The Effects of Traditional Cooking Technologies and Small Control Interventions on Indoor Air Quality in Cayo Paloma, Panama

By

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This report, "The Effects of Traditional Cooking Technologies and Small Control Interventions on Indoor Air Quality in Cayo Paloma, Panama", is hereby approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN ENVIRONMENTAL ENGINEERING.

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Preface

The study which forms the basis of this report was planned and implemented during the author's twenty-five month service with the Peace Corps in the Republic of Panama. During his service, the author was assigned to the small coastal town of Cayo Paloma, located in the Comarca Ngäbe-Bugle indigenous region, where he lived and worked at the local level. As an Environmental Health extension agent, the author's sector specific work involved helping to organize and train community water committees and also to help design, plan, and implement four water infrastructure improvement projects in Cayo Paloma and the surrounding communities. In addition to the water improvement projects the author worked with the local womens' artisan group and local health assistant to improve organization and community health awareness.

This report was completed in partial fulfillment of the requirements for a Masters of Science degree in Environmental Engineering as part of the author's participation in the Masters International Program through the Peace Corps and the Civil and Environmental Engineering Department at Michigan Technological University. The research and project plan of this study where coordinated with the author's advisor at Michigan Tech and the actual measurements of indoor air quality were coordinated with the local people, especially the women of the various households.

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Abstract

It has been estimated that around the world 2 million people die each year because of the effects of unhealthy indoor air quality. Acute respiratory infections, a likely effect of exposure to large amounts of air pollution in the home, are the number one killer worldwide of children under the age of five. Unhealthy indoor air quality is especially a problem in developing nations because upwards of about 90% of rural households use unprocessed solid fuels for their cooking and heating needs. The burning of biomass fuels produces many toxic compounds, carbon monoxide gas and, most importantly, coarse and fine particulate matter which can infiltrate the airways and deep into the lungs of those exposed to it. While there is thus a large impact on human health in the developing world from the use of solid fuels, information on pollutant exposures, specific health effects, control technologies and health interventions is much scarcer then that related to outdoor air pollution or indoor air pollution in the industrialized nations.

For this study carbon monoxide and PM2.5 monitoring took place in a total of ten households in a small indigenous community in rural Panama in an attempt to describe the current indoor air quality situation in the area and to judge the effect of different cooking technologies on the indoor environment. The cooking technologies studied were the traditional open cooking fire of the area, LPG stoves, and a modified version of the standard fire box. Measurements were made on a minute basis using the TSI DustTrak (PM2.5, resolution of 1 $\mu g/m^3$) and TSI Q-Trak (CO, resolution of 1 ppm). It was found that PM2.5 concentrations produced during the use of the traditional open fires exceeded background values by a large margin (on average by a factor of about ten to twenty times). The use of the traditional cooking fire resulted in 24-hr mean concentrations that were seven or more times greater than the guidelines recommended by the WHO. The use of the LPG stove was shown to reduce PM2.5 exposures by about 92% on average and CO exposures by about 47% on average as compared to the use of the standard cooking fire, but its cost prohibited wider use. It was found that the modification of one traditional fire box resulted in an 82% reduction in the geometric mean PM2.5 concentration experienced in the cooking space.

Acknowledgements

I would like to thank my advisor, Professor Kurt Paterson, for his willingness to provide me with the instruments needed to collect the indoor air quality data and for his guidance in analyzing this data and reporting its implications. I would also like to thank him for providing shelter for a thin-blooded RPCV unused to winter, never mind winter in Houghton, MI.

I would like to thank Professors Brad Baltensperger, Brian Barkdoll and Tom Van Dam for being part of my defense committee and for dealing with my rushed defense schedule.

I would like to thank Greg Branch, my APCD during my Peace Corps service, for helping with some of the logistics involved in my air quality study and for generally being a good director to work with.

I would also like to thank the rest of the staff of PC Panama for their inspiration and for allowing me to live and work and study knowing that all my administrative and medical issues were in good hands.

Thanks to Josephine for her support throughout my Peace Corps service and graduate school experience.

Thanks to the other PC Volunteers in Panama for making the experience enjoyable.

I would like to thank the people of Cayo Paloma and the surrounding area for sharing their lives with me and making my Peace Corps service worth it.

And finally, special thanks to Evangelino Goodman and his family, for being my friends and guides, to Alfredo Ellington for allowing me to destroy part of his house, to Leopoldo Santiago for his help in collecting community information, and to all the inhabitants, especially the women, of the test households who let me take over their kitchens for a while.

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Chapter 1: Introduction and Study Objectives

This chapter provides brief background and general health information on the country of Panama, the Comarca Ngäbe-Bugle, and the community of Cayo Paloma and then discusses the study's motivation and objectives. The chapter ends with an outline for the remainder of this report.

1.1 Background on Panama and the Comarca Ngäbe-Bugle

The Republic of Panama is historically known for its famous canal linking the Caribbean Sea and the Pacific Ocean and is considered to be one of the richer nations of Central America. Panama is described as having high human development by the United Nations with a HDI rank of 8.09 (UN 2006). It had an estimated GDP per capita of $4,325 with 75% of the GDP coming from services (the Canal, banking, the Colon Free Trade Zone), 10% from agriculture (mostly sugarcane, coffee and bananas) and about 12% from industry (UN 2006, worldinformation.com 2006).

This wealth is not evenly distributed throughout the country. While only 15% of the urban population lives below the poverty line, at least 65% of the population in rural areas does, and the richest 10% of the population controls 43.3% of the wealth while the poorest 10% control only 2.4% of the wealth (UN 2006, worldinformation.com 2006). This poorest 10% includes a very large majority of the indigenous population in Panama which makes up about 6% of the total population of 3.23 million (UN 2006, worldinformation.com 2006). A study of poverty and indigenous peoples found that 83% of the indigenous population of Panama lives below the poverty line (Vakis and Lindert 2000).

The most populous indigenous group is the Ngäbe (pronounced Nobay, sometimes spelled Ngöbe), which is also the poorest group in Panama with 92% living in poverty. In 2006, the Ngäbe population was reported as 132,376 and they have traditionally lived in part of the area which now compromises the provinces of Veraguas, Chiriqui and Bocas del Toro in western Panama (MINSA 2006). In 1997, the Comarca Ngäbe-Bugle, a semi-autonomous region, was officially acknowledged and territory was carved out of the three provinces mentioned above in order to allow the Ngäbe people (and the smaller group of culturally similar Bugle people) more political control over their culture and natural resources (see Figure 1).

Inside the Comarca Ngäbe-Bugle there exists both the Panamanian national government and its agencies which control public funding and revenue collection and a system of traditional leaders under the Comarca-wide Congress which has authority over natural resources and cultural issues. An indicator of the disparity in development between the area of the Comarca Ngäbe-Bugle and the Republic of Panama as a whole is that while 87.13% of the total population has access to improved potable water systems, only 30% of the population living in the Comarca does. The disparity in access to improved sanitation is similar with 90% of the total population having access as compared to only about 30% of the Comarca population (ANAM, 2006). According to the Ministry of Health, the principal cause of death in all age groups throughout the Comarca is common respiratory infections (MINSA 2006).

Figure 1: Political Map of Panama showing provincial and Comarca divisions (Wikipedia 2005).

Figure 2: Political Map of the Comarca Ngäbe-Bugle with Regional Boundaries (Adapted from Jaen, and Baules. 2002).

The Comarca is separated into three regions with Käderi and Nidrini in the south and Nö Kribö in the north (Figure 2). The Nö Kribö region is separated from the others by the existence of the main *Cordillera* (mountain range) which divides the western half of Panama. This region thus experiences a different seasonal pattern then the other regions. There are two rainier seasons (Nov – Feb, May – Aug) and two dryer ones (Mar – Apr, Sep – Oct) and an average yearly rainfall of about two and a half to three meters in the Nö Kribö region. The Ngäbe of Nö Kribö have lost more of their older traditions and generally have had more contact with the Afro-Caribbean culture and North American tourist and ex-patriot communities then the Ngäbe of the southern regions.

1.2 The Community of Cayo Paloma

Cayo Paloma, the small community where this indoor air quality study was performed and which was the author's home for two years, is located in the Nö Kribö Region of the Comarca Ngäbe-Bugle on the Peninsula Valiente, which sticks out into the Caribbean Sea (see Figure 3). The Peninsula Valiente is home to mostly people of indigenous Ngäbe ancestry though there are some Afro-Caribbean families and some of mixed Ngäbe/Afro-Caribbean/Caucasian blood. There are no roads on the Peninsula Valiente and transportation from the port of Chiriqui Grande on the mainland requires a two and a half to three and a half hour motorized boat ride. Transportation from Cayo Paloma to the district capital of Kusapin, where there is a medical center and a high school, involves a two hour walk, a 45 minute canoe trip or a 20 minute motorized boat ride. The medical center is run by the Ministry of Health (MINSA is the Spanish acronym) and staffs a doctor, who the local health assistants report to, as well as a dentist, nurses, vector control extensionists, two water and sanitation technicians and an emergency boat driver.

Figure 3: Map of the Peninsula Valiente region. (Adapted from Jaen, B. and A. Baules. 2002.)

Cayo Paloma is home to about 240 indigenous Ngäbe who are mostly fishermen and subsistence agriculturalists. In addition to fishing and low intensity farming some members of the community are carpenters, boat makers, masons, medicine men, lobster divers and store owners. One survey performed by the local health assistant found that the average household income in Cayo Paloma was about $44 per month putting them below the one dollar per day per person poverty mark. Many young men, and some younger women, migrate, generally for a few months but sometimes for a few years, to either the mainland banana plantations of Bocas del Toro Province or to the tourist hotspot of Isla Colon to earn extra money for their family. This movement of people affects the total population of Cayo Paloma during any period of time but generally the average family size is about 6.5 people though there are households that shelter up to 13 or more family members.

Culturally the area is heavily influenced by the Afro-Caribbean pop culture, exchange with the tourists and land owners on Isla Colon or with the banana company and is especially influenced by the many Christian denominations. The majority of the community members belong to the Jehovah's Witness organization though some families pertain to either the Methodist church or to the local MamaTata church which is a kind of "back to our roots" movement mixed with Catholicism. Very little of the older traditions now survive in Cayo Paloma or the rest of the Peninsula region. The only traditions that do remain can be found in some of the foods the community members cook, in some of the community's work ethic and in some of the artistry made for income generating purposes. There is a functioning and growing women's artisan group in Cayo Paloma which mostly concentrates on making modern coconut jewelry for sale to tourists but which has also begun trying to reinstitute some of the older arts both for income generation and to help with deteriorating community cohesion.

The community contains a relatively new elementary school, a meeting hall and community cooking area, a brand new Jehovah's Witness Kingdom Hall, a 20 year old community aqueduct, and an older small-sized health post. Currently most children graduate at least 6th grade though many of their parents have not. The school attendance rate drops off rapidly in the older grades in high school. The health post is manned by the local Health Assistant who lives in the community and whose job includes distributing vaccinations and medications (when there are any) as well as basic health consultation work and increasing health and hygiene awareness in the community. There is also an electrical generator that has been broken for at least the past three and a half years. Two community members own their own small diesel generators and one house, the health post and the new Kingdom Hall all have small solar cell/ battery systems mostly used to run lights and radios. Figure 4 is a photo of the main area of Cayo Paloma.

Figure 4: Photo of the community of Cayo Paloma.

About 90% of the households in Cayo Paloma are connected to and use water from the 20 year old aqueduct which has a clean spring source and a brand new water storage tank. The remaining households (numbering about four) obtain their water for washing, cooking, cleaning and drinking from uncovered springs on their own land. Standard pit latrine coverage is about 76%, thanks in part to a previous Peace Corps latrine project, and observed correct usage runs around 90% for those families that have latrines. Those without latrines or without the will to use their latrines as well as many very young children simply use the various small creeks that run through the community for their sanitary needs. Trash is buried, burnt or sometimes thrown into the ocean. The most common health problems in the village are the common cold/respiratory infections, skin infections, and diarrhea. Almost everyone, if not everyone, has enough to eat on a daily basis though some children suffer from a lack of proper protein, vitamins and minerals.

1.3 Study Motivation and Objectives

The motivation to study the indoor air quality in the households of Cayo Paloma came out of the author's experiences both living with a host family for three months at the beginning of his service and from visiting other homes in the area as part of daily life and work. Seeing and experiencing the heavy smoke in both cooking and living areas of many homes and speaking and visiting many men, children and especially women who coughed violently and complained about headaches and eye soreness led the author to take an interest in studying the indoor air quality and possible methods to improve it.

The general goals of this project were to determine the indoor air quality conditions in the homes of the area as a result of the traditional cooking technologies and methods and also to determine the effectiveness of different cooking technology and cooking space improvements in decreasing the exposure to indoor air pollution.

Specifically, there were three main objectives of this study:

1. To determine the indoor air quality in the homes in Cayo Paloma, measuring carbon monoxide and fine particulate, plus conducting household inspections and health surveys.

2. To study the effectiveness of using gas propane stoves in reducing exposure to carbon monoxide and fine particulate.

3. To study the effectiveness of simple modifications to the traditional cooking fire area in reducing exposure to high concentrations of carbon monoxide and fine particulates.

More specific information concerning each of these objectives and the process used in completing them is provided in Chapter 4: Experimental Methodology.

1.4 Report Outline

Chapter 2 provides a description of the indoor air quality in less developed countries and its important impact on public health. Also provided is a short discussion of possible health and technological interventions. Chapter 3 discusses the current climate, housing and cooking situation in Cayo Paloma in order to provide an idea of the experimental setting. Chapter 4 then describes the experimental design and methodology. Chapter 5 provides the results of the pollutant concentration measurements and their implications, and Chapter 6 contains the conclusions drawn from this study and recommendations concerning further work and research. Health and indoor air survey results and physical descriptions of the test houses can be found in Appendices A and B. The annotated raw test data for each of the test houses can be found in Appendix C and instrumentation information can be found in Appendix D.

Chapter 2: Indoor Air Quality and the Developing World

This Chapter provides the larger background picture for the study in terms of indoor air quality and health specifically focusing on issues that arise from the use of biomass fuels in the developing regions of the world.

2.1 Background on Indoor Air Pollution in the Developed World

Indoor air pollution has been a problem since human beings first moved into temperate latitudes and subsequently, inside. In fact, until the 1960s, air quality issues were mostly concerned with indoor air pollution in contrast to outdoor or ambient air pollution. Historically, at least in the more developed countries, these issues centered on indoor air quality as it related to comfort for the inhabitants of the indoor environment more so than how indoor air quality was related directly to the health of the inhabitants (Sundell 2004). In the most recent century, as more and more people have found themselves indoors whether it be for work or recreation or living, and because of technological and demographic changes, the effects of indoor air quality as relates to human health has become much more of an important issue. Indoor air quality has also become more of an issue in the industrial world because as homes are designed to be more energy efficient, in order to cut down on energy use and subsequent ambient air pollution, they are usually made to be more sealed off from the outside which decreases the exchange of fresh air.

In 1990 it was estimated that about 73% of the global person-hours take place inside of a human built structure with almost half (31%) of these person-hours taking place in the Rural Indoor setting of the developing world (Smith 1993). Over 50% of a person's air intake is said to occur inside the home over the course of that person's life. (Sundell 2004). Most ambient air pollution also eventually affects the indoor environment as well (Smith 2003). Thus, as Sundell points out, "Indoor air quality is a dominant exposure for humans" even though sources of ambient air pollution emit higher absolute quantities of pollutants.

If the indoor air was clean of pollutants and of a comfortable temperature and relative humidity it would not negatively impact human health as much. The most common indoor air pollutants that affect human health include carbon monoxide (CO), sulfur oxides, nitrogen oxides and particulate matter (PM2.5) emitted from incomplete combustion processes, ozone, volatile organic compounds (VOC) emitted from various sources, biological contaminants such as molds, and radon gas released from the soil.

Households in different areas of the world have differing indoor pollutant concentrations which lead to differing health concerns. In the industrialized nations health concerns stemming from indoor air pollution include allergies and airway infections due to high levels of biological contaminants, dust, and low ventilation rates, and cancer, which is linked to main stream or environmental tobacco smoke (ETS) as well as radon gas (Sundell 2004). As developing nations become wealthier these issues, especially ETS, are becoming more prevalent problems, adding to the burden of disease already experienced because of the use of unprocessed solid fuels (Bruce et al. 2002).

2.2 Developing Countries: Solid Fuel and Indoor Air

Indoor air pollution has been implicated in the deaths of more than two million people a year and it is calculated as being responsible for 2.6% of the all ill-health in the world (Smith-Siversten et al. 2004). This puts indoor air pollution, ranked 8^{th} by the World Health Organization (WHO) on a scale of worldwide risk factors, very close to the lack of clean water and appropriate sanitation in terms of its effect upon human health throughout the world.

Throughout the developing world in general the majority of air pollution is emitted from fuel combustion, especially unprocessed biomass fuels which emit mostly carbon monoxide and particulate matter as well as other toxic materials and gases. In the less developed countries up to 90% of the rural households use unprocessed solid fuels for their daily cooking and heating needs and thus the inhabitants of these households are exposed 3-7 hours a day to high levels of pollution (Bruce et al. 2002). In all, 4-5% percent of the total deaths and disability adjusted life years (DALY) for the less developed countries from acute respiratory infections (ARI), chronic obstructive pulmonary disease (COPD), TB, asthma, lung cancer, ischemic heart disease and blindness can be attributed to solid fuel use (Smith 2003).

ARI and COPD are the disease categories connected to indoor air pollution in the developing world by most studies available. In children under the age of five, ARIs caused by exposure to indoor air pollution is the largest category of deaths (64%) and DALYs (81%) (Smith 2003). In general, ARIs, which do have causes other than indoor air pollution, are responsible for more childhood mortality then the other main killer of children, diarrhea (Smith 2000). Also it has been calculated that 22% of the global burden of disease due to COPD, which is the world's sixth leading cause of death, can be attributed to indoor smoke. More striking is that 40-45% of the burden of this same category of disease experienced by women in the developing world is caused by indoor air pollution from solid fuel use (Smith-Sivertsen et al. 2004).

Other health effects from high concentrations of indoor air pollutants of the type found in developing nation homes include otitis media (middle ear infection) and low birth weight. In general though there is a lack of adequate research that would generate a more precise picture of the effects of indoor air pollution of the magnitude observed in the developing world generated due to solid fuel use (Bruce et al. 2002).

While other pollutants play a role in the effect on human health in rural indoor settings, particulate matter is seen as the most harmful, mostly because of the ability of these particles to impact the upper airways (PM10, or particles less than 10 μm in diameter) and, more importantly, to allow penetration deep into the lower lungs (PM2.5, particles less than 2.5 μm in diameter). With respiratory infections and other lung related diseases topping the list of dangers due to indoor air pollution, the properties of fine particulate matter make its impact on world health high. Like the scarcity of information on health effects, there is not much data on pollutant concentrations to which people of the rural developing world are exposed.

Noting the above, the data that is available suggests that particulate levels in rural homes can exceed standard health guidelines by many times. The WHO, in a study of published research, concluded that 24-hr mean concentrations for PM10 found in developing world homes ranged from 300 to more than 3000 $\mu g/m^3$ and that during stove use concentrations could reach 20,000 to 30,000 $\mu g/m^3$ (Bruce et al. 2002). The 2006 WHO air quality guidelines, based upon current estimations of the health impact of particulate matter, are set at only 50 $\mu g/m^3$ for PM10 (WHO 2006).

Fewer measurements have been taken of the concentrations of PM2.5 in the developing world even though it is generally considered more dangerous to human health. Studies of open cooking fires in rural Guatemala measured 24-hr mean PM2.5 concentrations of 520 to 868 $\mu g/m^3$ whereas current standards for the pollutant are set at 25 $\mu g/m^3$ (15 $\mu g/m^3$ in the U.S.) based on the most recent health data (Albalak et al. 2001, WHO 2006). Similar studies that incorporate carbon monoxide, another main solid fuel-emitted pollutant, show similarly high concentrations, surpassing current health standards.

While the WHO guidelines were developed for ambient air pollution, and it is unclear how health effects accumulate at such extreme pollutant concentrations, the fact that indoor concentrations of particulates can be so high and that such a large number of people are affected means that the issue of indoor air quality has great need of continued research and action (Smith 2002).

2.3 Air Quality Control Technologies and Health Interventions

In general, as a household moves up the "energy ladder", shown in Figure 5, the indoor air quality of the household improves in terms of particulate matter and carbon monoxide and it is assumed that ARI and COPD rates, as well as the rates of other diseases associated with indoor air pollution, decrease because of the improved situation.

Because moving up the energy latter almost always involves an associated rising of economic status, many households of the developing world continue to use inefficient open fires and cook stoves because of the lack of monetary resources. Liquefied petroleum gas (LPG) stoves are seen as a good transition technology but are costly (Bruce et al. 2002) and have the disadvantage of being non-renewable. The health and engineering development challenge of dealing with indoor air pollution in rural areas is to provide improved indoor air quality without the usual monetary costs associated with moving up the energy ladder. This would help to make people, "healthy before they are wealthy" and spur further development (Smith 2002). This involves both the implementation of new cooking technologies as well as new cooking methods and health interventions.

There is a wide range of factors that influence the indoor air quality and thus the human health in rural households (Figure 6). Interventions, whether technical, educational or social in nature, can be accomplished at different places along the general path from cooking technology to human effects (Figure 7).

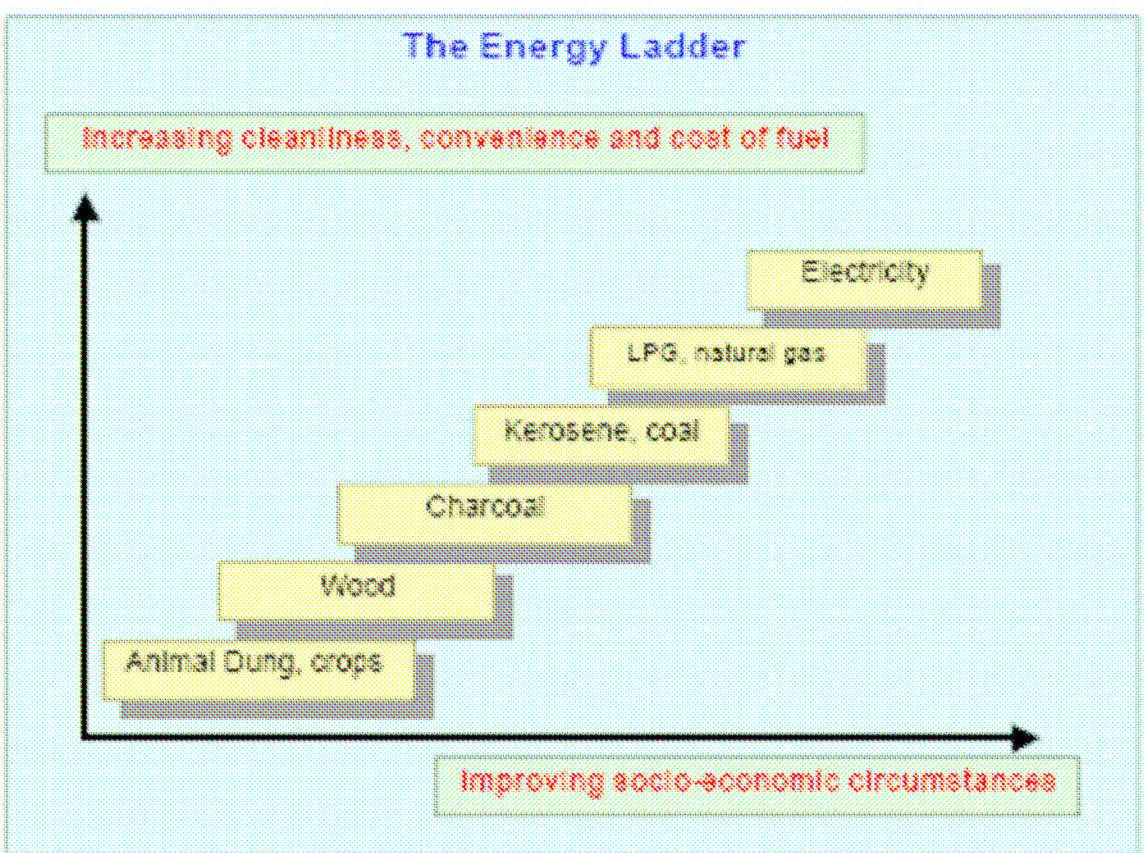

Figure 5: The Energy Ladder, showing cooking technologies and their association with household economic status and cleanliness (Adapted from Smith et al. 1994).

In terms of new cooking technologies there are three main approaches to ensure cleaner indoor air: substituting alternative fuels, increasing cook stove efficiency so that pollutant emissions are decreased and/or implementing flues and chimney structures to remove the pollutants from the cooking and living spaces. Substituting alternative fuels like biogas is one way to improve air quality but requires much more cultural and technological transition. A combination of the other two approaches would probably be the best if needed. The improved stove approach has the added benefit of decreasing fuel use but also the main drawback of being usually more expensive then the chimney approach and harder to accomplish engineering-wise. The chimney implementation approach has the advantage of being relatively simple but the drawback of shifting the pollution outside as opposed to actually preventing it. As alluded to above, any new technology must be appropriate to the cooking culture and habits of the local area and/or educational efforts must be undertaken to ensure the proper use of the new technologies.

The use of simple yet effective alternative intermediate technologies might also have their own advantages over simply rising up the traditional energy ladder as one becomes wealthier. The cost and non-renewable aspects associated with energy derived from fossil fuels such as propane or natural gas could possibly be circumvented through the use of high efficiency wood stoves or other alternative technologies that work on simpler and/or more local technologies. For example, LPG stoves emit much less indoor air pollution than open cook fires but also make the households using them more dependent on external economic conditions whereas highly efficient wood stoves could improve indoor air quality while depending only on local renewable resources.

Unfortunately, research into the development and efficiency of new cooking technologies for the developing world is scarcer than that for industrial nations. Of the few studies that have been done, most have relied on observational designs as opposed to strict randomized trials and, as mentioned above, few have actually measured pollutant exposure directly (Smith 2004).

