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A Method for Quantifying the Acute Health Impacts of Residential Non-Biological Exposure Via Inhalation

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SUMMARY

INTRODUCTION The inability to monetize the health costs of acute exposures in homes and the benefits of various control options is a barrier to justifying policies and approaches that can reduce exposure and improve health.

METHODS We synthesized relationships between short-term outdoor concentration changes and health outcomes to estimate the health impacts of short-term in-home exposures. Damage and cost impacts of specific health outcomes were taken from the literature. We assessed the impact of vented and non-vented residential natural gas cooking burners on Southern California occupants for two pollutants (NO_2 and CO).

RESULTS Despite only looking at the impact of two pollutants on acute exposure-related health outcomes, the annual health benefits of using venting range hoods exceed the costs.

CONCLUSIONS The established methodology will provide a useful tool for quantifying the costs of acute exposures in homes and will allow for identification of cost effective methods for reducing exposures.

IMPLICATIONS Acute exposures in homes can have substantial impacts on the health of occupants especially for those in an already compromised state of health. Range hoods have the potential to significantly reduce acute exposures associated with cooking as well as reduce chronic exposure that result from aggregate cooking emissions. This report quantified the costs and benefits of mitigating two pollutants (NO_2 and CO) associated with gas cooking and indicated that range hoods are cost effective based on those two pollutants alone. It is expected that particle emissions could have a much larger effect than NO_2 and CO. Particle emissions are associated with food cooking and not just fuel usage. The benefits of removing cooking-related particles increase the value for gas cooking appliances and provide value for cooking with electric appliances as well.

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INTRODUCTION

Previous work at LBNL has developed a methodology for assessing and quantifying the impacts of long term (chronic) health impacts (Logue et al. 2012). The previous methodology was used to determine the chronic health impacts of indoor exposure on occupants of the housing stock. This paper is intended to present a complementary methodology for assessing costs of acute health impacts. Homes contain a variety of short-term episodic sources that impact indoor concentrations on timescales of a few hours to a few days. These short-term spikes in concentration may have a minimal effect on long-term concentrations but a significant effect on concentrations on shorter timescales. The objective of this work was to develop a method to identify illnesses associated with specific exposures, quantify the associated illness rates, quantify the health burden in Disability Adjusted Life Years (DALYs), and estimate the resulting costs of health care.

Initial assessments of the relationship between extremely high exposures during air pollution episodes and illness were easily quantifiable using graphical methods. As outdoor concentrations decreased due to increased regulation, statistical tools became necessary to characterize these relationships (Carracedo-Martinez et al. 2010). Initial large-scale assessments of population impacts of changes in outdoor pollutant concentrations on health predominantly used Poisson regression-based assessments, either parametric or nonparametric, that linked changes in outdoor concentrations to changes in population health outcomes. In recent years, case-crossover (CCO) assessments have increased in popularity because they eliminate problems with confounding and selecting correct degrees of freedom. Using these approaches, a large literature exists linking changes in outdoor concentrations with changes in population health outcomes. These studies, in conjunction with estimates of changes in home concentration resulting from changes in outdoor concentrations, allowed us to develop relationships between indoor concentrations and health outcomes.

In order to apply the methodology for acute exposures due to specific sources, we needed to determine time-resolved exposure concentrations for occupants of the US housing stock due to episodic and intermittent sources. LBNL recently developed a Population Impact Assessment Framework that allows for assessment of minute-by-minute concentrations due to specific sources in a representative subset of homes (Logue et al. 2013). This modeling framework allows us to determine the impact of sources on concentrations over a variety of timescales relevant to acute exposures. This document presents initial results for quantifying the health damage and health costs associated with exposure to nitrogen dioxide (NO_2) and carbon monoxide (CO) emitted by natural gas cooking burners in California homes.

