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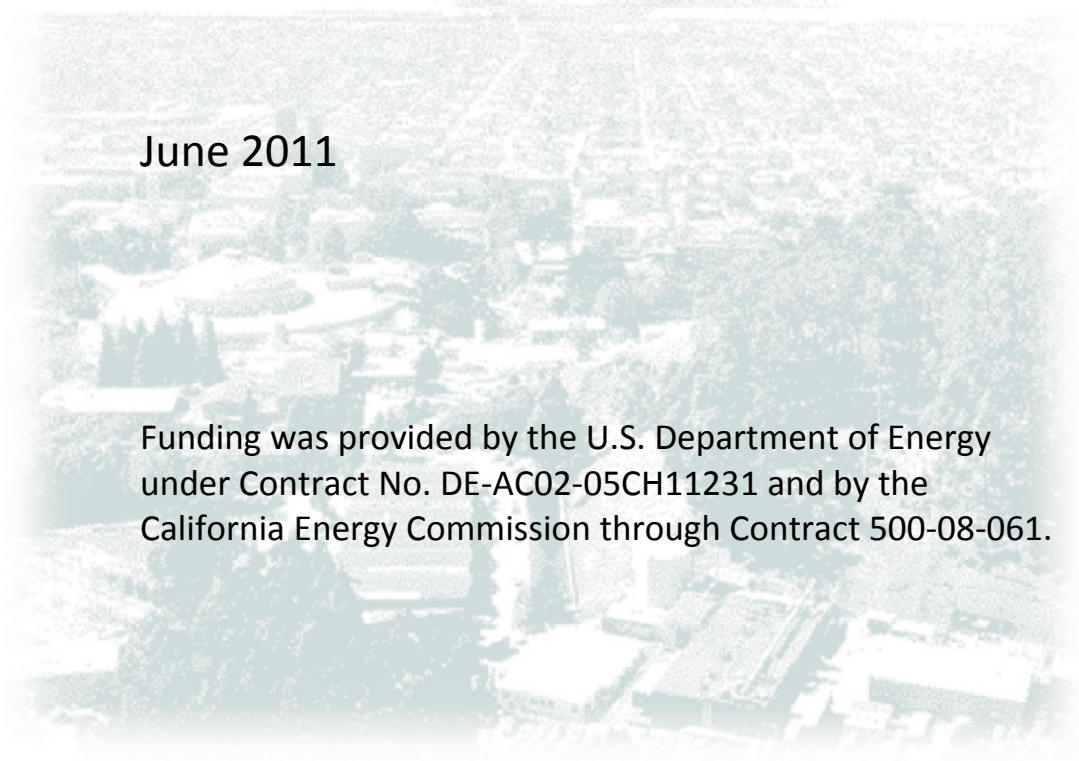
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SUMMARY

Capture efficiency (CE) of exhaust from a natural gas cooking range was quantified for three common designs of residential range hoods in laboratory experiments: (A) microwave exhaust combination; (B) short hood with grease-screen-covered air inlet at bottom; and (C) deep, open hood exhausting at top. Devices were evaluated at varying installation heights, at highest and lowest fan settings, and with the hood installed 15 cm away from back wall with intent to improve CE for front burners. Each configuration was evaluated for the oven and for three cooktop burner combinations (two back, two front, one front and one back). At highest fan settings and standard installation against the wall, Hoods A and C captured back cooktop burner exhaust at >90% and Hood B at >80%. In this configuration, CE for front burner exhaust was 73-78% for Hoods A and C but only 46-63% for Hood B. CEs followed similar patterns but were substantially lower on the lowest fan speed. Installing the hood away from the wall improved CE for oven and front burners on Hood A at low speed, but substantially reduced CE for back burners for all hoods at low and high speed.

IMPLICATIONS

This study reinforces past findings that common range hood designs can effectively remove pollutants when operated on the highest available setting and cooking is preferentially done on back burners. Yet, the considerable noise generated at high fan speed operation impairs their utility. Under ideal lab conditions, lower and quieter fan settings still capture more than half of the burner exhaust when using back burners but less than 40% is captured from front burners. Capture of the cooking-related pollutants under real world conditions is likely less efficient. These results indicate opportunities to improve range hood designs.

