TESTING THE EFFECTIVENESS OF TWO IMPROVED COOKSTOVE INTERVENTIONS IN THE SANTIAGO DE CHUCO PROVINCE OF PERU

by

CHRISTOPHER LINTON FITZGERALD

(Under the direction of Luke Peter Naeher)

ABSTRACT

Three Andean communities within the Santiago de Chuco province of Peru received two different models of improved cookstoves; one from the Peruvian government and one from a local industry. The impact of these stoves in reducing personal exposures and kitchen concentrations of particulate matter ($PM_{2.5}$) and carbon monoxide (CO) was evaluated separately in 64 homes (32 in each community) with the use of air monitoring equipment. In one community, 48-hr personal exposure and kitchen concentrations of $PM_{2.5}$ were reduced by 41.3% and 59.2%, respectively, and 48-hr personal and kitchen CO levels reduced by 69.6% and 77.7%. Corresponding levels in the second community were reduced by 53.8, 70.5, 25.9 and 65.6%. Both stoves were effective at improving indoor air quality in these communities.

INDEX WORDS: Indoor Air, Developing World, Improved Cookstove, Personal Exposure, CO, $PM_{2.5}$

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DEDICATION

I would like to dedicate this work to my wife, Jessica B. Fitzgerald

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CHAPTER 1

INTRODUCTION

Chapter 1 outlines the information in each chapter. Chapter 2 contains the literature review of the topics contained in the thesis. Chapter 3 consists of an article to be submitted for publication to *Environment International*. The study investigates two improved cookstove intervention programs in the Santiago de Chuco Province of Peru using pre- and post-intervention air quality monitoring of kitchen concentrations and personal exposure to $PM_{2.5}$ and CO. It focuses on two specific stove models which had yet to be properly or adequately tested for effectiveness, and it took place in three separate communities that were receiving first-time stove interventions. Chapter 4 contains a discussion and conclusions of the findings of the study.

CHAPTER 2

RELEVANT LITERATURE REVIEW OF RESEARCH TOPICS

Indoor Air Pollution

More than half the world's population – 3.2 billion people – still relies on coal and biomass fuels such as wood, dung and crop residues to meet their basic energy needs (Rehfuess and others 2006b). 90% of people residing in rural areas of less-developed countries cook with such solid fuels, often using open fires or poorly constructed stoves in unventilated rooms, which lead to high human exposures to the products of incomplete combustion (Bruce and Perez-Padilla 2000). According to the World Health Organization (WHO), indoor air pollution (IAP) from solid fuel use is among the world's top ten causes of mortality and morbidity (Rehfuess and others 2006a), leading to approximately 2.5 million deaths each year in developing countries (Bruce 2002). Pollutants from solid fuel combustion are known, with various degrees of certainty, to cause acute respiratory infections (ARIs), chronic obstructive pulmonary disease (COPD), asthma, nasopharyngeal and laryngeal cancers, tuberculosis, and diseases of the eye (Ezzati 2005). Such pollutants have also been shown to double the risk of pneumonia, which, when coupled with ARIs, represent the combined leading cause of death in children under five years of age (Emery 2007).

Exposure to woodsmoke not only leads to multiple health complications, but it has also been shown to exacerbate existing conditions, such as pneumonia, acute lower respiratory infections (ALRI) and asthma in children and COPD in women (Hruba and others 2001; Schei and others 2004; Smith 2000; Zanobetti 2000). In poorer countries, where this issue is most prevalent, women and children bear a vastly disproportionate burden of such diseases, as they are more likely to spend most of their time at home (Smith 2006a). Also, children are more susceptible to the negative effects of IAP during their developmental stages, and they breathe a greater volume of air than adults in proportion to their body weight (Bearer 1995). As a result, 56% of all indoor air pollution-attributable deaths occur in children under five years of age (Rehfuess and others 2006b). Multiple studies have shown that maternal exposure to biomass smoke may also be responsible for reduced birth weight (Boy and others 2002; Mishra and others 2004). Low birth weight is well established as a major determinant of mortality, morbidity and disability in infancy and childhood and may potentially lead to negative health outcomes in adult life (2003).

In many regions of the world, a kitchen full of smoke is quite commonplace, and families breathe in harmful pollutants daily as they go about their lives. Such woodsmoke is known to contain a slew of dangerous compounds, including several carcinogens (e.g., polycyclic aromatic hydrocarbons, benzene, aldehydes, respirable particulate matter, carbon monoxide [CO], and others) (Naeher and others 2007). The two pollutants most commonly used in IAP assessments are $PM_{2.5}$ (particulate matter with an aerodynamic diameter smaller than 2.5 μm) and CO, which serve as indicators of overall woodsmoke exposure and are themselves extremely harmful to health.

Pollutants

Particulate matter (PM) is an air pollutant consisting of a complex mixture of organic and inorganic particles suspended in the air, whose main components are sulfates, nitrates, ammonia, sodium chloride, carbon, mineral dust, and water (WHO 2005). These particles vary in size, composition and origin, and are separated into two groups (PM_{10} and $PM_{2.5}$) based on their aerodynamic diameter. The smaller, finer particles ($PM_{2.5}$) are more dangerous to human health, as they penetrate deeper into the lungs and may reach the alveolar region, potentially interfering with gas exchange (WHO 2008). Also, these smaller particles may remain suspended in the atmosphere for days or even weeks, leading to lengthier exposures and the potential for particulate transfer over long distances (WHO 2005). Overall, it is estimated that 80% of the total global exposure to airborne particulate matter occurs indoors in developing countries (Ezzati and Kammen 2002a). In these environments, exposure to $PM_{2.5}$ from indoor combustion of solid fuels on open fires or traditional stoves increases the risk of acute lower respiratory infections (ALRI) among young children, as well as chronic obstructive pulmonary disease and lung cancer among adults (WHO 2008). The risk for all such outcomes increases with exposure, and there has been little evidence to support a threshold below which no adverse effects would be seen (WHO 2006). Although woodsmoke is known to contain thousands of harmful chemicals, small particles are thought to be the best single indicator of the health hazard of combustion smoke (Smith 2006b). Exposure to $PM_{2.5}$ also shows a strong association with mortality on the population level, indicating a 6% increase in all deaths per 10-$\mu g/m^3$ increase in long-term $PM_{2.5}$ concentration (Pope III and others 2002) . In 2005, the WHO set first-time guideline values for particulate matter. They recommend a 24-hour mean exposure no higher than 25 $\mu g/m^3$ (WHO 2008). The United States Environmental Protection Agency (EPA) National Ambient Air Quality Standards (NAAQS) set this 24-hour exposure limit at 35 $\mu g/m^3$ (EPA 2005). These two guidelines were originally meant for ambient exposure to pollutants (WHO 2006) and are not as applicable to the rural developing world. The United States Occupational Safety and Health Administration (OSHA) suggests maximum exposure of 5 mg/m^3 as an 8-hour time weighted average (TWA) (OSHA 1992). Since there is no known threshold for $PM_{2.5}$, the purpose of these guidelines is to achieve the lowest concentrations possible in the context of local constraints, capabilities and public health priorities (WHO 2006).

Carbon Monoxide (CO) is a colorless, odorless, tasteless gas with a slightly lower density than air (WHO 2000). In the developing world, especially in rural areas, CO is commonly formed as a by-product of incomplete combustion of carbonaceous materials, such as those used for fuel in traditional stoves, and is the most abundant by-product emitted from the fire (Smith 1987). In the human body, it reacts readily with haemoglobin (Hb) to form carboxyhaemoglobin (COHb), which hinders delivery of oxygen to the body. The toxic effects of this vary from headaches, flu-like symptoms, and other relatively mild effects, to more severe outcomes including permanent damage to the brain or heart, delayed neurological injury, and death (Lofgren 2002). Pregnant women and their fetuses, young infants and the elderly are at even greater risk (EPA 2000). Currently, no standards for CO have been agreed upon for indoor air. However, the U.S. NAAQS for outdoor air are 9 ppm for 8 hours, and 35 ppm for 1 hour (EPA 2009). The OSHA standard is no more than 50 ppm for an 8-hour TWA (OSHA 1992). The American Conference of Governmental Industrial Hygienists (ACGIH) has assigned carbon monoxide a threshold limit value (TLV) of 25 ppm as a TWA for a normal 8-hour workday and a 40-hour workweek (ACGIH 1994). Also, The National Institute for Occupational Safety and Health (NIOSH) has established a recommended exposure limit (REL) for CO of 35 ppm as an 8-hour TWA and 200 ppm as a ceiling limit (NIOSH 1992).

In sum, the effects of exposure to indoor woodsmoke are many and varied. Typically, inhalation of air pollutants will lead to direct effects at the points of contact (eyes, nose and throat) and more severe effects in the lungs and respiratory system. Absorption into the bloodstream is also possible, leading to future complications, and there is evidence that IAP may increase the risk for multiple types of cancers, though more research is needed to quantify this relationship (Bruce 2002; Naeher and others 2007). Due to the many mixed exposures experienced in a room full of smoke, it is difficult to attribute specific health outcomes to one or two pollutants alone. While they are only two of a plethora of pollutants emitted from the fire, $PM_{2.5}$ and CO operate as a representation of overall exposure, as well as being independently damaging to human health.

Exposure Assessment

In the developing world, ambient pollution levels in the home can be ten to a hundred times higher than recommended standards (Smith 2006b). Efforts are underway around the world to help abate this problem, and an important first step in reducing pollution is to understand the level of exposure experienced by a particular population. Exposure assessments help to identify and measure main sources of pollution as well as quantifying the extent to which certain types of intervention strategies do or do not work. Most epidemiological studies of health impacts from IAP only consider indirect measures of exposure, such as fuel type, household characteristics, or self-reported hours near the fire (Bruce 1998). The correlations between these proxy measures and health outcomes are real, but without quantitative measurements of exposure it is difficult to understand the whole picture. As an alternative, personal and area monitors are often used to record real-time and time-integrated pollutant concentrations over multiple hours or days. This method provides a detailed look at daily fluctuations and peak concentrations of pollutants, as well as producing average daily exposures for individual people or locations.

It is known that cookstove emissions vary greatly throughout the day due to combustion characteristics of the fire (Ballard-Tremeer 1996) as well as the status of the fire (whether it was off, starting, burning or smoldering), the type of food prepared, and general cooking behaviors

(Ezzati 2000). Peaks in cookstove emissions commonly occur when fuel is added or moved, the stove is lit, the cooking pot is placed on or removed from the fire, or food is stirred (Ezzati and Kammen 2002b). Assessing IAP exposure can be a complex venture with many factors to consider. However, when such level of detail is not desired, the simple use of a time-activity diary will help to explain fluctuations in exposure (both between-home and in-home) and may assist in understanding outliers as well.