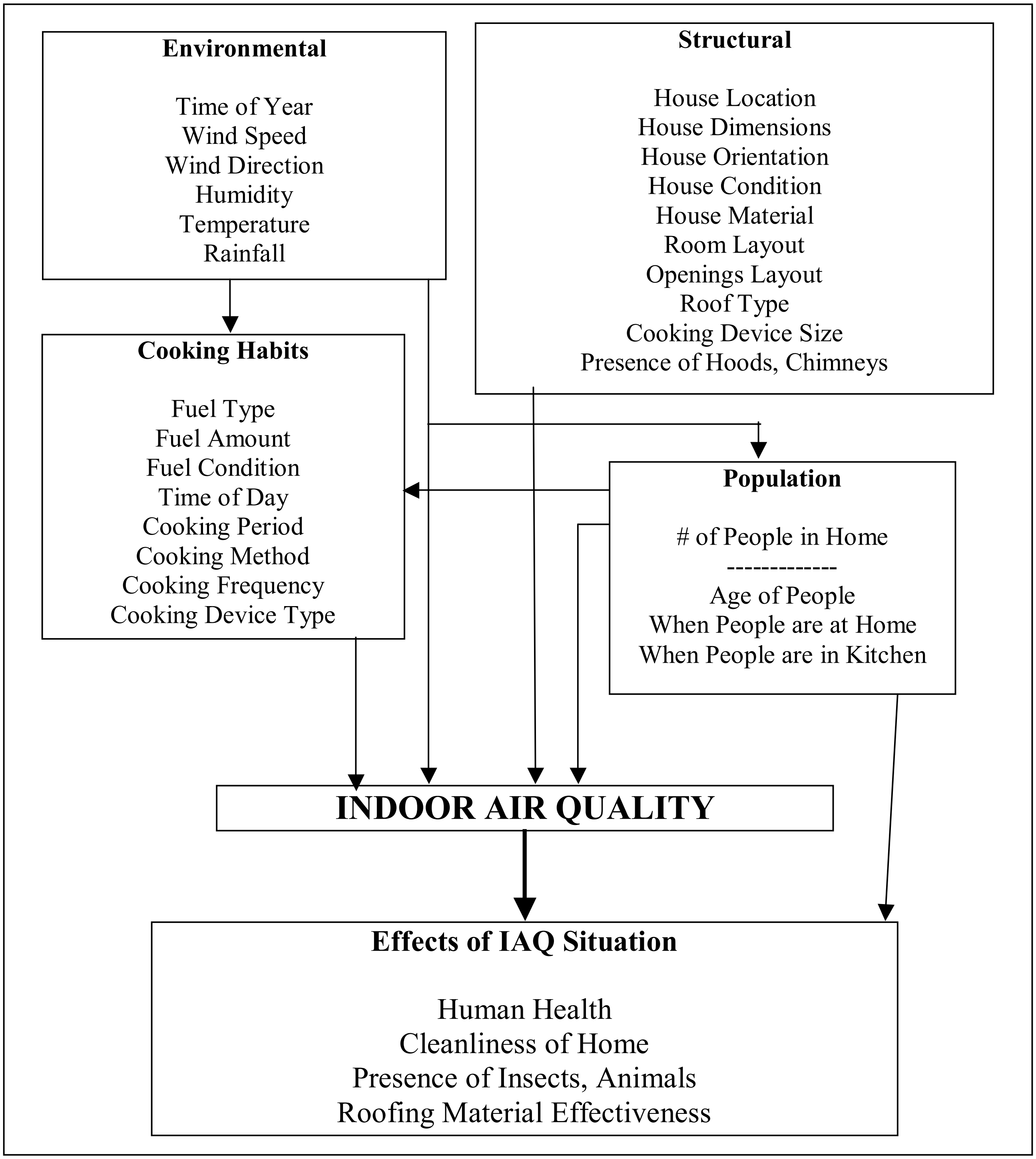

Figure 6: Schematic of factors that can influence indoor air quality in rural households.

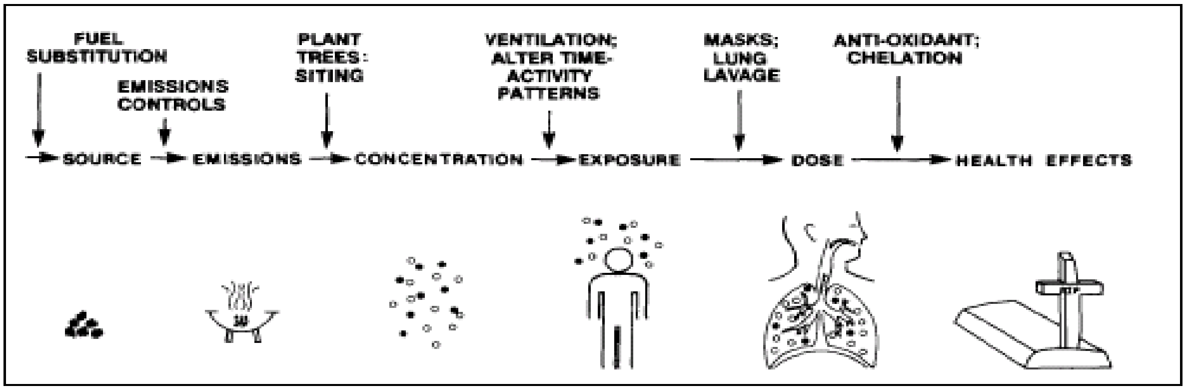

Figure 7: Schematic showing pathway for combustion-derived air pollution affecting human health. At different locations along the pathway different options are available in terms of health interventions (Adapted from Smith 1993).

The largest group study to measure the efficiency of new stove design, as well as gather exposure and health data has taken place in the rural highlands of Guatemala (Naeher et al. 2000, Albalak et al. 2001, Smith-Sivertsen et al. 2004). In one study that took place in 1993, kitchen area monitoring taken over 22-hr periods in nine houses and personal monitoring taken over 10-12 hr periods supported the implication that the *plancha*-style improved cook stoves could be expected to reduce indoor exposures to the same level as using a LPG stove (Naeher et al. 2000). The *plancha* is an improved cook stove that consists of a brick and mortar base, a top with three steel burners surrounded with tile and a chimney. A similar study of 30 households that took place from December 1998 to July 1999, showed that using an LPG stove/open fire combination led to a 45% reduction in the PM 3.5 concentrations and that using the *plancha* cook stove led to an 85% reduction as compared to the standard open fire (Albalak et al. 2001). This same workgroup has developed and implemented the first randomized intervention trial and includes 534 households as well as personal monitoring of many more family members in an attempt to define the relationship between indoor air pollution and human health (Smith-Sivertsen 2004).

Another improved stove type that has been implemented in rural areas of Central America is the *lorena* type which consists of a hollowed out base made of a sand and mud mix that is built with a number of cooking spaces on its surface and a chimney structure. It can be considered a less complex form of the *plancha* design. The construction of a *lorena* type improved stove is less dependent on outside materials and expertise but these types of stoves are also prone to cracking if not made properly. Naeher and colleagues mention the deteriorated condition of many old *lorena* stoves that were functioning more or less as open fires (Naeher et al. 2000). One small study performed by Peace Corps volunteers from the Environmental Conservation sector, who built *lorena* type stoves in many communities in rural Panama, concluded that the use of the *lorena* stove is more fuel efficient, but did not incorporate any indoor air quality measurements or analysis.

Chapter 3: Experimental Setting

3.1 Climate

As literature given to new Peace Volunteers states, "the weather in Bocas del Toro Province can best be described as wet and wetter" (Peace Corps Panama 2004). As was stated before, annual rainfall in the Nö Kribö region is between two and a half to three meters. Out on the Peninsula Valiente the roughness of the seas depends on both the daily wind and also on the season, being roughest during the middle of the rainy seasons in January and July. In Cayo Paloma the general wind pattern throughout the year consists of an inland breeze in the mornings and a seaward breeze in the afternoons and evenings though weather can also change very rapidly as storms pass by. Average daily temperatures typically range between 70 and 90° F, though it can reach extremes into the low 60s and high 90s. Relative humidity is usually at a comfortable level.

3.2 Housing and Cooking Areas

Most housing in Cayo Paloma is of the Bocas del Toro/Nö Kribö standard type meaning that it consists of a wooden house raised on posts usually three to six feet off the ground, with either a corrugated metal or thatched roof. Only two houses in the community have concrete floors and walls. Most houses consist of one or more closed off bedrooms, a cooking area and a gathering/resting area. Figure 8 shows some standard housing. Except for the bedrooms, most rooms of many houses do not have walls connecting the floor and roof but rather half-walls or no walls at all. While it does get slightly chilly sometimes during the stormy season or early in the morning, walls are not built to keep heat in as much as for privacy and to keep rain out. Thatch roofing often extends below eye level of a standing adult in many houses, again in an effort to keep the wind and blowing rain out.

Figure 8: Photo of standard style houses in the Cayo Paloma area.

The cooking area is separated at least partially from the living area in most homes usually through low wood walls though in some households the living and cooking areas are one in the same. In some households the cooking area is not separated from the living area by a wall but by locating the cooking area in a separate structure connected to the main structure by a small bridge.

Most cooking areas consist of at least a sink area, called a *pila*, and a cooking fire area as well as the normal shelves and tables. Some cooking areas are also used as dining areas though many times other areas of the house are used for eating.

Women of all ages are the usual inhabitants of the cooking areas and spend much of their time there as do the small children accompanying them. Small children are usually placed on the floor and very young babies are placed in hammocks hanging around the cooking area near to the floor. There was not any observable social stigma concerning men being in the cooking area though the majority of the cooking is done by the women and girls. Men do cook many times as well but usually only when there are no women around to help.

3.3 Cooking Times and Eating Habits

The main staple of the people of Cayo Paloma and throughout the area of the Peninsula Valiente are green bananas and assorted root vegetables like yucca and taro. Rice and pasta are frequently bought from the small stores in town and cooked as well. Added to most meals are onion, garlic, small peppers called aji, salt, cilantro and assorted store bought seasonings. Protein sources include eggs, sardines, fish, sometimes chicken and, during part of the year, sea turtle. Coffee and Kool-Aid and sugar are bought or oranges and cacao are used to make drinks. Also eaten depending upon the season are avocados and palm nuts. Newborns and school children are provided with vitamin enriched porridge and cookies by the Ministries of Health and Education. Candy, cookies, potato chips, soda and alcohol can also be bought in the local stores.

Depending on the household, the people of Cayo Paloma eat between one and three main meals a day. The majority of the households eat two main meals, breakfast and dinner, and usually make *michila*, a hot, smashed-banana drink, or similar simple foods to eat around midday or upon return from their farmland. The cooking time for a full meal usually takes from one to two hours and smaller meals take from 20 to 45 minutes. When there is fish or sea turtle meat in the household it is usually smoked for long periods sometimes using the main cooking fire. This activity as well as the bread making activities some households participate in both lead to the situation where the cooking fire is used intentionally more than the just the two or three times a day for meals.

3.4 The Fogon

The traditional cooking fire used throughout rural Panama is named the *fogon*, which loosely translates to hearth from Spanish, and it consists usually of three logs or large stones that give support to cooking pots and structure to the cooking fire. When three large stones are used, as is usual for cooking on the floor in a community house or school with large pots, they are arranged in a triangle formation, with the cooking pots placed on top of them and the fire started in the middle of them. Sometimes in addition to the three stones, there are also three smaller logs used which are placed in between the stones.

When three large logs are used, as is the usual case for household cooking fires, the three logs are placed at angles to each other with their ends facing toward the center. For household fires, the logs and additional firewood are placed on top of packed earth and ash, usually totaling about one to two feet high, which is contained within a box of wood (Figure 9). Many times the wood box is covered with flattened sheet metal in order to contain the packed earth and ash more completely and many times this sheet metal or the wood siding itself extends slightly above the level of the packed earth surface. In many households there is a makeshift metal grate placed above the main logs to hold the cooking pots. If there is no grate used then usually coconut husks are used to stabilize cooking pots placed directly onto the main logs.

Figure 9: A standard household *fogon*.

Most fire boxes are extended outside of the kitchen through a low window and above most *fogones* is constructed a corrugated metal roof extending from the main roof whether the main roof is metal or thatch (Figure 10). A few *fogones* are roofed with thatch and some are not extended out of the kitchen space. One *fogon* in Cayo Paloma is setup directly on the kitchen floor. Above many *fogones* are hung metal racks for smoking fish and sea turtle. Many *fogon* roofs are covered with soot on their bottom side and sometimes on the top side as well and this soot cover usually extends on the bottom side of the main room as well.

Figure 10: *Fogon* built in a section extended off of the main cooking area.

Cooking fires are started with wood kindling, coconut husks and sometimes plastic, paper or kerosene. Normal cooking fires for meals after the first one of the day are rarely started with matches, and banana leaves or homemade brooms are used to create air movement to instead re-ignite smoldering fuel wood (See below). Firewood, and sometimes more coconut husks if there is no firewood, is then added in between the three logs or stones to build the fire in the center area and to eventually begin burning the ends of the three logs. The ends of the main logs act both to block the wind and to produce continued heating and maybe to even act as charcoal.

Firewood used in Cayo Paloma is of many different types though especially Laurel and May Tree woods are used. Splintered, old, dry lumber that is usually stored below the household is also used occasionally. Due in part to the wet climate, wood that is not completely dry is used often as well. Main *fogon* logs are collected usually about once a week while smaller sized firewood is collected sometimes more frequently, about two or three times a week. In terms of the division of labor it is almost exclusively the men who cut down, carry home, and splinter large logs while smaller firewood is many times collected by family members of both sexes and a range of ages. Much of a household's firewood comes from the family's farmland, which is tropical forest worked at a very low intensity, though scavenging of firewood from fallen trees near the main walking paths is common as well.

Fogones are almost exclusively utilized for cooking and preparing food and drink. Because of the year round warm climate they are not used for household heating or for preparing hot water for bathing purposes except sometimes in the cases of pregnant women, newborns and/or sick family members. Because of the existence of kerosene lamps and flashlights, *fogones* were very rarely if at all used for lighting purposes in Cayo Paloma. While this is true in the coastal and lowland regions of the Comarca Ngäbe-Bugle, in the higher elevation areas, where the climate can be colder, *fogones* might be used for heating purposes as well as cooking purposes.

Saying this though might the give the false impression that the *fogon* is producing smoke and emitting other pollutants only during the cooking of meals which is in most cases not true. *Fogon* fires are very rarely completely put out after cooking. In fact, though the fuel wood is usually partially dispersed after cooking to prevent immediate re-ignition, it continues to smoke and smolder for between a period of many minutes up to a couple of hours when the next meal is cooked. With variable winds and weather conditions different levels of smoke are sometimes experienced throughout the day even though the cooking fire was only "lit" or used for cooking three discrete times a day.

While the majority of people said that they did not like the presence of too much smoke in their homes because it caused coughing, eye irritation and headaches, some people in Cayo Paloma claimed that the smoke from the *fogon* entering their homes was beneficial because it kept away insects and cleaned their thatch roof of other animals. In one house it was said that the smoke helped make the thatched roofing more water resistant and, as was mentioned above, fire smoke is also used for the preparation of fish and sea turtle meat.

3.5 The LPG Stove

Out of a total of 37 households in Cayo Paloma, 14 have LPG stoves that are used for a variable percentage of the family cooking needs. In only two houses is the LPG used almost exclusively to cook with, in three other houses the stove is used about half the time and the *fogon* half of the time, and in the remaining nine houses the stove is used rarely to supplement the cooking done using the *fogon*. The houses that use the stove very sparingly use it mostly to make coffee or chocolate drink and maybe to fry an egg. The houses that use the stove about half of the time usually use it for these purposes as well as for boiling standard root vegetables or making rice and the houses that use the stove almost exclusively cook everything on it. This last group is limited to only about one or two households both of which have either small families or more steady sources of income (e.g. the store owner). For the other families LPG usage is heavily dependent upon gas availability so that when the tank is empty the family switches back to full time use of the *fogon* setup. Figure 11 shows a LPG stove type regularly used in Cayo Paloma.

Figure 11: Type of LPG commonly used in Cayo Paloma.

Stoves are more expensive then the *fogon* which only requires the purchase of the occasional box of matches. The stove apparatus usually costs between $20 and $30, depending upon the model and the nearest places of purchase are at the district capital of Kusapin or from the port of Chiriqui Grande on the mainland. Gas tanks can be bought from the two mentioned places for about $25 to $35 thus many people obtain old stoves but then have to wait to buy gas tanks. To refill a gas tank costs $7 to $8 depending upon where it is refilled. Sometimes the two store owners in Cayo Paloma will simply charge the $7 or $8 to swap an empty tank for a full one. Stoves and tanks are usually transported by boat. Gas tanks lasted from between two weeks to almost two months in different houses depending upon use frequency and family size.

Almost all families in Cayo Paloma said that they wanted to have a LPG stove but that costs and availability limited them. Some families said that they would only use the stove for cooking small amounts of food since their larger families required larger pots that fit better on the *fogon* setup then on the gas stove and some said that they only used the stove when there was not any dry firewood close to home.

Chapter 4: Experimental Methodology

Roughly following the outline of the study's three main objectives, three different types of experiments were set up over the course of about one and a half months in the host site of Cayo Paloma. The experimental methods used for each of the types of experiments performed are discussed in this chapter as are the methods used for a home health survey that was also completed.

4.1 Home Health and Indoor Air Survey

In order to obtain a clearer picture of the health and perceived air quality situation in the households of Cayo Paloma a home health survey was designed and performed. All the available households in Cayo Paloma (some were vacant at the time of the survey) were included in the survey. In general, information was collected as to how many people lived in the household and of what age, what was the perceived frequency of disease in the household, and whether smoke from cooking fires was perceived as a danger or nuisance.

Along with the survey an inspection of the household was performed which included noting the general condition of the household, the building materials used, the building orientation to the wind, the surrounding environment and topographic features and the floor layout.

In addition to obtaining a better picture of the standard household setting, this survey and inspection were used to locate houses which used both LPG stoves and standard *fogones* for cooking and those willing to let the author set up air quality monitoring equipment in their kitchen areas. The survey was completed in late February of 2006 which was similar weather-wise to the actual measurement period of late July through early September. See Appendix A for the compiled results of the survey.

4.2 LPG Stove/Standard Fogon Comparison

The purpose of the this set of tests was to compare the indoor air quality experienced in the cooking area during the use of a LPG stove to that experienced in the cooking area during the use of the standard household *fogon*. More specifically, both LPG stoves and standard *fogones* were used to cook a set amount of rice, and pollutant concentrations resulting from these cooking devices were measured, notably PM2.5 and CO.

Households selected to participate were determined by the work schedule of the author, family availability and family permission. Because of these constraints, especially the first one, only eight different sets of measurements were made in eight different households. The eight households ranged in family size, monthly income, building structure, and building orientation to the wind. In six of the eight households pollutant concentrations were measured during both the use of a LPG stove and during the use of a standard *fogon*. Of the remaining two households, pollutant concentrations were measured during the use of only a *fogon* in one household and during the use of only a stove in the other. (Thus, as will be detailed below and in the Results, when the average, minimum and maximum values for the pollutant concentrations were calculated to obtain a general idea of the indoor air quality in Cayo Paloma, seven different household data sets were used whereas when the average, minimum and maximum values were calculated in order to compare the emissions of the two cooking technologies, the *fogon* and the stove, only six data sets were utilized representing the six data sets in which both a *fogon* and stove were tested.) Measurements at the first test house in this set took place at the end of July and the last measurement took place in the third week of August, this time period being, as mentioned above, in the middle of the rainy season.

At each test house CO, CO_2, PM2.5, temperature and relative humidity were measured using the TSI DustTrak and QTrak air quality monitors, which were both set to record the data at time intervals of one minute. Both air quality monitors were factory calibrated before their use in this study. Time constants were set at ten seconds for the DustTrak and at five seconds for the QTrak. The pollutants of interest were PM2.5 and CO. Carbon dioxide, temperature and relative humidity were recorded to obtain a better final description of the cooking environment and a more precise measurement of the weather conditions. See Appendix D for more information on the air quality monitors including photos.

Measurements were continuously made throughout a cooking setup period, the cooking of one pound of rice using the LPG stove, a second setup period, the cooking of one pound of rice using the *fogon* and, in some test houses, during a short period after the dampening of the *fogon*. Throughout the measuring period the author noted the start and stop times for the monitors, for the rice cooked using the LPG stove and for the rice cooked using the *fogon*.

The first cooking setup period was a period of about five to ten minutes before either the stove or the *fogon* was put into use and was measured to obtain a rough estimate of the normal background PM2.5, and CO concentrations. The intermediate setup period was also used to help gather a background value for the pollutants of interest if possible; sometimes the situation was that the *fogon* was lit right as the stove was turned off and thus there was no intermediate time and sometimes the *fogon* was lit and started a couple of minutes before the actual rice was put on. The monitors were usually left on for a little while after the cooked rice was removed from the *fogon* in order to obtain more emissions data but this was also done for different periods of time depending on the household and how quickly the *fogon* went out.

The air quality monitors were set up near each other usually on a table, shelf or makeshift table (e.g. stacked upside down plastic tubs). Care was taken to try and locate the monitors in the area most likely to be occupied by the usual cook of the household though this was sometimes not possible due to the kitchen size, layout or the existence of hazards such as the kitchen sink. In most households the monitors were set up on shelves of tables normally used for meal preparation. Sometimes books and/or pieces of wood were used to lift the monitors in order to have the height of the monitors be similar to that of the adult female inhabitants who were the main kitchen occupants on a daily basis.

The rice was cooked first on the stove and then on the *fogon* in order to prevent the over measurement of pollutants emitted by the *fogon* but recorded during the use of the LPG stove. Each test was scheduled the day before with the heads of each household and each household was asked to not use the *fogon* for at least two hours before the test starting time. This was asked in order to assure that the measurements would begin in a relatively "clean" environment. This rule was followed in most households though in some the *fogon* was still smoldering upon the arrival of the author and the monitoring equipment.

The one pound of rice was cooked in the standard way which consisted of adding one half of a small bag of cooking oil (about three tablespoons) to the pot, placing the pot on the fire, whether using the stove or the *fogon*, waiting for the oil to be heated, adding the one pound of rice to and mixing with the oil, letting the rice cook in just the oil for a few minutes, adding enough water to cover the rice and stirring, waiting for the rice to absorb the water, sometimes needing to add more water and finally, taking the pot back off of the flame and setting it on the table to cool. The actual cooking was done by one of the women of the household in most cases and sometimes by the author himself. The rice and oil were both provided by the author.

Minimum, maximum and average values of all the measured variables were noted at the end of each test as a precaution.

4.3 Fogon Modification Experiment

The overall purpose of this experiment was to determine the effectiveness of the addition of a chimney structure to a *fogon* setup in decreasing the concentration of indoor air pollutants in the cooking area as well as to compare this effectiveness with that of using a LPG stove instead of a *fogon*. The general outline of this experiment consisted of taking measurements during the use of the LPG stove and *fogon*, and then designing a modification to the *fogon* that included the addition of a chimney. The next phase involved the demolishing of the existing *fogon* and the rebuilding of it with the designed modifications, and finally taking a last measurement of indoor air quality using the new *fogon*. These measurements were taken during the period of late August and early September 2006 near to the end of the author's service in Panama.

This experiment was performed in only one household, again due mostly to time constraints. The household was chosen because it had been noted on various home visits that there seemed to be a very large amount of smoke in the cooking area as compared to the other houses and because of the head of the household's willingness to make substantial changes to the cooking space. The household is located on the top of one of the higher hills that surround the main part of the community of Cayo Paloma and partly due to its location experiences strong winds on a daily basis. As was mentioned in the previous chapter, the wind direction experienced in the community's households shifts directions during the day, usually from blowing inland during the morning and then seaward during the afternoon and evening. Because of its location the test house experienced strong winds that followed this generally directional pattern and this in turn influenced the direction the smoke traveled during the day.

The first two measurements, one of the stove and one of the *fogon*, were performed following the same methodology as the first set of experiments explained in the previous section. A second *fogon* measurement was taken in a similar fashion on a different day in the morning so as to obtain data both during a period when the wind pushed more smoke into the cooking area and when the wind pushed the smoke outside.

This household was the one from which only the stove measurement was used in the previous experiments. This was so because of differences in its *fogon* setup. Most *fogones* in Cayo Paloma, as mentioned in Chapter 3, consist of three large logs placed in the firebox angle toward one another which continuously burned at their ends and also sometimes a grate of metal was used to support cooking pots. In House #7, which was used in the *fogon* modification experiment, the cooking fire differed from the standard *fogon* in a couple of ways. First, instead of three large logs and a supporting supply of small firewood, the cooking fire of House 7 consisted of just a supply of small wood usually setup in a small tent shape similar to a campfire. This small pile of firewood was laid on a bed of packed dirt and a metal grate was used to support pots as in a standard *fogon* but instead of having low wooden walls surrounding the fire pit, the walls on three sides of the pit were much higher, in fact almost half the height to the ceiling, and were made of corrugated metal. Thus, this cooking fire was much more enclosed than the more common *fogon* (Figure 12).

Figure 12: The original design of the *fogon* of House #7.

After observing the generated smoke's movement during the first couple of measurements, a design for the modification of the *fogon* was created. The design involved extending the corrugated metal walls of the fire box to connect with the roof which was also made of the same metal material, cutting a hole in the roofing material, building a small chimney to cover the new hole in the roof, the addition of another section of metal that covered the open side of the firebox from about 75% of the height of the space to the roof, and finally cutting air holes in the bottom of the metal walls and placing air hole covers that can be used to control the air flow to the firebox (Figure 13).

Figure 13: Front view of the completed modified *fogon* design.

Because of the original structure of the *fogon* area, the inland breeze would usually blow much of the smoke from the cooking fire into the cooking/eating area during the period from late morning until late evening. Having the *fogon* only being closed in by metal walls half way up to the roof allowed this breeze to enter and push the smoke further indoors where it was trapped under the low metal roof of the kitchen. Sealing the walls of the *fogon* to the roof was done in an attempt to limit the ability of the wind to push the smoke further inside.

The extra section of metal on the open side of the *fogon* was added in order to trap the increased amount of smoke above the fire (increased because of the lack of wind to disperse it) and prevent it from enter the cooking space. The chimney was added to allow this newly trapped smoke to escape outside above the roof of the kitchen.

In order to assure a good observed airflow to the fire, air holes were cut into the bottom of the *fogon* walls on two sides. Since the wind shifts directions each day, small sections of metal, wood and stones where place around the edge of the *fogon* to be used in controlling the airflow by blocking or leaving open the new air holes. Figure 14 is a schematic drawing of the observed air flow conditions before and theoretical conditions after the *fogon* modification.

