Sources and Controls for NO_2 in Residences

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Berkeley Lab research presented here was supported by the following institutions:

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Thanks to my colleagues and collaborators!










Top row: Rengie Chan, Haoran Zhao, Dave Lorenzetti, Yang Seon Kim, Jennifer Logue, Max Sherman
Bottom row: Iain Walker, Brennan Less, Woody Delp, Randy Maddalena, Melissa Lunden, Liu Sun (Health Canada)

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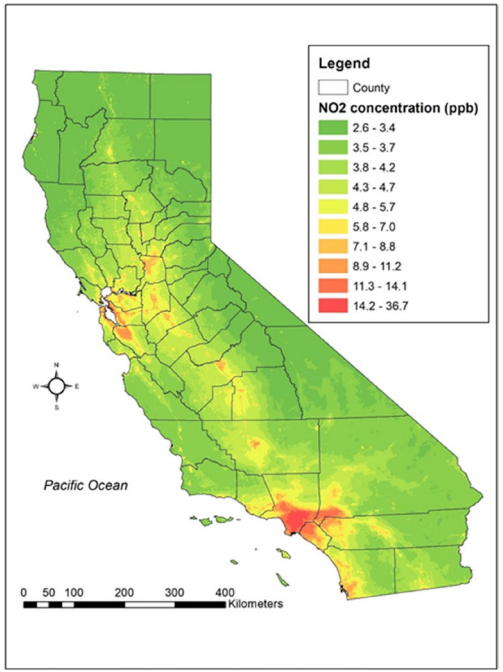
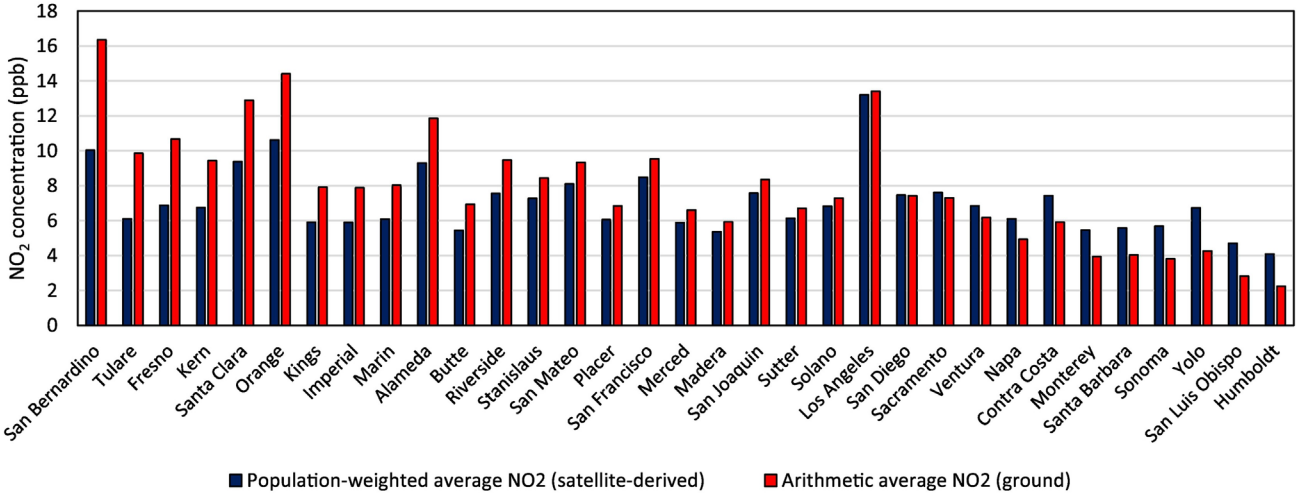
Key Points

- The main sources of NO_2 in California non-smoking homes are outdoor air and gas cooking burners.
- Other gas appliances are vented to release their combustion products directly to outdoors.
- “Vent-free” gas heaters and hearth products are not legal for sale in California.
- Using gas burners to cook a single meal without also using a venting range hood can result in NO_2 concentrations above health-based thresholds for 1-h exposures; and cooking multiple meals in a day can result in NO_2 above the Canadian residential IAQ guideline level of 10.5 ppb.
- The likelihood of exceeding a threshold increases with amount of cooking and in smaller homes.
- Effective use of a venting range hood greatly reduces the likelihood of exceeding 1h or 24h health-based NO_2 guideline levels even when gas burners are used to cook multiple meals in a day.

NO_2 in Outdoor Air

Ambient NO_2 is spatially heterogeneous





Lee et al. Neighborhood-scale ambient NO_2 concentrations using TROPOMI NO_2 data: Applications for spatially comprehensive exposure assessment. Science of the Total Environment Volume 857, Part 3, 20 January 2023, 159342

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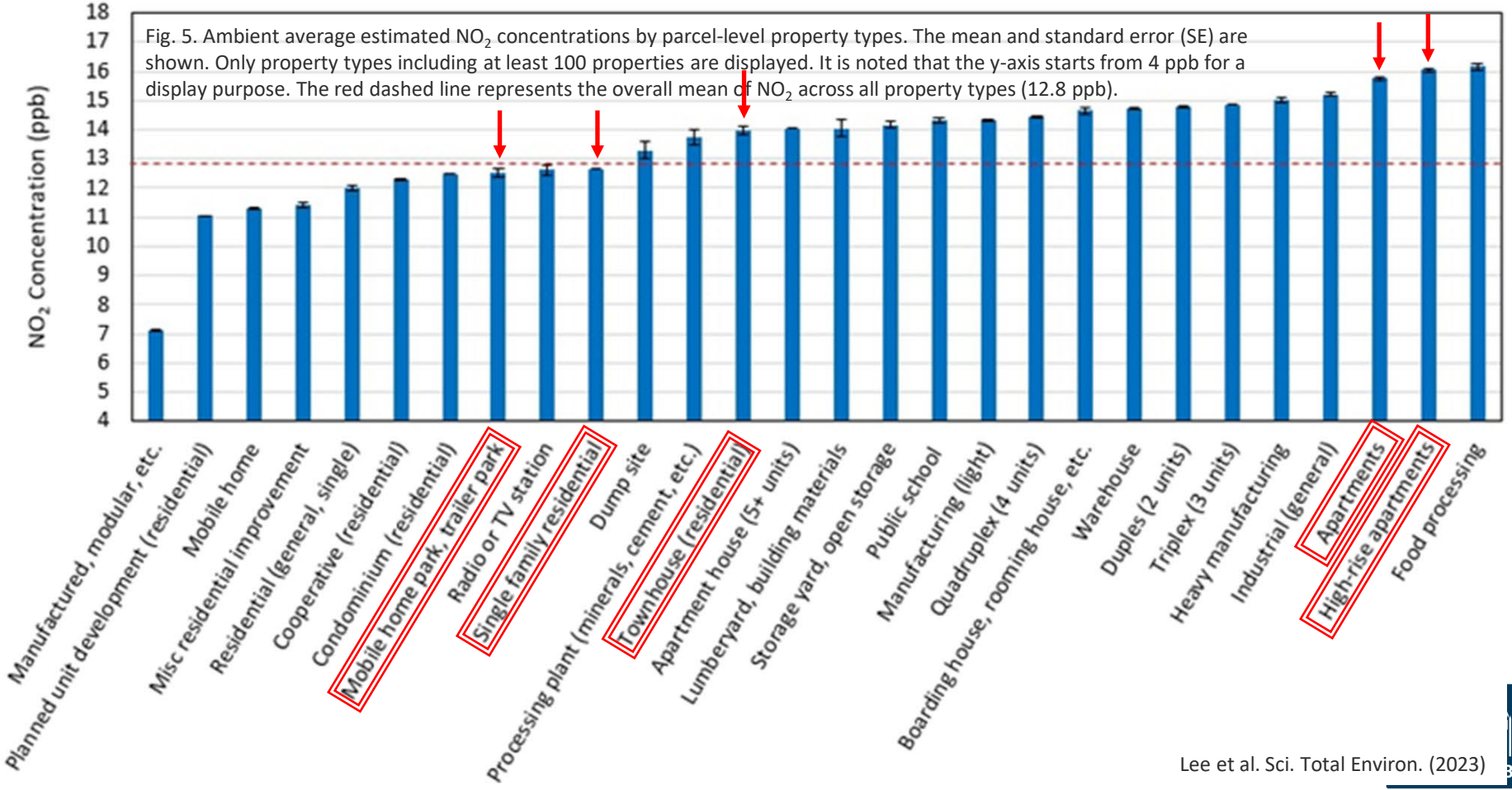
NO_2 highest outside of apartments



Lee et al. Sci. Total Environ. (2023)

NO_2 Emissions from Burners

Air pollutants are emitted from burners *and* cooking

CO_2 & H_2O

NO, NO_2, HONO, Formaldehyde

Ultrafine particles

Sometimes CO

$PM_{2.5}$, Ultrafine particles

Formaldehyde, Acrolein, PAH, etc.

