

**ADDIS ABABA UNIVERSITY SCHOOL OF GRADUATE STUDIES, ENVIRONMENTAL
SCIENCE PROGRAM**



**ASSESSING ENVIRONMENTAL BENEFITS OF MIRT STOVE WITH PARTICULAR REFERENCE TO
INDOOR AIR POLLUTION (Carbon monoxide & Suspended particulate matter) AND ENERGY
CONSERVATION**

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**THESIS SUBMITTED TO SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY, IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR DEGREE OF MASTER OF SCIENCE IN
ENVIRONMENTAL SCIENCE**

**JUNE 2007
ADDIS ABABA, ETHIOPIA**

Acknowledgement

First of all I would like to express my heart felt thanks to my advisors, Dr Araya Asfaw and Dr Hameed Sulaiman for their assistance in developing this research

I need to also thank Addis Ababa University for giving me the chance to join the graduate studies of environmental science program and financial support to the research.

I am particularly indebted to GTZ – SUN Energy project who gave me logistic support for accomplishing this thesis. Special thanks go to Ato Anteneh Gulilat and Ato Samson Tolessa of GTZ – SUN Energy, without whose assistance and encouragement this study could not be realized. I am also grateful to Hiwote Teshome of the same organization for her encouragement and support in conducting stove performance evaluation. I need also to acknowledge Dr David Pennise of California University for his valuable comment on how I can use the IAP instruments for this study.

I need to thank my brother Mesfin Assefa and my sister Yeshe Assefa for their relentless support until the end of my study in the university. I also need to give credit to my uncle Alemu Zenebe and his family for their encouragement and support to continue my study with out problem.

My special gratitude goes to Ato Dereje Bekele for his assistance in collecting data for the study. I wish also to recognize W/t Selamawit and W/t Konjt for their cooperation in supplying me the necessary documents and other facilities during proposal development and data collection.

I need to extend my special thanks to my friends – Leul Mekonnen, Alebachew Kassa, Tamirat Sahilu and others for their encouragement to do my study in AAU.

Finally, although I cannot list all individuals' names, I sincerely appreciate the dedicated efforts of all those people who contributed either directly or indirectly towards the accomplishment of my study.

Table of Contents

Acknowledgement.....	i
List of tables.....	iv
List of Figures.....	v
List of Plates.....	v
Acronyms.....	vi
Abstract.....	vii
Introduction.....	1
1.1 Background.....	1
1.1.1 Overview.....	1
1.1.2 Stove improvement in Ethiopia.....	3
1.1.2.1 Development and dissemination of Mirt stove.....	3
1.1.2.2 Description of Mirt stove.....	4
1.1.3 The problem context.....	5
1.1.3.1 Environmental Impacts.....	6
1.1.3.2 Health Impacts.....	6
1.1.3 Benefits of improved stoves.....	9
1.2 Objectives of the study.....	10
1.2.1 General objectives.....	10
1.2.2 Specific objectives.....	10
2. Literature review.....	10
2.1 The combustion process.....	10
2.1.1 Improving combustion efficiency and fuel efficiency.....	11
2.2 Existing Methods of Emission and Exposure Measurement.....	12
2.2.1 Measurement of Gaseous Pollutant Concentration.....	14
2.2.2 Measurement of Solid Suspended Particulates.....	14
3. Material and Method.....	15
3.1 Study site.....	15
3.2 Data Collection.....	16
3.2.1 Indoor air pollution Monitoring equipments and data collection techniques.....	16
3.2.1.1 UCB Particle monitor.....	18
3.2.1.2 HOBO Carbon Monoxide data logger.....	18
3.2.2 Stove efficiency Evaluation.....	19
3.2.2.1 Controlled cooking Test (CCT).....	20
3.3 Data processing.....	21
3.3.1 Indoor Air Pollution.....	21
3.3.2 Efficiency Evaluation Procedure.....	21
3.4 Statistical Analysis.....	22
4. Results and Discussion.....	23
4.1 Indoor Air Emission.....	23
4.1.1 The 8-hour Average Pollutant Concentration.....	24
4.1.1 Maximum Pollutant Concentrations.....	28
4.1.2 Pollutant Concentrations in Baking Time.....	30
4.1.3 Pollutant concentrations and fuel use.....	Error! Bookmark not defined.
4.1.4 The relationship of Carbon Monoxide and Suspended Particulate Matter.....	33
4.2 Efficiency of Mirt stove.....	36
4.2.1 Specific fuel consumption and time.....	36
5. Conclusion and recommendation.....	39
References.....	41

