Guidance on Evaluating Indoor Particles and Filtration Effectiveness

Chan WR and Singer BC. Measurement-Based Evaluation of Installed Filtration System Performance in Single-Family Homes. Lawrence Berkeley National Laboratory, Berkeley, CA. April 2014. LBNL-6607E.

Available at eetd.lbl.gov/publications

Search for “Singer”

Addressing Kitchen Contaminants for High Performance Homes

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ACEEE Summer Study

September 12, 2014
San Francisco, CA

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Summary I

Cooking burners and cooking emit air pollutants, moisture, and odors that can negatively impact indoor air quality.

Cooking emits relatively large quantities of pollutants over short durations; this leads to **acute** IAQ hazards.

Pollutant concentrations higher in smaller homes.

An incremental increase in the general ventilation rate is typically not adequate to address these acute hazards.

Summary II

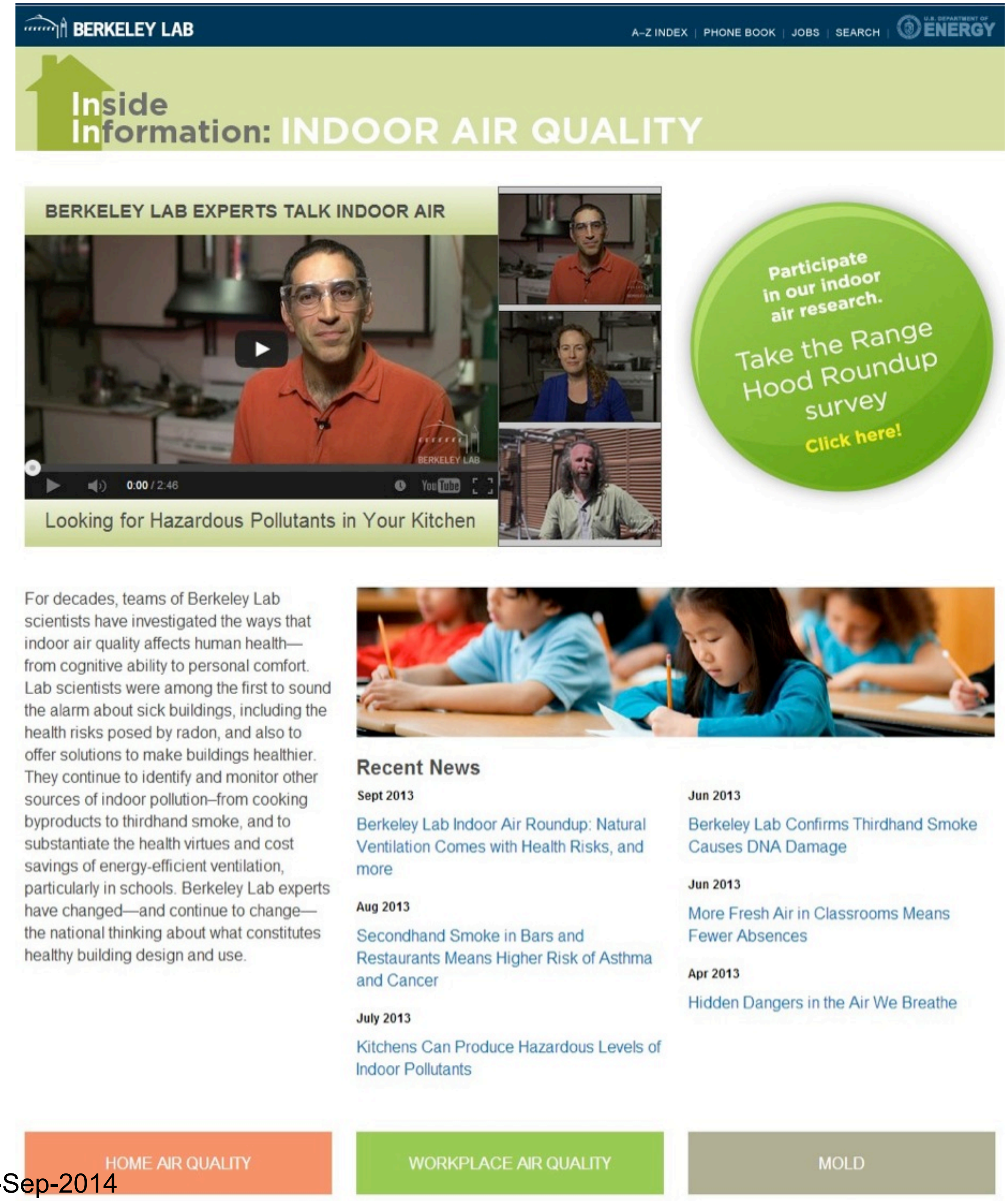
The best currently available approach is to *install and use* a venting hood with high capture efficiency at low airflow.

General kitchen ventilation not as effective or efficient.

There are hoods available that capture ~80% at ~200 cfm *for cooking on back burners*.

Key design feature: hood; covers burners; not too high; quiet

Recirculating hoods that remove pollutants are theoretically a good option; but do any such products exist?



indoorair.lbl.gov

Info about LBNL IAQ research

Kitchen Ventilation Survey

Sponsors of Kitchen Ventilation Work

U.S. Department of Energy Building America

State of California Energy Commission — pier: Public Interest Energy Research, "Research Powers the Future"

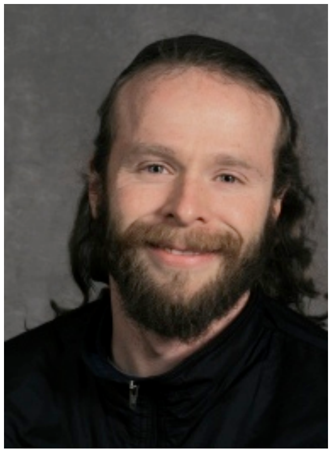
U.S. Department of Housing and Urban Development — *Office of Healthy Homes and Lead Hazard Control*

United States Environmental Protection Agency — *Indoor Environments Division*

Bay Area Air Quality Management District

California Environmental Protection Agency Air Resources Board

Thanks to Kitchen Ventilation Research Team



Woody Delp

Jennifer Logue

Melissa Lunden

Tosh Hotchi

Marion Russell

Max Sherman

Chris Stratton

Iain Walker

Thanks also to: Marcella Barrios, Omsri Bharat, Victoria Klug, Jina Li, Nasim Mullen, Angela Simone

Cooking produces air pollutants

Carbon dioxide
Water vapor
Carbon monoxide
Nitrogen dioxide
Nitrous acid
Formaldehyde
Ultrafine particles

Ultrafine
particles

Formaldehyde
Ultrafine particles
Acetaldehyde
Acrolein
$PM_{2.5}$
PAH
Etc.

Emissions and IAQ impacts of cooking – Selected studies (there are lots more)

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.

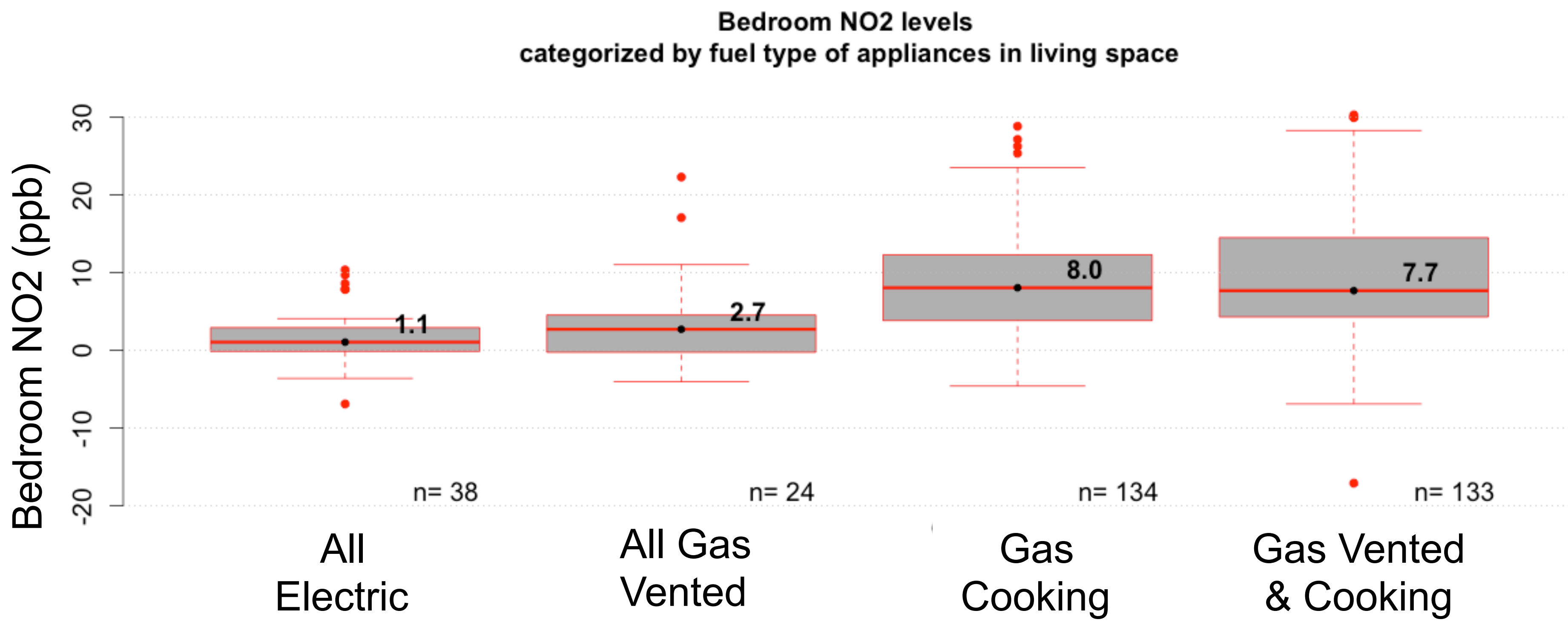
* Available via http://eetd.lbl.gov/publications

Recent Study of IAQ in Homes with Gas Appliances

Mailed samplers to 350 California homes including all electric

Oversampled in homes with gas appliances in living space and those that use cooking burners

Homes with gas cooking have higher NO_2



Results from study that measured pollutants in 350 California homes in 2011-2013.
Estimated contribution from indoor sources.

