IAQ @Home: How are we doing?

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The Corsi Code

Average life expectancy	Indoors	At home	In bed	In vehicles	Outside
79	69	54	26	4.3	6

Fraction of time indoors, at home, in transit and outside based on Klepeis et al., J Exp Anal Env Epid 2001, 11, 231

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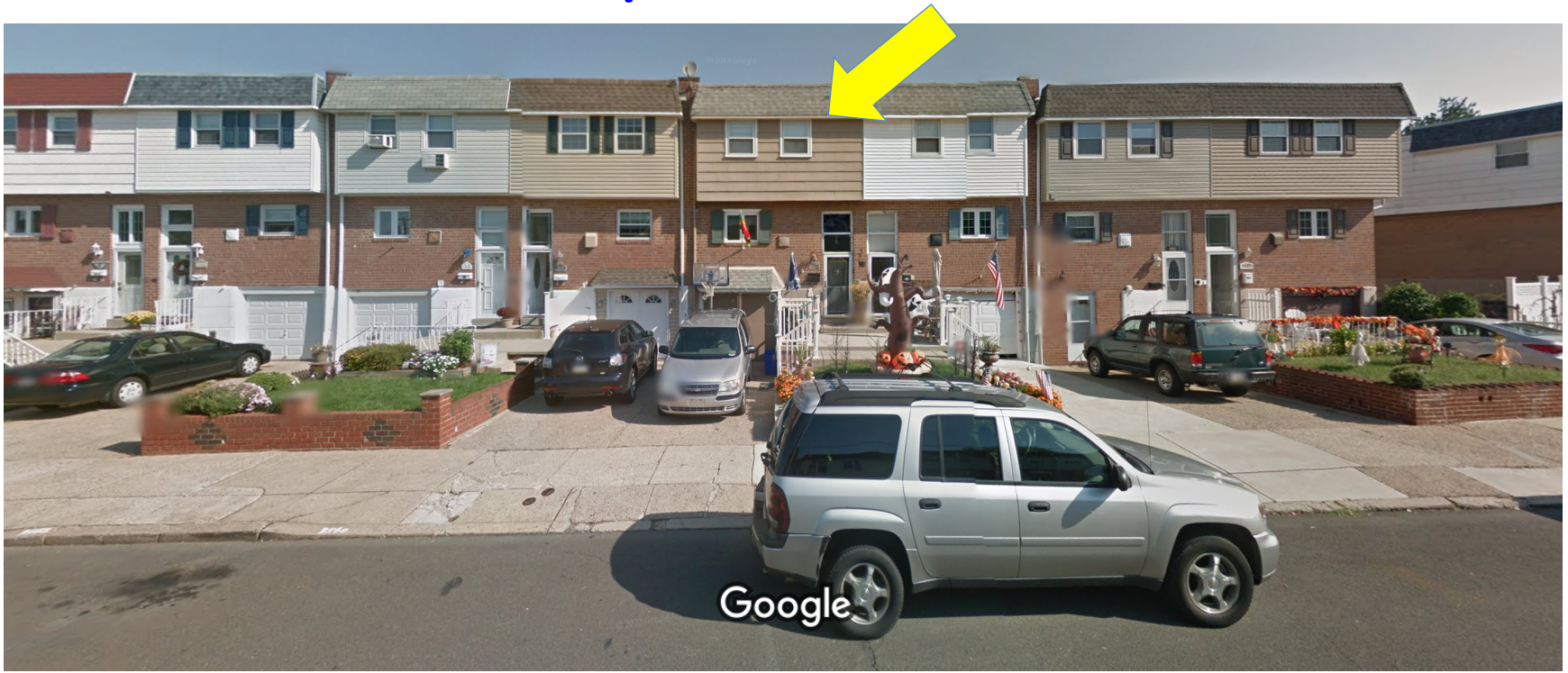
My first home



The indoor environment of my youth

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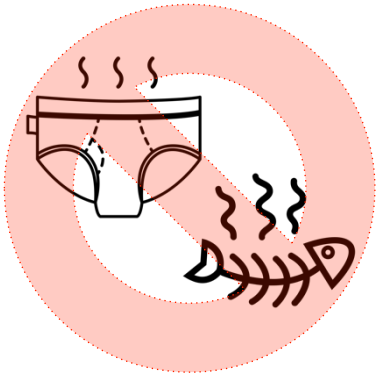
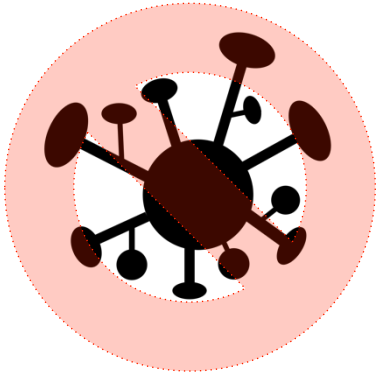
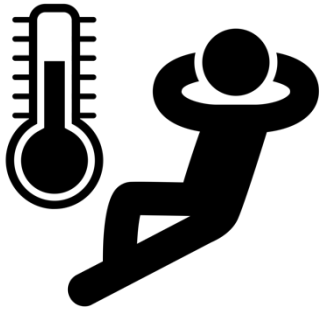
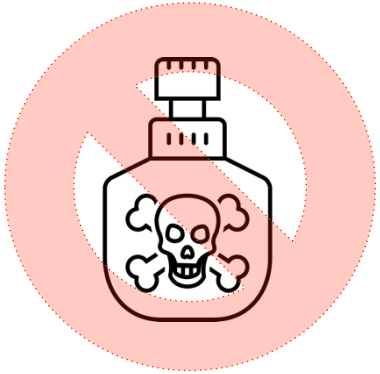
What is Indoor Air Quality?

Indoor air quality is…









What do we have to worry about?

Particulate matter:

- PM_{10}, $PM_{2.5,}$Ultrafine particles
- Metals; PAH
- Acids

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

The Dose Makes the Poison

"Alle Ding sind Gift und nichts ohn Gift; alein 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

$PM_{2.5}$

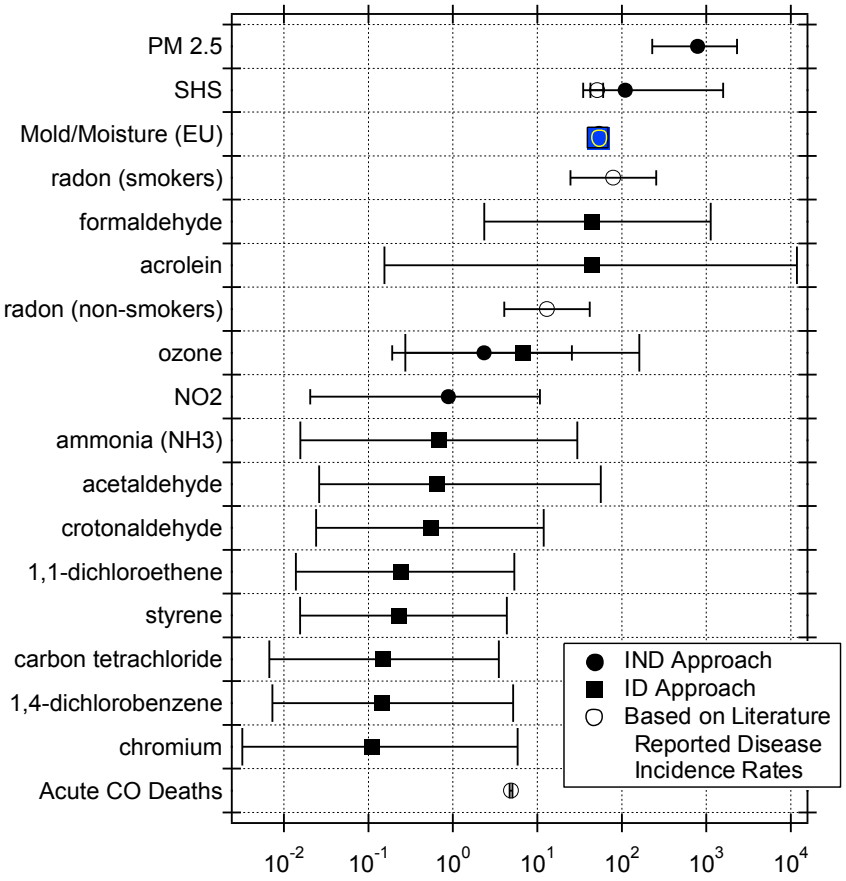
Secondhand smoke

Mold / moisture

Radon

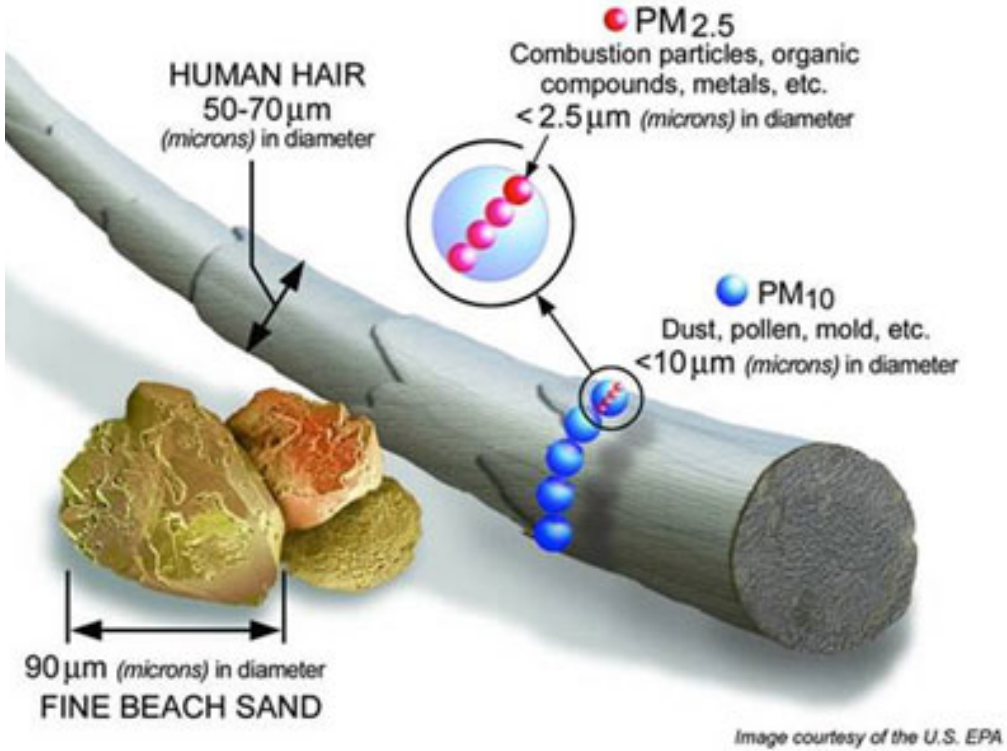
Formaldehyde

Acrolein, Ozone, NO_2



Logue et al., Environmental Health Perspectives, 2012

Fine particulate matter ($PM_{2.5}$)



- **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

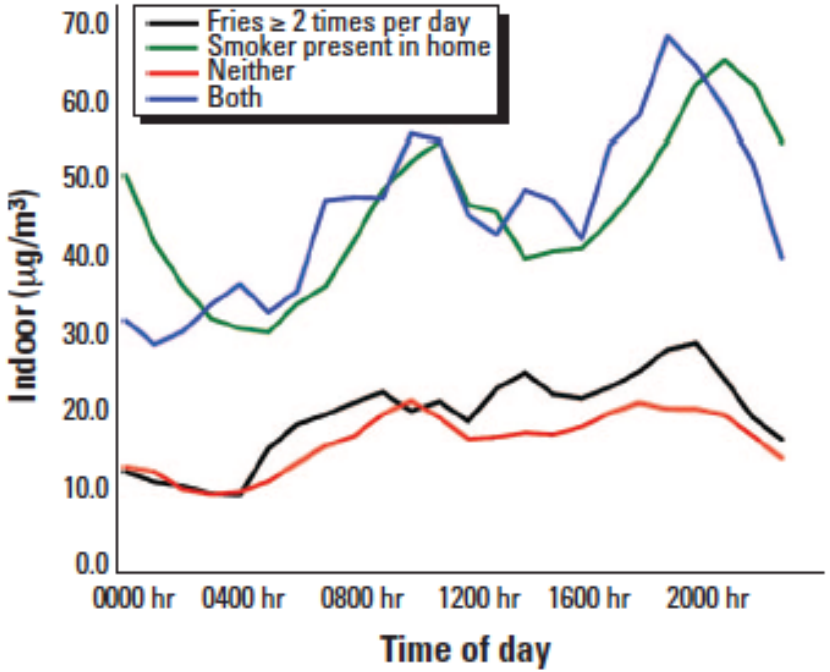


Figure 4. Diurnal variation of hourly average concentrations in homes with smokers, homes reporting frequent frying (twice a day or more), homes with both characteristics, and homes with neither characteristic.

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

Particulate matter is really complicated

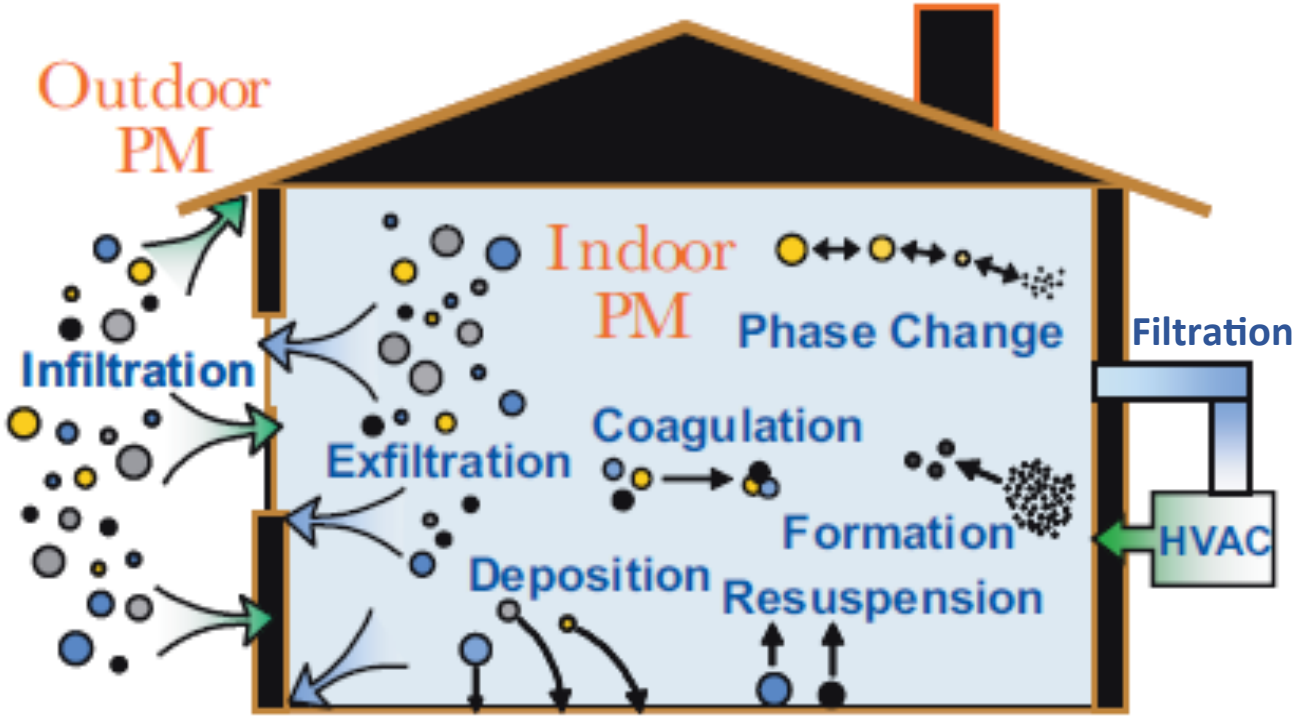


Image Ref*:* http://eetd.lbl.gov/newsletter/nl14/

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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

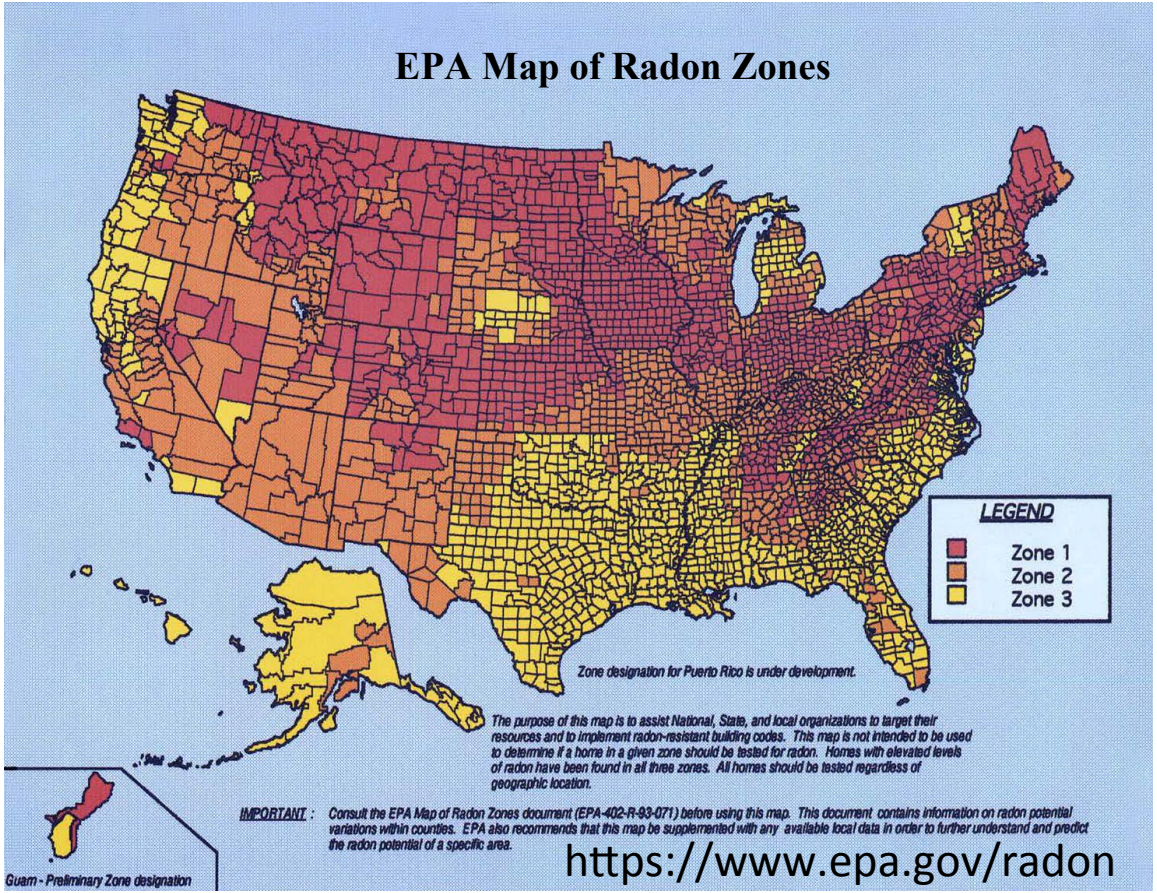
80% had NO2 above ambient std

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



Formaldehyde

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

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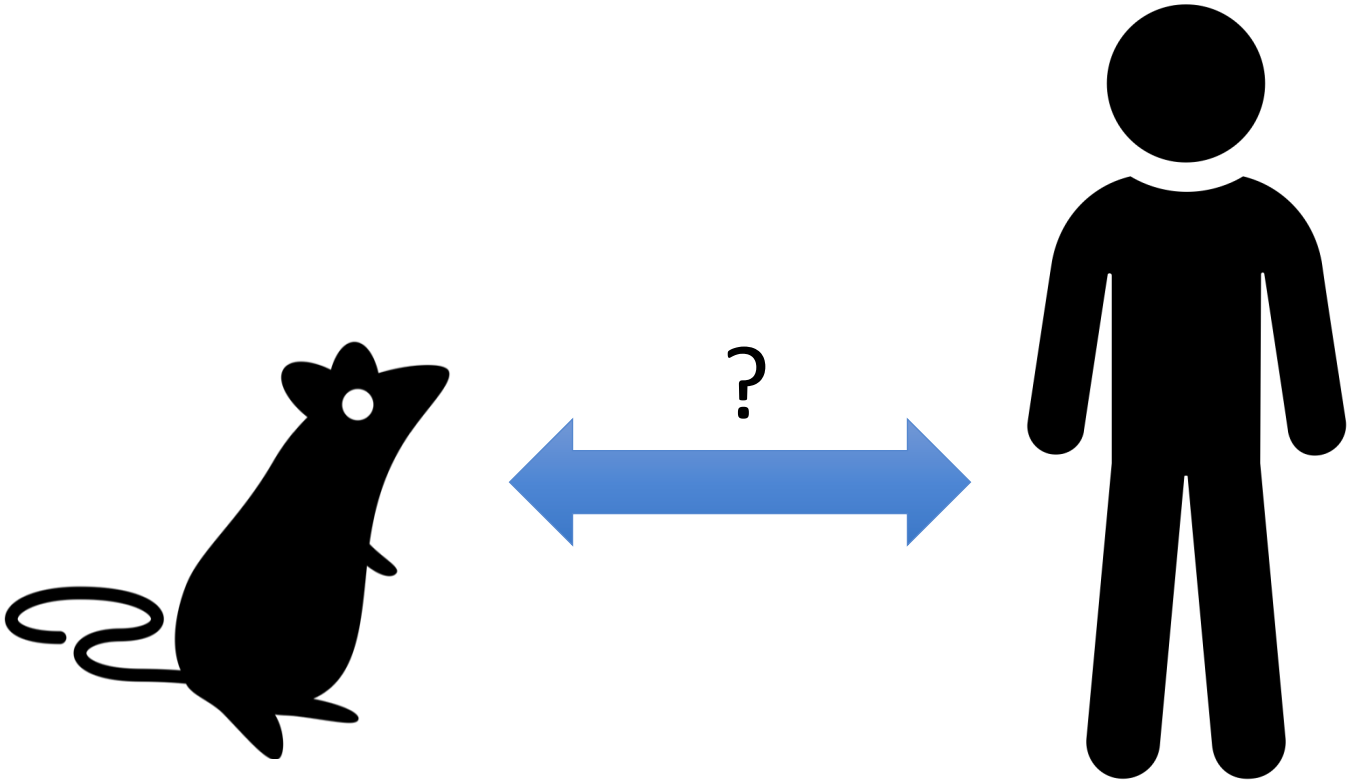
Uncertainty in formaldehyde guidelines

