Kitchen Ventilation Solutions to Indoor Air Quality Hazards from Cooking

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California Air Resources Board Research Seminar
October 10, 2013
Sponsors of Research Presented

Indoor Environments Division

Office of Healthy Homes and Lead Hazard Control
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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


• 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.


* 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
Cooking releases ultrafine particles
Data from 97 homes in Ontario, Canada

Wheeler et al. 2011; AS&T 45: 1078-1089
Particles from cooking
Data from 12 homes in Hong Kong (40-150 m²)

Wan et al. 2011; Atmos Environ 45: 6141-6148
Particles from cooking
Data from 12 homes in Hong Kong (40-150 m²)

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)

• **Task Ventilation**

• **General Ventilation**

• **Filtration/ Air cleaning**
Ventilation characteristics

- General or Local
- Passive or Mechanical
- Manual or Automatic
- Continuous or Intermittent
<table>
<thead>
<tr>
<th>General or Local</th>
<th>Passive or Mechanical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual or Automatic</td>
<td>Continuous or Intermittent</td>
</tr>
</tbody>
</table>
Types of kitchen ventilation

Wall exhaust fan near range

Range hoods

Window

Ceiling exhaust fan
Categories of cooking exhaust devices

Under cabinet hood

Chimney hood

Microwave range 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
\[ \geq 2.8 \text{ cfm} / \text{W at 25 Pa} \]
\[ \leq 2 \text{ sone} \]
\[ < 500 \text{ cfm} \]

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 Series:

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) function 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

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

- Range hood: $\geq 100$ cfm at $\leq 3$ sones
- Kitchen exhaust: $\geq 5$ kitchen ach at $\leq 1$ sone
- 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”

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

- Installed kitchen ventilation should be $\geq 100$ cfm on demand or $\geq 25$ 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

Environmental Energy Technologies
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

\[
CE = \frac{\text{removal}}{\text{production}} = \frac{Q_{\text{air}} \left( \text{CO}_2_{\text{hood}} - \text{CO}_2_{\text{room}} \right)}{Q_{\text{fuel}} \left( C \text{ in fuel} \right)}
\]
Measure capture efficiency using 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)
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
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

Environmental Energy Technologies
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

- Burger added
- Gas off
- Covered and removed

CPC Cn (#·cm⁻³)

Time from Pan on burner (s)

- No Hood
- Hood E2 Low

Environment
Conducted many replicates to overcome variability in emissions (log scale)
CO$_2$ data from same experiments as previous two slides
Burger On Back

DRAFT RESULTS;
DO NOT CITE OR QUOTE

Measured in duct

<table>
<thead>
<tr>
<th>CO2 Based</th>
<th>Particle Based</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Measured in room

Large Sump 275cfm
Microwave Low 144cfm High 276cfm
Flat Low 108cfm High 234cfm
Economy Low 105cfm High 165cfm

Pots Pans Cook CPC
Total

0.3μm 0.5μm 0.7μm

MetOne Channel 1μm 2μm

DRAFT RESULTS;
DO NOT CITE OR QUOTE

Environmental
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

Separate kitchen

Open floor plan

Environmental Energy Technologies
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

![Graph showing CO concentration over time in different scenarios: Low Mixing, No Exhst, Kit. Exhst, Hood.](image)

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

![Bar chart showing 1 hr Average CO (ppm) for different exhaust systems: No Exhaust, Kitchen Exhaust, Hood.](image)

- **No Exhaust**
  - No change

- **Kitchen Exhaust**
  - -51% reduction

- **Hood**
  - -90% reduction

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 with different kitchen exhaust scenarios.]

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

![Bar chart showing 1 hr Average CO (ppm) for different scenarios.]

- **No Exhaust**
- **Kitchen Exhaust**:
  - -45%
- **Hood**:
  - -89%

Environmental Energy Technologies
Range hoods better than general kitchen
200 cfm range hood or kitchen exhaust (simulations)

CO concentration throughout the home: OPEN FLOOR PLAN

Environmental Energy Technologies

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)
- 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

Mullen et al. LBNL-6347E

64% Venting
36% Non-Venting

- None
- Other location in kitchen
- Wall / ceiling over stove
- Microwave
- Downdraft
- Range hood
## Kitchen exhaust use in Cal. IAQ study:

<table>
<thead>
<tr>
<th>Self-reported usage</th>
<th>Number</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most times (&gt;75%) when cooktop or oven used</td>
<td>44</td>
<td>13%</td>
</tr>
<tr>
<td>Most times when cooktop used, but not oven</td>
<td>39</td>
<td>11%</td>
</tr>
<tr>
<td>About half the time</td>
<td>45</td>
<td>13%</td>
</tr>
<tr>
<td>Infrequently, only when needed</td>
<td>113</td>
<td>32%</td>
</tr>
<tr>
<td>Never</td>
<td>35</td>
<td>10%</td>
</tr>
<tr>
<td>No exhaust fan</td>
<td>73</td>
<td>21%</td>
</tr>
</tbody>
</table>
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?

Likelihood of range hood use increased with amount of cooking.

Klug et al. LBNL-5028E
## 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 heat</td>
<td>11</td>
<td>5%</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>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>
### Reasons for NOT using exhaust system

<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>Don’t think about it</td>
<td>31</td>
<td>16%</td>
</tr>
<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>Wastes energy</td>
<td>3</td>
<td>&lt;2%</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>No reason selected or don’t know</td>
<td>23</td>
<td>12%</td>
</tr>
</tbody>
</table>
## Kitchen exhaust use in Cal. IAQ study:

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

<table>
<thead>
<tr>
<th>Envelope Airtightness</th>
<th>-2Pa</th>
<th>-5Pa</th>
<th>-10Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air-sealed older home: 8 ACH50</td>
<td>300</td>
<td>540</td>
<td>850</td>
</tr>
<tr>
<td>Typical CA new home: 5 ACH50</td>
<td>185</td>
<td>335</td>
<td>530</td>
</tr>
<tr>
<td>Very tight new home: 2 ACH50</td>
<td>75</td>
<td>135</td>
<td>215</td>
</tr>
<tr>
<td>Passive House: 0.6 ACH50</td>
<td>25</td>
<td>40</td>
<td>65</td>
</tr>
</tbody>
</table>

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?

Contact info and resources:

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

![Graph showing CO concentration reductions with various ventilation options.]
Range hoods better than general kitchen

Highest 1-h CO concentrations: SEPARATE KITCHEN

Note: 5 kitchen ach = 138 cfm

CO_{Max}^{1hr} (ppm)

- Base
- Inter. 200cfm Kitchen Vent.
- Inter. 5ach
- Cont. 5ach
- 200cfm 100cfm 80% 58% Hoods

- Base
- Inter. 200cfm Kitchen Vent.
- Inter. 5ach
- Cont. 5ach
- 200cfm 100cfm 80% 58% Hoods

-43% -33% -39% -89% -69%

-50% -38% -54% -90% -71%

Environmental Energy Technologies

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

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

Environmental Energy Technologies
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