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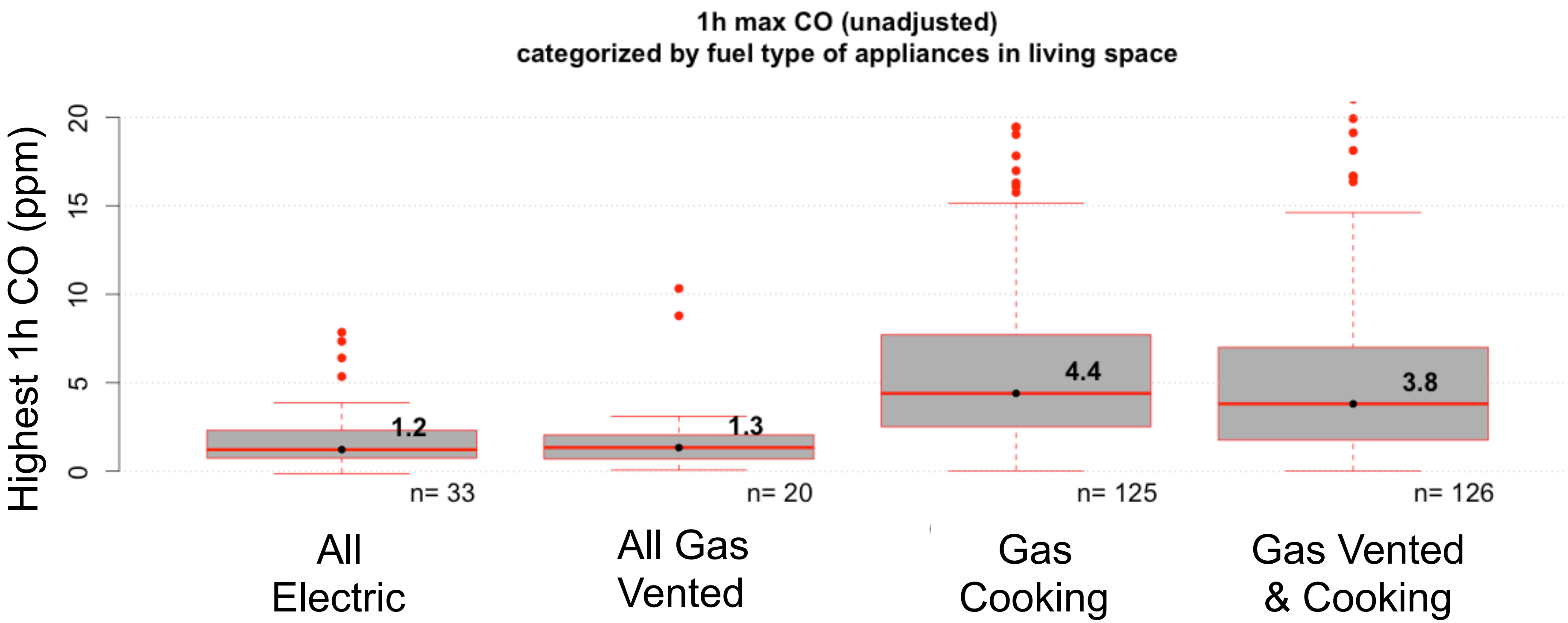
Cooking burners also impact CO



Results from study that measured pollutants in 350 California homes in 2011-2013

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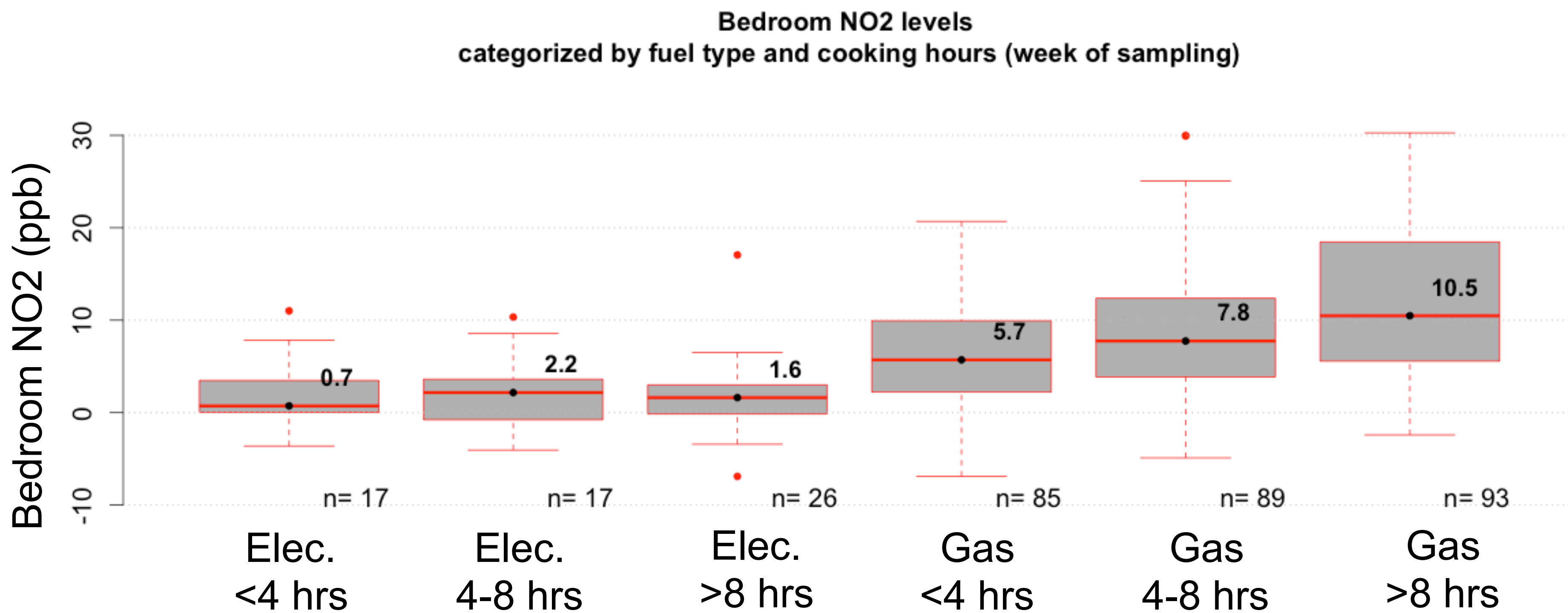
More gas cooking means more NO_2



Results from study that measured pollutants
in 350 California homes in 2011-2013.
Estimated contribution from indoor sources.

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Gas cooking impacts IAQ in many homes

Simulations for 6634 SoCal homes in 2003 RASS

These homes have higher AERs than PH Mech Vent.

	Fraction of homes above std.	Estimated number of Californians impacted	Estimated number impacted across U.S.
CO: 1-h & 8 h	7-9%	1.7M	10M
NO_2: 1-h	55-70%	12M	66M

Typical Week in Winter, Constant AER from Empirical Distribution

Logue et al., EHP, 2014

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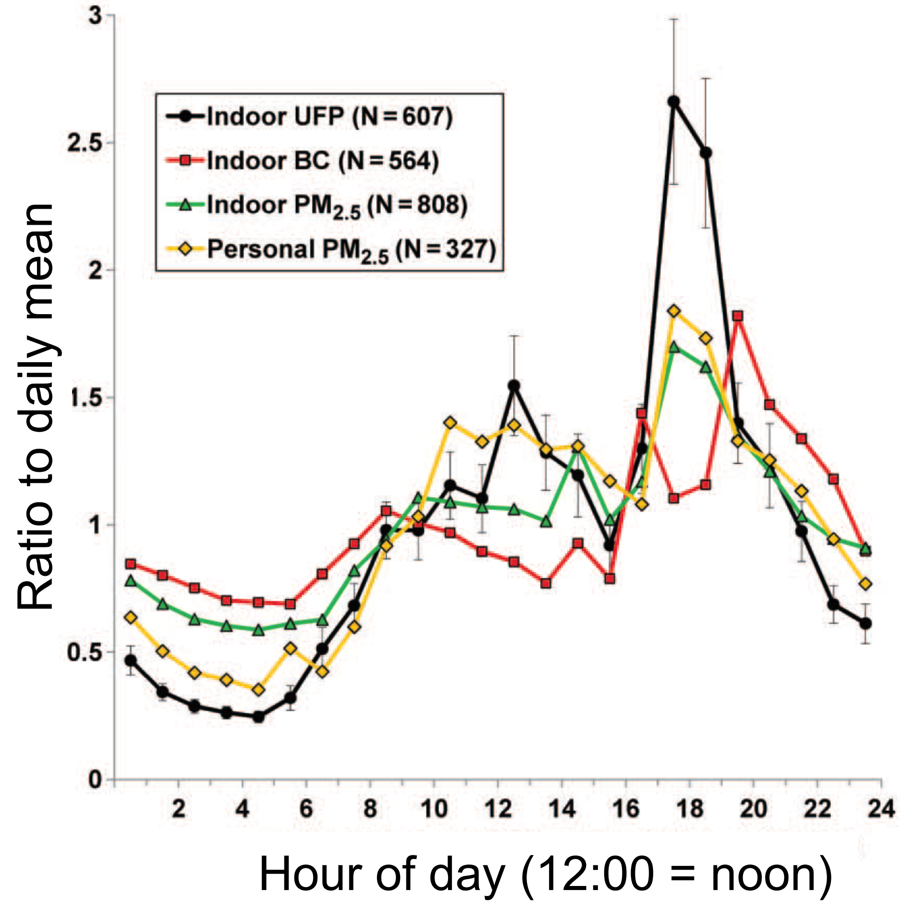
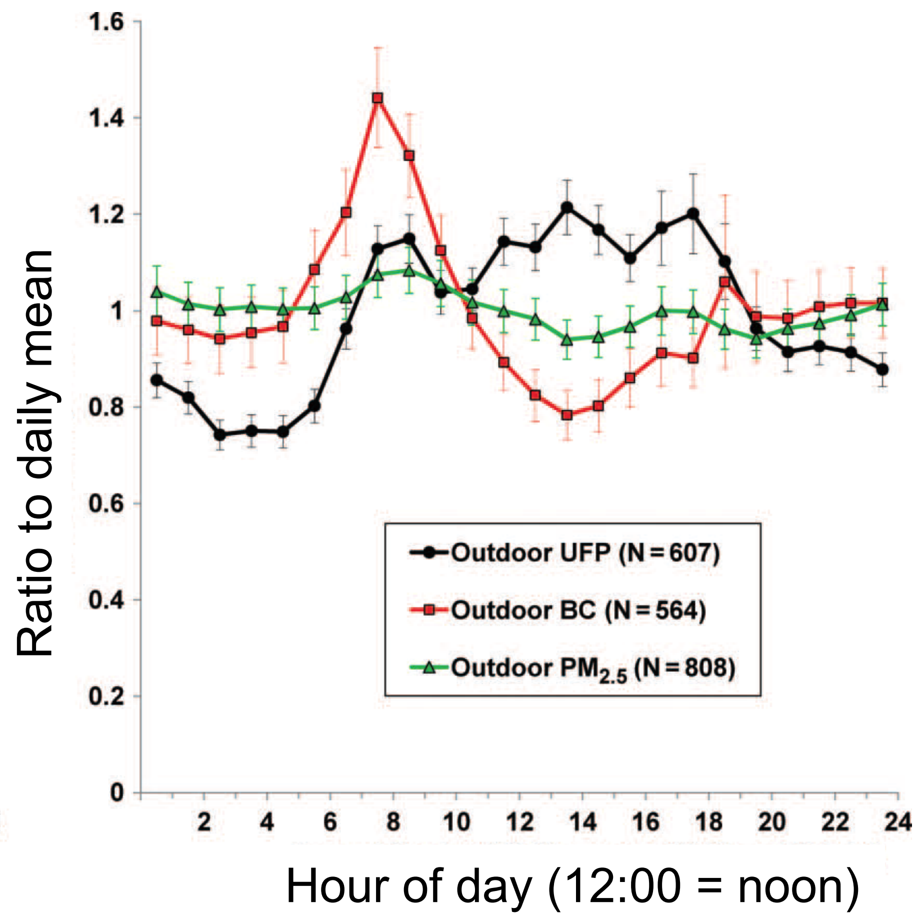
Cooking releases ultrafine particles