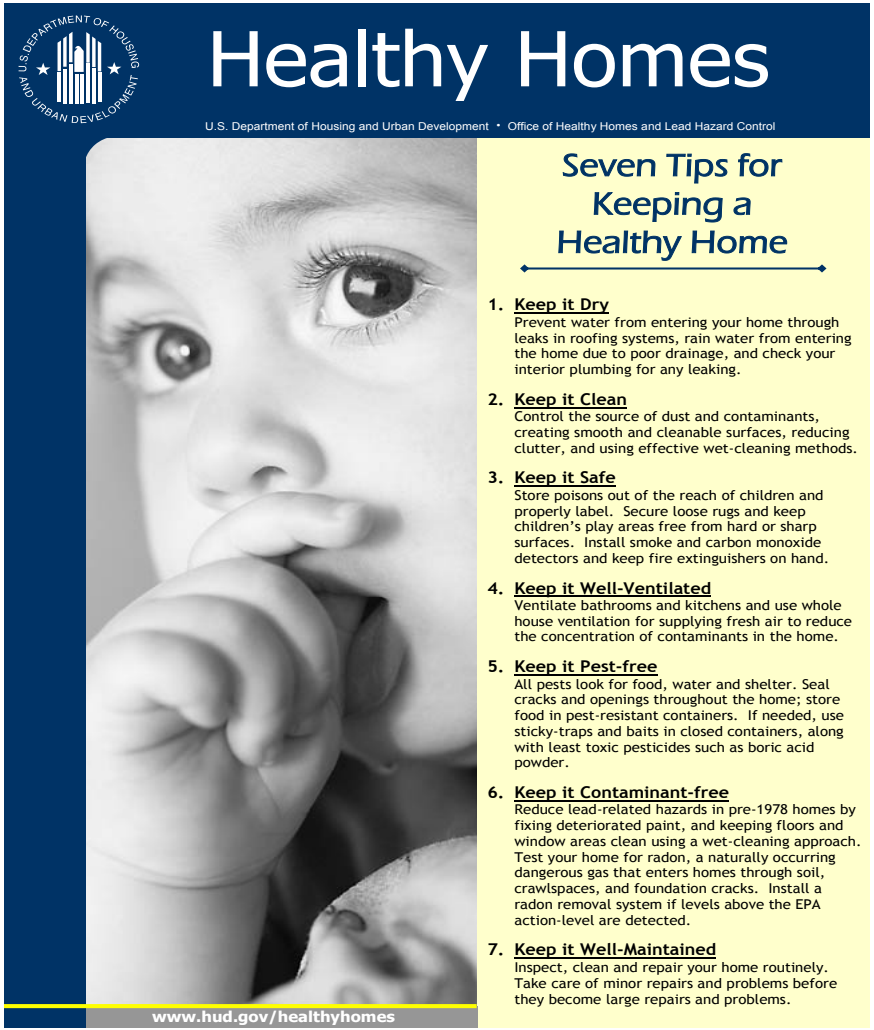


Reducing IAQ Risks

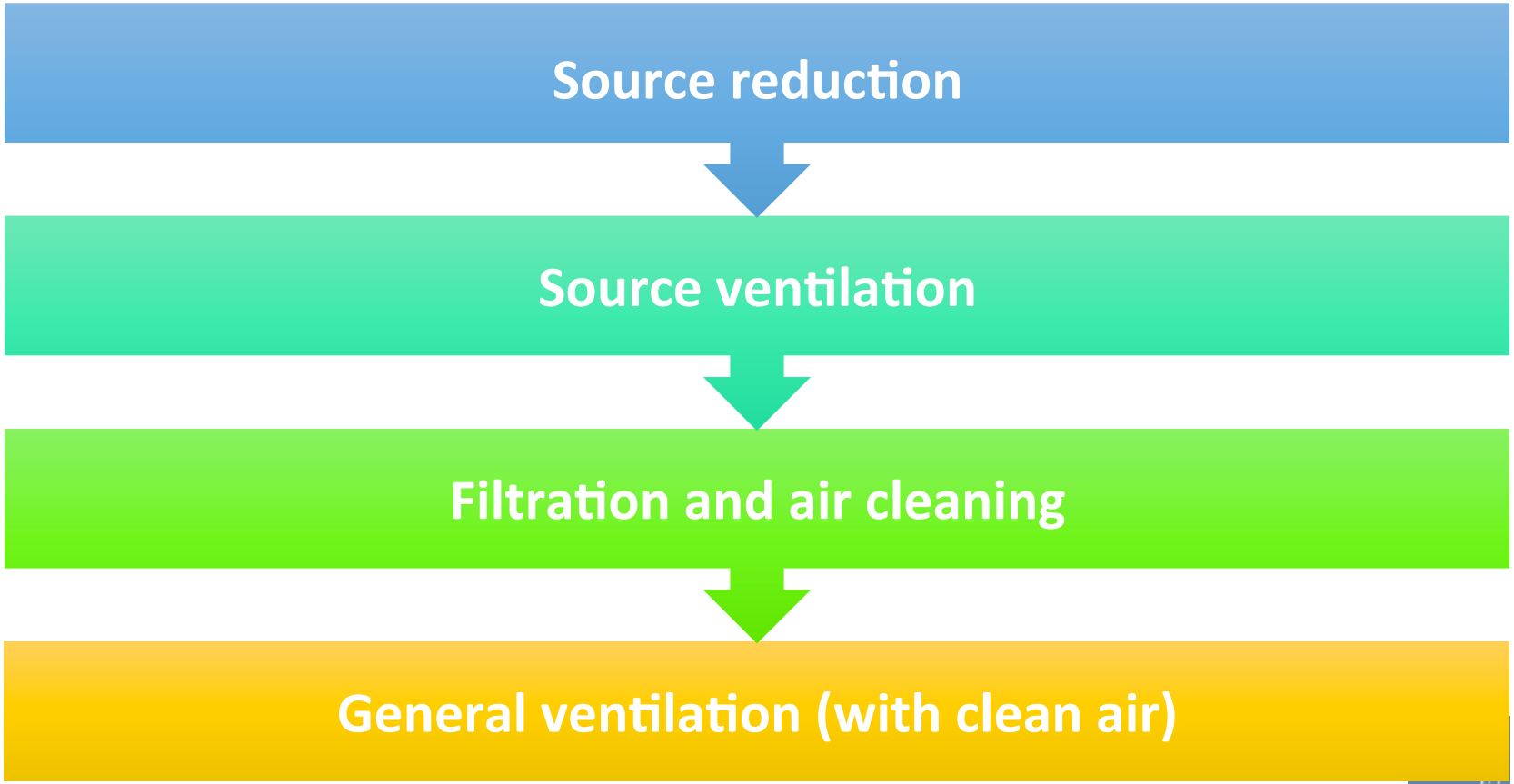
The Healthy Home Code

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



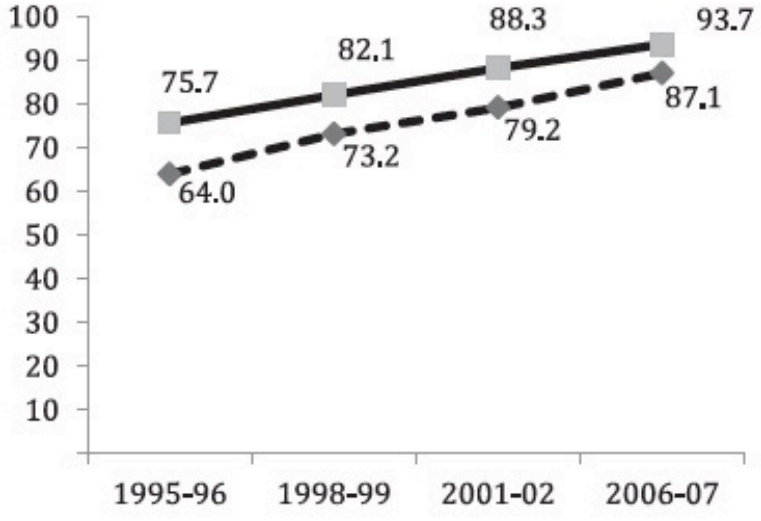
How do we reduce our risk?



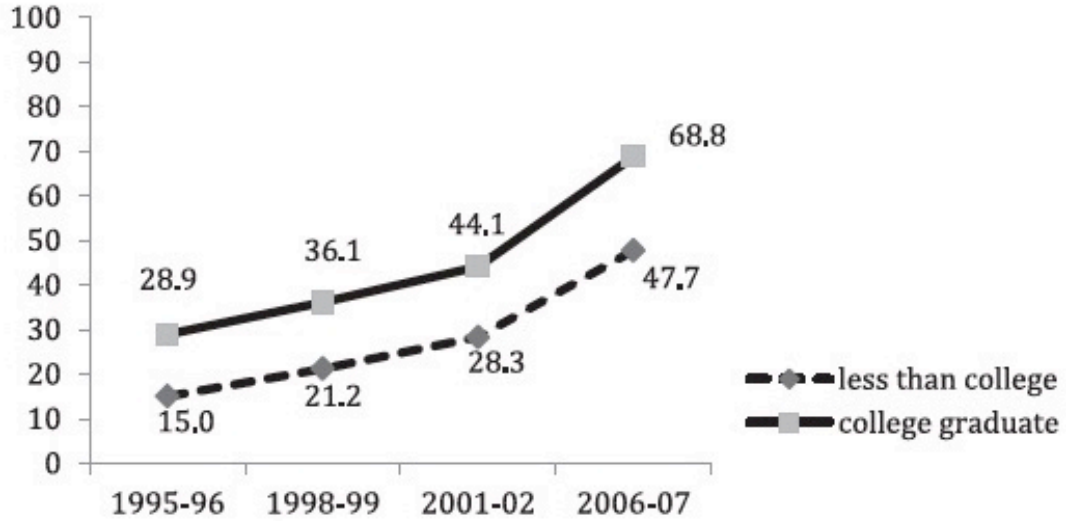
Pollutant Source Reduction

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

MERRIT KENNEDY

Implemented 8/1/2018

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

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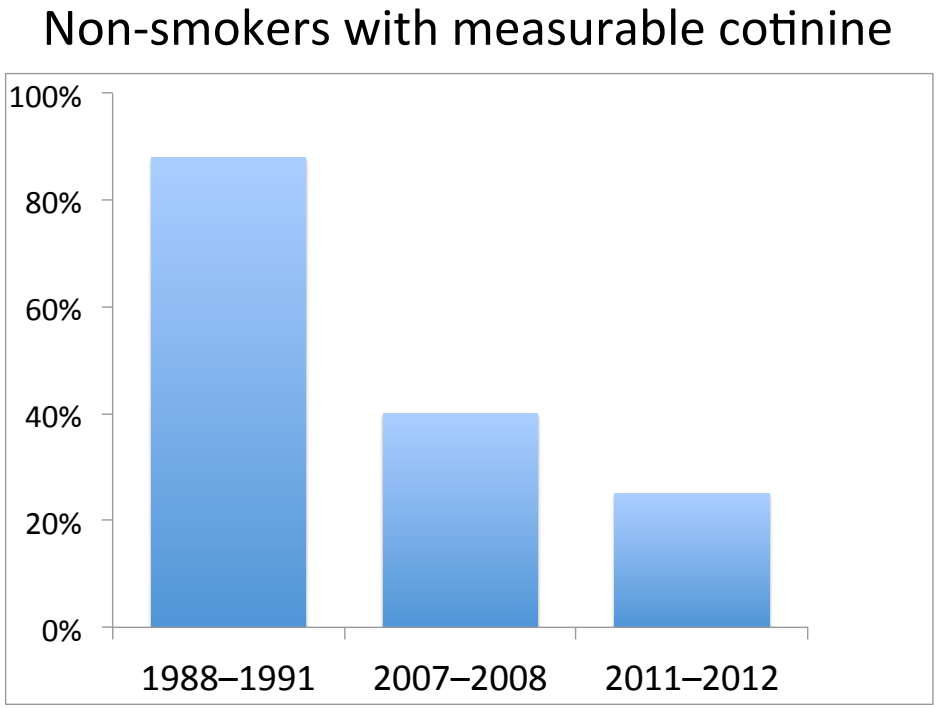
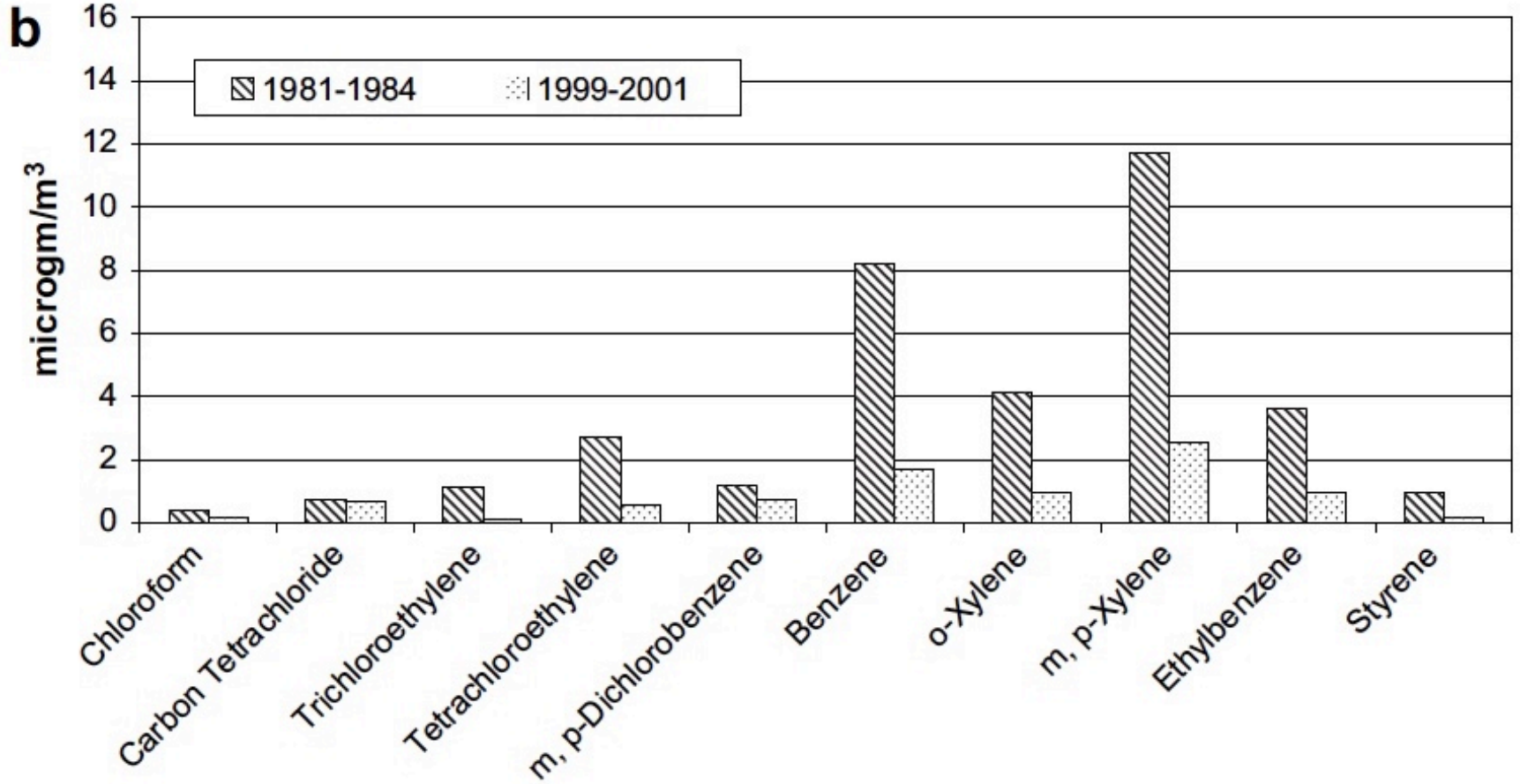
Smoking bans reduce exposure



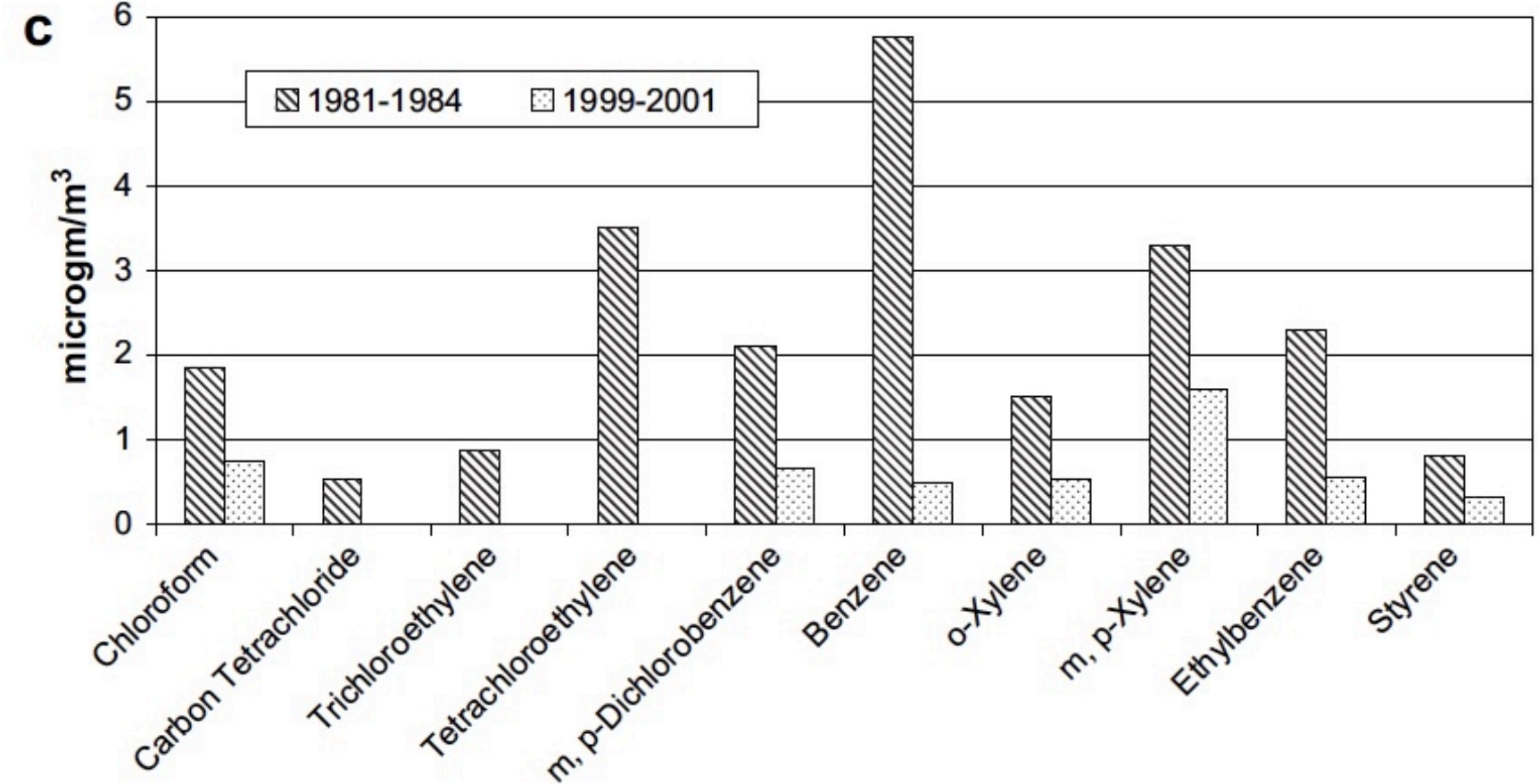
Data from https://www.cdc.gov/tobacco/data_statistics/fact_sheets/secondhand_smoke/general_facts/index.htm
Accessed 8/4/18

