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ABSTRACT

Burners and cooking activities are both major sources of air pollutants in many residences. Mechanical kitchen ventilation can effectively reduce cooking-related indoor air pollution but the knowledge about kitchen ventilation device performance and usage in real homes remains limited. We reviewed recent lab, field and survey studies that investigated the performance and occupant use patterns for mechanical kitchen ventilation devices. We have found the following three major issues. Firstly, in-home performance is lower than what was certificated in laboratory testing. In several recent field studies, researchers investigated 125 US single family homes and 23 apartments and found 82 homes had range hoods or over-the-range microwaves (OTR) certificated by Home Ventilating Institute (HVI) that had working airflows greater than 100 cfm. However, the field measurements showed only 44 of them had installed airflow that matched the rated, with the average ratio of installed versus rated flow of 0.76. The lower installed airflows were due to high air flow resistance of duct venting systems, incorrect installation and dirty hood inlets. Second, the knowledge of range hood performance for pollutant removal before mixing into the room (i.e. capture efficiency) is very limited. We found the capture efficiency was only measured for 57 hoods in 9 studies in the US, either in the lab or in the field. The measured capture efficiency ranged from 10% to 100%, generally increasing with the airflows. The capture efficiency can be influenced by the burner location, hood airflow, range hood geometry and test conditions. The main reason for limited capture efficiency data was the difficulty in conducting field measurements. Third was that the actual usage of the kitchen ventilation during cooking is low. Occupants often do not use their range hood due to the lack of awareness of the benefits of kitchen ventilation. A large survey study in Canadian homes showed that 30% of households reported regularly using their range hood. After being informed of the benefits of kitchen ventilation, the overall willingness to use the range hood was significantly higher. Field data from California showed range hoods were only used for 36% of cooking events in houses and 28% in apartments, though the occupants claimed they used them more frequently.

INTRODUCTION

Cooking has a significant impact on indoor air quality (IAQ). The heating of oil, fat, and other food ingredients that occurs during cooking releases quantities of particulate matter (PM) and gas phase chemicals that can cause significant irritancy or health risk. Cooking-related PM can be comprised of coarse (>2.5 um diameter), fine (<2.5 um

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diameter, PM2.5) and ultrafine (<100 nm, UFP) particles with elemental and organic carbon constituents including carcinogenic polycyclic aromatic hydrocarbons, and water-soluble ions (Abdullahi et al. 2013; Buonanno et al. 2009; Traynor et al. 1996). Hazardous gasses include irritants such as acrolein and formaldehyde, other carbonyls including acetaldehyde, and higher volatility polycyclic aromatic hydrocarbons (Fullana et al. 2004; Seaman et al. 2009; Y. J. Zhao & Zhao 2018). Combustion cooking burners also release UFP, nitrogen oxides (NOx) including the respiratory irritant nitrogen dioxide (NO_2) and carbon monoxide (CO) in quantities that can sometimes or often exceed hazard thresholds, depending on house size, cooking quantity and ventilation (Logue et al. 2014). UFP and potentially other pollutants can also be emitted from electric resistance elements as well as cooking pots and pans depending on materials deposited on their surfaces (Dennekamp et al. 2001; Wallace et al. 2008). Exposure to pollutants from cooking may have harmful impacts on the respiratory and nervous systems, causing oxidative stress, inflammatory response, and DNA damage (Elder & Oberdörster 2006). Epidemiological studies have linked exposure to pollutants from cooking and gas burners with respiratory diseases, cardiovascular diseases, and lung cancer (US EPA 2009; Yu et al. 2006).