Stove Interventions

For rural residents in the developing world, solid fuel is most commonly burned in inefficient simple stoves in poorly ventilated areas. Efforts to reduce indoor air pollution from solid fuel use center on four general categories of interventions: behavioral modifications to reduce exposure, household changes to improve ventilation, improvements to cooking stoves, and interventions to enable the use of higher-quality, lower-emission liquid or gaseous fuels (Desai 2004). Fuel improvements typically prove most effective, but they are also the most expensive and are thus not generally feasible in poor, rural communities lacking access to such resources. As a more practical alternative, improved cookstove (ICS) intervention has become a common and cost-effective answer to this public health problem worldwide (Mehta 2004). These stoves, when adequately designed, installed and maintained, are effective in reducing indoor pollution because of better combustion, improvements in ventilation (e.g. through construction of a chimney), lower emission levels and potentially shorter cooking times (WHO 2009). Furthermore, by educating communities on the danger of indoor pollutants and the importance of improved stoves, behavioral modifications and household changes may very well follow suit.

Cookstove intervention programs have been implemented and studied extensively across the globe. In 2001-2003, China's National Improved Stove Program (NISP) was reviewed by independent researchers from the United States and China. This program began in the 1980s and introduced more than 180 million improved stoves before ending in the mid 1990s (Zhang and Smith 2007). The stoves were shown to reduce 24-hour particulate matter by up to 43% and CO by up to 62% (Edwards and others 2007). Even so, these reductions still do not achieve levels that meet Chinese health standards, and with the NISP now dissolved, there is little being done to combat IAP in China (Edwards and others 2007). Additionally, because the NISP focused primarily on biomass, rural residents increased their use of coal, often in stoves without chimneys (Zhang and Smith 2007).

A similar organization in India, the National Program on Improved Chulha (NPIC), began distributing improved cookstoves in 1984. As in China, these new stoves brought reductions in IAP, ranging from 24-44% for $PM_{2.5}$ and 38-70% for CO, as reported by Chengappa et al. and Dutta et al. (Chengappa 2007; Dutta 2007). Unlike China, however, the NPIC was well run from the top down. The program included multiple stove types to suit the needs of individual locales (e.g., different materials, varying designs, and a special high-altitude version as well), community demonstrations of proper stove use, and many tiers of people and groups specifically trained to help carry on the program in their region (Aggarwal and Chandel 2004).

RESPIRE (Randomized Exposure Study of Pollution Indoors and Respiratory Effects) Guatemala was the first randomized controlled trial to study the health effects of reduced exposure to IAP *(*Smith-Sivertsen 2004*)*. This multi-part study was based around the introduction of locally produced improved chimney stoves, known as *Planchas.* In general, the introduction of these new stoves produced significant reductions in both kitchen (up to 85%) and personal (up to 45%) exposure levels to particulate matter and CO (Bruce and others 2004; Diaz and others 2007). Also within this large scale study, Smith (Smith 2006c) found that the introduction of a *Plancha* did significantly lower the occurrence of ALRI in children under 18 months of age. Díaz (Diaz and others 2007) observed significant reductions in headaches and eye irritation among the Guatemalan women, and McCracken (McCracken and others 2007) reported that the new stoves lowered blood pressure in the women as well. A later evaluation of self-rated health in this region found that a majority of women perceived their health to be improved after the introduction of the *Plancha* (Diaz and others 2008). Most women also associated the reduction of smoke with alleviation of non-respiratory symptoms (e.g. headache and eye discomfort), but more education would be necessary to help the community understand the long-lasting positive health effects of an improved stove (Diaz and others 2008).

In Michoacán, Mexico the introduction of the Patsari improved stove by the Household Energy and Health (HEH) Project not only produced 66-67% reductions in 48-hour kitchen concentrations of CO and $PM_{2.5}$, but also inspired public policy related to health, climate and the environment (Masera 2007). Reductions in personal exposures were also reported, with a 35% reduction in median 24-hour $PM_{2.5}$ and a 78% reduction in median 24-hour CO (Cynthia and others 2008). The HEH Project put a great deal of emphasis on monitoring and evaluation (M&E) of improved cookstove programs, which was determined to be paramount to effective, long-lasting interventions (Smith 2007).

Throughout the world, cookstove intervention programs are put to the test with various outcomes of interest. In the Sindh province of Pakistan (Khushk and others 2005), researchers observed decreases in CO exposure along with potentially significant reductions in symptoms of dry cough, sneezing and tears while cooking, though the sample size was too small in this pilot study. Nazmul Alam et al. (Nazmul Alam 2006) observed self-reported improvements in health, reduced fuel usage and reduced cooking time after the introduction of improved earthen stoves in Bangladesh. Limmeechokchai and Chawana (Limmeechokchai and Chawana 2007) employed predictive modeling and cost-benefit analyses to quantify the potential benefits of improved cookstoves in Thailand, measuring theoretical emission reductions and CO_2 mitigation over a thirty year period.

In a rural village of Honduras, a three-phase ICS project began in early 2007 with the purpose of distributing the Lorena stove (Emery 2007), which is similar in design to the *Plancha* used in Guatemala (Smith-Sivertsen 2004). The two-fold purpose of the Honduras Lorena Stove Project is that it will not only reduce exposure to IAP in the home, but also that the construction, distribution and maintenance of these new stoves will allow the development of a micro-enterprise designed to retrain the rural elderly, potentially improving their mental health status (Emery 2007).

Generally speaking, the majority of research on improved cookstove intervention tells a similar story. Traditional cookstoves in most of the developing world are inadequate, producing unacceptably high levels of pollution and endangering human health. Interventions to improve such stoves will not only reduce exposure to harmful IAP but also greatly improve quality of life (Chapman and others 2005; Diaz and others 2008; Diaz and others 2007; McCracken and others 2007; Smith 2006c).

Despite these positive findings, there are many barriers to the implementation of improved cookstove programs. To begin with, a lack of education within the community has the potential to keep a project from moving forward. If women do not understand the purpose and benefits of a new stove, they will have little reason to make the necessary sacrifices and adjustments for it (Barnes 1994). The improved stove must also be suitable for all regular cooking tasks (Agarwal 1983). Otherwise, women will likely continue to use their old stoves for certain foods and the new stove for others, effectively negating any household reductions in IAP exposure (Edwards and others 2007). Most importantly, the stoves must be accepted by the local population. Use of local materials and a simple design that is easy to use will likely aid in this goal (Barnes 1994), but if the improved stove model is not acceptable, the effort becomes futile.

Objectives

As of 2002, 33% of homes in Peru were using solid fuels for cooking and heating (WHO 2007), although this number is likely closer to 90% in rural areas (Bruce and Perez-Padilla 2000). The Peruvian government has begun a nationwide stove intervention program, which has great potential to improve quality of life countrywide. Simultaneously, companies that have influence in rural Peru have reached out to their local communities and offered new, improved stoves as well. In both scenarios, there was a lack of solid data on the ability of these stoves to reduce exposure to indoor air pollution. The goal of this research is the same for both stove types: to test the effectiveness of the new stove in the natural field environment. We believe that both improved stove models will greatly reduced exposure to $PM_{2.5}$ and CO, both on the kitchen and personal level. This research will provide the Peruvian government and other invested organizations with essential data and information on the potential impact of their respective stove interventions.

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CHAPTER 3

TESTING THE EFFECTIVENESS OF TWO IMPROVED COOKSTOVE INTERVENTIONS IN THE SANTIAGO DE CHUCO PROVINCE OF PERU[1]

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Abstract

Three Andean communities within the Santiago de Chuco province of Peru received two different models of improved cookstoves; one from the Juntos National Program (stove 1) and one from Barrick Corporation, as provided by its community relations area (stove 2). The impact of these stoves in reducing personal exposures and kitchen concentrations of particulate matter ($PM_{2.5}$) and carbon monoxide (CO) was evaluated separately in 64 homes (32 homes with each stove model) with the use of air monitoring equipment. Due to a variety of study subject issues, some homes in each community were lost to follow-up over the course of the study, and

only homes with complete pre- and post-intervention data were included in the final analyses. In the community receiving stove 1, baseline aggregate 48-hr personal exposure (n = 27) and kitchen concentrations (n = 26) of $PM_{2.5}$ were 116.4 and 207.3 µg/m^3, respectively, and 48-hr personal (n = 25) and kitchen (n = 25) CO levels were 1.2 and 3.6 ppm. After introducing the new stove to this community, exposures to $PM_{2.5}$ reduced to 68.4 and 84.7 µg/m^3, and exposures to CO reduced to 0.4 and 0.8 ppm, representing reductions of 41.3%, 59.2%, 69.6% and 77.7%. In the communities receiving stove 2, corresponding pre-intervention levels of $PM_{2.5}$ were 126.3 µg/m^3 (n = 18), 173.4 µg/m^3 (n = 19), and CO levels were 0.8 ppm (n = 19), and 2.5 ppm (n = 17). After installation of new stoves, levels of $PM_{2.5}$ reduced to 58.3, 51.1 µg/m^3 and levels of CO to 0.6, 0.8 ppm. Overall, homes receiving stove 2 saw reductions of 53.8, 70.5, 25.9 and 65.6%. All values are statistically significant ($p < 0.05$) with the exception of personal CO reductions in the stove 2 community. Both stoves were effective at improving indoor air quality.

Introduction

More than half the world's population, and 90% of people residing in rural areas of less-developed countries rely on solid fuels (e.g. wood, crop residues) and coal for their basic heating and cooking energy needs (Bruce 2002). This often involves using open fires or poorly constructed stoves in unventilated rooms, which lead to high exposures to the many products of incomplete combustion (Bruce and Perez-Padilla 2000). According to the World Health Organization (WHO), indoor air pollution (IAP) from solid fuel use is responsible for approximately 2.5 million deaths each year in developing countries (Bruce 2002) and is among the world's top ten causes of mortality and morbidity (Rehfuess and others 2006a).

Pollutants from solid fuel combustion are known, with various degrees of certainty, to cause or exacerbate many serious health problems, including but not limited to acute lower respiratory infections (ALRIs), chronic obstructive pulmonary disease (COPD), asthma, nasopharyngeal and laryngeal cancers, reduced birth weight, tuberculosis, and diseases of the eye (Ezzati 2005). In poorer countries, where this issue is most prevalent, women and children bear a vastly disproportionate burden of such diseases, as they are more likely to spend most of their time at home (Smith 2006a). Specifically, women between the ages of 15 and 40 years old tend to be most heavily involved with cooking (Balakrishnan and others 2004). Also, children are more susceptible to the negative effects of IAP during their developmental stages, and they breathe a greater volume of air than adults in proportion to their body weight (Bearer 1995). As a result, 56% of all indoor air pollution-attributable deaths occur in children under five years of age (Rehfuess and others 2006).

