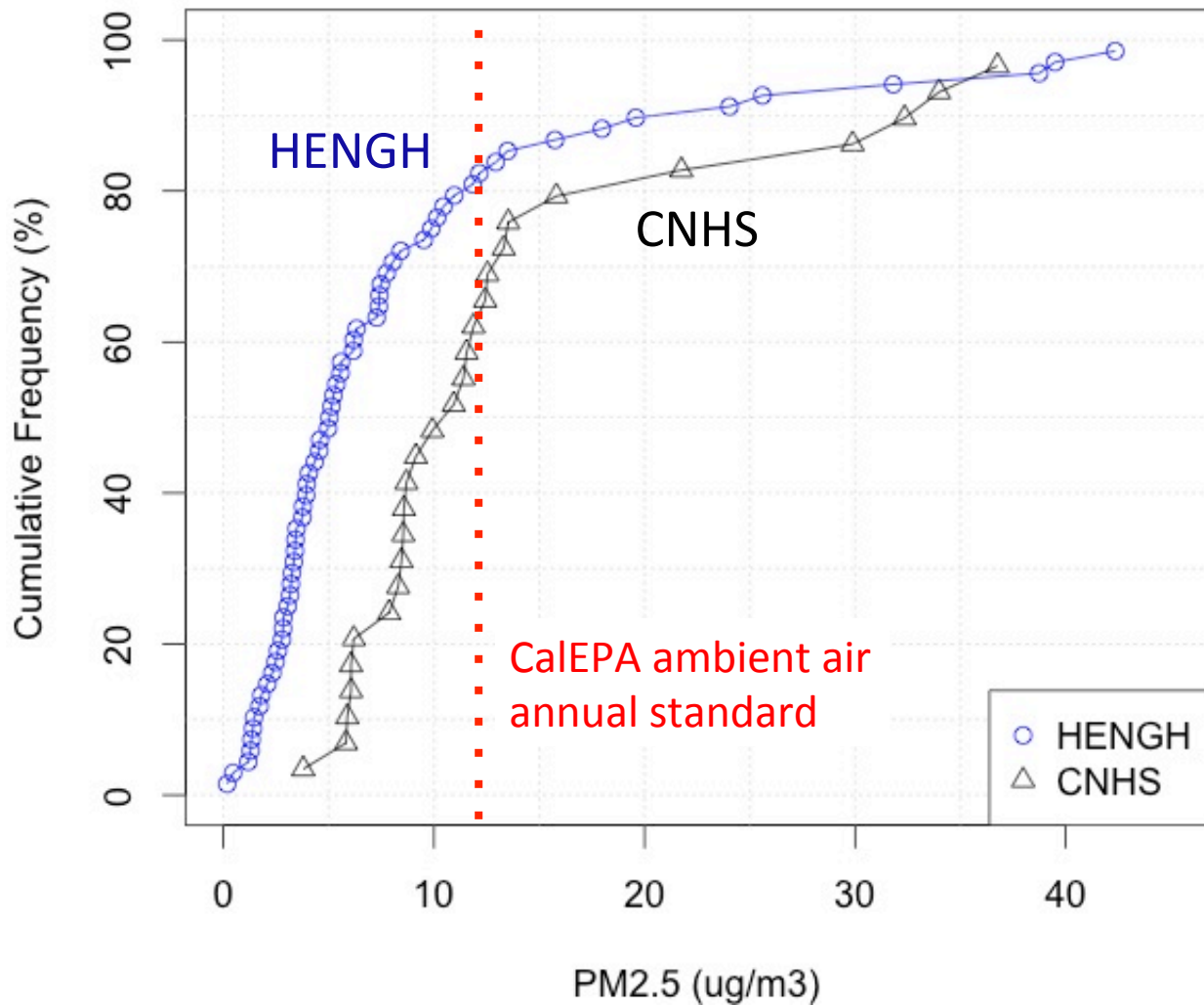
Median Indoor Concentration	CNHS* – 98% Electric 2006–07	HENGH - Gas Homes 2016–18
Formaldehyde	36 ppb	18 ppb
PM _{2.5}	11 microg/m ³	5.0 microg/m ³
NO ₂	3.1 ppb	4.4 ppb



