Measured Pollutant Performance of Island Overhead Kitchen Exhaust

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ABSTRACT

Cooking is one of the most substantial sources of indoor air pollution in most residences. This is mitigated most often by exhaust devices located near cooking surfaces. In this study, we measured the efficacy of one type of kitchen ventilation device: an island overhead kitchen exhaust. Laboratory tests using tracer gas capture were performed on a full-scale mock-up of a kitchen with a cooktop in an island. The results show that the Capture Efficiency (CE) varies greatly from about 10% to nearly 100%. CE generally increased with exhaust flow rate, but results did not show clear trends when changing hood mounting height or the power input to the cooktop burners. Burner power had an effect on measured capture efficiency of the same magnitude as exhaust flow rate. As with earlier work on wall-mount exhaust hoods, these results indicate that standardized testing will have to clearly specify mounting heights, power input (and or temperatures) and the geometry of the tracer gas emitter.

KEYWORDS

Range hoods, indoor air quality, kitchen ventilation, source reduction

1 INTRODUCTION

Cooking is one of the greatest sources of air pollution in homes: carbon monoxide, volatile organic compounds, NOx, water vapor, and particulate matter are generated during cooking and associated with a wide array of health effects including cardiovascular disease and cancer. These by-products are often removed to some degree with a kitchen exhaust device located above or near cooking surfaces.

However, until recently, no internationally accepted method of test existed for rating these devices, leading to large inefficient devices and installed air flows far from those at rated conditions (Singer et al. 2011). For these reasons, a report summarizing the state of the art in kitchen ventilation (Singer and Stratton (2014)) identified the development of a test-method for kitchen range hoods as a “specific high-priority near-term objective” .This test method would move the quantification of kitchen range hood performance from solely a rated flow rate to a measured metric that more fully captured the ability of the hood to improve air quality. This was followed by the development of an ASTM test method for wall-mounted kitchen range hoods (ASTM 2017), whose development is discussed in Kim et al. (2018). This study aimed to build on the lessons from these works and others and better understand the operation of a subset of kitchen range hood devices which is increasing in popularity: overhead island exhaust hoods.

Specifically, this work examined the effect burner location and number of active burners have on the capture efficiency of an overhead island exhaust.

2 METHODOLOGY

A new testing chamber was built at the Lawrence Berkeley National Laboratory for the purposes of developing a testing protocol for kitchen ventilation devices. The chamber is a wood frame structure with gypsum board installed on interior faces and sealed except at the dedicated makeup air vents as shown in Figure 1 below.

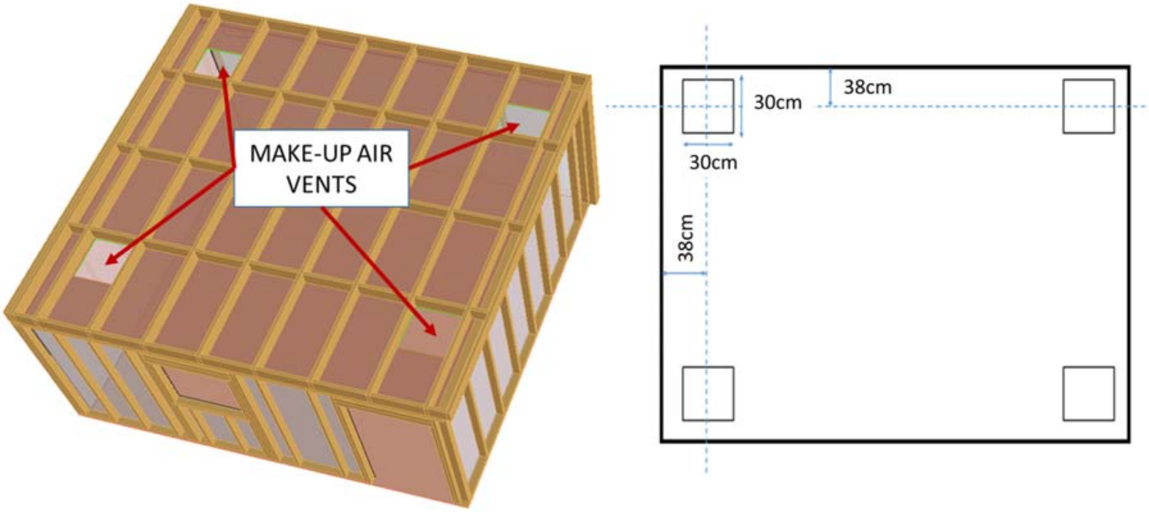


Figure 1. Chamber rendering and make-up locations

Inside the chamber we constructed an island that approximated an island that might be found in a residential kitchen. Integral to the island was a cooktop mock-up: a stainless steel surface with machined pieces which could be moved to adjust burner location. The burners fit snugly into machined holes in a stainless steel piece that could also be moved and switched with the rectangular pieces, as shown in Figure 2.

