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The benefit of kitchen exhaust fan use after cooking - An experimental assessment

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ABSTRACT

Cooking is one of the main sources of indoor air pollutants, and may even exceed the contribution from outdoor sources. This pilot study examines the use of different flow-rate fans during cooking and tests whether continuing to run the fan after cooking significantly improves pollutant removal rates and integrated exposures. Tests were carried out in the Canadian Centre for Housing Technology's twin research houses, in Ottawa, Ontario. We completed the same cooking protocol 60 times on a gas stove, testing 6 different flow rates on three different over-the-range exhaust fans, while continuously measuring UFP, $PM_{2.5}$, NO_2, and NO. The fan was operated during cooking for all tests and then either turned off or left on after cooking for the duration of the three hour test. We estimated decay rates, source emission rates, and integrated exposures to measured pollutants following the cooking test. The results showed that while leaving the fan on after cooking generally increased decay rates, it had a relatively small effect on integrated exposures compared to the effects of fan flow rate and the specific fan used during cooking. For $PM_{2.5}$, the effect of running an exhaust fan for 15 min after cooking was similar in magnitude to the impact of a 100 cfm increase in the flow rate used while cooking: both were associated with a decrease in 15-min integrated exposure of roughly 3 $\mu g\,m^{-3}$. This suggests that one can partially compensate for a low flow rate exhaust fan by continuing to run the fan after cooking.

1. Introduction

Cooking is a significant source of indoor pollutants. High emissions of particles from cooking activities have been reported in many studies [1–9]. Kearney et al. [5] found that about two-thirds of the 100 Canadian homes studied had higher contributions of ultrafine particles (UFPs) from indoor sources (mainly cooking) than from the entry of outdoor UFPs. Wallace et al. [10] found that cooking was associated with an increase of a factor of ten in the concentration of UFPs and an increase of a factor of three in fine $PM_{2.5}$. Wheelet et al. [8] reported that during the dinnertime cooking period, indoor UFP and $PM_{2.5}$ concentrations exceeded their daily mean values by, on average, 160% and 60%, respectively.

For homes with natural gas cooking stoves, higher residential levels of nitrogen dioxide (NO_2) are an additional concern [11,12]. A recent simulation study [13] found that gas burner use may routinely lead to NO_2 concentrations that exceed the 1 h U.S. ambient air quality standard of 100 ppb and follow-up measurements found that the threshold was exceeded by moderate burner use in four of nine homes in which experiments were conducted [14].

Many studies, both experimental and simulation, have demonstrated that kitchen exhaust fans can reduce cooking-related air pollutants [14–21]. However, the efficiency of exhaust fans to capture cooking-related pollutants can vary widely based on a number of factors, including equipment type, size and location, exhaust flow rate, exhaust ducting, installation details and use behavior [15,19,22,23]. Use behavior is an important factor to maximize effectiveness, especially for those who are not able to purchase a higher performance unit or make improvements to the installations, such as renters.

Kitchen exhaust fans reduce cooking emission in two ways: 1) by removing emissions directly at the stove before they mix into the surrounding air and 2) by increasing overall air exchange in the home to remove pollutants from the indoor environment. A number of studies have measured the fraction of emissions captured by kitchen fans at the source, which is referred to as capture efficiency [15,17,19]. Capture efficiencies during cooking can vary widely but are typically below 75%

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[19].

After cooking, when the emission source has stopped, the kitchen fan can continue to reduce pollutant concentrations by increasing air exchange. To our knowledge, the impact of leaving a fan running after cooking has not previously been studied experimentally. Our goal was to evaluate the impact of different fan flow rates and of leaving a fan running for 15 min after cooking on cooking-related pollutant concentrations.

2. Methods

2.1. Measurements

The cooking experiments were conducted in the Canadian Centre for Housing Technology's (CCHT's) twin research houses, in Ottawa, Ontario. They are identical two-story, four-bedroom, three-bathroom, detached houses with a floor area of 2260 ft^2, and are unfurnished with tiled floors in the kitchen and family rooms, and carpets in the other areas (see supplemental information Figure S1 for floor plan). There is a standard 30-inch gas stove, over which we installed the 30-inch under-cabinet exhaust fans. Fan A had a depth of 18 inches, while fans B and C each had a depth of 20 inches, over a standard 25-inch deep cooktop (See supplemental Table S1 for fan details and Figure S2 for diagrams).

Three kitchen exhaust fans were selected for the study. Fan A was a Broan-Nutone, model RL6100F (existing fan in the home, no current price available, comparable current models are $100-$120 retail). It is a single-speed fan with a stated exhaust airflow rate of 180 cfm. Fan B was a Broan-Allure, model QS1 30SSN ($211 retail). It has two speed settings and the unit specifications state exhaust airflow rates of 110 and 220 cfm. Fan C was a BOSCH model DUH30252UC ($550 retail). It is a higher performance model that has four fan speeds; the unit specifications stated exhaust airflow rates were between 150 and 400 cfm, of which the low, high, and maximum settings were tested. The high speed setting did not have a manufacturer specified flow rate.

