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Abstract

This study assessed the performance of seven new residential cooking exhaust hoods representing common U.S. designs. Laboratory tests were conducted to determine fan curves relating airflow to duct static pressure, sound levels, and exhaust gas capture efficiency for front and back cooktop burners and the oven. Airflow rate sensitivity to duct flow resistance was higher for axial fan devices than for centrifugal fan devices. Pollutant capture efficiency (CE) ranged from <15% to >98%, varying across hoods and with airflow and burner position for each hood. CE was higher for back burners relative to front burners, presumably because most hoods covered only part of the front burners. Open hoods had higher CE than those with grease screen and metal-covered bottoms. The device with the highest CE – exceeding 80% for oven and front burners – had a large, open hood that covered most of the front burners. The airflow rate for this hood surpassed the industry-recommended level of 118 $L \cdot s^{-1}$ (250 cfm) and produced sound levels too high for normal conversation. For hoods meeting the sound and fan efficacy criteria for Energy Star, CE was <30% for front and oven burners.

Introduction

Residential gas cooking burners emit air pollutants[1-3] at rates that can lead to indoor concentrations exceeding health-based standards.[4] Cooking also produces air pollutants[5-6] in addition to moisture and odors. Removal of these contaminants is important for maintaining acceptable indoor air quality in homes.

Devices designed to remove cooking-related contaminants include exhaust hoods and combination microwave / exhaust fans mounted above the cooktop, exhaust fans mounted in a kitchen wall or ceiling, downdraft exhaust fans built into the cooktop, and venting ovens. Performance metrics include airflow, loudness, power consumption, and effectiveness at removing contaminants before they mix throughout the home.

The airflow of an installed exhaust device depends on the performance curve of the fan, flow resistance within the device, and flow resistance through the venting system.[7] Exhaust fan flow also can be impacted by coincident operation of other fans and by restrictions associated with an airtight building envelope. The fan curve relates volumetric flow to the static pressure difference across the fan. Each fan operating speed will have a distinct fan curve. There is also a pressure vs. flow performance curve associated with the airflow pathway, comprising the hood and vent system. Figure S1 in the Supporting Information presents an example pressure trace as air moves through a system starting with grease screens at the hood inlet. Flow resistance through the grease screen varies with use and cleaning. The actual airflow rate is determined by the intersection of the fan curve and system curve. The Home Ventilating Institute (HVI) certifies and publishes exhaust fan flow measurements at a static pressure difference of 25 Pa.[8]

The residential ventilation standard (62.2) promulgated by the ASHRAE building technology society requires a "local mechanical exhaust system" to be installed in each kitchen. The requirement can be met by an exhaust flow of 5 kitchen air volumes per hour (ach) continuously or 47.2 L s^{-1} (100 cfm) on-demand; if the on-demand system exhausts less than 5 kitchen ach, it must be a range hood.[9]

HVI provides guidance on minimum and "recommended" airflows based on cooking appliance width and installation. For wall-backed installation, minimum and recommended rates are 62 and 155 $L \cdot s^{-1}$ per meter of appliance width (40 and 100 $cfm \cdot ft^{-1}$). For island installations, minimum and recommended rates are 77.4 and 232 $L \cdot s^{-1} \cdot m^{-1}$ (50 and 150 $cfm \cdot ft^{-1}$).

Sound level is an important performance metric. Research indicates that hood use is infrequent and noise is one main reason cited.[10-13] The HVI Loudness Testing and Rating Procedure[14] entails operating devices in a reverberation chamber to measure relative loudness as perceived by human hearing, in units of sone. HVI certifies and publishes loudness results for many but not all commercially available hoods. The ASHRAE ventilation standard specifies a 3-sone limit at the required kitchen exhaust rate.

Power consumption varies with fan setting and can be described in absolute terms (W) or as fan efficacy, which characterizes airflow per unit power consumption ($L\ s^{-1} \cdot W^{-1}$). Power consumption information is not available for most cooking exhaust devices. In the U.S., range hoods qualify for the Energy Star label if they achieve 1.3 $L\ s^{-1} \cdot W^{-1}$ (2.8 $cfm \cdot W^{-1}$) at 2 sone or less and the product does not have airflow capacity exceeding 236 $L \cdot s^{-1}$ (500 cfm) at any setting. Very high airflow rates are prohibited because they are more likely to cause backdrafting of combustion appliances[15] and can substantially impact thermal conditioning loads that impact building energy use.

Capture efficiency (CE) is the fraction of pollutants generated at the cooking device that are removed by the exhaust fan. While there is no standard method to quantify CE for residential exhaust devices, the effect of design parameters and physical processes on CE has been examined using airflow models[16-18] and through controlled experiments, typically with a single hood or test system.[19-22] CE has been quantified experimentally using water vapor,[19] particles,[19, 22] an inert tracer released at the cooktop,[20] and carbon dioxide.[23] CE may differ for burner and cooking-generated contaminants.

Published data on installed cooking exhaust fan performance are limited. Measurements of 9 models in 17 Canadian houses in the 1980s found installed airflows averaging only 31% of rated values with only 3 units exceeding 50% of rated flow.[13] A more recent study reported airflow, sound, and capture efficiency for cooking exhaust devices installed in 15 California residences. [23] Measured airflows were at least 70% of advertised values for only 5 of 15 units. Capture efficiency depended on exhaust airflow rate, device design, and the extent to which the device covered the burners being used.

In the study reported in this paper, the performance of seven over-the-range hood designs available in the U.S. in 2011 was measured under controlled conditions in a laboratory setting configured to mimic a common kitchen installation.

Materials and Methods

Performance was evaluated for seven under-cabinet hoods under controlled conditions using two experimental configurations. The first configuration was used to measure electrical power and airflow over a range of static pressures to characterize a fan curve for each hood and to measure the sound produced at each fan setting. The second configuration was used to measure burner exhaust capture efficiency.

Exhaust Hoods Evaluated. Table 1 summarizes characteristics for the seven hoods. Pictures and additional details are provided in the Supporting Information (SI). The codes in Table 1 are used to identify hoods throughout the remainder of the paper. Devices were selected to represent common under-cabinet models available in the U.S. in 2011. The listed retail prices are the lowest identified during a limited search of major vendor web sites in November 2011. Prices ranged from a $40 economy hood to a high performance product costing $600. Sound and airflow ratings are from manufacturer specification sheets. L1 and B1 each have a shallow hood with the fan and motor housing at the back center inside the hood. Air inlets covered with grease screens (25×21 cm for L1, 28.5×29.5 cm for B1) are at or near the bottom plane of each hood. E1 and E2 were the lowest priced of the Energy Star rated models. A1 is marketed as an ultra-quiet hood that is compliant with ASHRAE 62.2. A1, E1, and E2 have slim profile designs with grease screens covering air inlets that extend across the hood bottoms but not entirely from front to back (see photos in SI). For M1, approximately two-thirds of the exhaust air is drawn through two 19.5×22 cm grease screens on the bottom and one-third is drawn through an inlet above the microwave door. P1 is distinct within the sample with a large collection hood extending entirely over cooktop burners, an air inlet up inside the hood and an impaction plate instead of screens to collect grease.

Fan and Airflow Performance. Fan curves were characterized with an apparatus similar to that used to measure airflows for HVI certification.[8, 24] Our apparatus (Figure S2 of SI) had a settling chamber for stable static pressure measurement, a throttling device, and a calibrated fan (The Energy Conservatory (TEC) "Duct Blaster") for volumetric airflow measurement. Static pressure was measured with four surfaced-mounted taps connected in a manifold attached to an Automated Performance Testing (APT) system (from TEC). A 25-cm iris damper (Fantech IR10) throttled flow for gross control and the Duct Blaster was used for fine control and measurement, with an estimated uncertainty of 3%. Power was measured with a WattsUp? inline power meter (Electronic Educational Devices).