Ultrafine particles

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NO_2 from gas cooking has been known for many years

Nitrogen Dioxide Inside and Outside 137 Homes and Implications for Ambient Air Quality Standards and Health Effects Research

John D. Spengler*

Department of Environmental Health Sciences, Harvard School of Public Health, Boston, Massachusetts 02115

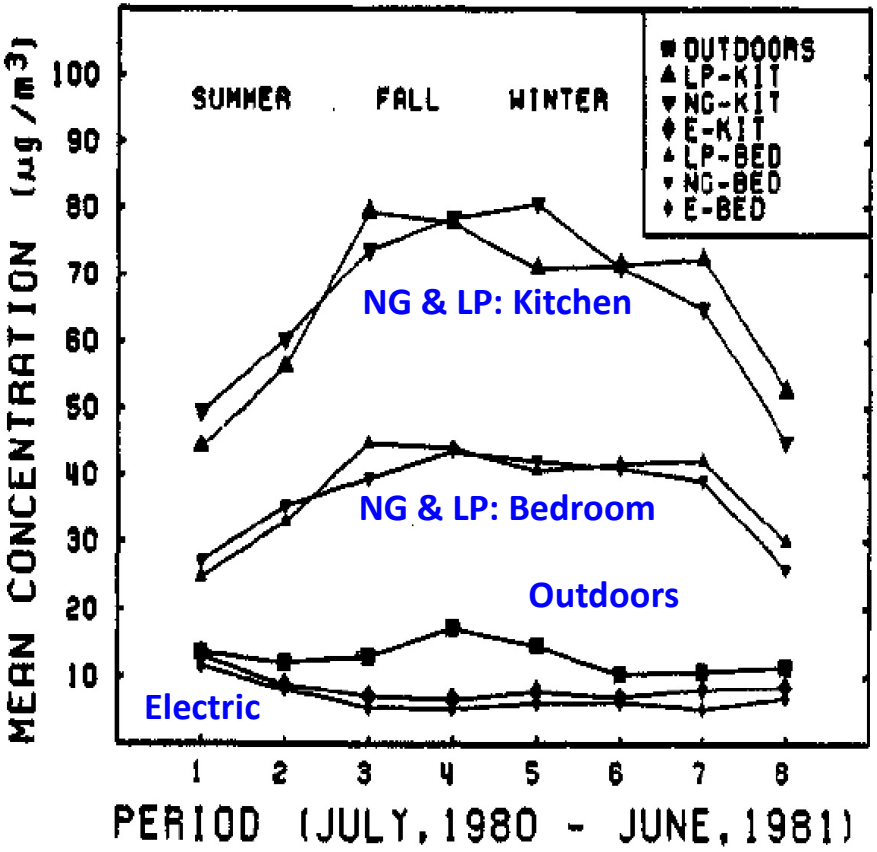
1983

Spengler reported 1-wk average NO_2 in 137 homes in Portage WI in 1980-1981

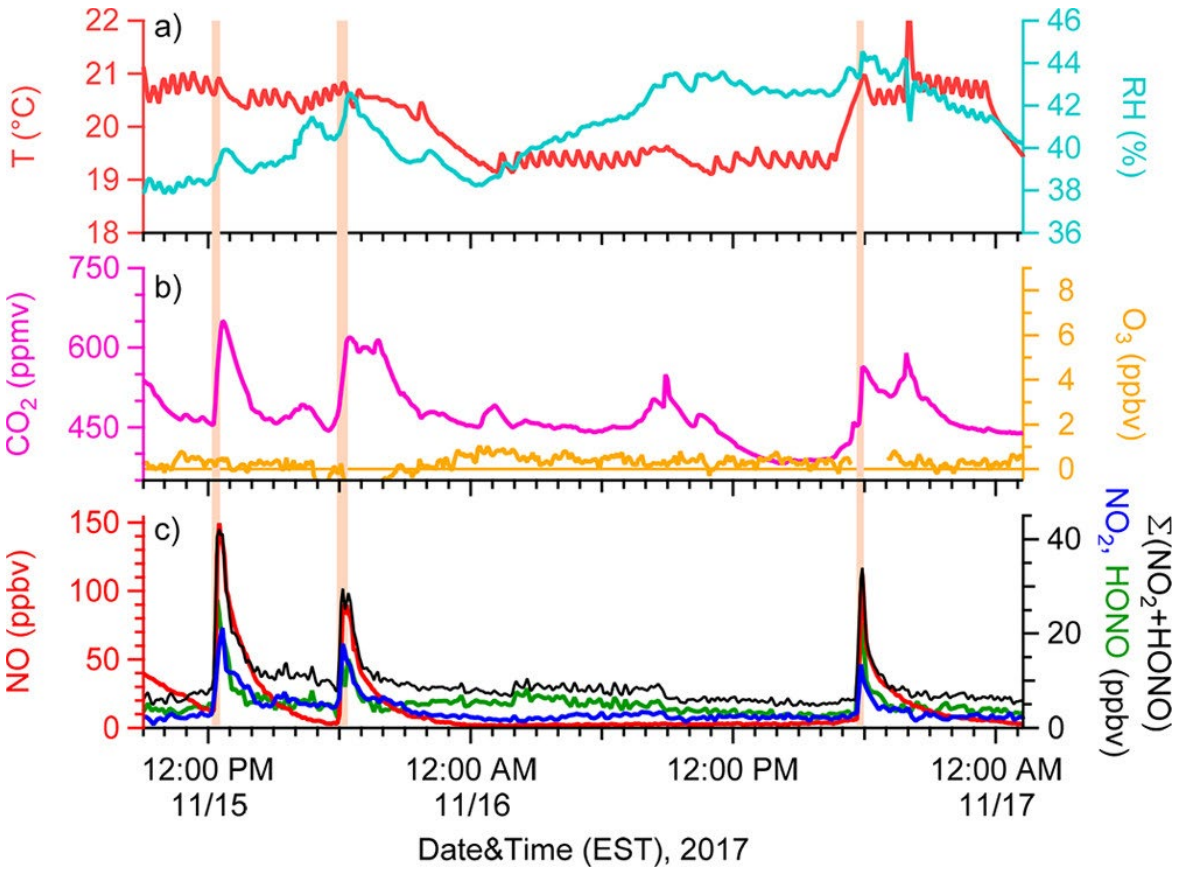
Gas homes in fall/winter

- **Kitchens ~40 ppb**
- **Bedrooms ~21 ppb**
- **Outdoors ~7 ppb**

Homes with electric burners had lower NO_2 than outdoors!



Gas cooking creates the highest acute exposures and contributes to chronic exposures



Zhou et al. "Time-Resolved Measurements of Nitric Oxide, Nitrogen Dioxide, and Nitrous Acid in an Occupied New York Home." *ES&T*, 52, 15, 8355–64, https://doi.org/10.1021/acs.est.8b01792.

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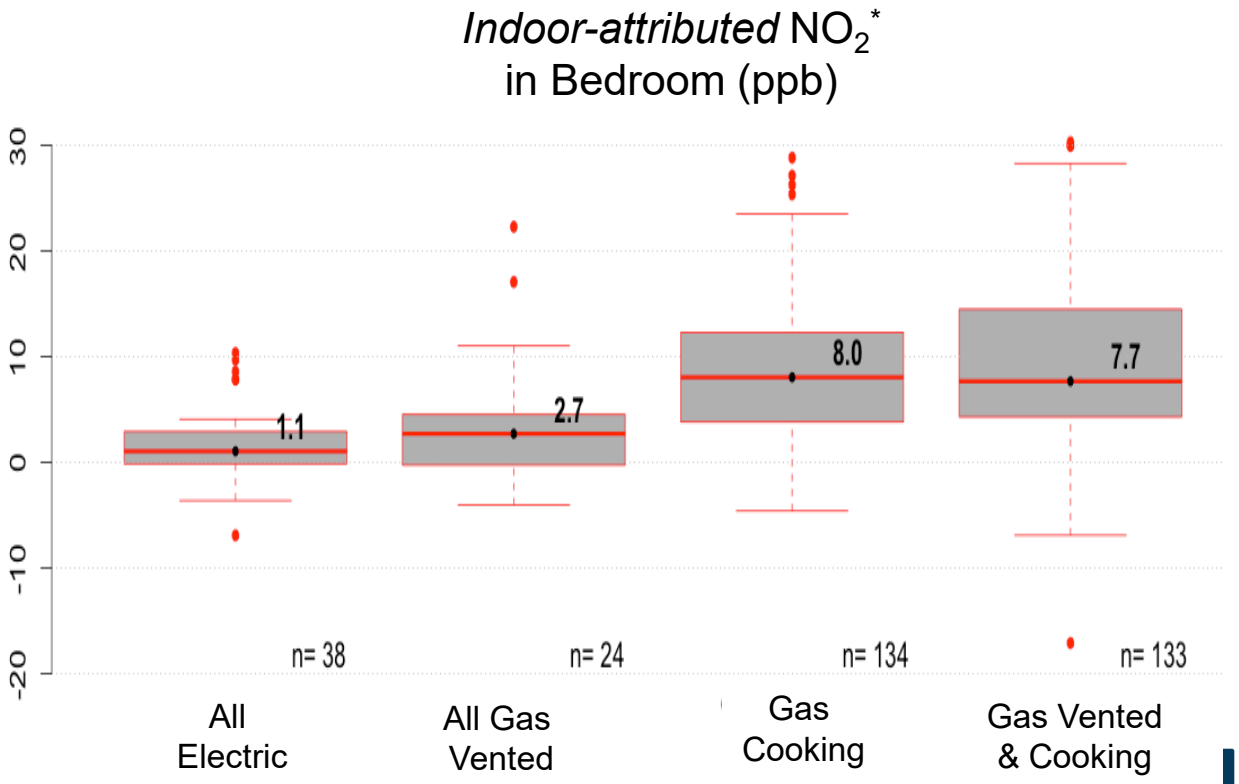
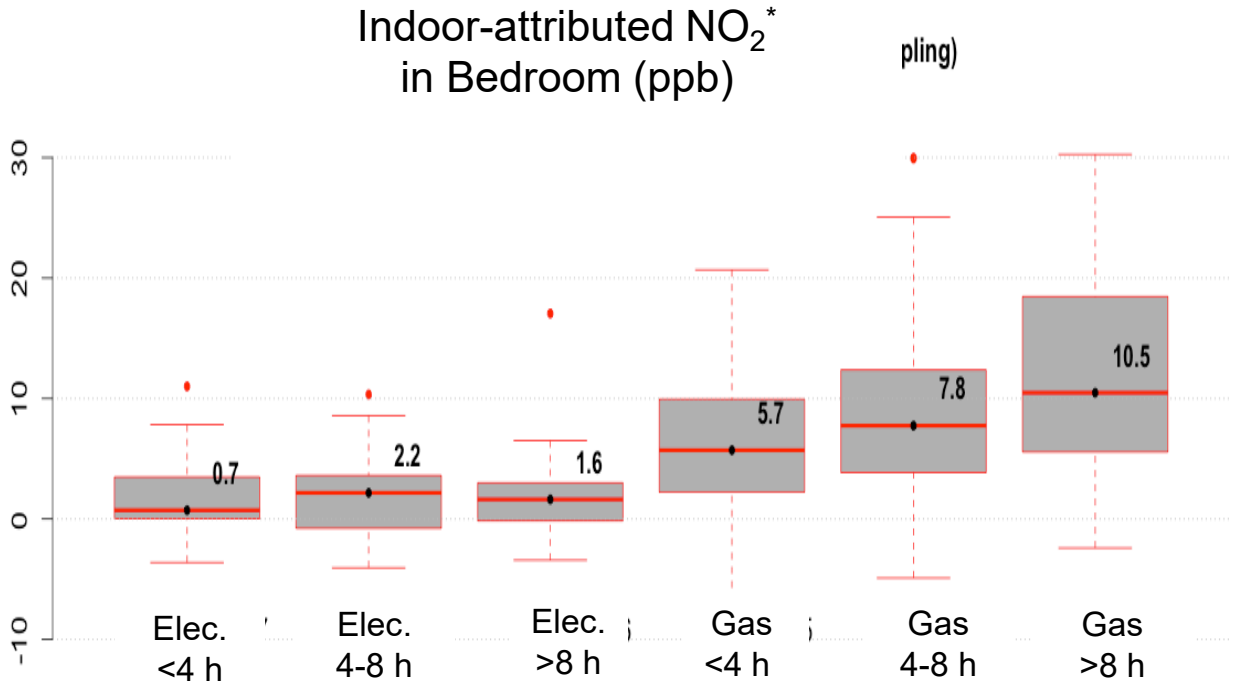
Homes with gas cooking still have higher NO_2

