Kitchen Ventilation Solutions to Indoor Air Quality Hazards from Cooking

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Sponsors of Research Presented

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Kitchen Ventilation Simplified

CHALLENGE:

- Cooking burners & cooking produce odors, moisture and pollutants that can degrade indoor air quality

SOLUTION:

- Install and use exhaust ventilation in kitchen

OPTIMAL SOLUTION:

- Effective, low-energy and quiet range hoods that operate automatically as needed

What do “we” want from kitchen ventilation?

- Remove smoke as needed
- Enhance kitchen aesthetics
- Remove odors & moisture
- Affordable

- Remove pollutants from burners and cooking
- Quiet, low-power operation
- Automatic operation

What do we NOT want?

- Fire
- Noise
- Maintenance
- Bad aesthetics

- Higher energy bills
- Depressurization-induced spillage from natural draft appliances

Overview of Presentation

- Why do we need kitchen exhaust ventilation?
- What designs and types of products are available?
- What are current codes and standards?
- How well do range hoods perform?
- Is capture the same for cooking particles & burner gases?
- Is general kitchen exhaust an adequate alternative?
- What are the challenges to improving performance?

Pollutants from burners and cooking

- Moisture & CO_2
- NO_2 and formaldehyde
- Ultrafine particles & CO

- Ultrafine particles

- Ultrafine particle
- VOCs including acrolein
- Moisture and odors

Emissions and IAQ impacts of cooking related pollutants – selected references

- Dennekamp et al., 2001. Ultrafine particles and nitrogen oxides generated by gas and electric cooking. *Occup Environ Med* **58**: 511-516.
- Fortmann 2001. Indoor air quality: residential cooking exposures. Final Report, ARB Contract 97-330.
- Hu et al., 2012. Compilation of published $PM_{2.5}$ emissions rates for cooking… LBNL-5890E*.
- Lee et al., 1998. The Boston residential nitrogen dioxide characterization study: Classification and prediction of indoor NO2 exposure. *JA&WMA* **48**: 736-742.
- Logue et al., 2013. Pollutant exposures from unvented gas cooking burners: A simulation-based assessment for Southern California*. Environ Health Persp;* Provisionally accepted.*
- Singer et al., 2009. Natural Gas Variability in California…Experimental evaluation of pollutant emissions from residential appliances. CEC-500-2009-099; LBNL-2897E*.
- Wallace et al., 2004. Source strengths of ultrafine and fine particles due to cooking with a gas stove. *Environ Sci Technol* **38**: 2304-2311.
- Wan et al., 2011. Ultrafine particles and PM2.5 generated from cooking in homes. *Atmos Environ* **45**: 6141-6148.
- Wheeler et al. 2011. Personal, indoor, and outdoor concs of fine and ultrafine particles using continuous monitors in…residences. *Aerosol Sci Technol* **45**: 1078-1089.

* Available via http://eetd.lbl.gov/publications

The pollutant thing is a serious issue!

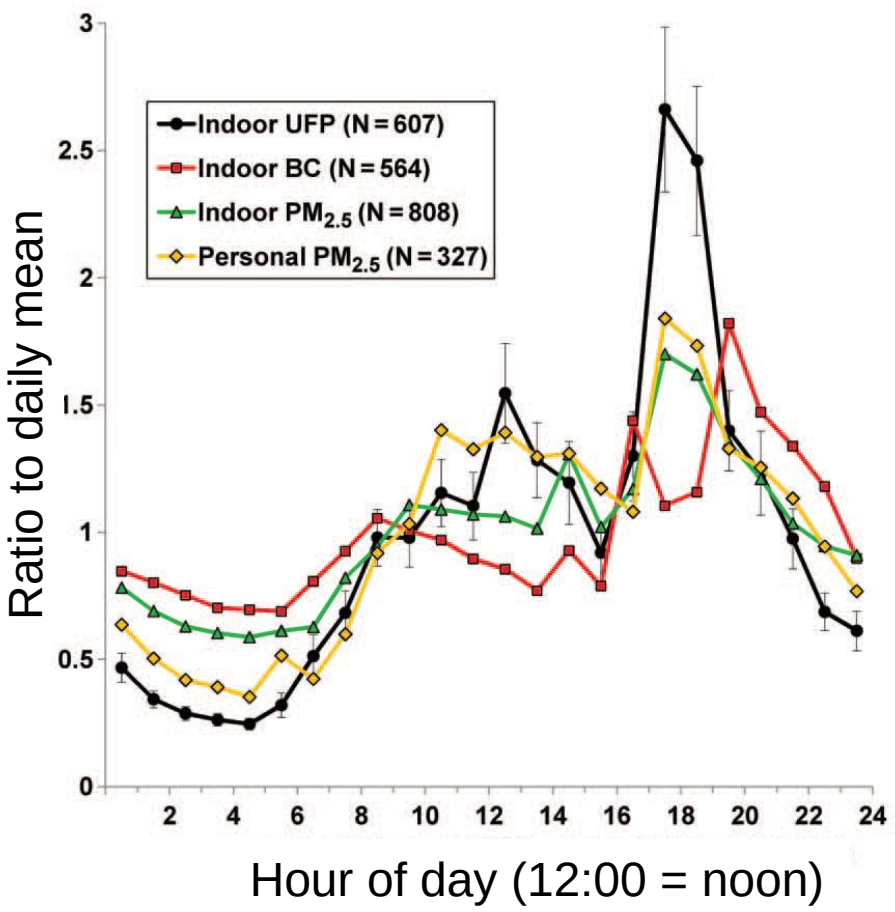
Among homes that cook with gas & don't use a range hood, many exceed air quality standards

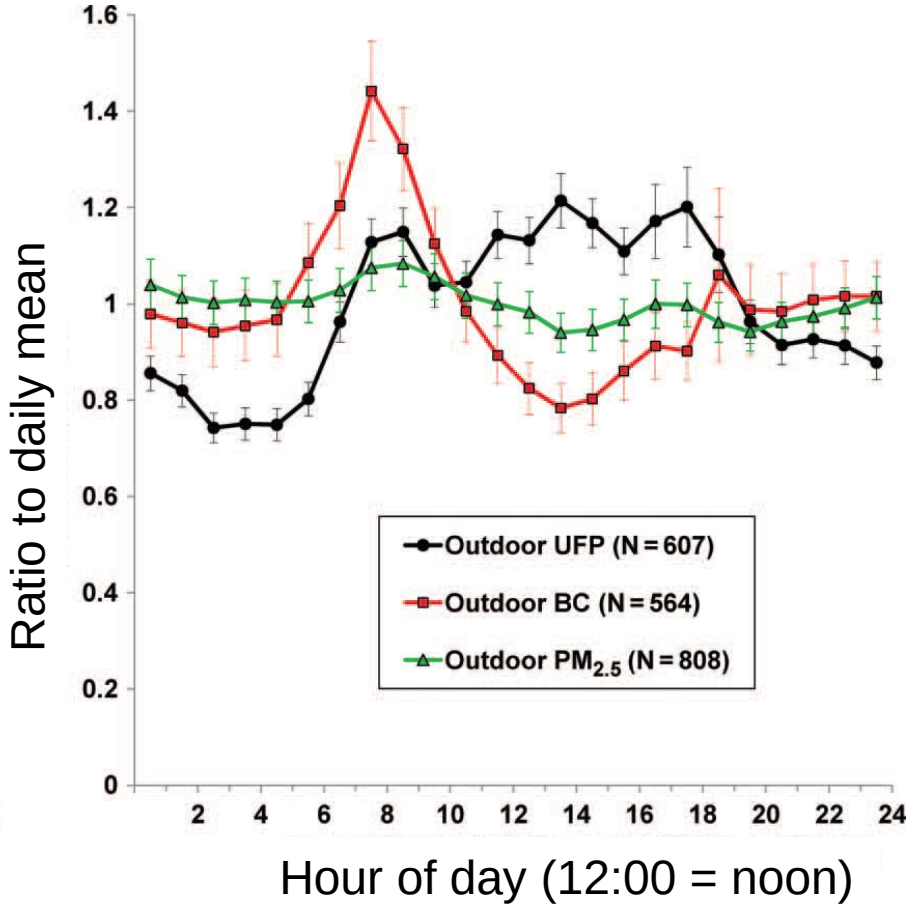
- 55 - 70% exceed federal 1-h ambient NO_2 standard
- 27% exceed acute ATSDR minimum risk level for HCHO
- 8% exceed California 1-h and 8-h ambient CO standards

Results of a physics-based simulation model applied to a representative sample of actual Southern California households with reported cooking frequencies and using data on emission factors, cooking times, etc. Logue et al., EHP, provisionally accepted

Cooking releases ultrafine particles

Data from 97 homes in Ontario, Canada





Wheeler et al. 2011; AS&T 45: 1078-1089

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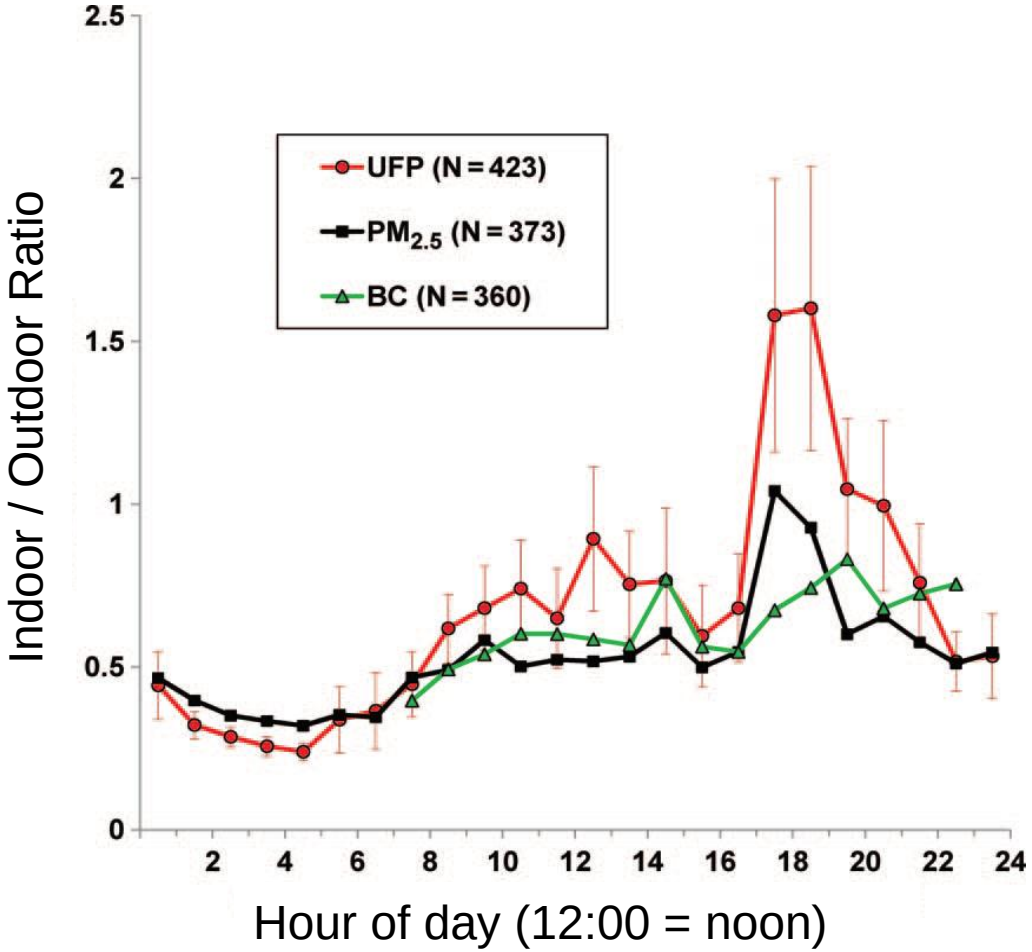
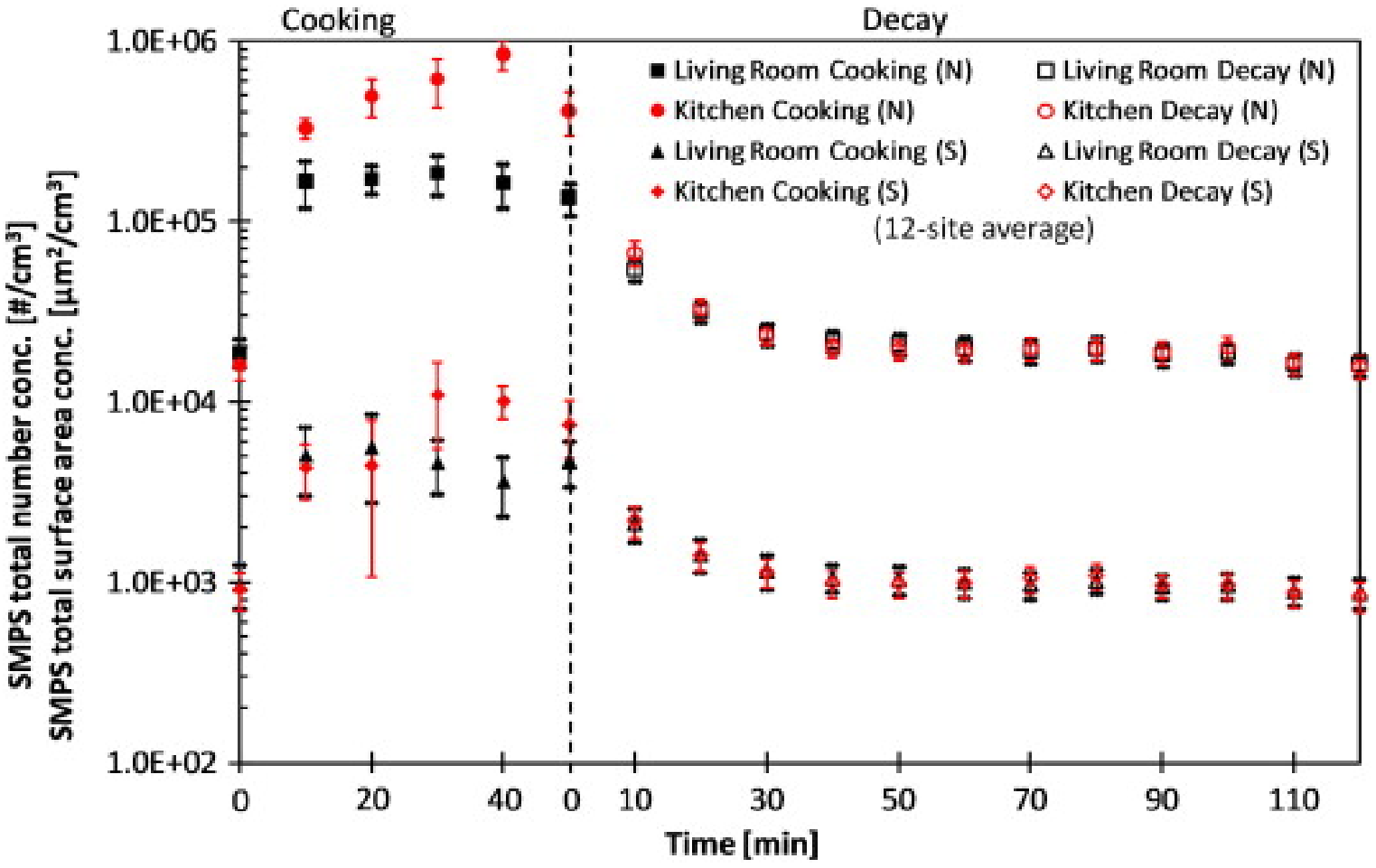


Wheeler et al. 2011; AS&T 45: 1078-1089

Particles from cooking

Data from 12 homes in Hong Kong (40-150 m^2)