Fan curves were measured by operating the fan at the lowest, highest and intermediate settings. At each setting, the damper was set to a target of 50 Pa maximum pressure difference across the hood. The calibrated fan was then used to reduce the pressure from

50 Pa down to zero while the data logger recorded the airflow, power and pressure over a period of several minutes. Data were recorded every 2 s.

Sound. In place of the HVI loudness measurement, we measured A-weighted sound pressure levels.[25] These were measured for each hood at each fan setting with the hood connected to the airflow apparatus, the damper fully open, and the Duct Blaster removed from the system. Sound pressure measurements were conducted in a room-sized chamber with background sound levels of approximately 35 dB_A. Sound was measured with an Extech model 407736 Digital Sound Level Meter placed 0.5 m in front of the hood, level with the hood bottom opening and horizontally on center.

Capture Efficiency. Figure 1 presents a schematic of the apparatus used to determine capture efficiency. Each hood was mounted to metal strut 76-cm above the cooktop of a U.S. standard 76-cm wide cooking range. Over-the-range microwaves are generally installed with bottom air inlets lower than other hoods and they typically project less from the wall to minimize interference with cooktop use. M1 was installed with the bottom 37 cm above the cooktop. Installation height was within manufacturer recommendations for all devices. Hoods were installed between plywood boxes to simulate the cabinets in a typical “under-cabinet” installation (Figure 1). The range was installed between plywood boxes simulating countertops. Burners used for capture efficiency experiments were one 12.7 $MJ \cdot h^{-1}$ (12.0 $kBtu \cdot h^{-1}$) and three 10.0 $MJ \cdot h^{-1}$ (9.5 $kBtu \cdot h^{-1}$) cooktop burners and a 19.0 $MJ \cdot h^{-1}$ (18.0 $kBtu \cdot h^{-1}$) oven burner; the larger cooktop burner was in the front.

A 61 cm long, straight section of 15 cm diameter duct was connected to the top of the hood via a collar. Above this section was a butterfly damper then a 3 m long section of flexible aluminum ducting installed with bends to increase pressure drop. The flexible ducting was connected to the Duct Blaster. A pressure transducer installed 30.5 cm above the hood provided an estimate of static pressure just downstream of the hood.

Carbon dioxide concentrations in the exhaust duct were measured with an EGM-4 infrared analyzer (ppsystems.com) approximately 3 duct diameters downstream of the hood. The APT recorded pressure and CO_2, and controlled and recorded flow measurement data from the Duct Blaster. The logging interval was 2 s. The time to burn 10 l of natural gas was measured twice for each burn cycle using an American/Singer DTM-115 dry gas meter.

Capture efficiencies were determined at 3–6 operating points per hood that were achieved using the damper and powered Duct Blaster. Capture efficiency was measured for three burner configurations at each fan operating point: 1) both back burners, 2) both front burners, and 3) the oven. Covered 5 l pots filled with approximately 3 l water were placed on cooktop burners to simulate use. The oven was set to 232 ^{0}C. Each burn lasted 2–6 min, terminating when the researcher observed a steady exhaust CO_2 concentration. During these short burns, the oven never reached the temperature set point and water on the cooktop did not boil. The time to reach steady CO_2 was longer for the oven than for the cooktop. The researcher did not approach the range during experiments to minimize activity-induced air currents that can influence capture efficiency.[26]

Capture efficiency (CE) was calculated from airflow (Q), the increment in CO_2 concentration above room background (ΔCO_2) and the CO_2 emission rate (S) as summarized in Eq. 1. Details of this calculation are provided elsewhere.[27]

$$CE = \frac{Q \cdot \Delta CO_2}{S} \tag{1}$$

Figure 2 presents illustrative CO_2 concentration profiles for two burner configurations at the same airflow. Red and blue lines show average concentrations during burner on and off periods. Including the larger burner, the front cooktop burners had a higher firing rate and correspondingly higher CO_2 generation rate, but CO_2 concentrations were lower for front vs. back burners owing to lower capture efficiency.

The effect of CO_2 measurement uncertainty was calculated by combining in quadrature the standard deviations for concentrations measured during burner on and off conditions. This ΔCO_2 uncertainty was inserted into Eq. 1 to show the effect on calculated CE. For these examples, higher variability in exhaust CO_2 resulted in larger uncertainty in calculated CE for the front burners (±6%) compared to back burners (±2%). Overall uncertainty in the calculated capture efficiency values is larger as it includes uncertainty of at least 1-2% in the accuracy of the calibrated CO_2 analyzer, approximately 3% in the uncertainty of airflow, and up to a few percent uncertainty related to fuel flow measurement and gas composition.

Results and Discussion

Airflow Performance. Figure 3 presents results of airflow and fan efficacy measurements. The bottom panel displays the fan curve for each evaluated fan setting, and the top shows fan efficacy. The fan curves are fits to series of data that are presented in the SI. The shape of the fan curve determines how the hood will perform across installations with varying pressure characteristics. A steeper curve will better maintain flow as system pressure increases and is therefore more tolerant to poor installation. L1 and B1 have axial (propeller style) fans; for these devices flow on the high speed setting dropped 34% and 26% from free air delivery to the 25 Pa rating point. With the exception of E1, the centrifugal fans featured in the other devices produced much more robust fan curves with airflow reductions of only 7 to 10% from free air delivery to 25 Pa. E1 airflow dropped by 23% over the same difference in duct static pressure.

Efficacy is a measure of how much air is moved per unit input of electrical power. The two Energy Star qualified units met the benchmark efficacy of 1.3 L $s^{-1} \cdot W^{-1}$ (2.8 cfm$\cdot W^{-1}$) at 25 Pa and the 2-sone limit only at low speed. Interestingly, the L1 economy hood achieved the efficacy benchmark during high-speed operation at static pressures up to about 30 Pa and during low speed operation at pressures up to about 20 Pa. But the loudness of the device – rated at 6 sone on high speed and unrated at low speed – does not meet the Energy Star criterion for sound. The last column of Table 1 presents measured airflow performance compared to values in product specification sheets. Four of the hoods had flows above 90% and two had flows that were 80-85% of specified values. The Energy Star rated E1 moved only about 50% of the rated flow. We confirmed this result by procuring and testing a second unit of the same make and model that had the same test results, as shown in the SI.

Sound Levels. The left panel of Figure 4 presents measured sound level versus airflow for each hood connected to the flow measurement apparatus with the damper fully open and the Duct Blaster disconnected. Airflows were estimated using the flow vs. pressure relationships shown in Figure 3 and pressure measurements downstream of the hood (SI Figure S2). Sound levels generally increased with airflow, but the amount of change varied by hood. At airflows approaching or meeting the HVI recommended rate of 118 L$\cdot s^{-1}$ for this appliance width, measured sound levels exceed those associated with conversation. The right panel presents measured versus rated sound levels. By definition, a pure tone at 1 kHz, 1 sone corresponds to 40 dB_A. Doubling would raise the sound pressure to 50 dB_A or 2 sone; doubling again would yield 60dB_A or 4 sone. The 1:1 line in the right panel shows this relationship. Most of the measured data are above this line, reflecting slightly noisier operation than expected based on sound ratings. Four of the devices – B1, A1, E2, and M1 – had measured sound levels below 50 dB_A (corresponding to <2 sone) at low speed operation. Airflows at these settings were in the range of 40-70 L s^{-1}.