- Data from 2011-2013
- Mailed samplers to 352 California homes with no smoking
- Focused on homes with:
  - Confirmed cooking
  - Smaller volume
  - Wall or floor furnaces
- 1-week of sampling
- Mullen et al. (2016)



More gas burner use leads to more NO_2

- Mullen et al. (2016)
- Cooking time based on activity log



Population-based simulations indicate that acute thresholds may be commonly exceeded in homes using gas burners

- Physics based simulations of 6634 SoCal homes from 2003 RASS
- Self-reported cooking frequencies by meal
- Cooking durations from web-based survey
- Emissions measured from 10 used ranges
- Winter week including NO_2 from outdoors
- Compare to acute ambient AQ standards
  - NO_2: 100 ppb for 1 h
  - CO: 20 ppm for 1 h
    9 ppm for 8h

	% of homes above acute standard – No RH use	Estimated # of CA homes affected
CO	**7-8%**	**1.7M**
NO_2	**55-70%**	**12M**

Notes:
Cooktop CO emissions lower with modern burner designs with higher grills, better air supply. Ovens likely still susceptible to higher CO as spreader plates degrade.

Similar NO_2 emission rates reported in recent study of 32 cooktops and 24 ovens (Lebel et al., 2022)

Logue et al., 2014, Environ. Health Perspectives.

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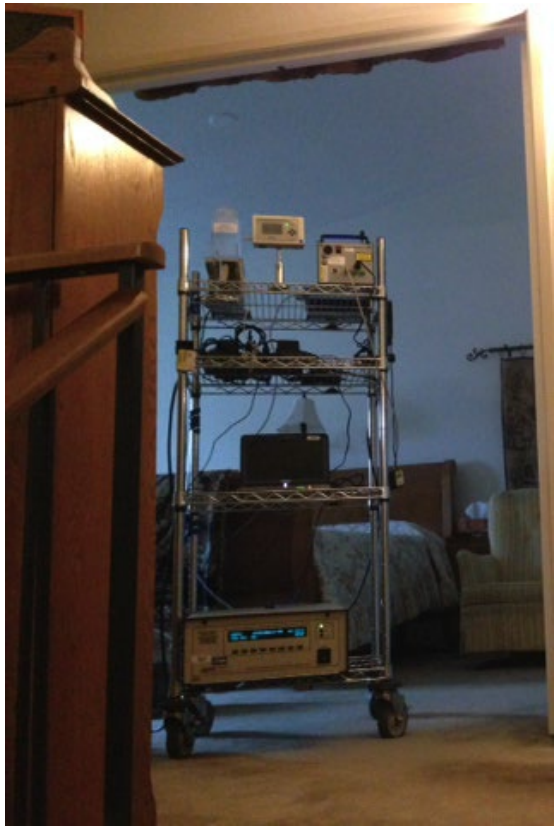
In-home measurements to verify model results…

Use burners to heat water: no cooking

- Cooktop, oven, broiler use

Measure CO, NO_2, NO_X, Particles >6 nm in kitchen and bedroom areas of 9 homes



Singer et al., 2017, Building Environment

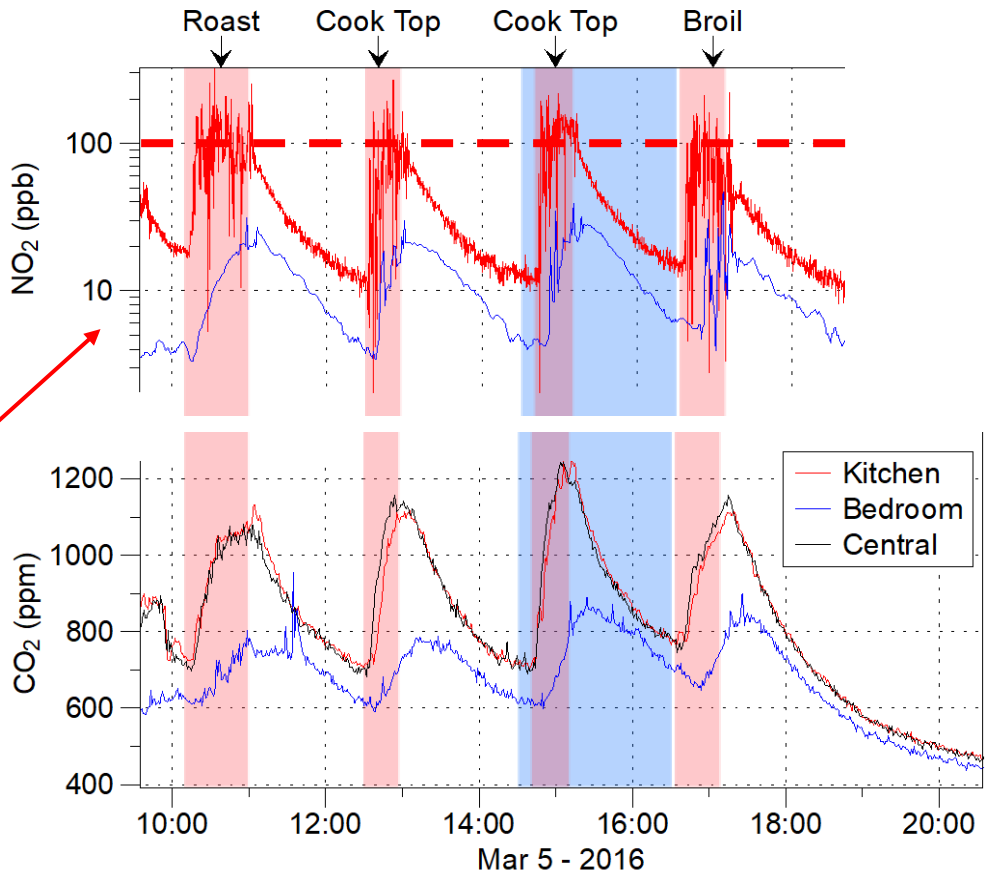
Measurements in homes support simulation results for acute concentrations

Burner use for a modest meal

Example: 1400 sf house with continuous ventilation of 0.5 ach by ERV

- NO_2 in kitchen exceeds ambient AQ threshold value

Kitchen NO_2 exceed 100 ppb over 1h in 6 of 9 homes studied.

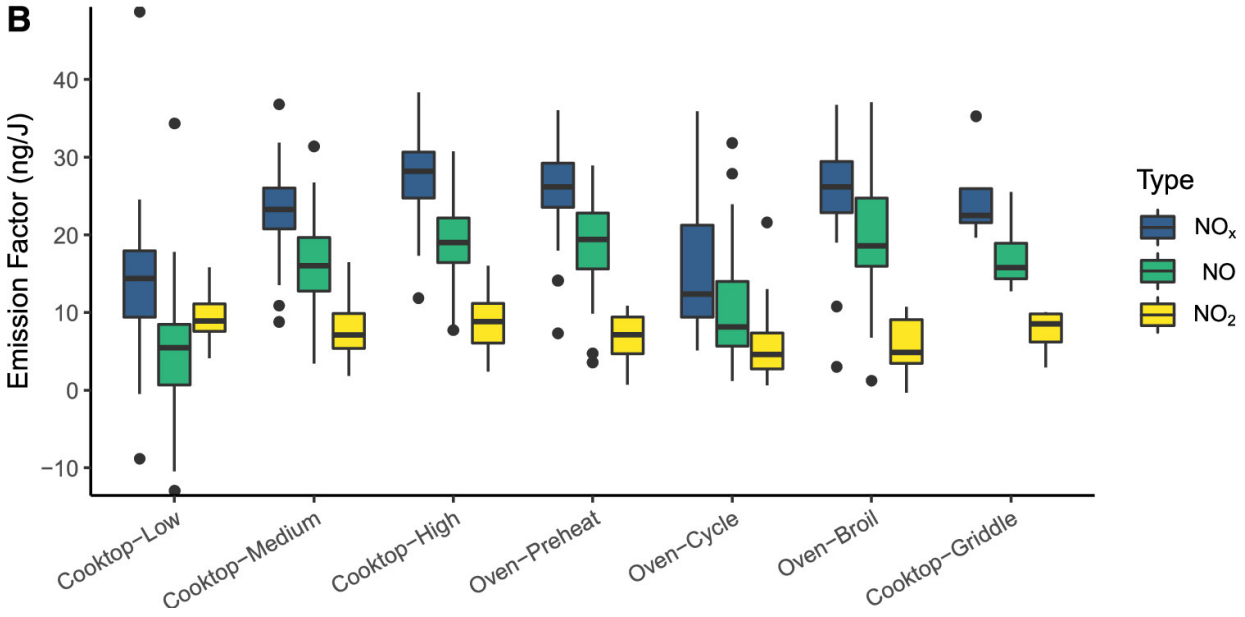


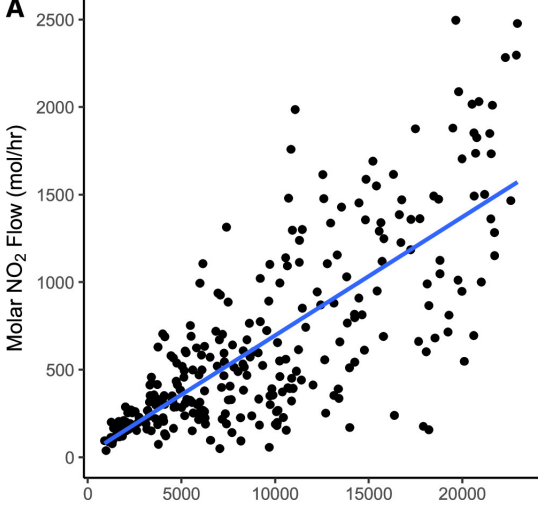
Singer et al., 2017, Building Environment

