Symposium on Indoor Air Quality in Developing Countries

June 6-7, 2011, Indoor Air 2011, Austin, TX

Full Meeting Report
October 2011

Prepared by:
Ellison Carter, C. Matt Earnest, Elliott T. Gall, and Brent Stephens

Department of Civil, Architectural and Environmental Engineering
The University of Texas at Austin
Austin, TX 78712

IA2011 Student Program

Sponsored by the National Science Foundation's IGERT Program

Student Symposium on Indoor Air Quality in Developing Countries

June 6-7, 2011
Indoor Air 2011
Austin, TX

Full Meeting Report

Abstract

Nearly half the world's population depends on solid fuels to meet their basic household energy needs. Indoor burning of solid fuels for cooking and heating generates hazardous air pollutants, including particulate matter, carbon monoxide, and numerous other toxic pollutants. The resulting indoor air pollution (IAP) levels are often 20 to 100 times greater than the World Health Organization's (WHO) air quality guidelines, and exposure to IAP in developing countries accounts for approximately 4% of the global burden of disease, a burden which is shouldered disproportionately by women and children. Indeed, the WHO estimates that 1.5 million people die prematurely each year from exposure to indoor smoke from burning solid fuels. Unfortunately, unless swift and effective action is taken, the health risks associated with IAP are projected to rise as the number of people using these fuels increases.

The objectives of this report are to:

1) Provide an overview of and historical context for research on IAP in developing countries;
2) Summarize the events of and framework for discussions at a symposium on indoor air quality and cookstoves in developing countries held during the Indoor Air 2011 conference, which was funded by the National Science Foundation's Integrative Graduate Education Research and Traineeship (IGERT) program; and
3) Communicate the research and implementation needs identified at this symposium.

This report begins by introducing the topic of IAP in developing countries, particularly as motivation for this symposium. This report then provides an overview of previous research on IAP in developing countries, which is divided among five general categories: modeling, health outcomes, exposure measurements, combined health outcomes with exposure measurements, and cookstove testing. Although not an exhaustive review, several representative studies are highlighted to represent each category. Next, this report provides a summary of cookstove implementation efforts by regional, national, and international agencies and organizations before reflecting on knowledge gaps, limitations, and research needs cited in the literature by experts in the field. Then, the report describes the development of the symposium and its major components, including technical research presentations, invited speaker presentations, a student panel discussion, and focused group discussions between experts and students. Finally, conclusions and recommendations for future research in the field resulting from the symposium are presented.

The major outcome of the symposium described herein was a set of recommendations to guide the manner in which research is carried out regarding IAP in developing countries, in contrast to a list of research priorities, which has been revisited several times in recent years by recognized leaders in the field. Several compelling recommendations include the following:

1) The presence of new researchers in the field of IAP in developing countries should be encouraged and sustained;
2) The role of researchers in relationship to large-scale dissemination of cookstoves and related cookstove performance, exposure, and health outcomes should be identified and clarified; and
3) New, interdisciplinary approaches to research that emphasize collaboration between many relevant fields should be pursued and encouraged.

Table of Contents

Introduction

Indoor air pollution (IAP) is responsible for several health, environmental, and social issues that disproportionately and adversely affect women and young children around the globe (Martin et al., 2011). Around 3 billion people burn solid fuels (e.g., coal, biomass, and animal dung) as their principle household fuel for cooking and heating around the world (Dherani et al., 2008). IAP in those households was estimated to be responsible for almost 2 million premature deaths in 2001, and represented approximately 3% of the global burden of disease (Lopez et al., 2006). In addition to impacts on indoor air quality and health, carbon dioxide and carbon black emissions from solid fuel cookstoves are also important contributors to global climate change (Ramanathan and Carmichael, 2008). Furthermore, improved cookstove efficiency could potentially slow rates of deforestation (Wallmo and Jacobson, 1998), which in turn could limit adverse effects on ecosystems that result from deforestation and restrain the loss of valuable forest sinks for carbon dioxide.

Cookstoves are also part of a complex web of suffering in refugee camps. For example, the majority of over 2 million refugees in Darfur, in western Sudan, cook on inefficient stoves that require substantial foraging for biomass fuels, and it is during foraging that many people, mostly women and young girls, are brutally attacked by militia and rebels (Chen, 2006; Patrick, 2007). Improved cookstove technologies could reduce the extent of foraging activities and thus reduce the amount of attacks on these refugees. Furthermore, improvements in cookstove technologies will provide more time to hundreds of millions of women who could thus engage in other social and economic activities that improve their lives, as well as the lives of their families and communities.

Regional and international organizations, as well as several national governments, have initiated intervention efforts focused on improving cookstove design and performance in order to address the public health and environmental problems posed by IAP from unclean combustion and inefficient stoves. However, efforts to distribute improved cookstoves have achieved mixed results. There are combined technical and social complexities associated with effective cookstove implementation in developing countries, and there remains a significant need for intervention studies and interdisciplinary research to address cookstoves as sources of poor indoor air quality and agents of global climate change.

The symposium described herein represents an effort organized, managed, and run entirely by graduate students at the University of Texas at Austin, whose university hosted the triennial international Indoor Air conference in Austin, Texas, USA on June 5-10, 2011. Indoor Air is the official conference of the International Society of Indoor Air Quality and Climate (ISIAQ), which publishes *Indoor Air*, The International Journal of Indoor Environment and Health. The goals of this symposium were two-fold: 1) to provide an interdisciplinary framework for researchers who have worked on this issue to share their collective experiences with students who want to contribute to solutions to this important problem and 2) to provide an opportunity for brainstorming future research and solutions. The graduate students involved aimed to make IAP in developing countries a primary issue at the conference, particularly for young researchers entering the field. As an example of where the priority currently stands in the state of indoor environmental and health sciences, *Indoor Air* currently publishes about 50 research articles per year, and has been doing so since 2004. However, we found only 19 articles since 2004 that related to IAP in developing countries, or approximately 5%. Although we understand that articles published in a scientific journal must maintain a certain technical rigor and that many issues surrounding IAP in developing countries may not stem from inadequate research, but rather inadequate implementation and intervention efforts, we feel that this statistic is a good indicator of the amount of attention environmental health in developing countries receives in the research community; people are aware, but few are conducting research. Thus, one of the goals of this symposium was to bring broader attention to the problems of and solutions to IAP in developing countries.

Previous Research on IAP in Developing Countries

Inefficient and poorly ventilated cookstoves place a disproportionate burden of pollutant exposure on women and children in developing countries, particularly in rural settings. Simple household cookstoves can emit large amounts of carbon monoxide (CO), volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), metals, and particulate matter (PM). For example, in homes that use solid fuel, 24-hour mean concentrations of PM_{10} (mass of particulate matter with aerodynamic diameter less than 10 μm) routinely reach 300-3,000 $\mu g/m^3$ and may peak as high as 10,000 $\mu g/m^3$ during cooking (Adler, 2010). By comparison, the World Health Organization recommends no more than a 24-hour mean PM_{10} concentration of 50 $\mu g/m^3$ (WHO, 2005). $PM_{2.5}$ (mass of particulate matter with aerodynamic diameter less than 2.5 μm) poses even greater risks to respiratory health due to its smaller size and deposition deeper in the respiratory system. Although WHO air quality guidelines state that the 24-hour mean $PM_{2.5}$ concentration should not exceed 25 $\mu g/m^3$, researchers generally report concentrations of several hundred $\mu g/m^3$ in homes with solid fuel-burning cookstoves (Cynthia et al., 2008).

Documented adverse health effects of indoor solid fuel burning include acute respiratory infections in young children, chronic obstructive pulmonary disease, pulmonary tuberculosis, cataracts, low birth weight, perinatal and infant mortality, nasopharyngeal and laryngeal cancer, and lung cancer (Bruce et al., 2000; Smith et al., 2000). Smith (2000) reviewed existing epidemiological studies on the health risks of burning solid fuels indoors and applied the risks to the more than three-quarters of all Indian households dependent on such fuels, estimating that some 400,000 to 550,000 premature deaths could be attributed annually to use of biomass fuels. Using a disability-adjusted lost life-year approach, premature deaths account for 4–6% of the Indian national burden of disease, placing IAP as a major risk factor in the country. Confidence in the association between particular health risks and IAP varied with the type of health effect considered. Sufficient evidence was available to estimate risks most confidently for acute respiratory infections (ARI), chronic obstructive pulmonary disease (COPD), and lung cancer. Estimates for tuberculosis (TB), asthma, and blindness were of intermediate confidence, estimates for heart disease had the lowest confidence, and there was insufficient quantitative evidence available to estimate the impact of adverse pregnancy outcomes (e.g., low birth weight and stillbirth).

Smith and Mehta (2003) estimated the burden of disease due to IAP from household solid fuel use in developing countries using four different methods. They estimated that 4–5% of the global totals for both deaths and DALYs (disability adjusted life years) from acute respiratory infections, chronic obstructive pulmonary disease, tuberculosis, asthma, lung cancer, ischaemic heart disease, and blindness could be attributed to solid fuel use in developing countries. Acute respiratory infections in children less than five years of age were the largest single category of deaths (64%) and DALYs (81%) from IAP and responsible globally for about 1.2 million premature deaths annually in the early 1990s.

These broad population estimates have provided great motivation for much of the research on IAP in developing countries in recent years. Taking a closer look at published articles over the last 30 years, we found that research on IAP in developing countries to date can be categorized into several general categories, including:

1) Modeling studies
2) Health outcome studies
3) Exposure measurements
4) Health outcome studies combined with exposure measurements
5) Testing of cookstoves and other indoor combustion devices

Several studies of each kind are summarized below. Although certainly not an exhaustive list, these are generally representative of most studies typical of their kind.

1) Modeling Studies

Smith et al. (1983) authored one of the first studies to investigate IAP in developing countries. They used a simple well-mixed reactor "box" model to estimate possible indoor concentrations of PM in typical homes in villages in Gujarat, India, using data on home volumes and PM emission factors from studies of fireplaces in the U.S. They had no data on air exchange rates, but their simple models showed that indoor concentrations of PM in these rural huts could be tremendous: on the order of 200-10000 $\mu g/m^3$, where we typically regulate on the order of 10-100 $\mu g/m^3$ in the developed world. More recently, Johnson et al. (2011) performed a Monte Carlo analysis of a simple, single-zone, well-mixed model of indoor $PM_{2.5}$ and CO concentrations from cookstove emissions in developing countries, using estimated cookstove emission rates and expected distributions of kitchen volumes and air exchange rates (due to lack of measured data). Among their findings, they predicted that only about 4% of homes using wood fuel in a rocket stove (a widely known cleaner and more efficient stove) would achieve WHO annual $PM_{2.5}$ guidelines.

As Johnson et al. (2011) suggest, modeling studies that evaluate IAP and cookstove performance in developing countries are under-utilized and lag behind their outdoor air pollution counterparts. It is desirable to predict not only the concentrations of a handful of traditional pollutants, such as CO and PM, but also other hazardous air pollutants of great concern, such as NO_x, aldehydes, dioxins, PAHs, and others. Modeling efforts in this field would benefit from adopting more complex models of reaction chemistry similar to those used regularly to model outdoor air pollution. Furthermore, taking into consideration a more comprehensive range of environmental, household, and human behavioral conditions would improve the relevance of modeling results to sustained and proposed intervention strategies to reduce IAP in developing countries.

2) Health Outcome Studies

These studies have typically measured or assessed only health outcomes in populations without actual pollutant concentration or exposure measurements, and can be either longitudinal (i.e., following certain populations in time) or cross-sectional (i.e., large populations with different characteristics at one point in time). These studies often group populations into those that use different types of cookstoves. For example, Pérez-Padilla et al. (1996) performed a case-control study in women older than 40 years of age to evaluate the risk of cooking with traditional wood stoves for chronic bronchitis and chronic airway obstruction (CAO). They recruited 127 patients with chronic bronchitis or CAO from a chest hospital in Mexico City and compared to 375 healthy control subjects. Exposure to wood smoke was assessed by interview and categorized as "any," "none," and as *hour-years* (the years of exposure multiplied by hours of exposure per day) and was significantly higher in patients with chronic bronchitis or CAO than in controls. Risk of chronic bronchitis alone and chronic bronchitis with CAO increased linearly with hour-years of cooking with a wood stove, supporting a causal role of domestic wood smoke exposure in chronic bronchitis and CAO.

Mishra et al. (1999) analyzed the relationship between type of cooking fuel and the prevalence of partial and complete blindness in India using data on over 170,000 people age 30 and over from a national family health survey. After controlling for availability of a separate kitchen, house type, crowding, age, gender, urban-rural residence, education, religion, caste/tribe, and geographical region, those living in biomass fuel-using households were found to have a considerably higher prevalence of blindness (partial or complete) than those living in households using cleaner fuels (OR 1.32; 95% CI 1.16–1.50). The effects were large and statistically significant for both men (OR 1.31; 95% CI 1.12–1.52) and women (OR 1.30; 95% CI 1.12–1.50) and for urban areas (OR 1.22; 95% CI 1.01–1.49) and rural areas (OR 1.49; 95% CI 1.23–1.80). The level of risk and extent of biomass fuel use in India indicated that ~18% of partial and complete blindness among persons age 30 and older may be attributed to biomass fuel use.

Boy et al. (2001) studied over 1700 women and newborn children in communities in rural Guatemala and reported that children born to mothers who habitually cooked over open fires had the lowest mean birth weight, followed by those whose mothers used a chimney stove, followed by those whose mothers used the cleanest fuels (e.g., electricity or gas vs. an open fire). Mishra (2003) investigated the association between household use of biomass fuels for cooking and acute respiratory infections (ARI) in 3559 preschool age children (< 5 years old) in Zimbabwe. ARI symptoms were defined as a cough followed by short, rapid breathing. After adjusting for child's age, sex, birth order, nutritional status, mother's age at childbirth, education, religion, household living standard, and region of residence, children in households using wood, dung, or straw for cooking were more than twice as likely to have suffered from ARI as children from households using LPG/natural gas or electricity (OR = 2.20; 95% CI 1.16-4.19).

More recently, Hosgood et al. (2011) performed a meta-analysis on 25 case-control studies to summarize the association between household coal use for cooking and/or heating and the risk of lung cancer. Throughout the world, household coal use was associated with increased lung cancer risk (OR = 2.15; 95% CI 1.61-2.89), and the association was particularly strong in mainland China and Taiwan. Their results provide evidence that although the carcinogenic effect of coal use varies by location, coals from many locations exhibit elevated lung cancer risks.

Studies of associations between health outcomes and IAP frequently focus on a single health outcome relative to one or several cooking, cookstove, and/or fuel use variables, but this field of research continues to expand to encompass cardiovascular, neural and cognitive, and even genetic health outcomes in addition to more traditional respiratory health outcomes. For example, Li et al. (2011) performed a case-control study of 610 babies with neural tube defects (NTDs, or birth defects involving the failure of the neural tube to develop properly during the embryonic stage) and 837 normal controls in Shanxi Province, China. They qualitatively estimated mothers' exposure to household coal combustion by dwelling and lifestyle surveys. Women with any exposure to coal-based IAP had a 60% greater risk of having a child with an NTD (OR = 1.6; 95% CI 1.1-2.1). An increased NTD risk was linked to both residential heating (OR = 1.7; 95% CI 1.1-2.4) and cooking (OR = 1.5; 95% CI 1.1-2.1). As health-related research efforts become more multidisciplinary, understanding of the adverse impacts that household air pollution has on health should become more sophisticated and thus, enrich the development of health indicators used to evaluate the impact of health intervention strategies.

It is important to note major differences between epidemiologic studies of IAP in developing countries and those performed on air pollution in developed countries. For example, the relative risks and odds-ratios previously mentioned for adverse health effects of IAP in developing countries have consistently been in the range of 1.3 to 2.5, meaning that the excess risk of experiencing many adverse health effects ranges generally from +30% to +150%. In the U.S., typical elevations in outdoor PM concentrations have been linked with ~4 to 8% increases in the prevalence of adverse health effects (e.g., Pope et al., 2002). Smith and Peel (2010) showed that the typical inhaled dose of $PM_{2.5}$ from IAP in developing countries (and subsequent health risks) likely lies directly in between ranges inhaled via outdoor air and secondhand smoke in developed countries (RR ~1-1.2) and those inhaled by active smokers (RR ~1.7-2+).

3) Exposure Measurement Studies

Exposure measurement studies have typically measured concentrations of pollutants in and around homes and/or on persons in households with indoor combustion devices. They often combine time-activity surveys as well to estimate exposures (exposure = concentration × time). Exposure assessments are sometimes estimated using surrogate measures, such as fuel consumption, time-activity patterns alone, or household characteristics and conditions. Most exposure studies to date continue to be limited by instrumentation; that is, only a few criteria pollutants are usually measured for a combination of reasons, including cost or availability of instrumentation to measure the pollutants, ease of measuring the pollutants, and the role of pollutants as either the major pollutants of concern or as indicators of all pollutants of concern. Additionally, exposure studies may be limited by the time scale over which collected measurements are averaged. Many of these studies have also differentiated between types of cookstoves, and although they vary in project location, they tend to center around regions of the world that are familiar to the individual researchers or research teams. For example, work by Smith et al. (1983) was one of the first studies to investigate air pollution from biomass burning. They measured exposures to total suspended particles (TSP) and particle-bound benzo(a)pyrene by women cooking on simple stoves using traditional biomass fuels in four Indian villages.

Saksena et al. (1992) measured personal and indoor TSP mass and CO (using an electrochemical detector) in six microenvironments in villages in the central Himalayan region of northern India. Concentrations of pollutants measured at the time of cooking were found to be very high but comparable to those measured in the Indian plains (56 mg/m^3 and 21 ppm for TSP and CO, respectively). The daily exposure of adult women to TSP and CO was estimated to be 37 $mg\text{-}hr/m^3$ and 110 ppm-hr, respectively.

Daily exposure within each of the four population groups was found to be very uniform across individuals for both the pollutants.

Naeher et al. (2000) measured 22-hour average concentrations of CO, TSP, PM_{10}, and $PM_{2.5}$ in three test homes of rural highland Guatemala in kitchens, bedrooms, and outdoors, before and after introduction of potential exposure-reducing interventions. Four cookstove conditions were studied sequentially: background (no stove in use); traditional open woodstove, improved woodstove with flue (plancha), and bottled-gas (LPG) stove. With nine 22-hour observations each, kitchen $PM_{2.5}$ levels were 56 $\mu g/m^3$ under background conditions, 528 $\mu g/m^3$ for open fire conditions, 96 $\mu g/m^3$ for plancha conditions, and 57 $\mu g/m^3$ for gas stove conditions. Corresponding PM_{10}/TSP levels were 173/174, 717/836, 210/276, and 186/218 $\mu g/m^3$. Corresponding CO levels were 0.2, 5.9, 1.4, and 1.2 ppm. Comparisons with other studies in the area indicate that the reductions in indoor concentrations achieved by improved wood-burning stoves with flues deteriorate with stove age and lack of maintenance. Mother and child personal CO and $PM_{2.5}$ measurements for each stove condition demonstrate the same trend as area measurements, but with less differentiation.

Albalak et al. (2001) measured 24-hour $PM_{3.5}$ (particles with an aerodynamic diameter of roughly 3.5 µm, rather than the traditional $PM_{2.5}$, PM_{10}, or TSP) mass concentrations using personal exposure monitors (PEMs) in 30 households in rural Guatemala, split equally between those with traditional open fire cookstoves, improved cookstoves (*plancha mejorada*), and a liquefied petroleum gas (LPG) stove open fire combination. The PEMs (which can be attached to people to measure personal exposure or simply placed in other environments to obtain a representative sample of that environment) were placed at a height of 1.25 m at a distance of about 1 m from the outside perimeter of the stoves (representing a cook's breathing zone), and at least 1.5 m from doors and windows where possible (to avoid direct influence by outdoor air). They measured 24-hour geometric mean $PM_{3.5}$ concentrations of 1560 $\mu g/m^3$, 280 $\mu g/m^3$, and 850 $\mu g/m^3$ for the three stove combinations, respectively.

Balakrishnan et al. (2002) quantified exposures to respirable PM from biomass fuel combustion in 436 rural homes in four districts of Tamil Nadu, India. They used PM measurements and time-activity records to reconstruct 24-hour exposures. They measured PM gravimetrically using pumps with cyclones with a 50% cut-off of 4 µm, according to a protocol from the National Institute of Occupational Safety and Health (NIOSH Protocol 0600). Personal samplers were attached to cooks during both cooking and non-cooking times. Indoor "area" and outdoor measurements were also made. Concentrations of respirable PM ranged from 500 to 2000 $\mu g/m^3$ during cooking in biomass-using households, and average 24-hour personal exposures were 90±21 $\mu g/m^3$ for those not involved in cooking and 231±109 $\mu g/m^3$ for those who cooked. 24-hr PM exposures were 82±39 $\mu g/m^3$ for those in households using clean fuels. Fuel type, type and location of the kitchen, and the time spent near the kitchen while cooking were the most important determinants of exposure across the households.

Bruce et al. (2004) assessed the impact of improved stoves, house ventilation, and the location of children during cooking events on indoor levels of and child exposure to CO and $PM_{3.5}$ in 204 households using wood fuel in rural Guatemala. CO concentrations were measured in the kitchen and on children using diffusion tubes, and PM was measured in the kitchen only with an air sampler and cyclone. The 24-hour kitchen CO concentration was lowest (mean = 3.09 ppm) for homes with self-purchased planchas, relative to 12.4 ppm for open fires. The same relative relationship between stove types was found for child CO exposure, but with proportionately smaller differentials. The 24-hour kitchen $PM_{3.5}$ concentrations showed similar differences. The study concluded that the improved stoves in the community were effective in reducing indoor air pollution and child exposure, although both measures were still high by international standards, and that large donor-funded stove programs need to aim for wider acceptance and uptake by the local families. Another important outcome of this study was the successful agreement between 24-hour CO concentrations and group mean PM concentrations, which substantiate earlier work by Naeher et al. (2001) exploring the use of 24-hour CO concentrations as a surrogate for PM concentrations in the same microenvironment (CO measurements are typically much less cumbersome than PM measurements). This relationship is valuable to the degree that it could potentially reduce costs during exposure assessments and thus, make it increasingly possible to study larger sample sizes.

More recently, Smith-Sivertsen et al. (2009) conducted a randomized trial in Guatemala and observed significantly decreased incidences of pulmonary morbidity associated with decreased wood smoke concentrations in those living in homes with improved cookstoves. Finally, Smith et al. (2010) reported on the protocols and validations of a method to measure CO using diffusion tubes, as well as trends in personal exposure for mothers and their young children and the efficacy of improved chimney stoves in reducing personal exposures and kitchen concentrations in Guatemala (from the Randomized Exposure Study of Pollution Indoors and Respiratory Effects study, or RESPIRE). The diffusion tubes showed a nonlinear response in comparison to a continuous electrochemical CO monitor, but could be calibrated to reduce the bias. They found CO levels to be significantly lower among a stove intervention group during the trial period, with geometric mean CO concentrations 90% lower in kitchens, 61% lower on mothers, and 52% lower on children.

4) Health Outcome Studies Combined with Exposure Measurements

These studies typically combine measured/assessed health outcomes with actual exposure measurements. For example, Ellegård (1996) investigated the association between exposure to IAP from cooking fuels (wood, charcoal, electricity, and LPG) and several health outcomes in 218 women in Maputo, Mozambique. On average, wood users were exposed to higher PM levels during cooking times (1200 $\mu g/m^3$) than charcoal users (540 $\mu g/m^3$) and LPG users (200-380 $\mu g/m^3$). Wood users also had significantly more cough symptoms than other groups (which were measured by surveys with a 3-week recall period). PM mass was measured roughly as PM_{10} using air pumps and a cyclone with a cutoff of 7.1 μm.

Ezzati and Kammen (2001) used longitudinal health data coupled with monitoring and personal exposure estimations from more than 2 years of field measurements in rural Kenya to estimate the exposure-response relationship for PM_{10} exposure from biomass combustion and acute respiratory infections (ARI). They performed continuous real-time measurements of indoor PM_{10} and CO in 55 randomly selected homes. Monitoring took place for 14–15 hours per day for more than 200 days. They also recorded the location and activities of all members of the households during days of monitoring. Personal exposures were calculated using the measurements and the time budget, activities of individuals, and spatial dispersion of pollution in the houses. Exposure-response curves were developed for both acute respiratory infections and acute lower respiratory infections in adults.

More recently, Clark et al. (2009) examined relationships between measured indoor and personal concentrations of $PM_{2.5}$ and CO and pulmonary function (using finger-stick blood spot samples to measure C-reactive protein) and respiratory symptoms (reported) using a cross-sectional survey of 79 Honduran women cooking with traditional or improved cookstoves. The use of improved stoves was associated with lower levels of both personal and indoor $PM_{2.5}$ and only indoor CO (not personal), as compared to traditional stoves. Although women using traditional stoves reported respiratory symptoms more frequently than those using improved stoves, there was no evidence of associations between cookstove type or air quality measures and pulmonary health indicators. In another recent study, Clark et al. (2011) measured 48-hour indoor $PM_{2.5}$ and indoor and personal CO concentrations in 124 households using open-fire cookstoves in Nicaragua. They detected evidence of a trend between IAP and two indicators of cardiovascular health (blood pressure and heart rate), which they monitored; however, the increases in systolic blood pressure they observed were non-significant. Indoor CO levels were significantly associated with increased systolic blood pressure in obese participants (8.51 mmHg increase per 24 ppm increase in 48-hour average CO levels; 95% CI 3.06-13.96).

Similarly, Baumgartner et al. (2011) measured 24-hr integrated personal exposure to $PM_{2.5}$ and systolic (SBP) and diastolic blood pressure (DBP) in the winter and summer among 280 women 25 years or older living in rural households using biomass fuels in Yunnan, China. Personal exposure ranged from 22 to 634 $\mu g/m^3$ in winter and 9 to 492 $\mu g/m^3$ in summer. A one-log increase in $PM_{2.5}$ exposure was associated with 2.2 mmHg (95% CI 0.8-3.7) higher SBP and 0.5 mmHg (95% CI -0.4-1.3) higher DBP among all women, varying by age group. Among women older than 50 years, a one-log increase in $PM_{2.5}$ exposure was associated with a 4.1 mmHg (95% CI 1.5-6.6) increase in SBP and a 1.8 mmHg (95% CI 0.4-3.2) increase in DBP, suggesting that $PM_{2.5}$ exposure from biomass combustion may be a risk factor for elevated blood pressure, and hence for cardiovascular events. They recommended that their findings be confirmed in longitudinal studies.

5) Testing of Cookstoves and Other Indoor Combustion Devices

These types of studies have typically measured the performance of stoves or lamps in lab conditions or simulated or actual field conditions. Device performance is often quantified in terms of energy (e.g., thermal efficiency or rates of fuel consumption), pollutant emissions (e.g., mass of pollutants emitted per time, or per mass of fuel burned, or per unit of energy delivered), or both. For example, McCracken and Smith (1998) compared the thermal efficiency and emissions (PM and CO) of traditional three-stone fires to the "plancha" improved wood-burning stove, both during a Water Boiling Test (WBT) and a Standardized Cooking Test (SCT), as performed in kitchens in Highland Guatemala. Although there was no difference in thermal efficiency, the plancha emitted 87% less $PM_{2.5}$ and 91% less CO per kJ of useful heat delivered during the WBT. Emissions reductions were even larger for the SCT. Additionally, CO and $PM_{2.5}$ concentrations were highly correlated in the kitchen, indicating that CO could be an inexpensive alternative with which to infer $PM_{2.5}$ concentrations (as later explored quite successfully by Naeher et al., 2001 and Smith et al., 2010).

Roden et al. (2009) characterized emissions from traditional and improved biofuel cookstoves in both field and laboratory conditions and found that field-measured PM emissions of actual cooking were three times higher than those measured during simulated cooking in the laboratory, on average. Emission factors were highly dependent on the care and skill of the operator. Over the course of three summers in Honduras, they measured field emissions from traditional cookstoves, relatively new improved cookstoves, and ''broken-in'' improved cookstoves, finding that well-designed improved cookstoves can significantly reduce PM and CO emission factors below those of traditional cookstoves. For improved stoves, the presence of a chimney generally resulted in lower emission factors but left the single scattering albedo (a measure of climate forcing) unaffected. Traditional cookstoves had an average PM emission factor of 8.2 g per kg, which was significantly larger than previous studies. PM emission factors for improved cookstoves without and with chimneys averaged about 6.6 g per kg and 4.5 g per kg, respectively. The elemental carbon (EC) fraction of PM varied significantly between individual tests, but averaged about 25% for each of the categories.

Jetter and Kariher (2009) investigated 14 different stove-fuel combinations in a lab setting and identified significant differences in combustion performance and pollutant emissions during water boiling tests (WBTs). They measured CO, CO_2, total hydrocarbons, $PM_{2.5}$ mass, and size-resolved particle concentrations. They noted challenges of the need for small mass of stove components, acceptable durability, and cost.

In a study of fuel-based lamps (another indoor combustion source commonly used in the developing world), Apple et al. (2010) characterized PM concentrations due to fuel-based lighting in kiosks in Kenya. They demonstrated that vendors who use a single simple wick lamp in market kiosks will likely be exposed to $PM_{2.5}$ concentrations an order of magnitude greater than ambient health guidelines, and that using a hurricane lamp would reduce exposure to $PM_{2.5}$ and PM_{10} concentrations by approximately the same amount, although not necessarily for ultrafine particles. Kerosene lamps may be important, but often overlooked, indoor combustion devices, as a recent study found higher risks for tuberculosis associated with their use than the risk associated with the use of biomass stoves and/or heaters and kerosene stoves (Pokhrel et al., 2009).

Most recently, Shen et al. (2011) measured emission factors of oxygenated polycyclic aromatic hydrocarbons (OPAHs) for nine commonly used crop residues and five coals burned in typical residential stoves widely used in rural China under simulated kitchen conditions. OPAH emission factors ranged from 2.8 to 8.1 mg/kg for crop residues and from 0.043 to 71 mg/kg for coals. OPAHs showed a higher tendency to be associated with particulate matter (PM), especially fine PM, and the dominant size ranges were 0.7-2.1 μm for crop residues and high caking coals and <0.7 μm for the tested low caking briquettes.

The technical complexity and variety of stoves (and other combustion devices) involved in recent studies is growing. Previous research has identified a great need for standardized device tests, as well as better agreement with actual field performance. Some researchers of late have proposed new approaches to stove/device testing for combustion efficiency and/or emissions, including simpler and more economical proxy methods for combustion efficiency that can be more representative of cooking cycles in the field (Johnson et al., 2010), moving from mass-based particle dose parameters (e.g., $PM_{2.5}$) to those based on surface area concentrations that would deposit in the lungs (Sahu et al., 2011), and even using computational methods to model heat transfer in and around cookstoves (Wohlgemuth et al., 2009).

Cookstove Implementation Efforts and Barriers to Widespread Adoption

Large-scale Implementation Efforts

There are currently more than 160 operating cookstove programs in the world (Gifford, 2010), although few have been able to scale beyond a few thousand stoves (Bailis et al., 2009). The largest and most successful stove implementation program in history is the Chinese National Improved Stove Program (NISP), which introduced 180 million stoves from 1983 to the mid-1990s, although they unfortunately did not continue to monitor sustained use of the disseminated stoves (Sinton et al., 2004; Ruiz-Mercado et al., 2011). In contrast, a large program was also started in India around the same time as the NISP (the Indian National Programme for Improved Chulas, or NPIC), and its relatively meager dissemination of almost 30 million cookstoves became one of the largest examples of cookstove program failures (Kishore and Ramana, 2002); its top-down model, lack of feedback, and poor quality stoves have been attributed to its failure (Gifford, 2010). One relatively successful large-scale program in Africa is the Kenya Ceramic Jiko, which has reached over two million homes in Kenya and has been replicated across the region (Bailis et al., 2009).

Manibog (1984) reported that between 1977 and 1985, almost 43 million improved cookstoves were distributed in developing countries at a cost of at least $40 million USD, although 10-20% of stoves were not used and 20-30% were only used intermittently. Interestingly, Gifford (2010), which provides a unique exhaustive review of cookstove implementation programs over the past few decades, also found that only 14 of the 101 current cookstove programs surveyed met or exceeded their cookstove dissemination goals, and only 33% of programs in the 1990s and 2000s met their goals. Gifford (2010) also found that a wide range of cookstoves have been sold or distributed in these programs and that laboratory and field testing requirements also range widely.

Recent calls for widespread improved stove implementation efforts have often emphasized a market-based approach, with stove producers ultimately acting as self-sustaining entities without outside funding or governmental support. However, Bailis et al. (2009) argued that some level of donor-driven or government-subsidized investments may be crucial to success because of the difficulty for individuals to start a business in some of the countries most affected by IAP, as well as the historical record of better investment and cost effectiveness in research and development, marketing, financing, monitoring and evaluation, and quality assurance and control by the public sector (relative to the private sector). Gifford (2010) echoed this thought, finding that while half of the currently active cookstove programs are led by nongovernmental organizations (NGOs), the most successful (in terms of number of stoves disseminated) have been led by governments.

Recent Organizational Collaborations

In recent years, several large-scale efforts have been mounted to promote collaboration in the clean cookstoves community and to alleviate the health burden of IAP in developing countries worldwide. In 2002 at the World Summit on Sustainable Development, a group of organizations joined to launch the Partnership for Clean Indoor Air (PCIA).[1] More than 400 public and private organizations have joined the

[1] More information about the PCIA can be found at http://www.pciaonline.org.

PCIA and are contributing their resources and expertise to improve health, livelihood, and quality of life by reducing exposure to indoor air pollution, primarily among women and children, and reducing household energy use. The PCIA focuses on four priority areas for sustainable household energy and health programs in developing countries, including meeting social and behavioral needs, developing local markets, improving technology design and performance, and monitoring the impacts of interventions.

In 2010, the UN Foundation's Global Alliance for Clean Cookstoves[2] was launched at the Clinton Global Initiative meeting. The GACC is a public-private partnership to save lives, improve livelihoods, empower women, and combat climate change by creating a thriving global market for clean and efficient household cooking solutions. The GACC has a "100 by '20" goal calling for 100 million homes to adopt clean and efficient stoves and fuels by 2020. The GACC plans to work with public, private, and non-profit partners to help overcome the market barriers that currently impede the production, deployment, and use of clean cookstoves in the developing world.

Barriers to Stove Adoption

Several regional and international organizations have initiated intervention efforts focused on improving cookstove design and performance in order to address the public health and environmental problems posed by inefficient stoves, but efforts to address pollutant emissions through the distribution of improved cook stoves have achieved mixed results. Wallmo and Jacobson (1998) encountered problems with improved cook stove implementation in Uganda, including malfunctions of improved stove components, high cost of stoves, and no net change in fuel consumption. Muneer and Mohamed (2003) described the importance of gender roles in stove adoption in Sudan, showing that failing to include women in the household decision making process led to decreased adoption of improved stoves. Cynthia et al. (2008) reported substantial reductions in women's exposure to CO and PM in rural Mexican homes equipped with improved cookstoves, but also described the difficulty in adoption and reliance on multiple fuels and technologies for cooking needs. Often, cooks do not want to give up their old stove simply because of tradition or cooking preference (Victor, 2011). Most recently, Ruiz-Mercado et al. (2011) described challenges to the adoption and sustained use of improved cookstoves, noting that "stove stacking," or the use of several available stove and fuel types for different purposes, is common in households with improved cookstoves over time. These and other findings over the past decade reflect mixed results and the combined technical and social complexities associated with effective cookstove implementation in developing countries.

Previously Identified Knowledge Gaps, Limitations, and Research Needs

Previous research and evaluations of implementation programs have identified a wide range of opportunities for improvements in widespread reductions in the adverse health effects of IAP in developing countries through the adoption of cleaner cookstoves and other combustion devices. Some of these opportunities and research needs to date are summarized below.

Bruce et al. (2000) noted that because most health studies were observational at the time, lacking direct exposure measurements and not dealing with confounding variables, risk estimates were poorly quantified and may have been biased. Ezzati and Kammen (2002) reviewed the current knowledge on the relationship between IAP exposure and disease and on interventions for reducing exposure and disease, considering the details of both exposure and the health effects that are needed for successful intervention strategies. They identified knowledge gaps and detailed research questions that are essential to successful design and dissemination of preventive measures and policies, concluding that, given the interaction of housing, household energy, and day-to-day household activities in determining exposure to IAP, research and development of effective interventions can benefit tremendously from integrating methods and analysis tools from a range of disciplines in the physical, social, and health sciences.

Ezzati (2005) assessed recent developments in the state of knowledge on IAP in developing countries and provided several recommendations for both research and implementation, including the

[2] More information on the Global Alliance for Clean Cookstoves can be found at http://cleancookstoves.org.

need for: 1) ambitious research and development on alternative technologies for accessible and clean energy sources and on the economic and regulatory institutions required for large-scale dissemination of these technologies; 2) interventions that lower emissions by modifying specific aspects of current fuel and stove combinations and energy-use behaviors; 3) more nuanced understanding of barriers to and complexities of stove interventions (e.g., barriers to stove adoption or highly variable performance caused by technical complexities of stove design, lack of maintenance, and users' behaviors) to be taken into account in future research; 4) evaluations of the effectiveness of stove interventions that quantify hazard along a continuum of exposures (because many interventions for IAP partly reduce exposure); 5) establishment of the temporal dimensions of exposure and hazard, including the effects of exposure during pregnancy, at a young age, and as adults on various disease outcomes and reversibility of risk after exposure reduction; and 6) investigations of the hazards of multiple exposures and benefits of individual and combined interventions because the health outcomes caused by IAP also have other common risk factors (e.g., childhood and maternal under-nutrition for low birth weight and acute respiratory infections, and smoking for chronic obstructive pulmonary disease and lung cancer).

In 2006, the International Academy of Indoor Air Sciences, the honor society of the world's foremost experts on indoor air pollution, published an editorial in *Indoor Air* declaring IAP in developing countries an issue of immediacy, and concluded that there is evidence that "this is a solvable problem given the right commitment from political, corporate, institutional, and scientific leaders." They called upon "the governments, institutions and corporations of the world to take actions to reduce the devastating effects of indoor air pollution in developing countries," offering "the scientific backing and knowledge to work together to rid human kind of this tragic but very solvable problem" (IAIAS, 2006).

Recent Meetings on IAP in Developing Countries

In January 2011, the US Department of Energy organized a two day meeting to "identify technical challenges and opportunities for reducing cookstove emissions and improving efficiency" (DOE, 2011). The recommendations of this meeting reflect the opinions of 80 experts convened and may support a DOE cookstove research and development program. Key needs identified in this meeting for the use of cookstoves to reduce IAP and greenhouse gas emissions are: 1) an initial target of 90% emissions reduction and 50% fuel usage reduction, 2) adoption of multiple combinations of stoves and fuels to address diverse cookstove and economic needs in a variety of regions throughout the world, 3) establishment of strong communication between field studies, laboratory research, and stove design, and 4) further investigation regarding the relative merits of processed fuel and unprocessed fuel and applicability in addressing need #3.

In May 2011, the National Institutes of Health (NIH) organized a two-day workshop on the health burden of IAP on women and children in developing countries.[3] They brought together research and policy experts to outline research priorities to reduce the health risks of cookstoves to women and children. NIH led the workshop to present the state of the science on the health impacts of IAP and to determine critical research gaps that, if addressed, would foster effective strategies to reduce the impact of IAP and improve health for impoverished women and children. Funding for the workshop was provided by NIH, the US State Department, and the US Environmental Protection Agency, and the workshop outcomes will feed into the recommendations of the Health Working Group, one of nine such groups that will contribute to a list of research priorities to be announced by the GACC in 2011. Nine white papers on research topics ranging from cancer to women's empowerment will be released in the coming months, and authors from NIH recently published an article in *Science* describing the need for more research trials and new approaches to evaluate the health benefits of implementation programs (Martin et al., 2011).

