Guidance on Evaluating Indoor Particles and Filtration Effectiveness


Available at eetd.lbl.gov/publications
Search for “Singer”
Addressing Kitchen Contaminants for High Performance Homes

Brett C. Singer
Lawrence Berkeley National Lab

ACEEE Summer Study
September 12, 2014
San Francisco, CA

bcsinger@lbl.gov
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?
For decades, teams of Berkeley Lab scientists have investigated the ways that indoor air quality affects human health—from cognitive ability to personal comfort. Lab scientists were among the first to sound the alarm about sick buildings, including the health risks posed by radon, and also to offer solutions to make buildings healthier. They continue to identify and monitor other sources of indoor pollution—from cooking byproducts to thirdhand smoke, and to substantiate the health virtues and cost savings of energy-efficient ventilation, particularly in schools. Berkeley Lab experts have changed—and continue to change—the national thinking about what constitutes healthy building design and use.

Recent News

Sept 2013
Berkeley Lab Indoor Air Roundup: Natural Ventilation Comes with Health Risks, and more

Aug 2013
Secondhand Smoke in Bars and Restaurants Means Higher Risk of Asthma and Cancer

July 2013
Kitchens Can Produce Hazardous Levels of Indoor Pollutants

Jun 2013
Berkeley Lab Confirms Thirdhand Smoke Causes DNA Damage

Jun 2013
More Fresh Air in Classrooms Means Fewer Absences

Apr 2013
Hidden Dangers in the Air We Breathe
Sponsors of Kitchen Ventilation Work

Office of Healthy Homes and Lead Hazard Control

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

12-Sep-2014
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)


Hu et al., 2012. Compilation of published PM$_{2.5}$ emissions rates for cooking… LBNL-5890E*.


Singer et al., 2009. Natural Gas Variability in California…Experimental evaluation of pollutant emissions from residential appliances. CEC-500-2009-099; LBNL-2897E*.


Wan et al., 2011. Ultrafine particles and PM2.5 generated from cooking in homes. *Atmos Environ* 45: 6141-6148.


* 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 NO₂

Results from study that measured pollutants in 350 California homes in 2011-2013. Estimated contribution from indoor sources.
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 NO₂

Bedroom NO₂ levels categorized by fuel type and cooking hours (week of sampling)

Results from study that measured pollutants in 350 California homes in 2011-2013. Estimated contribution from indoor sources.
# Gas cooking impacts IAQ in many homes

*Simulations for 6634 SoCal homes in 2003 RASS*
*These homes have higher AERs than PH Mech Vent.*

<table>
<thead>
<tr>
<th></th>
<th>Fraction of homes above std.</th>
<th>Estimated number of Californians impacted</th>
<th>Estimated number impacted across U.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO: 1-h &amp; 8 h</td>
<td>7-9%</td>
<td>1.7M</td>
<td>10M</td>
</tr>
<tr>
<td>NO₂: 1-h</td>
<td>55-70%</td>
<td>12M</td>
<td>66M</td>
</tr>
</tbody>
</table>

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

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Particles from cooking
Data from 12 homes in Hong Kong (40-150 m²)

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Kitchen ventilation options

- Exhaust fan on wall above range
- Ceiling exhaust fan
- Window
- Venting range hood
- 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

Separate kitchen

Open floor plan

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

1 hr Average CO (ppm)

- No Exhaust: -51%
- Kitchen Exhaust: -90%
- Hood: -90%

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**

![Graph showing CO concentration over time for different scenarios.]

- **Low Mixing**
- **No Exhst**
- **Kit. Exhst**
- **Hood**

**1 hr Average CO (ppm)**

- **No Exhaust**
- **Kitchen Exhaust**
- **Hood**

15,000 btu/h
800 ng/J CO
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

![Graph showing CO concentration over time and 1 hr average CO](image)

15,000 btu/h
800 ng/J CO
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

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Standards and Codes

**ASHRAE STANDARD**
Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings

- 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

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

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How do we know which hoods work?

The effectiveness of range hoods at capturing cooking pollutants is called capture efficiency.
Measure capture efficiency using $\text{CO}_2$

Emission rate based on fuel $\text{CH}_4 \rightarrow \text{CO}_2$

Measure concentration in hood exhaust and room

Separately measure flow in hood exhaust

$$CE = \frac{\text{removal}}{\text{production}} = \frac{Q_{\text{air}} (\text{CO}_2{}_{\text{hood}} - \text{CO}_2{}_{\text{room}})}{Q_{\text{fuel}} (C \text{ in fuel})}$$

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 $\text{CO}_2$

CE = 91%

CE = 7.5%
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)

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Duct pressure impacts airflow for some hoods more than others

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

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


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.*


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.


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

Minneapolis Sound Insulation Program
  n=73 survey respondents
## Kitchen exhaust use in Cal. IAQ study:

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

Mullen et al. LBNL-5970E
## Kitchen exhaust use in Cal. IAQ study:

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

Mullen et al. LBNL-5970E
Some advertised flows exaggerated!

(Unpublished measurements at LBNL)
Capture of Cooking Particles

Experiments comparing CE of CO₂ 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.
Facility for particle capture experiments

- Mixing Fan, Instrument Rack
- Booster Fan
- Hood
- Flow Meter
- Room Pressure Control
- HEPA Filter
- Mixer Fan
- Desk
- Particle & NOx sampling point
- HEPA Filters
- Range
- Hood
- Cabinet
- Calibrated Fan
- CO₂ Sample
- Flex-duct
- Depth
- Back Wall
- 76.2 cm
- 91.4 cm
- Cabinet
- Sample Inlet
- Sample Range
LBNL Kitchen and Range Hood Lab
Conducted many replicates to overcome variability in emissions & room concentrations

- Burger added
- Gas off
- Covered and removed

CPC Cn (#·cm$^{-3}$)

Time from Pan on burner (s)

- No Hood
- Hood E2 Low

2×10$^5$ - LINEAR SCALE

0 500 1000 1500
Conducted many replicates to overcome variability in emissions (log scale)
Cooking Particle vs. CO₂ Capture Efficiency

- P1: High 138 L·s⁻¹
- M1: High 137 L·s⁻¹, Low 68 L·s⁻¹
- E2: High 109 L·s⁻¹, Low 52 L·s⁻¹
- L1: High 81 L·s⁻¹, Low 51 L·s⁻¹
Cooking Particle vs. CO₂ Capture Efficiency
Cooking Particle vs. CO₂ Capture Efficiency

CO₂ Based

Particle Based

E2
High 109 L·s⁻¹
Low 52 L·s⁻¹