Capture Efficiency. Figure 5 presents capture efficiency results. At the ASHRAE and HVI minimum flow, CE was only about 60% for back burners and 25-30% for oven and front burners. Hoods that achieved HVI-recommended airflows had capture efficiencies of about 80% or greater for back burners, but only 60% or greater for the oven and 50% or greater for front burners. For front burners, several of the hoods had CE decrease at higher airflows, presumably owing to changes in airflow patterns. These results reinforce previous findings[23] that back burners should be used preferentially to enhance pollutant capture – and thus achieve better IAQ – with any given hood installation.

Figure 5 indicates performance differences between hood designs and models. P1, a large open hood with better coverage of front burners, had the best overall CE performance with high efficiencies for all burner configurations. As a design group, the flat profile hoods A1, E1, and E2 had CEs lower than open hoods – including the basic units B1 and L1 – at similar airflows. That E1 had such low CE – not exceeding 50% for front and oven burners even at the maximum potential airflow – points to the importance of considering multiple criteria to assess performance. The higher fan efficacy of E1 is of questionable value if it does not achieve the primary intended utility of effectively removing cooking fumes and burner exhaust. An alternative rating could relate fan power to capture efficiency or to the product of airflow and CE.

In addition to capturing pollutants during the first pass of the rising exhaust plume (Figure 5), cooking exhaust fans aide in pollutant removal by increasing overall home ventilation. To explore this effect we used a single-zone mass balance model to calculate pollutant concentrations *C(t)* throughout a theoretical home with perfect mixing:

$$\frac{dC(t)}{dt} = \frac{S(t)}{V} + \lambda(t)C_{out} - \lambda(t)C(t) \tag{2}$$

In this model, *S(t)* is the exhaust pollutant generation rate, *V* is home volume, *λ(t)* is the outdoor air exchange rate, and C_{out} is the concentration of the pollutant outdoors (assumed as 0 for this analysis). We calculated time-integrated exposure over a 4-h period following a 30-min cooking event. Our reference condition was burner use without hood operation. The generation rate was *S(1-CE)* with hood use. The model was run for two home volumes based on the 25th and 75th percentile floor areas (82.6 and 232 m^2) in the 2005 Residential Energy Consumption Survey database[28] and assumed ceiling heights of 2.4 m and 2.6 m for the two home sizes. Base air exchange rates of 0.20 and 0.65 h^{-1} were used to represent relatively airtight and leaky homes with windows closed. The air exchange rate with hood use was calculated by combining base ventilation and range hood airflow using the quadrature approximation.[29-30] This captures the first order effect that in most cases air exchange will not increase by the full amount of the fan flow rate. The actual change in total ventilation depends on a complex suite of physical parameters and interactions.[30]

Figure 6 displays results for this analysis. The bottom panel compares time-integrated exposures normalized to the reference of no hood use. For each case the thin solid and dashed lines are for base ventilation rates of 0.65 and 0.20 h^{-1}, respectively. The upper set of lines in each band is for hood airflow of 47 $L \cdot s^{-1}$ (100 cfm), and the lower set for 118 $L \cdot s^{-1}$ (250 cfm). The thick solid line shows 1-CE. Differences between this line and the bands below result from increasing home ventilation with the exhaust fan. This difference is more pronounced for the small volume as the extra ventilation has a larger impact on the air exchange rate. The upper panel presents the same data, but as overall capture efficiency. With a smaller home (or an isolated kitchen) the temporary increase in ventilation can substantially enhance capture efficiency.

Discussion. This study demonstrates the importance of considering multiple criteria to evaluate cooking exhaust hood performance. The low- to moderately-priced devices evaluated in this study achieved high CE, high fan efficacy, and quiet operation, but not all at the same time. A microwave hood (M1) and an ultra-quiet hood (A1) demonstrated capacity for quiet operation at low speed and first-pass CE exceeding 70% for oven and front burners and exceeding 90% for back burners when operated at high speed. These devices use very high flow rates to overcome physical designs that are less conducive to capturing cooktop burner exhaust. The best and most robust device for CE (P1) has a large volume, open hood that extends farther over the cooktop and exhausts air at HVI-recommended flows. This hood achieved CEs exceeding 90% for back burners and >80% for oven or front burners even when added airflow resistance reduced air flow rates below HVI recommended levels. Fan efficacy for this device was just below the Energy Star criterion but sound levels were significantly above the 2-sone Energy Star limit. Current Energy Star standards do not consider the pollutant removal purpose of cooking exhaust fans and therefore do not adequately address performance efficiency.

Currently there is no standard test or rating system for CE of residential cooking exhaust hoods. Development of a test and rating system would allow incorporation of capture efficiency into Energy Star, ASHRAE 62.2 and other standards.

To avoid increasing the backdrafting risk for natural draft appliances[15] and to reduce energy penalties, it is necessary to improve pollutant removal performance without resorting to increased air flows. Our results indicate that products can be improved by (1) improving geometry of hood construction by being deeper front to back, and having recessed grease traps and blower entries up inside the hood; and (2) incorporating better fans and motors.

Routine use of even moderately effective venting range hoods can substantially reduce in-home exposures to cooking and burner-generated air pollutants. Effectiveness can be substantially enhanced by preferential use of back versus front cooktop burners and by using higher fan settings.

Acknowledgments

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Figures

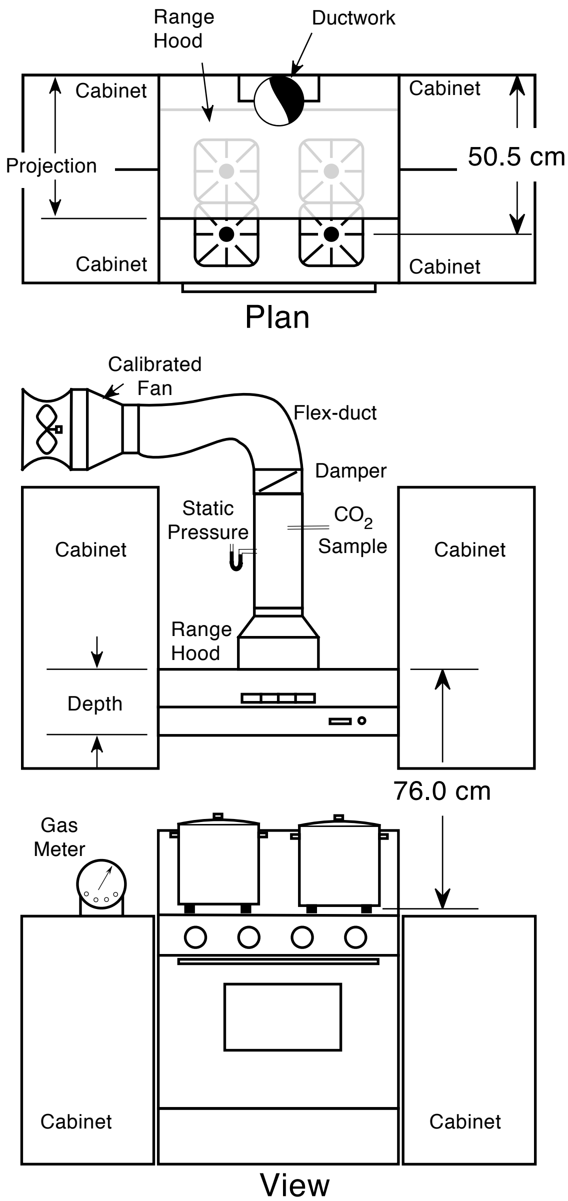

Figure 1. Experimental configuration used to measure capture efficiency.