METHODOLOGIES

For this analysis, we compiled and reviewed studies of the acute health impacts for NO_2 and CO. We included studies examining the US population as well as those in other countries with similar lifestyles. These studies estimate the change in a given morbidity/mortality outcome within a studied population, as a function of short-term (acute) changes in outdoor concentrations. Distributions of relative risks (RRs) and odds ratios (ORs), the two “measures of effect”, were used in these studies to describe the change in the probability of an outcome per change in exposure. To identify relevant CCO-based studies, we used the ISI Web of Knowledge database with combinations of the keywords: "case-crossover", "air pollution", "acute", "health", "United States", "nitrogen dioxide", and "carbon monoxide". We also considered the relationships between changes in exposure and changes in health outcomes included in the Cost Benefit Analysis of the Clean Air Act (EPA 1999). The search resulted in 11 studies that covered 15 acute health outcomes. Table 1 presents the top 5 relationships that drove the damage and health costs for NO_2 and CO in this analysis. The remaining studies did not have an appreciable effect on study outcomes.

In order to translate RR and OR data into changes in incidence of outcomes as a function of changes in exposure, we needed to select concentration response (C-R) functions. For the relationships used in the EPA Cost Benefit Analysis of the Clean Air Act (1999), a specific C-R function is specified. For the literature-derived CCO relationships, we used the log linear concentration response function:

$$\Delta Incidence = -\left[y_o * \left(exp\left(-\beta \Delta C_{exposure}\right) - 1\right)\right] * population \quad (1)$$

where *population* is the population exposed, $\Delta C_{exposure}$ is the absolute change in exposure concentration, and *yo* is the baseline incidence of illness in the population, Table 2. Health outcome-specific values for *yo* are listed in Table 2. The β value is traditionally determined from the relationship of the change in relative risk per change in outdoor concentration in each study, $\Delta C_{outdoor}$, Equation 2.

$$\beta_{indoor\ exposure} = \frac{\ln(RR)}{\Delta C_{outdoors}} \quad (2)$$

In order to use the selected concentration-response relationship, Equation 1, for studies that reported *OR* values, we used the relationship developed by Zhang and Yu (1998) to translate *OR* to *RR*.

Table 1: Case-crossover and Poisson distribution acute health impact studies included in analysis. Min age and max age are the age range for which the relationship is valid.

References	***Pollutants***	***Outcome***	***Location(s)***	***Time frame***	***Min Age***	***Max Age***
(Burnett et al. 1999)	NO2, CO	HA: Ischemic Heart Disease	Toronto, CA, USA	1980-1994	NA	NA
(Burnett et al. 1997)	NO2	HA: All Respiratory	Toronto, CA, USA	Summers 1992-1994	NA	NA
(Dennekamp et al. 2010)	CO	OHCA: All Cardiac	Melbourne, Australia	2003-2006	35	NA
(Mustafic et al. 2012)	CO, NO2	MI	Various (Meta Analysis)	1988-2011	NA	NA
(Wellenius et al. 2005)	CO, NO2	Stroke: Ischemic	9 US Cities nationwide	1986-1999	65	NA

All respiratory includes asthma, COPD, lung cancer, pneumonia, and tuberculosis. HA=hospital admission, OCHA=out of hospital cardiac arrest, COPD=chronic obstructive pulmonary disease, MI=myocardial infarction, NA= not applicable.

Table 2: Disease prevalence rates in United States and likelihood of mortality.

Outcome	***Yo***	***Reference***	***Mortality rate***	***Reference***
HA: All respiratory	1.85 E-5	(ALA 2008; Wier et al. 2011; ALA 2012; CDC 2012; AAAA&I 2013)	19.7%	(Dalal et al. 2011; ALA 2012; CDC 2012; Joynt et al. 2013; AAAA&I 2013)
HA: Ischemic Heart Disease	3.69 E-6	(Murphy et al. 2013)	89.7%	(Murphy et al. 2013)
MI	3.76 E-5	(ALA 2008)	18.5%	(Joynt et al. 2013)
OHCA: All Cardiac	2.57 E-6	(Roger et al. 2011)	90.4%	(CDC 2011)
Stroke: Ischemic	5.41 E-6	(Roger et al. 2012)	25.0%	(Hankey 2003)

The available studies that look at the relationship between exposure and health compare changes in outdoor concentrations to changes in health outcomes. US residents spend more than 90% of their time indoors and more than 70% in their homes (Klepeis et al. 2001). Since the indoor environment provides protection from outdoor-generated pollutants, both the concentrations indoors and the concentrations people are actually exposed to will be lower than the concentrations measured outdoors. Using β values derived from the outdoor concentrations measured in these studies to assess relationships of these pollutants with health outcome may underestimate the impact of indoor exposures on health. For this reason, we attempted to determine the change in indoor concentrations resulting from the reported change in outdoor concentration for each study when possible so that we can use Equation 3 to calculate a β value for use with indoor exposures. This approach does not consider the increased variability in indoor levels for any specific outdoor level and may introduce bias into the effects estimates.