Woodsmoke is known to contain many dangerous pollutants, and the two most commonly used in IAP assessments are particulate matter with an aerodynamic diameter less than 2.5 micrometers ($PM_{2.5}$) and carbon monoxide (CO), which serve as indicators of overall woodsmoke exposure and are themselves harmful to health. Guideline values have been set for $PM_{2.5,}$ but their target populations do not encompass the rural developing world, and thus these values would not make sense in such a context. This is also true of guidelines for CO. In the developing world, especially in rural areas, CO is commonly formed as a by-product of incomplete combustion of carbonaceous materials, such as those used for fuel in traditional stoves, and is the most abundant by-product emitted from the fire (Smith 1987).

The most cost-effective answer to the problem of IAP is found in improved stoves, which when adequately designed, installed and maintained are effective in reducing indoor pollution because of better combustion, improvements in ventilation (e.g. through construction of a chimney), lower emission levels and potentially shorter cooking times (WHO 2009). To assess these stoves, an important first step is to understand the level of exposure experienced by the population to be studied. Indirect measures such as fuel type, household characteristics, or hours near a fire are often used to this end (Bruce 1998), but the incorporation of personal and area air sampling monitors is preferable as it offers a more detailed and quantitative understanding of total exposure.

Cookstove intervention programs have been implemented and studied extensively across the globe. Beyond the significant reductions of IAP offered by improved stoves (Bruce and others 2004; Chengappa 2007; Cynthia and others 2008; Dutta 2007; Ezzati 2000; Masera 2007), they have been shown to potentially reduce risk of ALRI in children under 18 months (Smith 2006b), reduce headaches, eye irritation (Diaz and others 2007), and blood pressure (McCracken and others 2007).

It is evident that improved stoves potentially offer great improvements and changes, both in the kitchen and beyond. In Peru, 33% of homes (90% in rural areas) use solid fuels for cooking and heating (WHO 2007). The Peruvian government has begun a nationwide stove intervention program which has great potential to improve quality of life countrywide. Simultaneously, the Barrick Corporation has reached out to their local communities and begun providing new, improved stoves as well. The goal of this research is the same for both stove types: to test the effectiveness of the new stove in the natural field environment. We believe that both improved stove models will greatly reduce exposure to $PM_{2.5}$ and CO, both on the kitchen and personal level. This research will provide the invested organizations with essential data and information on the potential impact of their respective stove intervention projects.

Methods

Study Sites and Populations

This investigation took place in three locations within the Santiago de Chuco Province, in the region of La Libertad, in the Andes Mountains of North-Central Peru (Figure 3.1). The study was split such that two different improved stove models might be assessed independently. Every effort was made to maintain a cohesive study design and implementation across these three locations. A town-hall-style meeting was held at each site, with support from the mayor and local community leaders, to explain our presence there and to enlist volunteers. In both communities, women were chosen to be part of the study population based upon three main criteria: 1) Woman uses an open woodfire for cooking indoors (with at least three and a half full walls and a roof over the kitchen), 2) she must be of child-bearing age (18-45), and 3) she must be a willing participant, prepared to carry the study out to completion. Beyond these criteria, the homes were chosen out of convenience, due to the limited pool of potential participants. Each woman was given a detailed questionnaire and time activity diary (to be updated every 15 minutes), both before and after the installation of the improved cookstove. This was done to better understand the lifestyles of the individual women and potential influences of their activity patterns on exposure. In all communities, air monitoring was carried out with an identical sampling protocol, and everything possible was done to ensure that the new stoves were installed and studied within a comparable timeframe across homes and across study locations.

Huayatan

The improved stoves offered by the Juntos National Program (Figure 3.2), hereafter referred to as “stove 1,” were installed and assessed throughout the rural community of Huayatan, just outside the city of Santiago de Chuco. Huayatan is a small, agricultural community of no more than 100 homes dispersed throughout rolling hills and rugged terrain. There is one main dirt road through Huayatan, which sees very little motor vehicle traffic. Twelve of the homes included in the final assessment are located along or near this road, while the other 15 are scattered among the surrounding hills. The elevation in Huayatan is approximately 3400 m above sea level, and the time of this study fell during the dry season, so little rain was ever experienced. 35 subjects were chosen from this community, and 30 of these saw the study to completion. The portion of the study in Huayatan was conducted from June 2 – August 13, 2008. This time period includes both the pre-intervention and post-intervention phases of the study. All homes in this community use wood for their cooking and heating purposes.

Chaguin and Cachulla Baja

The improved stoves provided by Barrick (Figure 3.3), hereafter referred to as "stove 2," were installed and assessed in two neighboring rural communities, Chaguin and Cachulla Baja. These communities are both very small, with a combined population of no more than 60 homes, and were chosen because they represent typical communities in which these stoves would be installed. The people's lifestyles and homes are very similar to those in Huayatan, as well as the geography of the region. This area is, however, slightly lower in elevation (3000 meters above sea level), which means a somewhat warmer average temperature, and rain is more common here than in Huayatan, even in the dry season. There is also only one dirt road through this area that sees less motor vehicles traffic than Huayatan, and most homes (83% of those in the study) are located away from the road. 32 total subjects were chosen from these two communities, and 27 saw the study to completion. In this community, the first phase of the study (pre-stove intervention) ran from June 12 – July 1, 2008. Due to delays in stove construction, the second phase of the study (post-stove intervention) was not begun until September 22, and it was completed on October 3, 2008. All homes in this community use wood for their cooking and heating purposes.

The Distribution of Stoves

In Huayatan, stove 1 was delivered to the homes in three pieces: a 3-hole stove-top called a plancha, an aluminum chimney, and an aluminum tube to connect the chimney to the plancha. These pieces were constructed locally by metalworkers from Santiago de Chuco, and cost approximately 70 soles (~21 USD). The Santiago de Chuco City Hall donated these materials, and each household participating in the study provided other stove materials at their own expense. The responsibility of constructing the final stove product lay on the families, as it was necessary for them to build an adobe base for the plancha to sit on, and to seal the stove with adobe all around. The Juntos Program provided basic instructions on how to build the improved stove and a timeline for completion. The model for stove 2 was a bit more complex, and the job of building/installing the stoves was subcontracted by Barrick Corporation to a local brick mason. Installation of these new stoves did not begin until early September, which meant that a second team from UGA was needed to be sent back to finish the study.

Air Monitoring

Air quality monitoring in the homes was carried out for personal exposure and kitchen area exposure, and a fixed sampling site was set up in the middle of town to capture background levels. To reduce the impacts of wide daily variability on the uncertainty in our exposure measurements (Bhangar, Smith et al. 2004), the homes were sampled for a 48 hour period. In phase I air sampling, the homes were monitored for two days while the original stove was still in use. The women were told to live and act as though nothing were different, doing whatever they would normally do. Once the new stoves were installed, the women were given approximately three weeks to adjust, and then phase II was begun (despite the delay in construction of stove 2, this three-week adjustment period was still maintained). In phase II air sampling, everything was done exactly the same as in phase I, with the only controllable difference being the new stove. On the occasion that a measurement was lost due to equipment failure or other factor, the home was re-sampled in its entirety. Only homes with complete pre- and post-installation measurements are included in the final analyses.

The UGA team did not possess the resources to access the communities of Chaguin and Cachulla Baja. As a result, two local technicians from Barrick Corporation were trained to do the air exposure monitoring field work in these areas. Everything else was carried out by the UGA team as normal.

Personal Sampling

Each woman was fitted for two days with an adapted firefighter vest (Figure 3.4) which held the personal air sampling equipment at or near their breathing zone. The women were told to wear the vest at all times, and only to remove them when sleeping or if they might be getting excessively wet. At night, the women were asked to place the vest on a chair, at breathing height, next to their bed. To measure real-time CO exposure, each vest held a Pac III CO monitor (Draeger Safety Inc., Pittsburgh, PA), set to record concentration levels at 30-second intervals. Forty-eight-hour time-integrated $PM_{2.5}$ samples were collected using 37mm Teflon filters (Pall, East Hills, NY, Teflo 2.0µm), particle-size-selective Triplex Cyclones (BGI Inc., Waltham, MA, Model SCC 1.062) and SKC universal sampling pumps (SKC Inc, Eighty Four, PA, Aircheck® XR5000), set to pull air at 1.5 liters per minute. After 48 hours, the vests were retrieved, sampled filters were stored in a freezer, and runtimes were recorded for each piece of equipment. The filters were analyzed in the Air Quality Lab in the Department of Environmental Health Science at UGA. Filters were desiccated in climate-controlled conditions (20.6 ± 1.4°C; 31 ± 13% relative humidity) for a 48-hr period prior to the initial weighing of the unused filters and the weighing of the sampled filters. Each filter was weighed twice before and after sampling using a Cahn C-35 microbalance (Thermo Scientific, Waltham, MA, Orion 10935-01) with a sensitivity of ± 1 μg in accordance with – and exceeding the requirements of – the EPA's Quality Assurance Guidance Document (EPA 2005) .

To account for potential contamination from the loading and unloading of filters, we incorporated the use of field blanks on intermittent sampling days. After returning to UGA and recording post-weights for these field blank filters, the average mass was 0.88 $\mu g/m^3$ (n=30). This amount was subtracted from every value used in our analyses to reduce the impact of human error and outside contamination from the reported concentrations of $PM_{2.5}$.

Area Sampling

In the kitchen of each home, a stationary sampling box (Figure 3.5) was placed within 1 m of the stove. The sampling boxes were made of local materials and were constructed by a local carpenter. They were designed to hold all the necessary equipment and batteries, and attached to one end was a piece of PCV piping which rose to approximate breathing height (1.5 m). As with the personal vests, each box contained a universal sampling pump (SKC Inc, Eighty Four, PA, Aircheck® 2000) complete with the aforementioned filter/cyclone sampling train attached to the piping, and a Pac III CO monitor (Draeger Safety Inc., Pittsburgh, PA) attached to the top of the piping as well. All details described above for the handling of filters were carried out. In certain, randomly chosen homes, the box also contained a DustTrak™ aerosol particulate monitor (TSI Inc., Shoreview, MN, Model 8520), which measures real-time $PM_{2.5}$ particle concentrations using a laser photometer. A tube ran from the intake of the unit to the top of the PCV piping. To account for known limitations with this equipment (MacIntosh 2002; Volckens 1999), DustTrak values were later reduced by 41% based on the differences seen between DustTrak and gravimetric $PM_{2.5}$ samples collected during a similar study (Naeher 2004) in Arequipa, Peru. The same equipment used in Arequipa was used in this study. All reported DustTrak results reflect these adjustments and should only be interpreted as relative measures.