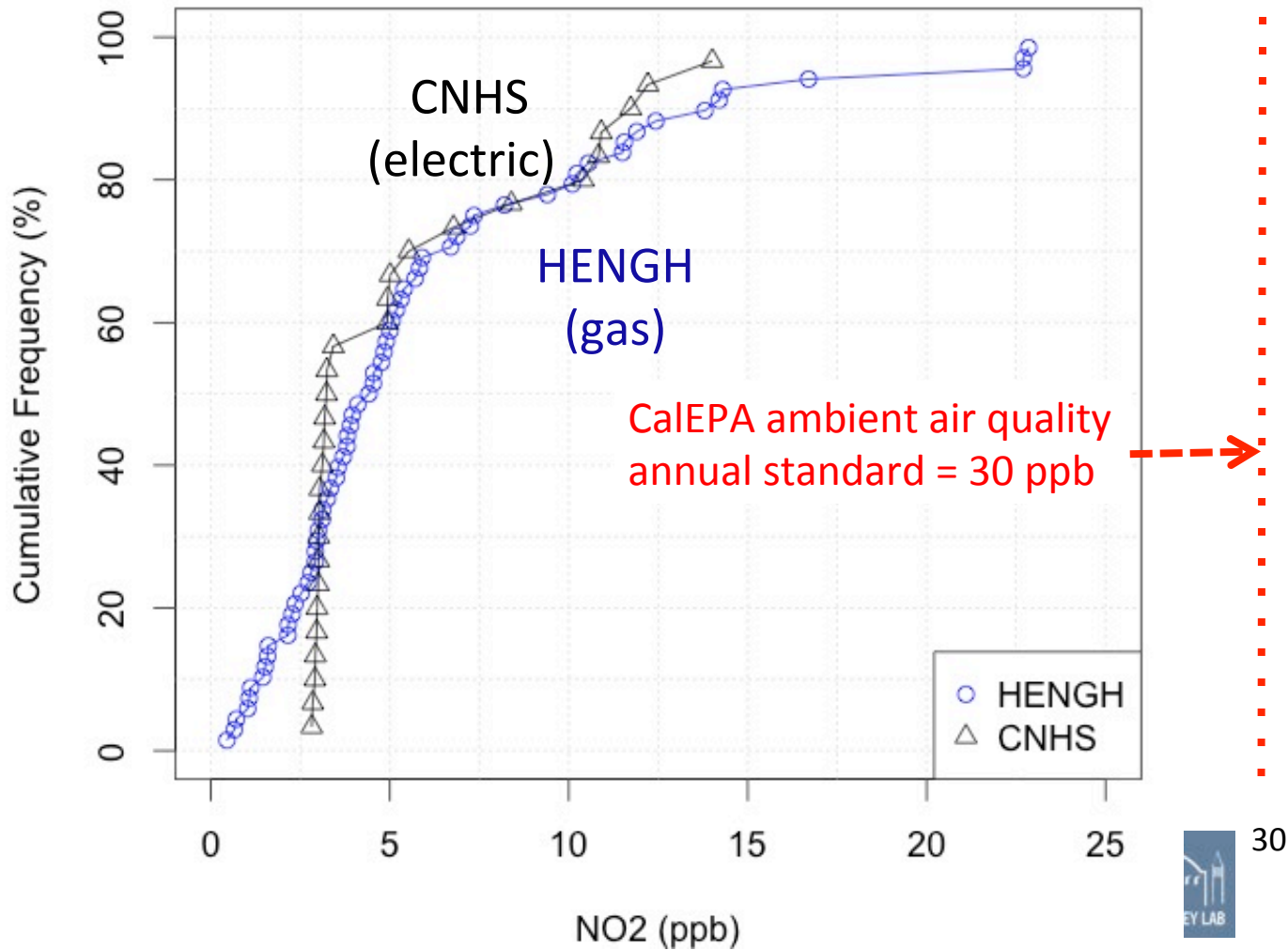
Formaldehyde



PM_{2.5}



NO₂



Mission Accomplished?



Photo Credit: J Scott Applewhite, Associated Press, May 1, 2013

Problems Affecting Occupant Comfort a Few Times per Week or More Frequently	Online Survey Mostly 2002-8 (N=2271)	Field Study Built 2011-7 (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%

In California, only **1 in 4** homes had the central ventilation system running as found.

Labels matter!

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%



Does the code need to be more prescriptive?