Data from 97 homes in Ontario, Canada





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

Cooking releases ultrafine particles

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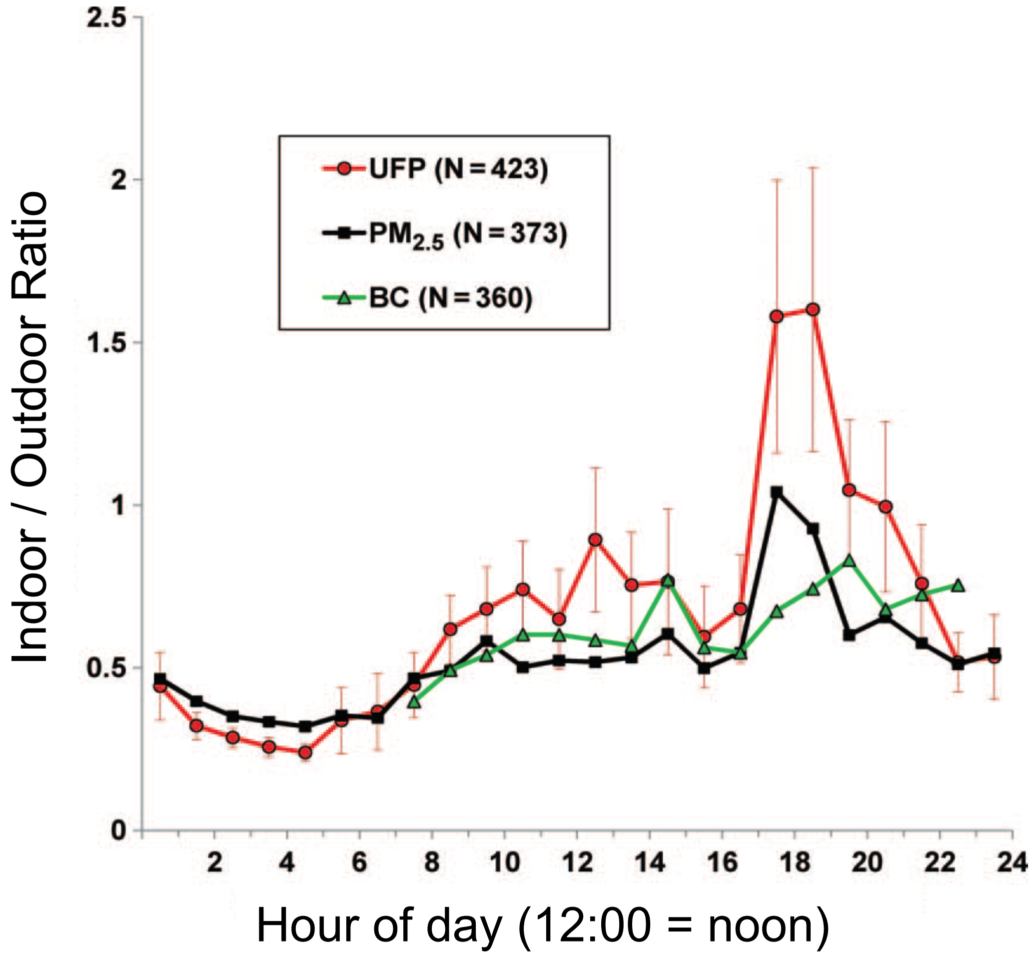
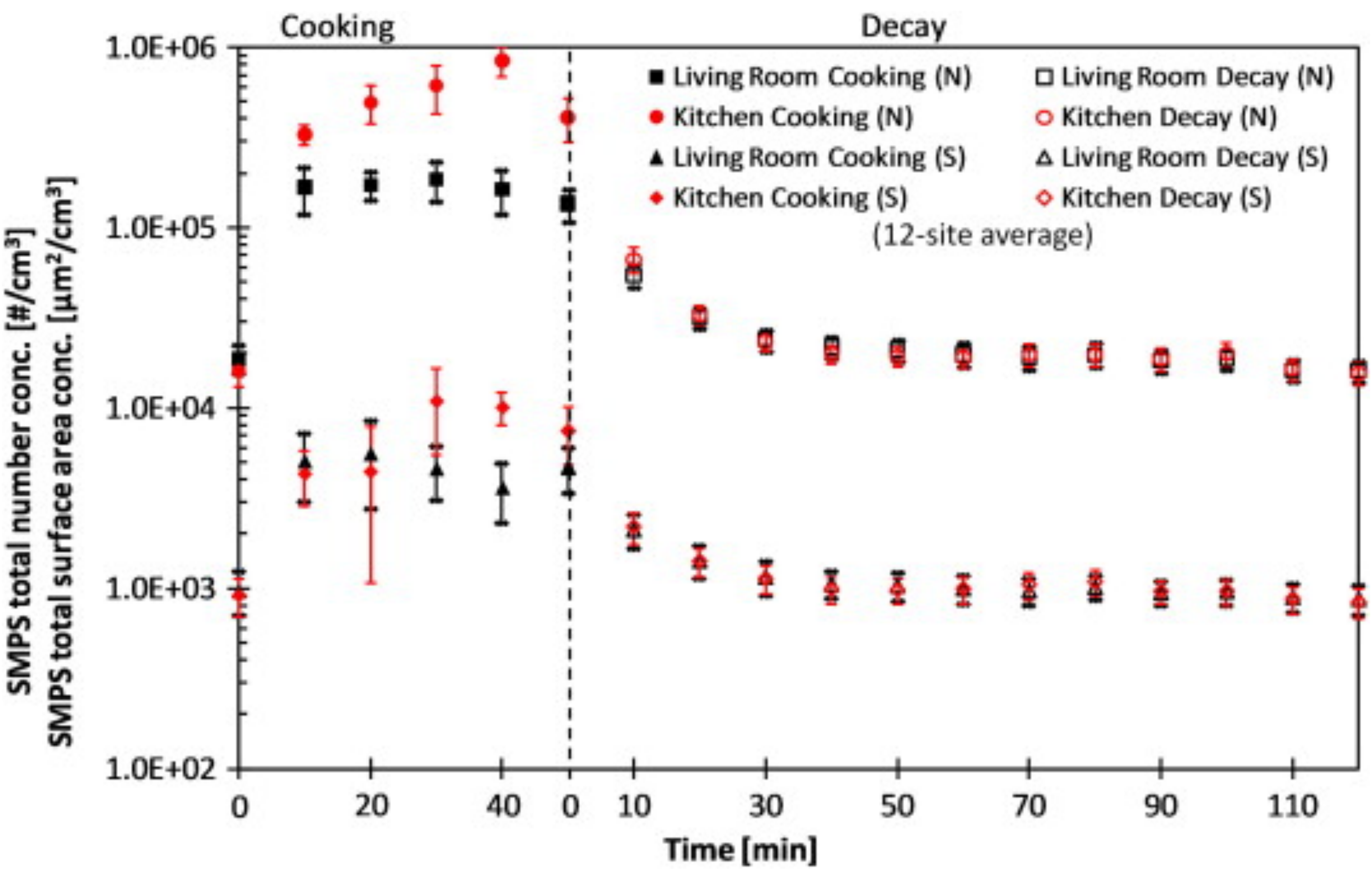


Wheeler et al. 2011; AS&T 45: 1078-1089

12-Sep-2014

Particles from cooking

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



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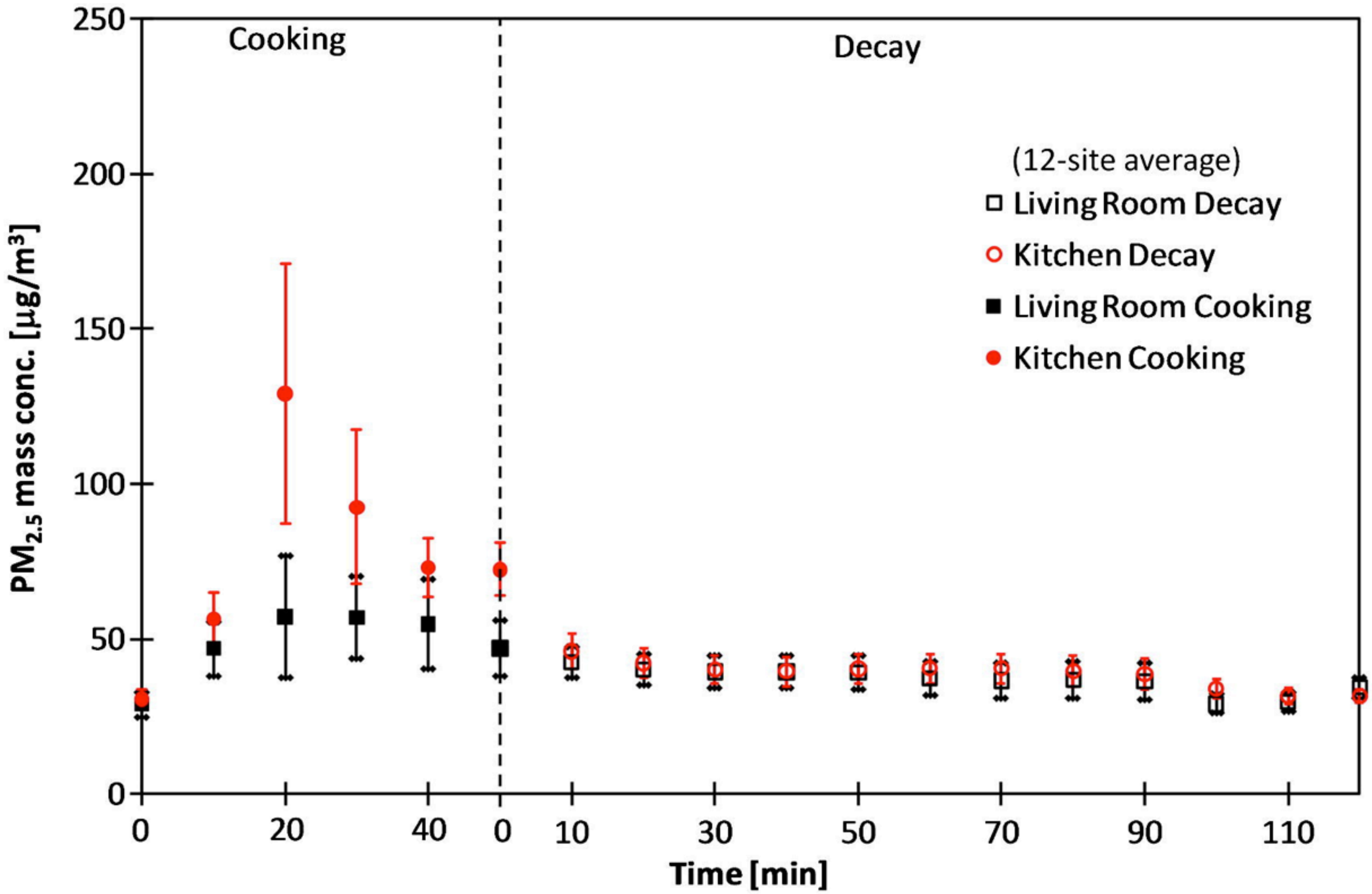
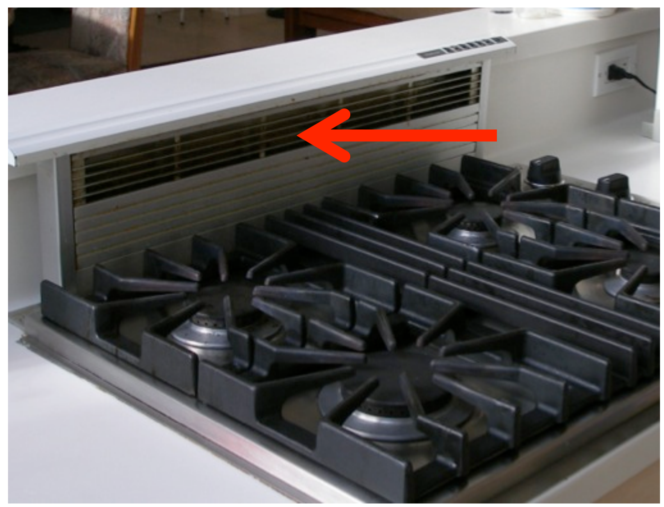