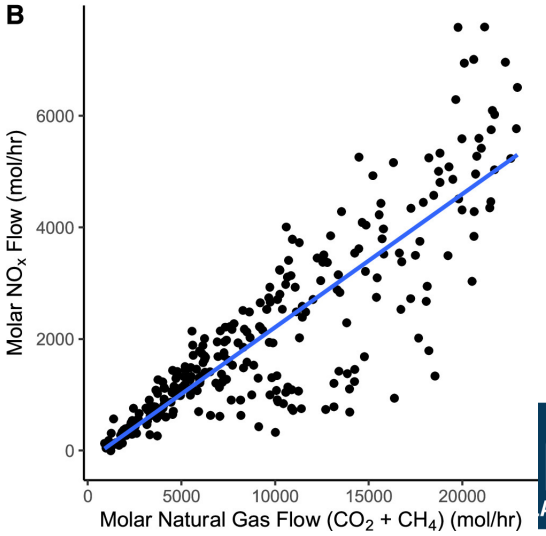
NO_X emissions increase with fuel use

Lebel et al. “Methane and NO_x Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes” ES&T 2022, 56, 4, 2529–2539

Measured emissions for 32 cooktops and 24 ovens as found in homes







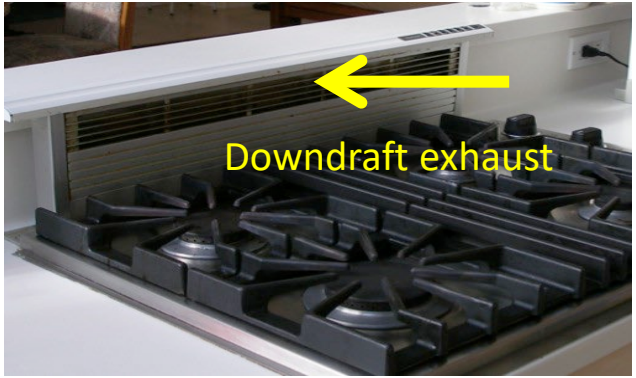
Controls

Removal of gas cooking address combustion pollutants but not cooking pollutants.
Kitchen ventilation addresses both.

Kitchen ventilation options

Ceiling exhaust fan

Wall exhaust fan



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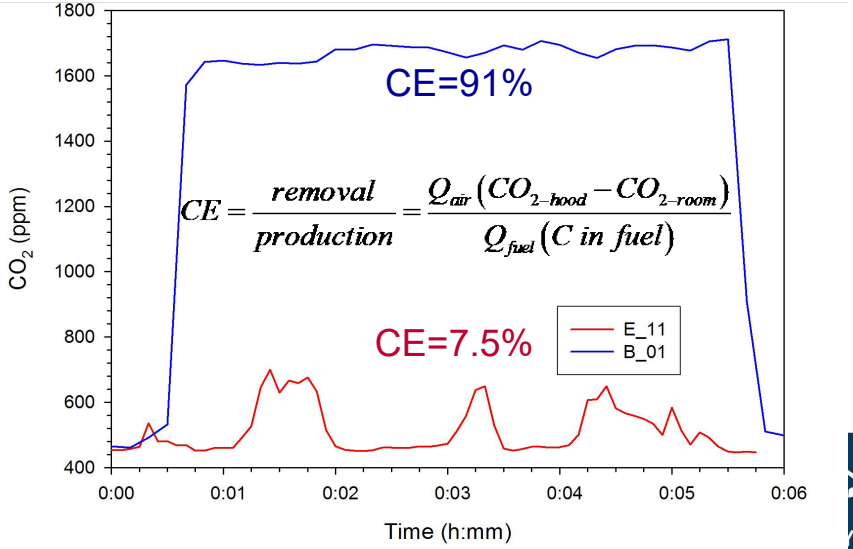
How do we know if range hoods are effective?

Capture efficiency (CE): Fraction of pollutants released at cooktop or oven that are removed before mixing into home

Calculated by CO_2 from gas burners or tracer release
(Different approach needed for particles)

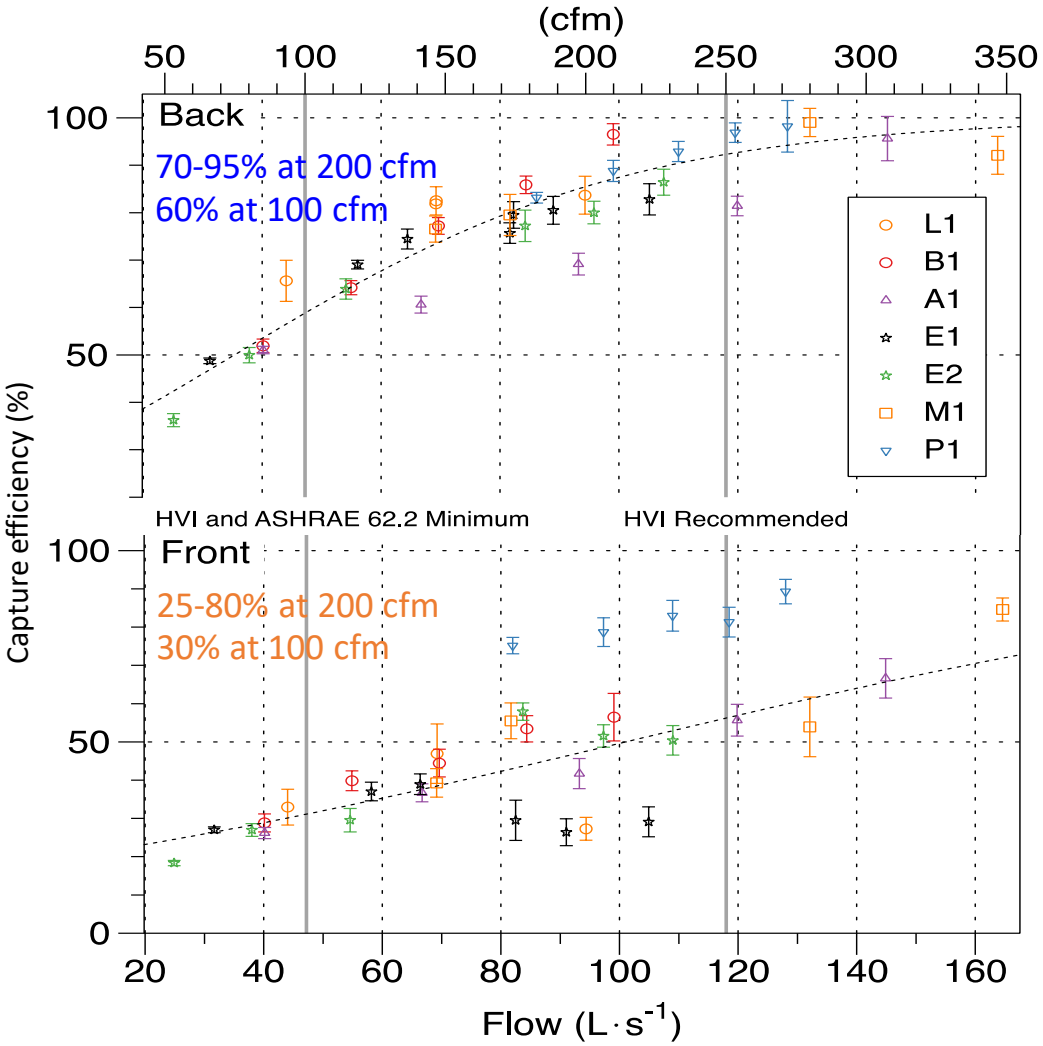


Capture eff. for combustion pollutants, lab testing

7 off-the-shelf hoods (2012 cost)
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

Capture increases with airflow.
Much better for back burners!