Annexes	45
Annex 1. Summary data for the tests with open fire and Mirt stove conditions	45
Annex 2. Standard Operating Procedure for HOBO Carbon Monoxide Logger	46
Annex 3. Standard Operating Procedure for UCB Particle Monitor	50
Annex 4: Standard Operating Procedure: Installing IAP Instruments in a Home.....	56
Annex 5. Controlled Cooking Test Data and Calculation Form for Biomass Injera Stove	59
Annex 6: UCB Particle Monitor Sampling Data Form	60
Annex 7: HOBO CO Sampling Data Form	61
Annex 8: Stove Efficiency Evaluation Protocol.....	62

List of tables

<i>Table 1: Health affecting limits according to WHO's Exposure Guidelines</i> -----	7
<i>Table 2. principal differences between emission and exposure measurements</i> -----	13
Table 3. Basic Monitoring Principles -----	13
Table 4. 8-hour Mean Pollutant Concentrations by Stove type -----	24
Table 5: Maximum 15-minute CO and PM concentrations by stove type -----	30
Table 6. Average CO and PM concentrations during the baking period -----	31
Table 7. Fuel use impact on indoor CO concentrations regression estimate -----	33
Table 8. Impact of fuel use on indoor PM concentration -----	34
Table 9. Summary of measurements for Comparing Mirt stove and Open fire -----	39
Table 10. Stove efficiency test results from the first three pairs of cooking -----	40
Table 11. Stove efficiency results from the second three pairs of cooking -----	40
Table 12. Stove efficiency test results from the 3 rd three pairs of cooking -----	41

List of Figures

Figure 1. Histogram of 8-hour mean concentration of CO (ppm) -----	25
Figure1. Histogram of 8-hour mean PM concentration mg/m ³ -----	25
Figure3. 8-hour Monitoring data for a representative test showing CO, PM and Temperature in Mirt stove condition -----	26
Figure 4. 8-hour Monitoring data for a representative test showing CO, PM and Temperature in Open fire condition -----	27
Figure 5. Histogram of 15-minute maximum CO concentration (ppm) -----	29
Figure 6. Histogram of 15-minute maximum PM concentration -----	29
Figure 7. Histogram of mean concentration of CO during baking time -----	32
Figure 8. Histogram of mean PM concentration in the baking time -----	32
Figure 9: the association between PM and CO in the Mirt stove condition -----	37
Figure 10: The Association Between PM and CO in the Open fire Condition -----	37

List of Plates

Plate 1. Pictorial description of Mirt Injera stove -----	5
Plate 2. Picture showing placement of indoor air pollution monitoring instruments in the kitchen – baking with the Mirt stove -----	16
Plate 3. Picture showing placement of indoor air pollution monitoring instruments in the kitchen – baking with the Open fire -----	17
Plate 4. Indoor air pollution monitoring instruments -----	19

Acronyms

ANOVA	Analysis of Variance
CCT	Controlled Cooking Test
CEINFMP	Cooking Efficiency Improvement and New Fuel Marketing Project
CO	Carbon Monoxide
CO ₂	Carbon dioxide
COPD	Chronic Obstructive Pulmonary Diseases
CSV	Comma Separated Variables
EESRC	Ethiopian Energy Studies and Research Center
ESD	Energy for Sustainable Development
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
IAP	Indoor Air Pollution
IEA	International Energy Agency
KPT	Kitchen Performance Test
LED	Light Emitting Diode
MGP	Megen power Ltd. (private consultant company)
NO	Nitrogen Oxide
PE	Photoelectric
PM	Particulate Matter
SO ₂	Sulfur dioxide
SPM	Suspended Particulate Matter
SPSS	Statistical Package for Social Sciences
TSP	Total Suspended Particles
UCB	University of California, Berkley
UNDP	United Nations Development Program
VITA	Volunteers in Technology Assessment
WBT	Water Boiling Test
WHO	World Health Organization of the United Nations

Abstract

Biomass fuels account for more than one-half of all energy use in many developing countries and as much as 95% of all energy use in some of the poorest nations. In Ethiopia, it accounts more than 90% of total energy consumption. The dominant utilization of traditional fuels – biomass – coupled with use of technologies of low efficiency is contributing to environmental degradation and prevalence of health problems due to indoor air pollution.