The use of mechanical kitchen ventilation can effectively reduce exposure to cooking-related pollutants. A ventilation device placed over the cooktop—a range hood or over-the-range (OTR) microwave with an exhaust fan ducted to the outside—can capture pollutants from cooking and cooking burners before they mix into the room air. The importance of kitchen ventilation as source control is recognized in residential building ventilation standards. The ASHRAE residential ventilation standard (ASHRAE 62.2-2022) has required kitchen exhaust ventilation for decades, with minimum on-demand airflow of 100 cfm (50 L/s) at a maximum sound rating of 3 sones. The Energy Star program requires kitchen ventilation consistent with Standard 62.2 and additionally requires a minimum efficiency of 2.8 cfm/W (1.3 l/s/W) and a maximum sound level of 2.0 sones for range hoods with power consumption less than 75 Watts.

The device's intrinsic performance influences the effectiveness of kitchen ventilation to control cooking emitted pollutants. The two most commonly evaluated metrics are airflow and sound level. These metrics are measured using standard test procedures published by the Home Ventilating Institute (HVI Publications 915 and 916), with test results certified and published by HVI and the Association of Home Appliance Manufacturers (AHAM) via free online directories. However, many devices sold in North America and installed in American homes do not have certified airflows or sound ratings. In addition, the airflow of a range hood installed in a home can differ from the value published by HVI and AHAM because the static pressure in the duct system may be substantially higher than the duct static pressure in the HVI test. The ASHRAE 62.2 and California building code require range hoods that have at least 100 cfm (50 L/s) of airflow with a downstream duct static pressure of 62.5 Pa. However, many range hoods listed in the HVI catalog have been tested at downstream static pressures of only 25 Pa when the fan is operating at high speed and even lower at working speed.

A third metric, which has very limited data, is capture efficiency (CE). CE is defined as the fraction of contaminants emitted at the cooktop that are directly pulled into the range hood and exhausted to the outdoors before mixing throughout the house. In 2018, ASTM international published a standard test method for range hood capture efficiency (ASTM 2018) using a CO_2 mass balance method under steady state condition in a controlled lab. Other standard test methods to directly evaluate the removal of cooking pollutants (e.g., IEC 2005), are also conducted in a controlled laboratory environment, and are not applicable to field testing.

Venting range hoods help with IAQ management only if they are used when cooking occurs. Usage can be influenced by numerous factors including the cook's awareness of cooking-related pollutant hazards, the perceived need during specific cooking activities, the perceived effectiveness of the installed device, and the nuisance of the operating noise. In many studies, range hood use has been estimated based on participant self-reporting, either by a survey questionnaire to inquiry frequency or reasons for using the device (Chan et al. 2016; Klug et al. 2011; Piazza et al. 2007), or a daily activity log recorded in some IAQ studies (Sun & Wallace 2021). Studies that directly measured the usage of range hoods remain very limited, especially in North American homes.

SCOPE

This paper focuses on the performance and usage of kitchen exhaust ventilation in North American homes. We first review studies of intrinsic product performance, including those conducted under controlled laboratory conditions and measurements of devices as installed in homes. Intrinsic performance parameters include airflow, sound level, and contaminant capture efficiency. Our synthesis of these results aims to highlight the factors that appear to most impact in-situ performance. We do not directly analyze data from certification tests for airflow and sound; but we do compare measurements of installed performance to the certified values and to ventilation standard requirements. We next summarize measurement- and model-based studies of kitchen ventilation effectiveness in reducing pollutant concentrations for North American homes. Finally, we summarize results from several large surveys which aimed to quantify both the actual usage patterns of kitchen exhaust ventilation in occupied homes and the factors that impact usage. The paper focuses on studies conducted over the past 20 years.

DISCUSSION

Kitchen ventilation product performance in laboratory or field settings

The HVI air flow measurement method cannot be applied to devices installed in homes. An alternative method to measure airflow of installed ventilation fans was described by Walker et al. 2001. The air flow is measured using an adjustable, calibrated fan and flow meter to neutralize the pressure at the inlet or outlet to the ambient conditions and thus obtain the air flow under installed operating conditions. The method has been used to measure installed airflow in homes and lab studies that mimic real home setups. Table 1 summarizes recent studies that reported airflows for various types of range hoods as installed in homes and in laboratory settings that mimic home kitchens.