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

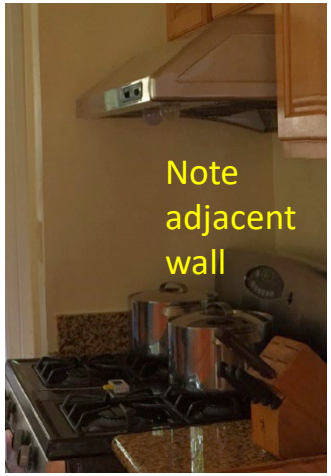


Delp and Singer, 2012

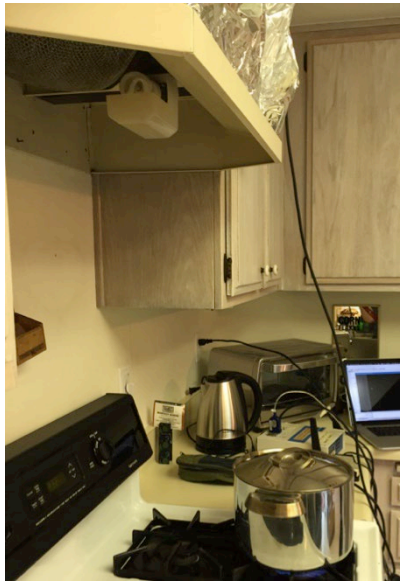
Testing of range hoods in 9-home study…

H1: 134 m^2

H2: 124 m^2



H5: 108 m^2



H9: 139 m^2

H8: 219 m^2

H6: 119 m^2

Singer et al., 2017, Building Environment

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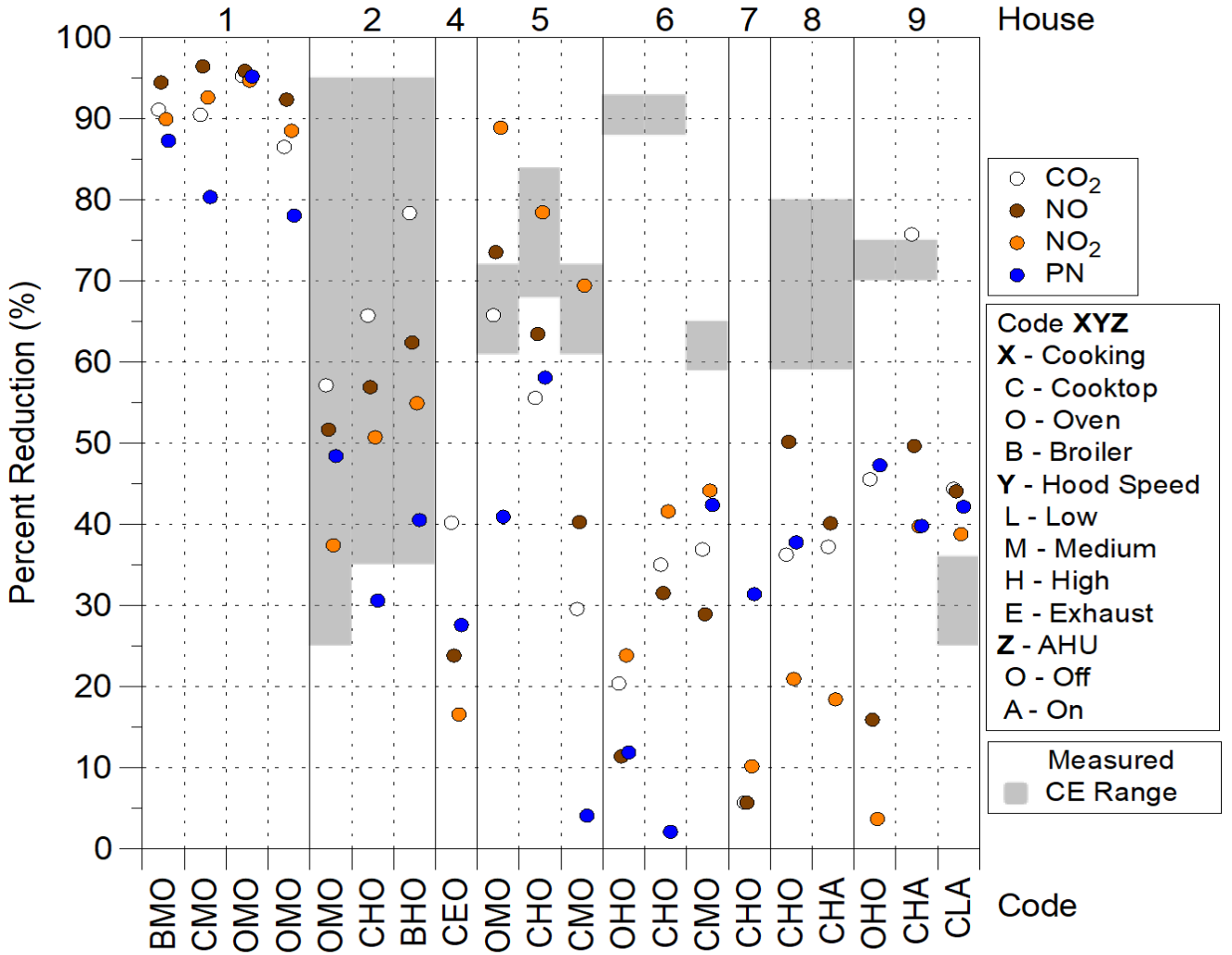
Range hood use provided varied levels of exposure reduction to combustion pollutants

Results for kitchen measurements

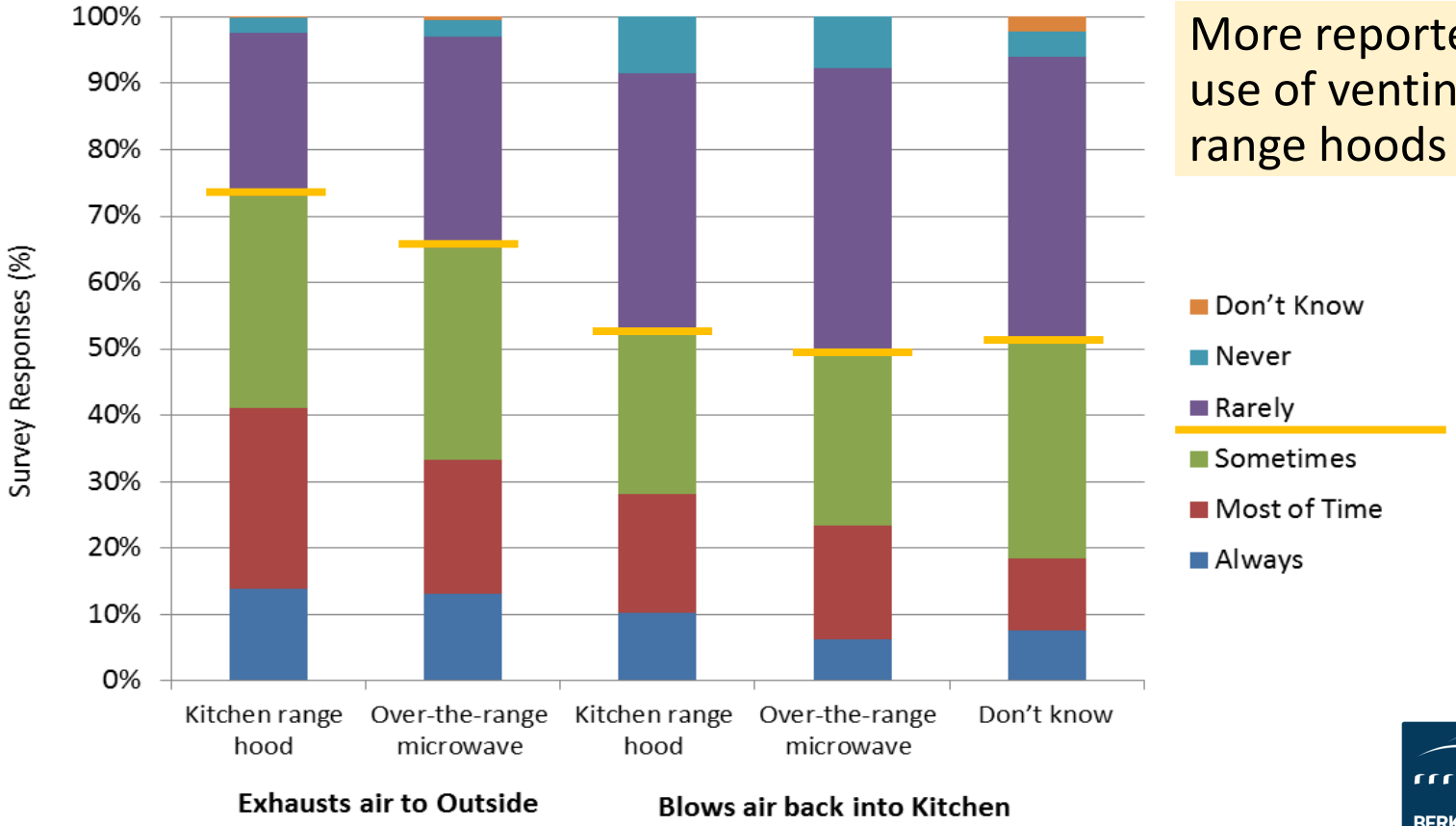


Singer et al., 2017, Building Environment

Challenges

How frequently do you use range hood with cooktop?

Web-based survey of 2400 mostly SoCal homes built 2003-2010



More reported use of venting range hoods

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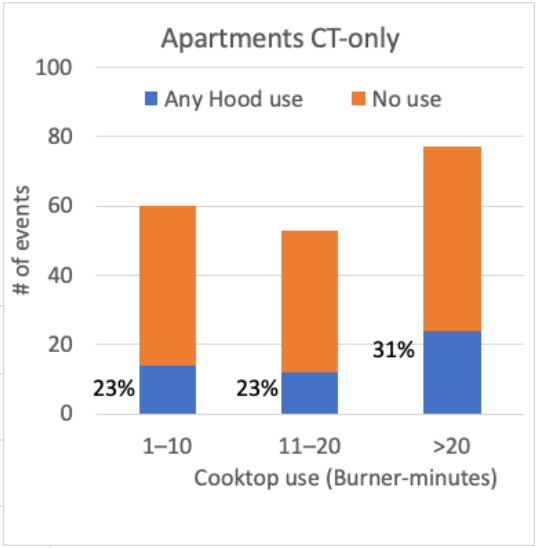
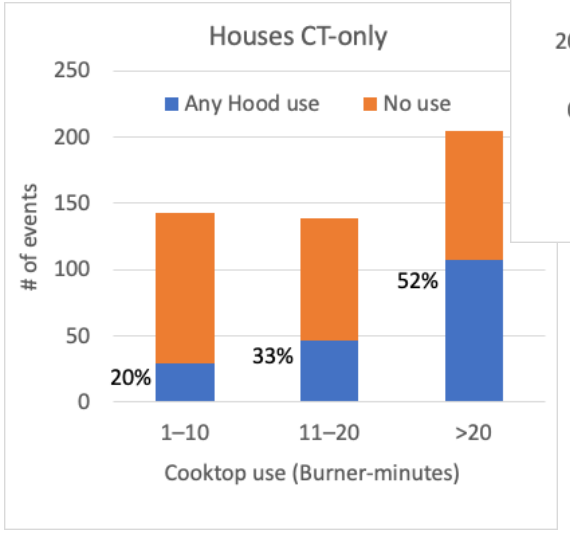
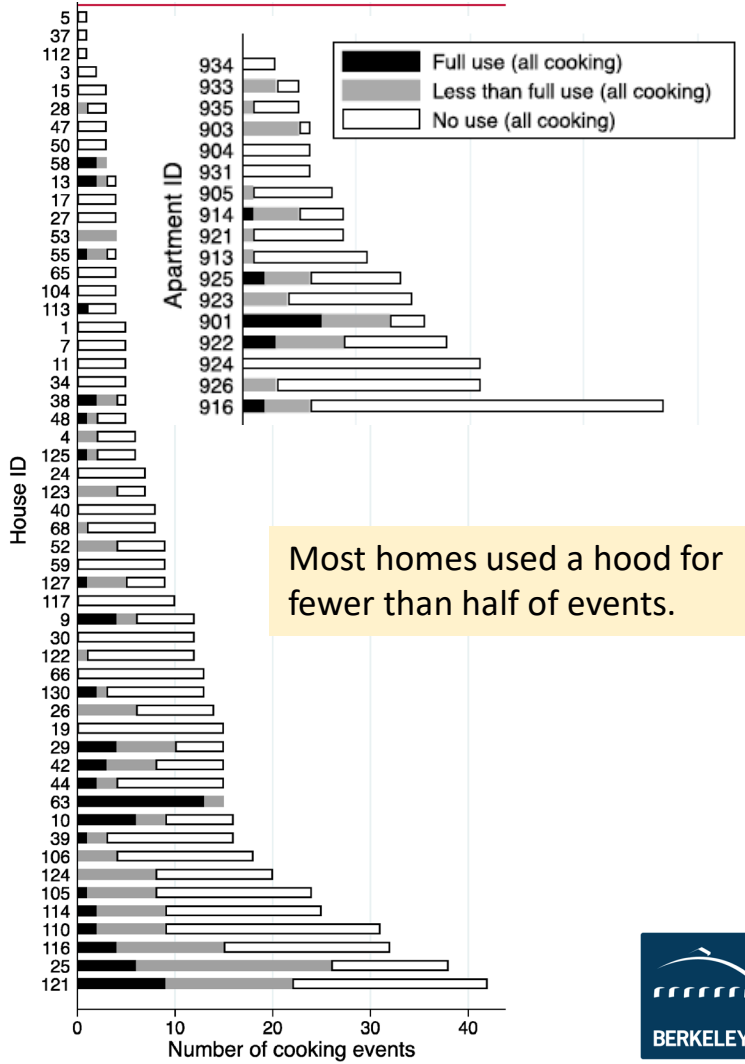
Actual Range Hood Use in California Houses and Low-Income Apartments