$$\beta_{indoor\ exposure} = \frac{\ln(RR)}{\Delta C_{indoor}} \qquad (3)$$

Chen et al. (2012) looked at the influence of city-by-city variations on the impact of outdoor concentration on indoor home concentrations and estimates of mortality resulting from short-term changes in outdoor concentration. Chen et al. found, for PM10, strong associations between changes in city-specific derived mortality coefficients and changes in indoor exposure. Since we are interested in the impacts of indoor exposures on health, we used the same method as Chen et al. to determine the equivalent change in indoor concentrations associated with changes in outdoor concentrations for the city in which each of the studies was conducted. We could only do this for studies conducted in the US and Canada. For Canadian studies we used the data from the closest US city. Studies conducted outside the US where not corrected and likely underestimate health impacts.

Several authors have determined the DALYs lost per incidence of specific diseases using the preeminent work of Murray and Lopez (Murray and Lopez 1996a; Murray and Lopez 1996b). Multiplying disease incidence by a "DALY factor" yields total DALYs lost.

$$DALYs=(\partial DALYs\ /\ \partial Disease\ Incidence)*\ Disease\ Incidence \qquad (4)$$

Equation 4 uses a partial derivative in recognition that DALY losses are incrementally impacted by causes other than disease. The total burden of disease in a community can be calculated as the aggregate, across all diseases, of DALY factors multiplied by disease incidence rates. One major question in public health costing is whether acute exposure related deaths result in a substantial loss of life or merely accelerate the death of those is an already frail state of health who would have died soon anyway. Advancing death by only a few days is often referred to as "mortality displacement" or "harvesting. Several studies have addressed the harvesting question using distributed lag models (DLM) (Zanobetti et al. 2002; Dominici et al. 2003; Roberts and Switzer 2004; Murray and Lipfert 2012). One issue with using existing DLM approaches is that the only option for exit from the frail population is death, and there are only two life states: healthy and frail. As Zanobetti and Schwartz (2008) point out, for certain health outcomes there is also the option of getting healthier. They specifically reference myocardial infarction and pneumonia, which, if survived, usually lead to a recovery and re-entry to the healthy pool, or at least a healthier state than the frail pool.

In order to determine the DALYs associated with each of these outcomes, we divided the outcomes into three groups: 1) those who were hospitalized but survived (independent of the reason for hospitalization), 2) those who were hospitalized due to chronic health issues and died, and 3) those who were hospitalized due to a one-time event not related to a chronic health issue and died. For those in the first group, we assumed the event did not have a long term impact on occupant health and assigned a DALY loss of 4 per 10,000 hospitalizations based on Lyvovsky (2000). This assumes that any loss of life or life quality is attributed to an underlying chronic health issue and not a particular acute event. For those in the second group, we assume that that death results in a short-term mortality shift but did not result in a substantial loss of life. For those with chronic health issues that die, we will assume that they are part of the frail population with life expectancies of 11.8 days to 102 days, representing the range of values found in the literature for populations identified as frail or having the shortened expected life span (Manton et al. 1993; Murray and Nelson 2000; Murray and Lipfert 2012). When assigning DALYs to each incidence, we assumed a log normal distribution with a 95th percentile range of 2.4 to 31 days or 0.0065 to 0.084 DALYs with a central estimate of 0.023 DALYs/incidence. For the third group, those that died due to one-time events (stroke, cardiac arrest or myocardial infarction), DALYs assigned are based on the estimated life expectancy if the patient had survived the event. The DALYs assignments per health outcome are specified in Table 3, and the survivability of hospital admissions for each health outcome is included in Table 2. Medical costs for each health outcome are summarized in Table 3.

Table 3: Treatment cost and DALYs lost for each health outcome.