Also in May 2011, the World Bank published a generalized report on household cookstoves, environment, health, and climate change, drawing on the expertise of a wide range of researchers and decision-makers in this field from universities, non-profit organizations, and the UN Foundation GACC,

[3] More information on the NIH workshop can be found at http://www.fic.nih.gov/News/GlobalHealthMatters/June2011/Pages/cookstove-workshop.aspx.

as well as from within the World Bank. This report complemented the reports from the DOE and the NIH by reiterating the need to consider social and cultural desires concomitant with cookstove performance and health-based needs. Building on lessons learned from the results of past and ongoing stove programs, this report also emphasized the need to develop new sources and mechanisms of financing, highlighting the potential to leverage links to climate change mitigation and forest and agricultural management. The value chain related to cookstoves was presented as "an opportunity to put the integrative idea of sustainable development into practice." As support of clean cookstove and clean cooking has grown, the World Bank has sought with this report to "re-engage in the development community on many dimensions of a field that can benefit most from the reach, lessons sharing, and practical focus that a multinational development agency can offer."

Indoor Air 2011 Symposium Development

This symposium was organized by graduate students in the National Science Foundation's Integrative Graduate Education Research and Traineeship (IGERT) program in Indoor Environmental Science and Engineering at the University of Texas at Austin. In seeking to encourage student participation at all levels of the conference, the Indoor Air 2011 President and Technical Chair reserved five 2-hour blocks of conference time to allow student conference organizers to pursue subjects of particular interest to new researchers in the field of indoor air quality. Four doctoral students, Ellison Carter, Elliott Gall, Matt Earnest and Brent Stephens (the authors of this report), along with a few other graduate students from both the University of Texas at Austin and the Missouri University of Science and Technology, agreed that there was a fundamental need, both within the Indoor Air community and beyond, to explore and discuss the state of the science of IAP in developing countries, to bring new researchers in this field together, and to assess efficient integration of research into advocacy and implementation efforts.

We drafted a proposal to the National Science Foundation's IGERT program to sponsor the symposium, and with this support awarded 28 scholarships to motivated students conducting research and implementation in the field of IAP in developing countries, with a particular focus on cookstoves. We arranged the symposium based on the abstracts submitted to the conference at-large and abstracts and personal statements submitted by students during the scholarship application process. The research presentations were organized by topic into three technical tracks (conducted on June 6, 2011), followed the next day by presentations from three invited speakers and roundtable discussions among leading experts in the field and students (conducted on June 7, 2011). Technical presentations were included to provide a forum for researchers to formally present novel research categorized according to one of three themes: 1) Field Studies, 2) Health Studies, and 3) Stoves and Lamp Studies. Invited speakers were selected to provide high level overviews of the past, current, and future state of the science to seed discussions throughout the day and to provide motivation for students to continue working in the field. Student roundtable discussions were included to foster discussion about the details of performing research in this field, which may go unnoticed in publications and meeting summaries. Finally, roundtable discussions nurtured communication among all symposium attendees to better understand connections between multiple research disciplines and to identify interdisciplinary research needs. The symposium brought many first time attendees to the Indoor Air conference and community, forging networks that will allow cross-communication between researchers across the world in a variety of related disciplines.

Indoor Air 2011 Symposium Details

Research Presentations (Monday, June 6, 2011)

Research presentations were organized into three technical session blocks on Monday June 6, 2011, as follows:

1. Field Studies: 9:55am – 12:00 pm
   Student Chairs: Ellison Carter and Jill Baumgartner
2. Health, 1:00 pm – 3:05 pm
   Student Chairs: Brent Stephens and Christian L'Orange
3. Stoves and Lamps, 3:25pm – 5:30 pm
   Student Chairs: Elliott Gall and Odessa Gomez

Each session was chaired by one of the student organizers from UT and co-chaired by a student scholarship winner. Each paper is included in the appendix of this report, in the order that they were presented.

Field Studies Session

The Field Studies session featured three presentations of fieldwork conducted in three different rural locations. Odessa Gomez presented the results from a pollutant monitoring study she and her colleagues conducted in a rural town in the highlands of Peru, where they measured indoor concentrations of $PM_{2.5}$ and black carbon (BC). These researchers measured concentrations of these pollutants before and after installation of locally designed, improved cookstoves and found there to be a 98% and 96% decrease in indoor $PM_{2.5}$ and BC concentrations, respectively. In addition to the quantitative results, these researchers emphasized the ongoing partnerships with the local community members and organizations, without which their work would not have been possible. Lindsay Davis also focused on the role of building trusting relationships between researchers, stove implementation organizers, and community members when presenting the work she and her colleagues conducted in a small town of El Fortin, Nicaragua, where they made observations of stove use and maintenance and interviewed 124 primary household cooks. These researchers found that barriers to stove adoption extended beyond factors such as stove durability and performance. Even when the primary cooks stated that they felt the improved stove performed better and was less smoky, their use of the stove was inconsistent or minimal, and these observations highlighted the need to further explore what social barriers might hinder the rate of stove adoption. The final presentation given by Pengfei Chen documented indoor concentrations of $PM_{2.5}$ and CO in the tents of nomadic Tibetan yak herders during summer months. From these concentrations and daily activity logs, individual exposures to these two pollutants were estimated, and were found to agree with prevailing literature that women and children spent significantly more time near the source of pollutants—often three to four more hours per day than other household members. The primary fuel source for these communities is yak dung, which generated high levels of the monitored pollutants. However, with installation of a chimney, these pollutant levels were greatly reduced.

Health Studies Session

In the Health Studies session, Jill Baumgartner first presented a study measuring personal $PM_{2.5}$ exposure to 280 rural Chinese women, which was significantly and positively associated with increased systolic and diastolic blood pressure, particularly in women aged more than 50 years old. Miles Elledge then presented a review of the use of biomass stoves and the associated environmental health risks in Sri Lanka, an understudied but likely important area for cookstove implementation. Next, Ananya Roy reported new data from a mid-1990s study of IAP and lung function growth among over 3000 children in China, finding that almost one-third of the children lived in homes that used coal for heating or cooking, and that coal use was associated with poorer lung growth (in terms of the increase in forced vital capacity of the lungs, or FVC, per year). Next, Jennifer Peel presented on a study of Nicaraguan women that measured indoor $PM_{2.5}$ and indoor and personal CO in 124 households. They also measured lung function (in terms of forced expiratory volume in one second, or FEV_1), heart rate, and blood pressure of the women, finding significant increases in heart rate with increased personal CO exposure, and non-significant increases in systolic blood pressure with indoor CO (this relationship was significant when limited to obese women). Line Alnes followed by presenting a cross-sectional study of hypertension and solid fuel use among over 1700 women in rural China, finding that there were statistically significant increases in blood pressure associated with poorer functioning stove categories. Sarah Yoder then presented a study of an improved stove intervention on exposure and health among women in Nicaragua, and Linda Dix-Cooper presented a study of the relationship between chronic prenatal exposure to CO from wood smoke and children's neurodevelopment in rural Guatemala. Dix-Cooper found inverse associations between pregnant mothers' personal CO exposure during their third trimesters and several child neurodevelopmental performance scores at age 6, including scores for visuo-spatial integration, short-term memory recall, and fine motor performance. This study appears to be the first of its kind to assess cognition in terms of exposure to IAP.

Stoves and Lamps Session

In the Stoves and Lamps session, most presentations described measurement of emissions and fuel usage. Susan Doll began the session presenting results of a study on locally available stoves in rural Rwanda. Her results indicated that of the five stoves tested, all had lower $PM_{2.5}$ and CO emission levels, but rates of fuel consumption varied. She concluded that cooking practices are an important opportunity for reducing both emissions and fuel consumption. Thomas Kirchstetter compared emissions rates of CO, $PM_{2.5}$, and BC from a three stone fire arrangement and the Berkeley-Darfur Stove and discussed implications for health and safety benefits from decreased fuel usage, particularly in areas of global strife, like Darfur. Andrea Yarberry presented particle emission rates from various kerosene lamps used in rural houses in Kenya and showed that the $PM_{2.5}$ contributions from these lamps alone can result in concentrations of $PM_{2.5}$ that exceed WHO guidelines after less than one hour of use. James Jetter then presented the results of a comprehensive laboratory study that compared emissions of black carbon, elemental, organic, and total carbon, gravimetric PM, size-resolved particle number, aerosol light scattering, CO, CO_2, and CH_4, and fuel consumption, energy efficiency, and fire/cooking power from about 20 combinations of fuel and stove types during Water Boiling Tests, and found a wide variety of fuel efficiency and emission rates. Jetter concluded that studies that compare laboratory results to field results under similar conditions are needed.

The remaining presenters proposed new methodologies for assessing cookstoves, at both the user and global level. John Field then presented a study that integrated improved cookstoves into a cost-benefit analysis for carbon abatement costs, finding that wide scale dissemination of clean cookstoves is an effective means of reducing anthropogenic emissions of climate altering gases and particles. Christian L'Orange proposed a methodology that shifts the range of fuel usage test from "boiling" tests to those based on a range of temperatures less affected by the vaporization of water (a process that significantly alters test results at different elevations). Anoop Muniyappa presented a methodology using durable and inexpensive Stove Use Monitors to estimate temperatures of cookstoves over month-long timescales. The Stove Use Monitor output illustrated significant deviations from survey data, potentially providing robust data on true stove use habits.

Presentations by Invited Speakers (Tuesday, June 7, 2011)

Three speakers were invited to present on Tuesday, June 7, 2011:

- Kirk Smith, University of California, Berkeley
- Corinne Hart, Global Alliance for Clean Cookstoves
- Bob Thompson, United States Environmental Protection Agency

Their presentations are summarized below.

Kirk Smith, UC-Berkeley

Kirk Smith, Professor of Global Environmental Health at the University of California, Berkeley covered the general history and recent developments in the field.[4] He began by describing estimates of man's early use of fire starting around 300-400 thousand years ago (Roebroeks and Villa, 2011), and described that the fraction of people using solid fuels for household purposes has been decreasing in recent years (to about 40%), but because the overall population continues to increase, the absolute number of people in the world using solid fuels is still increasing. Thus, the number of people using solid fuels today is actually greater than the total world population was in 1950.

Professor Smith then described the wide ranges of toxic pollutants found in biomass fuel smoke (particularly wood smoke), including particulate matter, carbon monoxide, hydrocarbons (e.g., n-hexane, 1,3-butadiene, benzene, styrene, and benzo(a)pyrene), oxygenated organic compounds (e.g., formaldehyde, acrolein, methanol, catechol, hydroquinone, and radicals), and chlorinated organic compounds (e.g., methylene chloride and dioxin) (Naeher et al., 2007). Typical indoor concentrations of many of these pollutants are higher than many regulatory health standards (e.g., the International Agency for Research on Cancer, or IARC).

Professor Smith then described one of the first studies of air pollution and biomass burning in developing countries, a study in Gujarat, India in 1981 (Smith et al., 1983). At that point in time, more than 85% of households in India were using biomass fuels, and smoke was often visible inside households in rural villages. In this early paper, they performed a simple well-mixed reactor "box" model to estimate possible indoor concentrations of particulate matter in a typical home using data on home volumes and PM emission factors from studies of fireplaces in the U.S. They had no data on air exchange rates, but their simple models showed that indoor concentrations of PM in these rural huts could be tremendous (on the order of 2-10 mg/m^3, where we typically regulate on the order of 10-100 $\mu g/m^3$ in the developed world). So they then visited homes in India and measured mean PM mass concentrations (TSP) of approximately 7 mg/m^3. They investigated several factors that related to exposures (e.g., location of cooking, income, age, fuel use, stove type, etc.), and found some correlations, but all exposures were still far too high to be considered safe.

Professor Smith also noted that they were using bulky and cumbersome PM mass monitors in their study in the early 1980s, but not much has changed since then. PM mass monitors are "*still terrible*" for measuring personal exposures. And although there were some "improved cookstoves" in their early study, they were often poorly functioning or improperly used, thus ceasing to be "improved." Professor Smith noted that perhaps the field should be getting away from the term "improved cookstoves" altogether, as it is not a term detailed enough to indicate the effectiveness of a cookstove in reducing exposure to biomass smoke. One improvement that has been more recently by Professor Smith and his research group is to use the terms "neighborhood pollution" or "household air pollution," which includes both indoor exposures and neighborhood exposures, or those immediately outside of residences. The logic for this is that while chimneys can effectively dilute indoor smoke, the result is simply the transport of smoke outdoors where children are still exposed to it. In fact, their group has measured CO exposures in Guatemala and found that although kitchen concentrations decreased by a factor of ~10 after a chimney stove intervention, child exposures only decreased by a factor of ~2, simply because children don't spend their entire day in the kitchen and spend a lot of time outdoors where household or "neighborhood" pollution from both chimney and non-chimney stoves is high.

Professor Smith spoke about developing simple metrics to assess exposures, one example being the Kitchen Exposure Factor (KEF), or the personal exposure divided by concentration measured in the kitchen. In their large study in Guatemala (RESPIRE), kitchen levels decreased by a factor of ~10, but the KEF increased by a factor of ~5, reducing overall exposure by only a factor of ~2.

Then Professor Smith turned to recent work by one of his students Zoe Chafe (in attendance), who used satellite data of $PM_{2.5}$ in rural areas of India and China to estimate the fraction of $PM_{2.5}$ emissions *to the outdoors* attributed to households burning biomass *indoors*. Chafe estimated that

[4] Kirk Smith's presentation can be found at http://ehs.sph.berkeley.edu/krsmith/presentations/2011/IA11.pdf.

approximately 30% and 53% of $PM_{2.5}$ emissions were attributed to households in China and India, respectively. Chafe presented her work at another technical session at Indoor Air outside of the student symposium (indoor and outdoor connections). Professor Smith noted that ultimately, this is all why we really need clean combustion. Chimneys don't do much to alleviate outdoor air pollution, exposures, or climate, and they are insufficient to achieve WHO guidelines for health.

Professor Smith mentioned some gaps in our information related to health effects of exposure to biomass smoke, particularly in our knowledge of the risks of heart disease relative to $PM_{2.5}$ dose. In their 2010 publication, Smith and Peel (2010) noted that there is a gap in the evidence along the dose–response curve (between risk of heart disease and $PM_{2.5}$ dose) between exposures to outdoor air pollution and environmental tobacco smoke (ETS) at the low end, and active smoking at the high end. This gap represents the dose range experienced by half the world's population from indoor biomass and coal burning for cooking and heating. And because of the nonlinear shape of the dose-response curve, there may be much larger public health benefits of reductions at the lower end of the dose spectrum than from reducing the rate of active smoking; that is to say that because so much of the population is exposed to relatively low $PM_{2.5}$ mass in ambient air and moderate-to-high $PM_{2.5}$ mass from biomass burning indoors, and so few of the population are active smokers exposed to $PM_{2.5}$ at the highest ends, the greatest benefit to public health could actually be achieved not by targeting the relatively few smokers in the world but the abundance of people that breathe and cook indoors with biomass fuels (about 40% of the world). Additionally, Smith and Peel (2010) recommend that epidemiologic studies are urgently needed to quantify the cardiovascular risks of particulate matter exposures from indoor biomass burning in developing countries, as no studies have been done to date on heart disease and household air pollution.

Finally, Professor Smith finished a quote from Henry David Thoreau, who said:

"Wood is the fuel that warms you twice, once when you chop it, and once when you burn it."

But then asked, "or is it four times?" The first two, then burns from respiratory infection and global warming. "Better combustion will get rid of the second pair."

Corinne Hart, Global Alliance for Clean Cookstoves

Corinne Hart, Senior Associate at the Global Alliance for Clean Cookstoves (GACC), spoke about the objectives and approach of the GACC. The GACC is a $250 million, 10-year public-private partnership dedicated to saving lives, empowering women, improving livelihoods, and combating climate change by creating a thriving global market for clean and efficient household cooking solutions. Their focuses are on advocacy (e.g., the actress Julia Roberts recently joined as a Global Ambassador), research, a state of the sector mapping, market-based solutions, standards and testing (e.g., responsibilities similar to those of the National Institute for Standards and Technology), financing, and governance (building a structure that works for the organization).

The GACC was formed because its founders saw a lack of a comprehensive global vision and strategy for reducing the global health burden due to biomass burning. They observed very little funding and wanted to bring in different kinds of donors into a historically fragmented sector, and were inspired by seeing developments in new stove technologies. The GACC is currently coordinating with cookstove efforts on all scales, including government-led efforts, local factories selling directly, international manufacturers with local distribution, and impact investing with local partners. They are partnering with those working to make better devices, such as the UC-Berkeley monitors, Aprovecho RC kits, and iButton stove use monitors.

Ms. Hart also discussed the GACC's focus on women's empowerment; that is, empowering women to achieve better health and wellness through the use of cleaner cookstoves, promoting decision making (e.g., gathering input on stove design, teaching women to teach others, and engaging men in cultural attitudes towards women), and enriching their lives economically (e.g., by starting businesses around the stoves value chain).

The GACC has established several alliance working groups, who started by identifying "quick wins," making a priority roadmap and strategic plan, and providing strategic advice, all of which will be summarized in a "tipping point" report in the fall of 2011. Some of their early action recommendations include generating interim tiered ratings systems for benchmarking stoves, creating a toolkit for countries to build internal support for clean cookstoves, and enhancing testing centers, among several others.

The GACC plans to measure success in 10 years by demonstrating the health, climate, and economic benefits of clean and efficient coking solutions, observing the adoption of clean and efficient cookstoves by 100 million households by 2020 (roughly 20% of globally affected population).

Bob Thompson, US EPA

Bob Thompson, manager of the indoor air research lab for the US Environmental Protection Agency, spoke broadly about the future of clean cookstoves. Mr. Thompson first confirmed that the attendance throughout the day was consistent at approximately 50 people, and advertised a post-doctoral position at the US EPA, seeking candidates with experience in chemistry, who would be particularly focused on black carbon emissions and field studies in developing countries.

Mr. Thompson outlined the issue: an estimated 500 million cookstoves are needed globally to eliminate the associated public health burden. Mr. Thompson recommended that we all confirm our consensus that it's going to take a wide range of stoves, appropriate for wide varieties of marketplaces. He also spoke of the need to balance measurements and mitigation and sees value in EPA stove testing. Mr. Thompson made an analogy to the $32 billion iPhone: that is that it was once believed that the cost of computer memory would never decrease below $1 per byte, so the iPhone he was holding should have cost about $32 billion dollars. Instead, it cost only a few hundred dollars. He envisioned a similar future for cookstoves, and believes that costs for all stoves must decrease, and encouraged the audience to not be limited by current norms.

Mr. Thompson discussed several metrics that participants in the symposium had identified that would make a clean cookstove and encouraged that we all rethink how we discuss costs (i.e., moving more towards a lifecycle cost approach), and that we consistently miss health performance and productivity externalities.

Mr. Thompson then finished with motivating remarks to the audience (composed mostly of graduate students), urging that they do not get discouraged, avoid "silos" in our research, and pursue areas ripe for significant change, including stove technology, materials (durability), biomass fuel efficiency, cleaner fuels, carbon credits, value of clean (health, performance and productivity), and market awareness and acceptance. He summarized by urging that there are many opportunities for improvements and profits and that it's up to the young researcher to decide what his or her role is going to be.

Student Panel Discussion (Tuesday, June 7, 2011)

Seven student panelists were selected from the pool of attending scholarship winners based on their research submitted to Indoor Air 2011, their past research, and their personal statements. The panel discussion sought to showcase the student experience related to IAP work, both laboratory work performed domestically and research and implementation work conducted abroad in developing countries. The students were chosen to offer the audience a breath of research experience, community involvement, and career status. Students provided one presentation slide to introduce themselves at the beginning of the panel discussion. Then, a moderated discussion with input solicited from the audience followed, intended to cover topics of interest to students and researchers seeking to begin a career in this field. Some specific topics covered included the integration of developing countries work in their technical thesis or dissertation research, the role of their advisers in supporting their work, and finding funding for their work.

The seven participating students and their affiliations included:

- Odessa Gomez, University of Colorado, Civil, Architectural and Environmental Engineering
- Christian L'Orange, Colorado State University, Engines and Energy Conversion Lab
- Jarod Maggio, Michigan Technological University, Environmental Engineering
- Anoop Muniyappa, University of California Berkeley, Public Health
- Jessica Vechakul, University of California Berkeley, Mechanical Engineering
- Lindsay Davis, Colorado State University, Environmental Health, Veterinary and Biomedical Sciences
- John Field, Colorado State University, Mechanical Engineering

After brief introductions from each member of the panel, a moderated discussion covered the major discussion topics below (with questions asked to each panelist), followed by an open discussion with the audience. Here we have outlined the discussion topics as well as some of the key findings of the discussion itself.

Student Discussion Topics

- What are good ways that a student who might be interested can get involved?
- How did you get involved in work in developing countries? Was there a program already established at your university or were you able to create your own?
- Would you pursue developing country work as a career path? Why or why not?
- Do you see yourself continuing with this type of work after you graduate?
- What can PIs and funding agencies do to improve the student experience, recruitment and retention?

Findings from Student Discussion

Q: How did you get started?

Odessa Gomez offered her story of how she switched careers from Chemical Engineering to Environmental engineering, and is now perusing a dual PhD in the U.S. and at a university in Chile. Christian L'Orange encouraged the audience to not become to beholden to any one career path, telling his personal story of how he entered his Mechanical Engineering PhD (he was originally hired to work on natural gas engines, but he ended up travelling to Europe and when he came back, his project was gone, so he used his skills to begin work on cookstove testing).

Jarod Maggio is researching household cooking innovations at Michigan Tech in their Peace Corps masters program and John Field came to cookstove work in his NSF IGERT program at CSU. Jessica Vechakul had been working with developing countries on a range of projects since 2004, and undergraduate students Lindsey Davis and Anoop Muniyappa have sought out cookstove research early in their careers. Lindsey had been doing development work at CSU and is now moving to the Michigan Tech University Peace Corps masters program. Anoop sought out Kirk Smith as an undergraduate at UC-Berkeley and got involved with the Berkeley Air Monitoring group through which he traveled to India (Anoop plans to apply to medical school next).

Q: Was there a program already established at your university or were you able to create your own?

All of the panelists had some pre-existing framework at their university to which they could credit some of their success. Two examples are Christian and Jessica. Christian explained that CSU had excellent industrial combustion testing equipment at their facilities, and groups would come to them for testing. This allowed him to perform quality tests on stoves without having to setup a lab on his own. Jessica described the "decal program" where UC-Berkeley students can teach their own courses. This was used by students to do cookstoves research and offers ample flexibility and resources for students to peruse their interest

Open discussion

The first question that drew significant interest and discussion from the audience was posed by Danny Wilson, a CSU graduate, previously a high school teacher, and a current graduate student at UC-Berkeley, who wondered how to maintaining developing country work while perusing a tenure-track position in academia. Being students, the panelists were not able to specifically answer this question so the audience stepped up. Susan Doll of Appalachian State University began by explaining the importance of attaching meaning and relevance to your proposed developing country work, meaning that a potential employer (or tenure review committee) is looking for certain skills and what needs to be shown is the application of one's skills and accomplishments in a well-packaged way. She also made clear her belief that students should "follow their bliss." Lidia Morawska, of Queensland University of Technology in Brisbane, reiterated the message saying; don't look for a topic that's important for a job now, choose something you're passionate about for the rest of your life.

The discussion then shifted away from employment and to dissertation topics and dissertation committee selection. John Field noted that finding a common thread between the many topics in his dissertation helped him. In his case, this meant finding similarities between both US and global biofuels. He also believed that a supportive adviser was paramount. Jarrod Maggio agreed on all accounts. Christian went one step further, explaining that two teams of advisers that are very different (one practical and one academic) help him solve problems in different ways. His project involved test methods and how to apply fundamental scientific knowledge, so having advisors in both the applied and the academic realm benefited him. Jessica explained the benefits of flexible advisers and said that if you find your own funding you can have even more flexibility.

The undergraduates on the panel also shared their experiences. Lindsay Davis explained how she was able to gain exposure to every aspect of projects as an undergrad instead of focusing on just one part as graduate students tend to; graduate students should take this advice and use their academic status as an advantage. Anoop shared that he thought that his experience with MDPH would make his medical schools applications more competitive. Finally, Odessa Gomez highly encouraged collaboration with local Engineers Without Borders (EWB) chapters, although there was some concern about EWB ability to sustain their projects and the high cost of training associated with EWB because of the high turnover rate.

Group Discussions (Tuesday, June 7, 2011)

During the months prior to the symposium, the student organizers contacted several researchers with experience in the field of IAP in developing countries to solicit their support and participation. Seven of these people agreed to help and offered valuable input during the planning process. Upon attendance, they served as group discussion leaders, split into six discussion groups. The group leaders were as follows:

- Susan Doll, Assistant Professor, Department of Technology and Environmental Design, Appalachian State University (Group 1)
- Corinne Hart, Senior Associate, Global Alliance for Clean Cookstoves (Group 2)
- Jim Jetter, Research Project Engineer, US Environmental Protection Agency (Group 3)
- Jennifer Peel, Associate Professor, Department of Environmental and Radiological Health Sciences, Colorado State University (Group 4)
- Kirk Smith, Professor, Department of Environmental Health Sciences, University of California, Berkeley (Group 5)
- Xudong (Don) Yang, Professor, Department of Building Science, Tsinghua University (Group 6, with Zhang)
- Junfeng (Jim) Zhang, Professor, Department of Environmental and Occupational Health, University of Southern California (Group 6, with Yang)

Each group was given a set of specific questions to discuss, which were developed prior to the symposium by the student organizers (and aided by the group leaders). Each set of questions were tailored to each group leader's expertise, and audience members were allowed to select which group they wished to join and enlist prior to discussions. The group discussions lasted approximately one hour, and the entire group reconvened to hear short summaries by one member of each group of their discussions.

Some research needs of general consensus that surfaced were:

1) The need for appropriate user input when designing and implementing improved cookstoves;
2) The need/opportunity to integrate renewable fuels into the improvement of cookstoves;
3) The need for standardization of what to measure and how to measure when assessing cookstoves and health outcomes;
4) The need for behavior assessments;
5) The need for market research for stoves;
6) The need for clarity and consensus on nomenclature within the field; and
7) The need for more health assessments. There was also some agreement that much can be learned from previous work in the water and sanitation development community, as well as from the outdoor air pollution field in meeting some of these needs.

Some of these research needs have been previously identified in the literature, while others appeared to be new. Attendees to this symposium also highlighted an interesting need for market research for stoves, which could be a novel way to address the previously identified problems of lack user adoption. Also, a desire for clarity, consensus on nomenclature, and standardization within the field came out of the group discussion with a strength that has not been collectively expressed before.

Summary of Group Discussions

A short summary of each group discussion is below, as noted and interpreted by the student organizers after hearing each summary.

Group 1

Group 1 discussed user acceptance of stove designs, and the advantages and disadvantages of outsourcing stove manufacturing. They discussed the importance of gender roles in the purchase of a stove, as well as the need to address cooking types, cooking duration, and ergonomics in stove design. They also discussed the need for standardized metrics to determine if a stove is affordable and low-emitting. They discussed the idea of an organic growth model for cookstoves, which would include various stove options and a progression of improvement (or various tiers) of cleaner stoves. They also asked where does the global need lie: are we trying to serve the most needy or the most accessible? They discussed the need for stove lifecycle assessments and agreed that local skills and materials should be a baseline criterion.

Group 2

Group 2 discussed global policy tools, many of which the GACC is trying to provide (e.g., tariffs, helping with administration, carbon financing, and fund matchmaking). The group agreed that the IAP field could learn much from leveraging previous water and sanitation work in developing countries. They agreed that there was a need for the development of standards for clean and efficient cookstoves, connected to labeling, which would allow for branding of stoves. They envision standards that focus on incremental improvements of stoves and differentiate between what is "clean" and what is "clean enough." The GACC is committed to signing up strategic partners and developing a comprehensive global database that will allow all kinds of people (implementers, donors, researchers, etc.) to develop networks and partnerships. The group discussed the need for more peer-reviewed scientific research on behavior change and stove adoption issues. They ultimately envision a database of field measurements that would be searchable and allow users to learn what stoves are associated with what exposures, and how well stoves were adopted. Last, they discussed the importance of national policies; that is, getting large national governments signed on to support cookstove implementation programs.

Group 3

Group 3 discussed the need for coordination of lab and field testing of stoves, and listed several important issues that need to be standardized and prioritized, including stove performance parameters (e.g., fuel efficiency), health based parameters (e.g., pollutant emissions), and global warming potential parameters. They made the analogy of car crash testing – crash testing is performed on a select few cars, but we do emissions testing (in some states) on ALL cars. What's right for stoves? They also discussed the need for standardizing test practices, as bad practices can (e.g., overfeeding fuel) can distort stove testing results. They envision regional test centers of independent labs, funded by industry, that test stoves and rate them according to a standardized system, but acknowledged that there is not yet agreement on what exactly to rate? And what does the end user care about? Finally, if we do setup regional test centers, they discussed the need for uniform test protocols and hardware.

Group 4

Group 4 discussed whether research programs and stove dissemination programs are conflicting or complementary, and generally agreed that they are both, depending on the goals and scale of projects. The discussed the need to integrate local communities into both dissemination and research program, and the need to build infrastructure within a community so dissemination can continue after research has been done. They also noted that students tend to observe other adverse health issues within the communities they're visiting for stove projects, which led to the idea of a new approach that is not just focused on stoves, but overall health in the community. For example, they envisioned a program that covered all environmental and health concerns, e.g., "Water+Stoves+Food." They asked is this scalable? Can we do this well? And how good is good enough? An approach like this would need to bring the organizational structure up (need a project manager). They also envision complete and open access to information and data, and noted that health reports do not report to the same standards, which makes it difficult to share data from different kinds of studies, thus again demonstrating the need for standardization in the field.

Group 5

Group 5 agreed that we need to know more about health impacts, and gave the example that the Indian government has not agreed to large scale stove implementation programs because they require to know more about the health *impacts* of programs. They cautioned that advocacy might be running ahead of our knowledge, and that more follow-up is required. They recommended to improve adoption by developing a range of cookstove options for developing communities, and to focus on ergonomics in cookstove design. They recommended striving for alternative fuels, giving the example that biogas might be a win-win as renewable fuel for stoves that would help sanitation. They compared this hypothetical jump to renewable fuels to the cellular telephone industry, forgoing a lot of infrastructure that exists in the developed world but which is rapidly becoming obsolete with new technology. They also questioned how many stoves the developing world really needs, and perhaps only one or two types of stoves serve all the developed world's needs. Finally, they described that women tend to see improved stoves as a modern status symbol and recommended harnessing that mentality.

Group 6

Group 6 focused specifically on research on IAP in China for a substantial portion of their discussion. They recommended expanding the term cookstove to "combustion device" in order to capture other appliances (e.g., heaters). They discussed the need to develop new high-tech, breakthrough, performance-based fuels and technologies to replace coal, particularly in China. They generally agreed that any initial dissemination of stoves would need to be subsidized, particularly in China. They, too, discussed the need to integrate renewable fuels into the discussion. They also discussed the need to understand the different health impacts, if they do indeed differ, between coal PM, wood PM, and biomass PM. They discussed the feasibility of using state-of-the-science bio-monitoring tools to monitor health outcomes (e.g., using breath condensate to measure exposure or outcomes). Finally, they described the need for standardization in reporting, noting that we don't currently have much Chinese research translated, so we may not be transferring knowledge as efficiently or completely as possible.

Conclusions and Symposium Recommendations

The insight, connections, and enthusiasm generated at this symposium will help guide and enable the next generation of researchers in their endeavors to conduct research on indoor air pollution (IAP) in developing countries. The major themes and results of this symposium were: 1) forging connections between new and established researchers in the field to accelerate new researchers' entry into the field, 2) discussing the role of researchers, ranging from engineering and health sciences to social sciences, within new cookstove dissemination programs and frameworks, and 3) determining opportunities for future interdisciplinary research to provide necessary data and findings to move the field forward and ultimately alleviate this pressing global health burden.

This symposium provided ample opportunities for discussion between new and established researchers, which is important for growth in any field. The student discussion panel provided insight regarding best practices for successful introduction of young researchers into this unique and demanding field, potentially highlighting opportunities for engaging and assembling future research teams. The panel discussion provided an opportunity for networking with established professionals, a key asset which can provide young researchers with guidance and mentorship while, for example, establishing new research programs in this field as their careers advance.

Panel discussions and presentations from government and non-profit organizations (e.g., the Global Alliance for Clean Cookstoves and the U.S. Environmental Protection Agency) provided opportunities to critically assess the role of researchers in this field, particularly on the issue of dissemination of cookstoves to end-users. The challenges associated with large-scale implementation in this field are unique compared to many traditional academic goals, and continued discussion of the impact of wide-scale implementation milestones on research methods and goals are warranted.

Finally, technical presentations and panel discussions provided an interdisciplinary perspective on current cookstove research, while invited presentations and small group discussions among young researchers and established experts in the field provided a forum to discuss future directions. Important issues included the need for improved, field-ready, standardized stove test methods to complement wide-scale dissemination of cookstove infrastructure. The need for data and new information regarding specific stoves and interventions was weighed against the demonstrated need for action, while considering the additional dimension of the political environment of both developed and developing nations. Continuing to provide a forum for researchers and field-workers with varying backgrounds and experience at academic- and practitioner-oriented conferences will help address these difficult questions as they evolve during this time of rapid change. The interdisciplinary approach supported by this symposium will empower researchers to pursue the most critical research efforts and support the rapid reduction of household air pollution into developing nations.

References

Adler, T., 2010. Better Burning, Better Breathing: Improving Health with Cleaner Cook Stoves. Environ Health Perspect 118, a124-a129.

Albalak, R., Bruce, N., McCracken, J.P., Smith, K.R., de Gallardo, T., 2001. Indoor Respirable Particulate Matter Concentrations from an Open Fire, Improved Cookstove, and LPG/Open Fire Combination in a Rural Guatemalan Community. Environmental Science & Technology 35, 2650-2655.

Apple, J., Vicente, R., Yarberry, A., Lohse, N., Mills, E., Jacobson, A., Poppendieck, D., 2010. Characterization of particulate matter size distributions and indoor concentrations from kerosene and diesel lamps. Indoor Air 20, 399-411.

Bailis, R., Cowan, A., Berrueta, V., Masera, O., 2009. Arresting the Killer in the Kitchen: The Promises and Pitfalls of Commercializing Improved Cookstoves. World Development 37, 1694-1705.

Balakrishnan, K., Sankar, S., Parikh, J., Padmavathi, R., Srividya, K., Venugopal, V., Prasad, S., Pandey, V.L., 2002. Daily average exposures to respirable particulate matter from combustion of biomass fuels in rural households of southern India. Environ. Health Perspect 110, 1069-1075.

Baumgartner, J., Schauer, J.J., Ezzati, M., Lu, L., Cheng, C., Patz, J.A., Bautista, L.E., 2011. Indoor Air Pollution and Blood Pressure in Adult Women Living in Rural China. Environ Health Perspect.

Boy, E., Bruce, N., Delgado, H., 2001. Birth Weight and Exposure to Kitchen Wood Smoke During Pregnancy in Rural Guatemala. Environ Health Perspect 110, 109-114.

Bruce, N., McCracken, J., Albalak, R., Schei, M.A., Smith, K.R., Lopez, V., West, C., 2004. Impact of improved stoves, house construction and child location on levels of indoor air pollution exposure in young Guatemalan children. J Expo Anal Environ Epidemiol 14, S26-S33.

Bruce, N., Perez-Padilla, R., Albalak, R., 2000. Indoor air pollution in developing countries: a major environmental and public health challenge. Bull. World Health Organ 78, 1078-1092.

Chen, A., 2006. Science@Berkeley Lab: A Mission to Darfur [WWW Document]. URL http://www.lbl.gov/Science-Articles/Archive/sabl/2006/Mar/01-Darfur.html

Clark, M.L., Bazemore, H., Reynolds, S.J., Heiderscheidt, J.M., Conway, S., Bachand, A.M., Volckens, J., Peel, J.L., 2011. A baseline evaluation of traditional cook stove smoke exposures and indicators of cardiovascular and respiratory health among Nicaraguan women. Int J Occup Environ Health 17, 113-121.

Clark, M.L., Peel, J.L., Burch, J.B., Nelson, T.L., Robinson, M.M., Conway, S., Bachand, A.M., Reynolds, S.J., 2009. Impact of improved cookstoves on indoor air pollution and adverse health effects among Honduran women. International Journal of Environmental Health Research 19, 357-368.

Cynthia, A.A., Edwards, R.D., Johnson, M., Zuk, M., Rojas, L., Jiménez, R.D., Riojas-Rodriguez, H., Masera, O., 2008. Reduction in personal exposures to particulate matter and carbon monoxide as a result of the installation of a Patsari improved cook stove in Michoacan Mexico. Indoor Air 18, 93-105.

Dherani, M., Pope, D., Mascarenhas, M., Smith, K.R., Weber, M., Bruce, N., 2008. Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis. Bull World Health Organ 86, 390-398.

DOE, 2011. Biomass Cookstoves Technical Meeting: Summary Report.

Ellegård, A., 1996. Cooking fuel smoke and respiratory symptoms among women in low-income areas in Maputo. Environ. Health Perspect 104, 980-985.

Ezzati, M., 2005. Indoor air pollution and health in developing countries. The Lancet 366, 104-106.

Ezzati, M., Kammen, D.M., 2001. Quantifying the Effects of Exposure to Indoor Air Pollution from Biomass Combustion on Acute Respiratory Infections in Developing Countries. Environ Health Perspect 109, 481-488.

Ezzati, M., Kammen, D.M., 2002. The health impacts of exposure to indoor air pollution from solid fuels in developing countries: knowledge, gaps, and data needs. Environ. Health Perspect 110, 1057-1068.