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Particles from cooking

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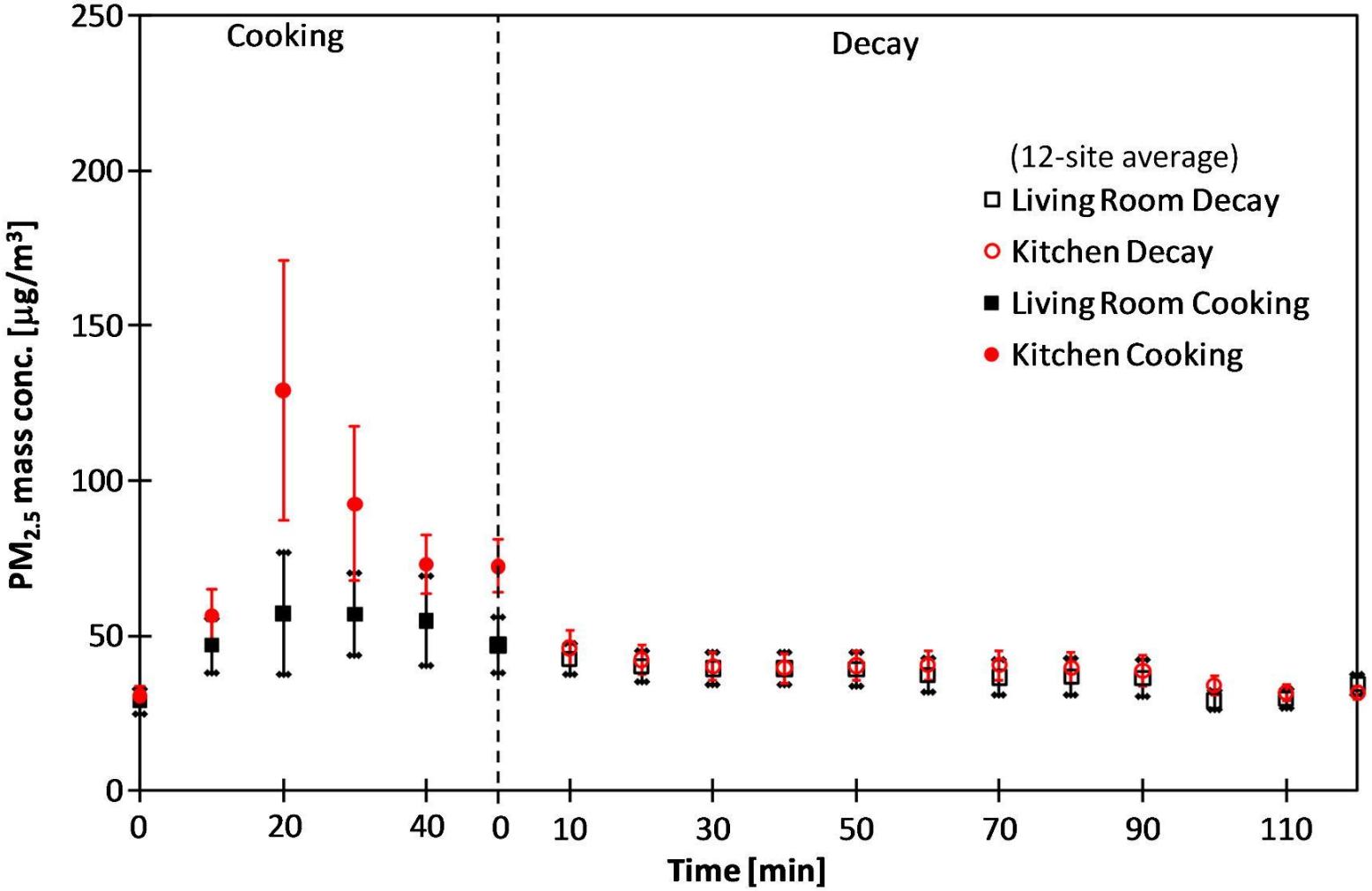
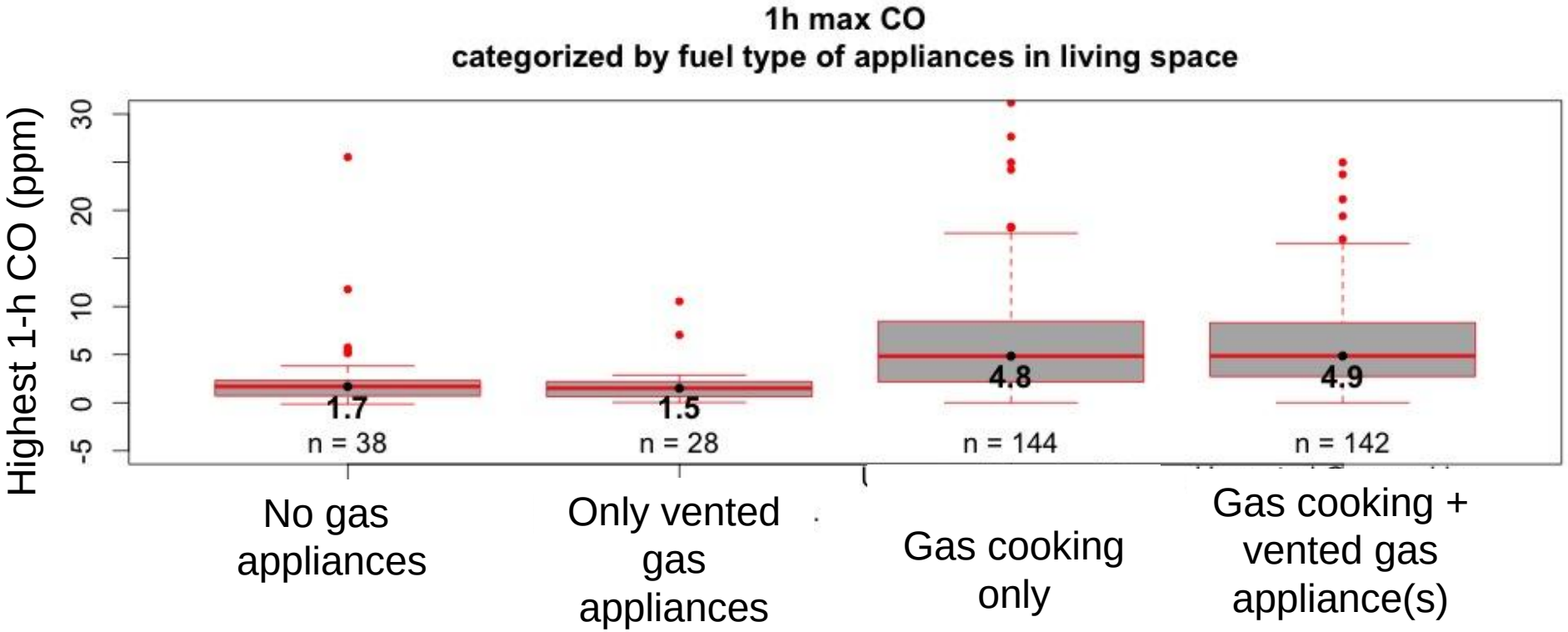


Wan et al. 2011; Atmos Environ 45: 6141-6148

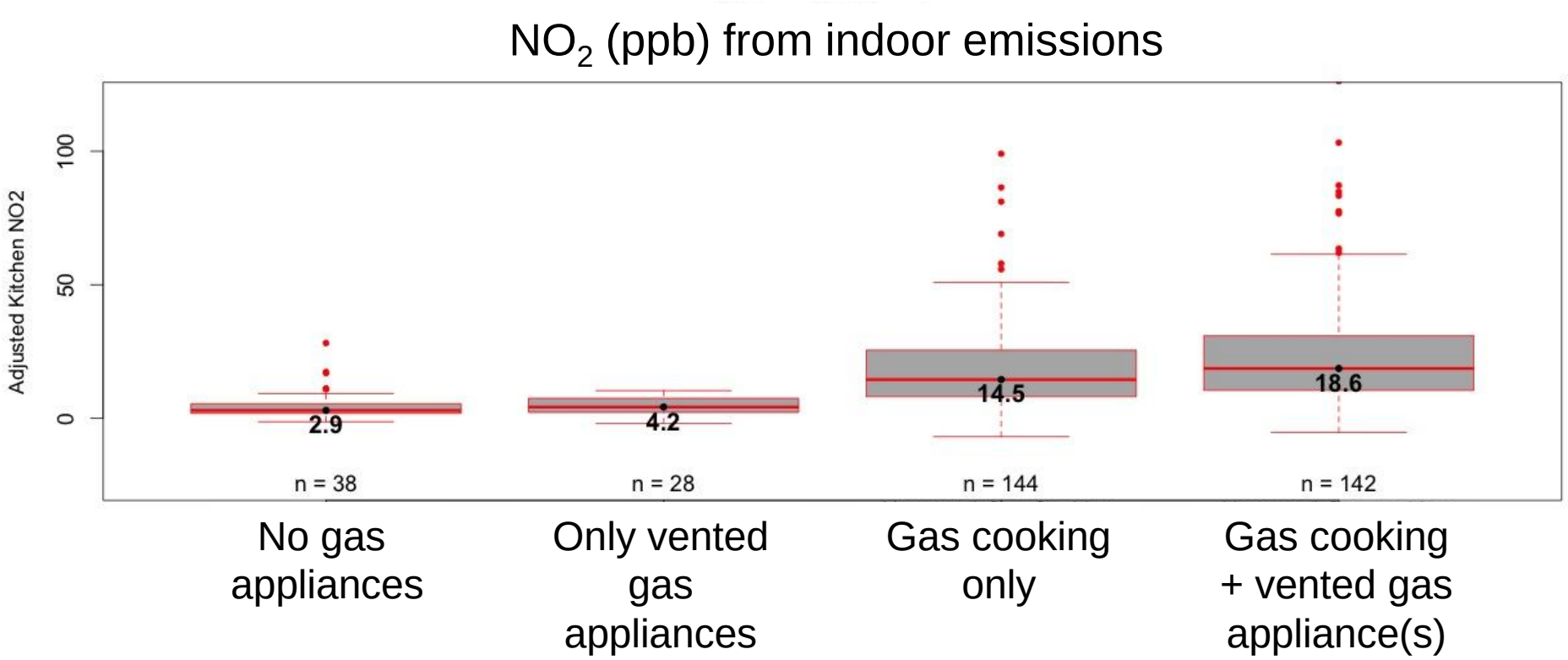
Data show that cooking burners are still an important source of CO in California homes



Measured concentrations indoors over a 6-day period in winter 2011-2013

Mullen et al. 2012; Mullen et al. 2013 (LBNL reports; manuscript in preparation)

Cooking burners are the largest NO_2 source in California homes



Measured concentrations indoors minus estimated contribution from outdoors

Mullen et al. 2012; Mullen et al. 2013 (LBNL reports; manuscript in preparation)

Is kitchen ventilation needed for electric cooking?

- ✓ Remove smoke as needed
- ✓ Remove odors & moisture
- ✓ Remove pollutants from burners and cooking

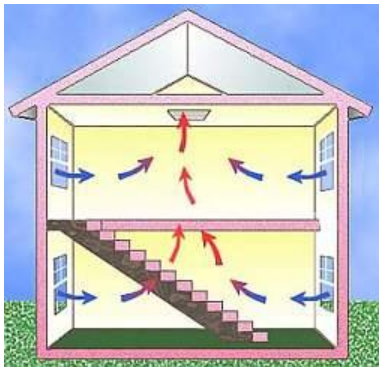
So…yes

IAQ Control Strategies

- Source Control

Formaldehyde std for comp-wood (CARB)

- General Ventilation



- Task Ventilation

- Filtration/ Air cleaning

Ventilation characteristics

General or Local	Passive or Mechanical
Manual or Automatic	Continuous or Intermittent

Kitchen Ventilation

General
or
Local

Passive
or
Mechanical

Manual
or
Automatic

Continuous
or
Intermittent

Types of kitchen ventilation

Wall exhaust fan near range

Range hoods

Window

Ceiling exhaust fan

Categories of cooking exhaust devices

Under cabinet hood

Microwave range hood

Chimney hood

Downdraft

Downdraft designs

Island

Center

Rear

Range hood designs

Flat

Small sump

Large sump

Available performance information

Certified ratings based on standard tests

- Airflow (cfm)
- Sound (sone)
- Most range hoods tested at 25 Pa
- Some exhaust fans tested at 62.5 Pa

Range Hood Products

≥ 2.8 cfm / W at 25 Pa

≤ 2 sone

< 500 cfm

Manufacturer specifications

- Airflow (cfm), Sound (sone) at each setting
- Advertised flow inflated on some high-end models
- Fan curves available; needed for make-up air

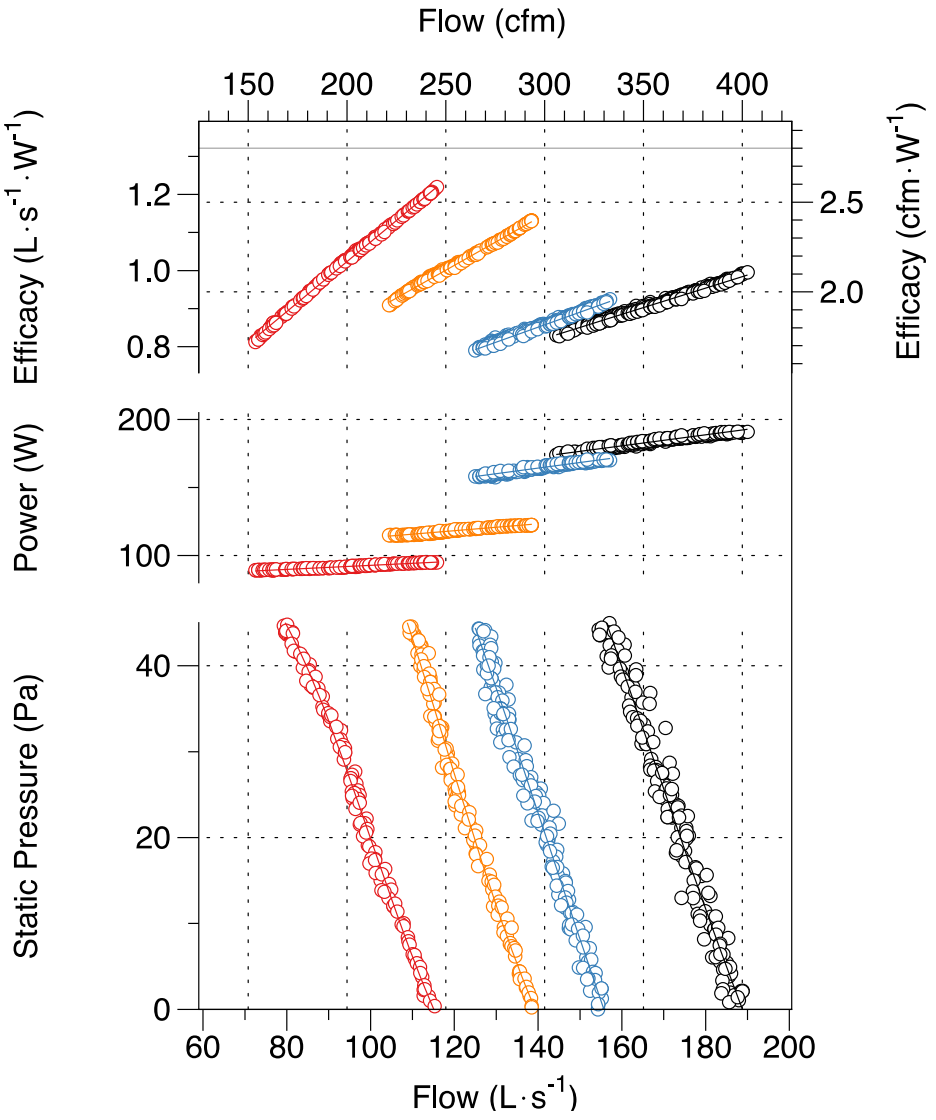
Some advertised flows exaggerated!

Product Description

Product Series: [redacted]

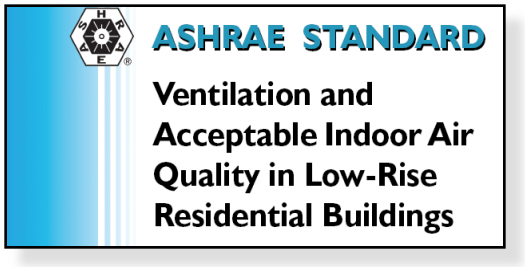
At a Glance:

- Mounting version - Under Cabinet
- Dual squirrel cage ultra quiet motors
- 900 CFM centrifugal blower
- Four-speed touch sensitive electronic LCD control panel with heat sensor and remote control
- Unique Heat Sensitive Auto Speed (HSAS) fucntion controls fan speed automatically!
- Credit card size wireless remote control system, operates the range hood from more than 20ft away!
- Delayed power auto shut off (15 minute pre-set)
- Two 35W halogen lights (GU-10 type light bulbs))
- Stainless steel baffle filter (dishwasher-friendly)
- Heavy duty 19 gauge stainless steel (brushed finish)
- 8" round duct vent exhaust
- Full seamless stainless steel construction
- For residential use only, one-year limited factory warranty



(Unpublished measurements at LBNL)

Current standards and codes



- Range hood: ≥100 cfm at ≤3 sones
- Kitchen exhaust: ≥5 kitchen ach at ≤1 sone
- Verify airflows or prescribed ducting with hood rated at 62.5 Pa

HVI
HOME VENTILATING INSTITUTE

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

ENERGY STAR

ENERGY STAR Certified Homes, Version 3

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

International Residential Code

- Installed kitchen ventilation should be ≥100 cfm on demand or ≥25 cfm continuous – or recirc!
- Make-up air required for >400 cfm exhaust

What's missing?