All experiments used a tracer gas (CO_2) method developed previously by Walker et al. (2016) and codified in ASTM E3087-17: Standard Test Method for Measuring Capture Efficiency of Domestic Range Hoods. Tracer gas is emitted from machined aluminium emitters concentric with a corresponding burner. More details of the burner are given in ASTM E3087-17. The Cadco-CSR-3T electric burners were selected because their control mechanisms allowed us to carefully control their output, their physical dimensions fit into the experimental apparatus, and their build quality allowed for continuous operation at high output. Photographs of the island, emitters, CO_2 distribution system and island dimensions are given in Figure 2.

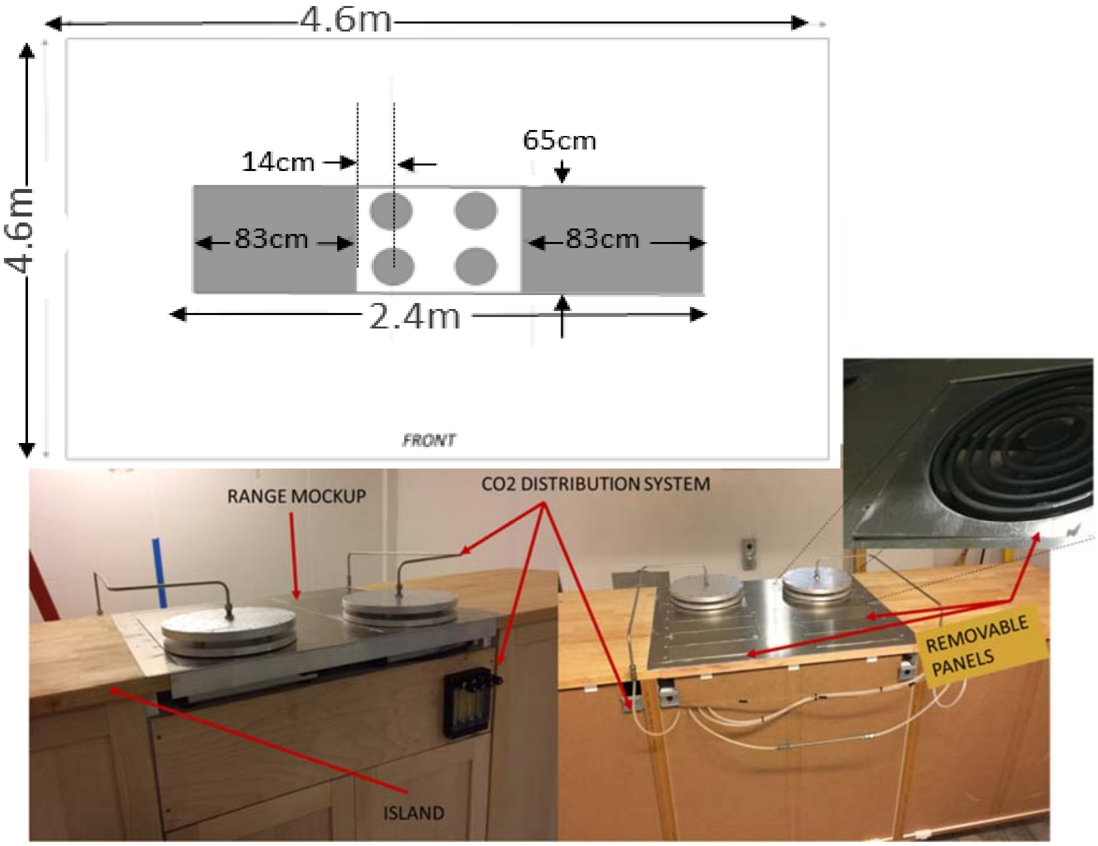


Figure 2. Test Laboratory island cooktop apparatus

The location of the burners in the direction parallel to the island corresponds to that location standardized in ASTM-E3087-17 for wall-mounted hoods. It was also virtually the only position which would allow for two burners to be placed underneath simultaneously because of the dimensions of the housing in which the burners were packaged. The location of the burner in the direction perpendicular to the long axis of the island was changed throughout the experimental campaign.