VOCs have decreased *outside*



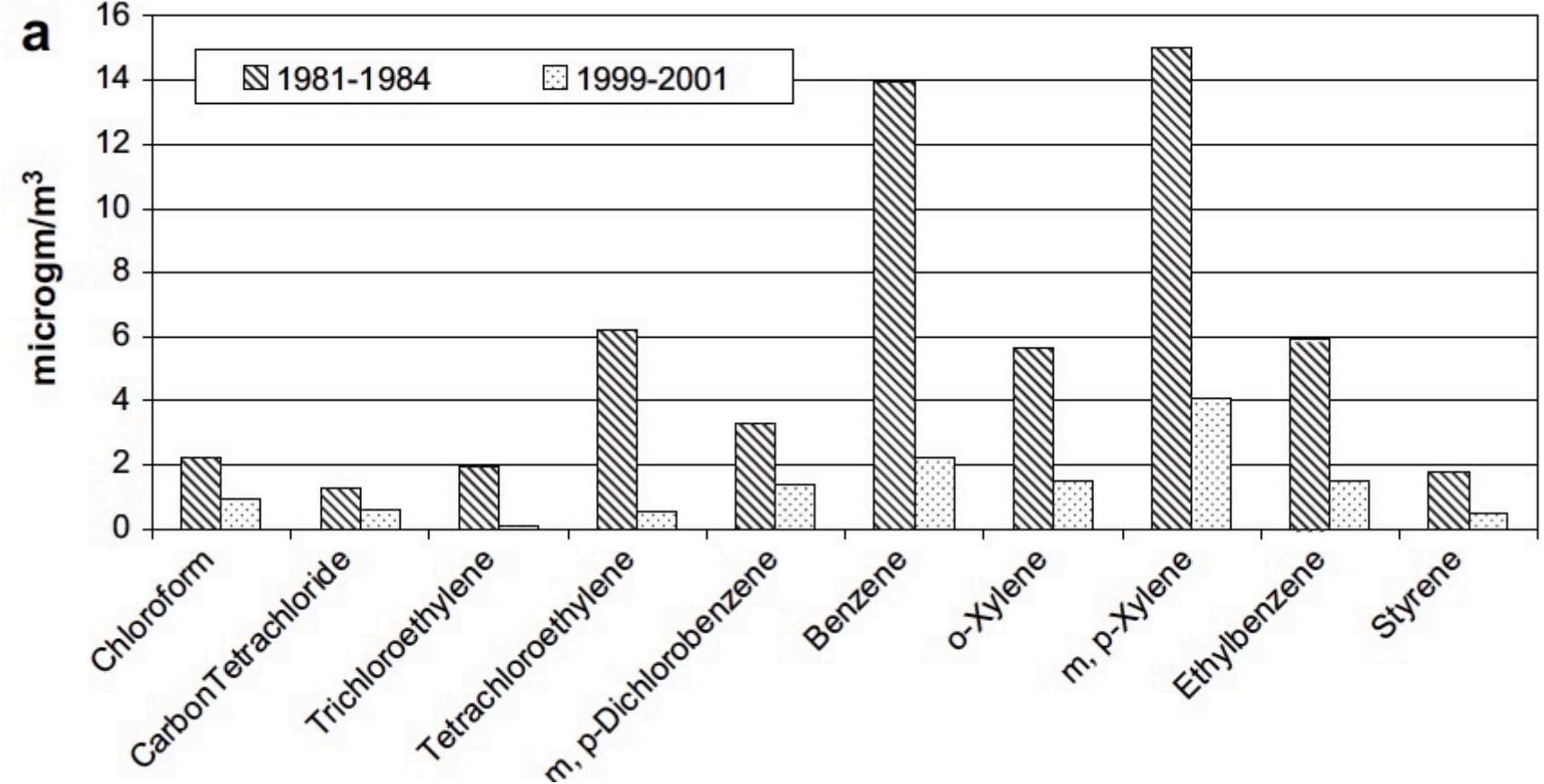
Weschler, 2009, Atmos. Env., citing data from Weisel et al., Health Effects Inst., 2005 and Wallace, 1987, EPA/600/6-87/002a

Emissions have decreased inside



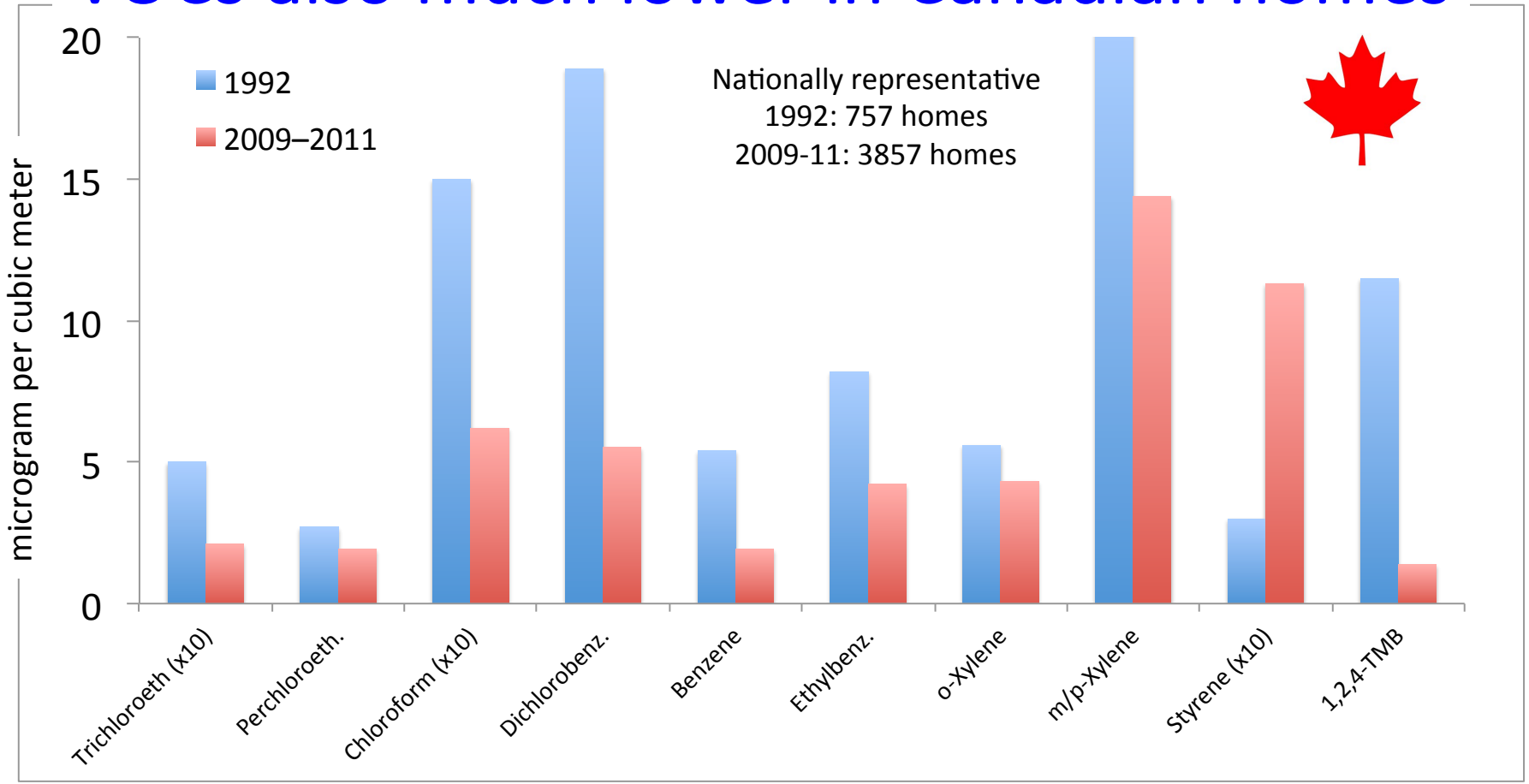
Weschler, 2009, Atmos. Env., citing data from Weisel et al., Health Effects Inst., 2005 and Wallace, 1987, EPA/600/6-87/002a

…leading to VOC reductions inside homes



Weschler, 2009, Atmos. Env., citing data from Weisel et al., Health Effects Inst., 2005 and Wallace, 1987, EPA/600/6-87/002a

VOCs also much lower in Canadian homes



2009-2011: Zhu et al., *ES&T.* 2013;47:13276-13283; 1992: Davis & Otson. Estimation of emissions of VOCs from Canadian residences. In ASTM STP 1261, 1996; pp 55–65

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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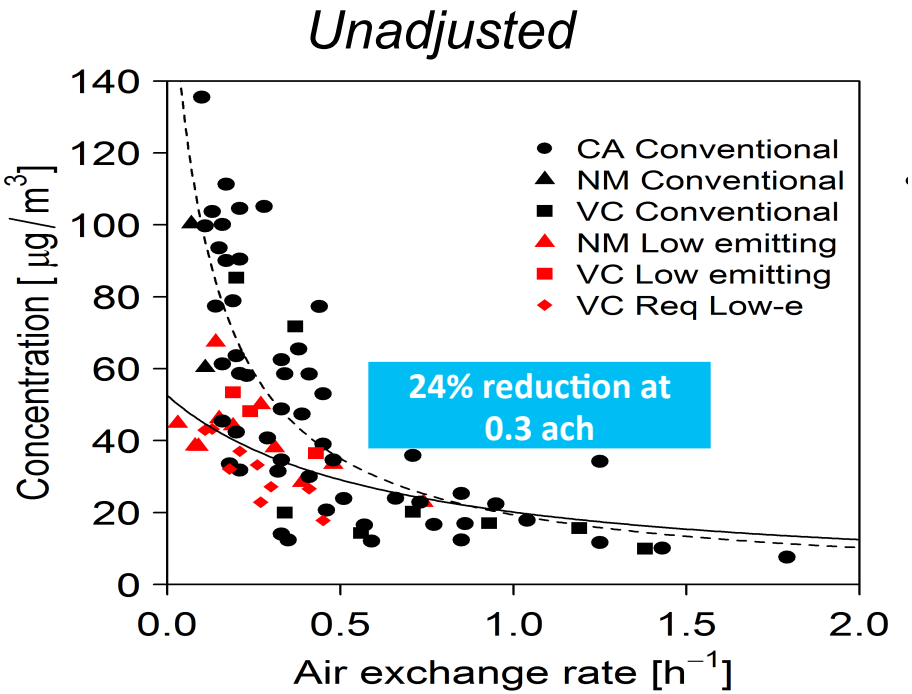
Homes built with low-emitting materials have lower formaldehyde concentrations



Hult et al., Indoor Air, 2015

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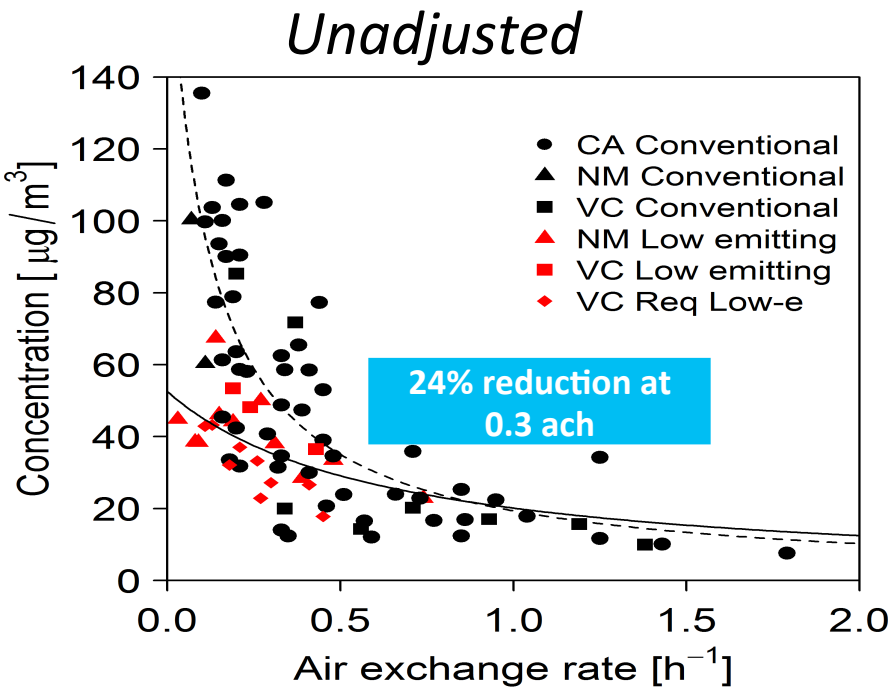
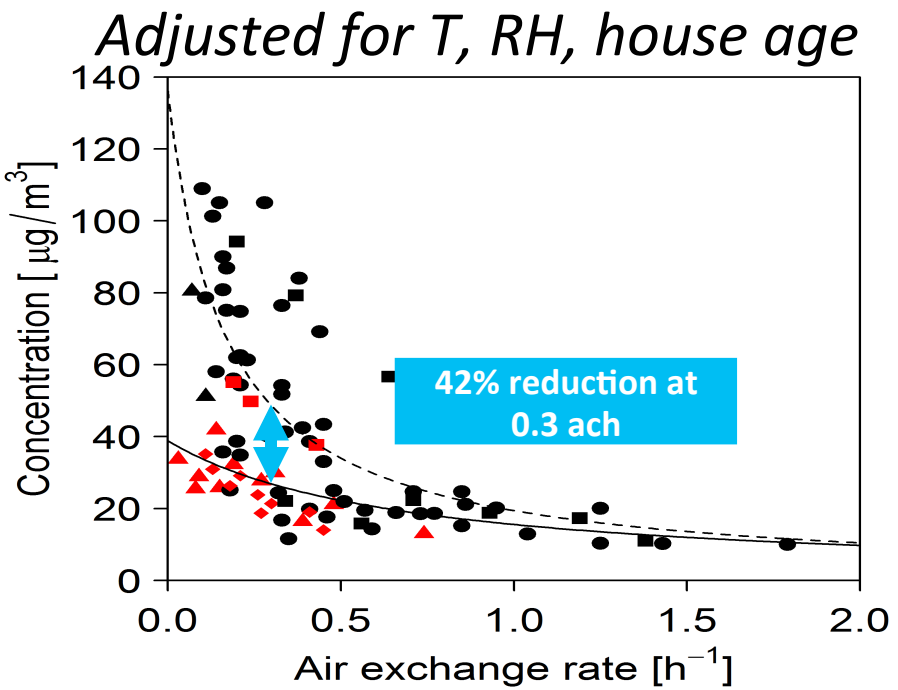




Hult et al., Indoor Air, 2015

Benefits of exposure reduction vary

Reducing	by	Saves how many cancers?
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 *non-smokers*

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 Study[1]

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

MESA Air[2] (n=353 homes) – 80%

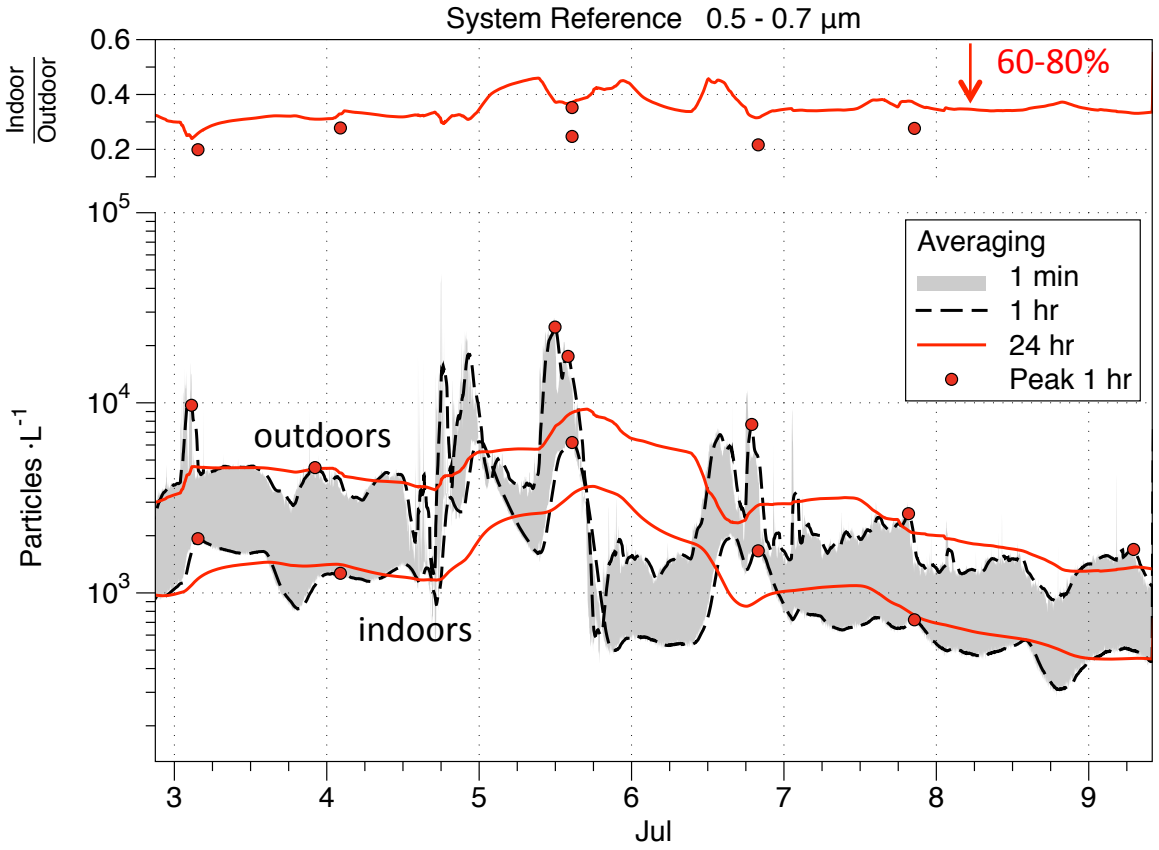
- Baltimore,
- Chicago,
- Los Angeles,
- New York,
- Rockland,
- St. Paul,
- Winston-Salem

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

Air tightness helps reduce outdoor particles

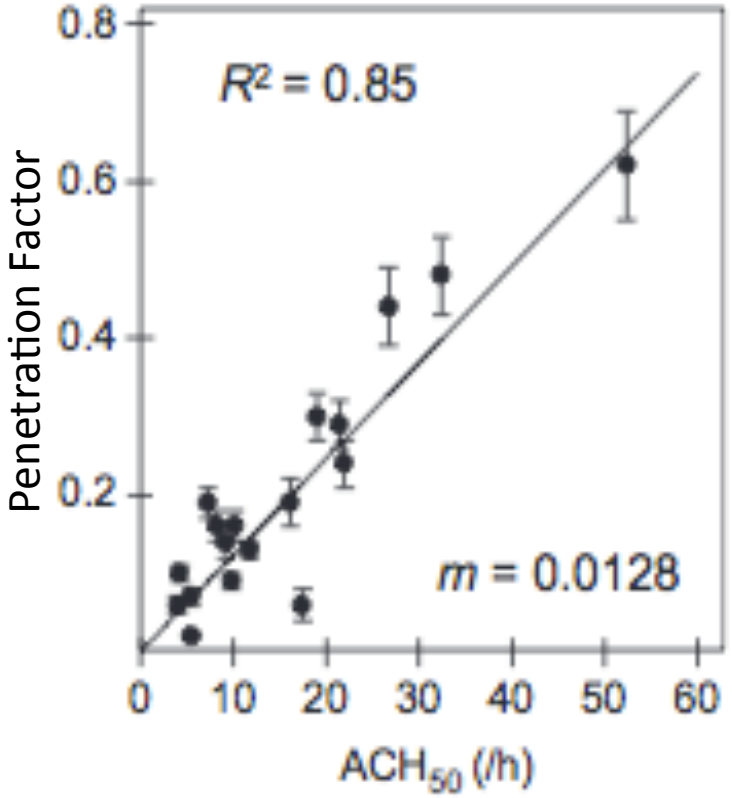
Built 2006, 1200 sf, 5 ach50,
Sealed ducts, 0.22 ach natural
Exhaust ventilation, MERV4 filter