Capture efficiency has been studied less than airflow, mainly because of the difficulty of the measurement. Previous studies have applied varied methods to measure CE in both laboratory and field settings, as shown in Table 1. Singer et al. 2012 used a dynamic CO_2 mass balance method that involved heating pots of water on a gas cooktop. CO_2 mass flow through the exhaust duct was determined as the product of the measured airflow and the measured CO_2 concentration in the duct. The CO_2 mass emission rate from natural gas combustion was calculated based on the firing rate of the burners and estimates of natural gas composition, and assuming complete combustion. Capture efficiency was calculated as the ratio of the exhausted CO_2 flow to the calculated emission rate. The study reported CE for 15 range hoods in occupied homes with varied burner selection and airflow settings with a range of CE from about 20% to almost 100%, with generally increasing CE at higher air flows and how well the burners were covered - with back burners heaving higher CE. Delp & Singer 2012 conducted laboratory tests for 6 range hoods and one OTR using the same approach, which showed very similar results to the field study, with CE values ranging from 17%–100% with a strong dependency on airflow and burner, pot, and range hood geometries. Zhao et al. 2020 used the same method to measure the CE for six OTRs and compared to regular range hoods and showed that OTRS had similar CEs and ranges of CE (10% to 100%) with a strong dependence on air flow and how well the burners were covered. Lunden et al. 2015 determined the CE with real cooking: pan frying meat and stir-frying beans, in a test room. CO_2 and particle concentrations were measured at the room exhaust with and without the range hood operating to determine the CE, which showed similar CE values for PM and CO_2 when cooking on a back burner but lower for PM when stir frying on a front burner.

Walker et al. 2016 and Kim et al. 2018 describe development of a steady-state CE test method in a controlled chamber. Instead of using gas burners with boiling pots of water as a source, a standardized tracer gas emitter was used to emit CO_2 over the heated surface in a consistent, repeatable way. This approach was adopted as ASTM Standard E-3087-2018. Walker et al. measured CE for eight hoods with CEs from about 55% to 95% with a strong trend to better CE at high airflow and large ranges (65% to 95%) at typical air flows of 150 cfm (75 l/s). Kim et al. measure two hoods at mounting heights that differed by 3.5 to 6 in. (8-15 cm) and showed consistently lower CE (by 2-4%) for the higher mounting. Two studies by Meleika (Meleika and Pate 2020 and Meleika et al. 2020) further evaluated the ASTM method and investigated the cooktop temperature influence on capture efficiency for four range hoods and one OTR at various airflow settings. Clark et al. 2018 adapted the ASTM test method for an overhead (or island) hood and investigated the sensitivity to tracer injection system and burner power and showed that CE generally decreased as burner power increased and increased at higher air flows, similar to wall-mounted hoods.

Table 1. Studies that have measured kitchen ventilation product performance in laboratory or field settings

Lead author, Yr	Brief description	# devices	Sound	Airflow	CE
Lab study					
Delp and Singer 2012	POW, CE using CO_2 mass balance, airflow measured at exhaust	7 (1 OTR)	Y	Y	Y
Lunden et al. 2015	Real cooking, CO_2 mass balance, particle mass balance, airflow measured at exhaust	4 (1 OTR)	N	Y	Y
Walker et al. 2016	Chamber steady-state CO_2, developing ASTM method	8 (1 OTR)	N	Y	Y
Kim et al., 2018	Chamber steady-state CO_2, developing ASTM method	2	N	Y	Y
Clark, 2018	Overhead/island Hood, CO_2 as tracer	1	N	Y	Y
Meleika and Pate, 2020	ASTM, cooktop temp on CE	5 (1 OTR)	N	Y	Y
Meleika et al., 2020	ASTM	7	N	Y	Y
Zhao et al., 2020	LBNL report comparing OTRs to RHs	8 (6 OTR)	Y	Y	Y
Field study					
Singer et al., 2012	CO_2 mass balance, airflow measured at inlet	15 (2 OTR, 2 downdraft)	Y	Y	Y
Chan et al. 2019; Singer et al., 2020	70 California homes with code-required MV	70	Operating dB only	Y	N
Zhao et al., 2021	California Apartments	23	N	Y	N
Antonopoulos et al., 2023	Oregon and Colorado Single Family homes	55	Operating dB only	Y	N