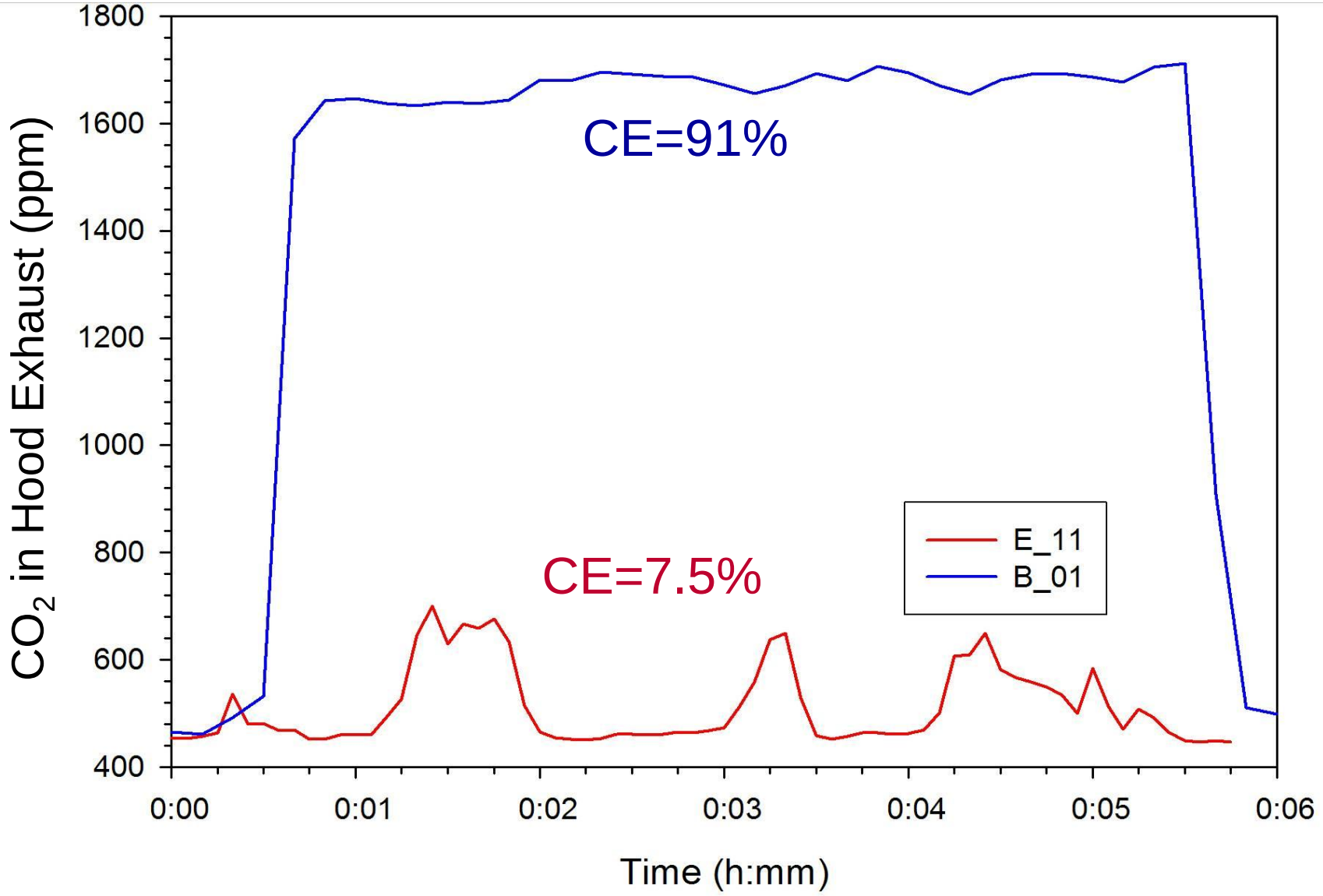
- CAPTURE EFFICIENCY
  - Fraction of emitted pollutants removed by hood
  - May differ for burner and cooking

Measure capture efficiency using CO_2

- Emission rate based on fuel CH_4 ➔ CO_2
- Measure concentration in hood exhaust and room
- Separately measure flow in hood exhaust

$$CE = \frac{removal}{production} = \frac{Q_{air}\left(CO_{2\text{- }hood} - CO_{2\text{- }room}\right)}{Q_{fuel}\left(C\ in\ fuel\right)}$$

Measure capture efficiency using CO_2



Range Hood Performance Evaluation

Laboratory

- Selected sample
- New, no wear
- Standard height(s)
- Control, vary pressure
- Measure airflow vs. system pressure
- Measure CE vs. flow
- Sound pressure (dB)
- Power (W)

In home

- Opportunity sample
- Used, uncertain wear
- As installed height and system pressure
- Measure airflow and CE at each setting
- Sound pressure (dB)

Laboratory Performance Study

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

Measurements:

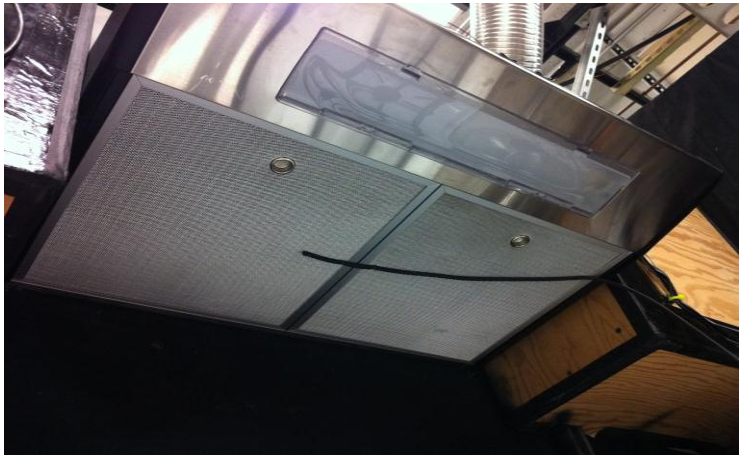
- Fan curves (flow vs. P)
- CE for varied flows
  - Vary duct P, fan setting
- Power and efficacy

Lab Performance Study

M1: Microwave

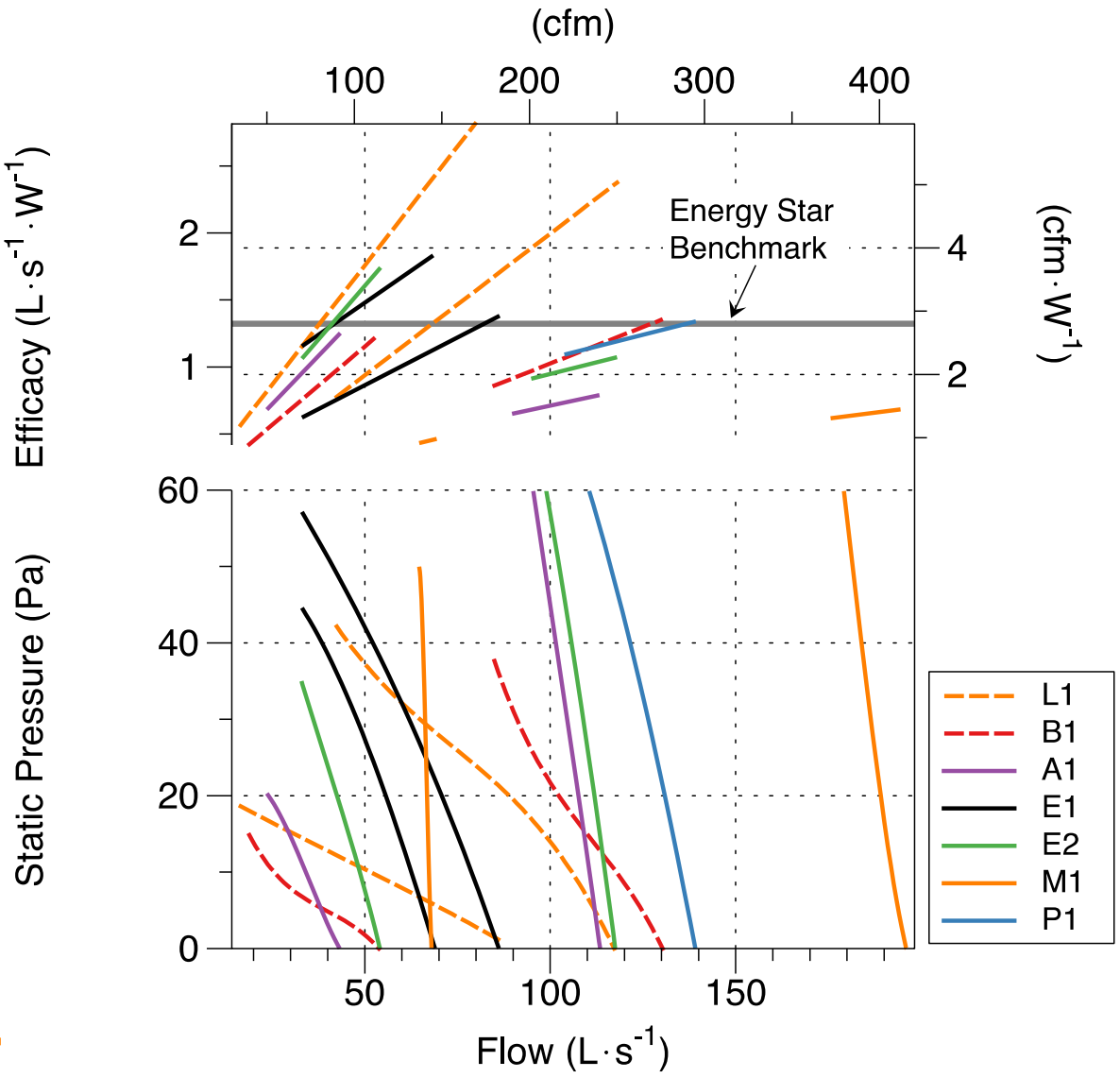
B1: Basic, quieter hood

P1: Performance: grease captured by impaction



E1: Energy Star

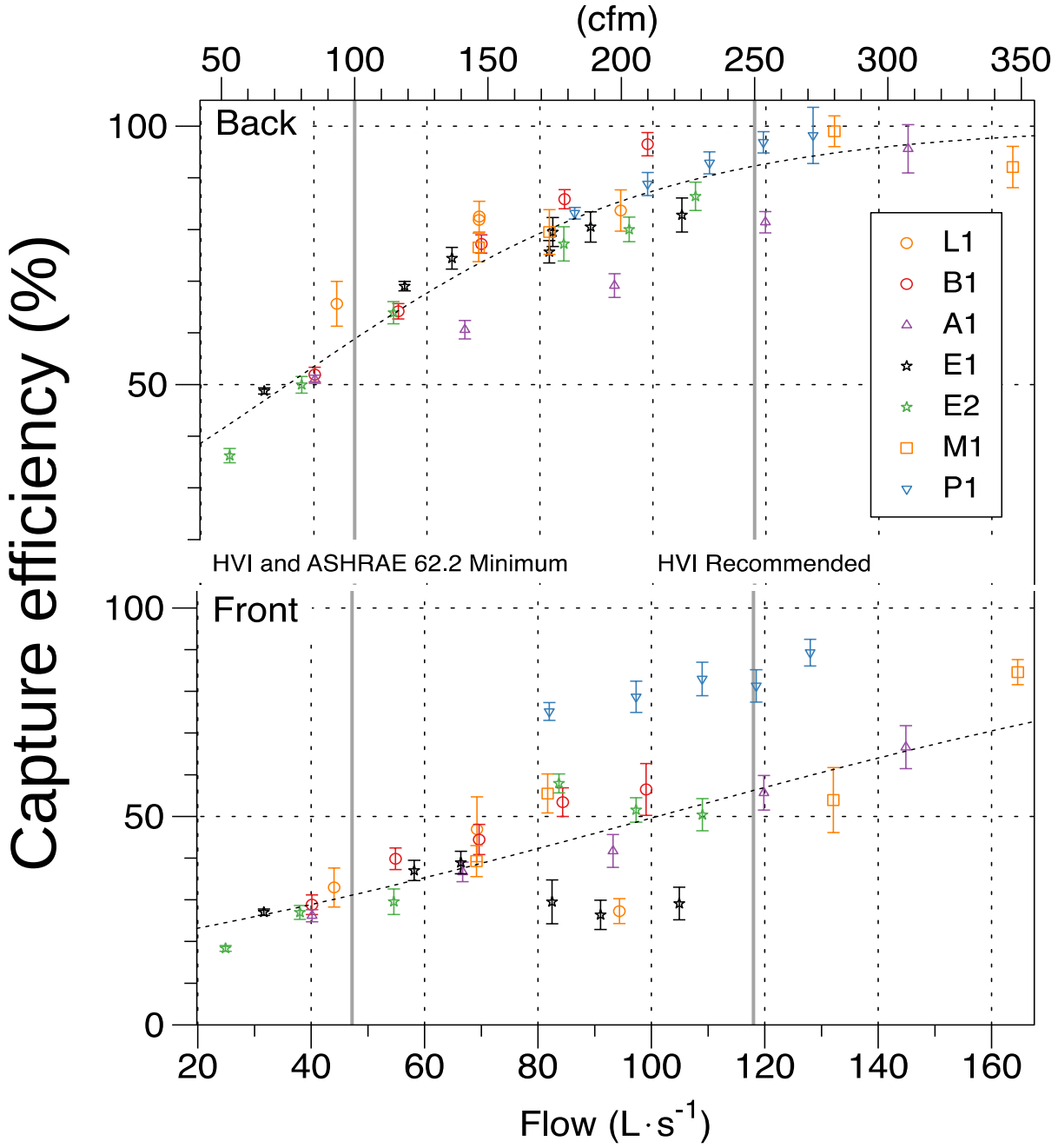
Impact of duct pressure on airflow



Delp and Singer
Environ. Sci. & Technol.
2012, 46(11): 6167-6173
LBNL-5545E

Vertical curves are devices that are less sensitive to duct pressure; more likely to be close to rated flow when installed.

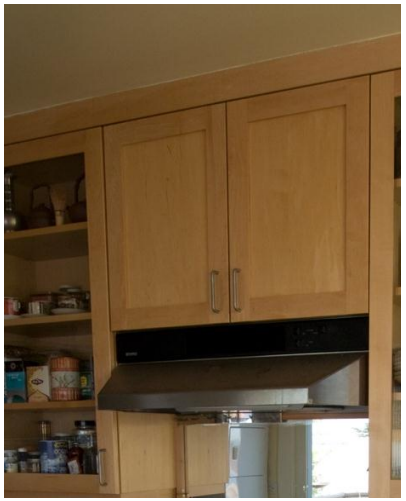
Capture Efficiency Results



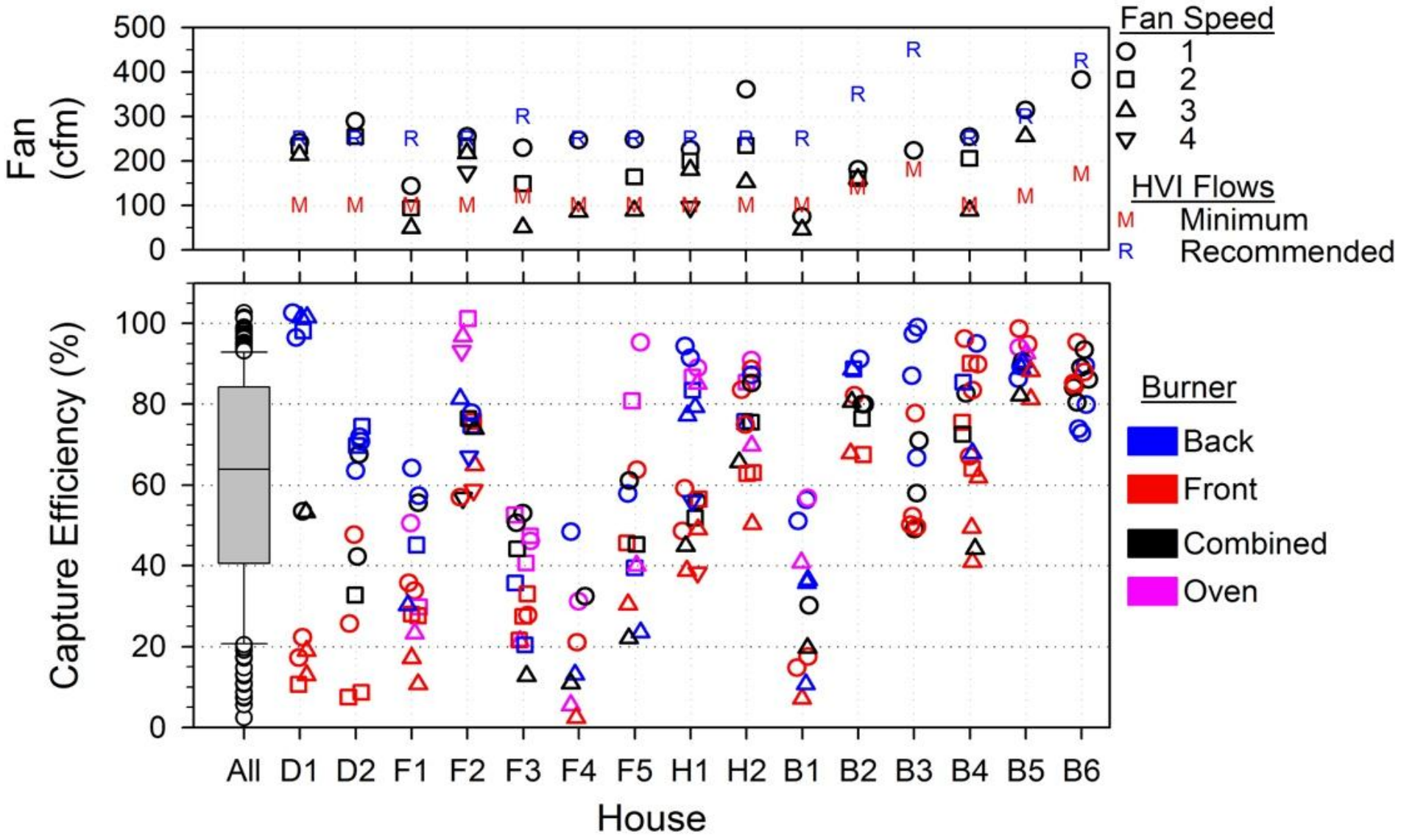
- 100 cfm
  - 60% back
  - 30% oven, front
- 200 cfm
  - ~80% back
  - 40-80% oven
  - 25-80% front