Outcome	*Cost of Treatment*	*Reference*	*DALYs Lost (If patient dies)*	*Reference*
HA: All Respiratory	\$2,521	MEPS	88.8% [0.023], 11.2% [1.2]	(Manton et al. 1993; Murray and Nelson 2000; Dick et al. 2012; Murray and Lipfert 2012)
HA: Ischemic Heart Disease	\$3,159	MEPS	0.023	(Manton et al. 1993; Murray and Nelson 2000; Murray and Lipfert 2012)
MI	\$15,631	(Azoulay et al. 1999)	5	(Goldberg et al. 1998)
OHCA: All Cardiac	\$3,159	MEPS	5	(Cobbe et al. 1996)
Stroke: Ischemic	\$9,526	(Russo and Andrews 2008)	2	(May et al. 1994)

As an initial application of this acute assessment methodology, we assessed the impact of select natural gas cooking pollutants on acute exposure related health outcomes for the population living in Southern California (SoCal) homes. The two pollutants analyzed were nitrogen dioxide (NO_2) and carbon monoxide (CO). A previous study that used the PIAM framework assessed the minute-by-minute concentration impacts of natural gas cooking on 6,969 representative SoCal homes that reported natural gas cooking in the home at least once a week and on the 19,465 occupants of those homes (Logue et al. 2013). We used the modeled occupant exposure concentrations to assess the impacts of cooking with no range hood, and the benefit of cooking using venting range hoods during all cooking events on the exposure of the occupants over the time frames of exposure specified by the aggregated studies. Logue et al. (2013) assumed an average range hoods capture efficiency (CE) of 55%.

RESULTS AND DISCUSSION

We used the studies included in Tables 1 through 3 to determine the population impacts on health outcomes and the impact of those outcomes on DALYs lost and medical costs. We calculated the incidence of disease and DALYs per incidence of disease for each C-R function for each occupant using a Monte Carlo approach. We repeated this process for 5000 iterations. The resulting distribution of total DALYs lost and medical cost for the population derived from the 5000 iterations per modeled occupant was used to report the median and 95th percentile confidence interval of the total disease burden.

Across the SoCal population, per 100,00 people weekly in winter, exposure to gas cooking related pollutants (NO_2 and CO) if no range hood is used results in an estimated 0.38 (95%CI: 0.38-0.39) DALYs lost due to health impacts and $18,850 (95%CI: $18,800-18,950) in medical expenditures. Over the course of a year, this translate to a loss of 19.2 DALYs (95%CI: 18.7-19.6) and a medical cost of $943,200 (95%CI: $938,200-948,200) per 100,000 SoCal occupants of homes that cook with natural gas. The DALYs lost due to acute exposures calculated here for NO_2 and CO exceed, on an annual basis, the estimates for DALYs lost due to NO_2 and CO chronic exposures in the average US home (Logue et al. 2012).

If homes use range hoods during all cooking events with average capture efficiency (55%), the health impact of cooking is reduced to an annual DALYs loss of 8.9 (95%CI: 8.7 - 9.2) and a medical cost of $458,200 (95%CI: $455,200 - 461,200) per 100,000 SoCal occupants of homes that cook with natural gas. Using the assumed cost of $100,000 per DALY lost (Logue et al. 2012), the total cost saved by using standard range hoods during all cooking events due to reductions in NO_2 and CO exposure is estimated to save $1,430,000-1,580,000 per 100,000 SoCal occupants annually. The calculated benefits of range hood use only apply to homes with gas cooking burners that also have venting range hoods.

Logue and Singer (2013) have previously reported on the annual energy cost of using venting range hoods. The results for IECC climate zone 3C, the climate zone that contains the majority of the SoCal region, indicated that using currently available venting range hoods during all cooking events would result in an energy cost to consumers of $385,000 to $729,000 per 100,000 SoCal occupants. The study also found that the cost could be reduced by 23% though increases in system efficiency.

CONCLUSIONS

This analysis only estimated the cost of acute health impacts from two pollutants (NO_2 and CO). Several other pollutants, particularly PM2.5, will have a significant impact on health and health related costs on acute and chronic time scales due to cooking emissions (both from natural gas cooking burners and food preparation). Despite only looking at the impact of two pollutants on acute exposure related health outcomes, the annual health benefits of using venting range hoods exceed the annual energy cost. Further analysis is needed to determine the impact of other pollutants and to determine installation costs for venting range hoods in homes based on home characteristics.

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