Kitchen ventilation effectiveness to reduce indoor air pollutants

Several experimental studies have examined the effectiveness of range hood use to reduce cooking-related indoor air pollution. The studies were typically conducted in a controlled test house or a controlled kitchen area, as shown in Table 2. Rim et al. 2012 investigated the effectiveness of two kitchen exhaust hoods in reducing indoor levels of UFP emitted from a gas stove and an oven in an unoccupied house. Tests found number-weighted particle reductions for range hood flow rates varying between 60 cfm and 400 cfm (30 l/s and 200 l/s) range from 31% to 94% for the front burner, from 54% to 98% for the back burner, and from 39% to 96% for the oven. Singer et al., (2017) measured the effectiveness of the installed range hoods to reduce combustion pollutants from the gas stoves in six homes. Scripted burner operating procedures were used for cooktop, oven and broiler. The range hood performance varied widely with pollutant concentration reduction from <5% to 95%. Dobbin et al. 2018 conducted the same cooking protocol 60 times on a gas stove and tested three range hoods at six different airflow settings. They found kitchen exhaust fan use after cooking generally increased decay rate and the flow rate and physical characteristics of the exhaust fan used during cooking were the most important determinants of integrated exposures following cooking. Sun et al. 2018 analyzed the same experimental data and found total UFP peak reduction ranged from 25% at lowest fan flow rate of 75 cfm (36 l/s) to 98% at the highest flow of 310 cfm (146 l/s).

Kitchen ventilation effectiveness to reduce indoor air pollutants has also been investigated in IAQ field studies. Mullen et al. 2016) collected passive sampler data from 352 California homes and results suggest that even occasionally using a kitchen exhaust fan reduces peak CO in the kitchen and time-integrated NO_2 and NOx in the kitchen and master bedroom. Sun & Wallace 2021 used measured data from 132 Canadian households and found that using a range hood or opening windows can increase the PM2.5 decay rate by a factor of two. The Studying the Optimal Ventilation for Environmental Indoor Air Quality (STOVE) study by the National Center for Healthy Housing (NCHH 2022) also compared measured indoor air pollutants in homes with code required ventilation to those without ventilation. They found significant reduction in PM2.5, carbon monoxide and formaldehyde concentrations in homes with kitchen ventilation that met ASHRAE 62.2.

Table 2. Studies of kitchen ventilation effectiveness to reduce indoor air pollutants from cooking

Lead author, Yr	Condition	# homes	Airflow msd?	Pollutants measured
Study in Controlled homes				
Rim et al., 2012	Controlled unoccupied house	1	Y	Ultrafine particles (UFP)
Singer et al., 2017	Study of 9 homes, 6 w/KV, in controlled kitchen	6 (2 OTR)	Y	CO_2, NOX, particles
Dobbin et al., 2018	Controlled unoccupied test house	2	Y	UFP, PM2.5 NO, NO_2
Sun et al., 2018	Controlled unoccupied test house, 6 flow setting of 3 hood, real cooking protocol	1	Y	UFP
Observational field studies				
Mullen et al. 2016	California homes measured with pass samplers	352	N	NO_2, NO, CO, HCHO
Sun and Wallace 2021	Calculated PM decay rates when KV used or not.	132	N	PM2.5
STOVE study by NCHH	3 visits, study group and comparison group, multifamily and townhomes	152 total; 76 met ASHRAE 62.2 WHMV	About 80% homes	NO_2, PM2.5, CO_2, CO, HCHO

Usage of kitchen ventilation in homes

Estimates of kitchen ventilation use have been made in field studies based on online surveys and daily activity logs. Mean values of self-reported use during cooking ranged from 10% to 34%, as shown in Table 3. We are aware of only one study that performed measurement of range hood usage in US homes (Zhao et al. 2021). The study reported the actual hood use was far lower than self-reported frequency and that the likelihood of hood use during a cooking event increased with the duration of cooktop burner use.