Fixed Site

A central location was chosen in each town to serve as a fixed sampling site, providing background levels of both CO and $PM_{2.5}$. A sampling scheme similar to that seen in the study homes was set up outside a window in this fixed site. To measure real-time CO, a Langan CO monitor (Langan Products Inc., Elmwood Park, NJ, model T15n) was used instead of a Pac III. Forty-eight-hour time-integrated $PM_{2.5}$ was measured with the same equipment used in the kitchens.

Statistical Analysis

SAS version 9.1 (SAS Institute, Cary, NC) was used for all data analysis. Measurement durations shorter than 42 hours or longer than 54 hours were eliminated from the analysis dataset. Due to the right-skewed distributions, concentration variables were log-transformed for analysis purposes. Arc sin square root transformations were carried out whenever calculating percentages. Statistical significance was defined by $p < 0.05$. A two-way analysis of variance (ANOVA) was employed to model the transformed response variables as a function of study subject and time (pre- vs. post-intervention). Means of transformed data before and after installation of the new stoves were adjusted for subject effects.

Results

Household Characteristics

The numbers shown here represent the population of Huayatan first, with Chaguin/Cachulla Baja given in parentheses. These data are summarized in Table 3.1.

In these communities, the main responsibilities of the women were mostly cooking, taking care of livestock, and taking care of the children. The homes are constructed of adobe, with shingle-type roofing, and more than 95% (100%) have dirt floors. The kitchen in most homes is a separate room, although it often serves as a bedroom as well, especially during the winter. The average age of the women in this study was 33 (33) years. Approximately 37% (35%) of women had more than five people in their home, and many of these women had a child under the age of 5. Such young children are carried in a cloth wrap across the back (Figure 3.6), exposing them to whatever their mother is exposed to. The women spend an average of 3.9 (3.7) hours cooking each day, and many more hours in the kitchen doing other tasks, relaxing or just staying warm. None of the women in any community were smokers and zero (2) households reported other smokers in the home.

Study Participation

Our original goal was a sample of 64 homes, before and after the cookstove intervention, broken down by 32 homes receiving stove 1 and 32 homes receiving stove 2. We chose these numbers after calculating a conservative estimate that a sample size of between 24 and 25 homes in each community was enough to obtain the statistical power to test our hypotheses. It was expected that the sample size would decrease over the course of the study for a variety of unforeseeable reasons, and this assumption held true. As the purpose of our study was to investigate the effects of a new stove, we only included in our final analysis those homes from which we collected complete pre- and post-intervention data for at least one exposure measure.

Of the 35 subjects who enrolled in the study in Huayatan (in which improved stove type 1 was installed), 30 of them completed both phases and allowed us to collect both pre-stove installation and post-stove installation measurements. Reasons for loss to follow-up included personal reasons (n=4) and travelling away from town for an extended period of time (n=1). Of the 32 subjects who enrolled in the study in Chaguin/Chaculla Baja (where improved stove type 2 was installed), 27 of them completed both phases, allowing us to collect both pre-stove installation and post-stove installation measurements. Reasons for loss to follow-up included personal reasons (n=2), travelling away from town for an extended period of time (n=2), and illness (n=1).

Other complications associated with exposure assessment, such as equipment failure or sample loss, reduced the sample sizes further for the final analysis. In sum, we had a valid pre- and post-intervention measure for homes receiving stove model 1 from: 26 homes for kitchen $PM_{2.5}$, 27 homes for personal $PM_{2.5}$, 25 homes for kitchen CO, and 25 homes for personal CO. We had a valid pre- and post-intervention measure for homes receiving stove model 2 from: 19 homes for kitchen $PM_{2.5}$, 18 homes for personal $PM_{2.5}$, 17 homes for kitchen CO, and 19 homes for personal CO.

Background Levels

In each community, background pollutant levels were measured at a fixed location away from any active pollution sources. In Huayatan, the average background CO level for the entire course of our study was 0.25 ppm, and average $PM_{2.5}$ concentration was 12.1 $\mu g/m^3$. In Chaguin/Cachulla Baja, the average background CO level for that portion of our study was 0.53

ppm, and average $PM_{2.5}$ concentration was 11.6 µg/m^3. These daily levels are displayed in Figure 3.7. Our main purpose in reporting background levels in each community was to catch any large changes or differences across days and across the two phases of our study that may have significantly impacted our results. We observed no such trends.

Effects of New Stoves

Kitchen concentrations and personal exposure levels for each individual home are recorded in Table 3.2. Total average reductions for each indicator in call communities are displayed in Figure 3.8. All reductions shown are statistically significant ($p < 0.05$) with the exception of personal CO for stove 2. Figure 3.9 demonstrates typical real-time reductions in kitchen concentrations of $PM_{2.5}$ and reductions of both kitchen and personal exposure to CO over a 48-hr monitoring period before and after the installation of stove 1 in a representative home. Times of intensive stove use are evident, and the highest peaks occur around lunchtime, which is traditionally the largest meal in Peru.

Reductions in Personal Exposure and Kitchen Concentrations – Stove 1

After approximately three weeks using the new stoves, the geometric mean 48-hr personal exposure to $PM_{2.5}$ in stove 1 homes reduced from 116.4 µg/m^3 (95% C.I. 94.6, 143 µg/m^3) to 68.4 µg/m^3 (95% C.I. 55.6, 84.2 µg/m^3), which represents an aggregate reduction of 41.3% (n=27, $p < 0.01$). 48-hr personal exposure to CO reduced from an average of 1.2 ppm (95% C.I. 0.74, 1.84 ppm) to 0.4 ppm (95% C.I. 0.23, 0.56 ppm), which is an overall reduction of 69.6% (n=25, $p < 0.001$). The average highest peak exposures to CO reduced almost 50%, dropping from 67.8 to 38.4 ppm. Further details of these peak reductions are given in Table 3.3.

The geometric mean 48-hr kitchen concentration of $PM_{2.5}$ reduced from 207.3 µg/m^3 (95% C.I. 163, 265 µg/m^3) to 84.7 µg/m^3 (95% C.I. 66.4, 108 µg/m^3), representing an aggregate reduction of 59.2% (n=26, $p < 0.0001$). Real-time kitchen exposure data was collected for at least part of the 48-hr sampling period in a total of 19 homes receiving stove 1. In this subsample of homes, the average highest peak reduced from 29 mg/m^3 to 10 mg/m^3 after installation of the new stove (Table 3.3). 48-hr kitchen concentrations of CO reduced from 3.6 ppm (95% C.I. 2.6, 4.9 ppm) to 0.8 ppm (95% C.I. 0.58, 1.09), which is an overall reduction of 77.7% (n=25, $p < 0.0001$). The average highest peaks in CO concentration dropped over 50% with the introduction of the improved stove, reducing from 126.9 to 60.9 ppm (Table 3.3). Only homes with complete paired before and after measurements were included in these analyses. This information is summarized in Table 3.4.

Reductions in Personal Exposure and Kitchen Concentrations – Stove 2

After approximately three weeks using the new stoves, the geometric mean 48-hr personal exposure to $PM_{2.5}$ in stove 2 homes reduced from 126.3 µg/m^3 (95% C.I. 96.3, 166 µg/m^3) to 58.3 µg/m^3 (95% C.I. 44.5, 76.5 µg/m^3), representing an aggregate reduction of 53.8% (n=18, $p < 0.001$). 48-hr personal exposure to CO (n=20) reduced from 0.8 ppm (95% C.I. 0.53, 1.31 ppm), to 0.6 ppm (95% C.I. 0.39, 0.97 ppm), representing minimal change in exposure. From all communities, this was the only exposure indicator to not significantly reduce.

The geometric mean 48-hr kitchen concentration of $PM_{2.5}$ reduced from 173.4 µg/m^3 (95% C.I. 112, 268 µg/m^3) to 51.1 µg/m^3 (95% C.I. 33.1, 78.8 µg/m^3), representing an aggregate reduction of 70.5% (n=19, $p < 0.001$). Due to logistical issues during this portion of our study, real-time kitchen exposure data was only collected in three of the homes receiving stove 2. As such, that data is not presented here. 48-hr kitchen concentration of CO reduced from 2.5 ppm (95% C.I. 1.71, 3.54 ppm) to 0.8 ppm (95% C.I. 0.59, 1.22 ppm), which is an overall reduction of 65.6% (n=18, $p < 0.001$). There is no evidence that stove 2 reduces the peak exposures to CO.

Only homes with complete paired before and after measurements were included in these analyses. This information is summarized in Table 3.4.

Discussion

Large-scale dissemination of improved cookstoves has great potential to reverse the trends of mortality and morbidity caused by indoor air pollution, especially in the developing world. Realizing this fact, many organizations – governmental and non-governmental – have responded with improved stove models such as stove 1 and stove 2 presented here. As every community is different, and daily use inside a rural kitchen is quite different from a laboratory, field testing of these new stoves is absolutely essential to understanding their true potential impact. The information discussed here is meant to aid those offering these new stoves in their continued efforts to lower pollution and improve health.

Improved cookstove programs around the world have consistently proved successful in the reduction of kitchen concentrations and personal exposures to indoor air pollution (Table 3.5). Our research indicates similarly positive results from these two different stoves in three separate communities of North-Central, Andean Peru.

Effectiveness of Intervention – Stove 1

The results from this study represent one of the multiple stove models offered by the Juntos National Program, as distributed in one of many thousand small communities throughout Peru. As such, the potential reductions in CO and $PM_{2.5}$ exposures and kitchen concentrations implied by our findings with stove 1 are most accurately applicable to this particular model of improved cookstove and to communities of similar makeup and open-fire woodstove usage.

In the study population as a whole, paired comparisons of 48-hr personal exposure to CO and $PM_{2.5}$ indicated reductions of 69.6% and 41.3%, respectively. Similarly, paired comparisons of 48-hr CO and $PM_{2.5}$ kitchen concentrations revealed overall reductions of 77.7% and 59.2%. These results are consistent with percent reductions seen in other studies of stove interventions around the world (Table 3.5). Kitchen and personal CO exposures were reduced at levels on the high end of what would be expected from the literature. Kitchen and personal $PM_{2.5}$ fell in the middle of the normal range of potential percent reductions.