Gifford, M.L., 2010. A Global Review of Cookstove Programs.
Hosgood, H.D., Wei, H., Sapkota, A., Choudhury, I., Bruce, N., Smith, K.R., Rothman, N., Lan, Q., 2011. Household coal use and lung cancer: systematic review and meta-analysis of case-control studies, with an emphasis on geographic variation. International Journal of Epidemiology 40, 719-728.
IAIAS, 2006. Deadly household pollution: a call to action. Indoor Air 16, 2-3.
Jetter, J.J., Kariher, P., 2009. Solid-fuel household cook stoves: Characterization of performance and emissions. Biomass and Bioenergy 33, 294-305.
Johnson, M., Edwards, R., Berrueta, V., Masera, O., 2010. New Approaches to Performance Testing of Improved Cookstoves. Environ. Sci. Technol. 44, 368-374.
Johnson, M., Lam, N., Brant, S., Gray, C., Pennise, D., 2011. Modeling indoor air pollution from cookstove emissions in developing countries using a Monte Carlo single-box model. Atmospheric Environment 45, 3237-3243.
Kishore, V.V.N., Ramana, P.V., 2002. Improved cookstoves in rural India: how improved are they?: A critique of the perceived benefits from the National Programme on Improved Chulhas (NPIC). Energy 27, 47-63.
Li, Z., Zhang, L., Ye, R., Pei, L., Liu, J., Zheng, X., Ren, A., 2011. Indoor Air Pollution From Coal Combustion and the Risk of Neural Tube Defects in a Rural Population in Shanxi Province, China. American Journal of Epidemiology 174, 451-458.
Lopez, A.D., Mathers, C.D., Ezzati, M., Jamison, D.T., Murray, C.J., 2006. Global and regional burden of disease and risk factors, 2001: systematic analysis of population health data. The Lancet 367, 1747-1757.
Manibog, F.R., 1984. Improved Cooking Stoves in Developing Countries: Problems and Opportunities. Annu. Rev. Energy. 9, 199-227.
Martin, W.J., Glass, R.I., Balbus, J.M., Collins, F.S., 2011. A Major Environmental Cause of Death. Science 334, 180-181.
McCracken, J.P., Smith, K.R., 1998. Emissions and efficiency of improved woodburning cookstoves in Highland Gatemala. Environment International 24, 739-747.
Mishra, V., 2003. Indoor air pollution from biomass combustion and acute respiratory illness in preschool age children in Zimbabwe. International Journal of Epidemiology 32, 847 -853.
Mishra, V.K., Retherford, R.D., Smith, K.R., 1999. Biomass cooking fuels and prevalence of blindness in India. J. Environ. Med. 1, 189-199.
Muneer, S.E.T., Mohamed, E.W.M., 2003. Adoption of biomass improved cookstoves in a patriarchal society: an example from Sudan. The Science of The Total Environment 307, 259-266.
Naeher, L.P., Brauer, M., Lipsett, M., Zelikoff, J.T., Simpson, C.D., Koenig, J.Q., Smith, K.R., 2007. Woodsmoke Health Effects: A Review. Inhalation Toxicology 19, 67-106.
Naeher, L.P., Leaderer, B.P., Smith, K.R., 2000. Particulate matter and carbon monoxide in highland Guatemala: indoor and outdoor levels from traditional and improved wood stoves and gas stoves. Indoor Air 10, 200-205.
Naeher, L.P., Smith, K.R., Leaderer, B.P., Neufeld, L., Mage, D.T., 2001. Carbon Monoxide As a Tracer for Assessing Exposures to Particulate Matter in Wood and Gas Cookstove Households of Highland Guatemala. Environmental Science & Technology 35, 575-581.
Patrick, E., 2007. Sexual violence and firewood collection in Darfur. Forced Migration Review 40-41.
Pérez-Padilla, R., Regalado, J., Vedal, S., Paré, P., Chapela, R., Sansores, R., Selman, M., 1996. Exposure to biomass smoke and chronic airway disease in Mexican women. A case-control study. Am. J. Respir. Crit. Care Med 154, 701-706.
Pokhrel, A.K., Bates, M.N., Verma, S.C., Joshi, H.S., Sreeramareddy, C.T., Smith, K.R., 2009. Tuberculosis and Indoor Biomass and Kerosene Use in Nepal: A Case–Control Study. Environ Health Perspect 118, 558-564.
Pope, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K., Thurston, G.D., 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA 287, 1132-1141.

Ramanathan, V., Carmichael, G., 2008. Global and regional climate changes due to black carbon. Nature Geosci 1, 221-227.
Roden, C.A., Bond, T.C., Conway, S., Osorto Pinel, A.B., MacCarty, N., Still, D., 2009. Laboratory and field investigations of particulate and carbon monoxide emissions from traditional and improved cookstoves. Atmospheric Environment 43, 1170-1181.
Roebroeks, W., Villa, P., 2011. On the earliest evidence for habitual use of fire in Europe. Proceedings of the National Academy of Sciences 108, 5209 -5214.
Ruiz-Mercado, I., Masera, O., Zamora, H., Smith, K.R., 2011. Adoption and sustained use of improved cookstoves. Energy Policy.
Sahu, M., Peipert, J., Singhal, V., Yadama, G.N., Biswas, P., 2011. Evaluation of Mass and Surface Area Concentration of Particle Emissions and Development of Emissions Indices for Cookstoves in Rural India. Environmental Science & Technology 45, 2428-2434.
Saksena, S., Prasad, R., Pal, R.C., Joshi, V., 1992. Patterns of daily exposure to TSP and CO in the Garhwal Himalaya. Atmospheric Environment. Part A. General Topics 26, 2125-2134.
Shen, G., Tao, S., Wang, W., Yang, Y., Ding, J., Xue, M., Min, Y., Zhu, C., Shen, H., Li, W., Wang, B., Wang, R., Wang, W., Wang, X., Russell, A.G., 2011. Emission of Oxygenated Polycyclic Aromatic Hydrocarbons from Indoor Solid Fuel Combustion. Environmental Science & Technology 45, 3459-3465.
Sinton, J.E., Smith, K.R., Peabody, J.W., Yaping, L., Xiliang, Z., Edwards, R., Quan, G., 2004. An assessment of programs to promote improved household stoves in China. Energy for Sustainable Development 8, 33-52.
Smith, K.R., 2000. Inaugural Article: National burden of disease in India from indoor air pollution. Proceedings of the National Academy of Sciences 97, 13286-13293.
Smith, K.R., Aggarwal, A.L., Dave, R.M., 1983. Air pollution and rural biomass fuels in developing countries: A pilot village study in India and implications for research and policy. Atmospheric Environment (1967) 17, 2343-2362.
Smith, K.R., Mccracken, J.P., Thompson, L., Edwards, R., Shields, K.N., Canuz, E., Bruce, N., 2010. Personal child and mother carbon monoxide exposures and kitchen levels: Methods and results from a randomized trial of woodfired chimney cookstoves in Guatemala (RESPIRE). J Expos Sci Environ Epidemiol 20, 406-416.
Smith, K.R., Mehta, S., 2003. The burden of disease from indoor air pollution in developing countries: comparison of estimates. International Journal of Hygiene and Environmental Health 206, 279-289.
Smith, K.R., Peel, J.L., 2010. Mind the Gap. Environ Health Perspect 118, 1643-1645.
Smith, K.R., Samet, J., Romieu, I., Bruce, N., 2000. Indoor air pollution in developing countries and acute lower respiratory infections in children. Thorax 55, 518-532.
Smith-Sivertsen, T., Diaz, E., Pope, D., Lie, R.T., Diaz, A., McCracken, J., Bakke, P., Arana, B., Smith, K.R., Bruce, N., 2009. Effect of Reducing Indoor Air Pollution on Women's Respiratory Symptoms and Lung Function: The RESPIRE Randomized Trial, Guatemala. American Journal of Epidemiology 170, 211-220.
Victor, B., 2011. Sustaining Culture with Sustainable Stoves: The Role of Tradition in Providing Clean-Burning Stoves to Developing Countries. Consilience - The Journal of Sustainable Development 5, 71-95.
Wallmo, K., Jacobson, S., 1998. A social and environmental evaluation of fuel-efficient cook-stoves and conservation in Uganda. Environmental Conservation 25, 99-108.
WHO, 2005. Air quality guidelines for particulate matter, ozone, nitrogen dioxide, and sulfur dioxide: global update 2005:
Wohlgemuth, A., Mazumder, S., Andreatta, D., 2009. Computational Heat Transfer Analysis of the Effect of Skirts on the Performance of Third-World Cookstoves. J. Thermal Sci. Eng. Appl. 1, 041001.

Appendix – Symposium Handouts and Indoor Air 2011 Conference Papers

Symposium on Indoor Air Quality in Developing Countries

June 6-7, 2011, Indoor Air 2011, Austin, TX

IA2011 Student Program

Sponsored by the National Science Foundation's IGERT Program

Indoor air pollution in households that burn solid fuel is responsible for an estimated 1.6 million premature deaths worldwide each year, representing up to 4% of the global burden of disease. In addition to impacts on indoor air quality, carbon dioxide and carbon black emissions from cookstoves are also important contributors to global climate change.

To address some of the challenges to and opportunities for alleviating this important global health burden, students from the University of Texas at Austin have planned an entire symposium on indoor air quality in developing countries, sponsored by the National Science Foundation. The program will feature three technical sessions on Monday, June 6, 2011, covering field measurements, health interventions and outcomes, and stove and lamp testing. On Tuesday, June 7, 2011, the symposium will cover two session blocks, featuring presentations from leaders in the field, a student panel discussion with 7 graduate and undergraduate panelists, and a group discussion led by 7 group leaders from a variety of disciplines.

Symposium Agenda

Monday June 6, 2011 Technical Sessions

9:55 am – 12:00 pm Field Studies
1:00 pm – 3:05 pm Health
3:25 pm – 5:30 pm Stoves and Lamps

Tuesday, June 7, 2011 Symposium Events

Three mini-plenary talks
Student panel discussion
Group discussion with several leaders in the field
Detailed agenda on the inside of this handout

Tuesday, June 7, 2011 Symposium Events

9:55 am – 10:00 am Introduction and acknowledgements
Dr. Richard Corsi, The University of Texas at Austin

10:00 am – 10:30 am Historical glance
Kirk Smith, University of California, Berkeley

10:30 am – 11:30 am Student panel discussion
Featuring 7 student panelists (details below)

11:30 am – 11:50 am Policy tools & women's empowerment
Corinne Hart, Global Alliance for Clean Cookstoves

11:50 am – 12:00 pm Introduction of group leaders
Featuring 7 group discussion leaders (details on back)

12:00 pm – 1:00 pm Lunch break
Feel free to begin discussions with group leaders

1:00 pm – 1:55 pm Small group pairings and discussion
Join one of 7 small group discussions [move to Room 12B]

2:00 pm – 2:40 pm Reconvene [Back in room 18A]
Two-minute summaries by group leaders + open forum

2:40 pm – 3:00 pm Closing remarks
Bob Thompson, US Environmental Protection Agency




Photos courtesy of Jill Baumgartner, Lindsay Davis, Susan Doll, Christian L'Orange, and Jarod Maggio

Student Discussion Panelists

Lindsay Davis
Colorado State University
Environmental Health, Veterinary and Biomedical Sciences

John Field
Colorado State University
Mechanical Engineering

Odessa Gomez
University of Colorado
Civil, Architectural and Environmental Engineering

Christian L'Orange
Colorado State University
Engines and Energy Conversion Lab

Jarod Maggio
Michigan Technological University
Environmental Engineering

Anoop Muniyappa
University of California Berkeley
Public Health

Jessica Vechakul
University of California Berkeley
Mechanical Engineering

Featured Speakers

Kirk R. Smith is Professor of Global Environmental Health and Chair of the Graduate Group in Environmental Health Sciences at the University of California, Berkeley. He is the founder and coordinator of the Masters Program in Global Health and Environment and Associate Director for International Programs of the Center for Occupational and Environmental Health. His research work focuses on environmental and health issues in developing countries, particularly those related to health-damaging and climate-changing air pollution, and climate-changing air pollution, and includes ongoing field projects in India, China, Nepal, and Guatemala.

Corinne Hart joined the United Nations Foundation in 2008 and is the Senior Associate for Energy Access. She works primarily on the Global Alliance for Clean Cookstoves, a new public-private partnership to promote clean cookstoves in the developing world, and has played a key role in its launch and expansion.

Bob Thompson manages the indoor air research lab for the US EPA, and has 25 years experience with green building technologies and policies. Bob is a founding member of the US Green Building Council, serves on the LEED Steering Committee, and is chair of the Environmental Quality Technical Advisory Group.

Student Scholarship Winners

Yumchindorj Argo
University of California, Berkeley
Jill Baumgartner
University of Minnesota
Zoe Chafe
University of California, Berkeley
Sean Clarke
MIT
Lindsay Davis
Colorado State University
Linda Dix-Cooper
University of California, Berkeley
Sam Evans
Colorado State University
John Field
Colorado State University
Odessa Gomez
University of Colorado, Boulder
Kristine Guzak
Michigan Technological University
Nick Lam
University of California, Berkeley
Seth Lamble
Missouri University of Science and Technology
Jared Langevin
Drexel University
Christian L'Orange
Colorado State University
Jarod Maggio
Michigan Technological University
Jon McKinney
Missouri University of Science and Technology
Benjamin Mitchell
Michigan Technological University
Anoop Muniyappa
University of California, Berkeley
Ajay Pillarisetti
University of California, Berkeley
Jason Prapas
Colorado State University
Laura Read
University of Texas at Austin
Laura Roberts
Michigan Technological University
Nick Schreiner
Michigan Technological University
Alicia Sherrin
Michigan Technological University
Jessica Vechakul
University of California, Berkeley
Kelli Whelan
Michigan Technological University
Daniel Wilson
University of California, Berkeley
Sarah Yoder
Colorado State University

Group Discussion Leaders

Susan Doll
Assistant Professor, Department of Technology and Environmental Design
Appalachian State University

Corinne Hart
Senior Associate
Global Alliance for Clean Cookstoves

Jim Jetter
Research Project Engineer
US Environmental Protection Agency

Jennifer Peel
Associate Professor, Department of Environmental and Radiological Health Sci.
Colorado State University

Kirk Smith
Professor, Department of Environmental Health Sciences
University of California, Berkeley

Xudong (Don) Yang
Professor, Department of Building Science
Tsinghua University

Junfeng (Jim) Zhang
Professor, Department of Environmental and Occupational Health
University of Southern California

Symposium on Indoor Air Quality in Developing Countries

June 6-7, 2011, Indoor Air 2011, Austin, TX

IA2011 Student Program

Sponsored by the National Science Foundation's IGERT Program

Meet your group discussion leaders

Susan Doll
Assistant Professor, Department of Technology and Environmental Design
Appalachian State University

Dr. Susan Doll is professor of Building Science and Appropriate Technology at Appalachian State University in Boone, NC. She has a B.S in Medical Technology, M.S. in Energy Engineering and Sc.D. in Environmental Health Sciences. Her current research includes interactions between energy-efficient buildings and indoor environment quality, and energy and water technology applications in developing countries, most recently household energy use (cooking, lighting) and solar water pasteurization. Dr. Doll lived and worked in Rwanda for two years following her appointment as Earth Institute Fellow at Columbia University. Her work there as researcher and acting Infrastructure Coordinator for the Millennium Villages Project involved energy, water, transportation, communication, and construction projects across sectors in the community including agriculture, health, education, business development and households.

Corinne Hart
Senior Associate
Global Alliance for Clean Cookstoves

Corinne Hart joined the United Nations Foundation in 2008 and is the Senior Associate for Energy Access. She works primarily on the Global Alliance for Clean Cookstoves, a new public-private partnership to promote clean cookstoves in the developing world, and has played a key role in its launch and expansion. Prior to her work on increasing access to energy and clean cooking technology in the developing world at the UN Foundation, she worked in the Capitol Hill office of California Congresswoman Grace Napolitano. From 2003-2005, Ms. Hart was a corps member of Teach for America and taught special education for two years in New York City. In 2005, she traveled extensively through Latin America and taught at an orphanage in Sucre, Bolivia. She has a Bachelor's in Critical Gender Studies and Political Science and a Master's of Science in Education.

Jim Jetter
Research Project Engineer
US Environmental Protection Agency

Jim Jetter is a Senior Research Engineer with the U.S. Environmental Protection Agency, where he has been since 1991. He has been working in the area of indoor air quality since 2000. His interest in developing countries began when he was a Peace Corps volunteer in the 1980s. At the 2002 Indoor Air conference in Monterey, he was inspired by Kirk Smith's compelling plenary presentation on cook stoves, and he joined PCIA (Partnership for Clean Indoor Air) when it was launched in 2002. Since then, he has provided technical support to PCIA, led testing of cook stoves, published results, served as a trainer for stove testing, and participated in stove testing protocol development. Mr. Jetter has a BS in Mechanical Engineering from North Carolina State University, has an MS in Environmental Engineering (with a focus on Aerosol Science) from the University of North Carolina, and is a licensed Professional Engineer.

Jennifer Peel
Associate Professor, Department of Environmental and Radiological Health Sciences
Colorado State University

Jennifer L. Peel, PhD, MPH is an Associate Professor of Epidemiology in the Department of Environmental and Radiological Health Sciences at Colorado State University, Fort Collins, Colorado, with an appointment in the Colorado School of Public Health. She has a doctoral degree in epidemiology and a Masters of Public Health degree from Emory University in Atlanta. Dr. Peel's research focuses on the health effects of air pollution – both urban ambient air pollution and indoor air pollution from biomass cookstoves in developing countries. She is currently conducting studies (in conjunction with colleagues at the University of Colorado Boulder, the University of Washington, and the Colorado School of Mines) examining the short-term health effects of particulate matter species and size fractions in Northern Colorado (funded by EPA, NIH). Dr. Peel is also the PI of a project examining the impact of improved biomass cookstoves on exposure and health among Nicaraguan women (funded by NIH), and has been an investigator for a similar study in Honduras. Dr. Peel was an invited participant of the recent NIH Indoor Air Pollution workshop in conjunction with the Global Alliance for Clean Cookstoves ("Health Burden of Indoor Air Pollution on Women and Children in Developing Countries"). She currently serves as an Associate Editor of Environmental Health Perspectives and serves an advisor and writer for the U.S. Environmental Protection Agency national air quality assessment documents.

Kirk Smith
Professor, Department of Environmental Health Sciences
University of California, Berkeley

Kirk Smith is Professor of Global Environmental Health and is also founder and coordinator of the campus-wide Masters Program in Global Health and Environment. Previously, he was founder and head of the Energy Program of the East-West Center in Honolulu, where he still holds appointment as Adjunct Senior Fellow in Environment and Health after moving to Berkeley in 1995. He serves on a number of national and international scientific advisory committees including the Global Energy Assessment, National Research Councils Board on Atmospheric Science and Climate, the Executive Committee for WHO Air Quality Guidelines, and the International Comparative Risk Assessment. He participated along with many other scientists in the IPCC's 3rd and 4th assessments and thus shared the 2007 Nobel Peace Prize. He hold visiting professorships in India and China and bachelors, masters, and doctoral degrees from UC Berkeley and. in 1997, was elected member in the US National Academy of Sciences, one of the highest honors awarded to US Scientists by their peers. In 2009, he received the Heinz Prize in Environment. Dr. Smith's research focuses on environmental and health issues in developing countries, particularly those related to health-damaging and climate-changing air pollution from household energy use, and includes field measurement and health-effects studies in India, China, Nepal, Mexico, and Guatemala as well as development and application of tools for international policy assessments. He also develops and deploys small, smart, and cheap microchip-based monitors for use in these settings.

Xudong (Don) Yang
Professor, Department of Building Science
Tsinghua University

Xudong (Don) Yang is Chang-Jiang Professor in the Department of Building Science, Tsinghua University, China. He received his Ph.D. in Building Technology from MIT in 1999. He was a tenured associate professor in the U.S.A. before returning to Tsinghua University in 2006. His research aims at energy conservation technologies and environmental protection in built environment system. Dr. Yang is a co-author of the Technical Assessment Guide of Chinese Eco-Residential Buildings, the first green building assessment guide in China. Dr Yang's research efforts on building environmental systems are focused on simulating pollutant emission and transport using computational fluid dynamics (CFD) technique, and developing advanced technologies for air pollution prevention and control. Dr. Yang received the Special Emphasis Research Career Award (SERCA) from the U.S. Centers for Disease Control and Prevention (CDC) and the New Investigator Award from the ASHRAE in 2000. He is present secretary of ASHRAE TC 4.3 Ventilation Requirement and Infiltration. He has published more than 30 papers in various international journals and is an Editorial Board member of the Journal of the IEST.

Junfeng (Jim) Zhang
Professor, Department of Environmental and Occupational Health
University of Southern California

Junfeng (Jim) Zhang, PhD is a Professor and Chairman of Department of Environmental and Occupational Health, School of Public Health at University of Medicine and Dentistry of New Jersey (UMDNJ), where he is also Associate Dean for Global Public Health. He is on the faculty of Graduate Program in Toxicology and Graduate Program in Exposure Science, both at UMDNJ and Rutgers. Dr. Zhang is a guest professor at Peking University in Beijing, China. Dr. Zhang received a PhD in Public Health and Environmental Sciences jointly from Rutgers University and UMDNJ. Dr. Zhang's research interests include assessing human exposures to environmental contaminants and resulting health effects; developing biological markers of human exposure and health effects; and examining gene-environment interactions. He has co-authored more than 100 peer-reviewed papers. Dr. Zhang's work on greenhouse gas emissions from small-scale combustion devices made him one of the IPCC officially recognized contributing scientists to the 2007 Nobel Peace Prize. Dr. Zhang's laboratory developed a novel method to measure trace-level airborne acrolein and other toxic aldehydes. Dr. Zhang uses molecular epidemiological approaches to study health responses and biological mechanisms in free-living humans exposed to air pollution. His work, published in New England Journal of Medicine, demonstrated significant changes in both lung function and biomarkers of respiratory inflammation in asthmatics after having walked in a city street with diesel traffic. Dr. Zhang is currently leading a multidisciplinary study of molecular and physiological responses in humans to drastic changes in air quality during the Beijing Olympics.

Field Studies
Monday, June 6, 2011
9:55 AM -12:00 PM

1122. Indoor Air Pollution in an Indigenous Highlands Community in Peru
Odessa M. Gomez; Alina M. Handorean; Mark Hernandez; Erica L. Brandt; Amalia A. Lopez; Lupita D. Montoya

1509. Social barriers to improved stove adoption in El Fortin, Nicaragua
Lindsay Davis; Maggie Clark; Judy M. Heiderscheidt; John Volckens; Stephen J. Reynolds; Bevin Luna; Kirsten Koehler; Stuart Conway; Annette Bachand; Jennifer Peel

1093. Effect Of Fossil-fuel Electric Power Generators On Indoor Air Quality In Kaduna Nigeria
Andrew Mhya Stanley; Ikemefuna Mbamali; Afolabi A. Dania

229. Health Hazards of Home Based Economic Activities In Residential Areas
Mayank Mathur

176. Concentrations And Variations Of PM2.5 And Co In Tents Of Nam Co And Ando, Tibetan Plateau
Chaoliu Li; Pengfei Chen; Shichang Kang; Qianggong Zhang; Junming Guo

Indoor Air Pollution in an Indigenous Highlands Community in Peru

Odessa M. Gomez, Alina M. Handorean, Erica L. Brandt, Amalia A. Lopez, Mark T. Hernandez, Lupita D. Montoya*

University of Colorado at Boulder, Boulder, CO

**Corresponding email: Lupita.Montoya@colorado.edu*

SUMMARY

A pilot study was conducted to determine the levels of several air pollutants inside the homes in the small highlands (Andean) town of Langui, Peru. The measured pollutants included fine particulate matter ($PM_{2.5}$) and black carbon (BC) in addition to carbohydrate and protein levels, which were used as markers for biological aerosols. Sources of indoor aerosols mainly included combustion in traditional biomass stoves, indoor biomass fuel storage, and small animals. An initial assessment of health outcomes (respiratory disease) in this population was conducted through surveys in 30 homes. In addition, a modified traditional stove was evaluated and indicated a 99% reduction in $PM_{2.5}$ levels over a 24-hour period and a 96% reduction in BC emissions during cooking. This study demonstrated that significant improvements in indoor air quality can be achieved using local resources.

IMPLICATIONS

This study examined indoor air pollution in high altitude households that burn dung in traditional stoves. Inefficient combustion in combination with the presence of animals indoors significantly exacerbated indoor levels of combustion and biological aerosols. Implementing simple controls, however, can have a drastic effect on improving indoor air quality.

KEYWORDS

Biomass combustion; Black carbon; $PM_{2.5}$; Carbohydrates; Proteins

INTRODUCTION

Most households in the developing world use biomass for cooking and heating (Smith et al. 2004) and in deforested communities, like the highlands of Peru, they often use dried dung. Poor indoor air quality in these communities results from a combination of fuel type, stove design, combustion conditions, and inadequate room ventilation. Such conditions yield acute and long-term exposures to emissions that lead to respiratory (Torres-Duque et al. 2008) and cardiovascular disease (McCracken et al. 2007). Black carbon (BC) from incomplete combustion has also been associated to negative health outcomes (Mordukhovich et al. 2009) and with global climate change (Ramanathan et al. 2008). Most health studies on BC have focused on emissions from diesel exhaust (Jansen et al. 2005; Mordukhovich et al. 2009). Additional studies have determined that combustion and biological aerosols can work synergistically to exacerbate respiratory and allergic responses (Ryan 2008; Arimoto 2005). Aerosols originating from biological sources, like plant and animal debris and microbial cells, have shown negative impacts on allergic response and respiratory health (Gruchalla et al. 2005). Biological sources have been reported to constitute between 5% and 10% of PM found in urban and rural areas (Menetrez et al. 2009). Biopolymers (DNA, phospholipids, carbohydrates, and proteins) have been previously measured to assess fine primary biogenic aerosol in an urban area (Coz et al. 2010). This pilot study examined the levels of indoor air pollutants (BC and $PM_{2.5}$), and evaluated the carbohydrate and protein content in the fine PM.

Social barriers to improved stove adoption in El Fortin, Nicaragua.

Lindsay A. Davis[1*], Maggie L Clark[1], Judy M. Heiderscheidt[1], John Volckens[1], Stephen J. Reynolds[1], Bevin Luna[1], Kirsten Koehler[1], Stuart Conway[2], Annette Bachand[1], Jennifer L. Peel[1]

[1]Department of Environmental and Radiological Health Sciences, Colorado State University, Fort Collins, CO

[2]Trees, Water & People, Fort Collins, CO

*Corresponding email: lindzd@rams.colostate.edu

Keywords: barriers, cookstoves, health, indoor air pollution, surveys

1 Introduction

Barriers to improved cookstove adoption exist on a variety of levels and are a critical component of cookstove intervention studies. Adoption of improved cookstoves in intervention research studies is often low or not reported. For example, an improved stove intervention study in rural Mexico noted that 92% of surveyed homes still had an open fire during follow-up visits (Zuk, et al., 2006).

Some of the most difficult barriers to overcome are social, physical and financial barriers. In order to stage a successful stove intervention, all of the types of barriers must be evaluated and dealt with appropriately to encourage adoption by the community. Edelstein, et al. (2008) suggested that poor stove quality, failure to maintain stoves, inappropriate stove design, and inadequate education on cooking methods are factors that exacerbate social barriers and therefore inhibit stove adoption.

Social barriers are likely specific to each community and must be ascertained by direct communication with the stove users. Smith (2006) suggests that adoption of "culturally unfamiliar" stoves and fuel types may be difficult for communities. Direct knowledge of the target population must be considered because, as noted by Fullerton, et al. (2008), behaviors of women as well as social and cultural variations may impact stove interventions.

This paper will report preliminary results assessing barriers to improved stove adoption in a study population in El Fortín, Nicaragua, a semi-rural community near Granada.

2 Materials/Methods

Barriers to improved stove adoption were assessed for 124 cooks (one primary cook per household) in El Fortín, Nicaragua approximately one year after the introduction of improved stoves. A survey was designed to assess overall stove use of study participants including both the EcoFogon improved stove and traditional open fire. Closed and open-ended questions were constructed to evaluate if and how often the traditional stove was still used, and under what circumstances the use of the traditional stove was preferred. Specific topics included: preferences for the amount of the wood, the size of the wood needed, amount of time needed to cook, maintenance, cleanliness, and amount of smoke in the kitchen. Open-ended questions were administered prior to the specific questions in an attempt to achieve unconstrained and unprompted responses. Examples of open-ended question included: what do you use your open fire for and what do you like most about your new stove.

3 Results

A substantial number of the study participants reported that they utilized both their improved (Ecofogon) and traditional stoves. Based on the stove use survey, 48% (57/119) of the participants reported still using their traditional stoves (open fires); this may include exclusive use of the traditional stove as well as mixed use of both the traditional and improved stoves. The reported stove preference of the women with regard to several factors is reported in Table 1. The vast majority of the participants reported that they preferred the improved stove both overall and in response to specific factors of use.

Table 1. Stove preferences reported among respondents (percent calculated from total number who responded to question).

Stove Factor	**Old Stove**	**New Stove**	**No Preference**
Overall preference	2 (3%)	69 (97%)	0 (0%)
Time to cook	4 (8%)	38 (81%)	5 (11%)
Smoke in kitchen	1 (2%)	46 (98%)	0 (0%)
Amount of wood	1 (2%)	44 (98%)	0 (0%)
Maintenance	2 (4%)	42 (89%)	3 (6%)

Many of the participants also reported additional observations in the open-ended questions. Participants often appreciated the lack of smoke when using their improved stove; however many noted that their stove was not durable enough. In addition, many participants found that, while their traditional stove was much faster at heating up, their improved stove was able to be left unattended while they were cooking, and thus allowed them more time for other cooking and daily tasks.

Preliminary data indicate that participants made adjustments to their new stoves such as removing the plancha or not sealing the edges, possibly to save time. These modifications greatly decrease the effectiveness of the stoves and allow smoke to escape from the stove rather than being vented out through the chimney.

4 Conclusions

After one year of use, most of the participants reported that they prefer their new stove to their open fire. Despite this reported preference for the improved stove, at least 48% of the women reported that they still use their open fire stove (alone or in conjunction with their improved stove). This may be attributable to a lack of practical incentives to encourage sole use of the improved stoves. Motives to change cooking methods must include making their lives easier; this study focused on marketing improved health which may not be sufficient. Continued use of open pit fires and modification of stoves may be partially due to social barriers, such as cultural significance of using an open fire, or to inadequate education of the women on proper stove use and maintenance. The first and second years of the study included installation and demonstration of stove use by the manufacturer directly to the women but did not include hands-on training. Questions that participants had after using the stoves themselves often went unanswered. This could be improved in future studies by educating multiple community leaders about how to best use the stove, as this was a resource some of the self-motivated women took advantage of. Further research will attempt to identify additional factors that are acting as barriers to improved stove use in this population. Systematic evaluation of barriers to improved stove interventions should be included when designing epidemiological studies.

5 References

Edelstein, M., Pitchforth, E., Asres, G., et al. (July, 2008). Awareness of health effects of cooking smoke among women in the Gondar Region of Ethiopia: a pilot survey. *BMC International Health and Human Rights 8: 10.*

Fullerton, D., Bruce, N. and Gordon, S. (May, 2008). Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. *Royal Society of Tropical Medicine and Hygiene 102: 843-851.* Retrieved from Science Direct database.

Smith, K. (2006). Health impacts of household fuelwood use in developing countries. *Unasylva 57: 41-44.*

Zuk, M., Rojas, L., Blanco, S., Serrano, P., et al. (May, 2006). The impact of wood-burning stoves on fine particulate matter concentrations in rural Mexican homes. *Journal of Exposure Science and Environmental Epidemiology 17: 224-232.*

In this study, the carbohydrate and protein content in $PM_{2.5}$ were measured as a first step toward determining the biological content in the samples collected. The air quality improvements achieved by the implementation of a locally improved stove were also evaluated using these metrics.

METHODS

Thirty households participated in this study. Institutional Review Board approval was obtained from the University of Colorado at Boulder. A survey that incorporated modified sections from the International Study of Asthma and Allergies in Childhood Survey (ISAAC, 1993) was used. Information collected included basic household features, time spent in the kitchen, and respiratory and general health of the family members. Interviews were conducted in Spanish or Quechua and were completed by the person who performed the household cooking.

In each household, $PM_{2.5}$ concentrations were measured using UCB Particle Monitors (Berkeley Air, Berkeley, CA) over 24-hours and following published protocols (Chowdhury et al. 2007). Data were downloaded to a personal computer for data analysis using the UCB Particle Monitor software (Version 2.5). A DustTrak (TSI, Shoreview, MN) was collocated with the UCB monitors for instrument validation. Results were reported as average concentrations plus/minus standard deviation (±SD). Raw DustTrak data were corrected as determined by previous studies (Mondal et al. 2010). MiniVol with $PM_{2.5}$ or PM_{10} impactor heads (Airmetrics, Eugene, OR) collected air samples at 4 L/min onto 47-mm quartz filters (Pallflex Tissuquartz) for 24-hours for subsequent BC and biopolymer determinations. Real-time BC data were collected with a collocated MicroAethelometer (Model 51, McGee Scientific, Berkeley, CA) for 15 minutes during burn times (during stove use) and off-burn times to establish baseline conditions.

An Optical Transmissometer (Model OT21, McGee Scientific) was used to determine the BC 24-hour average concentrations from the 47-mm quartz filters at 880 nm wavelength and using a blank as a reference. The air quality improvements achieved by the implementation of a locally improved stove in a selected household were also evaluated using these metrics. Water-soluble compounds from the filters were then eluted in sterile water using a bead-beating technique to pulverize the filters (Clarke, 2004). The protein content in the eluates was evaluated in triplicate using a NanoOrange Protein Quantitation Kit (Invitrogen) as per protocol. Sample protein concentrations were deduced from a standard (bovine serum albumin) curve. A simple colorimetric technique based on a modified Molish Test (Coz et al. 2010) was used to measure, in triplicate, the carbohydrate levels present in each sample eluate. The total carbohydrate concentration in each sample was determined from a standard (D-glucose) curve.

RESULTS

Langui, Peru is located next to the lake Langui-Layo at 4000 m above sea level. Figure 1A shows the lake and GPS coordinates for each sampling location. Most households sampled were clustered in the center of Langui; however, some locations were selected on the outskirts of the town for a more complete assessment of the indoor air quality in the region.

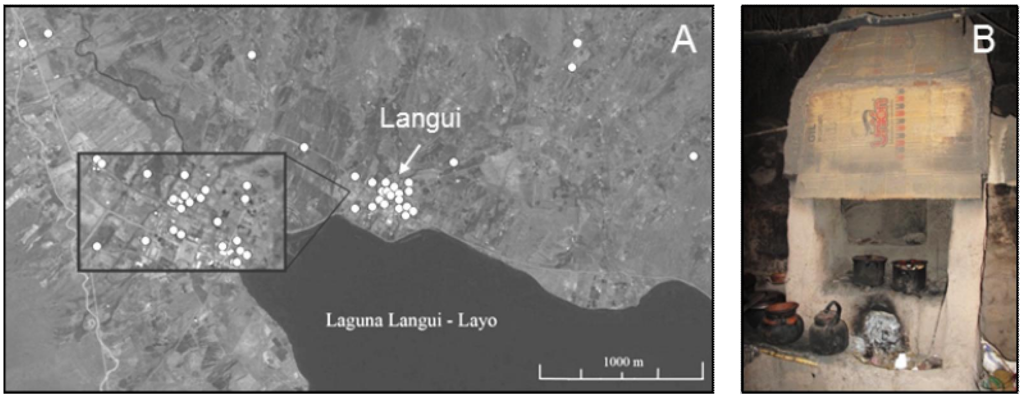
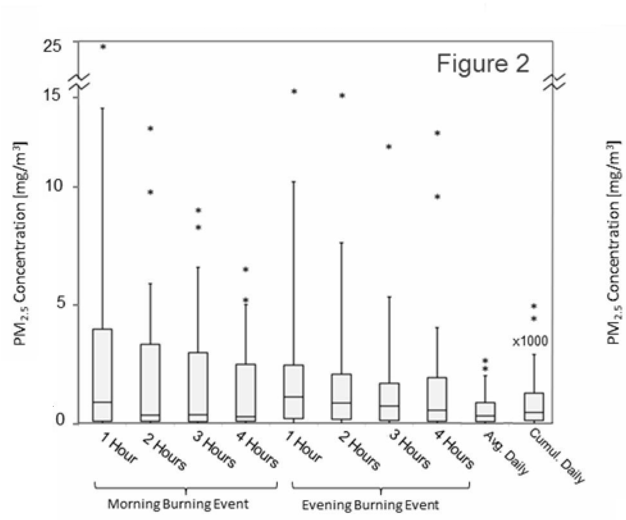


Figure 1**.** A) Sampling locations in the community of Langui, Peru (Langui, 2010). B) Example of a traditional stove used in the community.

Survey results showed that 100% of the households (n=30) used dried dung as a fuel source, 87% used a traditional stove and 67% had a makeshift “chimney” in the kitchen (Figure 1B) for cooking and heating. In this community, traditional cook stoves were made of adobe, had unvented combustion chambers and no exhaust for the emissions. The houses had dirt floors and thin metal (calamina) roofs of no insulation value, potentially increasing stove use for heating. The typical kitchen was about 20 m^3. Forty-seven percent (47%) of households kept (permanently) guinea pigs in the kitchens. They are an important source of food and income in the region that require warm temperatures for reproduction; therefore they are kept in the warmest place in the house. This study found that 77% of the women preparing the meals reported irritation to eyes, nose, and throat from stove emissions, while 51% reported coughing, and 37% suffered from wheezing episodes. Seventy three percent (73%) of the children surveyed (n=47), reported coughing, and most of them also reported bronchitis. Typically, children under 5 years of age spend a similar amount of time (4 hours) in the kitchen as the women. Of the men who spent time in the kitchen, 42% reported coughing.

The 24-hour average $PM_{2.5}$ concentration measured in the kitchens using traditional stoves was 0.640 (±0.874) mg/m^3 and ranged between 0.001 and 3.485 mg/m^3. The $PM_{2.5}$ levels in many homes exceeded 50 mg/m^3 for short periods during the early cooking stages. Over half the households sampled had $PM_{2.5}$ levels between 10 and 140 times over the World Health Organization (WHO) 24-hour mean $PM_{2.5}$ guidelines of 0.025 mg/m^3 (WHO, 2005). The average background $PM_{2.5}$ indoor level (during off-burning) was 0.021 (±0.009) mg/m^3 and the average outdoor level was 0.007 (±0.006) mg/m^3. Figure 2 shows the average indoor $PM_{2.5}$ concentrations for each of the first 1, 2, 3 and 4 hours of cooking events during the morning and evening cooking events. Morning $PM_{2.5}$ averages were consistently higher than evening averages and decreased with each hour of stove use. The 24-hr average BC levels in the homes, determined from filter samples, ranged from 2.40 to 34.50 $\mu g/m^3$. Levels of black carbon were also measured in a sub-group (n=13) of homes during cooking events using traditional stoves and they ranged between 1.23 and 151.51 $\mu g/m^3$. Background levels of BC, during off-burn times, were between 0.03 and 2.66 $\mu g/m^3$.

Indoor air quality in a selected household was improved significantly after installing an improved stove in the kitchen. The improved stove consisted of a vented combustion chamber, a chimney and a flat metal plate (plancha) that minimized emissions into the room and increased heat transfer. Figure 3 shows the $PM_{2.5}$ concentrations over a 24-hour period for this specific house. The gray line in the figure represents the PM levels before installing the improved stove, while the black line indicates the levels after improvements were made. The 24-hour average $PM_{2.5}$ concentration decreased from 2.01 mg/m^3 to about 0.04 mg/m^3, while the average 15-minute BC concentrations during burn time decreased from 0.94 mg/m^3 to 0.04 mg/m^3 after improvements to the stove.



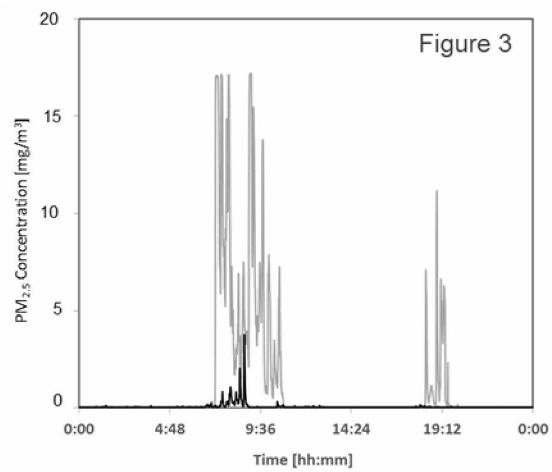


Figure 2. $PM_{2.5}$ averages for the first 1, 2, 3 and 4 hours of cooking events and average and cumulative daily exposure values. Note: reported cumulative daily exposure values are actually 1000 times the plotted value. Figure 3. Twenty-four (24) hour average $PM_{2.5}$ concentrations over a period for a traditional stove (grey) and the improved stove (black).