In-Home Performance Study

- 15 devices
  - 2 downdraft
  - 2 microwaves
  - 3 no-hood hoods
  - 2 hybrid
  - 6 with capture hood
- Cooktops
  - Pots with water
  - Front, back, diagonal
- Ovens
  - 425 F, door closed
  - Cool between tests



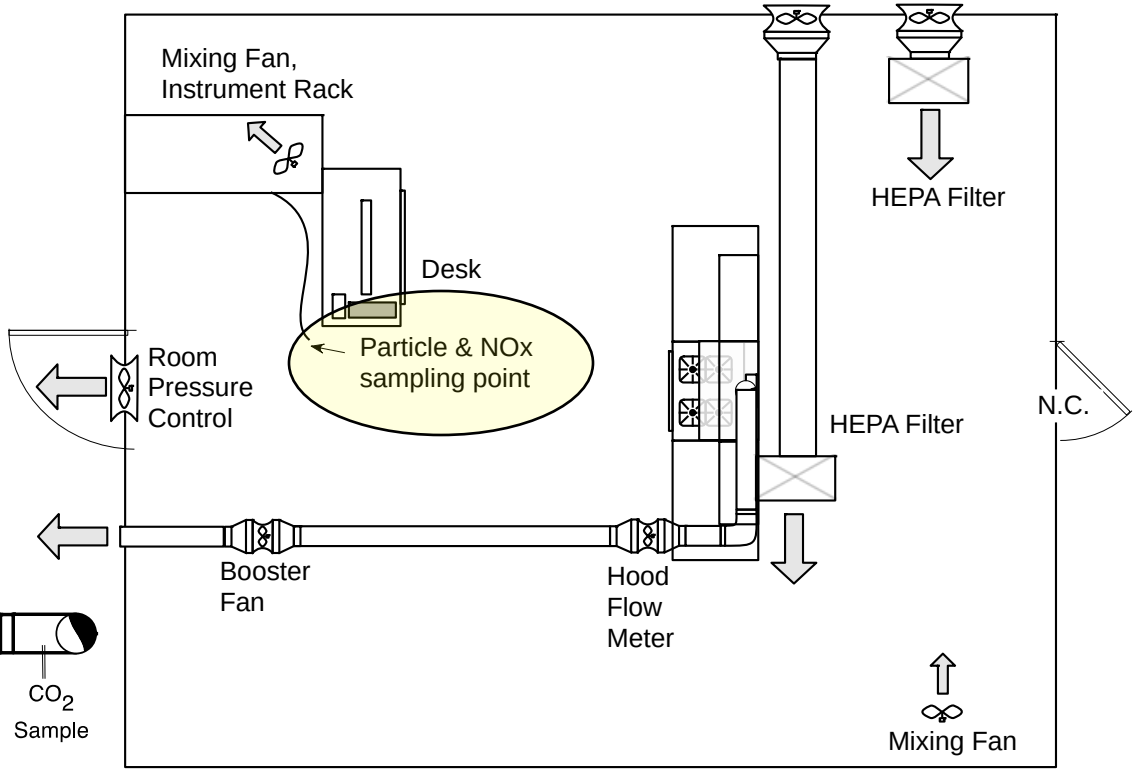
In-Home Performance Results

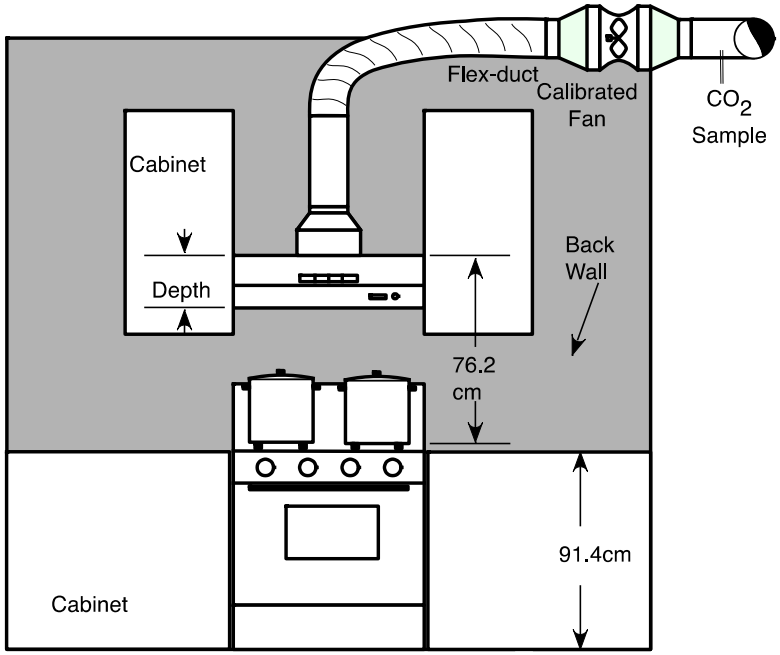


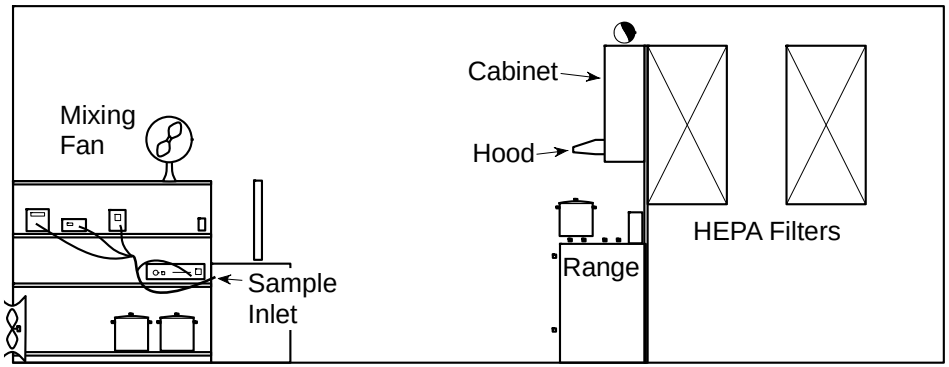
Lab evaluation of cooking particle vs. exhaust gas capture efficiency

- Two cooking activities that produce particles:
  - Pan-fry beef burger on medium heat, back burner
  - Stir-fry green beans in wok, high heat, front burner
  - Control EVERYTHING possible for consistency; emissions still ranged over factor of 2.
- Quantify gas CE based on measured hood airflow and CO_2 concentration
- Quantify cooking particle CE by difference in room concentrations between no-hood and hood experiments

Facility for particle capture experiments

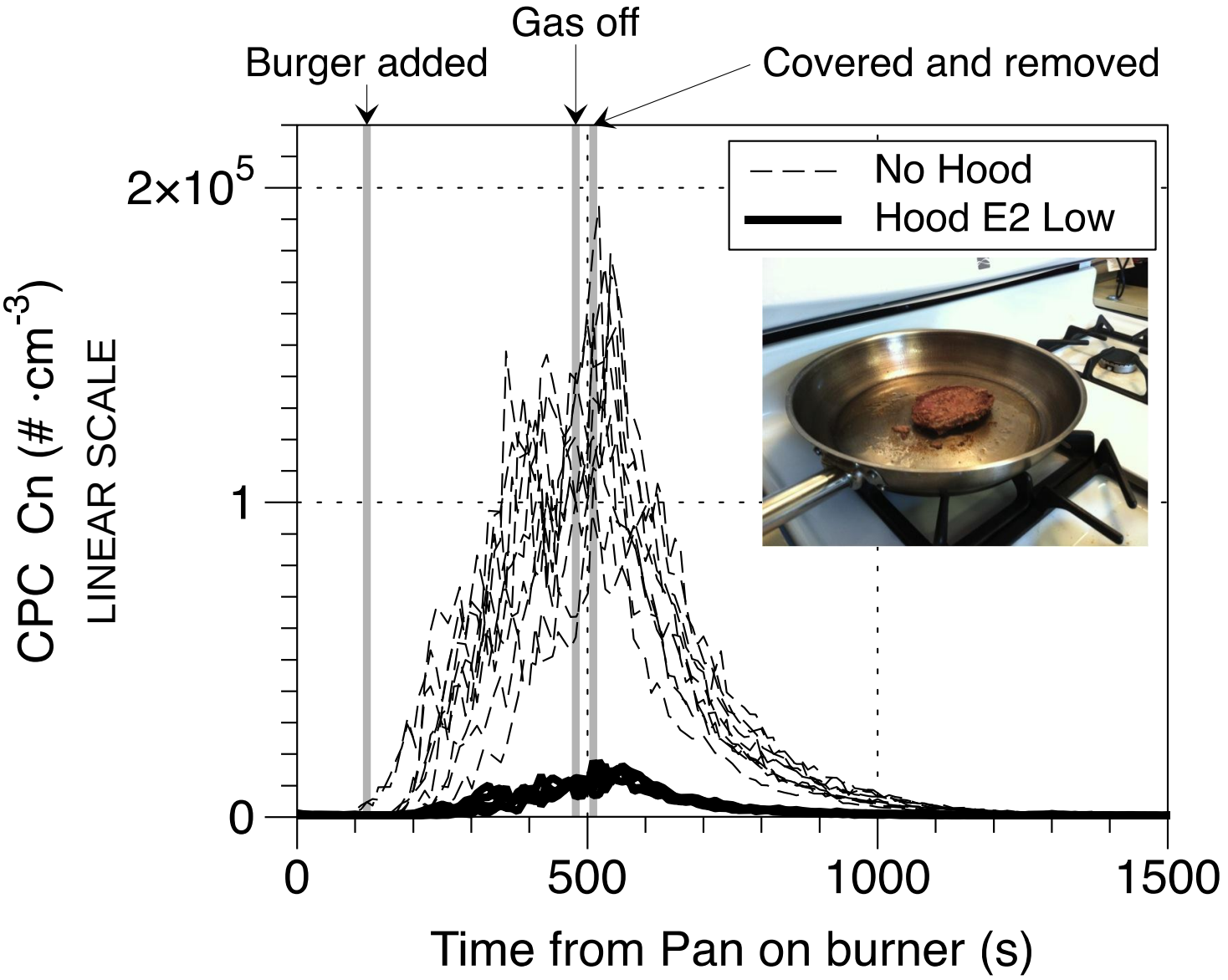




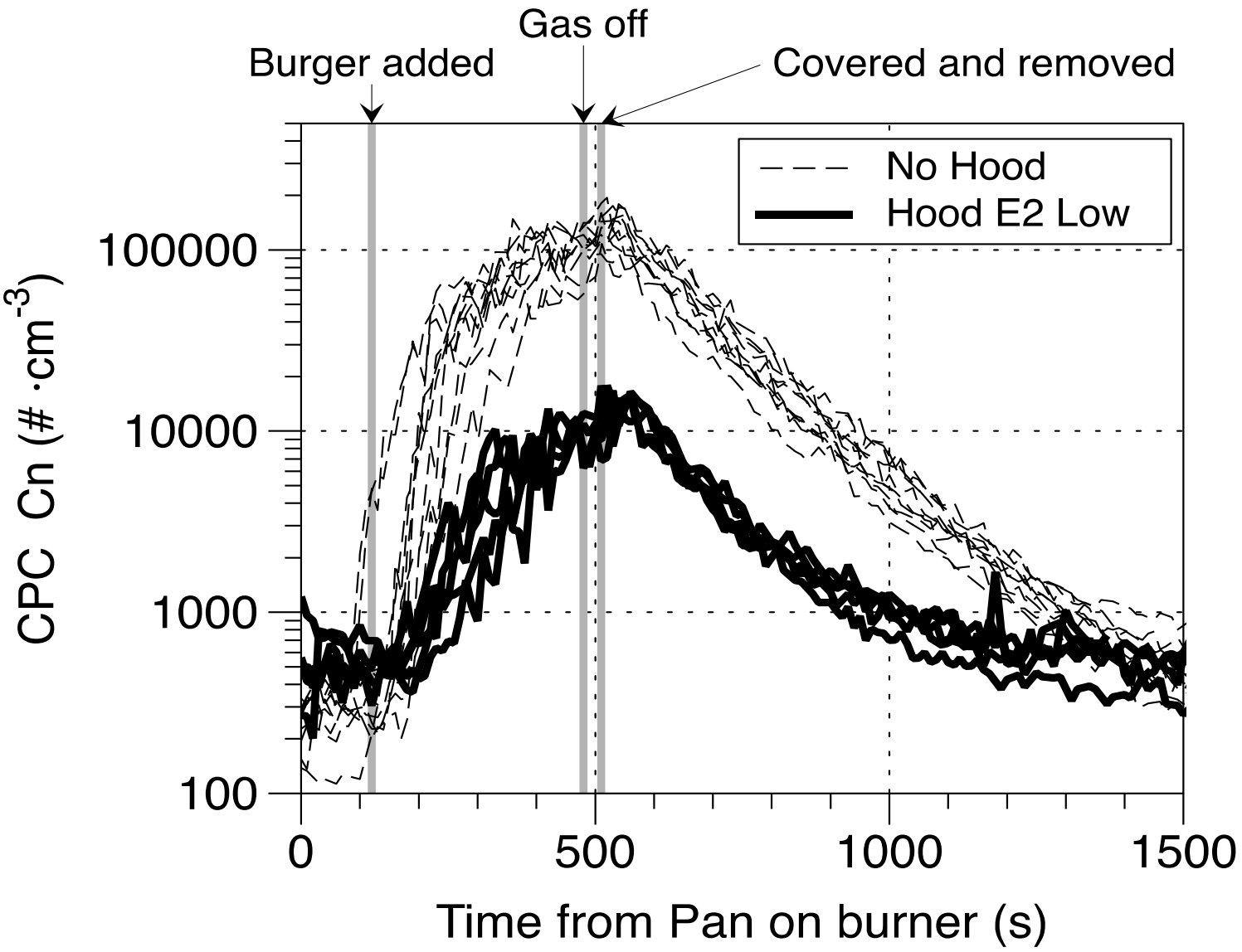


Facility for particle capture experiments

Conducted many replicates to overcome variability in emissions & room concentrations



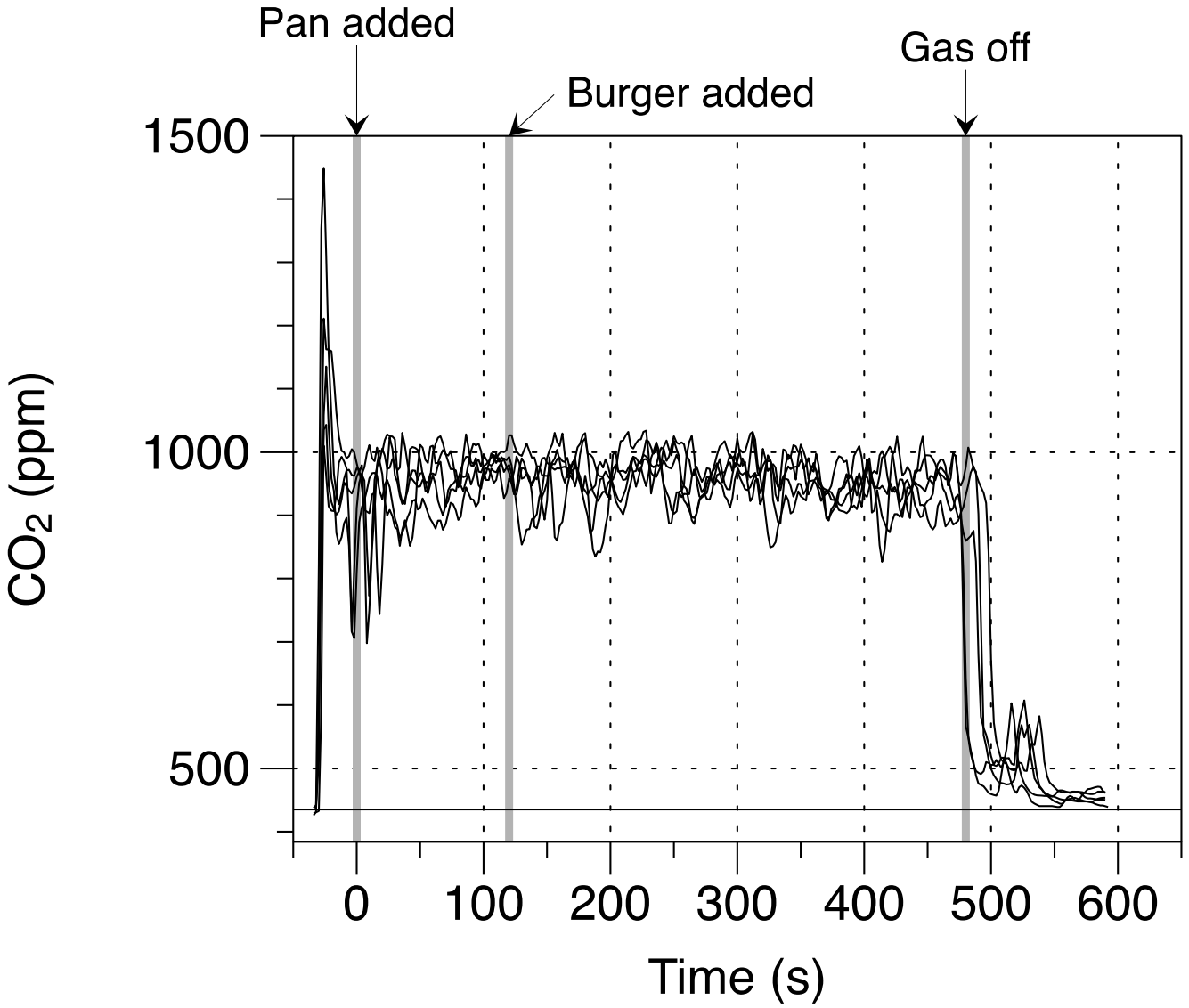
Conducted many replicates to overcome variability in emissions (log scale)