In the case of CO, average 48-hour levels seem quite low both before and after the stove intervention (kitchen and personal levels only reduced from 3.6 and 1.2 ppm to 0.8 and 0.4 ppm, respectively). However, the more notable change is actually the reduction of acute high exposures. Over the course of two days, women will likely spend large amounts of time away from any large source of pollution, which effectively drives down the overall average and may give rise to a false impression that CO exposures in this community are actually quite safe. On the contrary, while average exposures over two days are seemingly low, the true danger lies in acute exposure to high concentrations. The mean reductions in CO exposure look relatively insignificant, but in fact the seemingly small change in pollutant concentrations over 48 hours is indicative of many large changes in peak values throughout the sampling period. An example of this can be seen in Figure 3.9, where great reductions are shown in the acute CO exposures occurring during peak stove use each day.

Beyond the actual improvements shown by our air monitoring equipment, most participants also expressed true enjoyment of their new stove. Many women found that they needed less wood and less time to cook meals, which could potentially be a factor in the overall reduction of IAP. Personal exposures did not reduce as much as kitchen levels, but this is consistent with other studies (Cynthia and others 2008) and is not a surprising outcome, as women are exposed throughout the day to sources of pollution beyond their own kitchen (such as other homes still using traditional stoves). This also highlights the limitations in using kitchen concentrations alone as a proxy measure for potential improvements in human health. We chose to incorporate both kitchen and personal measurements so that we might not only see the drop in pollutant emissions within the home, but also to observe the extent to which that drop actually impacts personal exposure.

Overall, this new stove offers vast improvements on traditional methods, greatly reducing exposure to both aggregate and acute levels of indoor pollution. The post-intervention exposure levels may still seem high in comparison to the developed world, but they are truly impressive in the context of a rural kitchen in the developing world. In a region where background levels of pollution alone may often exceed WHO and EPA air quality guidelines (Table 3.6), the exposure reductions experienced by these women certainly indicate great progress.

Effectiveness of Intervention – Stove 2

Chaguin and Cachulla Baja were two communities chosen to receive stove 2. With these areas being relatively inaccessible to our team, we mostly observed the dissemination of stoves from afar. The job of stove-building in these communities was subcontracted by Barrick Corporation to one supplier, which greatly reduced the variability in stove construction. Concurrently, this system avoided placing responsibility for the stove installation on the women. The installation in the homes was quick and efficient because it did not depend upon the schedules and motivation of individual households. As mentioned before, this portion of the study is based upon one specific stove model in a specific community. Extrapolation of these results to other areas is only logical if the same stove model is being distributed to a community with similarly traditional cooking methods.

On an aggregate basis, paired comparisons of 48-hr personal exposure to $PM_{2.5}$ indicated a reduction of 53.8%. In the kitchens, paired comparisons of 48-hr CO and $PM_{2.5}$ concentrations revealed overall reductions of 65.6% and 70.5%, respectively. Personal exposure to CO was low in these communities to begin with, and thus the reductions seen (25.9%) were also quite low, and not statistically significant. Also, though average levels of CO in the kitchen did significantly improve, they did not show consistent reductions in peak levels. Closer analysis of the data from each individual home, along with the use of field notes and time activity diaries, afforded us no viable explanation for these results.

Stove 2 truly offers an improvement on traditional cooking methods, and the reductions seen here are encouraging. Apart from personal CO exposure, this stove works well, and percent reductions from this community lined up well with what has been seen elsewhere in the world (Table 3.5). In particular, percent reductions in personal exposure to and kitchen concentrations of $PM_{2.5}$ were in the upper range of what has been reported in the literature. Again, in the context of rural developing world, post-intervention levels of IAP with stove 2 represent positive progress.

Limitations

Research in the developing world carries with it some inherent limitations, and the experience of our team was no different despite the relatively simple design of our study. Both communities had rather small populations, and there were a limited number of households in the area that both met the study criteria and were willing to participate. As such, we were unable to choose homes randomly and instead worked with a convenience sample. These sample populations were small to begin with, and issues with participants and with equipment resulted in some homes being lost. With stove 2, the complications inherent in training and sending a separate team to the field, coupled with delayed stove installation and the necessity of training a second team from UGA, reduced the sample size even more.

With stove 1, persistence and persuasion were necessary in convincing participants to build and use their stoves. This fact may have biased our study, as we were unable to accurately assess the intervention program apart from our involvement. We are limited in our knowledge of the community receiving stove 2, as we did not live as close or interact as regularly with the people there. This, coupled with the difficulties inherent in the two-team model, is a potential source of error in our analyses.

Seasonal differences could not be accounted for in such a small-scale study, and while the climate remained similar across the pre- and post-intervention phases, habits and activities of the women did change. Harvest time fell during the second half of our study, and any impact that this change in daily life may have had on personal exposure levels is unknown. There remain many factors that simply could not be accounted for in this study, whether due to the small population, short time-frame, lack of equipment or some other cause. These include, but are not limited to: long-term value of new stove; day-to-day variability in exposures; differences in kitchen size/design; location of stove within household; the use of multiple stoves in one home; differences in ventilation within the home; and contribution to personal exposure and kitchen concentrations from a neighboring home’s stove.

Conclusions

Despite the differences in the people of Huayatan and Chaguin/Cachulla Baja, as well as the differences in the improved stove models we investigated, the final conclusions of this study are virtually the same for everyone involved. Both stoves, when properly distributed, installed and used, will markedly reduce levels of CO and $PM_{2.5}$, especially in the kitchen environment.

In communities and environments similar to those discussed here, we have seen that both stoves have the potential to improve quality of life and perhaps to help reverse the trends of ill health caused by indoor air pollution.

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TABLES AND FIGURES

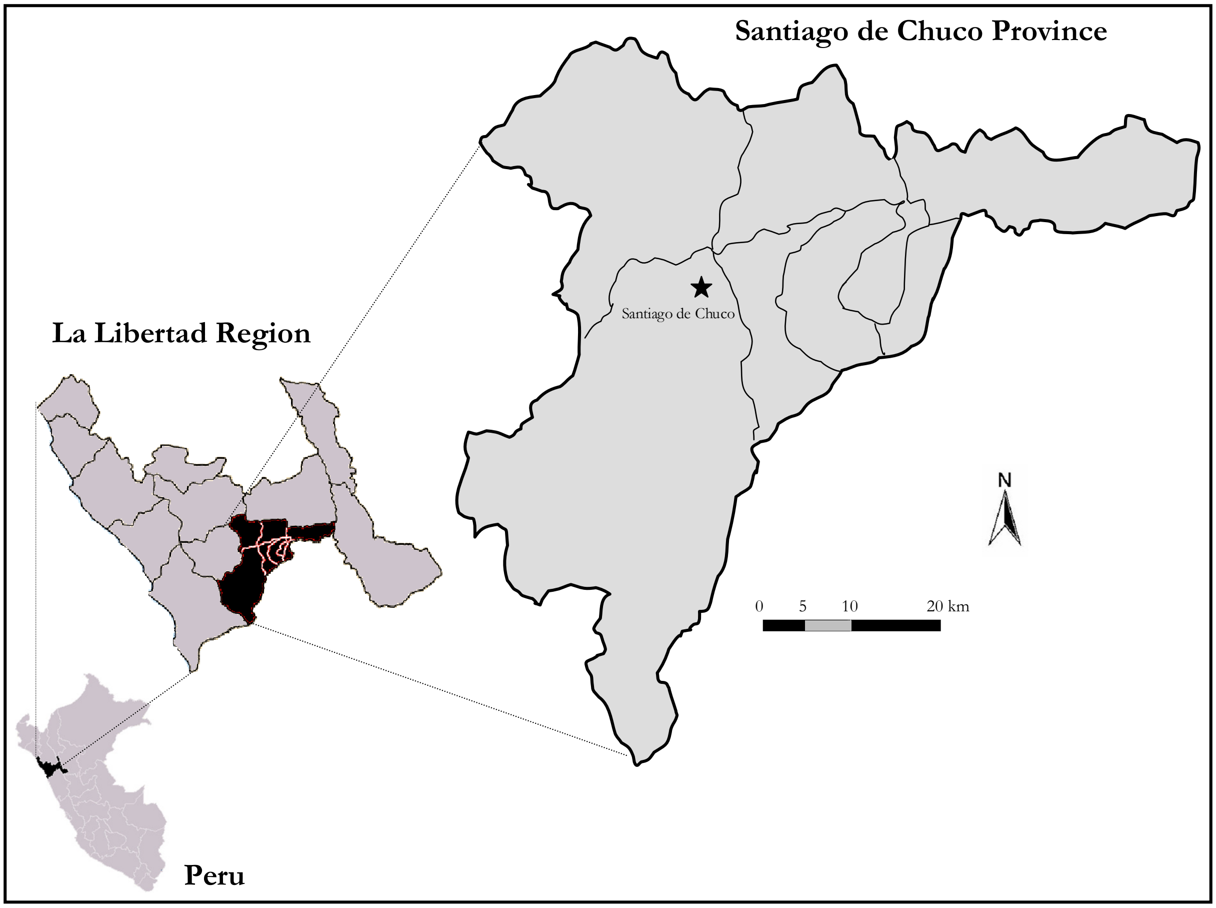

Figure 3.1. Map of Santiago de Chuco Province in the La Libertad Region of Peru

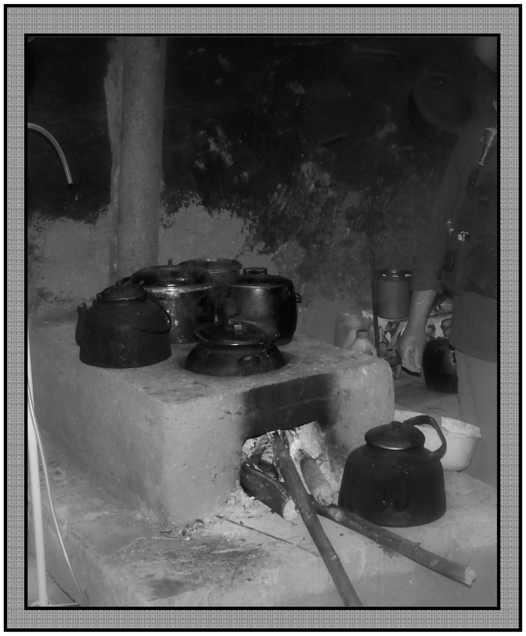

Figure 3.2. Example of improved stove 1

Figure 3.3. Example of improved stove 2

Figure 3.4. Study Participant wearing personal sampling vest

Figure 3.5. Stationary sampling box

Table 3.1. Baseline characteristics among all households participating in study, by region