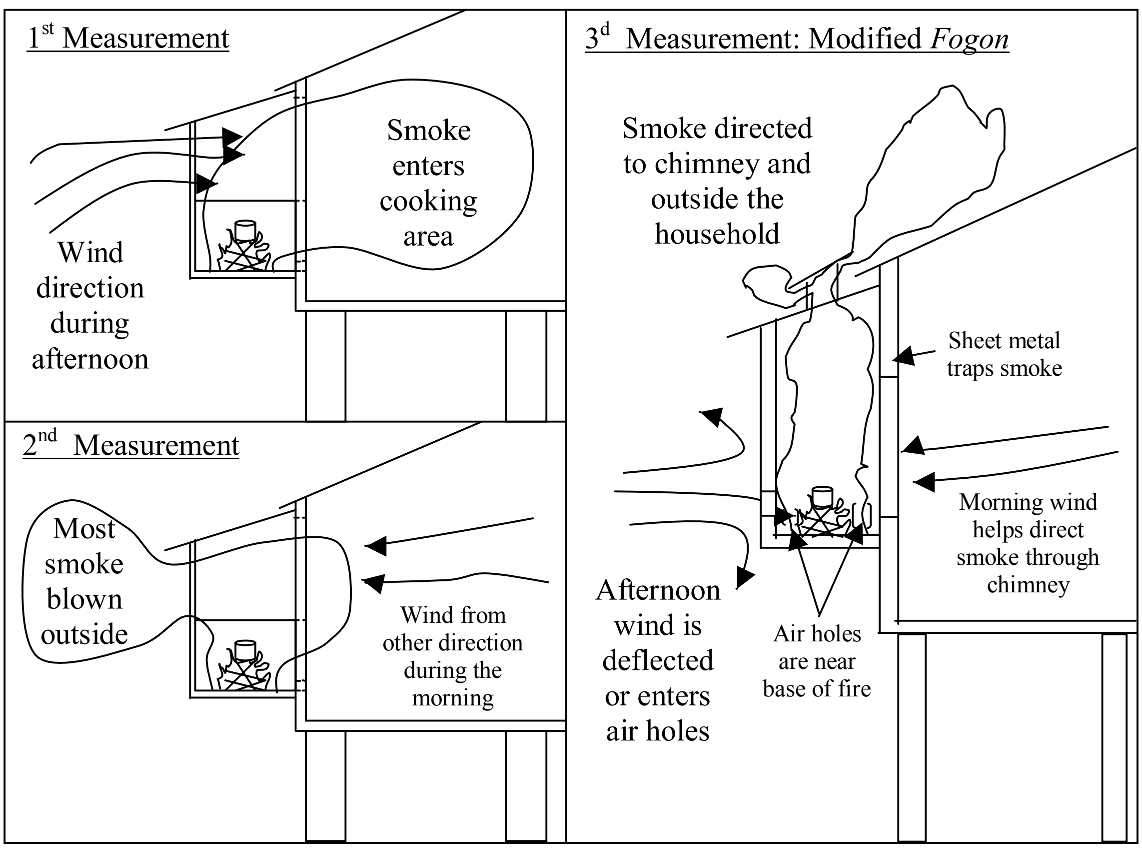

Figure 14: Diagram showing the different smoke situation in the test house during the morning and afternoon periods and after the modification of the *fogon* structure.

After construction of the modified *fogon* another rice cooking test was performed, measuring the same variables as the previous tests, and the data was recorded by the DustTrak and QTrak monitors.

4.4 "Standard Day" Measurements

In order to get a better picture of the indoor air quality that is actually experienced on a daily basis by the families of Cayo Paloma a test was set up to measure the indoor air quality in one home over the course of almost twelve hours. Data was again collected on PM2.5, CO, CO_2, temperature and relative humidity.

In this experiment, instead of arbitrarily cooking one pound of rice the family was asked to cook their normal daily meals, and go about a normal day. The only thing asked of the mother of the household and the children was not to interfere with the measurements by touching the air quality monitors or by breathing too near to the CO_2 monitor. House #9 was chosen as the test site because its family was one of the most trusted ones in Cayo Paloma and the air quality monitors could be left for long periods with confidence that they would not be damaged or interfered with.

House #9 was also located on the top of a low hill like House #7 but in general experienced less powerful winds due to its being surrounded by some orange, mango and maronon trees. The *fogon* was extended off of the main section of the house like in many homes in the area (Figure 15)

The air quality monitors were set up to begin measurements at around 7:30 AM and to measure continuously, recording at minute intervals, until about 7:10PM. This was to allow for data collection from before breakfast until after the evening meal and included the measurement of data during a small midday meal. The author kept track of the start and stop times for the air quality monitors and the family was asked to keep track of the cooking times for the three meals. This test was performed in early August of 2006.

In mid-August another similar test (also a standard meal preparation) was setup to measure only from before breakfast until after breakfast in the same household in order to collect more data on the pollutant emissions experienced during the cooking of a common meal.

Figure 15: The *fogon* area of House #9. This *fogon's* emissions were measured over a 12 hour period.

Meals cooked during the day-long test included a bowl of boiled green bananas, locally called *buchu*, with salt for breakfast, a cup of *michila*, a chunky drink made from bananas and sugar, for a midday meal and another bowl of boiled green bananas with boiled sardines for dinner. The dinner meal was a little larger than the rest due in part to the presence of another family member. The test meal for the second test was another bowl of boiled green bananas.

4.5 Background Research

Additional background research for this report was performed somewhat during the author's time in Panama but the majority was accomplished once the author returned to Michigan Tech in late October of 2006. Studies of indoor air quality and the developing world's experience with it were looked at as was research into using emissions to estimate health responses and indoor air quality intervention possibilities.

In September 2006, the data collected with the air quality monitors was downloaded onto a PC and saved to a flash drive using TSI's air quality monitoring software, TrakPro. Files were saved both as WordPad documents and as TrakPro files. The collected data, presented in Chapter 5, was then analyzed back at Michigan Tech.

Chapter 5: Results and Discussion

5.1 Sample Standard Day Test

The sample standard day test that was performed at House #9 measured the concentration of PM2.5, CO and CO_2, as well as the temperature and relative humidity, at minute intervals beginning before the first meal of the day and ending after the evening meal. The results and discussion for all three experiments presented in this chapter are concerned with the PM2.5 and CO concentrations. Figure 16 shows the concentration of PM2.5 and CO throughout this period of time. The three distinct periods of high concentration correlate with the three meal times as measured by the author and a household family member during the testing.

The fluctuations in the concentration of CO during the testing period mirror closely those of the concentration of PM2.5 which seems appropriate since they are both products of incomplete combustion. The data for all three meals shows a similar pattern over time in that at the beginning of the cooking time there is a large spike in concentration levels for both PM2.5 and CO, which is sometimes sustained for a while, and then, as cooking continues, the pollution levels seem to decrease more steadily. The flat areas in between meals are the background periods when no *fogon* was in use.

Table 1and Table 2 show the average values of PM2.5 and CO experienced during this test and accompanying statistical information. Measurements during the peak periods indicate that the average concentration of PM2.5 experienced when the *fogon* is in use can be ten to twenty times greater than the background levels. The actual concentration at any given minute was found to range greatly throughout both the background and *fogon* periods which may have been due to changes in wind direction and/or the unintentional stirring up of ash by the inhabitants of the household. While the CO concentration also fluctuated throughout the *fogon* use times it did not do so as extremely as the concentration of PM2.5.

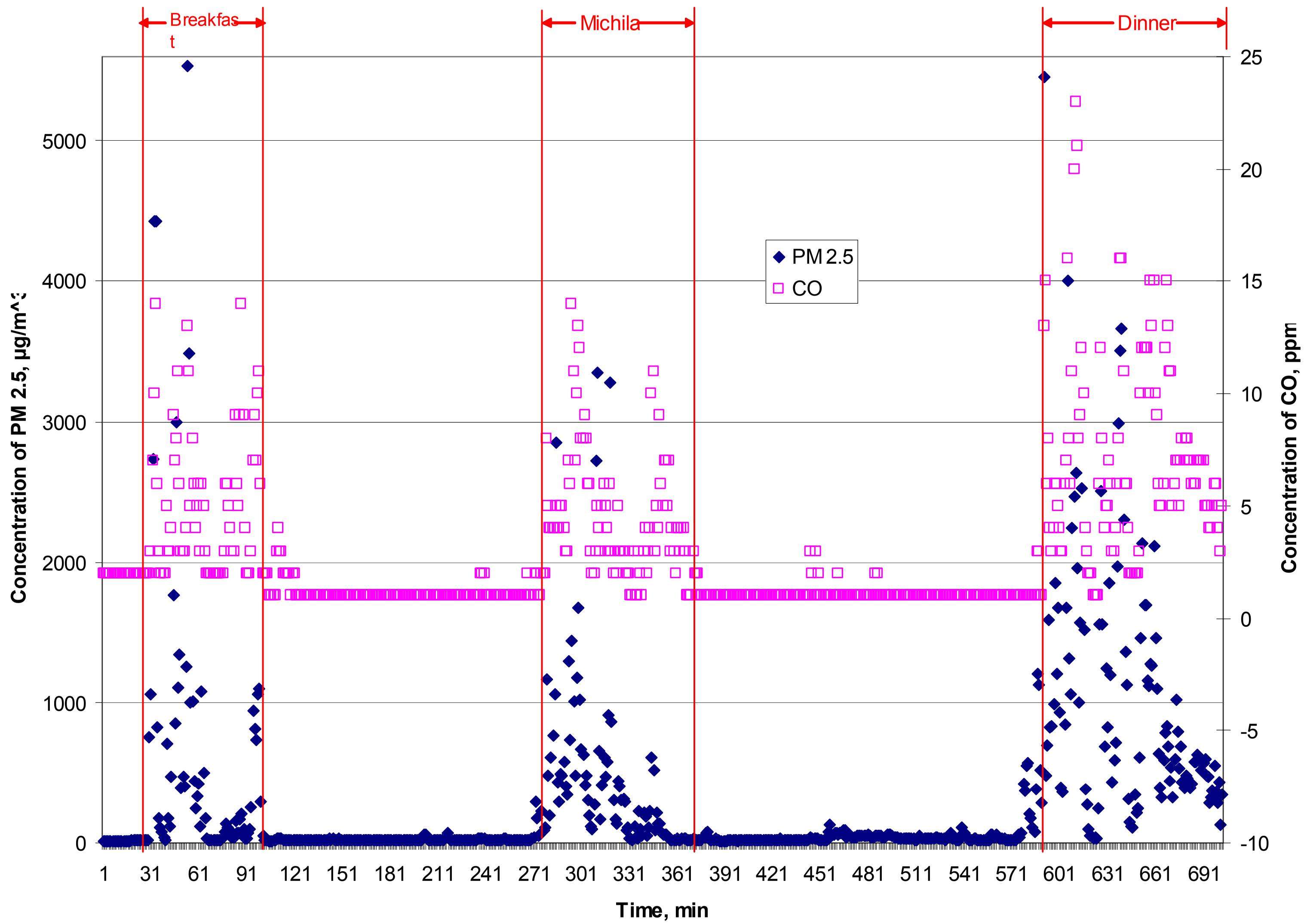

Figure 16: PM2.5 and CO Concentrations over a 12 hr period beginning at 7:26AM.

Table 1: Average PM2.5 concentrations (in μg/m^3) and accompanying statistical information for both the Background and *Fogon* cooking conditions and for the complete data set taken from House #9 during the Standard Day test.

Cooking Condition	n	mean ± SD	geometric mean (95% CI)	median	range
Background	415	41 ± 99	25 (16 , 35)	20	12 - 1208
Fogon	288	707 ± 914	295 (190 , 401)	414	15 - 5530
Full Day	703	314 ± 675	69 (19 , 119)	32	12 - 5530

Table 2: Average CO concentrations (in ppm) for both the Background and *Fogon* cooking conditions and for the complete data set taken from House #9 during the Standard Day test.

Cooking Condition	n	mean ± SD	geometric mean (95% CI)	median	range
Background	415	1.2 ± 0.4	1.1 (1.1 , 1.1)	1.0	1.0 - 4.0
Fogon	288	5.6 ± 3.8	4.5 (4.1 , 4.9)	5.0	1.0 - 23.0
Full Day	703	3.0 ± 3.3	2.0 (1.7 , 2.2)	1.0	1.0 - 23.0

An important thing to note is that the some of the values for the standard deviation given in Table 1 are greater than the mean values. This occurs throughout the LPG/*fogon* comparison tests and the *fogon* modification test as well. The reason for this is that the PM2.5 concentration over the time of the tests is not normally distributed but rather most likely log-normally distributed.

Out of the almost twelve hours for which air pollutant concentrations were measured, the *fogon* was lit or in use a total of about five hours meaning almost 42% of the total recorded period occurred with the *fogon* in use or at least lit. Another way to look at these numbers is that the *fogon* was in use or lit a little bit more than 1/5 of the entire 24 hour day. This estimate may actually be lower than that experienced in many other households because House #9 only contains four inhabitants maximum which is less than the community average of six to seven people.

According to the health survey that was performed the average time it takes to cook a meal was said to be about an hour. Using this stated cooking time and the fact that a family eats two to three times a day, the total cooking time in a standard day should be about three hours maximum which would mean that the meal cooking in House #9 on the test date seems to have taken a extraordinarily longer time. Most likely this discrepancy exists because the survey only asked the meal cooking time and not the time the *fogon* is lit which might be substantially longer, and which is the time just used to calculate the percentage of the day taken up by cooking.

In order to see whether the time of day greatly affected the concentrations of PM2.5 and CO, the data from House #9 was split into four different meal periods (three from the full day test and one from the morning only test) and compared as reported in Table 3. This data seems to suggest that the indoor concentration of both PM2.5 and CO are influenced by the time of day since the recorded values that occurred during the Midday and Evening time periods lie outside a 95% confidence interval constructed from the data. Part of reason for this situation might be explained by the fact that House #9 is located on a hill and thus wind direction shifts are experienced daily. It should also be noted though that there were only a limited number of time periods to compare and they were of different lengths and different meals were involved so more data is needed to be more certain about the effect of the time of day on the indoor air quality in House #9.

Table 3: Average and geometric mean values for PM2.5 and CO for the four different time periods recorded at House #9.

Time Period	n	Meal Type	Avg. PM2.5 (μg/m^3)	Geo. Mean PM2.5 (μg/m^3)	Avg. CO (ppm)	Geo. Mean CO (ppm)
Morning2	73	*buchu, sardines*	711	245	5.15	4.11
Morning1	87	*buchu*	658	197	5.04	4.16
Midday1	100	*michila*	430	170	4.33	3.55
Evening1	113	*buchu*, sardines	997	659	7.18	5.90

The complete data from House #9 was also used to estimate the range of PM2.5 and CO concentrations over the *fogon* and background periods as shown in Figure 17 and Figure 18. The erratic nature of these ranges may be attributed in part to the effect of the wind on the measurements and in part to the composite nature of the charts. These average values were also taken at each minute of cooking time for the four different cooking periods that were recorded in House #9. Because the concentrations of PM2.5 and CO at each moment across the four periods were not the same or even necessarily near the same due to wind a more accurate picture of the how this range changes as cooking time increases is difficult to create.

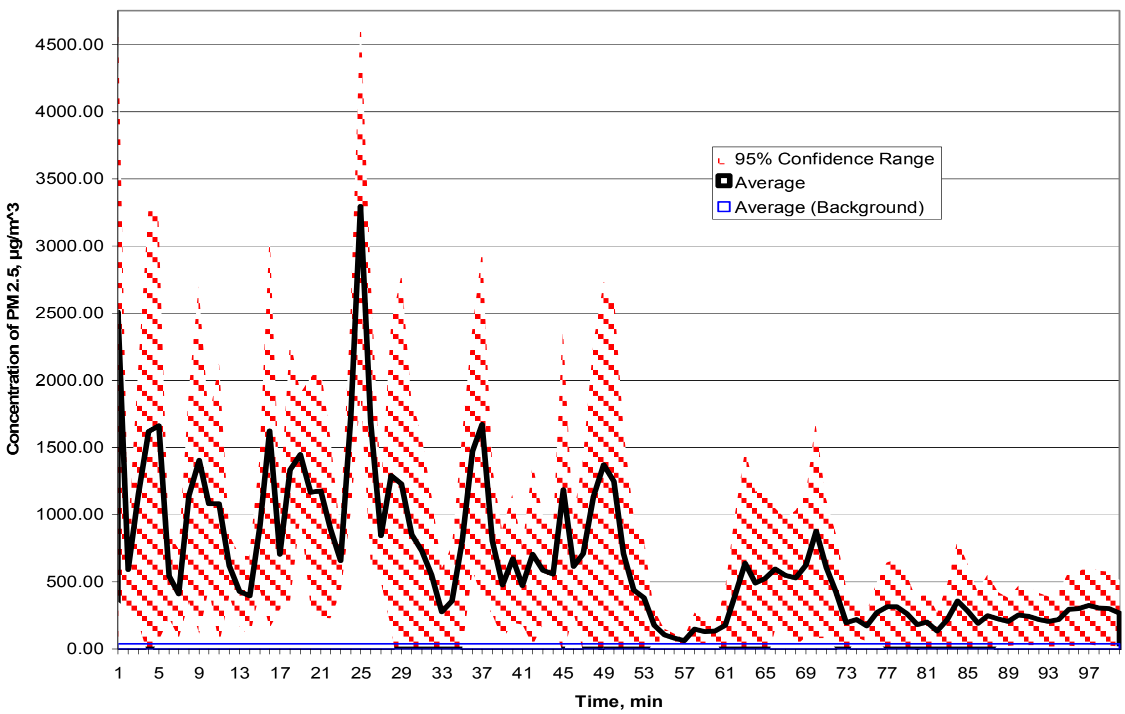

Figure 17: 95% Confidence Range for the value of the average concentration of PM2.5 during each minute of cooking using the *fogon* in House #9.

In general it seems that while both the concentration of PM2.5 and the concentration of CO rise rapidly at the beginning of the cooking time and then decrease more gradually, the PM2.5 concentration decreases more rapidly than that of the CO.

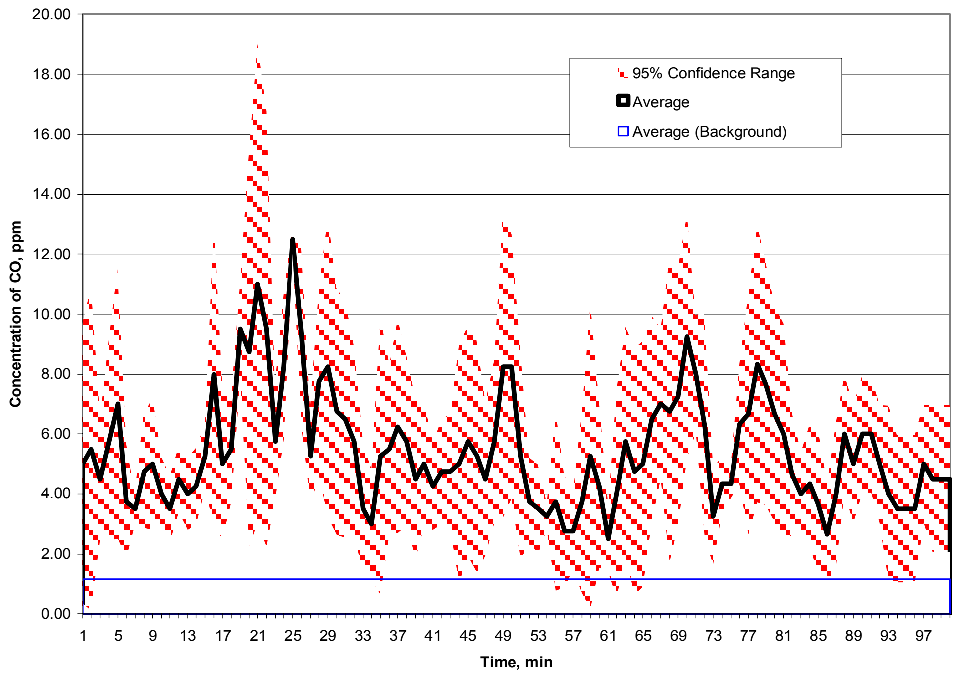

Figure 18: 95% Confidence Range for the value of the average concentration of CO during each minute of cooking using the *fogon* in House #9.

Even though the average concentration over the entire testing period of about twelve hours was less than half the average during the use of the *fogon* (314 μg/m^3 as compared to 707 μg/m^3), it was still high, especially when compared to the WHO air quality guideline value of 25 μg/m^3 for a 24 hour exposure (WHO 2006). Even worse is that the average background concentration, 41 μg/m^3, was also found to be higher than this guideline.

To make the comparison to the WHO guidelines more accurate a theoretical 24 hour concentration was constructed by using the background average values as representative of the values experienced during a theoretical night period from about 7:00PM to 7:30AM. Because the men stay out fishing late into the night in some households, *fogon* use is necessary during the 7PM to 7AM period in order to fry that evening's or night's catch. Assuming the nighttime values for the PM2.5 and CO concentrations to be the same as those experienced as background values during the day results in a conservative estimate of the twenty-four hour concentration that is lower than what might be the true situation. There is still uncertainty in whether this average value is entirely appropriate because of the difference between the shorter intermediate background periods during the day and the longer single background period during the night. The length of time between dinner and breakfast being so long the concentrations could be even lower. To know whether this model is perfectly legitimate would require performing a true 24-hr test.

From the 24 hour construction the average PM2.5 concentration was calculated to be 174 $\mu g/m^3$ which is almost seven times the WHO guideline value. The WHO guideline is set at 25 $\mu g/m^3$ based on the relationship between 24-hour and annual PM2.5 levels that are, “the lowest levels at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to long-term exposure to PM2.5” (WHO 2006).

The impacts from exposure to these high PM2.5 levels are uncertain though due to the lack of information on the health effects at such high concentrations. As a consequence of most exposure/response relationships being developed for ambient air pollution as opposed to indoor air pollution, it is still unknown as to how the health response rate behaves relative to the increase in average concentration for increases at such high magnitudes.

Nevertheless, it is known that at PM2.5 levels of 75 $\mu g/m^3$, three times the WHO guideline value, there is an associated 5% increase in short-term mortality over that guideline value (WHO 2006). Thus, it can be stated with confidence that the inhabitants of House #9, especially the females who spend much of their day in the cooking space, could be experiencing increased risk of mortality of at least 5%.

Table 4 shows how the theoretical 24-hour average PM2.5 values (or PM 3.5 values in one case) found in three other studies of indoor air quality in rural areas compare to that found in this study. The three other studies were all conducted in an indigenous area of highland Guatemala where the houses are constructed on the ground and thus the higher PM2.5 levels experienced might be an effect of having more enclosed living and cooking spaces. This kind of housing (ground level, enclosed) is also more common in the highland areas of the Comarca Ngäbe-Bugle, especially on the Chiriqui side (southern side) of the *Cordillera.* It could be possible that the PM2.5 levels experienced in House #9, which might be on the lower end of the actual range experienced in the households of Cayo Paloma, also might be lower compared to these other areas of the Comarca Ngäbe-Bugle in part due to the difference in housing structure and ventilation.

Table 4: Mean PM2.5 (or PM 3.5) concentrations for the open fire/*fogon* cooking condition found across four studies.

	Mean PM2.5 ± StDev (n)
This Study (2006) (24-hr)	707 ± 914 (4)
Albalak et al. (2001) (24-hr, PM 3.5)	1930 ± 1280 (58)
Naeher et al. (2000) (24-hr)	520 ± 260 (9)
Naeher et al. (1996) (24-hr)	868 ± 520 (17)

The main reason why it is hard to draw more accurate conclusions from this test is that there is only little more than a day's worth of information. In order to provide a more accurate account of the 24-hour average concentrations experienced in House #9 and in Cayo Paloma in general, more measurements that are longer in duration are needed. Time constraints on the author were the reason for the lack of more or longer tests.

5.2 LPG Stove/Fogon Comparison Tests

Each data set recorded with the air quality monitors for the LPG/*fogon* comparison tests contains measurements taken at minute intervals, starting from a couple of minutes before LPG use and ending usually a couple of minutes after *fogon* use. A representative example of the test data is shown below in Figure 19.

Figure 19 presents a good example of the general trend in indoor air quality over the time period of the comparison tests: concentrations of both PM2.5 and CO begin relatively low (background concentrations), the CO concentration usually then rises slightly for a brief time during the use of the LPG while particles remain low, both CO and PM2.5 rise rapidly as the *fogon* is lit and finally the pollutant concentrations decrease much more gradually to a more stable range of values for the remainder of the cooking time.

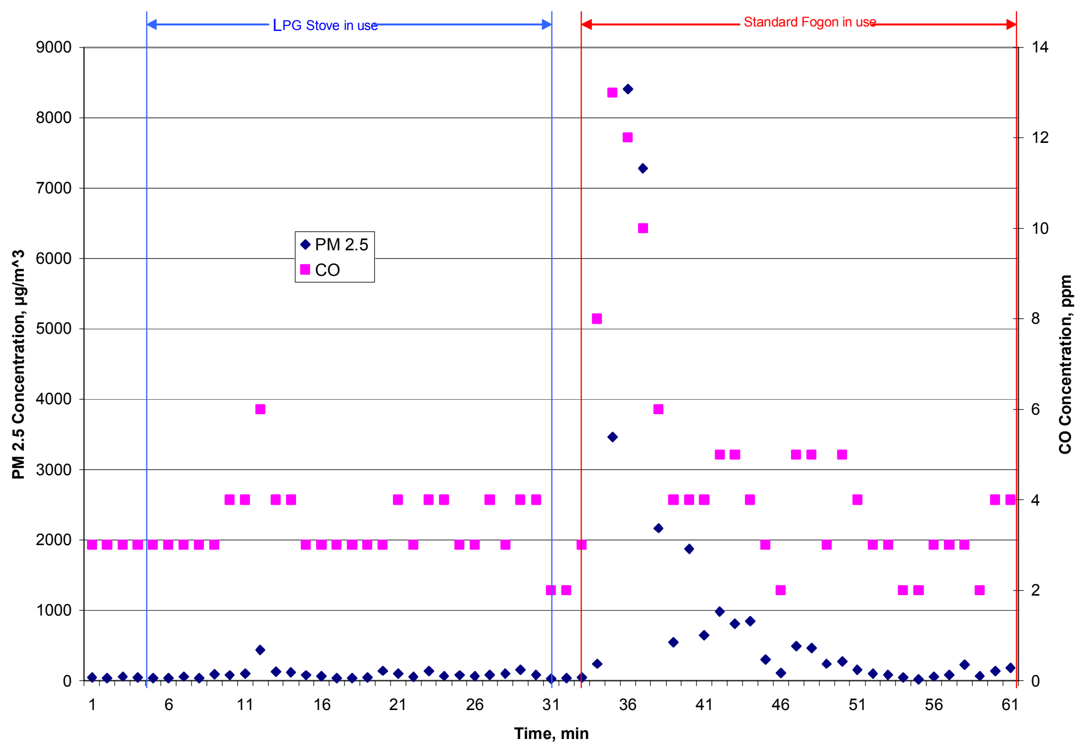

Figure 19: Graph of PM2.5 and CO measurements made at one of the LPG/*fogon* comparison test houses annotated to show the start and stop times of the cooking of one pound of rice for both the LPG stove and the standard *fogon*.