Environ

Berkeley Lab

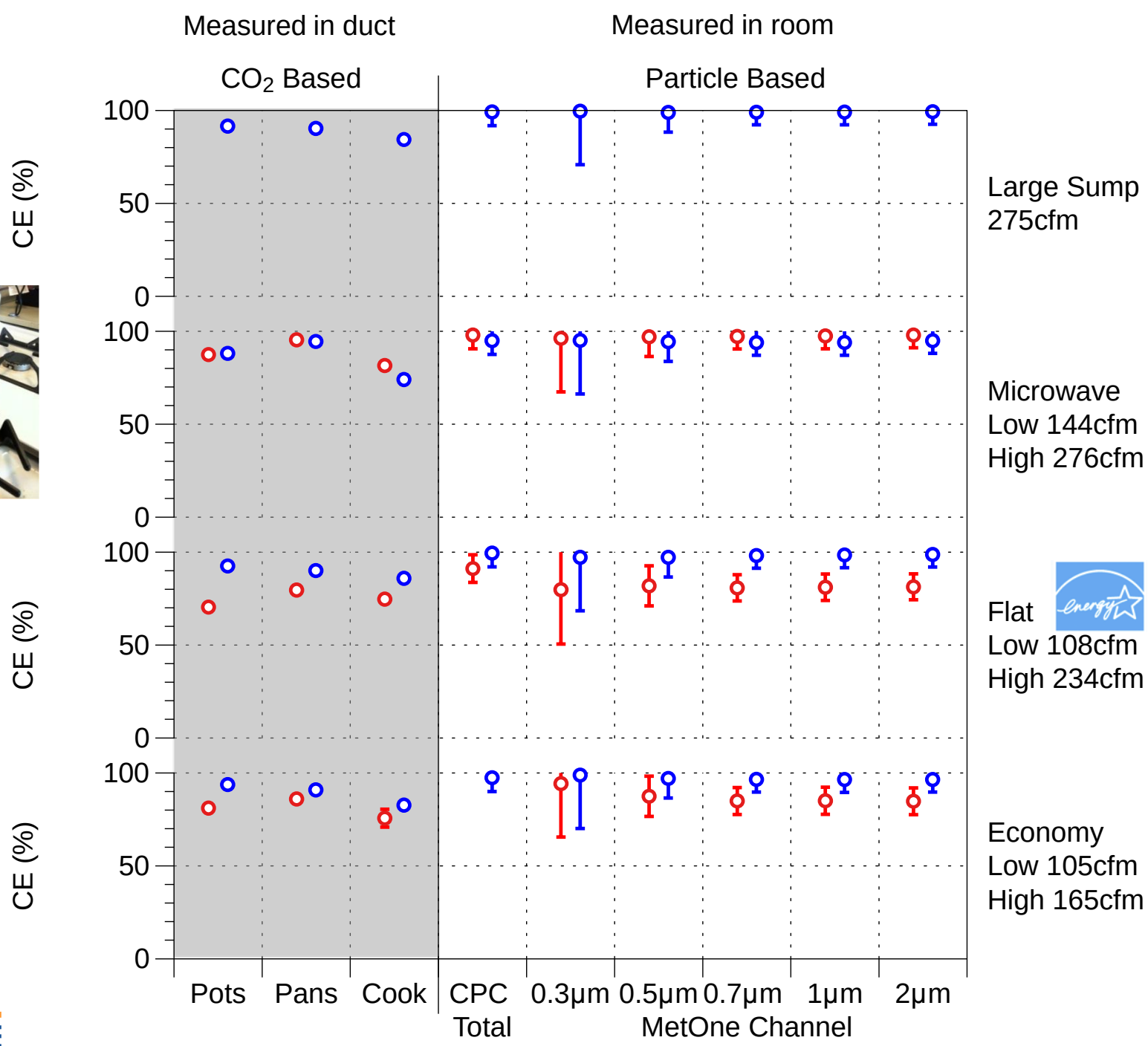
CO_2 data from same experiments as previous two slides



Burger On Back

DRAFT
RESULTS;

DO NOT CITE OR QUOTE



Green Beans On Front

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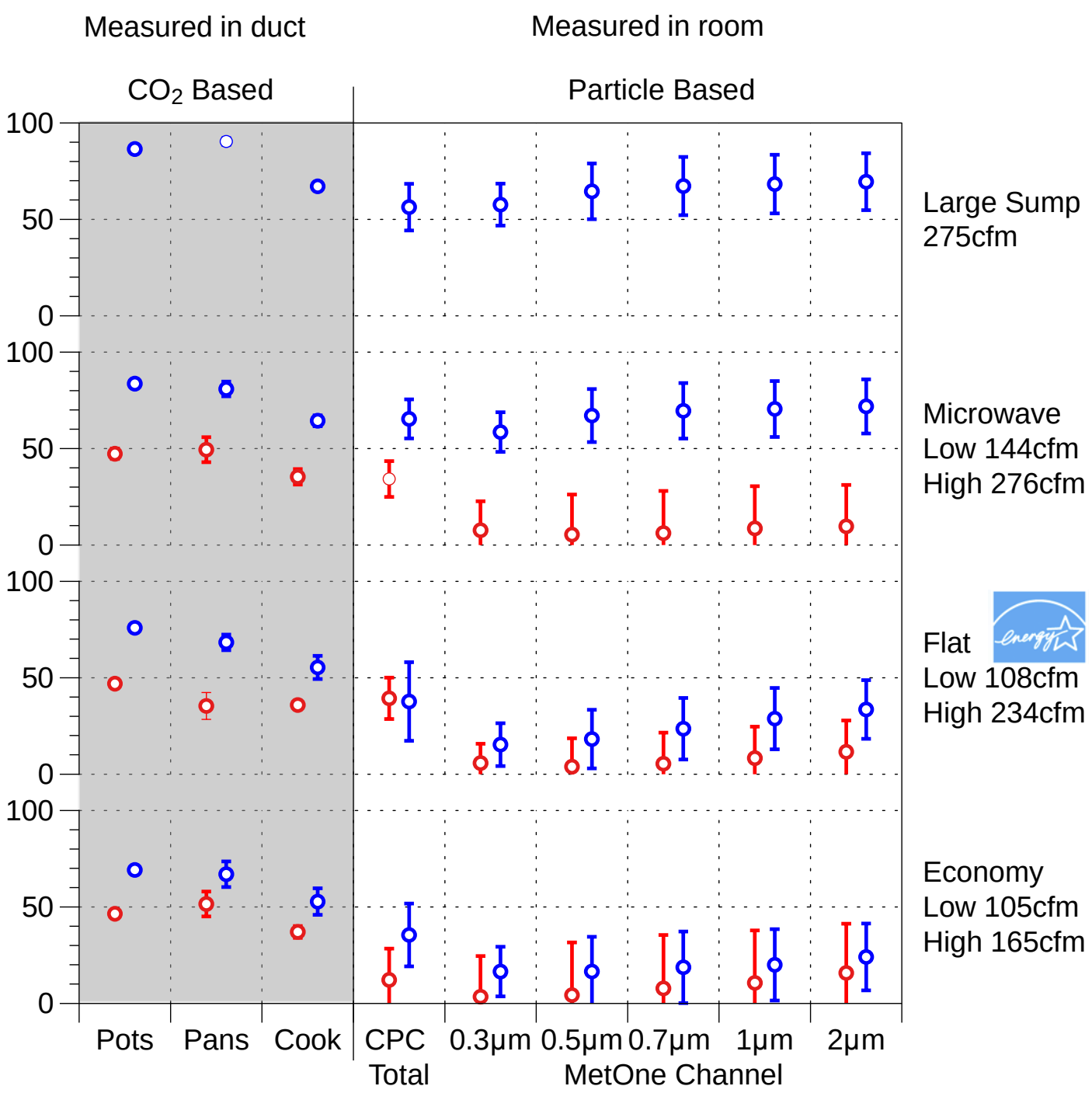
RESULTS;

DO NOT CITE OR QUOTE

Environmental E

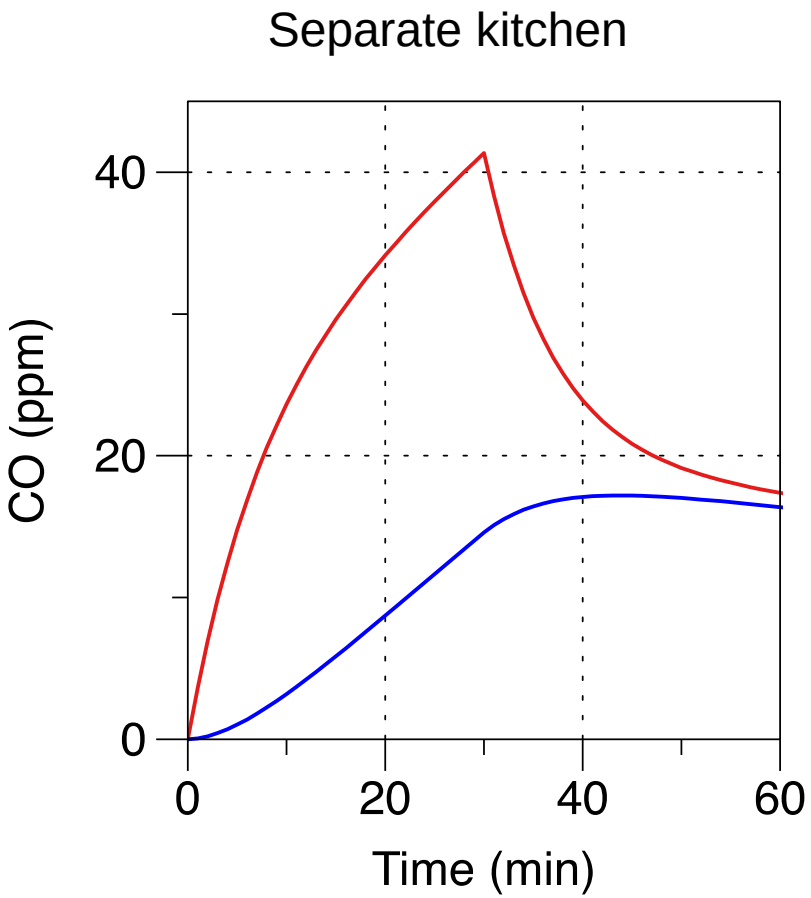


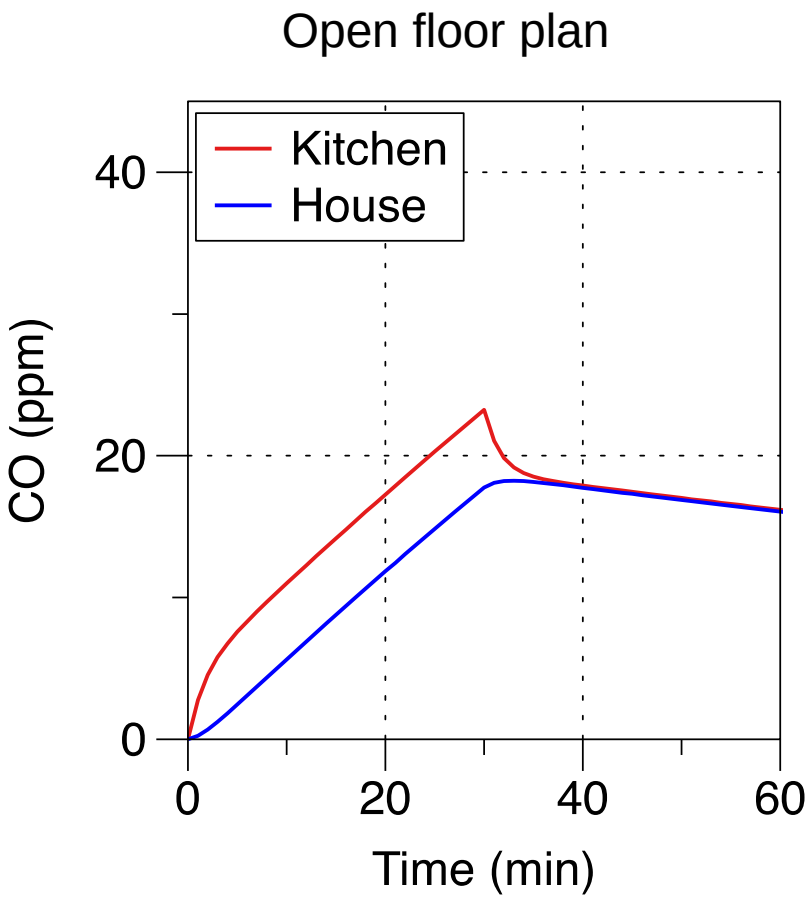
Are range hoods really much better than general kitchen ventilation?

Yes, they are.

Example of cooking without ventilation

Simulate 1200 ft^2 house, 200 ft^2 kitchen



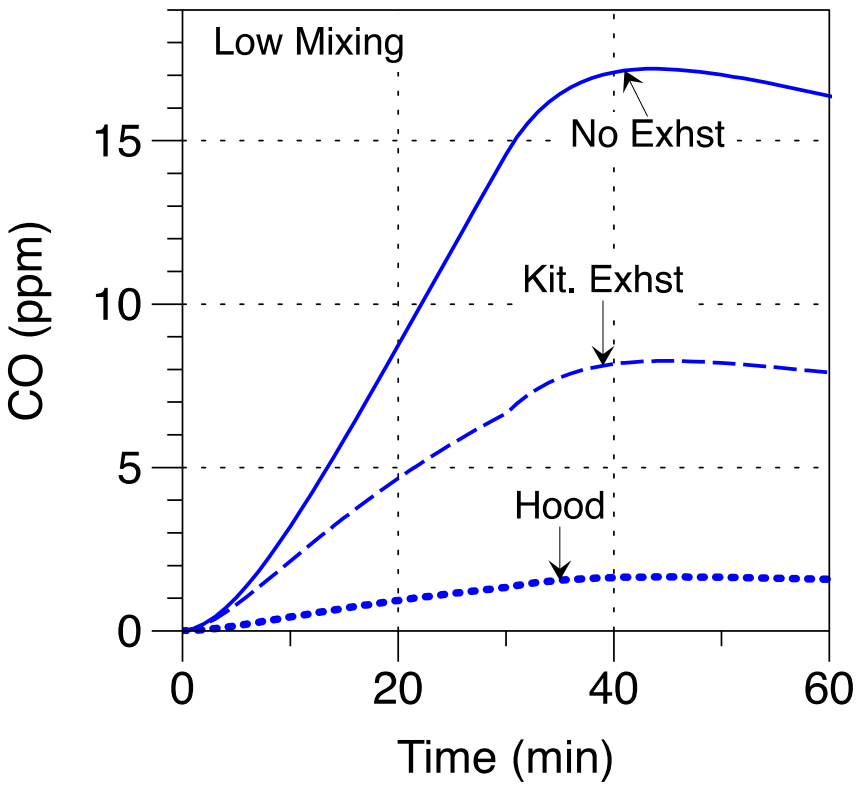


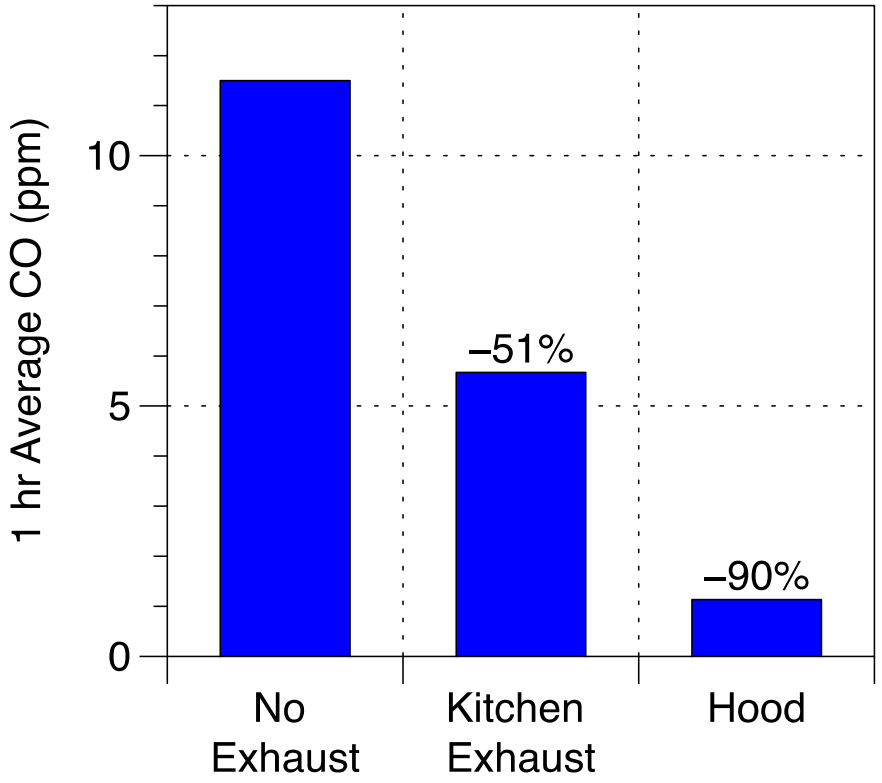
15,000 btu/h
800 ng/J CO

Impact of ventilation: range hoods better!