Table 3. Studies of kitchen ventilation usage during cooking

Lead author, Yr	Type	Condition	Result
Piazza et al., 2003	In home survey	1448 detached home in California	28% reported using KV with cooktop, 15% with oven
Chan et al., 2019	Web-based survey	2781 California homes built since 2003	34% reported always use a hood, 30% sometimes use and 32% rarely or never
Klug et al., 2011	Web-based survey	372 homes	34% reported using range hood during cooking
Sun and Wallace 2021	Activity log	132 Canadian homes	13% reported range hood use in winter and 10% in summer
Zhao et al., 2021	In home measurement	54 houses and 17 apartments in CA	Range hood actually used in 36% of cooking events in houses and 28% in apts

SUMMARY AND CONCLUSIONS

Our review of the studies in Table 1 2 and 3 identified three key findings about kitchen ventilation device performance and usage in residences.

1. The airflow of devices installed in homes is often lower than the certified airflow of the product and also lower than the minimum airflow requirements of ventilation standards.

- In several recent field studies shown in Table 1, researchers investigated 125 US single family homes and 23 apartments in California, Oregon and Colorado. Total 144 range hoods were identified with valid model number and only 82 of them (57%) have a certificated airflow greater than the minimum air flow requirement of 100 cfm (50 l/s) in ASHRAE 62.2.
- In-situ airflow measurements were successfully conducted in 142 homes and showed that only 79 (55%) had installed airflow at low speed that met the airflow requirement of 100 cfm (50 l/s). 127 homes had a range hood with a speed setting that can meet 100 cfm requirement. Of the 82 range hoods with certificated airflow, only 44 of them had installed airflow that matched the rating. The average ratio of installed versus rated flow was 0.76, as shown in Figure 1.
- Preliminary findings show the lower installed airflows were due to a mismatch between the pressure differences across the fan used in certification processes and those found in actual installation. Other factors were incorrect installation and fouled air inlets. To improve this requires a combination of improving the certification test methods to reflect real in-home conditions, improving installation instructions/guidance and together with indicators to remind users to maintain the equipment. In

particular the pressure differences used in air flow ratings are extremely low: from 0.01 w.g. (2.5 Pa) to 0.1w.g. (25 Pa) compared to field installations.

- Range hoods with certified had an average installed airflow of 109 cfm and 206 cfm (51 l/s) for working and high speed, while range hoods without certified were 139 cfm (66 l/s) and 278 cfm (131 l/s). No obvious differences in installed airflow were found between the certified and no-certificate hoods.