The rapid rise of the PM2.5 concentration during the lighting of the *fogon* results in part from the fanning of the tinder and kindling which disturbs the ash resting in the fire box. The parallel rise in CO might be attributable to the incomplete combustion as the smoldering wood takes time to burn more efficiently, even though there is increased airflow as a result of the fanning. In some of the test cases the spike in the concentration of CO occurred a couple of minutes after that of PM2.5. This might be explained by differences in *fogon* and cooking space structure and maybe in wind direction.

The seven sets of data that comprised the *fogon* testing part of this experiment were used to estimate the ranges of values for PM2.5 and CO were estimated at each minute of cooking time. These ranges are presented in Figure 20 and Figure 21 and the pattern they follow is similar to that found in the standard day test. Again the fluctuation of the CO range over time is more gradual than that of the PM2.5 range. One difference to note is that the CO pattern does not follow that of PM2.5 as closely as it had in the standard day test in that it does not rise rapidly in the beginning of the cooking period. This may be due to the use of seven different households, and thus seven different cooking spaces, in preparing the ranges as well as because of wind conditions during the testing.

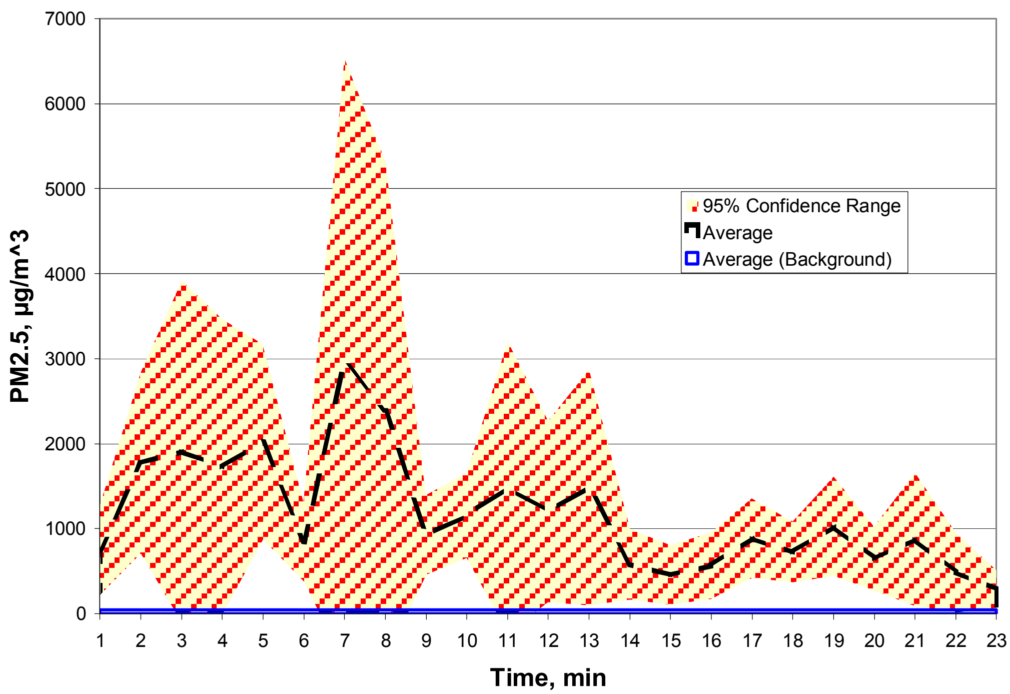

Figure 20: 95% Confidence Range for the value of the average concentration of PM2.5 during each minute of cooking using the fogon (N = 7).

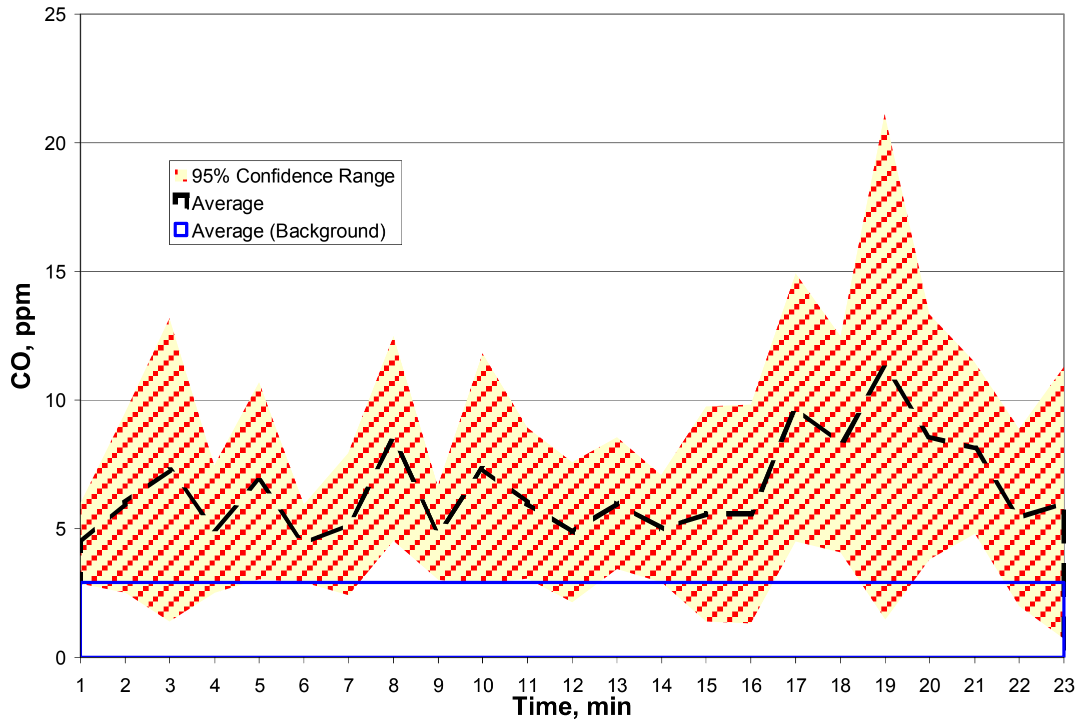

Figure 21: 95% Confidence Range for the value of the average concentration of CO during each minute of cooking using the fogon (N = 7).

In order to compare the indoor air quality that exists in the household during the use of the gas stove with that which exists during the use of the standard *fogon* and with that which exists when no cooking device is in use it was necessary to split up the test data from each test house into three different sections. All similar sections from the different test households were then combined to produce average concentration values and other statistical information for each type of cooking condition. As described in Section 4.3 of this report, concentrations of PM2.5 and CO were taken in six houses for both the LPG and *fogon* cooking conditions, taken for only the LPG condition in the seventh house and taken for only the *fogon* condition in the eighth house. For the LPG and *fogon* conditions therefore, there were seven sets of data to combine each.

Table 5 and Table 6 show the average values for the concentrations of PM2.5 and CO taken from the comparison tests. In the calculation of the mean and the other statistics for each cooking condition every minute of data from the various houses was combined into one population of data. As explained above data from seven houses were used to calculate the LPG and *Fogon* conditions each and, due to some instrumentation errors, data from only five houses were used to calculate the Background condition.

Table 5: Mean PM2.5 concentrations (in µg/m^3) and accompanying statistics for the Background, LPG stove, and *Fogon* cooking conditions based on data from the eight houses involved in the stove/*fogon* comparison test.

Cooking Condition	n	mean ± SD	geometric mean (95% CI)	median	range
Background	51	38 ± 34	30 (20 , 39)	29	4 - 225
LPG Stove	184	56 ± 60	38 (29 , 47)	40	1 - 441
Fogon	209	1042 ± 1703	497 (266 , 728)	549	26 - 14648

Table 6: Mean CO concentrations (in ppm) for the Background, LPG stove and *Fogon* cooking conditions based on data from the eight households involved in the stove/*fogon* comparison test.

Cooking Condition	n	Mean ± SD	geometric mean (95% CI)	median	range
Background	51	2.9 ± 1.9	2.6 (2.1 , 3.1)	2.0	2.0 - 10.0
LPG Stove	184	2.8 ± 1.3	2.6 (2.5 , 2.8)	2.0	2.0 - 11.0
Fogon	209	6.8 ± 6.1	5.0 (4.1 , 5.8)	5.0	1.0 - 43.0

As was the case in the Standard Day test, wide ranges for the PM2.5 measurements can be attributed in part to the variable wind strength and direction. In the LPG/*fogon* comparison tests, which were conducted in different houses, the range of PM2.5 values may have also been the result of the different cooking spaces and situations.

In general the cooking time tended to be a little longer when the *fogon* was used (average: 29.9 min) than when the gas stove was used (26.3 min).

The mean concentration of PM2.5 over the cooking time for the *fogon* for these tests showed that the cooking spaces experienced levels of PM2.5 higher than those found in the Standard Day tests which by themselves were high enough to create a dangerous situation in the home over the course of one day. What is more problematic is that these LPG/*fogon* comparison test values while very high, come from cooking with the *fogon* for only about half as long as a Standard Meal meaning that daily pollution levels in these test houses could really be much higher than those calculated for House #9.

As can be seen in both Table 5 and Table 6 above, cooking with a standard *fogon* exposes the cooks and other occupants of the cooking space to higher concentrations of CO and much higher (almost twenty times higher) concentrations of PM2.5 than cooking with a LPG stove. The differences between the concentrations of CO and PM2.5 experienced during the use of the LPG stove and that experienced during background conditions were very small almost to the point of being negligible. A graphic representation of some of the data from Table 5 is presented in Figure 22.

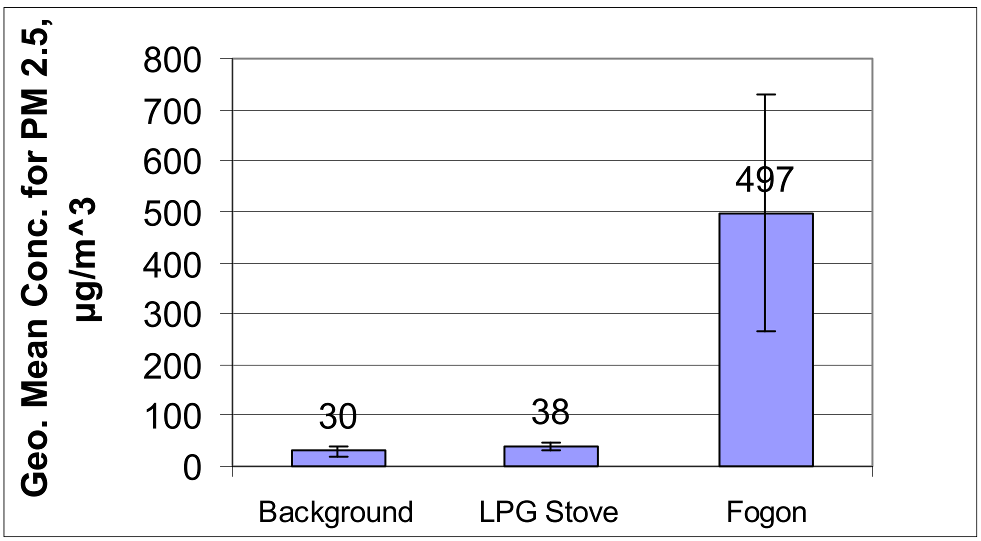

Figure 22: Geometric mean concentrations of PM2.5 for the Background, LPG and *Fogon* conditions (w/95% confidence intervals).

In all, the combined data from the total of the eight houses used in the LPG/*fogon* comparison tests shows a 92.4% reduction in PM2.5 when using the LPG stove in place of the standard *fogon* as well as a 46.7% reduction in CO. These calculations exclude the impact of other factors including the differences in house structure, the time of day and the weather.

To obtain a more accurate description of how the use of the LPG stove affects the indoor air quality in each household the PM2.5 data was again broken apart by test house and the percent reduction in concentration of PM2.5 was recalculated. For these calculations the data from only the six households that had both LPG stove and *fogon* measurements were used.

As can be seen in Figure 23 and in Table 7, the degree to which using the LPG affected the indoor air quality varied depending on the household. The PM2.5 concentrations were affected similarly in Houses #3, 4, 5 and 6 all of which had reductions in the geometric mean concentration of 94% to 97%. The calculated reduction was less in House #1 and much less in House #2 and the absolute values of the geometric mean concentrations for these two houses were also less than the other four.

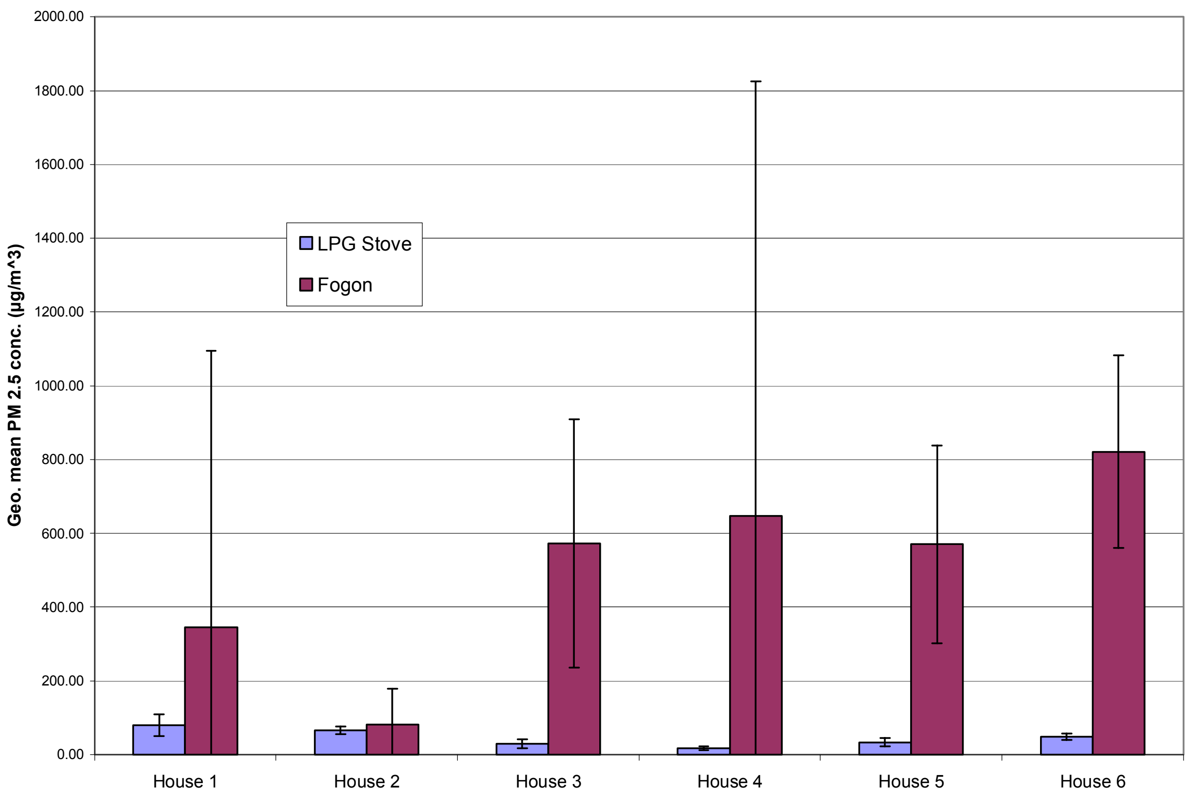

Figure 23: Geometric mean concentrations of PM2.5 for the two cooking conditions in each of the six test houses.

Acknowledging that the various factors that influence indoor air quality were not controlled and that only one test was performed in each house, a brief look at the data in Table 7 suggests the extent to which some housing, time of day and economic factors influence the mean concentration and the percent reduction between the of PM2.5 for the two cooking conditions. Information about cooking space size and cooking space type was taken from the home inspections performed during both the health survey and during the individual testing periods. Appendix B presents the individual floor plan of each of the test households and other physical characteristics related to indoor air quality.

Table 7: Percent reduction in the geometric mean concentration of PM2.5 and physical and economic information for each of the six test houses.

Test House	Start Time of Test	PM2.5 LPG (μg/m^3)	PM2.5 *Fogon* (μg/m^3)	% Reduction b/w LPG and *Fogon*	Cooking Space Size[1]	Cooking Space Type	Economic Status[1]
1	8:56	80	344	76.86	4	Standard[2]	3
2	11:36	66	80	18.16	1	Extended hall[3]	1
3	10:30	29	572	94.90	4	Standard	2
4	16:53	18	646	97.29	3	Standard	1
5	17:05	33	570	94.20	2	Open[4]	1
6	17:13	48	821	94.16	3	Standard	4

1 Cooking space size and economic status rated on a scale of 1 (smallest, poorest) to 4 (largest, richest)
2 Standard cooking space type consists of a rectangular kitchen room with a fire box that is extended out a low opening
3 Extended hall cooking space type refers to a hallway open on one end connected to a *fogon* area by a non-walled bridge.
4 House #5 has modified Standard cooking space called an Open cooking space because of the lack of a wall separating the cooking and living areas of the household.

The results suggest that economic status of the test household does not have a great influence on the PM2.5 concentration experienced during the use of the *fogon* nor on the percentage difference in PM2.5 between the use of the LPG and the *fogon*. This is true for at least these LPG/*fogon* experiments. Testing over a longer period of many days and monitoring normal cooking conditions as opposed to the imposed rice test conditions would most likely show that economic status does have a strong influence on the indoor air quality of a household since the richer a household is the more it is able to refill the gas tanks and continuously use the LPG stove. This suggestion that the richer the family the more the LPG stove is used is supported by the author's observations and from the survey performed in the community.

The high value for the LPG stove test and the lower reduction percent that were found for House #1 could have been due to the presence of disturbed ash in the environment during the LPG stove part of the test. The lower geometric mean concentration experienced could have been due in part to both the time of day/wind conditions and the largeness of the cooking space.

House #2 deserves special attention because the reduction percentage was found to be so low even though its cooking space was the smallest of the six cooking areas. This discrepancy could be due to the cooking space layout of House #2 which was very different from the other test houses and to the strong winds that were present on the testing day. Since the *fogon* site was so open and extended away from the house, PM and CO were most likely adverted from the house by the wind. Whether this could be said to be the case during the late afternoon when the wind direction is different or when there is no wind would have required more tests in this household at different times on different days.

The results from House #2 suggest that perhaps an effective way to maintain the indoor air quality of a household that uses a *fogon* setup for cooking is to move the *fogon* further outside the kitchen space. For this to be effective extra construction materials would be required and care would need to be taken to position the cooking space, house and extended *fogon* section so that, no matter which direction it blows, the wind removes the combustion emissions from the area as opposed to trapping the emissions inside the cooking space. This approach might not work as well when there is no wind to carry the pollutants away from the house. There is at least one household in the Cayo Paloma area that has its cooking space in a totally separate structure connected to the main house by a walkway but this required building a second housing structure and thus was probably very costly.

The data from the remaining four tests seems to show little correlation between cooking space size, economic status or time of day and indoor air pollution levels, and while fuel wood type and other indoor air quality factors were not looked into the data seems to suggest that using the LPG stove instead of the *fogon* in most households leads to a reduction in PM2.5 concentrations of about 95%. This value is close to the reduction percentage of 90% found in one of the Guatemalan studies (Naeher et al. 2000).

The preceding results and those in the next section bring up the issue of whether or not to promote LPG stoves in order to improve indoor quality since their use seems to drastically reduce the exposure to high levels of PM2.5 and CO. While LPG stoves are simple to use and common throughout the developing world and households tend to be aware of them and their benefits and disadvantages, they are not put into use unless the household is of a higher economic status. Even if the household has higher economic status family members might still limit the use of the LPG in order to save money.

If better exposure/response relationships were available for use in the rural, indoor, developing world setting, it might be possible to perform an accurate health based cost-benefit analysis of the use of the LPG stove. This analysis would be able to help convince local people of the health importance of LPG stoves or to help inform governments who then could possibly subsidize gas tank fuel in an effort to decrease indoor air pollution. But, barring this kind of analysis and keeping in mind the unsustainable aspects of LPG stoves, it is still probably most helpful for research to be focused in the area of alternative cooking technologies and simple modifications.

5.3 Fogon Modification Tests

House #7 was asked to participate in the *fogon* modification tests both because of its unique *fogon* structure and because of the extremely high pollutant concentrations that were observed in the cooking space. The pollution concentrations were so high during the Midday test measurements that the author had to leave the area every couple of minutes.

From data presented in Figure 24 it is apparent that the pollutant concentrations experienced during the first Midday test period were much higher then, and that these high concentrations did not taper off near the end of cooking as rapidly as those of the LPG/*fogon* comparison or Standard Day tests. The high concentration levels, as mentioned above, seemed to have been caused by the strong wind blowing into the house that pushed the majority of the emissions from the *fogon* into the cooking space. Also adding to the high concentrations was the closed-in setup of both the fire box and the cooking space as a whole which acted to trap the emissions. The sustaining of the higher concentrations may also have been an effect of the different and smaller *fogon* design that House #7 used.

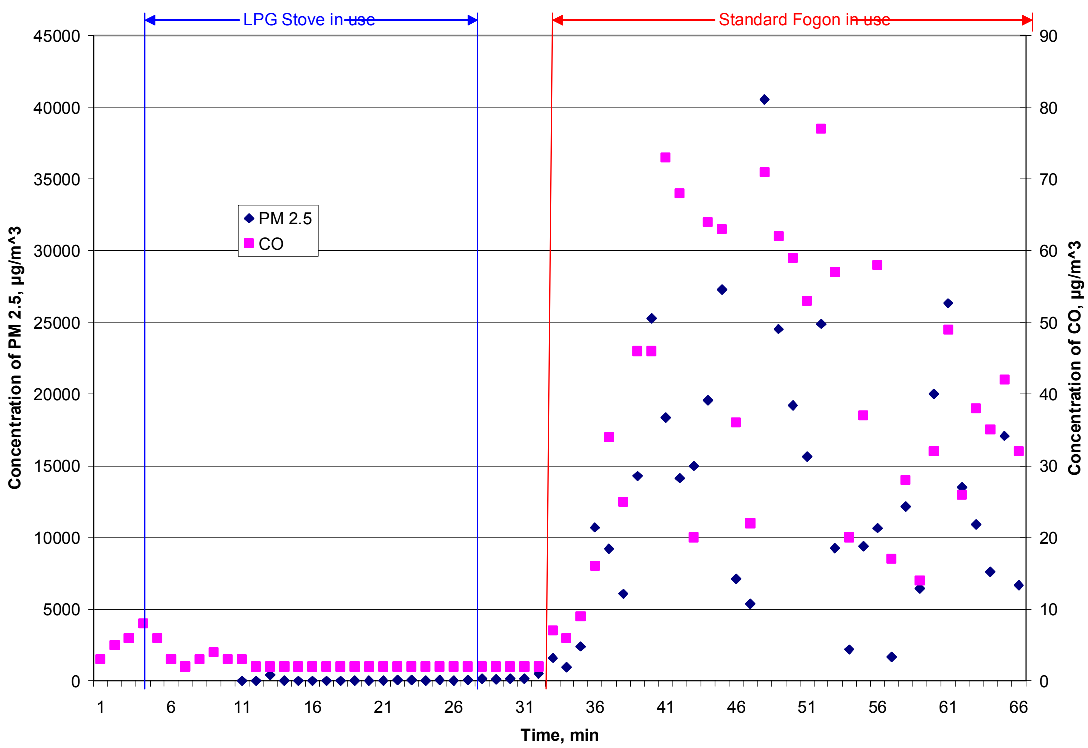

Figure 24: Concentrations of PM2.5 and CO recorded over the cooking period with annotations to show the start and stop times of the cooking of one pound of rice using both the LPG stove and the household *fogon*.

The data from this first Midday test period was split up into the LPG stove period and that of the standard *fogon* in order to calculate the average concentrations of PM2.5 and CO for each cooking condition as was done in the LPG/*fogon* comparison tests. The average concentrations of the pollutants and other statistics were also calculated for a Morning test period that occurred before the *fogon* was modified and the chimney added and a second Midday test period that occurred after the modifications were implemented. The values calculated for the average and geometric mean concentrations of PM2.5 and CO for the four different testing periods are displayed in Table 8and Table 9. Figure 25 compares the geometric mean concentrations for the four testing periods graphically.

Table 8: Mean PM2.5 concentrations (in µg/m^3) and accompanying statistics for the LPG Stove, Midday 1, Morning, and Midday 2 (post modification) time periods for the *Fogon* Modification test in House #7.

Cooking Condition	n	mean ± SD	geometric mean (95% CI)	median	range
LPG Stove	23	34 ± 78	11 (-21 , 42)	13	1 - 390
Midday 1	30	13361 ± 9594	8937 (5504 , 12370)	11433	529 - 40552
Morning	22	508 ± 646	136 (-133 , 406)	179	1 - 1930
Midday 2	36	2220 ± 1885	1585 (970 , 2201)	1488	270 - 7717

Table 9: Mean CO concentrations (in ppm) for the LPG Stove, Midday 1, Morning, and Midday 2 (post modification) time periods for the *Fogon* Modification test in House #7.

Cooking Condition	n	mean ± SD	geometric mean (95% CI)	median	range
LPG Stove	23	2.4 ± 0.9	2.3 (1.9 , 2.7)	2.0	2.0 - 6.0
Midday 1	30	39.0 ± 22.4	29.9 (21.9 , 37.9)	36.5	2.0 - 77.0
Morning	22	4.5 ± 3.5	3.6 (2.1 , 5.0)	3.5	1.0 - 13.0
Midday 2	36	25.3 ± 8.6	23.9 (21.1 , 26.7)	22.0	12.0 - 44.0

While the average PM2.5 and CO values for House #7 are similar to those experienced by the eight households in the LPG/*fogon* comparison study for the Stove and Morning *fogon* conditions, these values exceeded those of the eight other households by about thirteen times for PM2.5 and about five to six times for CO for the first Midday *fogon* condition. Even with the chimney addition and other modifications the average concentrations for House #7 still exceed the combined data from the other houses by a factor of two or more. Thus, during the midday and afternoon periods of the day the indoor air quality situation in House #7 was much worse than that of the other test houses in Cayo Paloma and during the morning period it is about the same as the other test houses.

Since all the households experienced concentrations of PM2.5 and CO magnitudes greater than the WHO health guidelines, and because information on the health impact of such extreme exposures is still scarce, it is hard to state with certainty that the situation in House #7 is that much more dangerous to its inhabitants than that of the other households, but from the author's personal experience the situation in House #7 effected his immediate short term health much more than the situation in any of the other test households.