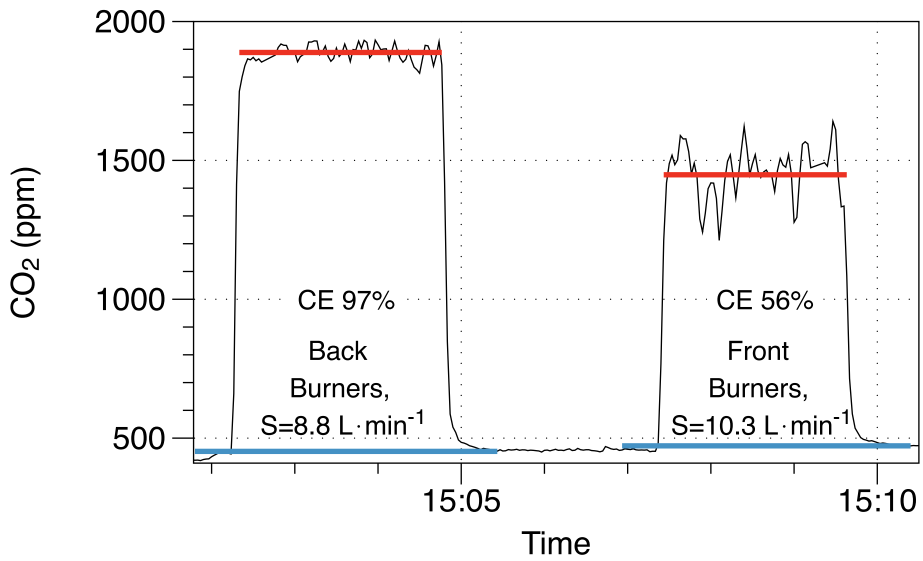

Figure 2. Example CO_2 concentration profiles during capture efficiency experiments. Red lines are averages over periods of burner operation. Blue lines are background concentrations in the room air, measured before and after burner operation. Differences in concentration are multiplied by airflow rates to calculate mass flows of CO_2 into the hood and capture efficiency.

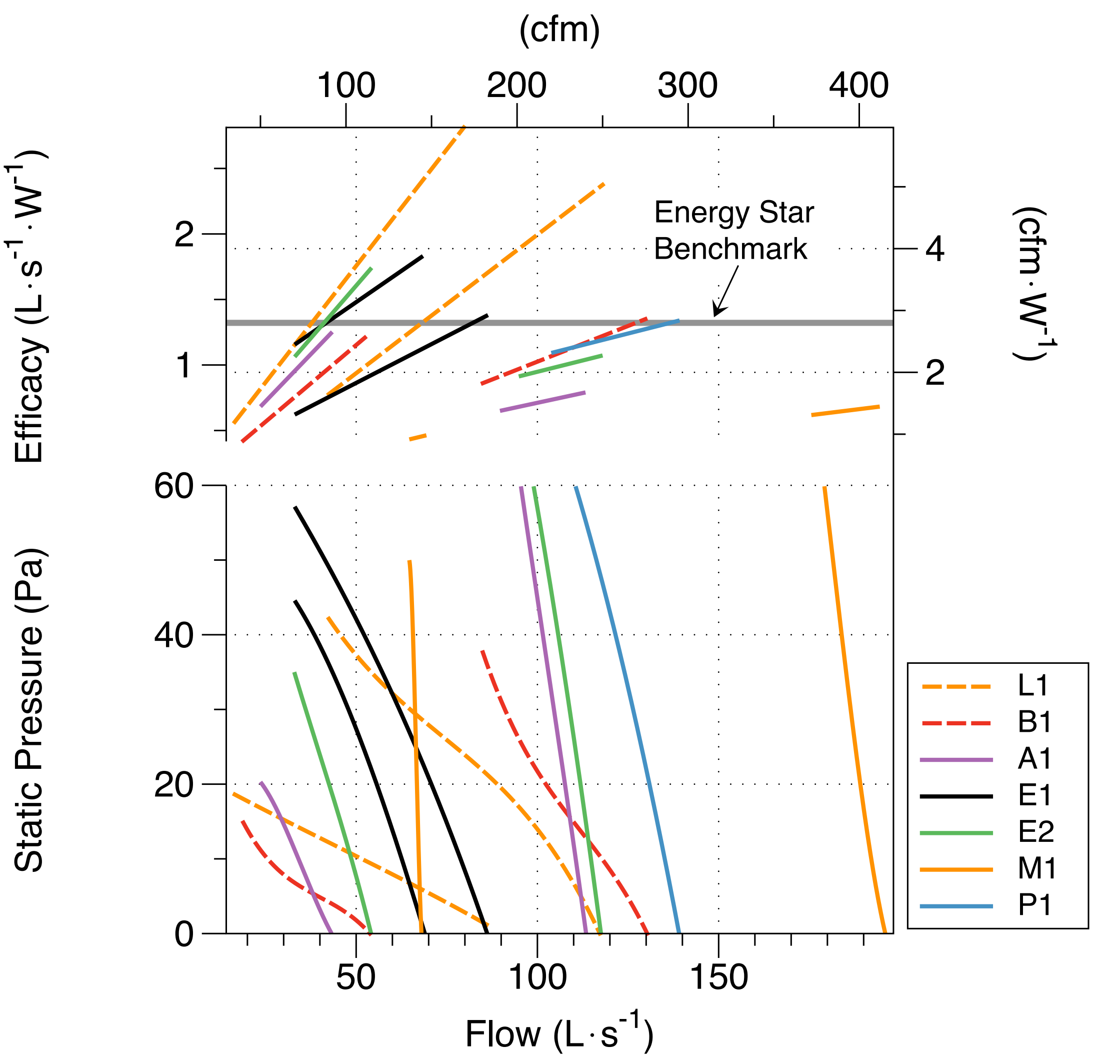

Figure 3. Measured flow performance of common U.S. cooking exhaust hoods. Dashed lines used for devices with axial fans, solid lines for devices with centrifugal fans. Lines in bottom panel are polynomial fits to data series presented in Supporting Information. Refer to Table 1 for device descriptions.