Wan et al. 2011; Atmos Environ 45: 6141-6148

Kitchen ventilation options

Exhaust fan on wall above range

Downdraft exhaust



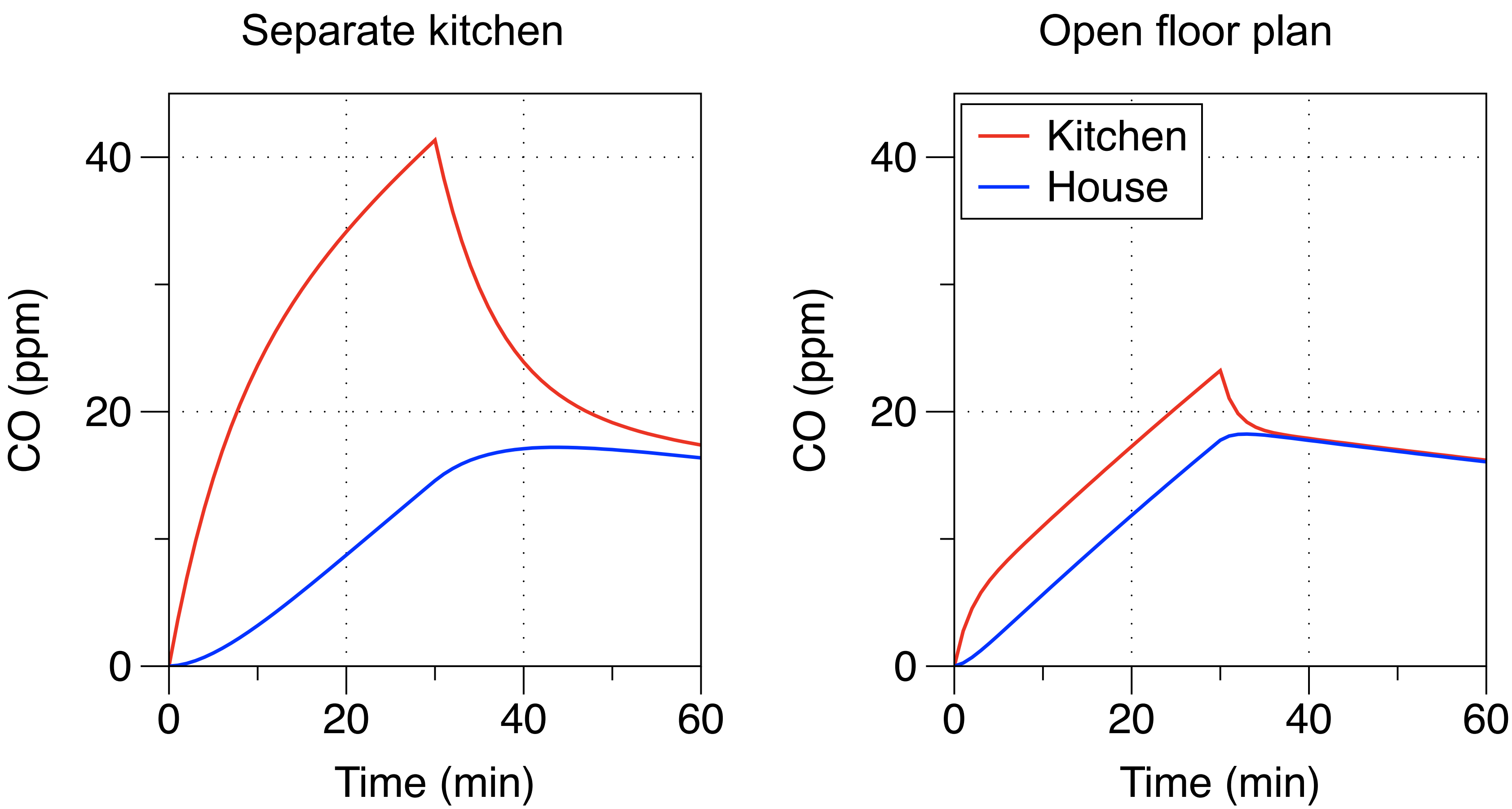
Are range hoods that much better than general kitchen ventilation?

Yes, they are.

Example of cooking without ventilation

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

CO concentration in **kitchen** and throughout the **home**

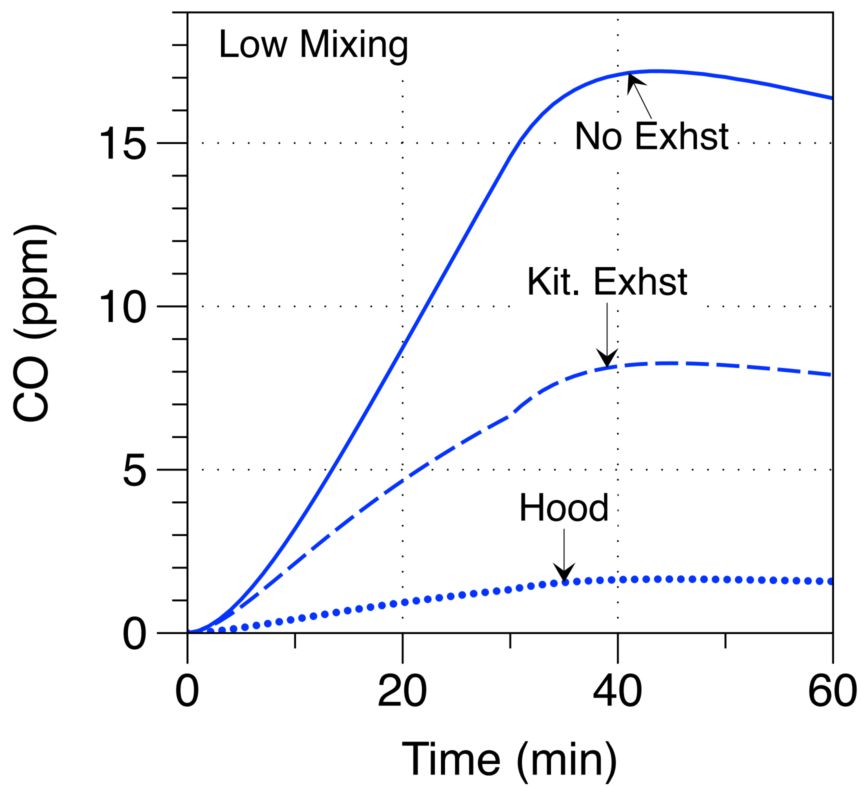


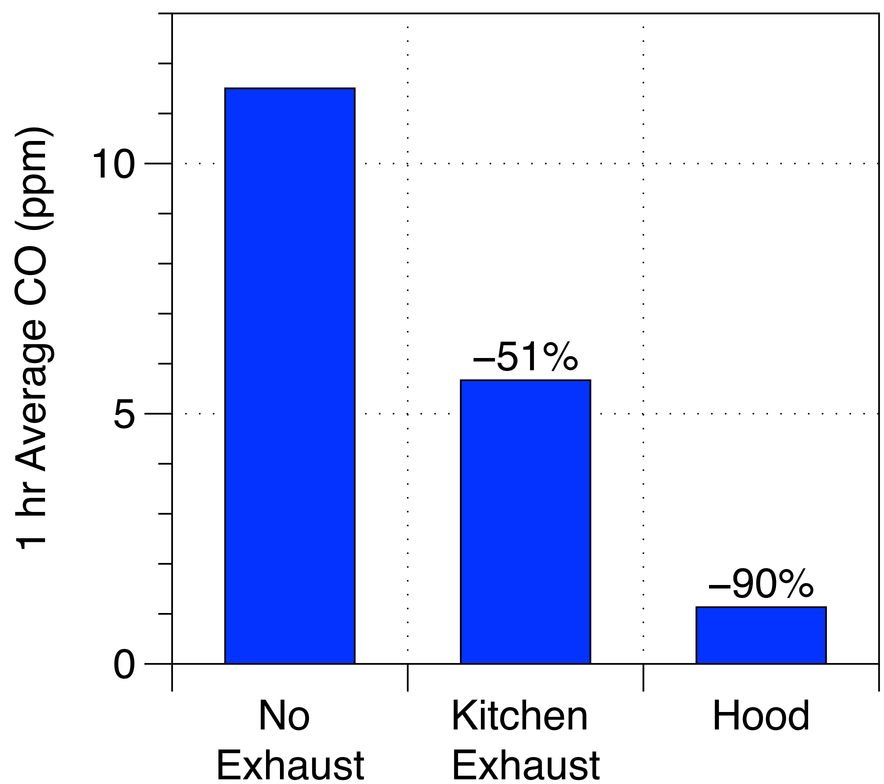
15,000 btu/h
800 ng/J CO

Impact of ventilation: range hoods better!

200 cfm range hood or kitchen exhaust (simulations)