	Huayatan (n=27)	Chaguin/Cachulla Baja (n=23)
Household Characteristics		
Approximate altitude above sea level, in meters	3400	3000
Dirt floor in home, number (%)	26 (96)	23 (100)
Proximity of home to main road, number (%)		
< 50 meters	12 (44)	4 (17)
> 50 meters	15 (56)	19 (83)
People living in home, number (%)		
< 5	17 (63)	15 (65)
> 5	10 (37)	8 (35)
Smoker present in home, number (%)	0	3 (13)
Participant Characteristics		
Age, mean (SD)	33 (6.8)	33 (7.8)
smoker	0	0
Hours spent cooking each day, mean (SD)	3.9 (0.9)	3.7 (1)

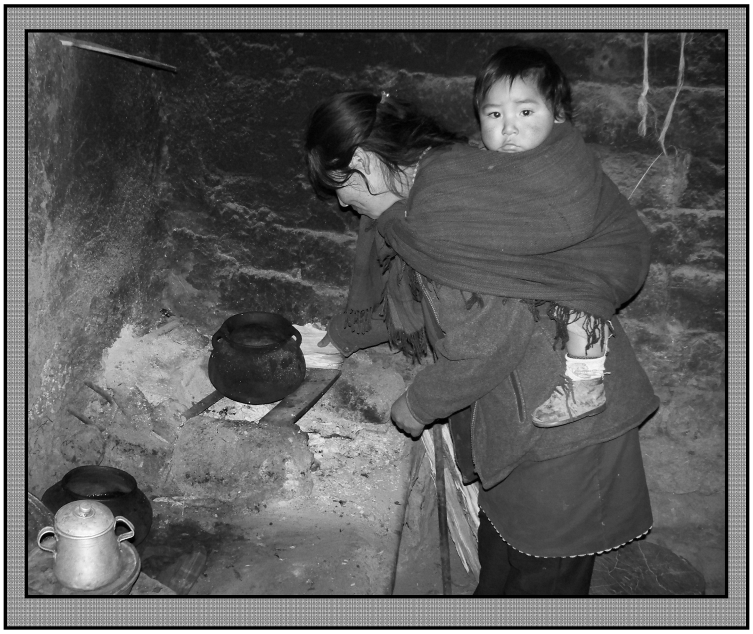

Figure 3.6. Study participant with her young child

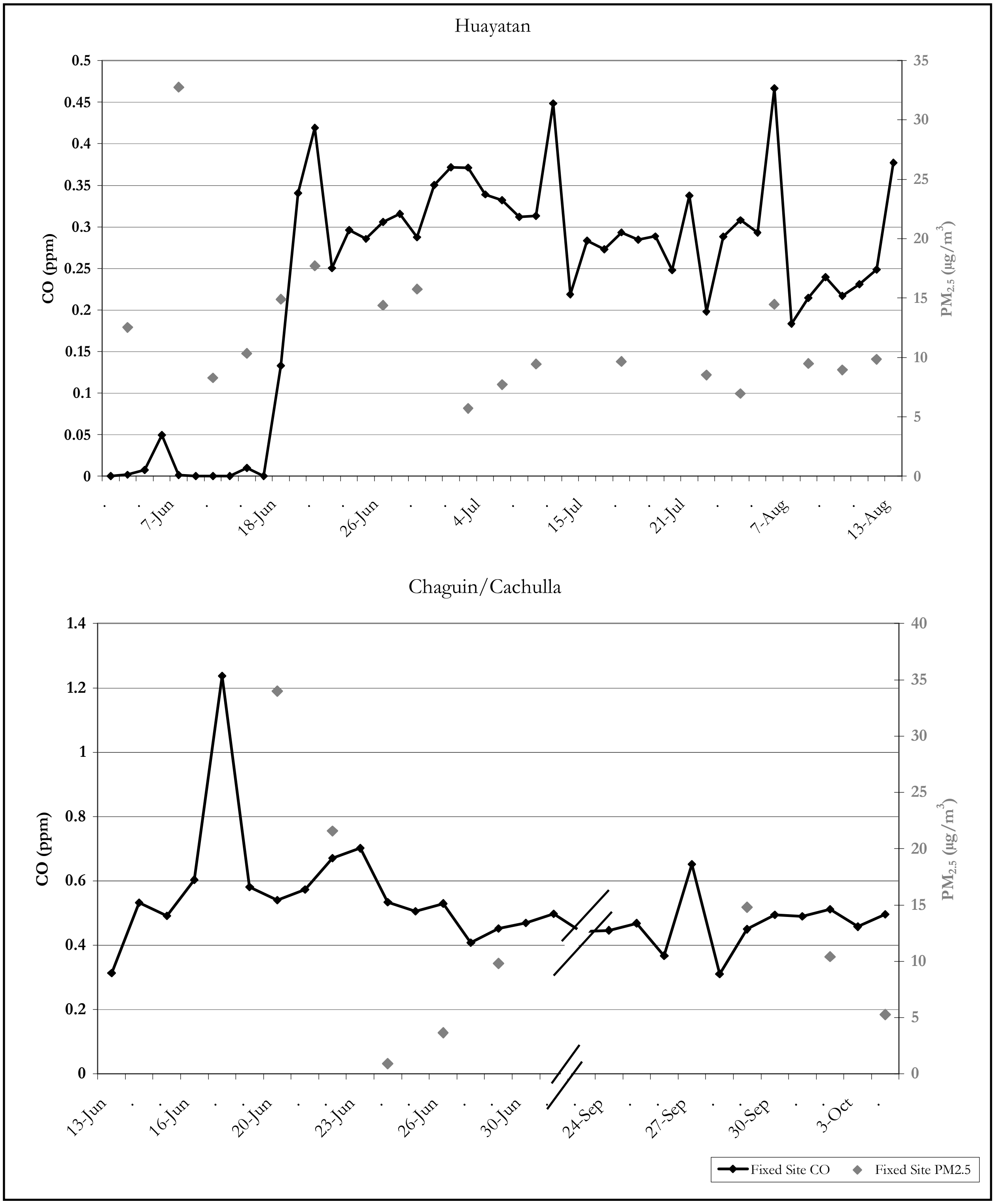

Figure 3.7. Background concentrations of CO and PM$_{2.5}$ as measured at fixed location in each region

Table 3.2. Kitchen concentrations and personal exposure levels for each home, stoves 1 and 2

		$PM_{2.5}$ (µg/m^3)						**CO (ppm)**					
		Kitchen (n=26)			*Personal (n=27)*			*Kitchen (n=25)*			*Personal (n=25)*		
	Home ID	PRE	POST	% RED*	PRE	POST	% RED*	PRE	POST	% RED*	PRE	POST	% RED*
	1	161.6	88.7	*45.1*	65.3	70.0	*-7.1*	4.5	1.9	*58.1*	1.2	0.7	*37.3*
	2	82.8	36.3	*56.2*	40.9	24.8	*39.4*	0.9	0.1	*92.3*	1.7	0.1	*92.1*
S	3	228.0	28.5	*87.5*	152.1	46.6	*69.4*	4.3	0.2	*94.9*	2.3	0.6	*74.6*
T	6	-	-	-	186.2	164.3	*11.8*	6.7	2.6	*60.3*	2.0	1.9	*6.0*
O	7	150.3	48.9	*67.5*	72.7	73.8	*-1.6*	-	-	-	0.5	0.4	*21.6*
V	8	60.8	77.0	*-26.6*	55.8	48.4	*13.3*	-	-	-	-	-	-
E	9	83.4	71.3	*14.5*	36.7	26.2	*28.5*	1.2	0.7	*38.9*	0.1	0.1	*31.5*
	10	85.9	62.5	*27.3*	49.0	89.5	*-82.6*	1.0	0.4	*64.8*	0.7	1.0	*-49.8*
1	11	29.8	33.1	*-11.1*	44.9	109.5	*-143.7*	2.4	0.1	*95.4*	0.5	2.2	*-363.6*
	12	100.9	48.2	*52.3*	46.5	17.2	*62.9*	1.2	0.4	*66.9*	1.9	0.0	*97.8*
	13	140.5	23.7	*83.1*	62.5	34.8	*44.2*	1.42	0.07	*94.7*	0.87	0.06	*93.4*
	14	390.4	89.3	*77.1*	484.3	59.3	*87.8*	3.90	0.85	*78.3*	3.49	0.01	*99.7*
	15	61.2	81.9	*-33.9*	108.2	44.5	*58.8*	0.4	0.5	*-42.2*	1.2	0.3	*74.8*
	17	1075.0	343.4	*68.1*	160.8	59.7	*62.9*	10.1	4.4	*56.4*	1.6	0.5	*71.6*
	18	324.2	87.8	*72.9*	159.0	66.3	*58.3*	5.7	2.9	*48.9*	2.5	0.6	*78.4*
	19	613.3	135.2	*78.0*	203.3	82.5	*59.4*	5.8	1.6	*73.0*	1.3	0.1	*94.4*
	22	29.4	129.5	*-340.4*	52.9	75.7	*-43.2*	3.2	1.2	*63.3*	0.4	0.5	*-20.0*
	24	260.6	73.5	*71.8*	103.8	96.7	*6.9*	4.0	0.8	*81.2*	0.9	1.1	*-26.9*
	25	61.3	60.0	*2.1*	109.4	63.8	*41.7*	0.6	0.2	*64.6*	0.4	0.4	*19.6*
	28	1331.4	376.8	*71.7*	262.8	63.7	*75.8*	12.0	3.6	*70.1*	0.8	0.0	*96.9*
	29	73.2	9.4	*87.1*	221.0	139.4	*36.9*	2.7	0.0	*99.3*	-	-	-
	30	1301.8	141.5	*89.1*	1565.2	116.6	*92.6*	11.1	1.6	*85.6*	3.4	1.4	*58.8*
	31	1067.0	673.8	*36.8*	320.4	269.3	*16.0*	24.8	23.7	*4.5*	2.9	2.3	*19.1*
	32	339.3	111.8	*67.1*	75.2	59.1	*21.4*	5.9	1.6	*72.7*	0.4	0.3	*4.9*
	33	245.4	111.6	*54.5*	69.3	76.4	*-10.2*	5.1	1.1	*78.9*	2.5	0.8	*67.7*
	34	1151.7	276.5	*76.0*	188.5	73.2	*61.1*	13.0	4.5	*65.7*	2.3	0.7	*70.8*
	35	651.7	113.7	*82.6*	180.3	129.4	*28.2*	9.6	1.6	*83.5*	2.6	1.4	*47.0*
	geo $\overline{x}$	207.3	84.7	**59.2**	116.4	68.4	**41.3**	3.6	0.8	**77.7**	1.2	0.4	**69.6**
	95% C.I.	(163, 265)	(66.4, 108)	**(42.4, 71.1)**	(94.6, 143)	(55.6, 84.2)	**(21.2, 56.2)**	(2.6, 4.9)	(0.58, 1.09)	**(65.1, 85.7)**	(0.74, 1.84)	(0.23, 0.56)	**(42.4, 84)**
		(n=19)			*(n=18)*			*(n=17)*			*(n=19)*		
	40	199.5	3.5	*98.2*	185.3	77.2	*58.4*	3.6	7.3	*-105.0*	1.3	2.8	*-118.0*
	41	184.4	70.5	*61.8*	-	-	-	-	-	-	1.3	0.2	*83.1*
S	43	-	-	-	127.2	113.7	*10.6*	3.2	1.8	*45.5*	0.8	0.2	*74.0*
T	45	51.2	70.1	*-36.8*	56.1	28.6	*49.0*	0.5	0.5	*-7.5*	0.2	0.9	*-326.9*
O	47	669.2	155.9	*76.7*	-	-	-	-	-	-	-	-	-
V	48	177.0	17.5	*90.1*	132.6	73.5	*44.6*	-	-	-	-	-	-
E	49	1419.4	825.3	*41.9*	191.1	16.6	*91.3*	-	-	-	2.5	0.7	*72.0*
	50	421.2	136.3	*67.6*	214.5	18.8	*91.2*	5.6	1.7	*69.7*	2.6	1.2	*52.5*
2	51	362.3	10.5	*97.1*	33.3	31.8	*4.5*	-	-	-	-	-	-
	52	52.1	21.8	*58.2*	54.9	28.6	*47.9*	1.2	0.2	*87.8*	0.3	0.0	*95.3*
	53	543.1	170.3	*68.6*	175.6	189.7	*-8.0*	9.7	4.6	*52.9*	1.9	2.0	*-2.1*
	55	170.1	101.6	*40.3*	97.9	137.5	*-40.4*	2.7	2.0	*27.0*	0.5	2.1	*-276.6*
	59	41.2	59.8	*-45.2*	84.1	88.3	*-5.0*	0.5	0.9	*-104.3*	0.2	1.3	*-526.8*
	60	-	-	-	-	-	-	0.7	0.3	*60.3*	0.2	0.5	*-140.1*
	61	160.3	75.4	*53.0*	142.7	80.4	*43.7*	2.9	0.7	*75.4*	1.9	0.7	*63.4*
	63	362.4	88.4	*75.6*	234.9	57.1	*75.7*	6.2	1.5	*75.2*	3.7	0.6	*83.1*
	64	15.8	2.7	*83.2*	281.3	104.8	*62.8*	-	-	-	-	-	-
	65	-	-	-	-	-	-	3.4	0.5	*84.7*	0.4	1.2	*-202.4*
	66	-	-	-	-	-	-	2.3	0.2	*92.0*	1.0	0.2	*78.3*
	67	69.4	16.9	*75.7*	88.9	67.8	*23.7*	0.9	0.2	*81.9*	0.2	0.2	*20.6*
	68	781.0	185.0	*76.3*	239.2	110.2	*53.9*	12.0	3.7	*68.9*	2.4	1.4	*39.4*
	69	17.6	105.0	*-495.5*	109.6	53.8	*51.0*	1.8	0.7	*58.8*	0.9	1.1	*-22.6*
	71	413.5	39.0	*90.6*	160.5	26.3	*83.6*	5.3	0.3	*93.7*	1.1	1.0	*3.8*
	geo $\overline{x}$	173.4	51.1	**70.5**	126.3	58.3	**53.8**	2.5	0.8	**65.6**	0.8	0.6	**25.9**
	95% C.I.	(112, 268)	(33.1, 78.8)	**(45.6, 84.1)**	(96.3, 166)	(44.5, 76.5)	**(32.2, 68.5)**	(1.71, 3.54	(0.59, 1.22)	**(42.4, 79.4)**	(0.53, 1.31)	(0.39, 0.97)	**(-40, 61)**