Longer cooking event -> range hood use more likely







Most homes used a hood for fewer than half of events.

Zhao et al, IJERPH, 2020

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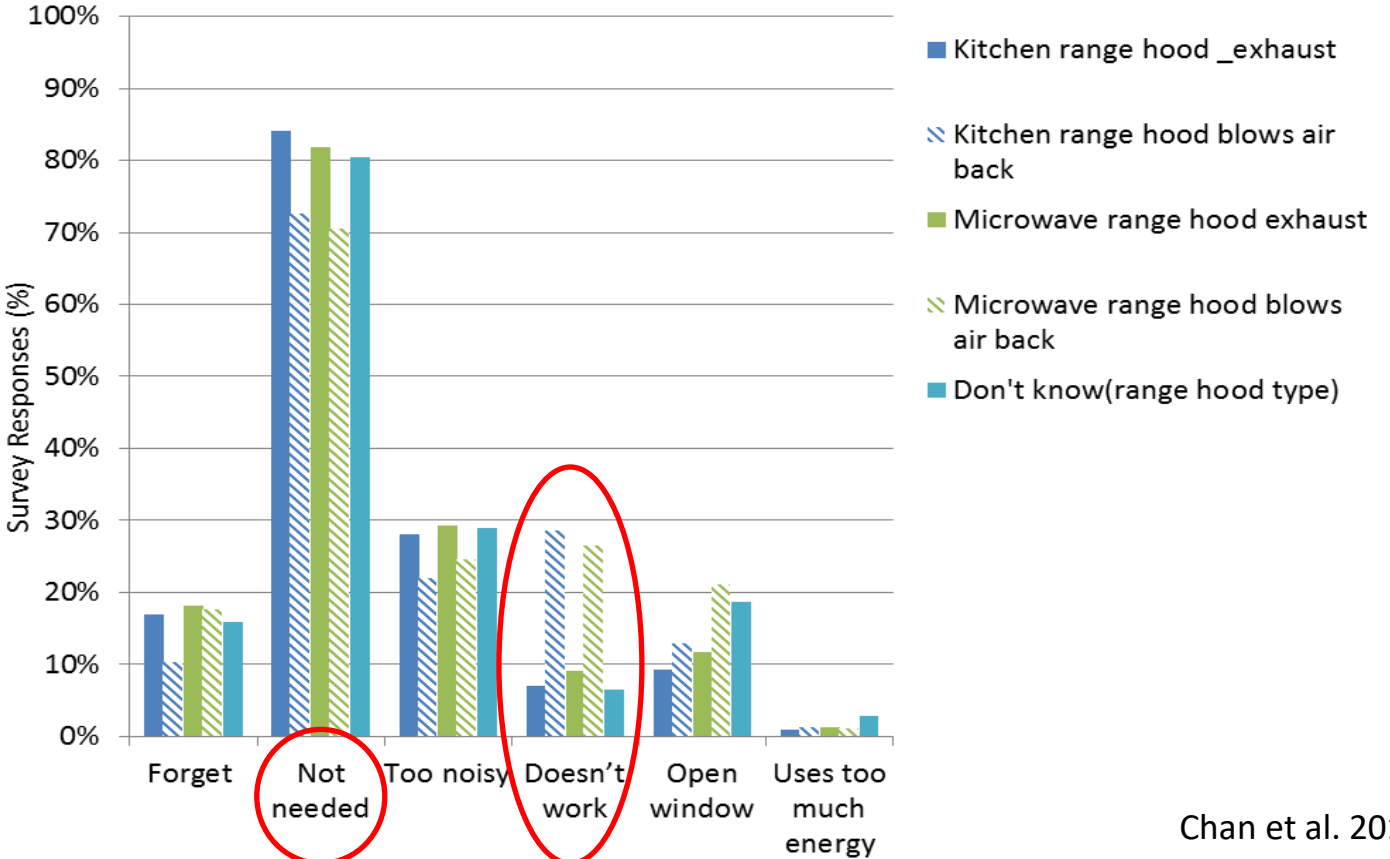
Why do you *not* use your range hood?

Web-based survey of 2400 mostly SoCal homes built 2003-2010



Chan et al. 2019

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Kitchen Ventilation Summary

- ***Venting*** range hoods ***can*** effectively capture cooking and burner pollutants.
- Capture efficiency varies by airflow, front vs. back burners, and form factor.
- Capture for cooking particles can be lower than for combustion gases.
- Over the range microwaves perform similarly to common range hoods.

- Many installed range hoods perform worse than rated.
- Range hoods not used routinely and much less than people claim.

- Need more studies of effectiveness for exposure reduction and health improvements when used as an intervention.

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Datasets

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Zhao H et al. (2020), Data from: Indoor air quality in new and renovated low-income apartments with mechanical ventilation and natural gas cooking in California, Dryad, Dataset, https://doi.org/10.7941/D1T050

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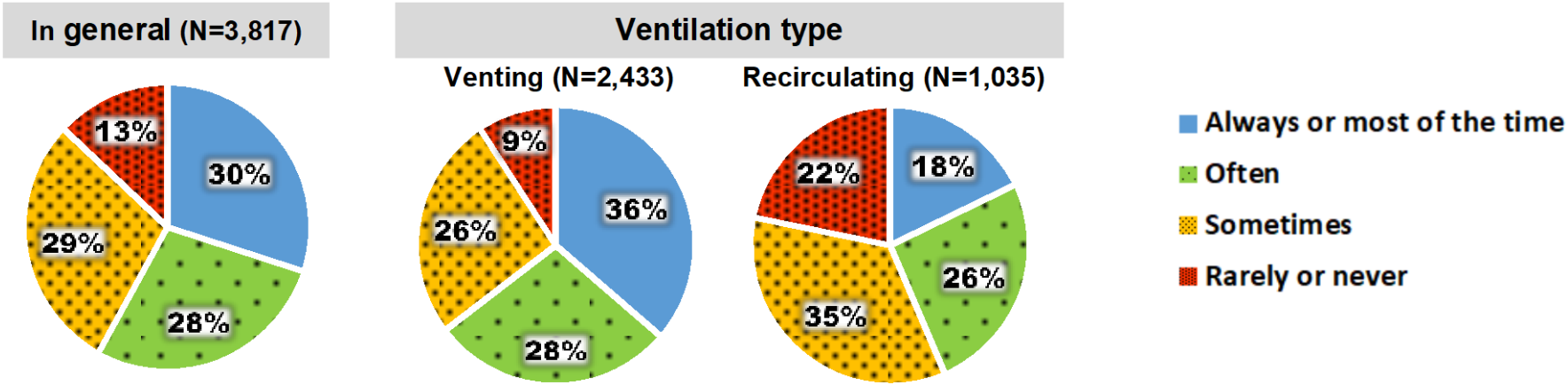
Extra Slides

Nationally representative survey of 4500 Canadian households

In general, how often do you use your ventilation device during cooking?



Sun and Singer. "Cooking Methods and Kitchen Ventilation Availability, Usage, Perceived Performance and Potential in Canadian Homes." *JESEE*, Apr. 2023, https://doi.org/10.1038/s41370-023-00543-z.