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



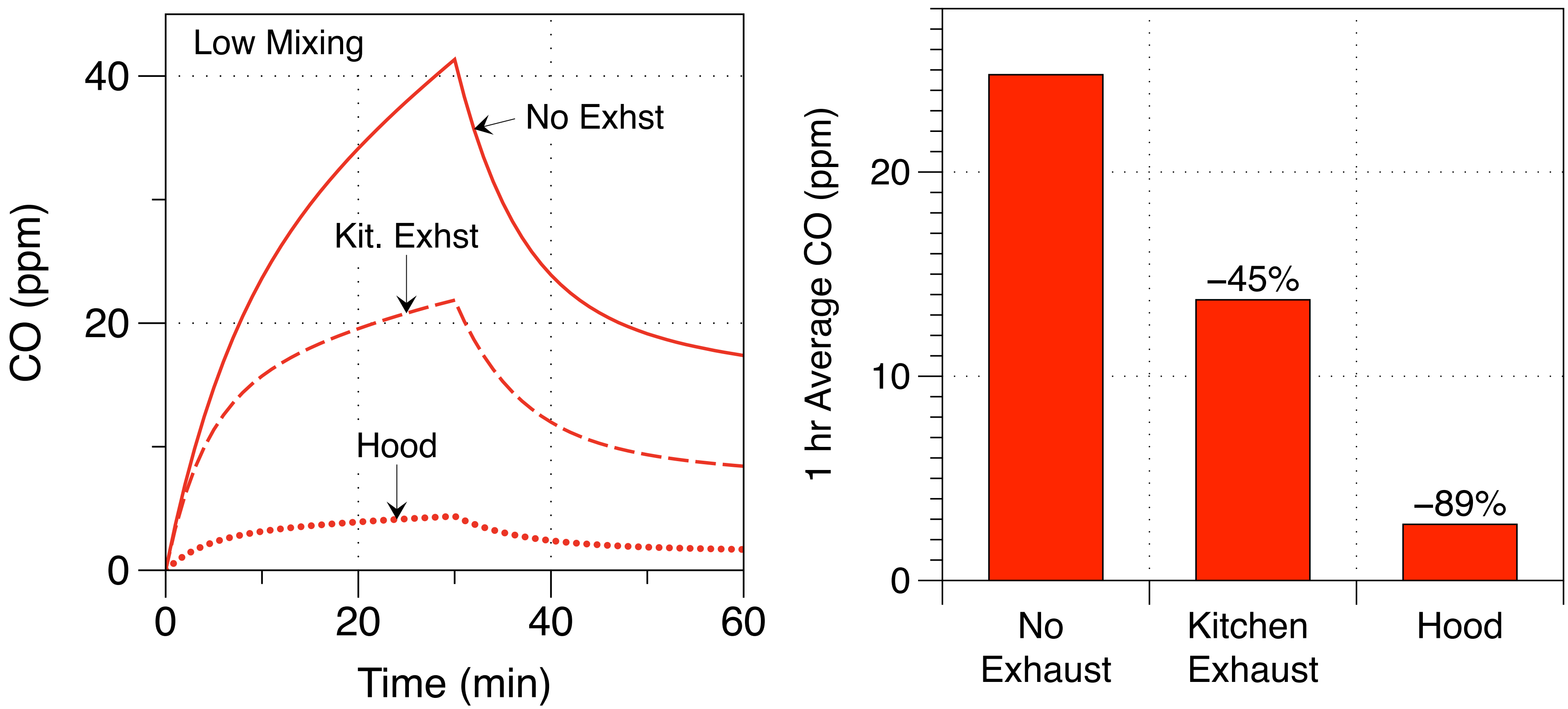


15,000 btu/h
800 ng/J CO

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

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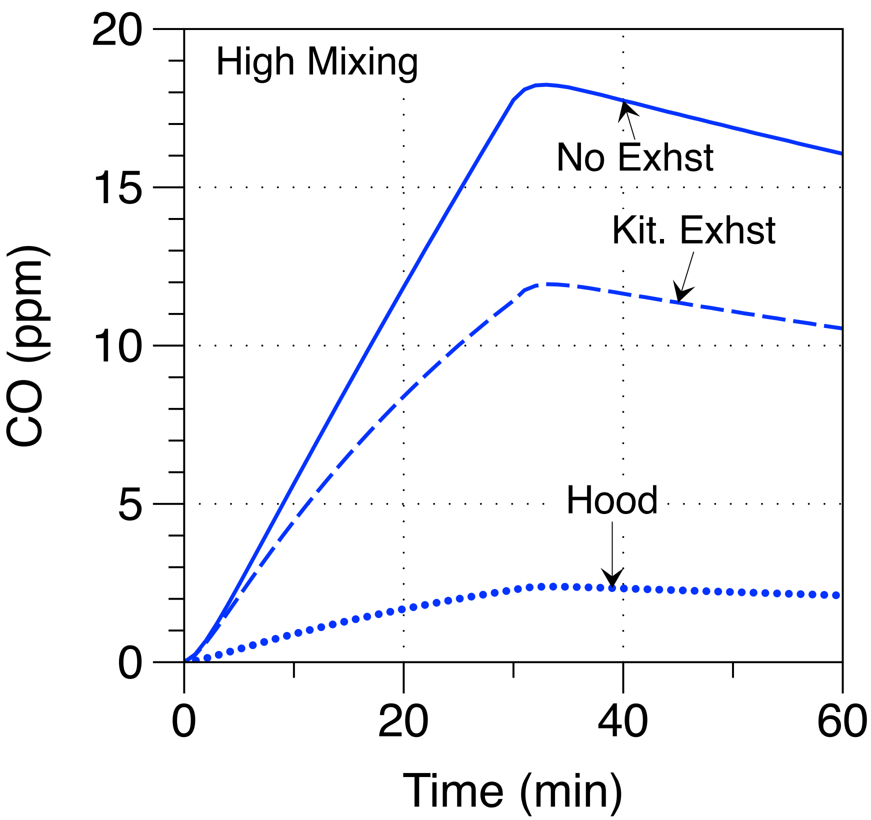
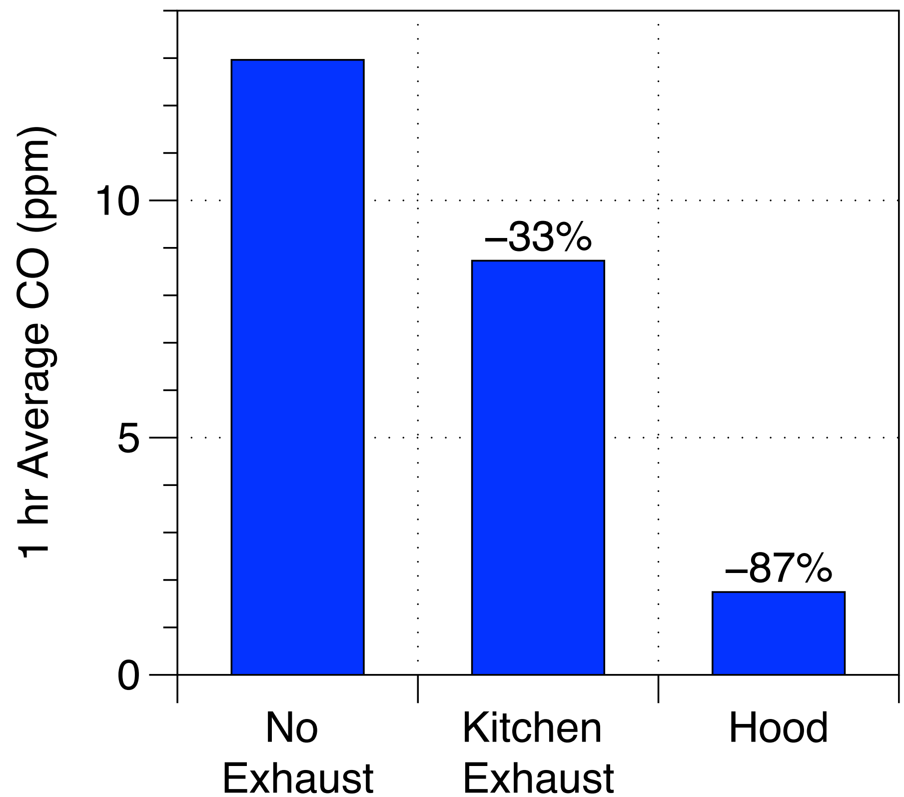
Range hoods better than general kitchen exhaust

Simulations of 200 cfm range hood or kitchen exhaust (80%)

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





15,000 btu/h
800 ng/J CO

12-Sep-2014

Range hood designs

Flat

Small hood

Large hood

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

Standards and Codes

- Range hood: ≥100 cfm at ≤3 sones
- Kit. exhaust: ≥5 kit. ach / 300 cfm at ≤3 sones
- Verify airflows or prescribed ducting with hood rated at 62.5 Pa

HOME VENTILATING INSTITUTE

Guidelines:

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

ENERGY STAR Certified Homes, Version 3

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

International Residential Code

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

How do we know which hoods work?

The effectiveness of range hoods at capturing cooking pollutants is called capture efficiency.

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

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

Currently no commonly used test; but LBNL is leading effort to develop ASTM standard method of test

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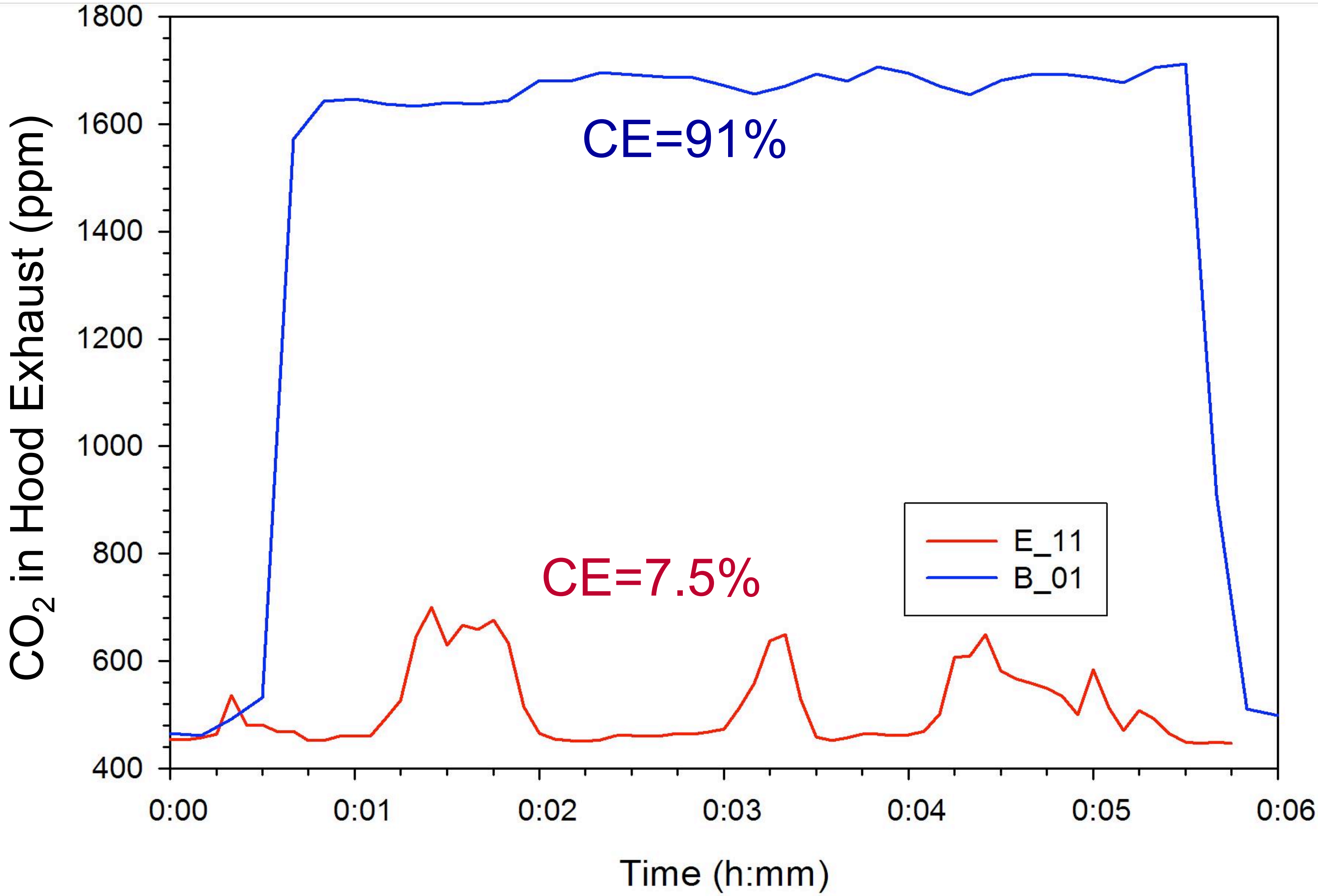
Measure capture efficiency using CO_2



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

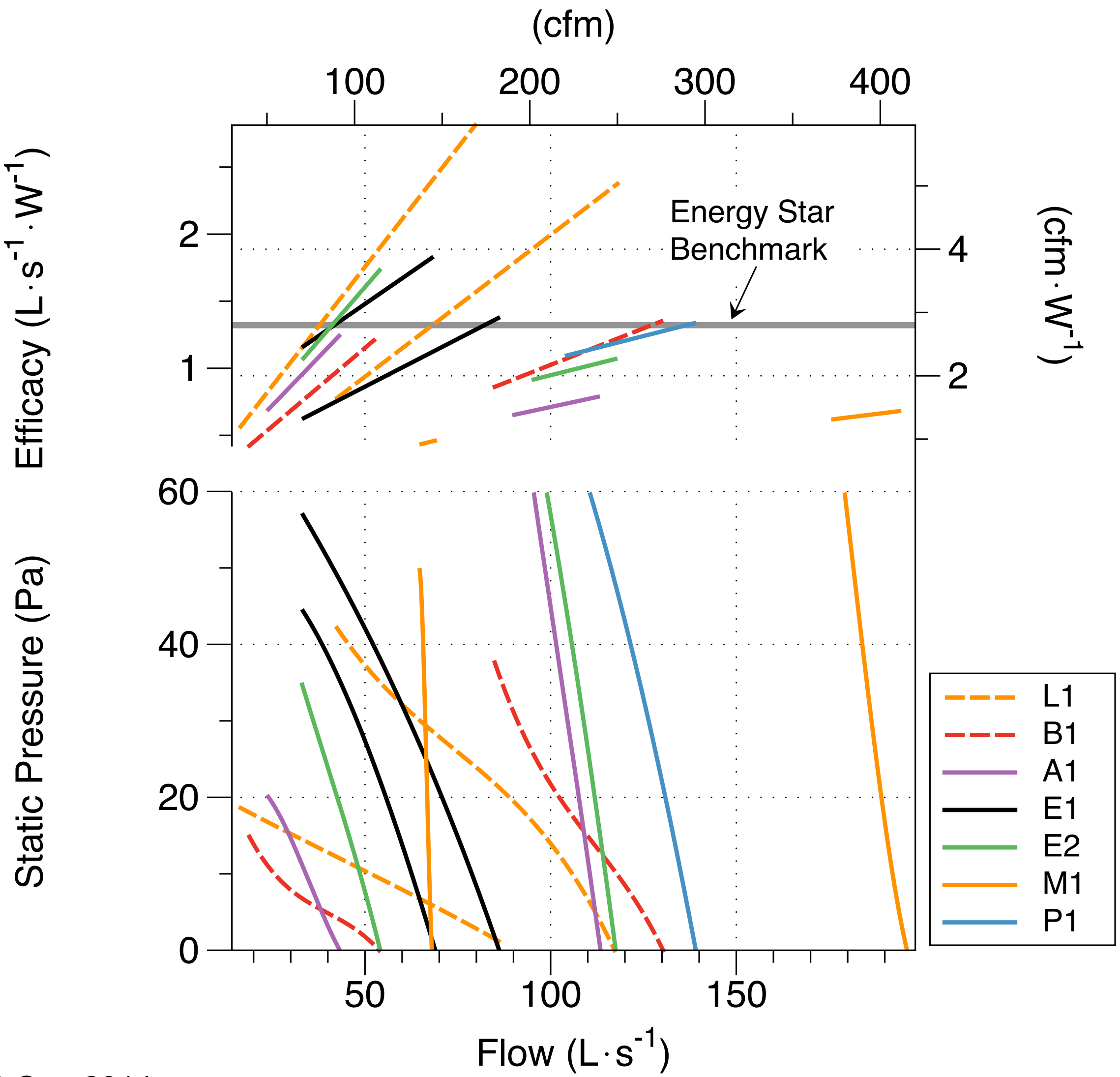
Used, uncertain wear

As installed height and system pressure

Measure airflow and CE at each setting

Sound pressure (dB)