62.2 and Title 24 refer to 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.

Actual labels not always clear

CONTINUOUS DUTY



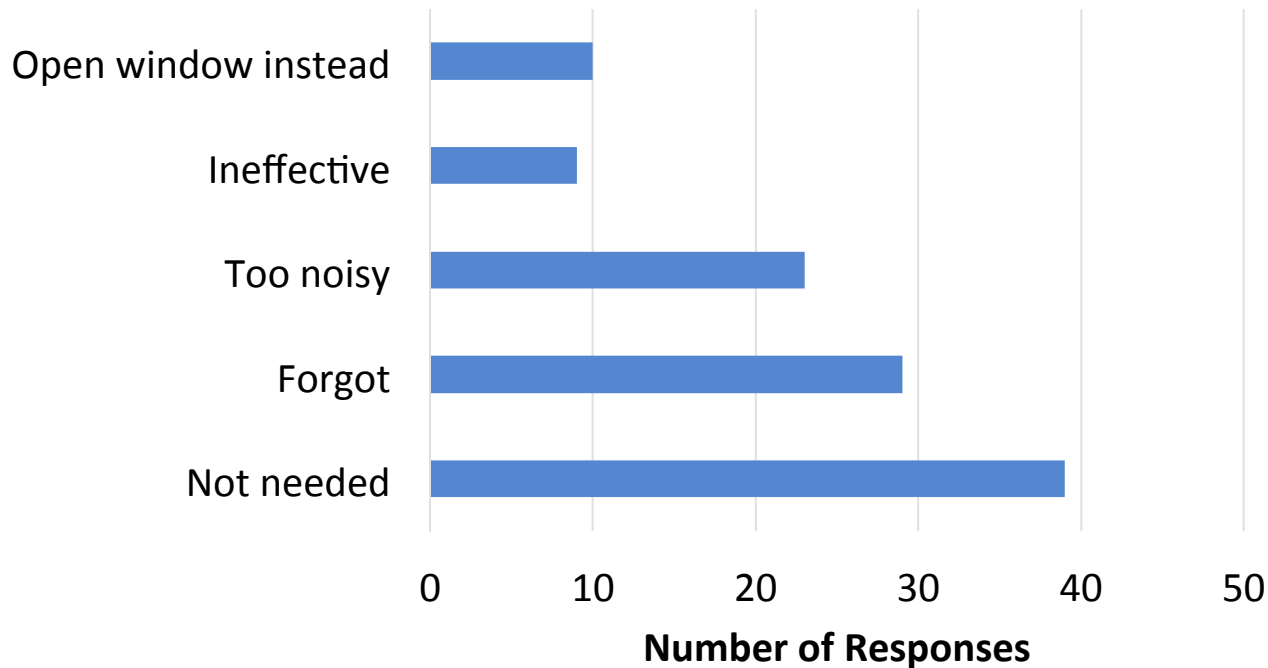
To maintain minimum levels of outside air ventilation required by the State of California, this fan should be on at all times when the building is occupied, unless there is outdoor air contamination.





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

Reasons for Not Using Range Hood





City Hall of Vienna,

<https://www.wien.gv.at/english/cityhall/images/cityhall.jpg>

Indoor air quality and health indicators in energy efficient new homes in Austria

Peter Tappler^{1*}, Peter Wallner², Bernhard Damberger¹, Michael Kundi², Hans-Peter Hutter²

¹ Austrian Institute for Healthy and Ecological Building, Vienna, Austria

² Department of Environmental Health, Medical University Vienna, Austria

Presented at Indoor Air 2018; Philadelphia PA, Jul 25, 2018

Slides courtesy of Peter Tappler

Wallner et al., Indoor Environmental Quality in Mechanically Ventilated, Energy-Efficient Buildings vs. Conventional Buildings. *Int J Environ Res Public Health*. 2015;12:14132-14147

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

Project Ventilation 3.0 (Austria)

Does mechanical ventilation provide healthy comfortable interiors?

Do their mechanical ventilation systems convince consumers?