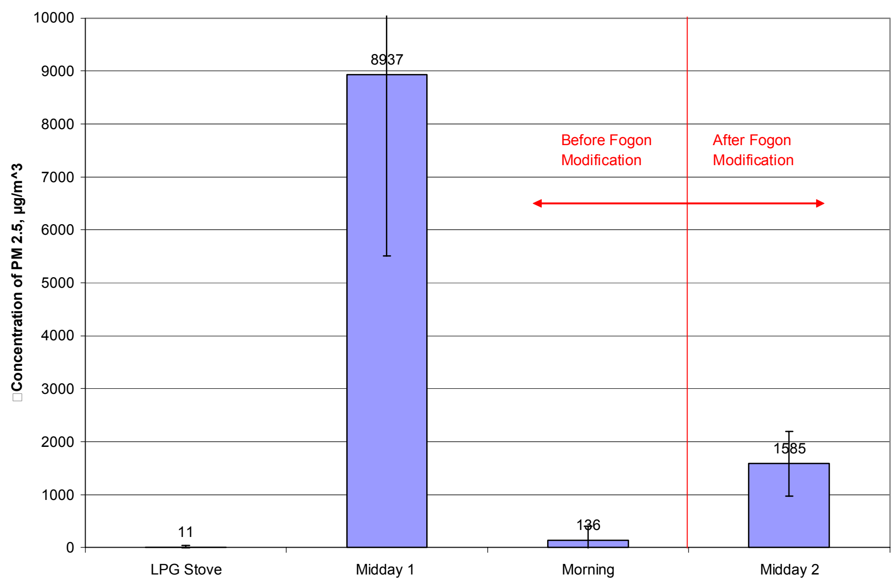

Figure 25: Geometric mean concentrations of PM2.5 for the Stove, Midday 1, Morning and Midday 2 conditions for the *Fogon* Modification test (w/95% confidence intervals).

While the *fogon* modification did result in a substantial reduction in the geometric mean concentration of PM2.5 (82.26% reduction between periods Midday 1 and 2), it was less of a reduction than that which occurred through the use of the LPG stove (99.88% reduction from Midday 1 fitting the pattern seen in the LPG/*fogon* comparison tests) and in the end resulted in a geometric mean concentration that was almost twelve times greater than that experienced during the Morning period. CO concentrations were only reduced 20.15% using the modified *fogon* compared to 92.24% using the LPG stove. \

To determine what the theoretical difference in the average concentration of PM2.5 would be over a three meal period, two different calculations were made with one calculation representing the use of the original *fogon* and the other calculation representing the use of the modified *fogon*. For the original *fogon* calculation it was assumed that out of the daily three meals, the model morning meal would be represented by the data from the Morning test period measurements and that the model midday and evening meals would be represented by the data from the Midday 1 test period. For the modified *fogon* calculation it was assumed that all three model meals would be represented by the data from the Midday 2 test period. These assumptions were made on the basis that the wind blows the pollutants out of the house during the morning and into the house in the afternoon when the original *fogon* was in use and that the wind direction has minimal impact when the modified *fogon* was in use since the modified *fogon* protects the fire box from the wind and directs the emissions through the chimney which is exposed almost equally to all wind directions.

Using the above assumptions the original *fogon* value for the average concentration of PM2.5 over a theoretical three meal period was 6003 $\mu g/m^3$ and the modified *fogon* value was 1585 $\mu g/m^3$ signifying about a 74% reduction in exposure with the use of the modified *fogon*. In reality the modified *fogon* should allow for even more of a reduction percentage since during the morning the average concentration of PM2.5 associated could be even less than that associated with the midday time period. Therefore even though the new *fogon* structure used during the midday period allowed for a higher average concentration of PM2.5 then the original structure did during the morning, throughout an entire day using the modified *fogon* would theoretically increase the indoor air quality by a substantial amount. The accuracy of these results are limited by the lack of multiple measurements at different times of day both before and after the modification was implemented.

Altogether, except for the LPG stove condition, all of the other cooking conditions including the modified *fogon* still allow for very high amounts of PM2.5 and CO that exceed the WHO health guidelines dramatically. It should be pointed out though that the *fogon* modification that was implemented at House #7 was carried out rapidly and with low quality materials and tools and therefore the new fire box was neither entirely sealed on three and a half sides as the design called for nor was the chimney built to the originally designed height. Perhaps with better quality local materials and tools and better general construction practices this style of modification could be made to be more efficient at reducing the PM2.5 levels in the cooking space.

Another suggestion to improve the *fogon* modification's efficiency would be to extend the half wall on the front face of the fire box to a lower height in order to create a more complete hood to trap and direct the *fogon* emissions towards the chimney. This extra step needs to be taken with the cook in mind since extending the wall too far down would interfere with daily cooking. These kinds of modifications could have been performed to most of the households in the Cayo Paloma area and it would be interesting to see how more efficient modifications affect the indoor air quality in those other houses.

Chapter 6: Conclusions

6.1 Major Findings

Based upon the results of all three groups of tests performed during the course of this study it can be stated that the use of the traditional *fogon*-style cooking fire has a substantial negative impact on the indoor air quality in the households of Cayo Paloma.

Use of these open fires in cooking household meals exposes cooks and other inhabitants of the cooking space to high levels of CO and extremely high levels of PM2.5. Over the cooking period average CO levels can reach upwards of 6.8 ppm and average PM2.5 levels can reach 1042 $\mu g/m^3$ (in one household the average PM2.5 was calculated to be at the extremely high level of 13,361 $\mu g/m^3$). Maximum levels of PM2.5 can reach extreme levels of up to 40,000 $\mu g/m^3$ and maximum CO levels can reach up to 80 ppm. These maximum levels are of concern since one extremely high pollution event could possible trigger latent respiratory disease. The data provided recording concentrations from early morning until after the evening meal suggested a 24-hr PM2.5 level of 174 $\mu g/m^3$ which is almost seven times higher than the WHO air quality guideline value.

The style of house in Cayo Paloma being fairly more open and better ventilated and the coastal weather creating a lot of air movement suggests that perhaps these indoor air quality results could be on the low end of what is actually experienced in other areas of the Comarca Ngäbe-Bugle and rural Panama in general.

The use of an LPG stove for cooking was seen to reduce PM2.5 emissions by 90-95% in most households. Household economic status, time of day and cooking space size did not seem to influence indoor air quality as much as cooking device type and cooking space type. House #2 most likely experienced low PM2.5 and CO readings due to the extended and open design of its fire box area and the accompanying wind.

Even though the implemented *fogon* modification in House #7 helped to reduce the daily average PM2.5 concentrations by about 74%, the average concentrations experienced still exceeded that of the WHO guidelines and those of the other households in Cayo Paloma.

6.2 Recommendations

Along with these conclusions, both the experience of the implementation of this study and its results provide the basis for many recommendations having to do with future action and research connected with this work.

The first recommendation is a simple one to say though harder to implement. Basically, more controlled experiments are needed in the Cayo Paloma area and throughout the Comarca Ngäbe-Bugle to determine the accuracy of the results found in this study and to gather more data for better health, economic and indoor air quality analysis in general. Specifically, measurements need to be taken in individual households multiple times in order to better control for time period, weather and seasonal variables and test households need to be chosen to better control for variables such as cooking space size, cooking space type, family size, economic status and fuel type.

Exposure/response relationships developed for the conditions in rural indoor areas of the developing world are badly needed in order to better quantify the health effects of the indoor air quality experienced by a large part of the world population. These relationships could help in performing cost-benefit analysis of not only LPG stoves but also other cooking technology and health interventions. This kind of information would be very beneficial for governments and NGOs trying to improve the country's health situation.

As was mentioned in Chapter 1, respiratory infections and other respiratory related diseases, many of which are linked to poor indoor air quality, are the number one killer across all age groups in Panama. These respiratory infections are partly responsible for the high infant mortality that exists in the Comarca Ngäbe-Bugle and in Panama as a whole. Table 10 compares these infant mortality rates to those of the United States and shows that the infant mortality experienced in the Comarca Ngäbe-Bugle is almost three and a half times greater than that experienced in the United States. Because of the large possible effect on human health in rural Panama due to extremely high concentrations of PM2.5 and even CO, more attention should be paid to promoting better indoor air quality by local health assistants, government agencies and NGOs that are concerned with improving human health.

Table 10: 2005 Infant Mortality in the United States, Panama and the Comarca Ngäbe-Bugle (From US Census Bureau and MINSA).

	Infant Mortality per 1000 births
United States	6.5
Panama	16.7
Comarca NB	22.6

Peace Corps Panama volunteers should be introduced to the importance of indoor air quality, its relationship to health and the relatively simple solutions available. This is especially true for the Environmental Health sector of Peace Corps Panama because of its emphasis on human health and for the Conservation sector which already has experience with *lorena* type improved cook stove designs. There is a need for more health education related to indoor air quality. More efficient *fogon* modifications than the one presented in this report could be implemented without much more effort or many more materials. Such activities are simple ways to help provide a healthier living environment.

In general there is also a need for more controlled testing of different *fogon* modifications and/or other more complex improved stove systems in rural Panama to see which ones work more efficiently in the local areas and are more accepted by the local people.

6.3 Future Work

Future projects specific to rural Panama and the Comarca Ngäbe-Bugle could be divided into two categories: improved indoor air quality/control testing, and educational outreach/simple modifications. The distinction between the two categories is that the first category would require access to indoor air quality monitors and a stricter, more controlled implementation plan.

As was mentioned above, more controlled indoor air quality experiments are needed to accurately assess the exposure to pollution and subsequent health impact of the use of the standard *fogon*. Since Peace Corps volunteers reside in their host communities for two years or more they might be able to provide a good opportunity to do more long term testing in rural households across the Comarca Ngäbe-Bugle and Panama. The air quality monitors used in this study were very user friendly and so they, or similar ones, could be given to a volunteer after they have settled into their host community and helped develop a monitoring program. These monitoring programs could be created by the volunteer with the help of Masters International (MI) students, health professionals or other people knowledgeable about indoor air quality and exposure assessment. The data collected would then be analyzed by either MI students or other researchers. Again, the air quality monitors are easy to use and testing would not take up too much of the Peace Corps volunteers' time to accomplish their primary and secondary work in their communities but rather be another health education opportunity or simply time to sit and chat. It would of course be the decision of the volunteer as to whether this kind of testing would be socially acceptable though in the author's experience it was as long a the process was explained and scheduling was worked out.

One set of air quality monitors could be shared by many volunteers covering a larger cross section of rural and even semi-urban communities. To begin with different communities that are representative of their region (coastal, lowland, highland) could be chosen. Also, testing could be done on different cooking technologies like the *lorena* stove which exist in some areas of Panama and with which Peace Corps Panama has much experience.

There are many possible testing scenarios but overall a good amount of helpful pollutant level specific data could be collected in this manner as well as social, economic and environmental data. The lack of funding for the air quality monitoring instrumentation could be made up by volunteers partnering with institutions or programs like the MI one at Michigan Tech.

For more long term testing perhaps the Panamanian Ministry of Health could be involved and its local Health Assistants used as testers though the funding might be more problematic and there most likely need to be extra training. For the most controlled and important experiments a dedicated group of researchers would probably be needed but a general picture of the indoor air quality situation might be able to be determined with volunteer-collected data.

Another set of recommended actions that involve either Peace Corps volunteers or local Health Assistants concerns air quality related health education and simple structural or behavioral modifications. These actions require less outside funding and materials though they could be made more effective with them.

While everyone is bothered by the presence of large amounts of smoke many do not know the possible health effects of the indoor air pollutants emitted by the combustion of wood. The following are some health talking points and ideas that could be included in small family talks or presentations to community organizations:

- The danger of gases released by burning plastic trash or by using plastic or kerosene to start cooking fires (which is commonplace in rural Panama) since there is a lack of knowledge in this area.
- Specific to communities that have experience with banana plantations: Use pesticides as an example of something that is hard or impossible to see but can hurt you in describing toxic gases or fine particulate released from combustion.
- The concept that over long periods of time decent exposure levels can cause chronic diseases. Connecting bad coughs or asthma to previous smoke exposure as opposed to an immediate effect of exposure to smoke. In general, besides the immediate negative effects of smoke (watering

eyes, headaches, coughing), most people did not know that indoor air pollution could cause longer term and different kinds of diseases.

- Connect local peoples knowledge of the effects of smoking (leads to cancer) to the idea that cooking fire smoke could be doing similar damage
- Describe the importance of the impact of good indoor air quality on the development of infants and small children.

Since the main source of indoor air pollution in the households of Cayo Paloma and throughout rural Panama is the family cooking fire the conversation between Health Assistant and volunteer and the family can not end with only the possible health effects. This is because the family will quite possibly absorb the information and then ignore it since they need to eat and they don't know how to improve their situation. Thus, the conversation needs to continue onto how to actually change the indoor air quality in simple ways. The conversations can be about changing the cook's behavior or the cooking space/technology or any of the other factors shown in Figures 6 and 7 presented earlier in this report. Some ideas include:

- As mentioned before, simple structural changes can be accomplished especially if the family is motivated by the importance of family health. These changes could include building a closed fireplace with a hood and chimney, separating the cooking area from the rest of the house, separating the *fogon* area and the work area of the cooking space etc.
- Improved stove designs that use local materials such as the *lorena* could be introduced as methods to improve indoor air quality.
- Cooks could be taught to wear some sort of protection ranging from a simple cloth to a mask like the type used in polluted urban areas. While this seems like a lot to ask from women cooking for their families there are maybe some places to begin the conversation since women already tend to at least cover their hair when baking bread.
- Maybe action concerning masks could be concentrated on women's groups who regularly make bread, pastries or coconut oil together for sale. Teaching the members to use some sort of masking while cooking might

not seem as weird when done in a group and if adequate masks could be provided.

- Another behavioral change that might be a bit harder to introduce is that of removing the small children and infants from the cooking areas. This is impossible in some households where there is no distinction between kitchen and living room and hard in households were all the women are needed to cook and thus no one can be sent into the other room to watch the children. Another problem with this approach is that people like to sit and talk in the same room and near to each other.

Again the closeness of the Peace Corps volunteers and some of the Health Assistants provides a good opportunity to at least get local people thinking about indoor air quality and starting to feel that there might be some ways to deal with it.

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Appendix A: Household Health and Indoor Air Survey Results

Survey Questions: (Translated from Spanish)

1. How many people sleep in this household currently?
2. Of what age are the current inhabitants? - How many kids, adults, elderly?
3. Is there a family member who is currently sick? With what sickness?
4. In the past month had there been anyone who was sick? With what?
5. With what frequency is someone sick with a strong cough?
6. With what frequency is someone sick with a strong headache?
7. With what frequency is someone sick with the flu?
8. With what frequency does someone have pain or discomfort in their eyes?
9. With what frequency does someone have trouble sleeping?
10. With what frequency is there a large amount of smoke in the house?
11. Does the family do anything to disperse the smoke in the house? What?
12. Does smoke from the cooking fire affect anyone while they sleep?
13. How many times a day is the cooking fire (fogon) lit?
14. How many times does the family usually eat during the day?
15. Does a large amount of smoke enter the house while the family is cooking?
16. How much time is spent in the cooking area by family members?
17. How long does a standard meal take to cook?
18 What type of firewood does the family use to cook with the most?
19 Monthly family income according to survey performed by local Health Assistant.

Survey Key:

K – Kids, 0 – 15 years old
A – Adults, 15 – 60 years old
E – Elderly, >60 years old

ST – Sometimes
MT – Many times
AL – Always

N – Never or No
Y – Yes
NR – No response

Home Physical Inspection Items:

1. Location of household in respect to neighbors, wind direction, terrain.
2. Layout of household with door, window, openings.
3. Housing material used and general house condition/age.
4. Roofing type: corrugated iron or penca (thatch).

Table 11: Results of Household Health and Indoor Air Survey[1]

	SURVEY QUESTIONS																					
	POPULATION (1,2)				HEALTH							INDOOR AIR									$	
FAMILY	K	A	E	Tot	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17 (MIN)	18	19	ADDITIONAL INFORMATION
Teresa S.	5	2	0	7	Y	Y	AL	MT	ST	ST	N	MT	N	N	3	3	AL	MT	60	WHATEVER WOOD WAS AVAILABLE, MAY TREE, LAURAL Etc.	100	TEST HOUSE 1 GAS STOVE, STORE,
Elida J.	3	4	0	7	N	N	NR	NR	NR	ST	NR	ST	N	N	3	3	ST	N	60		0	TEST HOUSE 2 GAS STOVE
Selestino W.	3	2	2	7	N	Y	AL	ST	ST	N	N	AL	N	N	3	3	AL	MT	60-90		200	TEST HOUSE 3 GAS STOVE, STORE
Manuel G.	3	2	0	5	N	N	AL	MT	ST	ST	ST	ST	N	N	3	3	ST	ST	60		25	TEST HOUSE 4 GAS STOVE
Rafael Chi	2	2	0	4	N	N	ST	MT	ST	MT	N	MT	N	N	2	2	AL	MT	30		15	TEST HOUSE 5 GAS STOVE
Leopoldo S.	4	2	0	6	N	Y	ST	N	ST	N	N	ST	N	N	3	3	N	N	60		200	TEST HOUSE 6 GAS STOVE
Alfredo E.	2	2	1	5	Y	N	ST	AL	ST	MT	N	MT	N	N	3	3	AL	ST	90		35	TEST HOUSE 7 GAS STOVE
Eliezer B.	2	2	0	4	N	N	ST	ST	ST	N	ST	MT	N	N	3	3	AL	ST	30		0	TEST HOUSE 8
Lupita M.	2	2	0	4	Y	N	ST	NR	NR	AL	ST	MT	N	N	2,3	2,3	AL	MT	60		25	TEST HOUSE 9
Clementino	1	2	2	5	Y	Y	ST	ST	ST	N	N	N	N	N	2	2	N	MT	60		309	GAS STOVE
Sebedeo J.	3	2	0	5	Y	Y	ST	MT	ST	MT	N	MT	N	N	3	3	AL	MT	60		NR	
Bianco A.	4	4	0	8	N	N	ST	ST	N	N	N	N	N	N	3	3	N	N	60		300	GAS STOVE, STORE
Mauricio J.	4	4	0	8	N	N	ST	ST	ST	ST	N	ST	N	N	3	3	AL	ST	60		10	GAS STOVE
Elisia S.	4	2	2	8	Y	N	ST	ST	ST	MT	NR	MT	N	N	3	3	AL	ST	60		0	
Merilo J.	4	6	0	10	N	N	ST	MT	ST	N	NR	AL	N	N	3	3	AL	MT	60		20	
Simon B.	4	3	0	7	N	N	ST	ST	ST	N	N	MT	N	N	3	3	AL	MT	60		NR	
Angelica T.	3	4	1	8	Y	N	ST	ST	ST	N	N	ST	N	N	3	3	ST	MT	60		NR	
Augustine J.	3	0	2	5	Y	N	ST	ST	ST	ST	NR	MT	N	N	3	3	MT	ST	45		10	
Livio M.	0	0	1	1	N	N	ST	ST	ST	N	ST	ST	N	N	3	3	ST	ST	30		0	
Marcario T.	5	2	0	7	Y	N	ST	ST	ST	AL	N	ST	N	N	3	3	ST	MT	90		NR	BREAD MAKER
Nivelio J.	4	7	2	13	Y	Y	ST	ST	ST	AL	ST	ST	N	N	1,3	1,3	AL	ST	60		NR	
Fermion C.	4	3	2	9	Y	N	ST	ST	ST	AL	ST	ST	N	N	2	2	ST	ST	90		200	GAS STOVE
Felipe B.	2	1	2	5	Y	N	MT	ST	ST	ST	ST	AL	N	N	2,3	2,3	AL	ST	120		NR	
Frank J.	7	2	2	11	Y	N	ST	MT	NR	NR	NR	ST	N	N	2,3	2,3	AL	MT	60		3	
Enrique F.	5	3	0	8	N	Y	AL	MT	AL	ST	N	MT	N	N	3	3	AL	ST	60		34	
Justina R.	0	0	1	1	Y	Y	ST	NR	ST	ST	ST	MT	N	N	2	2	AL	MT	20		NR	
Angelo R.	1	1	1	3	N	Y	AL	ST	ST	ST	NR	AL	N	N	2,3	2,3	ST	ST	90		1	
Nicasio C.	3	2	0	5	N	N	ST	ST	ST	MT	ST	ST	N	N	2	2	AL	MT	60		NR	
Nasario W.	6	4	2	12	N	N	ST	ST	ST	N	N	ST	N	N	3	3	ST	MT	30		247	GAS STOVE
Anival B.	5	3	0	8	N	N	MT	MT	ST	MT	AL	ST	N	N	3	3	AL	MT	60		5	

1 – Survey performed February 2006.

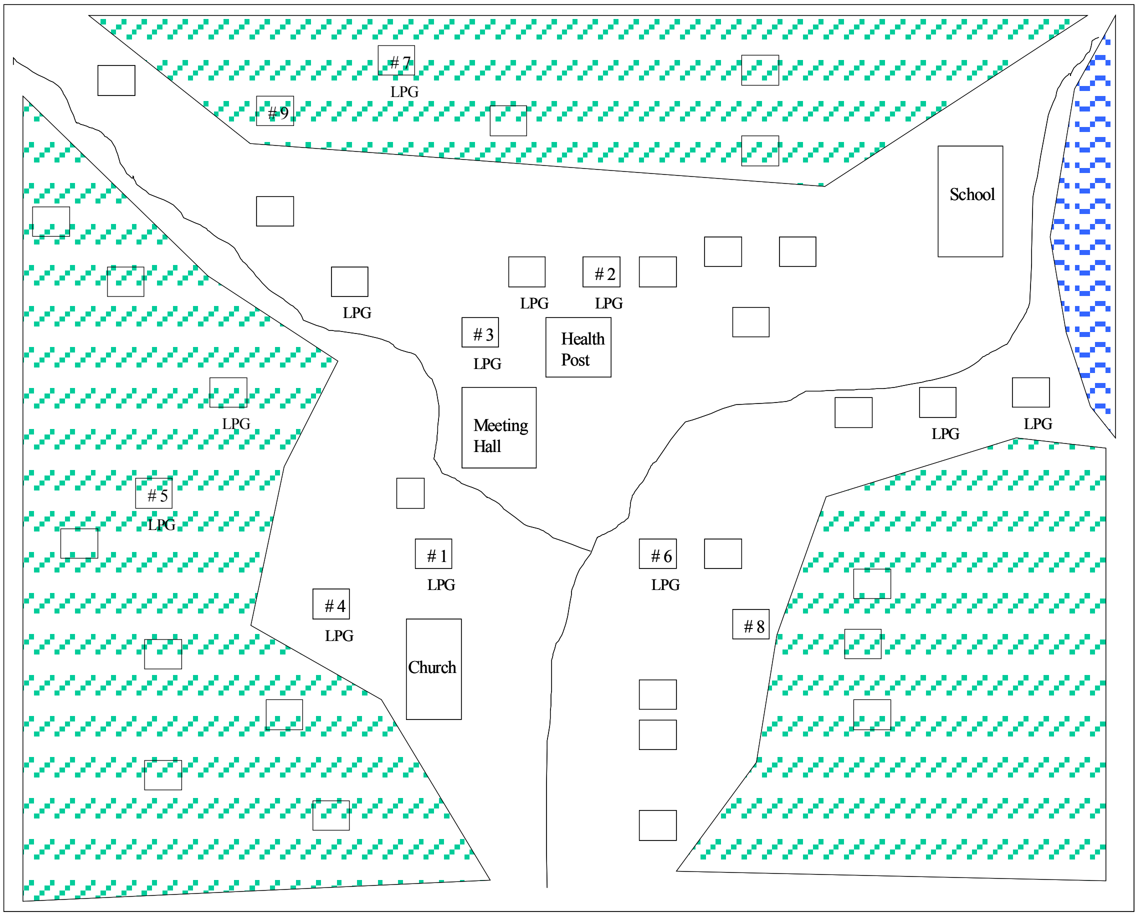


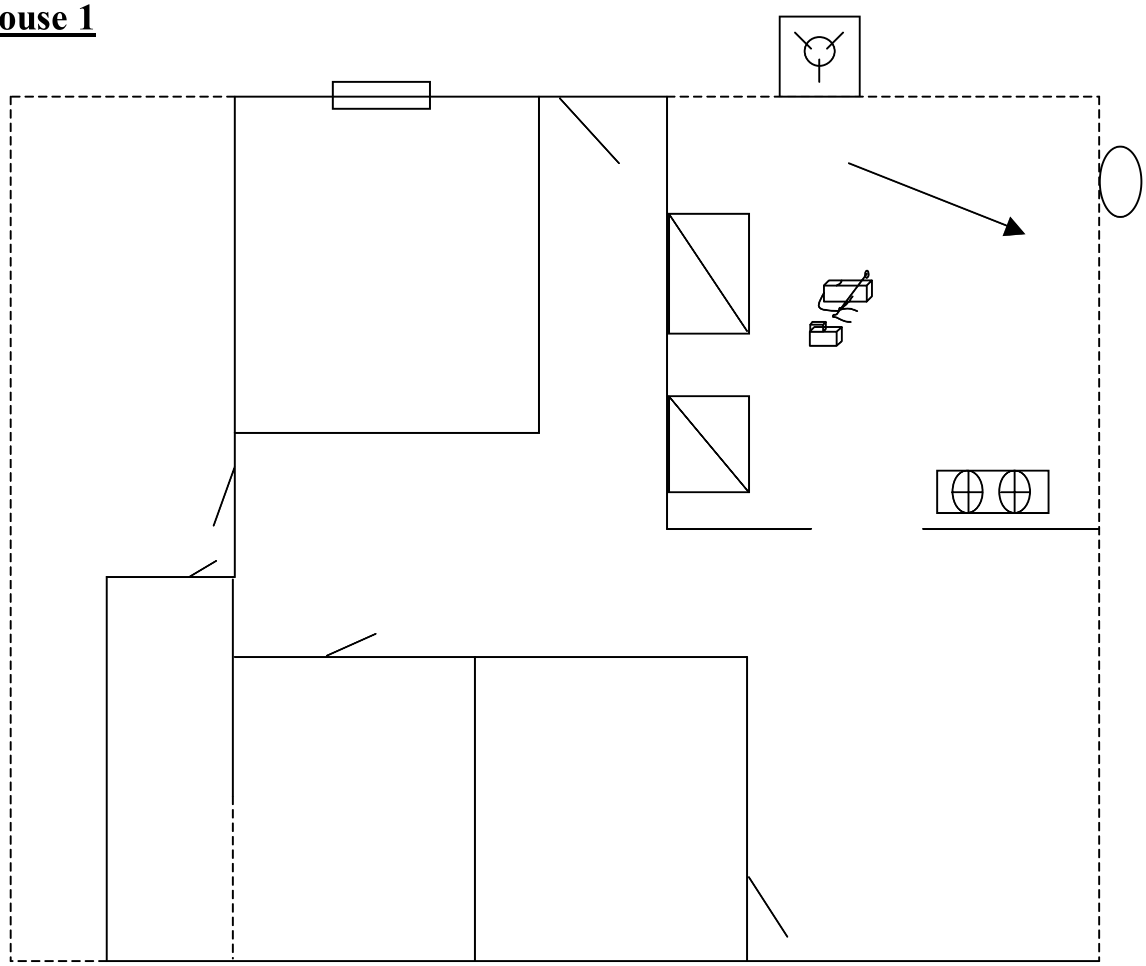
Figure 26: Map of Cayo Paloma showing test houses by number and other households with LPG stoves (Dashed areas are hills. Wave pattern represents the sea).