200 cfm range hood or kitchen exhaust (simulations)

CO concentration throughout the **home**: **SEPARATE KITCHEN**



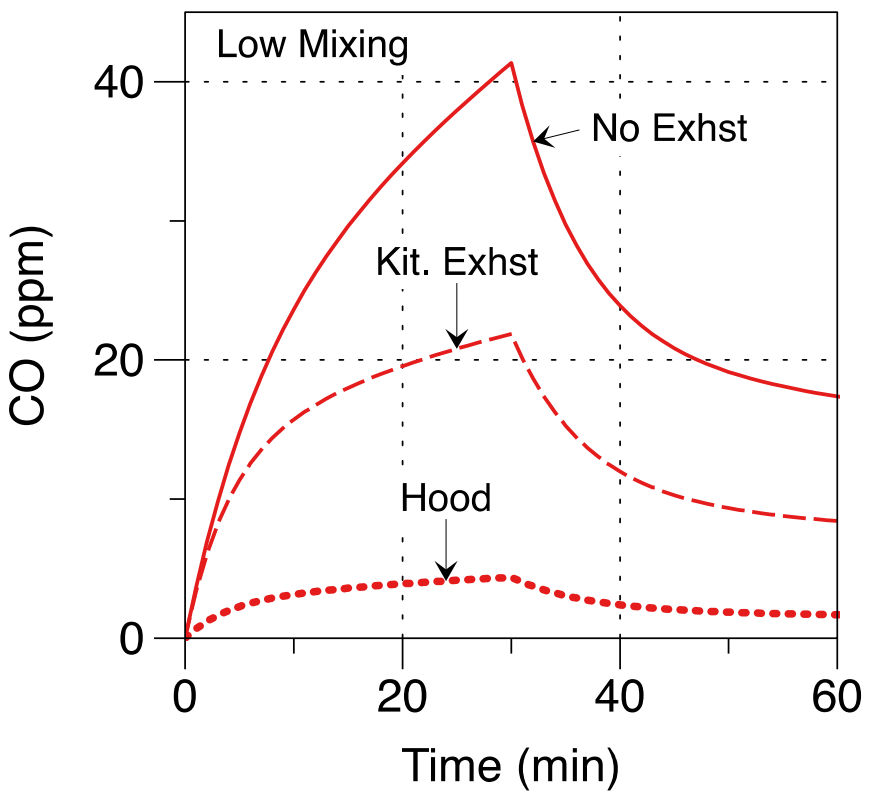


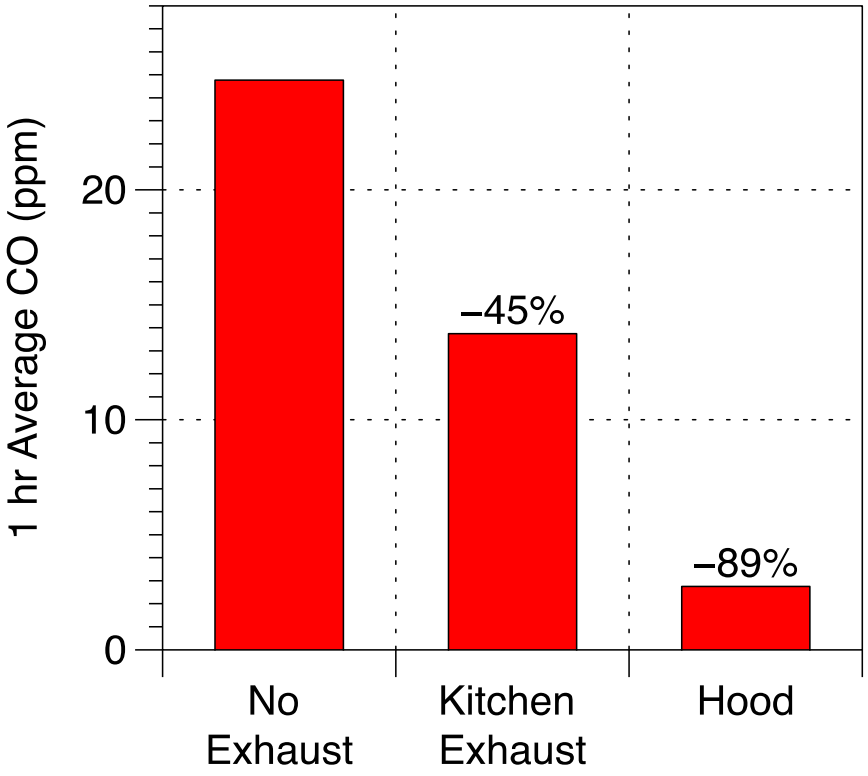
15,000 btu/h
800 ng/J CO

Range hoods better than general kitchen

200 cfm range hood or kitchen exhaust (simulations)

CO concentration in the **SEPARATE KITCHEN**



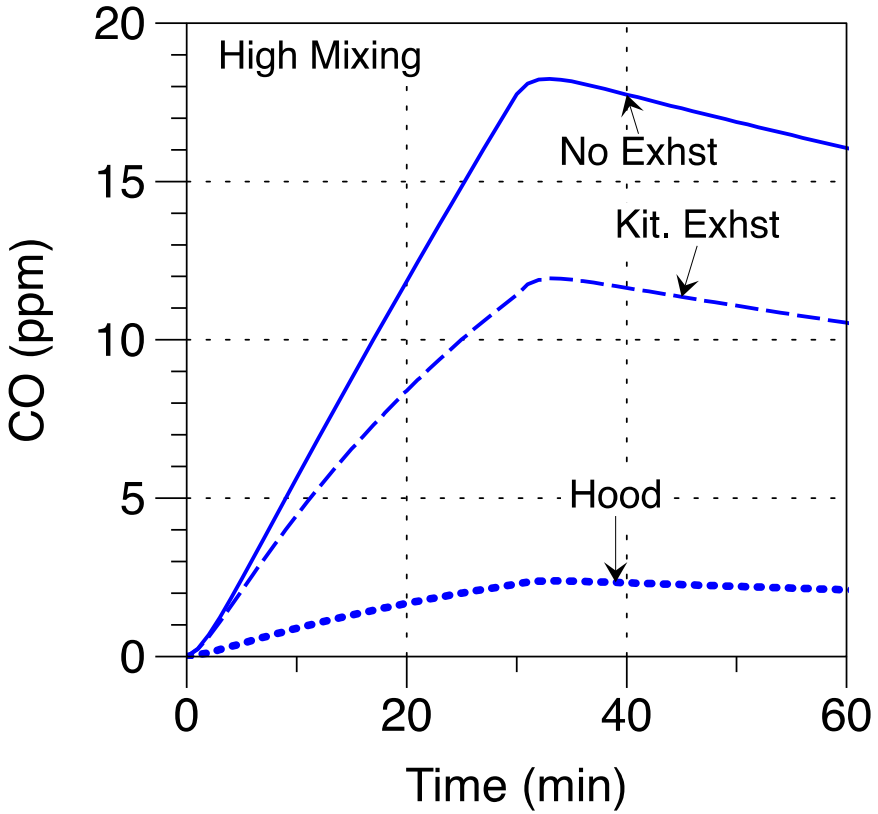


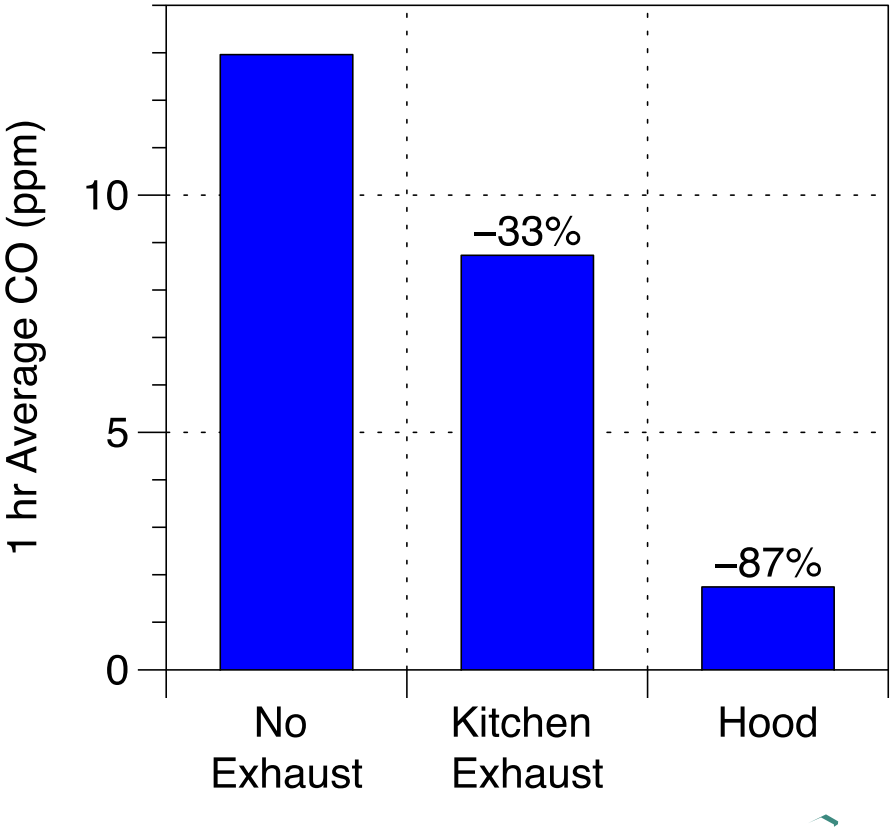
15,000 btu/h
800 ng/J CO

Range hoods better than general kitchen

200 cfm range hood or kitchen exhaust (simulations)

CO concentration throughout the **home**: **OPEN FLOOR PLAN**





15,000 btu/h
800 ng/J CO

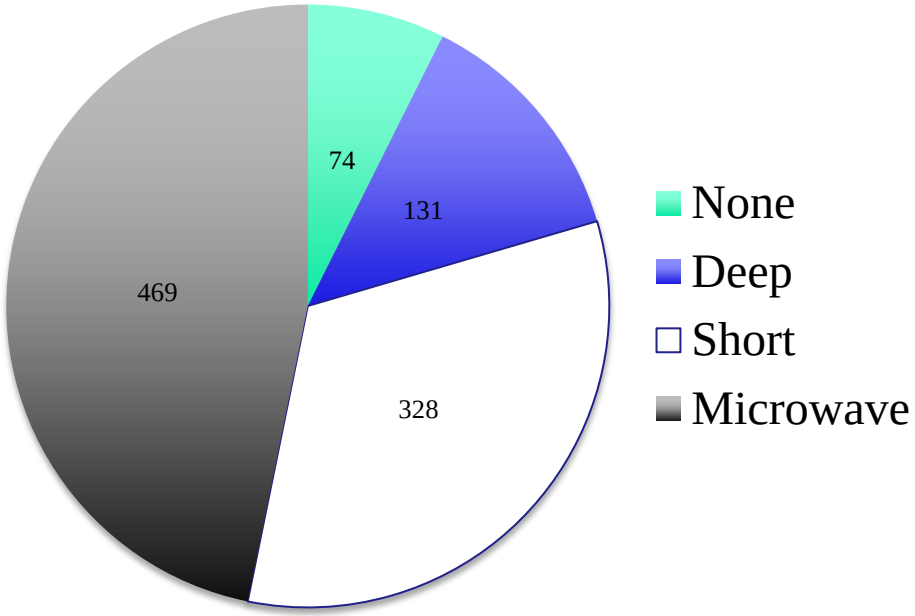
How often is kitchen ventilation used in US?

- Fraction of homes with ANY exhaust ventilation in kitchen unknown
  - Few states require it
  - Very uncommon in some regions
  - Some data exist, but have not been compiled, e.g. from healthy homes assessment
- Limited data on use rate; mostly from California

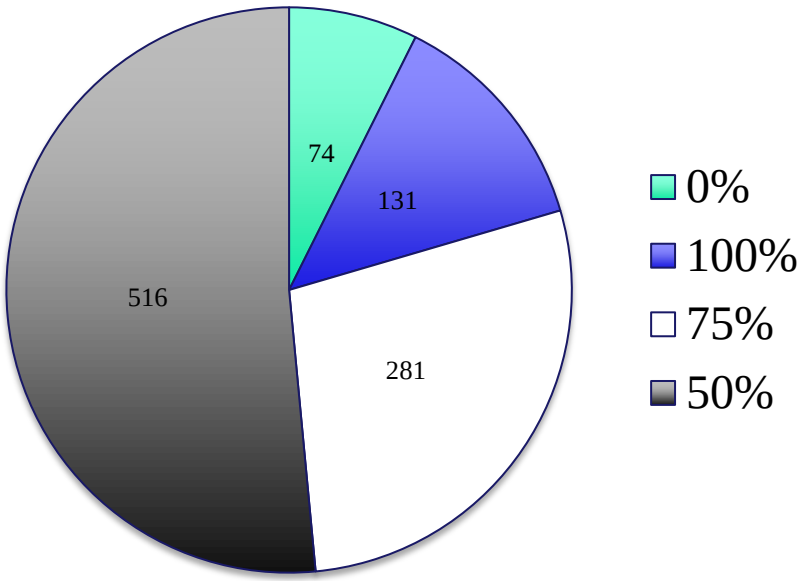
Installed equipment and usage data

- Web-based survey of cooking patterns, range hood presence & use (n = 372 respondents; Klug LBNL-5028E)
- Visual identification of range hood types from real estate listings – broad sample (n = 1002 homes; Klug LBNL-5067E)
- Interview-based survey of participants in California IAQ study
  - Mullen et al. LBNL-6347E (n=352)
- Mail-out survey to new California Homes (Piazza, Lee, Sherman, Price – CEC-500-2007-033)
- Minneapolis Sound Insulation Program (73 survey respondents)