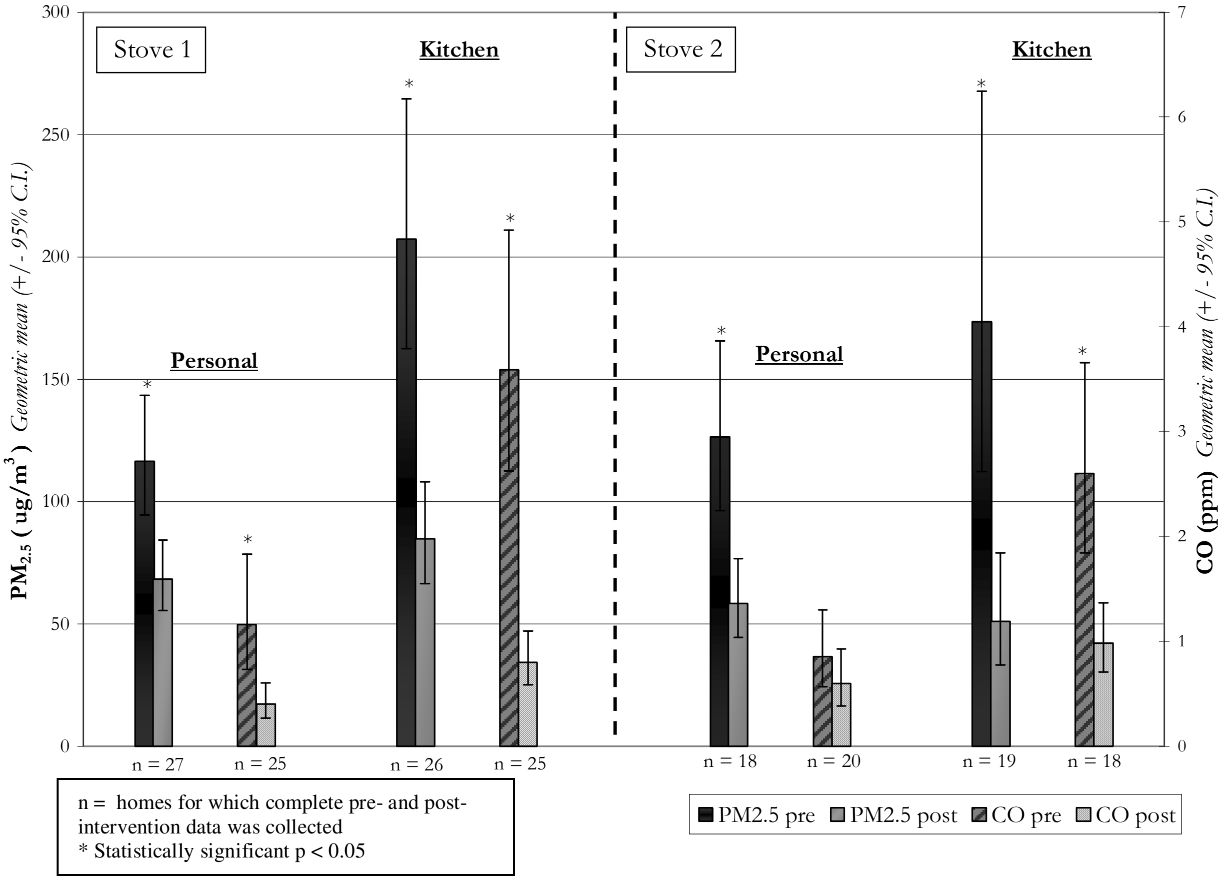

Figure 3.8. Geometric mean reductions of kitchen concentrations and personal exposure to $PM_{2.5}$ and CO, stoves 1 and 2

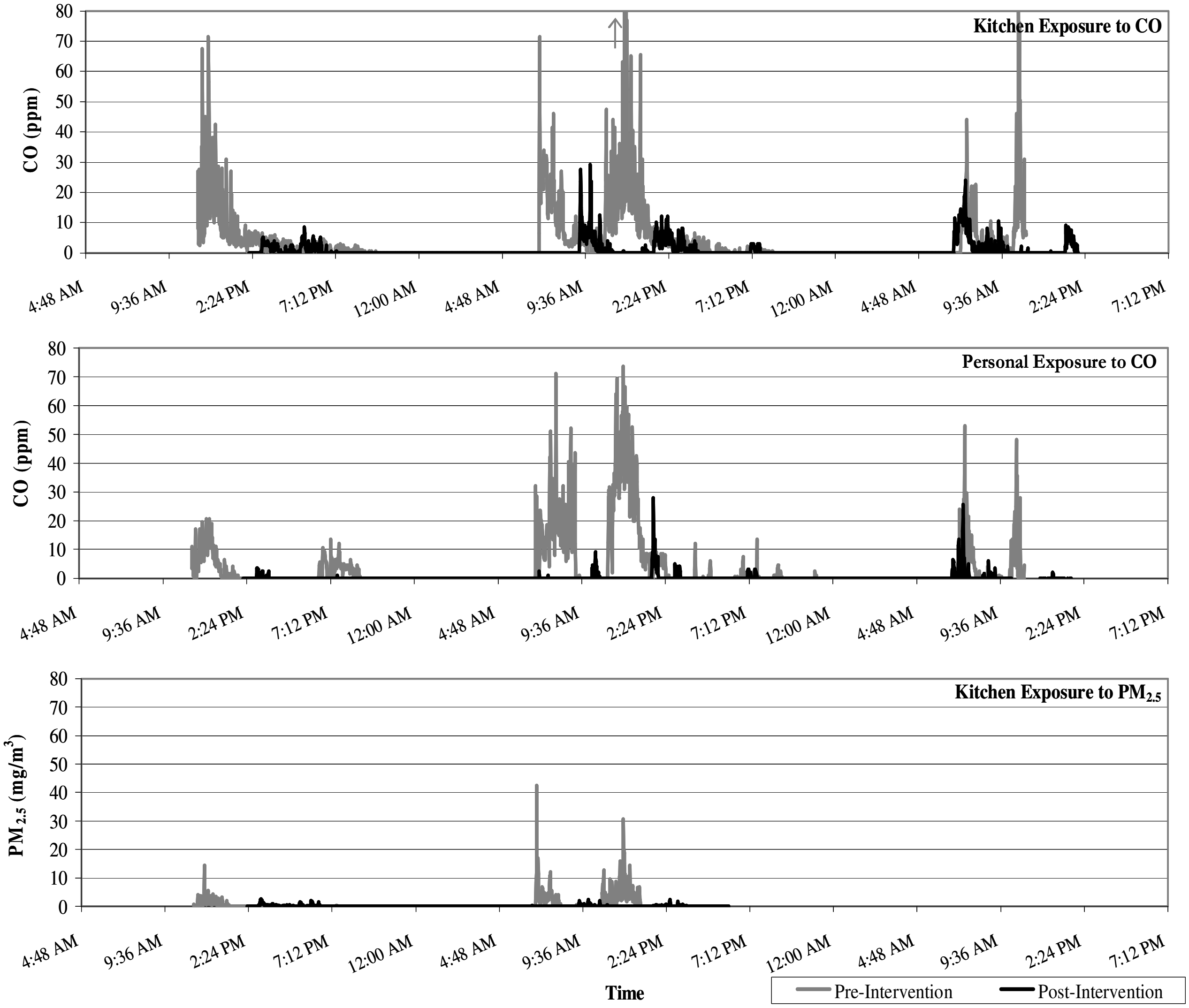

Figure 3.9. Carbon Monoxide and $PM_{2.5}$ real-time measurements in a representative home, before and after the installation of stove model 1