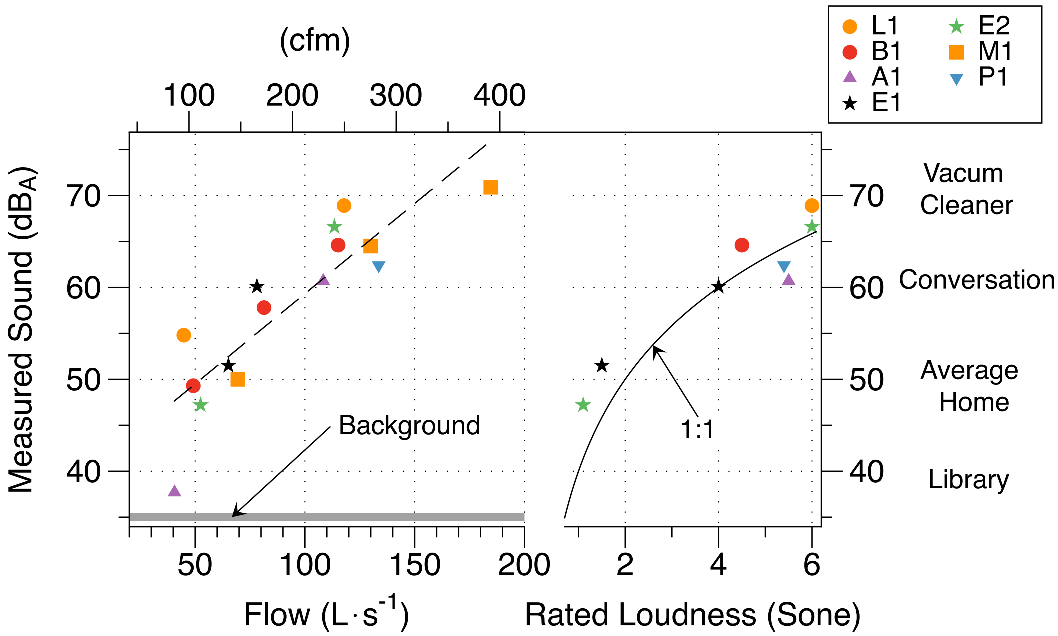

Figure 4. Measured and rated sound levels of common U.S. cooking exhaust hoods. Airflow values in left panel are estimated from pressure measurements just downstream of the hood and pressure vs. flow relationships shown in Figure 3.

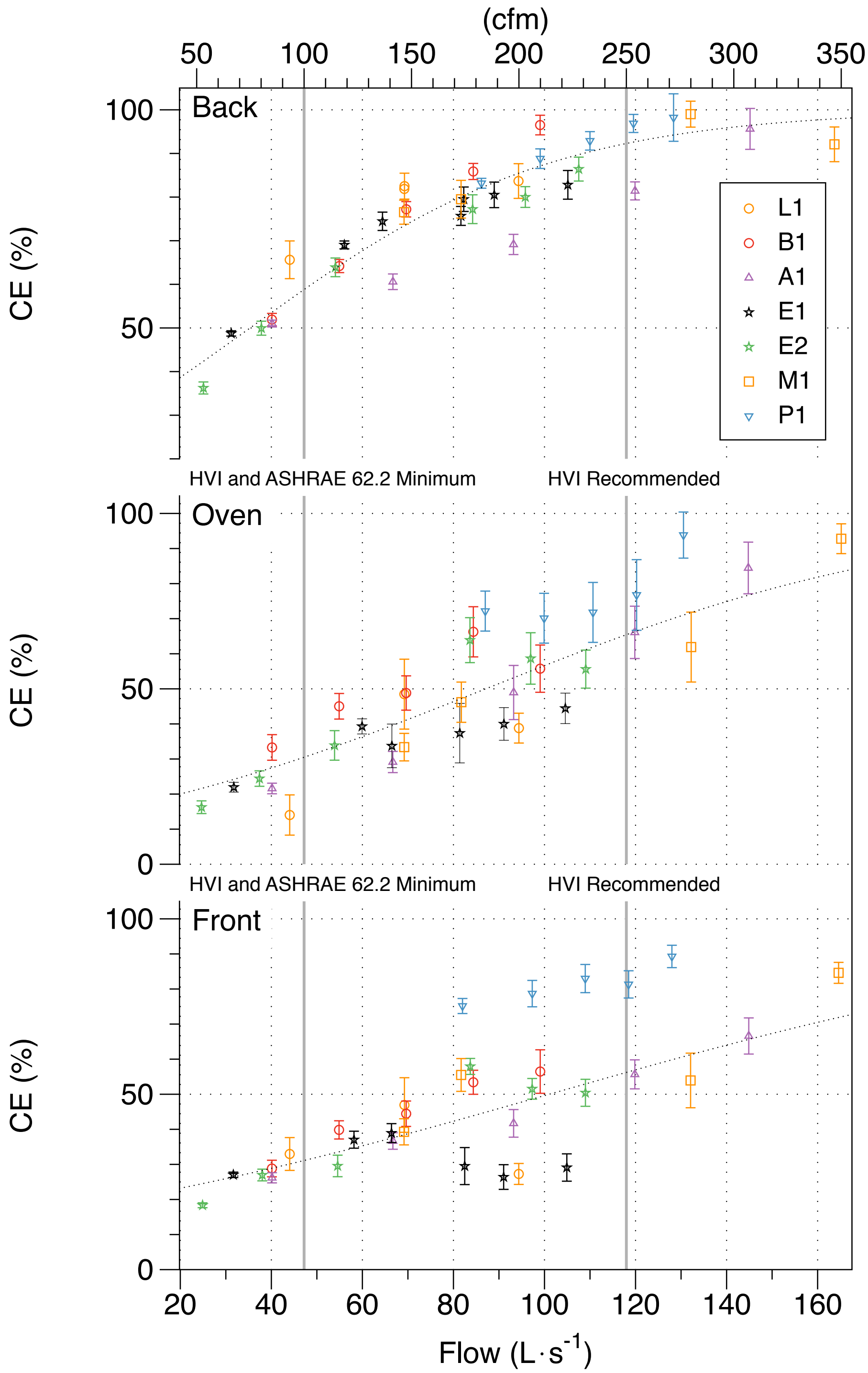

Figure 5. Measured capture efficiency of common U.S. cooking exhaust hoods. Stacked panels present results for back, oven, and front burners from top to bottom. The heavy vertical gray lines indicate minimum flow specified by HVI and ASHRAE 62.2, and the recommended flow by HVI. Error bars reflect variations in exhaust CO_2 measurements (refer to text for details). Dashed lines present a logistic function fit to the data to aid identification of hoods that perform better or worse than the trend.

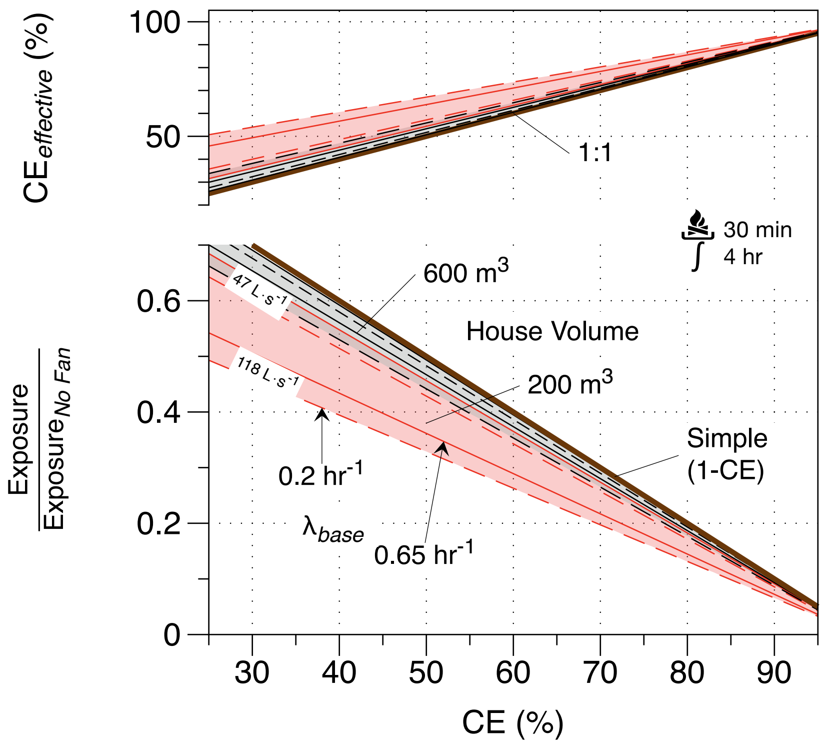

Figure 6. Relative exposures and effective capture efficiency based on modeling of range hood use in a small and a large home. Effective CE includes the benefit of increasing overall home ventilation rates when the exhaust fan is used. The thin solid and dashed lines are for base ventilation rates of 0.65 and 0.20 h^{-1}, respectively. The upper set of lines in each band is for hood airflow of 47 $L \cdot s^{-1}$ (100 cfm), and the lower set for 118 $L \cdot s^{-1}$ (250 cfm). The pink band is for a 600 m^3 space; the grey band is for a 200 m^3 space.