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



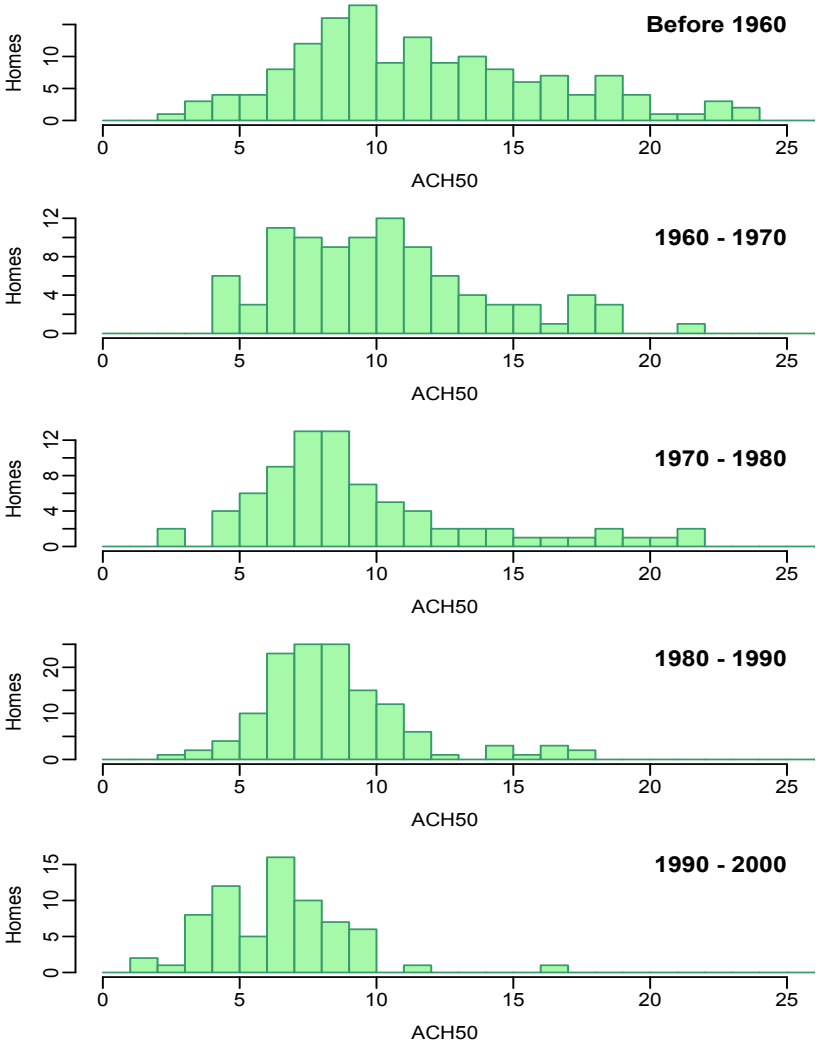
Singer et al., Indoor Air, 2016

More airtight homes have lower particle penetration rates

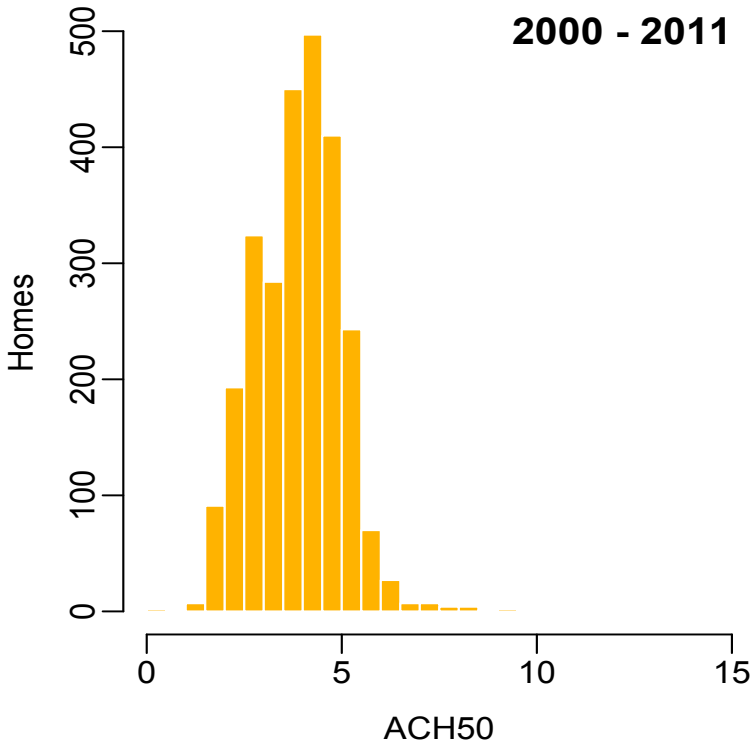


The penetration factor is the fraction of outdoor particles that make it into the house with infiltrating air

Stephens and Siegel, 2012



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

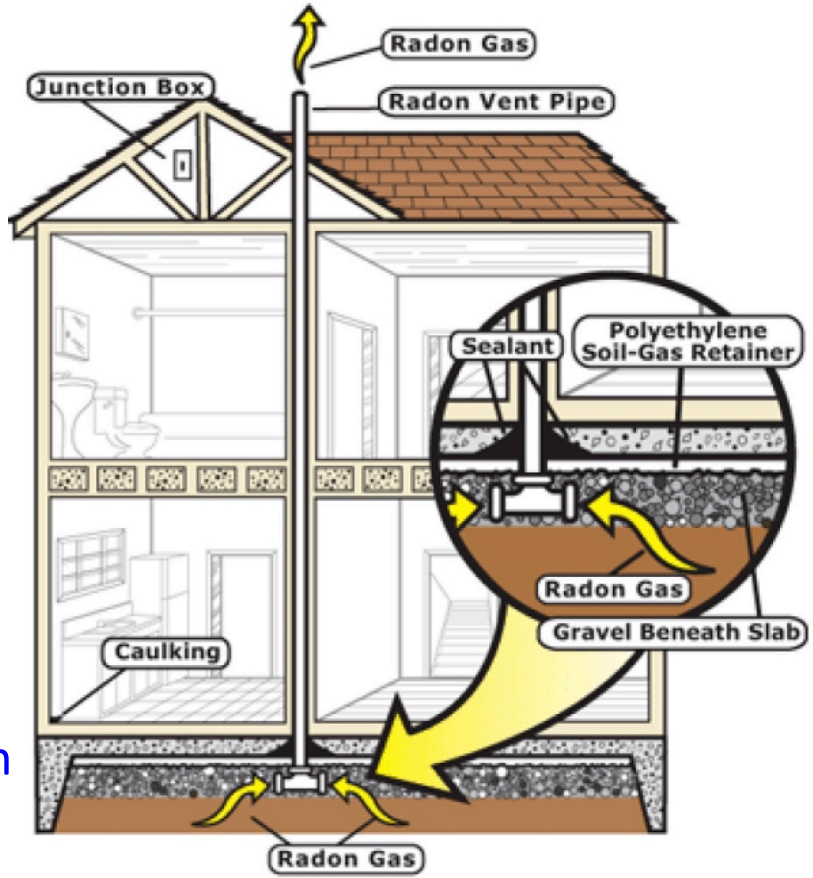
EPA guidance is to retest if first test is >4 pCi/L.

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



https://www.epa.gov/radon

Image: Radon Protection in New Homes Webinar presented on Jan 30, 208

Source (Kitchen) Ventilation

Cooking & burners are important sources

CO_2 & H_2O

NO,NO_2, HONO, Formaldehyde

Ultrafine particles

Ultrafine particles

Ultrafine particles, $PM_{2.5}$

Formaldehyde, Acetaldehyde

Acrolein, PAH

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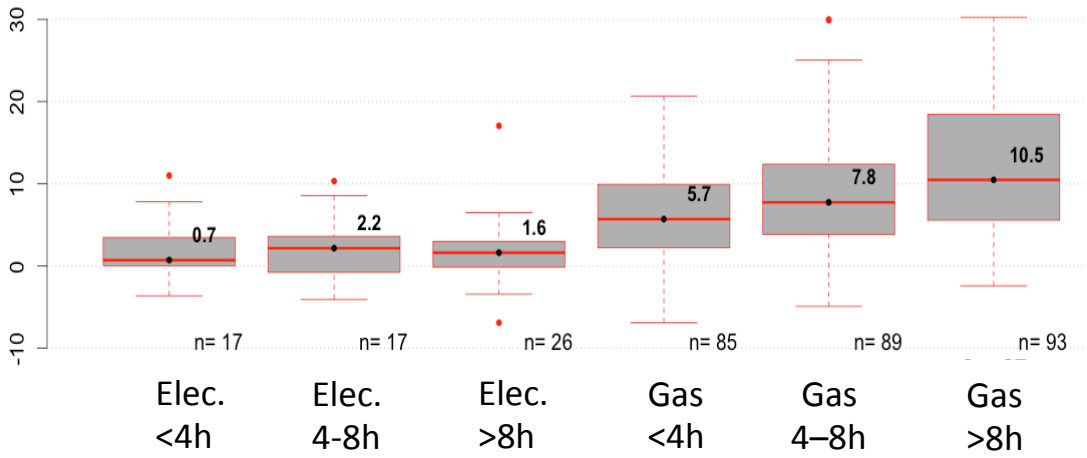
Gas cooking burners can have big impact

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

Mullen et al., 2015, Indoor Air

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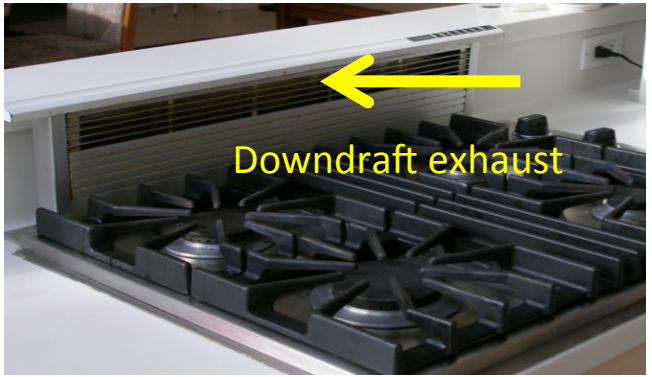
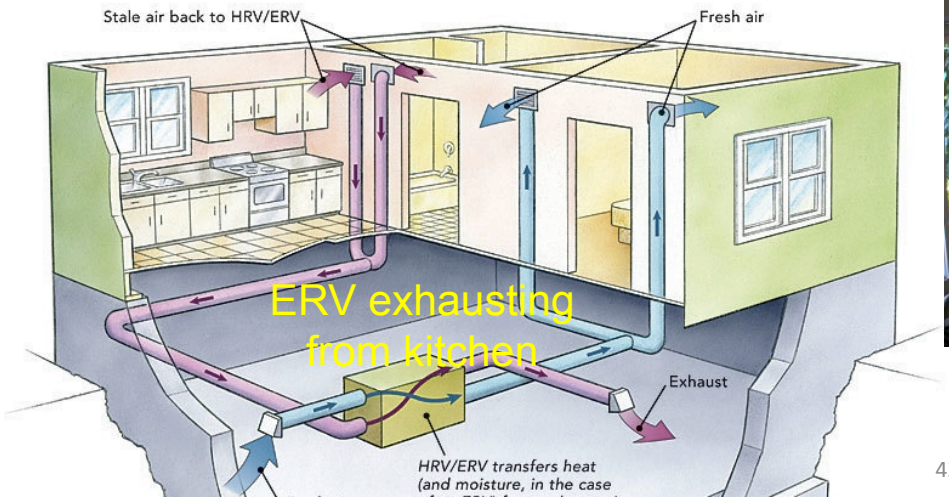
Kitchen ventilation options



Exhaust fan on wall



Ceiling exhaust fan

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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

Lab performance: Delp and Singer, 2014

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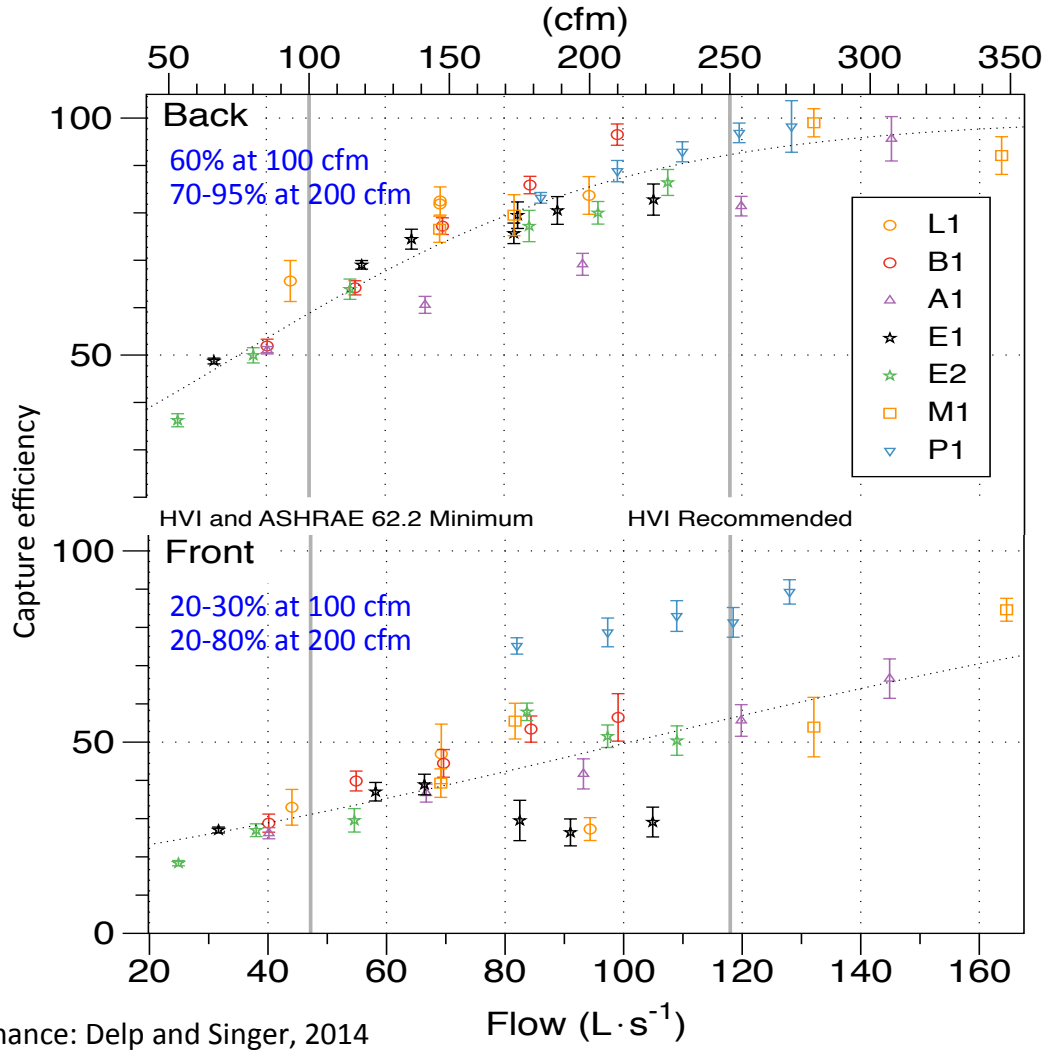
Studies of range hood performance

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



Lab performance: Delp and Singer, 2014

As installed range hood performance varies

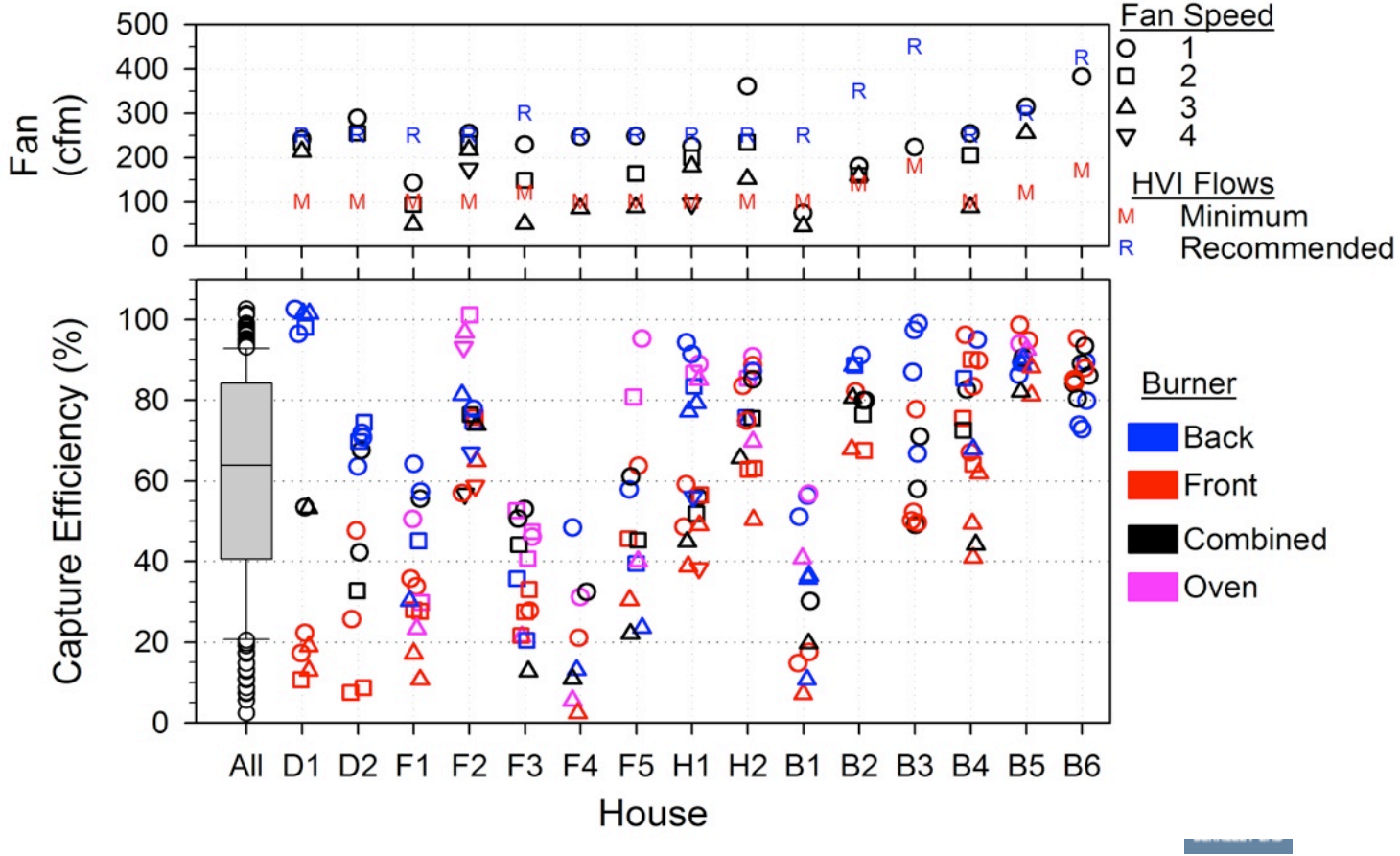
Singer et al., 2012, Indoor air

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 425ºF + 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 m^2 + 26 m^2 apt; 1-2 stories; Built 1904–1991
  - 6 with venting hood, 1 bath fan, 1 recirc hood

Singer et al., 2017, Building Environment

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Pollutant measurements

CO_2, NO_X, NO, NO_2, Particles ≥ 6 nm, $PM_{2.5}$ by scattering, CO, T, RH

Kitchen

Bedroom area

Singer et al., 2017, Building Environment

How we used to do it. (circa 2007)

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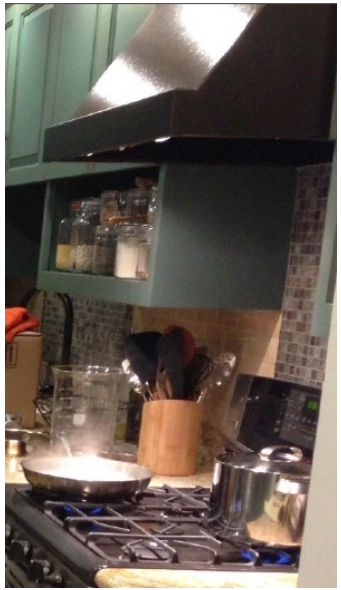
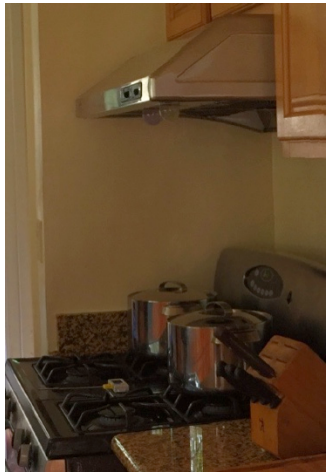
Range hoods in study homes