Table 3.3. Summary of air sampling results for reductions in peak concentrations and acute exposures to CO for both stoves and $PM_{2.5}$ for stove 1 only

Improved stove model	Sampling location	Measurement	N	Highest 15-min average† pre-intervention	Range	Highest 15-min average† post-intervention	Range	Average highest peak: pre-intervention‡	Range‡	Average highest peak: post-intervention‡	Range‡
1	Kitchen	$PM_{2.5}$ (mg/m^3)	19	9.2	0.27 - 26.3	1.7	0.3 - 5.0	29.0	2.0 - 71.8	10.0	1.3 - 32.9
		CO (ppm)	25	52.6	6.3 - 366	22.3	0.9 - 196	126.9	14 - 666	60.9	5 - 353
	Personal	CO (ppm)	25	19.4	3.7 - 51.4	10.4	1.7 - 35.8	67.8	18 - 174	38.4	4 - 128
2	Kitchen	CO (ppm)	17	31.7	3.8 - 135	28.4	3.6 - 160	58.5	14 - 155	62.7	9 - 294
	Personal	CO (ppm)	19	16.4	4.1 - 38.1	14.2	0.8 - 36.9	52.9	13 - 146	62.5	17 - 164

† Highest 15-minute average: the average of all the highest 15-minute concentrations recorded in each home

‡ Compare to the OSHA peak (or ceiling) limit of 200 ppm

Table 3.4. Summary results for improved stove models 1 and 2 compared with traditional stoves

Improved Stove Model	Sampling location	Measurement	Stove Type	N	Geometric Mean Concentration (95% C.I.)	**% Reduction** *(95% C.I.)*	F value	Pr > F
1	Kitchen	PM2.5 (µg/m3)	traditional	26	207.3 (163,265)	**59.2**	27.6	< 0.0001
			improved		84.7 (66.4,108)	*(42.4,71.1)*		
		CO (ppm)	traditional	25	3.6 (2.6,4.9)	**77.7**	45.99	< 0.0001
			improved		0.8 (0.58,1.09)	*(65.1,85.7)*		
	Personal	PM2.5 (µg/m3)	traditional	27	116.4 (94.6,143)	**41.3**	13.33	0.0012
			improved		68.4 (55.6,84.2)	*(21.2,56.2)*		
		CO (ppm)	traditional	25	1.2 (0.74,1.84)	**69.6**	14.15	0.001
			improved		0.4 (0.23,0.56)	*(42.4,84)*		
2	Kitchen	PM2.5 (µg/m3)	traditional	19	173.4 (112,268)	**70.5**	16.17	0.0008
			improved		51.1 (33.1,78.8)	*(45.6,84.1)*		
		CO (ppm)	traditional	17	2.5 (1.71,3.54)	**65.6**	19.32	0.0005
			improved		0.8 (0.59,1.22)	*(42.4,79.4)*		
	Personal	PM2.5 (µg/m3)	traditional	18	126.3 (96.3,166)	**53.8**	16.53	0.0008
			improved		58.3 (44.5,76.5)	*(32.2,68.5)*		
		CO (ppm)	traditional	19	0.8 (0.53,1.31)	**25.9**	0.97	0.3371
			improved		0.6 (0.39,0.97)	*(-40,61)*		

Table 3.5. Summary of results from improved cookstove research around the world

Reference	Year	Study Region	% Reduction
Naeher et al.	2000	Western highlands, Guatemala	22-hr kitchen PM2.5 reduced 84% 22-hr personal PM2.5 reduced 46.6% 22-hr kitchen CO reduced 76% 22-hr personal CO reduced 64%
Bruce et al.	2004	La Victoria, Guatemala	24-hr kitchen CO reduced 76%
Masera et al.	2007	Michoacán, Mexico	48-hr kitchen PM2.5 reduced 67% 48-hr kitchen CO reduced 66%
Cynthia et al.	2008	Michoacán, Mexico	24-hr personal PM2.5 reduced 35% 24-hr personal CO reduced 78%
Edwards et al.	2007	Throughout China	24-hr kitchen PM4 reduced 43% 24-hr kitchen CO reduced 62%
Dutta et al.	2007	Pune, India	48-hr kitchen PM2.5 reduced 49% 48-hr kitchen CO reduced 38%
Chengappa et al.	2007	Bundelkhand, India	48-hr kitchen PM2.5 reduced 44% 48-hr kitchen CO reduced 70%
Fitzgerald et al.	Current study	Santiago de Chuco, Peru	48-hr kitchen PM2.5 reduced 59.2% (70.5%)* 48-hr personal PM2.5 reduced 41.3% (53.8%) 48-hr kitchen CO reduced 77.7% (65.6%) 48-hr personal CO reduced 69.6% (25.9%)

* values are for stove 1 (stove 2)

Table 3.6. Air quality standards

Pollution	Averaging times	USEPA NAAQS[1]	NIOSH TLV[2]	OSHA TWA[3]	WHO[4]
Particulate matter with aerodynamic diameter 2.5 µm or smaller ($PM_{2.5}$)	24-hr	35 µg/m3			25 µg/m^3
	8-hr			5 mg/m^3	
Carbon monoxide (CO)	8-hr	9 ppm		50 ppm	8.7 ppm
	1-hr	35 ppm			26 ppm
	Ceiling limit		200 ppm		

1. EPA. "National Primary and Secondary Ambient Air Quality Standards," US E.P.A., 2005.
2. National Institute of Occupational Safety and Health Administration Threshold Limit Value (http://www.cdc.gov/niosh/pdfs/00-14075.pdf.html)
3. OSHA. "Occupational Safety and Health Standards: Toxic and Hazardous Substances," in OSHA, ed., 1910.1000, 1992.
4. WHO. "Air quality and health," Fact Sheet 313 (2008).

CHAPTER 4

DISCUSSION AND CONCLUSIONS

Discussion

As knowledge increases in both the health effects of indoor air pollution from solid fuel combustion and the potential solutions, improved cookstove intervention is becoming more common and widespread. Large-scale dissemination of improved stoves has great potential to reverse the trends of mortality and morbidity caused by indoor air pollution, especially in the developing world. The Peruvian government, local industries and other groups have reacted to that fact with the distribution of improved stove models such as stove 1 and stove 2 presented here. Field-testing is an essential component for understanding the potential benefits of these new stoves, as well as the overall effectiveness of the intervention programs. Every community is different, and the information discussed here is meant to aid those offering these particular stoves in their specific regions of influence. Even so, much of what follows also has a broader application for cookstove interventions around the world. ICS programs in developing countries have consistently proved successful in the reduction of kitchen concentrations and personal exposures to indoor air pollution. Our research indicates similarly positive results from these two stove models as evaluated in three separate communities of North-Central, Andean Peru.

In the community receiving stove 1, paired comparisons of 48-hr personal exposure to CO and $PM_{2.5}$ indicated reductions of 69.6% and 41.3%, respectively. Similarly, paired comparisons of 48-hr CO and $PM_{2.5}$ kitchen concentrations revealed overall reductions of 77.7% and 59.2%. In the second community, corresponding reductions after installation of stove model

2 were observed at 25.9%, 53.8%, 65.6% and 70.5%. All values for both communities are statistically significant ($p < 0.05$) with the exception of personal CO with stove 2. These new stoves offer improvements on traditional methods, and most of these percent reductions are consistent with other studies around the world, falling within or above the range of what might be expected from the literature (Table 3.5).

When considering CO, the average 48-hour levels seem quite low even before the intervention. However, the more important change offered by a new stove is actually the reduction of acute high exposures. These peak exposures occur around mealtimes or whenever the fire is tended to, and are generally lost in the averages. Thus, while the mean reductions in CO exposure look relatively insignificant, the seemingly small change in pollutant concentrations over 48 hours is indicative of many large changes in peak values throughout the sampling period. An example of this can be seen in Figure 3.9, where great reductions are shown in the acute CO exposures occurring during peak stove use each day. Reductions in acute exposure were consistent across the board with stove 1. Stove 2 did not show this trend, though an overall reduction in CO was still achieved.

A relatively smoke-free kitchen reverses what has been the norm for many generations, and the women could see no logical reason to change the way things were. This brings light to the importance of proper education about woodsmoke and health, which could be very helpful to the acceptance and continued use of any new cookstove. Personal exposures did not reduce as much as kitchen levels, but this is consistent with other studies and is not a surprising outcome, as women are exposed throughout the day to sources of pollution beyond their own kitchen (such as other homes still using traditional stoves). This also highlights the limitations in using kitchen concentrations alone as a proxy measure for potential improvements in human health. We chose to incorporate both kitchen and personal measurements so that we might not only see the drop in pollutant emissions within the home, but also to observe the extent to which that drop actually impacts personal exposure.

Beyond the actual improvements shown by our air monitoring equipment, most participants also expressed true enjoyment of their new stove. Many women found that they needed less wood and less time to cook meals, which could potentially be a factor in the overall reduction of IAP. Great improvements were seen in both communities with the installation of new stoves, and with the exception of one statistically insignificant reduction, both stoves worked as well as we had hoped. The post-intervention exposure levels may still seem high in comparison to the developed world, but they are truly impressive in the context of a rural kitchen in the developing world. In communities where background levels of pollution alone may often exceed WHO and EPA air quality guidelines (Table 3.6), the exposure reductions experienced by these women certainly indicate great progress.

Conclusions

Despite the differences in the people of each community, as well as the differences in the improved stove models and intervention programs we investigated, the final conclusions of this study are virtually the same for everyone involved. Both stoves, when properly installed and used, will reduce levels of Carbon Monoxide and $PM_{2.5}$, most notably in the kitchen environment but also on the personal level as well. In communities and environments similar to those seen here, these stoves have great potential to improve quality of life and help reverse the trends of ill health caused by indoor air pollution.