KEYWORDS

Carbon monoxide, Nitrogen dioxide, Range Hood, Unvented combustion, Ventilation

INTRODUCTION

Indoor cooking activities on a stovetop or in an oven produce air pollutants that can reach high concentrations in homes, especially when using natural gas burners. Residential cooking exhaust fans can remove pollutants, odors, and water vapor before they mix into the air of the home, thus mitigating exposure and moisture condensation (Li et al., 1997). A recent study by Singer et al. (2010, 2011) measured in-situ performance characteristics – including airflow, sound and pollutant capture efficiency (CE) – of fifteen exhaust systems and analyzed the impact on CE of design, airflow, height, and positioning of the hood relative to burners. A key finding was that full coverage of burners substantially improved CE but that many installed hoods – including almost all under-cabinet models – did not cover front burners. This paper reports on laboratory experiments designed to study the effect of horizontal position (burner coverage), installation height, and airflow on CE for three common under-cabinet range hood

designs. One hypothesis was that CEs of currently available hoods could be improved by offsetting installation from the back wall to cover more of the cooktop.

METHODS

Experiments were conducted in a simulated kitchen area within a larger laboratory. The area (shown in left panel of Figure 1) consisted of a back wall with simulated countertop and top cabinets installed on either side of an opening designed for a U.S. standard 30-inch (75 cm) standalone cooking range and under-cabinet range hood. Hoods were installed on steel strut that allowed variation in vertical and horizontal positioning. Exhaust from the hoods was vented upward with nominal 6 or 7 inch (15 or 18 cm) round ducting and connector suitable to each hood. A damper installed above the connector was set to provide 25 Pa static pressure at the highest airflow setting for each fan. Two standard residential gas ranges were used. The first – a range used for previous experiments – had two cooktop burners of 12.7 MJ/h and two of 9.7 MJ/h. The second range, purchased new when the oven of the first range stopped working, had one burner of 12.7 MJ/h and three of 10 MJ/h. To allow gas line connection, the range was 3.8 cm from the back wall.

Three exhaust hoods were selected to represent common designs, based on available models identified on manufacturer and retailer web sites, and an assessment of in-use prevalence in California residences through review of photographs of homes for sale listed on Zillow.com. The hoods are shown in Figure 1, and characteristics are provided in Table 1. The combined microwave exhaust appliance (A) appears to be the most common type in California homes built in the last 5 years. Device B is rated as compliant with sound requirements of the residential ventilation standard (62.2) of the American Society of Heating, Refrigerating and Air-conditioning Engineers. The shallow hood on this unit is similar to those featured on many lower cost (and generally noisier) hoods, though some have slanted inlets that may better utilize the capture volume. Hood C was selected for its large collection volume, fully open bottom inlet, and back-to-front depth – features expected to yield higher CE based on results from Singer et al. (2011). Hoods were purchased from online retailers and evaluated without any simulated aging or soiling of grease screens, i.e. under optimal conditions.



Figure 1. Exhaust hoods A, B, C shown from left to right; test area shown in left panel.

Inlet and outlet airflow for each hood was measured with a calibrated, pressure-controlled, variable-speed fan (Minneapolis Duct Blaster, www.energyconservatory.com) (Walker et al., 2001). For the inlet side, the fan was connected via a custom-fabricated transition and the fan speed was adjusted to achieve a neutral pressure. On the outlet side, the fan was attached using flexible aluminum ducting and operated to match the duct static pressure described above. In both cases, the fan speed was translated to air flow based on the flow calibration.

Hood performance was assessed using single-pass capture efficiency (CE), calculated as the ratio of incremental (above background) CO₂ mass flow through the hood divided by the CO₂

mass emission rate from the cooking burners (Eq. 1). Symbols are used as follows: Q_{exh} ($\text{m}^3 \text{min}^{-1}$) is the exhaust airflow; $\text{CO}_{2,\text{exh}}$ (mL m^{-3} or ppm) is the concentration of $\text{CO}_{2,\text{exh}}$ in hood exhaust, $\text{CO}_{2,\text{bkg}}$ is the level in room air, and E_{CO_2} (mL min^{-1}) is the CO_2 emission rate.

$$\text{CE} = Q_{\text{exh}} [\text{CO}_{2,\text{exh}} - \text{CO}_{2,\text{bkg}}] / E_{\text{CO}_2} \quad (1)$$