Appendix B: Floor Plans and Physical Descriptions of the Test Houses

Legend: Fogon LPG Stove Instruments
Sink

Overall wind direction during test Half
height wall

<u>Test House 1</u>



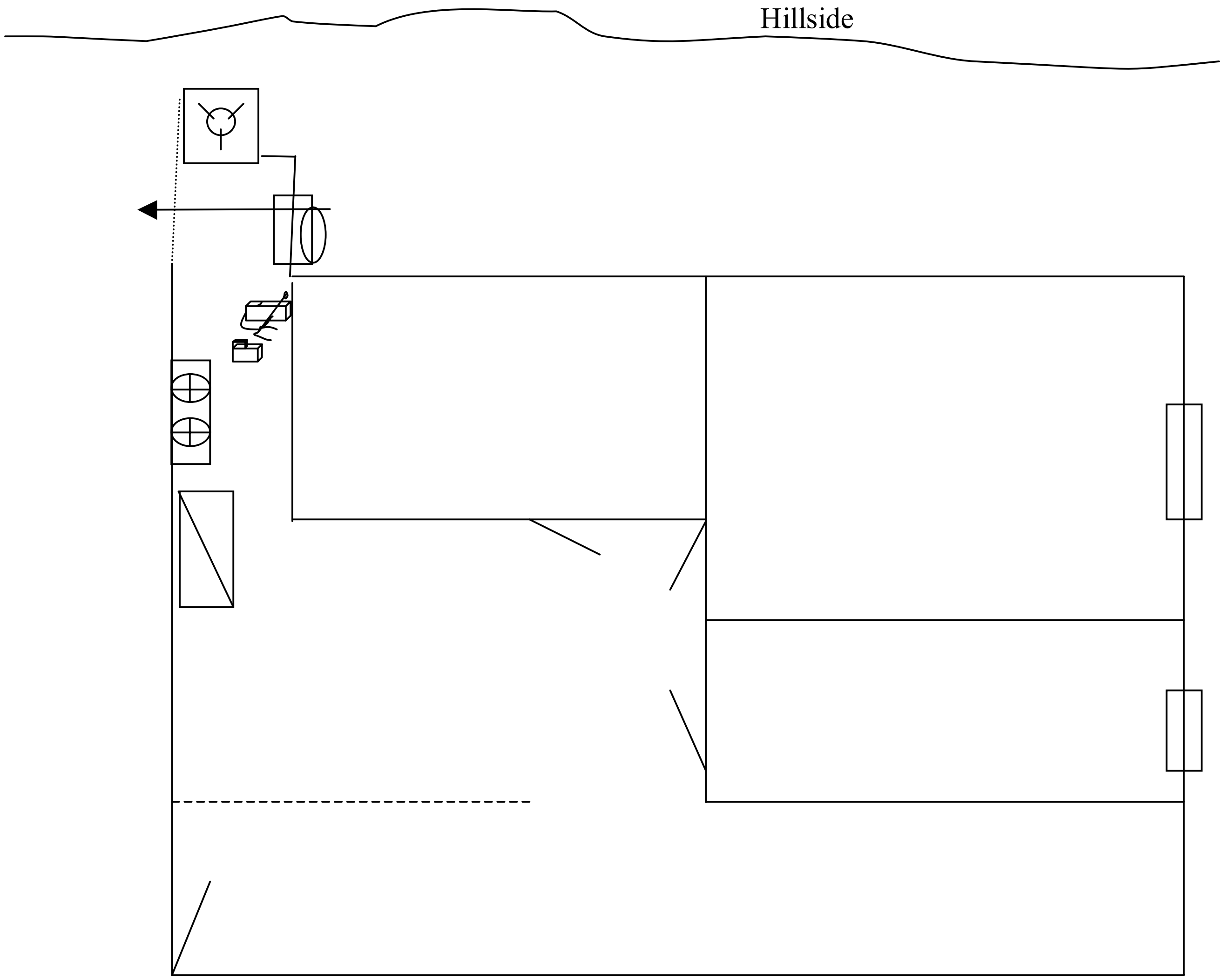
Household Description:

- 12 inhabitants
- Metal roof
- Good condition

Test Conditions:

- Initial presence of some smoke in cooking area
- Variable wind strength
- Test started at 9:00AM
- Test date: 7/27/06

Test House 2



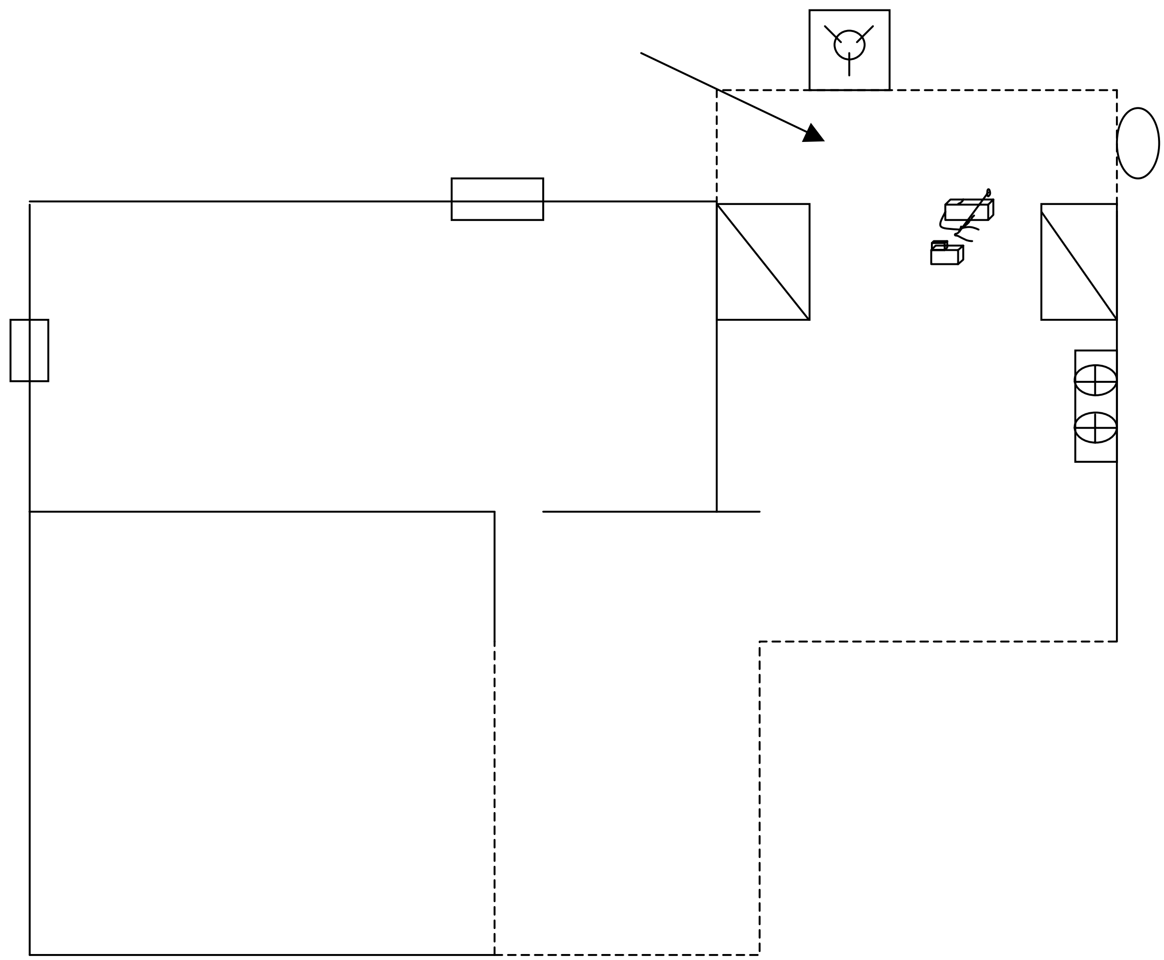
Household Description:

- 6 inhabitants
- Metal roof
- High roof
- Good condition

Test Conditions:

- Very strong wind throughout test
- Sunny and hot day
- Test started at 11:30AM
- Test date: 8/3/06

Test House 3



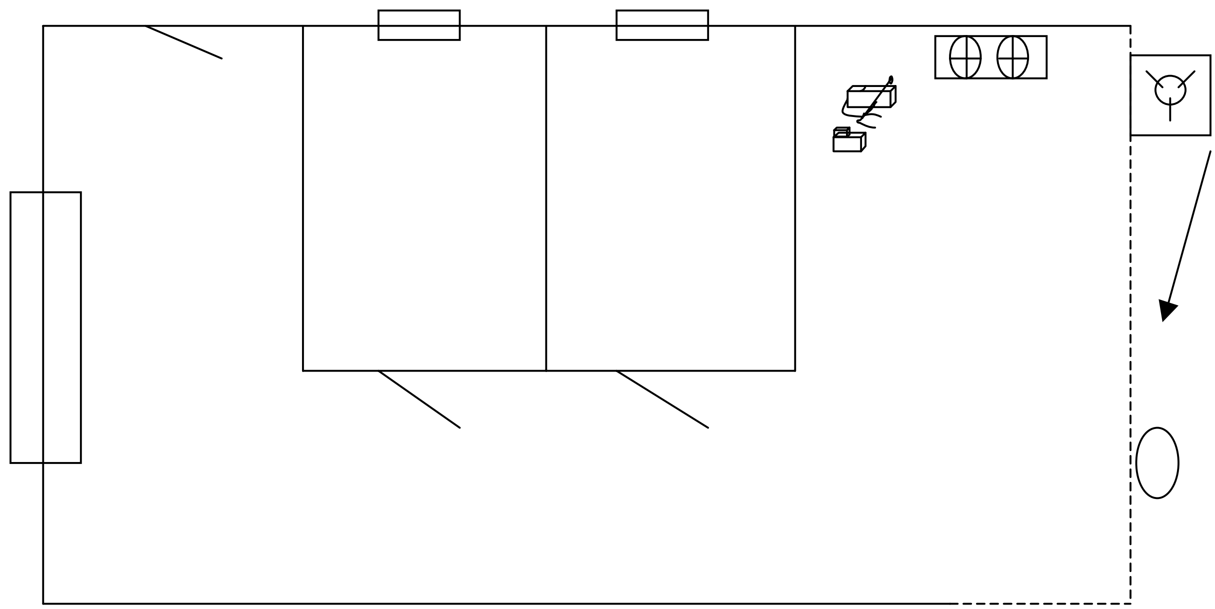
Household Description:

- 7 inhabitants
- Metal roof
- Low roof
- Good condition

Test Conditions:

- Light wind
- Strong rain
- Test started at 10:00AM
- Instruments set up on makeshift table
- Test date: 8/7/06

Test House 4



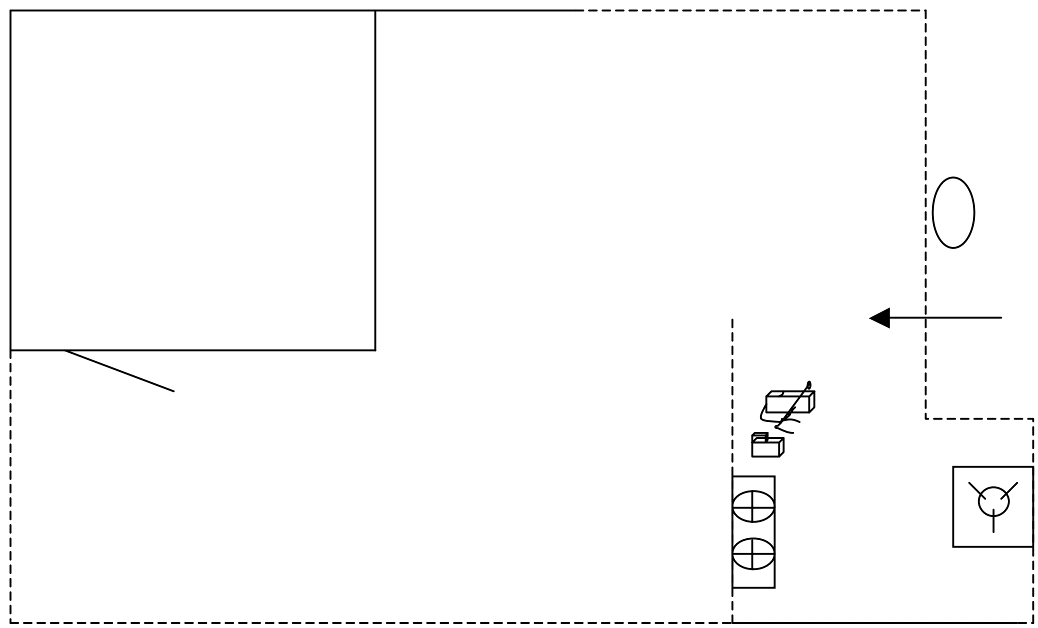
Household Description:

- 5 inhabitants
- Metal roof
- High roof
- Good condition

Test Conditions:

- Light wind
- Test started at 4:50PM
- Test date: 8/8/06

Test House 5



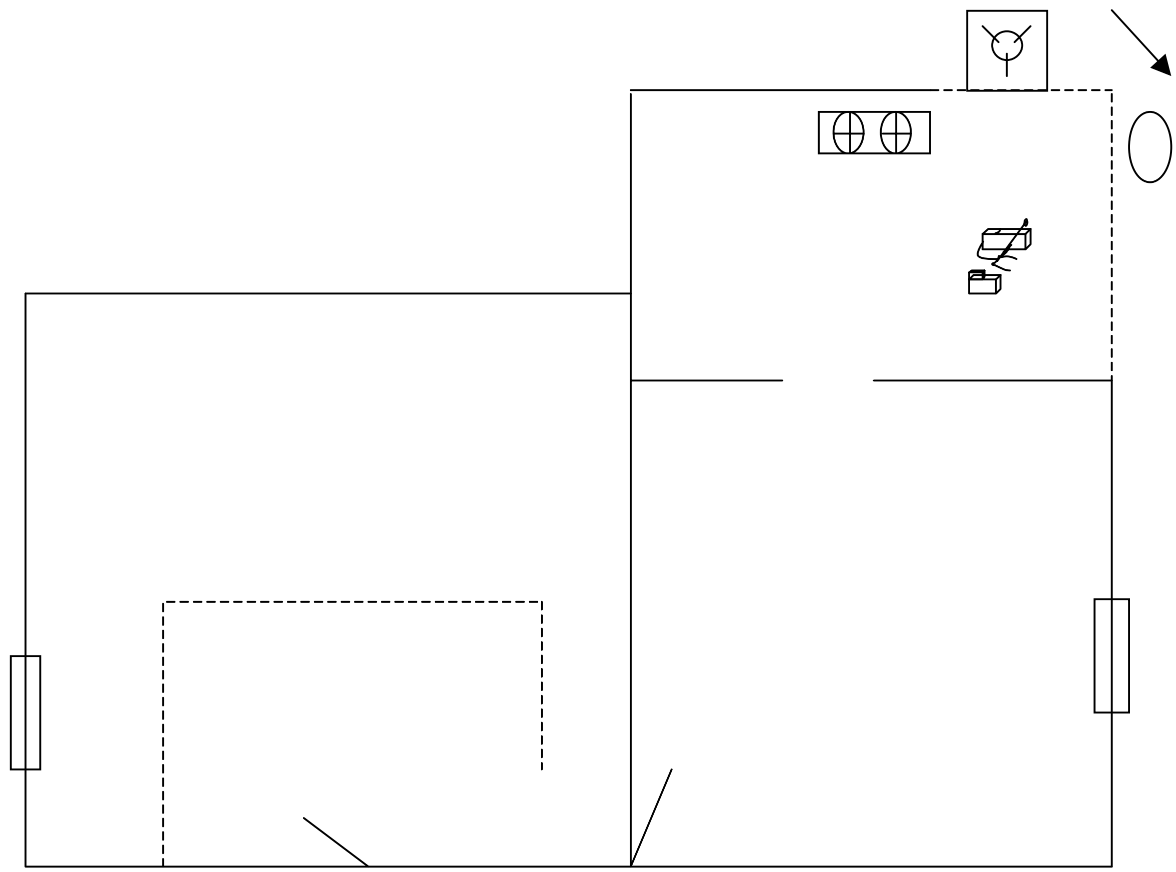
Household Description:

- 5 inhabitants
- Thatch roof
- Low roofing
- Decent condition

Test Conditions:

- Light wind and clouds
- Test started at 5:00PM
- Test date: 8/9/06

Test House 6



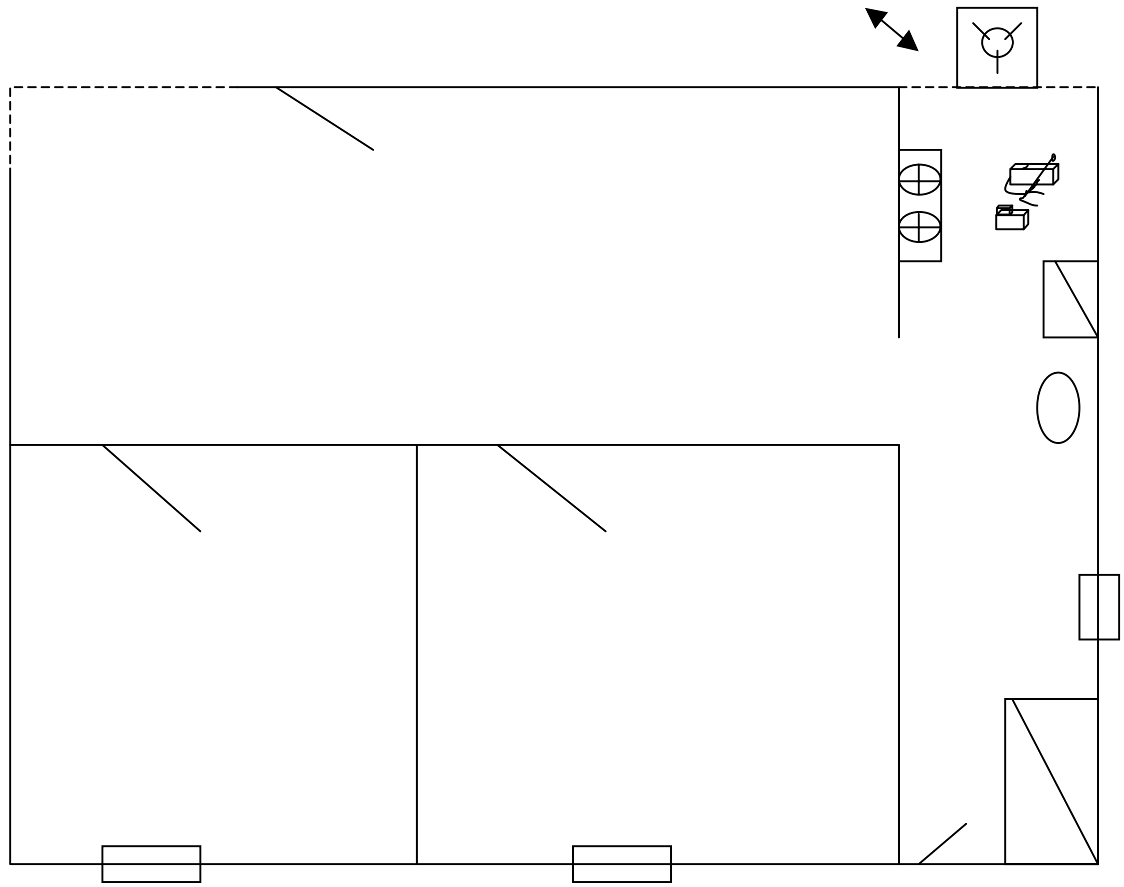
Household Description:

- 6 inhabitants
- Metal roof
- Good condition
- Fogon in bad condition

Test Conditions:

- Light wind
- Test started at 5:15PM
- Instruments on makeshift table
- Test date: 8/19/06

Test House 7



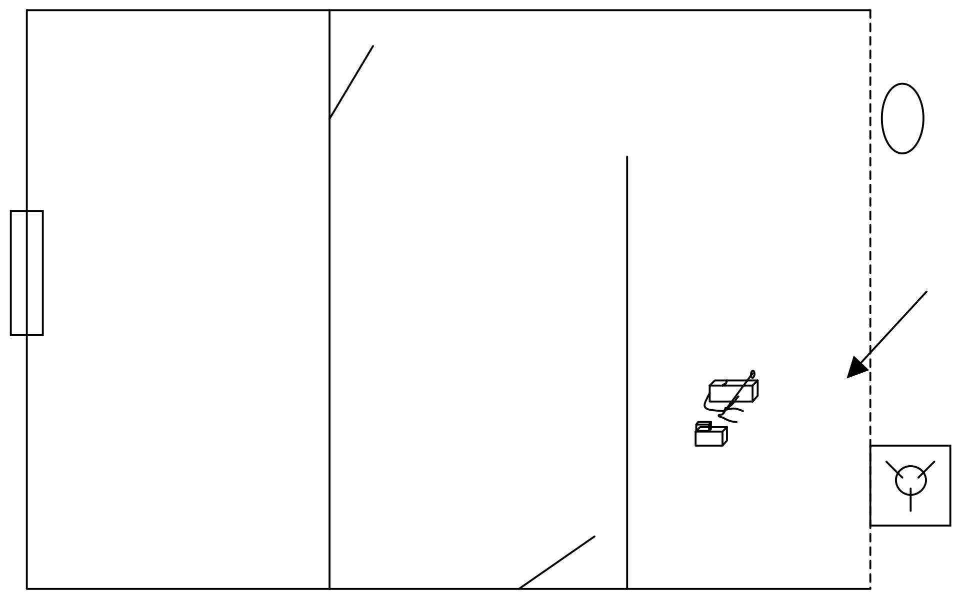
Household Description:

- 5 inhabitants
- Thatch roof
- Good condition

Test Conditions:

- Fogon modification test
- Test during midday, morning and second midday period
- Strong morning winds directed out of the home
- Strong afternoon winds directed into the home
- Test dates: 8/10/06, 9/7/06, 9/8/06

Test House 8



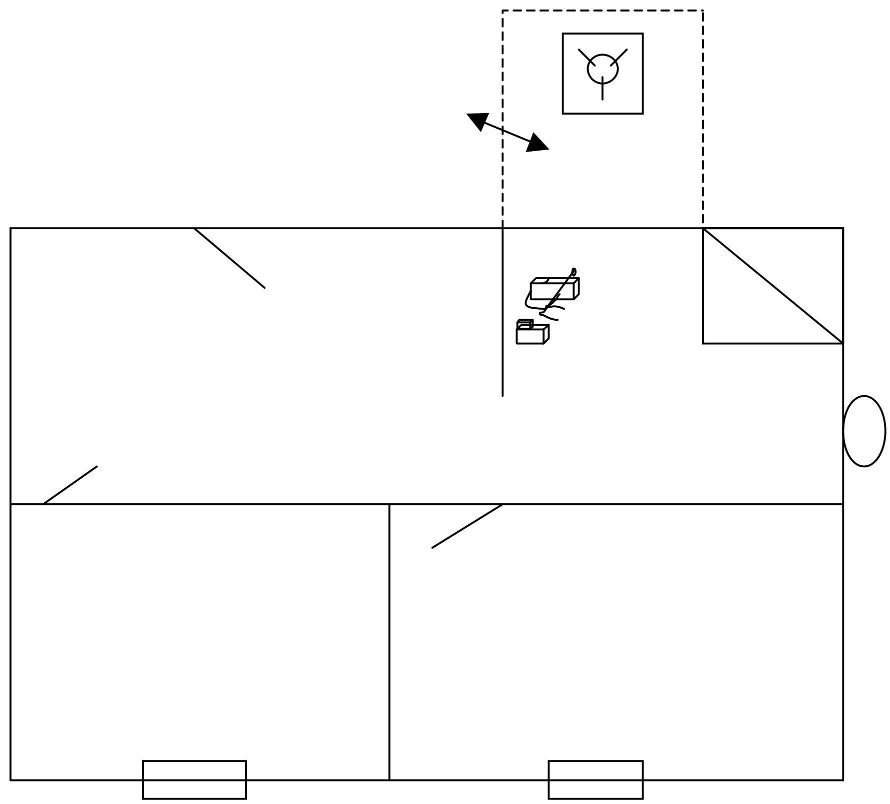
Household Description:

- 5 inhabitants
- No LPG stove
- Metal roof
- Low roof
- Good condition

Test Conditions:

- Variable wind
- Variable sun and clouds
- Test started at 11:30AM
- Test date: 8/18/06

Test House 9



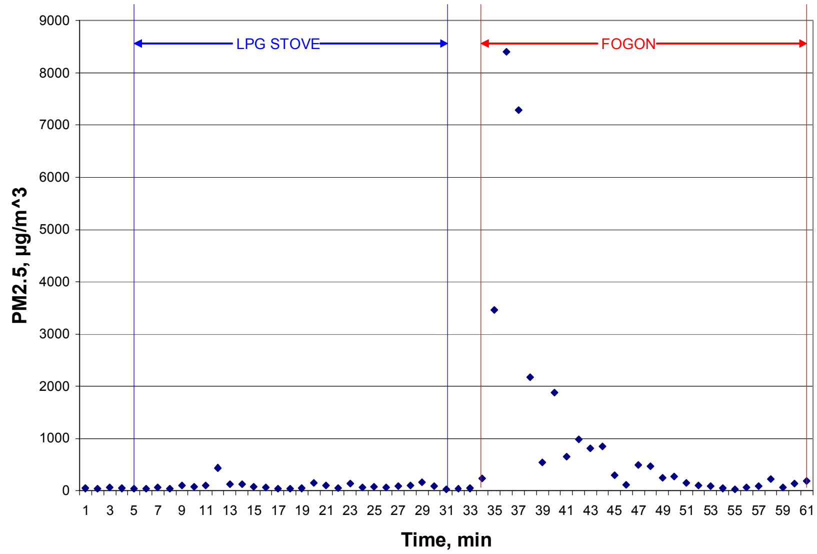
Household Description:

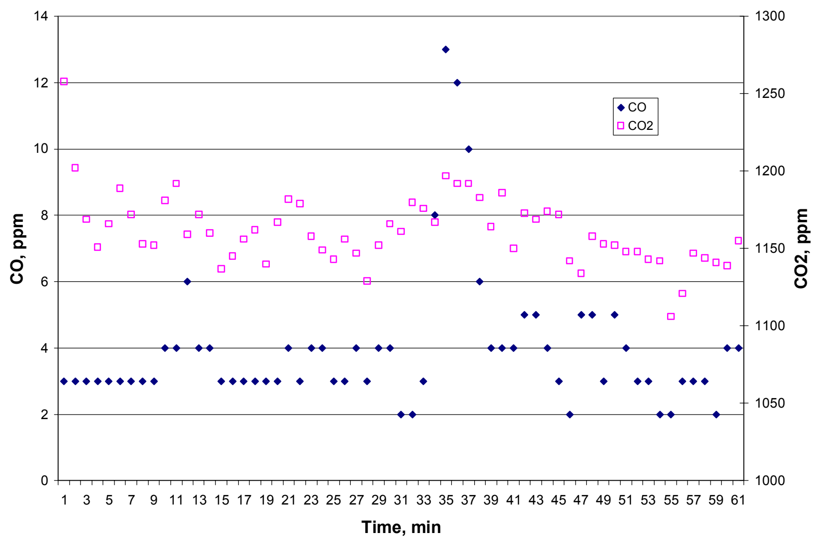
- 4 inhabitants
- Metal roof
- High roof
- Good condition

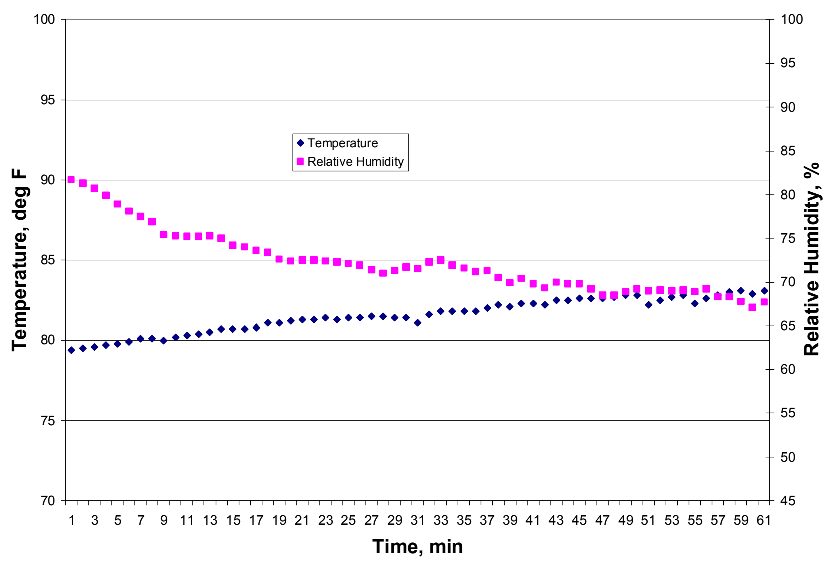
Test Conditions:

- Standard day test
- Variable weather and wind throughout test day
- Second morning test with slight wind
- Test dates: 8/2/06, 8/19/06

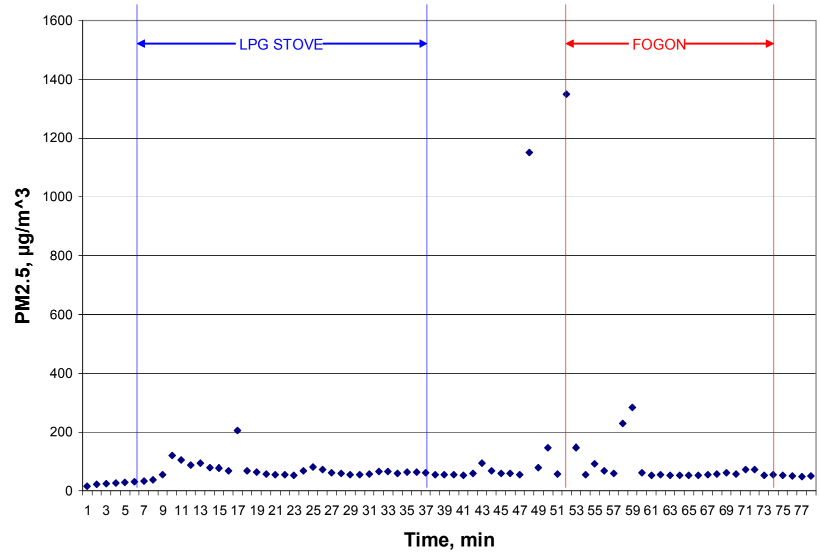
Appendix C: Individual Annotated Test Data
Test House 1:



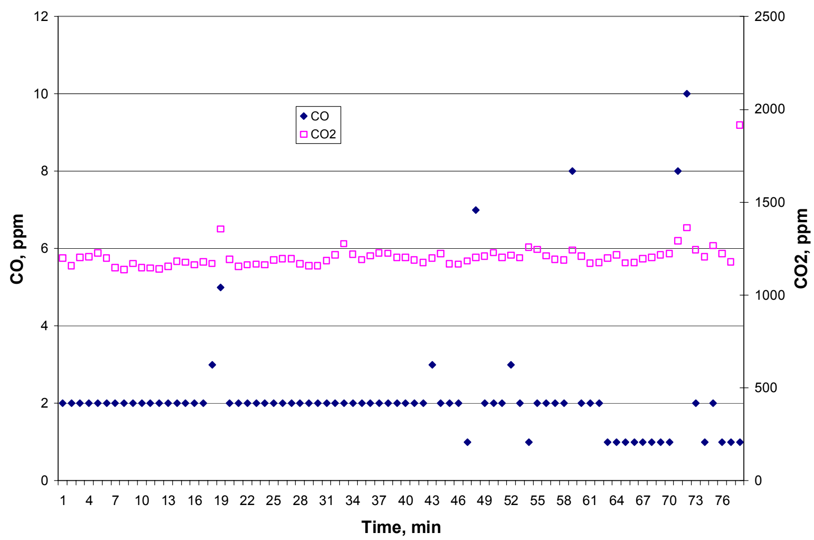




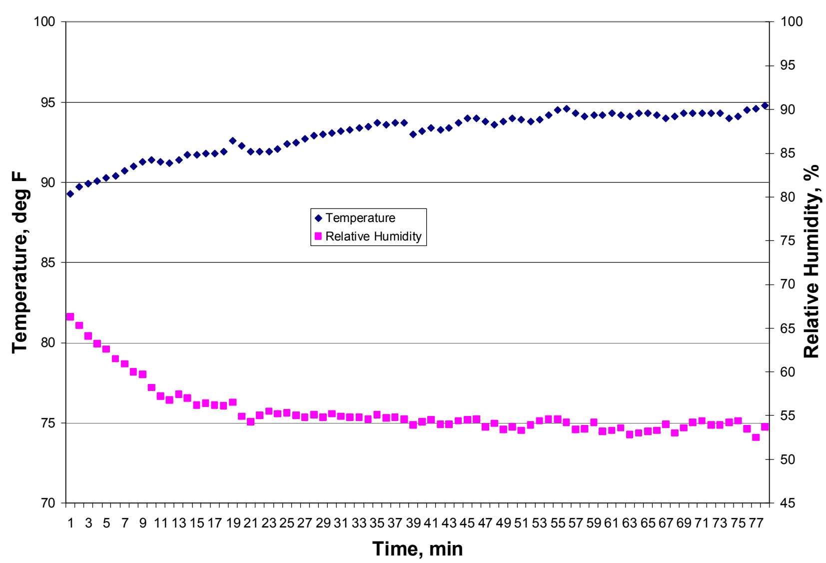
Test House 2:



LPG STOVE
FOGON
PM2.5, µg/m^3
Time, min

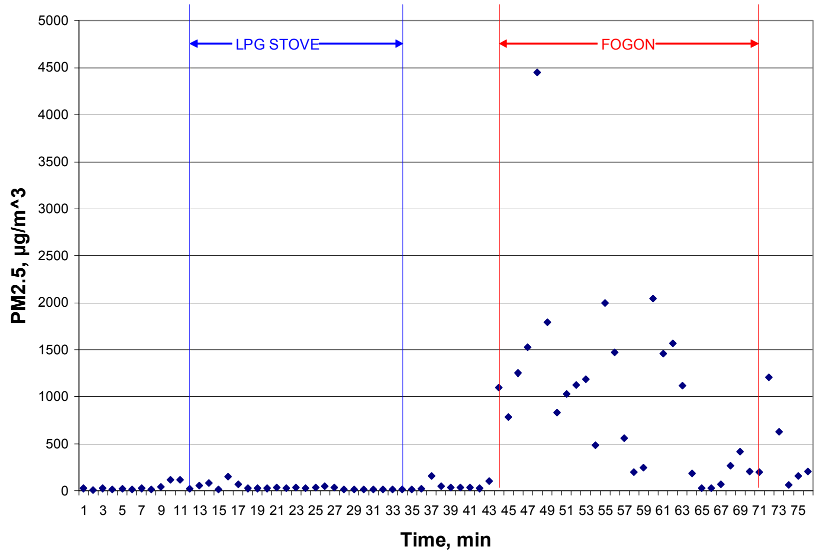


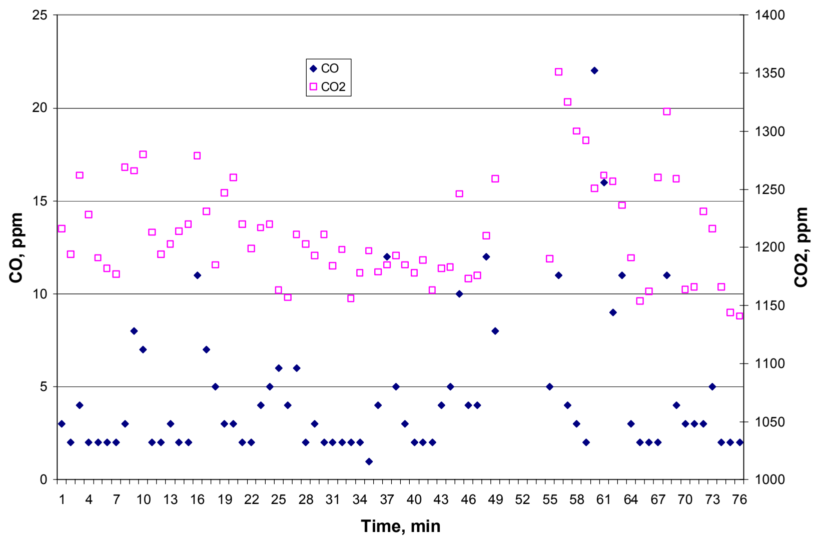
CO
CO2
CO, ppm
CO2, ppm
Time, min

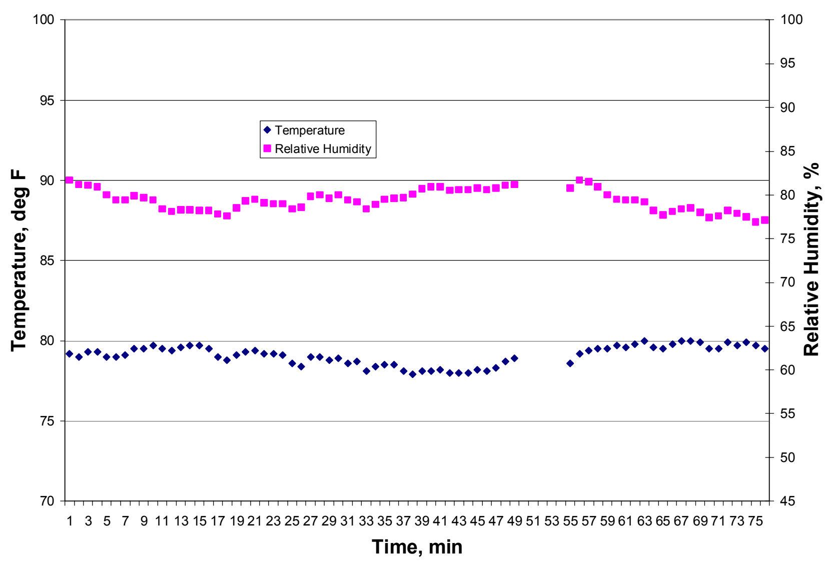


Temperature
Relative Humidity
Temperature, deg F
Relative Humidity, %
Time, min

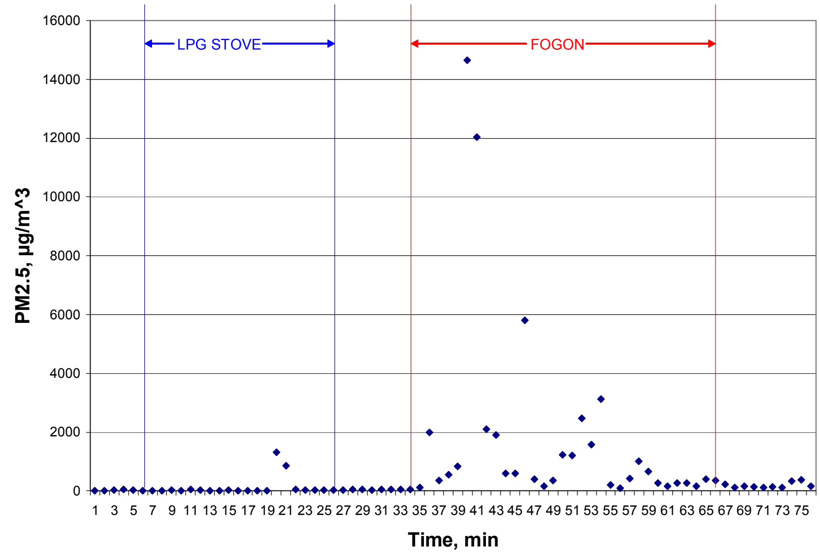
Test House 3:

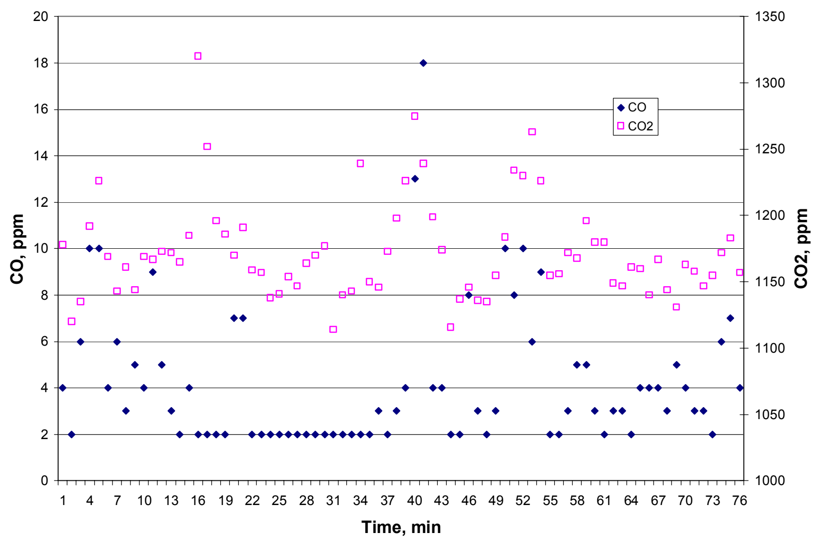

LPG STOVE
FOGON
PM2.5, µg/m^3
Time, min

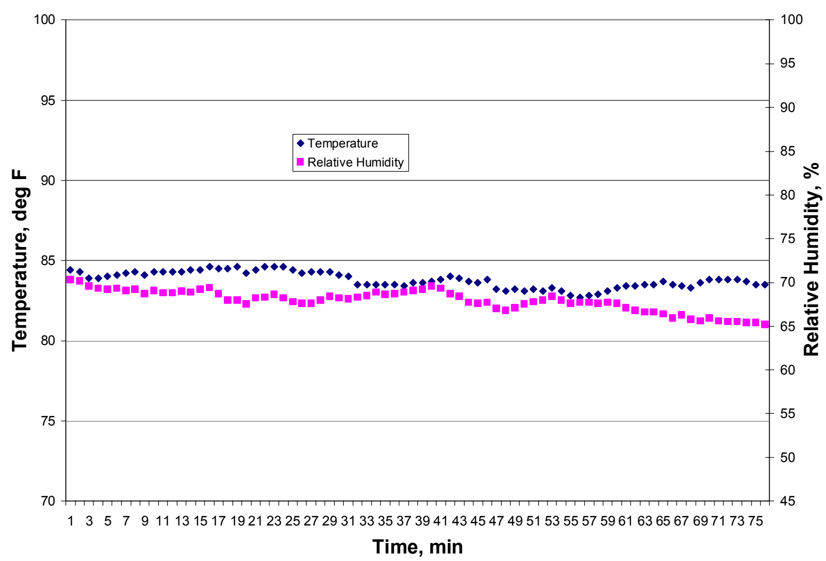

CO
CO2
CO, ppm
CO2, ppm
Time, min


Temperature
Relative Humidity
Temperature, deg F
Relative Humidity, %
Time, min

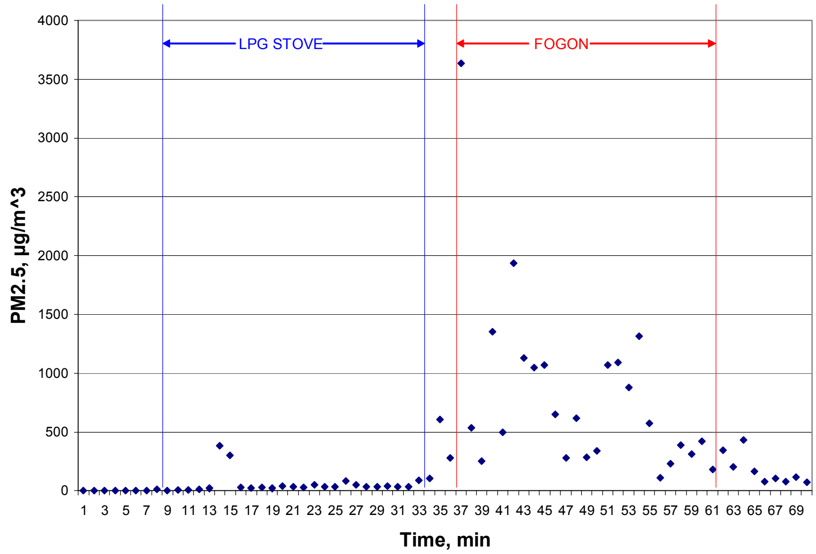
Test House 4:

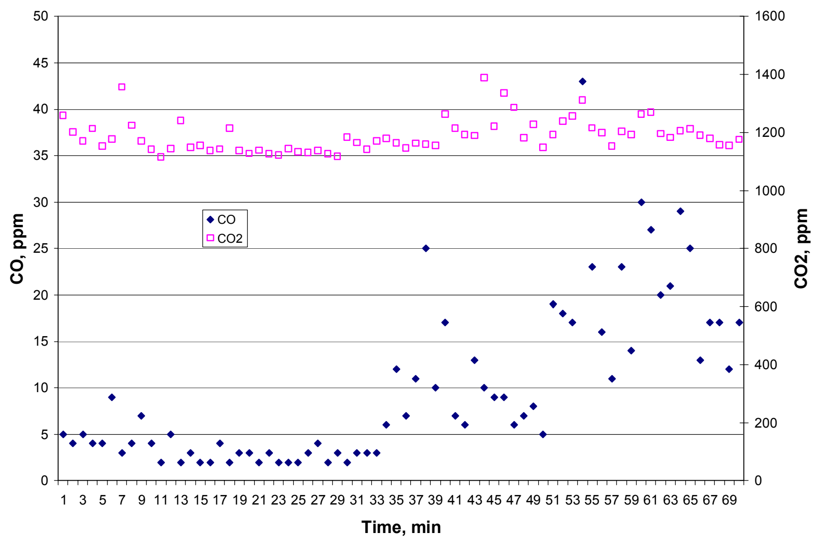

LPG STOVE
FOGON
PM2.5, µg/m^3
Time, min

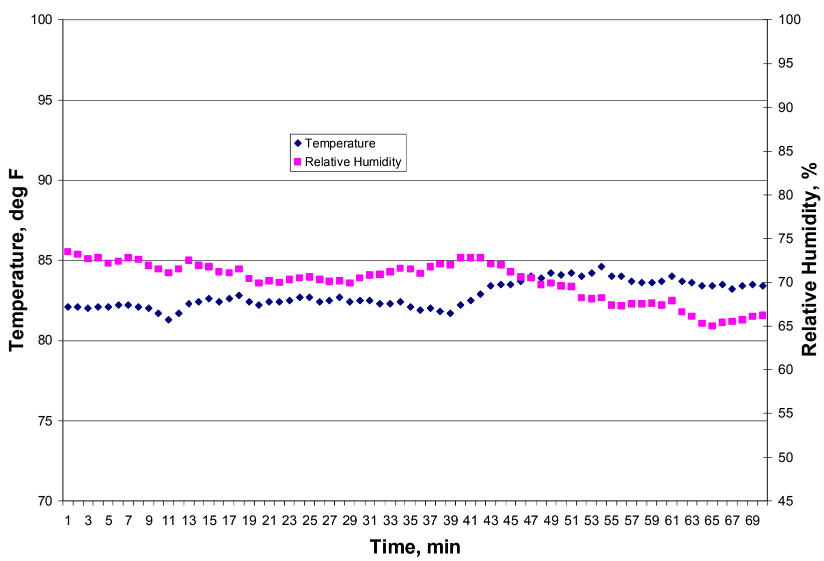

CO
CO2
CO, ppm
CO2, ppm
Time, min


Temperature
Relative Humidity
Temperature, deg F
Relative Humidity, %
Time, min

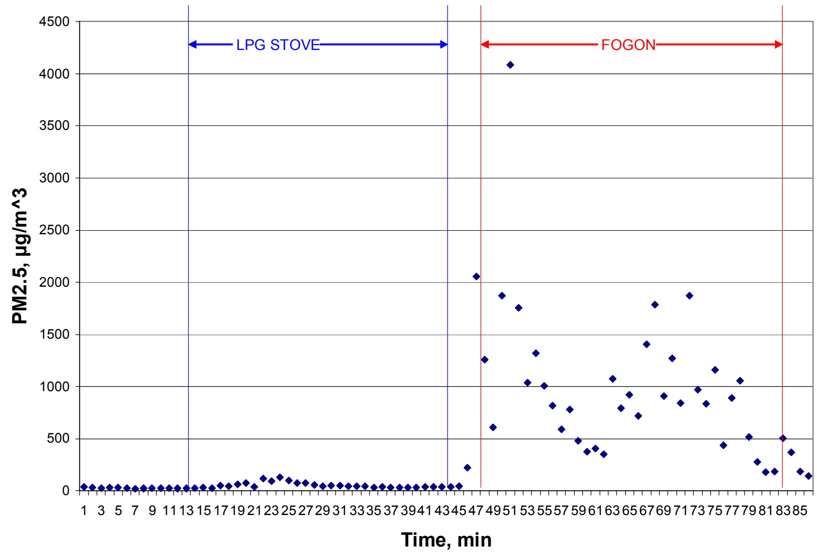
Test House 5:

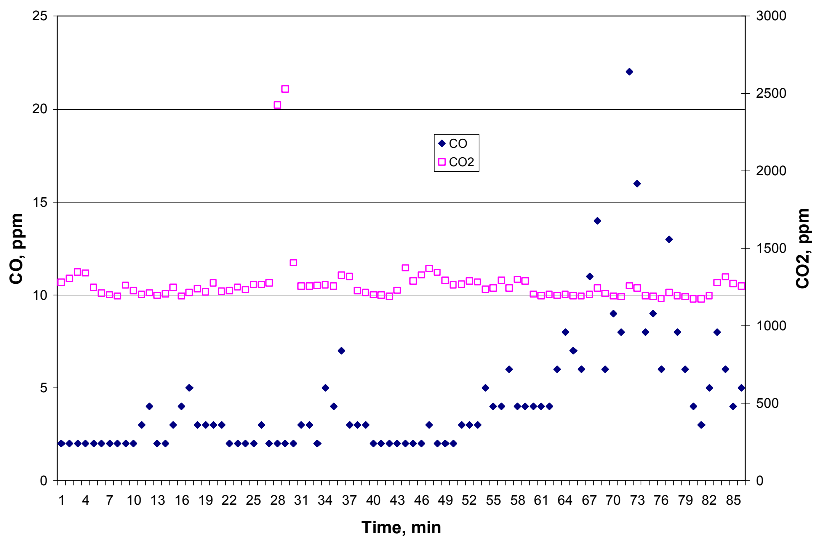

LPG STOVE
FOGON
PM2.5, µg/m^3
Time, min

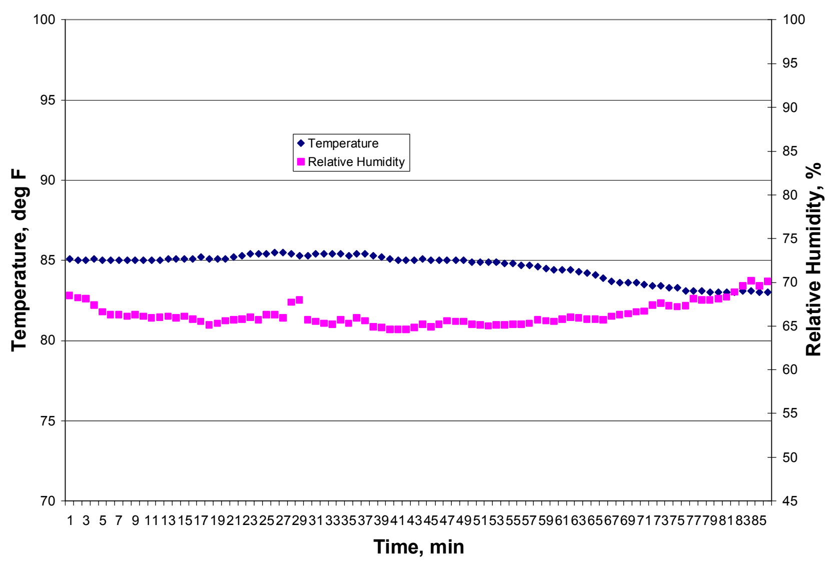

CO
CO2
CO, ppm
CO2, ppm
Time, min


Temperature
Relative Humidity
Temperature, deg F
Relative Humidity, %
Time, min

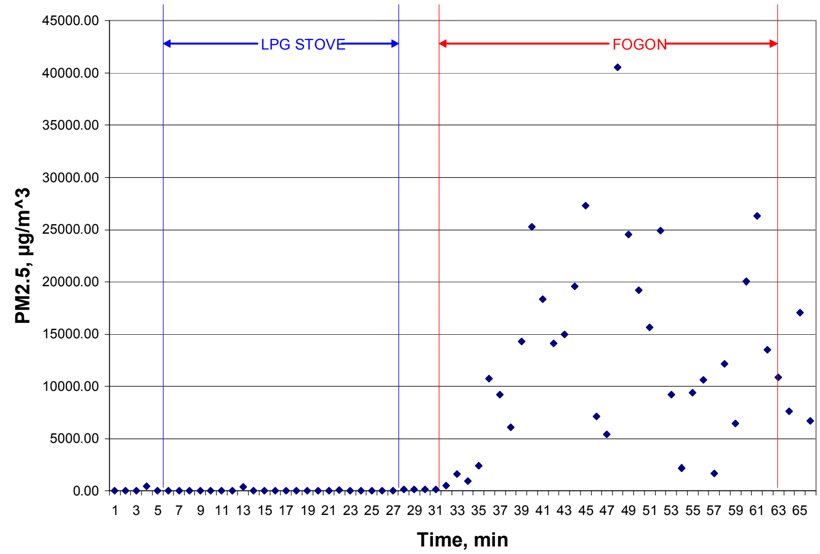
Test House 6:

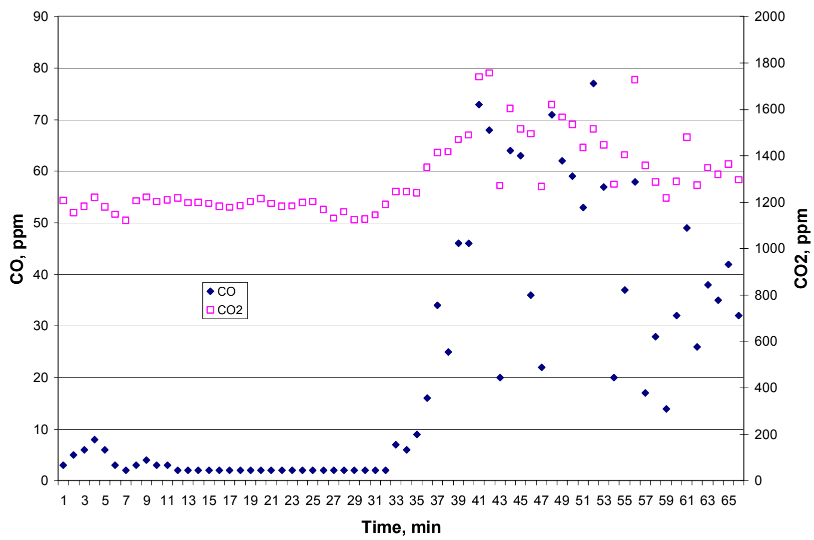

LPG STOVE
FOGON
PM2.5, µg/m^3
Time, min

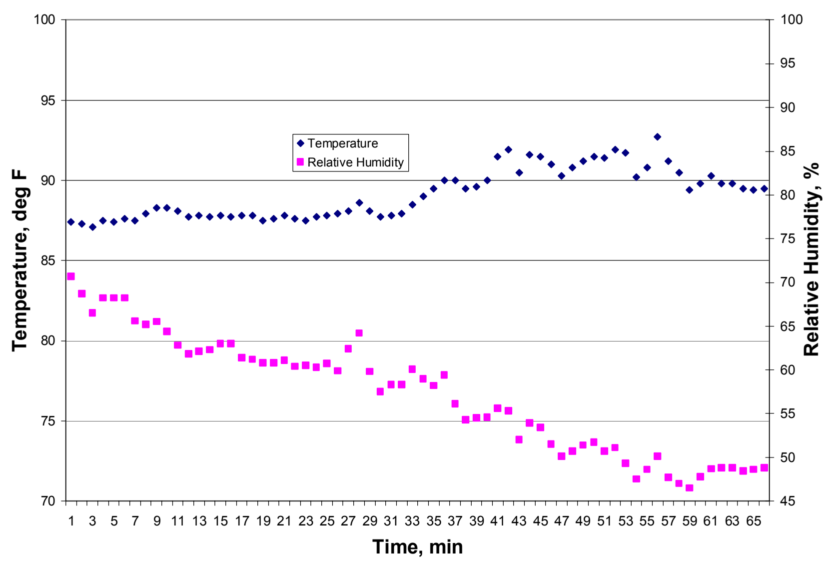

CO
CO2
CO, ppm
CO2, ppm
Time, min


Temperature
Relative Humidity
Temperature, deg F
Relative Humidity, %
Time, min

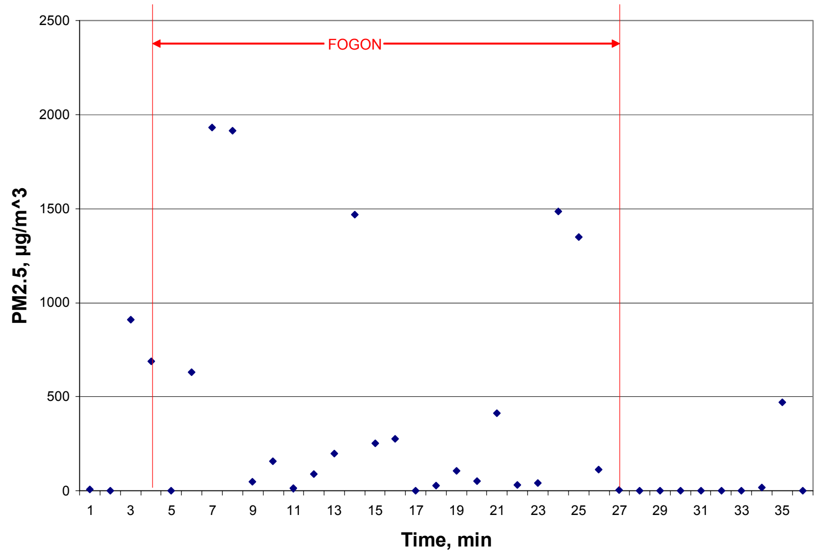
Test House 7 (First Midday Test):

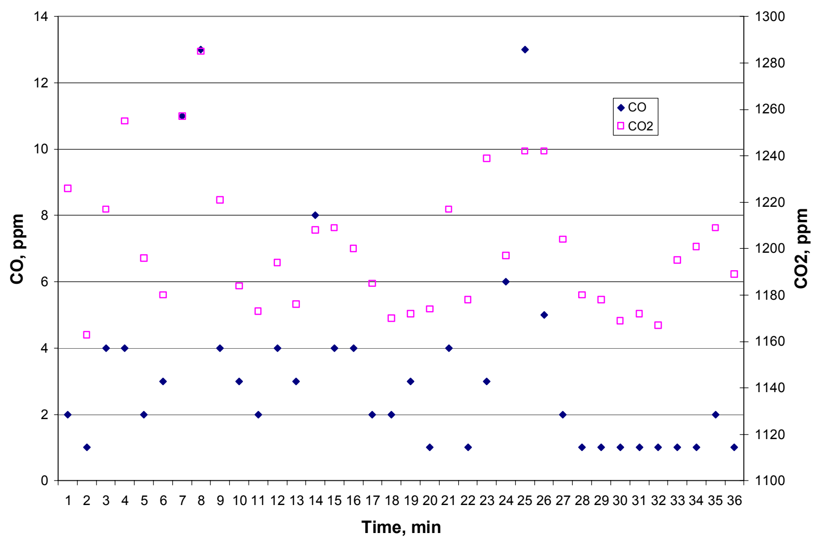


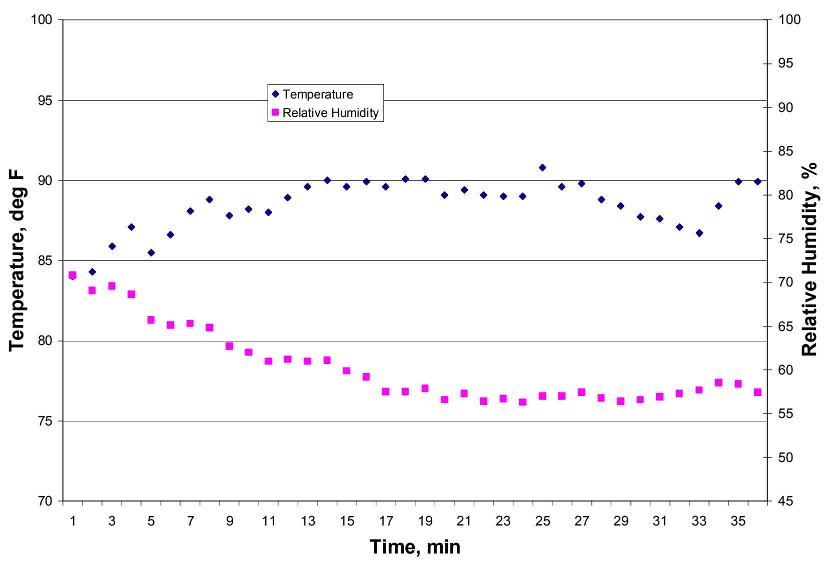




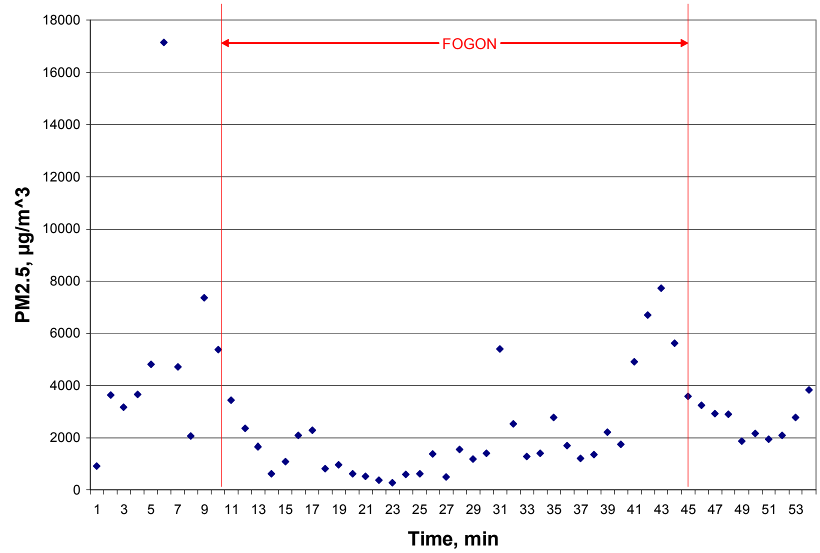
Test House 7 (Morning Test, *Fogon* only):

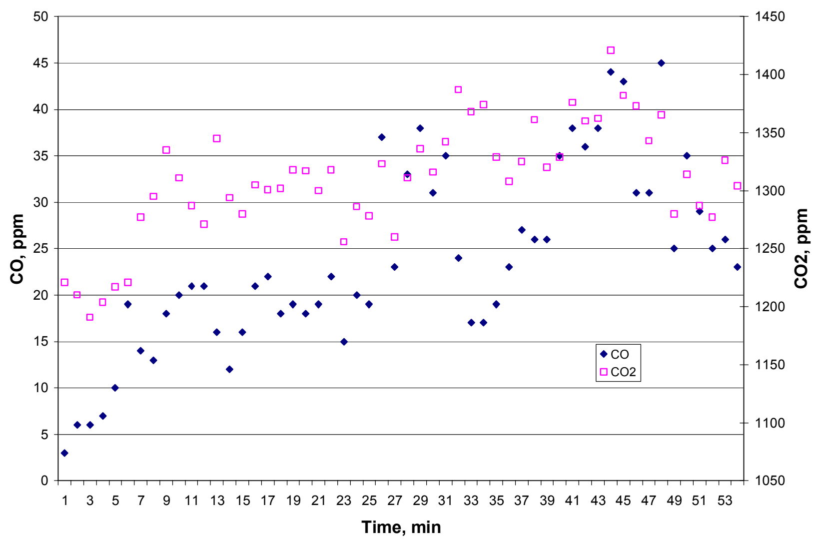


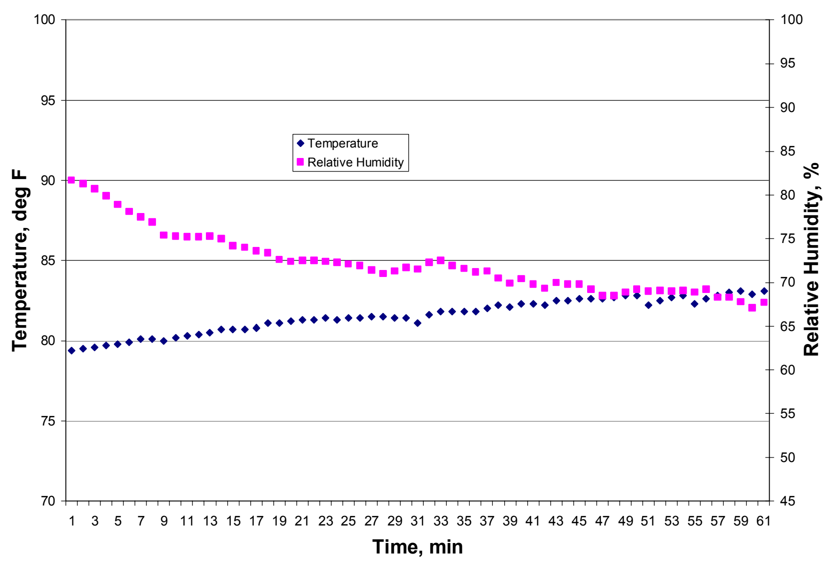




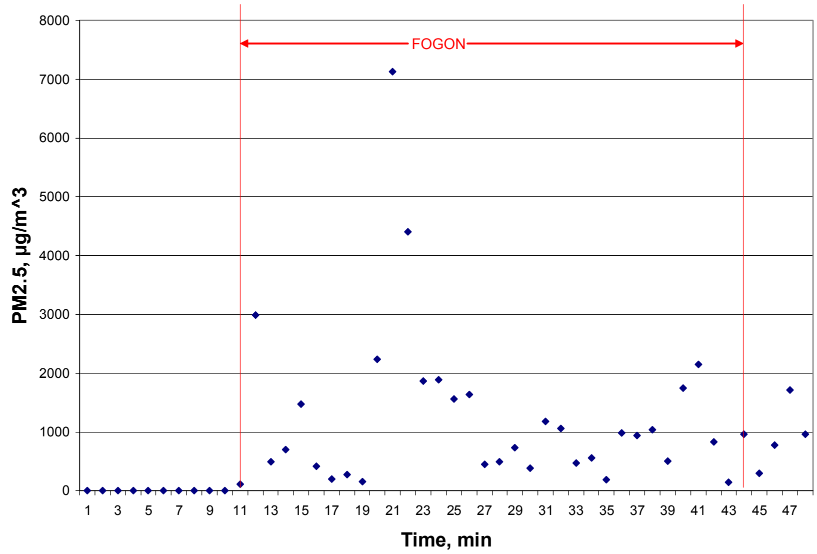
Test House 7 (Second Midday Test, *Fogon* only):

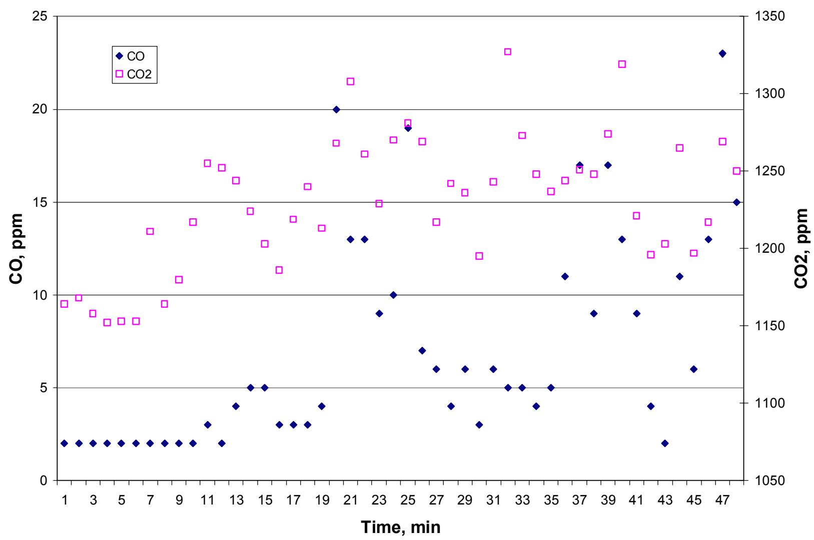


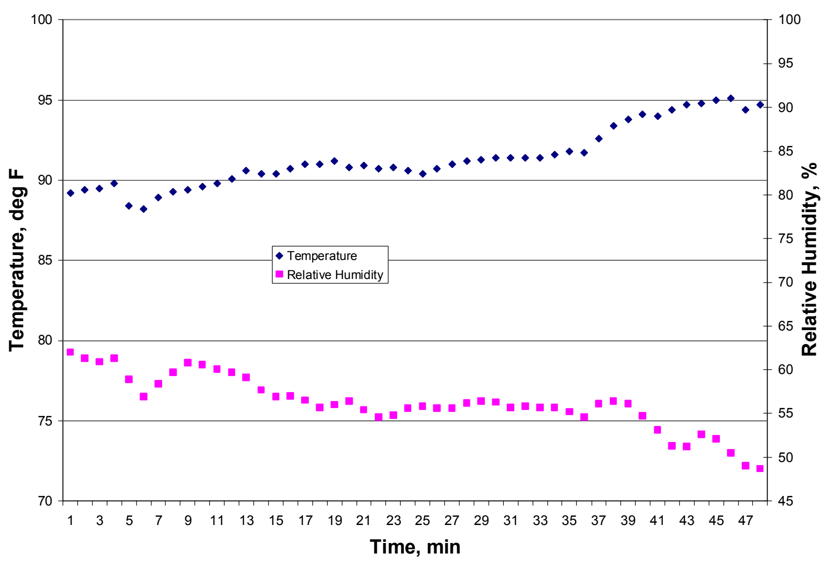




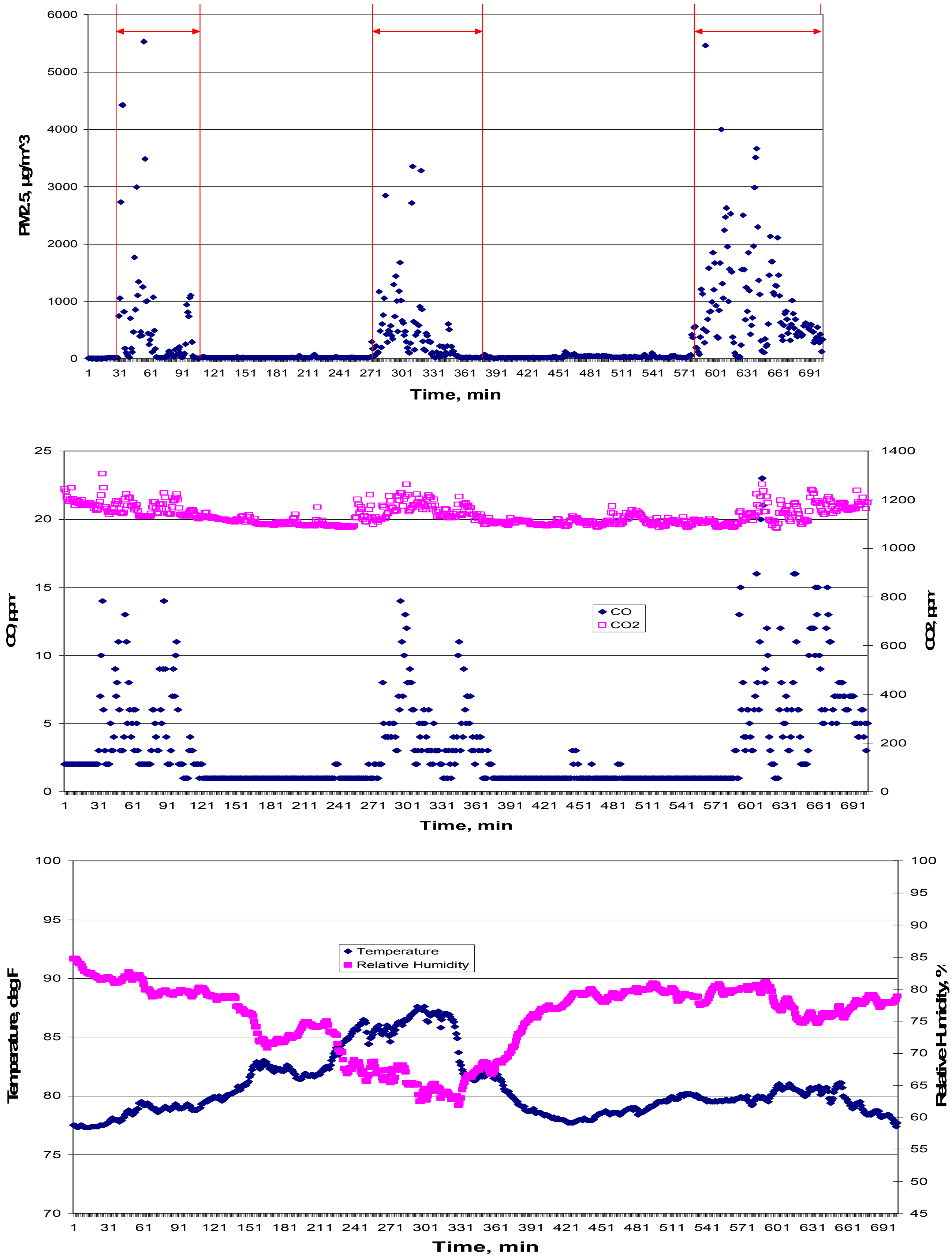
Test House 8 (*Fogon* only):



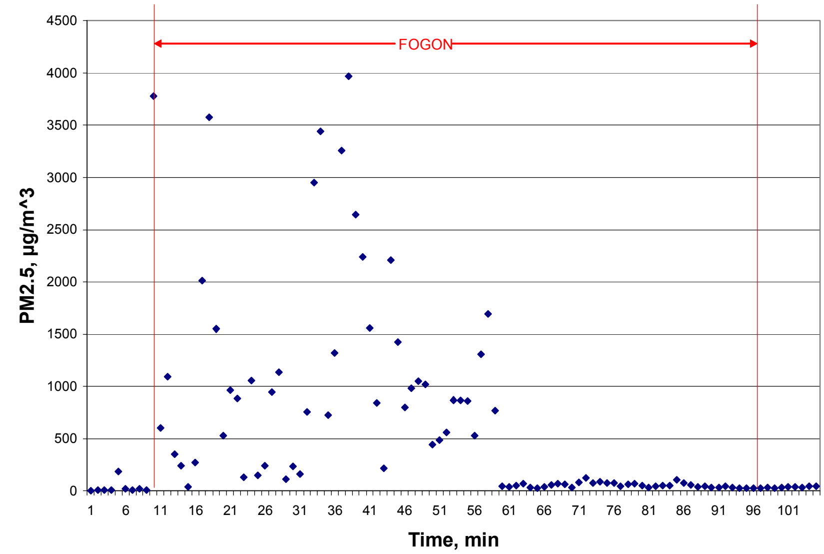


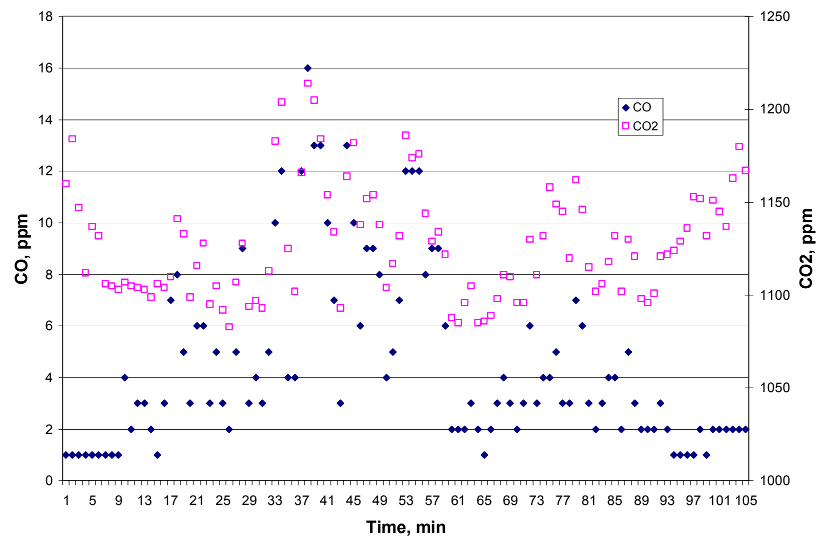


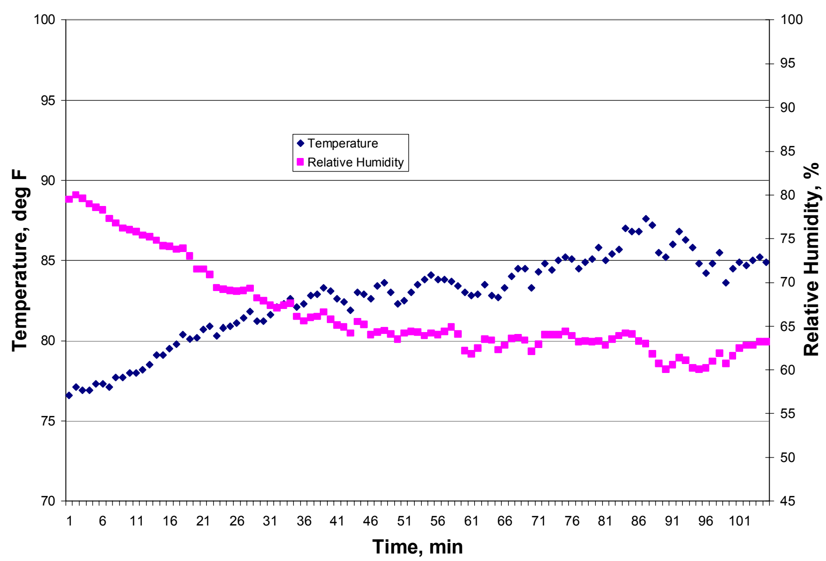
Test House 9 (Full Day Test, *Fogon* only):



Test House 9 (Second Morning Test, *Fogon* only):







Appendix D: Instrumentation

TSI DustTrak:

- Used to measure PM2.5
- Logging interval set to one minute
- Time constant set to ten seconds
- For full specifications:

  http://www.tsi.com/documents/2980077RevCWeb.pdf

TSI Q – Trak:

- Used to measure CO, CO_2, temperature and relative humidity
- Logging interval set to one minute
- Time constant set to five seconds
- For full specifications:

  http://www.tsi.com/documents/qtrak.pdf