Table 1. Characteristics of the U.S. cooking exhaust devices evaluated in this study.

Hood	Description	Price	Fan type	Dimensions [a] (cm)		Rated sound (sone) and flow ($L \cdot s^{-1}$) at 25 Pa				Measured flow at 25 Pa
						Low		High		High
				Depth	Height	Sound	Flow	Sound	Flow	(% of Rated Flow)
L1	Basic, Low cost	$40	Axial	44.5	15.2	n/a [b]	n/a [b]	6	90	86%
B1	Basic, Quieter	$150	Axial	44.5	15.2	n/a [b]	n/a [b]	4.5	104	93%
A1	ASHRAE 62.2 [c]	$250	Centrifugal	50.8	18.4	0.3	52	5.5	132	80%
E1	Energy Star	$300	Centrifugal	49.5	19.1	1.5	71	4	127	52%
E2	Energy Star	$350	Centrifugal	53.3	11.1	1.1	57	6	118	94%
M1	Microwave	$350	Centrifugal	41.9	38.7	n/a [b]	61 [d]	n/a	198 [d]	95%
P1 [c]	Premium	$650	Centrifugal	53.3	22.9	- [e]	- [e]	5.4	129	100%

[a] All devices were 30” (76 cm) nominal width, designed to mount against a wall. Depth is the length from back to front of the device; air inlets spanned only part of this distance for most devices (see Supplemental Information for details).

[b] Rating information not available.

[c] Compliant with requirements of the ASRHAE 62.2 residential ventilation standard. Hood A1 was the least expensive hood that we found to be commonly available hood and compliant with the standard.

[d] Airflow and sound provided in product literature without a specified backpressure condition.

[e] Single speed unit.

Performance Assessment of U.S. Residential Cooking Exhaust Hoods

Supporting Information

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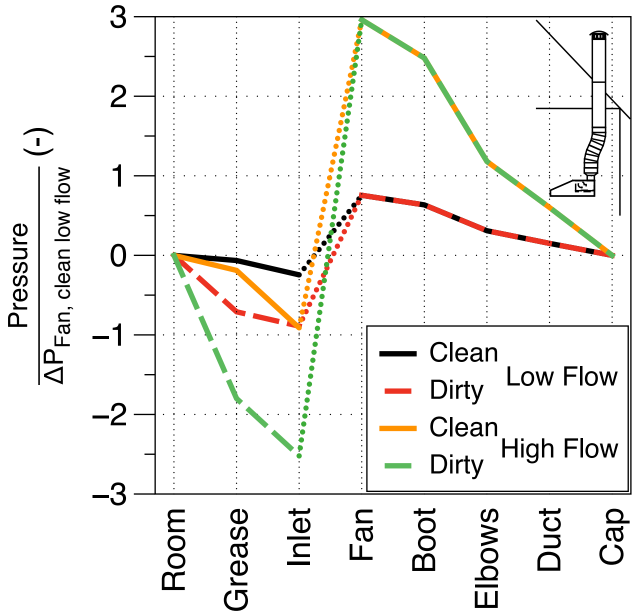

Figure S1. Pressure profiles through an example exhaust system.
The low and high flow settings for this example are 47.2 L·s^{-1} (100 cfm), and 94.4 L·s^{-1} (200 cfm). The pressures are normalized to the pressure rise across the fan at low flow with a clean filter and air pressure in the kitchen is taken as the reference. Upstream flow resistance is associated with grease screens (if present) and frictional losses as the air stream turns and reorients to pass through the fan. Downstream the air passes through a collar that connects the hood to ductwork then moves through the ductwork to exit through a rain cap.

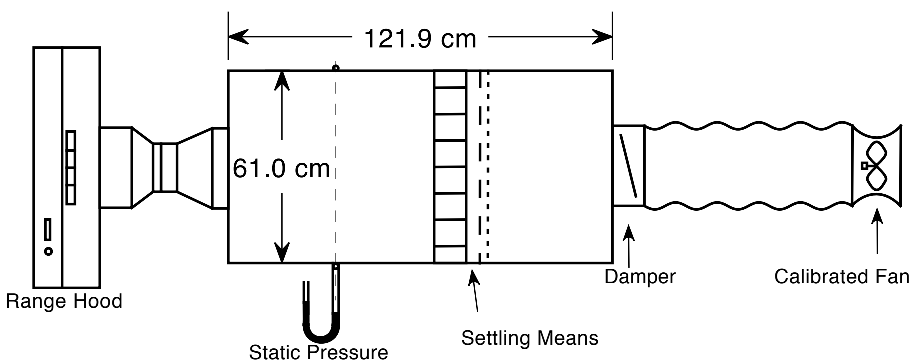

Figure S2. Apparatus used to measure airflow and pressure to characterize fan curves.

Unit Models

A brief description, pictures, pressure, flow, power and efficacy data for each hood follows. The description includes details pertaining to the bottom of the unit (flat, bowl, and grease screens). The data shows the complete airflow data, along with the fits used in the main paper.

Hood L1: Basic, Low cost

BROAN 42000 Series, Model 423001

This hood is an inverted "bowl." This hood is a basic low cost model. The fan is an axial type mounted in the center of the hood. There is a single grease screen mounted at an angle in front of the fan. The grease screen dimensions are 25.0cm x 21.0cm

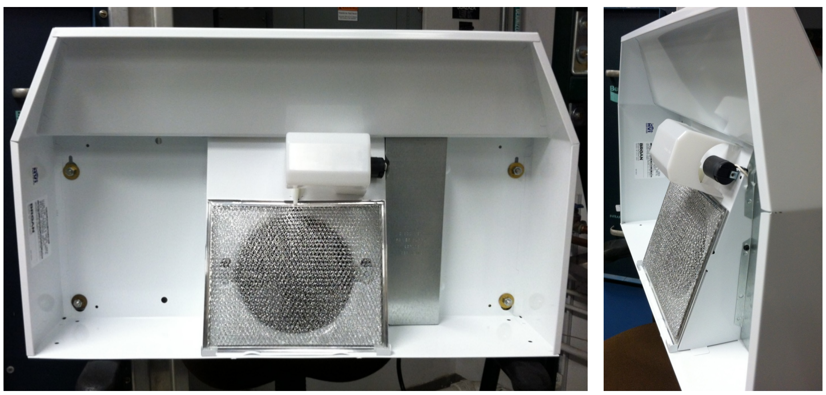

Figure S3. Bottom and side views of L1: BROAN 42000.