The CO_2 emission rate was calculated assuming complete combustion of a typical Northern California fuel with 95% methane, 3% ethane, 0.2% propane, 0.9% CO_2 , 0.9% N_2 , and a heating value of 38.1 MJ m^{-3} . The CO_2 emission rate is calculated with Equation 2; Q_{fuel} is the fuel volume flow rate (mL h^{-1}) and N is the molar fraction of carbon in the fuel (mol C per mol fuel), equal to 1.0246 for the fuel noted above (Singer et al., 2010).

$$E_{\text{CO}_2} = Q_{\text{fuel}} N \quad (2)$$

Carbon dioxide concentrations were measured with an EGM-4 analyzer (ppsystems.com) sampling from the center of the exhaust duct 68 or 73 cm above the hood with data logged at 5 sec intervals. Background CO_2 was determined before and after burner operation. Exhaust CO_2 was the steady concentration achieved during burner operation. The analyzer was calibrated at the start of each day at 2473, 1483 and 494 ppm.

Fuel flow rates were measured with an inline dry gas meter and a stopwatch. Fuel flow rates were measured prior to the first experiments with each range then infrequently, based on prior experience showing little variability for residential gas ranges. Measurement frequency increased after flow rates for the Kenmore range were observed to vary.

Table 1. Characteristics of hoods evaluated.

ID	Make & model ^a	Cost ^b	Depth ^c [cm]	Fan levels	Nominal airflow ^d [cfm]	Nominal sound ^e [sone]	Recom. height ^f [cm]	Measured airflow ^g [cfm]
A	Panasonic NN-SD277	\$310	38.1	4	420, 300, 160, 130	NL ^h	≥ 35	360, 275, 164, 140
B	Broan QT230	\$109	44.5	Cont.	220 ⁱ	4.5 ^j	46-61	188, 87
C	Vent-a-hood PR9-130	\$471	53.3	1	273 ⁱ	5.4	61-69	238

(a) Excludes color code. (b) Actual purchase price. (c) From back to front of appliance; inlets for hoods A-B extend only part of this distance. Hood C is open at bottom with grease collection via impaction at exhaust near top of hood. (d) Nominal airflow (cubic feet per min.) from product literature, based on vertical venting. (e) – (f) Nominal sound and recommended installation height from product specifications. (h) Not listed. (g) Exhaust airflow with damper set to 25 Pa static pressure at highest fan setting; Hood B at lowest and highest settings (i) Rating at 25 Pa static pressure. (j) Compliant with ASHRAE 62.2, sound level must be <3 sone at ≥ 100 cfm.

Each experiment started with the hood in operation at the specified fan setting. A covered 5-L stainless steel pot filled with 3-4.5 L of room temperature water was placed on the cooktop burners being used. Cooktop burners were set to maximum; the oven was set to 450 F. After starting burner(s), the operator remained moved away from the range. At 5 min, the operator approached and stirred the water in each pot for about 30 s total or opened the oven for 10 s, then walked away. This was done to explore the impact of cooking activity on capture efficiency. Burners were turned off at 7 min and data were collected for at least 1 more minute to establish the final background CO_2 level. For this paper, CE was calculated based on the steady mean concentration over the first 5 min.

Each exhaust system was evaluated at 3 different installed heights while flush against the wall and at 1-2 heights while extended 15 cm horizontally to improve coverage of front burners.

For the extended position, the gap behind the hood was sealed with a strip of wallboard and tape to avoid leakage of exhaust gases. Installation height was measured from the cooktop surface to the bottom edge of the exhaust appliance. The range of installed heights reflected manufacturer recommendations and judgment by our research team of likely installations, based on Zillow.com photos and a field study of installed exhaust fan performance (Singer et al., 2010). The microwave (A) was tested at heights of 35, 45 and 60 cm at the wall and 60 cm extended 15 cm from the wall. The other two hoods were tested at heights of 45, 60, and 75 cm at the wall and at 60 and 75 cm extended to cover burners. For each installation we evaluated a hood at the highest and lowest available fan flow settings for these burner combinations: two back burners, two front burners, highest firing rate diagonal combination of front and back burner, and oven (vents at back of cooktop).

Data quality was assessed through analysis of repeated conditions and by conducting several experiments with a custom hood designed to capture 100% of cooktop exhaust.