Compare homes with/out mechanical ventilation

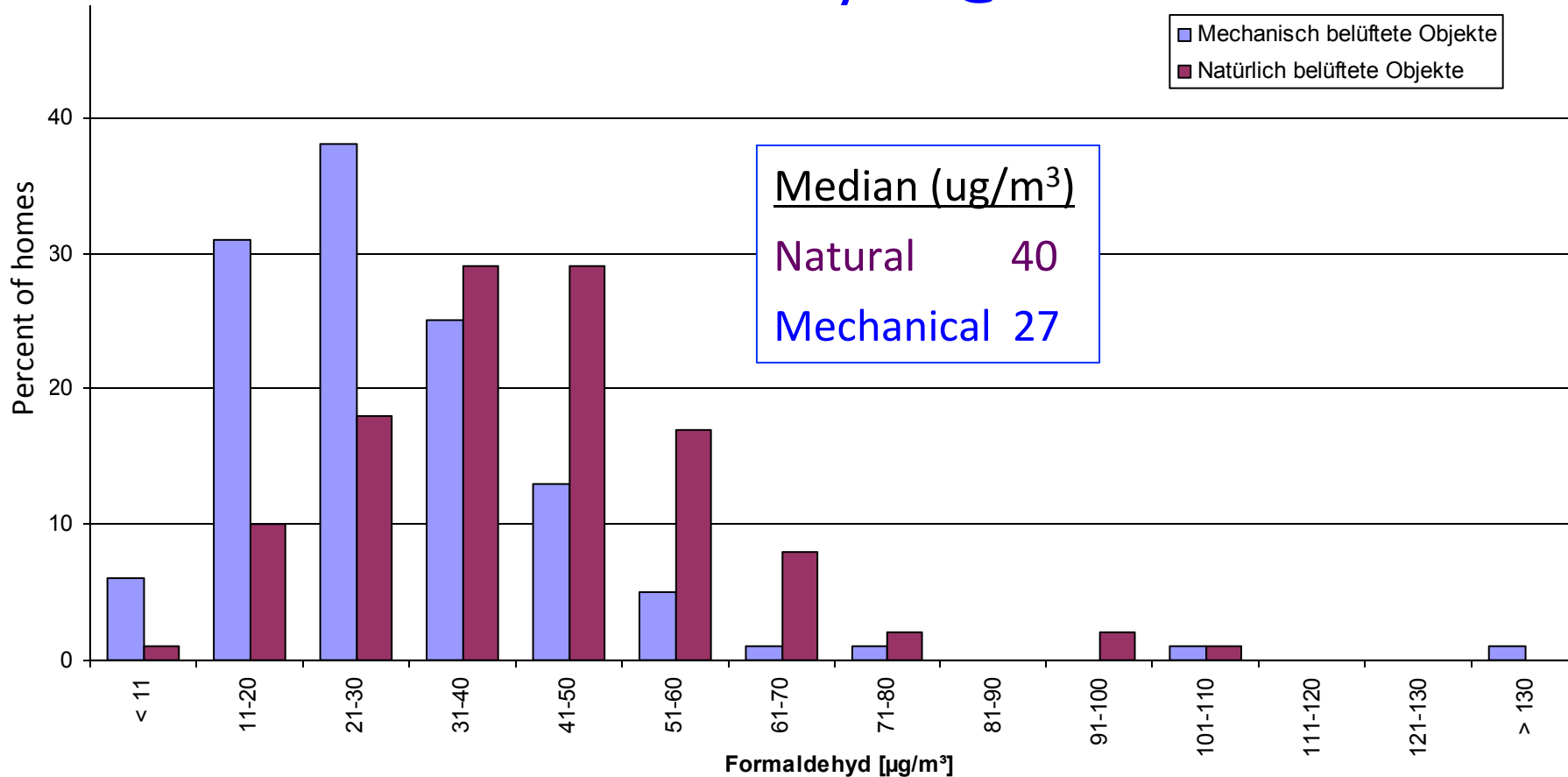
- 62 low-energy or passive std – mechanical ventilation with heat recovery
- 61 conventional construction – natural ventilation (windows)
- Built 2010-2012; 70% detached, 30% apts. in each group:

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

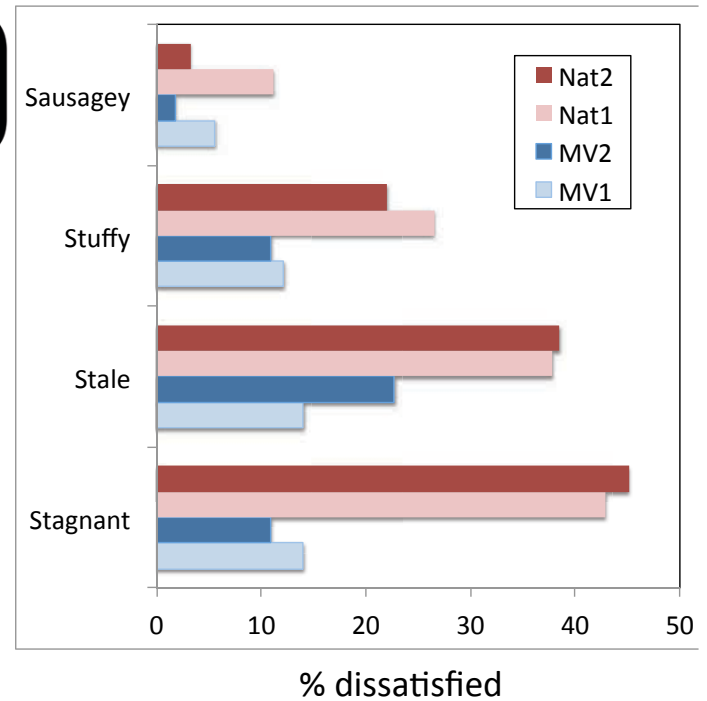
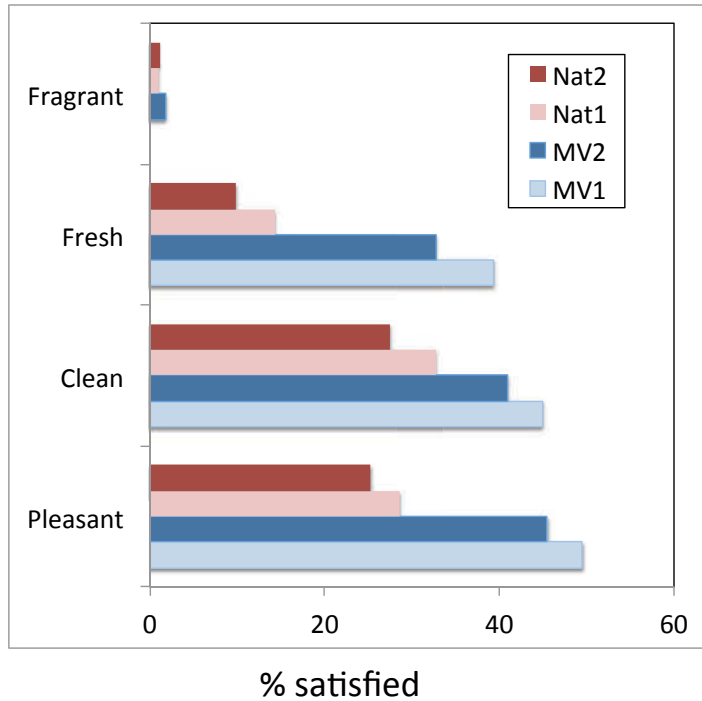
Survey of perceptions, satisfaction and health status