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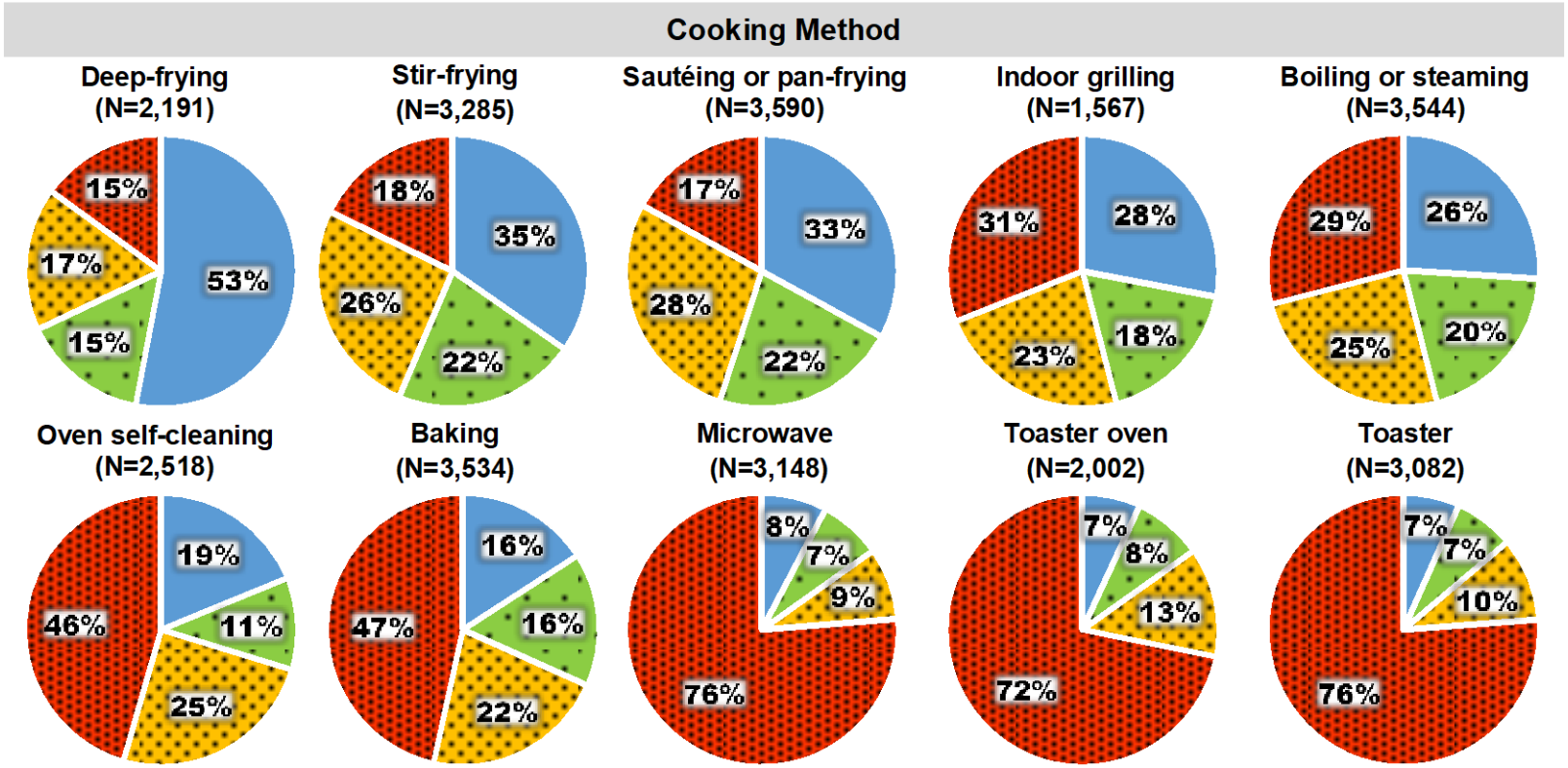
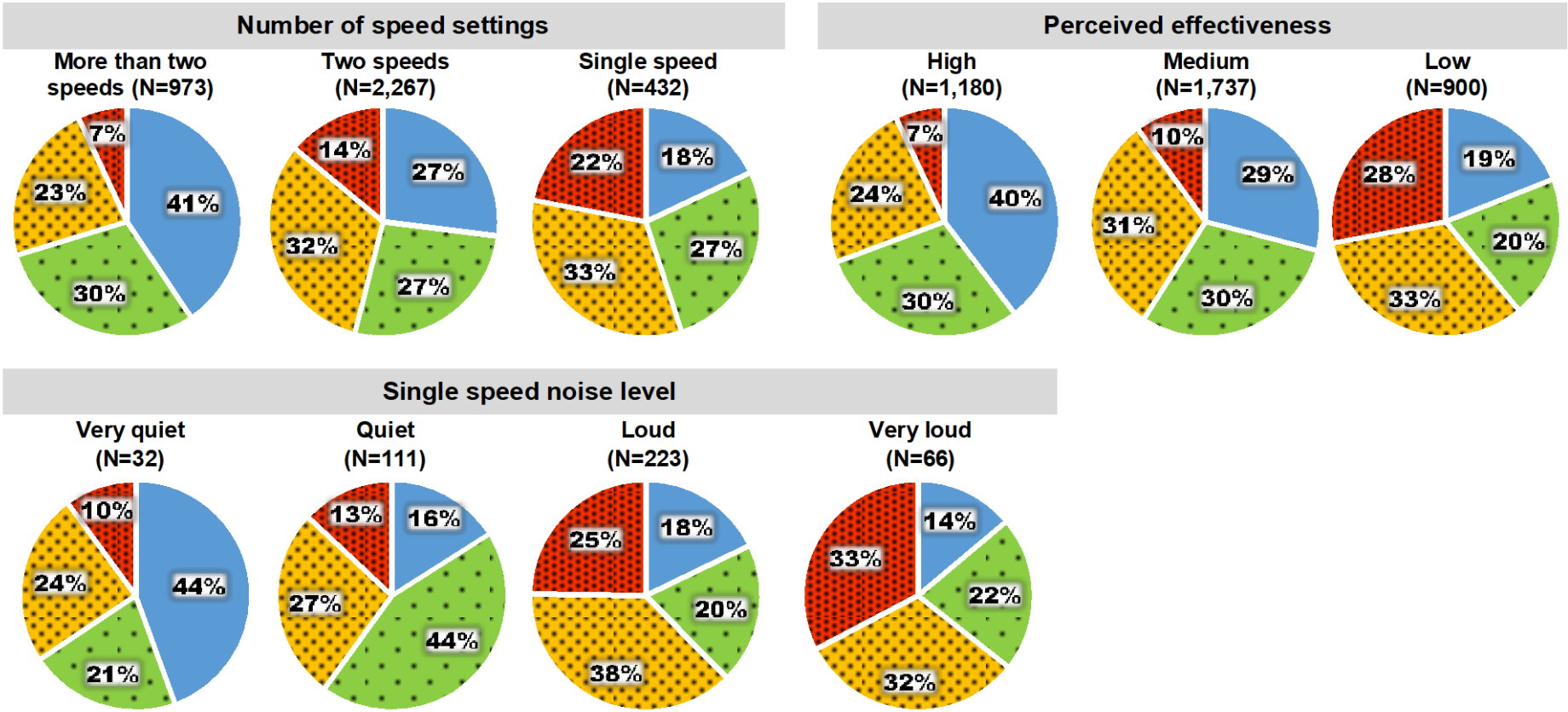
How often is your ventilation device turned on while…?



*Based on nationally representative sample of 4500 Canadian households (Sun & Singer 2023)

People say they use range hoods more when they work*



*Based on nationally representative sample of 4500 Canadian households (Sun & Singer, 2023)

Simple Range Hood Guidance

Builder / Contractor

- Low-resistance ducting
- Quiet at 150–200 cfm
- 250 cfm available

User

- Use it, especially for frying & ovens
- Cook on back burner
- Higher settings as needed

Roofer

- Don’t drop debris down the vent

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

Goal	Reality
Venting range hood in all homes, required by code	Above the stove venting not required in most building codes, absent from many homes; renters especially vulnerable
Effective for front burners Quiet at 200+ cfm Automatic	Large & quiet both exist; rarely together. Quiet @150-200 cfm and >250 cfm $250+ Auto hood coming to market
Use with frying, bake, broil, meals; Cook on back burners	Variable use; as need is perceived Most cook on front; use less with oven
Effectiveness confirmed with home IAQ monitors	$200 monitor not accessible to many

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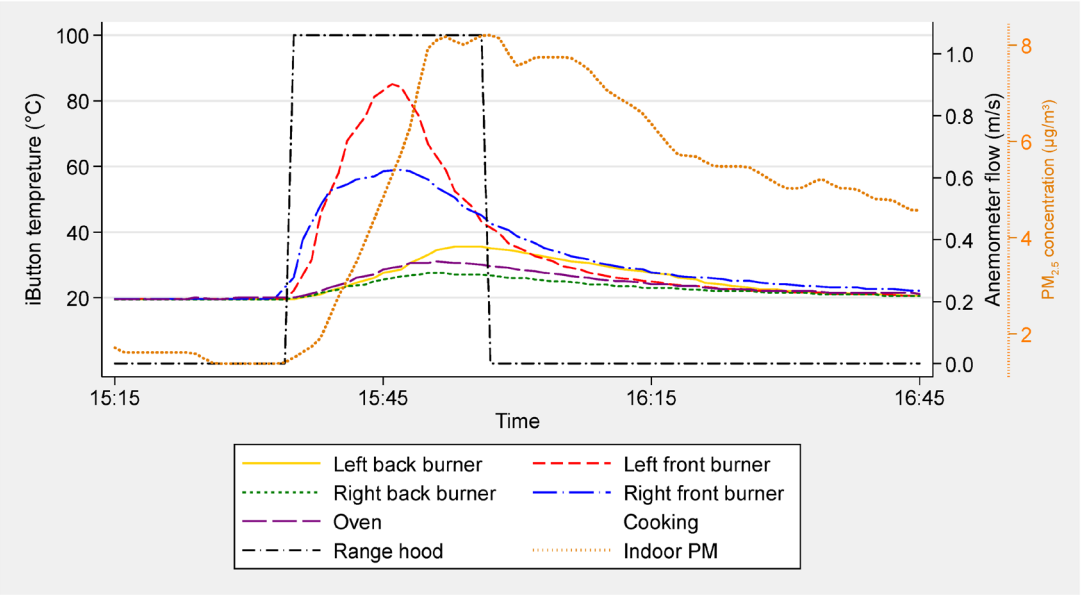
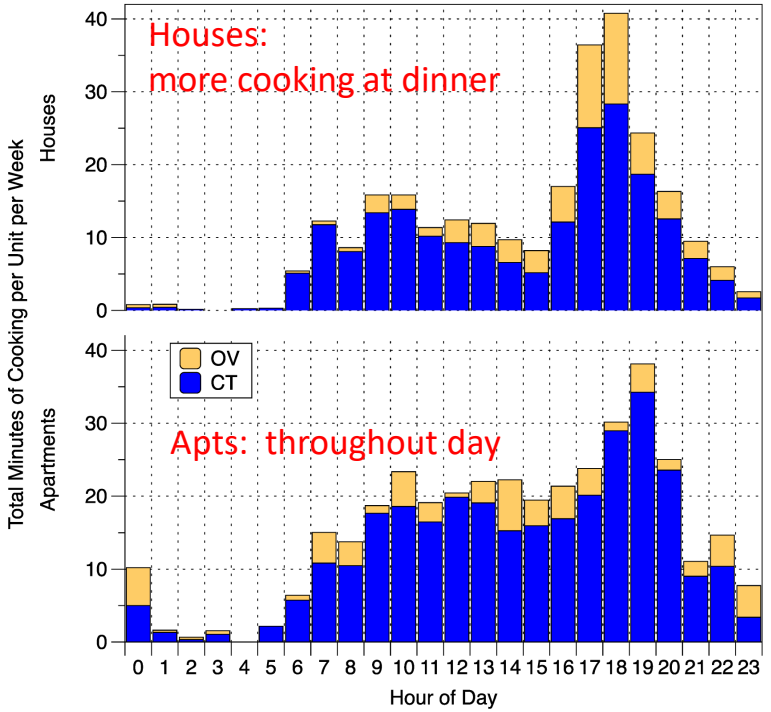
Do people actually use their range hoods as frequently as they claim?