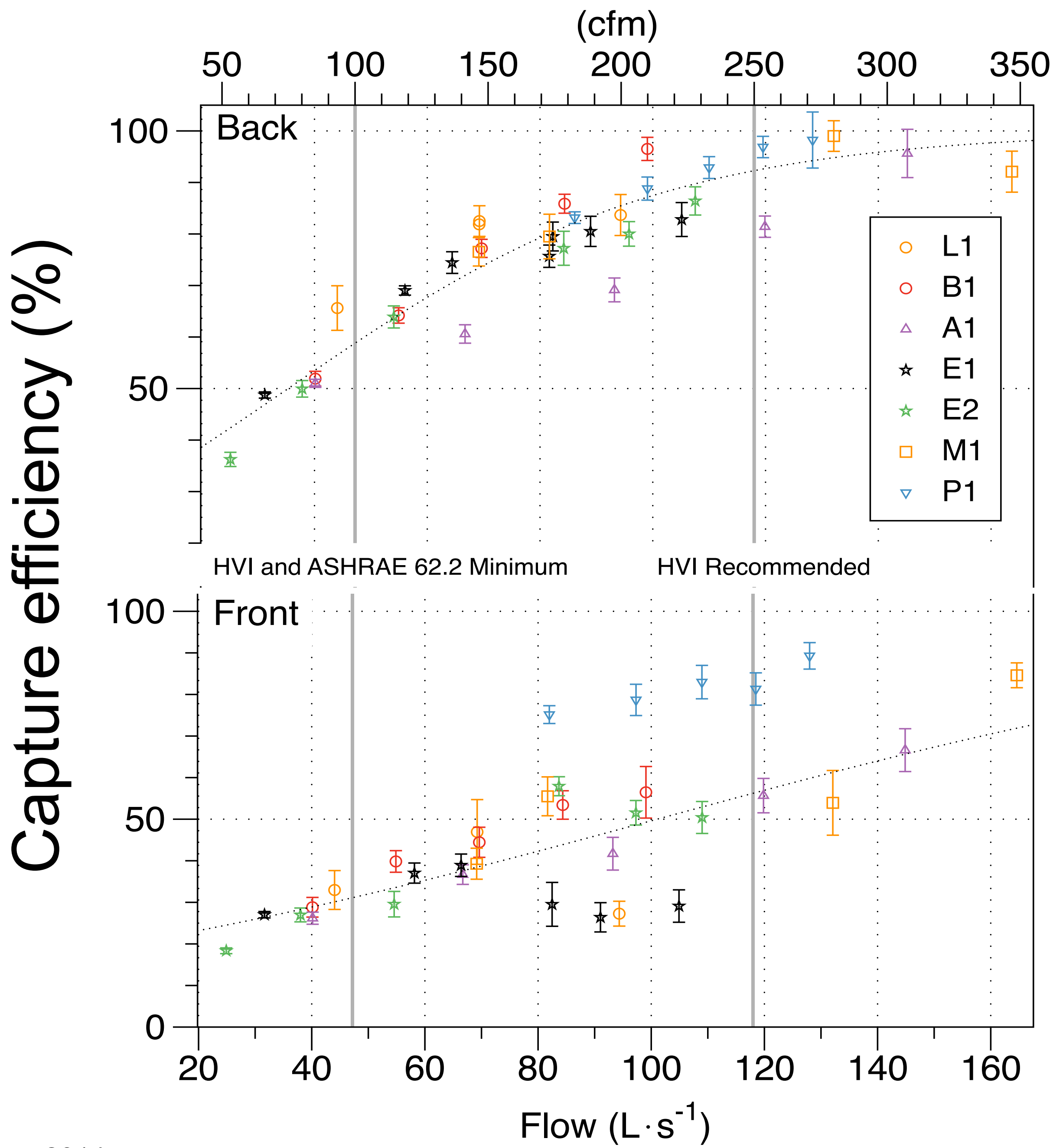
Duct pressure impacts airflow for some hoods more than others



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.

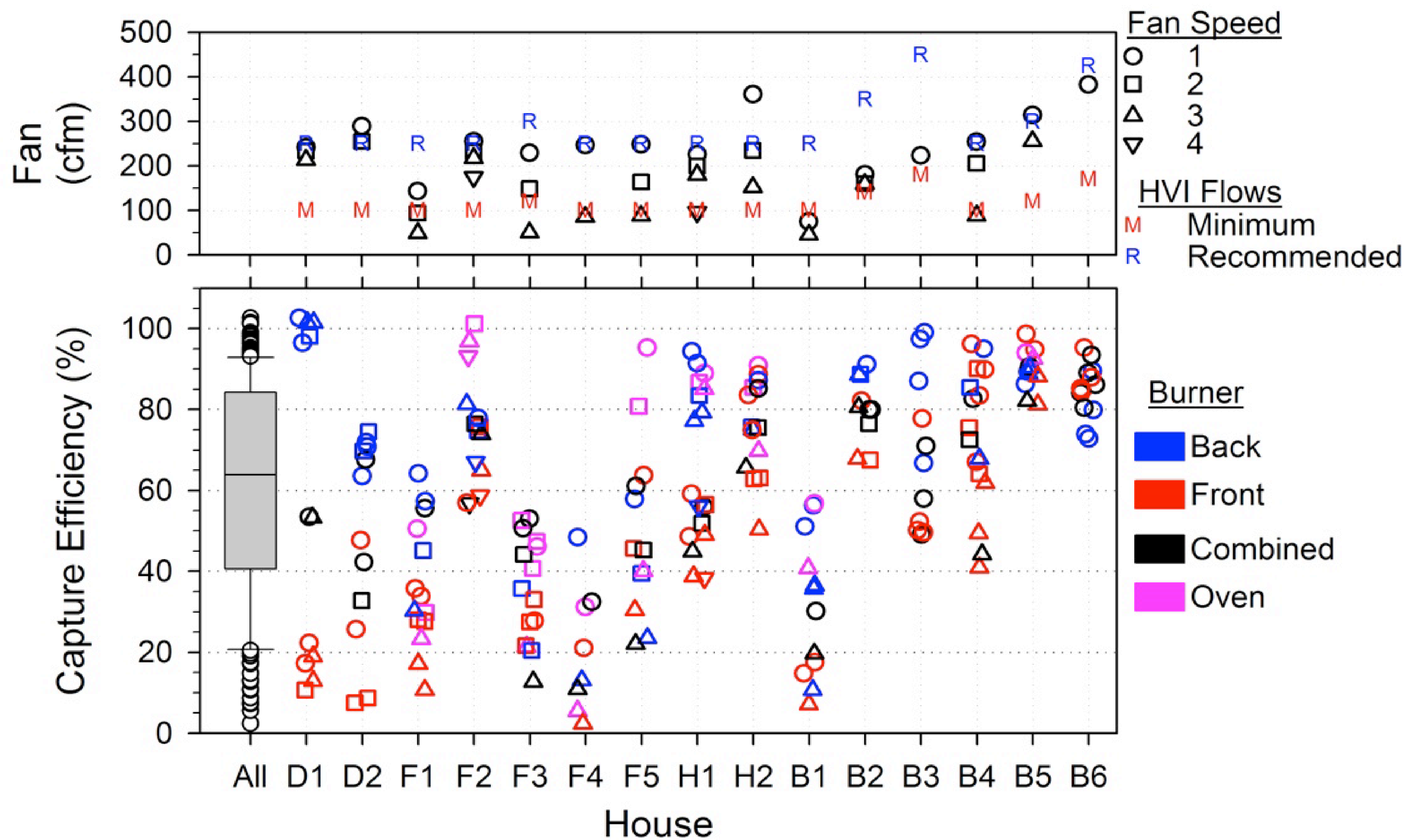
Capture Efficiency Results in Lab



100 cfm
- 60% back
- 30% oven, front

200 cfm
- ~80% back
- 40-80% oven
- 25-80% front

In-Home Performance Varies



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Summary of Installed Performance
(Burner Combustion Products)

200 cfm needed for 80% capture on back burners

Lower and more variable on front burners and ovens

Devices with large capture hoods do better

Many airflows below advertised values

Low pressure drop venting helpful

Advances Targeted for Near Term

Standard test method for capture efficiency

Advance awareness of need to install & use kitchen ventilation

Awareness of high-CE range hoods as best practice

Incorporate minimum CE into ventilation standards

CE performance info available to purchasers

OTR microwave that that meets standard specs

Firm requirement for kitchen ventilation in IRC

Longer Term Goals

Automatic hoods that do not require user initiation

Standards include comprehensive performance

- Low-airflow and power for energy efficiency
- High capture efficiency & quiet
- Automatic operation

Codes incorporate minimum CE performance

Issues for Passive House

Air leakage and heat transfer associated with venting

Make-up air needed at airflows <<400 cfm

- In tight, small homes even 100 cfm could necessitate MUA
- For standard home, energy for RH use not such a big deal
- Energy cost for thermal conditioning > fan energy

Can reduce energy costs with integrated smart ventilation

Secondary capture may be much better when all airflow going out through kitchen exhaust ventilation

Selected References

Delp WW and Singer BC. 2012. Performance assessment of U.S. residential cooking exhaust hoods. *Environmental Science & Technology* 46(11): 6167-6173. LBNL-5545E.

Less BD, Singer BC, Walker IS, Mullen NA. Indoor air quality in 24 California residences designed as high performance green homes. *HVAC&R. Accepted 03-Sep-2014.*

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Logue JM, Klepeis NE, Lobscheid AB, Singer BC. 2014. Pollutant exposures from unvented gas cooking burners: A simulation-based assessment for Southern California. 2014. *Environmental Health Perspectives*. 122(1): 43-50. LBNL-6712E.

Lunden MM, Delp WW, Singer BC. 2014. Capture efficiency of cooking-related fine and ultrafine particles by residential exhaust hoods. *Indoor Air. Published online 24-May-2014.* LBNL-6664E.

Mullen NA, Li J, Russell ML, Hotchi T, Singer BC. Measured pollutant concentrations and analysis of associations with gas appliances in the California Healthy Homes Indoor Air Quality Study of 2011-13. *In preparation.*

Noris F, Adamkiewicz G, Delp WW, Hotchi T, Russell ML, Singer BC, Spears M, Vermeer K, Fisk WJ. 2013. Indoor environmental quality benefits of apartment retrofits. *Building and Environment,* 68:170-178. LBNL-6373E.

Singer BC, Delp WW, Apte MG, Price PN. 2012. Performance of installed cooking exhaust devices. *Indoor Air* 22: 224-234. LBNL-5265E.

Extra Slides Follow

Other Issues

- 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.