Table 1 shows 24-hour average concentrations of total carbohydrates and proteins measured from filter samples for specific cases. In the case where no animals were present in the home (House 4), about 90% of carbohydrates and 77% of the proteins were found in the fine fraction of suspended particulates. When animals were present in the home, most of the carbohydrates (~87%) and proteins (59-67%) were in the coarse fraction. Studies directly correlating carbohydrate concentration in PM with health effects have not been reported; however, it has been reported that a few micrograms of allergenic proteins per gram of house dust can be important in asthma morbidity, in inner-city children (Gruchalla et al. 2005).

Table 1. Levels of total carbohydrates, proteins, and black carbon content in 24-hour samples

	PM [μm]	Guinea pigs	House ID	Carbohydrates (+/-SE) [μg/m^3]	Proteins (+/-SE) [μg/m^3]
Indoor (no animals) $PM_{2.5}$ and PM_{10}	10	No	4	3.31 (0.03)	0.065 (0.011)
	2.5	No	4	2.99 (0.13)	0.050 (0.012)
Indoor (guinea pigs) $PM_{2.5}$ and PM_{10}	10	Yes	Cuyera*	10.27 (0.32)	0.038 (0.014)
	2.5	Yes	Cuyera*	1.35 (0.07)	0.016 (0.006)
	10	Yes	2	6.53 (0.12)	0.038 (0.006)
	2.5	Yes	2	0.82 (0.16)	0.013 (0.008)

* (Spanish word for guinea pig coop)

DISCUSSION

This study found that average $PM_{2.5}$ levels measured in the morning were higher than those measured in the afternoon. These results agree with another high-altitude study conducted in the region (Pearce et al. 2009). The BC levels during stove use corresponded with ranges reported from wood burning cook stoves in an urban environment of 35.3 – 83.8 μg/m^3 (Huboyo et al. 2009); however, the BC concentrations in this study remain substantially higher than those reported during cooking times for kitchens in a developed community ranging from 0.1 to 0.8 μg/m^3 (Zhang et al. 2010). The preponderance of the biopolymers measured were in the coarse fraction of PM, which suggests that they could originate from plant or animal debris (Menetrez et al. 2009). Biological sources of PM in this region most likely included dried dung stored indoors and guinea pigs kept in the kitchen. There was no correlation between total proteins measured and guinea pigs; however, it is possible that other biological sources contributed to the protein content. These sources were determined by visual inspection. Implementing an improved stove built with local materials in a selected household decreased indoor $PM_{2.5}$ concentrations by almost 99% and BC concentration by 96%.

CONCLUSIONS

The majority of the homes in the study exceeded the WHO guidelines for 24-hour $PM_{2.5}$, and the highest concentrations occurred within the first hour of stove use. Significant reductions in indoor $PM_{2.5}$ and BC concentrations were achieved after improving a traditional stove using local materials. Homes that housed animals had the majority of the carbohydrates and proteins measured in the coarse fraction of PM. Since previous studies have found that combustion aerosols and bioaerosols synergistically worsen respiratory health, it would be desirable to eliminate both sources of aerosols in these households. Though significant improvements were made with stove modifications, it is important to consider the biological sources of indoor air pollutants in developing communities in addition to combustion sources.

ACKNOWLEDGEMENTS

This work was partially funded by the Dorothy Martin Doctoral Student Award, and the CU Discovery Learning Apprentice and SMART programs. The authors thank Vanessa Pineda, Erin Lennox, and GRUPO-PUCP for assistance with the fieldwork and Natalia Rivera and Dr. Kevin McCabe with the analytical work.

REFERENCES

Arimoto T., Kadiika MB, Sao K., Corbett J, Mason RP. 2005. Synergistic production of lung free radicals by diesel exhaust particles and endotoxin. *Am. J. Respir. Crit. Care Med.*, 171, 379-387.

Chowdhury Z., Edwards R., Johnson M., Shields K., Allen T., Canuz E., and Smith K. 2007. An inexpensive light-scattering particle monitor: chamber and field validations with woodsmoke. *J. Environ. Monitor.*, 9(10), 1099-1106.

Clarke L. 2004. Primary Biopolymers Associations of Fine Particulate Matter. *Master's Thesis* University of Colorado, 226 pages.

Coz E., Artinano B., Clark L., Hernandez M., Robinson A., Causuccio G., Lersch T., Pandis S. 2010. Characterization of fine primary biogenic aerosol in an urban area in the northeastern Unites States. *Atmos. Environ.*, 44(2010), 3952-3962.

Gruchalla R., Pongracic J., Plaut M., Evans R., Visness C., Walter M., Crain E., Kattan M., Morgan W., Steinbach S., Stout J., Maldindzak W., Smartt E., and Mitchell H., 2005. Inner City Asthma Study: Relationships among sensitivity, allergen exposure, and asthma morbidity. *J Allergy Clin Immun*, 115(3), 478-485.

Huboyo H., Budihardjo A., and Hardyanti N. 2009. Black carbon concentrations in kitchens using fire-wood and kerosene fuels. *J. Appl. Sci. in Enron. Sanitation*, 4(1), 55-62.

ISAAC. 1993. *ISAAC Manual 2nd Ed.* Münster, Germany: International Study of Asthma and Allergies in Childhood.

Jansen K., Larson T., Koenig J., Mar T., Fields C., Stewart J., and Lippmann M. 2005. Associations between Health Effects and Particulate Matter and Black Carbon in Subjects with Respiratory Disease. *Environ. Health Persp.*, 113(12), 1741-1746.

Langui. 2010. 14°25’58.82’’S and 71°16’28.45”W. Google Earth. November 7, 2010.

McCracken J., Smith K., Diaz A., Mittleman M., and Schwartz J. 2007. Chimney Stove Intervention to Reduce Long-term Wood Smoke Exposure Lowers Blood Pressure among Guatemalan Women. *Environ. Health Persp.*, 115(7), 996-1001.

Menetrez M., Foarde K., Esch R., Schwartz T., Dean T., Hays M., Cho S., Betancourt D., and Moore S. 2009. An evaluation of indoor and outdoor biological particulate matter. *Atmosp. Environ.*, 43(34), 5476-5483.

Mondal N., Roy A., Mukherjee B., Das D., and Ray M. 2010. Indoor Air Pollution from Biomass Burning Activities Akt in Airway Cells and Peripheral Blood Lymphocytes. *Toxicol. Pathology*, 38(7), 1085-1098.

Mordukhovich I., Wilker E., Suh H., Wright R., Sparrow D., Vokonas P., and Schwartz J. 2009. Black Carbon Exposure, Oxidative Stress Genes, and Blood Pressure in Repeated-Measures Study. *Environ. Health Persp.*, 117(11), 1767-1772.

Pearce J., Aguilar-Villalobos M., Rathbun S., and Naeher L. 2009. Residential Exposures to $PM_{2.5}$ and CO in Cusco, A High-Altitude City in the Peruvian Andes: A Pilot Study. *Arch. Environ. Occup. Health*, 64(4), 278-282.

Ramanathan V. and Carmichael G. 2008. Global and regional climate changes due to black carbon. *Nat. Geoscience*, 1, 221-227.

Ryan P.H., Bernstein D.I., Lockey J., Reponen T., Levin L., Grinshpun S., Villareal, M., Khurana Hershey G.K., Burkle J., LeMasters G. 2009. Exposure to Traffic-related particles and endotoxin during infancy is associated with wheezing at age 3 years. *Am. J. Respir. Crit. Care*, 180, 1068-1075.

Smith K.R., Mehta S. and Maeusezahl-Feuz M. 2004. Indoor air pollution from household solid fuel use. In: *Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors*, Geneva: World Health Organization, pp. 1435-1493.

Torres-Duque C., Maldonado D., Perez-Padilla R., Ezzati M., Viegi G. 2008. Biomass Fuels and Respiratory Diseases: A Review of the Evidence. In: *Proc. of the Amer. Thoracic Soc.*, Vol. 5, pp. 577-590.

World Health Organization. 2006. *Air Quality Guidelines – Global Update 2005*. Copenhagen: World Health Organization, p. 278.

Zhang Q., Gangupomu R., Ramirez D., and Zhu Y. 2010. Measurement of Ultrafine Particles and Other Air Pollutants Emitted by Cooking Activities. *Int. J. Environ. Res. Public Health*, 7(4), 1744-1759.

Effect of fossil-fuel electricity generators on indoor air quality in Kaduna Nigeria

Andrew Mhya Stanley, Ikemefuna Mbamali, Afolabi Abdulsalam Dania

Department of Building, Ahmadu Bello University, Zaria-Nigeria

stanleywond@yahoo.com

SUMMARY
Fossil fuel electric generators are known to emit gaseous pollutants that negatively affect the Indoor Air Quality (IAQ). This paper assessed the effects of electric generator use on IAQ by households in Kaduna metropolis of Nigeria. The concentrations of Carbon monoxide (CO), Sulphur dioxide (SO_2) and Oxides of Nitrogen (NOx) in the indoor air for fourty eight (48) household, were measured using the IMR 1400C Gas Analyzer. Results indicated mean concentrations of CO, SO_2 and NOx within the World Health Organisation (WHO) and Environmental Protection Agency (FEPA) limits (10ppm, 0.01ppm and 0.04 – 0.06ppm) in majority (i.e. 81.25, 83.33 and 85.42%) of the households. However, few (18.57, 16.67 and 14.58%) households' concentrations were significantly high (85.33, 6.99 and 2.99ppm) which are alarming because these involve human lives. Conclusion was reached that about two-tenth of the population are at risk of poor IAQ associated with use of fossil fuel generator.

IMPLICATIONS
In Nigeria, most households use fossil fuel electricity generators to augment the shortfall of electricity supply. These generators emit harmful gases which can negatively affect IAQ. Findings of this study would expose the risks associated the widespread use of generators to policy makers and the public.

KEYWORDS: Air Pollutants,

INTRODUCTION
Increased awareness of the importance of indoor air quality (IAQ) in the recent times has caught the attention of scientists, manufacturers, regulatory bodies, public, etc. (White and Marchant, 2009). IAQ affects the well-being of building occupants who spent most of their time (80 – 90%) indoor (Ideriah et. al., 2007) and also affect the building components. Man's activities (fossil fuel combustion, cooking, construction activities, use of; building materials, heating and cooling systems, pesticides etc) have continued to alter the IAQ (Kandpal et. al., 1994, USEPA, 2009, and Stanley, 2010). Improper openings for ventilation in the building and several other factors also facilitate the accumulation of pollutants in the indoor which pose serious health problems. Concentration of pollutants such as carbon monoxide, nitrogen oxides, sulphur dioxide, microorganisms, etc. above certain limits in the indoor air, are found to affect the health of the building occupants (Ideriah et. al. 2007).

Nigeria, unlike the developed countries is faced with several environmental, social and economic challenges such as electric power supply, adequate waste disposal system, air pollution, water pollution, noise pollution, unemployment, lack of water supply, etc. (Akande and Owoyemi, 2008, Stanley et. al., 2010). Most households (60%) live on less than a dollar a day (CAPPS, 2007), not enough to cater for a minimum standard of living. These have affected the quality of life style and health of most Nigerians. Most households in Nigerian cities operate small capacity fossil fuel electric power generators for electricity supply (ECN, 2009). This was due to the fact that the Power Holding Company of Nigeria (PHCN) solely responsible for generation and supply of electricity to the public have not fared well in the discharge of its mandate (Stanley et. al., 2010). Study by Stanley et. al. (2010), showed that small household generators in Nigeria operate an average of six (6) hours daily, while average distance of generator away from building was 5.6m. These alongside poor ventilation (Okafor et. al., 2008) have influenced the quality of indoor air in the households.

Poor IAQ has been reported to claim over 1.6 million lives and has left 38.5 million disabled world over in 2000 (Smith et. al., 2003). Acute lower respiratory infections (ALRI) in children aged < 5 years, chronic obstructive pulmonary disease (COPD), lung cancer, asthma, tuberculosis, heart disease, irritation of the eyes, nose and throat, headaches, dizziness and fatigue, etc. are some illness associated with poor IAQ (Smith et. al., 2003, USEPA, 2009, White and Marchant, 2009). This study assessed the IAQ of some selected households in Kaduna metropolis who use fossil fuel electricity generators.

METHODS

Electric power generator has been the main source of alternative power supply in Nigeria for over a decade, following the crisis of unstable power supply from the national grid. This study assessed the IAQ of some selected households who use generators in Kaduna metropolis. Kaduna metropolis is characterized with population of about 1,570,331 (FGN, 2009) with lots of commercial activities, military, public and private institutions, etc. (Stanley, 2010). These and many other reasons made Kaduna metropolis suitable for the case study.

Fourty eight (48) households [grouped into eight (8) clusters: Kawo, Mando, Kurmin Mashi, Malali/Ungwan Yero Badarawa, Bakin Ruwa, Tudun Wada, Barnawa and Sabon Tasha. Six (6) per cluster] that operate small portable fossil fuel electric power generators were selected across Kaduna metropolis to assess their IAQ. Pollutants assessed were carbon monoxide (CO), sulphur dioxide (SO_2) and nitrogen oxides (NOx). IMR1400C Gas Analyzer was used to assess these pollutants. The gas analyzer was caliberated for 180 seconds before the start of measurement. At interval of subsequent measurement, re-caliberation of 30 seconds were carried out. Measurement of pollutants was at the periods of generator operation. The indoor pollutants concentration before operating the generator was recorded and subtracted from result recorded while generator was in operation to obtain actual pollutant emitted by generator into the building. An average of three (3) consecutive measurements for each pollutant was recorded for each household. The average period of generator operation was 6 hours daily (Stanley, 2010).

RESULTS

The results of the IAQ for the fourty eight households tested are showed in Tables 1 to 4 below.

Table 1. Range of the Indoor Air Pollutants Concentration

Pollutant	Minimum Range (ppm)	Maximum Range (ppm)
CO	1.00	85.33
SO_2	0.33	6.67
NOx	0.33	2.99

From Table 1, CO concentration in the indoor air range from 1.00 to 85.33ppm, while SO_2 from 0.33 to 6.67ppm and NOx range from 0.33 to 2.99ppm.

Table 2. Mean indoor concentration of CO

Concentration (ppm)	Frequency (No)	Percentage (%)
0 – 10	39	81.25
> 10	9	18.75
Total	48	100

The frequency of mean values (0 – 10ppm) for CO concentration within the WHO and FEPA limit (10ppm) was 81.25% higher than the frequency of mean values (18.75%) above the limit (Table 2).

Table 3. Mean indoor concentration of SO_2

Concentration (ppm)	Frequency (No)	Percentage (%)
0 – 0.10	40	83.33
> 0.10	8	16.67
Total	48	100

The frequency of SO_2 indoor gaseous pollutant mean concentration within the WHO and FEPA limit (0.01ppm) was 83.33% higher than the frequency of those above the limit (16.67%) (Table 3).

Table 4. Mean indoor concentration of NOx

Concentration (ppm)	Frequency (No)	Percentage (%)
0 – 0.06	41	85.42
> 0.10	7	14.58
Total	48	100

From Table 4, the frequency of mean indoor concentration of NOx within the WHO and FEPA limit (0.04 – 0.06ppm) in the households was 85.42% higher than mean frequency (14.58%) of those above the limit.

DISCUSSION

The concentration of CO in the indoor air is significantly high as shown in Table 1. However, this was observed in few (18.75%) households with concentration above the FEPA recommended limit of 10ppm (Appendix 2). This could be attributed to poor ventilation opening in the buildings (Ideriah et. al., 2007), the limited distance of generator to building while in operation (Stanley, 2010), effect of wind and dispersion (Ndoke and Jimoh, 2005; Abdulkareem and Koku, 2006). Majority (18.25%) of the households IAQ were within the recommended FEPA limit. This could also be attributed to the level of awareness of the control measures (distance away from building, kept exhaust along the direction of wind flow and adequate provision of opening for ventilation) adopted by the operators. Prolong exposure of CO above the FEPA and WHO limits is associated with severe headache, nausea dizziness, coma and death (Osuntogun and Koku, 2007). Other effects include binding strongly with haemoglobin which prevent oxygen transportation in the blood and may lead to adverse neuro-behavioural and cardio-vascular effects, permanent impairment or death in closed environment (WHO, 1987).

The range of SO_2 observed was 0.33 to 6.67ppm above the FEPA limit of 0.01ppm (Table 1 and Appendix 2). This was for few (16.67%) households but of great concern (Table 3).

Majority (83.33%) of the households have no trace of SO_2 in the indoor air (Table 3). The fuel quality, wind effect and direction of exhaust could be attributed to this. However, exposure to SO_2 above the FEPA limit is associated with coughing, chest pain, shortness of breath, emphysema and bronchitis (Osuntogun and Koku, 2007).

The concentration of NOx in the indoor air range from 0.33 to 2.99ppm above the FEPA limit of 0.04 to 0.06ppm (Table 4 and Appendix 2). This was observed in few (14.58%) households but is also be of great concern. Majority (85.42%) of the households' NOx concentration were below the FEPA limit (Table 4 and Appendix 2). There is control of NOx that enters into the building. However, exposure to NOx above the recommended limit can cause irritation of the eyes and the respiratory tract, shortness of breath, fluid build up in lungs, is highly toxic, corrosive, etc. (Osuntogun and Koku, 2007).

CONCLUSIONS

From the study, it could be concluded that indoor concentrations of CO, SO_2 and NOx in majority of the households are within normal exposure limits. However, few (two-tenth of the population) of the households whose concentrations were above the FEPA and WHO limits are exposure to health risk and should be of great concern, since this involves human life. Policies for minimizing use of generator and public enlightenment by stakeholders on long time effects of poor IAQ are recommended.

REFERENCES

Akande, T.M. and Owoyemi, J.O. (2008): Awareness and Attitude to Social and Health Hazards from Generator Use in Ayigba, Nigeria. Medwell Journal. *Research Journal of Medical Sciences*. Vol. 2. No. 4. Pp. 185 – 189.

CAPPS (2007): Country Report for Nigeria. DFID Research Strategy (2008 – 2013) Consultation-Africa. [Online]. Available from http://www.dfid.gov.uk/research/Nigeria-country-consults.pdf.

Energy Commission of Nigeria (ECN, 2009): 60 Nigerians Now Own Power Generators. Adopted from Vanguard Newspaper, 26th January, 2009. [Online] Available at www.energy.gov.ng.

Federal Environmental Protection Agency (FEPA) (1991): Guidelines and Standards for Environmental Pollution Control in Nigeria. Federal Republic of Nigeria.

Kandpal, J.B., Maheshwari, R.C. and Kandpal, T.C. (1994): Indoor Air Pollution from Combustion of Wood and Dung Cake and their Processed Fuels in Domestic Cookstoves. (Online) Available from www.eprint.iitd.ac.in/dspace/bitstream/2074/431/1/kanin95.pdf.

Okafor, E.E., Hassan, A.R. and Hassan, A.D. (2008): Environmental Issues and Corporate Social Responsibility: The Nigeria Experience. J. Hum. Ecol., Vol. 23, No. 2. Pg. 101 - 107.

Osuntogun, B.A. and Koku, C.A. (2007): Environmental Impacts of Urban Road Transportation in South-Western States of Nigeria. *Journal of Applied Sciences.* Vol. 7. No. 16. P. 2358.

Stanley, A.M. (2010): Air Pollutants Concentration and Noise Levels from Electric Power Generators. Seminar Presented at the Seminar Series of Faculty of Environmental Design, Ahmadu Bello University, Zaria.

Stanley, A.M., Mbamali, I., Zubairu, I.K., Bustani, S.A, Andrew, S.S & Joshua, I.A. (2010): Electric Power Generator Noise Level Characterization and Impact on Selected Commercial Areas of Zaria and Kaduna Nigeria. International Postgraduate Conference

on Infrastructure and Environment, The Hong Kong Polytechnic University, Hong Kong.
Smith, K.R., Mehta, S. and Maeusezahl-Fenz, R. (2003): Indoor Air Pollution from Household Use of Solid Fuels. [Online] Available from http://ehs.sph.berkeley.edu/krsmith/Publications/Chapt%2018%20IAP%20from%20Solid%20Fuels.pdf [accessed 17th May, 2009].
United State Environmental Protection Agency (USEPA) (2009): An Introduction to Indoor Air Quality.
White, L. and Marchant, P. (2009): An Overview of Residential Indoor Air Problems. Department of Health, Washington.
WHO (2010): WHO guidelines for indoor air quality: selected pollutants. WHO Regional Office for Europe. [Online] Available from http://www.euro.who.int/_data/assets/pdf_file/0009/128169/e94535 (Accessed 28th January, 2011).
WHO (1987): Indoor Air Pollution Study, Maragua Area, Kenya. In: Ideriah, T.J.K., Herbert, S.O. and Ideriah, B.J. (2007): Assessment of Indoor Air Quality in a Chemical Fertilizer Company, Onne, Nigeria. Research Journal of Applied Sciences Vol. 2, No. 3. Pp. 310 – 213.

Appendices

Appendix 1. Indoor carbon monoxide guidelines

Averaging time	Concentration (mg/m3)	Comments
15 minutes	100	Excursions to this level should not occur more than once per day Light exercise
1 hour	35	Excursions to this level should not occur more than once per day Light exercise
8 hours	10	Arithmetic mean concentration Light to moderate exercise
24 hours	7	Arithmetic mean concentration Awake and alert but not exercising

Source: WHO (2010)

Appendix 2: Guidelines for Sodium dioxide and Oxides of nitrogen

Pollutant	Range (ppm)
Carbon monoxide	10
Sodium dioxide	0.01
Oxides of nitrogen	0.04 – 0.06

Source: FEPA (1991)

Health Hazards of Home Based Economic Activities in Residential Areas

Dr. Mayank Mathur
Department of Physical Planning, SPA
4 Block B, I. P. Estate, New Delhi110002
matmayank@gmail.com

SUMMARY
There are towns in India that are famous for the products that are manufactured at the household level. This is a research work conducted to study the indoor pollution due to the home based economic activity. Interviews with the workers and their families and subsequently with professionals like doctors who were practicing closer to these settlement areas were done to know about the health conditions of the inhabitants. Inhabitants were found to be suffering from respiratory diseases. The study investigated in detail about how and why these kinds of hazards are occurring. I studied the process through which metal products are manufactured. We urgently recommend improvement of the spatial configuration of dwellings and options for such inhabitants proper ventilation, as there is hazardous pollution emission due to such home based economic activities, especially for the moulders. This study finally explores the remedial measures for the improvement of the living conditions for such settlements where indoor air pollution occurs.

IMPLICATIONS
This study is relevant for the reason that no such study has been done before wherein it has been discovered about the state in which low income inhabitants in these residential areas are living. There has never been an air pollution study for such settlements. This study shows that there are health hazards due to such home based economic activities.

KEYWORDS
Microenvironment, spatial configuration, moulding operation, health conditions, low income.

INTRODUCTION
Home-based income generating activities in residential areas are mostly part of informal sector economy. The housing produced and occupied by the informal sector is primarily an outcome of an inefficient formal process of housing supply. The non-fulfillment of housing demand by the development agencies in many cities in India is one of the contributing factors towards an ever-increasing share of housing being provided through informal sector activities. The contribution being made by the informal sector is also not estimated. The housing produced by this informal sector has a different environment, because it is also a production place when people use their home as a workplace. To make housing affordable to low-income groups, it is necessary to take into account that much of their income is earned in the informal sector. Contribution of the house as an investment within which economic activity takes place is so significant that it can be regarded as a part of the production process along with infrastructure, a product whose

purpose is to foster other activities' (Huws, 1995). Housing provides an intermediate input to economic activity, which is difficult to calculate but it is quite significant, particularly concerning economic activities carried out within dwellings and their immediate surroundings. This use of home as a workplace is relatively common in many cities in India.

In the inner city areas of Aligarh, Meerut, Moradabad and some of the towns in the state of Uttar Pradesh in India, one finds this `typical home based working' in which the process of manufacturing of various metal products takes place at home. The workers who have the skills, as well as their family members, are involved through miscellaneous supporting activities. This study deals with hazards of such activities on the workers and their family members and its affect on the spaces within the dwelling units. The hazards are identified in this study of the microenvironment that is the immediate environment of the workers. The town selected for the above purpose is Aligarh, a city close to the capital of India. As the study was based on a primary survey, it involved gathering of data from the field by means of questionnaires, interviews and carrying out scientific study of air monitoring. Therefore the objective of the study was to examine the nature of home based economic activities with reference to the process of manufacturing of the products and its impact on the microenvironment and the spatial configuration of the dwelling unit.

WORKERS AND THEIR FAMILY MEMBERS

It was found that there were dual roles of family members. Parents and children were often co-workers. This was demonstrated from case studies that showed that households mostly ranged from 4-7 people, in which workers ranged from 2-3 people. These workers were from the family as well as outside the family. The head of the family (head worker) imparted training to family members, and this is how trade progressed from father to son. Women workers involved in home-based economic activities combined such work with their domestic responsibilities. Although incidence of child labour was quite significant, the head of the family (worker) generally gave less hazardous work to his children. This was revealed during interviews. The study also revealed that there were non-family members also engaged as workers from within the neighborhood. It was observed that this sharing of work resulted in a socially cohesive group.

THE MICROENVIRONMENT

To study the microenvironment, it was important to know about the manufacturing process of metal products at the household level. The manufacturing process has four stages as follows: pattern making, moulding, filing and fitting, and finishing. Pattern making and moulding is done at one dwelling unit, filing and fitting is done at another dwelling unit, and finishing process at some other unit. It is like the manufacturing process of an industry that is taking place in a residential area. Pattern making is primarily preparation of the design and model of an item (or part of an item) to be manufactured. Moulding requires an oven to be dug in the earth to heat the metal to its molten state using certain chemicals. Filing and fitting requires use of files to remove the flaws and make finer touches with smooth files. Finishing process involves engraving and polishing, and finally packing is done in some other units, mostly in commercial areas. Health hazards were visible where pattern making, moulding, filing and fitting are done in the dwelling units of the workers.

Air quality was monitored for the moulding operation. The moulding operation showed a lot of visible air pollution, i.e., black smoke. Therefore it was envisaged that a further investigation would show the presence of hazardous substances and the level of air pollution. There were incidents reported by moulders that birds, such as pigeons etc., would sometimes sit on the wall near the oven to get warm in winter, and the birds would be affected by the air pollution and they would fall down in a subconscious state. This showed that the air quality was so bad that it affected the birds, and so also might affect the workers and their families.

Envisaging that the health of moulders is affected by the presence of polluted air, an air pollution study was conducted. It was done inside the dwelling unit where workers were involved in their economic activity and just outside the dwelling unit. However in certain cases it was not possible to study outside due to narrow streets where the High Volume Sampler could not be installed. The study was conducted in three places where moulding operation was found to be in progress. The level of pollution was checked at two points (1)SO_2, NO_2, CO and SPM inside the dwelling unit when the moulding operation was taking place, and (2)Suspended Particulate Matter outside the dwelling unit. Pollution level was checked up at three places (1) in one case study area where mostly brass idols were being made. The settlement area had high density. Here the Suspended Particulate Matter outside the dwelling unit could not be done as there was a constraint of using the High Volume Sampler due to narrow streets, (2) measurements of ambient concentrations of pollutants such as SPM, SO_2, NO_x , in another settlement area at the dwelling unit level and (3) a place where approximately six to seven moulding operation units were together.

Jaiganj was one of the case study areas where moulding operation of brass idols took place. This place had 2-3 storied development and it was not advisable to use High Volume Sampler as one may not get the correct result due to narrow streets so handy sampler and drag in instrument as provided by CPCB (Central Pollution Control Board of New Delhi) were used at the indoor level to collect the data regarding air pollution from moulding operation. It was found that during the moulding operation process the SO_2, NO_2, CO were found to be very high compared with the standard ambient air quality. In the process of moulding when the worker pours the brass into the vessel, visible pollution was evident as there were lots of fumes that came out, and this type work is generally accompanied by children. During the survey, it was found that a boy who was 14-15 yrs of age was helping his father in the preparation of the brass idols through the process of moulding. The family also included a small girl child age 7-8 yrs who also lived in this dwelling unit and therefore inhaled all the air pollution present inside the dwelling unit. It was also found that the process required one person to stoke the fire through using a bellows for pumping air, and that was mostly done by the lady of the house. Generally the man took the heavier work and the lighter work along with rearing of the children was done by the female member of the house. *Sarai Kaba* was another case study area that is famous for iron casting. This particular operation is the most hazardous of all the processes with lowest monetary return. Air monitoring was done at two locations (1) inside a dwelling unit where iron casting was done and outside the dwelling unit, i.e., on the road surrounded by the dwelling units where iron casting was done, and (2) where there were several units of moulding operation being done at one place, and the monitoring of air pollution was done inside the unit as well as outside the unit.

It was found that there existed pollutants in the form of suspended particulate matter, NO_x, SO_x and CO. This poor air quality generated due to the home based economic activities, especially moulding operations, created an adverse environment that likely affects the health of the workers.

ANALYSIS OF AIR MONITORING

The following graph shows suspended particulate matter level of air pollution in various cases. The first bar shows the standard per the Notification of Central Pollution Control Board that is 200 ug/m^3. It may be observed that the level of suspended particles is very high. The other bars are in the range of 957 to 2693 ug/m^3 as shown in Figure 1.

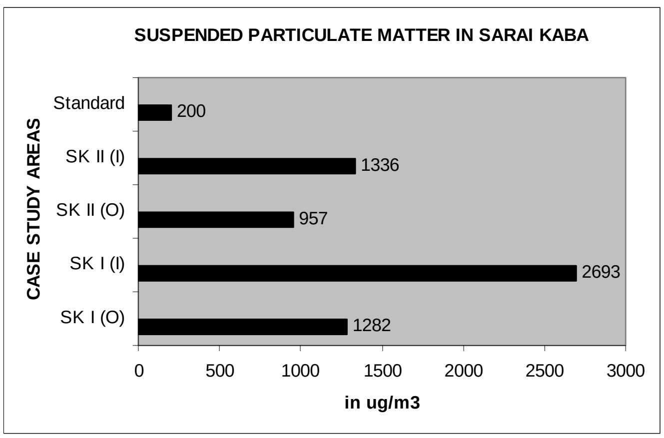


Figure 1. Level of Suspended Particulate Matter in various cases.

In Figure 2 the first bar shows the standard level of SO_2 per the Notification of Central Pollution Control Board that is 80 ug/m^3. It may be observed that the level of SO_2 is also very high. The other bars shows a range of 131 to 705 ug/m^3, far beyond the standards.

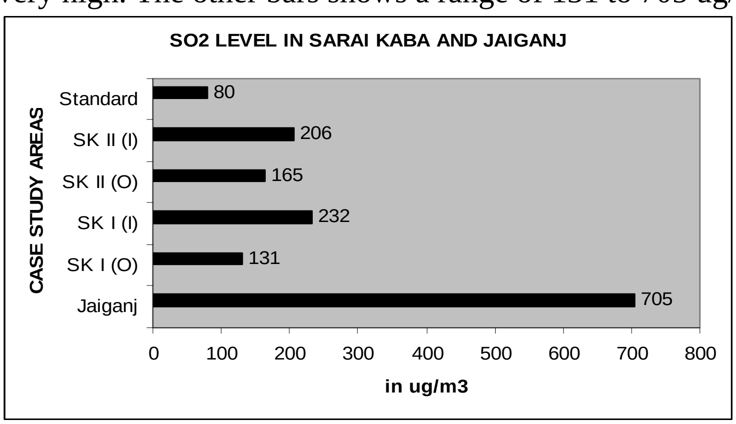


Figure 2. Level of SO_2 in various cases

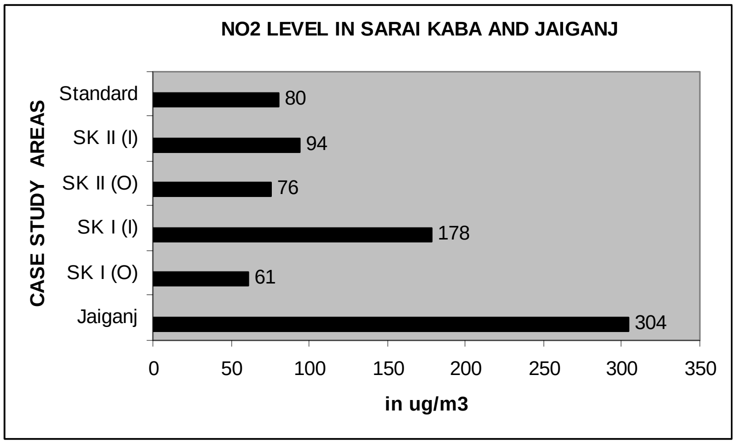


Figure 3. Level of NO_2 in various cases

In Figure 3, the first bar shows the standard level of NO_2 as per the Notification of Central Pollution Control Board that is 80 ug/m^3. It may be observed that the level of SO_2 is generally high in the indoor conditions. The other bars show a range of 61 to 304 ug/m^3.

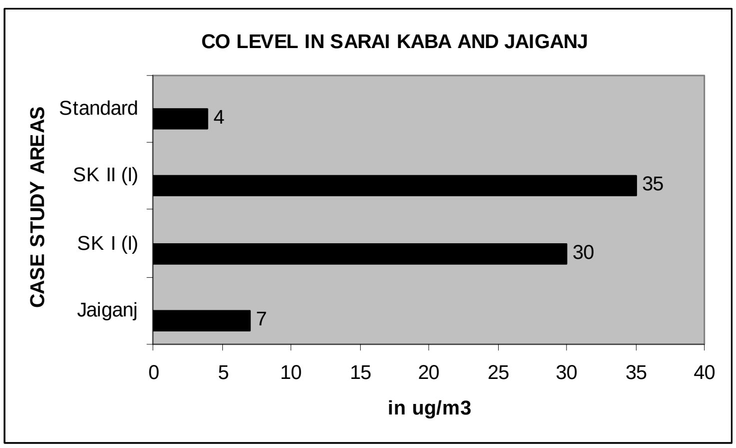


Figure 4. Level of CO in various cases

In Figure 4, the first bar shows the standard level of CO as per the Notification of Central Pollution Control Board that is 4ug/m^3. It may be observed that the level of CO is also quite high in the indoor conditions. The other bar shows a range of 7 to 35 ug/m^3.

In all the cases the pollution was far above the Air Quality Standards as prescribed by the Central Pollution Control Board. Consolidation of economic activity at one place was found to be most hazardous. It was the poor air quality that likely resulted in the poor health conditions of the workers, as most of them were suffering from respiratory illness. This was confirmed during the interviews with the allopathic doctors. Workers who were involved in moulding operations suffered from pneumoconiosis and pulmonary tuberculosis. It was found that 70-80 patients out of 150 patients per day suffered from this disease. The doctor also mentioned that due to the poor socio-economic conditions of these workers, there were a number of factors involved including unhealthy air, prevalent infection, mode of working, unhygienic conditions, malnutrition, habit of intoxication, and socio-economic status of the workers.

SPACES WITHIN THE DWELLING UNITS

Important factors for housing were spatial configuration, design of the dwelling unit, and the materials of construction. The home-based economic activities required a reasonable amount of space within a dwelling unit. The type of economic activity, i.e., moulding operation, or filing and fitting, precisely determined the extent of use. Dwelling units were comprised of space that included an area required by the workers: oven area, working area, area for storing raw materials and finished products etc. This generally amounted to a room approximately 2.5 m x 3 m for moulders. For filing fitting workers it was a little less. Home-based economic activities accounted for an average of 25% of the floor area of dwelling units. A positive correlation was found to exist between the working area and the total floor area in various case study areas. Owners of bigger dwelling units generally increased the space for income-generating activity while those of smaller sized dwellings did not. A positive correlation also existed between the size of working area and number of workers. It can be concluded that an increase in number of workers would demand space. An increase in number of workers was found where the workload was more. Also, in order to increase production, a greater number of workers were required to complete work in a stipulated time. This demanded more space to accommodate more number of workers. Home-based economic activity is labour intensive, since no modern equipment or large machines are used.

CONCLUSIONS

The relationship of housing with that of income generation is critical. It is generally found in this informal sector that there is an overlap of housing with income generating activities, while in modernistic planning; housing and industrial activities have been clearly separated into various land-uses. Although the income generating activities are informal in nature, the way the work is carried out at home is quite organized. The success of the income generation is due to the traditional and primitive methods of manufacturing in which the skill development is home based. On one hand this primitive method is a source of survival for many, on the other hand this primitive method is surviving in the market for the fact that the product created is better and stronger. However, the health hazards caused due to this home based activity are also visible from the level of air pollution and from the poor health conditions of the workers. Considering that this type of income generation will continue in the future, there is an urgent need to improve the design of the settlement and dwellings with proper ventilation to protect health. Mechanized ventilation and respiratory protection with appropriate equipment is desperately needed. The government needs to intervene as these are poor people.

Acknowledgment: Analysis of air pollution was done by Central Pollution Control Board, New Delhi.

REFERENCES

Huws, U., Ed. (1995). Action Programmes For The Protection Of Homeworkers, I.L.O. Geneva.

Indoor $PM_{2.5}$ and CO concentrations and variations in typical Tibetan tents, China

Chaoliu Li[1], Shichang Kang[1, 2*], Pengfei Chen[1], Qianggong Zhang[1], Junming Guo[1], Jue Mi[3], Puchi Basang[3], Quzhen Luosang[3]

[1] Key Laboratory of Tibetan Environment Changes and Land Surface Processes, Institute of Tibetan Plateau Research, CAS, Beijing, 100085, China;

[2] State Key Laboratory of Cryospheric Sciences, CAS, Lanzhou, 730000, China;

[3] Faculty of Science, Tibet University, Lhasa 850000, China

* *Corresponding email:* shichang.kang@itpcas.ac.cn

SUMMARY:

The objective of this study is to understand the concentrations and variations of $PM_{2.5}$ and CO in the tents of Tibetan nomadic yak herders living at 4700 meters under summer conditions. Results showed that the 24 hour average concentrations of $PM_{2.5}$ and CO in the tents with open cookfires were 1270 μg/m^3 (n = 5, SD = 829.94) and 5.0 ppm (n = 5; SD = 1.76), respectively, which are significantly ($p<0.05$) higher than those of tents with chimney stoves at 97 μg/m^3 (n=4; SD =69.89) and 0.09 ppm (n=4; SD = 0.11), respectively. Although a chimney stove can significantly improve indoor air quality, the concentration of $PM_{2.5}$ is still higher than the WHO Air Quality Guideline (IT-1, 35 μg/m^3). Daily variations of $PM_{2.5}$ and CO were similar with multiple peaks, and were closely connected to the activities of the residents within the tents. Therefore, the air of the Tibetan tents is seriously polluted, due mainly to the burning of yak dung for cooking and heating. High pollution level of PM2.5 and CO within the Tibetan tents might be a potential contributor to high prevalent of pollution-related diseases among the Tibetan people, such as cataracts, pneumonia, and chronic obstructive lung disease. Results of this study provide important background data for future indoor air pollution-related studies.

IMPLICATIONS

This is the first study on $PM_{2.5}$ and CO concentrations and their daily variations within Tibetan tents during summer period. Results indicated that burning of yak dung is an important source of exposure to indoor air pollutions.