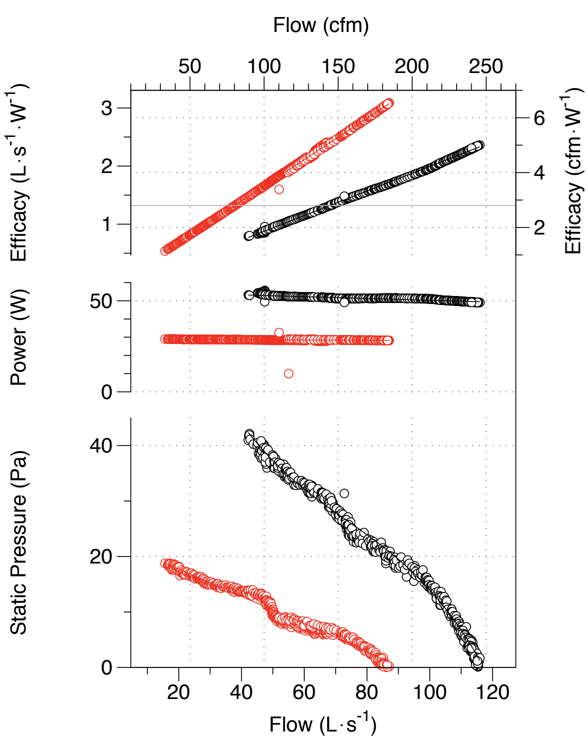

Figure S4. Pressure, flow, power, and efficacy data for L1: BROAN 42000.

Hood B1: Basic, Quieter

BROAN QT20000 Series, Model QT230BL

This hood is an inverted "bowl." This hood is a basic unit that is advertised as being quitter than the entry-level models. The fan is an axial type mounted in the center of the hood housed in a box-like enclosure. There is a single grease screen mounted flush with the bottom of the hood. The grease screen dimensions are 28.5cm x 29.5cm.

Figure S5. Bottom and side views for B1: BROAN QT20000.

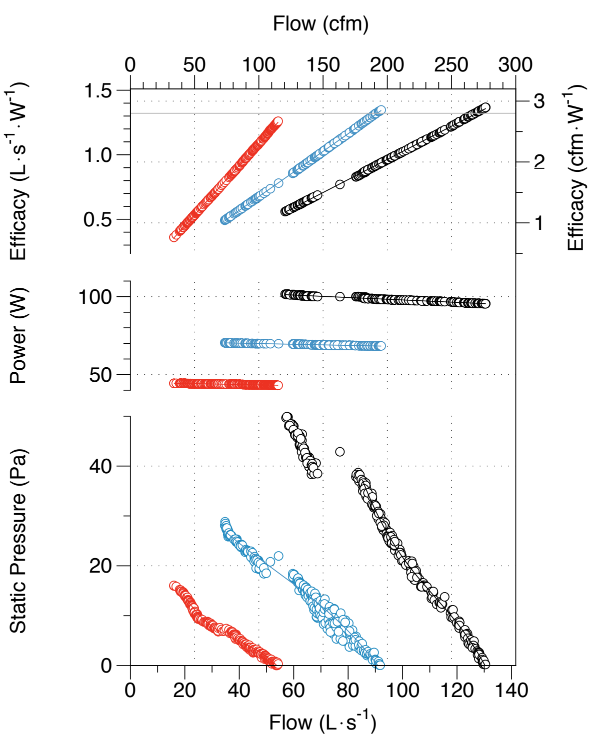

Figure S5. Pressure, flow, power, and efficacy data for B1: BROAN QT20000.

Hood A1: ASHRAE 62.2
BROAN QSIII Series (AllureIII), Model QS330WW
This is a flat-bottom hood, with no bowl-like structure. The hood is advertised as ultra quiet and meets ASHRAE 62.2 requirements. It has a single centrifugal fan mounted above the left-hand grease screen. The two grease screen each measure 36.5cm x 29.5cm.

Figure S6. Bottom and side views of A1: BROAN QSIII.

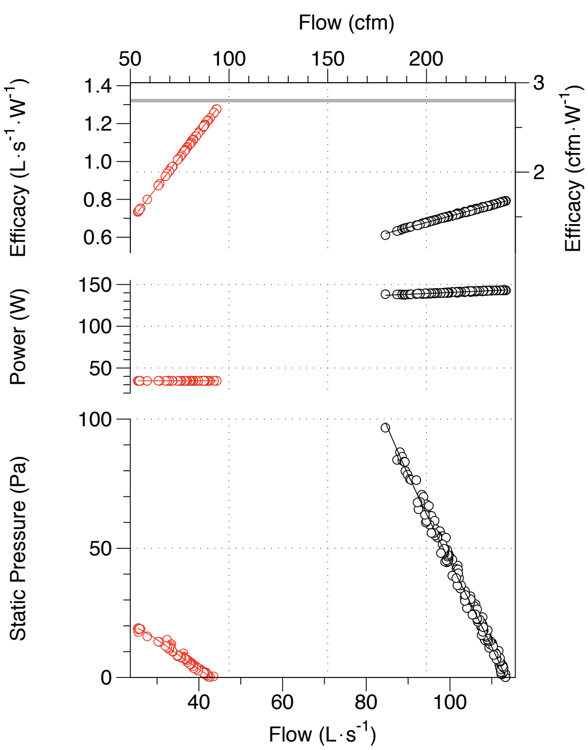

Figure S7. Pressure, flow, power, and efficacy data for A1: BROAN QSIII.

Hood E1: Energy Star
Air King ESDQ Series, Model ESDQ1303
This is a flat-bottom hood, with no bowl-like structure (the projection in the front houses the light and has no air path to the fan). The hood is advertised to meet EPA Energy Star requirements. It has a single dual-wheel centrifugal fan behind the solid panel on the bottom of the hood. Air is drawn in across both of the grease screens. The grease screens measure 23.0cm x 27.4cm.

Figure S8. Bottom and side views of E1: Air King ESDQ.

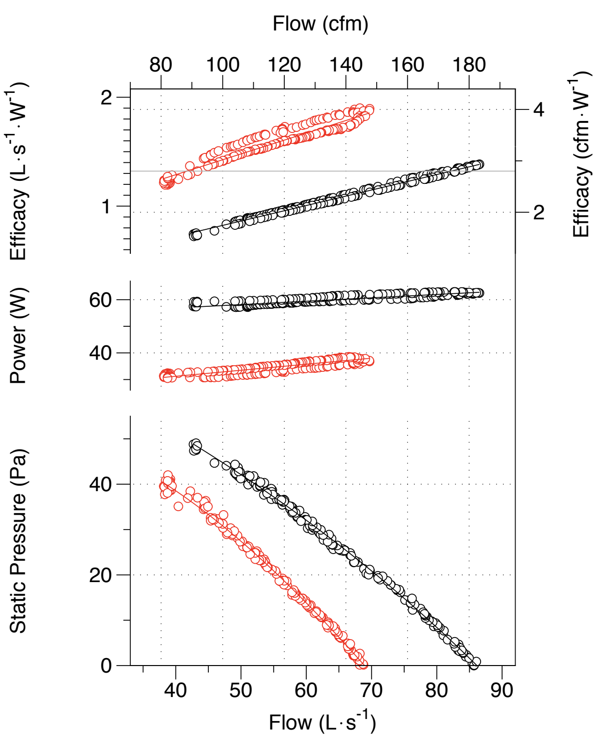

Figure S9. Pressure, flow, power, and efficacy data for E1: Air King ESDQ.

This hood fell considerably short of the manufacturer's published performance data. To see if the first hood tested was an anomaly another was purchased and tested. Figure S10 shows the results for both hoods and the published data. The performance data from the two hoods does behave somewhat differently but they are within 10% of each other. It should be noted that even though the hoods were purchased within a few weeks of each other, there were internal differences in the hood housings (electrical covers for one). It is not known if the differences between the two hoods can account for the performance difference. It is possible that changes were made in the manufacture of the hood since the initial test data was derived, and these changes have impacted the performance of the hood. All data in the main body of the report is based on Unit 1.