H1

H2



H5

H6

H9

H8

Singer et al., 2017, Building Environment

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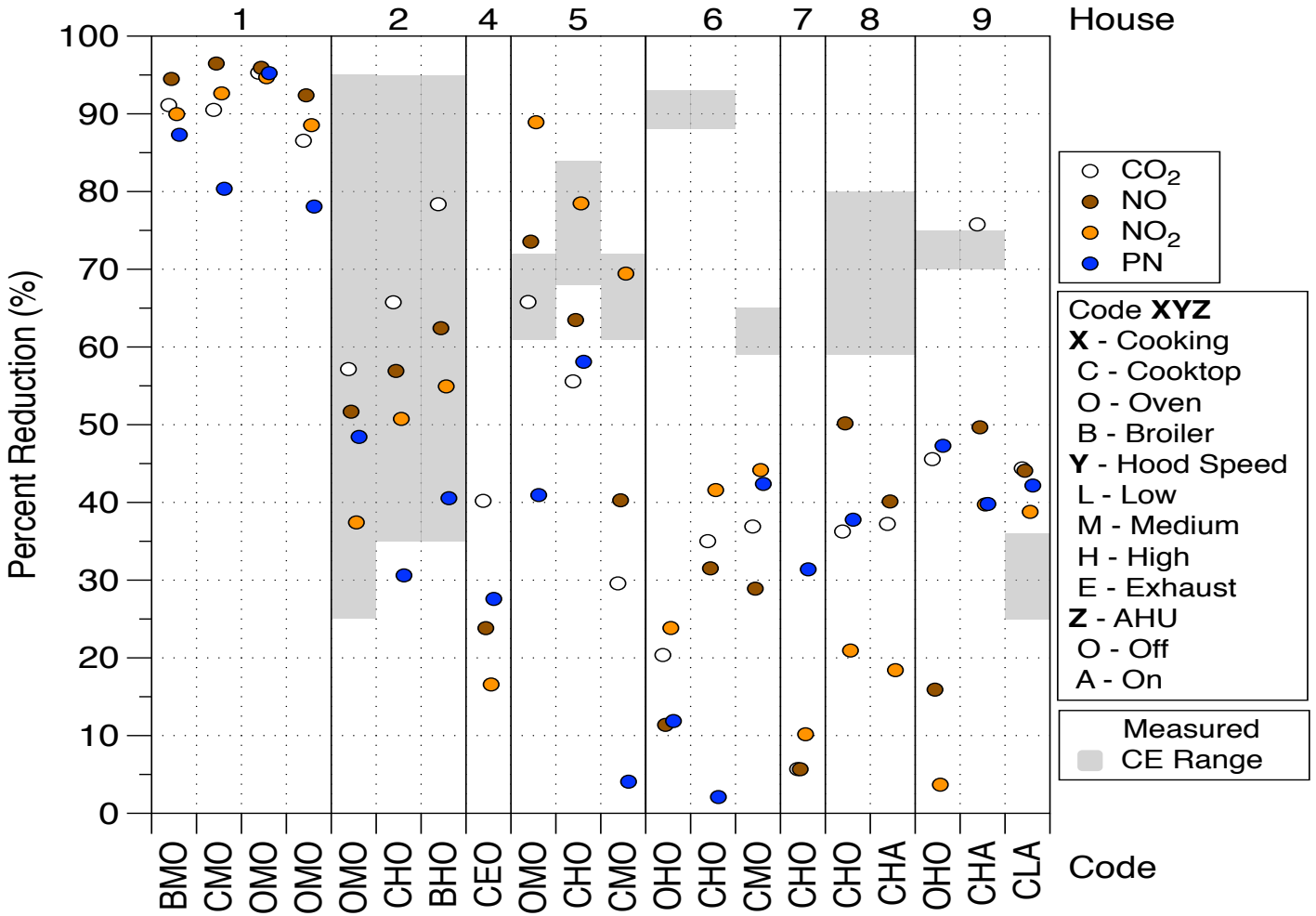
Reductions in pollutant levels with range hood use



Singer et al., 2017, Building Environment

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%

Mullen et al. LBNL-5970E

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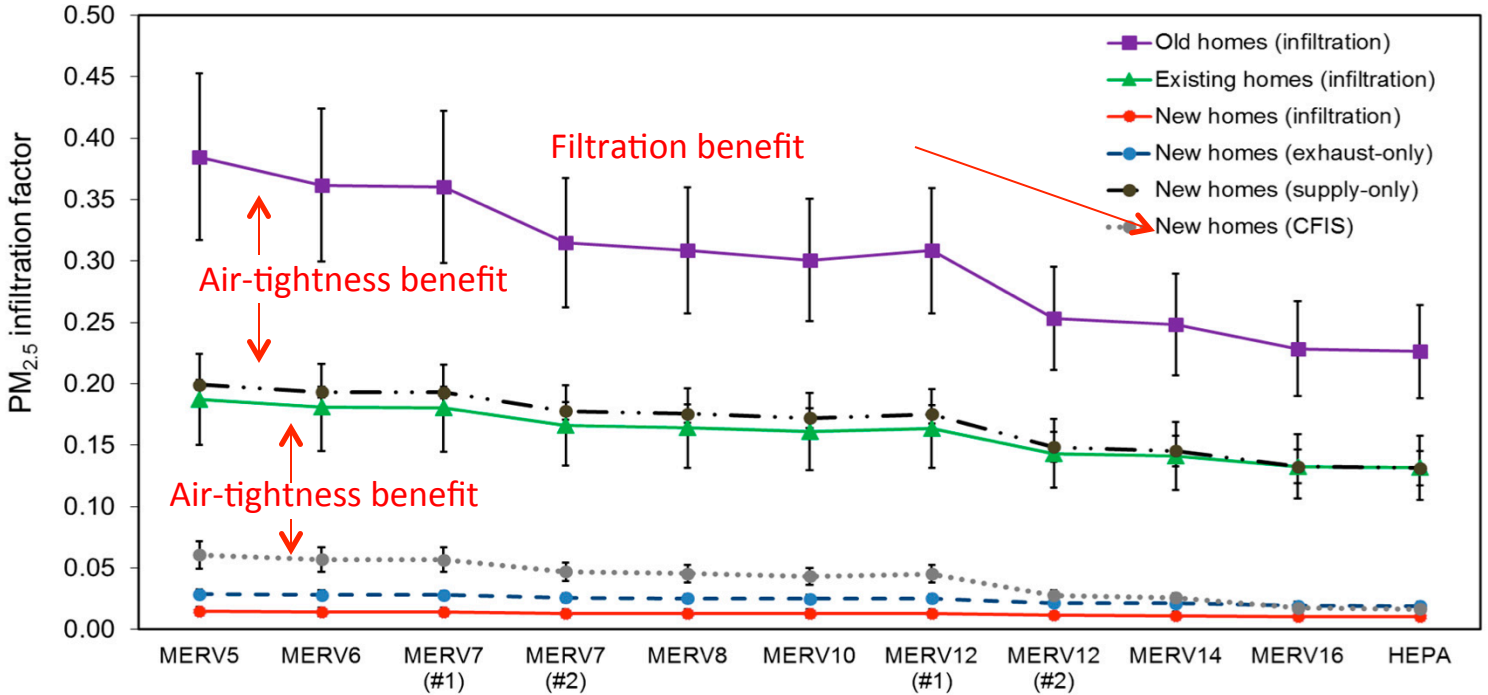
Infrequent use of kitchen exhaust:

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)



Zhao, Int. J. Environ. Res. Public Health 2015, 12

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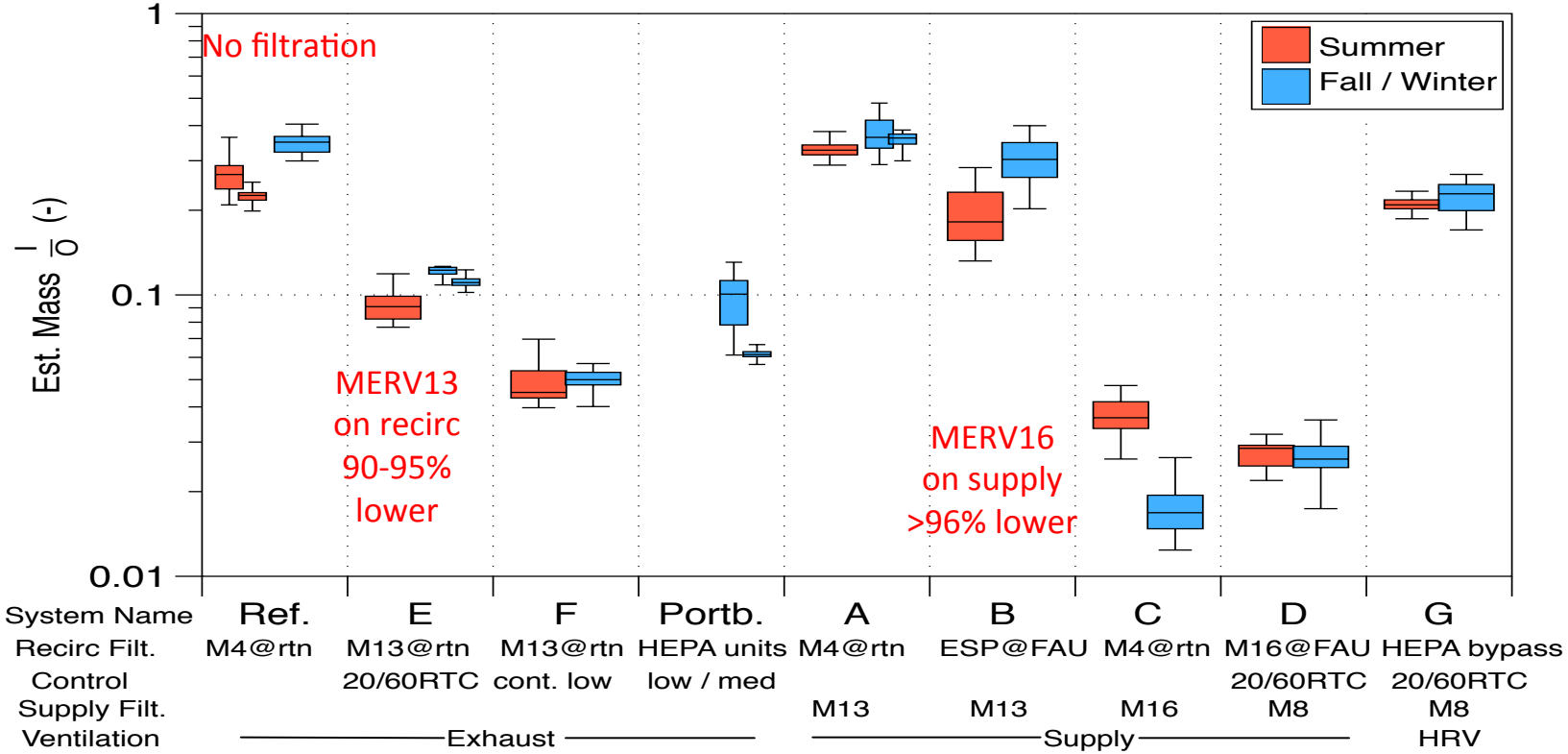
In test house, filtration greatly reduced PM from outdoors



Built 2006, 5.0 ACH50
Exhaust ventilation
AER = 0.22 h^{-1}

Singer et al., Indoor Air, 2016

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

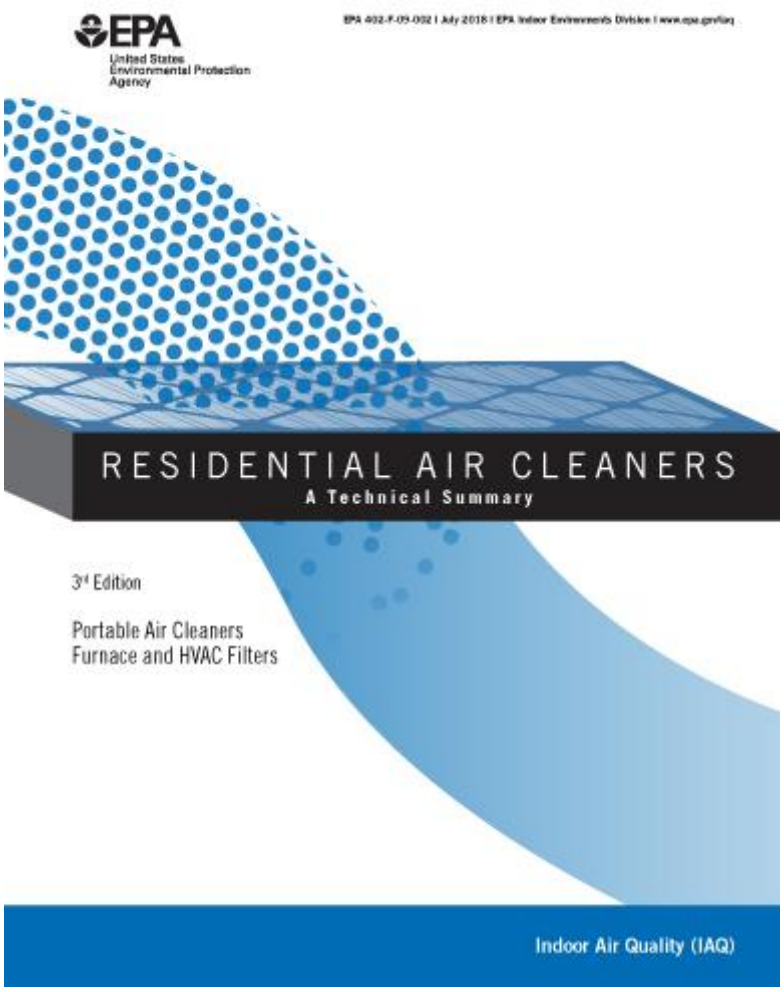
- Intervention study in 126 low-income homes of children with asthma
- Baseline and 3 seasonal follow-up visits
- Some homes had smokers (SHS tracers)

Mean±SD $\mu g\ m^{-3}$	**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)

Batterman et al., Indoor Air, 2012

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)

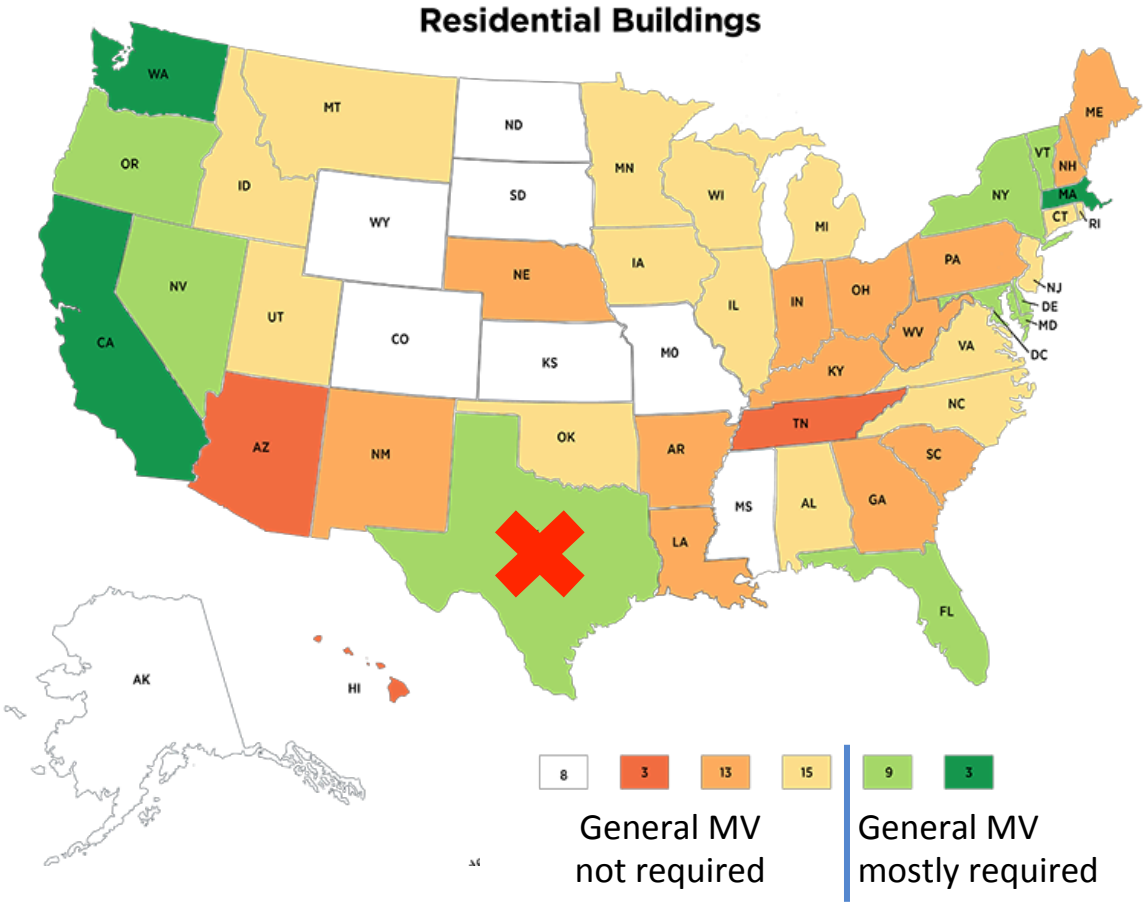


https://www.epa.gov/indoor-air-quality-iaq/air-cleaners-and-air-filters-home

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

Dirty outdoor air intake.

Faults

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

Dirty ERV filters.