KEYWORDS indoor air pollution; $PM_{2.5}$; carbon monoxide (CO); the Tibetan Plateau; tent

Introduction:

At present, approximately two billion people in the developing world use biomass fuels such as wood, crop-waste and dried animal dung, as their major source of domestic energy (Barnes et al. 1994). Generally, biomass combustion results in severe indoor air pollution, especially particulate matter (PM) and Carbon monoxide (CO) (Naeher et al. 2000). PM is generally considered the best indicator of the hazardous effects of the mixture of pollutants in biomass smoke (Dionisio et al. 2008). CO has been associated with effect on low growth in children of women exposed during pregnancy (Zhang and Smith, 2007). Consequently, exposure to these pollutions has been associated with increased risk for a suite of negative health outcomes (Smith et al. 2000; U.S. Environmental Protection Agency, 2004).

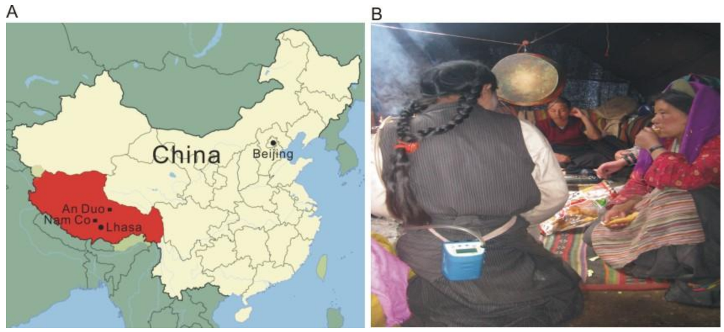


Figure.1 Map of study area (A) and participant with the personal monitor within tent using open stove (B).

Indoor air pollution from household solid fuel combustion is generally serious in China (Zhang and Smith, 1999). Although lots of studies have been done (Chen et al. 1992; Zhang and Smith, 1999; Zhang and Smith, 2005; Zhang and Smith, 2007), most of them were focused on coal combustion in rural regions of middle and east, and relatively fewer on the remote Tibetan Plateau (TP). Although the TP is normally considered as one of the cleanest regions of the world, existing few related studies all revealed its serious indoor air pollution due to use of solid biomass fuels, especially the yak dung (Shi, 1991). However, all these studies were conducted mainly based on data of stationary monitors, continuous personal PM monitoring is absent.

Based on the above reasons, we measured both stationary and personal indoor $PM_{2.5}$ and CO levels in typical Tibetan tents. Meanwhile, we recorded time-activity diaries were also by researchers directly. To be best of our knowledge, this is the first research to employ personal $PM_{2.5}$ and CO monitoring to assess individual exposures within Tibetan tents on the TP.

METHODS

Experiments were conducted in 9 typical tents at Nam Co region (N30°46.44′, E90°59.31′, 4730 m a.s.l.) and Anduo region (N 32°17′, E 91°41′), the central TP (Fig.1). The detailed information of these regions have been described previously (Kang et al. 2009). All the families being tested have similar tribal backgrounds, economic status, and living style (Table.1). Most participants speak only Tibetan language rather than Chinese. Each tent was measured for three days. All households in these areas burn yak dung exclusively for energy. Generally, the stove is burn for 17 hours (from 6:00 am to 23:00 pm) everyday for cooking/heating (Kang et al. 2009). Among the family members the women get up early and do most of houseworks. In contrast, men are in charge of herd and spend long time outside on grassland and only return the tent for meals during daytime.

Personal $PM_{2.5}$ exposures for participants were measured by model AM510 SidePak personal aerosol monitor (TSI Company，detection range：0.001～20 mg/m^3, resolution: 0.001 mg/m^3). The exact method of determining particle concentration by this instrument has been described in other researches (Jiang and Bell, 2008; TSI Inc, 2006). The monitor was attached to a belt on participant. Tubing connected the inlet of each monitor to the individual's collar to sample the breathing zone (Fig.1b). Carbon monoxide concentration was measured by an electrochemical CO monitor (TSI-7565, TSI Company, detection range：0.1～500 ppm, resolution: 0.1 ppm), which was placed 1.5m above the ground and 1m away from the stove horizontally (Kang et al. 2009). To monitor free outside air, these two instruments were placed at an open area of the grassland faraway from the Tibetan tents. To investigate relationship between CO and $PM_{2.5}$ within the tents, these two personal monitors were placed within the tents at same location. Meanwhile, $PM_{2.5}$ data of the monitor were calibrated against corresponding gravimetric samplers that collected within 20 cm with personal aerosol monitor (Fischer and Koshland, 2007). The result indicated that data of monitor were overestimated gravimetric mass concentration by a factor of 1.18 ($R=0.87$, $P<0.01$). All analyses were conducted with SPSS 13.0.

Table.1Sampling time and information for participants.

Tents	Age	Sex	Family member	Stove type	Sampling period
T1	25	female	5	open	10-12 Sep 2010
T2	26	female	8	open	13-15 Sep 2010
T3	35	female	5	open	16-18 Sep 2010
T4	65	female	5	open	28-31 Aug 2009
T5	21	female	6	open	5-8 Sep 2009
T6	34	female	4	improved	9-11 Aug 2009
T7	61	female	5	improved	13-15 Aug 2009
T8	24	female	6	improved	16-18 Aug 2009
T9	34	female	6	improved	3-5 Sep 2009

Results

Daily variations of $PM_{2.5}$ and CO

Diurnal variations of $PM_{2.5}$ and CO concentrations with 30 seconds logging interval for a representative tent (T5) using open stove and a respective tent (T9) using improved stove are shown in Fig.2a and b, respectively. Generally, variations of $PM_{2.5}$ and CO are closely associated with cook activities. For example, the higher $PM_{2.5}$ and CO levels occured when stove was active such as making breakfast, boiling meat and fueling. Meanwhile, the highest pollution levels occured when the stove was lit in the morning and extinguished at night because large amount of smoke was produced during these two processes (Zhang and Smith, 2007). The most unique characteristic is that the stove is continuously burned during entire waking hours of Tibetan residents. Generally, $PM_{2.5}$ and CO concentrations of the tent are always abnormally high during daytime. Furthermore, Yak dung has low heating value and has to be added to the stove frequently (about 20 times each day). Hence, it is hard to find peak pollution concentration caused by cooking activities. Stoves will be put out when the Tibetan people fall asleep. Therefore, both CO and $PM_{2.5}$ concentrations are generally very low with little variations, which is consistent with the aerosol researches in this area. Therefore, due to clean outside air and good permeability of the tent, the concentrations of $PM_{2.5}$ and CO declined quickly and stayed stable until next morning before the stove were relit. In contrast, peak concentrations of $PM_{2.5}$ and CO in tent using improved stove were far lower than those of tents using open stoves.

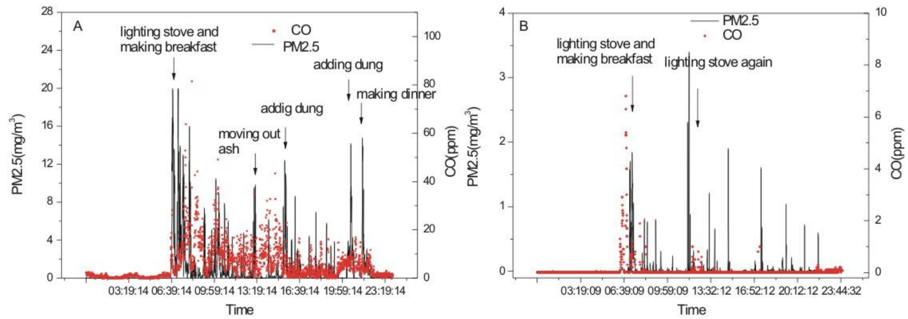


Figure. 2 Diurnal variations of $PM_{2.5}$ and CO concentrations in the tent without (A) and with (B) chimney. Status of the stove fire and activities of participants are also illustrated.

Fig. 3 shows box plots of the $PM_{2.5}$ (A) and CO (B) variations of every 30 seconds. It is clear that the average concentrations of $PM_{2.5}$ and CO in the tent with open stove are higher that than those of the tents with improved stove, especially for CO. In addition, the highest values of $PM_{2.5}$ concentrations of all the tents with open stoves reach or go beyond the upper limit (20 mg/m3) of the monitor. The highest level of $PM_{2.5}$ and CO for all the tents with open stove is higher than those of the other kind of tents. Furthermore, although the average $PM_{2.5}$ concentration within the tents using improved stoves is low (0.162 mg/m^3), it is still above the 24 h standard of WHO (35 µg/m3). Measured ranges of daily average and 1 h peak $PM_{2.5}$ concentrations within tents using open stove are 0.41-2.87 mg/m^3 and 2.30-16.61 mg/m^3, respectively. Mean peak 1 h $PM_{2.5}$ exceed 24 h daily average by a factor of 5.01. Correspondingly, Daily and 1 h peak CO concentrations are 2.19-7.81 ppm and 6.02-50.56 ppm, respectively, with the average peak 1 h concentration exceeding 24 h mean by a factor of 4.32.

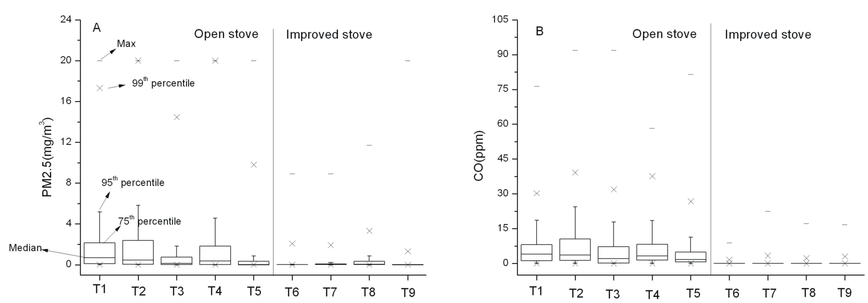


Figure.3 Distributions of $PM_{2.5}$ concentration (WHO standard: 0.025 mg/m^3 for 24 hours) (A) and CO concentration (WHO standard: 10ppm for 8 hours) (B).

DISCUSSION

$PM_{2.5}$ concentration in this study is higher than other standards. Since occasional over range (20 mg/m^3) concentrations of $PM_{2.5}$, the actual $PM_{2.5}$ concentration within the tents using open stove (type1 tent) was underestimated in this study. Observed daily mean $PM_{2.5}$ concentration in type1 tent extremely exceeds standards of WHO (35 $\mu g/m^3$). Meanwhile, this value is comparable to previous study on PM_{10} (2204 $\mu g/m^3$) of the Tibetan Plateau rural house (Sinton et al. 1995), assuming that the $PM_{2.5}$ contributed to about 48% of the PM_{10} (Dasgupta et al. 2006).

It is estimated that indoor air pollution is responsible for an estimated 4–5% of deaths in developing countries (Smith and Mehta, 2003). Therefore, the serious indoor air pollution within the Tibetan tents will inevitably induce some pollution-related diseases. For instance, research of investigation on diseases for 3095 inhabitants in Qinghai Province indicated that respiratory disease is the second serious disease in this region, of which disease incidence of female is higher than that of male; herder is higher than people of other businesses (Zhou et al. 2005). Therefore, further research is needed to investigate the relationship between indoor air pollution within Tibetan tents and potential diseases.

Although there are multiple intervention technologies of reducing indoor air pollution of the Tibetan herdsman, such as separating cooking area with living or sleeping areas, using liquid gas and introducing improved stove. Under present condition, however, the improved stove seems to be the only possible solution. Nevertheless, according to our investigation, so far still two thirds of herdsman at Nam Co region reluctant to use the improved stove during summer season due to economic reasons.

CONCLUSION

High concentrations of $PM_{2.5}$ and CO of type1 tent in this study is mainly due to the relatively small space of Tibetan tents, frequent fueling and continuous long time of burning yak dung during daytime. Large amount of pollution is produced and emitted into the small tent every time the yak dung is added into the stove.

Our study also shows the much lower $PM_{2.5}$ and CO concentrations within type1 tents compared to those of type2 tents. However, $PM_{2.5}$ concentration within type2 tent is still higher than the WHO Air Quality Guideline (35 $\mu g/m^3$). In addition, although smoke is emitted out of the tent by chimney, the final environment influence of smoke, especially for black carbon (an important warming agent) will still exist in atmosphere (Smith et al. 2010). Since many Tibetan tents are located near the mountain glaciers, smoke released from these tents is easily transported up to these glaciers, which will induce intensive retreatment of glaciers under the background of global warming (Xu et al. 2009). Therefore, present improved stove need to be further ameliorated to reduce the amount of pollutions released directly into the atmosphere.

REFERENCE:

Barnes D F, Openshaw K, Smith K R, Van der Plas R. 1994. What makes people cook with improved biomass stoves? A comparative international review of stove programs. *WORLD BANK, 1818 H STREET, N. W., WASHINGTON, DC 20433(USA)*. 1994.

Chen B H, Hong C J, He X Z. 1992. Indoor air pollution and its health effects in China: a review. *Environmental technology*, 13(4): 301-312.

Dasgupta S, Huq M, Khaliquzzaman M, Pandey K, Wheeler D. 2006. Indoor air quality for poor families: new evidence from Bangladesh. *Indoor air*, 16(6): 426-444.

Dionisio K L, Howie S, Fornace K M, Chimah O, Adegbola R A, Ezzati M. 2008. Measuring the exposure of infants and children to indoor air pollution from biomass fuels in The Gambia.

Indoor air, 18(4): 317-327.

Fischer S L, Koshland C P. 2007. Daily and peak 1 h indoor air pollution and driving factors in a rural Chinese village. *Environ. Sci. Technol*, 41(9): 3121-3126.

Jiang R, Bell M L. 2008. A Comparison of Particulate Matter from Biomass-Burning Rural and Non-Biomass-Burning Urban Households in Northeastern China. *Environmental Health Perspectives*, 116(7): 907.

Kang S, Li C, Wang F, Zhang Q, Cong Z. 2009. Total suspended particulate matter and toxic elements indoors during cooking with yak dung. *Atmospheric Environment*, 43(27): 4243-4246.

Naeher L P, Smith K R, Leaderer B P, Mage D, Grajeda R. 2000. Indoor and outdoor PM2. 5 and CO in high-and low-density Guatemalan villages. *Journal of exposure analysis and environmental epidemiology*, 10(6): 544-551.

Shi Q. 1991. A survey of indoor air pollution from different fuels in the plateau region. *Journal of Environment and Health*, 8(2): 80-81.

Sinton J E, Smith K R, Hansheng H. 1995. Indoor air pollution database for China. *Geenet Human exposure assessment series.*

Smith K R, Jerrett M, Anderson H R, Burnett R T, Stone V, Derwent R, Atkinson R W, Cohen A, Shonkoff S B, Krewski D. 2010. Public health benefits of strategies to reduce greenhouse-gas emissions: health implications of short-lived greenhouse pollutants. *The Lancet*, 374(9707): 2091-2103.

Smith K R, Mehta S. 2003. The burden of disease from indoor air pollution in developing countries: comparison of estimates. *International Journal of Hygiene and Environmental Health*, 206(4-5): 279-289.

Smith K R, Samet J M, Romieu I, Bruce N, 2000. Indoor air pollution in developing countries and acute lower respiratory infections in children. Br Thoracic Soc, pp. 518-532.

TSI Inc. 2006. Model AM510 SidePak™ Personal Aerosol Monitor User Guide. 1980456, *Revision E*. Shoreview, MN: TSI Inc.

U.S. Environmental Protection Agency. 2004. Air Quality Criteria for Particulate Matter. EPA/600/P-99/002aF, EPA/600/P-99/002bF. Research Triangle Park, NC: U.S. *Environmental Protection Agency.*

Xu B, Cao J, Hansen J, Yao T, Joswia D R, Wang N, Wu G, Wang M, Zhao H, Yang W. 2009. Black soot and the survival of Tibetan glaciers. *Proceedings of the National Academy of Sciences*, 106(52): 22114.

Zhang J, Smith K R. 1999. Emissions of Carbonyl Compounds from Various Cookstoves in China. *Environmental Science & Technology*, 33(14): 2311-2320.

Zhang J, Smith K R, 2005. In 10th International ConferenceonIndoor Air Quality and Climate. Beijing, China.

Zhang J J, Smith K R. 2007. Household Air Pollution from Coal and Biomass Fuels in China: Measurements, Health Impacts, and Interventions. *Environmental Health Perspectives*, 115(6): 848.

Zhou M R, Yue J N, Xu Z H, Jing Q, Long H Y, Xing J, Zhou S X, Zhang H J, Zhu H L, Sha Q Y. 2005. A survey of diseases among the dwellers in Banma county in Qinghai-Tibet Plateau. *Moden Preventive Medicine*, 32(1): 1465-1467.

Health
Monday, June 6, 2011
1:00 PM - 3:05 PM

324. Indoor Air Pollution and Blood Pressure in Adult Women in Rural China
Jill Baumgartner; James J. Schauer; Majid Ezzati; Lin Lu; Chun Cheng; Jonathan Patz; Leonelo Bautista

459. A Profile of Biomass Stove Use in Sri Lanka and Associated Environmental Health Risks
Myles F. Elledge; Sumal Nandasena; Michael Phillips; Vanessa Thornburg

813. Indoor Air Pollution And Lung Function Growth Among Children In Four Chinese Cities
Ananya Roy; Hu Wei; Cynthia Liu; Fusheng Wei; Robert S. Chapman; Junfeng Zhang

1057. A Baseline Evaluation Of Traditional Cook Stove Smoke Exposures And Indicators Of Cardiovascular And Respiratory Health Among Nicaraguan Women
Maggie L. Clark; Stephen J. Reynolds; Judy M. Heiderscheidt; Bevin R. Luna; Stuart Conway; Annette M. Bachand; John Volckens; Jennifer L. Peel

474. Hypertension And Solid Fuel Use Among Women In Rural Guizhou, China
Line W.H. Alnes; Kristin Aunan; Sveinung Berntsen; Zeqin Dong; Heidi E.S. Mestl

1511. Impact of an improved stove intervention on exposure and health among Nicaraguan women
Sarah Yoder; Maggie L. Clark; Judy M. Heiderscheidt; John Volckens; Stephen Reynolds; Bevin Luna; Kirsten Koehler; Stuart Conway; Annette Bachand; Jennifer Peel

1514. Chronic early life exposure to carbon monoxide in woodsmoke and children’s neurodevelopment in rural Guatemala: A pilot study
Linda Dix-Cooper; Brenda Eskenazi; Carolina Romero; John Balmes; Kirk Smith

The effects of indoor air pollution on blood pressure in adult women living in rural China

Jill Baumgartner[1,2,*], James J Schauer[2], Majid Ezzati[3], Lin Lu[4], Chun Cheng[4], Jonathan Patz[1,2] and Leonelo E Bautista[1]

[1] Dept of Population Health, University of Wisconsin, Madison, WI, USA
[2] Nelson Institute for Environmental Studies, University of Wisconsin, Madison, WI, USA
[3] MRC-HPA Center for Environment and Health, Department of Epidemiology and Biostatistics, School of Public Health, Imperial College London, UK
[4] Yunnan Provincial Centers for Disease Control and Prevention, Kunming, Yunnan, PRC

[*] *Corresponding email: jbaumgartner@umn.edu*

SUMMARY

In this study of 280 rural Chinese women, personal $PM_{2.5}$ exposure was positively and significantly associated with higher systolic (SBP) and diastolic blood pressure (DBP), with the strongest effects among women over 50 years old. These results support the previous study on this topic and extend the results to a novel population with low ischemic and high hemorrhagic stroke incidence relative to other regions.

IMPLICATIONS

This is the first study using personal exposure measurements to examine the cardiovascular health effects of indoor air pollution exposure. Although our findings should be confirmed in prospective cohort studies, they suggest that cardiovascular diseases may be an important component of the public health burden of indoor cooking and heating with biomass fuels. Issues of energy and IAP should therefore be considered in the formulation of policies and interventions aimed at reducing the cardiovascular disease burden in China as well as in other countries where domestic use of biomass fuels is common.

KEYWORDS: Biomass, solid fuels, cardiovascular health, particulate matter, China

INTRODUCTION

Biomass (wood, crop residues and animal dung) and coal are the primary domestic fuels for almost half the world's population, living mostly in low-income regions (Smith, 2004). These fuels are often burned inside poorly ventilated spaces with thermally inefficient stoves that emit a complex pollutant mixture of particulate matter (PM), gases and other toxic compounds at concentrations much higher than most urban ambient pollution levels (Smith, 2004).

Exposure to ambient air pollution and secondhand tobacco smoke has been associated with increased risk of myocardial infarction, stroke and cardiovascular mortality (Brook et al., 2010; Barnoya and Glantz, 2005). Several mechanisms have been proposed to explain these cardiovascular effects, including PM-induced increases in blood pressure (BP) (Pope 3rd et al., 2004). Both human experiments and observational studies suggest that ambient air pollution exposure could raise systolic (SBP) and diastolic blood pressure (DBP), though other studies failed to replicate these findings (Brook, 2010).

Only an intervention study in Guatemalan women demonstrated that transitioning from an open fire to improved biomass stove was associated with lower BP (McCracken et al., 2007).

The lack of epidemiologic data on the cardiovascular health effects of IAP limits our ability to assess its full public health impact. For example, the most recent World Health Organization (WHO) Comparative Risk Assessment did not attribute cardiovascular outcomes to household use of solid fuels (WHO, 2009).

METHODS

Subject Recruitment

We recruited women from 235 households in northwestern Yunnan, China between December 2008 and August 2009. Non-smoking and non-pregnant women over 25 years old who lived in the study area were eligible. Women interested in participation were read a consent form by field staff and provided oral informed consent. The study was approved by the Health Sciences Institutional Review Board at the University of Wisconsin-Madison and the Yunnan Provincial Health Bureau, Kunming, China.

Personal $PM_{2.5}$ pollution exposure measurement

We measured 24-hr personal integrated gravimetric exposure to fine particles less than 2.5 microns in aerodynamic diameter ($PM_{2.5}$) in winter and summer. Sampling occurred every day of the week except for holidays when cooking was not "usual". For gravimetric $PM_{2.5}$ measurements, subjects wore a portable, battery-operated pump in a small waistpack (<1 kg). The pump was connected to a 37 mm cassette and Teflon filter and attached downstream from a GK2.05 cyclone with a 2.5μm aerodynamic-diameter cut point. Field staff instructed subjects to perform routine daily activities and wear the waistpack when possible.

Blood pressure and other measurements

Field staff conducted BP measurements in the subject's household after the $PM_{2.5}$ sampling period. Following 5 min of quiet rest, we measured SBP and DBP in the supported right arm of a seated participant. Three consecutive BP measures were taken using an automated device (Omron HEM-705CP) in accordance with standard recommendations (Pickering, 2004). We also recorded the date and time, ambient air temperature, and whether the subject had consumed caffeine in the previous hour.

We also collected socio-demographic information including age, education, self-reported health status, cardiovascular history, passive smoking and ownership of selected household assets. We measured subjects' height, weight, waist circumference, 24-hr salt intake and 24-hr physical activity using a pedometer.

Statistical analysis

We log transformed $PM_{2.5}$ exposure to improve normality and variance homogeneity and used mixed-effects models with random intercepts at the individual, household, and village level to study the association between $PM_{2.5}$ exposure and BP (Laird and Ware, 1982). We assessed confounding by time-varying covariates (i.e., day and time of BP measurement, ambient air temperature, physical activity, caffeine intake and self-reported health) and covariates with no or minimal variation (i.e., age, years of education, waist circumference, socioeconomic status and salt intake). We retained variables in the final model if associated with BP at $p<0.10$ or if they changed the effect of PM exposure on BP by ≥10%. We also assessed effect modification by age. We used our final mixed-effects models to predict the average SBP and DBP in the population (i.e., marginal means) (StataCorp, 2009).

RESULTS

We enrolled 280 women ages 25-90 years old (mean age: 51.9 years). Out of these, 196 participated in both the winter and summer, 66 only in the winter and 18 only in the summer. Most declines to participate in both evaluations were due to the farming season schedule. Most participants had some formal education (52% primary and 31% secondary school). Also, 18% were overweight (body mass index (BMI): 25 to 30 kg/m^2) and 4% were obese (BMI≥30 kg/m^2). Personal 24-hr exposure to $PM_{2.5}$ mass ranged from 22-634 µg/m^3 in winter and 9-492 µg/m^3 in summer. The 24-hr geometric mean $PM_{2.5}$ exposure in summer was 55 µg/m^3 (95% CI: 49, 62), and increased to 117 µg/m^3 (95% CI: 107, 128) in winter.

PM-BP associations

Personal $PM_{2.5}$ exposure was positively associated with SBP and DBP, but the effect was dependent on age. In the crude analysis, an increase of one unit of log-$PM_{2.5}$ increased SBP by 2.7 mmHg (p<0.001), but the increase was considerably larger in women >50 years old (4.1 mmHg; p=0.001) than in those 25-50 years (1.6 mmHg; p=0.008). This stronger effect in older women persisted after adjusting for other risk factors. In fact, after adjustment the effect of log-$PM_{2.5}$ on SBP was no longer significant in younger women (0.7 mmHg; p=0.35), but did not change in older women. The interaction of the effects of age-group and $PM_{2.5}$ on SBP was statistically significant (p=0.03).

We observed similar results for DBP, with both crude and adjusted estimates indicating a non-significant effect of $PM_{2.5}$ among young women and significantly higher DBP among older women. In adjusted models, an increase of one log-$PM_{2.5}$ unit increased DBP by 1.8 mmHg (p=0.01). The interaction between $PM_{2.5}$ and age-group was also statistically significant for DBP (p=0.01).

Table 1. Crude and multivariate adjusted effects of personal $PM_{2.5}$ exposure (log-µg/m^3) on blood pressure by age

		Crude effects*		**Adjusted effects****	
		Systolic blood pressure			
Age (years)	**N**	**Difference in mmHg, (95% CI)**	**P-value**	**Difference in mmHg, (95% CI)**	**P-value**
25-50	142	1.6 (0.4, 2.8)	0.008	0.7 (-0.8, 2.1)	0.35
>50	138	4.1 (1.7, 6.5)	0.001	4.1 (1.5, 6.6)	0.002
All	280	2.7 (1.4, 4.1)	<0.001	2.2 (0.8, 3.7)	0.003
		Diastolic blood pressure			
Age (years)	**N**	**Difference in mmHg (95% CI)**	**P-value**	**Difference in mmHg (95% CI)**	**P-value**
25-50	142	0.1 (-1.1, 1.3)	0.88	-0.6 (-1.7, 0.5)	0.25
>50	138	1.2 (-0.1, 2.4)	0.06	1.8 (0.4, 3.2)	0.01
All	280	0.0 (-0.8, 0.8)	0.98	0.5 (-0.4, 1.3)	0.31

* The "effect" is the difference in BP associated with a one-unit increase in the log of $PM_{2.5}$. Results from a univariate mixed-effect model.
** The "effect" is the difference in BP associated with a one-unit increase in the log of $PM_{2.5}$, adjusted for other covariates. Results from a multivariate mixed-effects model.

As depicted in Figure 1, an average woman in this population exposed to the average $PM_{2.5}$ level observed in our study population (~100 µg/m^3) would have SBP and DBP of 128 and 76 mmHg, respectively. However, if the same woman was exposed to $PM_{2.5}$ concentrations in the upper decile of our exposure distribution (~500 μg/m^3), her SBP and DBP would increase to 135 and 79 mmHg, respectively.

Figure 1. Average systolic and diastolic blood pressure in the population by level of personal exposure to particulate matter ($PM_{2.5}$, μg/m^3) and age*

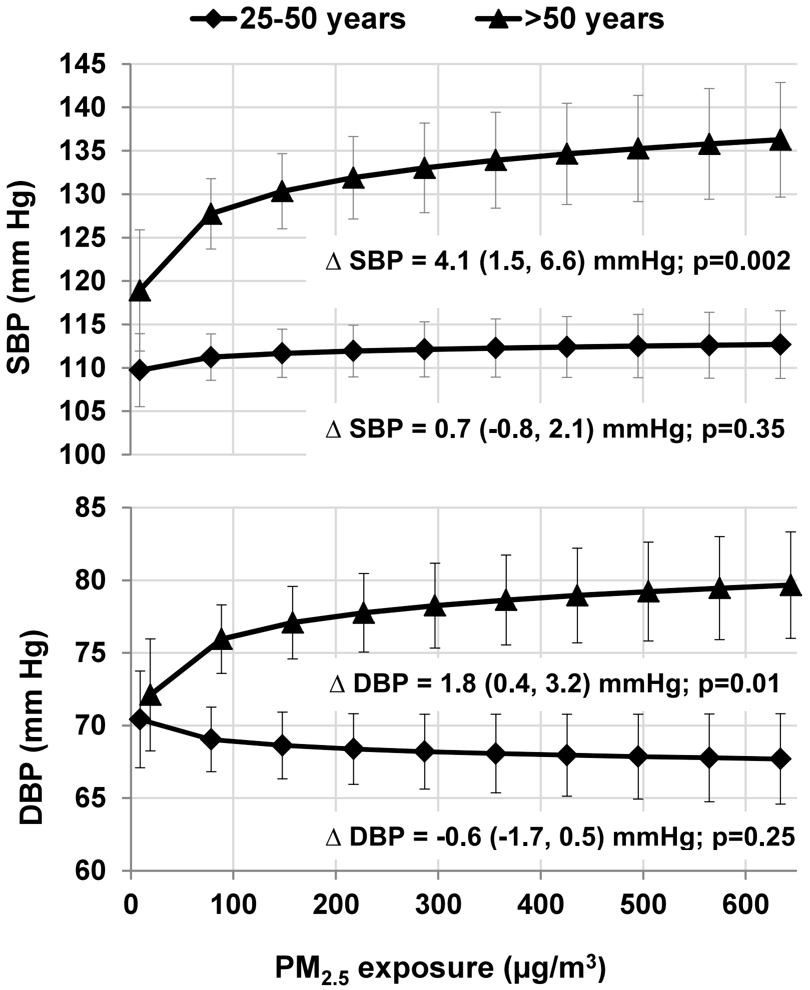


Figure notes:
DBP; diastolic blood pressure
SBP; systolic blood pressure
Δ; Difference in blood pressure by a log-$PM_{2.5}$ unit (Table 1).
*Average systolic and diastolic blood pressure in the population (marginal means) are predicted from a mixed-effects regression model (Table 1) using the mean values of age, physical activity, salt intake, socioeconomic status, waist circumference, day of the week, time of day, and ambient air temperature in the population and $PM_{2.5}$ exposure within the range of values observed in the study population.

DISCUSSION

The notable strengths of our study include measuring personal exposure, data on exposure and BP in summer and winter, and adjustment for important risk factors for increased BP including age, obesity, physical activity and salt intake. While residual confounding may remain, it is unlikely that unmeasured covariates are strong confounders in our mixed-effects models given the relative homogenous distribution of risk factors for elevated BP in our study population which facilitates control of un-measurable or difficult to measure risk factors.

An important limitation of this study is its apparent cross-sectional design. However, cooking with biomass is a long-term behavior and thus 24-hr PM exposure is a measure that is "usual" except for day-to-day variability. Also, PM exposure is not likely affected by an individual's BP given that increases in BP are usually asymptomatic. While it is possible that poor health status may lead women to reduce exposure to PM, adjusting for self-reported health status in our regression models did not change our findings.

The stronger effect among older women may be attributable to long-term oxidative stress and systemic inflammation due to lifetime PM exposure. PM inhalation has been shown to cause oxidative stress (Barregard et al., 2006) as well as systemic inflammation (Pope 3rd and Dockery, 2006) which is associated with the development of hypertension (Bautista et al., 2005). However, long term BP-effects of PM exposure could also be the result of a re-setting of BP-regulating mechanisms to higher levels as a consequence of repeated acute increases in BP after PM inhalation. Though underlying cardiovascular disease has been proposed as a potential driver of an age-by-exposure interaction (Brook et al., 2010), it does not likely explain our results given the low cardiovascular disease prevalence in our study population.

Previous studies indicate that transitioning from an open fire to an improved (i.e., enclosed and vented) wood stove (Albalak et al., 2001), gas (Naeher et al., 2000) or wood-charcoal (Ezzati and Kammen, 2002) can result in at least a one log-$\mu g/m^3$ reduction in indoor PM. Based on our results, such a change could result in ~4 mmHg lower SBP among older women. Strong evidence suggests that risk of cardiovascular mortality increases progressively and linearly with increasing BP at levels as low as 115 mmHg SBP and 75 mmHg DBP in Western and Asian populations (Lawes et al., 2004; Lewington et al., 2002). Based on results from Lawes et al. (2003), we estimate that 4 mmHg lower SBP on a population level would result in an 18% (95% CI: 15, 21) decrease in coronary heart disease and a 22% (95% CI: 21, 24) decrease in stroke among Asian women 50-59 years old (Lawes et al., 2003). Considering biomass fuels are the primary domestic energy source for over 2 billion people globally (Smith, 2004), the potential cardiovascular benefit of transitioning to cleaner-burning stoves and fuels on a macro-level would be considerable. For example, based on the published mortality data for Chinese women, an 18% decrease in coronary heart disease and 22% decrease in stroke would account for up to 230,900 fewer deaths per year in Chinese women >50 years old.

CONCLUSIONS

Our study shows that personal $PM_{2.5}$ exposure is positively associated with both SBP and DBP among adult women, particularly in those over 50 years old. Although our findings should be confirmed in prospective cohort studies, they suggest that cardiovascular diseases may be an important component of the public health burden of indoor cooking and heating with biomass fuels. Issues of energy and IAP should therefore be considered in the formulation of policies and interventions aimed at reducing the cardiovascular disease burden in China as well as in other countries where domestic use of biomass fuels is common.

ACKNOWLDGEMENTS

This research was supported by the Air and Waste Management Association, American Philosophical Society, Robert Wood Johnson Foundation and Casella-Beijing. Funding for J.B. was provided by the William J. Fulbright Foundation and the National Science Foundation Grant No. DGE-0549369.

REFERENCES

Albalak R, Bruce N, McCracken JP, Smith KR and de Gallardo T. 2001. Indoor respirable particulate matter concentrations from an open fire, improved cookstove, and LPG/open fire combination in a rural Guatemalan community. Environ Sci Technol 35: 2650-2655.

Barnoya J and Glantz SA. 2005. Cardiovascular effects of secondhand smoke: nearly as large as smoking. Circulation 111: 2684-2698.

Barregard L, Sällsten G, Gustafson P, Andersson L, Johansson L, Basu S, et al. 2006. Experimental exposure to wood smoke particles in healthy humans: effects on markers of inflammation, coagulation and lipid peroxidation. Inhal Toxicol 18: 845–853.

Bautista L, Vera L, Arenas I and Gamarra G. 2005. Independent association between inflammatory markers (C-reactive protein, interleukin-6, and TNF-α) and essential hypertension. J Hum Hypertens 19: 149-154.

Brook RD, Rajagopalan S, Pope 3rd CA, Brook JR, Bhatnagar A, Diez-Roux AV, et al. 2010. Particulate Matter Air Pollution and Cardiovascular Disease: An Update to the Scientific Statement from the American Heart Association. Circulation 121: 2331-2378.

Ezzati M and Kammen D. 2002. Evaluating the health benefits of transitions in household energy technologies in Kenya. Energy Policy 30: 815-826.

Laird NM and Ware JH. 1982. Random-Effects Models for Longitudinal Data. Biometrics 38: 963-974.

Lawes CM, Vander Hoorn S, Law MR, Elliott P, MacMahon S and Rodgers A. 2004. Blood pressure and the global burden of disease. In: Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors (Ezzati M, Lopez AD, Rodgers A. and Murray CJL, eds). Geneva: World Health Organization, 391-496.

Lawes CM, Rodgers A, Bennett DA, Parag V, Suh I, Ueshima H, et al. 2003. Blood pressure and cardiovascular disease in the Asia Pacific region. J Hypertens 21: 707–716.

Lewington S, Clarke R, Qizilbash N, Peto R and Collins R. 2002. Age-specific relevance of usual blood pressure to vascular mortality: a meta-analysis of individual data for one million adults in 61 prospective studies. Lancet 360: 1903–1913.

McCracken J, Smith K, Díaz A, Mittleman M and Schwartz J. 2007. Chimney Stove Intervention to Reduce Long-term Wood Smoke Exposure Lowers Blood Pressure among Guatemalan Women. Environ Health Perspect 115: 996–1001.

Naeher L P, Leaderer BP and Smith KR. 2000. Particulate matter and carbon monoxide in highland Guatemala: indoor and outdoor levels from traditional and improved wood stoves and gas stoves. Indoor Air 10: 200-205.

Pickering TG, Hall JE, Appel LJ, Falkner BE, Graves J, Hill MN, et al. 2005. Recommendations for blood pressure measurement in humans and experimental animals. Part 1: Blood pressure measurement in humans - a statement for professionals from the Subcommittee of Professional and Public Education of the American Heart Association Council on High Blood Pressure Research. Circulation 111: 697-716.

Pope 3rd CA, Burnett RT, Thurston GD, Thun MJ, Calle EE, Krewski D, et al. 2004. Cardiovascular mortality and long-term exposure to particulate air pollution: epidemiological evidence of general pathophysiological pathways of disease. Circulation 109: 71-77.

Pope 3rd CA and Dockery DW. 2006. Health effects of fine particulate air pollution: lines that connect. J Air Waste Manag Assoc 56: 709-742

Smith KR, Mehta S. and Maeusezahl-Feuz M. 2004. Indoor smoke from household solid fuels. In: Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors (Ezzati M, Lopez AD, Rodgers A. and Murray CJL, eds). Geneva: World Health Organization, 1435–1493.

StataCorp. 2009. Marginal means, adjusted predictions, and marginal effects. College Station, TX: Stata Press.

World Health Organization. 2009. Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks. Geneva, Switzerland: World Health Organization.

A Profile of Biomass Stoves Use in Sri Lanka and Associated Environmental Health Risks

Myles F. Elledge[1], Sumal Nandasena[2], Michael J. Phillips[1], and Vanessa E. Thornburg[1]

[1]RTI International, 3040 Cornwallis Road, Research Triangle Park, NC 27709, USA; E-Mails: melledge@rti.org; mjp@rti.org; thornburg@rti.org [2]National Institute of Health Sciences, Ministry of Health, Kalutara, Sri Lanka; E-Mail: sumalnandasena@gmail.com

Keywords: (Cook stoves, Indoor Air Pollution, Biomass, Respiratory Disease, Public Policy)

Introduction

Biomass cooking fuel is used by the majority of Sri Lankan households, primarily in simple non-ventilated three-stone cook stoves. The cook stoves emit significant indoor air pollutants (IAP); IAP is well-established as a global environmental health hazard. Exposures to IAP are disproportionately distributed among women, children, and elderly residents, who are most likely to be at home when cooking occurs. Sri Lanka's demographics show large populations of young and aging people who are particularly vulnerable to IAP exposures. This vulnerability can be seen in Sri Lanka health statistics that show a high prevalence of diseases associated with exposure to IAP. Unfortunately, IAP is a public health issue mostly ignored by Sri Lankan government agencies and its citizens. Thus, there is a strong need for research and education to inform new public health policy, advocacy, and program interventions.

Methods

This desk study included a review of published literature, government data sources, and reports about Sri Lanka and biomass fuel use. Online literature searches were made via PubMed and ScienceDirect. Government data sources include Sri Lanka's Annual Health Statistics, the Sri Lanka Census of Population and Housing, and the Demographic Health Survey (DHS). Other sources of data included World Health Organization (WHO) reports.