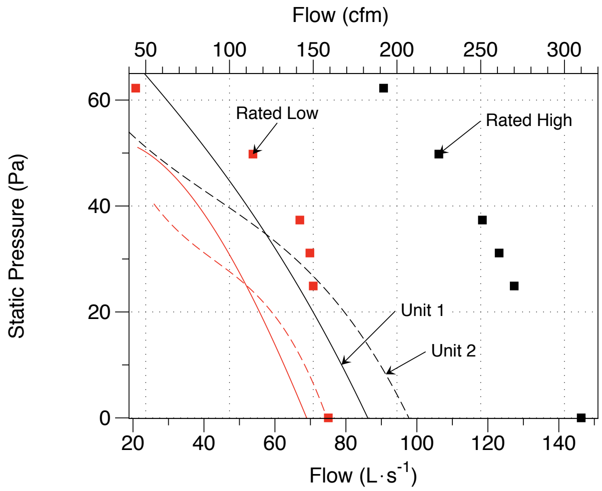

Figure S10. Comparison of two different Air King ESDQ units with manufacturer's published data.

Hood E2: Energy Star
BROAN QDE Series, Model QDE30SS
This is a flat-bottom hood, with no bowl-like structure. The hood is advertised to meet EPA Energy Star requirements. It has a single centrifugal fan mounted above the left-hand grease screen. The two grease screen each measure 35.0cm x 35.0cm.

Figure S11. Bottom and side views of E2: BROAN QDE.

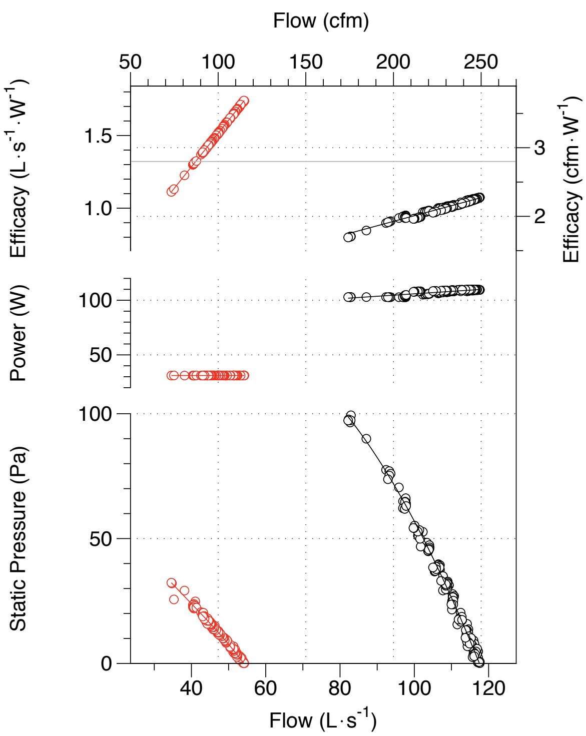

Figure S12. Pressure, flow, power, and efficacy data for E2: BROAN QDE.

Hood M1: Microwave

Panasonic Genius Prestige, Model NN-SD277BR

This "hood" is a microwave over range unit with an integrated exhaust fan. The bottom of the unit is flat with no bowl-like structures. It has a single dual-wheel centrifugal fan mounted near the center at the top of the unit, above the microwave. Air is drawn in through each of the grease screens on the bottom, as well as some vents above the microwave door. The grease screens each measure 19.5cm x 22.0cm.

Figure S13. Bottom and side views of M1: Panasonic Genius Prestige combined microwave and exhaust hood.

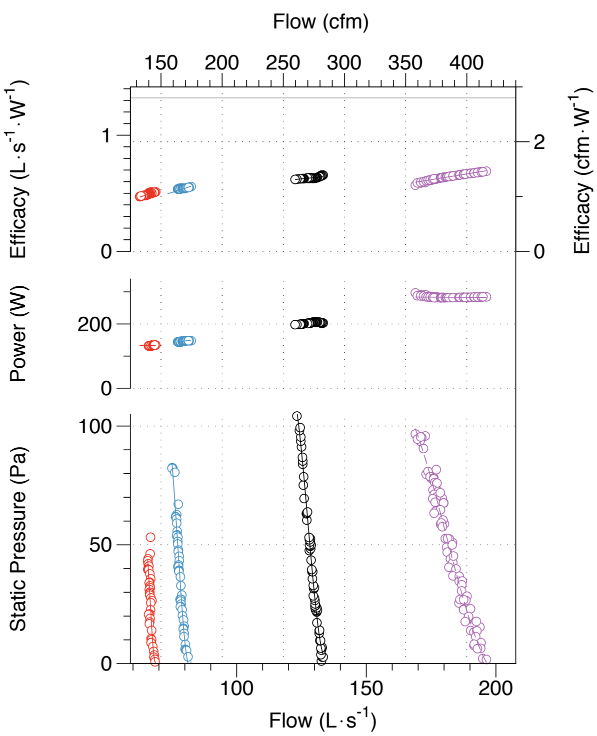

Figure S14. Pressure, flow, power, and efficacy data for M1: Panasonic Genius Prestige combined microwave and exhaust hood.

P1: Premium

Vent-A-Hood Professional Series, Model PR9-130

This hood is an inverted "bowl." This company sells premium hoods, and this is one of the lower end models. It is advertised as having a Magic-Lung™ blower, the claim is since there is no grease screen the unit moves an equivalent more air than one with a grease screen. The hood itself is essentially all bowl, with the centrifugal blower centrally mounted along the back wall. The panel in the picture serves as a grease drip pan; grease is removed from inertial impaction as the air changes direction to enter the fan.

Figure S15. Bottom and side views for P1: Vent-a-Hood Professional.
This device uses impaction and a pan to collect grease; there is no grease screen.

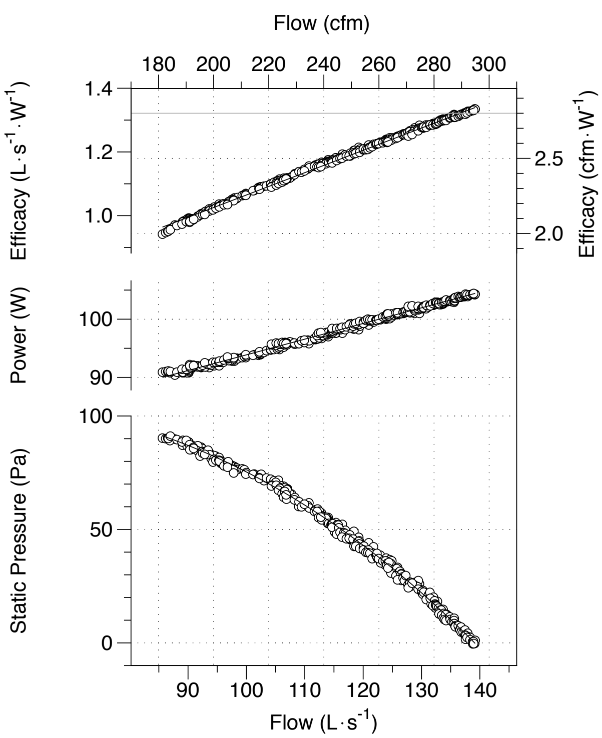

Figure S16. Pressure, flow, power, and efficacy data for P1: Vent-a-Hood Professional.

DISCLAIMER