Because biomass will continue to be dominant source of energy in developing countries in the foreseeable future, the development of more efficient biomass technologies is vital for alleviating the problems associated with biomass burning. The development of Mirt Injera stove in Ethiopia is one of the results of efforts made to address such problems. The purpose of this study is to assess the potential of this technology in reducing environmental problems – indoor air pollution and natural resource degradation. The two major pollutants quantified in this study are CO and PM. The concentrations of these pollutants in the kitchen were measured using UCB particle monitor and HOBO CO data logger.

The results obtained from this study shows that by installing Mirt stove in the kitchen it could be possible to reduce CO concentration by 88.8%, PM by 17.3% when the analysis is made based on the mean 8-hour time frame. The 15-minute maximum has also showed similar trend, 91.5% for CO and 19.3% for PM levels. The most important parameter to make comparisons of these stoves is mean pollutant concentration during baking time. In terms of this parameter, the reductions obtained are 91% and 19.3% for CO and PM respectively. Besides to characterizing the two systems using their pollutant generation, the study tries to highlight the fuel efficiency of Mirt stove in comparison with the open fire system. The result shows that it could achieve specific fuel consumption of 45% as compared to the open fire system.

Key words: CO, PM, Mirt stove, Open fire, Fuel efficiency,

Introduction

Technical advances in energy efficiency are critical for developing countries like Ethiopia whose populations depend primarily on biomass fuels such as wood, charcoal and agricultural residues. Overuse of these fuels depletes resources and degrades local environments, multiplies the time needed to collect fuel, and creates indoor air pollution that threatens the well being of the most vulnerable members of households.

In Ethiopia, a unique mode of cooking (Injera baking) requires the bulk of domestic energy demand. In most of the households of the country, this Injera baking is carried out using an open fire /three stone/ system. As it is known this technique is inefficient and wasteful. To address this problem, many efforts have been and are being made by the government and non-government organizations since the early 1990s. The development of 'Mirt' biomass Injera stove is one of the results of these efforts in the country. These days this stove is being widely promoted due to the fact that it can achieve fuel efficiency up to 50% as compared to the open fire system. It can also improve the kitchen environment by reducing indoor air pollution and other problems such as burn and exposure to excessive heat. This study tries to assess the potential of the stove for fulfilling these environmental requirements in quantitative terms.

1.1 Background

1.1.1 Overview

Approximately one-half of the world's population relies on biomass- wood, crop residues, dung and charcoal - as the primary source of domestic energy, burning 2 billion kg of biomass every day in developing countries (Ezzati et al., 2000). Biomass fuels account for more than one-half of all energy use in many developing countries and for as much as 95% of all energy use in some of the poorest nations (Manuel, 2003).

In Ethiopia, both traditional and modern energy forms are being used for household purposes such as cooking, baking, lighting and space heating. Traditional energy usually means unprocessed fuels close to their primary forms and low technology conversion devices (or no technology). The major

source of this traditional energy, particularly in Ethiopia, is biomass that can be partitioned into different components such as wood, crop residue, and animal dung and the like. In general biomass takes the largest share of household energy consumption- more than 90% of the total energy consumption (94% Megen Power Limited (MGP) & Ethiopian Energy Studies and Research Center (EESRC) (2000); 93.05% Wolde-Giorgis (2002); 95.8% Asres (2002)) in the country. From the total biomass consumption, fuel wood contributes about 82% (MGP and EESRC, 2000). As many literatures (Asres, 2002; MGP and EESRC, 2000; GTZ, 2000) indicated this traditional biomass, energy consumption for the household purposes is estimated to account for more than 50% of the total energy demand in most of the developing countries with per capita income of less than \$1,000 per annum. The case of Ethiopia is even too far from this estimate. Studies made in the 1980's show that household energy consumption in the country was estimated to be close to 90% of the total national energy consumption (MGP and EESRC, 2000). Earth Trends (2003) has estimated the total energy consumption of the country for the 1999 fiscal year to be 18,227 tons oil equivalent. From this energy derived from biomass sources account for 17,016 tons oil equivalent (93%). The Per capita energy consumption of Ethiopia (0.3 toe) is among the lowest in the world (GTZ, 2000). However, the energy requirements of a large and fast growing population and the fact that the major proportion is supplied by traditional energy sources have serious implications on the natural resource base.