Results

Sri Lanka government statistics show that nearly 90% of Sri Lankan households rely on firewood as their cooking fuel (Department of Census and Statistics, 2006). Approximately 70% of the households using biomass fuel cook inside their main household structure, while only 8% have a separate building for cooking (Department of Census and Statistics, 2008). In addition, fewer than 50% of the households using biomass cooking stoves have a chimney in their house (Bruce et al. 2002).

In Sri Lanka, the higher the education level, the lower the observed use of firewood. Sixty-five percent of females who have an education greater than grade 10 use biomass fuel, while 95 percent of the females having limited primary schooling use biomass fuel (Department of Census and Statistics, 2008).

When one examines the distribution of households by the principal cooking fuel used against the country's wealth index, one sees clear disparities across Sri Lanka households related to their socioeconomic status. Although the use of electricity and kerosene was similar across all wealth quintiles, over 90% of the 3 lowest wealth quintiles used wood as their primary cooking fuel, while only 24.5% of the wealthiest quintile used wood (Department of Census and Statistics, 2006). The poor are less likely to afford cleaner fuels or ventilated kitchens.

Biomass stove use is prevalent across all rural areas, with exceedingly high rates observed on rural agricultural plantations (estates). The poor and less-educated living in rural areas are at the greatest risk. These barriers (poverty, knowledge) must be overcome to reduce exposure to IAP.

Kitchens in which firewood was used with traditional stoves reported average $PM_{2.5}$ concentrations of about 1,200 µg/m3 (micrograms per cubic meter) (Amerasekera, 2004). These exposures are much higher than, the 25 µg/m3 WHO guideline for 24- hour ambient levels of $PM_{2.5}$ (World Health Organization, 2006).

Exposures to high concentrations of IAPs are linked to respiratory diseases; the second leading cause of Sri Lankan hospitalizations. Respiratory disease ranks fifth among all causes of neonatal death. Across all age groups, asthma and respiratory disease morbidity also are increasing in Sri Lanka. (Medical Statistics Unit, 2007). Women and elderly household residents are more likely to be inside the home during cooking and at increased risk for developing cataracts, heart disease, and certain types of cancer.

Low-birth weight deliveries also are associated with exposure to IAP; an estimated 22% of Sri Lankan infants are born with low birth weight (World Health Organization, 2009). And IAP exposure among pregnant women greatly increases the risk of fetal hypoxia which impairs fetal development. In addition, the risk of stillbirths increases with exposure to biomass smoke (Bruce et al. 2002).

Conclusions

Sri Lanka's sizable vulnerable population suggests that IAP poses a significant health threat to Sri Lankan citizens. The health hazards of IAP are reasonably well documented across the globe, yet limited studies have been conducted in Sri Lanka, especially those focused on the links between biomass fuel stoves, poverty, and cultural-defined cooking practices. There is a critical need for epidemiological research in Sri Lanka to improve the data set to deepen our understanding and to advocate for strategies to reduce exposures to IAP.

Such research requires the commitment of the Sri Lanka government and other in-country stakeholders to support IAP exposure and health research, policy development of IAP standards and monitoring, and household interventions to mitigate health risks.

References

Amerasekera RM. 2004. Proven interventions to reduce indoor air pollution due to cooking with biomass. In: *Proceedings of Air That We Breathe, First National Symposium on Air Resource Management in Sri Lanka*, 2004 December 2–4, 2004, Colombo, Sri Lanka.

Bruce N, Perez-Padilla R, Albalak R. 2002. The health effects of indoor air pollutant exposure in developing countries. Geneva, Switzerland: World Health Organization; 40 p.

Department of Census and Statistics, Sri Lanka. 2006. Census of Population and Housing 2001. Colombo, Sri Lanka.

Department of Census and Statistics, Sri Lanka, 2002. Sri Lanka Demographic and Health Survey 2000 Colombo, Sri Lanka.

Department of Census and Statistics, Sri Lanka, 2008. Sri Lanka Demographic and Health Survey 2006/7. Colombo, Sri Lanka.

Medical Statistics Unit, Department of Health Services, Sri Lanka. 2007. Annual Health Statistics, Sri Lanka, 2007, Colombo, Sri Lanka. 84 p.

World Health Organization. 2006. WHO air quality guidelines for particulate matter, ozone, nitrogen dioxide, global update 2005, summary of risk assessment. Geneva, Switzerland: WHO Press.

World Health Organization. 2009. World health statistics. Geneva, Switzerland: WHO Press.

Indoor air pollution and lung function growth among children in four cities in China

Ananya Roy[1], Wei Hu[2], Fusheng Wei[2], Cynthia Liu[3], Robert S. Chapman[3,4], Junfeng (Jim) Zhang[1,3,5]

[1] Environmental and Occupational Health Sciences Institute, Piscataway, NJ
[2] China National Environmental Monitoring Center, Beijing, China
[3] University of Medicine and Dentistry of New Jersey-School of Public Health, Piscataway, NJ
[4] College of Public Health Sciences, Chulalongkorn University, Bangkok, Thailand
[5]Department of Preventive Medicine, Keck School of Medicine, University of Southern California, CA

Corresponding email: aroy@eohsi.rutgers.edu
Keywords: FEV_1, FVC, growth, ventilation, coal

1 Introduction

Current estimates suggest China's rural household usage of solid fuel is as high as 80 % of which, coal use contributes 10% (Rehfuess et al. 2006; Zhang and Smith 2007). Combustion of coal or other solid fuels results in production of a mixture of air pollutants and indoor air concentrations depend on type of fuel being used, stove type and efficiency and housing characteristics. Studies carried out in China report indoor levels of PM_{10} levels in excess of 150 µg/ m3, the Chinese IAQ standard and as high as 3000 µg/ m3 (Edwards et al. 2007; He et al. 2005).

Indoor combustion of solid fuels has been associated with increased rates of asthma, pneumonia among children (Dherani et al. 2008; Qian et al. 2004). Recent studies suggest that exposure to ambient PM_{10} as well as gaseous (SO_2, NO_2) air pollutants are associated with decreased growth in lung function among children. (Gauderman et al. 2004; Horak et al. 2002; Rojas-Martinez et al. 2007). Children spend a majority of the time indoors, yet little is known about the impact of indoor air pollution on growth of lung function.

We hypothesize that housing and fuel characteristics associated with indoor air quality may modify the growth trajectory of lung function among a Chinese children living in four different districts.

2 Materials/Methods

Children (n=3512) aged 6-13 years were recruited from urban and suburban district schools in four different cities in China, in 1993-1996. All children in randomly selected classrooms with in the schools were enrolled in the study. They were followed for up to 4 years.

Assessment of indoor air quality and other covariates was carried out using a questionnaire completed by parents of each child. It included detailed questions on types and characteristics of dwelling, coal use for cooking and heating, location of kitchen, presence of home ventilation devices (hood, exhaust fan, chimney), age, sex, history of respiratory illnesses, parental education levels, parental occupation and parental smoking status.

Lung function was measured using computerized Warren E. Collins Survey II 8 liter water-seal volume spirometers. Forced vital capacity (FVC) and forced expiratory volume at 1 second (FEV_1) were measured twice a year, (warm season and cold season). FEV_1/FVC ratios were calculated. "Standardization of spirometry" formulated by American Thoracic Society was adopted as the standard procedure and quality control measurements were made.

The distribution of all variables were assessed and ANOVA was used for bivariate analyses. Multivariable generalized estimating equations were used to examine the association between the presence of ventilation devices, coal burning and lung function growth after accounting for repeated measures and clustering by district. Confounders were included if they changed the main effect estimate by >10% or biological plausibility.

3 Results

31.3 % of the children lived in homes which used coal for either cooking or heating and 24%

of the houses did not have any ventilation devices such as chimneys, fans or hoods for heating or cooking.

In bivariate analyses FEV_1 and FVC were associated (p-value<0.05) with age, height, asthma status, use of coal for cooking and heating, number of rooms in the house, presence of ventilation device, maternal and paternal educational attainment.

Within this cohort, average growth in FEV1 was 50.1 (95% CI:39.1,61.1) ml per year and 26.2 (95% CI: 25.0, 27.5) ml per cm increase in height; FVC growth was 52.5 (95% CI:40.6, 64.5) ml per year and 29.9 (95% CI: 28.4, 31.5) ml per cm increase in height.

Table 1: Effect of indoor coal use and presence of ventilatory device on lung function (ml) and lung function growth per year (ml/year)

	β (95% CI)	**p-value**
Indoor coal burning		
FEV1	-13.5 (-29.6, 2.6)	0.1006
FEV1 growth	-16.5(-23.6, -9.3)	<.0001
FVC	-34.8(-53.4, -16.3)	0.0002
FVC growth	-20.5(-28.3, -12.7)	<.0001
Presence of ventilation device in the house		
FEV1	14.6 (-1.1, 30.3)	0.0684
FEV1 growth	10.2 (2.5, 18.0)	0.0099
FVC	32.1 (13.7, 50.5)	0.0006
FVC growth	17.0 (8.5, 25.5)	<.0001

Controlling for confounding by age, sex, height, asthma, mothers education, fathers education, fathers smoking status and time trends. Also, accounting for clustering at sampling site and repeated measures

We did not see a statistically significant associtiion with FEV_1/FVC ratios and coal use or ventilation.

4 Conclusions

This is the first study carried out exploring the role of indoor air pollution and lung function growth among children. The reported effect on growth of lung function of coal use (~ 40% lower FVC growth/year) and ventilation (~32% higher FVC growth/year) is larger than that seen in the studies on ambient air pollution (~4% in FEV_1 growth/year/ 10μg/m^3 PM_{10}) (Gauderman et al. 2004). Further studies are required to confirm our findings.

It is not clear from this study whether the deficts in lung function due to lower growth persist into adulthood and increase the likelyhood of chronic obstructive pulmonary disease (COPD) in later life. But a recent study indicates that people with early life disadvantage have permanently lower lung function and a substantially increased COPD risk (Svanes et al. 2010). Given that the association between use of solid fuels and COPD has been seen in various studies, it warrants further research to determine if early life exposures to indoor cumbustion products contributes to later life COPD.

5 References

Dherani M, Pope D, Mascarenhas M, Smith KR, Weber M, Bruce N. 2008. Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: A systematic review and meta-analysis. Bull World Health Organ 86(5):390-398C.

Edwards RD, Liu Y, He G, Yin Z, Sinton J, Peabody J et al. 2007. Household CO and PM measured as part of a review of china's national improved stove program. Indoor Air 17(3):189-203.

Gauderman WJ, Avol E, Gilliland F, Vora H, Thomas D, Berhane K et al. 2004. The effect of air pollution on lung development from 10 to 18 years of age. N Engl J Med 351(11):1057-1067.

He G, Ying B, Liu J, Gao S, Shen S, Balakrishnan K et al. 2005. Patterns of household concentrations of multiple indoor air pollutants in china. Environ Sci Technol 39(4):991-998

Horak F,Jr, Studnicka M, Gartner C, Spengler JD, Tauber E, Urbanek R et al. 2002. Particulate matter and lung function growth in children: A 3-yr follow-up study in austrian schoolchildren. Eur Respir J 19(5):838-845

Qian Z, Zhang J, Korn LR, Wei F, Chapman RS. 2004. Factor analysis of household factors: Are they associated with respiratory conditions in chinese children? Int J Epidemiol 33(3):582-588

Rehfuess E, Mehta S, Pruss-Ustun A. 2006. Assessing household solid fuel use: Multiple implications for the millennium development goals. Environ Health Perspect 114(3):373-378 [Online 1/13/2011].

Rojas-Martinez R, Perez-Padilla R, Olaiz-Fernandez G, Mendoza-Alvarado L, Moreno-Macias H, Fortoul T et al. 2007. Lung function growth in children with long-term exposure to air pollutants in mexico city. Am J Respir Crit Care Med 176(4):377-384

Svanes C, Sunyer J, Plana E, Dharmage S, Heinrich J, Jarvis D et al. 2010. Early life origins of chronic obstructive pulmonary disease. Thorax 65(1):14-20

Zhang JJ, Smith KR. 2007. Household air pollution from coal and biomass fuels in china: Measurements, health impacts, and interventions. Environ Health Perspect 115(6):848-855

A Baseline Evaluation of Traditional Cook Stove Smoke Exposures and Indicators of Cardiovascular and Respiratory Health among Nicaraguan Women

Maggie L. Clark[1], Heather Bazemore[1], Stephen J. Reynolds[1], Judy M. Heiderscheidt[1], Stuart Conway[2], Annette M. Bachand[1], John Volckens[1], Jennifer L. Peel[1]*

[1]Department of Environmental and Radiological Health Sciences, Colorado State University, Fort Collins, CO

[2]Trees, Water & People, Fort Collins, CO

**Corresponding email: jennifer.peel@colostate.edu*

Keywords: cardiovascular health, cook stoves, indoor air pollution, respiratory health

1 Introduction

Half of the world's population relies on solid fuel combustion to meet basic domestic energy needs (Rehfuess et al., 2006). It is estimated that indoor air pollution from biomass and coal smoke is responsible for approximately 1.6 million premature deaths per year worldwide, representing about 3% of the global disease burden (Smith et al., 2004). However, mortality captures only a piece of the burden of disease. Relatively few studies have examined the cardiovascular effects of biomass burning (Smith et al., 2004; Smith and Peel, 2010), although evidence from ambient pollution studies suggest an association with numerous cardiovascular disease endpoints (Brook et al., 2010).

2 Materials/Methods

We collected baseline exposure and health measurements for the female primary cook in a convenience sample of 124 households in a semi-rural neighborhood (El Fortin) outside of Granada, Nicaragua, using traditional cook stoves. Traditional stoves generally consisted of homemade elevated open combustion areas without chimneys. Indoor $PM_{2.5}$ (particulate matter less than 2.5 micrometers in diameter) and indoor and personal carbon monoxide (CO) concentrations were assessed continuously via 48-hour monitoring using the UCB Particle Monitor (Berkeley Air Monitoring Group; Berkeley, CA, USA) and the Drager Pac 7000 (SKC, Inc; Eighty Four, PA, USA), respectively. Forced expiratory volume in one second (FEV_1) was measured using the portable PiKo-1 peak flow meter (nSpire Health, Inc; Longmont, CO, USA). We used the maximum FEV_1 value if the two highest values were within 0.2 liters. The portable PulseOx 5500 digital finger pulse oximeter (Micro Direct; Lewiston, ME, USA) was used to measure heart rate. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) measurements were taken manually between the hours of 8am and 12pm after the participant had been seated and at-rest for ten minutes. Three repeat measures were taken within a ten minute period of continued rest; the average of the second and third measures was used. Markers of inflammation were measured from dried blood spot samples. In addition to demographic information, occupation, and exposure to second hand smoke, we assessed usual symptoms of cough, phlegm, and headache during cooking via survey. Additionally, each participant's height and weight were measured and body mass index (BMI) was calculated. Air pollution concentrations were evaluated in relation to health endpoints using linear regression models (FEV_1, heart rate, SBP, and DBP) or logistic regression models (symptoms), adjusting for potential confounders (age, BMI or height, any reported second hand smoke exposure, and education). All results are presented for an interquartile range (IQR) increase in 48-hour pollutant concentration. For all regression analyses, we also assessed the potential for effect modification by categories of BMI (normal, <25 kg/m^2; overweight, 25-29 kg/m^2; and obese, ≥ 30 kg/m^2).

3 Results

The average age of participants was 34.7 years (standard deviation = 15.8 years; median= 31.0 years; range is 11 to 80 years). Forty-one women (34%) were in the overweight category (25 – 29.9 kg/m^2) and forty-two women (34%) were in the obese category (greater than or equal to 30 kg/m^2) for BMI. Large variability was observed for pollutant concentrations, with 48-hour $PM_{2.5}$, 48-hour indoor CO, and 48-hour personal CO ranging from 154 – 6901 μg/m^3, 0.40 – 123.82 ppm, and 0.07 – 14.08 ppm, respectively.

Non-significant elevations in SBP were related to increases in 48-hour indoor CO (1.78 mmHg [95% CI: -1.25, 4.81] per 24 ppm). This relationship was stronger among obese participants, p-value for interaction = 0.002. For example, among obese women (n=41) we observed an 8.51 mmHg (95% CI: 3.06, 13.96) increase in SBP per 24 ppm increase in 48-hour average indoor CO levels. There was no evidence of an association of $PM_{2.5}$ with SBP in the main effects model; however, a stronger association among obese women was observed, p-value for interaction = 0.04. Although the relationship between personal CO exposures and SBP was significant among overweight participants, there was no evidence of dose across the 3 levels of BMI. No evidence of associations was observed for air pollutant measures and DBP; however, there was weak but suggestive evidence of a stronger association between 48-hour indoor CO concentrations and DBP among obese participants, p-value for interaction = 0.004.

We observed a 1.97 beats per minute increase in heart rate (95% CI: 0.22, 3.72) per 2 ppm increase in 48-hour average personal CO levels. No consistent evidence of effect modification by BMI was observed between air pollutant concentrations and heart rate. No evidence of associations was observed for air pollutants and FEV_1 or reported symptoms. Dried blood spot analyses are in progress.

4 Conclusions

In this cross-sectional analysis of 124 households using traditional, open-fire cook stoves in Nicaragua, we observed high concentrations of $PM_{2.5}$ and CO with considerable variability between houses. We did not observe evidence of associations between $PM_{2.5}$ or CO concentrations with respiratory health endpoints, although the cross-sectional nature of the study and the relatively high air pollution concentrations observed for most of the population limit the interpretations of these results. There was weak but suggestive evidence of associations with indicators of cardiovascular health (blood pressure and heart rate), some of which were stronger among obese women than non-obese women. Although detailed data regarding obesity in most rural or disadvantaged populations are lacking, the general consensus is that the growing prevalence of obesity in many developing countries, including those of Latin America, is a serious health problem (Bautista et al., 2009; Martorell et al., 2000). It is probable that the estimated global burden of disease due to indoor air pollution from biomass burning will be even greater once the cardiovascular disease health impacts are more clearly understood.

5 References

Bautista LE, Casas JP, Herrera VM, et al. The Latin American Consortium of Studies in Obesity (LASO). Obes Rev. 2009; 10(3): 364-70.

Brook RD, Rajagopalan S, Pope CA, 3rd, et al. Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. Circulation. 2010; 121(21): 2331-78.

Martorell R, Khan LK, Hughes ML, and Grummer-Strawn LM. Obesity in women from developing countries. Eur J Clin Nutr. 2000; 54(3): 247-52.

Rehfuess E, Mehta S, and Pruss-Ustun A. Assessing Household Solid Fuel Use: Multiple Implications for the Millennium Development Goals. Environ Health Perspect. 2006; 114(3): 373-378.

Smith KR, Mehta S, and Maeusezahl-Feuz M. Indoor air pollution from household use of solid fuels. In: M. Ezzati, et al., Editors. Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors World Health Organization: Geneva;2004. p. 1435-1493.

Smith KR, Peel JL. 2010. Mind the Gap. Environ Health Perspect 118(12):1643-1645.

Hypertension and Solid Fuel Use among Women in Rural Guizhou, China

Line W. H. Alnes[1,*], Kristin Aunan[1], Sveinung Berntsen[2], Zeqin Dong[3] and Heidi E. S. Mestl[1]

[1] CICERO Center for International Climate and Environmental Research – Oslo
[2] University of Oslo, Faculty of Medicine
[3] Guizhou Research & Designing Institute of Environmental Science

[*] *Corresponding email: lwalnes@cicero.uio.no*

Keywords: Cardiovascular disease, indoor air pollution, rural China, residential

1 Introduction

Nearly half of the world's population depends on solid fuels such as wood, crop residues, or coal for cooking and space heating. Estimates from the World Health Organization (WHO) indicate that indoor air pollution from household solid fuel use is responsible for approximately 1.6 million premature deaths annually, about a quarter of which occur in China (Smith et al., 2004). The WHO risk assessment is only taking into account the health burden from respiratory diseases, because there are limited epidemiologic studies of the cardiovascular impacts of solid fuel use (McCracken et al., 2007). However, studies of ambient air pollution and second-hand cigarette smoke demonstrate an association with cardiovascular morbidity and mortality. Solid fuel use frequently leads to significantly higher exposure to fine particulate matter, and consequently exposure to smoke from solid fuel use is most likely associated with similar or even higher risks of cardiovascular morbidity and mortality (Smith and Peel, 2010; Pope et al., 2009).

The aim of the present study is to contribute to fill this knowledge gap by analyzing the systolic blood pressure (SBP) and diastolic blood pressure (DBP) of women cooking with different fuels and stoves in rural China.

2 Materials and Methods

We have conducted a cross-sectional survey in rural Guizhou. Guizhou is the poorest province in China as measured by GDP per capita, and solid fuels are widely used. The survey was carried out in Feb-May and Nov-Dec 2009, and included 1796 women >=30 years of age. The study was restricted to women because they are exposed to smoke from solid fuels through cooking activities and generally do not smoke cigarettes. Three counties were included to get a heterogeneous sample in terms of fuel and stove use. The survey consisted of an interviewer administered questionnaire to collect information on household characteristics and socioeconomic status (SES), and a health exam with height and weight measurements in addition to 3 repeated recordings of arterial blood pressure.

Based on existing literature it is clear that age and body mass index (BMI) is associated with hypertension. In addition, socioeconomic status (SES) may act as a confounder. An index was created as a measure of SES, and is the sum of binary indicators for having a motorcycle, phone, water access, an occupation other than farmer or caretaker, education, and owning 1-2 pigs. An additional point was added for having completed junior middle school and for owning more than 2 pigs. Households use a mix of different fuel and stove types, so the following 4 stove categories were created: The "open fire" group has at least one open fire present, while the "no chimney" group has a basic stove without chimney, but no open fire. The chimney group has at least one chimney stove, and no stoves of poorer quality. The chimney group is divided in two; "Chimney Coal" is using almost exclusively coal and electricity for cooking, while "Chimney Bio" is using biomass/biogas/electricity.

The mean of the 3 repeated SBP and DBP readings were used for the analysis. 24 participants had a coefficient of variation greater than 15%, and 10 participants reported to be smokers. These were excluded from the analysis.

Table 1: Preliminary results from multivariate linear regression of SBP (R^2=0.1744) and DBP (R^2=0.0945).

Covariate		Systolic blood pressure estimate	s.e	p	Diastolic blood pressure estimate	s.e.	p
Age		0.52	0.03	<.0001	0.19	0.02	<.0001
BMI		0.97	0.12	<.0001	0.59	0.08	<.0001
SES index		-0.54	0.32	0.0874	-0.25	0.20	0.2231
Stove category	Chimney - biomass	4.35	1.30	0.0009	3.26	0.83	<0.001
	Chimney - coal	-2.99	1.02	0.0033	-1.66	0.65	0.0104
	No chimney, no open fire	-0.12	1.10	0.9165	-0.19	0.70	0.7916
	At least one open fire	-	-	-	-	-	-
Number of windows for ventilating in the kitchen	2	-4.63	1.59	0.0035	-1.68	1.01	0.0973
	1	-1.56	1.45	0.2831	-0.48	0.92	0.6006
	0	-	-	-	-	-	-

3 Results

The average SBP and DBP was 122.8 (±17.4) and 77.2 (±10.6) mmHg, respectively. Preliminary analysis of SBP and DBP suggests a statistically significant association with stove category after adjusting for age, BMI and SES index. The participants using a coal stove with chimney have lower blood pressure than the participants that have at least one open fire. Surprisingly however, participants that are using a biomass chimney stove display higher blood pressure readings. There is no significant difference between the participants with at least one open fire and the ones with a stove without chimney and no open fire.

More windows that can be used to ventilate the kitchen are associated with lower blood pressure. The results from the multivariate linear regression are presented in Table 1. There was no statistically significant association between blood pressure and frequency of opening the doors/windows during cooking, or using cleaner fuels like biogas or electricity as main cooking fuel.

4 Discussion

Contrary to expectation, only one of the two chimney groups had lower blood pressure than the “open fire” group. Two important factors might influence these results. First of all, the frequent use of multiple stoves/fuels in the same household results in exposure misclassification. The households in the stove reference category have at least one open fire present, but they might very well use cleaner stoves/fuels most of the time. All households use solid fuels for heating, which might explain why we did not find significantly lower blood pressure among the participants cooking mainly with biogas or electricity. Secondly, the model only explains 10-20% of the variability in the blood pressure measurements. Other factors like diet, lifestyle and medical history are certainly also important. Several minority groups were included in the survey, and since they generally live in different areas and probably have dissimilar diet and habits it may confound the results as area is also associated with stove/fuel use. These results are preliminary, and a more refined analysis is required to properly adjust for confounding.

5 References

McCracken J.P., Smith K.R., Díaz A., Mittleman M.A., Schwartz J. 2007. Chimney Stove Intervention to Reduce Longterm Woodsmoke Exposure Lowers Blood Pressure among Guatemalan Women. Environ Health Perspect. 115:996–1001.

Pope C.A., Burnett R.T., Krewski D., Jerrett M., Shi Y., Calle E.E., et al. 2009. Cardiovascular mortality and exposure to airborne fine particulate matter and cigarette smoke. Circulation 120: 941-948.

Smith K.R., Mehta S., Maeusezahl-Feuz M. 2004. Indoor smoke from household solid fuels. In: Ezzati M, Rodgers AD, Lopez AD, Murray CJL (eds) Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors, Geneva, World Health Organization, Vol. 2, pp. 1435-1493.

Smith K.R. and Peel J.L. 2010. Mind the Gap. Environ Health Perspect. 118:1643-1645.

Impact of an improved stove intervention on exposure and health among Nicaraguan women

Sarah A. Yoder[1,*], Maggie L. Clark[1], Judy M. Heiderscheidt[1], John Volckens[1], Stephen J. Reynolds[1], Bevin Luna[1], Kirsten Koehler[1], Stuart Conway[2], Annette Bachand[1], Jennifer L. Peel[1]

[1] Department of Environmental and Radiological Health Sciences, Colorado State University, Fort Collins, CO
[2] Trees, Water & People, Fort Collins, CO

[*]*Corresponding email: yoder.sarah@gmail.com*

Keywords: cardiovascular disease, cookstoves, indoor air pollution, respiratory disease, stove adoption

1 Introduction

Approximately 1.6 million premature deaths per year worldwide and three percent of the global burden of disease can be attributed to indoor air pollution from solid fuel combustion (Smith et al., 2004). The World Health Organization's risk assessment of indoor air pollution attributes only respiratory diseases to indoor biomass burning (Smith et al., 2004). Few studies have examined the relationship between indoor air pollution and cardiovascular disease (McCracken et al., 2007; Smith and Peel, 2010). A limited number of studies have evaluated cook stoves and blood pressure (McCracken et al. 2007); blood pressure has been shown to be a predictor of cardiovascular morbidity (Urch et al., 2005; Vasan et al., 2001).

The mean systolic blood pressure among Central American women is 123 mmHg, whereas the mean among North American women is 118 mmHg (Danaei et al., 2011). Additionally, the prevalence of obesity in Central American women is about 30% (Finucane et al., 2011); comparatively, the worldwide prevalence is 14%. Given the high prevalence of solid fuel combustion and the increasing problems of cardiovascular disease and obesity in developing countries, including those of Latin America, it is important to conduct quantitative and longitudinal assessments of the potential cardiovascular effects of indoor biomass burning associated with cook stove intervention programs.

This paper will report preliminary results on the impact of the adoption of an improved cook stove on exposure and health from an improved stove intervention study conducted in a rural community outside of Granada, Nicaragua.

2 Materials/Methods

Data collection has been completed for a cook stove intervention study for 123 homes using traditional, open fire stoves at baseline in a rural community outside of Granada, Nicaragua. Indoor carbon monoxide (CO) and fine particulate matter ($PM_{2.5}$) concentrations were assessed continuously for 48 hours in each home using the Drager Pac 7000 (SKC, Inc; Eighty Four, PA, USA) and the UCB Particle Monitor (Berkeley Air Monitoring Group; Berkeley, CA, USA), respectively. Health endpoints were assessed for nonsmoking primary household cooks. Systolic and diastolic blood pressure measurements were taken manually between the hours of 8am and 12pm (to account for known diurnal variation) after the participant had been seated and at-rest for ten minutes. Three repeat measures were taken within a ten minute period of continued rest. We used the average of the second and third measures. A standardized respiratory symptoms and disease questionnaire developed and validated by the American Thoracic Society was translated into Spanish and administered to participants.

Changes in exposure and health outcomes from baseline to one year after installation of improved stoves will be examined. Improved stove use will be examined in relation to changes in cardiovascular and respiratory health indicators. The primary health indicators of interest are blood pressure, heart rate, and self-reported cough and headache symptoms. Further analysis of the association between stove adoption and changes in heath will be conducted to evaluate the presence of effect modification by age and body mass index (BMI). Indoor

$PM_{2.5}$ and indoor and personal CO will be compared among households using a traditional stove and those who have adopted the new stove. The change in pollution concentrations (from baseline to Year 2) will be examined in relation to the change in the health indicators.

3 Results

At baseline, the average age was 34.7 years (ranging from 11 to 80 years). Forty-one women (34%) were in the overweight category (25 – 29.9 kg/m^2) and forty-two women (34%) were in the obese category (greater than or equal to 30 kg/m^2) for BMI. Mean (standard deviation [SD]) systolic and diastolic blood pressure were 121.6 mmHg (22.0) and 76.5 mmHg (13.0), respectively; 62% of the women reported headache during cooking at baseline and 22% reported coughing. Large variability was observed for baseline pollutant concentrations, with 48-hour $PM_{2.5}$, 48-hour indoor CO, and 48-hour personal CO ranging from 154-6901 µg/m^3, 0.40-123.82 ppm, and 0.07-14.08 ppm, respectively. Changes in exposures and improved stove adoption from baseline to one year after introduction will be assessed in relation to changes in health endpoints. Heterogeneity of these relationships will also be presented by BMI and age categories.

4 Conclusions

The completion of this project could contribute to the knowledge of the relationship between cook stove use and the indicators of respiratory and cardiovascular disease. Evaluation of the study's health outcomes could help justify similar cook stove intervention programs and elucidate the effectiveness of these programs to improve cardiovascular and respiratory health outcomes. Determining the association between pollutants from indoor air pollution and cardiovascular health could substantially affect the measurement of the burden of disease due to indoor air pollution from cook stove use.

5 References

Boy E, Bruce N, Smith KR, Hernandez R. 2000. Fuel efficiency of an improved wood-burning stove in rural Guatemala: implications for health, environment and development. Energy for Sustainable Development 4(2): 21-29.

Danaei G, Finucane MM, Lin JK, et al., on behalf of the Global Burden of Metabolic Risk Factors of Chronic Diseases Collaborating Group (Blood Pressure). 2011. Lancet 377:568-577.

Diaz E, Smith-Sivertsen T, Pope D, et al. 2007. Eye discomfort, headache and back pain among Mayan Guatemalan women taking part in a randomized stove intervention trial. J Epidemiol Community Health 61(1): 74-79.

Ezzati M, Kammen DM. 2002. The health impacts of exposure to indoor air pollution from solid fuels in developing countries: knowledge, gaps, and data needs. Environ Health Perspect 110(11):1057-1068.

Finucane MM, Stevens GA, Cowan MJ, et al., on behalf of the Global Burden of Metabolic Risk Factors of Chronic Diseases Collaborating Group (Body Mass Index). 2011. Lancet 377:557-567.

Fullerton DG, Nigel B, Stephen BG. 2008. Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. Royal Society of Tropical Medicine and Hygiene 102:843-851.

McCracken JP, Smith KR, Diaz A, Mittleman MA, Schwartz J. 2007. Chimney stove intervention to reduce long-term wood smoke exposure lowers blood pressure among Guatemalan women. Environ Health Perspect 115(7):996-1001

Rehfuess E, Mehta S, Pruss-Ustun A. 2006. Assessing Household Solid Fuel Use: Multiple Implications for the Millennium Development Goals. Environ Health Perspect 114(3):373-378.

Smith KR, Mehta S, Maeusezahl-Feuz M. 2004. Indoor air pollution from household use of solid fuels. In: Comparative quantification of health risks : global and regional burden of disease attributable to selected major risk factors (Ezzati M, Rodgers AD, Lopez AD, Murray CJL, eds). Geneva:World Health Organization, 1435-1493.

Smith KR, Peel JL. 2010. Mind the Gap. Environ Health Perspect 118(12):1643-1645.

Urch B, Silverman F, Corey P, et al. Acute blood pressure responses in healthy adults during controlled air pollution exposures. Environ Health Perspect. 2005; 113(8): 1052-5.

Vasan RS, Larson MG, Leip EP, et al. Impact of high-normal blood pressure on the risk of cardiovascular disease. N Engl J Med. 2001; 345(18): 1291-7.

Chronic Prenatal Exposure to Carbon Monoxide in Woodsmoke and Children's Neurodevelopment in Rural Guatemala: a Pilot Study

Linda Dix-Cooper[1,*], Brenda Eskenazi,[2] Carolina Romero,[3] John Balmes,[1,4] Kirk R. Smith[1]

[1]Division of Environmental Health Sciences, School of Public Health, University of California, Berkeley, California, USA
[2]Center for Environmental Research and Children's Health (CERCH), School of Public Health, University of California, Berkeley, California, USA
[3]Centro de Estudios en Salud Universidad Del Valle, Guatemala
[4]Division of Occupational and Environmental Medicine, Department of Medicine, University of California, San Francisco, California, USA

[*]*Corresponding email: ldixcooper@berkeley.edu*

Keywords: indoor air pollution, child development, cookstove, prenatal exposures

1 Introduction

Globally, nearly 50% of all households use solid fuels such as biomass and wood on a daily basis for cooking and heating (Smith et al. 2004). Previous epidemiological studies suggest that reduced birth weight (Pope et al. 2010) and neurodevelopmental effects (Perera et al. 2009) of elevated chronic woodsmoke exposure are likely. Carbon monoxide (CO), the largest constituent of woodsmoke, causes acute neurologic symptoms by displacing oxygen from hemoglobin, leading to hypoxemia. We investigated whether chronic elevated exposure to woodsmoke in rural Guatemala, as determined by 3rd trimester personal passive 48-hour CO measures, was associated with children's neurodevelopmental and behavioral performance at age 6 years.

2 Materials/Methods

CO measures were collected among mother-child dyads during the Randomized Exposure Study of Pollution Indoors and Respiratory Effects (RESPIRE) stove intervention trial in San Marcos, Guatemala every 3 months from 2002 to 2005. Personal CO samples, taken using passive 48-hour Gastec tubes pinned to the participant's clothing in their breathing zone, *as described elsewhere* (Smith et al. 2010), represented chronic exposure to woodsmoke and environmental tobacco smoke (ETS). They were $\log_{10}$-transformed for analyses. Five years later (from March to June, 2010), follow-up neurodevelopmental assessments consisting of 11 brief nonverbal cognitive tests were selected, culturally adapted, and administered to study children through an iterative training and pilot testing period with feedback from examiners, the local research team, and consulting Guatemalan licensed child psychologist, Karla Carerra (from San Carlos University). Anthropometry (child height and weight), visual acuity (on the Snellen "tumbling E" eye chart), and exhaled breath CO (eCO) were also measured. Covariates were selected a priori based on the literature and piloting phase data and included in final multiple linear regression models and forward univariate and backward stepwise regressions. Poor vision was defined as 20/60 or 20/80. An asset index was generated for each household to control for socio-economic status, with scores ranging from 0 to 3 (one point allotted for each affirmative response for bicycle, radio, and/or television ownership). Administration quality of cognitive instruments was ensured through pilot testing and a quality control video review system.

3 Results

Nineteen girls and 20 boys (n=39) ages 6.24 to 7.44 years of age (mean=6.7-years-old) and their mothers (who had completed primary school level education or lower) were re-enrolled into the cognitive study. All children and mothers spoke Mam, an indigenous rural Mayan language. All children's eCO measures were within normal range at their cognitive interviews and retrospective mother and infant mean 48-h personal, passive CO measures were <13ppm. We found inverse associations between pregnant mothers' personal, passive 48-hour mean CO exposure during their 3rd trimesters and nearly all child neurodevelopmental performance scores at age 6 years. Scores on 4 out of 11 brief cognitive tests were significantly associated with maternal 3rd trimester CO, including tests for: visuo-spatial integration ($p<0.05$), short-term memory recall ($p<0.05$), long-term memory recall ($p<0.05$), and fine motor performance ($p<0.01$) measured using the Bender Gestalt-II's 3-phase drawing test (Copy, Immediate Recall, and Delayed Recall (adapted) Figures), and the Reitan-Indiana's finger tapping test, respectively (see table 1). The small sample size may explain the non-significant but still inverse associations between other cognitive tests administered and prenatal exposures. Excluding outlier scores and those of children who may have had an alternate reason for performing poorly, did not markedly change results. Significant associations persisted with adjustment for child sex, age, vision scores, and socio-economic status. Other variables that contributed variance, but to a lesser degree than those included in our final multiple regression models, included: home environment stimulation score, child examiner, WHO height-for-age percentile, and age that the infant stopped breastfeeding.

4 Conclusions

This seems to be the first study on biomass smoke and cognition, and the first longitudinal birth cohort study on chronic early life CO exposure that has used personal biomarkers of exposure and well-established, reliable child cognitive tests. Significant inverse associations between chronic prenatal CO exposure (<13ppm) and child neurodevelopment were detected, but further neurodevelopmental research is needed to replicate results and inform indoor air quality standards. The World Health Organization (WHO) recommends a 24-h limit of 7 mg/m^3 (~6ppm) for indoor air CO, giving consideration to possible effects of chronic exposures. Effective air quality interventions among vulnerable, chronically exposed populations are needed. Chimney stoves can reduce child 48-hour mean personal passive CO exposures by approximately half (McCracken et al. 2009), and new, advanced combustion biomass stoves may be capable of even larger reductions.

5 References

McCracken JP, Schwartz J, Bruce N, et al. 2009. Combining individual- and group-level exposure information: child carbon monoxide in the Guatemala woodstove randomized control trial. Epidemiology 20(1):127-36.

Perera FP, Li Z, Whyatt R, Hoepner L, et al. 2009. Prenatal airborne polycyclic aromatic hydrocarbon exposure and child IQ at age 5 years. Pediatrics 124(2):e195-202.

Pope DP, Mishra V, Thompson L, et al. 2010. Risk of Low Birth Weight and Stillbirth Associated With Indoor Air Pollution From Solid Fuel Use in Developing Countries. Epidemiol Rev.

Smith K, Mehta S, Maeusezahl-Feuz M. 2004. Indoor air pollution from household use of solid fuels. Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors. Geneva: World Health Organization:1436-93.

Smith KR, McCracken JP, Thompson L, et al. 2010. Personal child and mother carbon monoxide exposures and kitchen levels: Methods and results from a randomized trial of woodfired chimney cookstoves in Guatemala (RESPIRE). Journal of Exposure Science and Environmental Epidemiology 20:406-416.