Installed equipment and usage data

Web-based survey of cooking patterns, range hood presence & use

Klug LBNL-5028E; n=372

Visual identification of range hood types from real estate listings Klug LBNL-5067E; n=1002 homes

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

n=73 survey respondents

Kitchen exhaust use in Cal. IAQ study:

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

Mullen et al. LBNL-5970E

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Kitchen exhaust use in Cal. IAQ study:

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%

Mullen et al. LBNL-5970E

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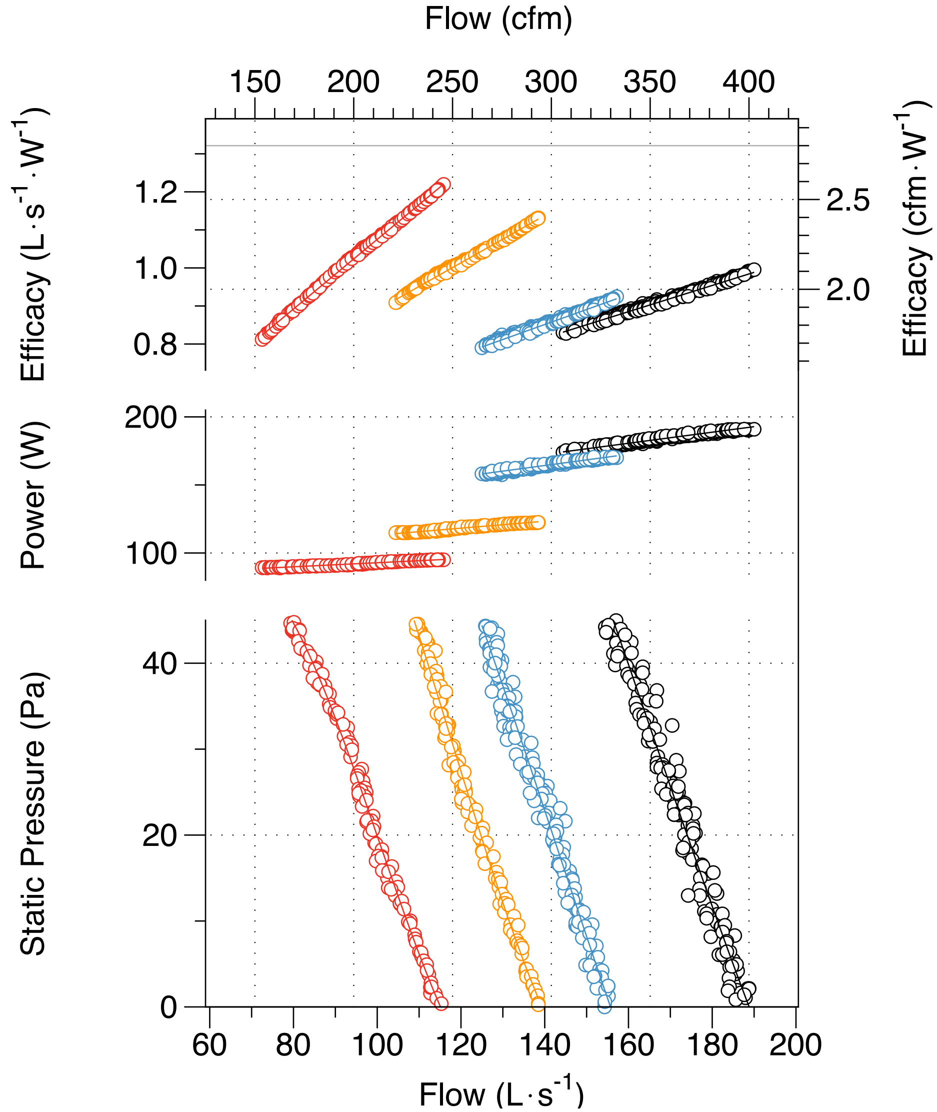
Some advertised flows exaggerated!

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)

Capture of Cooking Particles

Experiments comparing CE of CO_2 and cooking particles

Precise cooking protocols:

- Pan-fry burner on medium heat, back burner
- Stir-fry green beans on high heat, front burner

Reference:

Lunden MM, Delp WW, Singer BC. 2014. Capture efficiency of cooking-related fine and ultrafine particles by residential exhaust hoods. *Indoor Air. Published online 24-May-2014.* LBNL-6664E.

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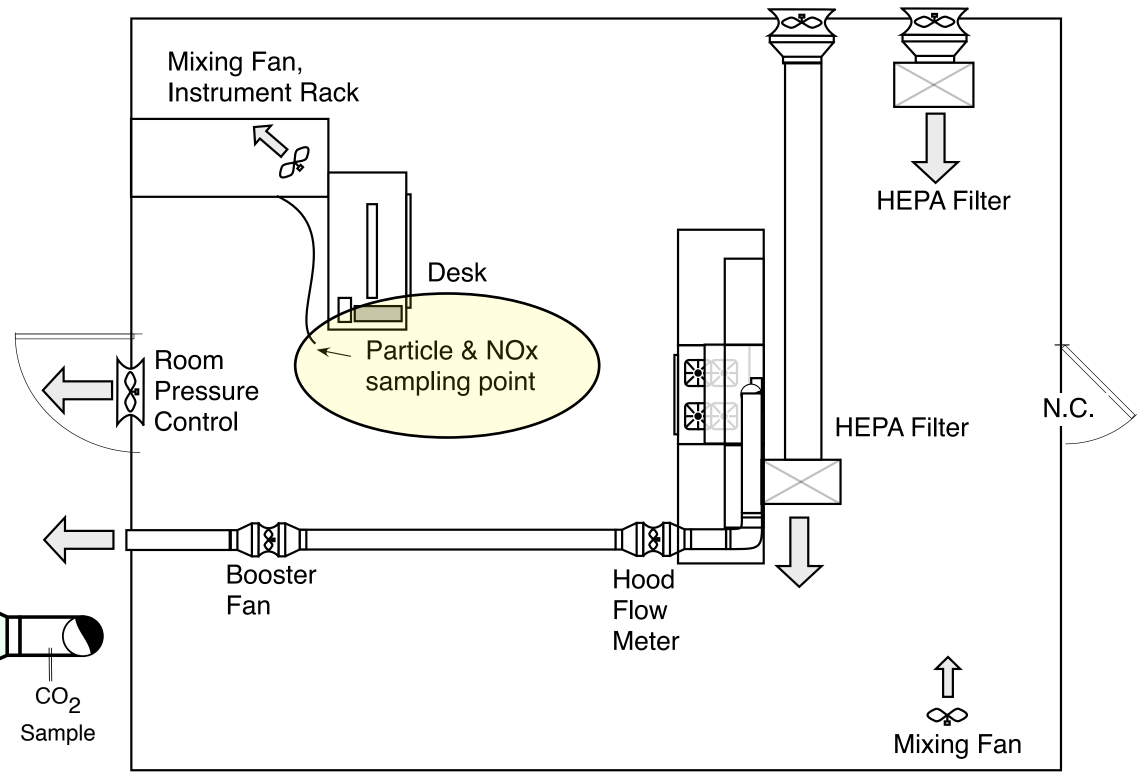
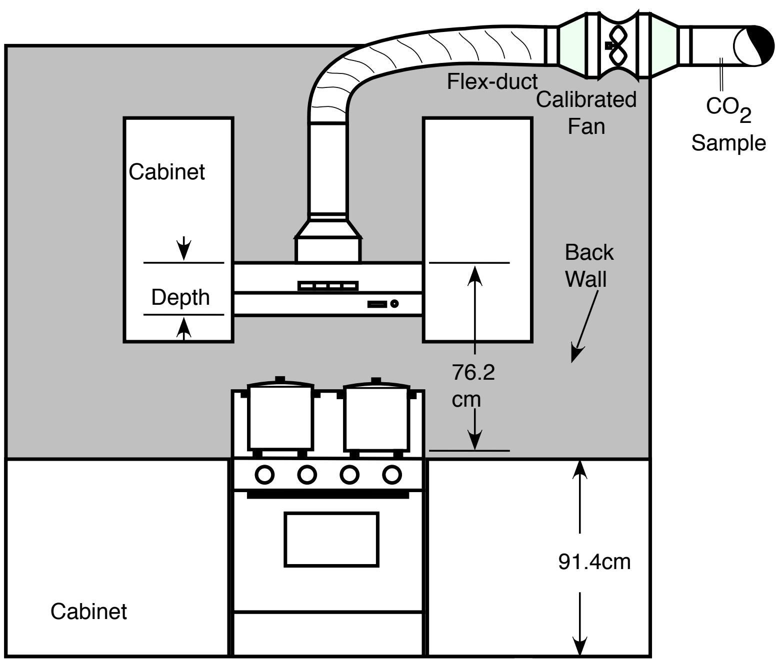
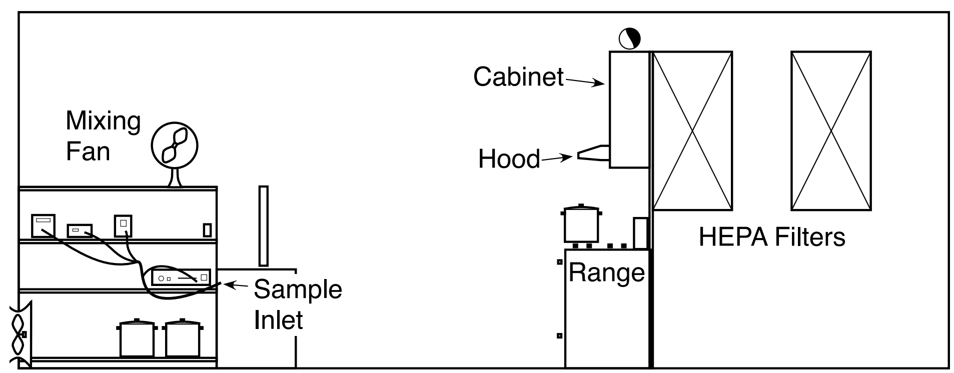
Facility for particle capture experiments







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LBNL Kitchen and Range Hood Lab