(Sonnes et al., 2015)

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

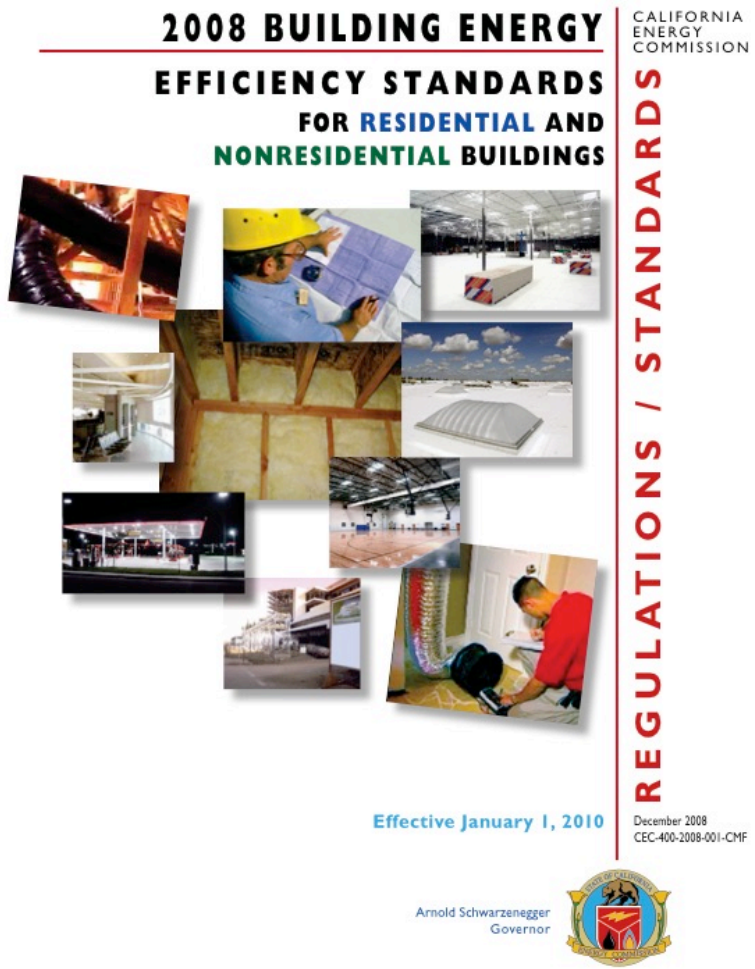
PG&E

SoCalGas A Sempra Energy utility

gti

Context

- Air sealing key strategy for residential energy efficiency
- 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



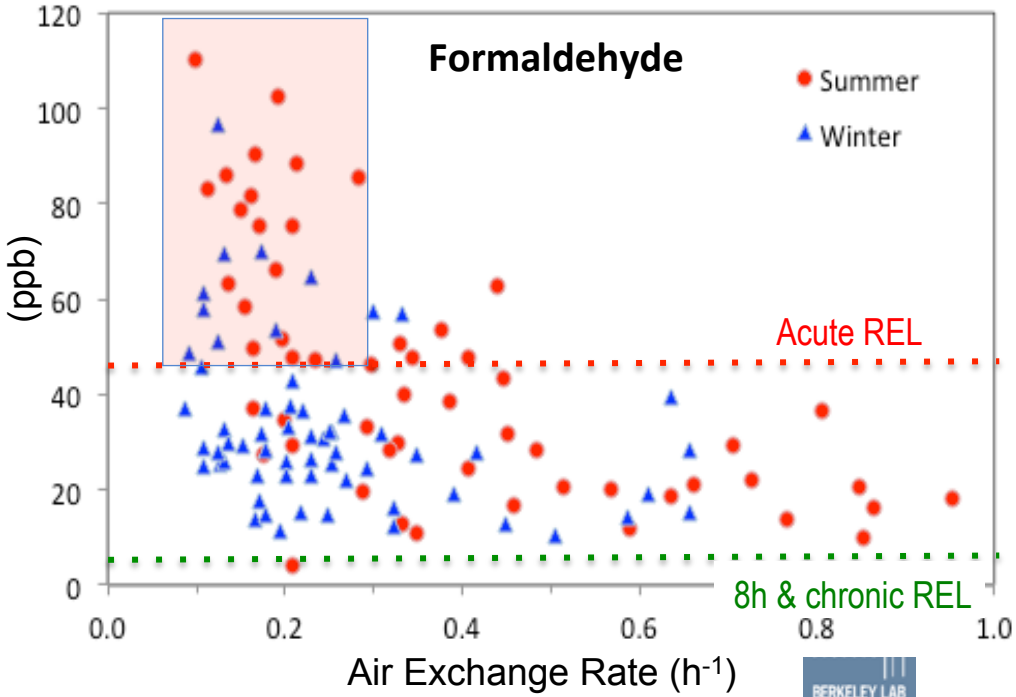
Prior California Studies

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

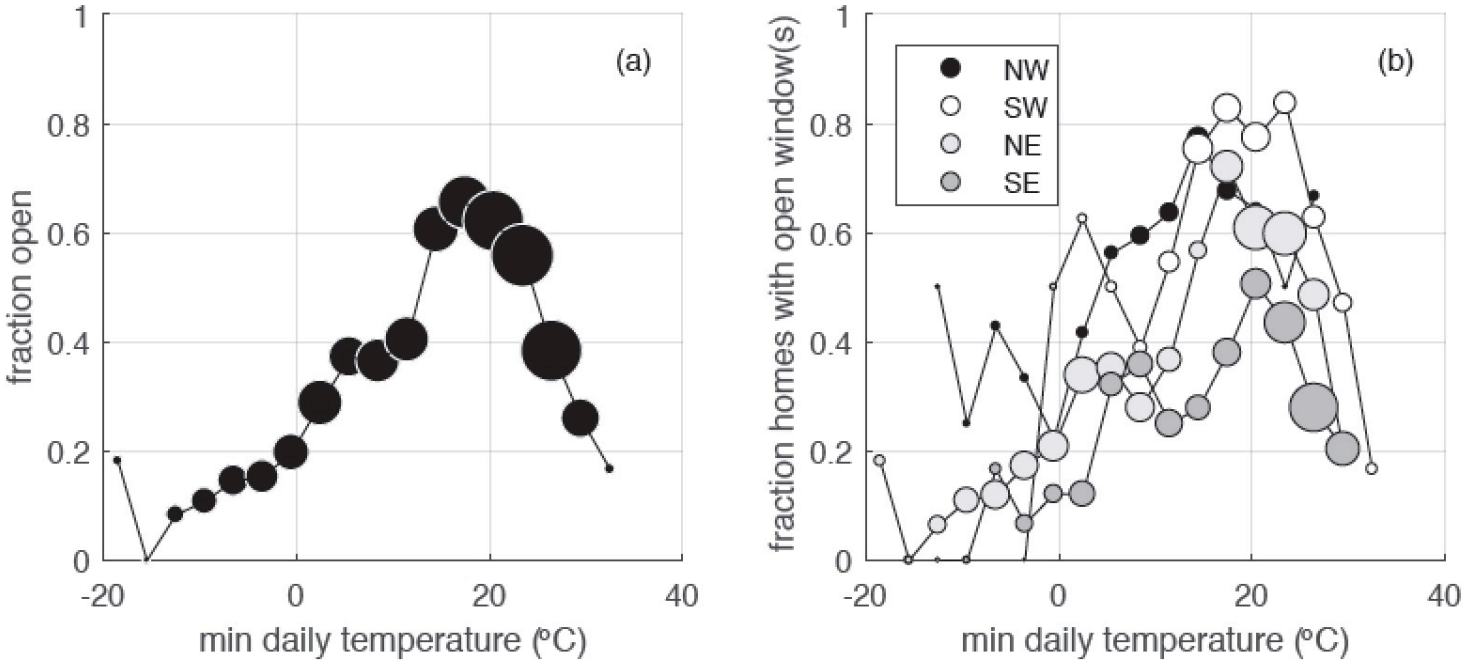
Field study: 2006-7 (CNHS)

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



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

Lots of people in US don’t use windows



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

Morrison and Date, Indoor Air 2018 Conference

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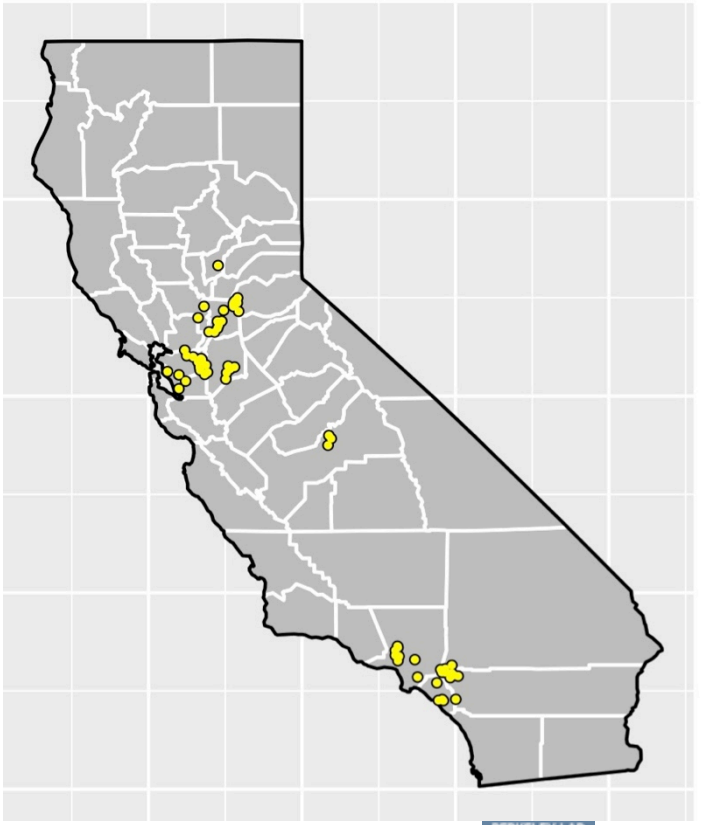
HENGH: Determine if current ventilation requirements are adequate to protect IAQ

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

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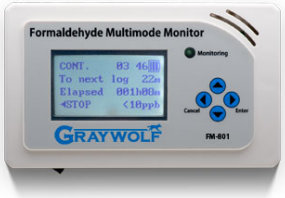
Indoor Air Quality Measurements

$PM_{2.5}$

CO_2
T,
RH

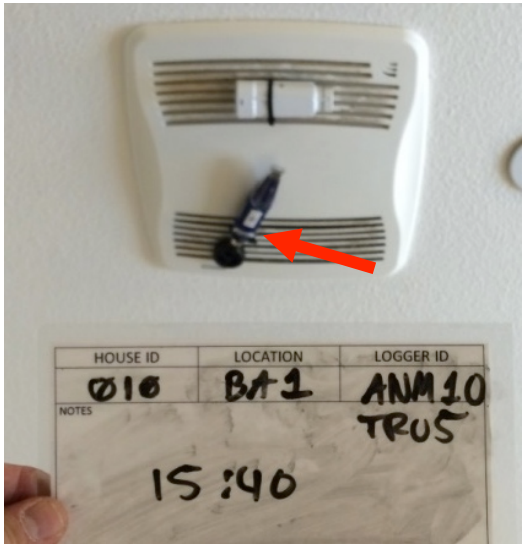
NO_2

Formaldehyde



Activity Monitoring

Range hood use



Exhaust fan use

Cooking (cooktop, oven)

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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

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

se enter your bes nates. If you are unsure, ovide your best guess.
ot list the na f any people.

number for home 13

1: Date 11-30-16 Date completed 11-30-16

	Midnight to 7am	7am to 11am	11am to 1pm	1pm to 5 pm	5pm to 9pm	9pm Midni
ber of people me	2	4	4	2	2	2
top use Number of minutes	0	30	0	0	.45	0
use Number of minutes	0	0	0	0	0	0
outdoor grill Number of minutes	0	0	0	0	0	0
uming Number of minutes	0	0	0	.25	0	0
low Use Number of minutes	0	0	0	0	45min 0	0
r notable or/outdoor events	3 air cleaners 24/7			carpet & floor clean		

example, use of fireplace, candle, air freshener, air cleaner, humidifier, unusual outdoor air y (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

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

Very Poor — Neutral — Excellent

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

Very Ineffective — Neutral — Very Effective

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).	☒	☐	☐	☐	☐
Too cold in some room(s).	☐	☐	☐	☒	☐

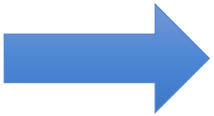
11. In summer, how often is the temperature in your home uncomfortable to any occupants because some room(s) are too hot or too cold?

	Never	Few times a year	Few times a month	Few times a week	Every day
Too hot in some room(s).	☐	☐	☐	☒	☐
Too cold in some room(s).	☒	☐	☐	☐	☐

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)

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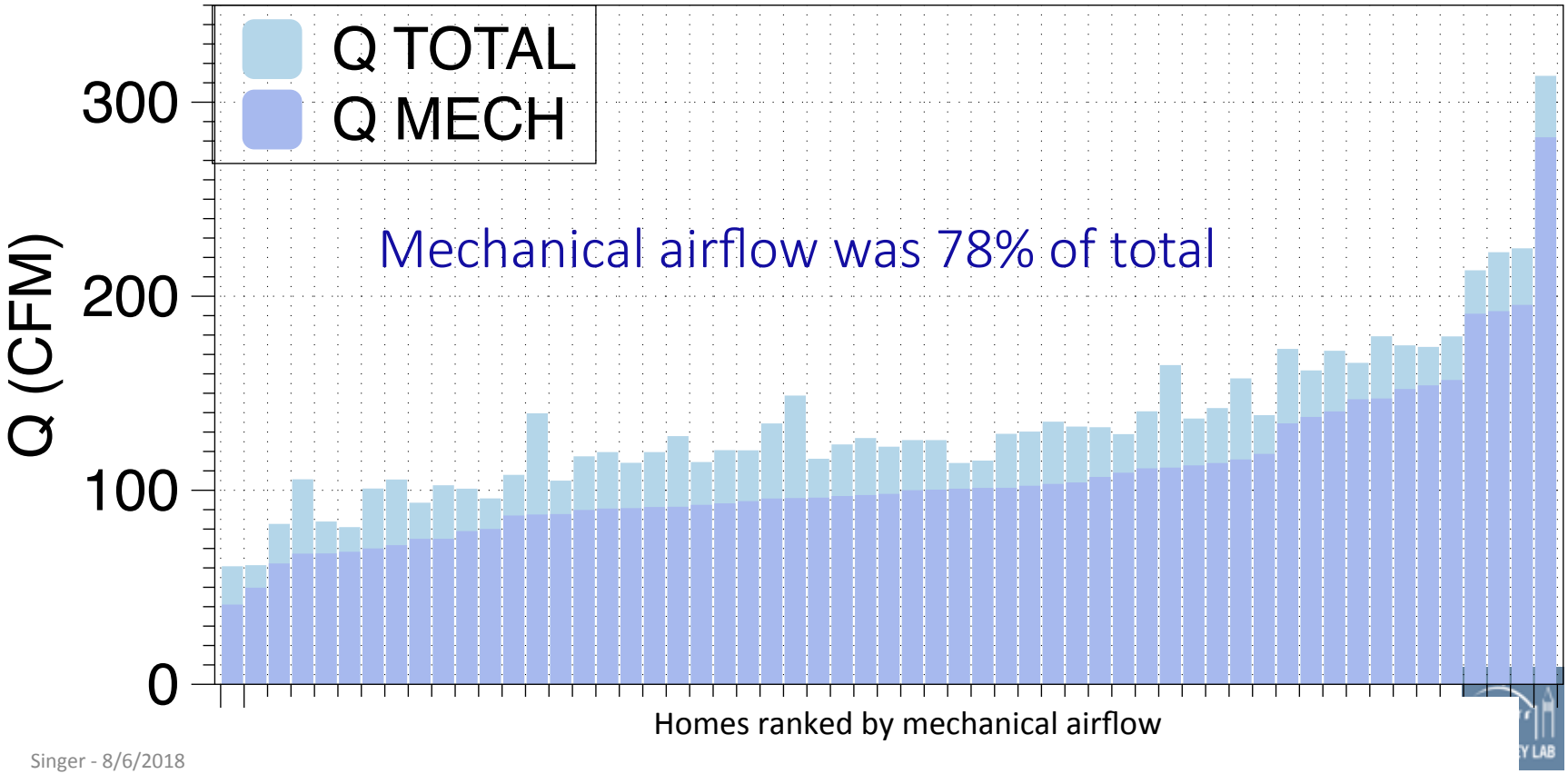
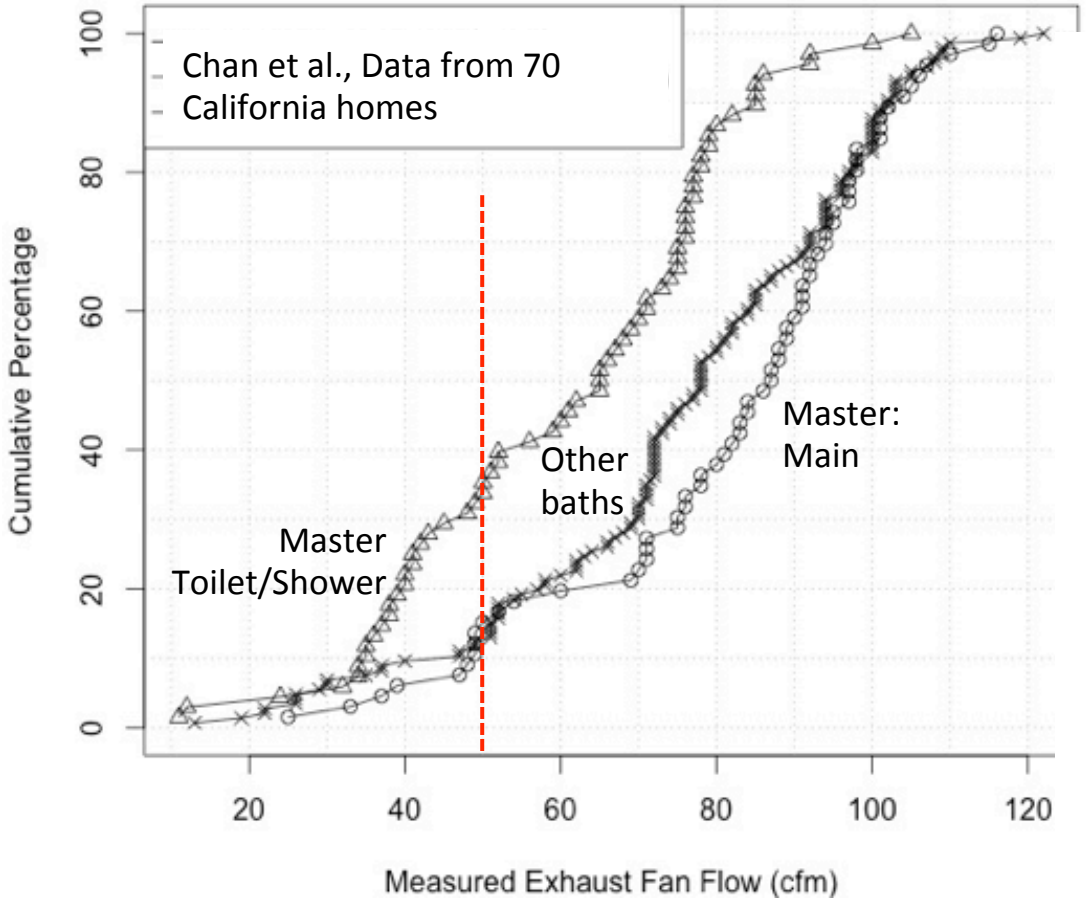
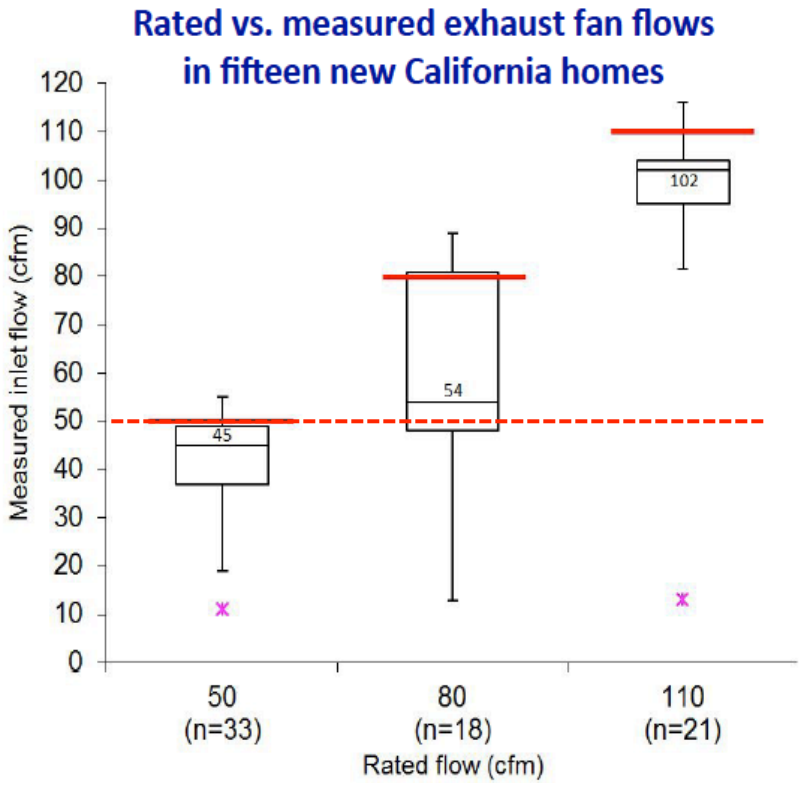
Outdoor Airflow: Mechanical and Total