Zhao et al, IJERPH, 2020

1 week each in 54 houses, 17 apts
All had mechanical ventilation & vented range hoods
Monitored cooking & range hood + activity log

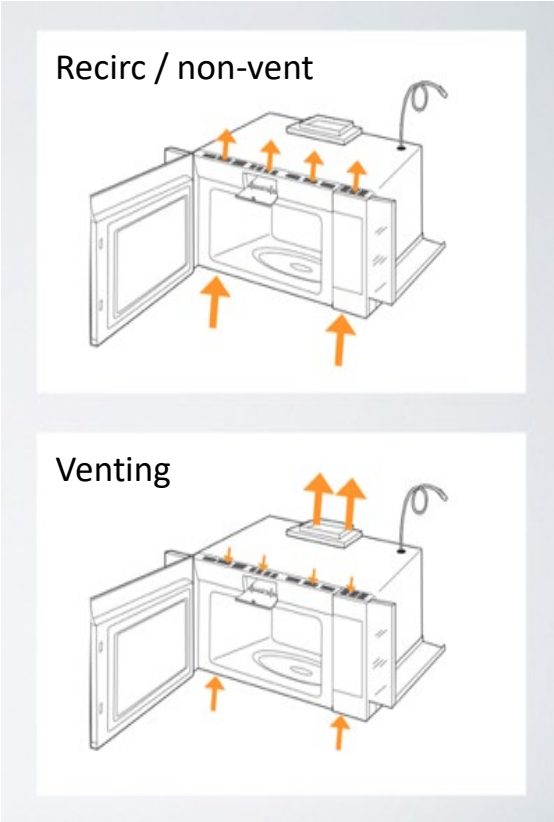




“Over-the-range” microwave range hoods

Can be installed as venting or recirculating. Shipped to recirc. Need to turn fan to vent.

Historically not rated for 62.2 and CA code compliance; now many certified models.



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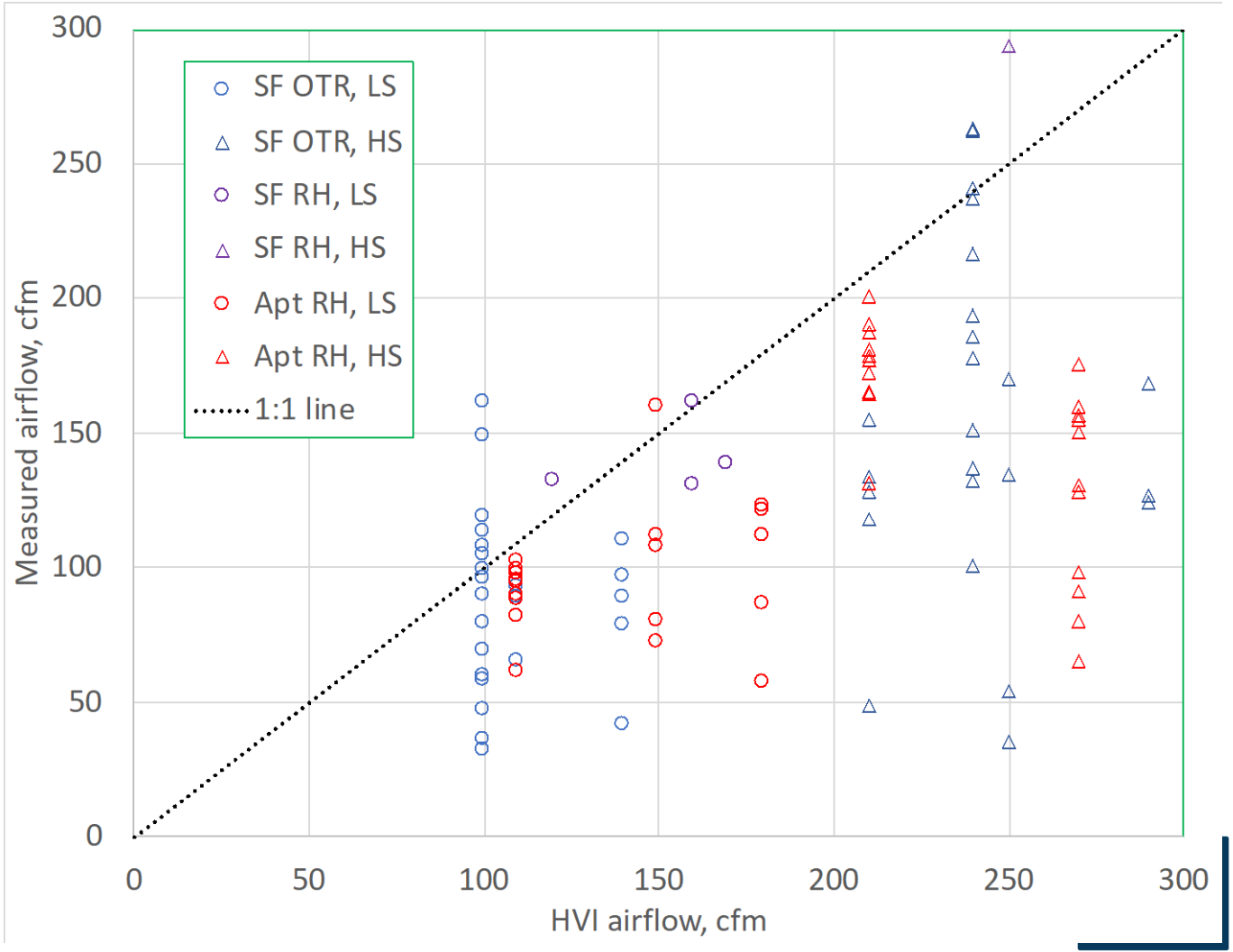
Airflows measured in California homes much lower than certification test results.

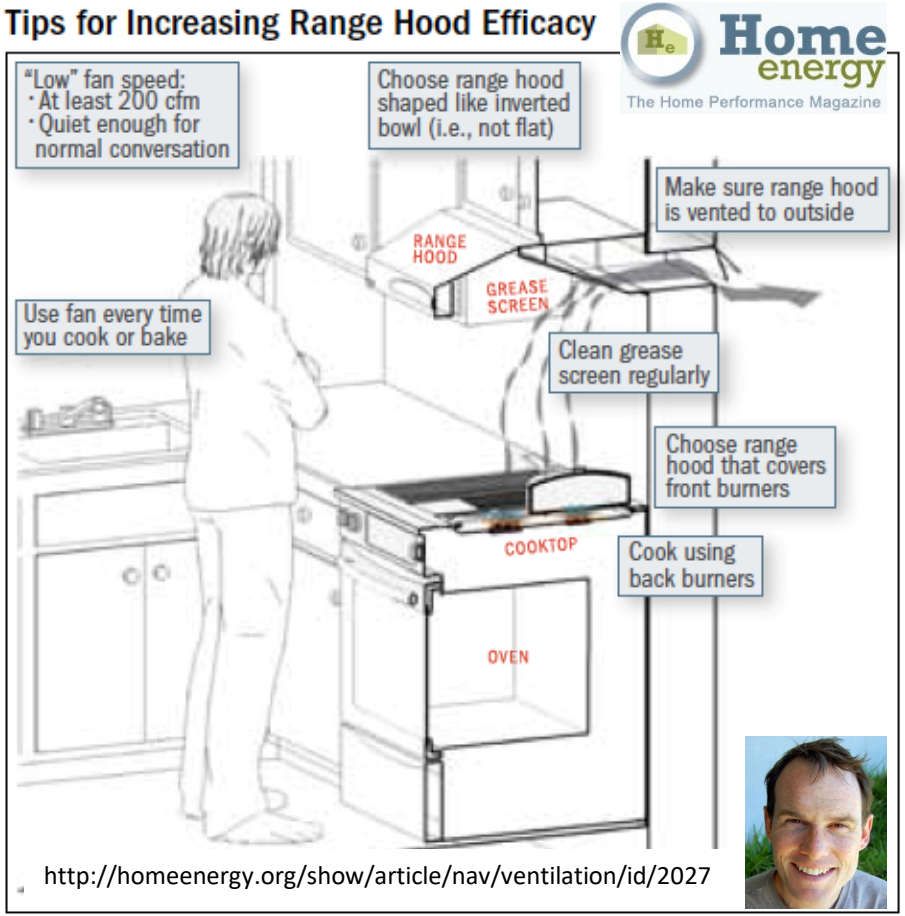
Why?

Consistent with static pressure as installed in homes being much higher than test conditions.



Data from Chan (2020) and Zhao (2019)

Guidance and Resources



Certified Airflow & Sound Ratings

CERTIFIED HOME VENTILATING PRODUCTS DIRECTORY

HVI HOME VENTILATING INSTITUTE

Certified Ratings in Air Delivery, Sound and Energy for Accurate Specifications and Comparisons

Not Listed = Not Certified

HVI Product Directory

AHAM ASSOCIATION OF HOME APPLIANCE MANUFACTURERS

Leadership ➤ Knowledge ➤ Innovation

AHAM VERIFIDE Independently Tested. Consumer Trusted.

AHAM Product Directory

Detailed Guidance & Webinar

http://rocis.org/kitchen-range-hoods

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Residential cooking and use of kitchen ventilation: The impact on exposure

Sun and Wallace, J&AWMA, 2021

132 homes in Halifax and Edmonton (Canada)

55% vented, 22% unvented, 18% none, 5% unknown

Cooking by daily log; Monitored range hood, windows

2.4 cooking events per day, GM: 17 min

22% of PM from cooking