In most cases, the traditional energy consumption is related to low technology energy conversion systems. Low technology energy conversion usually implies low efficiency and high pollution. Thus, technology is a critical link between the supply of energy services and access, affordability, and environmental compatibility.

The energy sector of Ethiopia is one of the least developed in the world despite the presence of an enormous energy endowment. This is reflected by low per capita consumption of modern energy. As it is indicated in a document prepared by MGP & EESRC (2000), average per capita consumption of the country in 1994 was estimated to be 302 kg oil equivalent per year. From this only about 18.12 kgoe (6%) was derived from modern energy sources. This shows that the country is highly dependent on traditional energy forms - exclusively biomass. When this consumption is compared with the 1989 figure of other African countries, modern energy consumption is still low. For example, traditional fuel consumption of Kenya was about 79%. That of Zambia and

Zimbabwe was estimated to be 58% and 25% respectively. The same study shows that the average for Africa was about 37%. Recently this average has grown to 59% (Heinrich Boll Foundation, 2006).

However, in the last two decades some intervention efforts have been made to address the energy consumption and associated problems of the country. Different documents indicate that there has been massive penetration of kerosene stoves in the urban households; use of electricity for Injera baking has enormously grown; and massive adoption of improved fuel-saving stoves such as Lakech charcoal-stove and Mirt Injera-stove among urban households has been seen. In addition, these days the household energy sector is being given better attention by the government. Increasing energy utilization efficiency, reducing wastage, and ensuring environmental protection associated with the production, supply and consumption of energy have been included in the energy policy document as the major policy objectives. As stated in this policy document, the government aims to address household energy problems by promoting agroforestry, increasing the efficiency with which biomass fuels are utilized, and facilitating the shift to greater use of modern fuels.

1.1.2 Stove improvement in Ethiopia

Since 1989, efforts to improve the stoves, mainly by the Ethiopian Energy Studies and Research Center (EESRC, currently, Ethiopian Rural Energy Development and Promotion Center) have resulted in the development of three types of improved stoves:

- Lakech charcoal stove
- Low cost electric Injera stove and
- Mirt improved biomass Injera stove

The development of the technologies were carried out by the project called Cooking Efficiency Improvement and New Fuels Marketing Project (CEINFMP) financed by World Bank and DANIDA between 1989 and 1995. As reported in GTZ (2000), the main success of CEINFMP project was the Lakech charcoal stove, which is used for non-Injera cooking.

1.1.2.1 Development and dissemination of Mirt stove

The study made by Ministry of Mines and Energy and Energy for Sustainable Development (ESD) (1988) showed that Ethiopia had a complex and highly commercial biomass fuel sector. However,

because of using open-hearth method, energy efficiency in the country is very low. Because of this ESD found that improving household cooking efficiency is the most important area in Ethiopia. Based on this fact Lakech ('excellent', 'good') improved charcoal stove could be developed in 1991. According to the ESD report, commercial production of Lakech (improved charcoal stove) was started in early 1992 in Addis Ababa. To date, millions of these improved stoves, which save over 25% charcoal relative to the traditional stove, are being in use. This has resulted in the saving of hundreds of hectares of ecologically and economically important dry land forest in Ethiopia. Each Lakech stove saves an average of 75 kg of charcoal per household per year (Bess 1998). This led to savings of over 20,000 tones of charcoal in 1996, worth over £4 million alone. More importantly, the forest savings from the use of Lakech was equal to the equivalent of over 2,000 hectares of important dry land forest in Ethiopia. However, from the earliest days of ESD's involvement with household energy in Ethiopia, its international and local team realized that the single most significant household energy demand side intervention was not in household charcoal use, important as this has been. Rather, the most crucial area for energy savings in Ethiopia is in household bread, or "Injera" baking.