California bathrooms: Most above code, below rated

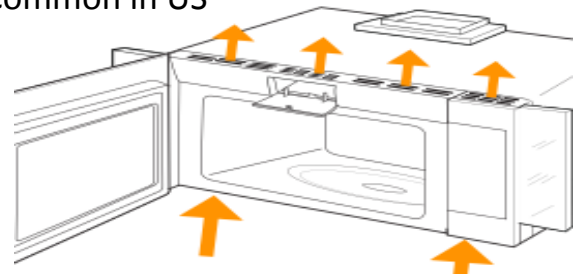




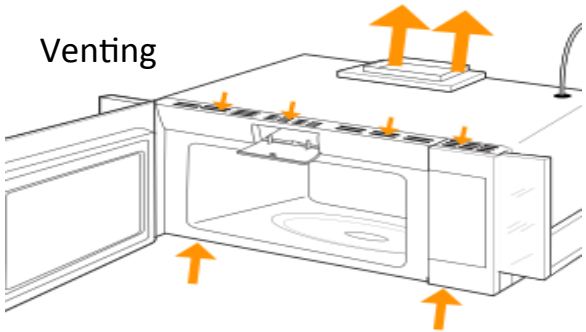
Stratton et al., 2012

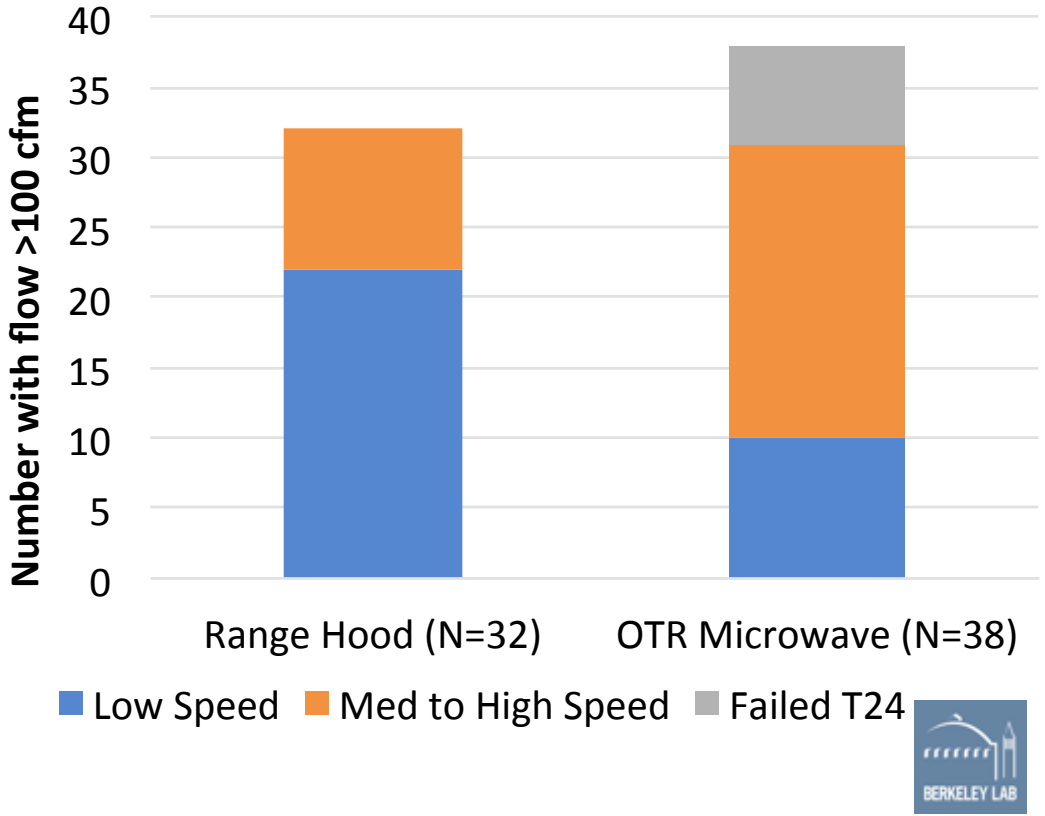
Kitchens: Most range hoods meet minimum airflow requirement; but many microwaves don't

Non-venting;
Common in US

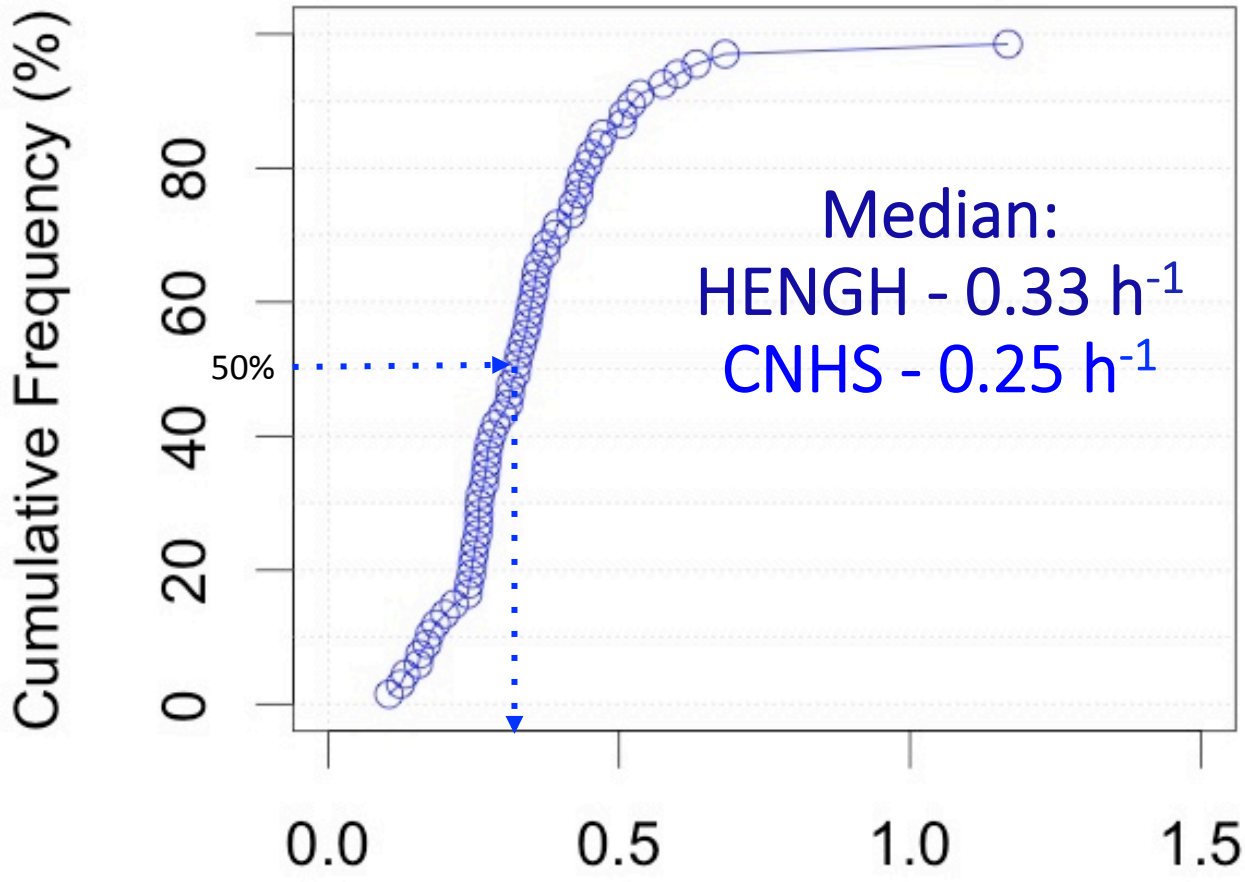


Venting





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

*Offermann (2009).

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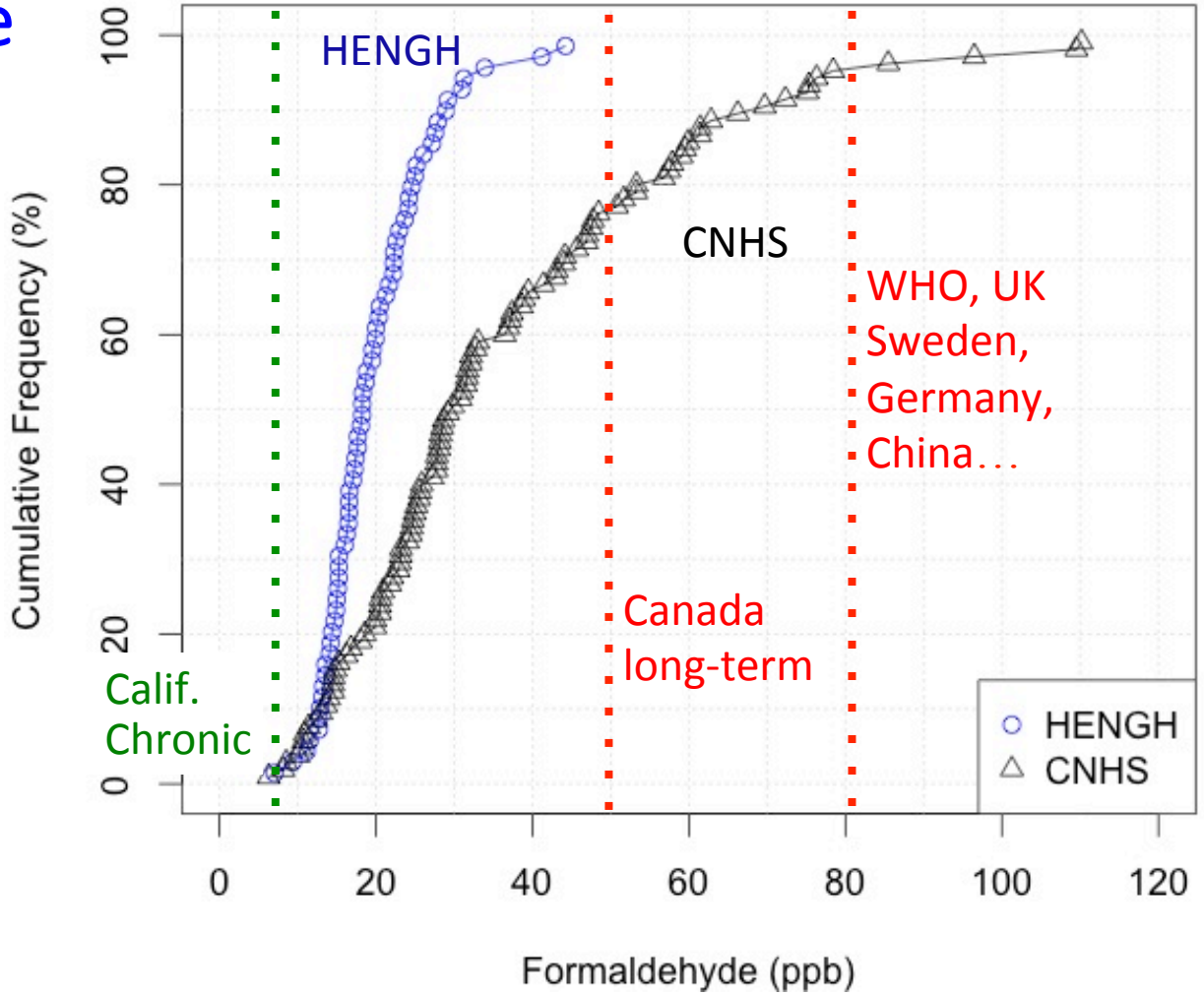
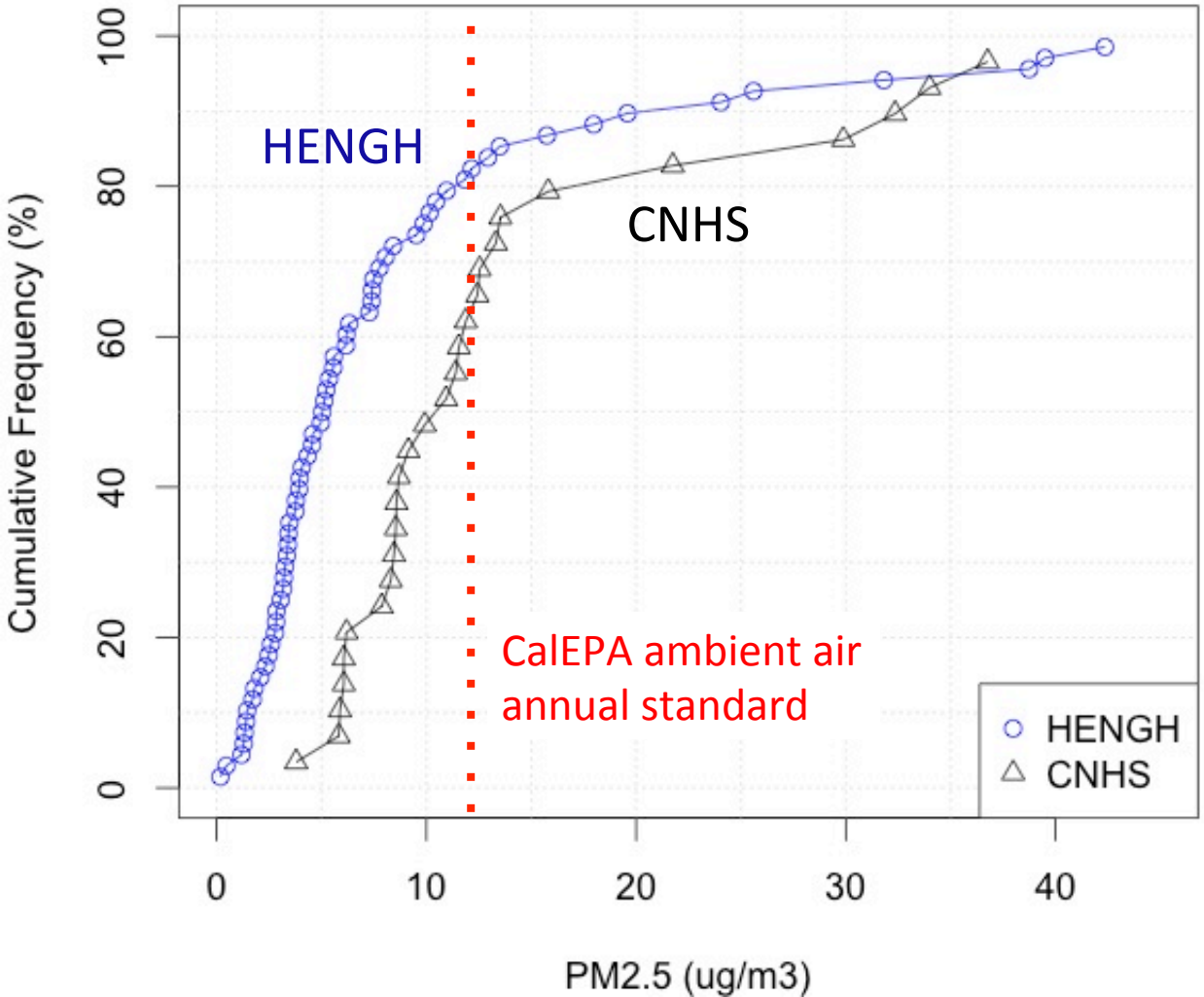
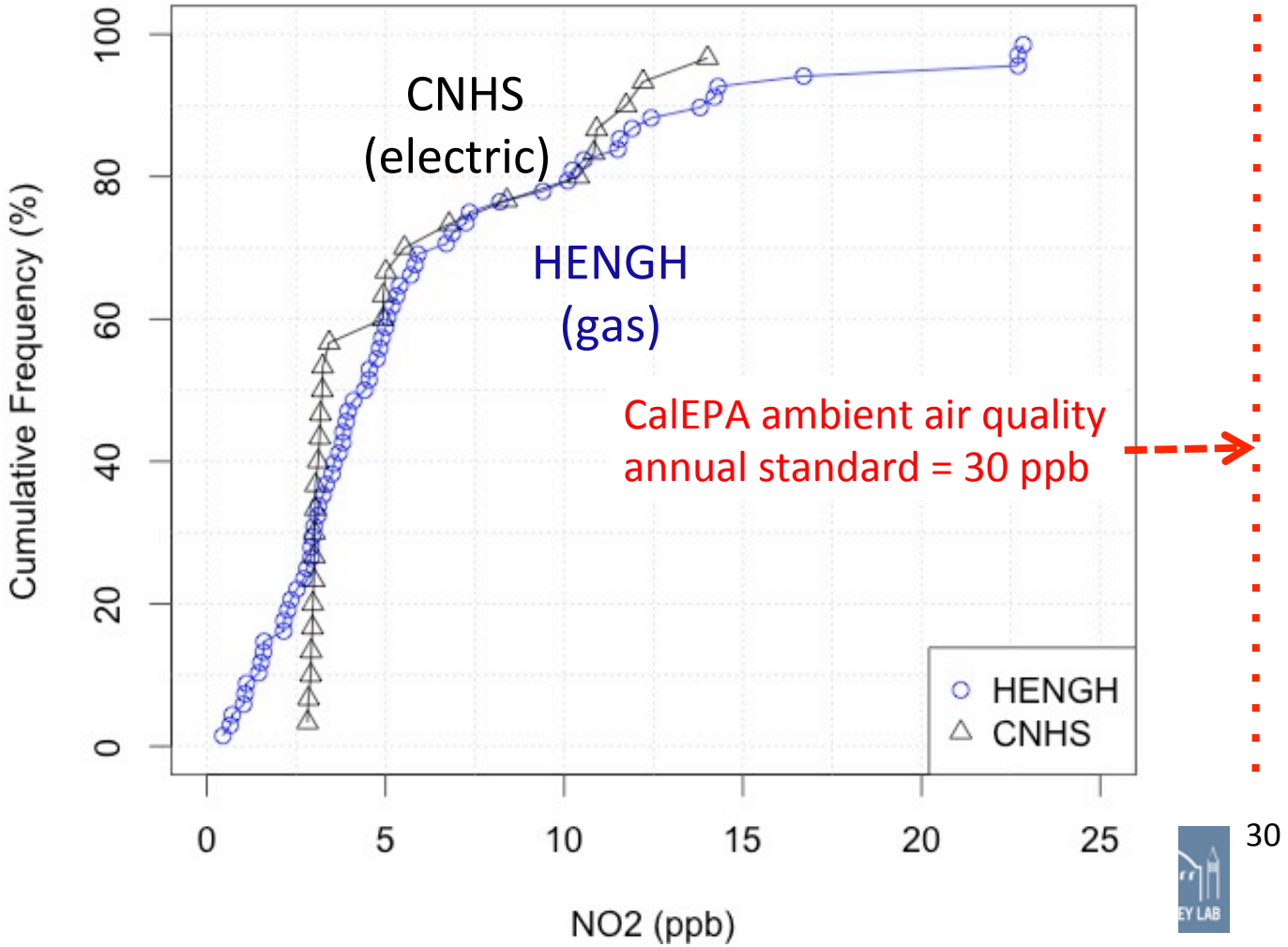
Formaldehyde



$PM_{2.5}$


HENGH
CNHS
CalEPA ambient air
annual standard
HENGH
CNHS
Cumulative Frequency (%)
0
20
40
60
80
100
0
10
20
30
40
PM2.5 (ug/m3)

NO_2


CNHS
(electric)
HENGH
(gas)
CalEPA ambient air quality
annual standard = 30 ppb
30
HENGH
CNHS
Cumulative Frequency (%)
0
20
40
60
80
100
0
5
10
15
20
25
NO2 (ppb)

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,

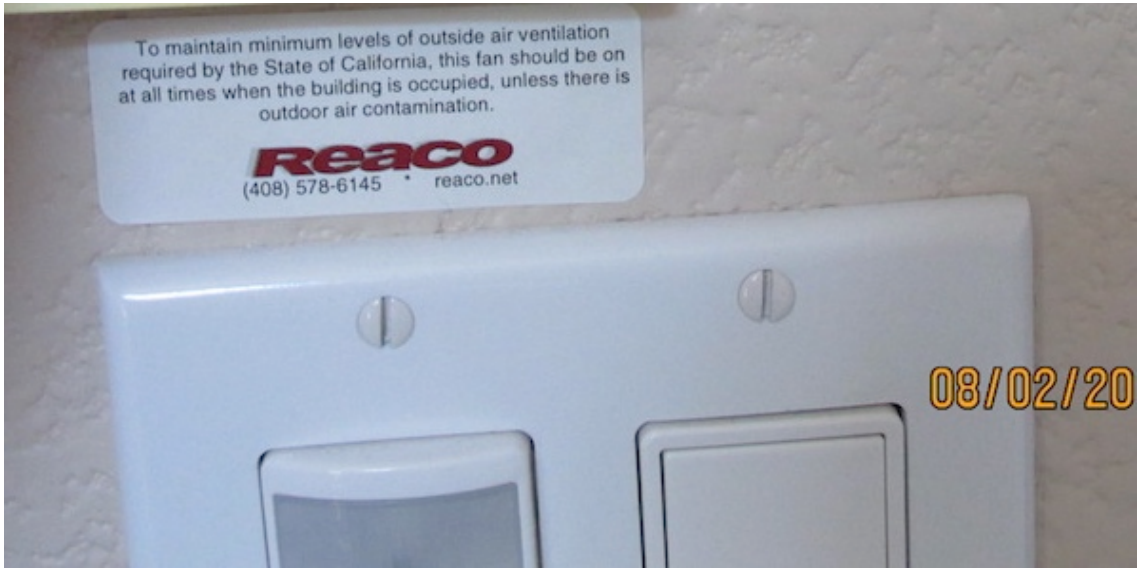
*"**This controls the ventilation system of the home. Leave on except for severe outdoor contamination.**"*

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

Actual labels not always clear

CONTINUOUS DUTY

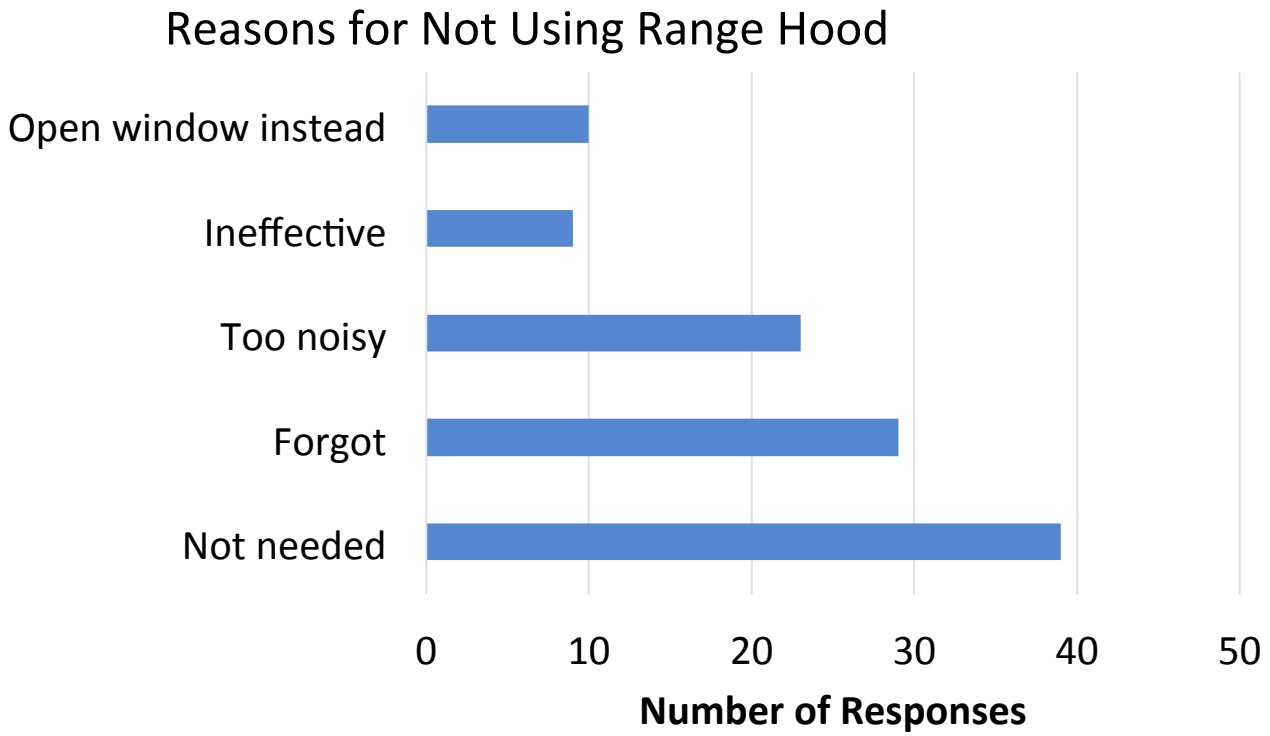
To maintain minimum levels of outside air ventilation required by the State of California, this fan should be on at all times when the building is occupied, unless there is outdoor air contamination.