Table 1: Adjusted Linear Regression Results between Maternal 3rd Trimester Personal Passive CO and Child Cognitive Performance at age 6 years

	Cognitive Tests β (95% CI)			
Covariates	Copy Figures	Immediate Recall(a)	Delayed Recall	Finger Tapping
n (%)	39 (100)	39 (100)	36 (92)	37 (95)
Mother CO (log_{10} ppm) 3rd trimester	-4.4 (-9.5, 0.7)**	-0.3 (-0.6 -.01)**	-4.8 (-9.8, 0.1)**	-5.7 (-9.7, -1.7)#
Child Age (Continuous)	1.2 (-5.3, 7.7)	0.2 (-0.2, 0.6)	4.7 (-1.8, 11.3)*	5.2 (.00, 10.4)**
Child Sex (Females vs. Males)	2.4 (-0.8, 5.6)*	0.1 (-0.1, 0.2)	0.4 (-2.7, 3.5)	-2.1 (-4.7, 0.5)*
Poor Vision (Yes vs. No)	-2.8 (-6.6, 1.0)*	-0.1 (-0.3, 0.1)	-2.4 (-5.8, 1.0)*	-1.5 (-4.3, 1.3)
Asset Index (0-3 Continuous)	2.5 (0.6, 4.4)#	0.1 (0.00, 0.2)**	1.2 (-0.8, 3.2)	0.8 (-0.8, 2.3)

One-tailed cut-off p-values are * ≤0.10, ** ≤0.05, # ≤0.01, ## ≤0.001
(a) Immediate Recall figures scores were log_{10}-transformed here as well as in the simple linear regressions

Stoves and Lamps
Monday, June 6, 2011
3:25 PM - 5:30 PM

470. Indoor Air Quality In Rural Rwanda: Intersection Of Engineering, Health And Culture
Susan C. Doll

670. PM2.5 Emission Rates from Kerosene Lamps
Andrea Yarberry; McCleland Jason; Lohse Nathan; Apple James; Vicente Ryan; Dustin Poppendieck

898. Solid-fuel Cook Stoves: Fuel Efficiency And Emissions Testing
James Jetter

999. Emission Rates of Pollutants Emitted from a Traditional and an Improved Wood-burning Cookstove
Thomas W. Kirchstetter; Odelle L. Hadley; Chelsea V. Preble; Ashok J. Gadgil

1506. A technology-specific methodology for evaluating the GHG mitigation potential of advanced improved cookstoves
Samual Evans; John Field

1512. Influence of vaporization losses on cook stove testing
Christian L'Orange; Morgan DeFoort; Bryan Willson

1507. Stove use monitors (SUMs) as a method to measure fuel use and savings in Bangalore, India
Anoop Muniyappa; Simone Brant; David Pennise

Indoor Air Quality in Rural Rwanda: Intersection of Engineering, Health and Culture

Susan C. Doll
Appalachian State University
Corresponding email: dollsc@appstate.edu

SUMMARY
Data from locally available, unvented stoves in rural Rwanda were collected for fuel/firewood consumption and indoor concentrations Particulate Matter of 2.5µm aerodynamic diameter ($PM_{2.5}$) and carbon monoxide (CO) using standard cooking test protocols. Five different stoves were initially tested by each of two women from the community in the same cooking hut, followed by further testing in village households of the two most commonly used. Fuel consumption of the test stoves varied with respect to the traditional 3-stone fire, but all had lower indoor $PM_{2.5}$ (45-80%) and CO levels (30-70%). The lowest fuel consumption (35% reduction) was the locally made clay rocket stove, while the lowest emissions were from the poorest performing mud stove. Fire tending practices had a significant effect on both fuel consumption and emissions.

IMPLICATIONS
Results show that stove type is a poor surrogate for IAP exposure as cooking practices contribute significantly to fuel-performance and emissions. Education and training to improve cooking practices and local stove construction can provide an accessible and affordable alternative to 'improved' stoves for reducing fuel use and IAP.

KEYWORDS
Cooking practices, fuel consumption, household testing, 3-stone fire, rocket stove

INTRODUCTION
The World Health Organization (WHO) identifies indoor smoke from solid fuels among the top 10 health risks in developing countries, with indoor air pollution responsible for an estimated 2.7 percent of the global burden of disease (2002). Women and children are disproportionately affected, because they typically spend more time close to cook stoves. Many of the more than 1.5 million people who are estimated to die prematurely each year, due to exposure to the smoke and other air pollutants from burning solid fuels, live under conditions of extreme poverty (Rehfuess, 2006). There are many ongoing efforts to develop and disperse improved cook stoves and extensive characterization of biomass fuel stove performance and emissions has been conducted under both laboratory conditions (Jetter 2008) and field conditions (MacCarty 2008). Researchers have found that solid biomass fuels often produce substantial amounts of products of incomplete combustion (PIC), some of which may adversely affect human health, and that sometimes so-called ''improved'' stoves tested for improved fuel efficiency actually had worse PIC emissions than traditional stoves. (Smith 2000)

Many people who live in areas of extreme poverty do not have access or financial means to purchase clean fuels or state-of-the-art improved stoves. The purpose of this study was to evaluate *locally* available stoves for fuel use and emissions and to identify factors that impact stove performance so that results could be used to inform an affordable and beneficial approach for reducing both fuel consumption and exposure to indoor air pollution (IAP).

Testing was conducted over a two-year period in a rural community in Rwanda with no household access to electricity or running water, with biomass fuel for cooking predominantly firewood or crop residue. Meals are cooked once or twice a day in separate kitchens that range in construction from mud brick with tin roof to tattered tent-like structures, all typically with very poor ventilation.

METHODS

Initial comparison testing of five locally available stoves was performed in a representative kitchen referred to as the "test hut" shown in Figure 1. The stoves tested included traditional 3-stone fire and mud stoves installed by the civilian army, and three portable 'improved' stoves (shown in Figure 2 with the test team). The two metal stoves were manufactured and donated by the Kigali Institute of Science & Technology (KIST) and the clay rocket-type stove was produced by a local group using the design principles developed at the Aprovecho Research Center (Bryden, 2005). Additional testing of the two most commonly used stoves, 3-stone fire and army mud (Figures 3a and 3b), was conducted in village households to compare controlled test hut results with fuel use and IAP levels under normal use conditions.

Data were collected for fuel consumption, and indoor air concentrations of Particulate Matter of 2.5μm aerodynamic diameter ($PM_{2.5}$) and carbon monoxide. Standard protocols for testing fuel consumption were used to conduct water-boiling (Bryden, 2008) and controlled cooking (Aprovecho, 2009) tests on each stove. The water boiling test (WBT) measures how much fuel is used to boil water under fixed conditions and the standard cooking test (SCT) provides a direct comparison of stove performance when the stoves are used by local cooks preparing traditional meals. Air sampling equipment shown in Figure 3c included a TSI DusTrak particle monitor and Onset carbon monoxide sensor that ran throughout each test.

Figure 1. Test hut - left side for testing, right side for storage (new doors with locks were installed for security)

Figure 2. Test Team (left to right): Susan Doll, Nyirabagenzi Denise, Mukarutesi Joyce, Mukantaganda Hyacentha

(a)

(b)

(c)

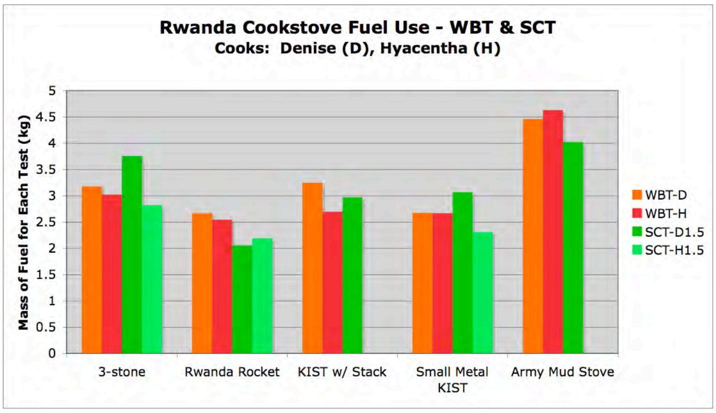
Figure 3. Shown inside the test hut a) traditional 3-stone fire, b) mud stove installed by civilian army, and c) air monitoring equipment

In this study, locally grown beans were used in the SCT and prepared by two female cooks per stove model, as they normally would with local practices and without any instructions about how to run the stove. The beans and firewood for all tests were purchased at the same time and used over a 2-3 week test period.

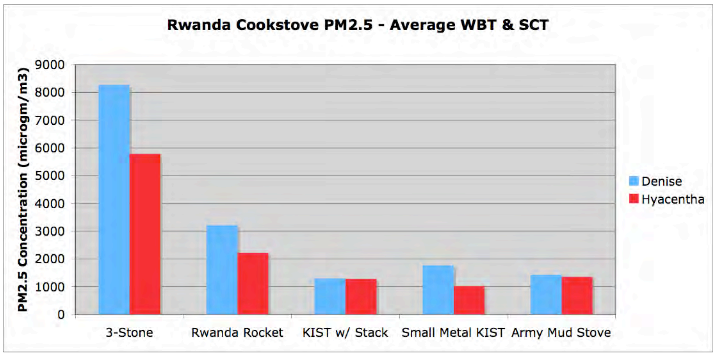
RESULTS

Data collected in the controlled environment of the test hut are shown graphically in Figure 4A, B and C, for fuel use and indoor concentrations of $PM_{2.5}$ and carbon monoxide, respectively, from five locally available stoves, All results are shown separately for the two cooks (Denise and Hyacentha) with WBT and SCT results averaged for the $PM_{2.5}$ and CO data.

(A)



(B)



(C)

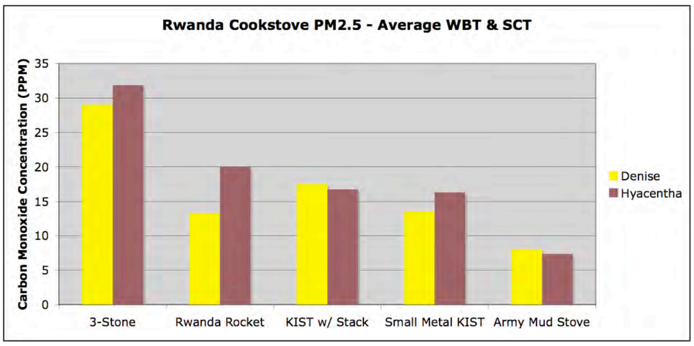
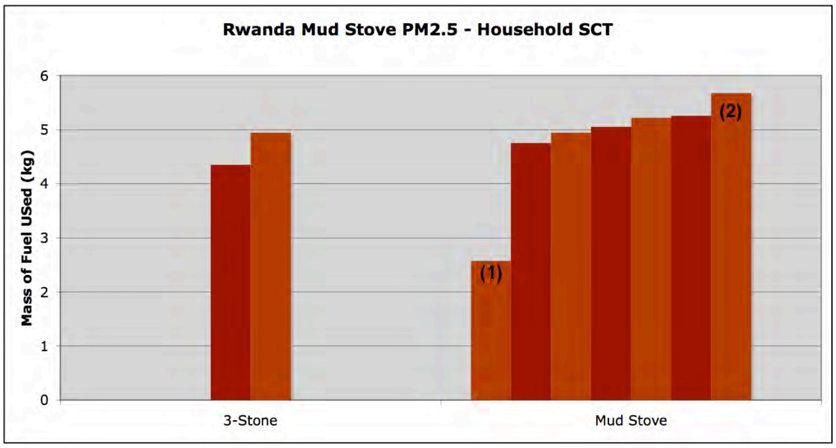


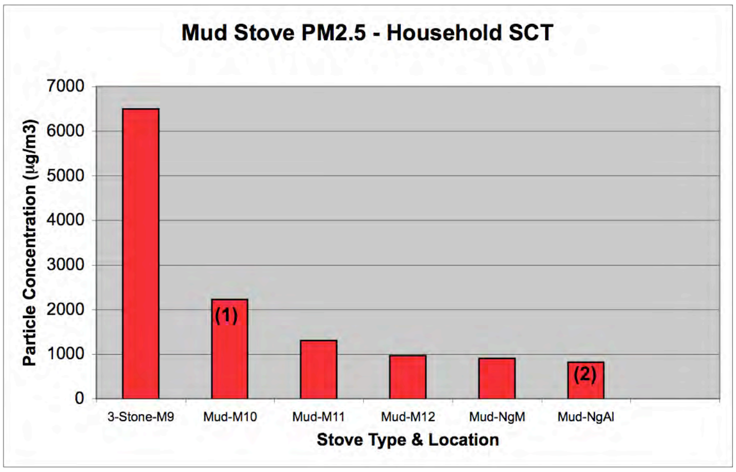
Figure 4. (A) water-boiling and standard-cooking test fuel consumption, and combined WBT and SCT average concentrations of (B) $PM_{2.5}$ and (C) carbon monoxide.

Figure 5 shows the results for the household testing of 3-stone fire and mud stoves. The relative fuel use results are similar to the test hut results with the mud stove consuming an average of ~ 13% more fuel. The relative indoor concentrations of $PM_{2.5}$ and CO are also similar with significantly lower concentrations for all of the mud stoves and ~80% average reduction.

(A)



(B)



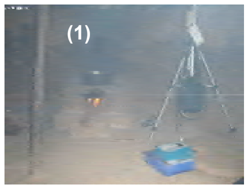


Figure 5. Fuel consumption and PM2.5 concentrations for 3-stone fire and mud stoves in households

DISCUSSION

Test Hut Results

Comparing average fuel consumption during the SCT, of the five test stoves, with the 3-stone fire results, the Rwanda rocket showed a the largest reduction at 35%, with the KIST small and stack stoves showing 18% and 10% reductions respectively, while the army mud stove showed a 22% increase. Some of the differences in fuel use are likely attributable to the stove construction with the metal stoves losing heat to the environment, the large mud stoves losing heat to significant thermal mass, and the rocket stove losing less heat due to the insulating material added to the clay.

Indoor concentrations of $PM_{2.5}$ and CO were lower than traditional 3-stone fire for all of the stoves tested. Average indoor concentration of $PM_{2.5}$ during the WBT and SCT, compared with the 3-stone fire results, show the largest reduction of 75% with the army mud stove and similar reductions of 45%, 51% and 44% for the Rwanda rocket, KIST small and stack stoves, respectively. An interesting observation is that the relative amounts of $PM_{2.5}$ to CO produced were not the same for the two cooks, with Denise typically having lower indoor concentrations of CO than Hyacentha, but the opposite trend for her $PM_{2.5}$ indoor concentrations. This difference may have been attributable to the observation that Hyacentha generally packed more sticks of firewood into the opening of the stove, thus blocking the airflow.

Household Testing Results

There are several interesting things to note from the data in figure 4A. The mud stove with highest fuel use (2) was the same mud stove from the test hut comparison, using 24% more fuel than the 3-stone fire, thus verifying the earlier results. The mud stove with the lowest fuel use (not included in the average) was in the household of a bachelor, the only male cook in the study. He had been involved with the construction of his stove and relayed through a translator that a considerable amount of sorghum chaff (a good insulator) had been added to the mud as the stove was built. It was observed that he also used different fire-tending practices, when compared with the women, of periodically removing ash from the combustion chamber (resulting in better airflow) and judiciously feeding in one stick of firewood at a time (heat from coals). When these differences, and the resulting 45% reduction in fuel use, were pointed out to the female cooks they wanted nothing to do with it and refused to try the new technique (at least while observers were present).

Overall, the household indoor air concentrations were lower than in the test hut, possibly because the household cooks were more familiar with the stoves in their homes and therefore able to make adjustments to minimize fuel use and IAP. For example, the cook using the stove in Figure 4B with the lowest $PM_{2.5}$ indoor concentration (1) was observed to have inserted a stone under the edge of her cooking pot to allow greater airflow between the pan and the top of the stove. The small photos (1) and (2) in Figure 4B correspond to the labeled $PM_{2.5}$ results and show the difference in visibility during the testing of two different stoves.

CONCLUSIONS

While relative fuel consumption is fairly consistent across users for different stove types, PM and CO emissions are not, indicating that stove type is a poor surrogate for differentiating IAP exposure except in extreme conditions (i.e. 3-stone versus improved).

Although indoor concentrations of $PM_{2.5}$ and CO for all of the 'improved' stoves tested were lower than traditional 3-stone fire, none of them were below the WHO recommended levels. There is still much debate about the value of implementing an intervention that does not meet "accepted" standards, though in this study the background outdoor air also did not meet the standard. In this author's opinion, an affordable, locally available option that reduces IAP from 30-80% is a good place to start until economic conditions are able to support 'cleaner' more expensive alternatives.

Other findings of this study that will be explored in follow-on studies are the impact of stove materials and construction on performance (mostly fuel use) and of fire tending techniques on both fuel consumption and IAP. Both of these issues can be addressed through training and education, and should be considered an integral part of any stove improvement and IAP reduction strategy.

ACKNOWLEDGEMENT

The author would like to acknowledge the support of the Rwanda Millennium Villages staff without which this study would not have been possible. Research was funded by a Cross-Cutting Initiatives grant from Columbia University awarded to the author as an Earth Institute Fellow.

REFERENCES

Aprovecho Center. 2009. Summarized version of Controlled Cooking Test. Available online at http://www.aprovecho.org/lab/pubs/testing.

Bailis, R., Ogle, D., MacCarty, N. and and Dean Still. 2007. Water Boiling Test (WBT). Household Energy and Health Programme, Shell Foundation. Available online at http://www.berkeleyair.com/publications

Bryden, Mark 2005. Design principles for wood burning cook stoves. Aprovecho Research Center, Shell Foundation, Partnership for Clean Indoor Air. Washington, DC : U.S. Environmental Protection Agency, Office of Air and Radiation. Available online at http://purl.access.gpo.gov/GPO/LPS118215>

Gupta S, Saksena S, Shankar VR, Joshi V. 1998. Emission factors and thermal efficiencies of cooking biofuels from five countries. *Biomass & Bioenergy* 14:547–59.

Jetter, J. 2009. Solid-fuel household cook stoves: Characterization of performance and emissions. *Biomass & Bioenergy* 33 (2): 294- 305

MacCarty, N. Still, D., Ogle, D., abd Thomas Drouin. 2008. Assessing Cook Stove Performance: Field and Lab Studies of Three Rocket Stoves Comparing the Open Fire and Traditional Stoves in Tamil Nadu, India on Measures of Time to Cook, Fuel Use, Total Emissions, and Indoor Air Pollution. Aprovecho Research Center.

Rehfuess E. 2006. Fuel for life: household energy and health. Geneva, Switzerland: World Health Organization.

Smith KR, Uma R, Kishore VVN, Lata K, Joshi V, Zhang J, et al. 2000. Greenhouse gases from small-scale combustion devices in developing countries, phase IIa, household stoves in India. Washington, D.C.: U.S. Environmental Protection Agency, Office of Research and Development. EPA/600/R-00/052.

World Health Organization. 2002. The World Health report 2002: reducing risks, promoting healthy life. Geneva, Switzerland: World Health Organization.

PM2.5 Emission Rates from Kerosene Lamps

Andrea Yarberry[1], Jason McCleland[1], Nathan Lohse[1], James Apple[2], Ryan Vicente[1], and Dustin Poppendieck[3]

[1]Humboldt State University, Arcata, CA
[2]Standford University, Palo Alto, CA
[3]University of Texas at Austin, Austin, TX

[*]*Corresponding email: poppendieck@gmail.com*

Keywords: LED, Lighting, Kerosene, Particulate Matter

1 Introduction

Every night up to 1.6 billion people worldwide face the challenge of conducting business, studying and performing other tasks after dark without the benefits of electricity (Mills 2005). A large majority of these people use kerosene lamps to provide limited illumination. The use of these lamps in limited ventilation indoor environments can result in exposure to high particulate matter concentrations that have potential to impair respiratory functions (Apple *et. al.* 2010).

Particle emission rates from various lamps were determined in order to calculate the PM2.5 concentrations kerosene lamp users are exposed to under a range of ventilation conditions.

2 Materials/Methods

Emission rates were measured for two types of kerosene lamps used for indoor lighting in Africa. The emission rates were determined by conducting fourteen experiments on simple wick lamps and four experiments on a small hurricane lamp in a 6.34 m^3 experimental chamber.

A fan maintained a constant air exchange rate in the chamber by pulling air through a three-inch diameter PVC outlet pipe. The chamber also had a three-inch diameter PVC ambient air inlet and an internal oscillating fan in the chamber ensured complete mixing. Air exchange rates were determined at the beginning and end of each experiment using carbon dioxide as a tracer and averaged 8.1/hr (1.1 standard deviation).

The lamps were burned from 4 to 17 hours depending on the emissions. Kerosene meeting ASTM 1-K grade specifications was used for all experiments. The burn rate for each lamp was varied by changing the wick height.

PM2.5 mass was measured gravimetrically. A BGI SCC 2.654 cyclone was connected to a Teflon filter holder. Particles were captured on a 0.2 μm quartz filter or a 2.0 μm PTFE filter. The filters were placed in a desiccator for 24 hours prior to initial and final massing.

A mass balance was used to determine the average PM2.5 emission rate during the sampling period. Ambient PM2.5 was assumed to be 5 $\mu g/m^3$ (averaged from local weather data). Preliminary calculations demonstrated particle deposition was negligible in the chamber due to high air exchange rates and minimal particle vertical velocities (diameters 2.5 microns and below).

In 2009 and 2010, air exchange measurements were made in rural houses in Kenya. Vinegar and baking soda were used to generate carbon dioxide. Measured PM2.5 emission rates and air exchange rates from Kenya homes were used in a mass balance model to determine PM2.5 concentrations in Kenyan homes that use kerosene lamps.

3 Results

The 18 emission rate experiments were conducted over a period of two months in Aracta, CA. Table 1 and 2 summarize the emission rate data.

Light output in a kerosene lamp can somewhat be controlled by the varying the kerosene burn rate. Burn rates varied for the simple wick lamp from 8-22 g/hr (average 13 g/hr) and from 15-20 g/hr (average 18 g/hr) for the small hurricane lamp. For both lamps the PM2.5 emission rates (mg/hr) increased with increasing burn rate (g/hr) (simple wick slope = 3.9, R^2 = 0.3; small hurricane slope = 2.4, R^2 = 0.9).

Table 1. Emission rates and emission factors for 14 experiments on simple wick lamps

	Emission Rate (mg/hr)	Emission Factor (g PM2.5/kg kero.)
Average	96	8.2
Standard Dev.	34	3.1
Min	50	3.7
Max	173	15.3

Table 2. Emission rates and emission factors for four experiments on one small hurricane lamp

	Emission Rate (mg/hr)	Emission Factor (g PM2.5/kg kero.)
Average	34	1.9
Standard Dev.	7	0.2
Min	28	1.7
Max	48	2.2

For the simple wick lamp the emission factor (g PM2.5/kg kero.) fell with increasing burn rate (slope = -0.3, R^2 = 0.3), while the hurricane showed minimal correlation (slope = 0.04, R^2 = 0.4). Emission factors can be used to put the contribution of kerosene lamps in context with the global black carbon emissions. The emission factors (Table 1 and 2) are comparable to emission factors found by Roden et al (2006) of 8.5±1.6 g PM/kg fuel for cook stoves.

Users of kerosene lamps typically live in houses that have high air exchange rates. Field studies associated with this research measured 22 air exchange rates in 14 homes in rural Kenya (Table 3). The average air exchange rate was 14.7/hr.

Table 3. Air exchange rates on 22 rooms in rural kenya

	Air Exchange Rate (/hr)
Average	14.7
Standard Dev.	9.8
Min	2.9
Max	37

A single simple wick lamp with an average emission rate (96 mg/hr) used in an average sized Kenyan room (28 m^3) with an average Kenyan air exchange rate (14.7/hr) would result in PM2.5 concentrations exceeding 260 µg/m^3 in less than one hour. If the same lamp was used in the home with the minimum air exchange rate the concentration would exceed 1,200 µg/m^3. Using multiple lamps in the same room would increase the PM2.5 concentrations by a direct multiple of the number of lamps. Although not directly applicable, the World Health Air Quality Guidelines (WHO 2006) provide a context to compare the particulate matter concentrations. The modeled PM2.5 concentrations in Kenyan homes exceed the WHO 24-hour average guideline (25 µg/m^3) by greater than an order of magnitude.

4 Conclusions

Simple wick lamps are the least expensive option for households to illuminate night time activities. Other lighting alternatives have higher capital and operational costs. The switch to more expensive lighting options may bring ancillary health benefits from the reduction in exposure to particulate matter. Switching lighting sources is likely to be cheaper than changing cook stove types.

Broader efforts are under way to introduce and study the health and economic effects of light-emitting diode (LED) based lamps in the developing world to reduce exposure to particulate matter from inefficient-burning light sources.

5 References

Apple, J., R. Vicente, A. Yarberry, N. Lohse, E. Mills, A. Jacobson, D. Poppendieck. 2010. Characterization of Particulate Matter Size Distributions and Indoor Concentrations from Kerosene and Diesel Lamps. *Indoor Air*, 20 (5), 399-411.

Mills, E. (2005). The specter of fuel-based lighting. *Science*, 308, 1263–1264.

Roden, C.A, T. Bond, S. Conway, A. B. N. Pitel. 2006. Emission Factors and Real-Time Optical Properties of Particles Emitted from Traditional Wood Burning Cookstoves. *Environ. Sci. Tech*. (40), 6750-7.

WHO. (2006). Air Quality Guidelines – Global Update 2005, WHO/SDE/PHE/OEH/06.02. World Health Organization (available at: http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf) last accessed 8 January 2010.

Solid-Fuel Cook Stoves: Fuel Efficiency and Emissions Testing

James Jetter

U.S. Environmental Protection Agency, Research Triangle Park, NC 27711

Corresponding email: jetter.jim@epa.gov

Keywords: developing countries, laboratory testing, air pollutant emissions, greenhouse gases, black carbon

1 Introduction

The World Health Organization estimates that approximately 1.6 million people prematurely die each year due to exposure to air pollutants from burning solid fuels for residential cooking and heating (WHO, 2010). Residential solid-fuel use accounts for approximately 25 percent of global black carbon emissions (Bond et al., 2004). The Partnership for Clean Indoor Air was formed in 2002 mainly to address important health problems associated with residential energy use in developing countries (PCIA, 2010). In 2010, the Global Alliance for Clean Cookstoves was launched "…to save lives, improve livelihoods, empower women, and combat climate change by creating a thriving global market for clean and efficient household cooking solutions." (GACC, 2010) U.S. EPA, in support of PCIA, published results of cook stove testing (Jetter and Kariher, 2009). More recently, EPA completed a second round of cook stove testing reported here.

2 Materials/Methods

Stoves tested are shown in Figure 1. Each solid-fuel stove was tested with low-moisture and high-moisture fuel. Fuels used with each stove are noted in the figure caption.

Fuel consumption, energy efficiency, fire power, and cooking power were measured. The Water Boiling Test (WBT, 2010) protocol was used as a framework, and we experimented with variables including the cooking pot, fuel burn-rate, and stove operation.

A schematic of the test system is shown in Figure 2.

Figure 1. Stoves Tested: A. Ceramic Jiko, charcoal; **B.** Metal Jiko, charcoal; **C.** Belonio, rice hull; **D.** Onil, wood; **E.** Protos, plant oil; **F.** Mayon Turbo, rice hull; **G.** Oorja, pellet; **H.** KCJ, charcoal; **I.** GERES, charcoal; **J.** StoveTec, charcoal; **K.** Jinqilin CKQ-80I, corn cobs; **L.** 3-Stone Fire, wood; **M.** Upesi, wood; **N.** Uhai, charcoal; **O.** Gyapa, charcoal; **P.** Envirofit G-3300, wood; **Q.** Sampada, wood; **R.** Berkeley Darfur, wood; **S.** StoveTec TLUD, pellet; **T.** Philips HD4012, wood; **U.** Philips HD4008, wood; **V.** StoveTec, wood.

Emissions of black carbon were measured with an aethalometer and a transmissometer. Emissions of elemental, organic, and total carbon were measured using thermal-optical analysis. Particulate matter (PM) was measured using the gravimetric method. PM was measured in real-time with an SMPS, APS, and nephelometer. Aerosol light absorption and scattering were measured *in situ* (not filter-based) with a photo-acoustic instrument. CO and CO_2 were measured in real-time with infrared analyzers, and CH_4 and

THCs were measured in real-time with FID analyzers.

3 Results

Preliminary results will be presented at Indoor Air 2011, and complete results will be published in a journal article. Emissions will be reported per task (defined in the WBT protocol). Emission factors will be reported based on mass of fuel, energy of fuel, and energy into the cooking pot. Emission rates will also be reported.

4 Conclusions

When data analysis and quality assurance are completed, conclusions will be discussed. We tested modern and traditional stoves, and we found a wide range of fuel efficiency and emissions characteristics. This independent laboratory study shows that certain stove designs can potentially reduce emissions of pollutants that harm health and affect climate change. Field studies will be needed in the future to verify actual reductions. EPA is planning the next round of stove testing and is coordinating with other partners doing field and lab testing. We will test additional stoves and fuels under various conditions similar to those in the field.

5 References

Bond TC, Streets DG, Yarber KF, Nelson SM, Woo J-H, and Klimont Z. 2004. A technology-based global inventory of black and organic carbon emissions from combustion. *J. Geophysical Research*, 109,

GACC. 2010. Global Alliance for Clean Cookstoves. http://cleancookstoves.org/

Jetter J. and Kariher P. 2009. Solid-Fuel Household Cook Stoves: Characterization of Performance and Emissions. *Biomass and Bioenergy*, 33, 294-305.

PCIA. 2010. Partnership for Clean Indoor Air. http://www.pciaonline.org/

WBT. 2010. Water Boiling Test, Version 4.1.2. http://www.pciaonline.org/files/WBT4.1.2_0.pdf

WHO. 2010. World Health Organization. http://www.who.int/mediacentre/factsheets/fs292/en/index.html

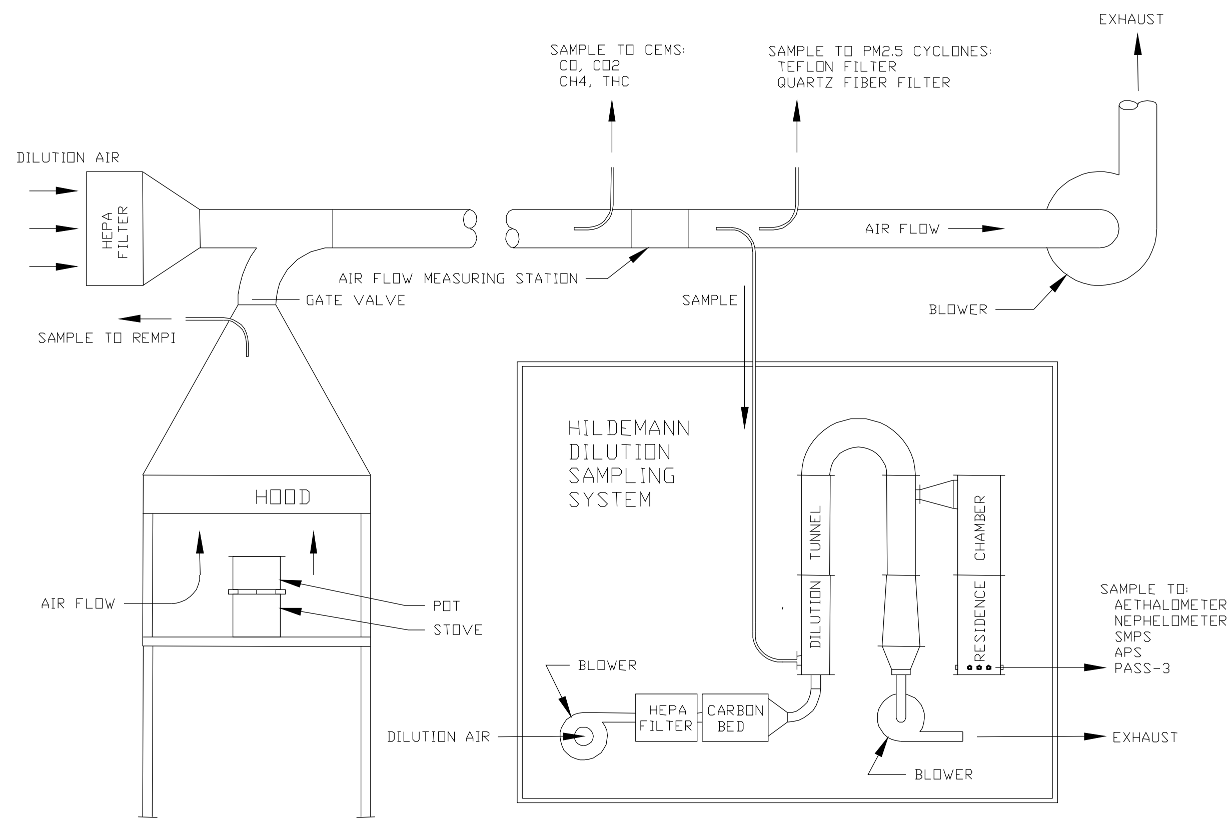


Figure 2. Cook Stove Test System

Emission rates of pollutants emitted from a traditional and an improved wood-burning cookstove

Thomas Kirchstetter[1,*], Chelsea Preble[1], Odelle Hadley[1] and Ashok Gadgil[1]

[1]Lawrence Berkeley National Laboratory, Berkeley

[*]*Corresponding email: twkirchstetter@lbl.gov*

Keywords: cookstoves, Berkeley-Darfur Stove, three-stone fire, particulate matter, carbon monoxide

1 Introduction

More than two billion people in developing regions continue to cook using traditional stoves that are inefficient and highly polluting. It is estimated that exposure to soot and toxic gases emitted from cookstoves, which is highest for women and children, causes 1.6 million deaths annually (WHO, 2005). Recognition of the enormous health impacts as well as the potential climate implications of these emissions has led to increased efforts to develop and disseminate improved cookstoves (USDOS, 2010).

At the Lawrence Berkeley National Laboratory (LBNL), the development and performance testing of improved cookstoves for the Darfur region of Sudan, Ethiopia, and Haiti is ongoing. In addition to the health impacts of traditional cooking practices, the people of these regions face increasing fuel shortages that exacerbate already challenging living environments.

In Darfur, women cook over open, unvented "three-stone fires" (TSF) and risk assault and rape when trekking for wood (Galitsky et al., 2006). In response, Berkeley scientists designed the Berkeley-Darfur Stove (BDS) as a more fuel-efficient replacement for the traditional TSF to reduce the frequency of dangerous trips for wood.

This study quantified the relative fuel efficiency and emissions of carbon monoxide (CO), fine particulate matter ($PM_{2.5}$), and black carbon (BC) of the TSF and the BDS.

2 Materials/Methods

This study was conducted at LBNL's cookstove testing facility. The concentrations of carbon dioxide (CO_2), CO, $PM_{2.5}$, and BC were measured at 1 Hz. CO_2 and CO concentrations were measured in a single instrument by nondispersive infrared absorption spectroscopy. $PM_{2.5}$ and BC concentrations were measured using a DustTrak and aethalometer, respectively. Time-integrated measurements of BC and $PM_{2.5}$ concentrations based on the analysis of filters periodically collected during cooking tests were used to develop calibration equations specific to woodsmoke for the DustTrak and aethalometer. Particulate matter light-absorption and light-scattering coefficients were measured at a wavelength of 532 nm using a photoacoustic absorption spectrometer and a nephelometer. The total dry mass of wood consumed during each test was also recorded.

The BDS and TSF were compared in this study using a water boiling test that was derived from field observations and simulated local cooking practices. In this test, a fire was ignited and maintained by periodic addition of wood to raise the temperature of 2.5 L of water in a metal Darfur pot to 100°C. A flaming fire was maintained to sustain boiling for 15 minutes, after which emissions testing was halted, the fire was extinguished, and the remaining wood was weighed.

Emission factors were computed as mass of pollutant emitted per unit mass of wood burned by relating total carbon emitted (mainly in the form of CO and CO_2) to the carbon content of wood:

$$EF_P\,(g/kg) = 10^3\left[\frac{\Delta[P]}{\Delta[CO]+\Delta[CO_2]}\right]w_c \qquad (1)$$

where EF_P is the emission factor (g emitted per kg of fuel burned) for pollutant P, Δ[P] is the increase in the concentration of pollutant P (μg m^{-3}) above background levels, Δ[CO] and

$\Delta[CO_2]$ are the increases in the carbon concentrations embodied in CO and CO_2 (μg of carbon m^{-3}) above background levels, and w_c is the fraction of carbon in wood. The carbon weight fraction of wood was assumed to be 0.5 based on literature values (Gaur and Reed, 1998). The total mass (g) of a pollutant emitted in each test was calculated as the product of the test-average fuel-based emission factor and the measured mass of wood burned during the test.

3 Results

Forty-one tests were completed (20 TSF, 21 BDS). On average, tests with the BDS were completed in 73% of the time and with 65% of the wood required for the TSF. Pollutant emissions are summarized in Table 1.

Table 1. Averaged pollutant emissions.

	TSF (n = 20)		BDS (n = 21)	
Pollutant	EF_P (g kg^{-1})	Total (g)	EF_P (g kg^{-1})	Total (g)
CO	57	30	42	17
$PM_{2.5}$	3.9	2.4	3.1	1.1
BC	1.3	0.57	1.5	0.44

The CO emission factor (g kg^{-1}) during tests with the BDS averaged 75% of that for the TSF. The distinction between the stoves is larger when factoring in the higher fuel efficiency of the BDS: the BDS emitted 61% of the CO (g) emitted by the TSF for the same cooking task.

The average $PM_{2.5}$ emission factor (g kg^{-1}) during tests with the BDS was 79% of that for the TSF. Including the higher fuel efficiency of the BDS, the BDS emitted 48% of the $PM_{2.5}$ emitted by the TSF. The BC emission factor (g kg^{-1}) and total emissions (g) during tests with the BDS averaged 115% and 77% of that for the TSF, respectively.

Emissions of $PM_{2.5}$ and BC varied more than CO from test-to-test with both stoves. Whereas the mass of CO emitted in the highest-emitting BDS test was less than the CO emitted in the lowest-emitting TSF test, there was some overlap in distribution of emissions from the TSF and BDS for both $PM_{2.5}$ and BC. The overlap was largest for BC, making the distinction between the two stoves least certain for this pollutant.

Based on measured optical properties, BDS $PM_{2.5}$ can be expected to absorb 20% more sunlight than TSF $PM_{2.5}$. However, replacing a TSF with a BDS should have a net climate-cooling effect since BDS $PM_{2.5}$ mass emissions are about half of those of the TSF.

4 Conclusions

The combined effects of increased fuel and combustion efficiencies reduced by about half CO and $PM_{2.5}$ emissions without significantly changing BC emissions of the BDS when compared to the TSF. The greater reduction in CO and $PM_{2.5}$ emissions than in fuel use (or CO_2 emissions) is due to improved combustion efficiency – a co-benefit of the stove designed primarily for increased thermal efficiency. Assuming that improved stoves designed for other regions also share the co-benefit of reduced pollutant emissions, their wide implementation of could abate the harmful effects of smoke exposure from traditional cookstoves in developing regions.

Fuel-efficient cookstoves are considered a tool for abating global warming and can be purchased for carbon credits because they emit less CO_2 than traditional cooking methods (e.g., Johnson et al., 2009). The results of the current study suggest that substantially lower $PM_{2.5}$ emissions of improved cookstoves may complement the climate warming abatement expected from lowered CO_2 emissions.

5 References

Galitsky C, Gadgil A, Jacobs M, and Lee Y. 2006. Fuel efficient stoves for Darfur camps of internally displaced persons: report of field trip to North and South Darfur, Nov. 16-Dec.17, 2005, Lawrence Berkeley National Laboratory, LBNL-59540.

Gaur S. and Reed T.B. 1998. Thermal data for natural and synthetic fuels. New York: Marcel Dekker.

Johnson M, et al. 2009. Quantification of carbon savings from improved biomass cookstove projects. *Environ. Sci. Technol.*, 43, 2456-2462.