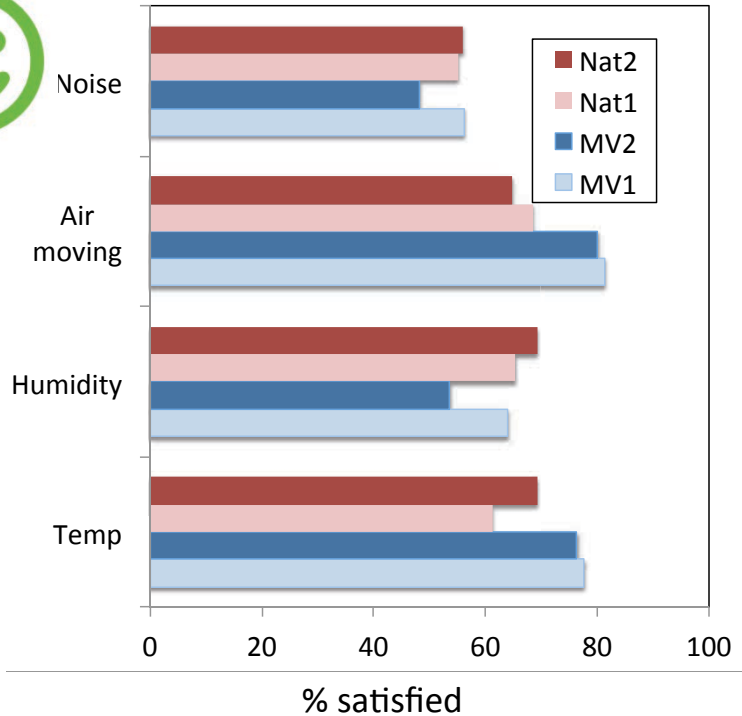
Results: Formaldehyde @ 3 months



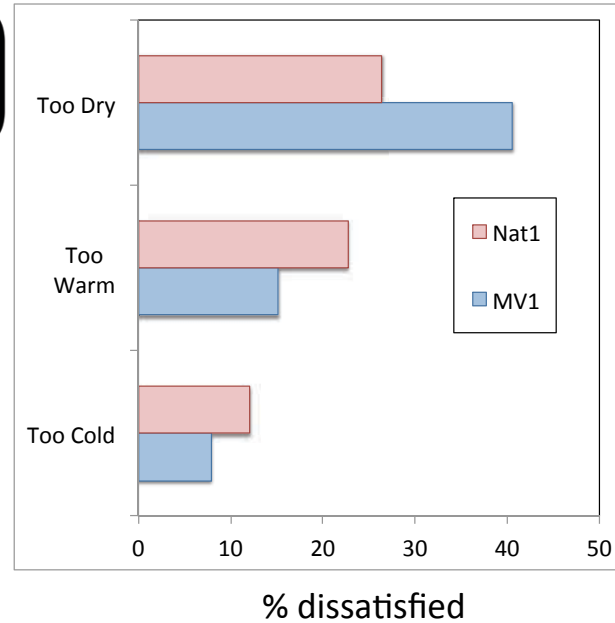
Ventilation improves satisfaction



Ventilation increases dryness in cold climates



MV homes better on all measures except dryness

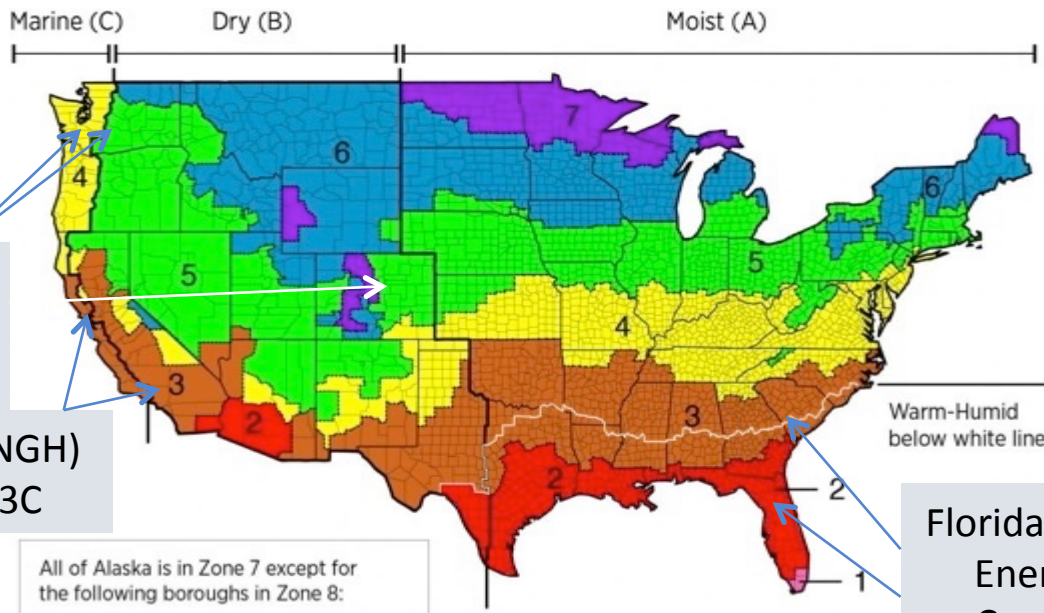


Advanced Ventilation

- Larger fans with controllable ECM motors enable smarter ventilation
- Distribution and mixing are valuable; working to understand this
- How problematic is it when people turn off their ventilation?