RESULTS

Measured exhaust airflows are presented in Table 1. Hood A exhaust airflows exceeded advertised values at the two lowest settings. Exhaust airflows were only 85-90% of advertised values for the two highest settings on Hood A, the high setting on Hood B and the single speed for Hood C. Flows measured at the inlet of Hood A were only about 67% of the flows measured in the exhaust duct for all fan settings. The extra airflow appears to be pulled from the microwave compartment. This result impacts the methods required to evaluate airflow and capture efficiency in residences where access to the exhaust side may be unavailable. We do not yet know if this design is common to microwave exhaust devices.

Calculated capture efficiencies (CE) are shown in Figure 2. Based on analysis of replicates (repeatability) and experiments conducted to verify overall method accuracy, any individual data point should be regarded as accurate to within $\pm 10\%$ of the value. Oven results are shown at right because the oven outlet directed exhausted from the back of the cooktop forward, with an effective release point assessed to be forward of the front burners.

Capture efficiency varied across the hoods, by airflow setting for each hood, by burners, and for some combinations of these factors, by installation location. For the two hoods with various fan settings, CE followed generally similar patterns across burner configurations and was in almost all cases substantially higher at the higher fan setting. Differences in CE between low and high fan settings were greatest for the front burner and oven for Hood A installed at the wall and for back burners for Hoods A and B installed away from the wall.

When installed flush to the back wall, all three hoods had substantially better CE for back burner versus front cooktop burner use. For one front and one back burner (diagonal), CE was generally between the values for two front or two back burners. Installed flush to the wall, CE for oven use was generally better than for front burners. At the highest fan settings and hoods flush to the wall, CE for back burners was at $>80\%$ for all three hoods, whereas CE for front burners varied from roughly 46-63% for Hood B to 73-78% for Hood A. At the lowest fan setting and hoods flush to the wall, CE for Hoods A and B was roughly 55-70% for back burners but only 20-40% for front cooktop and oven use. Still focusing on the panels at left of Fig. 2 (flush to the wall installations), the spread in CE seen for each hood, fan setting, and burner configuration is an indication of the impact of installation height. In almost all cases, install height caused less variability in CE than the other factors. The obvious exception is for

oven use with Hood B on highest fan setting. For this operational condition the lowest installation (45 cm) achieved substantially better CE than the higher installation of 75 cm.

When installed 15 cm from the wall there was a small CE improvement for front burner with Hood C and substantial improvement for front and oven burners with Hood B on the lowest airflow setting. In contrast, this installation lowered CE for back burners on all evaluated airflow settings for all three hoods.