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 CA households reported using range hood sometimes or less frequently



City Hall of Vienna,
https://www.wien.gv.at/english/cityhall/images/cityhall.jpg

Bundesministerium
Nachhaltigkeit und Tourismus

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

Peter Tappler[1]*, Peter Wallner[2], Bernhard Damberger[1], Michael Kundi[2], Hans-Peter Hutter[2]
[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.

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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

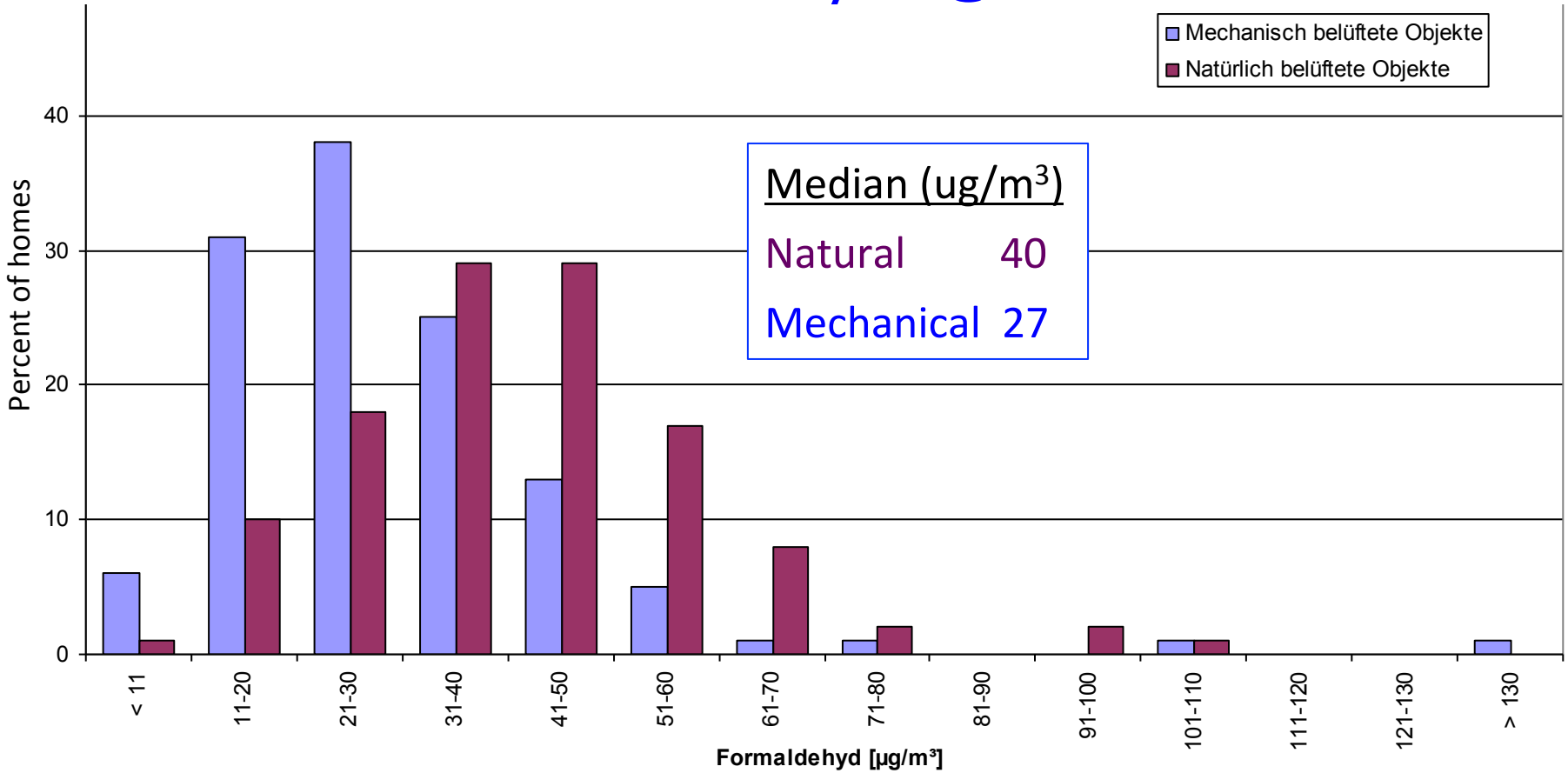
- 62 low-energy or passive std – mechanical ventilation with heat recovery
- 61 conventional construction – natural ventilation (windows)
- Built 2010-2012; 70% detached, 30% apts. in each group:

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

Survey of perceptions, satisfaction and health status

 Adapted from slide provided by Peter Tappler

Results: Formaldehyde @ 3 months



Adapted from slide provided by Peter Tappler

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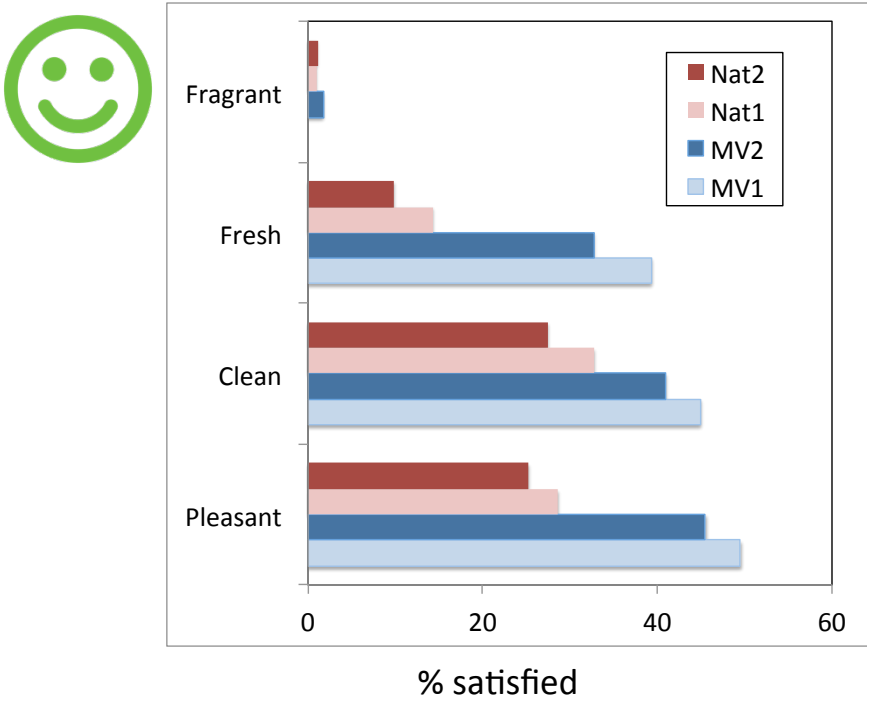
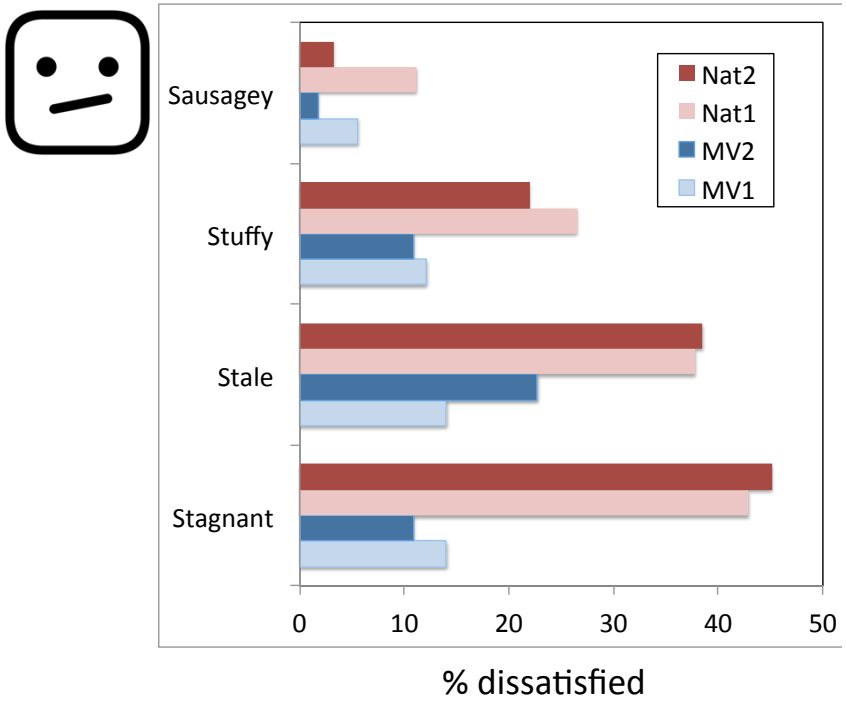
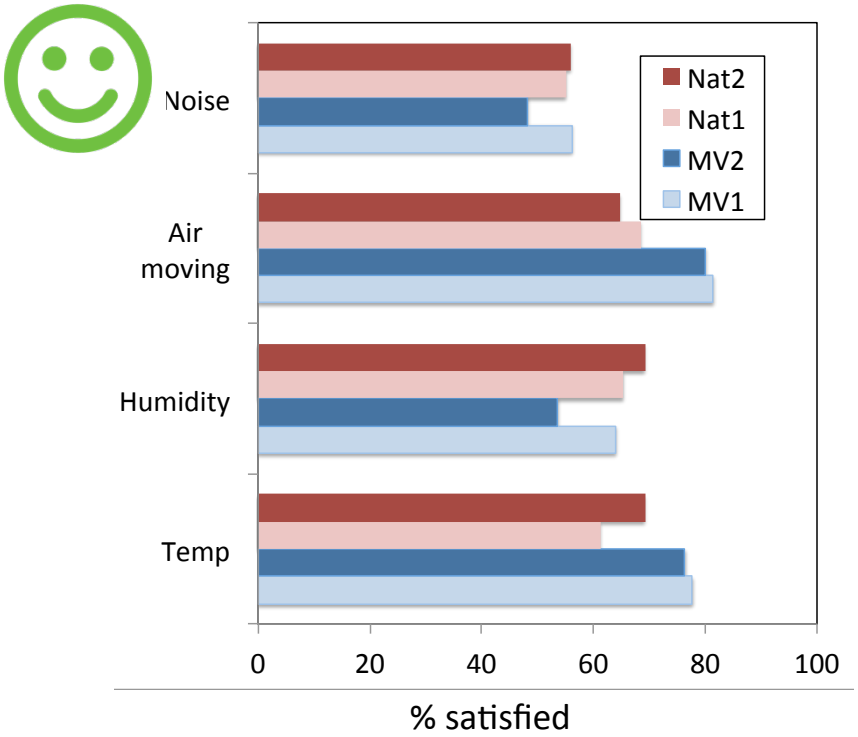
Ventilation improves satisfaction



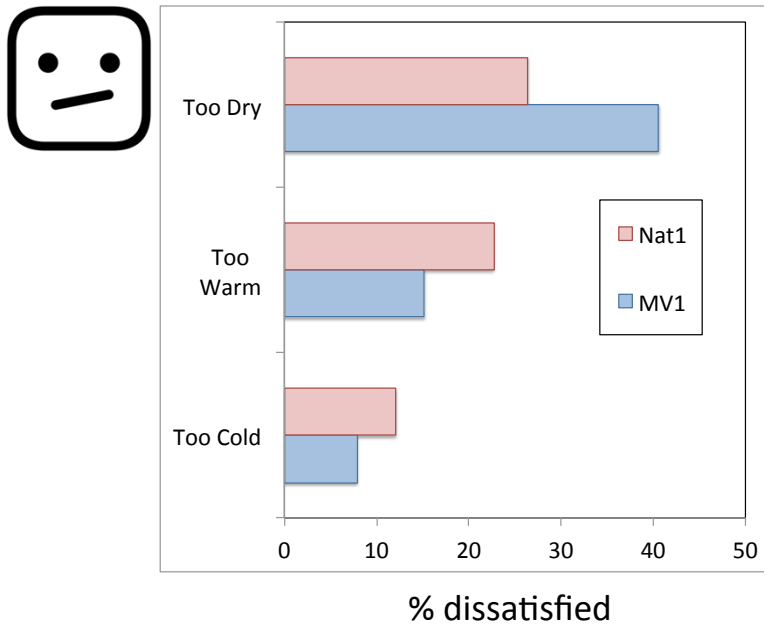


Wallner et al. Health and Wellbeing of Occupants in Highly Energy Efficient Buildings: A Field Study. *Int J Environ Res Public Health.* 2017;14.

Ventilation increases dryness in cold climates



MV homes better on all measures except dryness



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

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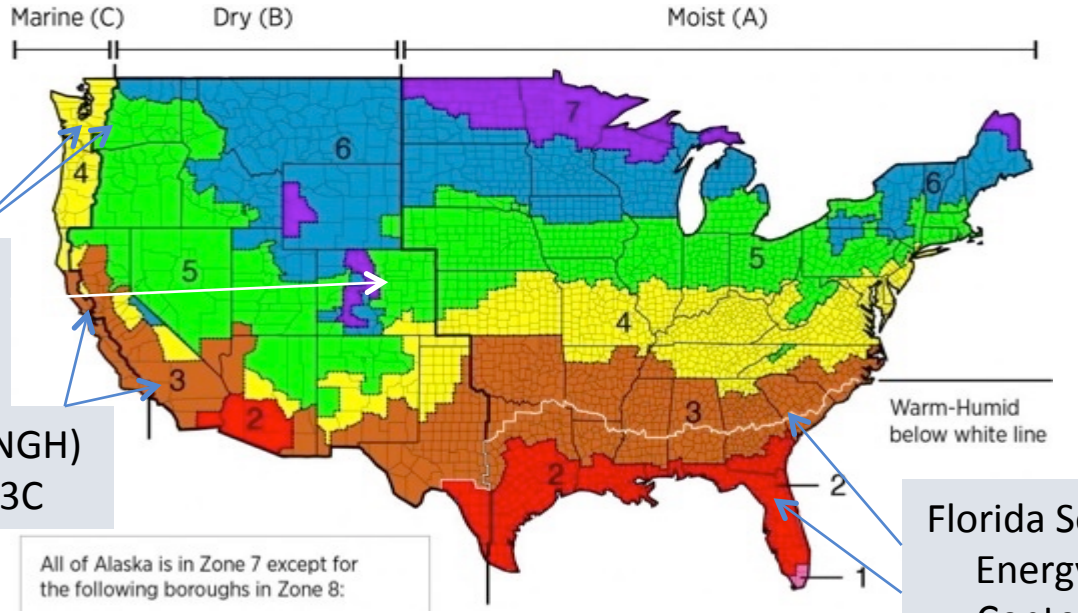
Advanced Ventilation

- 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

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,*]

[a] Department of Civil Engineering, University of Toronto, Canada
[b] Dalla Lana School of Public Health, University of Toronto, Canada

2018, Vol. 131, pp.231-241

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.

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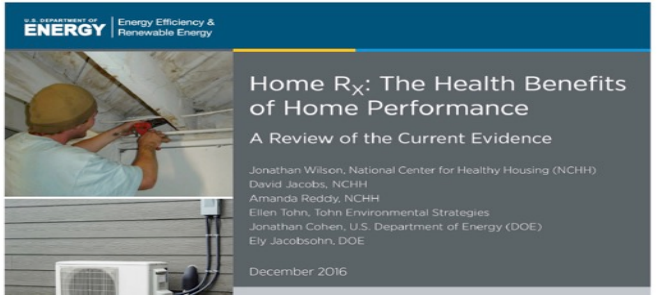
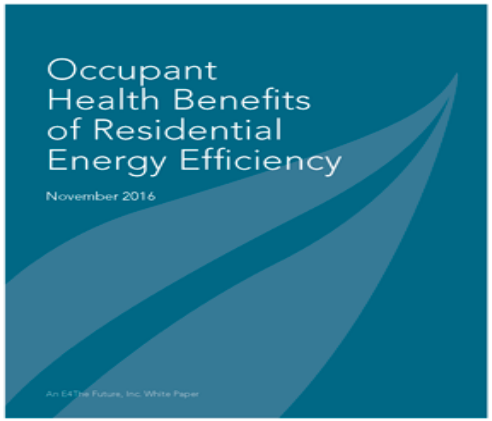
Efficient homes can have BETTER IAQ

- **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 effects[2]**





[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;

E4 THE FUTURE

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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

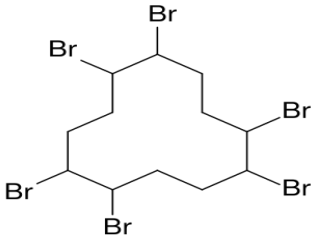
Water & microbiology hazards are increasing

Hurricane Sandy

Maxwell, CA 2017

Flame retardants (FRs) in building insulation

HBCD



hexabromocyclododecane

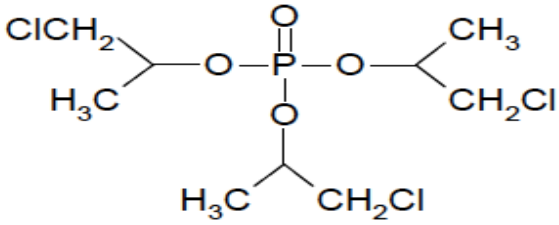
- bioaccumulative
- thyroid disruption
- affects developing nervous system
- developmental neurotoxicity in mice

Slide courtesy of Don Lucas, Green Science Policy Institute

Flame retardants (FRs) in building insulation

TCPP

tris (1-chloro-2-propyl) phosphate



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

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

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

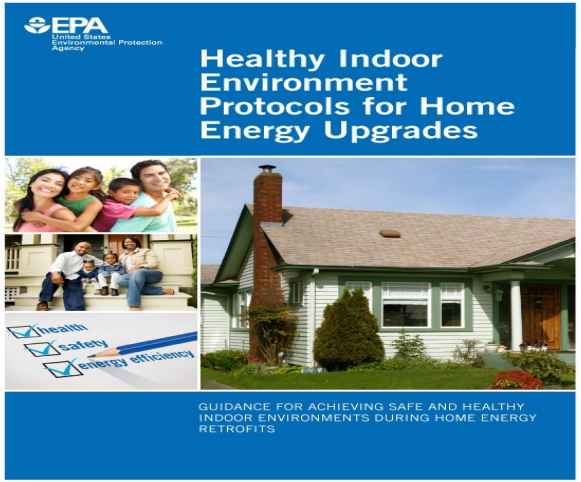
Climate change will modify outdoor environmental conditions which, in turn, will

IAQ in Schools

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

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

http://www.epa.gov/iaq/homes/retrofits.html

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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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