Building America IAQ Study

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



Pacific NW
National
Lab

LBNL (HENGH)
CZ: 3B, 3C

All of Alaska is in Zone 7 except for the following boroughs in Zone 8:

Warm-Humid
below white line

Florida Solar
Energy
Center
CZ: 2A, 3A

- Characterize home, mechanical equipment
- Monitor ventilation, IAQ, activities for 1 week; repeat for 2nd week in 8 homes / CZ
- Repeat monitoring to occur in homes with & without MV operating

How is IAQ in social housing?



Indoor environmental quality in social housing: A literature review

Ernesto Diaz Lozano Patino^a, Jeffrey A. Siegel^{a,b,*}

2018, Vol. 131, pp.231-241

^aDepartment of Civil Engineering, University of Toronto, Canada

^bDalla Lana School of Public Health, University of Toronto, Canada

Reviewed 49 articles



SH residents exposed to higher PM_{2.5}, heavily influenced by smoking in the building.

No evidence of higher levels of other pollutants such as formaldehyde or dampness.

Poor thermal comfort [is] an issue, but not enough data on comparable non-social housing to make a definitive statement about relative prevalence.

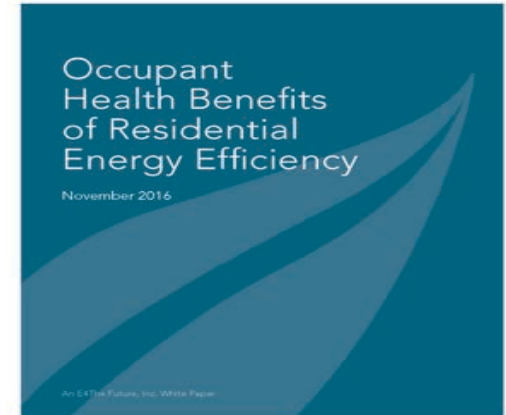
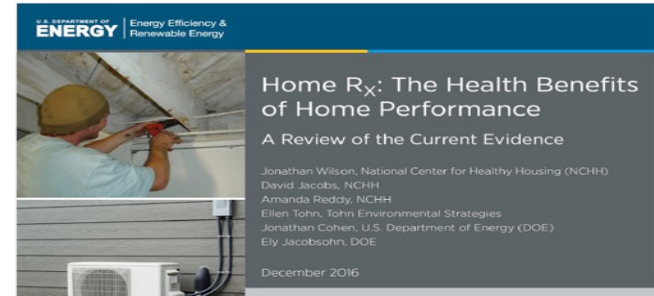
Strong indicators that residing in **social housing is associated with negative health effects**, with **high prevalence of respiratory problems**.

Green retrofits have the potential to improve IEQ, but they must be tailored to each building.



Efficient homes can have **BETTER** IAQ

- High performance homes can have lower pollutant levels and better occupant health ¹
 - Sealed crawlspaces have lower moisture
 - Less air from attached garages, attics, crawls
 - Mech. ventilation provides consistent dilution
 - Sealed combustion or all electric
- **Inattention to ventilation, source control & education may lead to higher pollutant levels and health effects²**



¹ Breysse et al., 2011; Jacobs, 2013; Leech et al., 2004; Kovesi et al., 2009; Weichenthal et al., 2013; Norris et al., 2012

² Tohn, 2012; Wilson et al., 2013; Emmerich, Howard-Reed, & Gupte, 2005; Milner et al., 2014; Offermann, 2009

³ Coulter et al., 2007; ⁴ Emmerich et al., 2003;

Summary

- Major improvements over past 40 years
- Still many homes with IAQ risk
- IAQ in *new*, single-family homes looks good
- Ventilation reduces VOCs and improves perceived IAQ
- Filtration can greatly reduce particles
- Many people turn off ventilation and filtration
- Kitchen ventilation not always used

Water & microbiology hazards are increasing

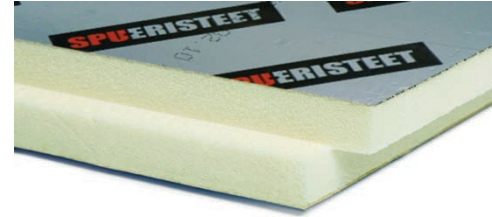


Hurricane Sandy

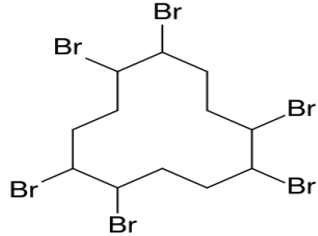


Maxwell, CA 2017

Flame retardants (FRs) in building insulation



HBCD



hexabromocyclododecane

- bioaccumulative
- thyroid disruption
- affects developing nervous system
- developmental neurotoxicity in mice