USDOS. Sept 2010. Global alliance for clean cookstoves: the United States' commitment by the numbers, retrieved from http://www.state.gov/r/pa/prs/ps/2010/09/147494.htm.

WHO. Jun 2005. Fact sheet no. 292: indoor air pollution and health, retrieved from http://www.who.int/mediacentre/factsheets/fs292/en/index.html.

A Technology-Specific Methodology for Evaluating the GHG Mitigation Potential of Advanced Improved Cookstoves

Samuel Evans[1], and John Field[2,*]

[1]Department of Agricultural and Resource Economics, Colorado State University
[2]Department of Mechanical Engineering, Colorado State University

[*]*Corresponding email: John.L.Field@colostate.edu*

SUMMARY

Though improved cookstove development has been driven primarily by the health benefits associated with reduced emissions, there is growing recognition of corresponding greenhouse gas (GHG) benefits. The goal of this study is to investigate the trade-off between stove cost and GHG emissions savings by performing a cost-benefit analysis along an improved cookstove technology gradient, evaluating the stove's ability to lower net GHG emissions associated with household cooking. Preliminary results suggest a near-constant abatement cost across the considered IC designs, with a low cost relative to other GHG abatement technologies. Sensitivity analysis around site-specific factors such as the fraction of non-renewable biomass and biochar yield is also conducted and found to significantly impact the overall abatement cost of each design but not their ordinal ranking. This methodology has potential value for cookstove designers, disseminators, and policy-makers.

IMPLICATIONS

It is anticipated this study will be the first to rigorously integrate engineering emissions measurements across a range of IC designs into an improved cookstoves cost-benefit analysis methodology. Results will aid stakeholders in identifying the most cost-effective IC technologies in terms of climate mitigation potential and inform the use of carbon trading for stove financing.

KEYWORDS

products of incomplete combustion, global warming potential, cost-benefit analysis, gasifier cookstove, carbon abatement cost

INTRODUCTION

Improved cookstove (IC) technologies have the potential to revolutionize household cooking with biomass fuel in the developing world, significantly increasing fuel use efficiency and lowering emissions of the products of incomplete combustion (PIC). The health benefits stemming from the resulting reduction in indoor air pollution (IAP) are well-characterized, and ICs are now a widely-recognized health intervention tool capable of combating the significant fraction of global morbidity directly attributable to IAP exposure. More recently, it has been recognized that many of the PIC generated during biomass combustion for cooking are also potent climate forcing agents (Smith & Haigler 2008), particularly black carbon (BC) or soot, a high-global warming potential substance with short atmospheric residence time. As a result, wide-scale IC dissemination has been targeted as a promising strategy for near-term climate mitigation (Molina et al. 2009).

Recognition of ICs as a climate-mitigation strategy suggests their potential inclusion in international carbon offset markets, raising the attractive possibility of using carbon financing to fund widespread stove dissemination with associated health co-benefits. Several attempts to evaluate the climate mitigation potential of ICs currently exist in the literature (MacCarty et al. 2008, Smith & Haigler 2008), though these studies typically stop short of a full policy-relevant assessment. In particular, existing studies do not consider all emissions in the cooking lifecycle (biomass fuel procurement, total PIC emissions during combustion, and char byproduct management), or fail to incorporate data on stove cost for a full cost-benefit analysis (CBA).

The term 'improved cookstoves' covers an extremely wide span of technologies, ranging from simple masonry combustion chambers all the way to advanced portable designs operating on the principle of gasification and employing electric fans for precision air control (Field et al. in preparation). Though advanced ICs typically cost more than simpler designs, their ability to reduce PIC emissions is potentially much higher. The goal of this work is to investigate this trade-off by performing a cost-benefit analysis along an IC technology gradient, evaluating the stoves' ability to lower net greenhouse emissions associated with household cooking.

METHODS

Stove Carbon Abatement

The net GHG balance of biomass cooking is a function of the sustainability of the biomass feedstock harvest, emissions of high-GWP PIC, and the yield and fate of the carbon-rich charcoal byproduct. The sustainability of the fuelwood feedstock is a primary driver of cookstove GHG performance, as the non-renewable harvest and combustion of biomass releases large quantities of CO_2 into the atmosphere. Feedstock sourcing sustainability is described analytically in terms of the fraction of non-renewable biomass (fNRB). The fNRB is a highly site-specific metric with values ranging from 0% to near 100%; a value of 25% is assumed in accordance with one particular regional estimate for an area in central Mexico (Ghilardi et al. 2009). The effect of variations in fNRB from region to region is explored further in a sensitivity study below.

Even in cases of perfectly renewable biomass harvest, the fact that many PIC have GWP values greater than unity implies that imperfect combustion of that biomass carries a positive GHG burden. The yield and distribution of PIC varies greatly between combustion processes. In this study, data and GWP computation methodology are taken from McCarty et al 2008 for a three-stone fire, a prototype rocket-elbow type stove, a natural-draft (ND) gasifier stove (the Karve stove, Appropriate Rural Technology Institute, India), and a fan-powered gasifier stove (the Philips stove, Philips Electronics, Netherlands). This methodology includes a detailed treatment of particulate matter emissions, including both black carbon and organic matter fractions.

Cookstove designs based on gasification technology produce significant amounts of charcoal as a byproduct, the ultimate fate of which can strongly affect the overall GHG balance of the cooking process. This so-called biochar can be re-used as fuel, but potentially has greater value as a soil amendment, improving crop yields and sequestering carbon over long timescales. This analysis assumes a char yield of 0.15 g/g fuel with a carbon content of 80% by mass, explored further in the sensitivity analysis section. Char is also assumed to be applied to soils where 80% remains recalcitrant to degradation and permanently sequestered (Roberts et al. 2009).

The emission global warming potentials associated with boiling 1 liter of water in each stove are shown in Figure 1. The GHG balances are largely dominated by CO_2 emissions (which scale linearly with fNRB), carbon sequestration in biochar, and emissions of CO and black carbon (also known as elemental carbon particulate matter, abbreviated PM-EC). The greenhouse footprint varies widely across the range of technologies, with the gasification-based stoves in particular demonstrating a large improvement over the three-stone fire baseline case.

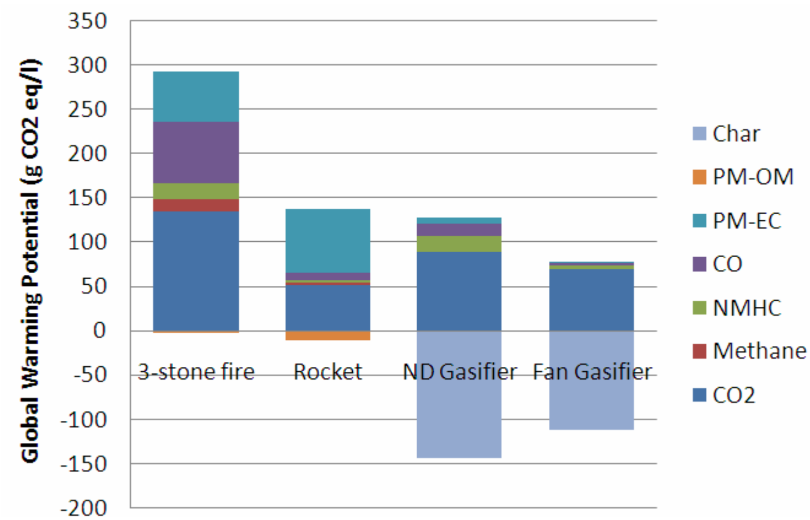


Figure 1. GWP breakdown by stove design

<u>Stove Cost</u>

Several methods are available for estimating the unit costs of improved cookstove designs. An industry or firm cost function can be specified and estimated econometrically using data on input prices. This method is most appropriate for established production processes with high volume production, which is often not the case for ICs. An alternative 'bottom-up' budgeting framework is another possible alternative for estimating design costs. This approach has been used in both the economics and engineering IC literature (Garcia-Frapolli et al, 2010; Bailis et al, 2009). A bottom-up budgeting framework establishes unit costs based on the direct costs of production, such as materials, labor, equipment, etc. Such an approach assumes a fixed-proportion relationship between inputs and outputs, with no responsiveness to input price changes in the production process. The appropriateness of this method depends on the projected path of development in the IC industry and whether production processes will change in response to relative changes in input prices.

While efforts to establish cost budgets for a variety of stove designs are ongoing, preliminary results were obtained using data on stove price, which can be used as an approximation of the marginal or average cost of production. Although prices are not necessarily indicative of the unit costs of production, it is assumed that they do reflect an ordinal approximation of unit production costs. Note that factors such as subsidies will tend to distort prices away from true unit costs. Table 1 shows the estimated prices for the three designs considered in this analysis. Because of the wide variability in price between individual designs within broad design categories, averages were taken across each category to generate a representative mean cost and filter out the effects of price distortions. Prices for individual gasifier designs were obtained from Field et al (in preparation), including six natural-draft designs and six fan designs. Likewise, price data for eight rocket-elbow stove designs were obtained from the HEDON stove database.

These estimates provide the foundation for the cost component of the greenhouse gas cost-benefit (C-B) ratio. This ratio is defined as the net present value of stove cost divided by the total CO_2 equivalent emissions savings, both measured over the lifetime of the stove. The CO_2eq savings of individual designs are measured against the baseline emissions of a three-stone fire. It is assumed that the improved stoves have a lifetime of seven years, and costs incurred with stove purchase are discounted at a rate of 7%. It is also assumed that the average household uses the cookstove to boil 10 litres of water per day (McCartey et al, 2008). While the magnitude of the final results is sensitive to these assumptions, the assumptions will not affect the ordinal ranking of the greenhouse gas saving between ICs.

RESULTS

Preliminary results suggest that there is significant variation in both cost and performance across the improved cookstove technology gradient. Figure 2 shows how carbon abatement potential varies with stove cost for the three IC designs considered in this analysis. Though the gasifier stoves are approximately twice as expensive as the rocket-elbow design, the avoided emissions are roughly twice as large, resulting in a near-constant abatement cost of ~$5/ton CO_2eq across the range of technologies (Table 1). These results are consistent with published IC abatement costs of $4-$5/ton CO_2e for the Patsari cookstove design (Johnson et al, 2009) and $4.23-$5.64/ton CO_2e for a Chinese gasifier stove design (Smith and Haigler, 2008).

Table 1: Stove Performance and Price

Design	Average Price	Avoided Emissions (ton CO_2eq)	C-B Ratio ($/ton CO_2eq)
Rocket-Elbow	$20.25 (10.44)	4.19	4.84
ND Gasifier	$39.50 (18.32)	7.84	5.04
Fan Gasifier	$44.83 (27.87)	8.31	5.40

* Standard deviations in parenthesis

As previously discussed, there are site-specific factors that affect total GHG abatement. Figure 3 shows the results of varying both the assumed fNRB and biochar yield for the natural-draft gasifier. Similar results are observed in the fan gasifier. Intuitively, abatement costs decrease as carbon sequestration in biochar increases. As the fraction of non-renewable biomass increases, however, abatement costs decrease. This is due to the fact that as fNRB increases so do CO_2 emissions from the three-stone fire baseline, providing more potential GHG abatement for the more efficient improved cookstoves.

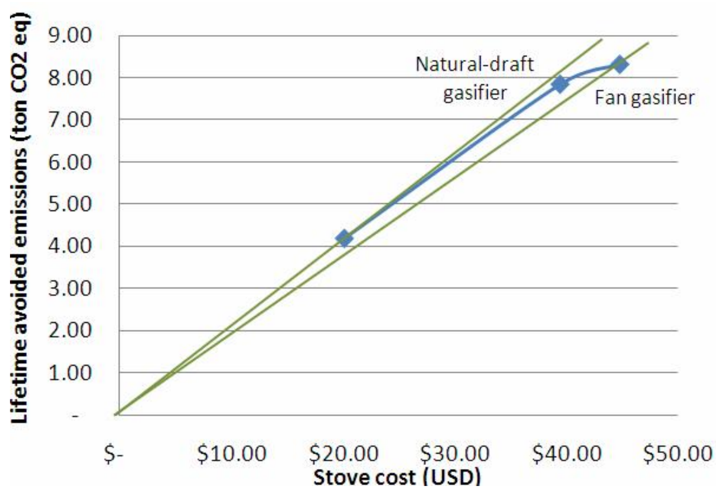


Figure 2. IC carbon abatement cost

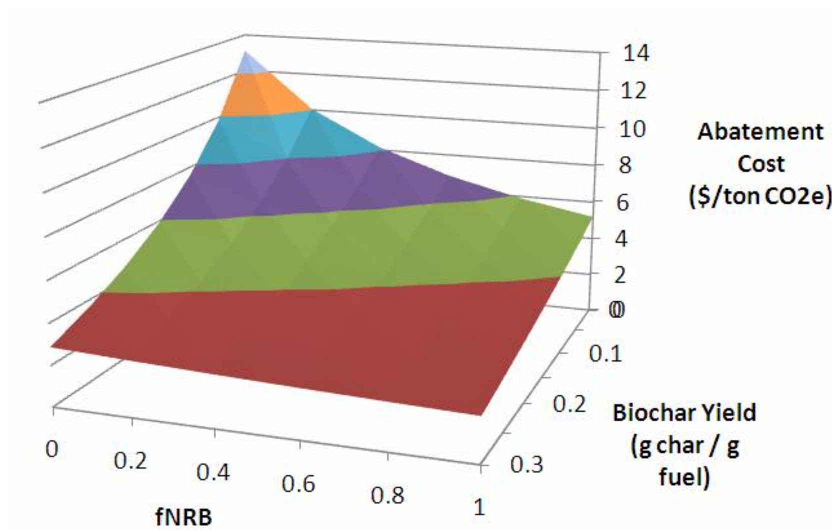


Figure 3. Sensitivity to fraction of non-renewable biomass (fNRB) and char yield

DISCUSSION/CONCLUSIONS

These results suggest that ICs are a low-cost option for greenhouse gas abatement. All of the stove designs considered in this analysis have abatement costs considerably lower than most electric power sector options (wind, solar, coal with carbon capture, etc.), forestry sector abatement options, and biomass-based abatement options (biodiesel or biomass co-firing) as evaluated in a study by McKinsey and Co. (Enkvist et al, 2007). This cost-effectiveness is likely maintained across the stove technology gradient, even for more complex and expensive gasification-based stove designs. Finally, the estimated IC abatement costs are significantly lower than the mid-range estimate of the social cost of carbon ($21/ton$CO_2$e) estimated by the U.S. government.

It is important to note that the results of this study are not appropriate to be used as benchmark figures for a carbon financing application. As Johnson et al. 2009 rightly suggest, quantification of emissions savings for inclusion in carbon finance schemes is best performed as a project-specific exercise. Accurate emissions abatement estimates must incorporate factors suggest as adoption rates, fuel type and use inventories, user specific emissions estimates, and other critical factors not used in the analysis conducted in this paper. However, this type of simplified analysis based on laboratory performance nonetheless yields useful insights to IC designers, disseminators, and policy-makers interested in realizing the climate-mitigation potential of IC technologies.

REFERENCES

Bailis R, Cowan A, Berrueta V, Masera O. 2009. Arresting the Killer in the Kitchen: The Promises and Pitfalls of Commercializing Improved Cookstoves. *World Development*, 37(10), 1694-1705.

Enkvist P-A, Naucler T, Rosander, J. 2007. A Cost Curve for Greenhouse Gas Reduction. *The McKinsey Quarterly*, 1, 35-45.

Field J, DeFoort M, L'Orange C, Willson B. A review of biomass gasifier technologies for household cooking applications. In preparation, expected submission April 2011.

Garcia-Frapolli E, Schilmann A, Berrueta, V, Rioja-Rodriguez H, Edwards R, Johnson M, Guevara-Sangines A, Armendariz C, Masera O. 2010. Beyond fuelwood savings: Valuing the economic benefits of introducing improved biomass cookstoves in the Purepecha region of Mexico. *Ecological Economics*, 69(12), 2598-2605.

Ghilardi A, Guerrero G, Masera. 2009. A GIS-based Methodology for High Lighting Fuelwood Supply-Demand Balances at the Local Level: A Case Study for Central Mexico. *Biomass and Bioenergy*, 33(6-7), 957-972.

HEDON Household Energy Network, Stove Database, accessed 3/1/ 2011 Available at http://www.hedon.info/Stoves+Database&bl=y&tr_offset=40.

Johnson M, Edwards R, Ghilardi A, Berrueta V, Gillen D, Frenk C, Masera O. 2009 Quantification of Carbon Savings from Improved Biomass Cookstove Projects. *Environmental Science and Technology*, 43(7), 2456-2462

MacCarty N, Ogle D, Still D, Bond T, and Roden C. 2008. A Laboratory comparison of the global warming impact of five major types of biomass cooking stoves. *Energy for Sustainable Development*, 12(2), 5-14.

Molina M, Zaelke D, Sarma KM, Andersen SO, Ramanathan V, Kaniaru D. 2009. Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO_2 emissions. *Proceedings of the National Academy of Sciences of the United States of America*, 106(49), 20616-21.

Roberts K, Gloy B, Joseph S, Scott N, Lehmann J. 2010. Life cycle assessment of biochar systems: estimating the energetic, economic, and climate change potential. *Environmental Science and Technology*, 44, 827-833.

Smith K.R. and Haigler, E. 2008. Co-benefits of Climate Mitigation and Health Protection in Energy Systems: Scoping Methods. *Annual Review of Public Health*, 29, 11-25.

Influence of Vaporization Losses on Cook Stove Testing

Christian L'Orange[1,*], Morgan DeFoort[1] and Bryan Willson[1]

[1]Colorado State University, 430 N College Ave Fort Collins, CO 80524

[*]*Corresponding email: clorange@engr.colostate.edu*

SUMMARY
Nearly half the world's population uses simple biomass stoves for domestic cooking (Bruce, 2000). Many of the stoves in use release immense amounts of toxic emissions into the homes in which they are used causing significant health and environmental impacts; the emissions have been attributed to causing 2.6% of global illness (Rumchev, 2007). While there are many improved stoves entering the market place in an effort to reduce indoor air pollution and minimize the impacts of cooking on the global environment, there is still not a robust test protocol available to characterize stove performance. Using existing protocols (Bailis, 2007) (Food and Agriculture Organization of the United Nations, 1993) (Bureau of Indian Standards, 1991) as a starting point, this research seeks to determine the impact of water vaporization on test repeatability.

IMPLICATIONS
This study seeks to explore the potential advantages of moving biomass cook stove testing from "boiling" tests to tests based on consistent heat transfer. The results present the reduction in test variability which can be expected when care is taken to minimize water vaporization when testing biomass cook stoves.

KEYWORDS
Biomass, Combustion, Cook Stoves, Test Protocol

INTRODUCTION
Despite efforts over multiple decades to introduce clean biomass cook stoves to the developing world, success has been limited. One of the challenges to large scale design and dissemination of cook stoves has been a lack of a testing protocol which provides consistent, reliable, and repeatable results. While many factors need to be considered when developing a standardized testing methodology, many of the protocols used have the same fundamental problem; the test performed is variable by its very nature.

The Water Boil Test (WBT) (Bailis, 2007) is arguably the most commonly used cook stove test protocol around the world. The importance and impacts of the WBT cannot be overstated, however there are challenges associated with the variable boiling temperature of water at different atmospheric condtions. The WBT states that a pot should be filled with water at 25C and then heated until boiling has been achieved; the challenge is that the temperature at which boiling occurs is not a fixed value. Water phase change temperatures are dependent on altitude, ambient barometric pressure, among other factors, will change with location and conditions. For example, at an altitude of 1500m water boils at 94.5-95.5C, depending on the barometric pressure, while water will boil closer to 100C at sea level.

The authors propose that a more appropriate method is changing the test from the arbitrary "boiling" temperature and instead require that a fixed amount of energy is transferred during all tests. By setting a testing standard in which a set amount of energy is transferred into the water the complications which arise from different boiling temperatures is removed.

Relying on "boiling temperature" leads to several complications, one of which is when to declare that a test has finished. The WBT relies on the tester determining the local boiling temperature on that day. An inaccuracy of even a few degrees can lead to significant variations in test results. When supplied with a constant heat flux, the heating rate of a pot of water can be approximated as linear until vaporization begins to occur. As the amount of energy leaving the system through vaporization increases, heating trends begin to deviate from linear. Variations in what is decided for "boiling" temperature can lead to significant test uncertainty. As illustrated in Figure 1, assuming the wrong temperature by as little as 1 Kelvin, for phase change may result in significantly different test durations when using "boiling" as the final temperature, Δt_2. As a result different total emissions and fuel consumption are observed. Using a fixed temperature, sufficiently spaced from the phase change point, minimizes the effect of inconsistent boiling points, Δt_1.

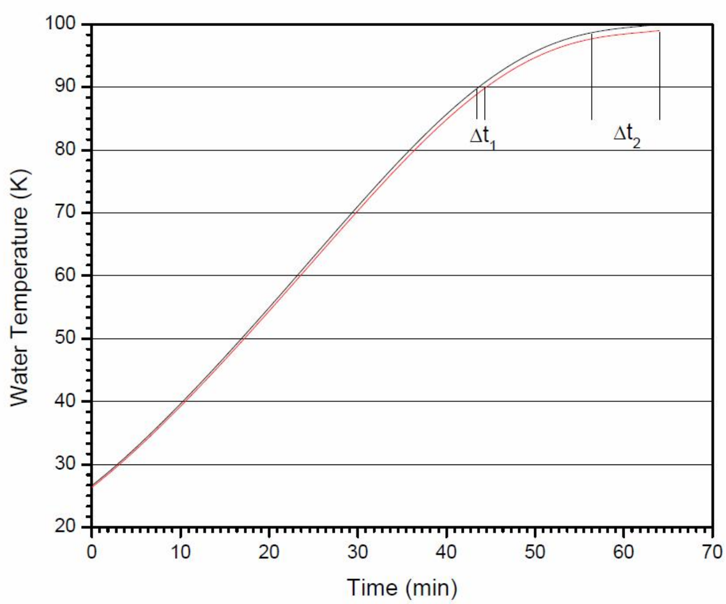


Figure 1: Non-linear heat transfer resulting from water vaporization.

Two test series were conducted to determine if test variability could be reduced by minimizing water vaporization. The first tests looked at the potential benefits of using a layer of insulation on top of the water. The second series explored the impacts of shifting the testing range from 25C-boiling to 15C-90C. This testing range was used as it would result in approximately the same amount of energy as a test run from 25C-95C, the typical boiling temperature for water in Fort Collins, CO.

METHODS

All tests were conducted in the main emissions fume hood of the Engines and Energy Conversion Laboratory at Colorado State University. The hood has been designed to capture all emissions emitted from a stove. The hood is sized to be large enough to not influence a stoves operation, and is equipped with HEPA filters to remove any background particles.

Carbon monoxide (CO) and wood use were used as the metrics of performance. The carbon monoxide reported represents the total mass emitted during each phase of the test. Fuel use was reported on a dry basis. Background emissions levels were measured and corrected for after each test. CO was measured using a Fourier Transform Infrared Spectrometer (FT-IR). Three iterations of each test were conducted with the average of the tests reported. The uncertainty for all tests is reported as the standard deviation. The statistical significance of each test was determined by calculating p-values following the unpaired, student t-test method. Based on convention, a p-value ≤ 0.05 was set as the critical value to determine a statistically significant difference.

To determine if the repeatability of tests could be improved by limiting water phase change an experiment was conducted in which vaporization was suppressed. A pot filled with 5kg of 15C±1 water was placed on an electric burner and allowed to heat to 90C. The same pot was then refilled and heated again with a piece of 2 inch thick rigid foam insulation floating on the surface. The time to heat and the mass of water vaporized was measured for each arrangement. Three test replicates were conducted.

To determine the effects of shifting the test temperature range, three tests were conducted following the traditional WBT and three tests were conducted where both operating temperature was reduced and a layer of foam insulation was used. The insulation was only used for the cold start and hot start phases of the tests. Fuel conditions were kept constant for all experiments. All tests were conducted using an Envirofit International (Fort Collins, CO USA) model B1100 stove, Figure 2. Fuel with a moisture content of 7%, on a dry basis, and dimensions of 1.5cm x 1.5cm x 30cm was used for each test. These values were set based on the moisture content which is typically achieved in Colorado from ambient conditions and geometry similar to those suggested in the WBT. Moisture content was measured using a Delmhorst J-4 handheld moisture meter for each test. The accuracy of the moisture meter was verified with the oven-dry moisture measurement method prior to testing.

Figure 2: Envirofit International B1100 biomass cook stove

RESULTS

Suppressing vaporization through the use of an insulative layer was found to have a large impact on test variability. Without insulation the coefficient of variation between tests was nearly 2% of the total energy. When insulation was used the coefficient of variation dropped approximately 4 fold to just over 0.5%.

Shifting the test away from vaporization temperatures reduced the variability seen for each test metric across all tests phases. Reducing water vaporization was found to decrease test variability without having a statistically significant impact on the average value of the tests, with the exception of simmer fuel use, Table 1. This is a very encouraging result as the goal of the modified test protocol was to improve test accuracy, not to change the performance of the stove.

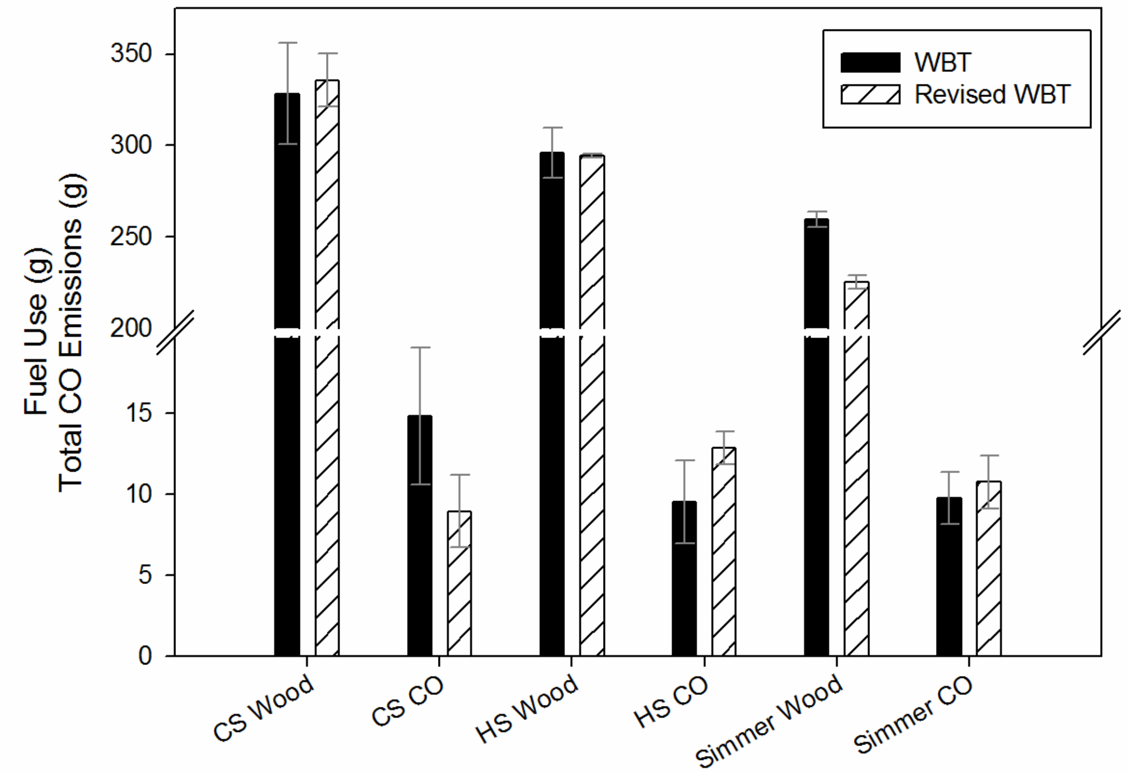


Figure 3: Effect of revised protocol on wood use and carbon monoxide emissions. The revised protocol included modifying the testing temperature range and the use of a layer of foam insulation to minimize water vaporization. Errors bars represent one standard deviation.

Table 1: Statistical significance of changing testing temperature range. Results are considered statistically significant with a p-value≤0.05

Test	p-value
Cold Start Wood Use	0.70
Cold Start Carbon Monoxide	0.10
Hot Start Wood Use	0.85
Hot Start Carbon Monoxide	0.10
Simmer Wood Use	<0.01
Simmer Carbon Monoxide	0.49

DISCUSSION

It was found that both methods of minimizing vaporization, reducing water temperature and introducing a layer of insulation, reduced test uncertainty. Reducing the temperature range of the test is particularly appealing. It is a simple, easy to implement solution which did not have a significant impact on many of the test metrics. While there is a level of arbitrariness to the Water Boil Test's choice of boiling 5kg of water instead of some other task, the goal of the modifications was not to fundamentally change the protocol, but instead to address an aspect of the test which leads to uncertainty. When comparing the amount of variation seen between test replicates, Figure 4, large improvements can be seen when using the modified WBT procedure for both the cold start and hot start phases. The improvements are not as large for the simmer phase but this is as would be expected, as heat loss from vaporization is a necessary component of the simmer phase in order to hold temperatures constant.

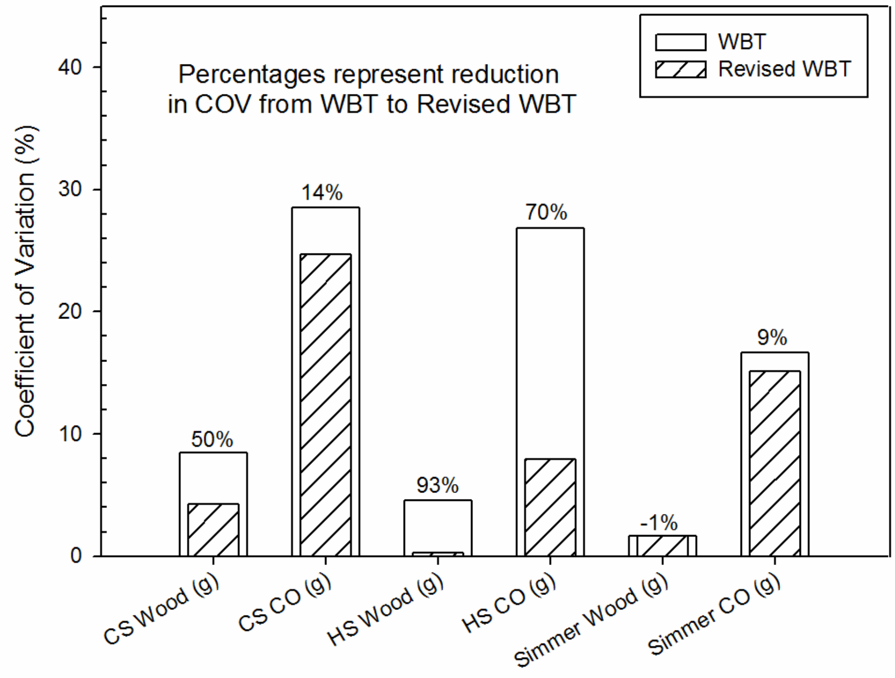


Figure 4: Coefficients of variation for WBT and modified WBT

CONCLUSIONS

Biomass combustion is a complex process which is inherently variable in its nature, leading to complications when testing, but some elements can be controlled. By adjusting the water temperature testing range it becomes possible to reduce the influence of local boiling temperature and variable vaporization. With the addition of a simple insulative layer on the surface of the water test variability can be further reduced by limiting the impacts of vaporization.

There are many aspects of test which need to be controlled or accounted for to achieve repeatable results. For a biomass cook stove protocol these factors would include things such as fuel geometry and moisture content. While care needs to be taken with these factors they are elements of a test which can be controlled. The same advantage is not possible with boiling temperature. There is no practical way to change or correct for the variations in vaporization temperature (and the resulting variations in fuel use, time to boil, emissions, etc) which occur in different regions of the world. These concerns are nearly completely removed when vaporization is eliminated.

ACKNOWLEDGEMENT

This research was made possible through funding provided by Envirofit International and support of Envirofit International, Colorado State University, and the Engines and Energy Conversion Laboratory.

REFERENCES

Bailis, R. (2007). *The Water Boiling Test (WBT)*. Retrieved January 2009, from School of Public Health - University of California, Berkeley: http://ehs.sph.berkeley.edu/hem/hem/protocols/WBT_Version_3.0_Jan2007a.pdf

Bruce, N. (2000). Indoor Air Pollution in Developing Countries: a major environmental and public health challenge. *Bulletin of the World Health Organization* , 1078-1092.

Bureau of Indian Standards. (1991). *Solid Bio-Mass Chulha - Specification.* BIS Procedure.

Food and Agriculture Organization of the United Nations. (1993). Chinese Fuel Saving Stoves: A Compendium.

Stove Use Monitors (SUMs) as a Method to Measure Fuel Use and Savings in Bangalore, India

Anoop Muniyappa[1,2,*], Simone Brant[2] and David Pennise[2]

[1]University of California, Berkeley, CA 94720, USA
[2]Berkeley Air Monitoring Group, 2124 Kittredge Street #57, Berkeley, CA 94704, USA
[*]*Corresponding email: anoop@berkeley.edu*

Keywords: indoor air pollution, improved cookstoves, kitchen performance test, fuel wood

1 Introduction

Over three billion people across the world use solid fuels to fulfill their cooking and heating needs (WHO, 2005). The traditional stoves used by much of the developing world to burn these fuels cause extremely high levels of indoor air pollution as a result of inefficient combustion of biomass. According to the World Health Organization, these lethal fumes are responsible for the deaths of more than 1.6 million people per year (2005). A significant number of projects already exist to distribute and monitor the use of improved cook stoves around the world. These simple and affordable appliances have great potential to both improve the health of the individual and reduce the impact of carbon emissions on the global climate. While current research has the ability to adequately monitor stove use, carbon monoxide, and particulate matter, there is no convenient way to monitor the actual biomass consumption of each stove. Present studies rely on manual weighing of solid fuels before and after cooking in order to determine the usage in a particular stove, which is a highly time-intensive and inefficient process.

Recently, low-cost temperature loggers have gained attention as monitoring devices for household energy and indoor air pollution studies. These devices are relatively cheap, durable, and compact. The loggers, called Stove Use Monitors (SUMs), offer accurate measurements of temperature changes which can be tracked and correlated with times and lengths of cooking activities. Using these devices currently has two major advantages: first, the SUMs eliminate the need to ask cooks to recall how often and for how long they engaged in cooking activities by providing an objective temperature trace. Second, they reduce the need for field researchers to manually assess stove use over long periods of time because the SUMs' batteries can last many months (Mercado et al., 2008). There is a third potential function of the SUMs that has yet to be thoroughly developed by the indoor air pollution research community. If a correlation can be established between the SUMs temperature readings and the amount of solid biomass consumed, these devices have the potential to save thousands of dollars through reducing the resources and time invested in collecting fuel use data by recording this information automatically over extended periods of time. Especially in light of current goals to distribute 100 million improved stoves by 2020 (GACC, 2011), there is a great need to further test and expand the applications of these devices. A project was recently conducted in India to assess the implementation and efficacy of the SUMs in comparing the fuel efficiency of traditional and improved cookstoves. The results of the study are presented in this paper.

2 Methods

In order to test the relative efficiency of traditional and improved cookstoves using the SUMs, a paired sample study was conducted with two phases. The study site in Doddaballapur, India was determined based on the village's known dependence on fuel wood for its heating and cooking needs. At the site, twenty households were selected based on the following criteria: participants cooked primarily with wood, they had not previously purchased an improved stove (to be distributed as part of the study), there was no metal chimney, and all cooking was completed indoors. The project followed the basic outline for Kitchen Performance Tests (KPTs) used in the Household Energy and Health Programme for the Shell Foundation (Bailis, 2007) with the addition of using the SUMs for temperature readings. This consisted of interviewing participants about daily fuel use, affixing sums to each of the household's stoves, weighing household fuel daily over a 4-day period (which provided data for 3 24-hour periods), and then downloading the temperature trace from the SUMs. In the first phase, household fuel use, surveys, and SUMs data were only collected from traditional stove use. After this 4-day cycle, each of the twenty households received an Envirofit G-3300 improved cookstove. Once houses were given four days to adjust to the new stove, the second phase of the project was conducted, during which households were asked to only use the Envirofit stove. All other study parameters were held constant in order to provide comparable fuel consumption data for the 'before' (only using the traditional stove) and 'after' (only using the improved cookstove) phases.

Table 1. Average fuel consumption data in Doddaballapur, India for houses using traditional stoves compared with fuel consumption after adopting the improved Envirofit G-3300 cookstove (data is for a 72-hour period unless otherwise stated)

Phase	Before (Traditional)	After (Improved)	p-value*
Average fuel use for 72 hours (kg)	16.93 (6.58)	11.71 (4.41)	0.0015
Average fuel use for 24 hours (kg)	5.64 (2.19)	3.90 (1.47)	0.0015
Average number of meals	6.85 (1.18)	6.60 (1.31)	0.6071
Average number of people per meal	5.30 (2.18)	5.50 (2.59)	0.3173
Average number of person-meals	36.95 (17.97)	38.45 (24.94)	0.8615
Average fuel per person-meal (kg)	0.5019 (0.15)	0.3792 (0.20)	0.0034

Standard deviations are shown in parenthesis
*p-values were determined using a Wilcoxon signed-rank test (paired)

3 Results

Analysis of the fuel use data in each household during the 'before' and 'after' phases showed statistically significant ($p=0.0015$) decreases in consumption during the 'after' period. The number of meals cooked and the number of people cooked for in each household were combined to establish the person-meal as an objective unit to which fuel consumption could be compared across households. While the amount of fuel consumed was determined from measurements taken during the study, the cooking events could be assessed based on evaluation of either the written survey or the SUMs data. Comparing the two sets of data revealed that results from the SUMs temperature trace were significantly more accurate than the responses gathered from the surveys. In the questionnaires, people were asked to approximate when and how long they cooked, and many estimations deviated from the SUMs time vs. temperature log by up to two hours. Accounting for temperature fluctuations due to weather and other occurrences, no event other than cooking could have caused the temperature changes recorded by the SUMs. Therefore, the SUMs temperature traces were used as the preferred method to determine number and duration of cooking events. As a result, average fuel use per person-meal could be assessed and used in the determination of fuel savings.
Further evaluation of this data showed that the average fuel savings totaled 1.74 kg per day or 0.13kg per person-meal, which represent a 27% decrease in fuel consumption when using the improved stove.

4 Conclusions

The results of the project show that the use of the SUMs provided much greater accuracy than manual assessments of cooking time and duration. In addition, eliminating these manual procedures could make large scale stove distribution and monitoring possible by decreasing the time and manpower required to conduct such studies. The next step in this effort ought to be the determination of a correlation between fuel consumption and the SUMs' temperature trace in order to increase the amount of data that can be extrapolated from these devices. Given the increased attention and funding being received by the SUMs, the benefits of this research will be highly significant as the technology is further developed and more widely implemented.

5 References

WHO. "Indoor Air Pollution and Health." *WHO Programmes and Projects*. June 2005. Web. 17 Feb. 2011. <http://www.who.int/mediacentre/factsheets/fs292/en/>.

GACC. "Goals." *Global Alliance for Clean Cookstoves*. United Nations Foundation, 2011. Web. 21 Jan. 2011. <http://cleancookstoves.org/the-alliance/goals/>.

Ruiz-Mercado, Ilse, Lam, N., et. al. 2008. Low-cost temperature loggers as stove use monitors (SUMs). Boiling Point 55:16-18.

Bailis, Rob. *Kitchen Performance Test (KPT)*. Tech. 3.0 ed. 2007. Print.