Above the island we installed an overhead island range hood (Broan EI5936SS) centered on the range. The glass canopy has nominal dimensions 35-3/8" X 25-5/8" (89 cm x 65 cm) and the hood can be mounted at distances from 61 cm to 91 cm from the hood face to the range surface. Maximum nominal flow rate was 236 L/s although we were only able to extract 189 L/s even with an auxiliary fan.

Figure 3. Front and bottom view of island range hood tested

In general, a typical test proceeded as follows:

1. **Two to four hours were needed until the range and room came into near-thermal equilibrium**. This somewhat long period of time needed was due to the thermal mass of the room, emitters and cooktop.
2. **After the room reached near-thermal equilibrium, CO_2 injection began, and another one half to two hours were required for the concentration field** in the space, and thus measured capture efficiency, to reach steady state- depending on the exhaust flow rate of the hood. Walker et al. 2016 showed that a good rule of thumb was that one should wait four complete air changes before measuring and then measurements should be averaged over at least a five-minute period. We chose to wait no fewer than 30 minutes after equilibrium for the concentration to stabilize, even at higher flow rates. Once at equilibrium, the measurements were recorded every 20 seconds over at least a 15 minute period and the mean and standard deviation were calculated.
3. After this, fan flow rate could be adjusted and another 0.5 to 1.5 hours was required for the concentration field to again reach steady state and another point recorded.

This process resulted in the ability to measure between three and five points in a given 9-hour period of testing.

RESULTS

Figure 4 shows a set of results, all measured at a 28-inch (71 cm) height and with a single burner energized, that demonstrate the large variation recorded in range hood capture efficiency when flow and burner power were varied. These two variables were by far the most influential independent variables and the effect of these variables is described in detail in other publications including Clark et al. (under review). In general, low flow rates resulted in low capture efficiency, and increasing power also had a negative effect on capture efficiency, as others have demonstrated (e.g., Yuguo Li and Delsante 1996, Walker et al. 2016). The effect is highly pronounced at low flow rates, where changing input power by only 200W can reduce capture efficiency by over 40%. The CE variability with input power was much reduced above 400W, indicating that for repeatable results we should test above this 400W lower limit. The emitter surface temperatures increased from 25 °C to about 185 °C over the zero to 1000 W power input range.