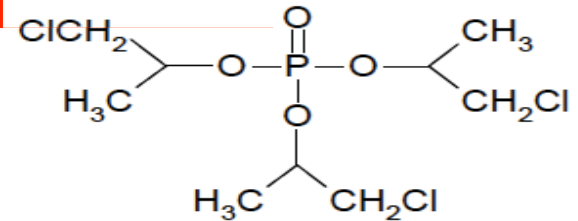
Flame retardants (FRs) in building insulation



tris (1-chloro-2-propyl) phosphate

- accumulates in liver and kidneys
- affects nervous system development
- potential carcinogen

TCPP



The Precautionary Principle

If the **consequences** of an action are **unknown**, but judged to have some **potential for major or irreversible negative consequences**, then it is better to ***avoid that action***.

Source: Wikipedia

- 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.



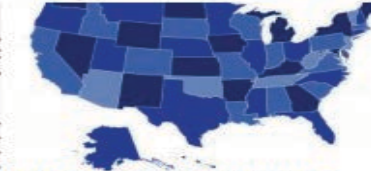
Volatile Organic Compounds

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 modify indoor environmental quality (IEQ).

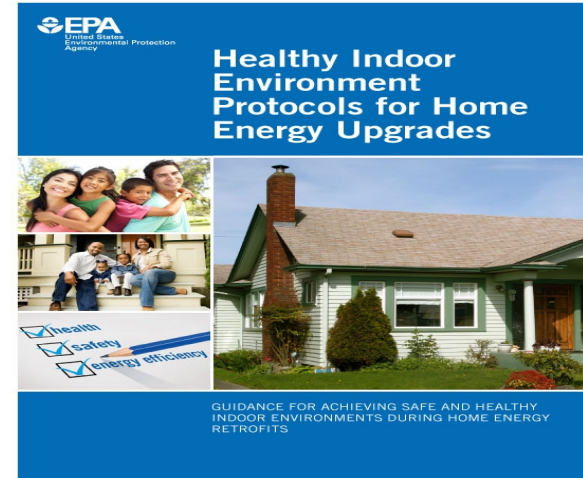


IAQ in Schools

This section provides an overview of indoor air quality (IAQ) in schools and its influence on the health, performance, and absence of

EPA Resource for IAQ in Retrofits

- Guidance to maintain & improve IAQ during energy upgrades, retrofits or remodeling
- Applies to existing single-family and low-rise multifamily residential bldgs



PRIORITY ISSUES

ASSESSMENT PROTOCOL

HEALTHY INDOOR ENVIRONMENTS

Minimum Actions

Expanded Actions

Issues that arise during energy retrofits

What to look for during an energy audit

Ensure work does not degrade IAQ or safety (Do No Harm)

Improve IAQ when feasible

Resources 1

- Healthy Products
 - Environmental Working Group
 - <http://www.ewg.org/>
 - Healthy Building Network—Pharos Database
 - <http://www.pharosproject.net/>
 - Good Guide
 - <http://www.goodguide.com/>
 - BuildingGreen chemical avoidance guidance
 - <https://www.buildinggreen.com/avoiding-toxic-chemicals>
 - Health Product Declaration
 - <http://hpdcollaborative.org/>
 - Green Science Policy Institute
 - <http://greensciencepolicy.org/>

Resources 2

- Overall Design
 - Building America Solutions Center
 - <https://basc.pnnl.gov/>
 - Building Science Corporation
 - <https://buildingscience.com/>
 - Indoor airPLUS
 - <http://www.epa.gov/indoorairplus/>
 - EPA Moisture Control Design Guide
 - <http://www.epa.gov/iaq/pdfs/moisture-control.pdf>
 - Healthy Indoor Environmental Protocols for Home Energy Upgrades
 - http://www.epa.gov/iaq/pdfs/epa_retrofit_protocols.pdf
 - National Center for Healthy Housing
 - <http://www.nchh.org/>

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