The duct was the same size for all fans (7 inches) and all were installed with the duct positioned vertically. As the airflow for installed exhaust fans has been found to be less than manufacturer's specification [15,18,19], the actual airflow rate inside the duct was measured for use in the analysis. The fans exhausted directly to the outside. Fan A was the existing fan in one of the test houses, while fan B and C were purchased for the study. Fan A and B were tested in one house and fan C was tested in the other house.

The protocol for each cooking test was as follows. First, the gas stovetop burner was started simultaneously with the exhaust fan. The next step was boiling four cups of water on the rear burner and once boiling, adding frozen broccoli to cook for five minutes. The pot was covered with a lid throughout. After this step, the rear burner was turned off. The next step was frying four beef hamburger patties on a frying pan on the front burner, using four tablespoons of vegetable oil to coat the pan initially. The patties were fried for five minutes on each side. After the stove was turned off at the end of cooking, the exhaust fan was either turned off (off condition) or left on for an additional three hours (on condition). Each set of test conditions (six total fan speeds, on/off condition) was repeated five times, for a total of 60 cooking tests. Air pollutant monitoring started 15 min before cooking and continued for approximately three hours following cooking. Two tests were completed in each house per day, one in the morning starting at 9:30 a.m. and one in the afternoon starting at 3 p.m.

Field work was completed in September and October 2015. During the tests, the furnace, hot water tank, and other ventilation systems in the home were turned off. Windows were closed and ventilation ducts were sealed off to minimize air exchange in the home aside from the kitchen exhaust fan. The air exchange rate in the homes was measured before the start of the experiments using the decay of the tracer gas sulfur-hexafluoride (SF_6) according to ASTM test method E 741-00 (ASTM, 2006) using an Innova Model 1312 photoacoustic field gas monitor.

Localized air exchange in the kitchen was measured during each test using the same tracer gas method. One deviation from the usual air exchange test method was not using mixing fans in the space, as this would interfere with the cooking test. The tracer gas was injected at three locations on the first floor of the research house one hour before each test and measured every 30 s thereafter until three hours following cooking. The AER was estimated based on decay from approximately 15 min to one hour following cooking. This measurement gives the integrated estimate of the AER during this period, but does not allow us to estimate the AER specifically during cooking.

Air quality monitoring instrumentation was placed next to the kitchen island, approximately 2–3 m from the stove. This location was chosen to approximate the exposure of people in the kitchen. $PM_{2.5}$, NO, and NO_2 were monitored continuously during the sampling period. Data was collected at one minute averages using an Airpointer ($PM_{2.5}$: Nephelometry, NO_2/NO: Chemiluminescence) (MLU-Recordum, Austria). The sampling inlet was at a fixed height of 1.7 m. UFP were measured continuously using condensation particle counters (CPC) model 3007s (TSI, St Paul, MN), collected at one minute averages. This model does not have a size selective inlet and counts particles from 10 nm to 1 μm in size; however, for freshly created particles from indoor sources the vast majority are UFPs [24]. The CPC was placed on a table, with the inlet at a height of 1.2 m. This sampling height was in the breathing zone of someone sitting at a table in the kitchen/dining room. The Airpointer has a fixed inlet height that is 50 cm above the CPC inlet, but the equipment was located centrally in the room in a well-mixed area, so this height difference is not expected to cause any appreciable difference for monitored concentrations. Temperature and relative humidity were recorded continuously during the sampling period at 1 min intervals using a Hobo Data logger U12-013 (Onset, Bourne, MN).

The flow rate for each kitchen exhaust fan was compared against the manufacturer's specifications for each fan speed setting. This was accomplished by measuring the exhaust flow rate downstream of the installed exhaust fan. Nailor Industries model 36FMS flow stations were installed in the exhaust ducting in both experimental homes, and the pressure differential across the flow station was measured using a TSI Model 9565-P multifunction ventilation meter.

All instruments were calibrated before the fieldwork. The CPC was calibrated by the manufacturer before the study. The manufacturer estimates accuracy within about 20% for the instrument. Inter-comparisons were made between instruments at the same location before and after the monitoring period to assess any problems between instruments. All continuous instruments were assessed for drift and zeroed daily. All data collected from continuous instruments were visually assessed for bias, instrument malfunction or abnormal peaks.

2.2. Statistical analysis

All pollutant concentrations were visually assessed in individual plots of each cooking test. The background concentration may vary over the course of the test due to changes in outdoor concentration so we used both the beginning and end concentrations to estimate it. Specifically, we calculated the average concentration during the 15 min before cooking and the average during the 15 min at the end of the test (three hours after cooking). For the majority of tests, the concentration at the end of the test was higher than at the beginning, likely because the cooking peak had yet to fully decay; for these tests we used the beginning concentration as the background. In cases where the end concentration was lower, we used a linear interpolation between the beginning and ending concentrations as the background. In both cases, the estimated background concentration was subtracted from all the readings for subsequent analyses [14].

Each unique set of fan conditions was tested five times. As the duration of cooking varied slightly from test to test, we used the end of