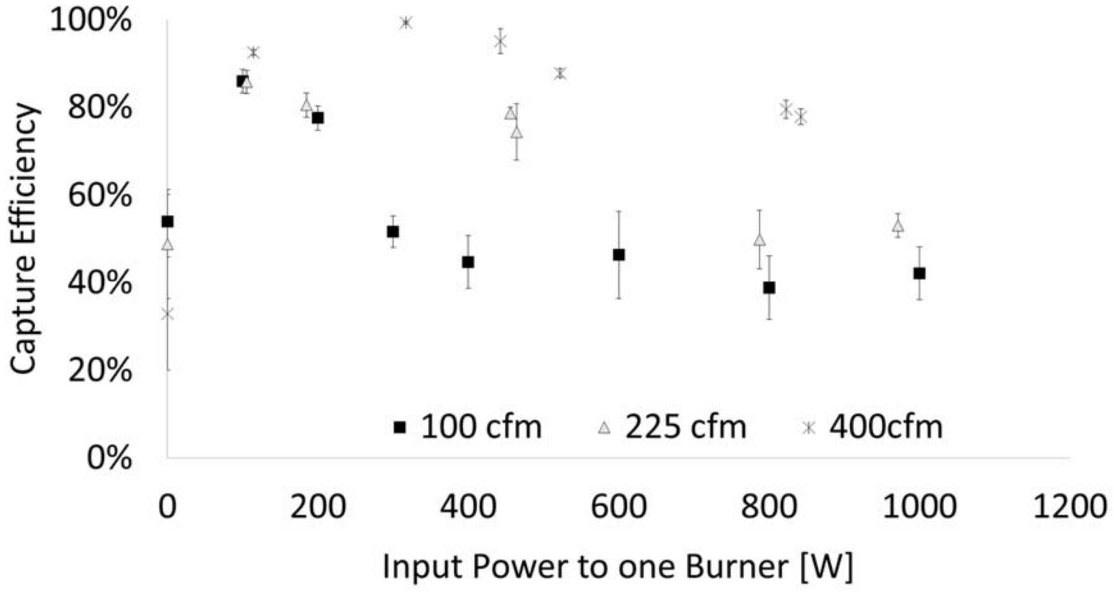
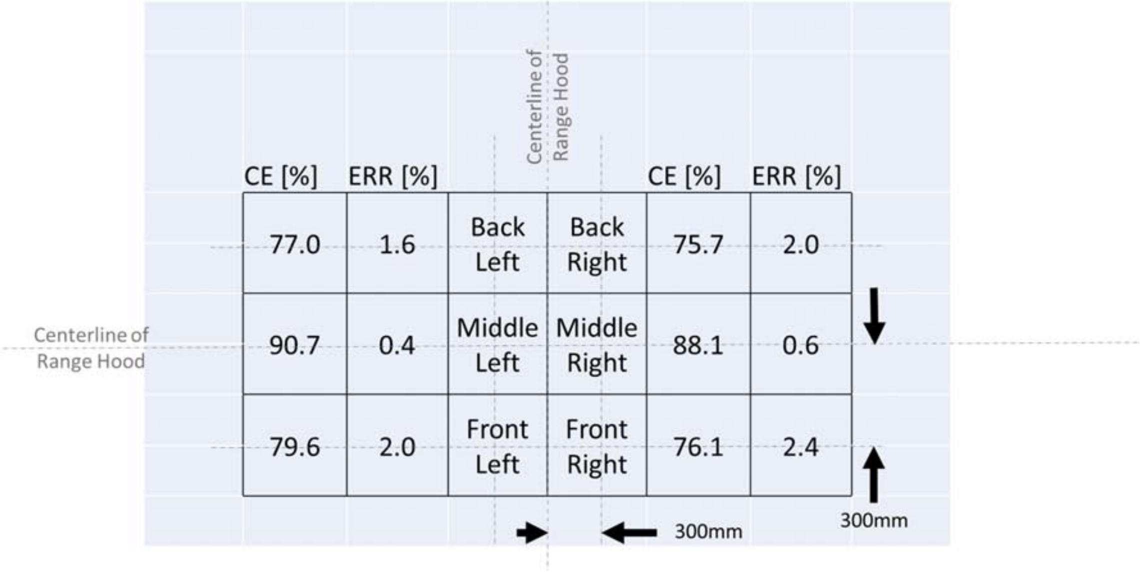


Figure 4. Capture efficiency as a function of burner power and range hood flow rate for a 28-inch hood height setting and a single burner

We did further tests to assess the effect of burner location on measured capture efficiency and whether burner performance was symmetric with respect to midplanes of the range hood. The results in Figure 5 show the results of these tests depending on burner location together with an uncertainty estimate (ERR) based on the standard deviation of the CE measurements taken during the 15 minute averaging period. All tests were performed at intermediate values of 435 W and 225 cfm (106 L/s) and at a 24-inch (61 cm) hood height. In general, corresponding right-to-left and front-to-back tests were within 3% of each other in regards to measured capture efficiency. Center burners had around 12% greater capture efficiency for the hood tested.



CE [%]	ERR [%]			CE [%]	ERR [%]
77.0	1.6	Back Left	Back Right	75.7	2.0
90.7	0.4	Middle Left	Middle Right	88.1	0.6
79.6	2.0	Front Left	Front Right	76.1	2.4

Figure 5. Effect of burner location on capture efficiency

In order to investigate the effects of having more than one burner operating at the same time and the resulting plume interactions, we performed experiments in which both "front" and "back" burners were turned on at 420 W each and tracer gas emitted through an ASTM Emitter on each in equal amounts. The results of this particular experiment are shown in Figure 6. For very low flow rates we found that the test results had poor repeatability (variability from test to test > 15%) so they are not included here. Other than for very low flow rates, the performance of the range hood under the two-burner conditions was extremely close to the performance of the single burner case. This may simplify a testing method in that at moderate power inputs and moderate flow rates, for this particular range hood, it seems one-burner performance is a good indicator of two-burner performance as well.