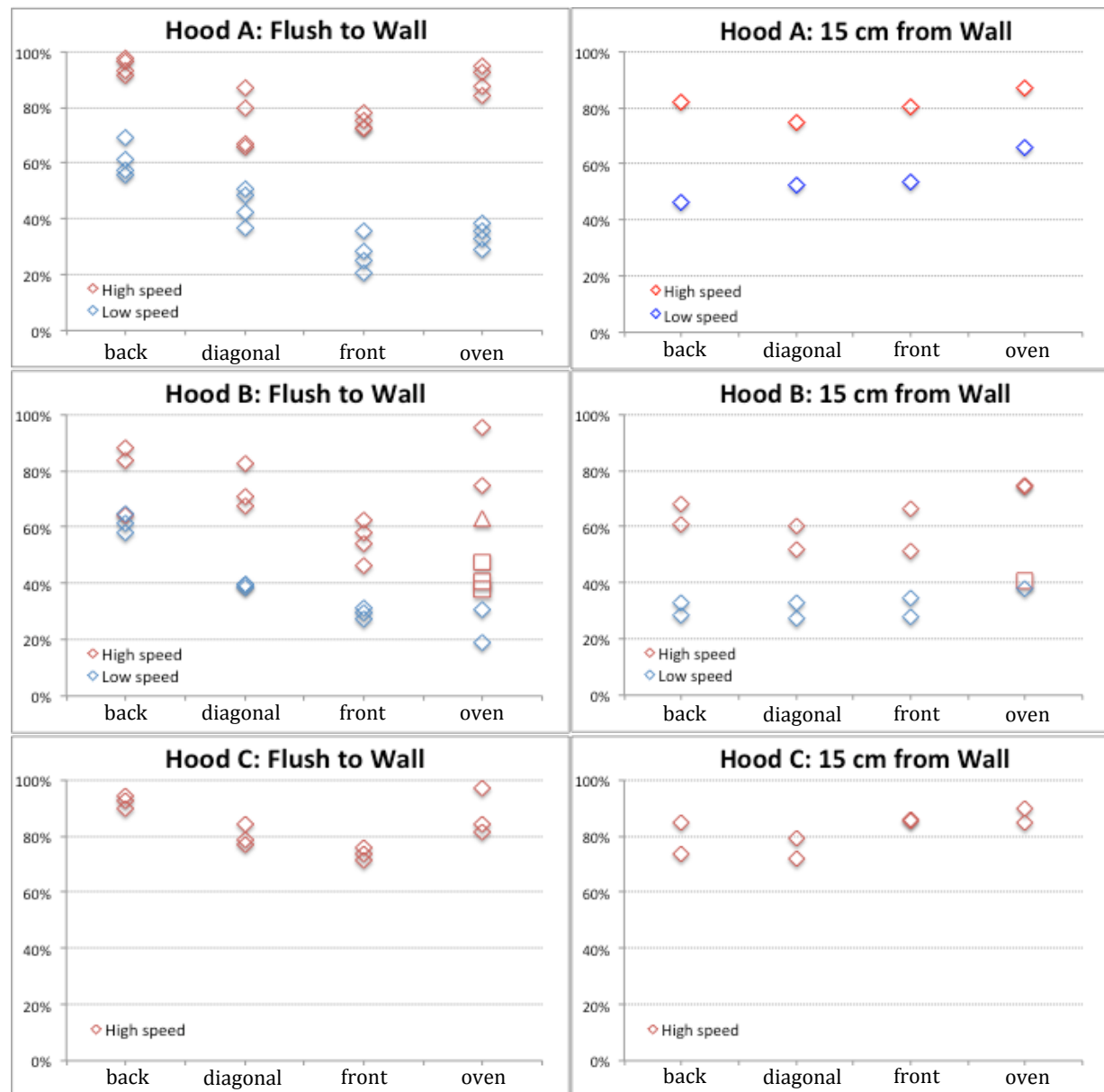


Figure 2. Capture efficiency by installation location and burners. Height distinguished only for Hood B oven experiments, with diamonds (45 cm), triangle (60 cm) and squares (75 cm).

DISCUSSION

The results presented in this controlled laboratory study should be considered as best case. Airflows for installed devices may be lower due to poor duct design, blocked ducts and attic grills and other flow restrictions. Capture efficiency may be reduced when open windows and movements of the cook interfere with airflow patterns. The use of higher heat (e.g. “power”) burners or more burners at one time is also expected to reduce capture efficiency.

Results presented in this paper are mostly consistent with results of recent performance measurements for a sample of 15 kitchen exhaust devices installed in residences (Singer et al., 2010, 2011). A multivariate model developed from the data in that study suggested that design, airflow, burner choice and the extent to which the hood covered the burners being tested all had significant influences on CE. The finding in the laboratory experiments that the microwave hood had higher exhaust than inlet airflow raises questions about the calculated CEs for microwaves in the field study. Calculated CE is based on CO₂ mass flow in the exhaust, which is calculated as the product of exhaust CO₂ and airflow (Eq. 1). For hoods installed in homes, airflow was measured only on the inlet side. If exhaust airflow is substantially higher than using the inlet airflow leads to an underestimate of CE. A tracer based approach – in which tracer gas is released at a known rate at a location that is fully captured by the hood, then measured in the exhaust - can be used to check the exhaust airflow from installed microwave hoods.

Preliminary results from screening photos of homes for sale on Zillow.com indicate that for new homes in California (built 2005-2010) the microwave over the range exhaust fans are the most common type. Results for Hood A suggest that these devices can be effective when cooking is preferentially done on back burners and the hood is operated at the highest airflow setting. The results of this study indicate that the lowest airflow settings – which are the most quiet and thus, assumed to be the most commonly used – fall far short of consistent, effective performance.

CONCLUSIONS

Exhaust pollutant capture efficiencies (CE) for common cooking exhaust devices vary substantially with airflow rate and device design, but not so much with installation height (range of 35 to 75 cm). In these and previous experiments, the best CE was achieved for cooking on back cooktop burners at airflow settings in excess of 200 cfm. Installing standard hoods farther from the wall does not consistently improve performance for front cooktop burners but does harm CE for back burner use. Information about hood performance would enable purchasers to select more effective models and might create market pressure to improve hood performance across the board.

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