Range hoods in California homes



Hood design

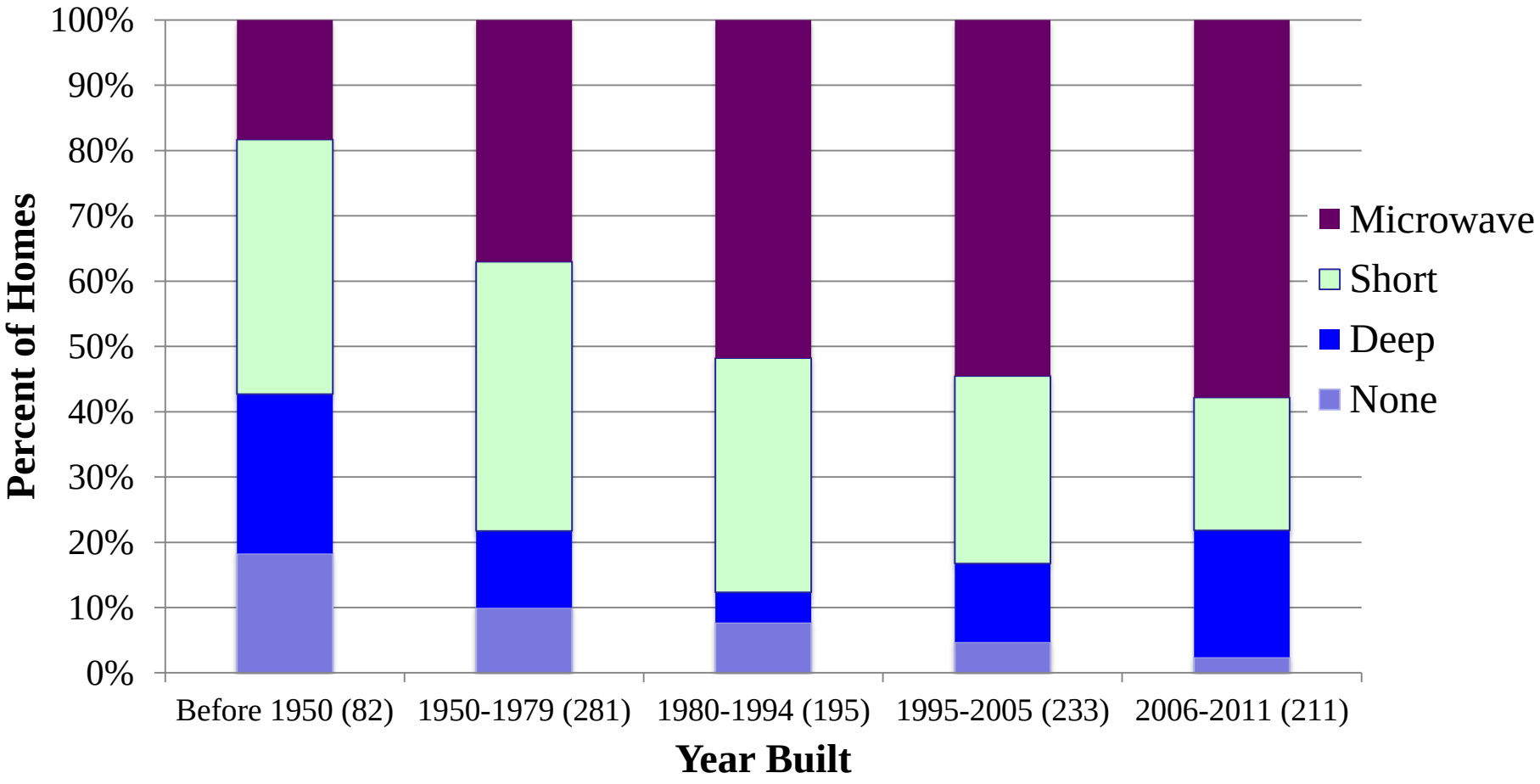


Coverage of cooktop

50% = front burners not covered

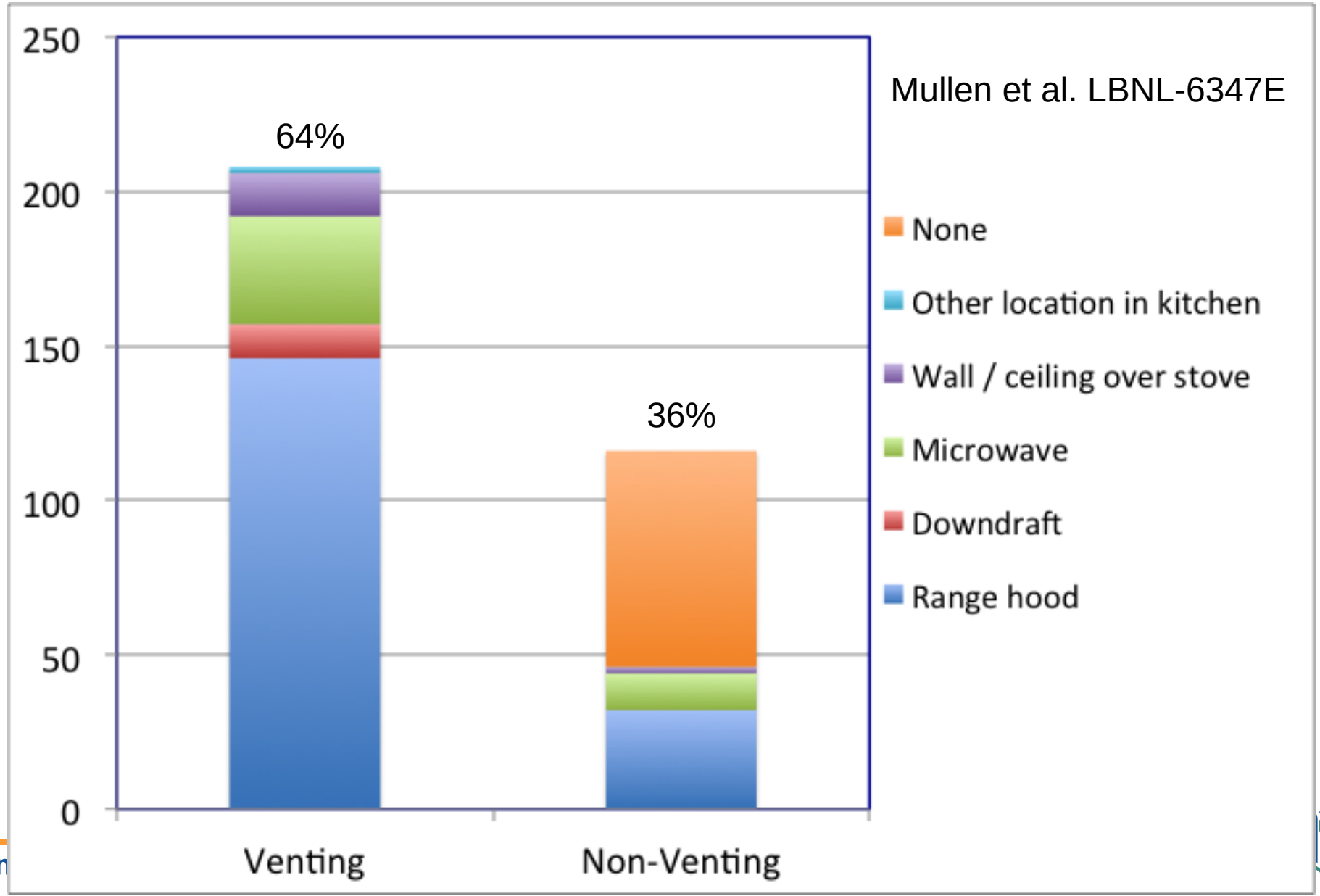
Klug LBNL-5067E

Microwaves common in newer CA homes



Klug LBNL-5067E

Kitchen ventilation in 2011-13 Cal. IAQ study



Kitchen exhaust use in Cal. IAQ study:

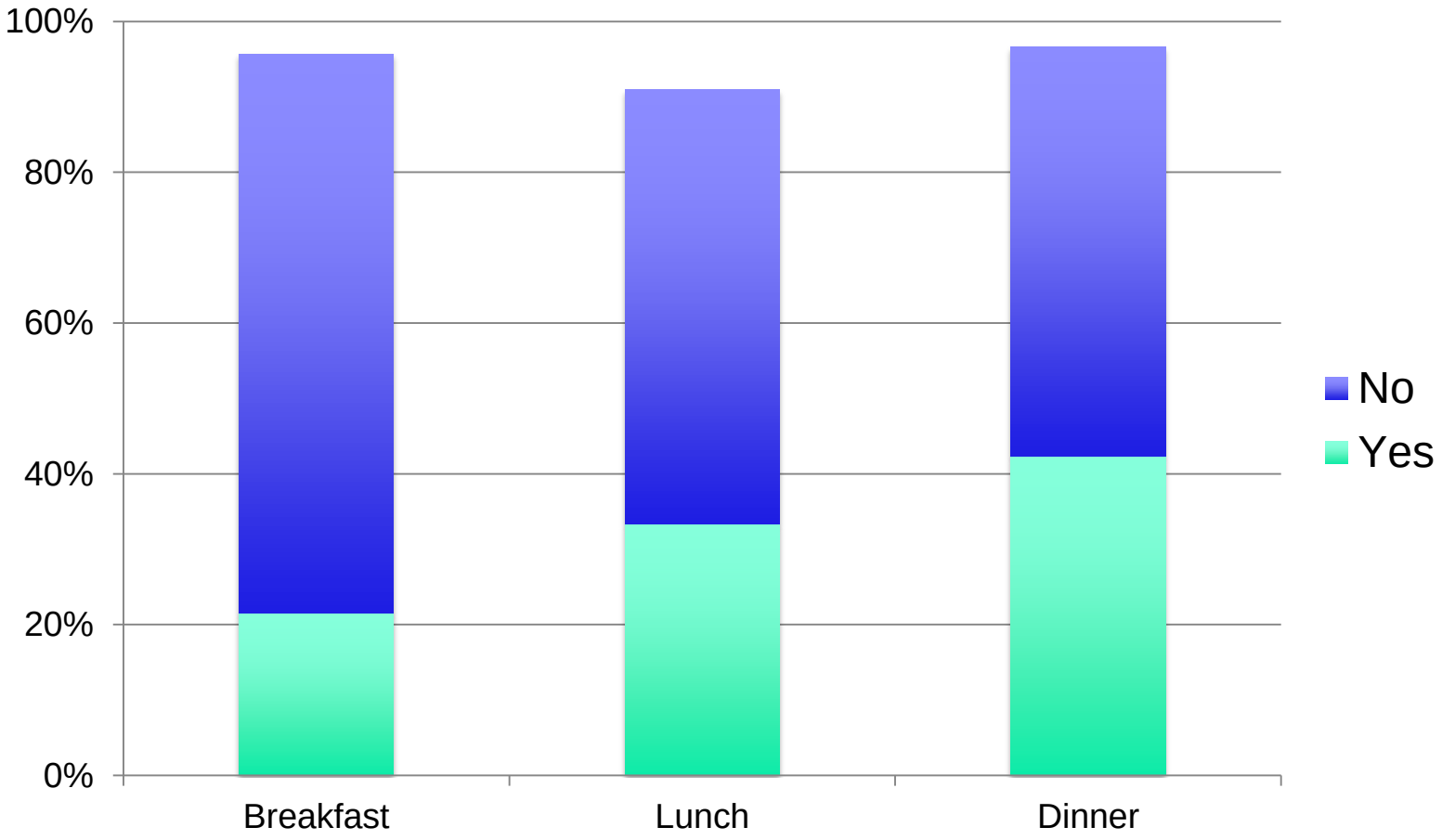
Self-reported usage	Number	Percent
Most times (>75%) when cooktop or oven used	44	13%
Most times when cooktop used, but not oven	39	11%
About half the time	45	13%
Infrequently, only when needed	113	32%
Never	35	10%
No exhaust fan	73	21%

California New Home Mail-out Survey

- Q65: When using the stovetop,
  - 28% always use the exhaust fan or range hood (if present)
  - 32% only use it when odor or humidity seems to be an issue
  - 26% “sometimes” use it
  - 11% rarely use it
  - 2% never use it
- Q66: When using the oven,
  - 15% always use the exhaust fan or range hood (if present)
  - 12% only use it when odor or humidity seems to be an issue
  - 15% “sometimes” use it
  - 21% rarely use it
  - 35% never use it

Web-based cooking survey: range hood used when cooking in previous 24 h?

Klug et al. LBNL-5028E



Likelihood of range hood use increased with amount of cooking.

Kitchen exhaust use in Cal. IAQ study:

Reasons for using exhaust system	Number	Percent of 241 users
Remove smoke	111	46%
Remove heat	11	5%
Remove odors	75	31%
Remove steam / moisture	38	16%
Other reasons	5	2%
No reason selected	80	33%

Kitchen exhaust use in Cal. IAQ study:

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

Kitchen exhaust use in Cal. IAQ study:

Fan speed used most often during study	Number	Percent
Only one speed available	44	13%
Highest	75	21%
Medium setting	29	8%
Lowest setting	57	16%
Depends on what is being cooked	31	9%
No exhaust fan or did not use	111	32%

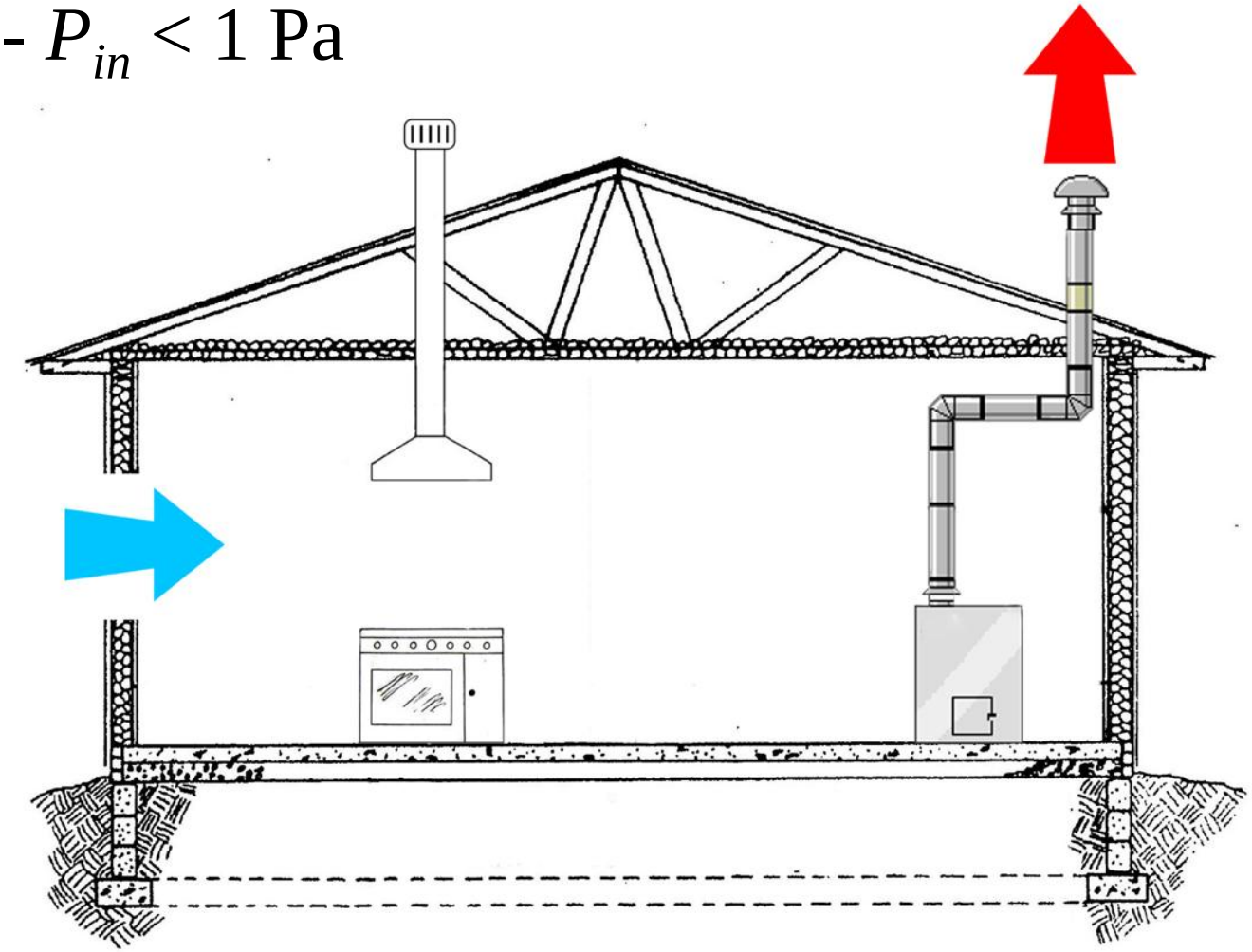
What deficiencies exist in installed capacity?

- Many homes don't have venting kitchen exhaust
- Even vented hoods not consistently effective
- People don't use them
- Many don't cover front burners
- Flows as installed don't match ratings
- Too noisy

Materials (287 g) extracted from range hood vent, above sheet metal damper, after roof replacement on N. Oakland detached house. Composition by M. Lunden.