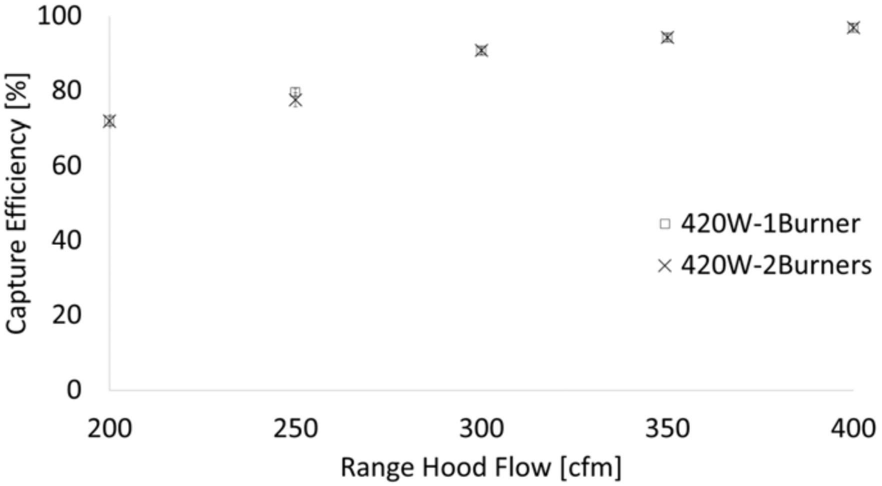


Figure 6. Effect of additional burner on capture efficiency at 420 W

Time did not permit testing at all power inputs to see if this behavior was replicated generally. However, one can consult long-established plume theory to assess whether and when it should be expected that the two plumes interact with each other. Below in Figure 7 is a to-scale depiction of the two plumes that would be expected above a cooking burner. This assumed a 20 degree angle of spread from a virtual origin. The 20 degree spread can be found by solving the governing equations according to Bejan (2004). One can see that the two plumes in this case are not expected to interact until well above the height of the hood, neglecting any low pressure region which may form between the two. This may be a path forward for standardization of a testing procedure regarding multiple burner locations.

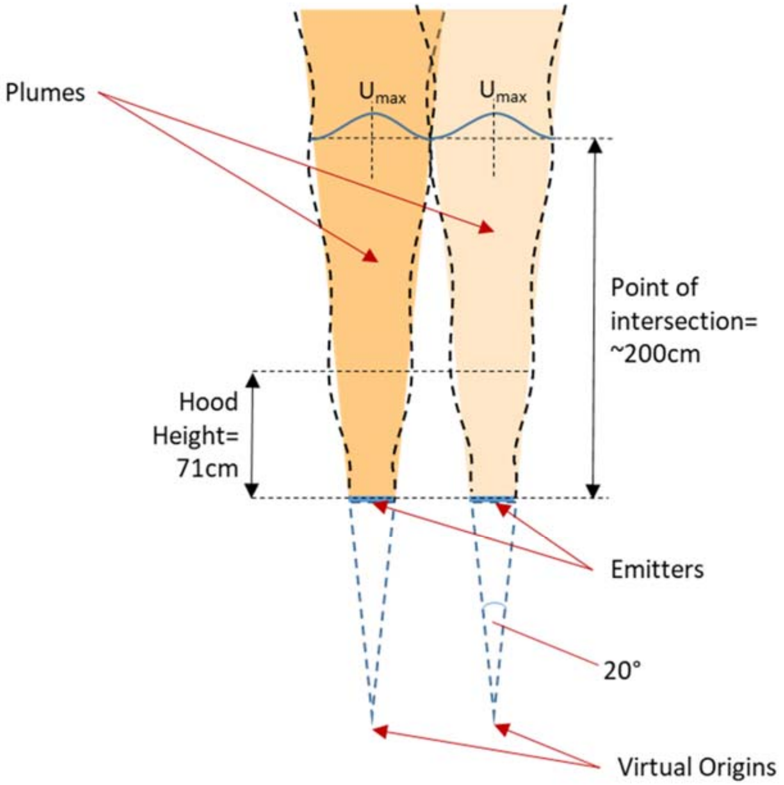


Figure 7. Predicted plume shapes based on simplified method in Bejan (2004)

3 CONCLUSIONS

Through the use of a tracer gas method for measuring capture efficiency of overhead island range hoods, we found that the effect of burner location on measured CE was about 12% - with central locations having higher CE. We also found that plume interaction was minimal for the geometries we typically expect to see for an island hood. These results will be used in the future development of CE test methods for island hoods. In general the results showed similar trends and variability as wall-mount hoods – one exception being the large variability in results at low air flows that implies some careful assessment and advancement of measurement techniques is needed if we are to reliably test low air flow CE.

4 ACKNOWLEDGEMENTS

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