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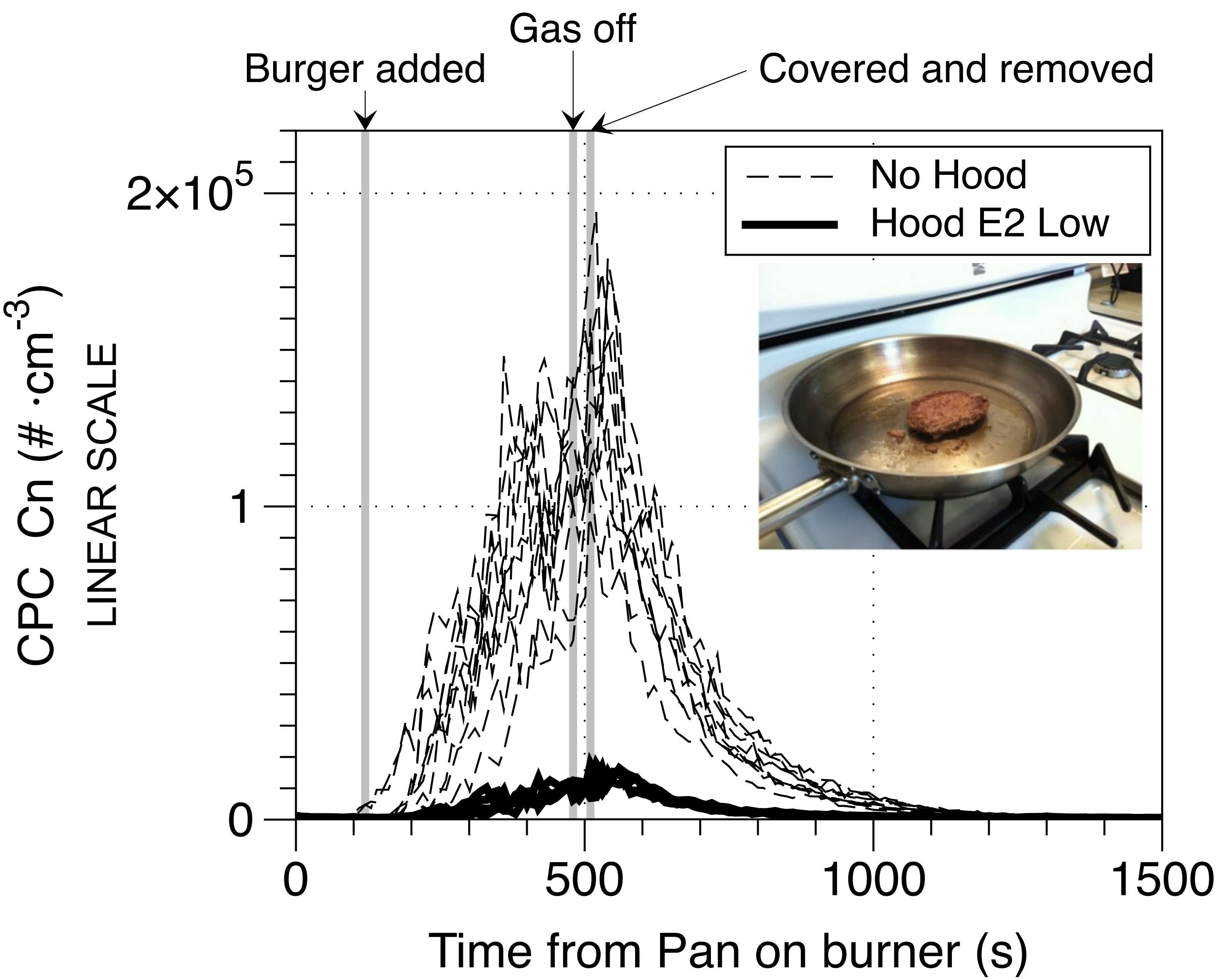
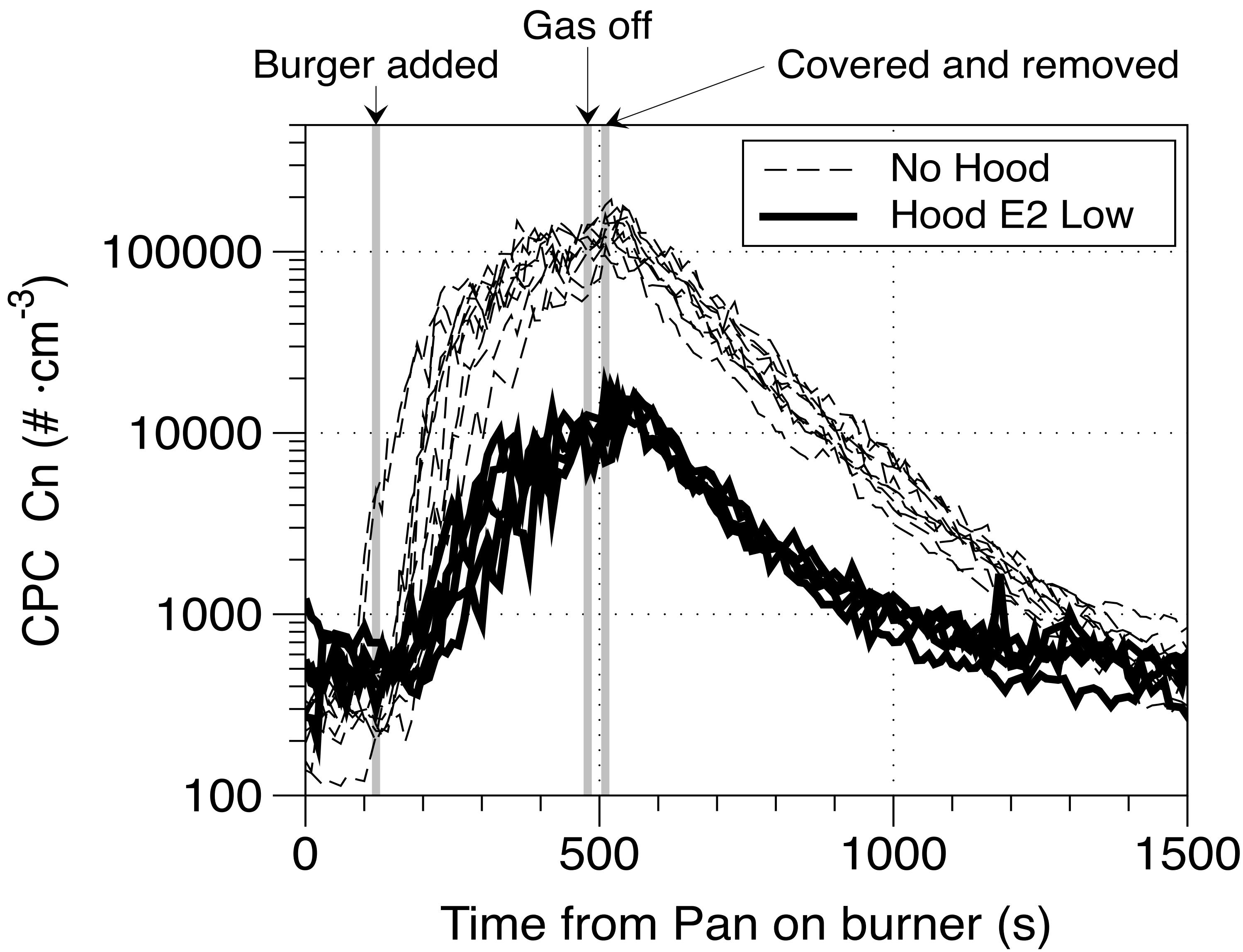
Conducted many replicates to overcome variability in emissions & room concentrations



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



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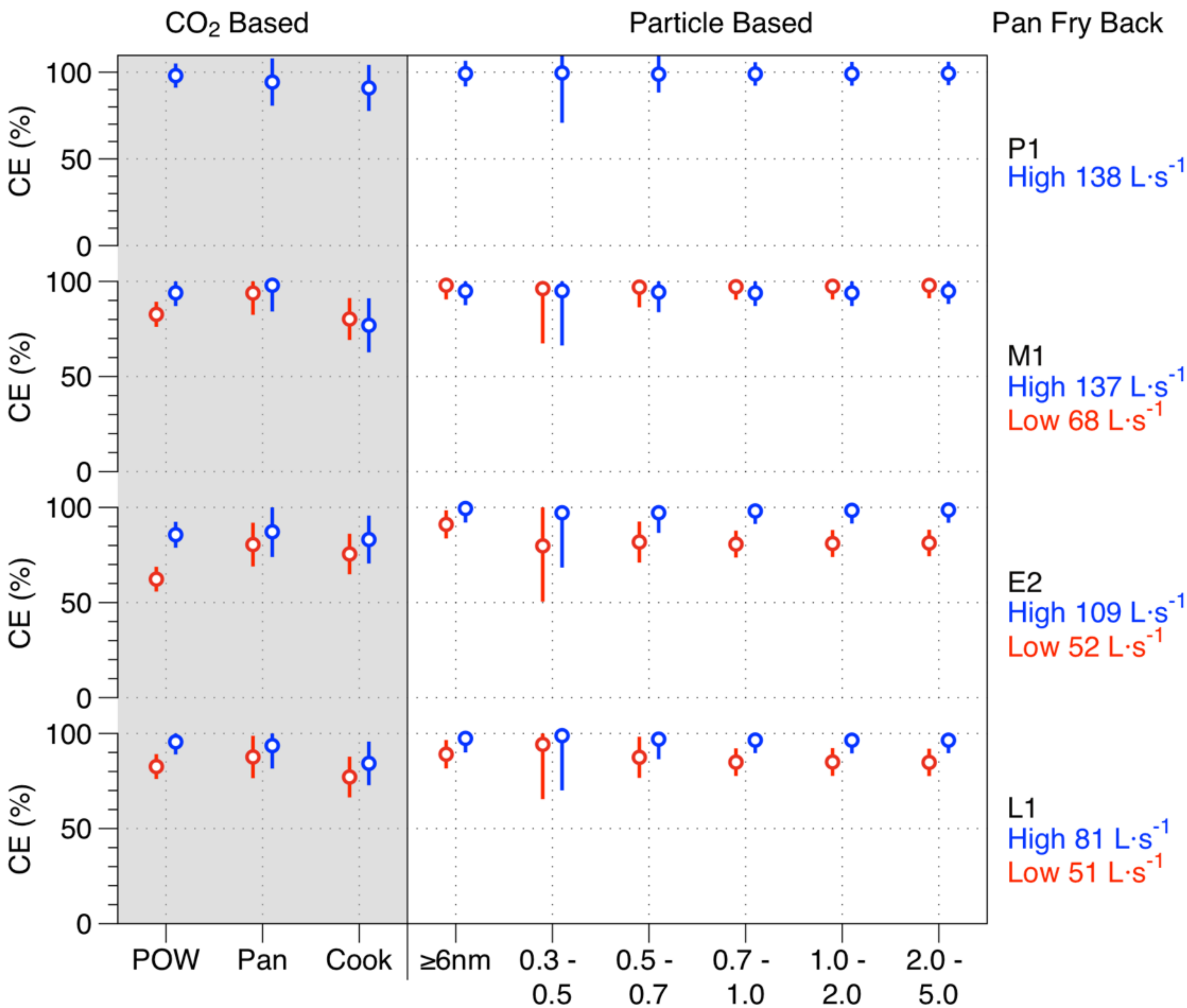
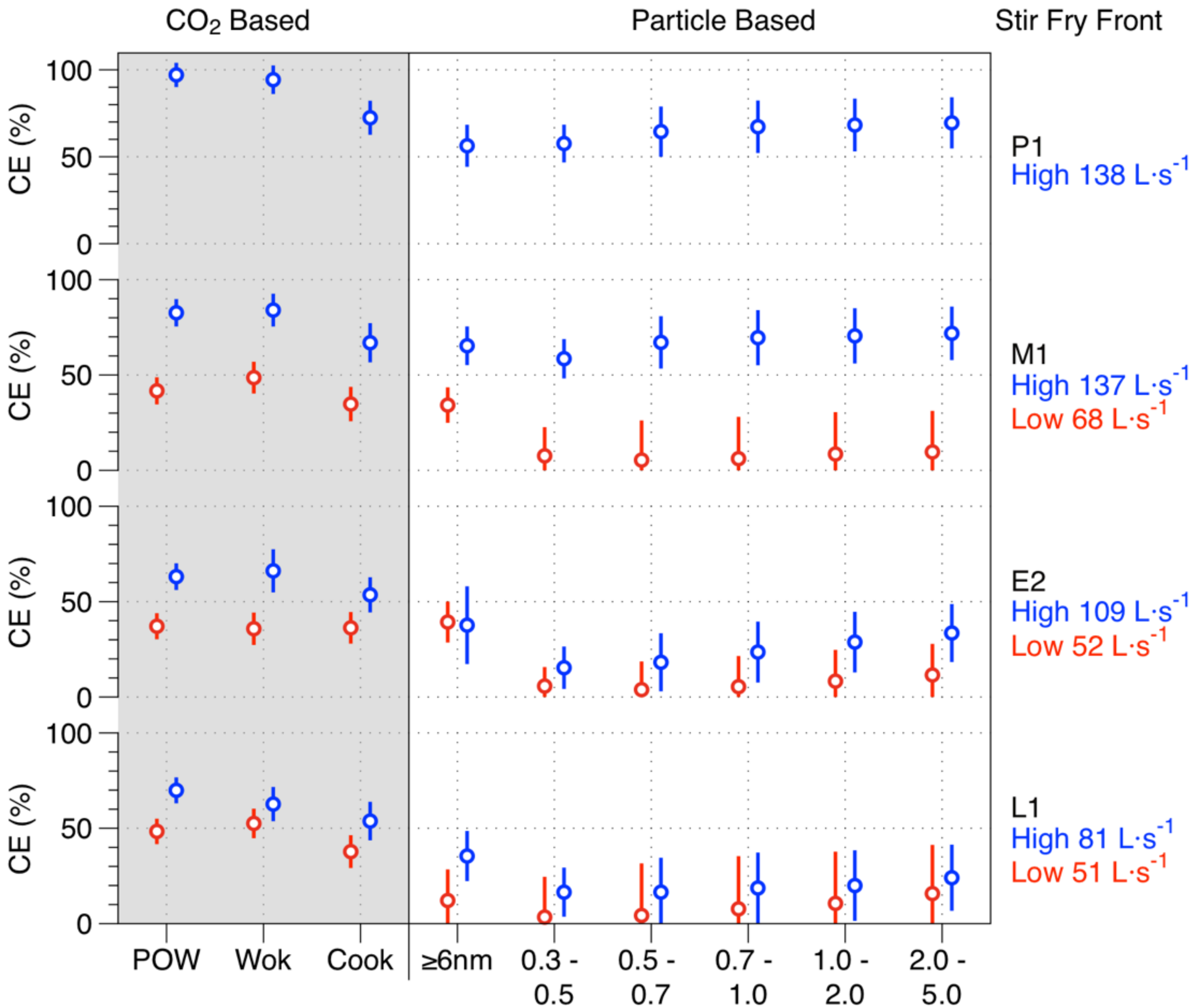
Cooking Particle vs. CO_2 Capture Efficiency



Cooking Particle vs. CO_2 Capture Efficiency



Cooking Particle vs. CO_2 Capture Efficiency