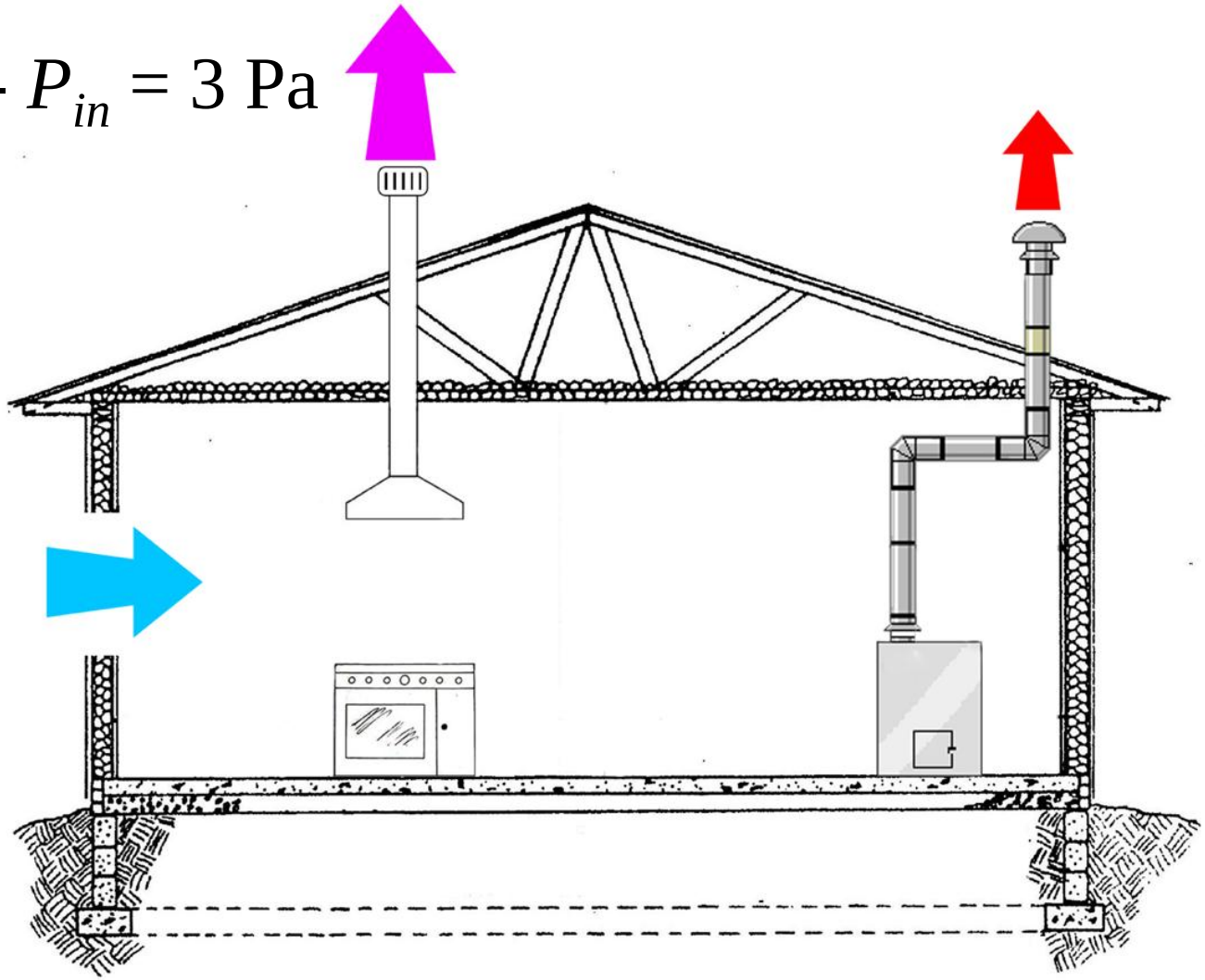
The depressurization concern

$$D_p = P_o - P_{in} < 1 \text{ Pa}$$



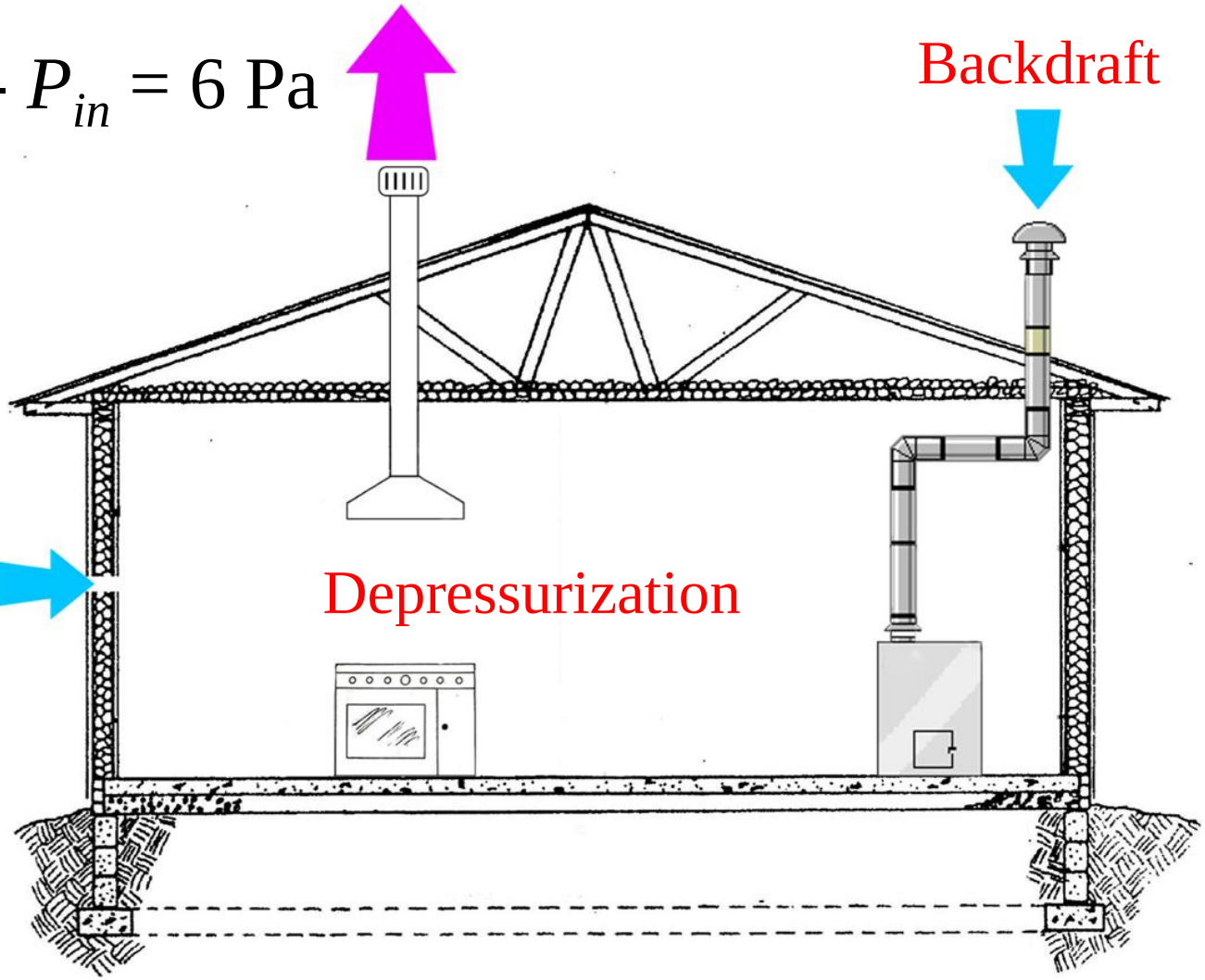
Exhaust fans fine when house is leaky

$$D_p = P_o - P_{in} = 3 \text{ Pa}$$



Air sealed houses more readily depressurize, increasing backdraft risk

$$D_p = P_o - P_{in} = 6 \text{ Pa}$$



What is the impact of high airflow range hoods on depressurization and combustion safety?

	Approximate total exhaust airflow (cfm) needed to induce depressurization		
Envelope Airtightness	**-2Pa**	**-5Pa**	**-10Pa**
Air-sealed older home: 8 ACH50	300	540	850
Typical CA new home: 5 ACH50	185	335	530
Very tight new home: 2 ACH50	75	135	215
Passive House: 0.6 ACH50	25	40	65

At 5 ACH50, 150 cfm range hood + 200 cfm dryer fails combustion safety test

(May not really be a problem; but that is another issue…)

Solutions to avoid depressurization problems

- Avoid exhaust fans with very high air flow rates
- Pressure relief damper – controlled barometrically or mechanically
- Make-up air system interlocked with range hood

What we have learned about performance

- Actual airflow often below ratings
  - Sensitivity to duct pressure varies by hood
- Pollutant capture varies from terrible to great;
  - Varies by hood, speed, installation, etc.
  - Capture much better for burners under hood
  - ~200 cfm needed for >80% gas capture
  - On front burners, capture of particles and gases can differ

What we still need to figure out…

- What are installed system pressures? Should tests for airflow and capture ratings use higher duct static P?
- Are recirculating range hoods or kitchen air cleaners with filtration and VOC removal a viable alternative?
- What standards – tests, metrics, requirements – are needed to support shift to automatic kitchen ventilation?

Policy Agenda

- Change codes to ensure that all new construction and major retrofits install kitchen exhaust ventilation
- Require minimum capture efficiency, not airflow
  - First enact standard test method
- More products with high capture; quiet and low energy
  - Over the range microwaves are a particular deficiency

Questions?

<u>Contact info and resources:</u>

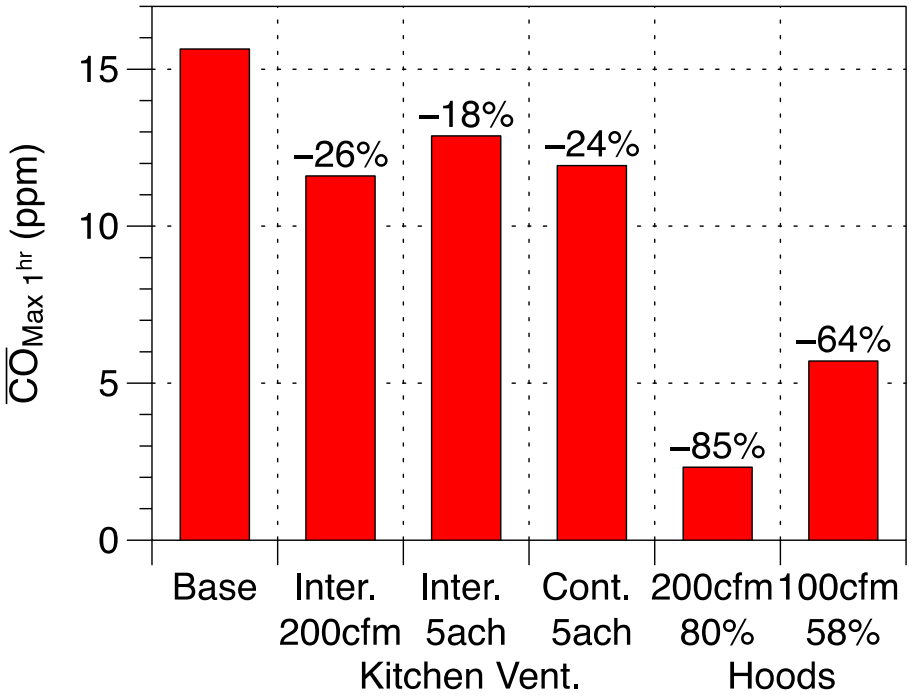
bcsinger@lbl.gov

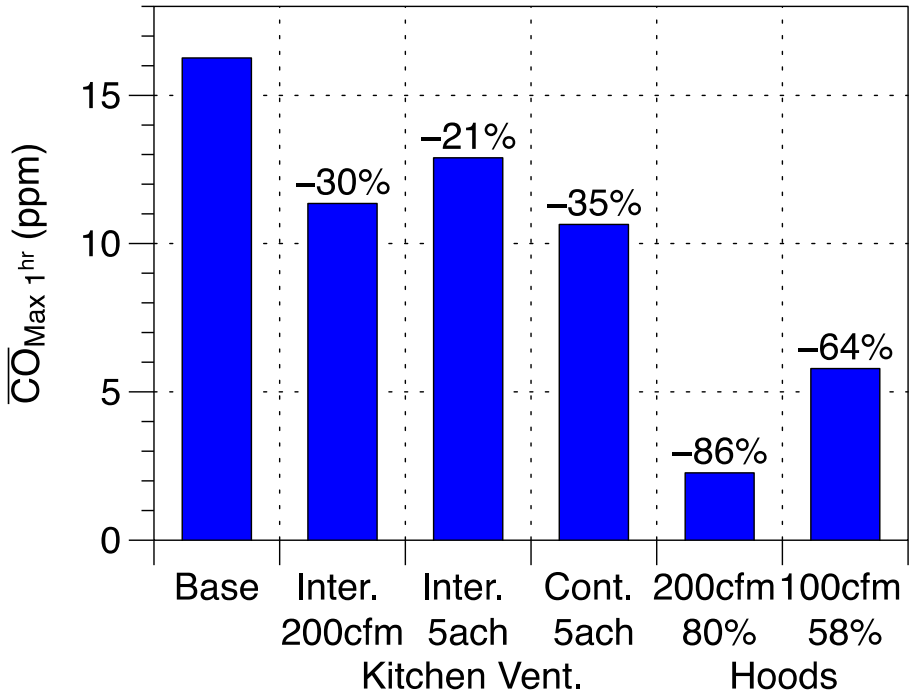
homes.lbl.gov/publications

Extra Slides Available for Q&A

Range hoods better than general kitchen

Highest 1-h CO concentrations: **OPEN FLOOR PLAN**
Note: 5 kitchen ach = 138 cfm

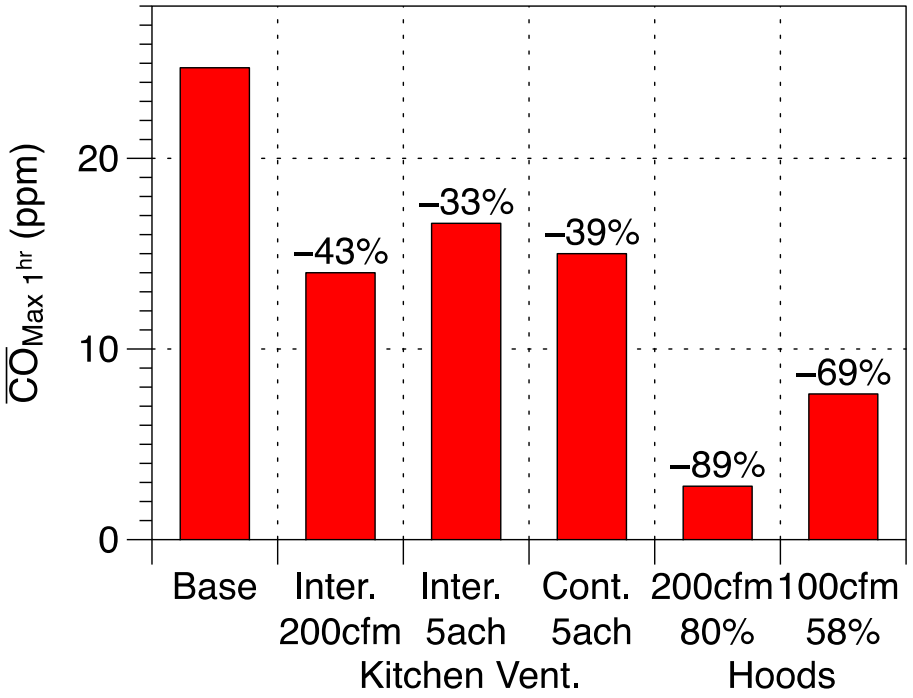


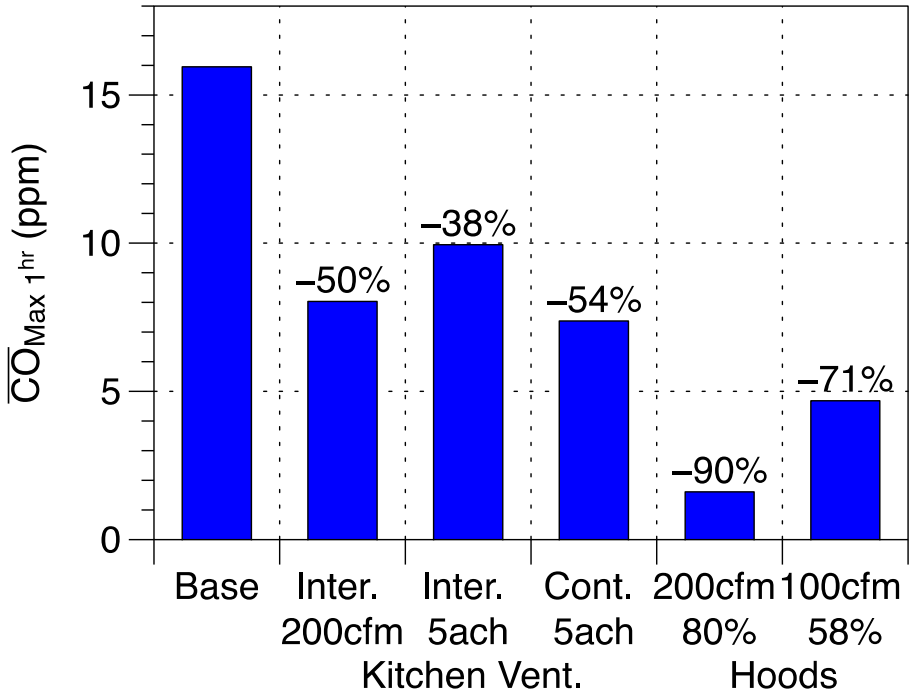


15,000 btu/h
800 ng/J CO

Range hoods better than general kitchen

Highest 1-h CO concentrations: **SEPARATE KITCHEN**
Note: 5 kitchen ach = 138 cfm





15,000 btu/h
800 ng/J CO

Kitchen ventilation and combustion safety

Combustion appliance hazards depend on several factors

- Fraction of exhaust entering home
- Pollutant concentration in exhaust (emission rate)
- Burner size & frequency of use
- Proximity to people

IAQ hazards from gas appliances

					
Exhaust into home	Always	Always, less w/range hood		Cracked H.E. or Backdraft	Backdraft
Carbon monoxide	Relatively common	Relatively common		Uncommon	Uncommon
Nitrogen dioxide	Common	Common		Not enough data	Rare
Particulate matter	Rare	Rare		Rare	Extremely rare
Burner kbtu/h	10-40	5-30		10-50	30-100
Use	Hours each day	5-40 min, 1-3x daily		Hours each day	5-30 min, hours daily
Proximity	Usually close	Usually close		Usually close	Varies

Expert / Stakeholders Webinars

- Webinar 1: Kitchen Exhaust Ventilation Today
  - What is kitchen ventilation?
  - What guidance and performance information is currently available?
  - Special issues and challenges today
- Webinar 2: Kitchen Exhaust Ventilation of the Future
  - How should ratings, standards and codes be revised to nudge the market to improve performance?
  - Technology development and assessment
  - Special issues and challenges in the future

Ventilation Key Points

- Effective at removing irritants from indoor sources
- Can increase exposure to irritants from outdoors
- Most valuable when linked to sources
  - Combustion appliances
  - Cooking, bathing, toilets
  - Chemical use & other activities
- Automatic systems more reliable than manual
- Air-sealing creates need for engineered ventilation