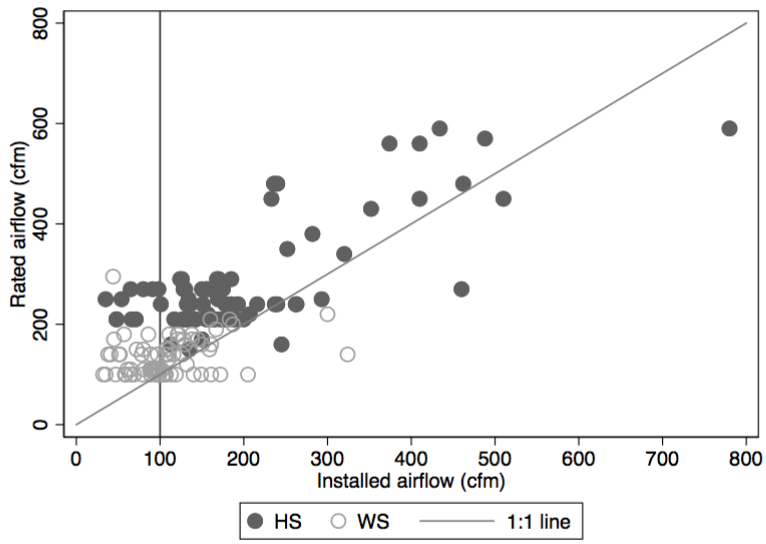

Figure 1. Rated airflow vs. installed airflow measured in 82 homes with certificated range hood

2. While data are limited, they show that pollutant removal effectiveness by range hoods has a large range.

- Measured capture efficiency has been reported for only 57 hoods in 9 studies in the US, either in the lab or in the field. The measured capture efficiency ranged from 10% to 100%, generally increasing with airflow, with back burner typically higher than front, as shown in Figure 2
- The capture efficiency can also be influenced by the range hood shape, burner coverage, model and test conditions. The main reason for limited capture efficiency data is the difficulty to conduct the measurement, especially in the field in real homes, which urges the need of a standardized and practicable test method.
- Measurements of the effectiveness based on contaminant measurements in homes show that concentrations decrease with increasing capture efficiency, as expected.

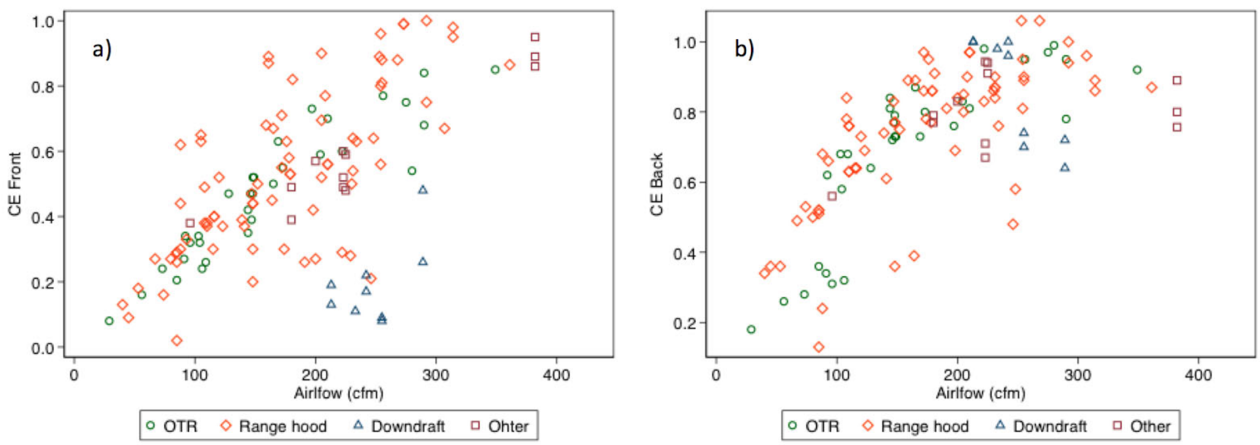

Figure 2. Summary of CE vs. airflow measured in 8 studies using CO_2 as tracer for a) front burner(s) and b) back burner(s)

3. Even when it is available, a minority of people report routinely using their kitchen ventilation.

- The occupants are unwilling to use their range hood due to noise issues, particularly at higher speeds, and the lack of awareness of the benefits of kitchen ventilation.
- A large survey study in Canadian homes showed that 30% of households reported regularly using their range hood. After being informed of the benefits of kitchen ventilation, the overall willingness to use the range hood was significantly higher.
- Field data from California showed range hoods were only used for 36% of cooking events in houses and 28% in apartments, but actual use was far lower than self-reported. The frequency of hood use increased with cooking frequency across homes. In both houses and apartments, the likelihood of hood use during a cooking event increased with the duration of cooktop burner use.

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