ESD worked with John Parry Workshops of the UK to develop a modular, prefabricated stove from cement and local construction materials that could be produced relatively easily, in large quantities, by a range of different scale producers, at inexpensive prices. While this proved difficult, the team was finally able to meet this challenge in early- 1994 with what was soon to be called the "Mirt" ("best") improved biomass Injera stove.

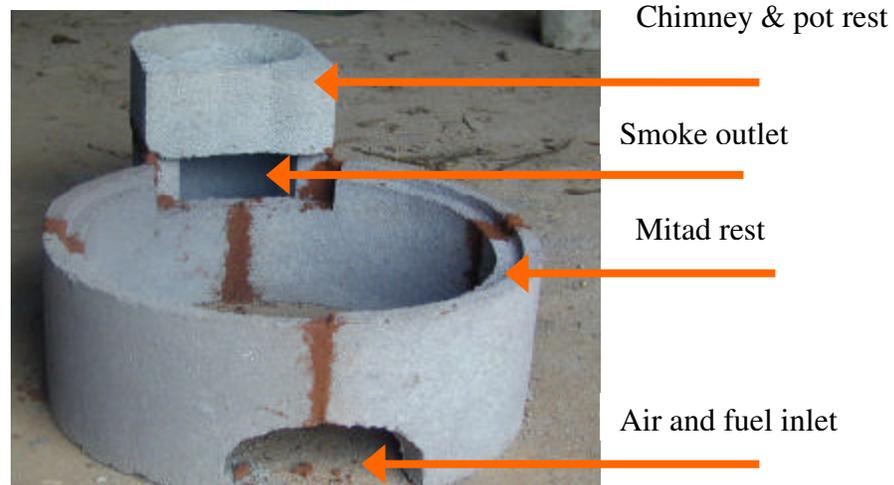
The whole process of designing and dissemination of the Mirt Stove followed series of steps. Large-scale dissemination was supported by media advertisement and cooking demonstrations. Intensive training for the private sector was provided in the process.

1.1.2.2 Description of Mirt stove

The Mirt stove has been specifically designed to cook Injera. The basic design of Mirt stove was adopted from the traditional Ambo & Burayu enclosed Injera stoves and optimized to handle different types of biomass fuels. The Mirt stove is a multi-section stove (Plate 1) made by moulds - one mould is used to construct the four pieces of the combustion chamber and two moulds are used for the chimney rest. The combustion chamber is made with height of about 24cm and diameter of

about 60cm. The pot rest or the chimney has inner diameter of around 14 cm. The fuel and air inlet is made with height of about 11cm and width of around 24cm. The stove is made using lightweight materials and can be assembled and disassembled in order to be moved or transported. Total weight of the stove is nearly 60 kg.

Plate 1. Pictorial description of Mirt Injera stove



The Mirt stove was originally designed using lightweight raw pumice with Portland pozzolana (cement) in a ratio of 5:1. Although pumice is a major source for constructing building materials in Addis Ababa and other areas in the Rift Valley, it is not found everywhere in Ethiopia. Another common material that is more widely found than pumice, and is used extensively in the building materials industry, is scoria or red ash. In areas where no pumice or scoria is found, sand and cement are used.

1.1.3 The problem context

People around the world use wood and biomass as their primary fuel source. However, burning wood raises many issues, which is of serious concern. The dominant utilization of traditional fuels coupled with use of technologies of low efficiency is contributing to the environmental degradation and prevalence of health problems due to indoor air pollution.

1.1.3.1 Environmental Impacts

The chief environmental impacts of household fuel cycle relates to harvesting and combustion. It has been common to read that fuel gathering in rural areas of developing countries causes deforestation. However, detailed studies in many areas around the world have rarely documented cases in which fuel demand is a significant cause of deforestation. Nevertheless, in Ethiopia this is not the reality. As stated in the document of MGP & EESRC (2000), World Bank (1994) indicated that the huge dependence on fuel wood coupled with its inefficient and unsustainable utilization has resulted in a massive deforestation and environmental degradation. This has been confirmed by Environmental Protection Authority of Ethiopia (1998) that the demand for increasing amounts of fuel wood and charcoal among others is one of the primary causes of forest destruction in the country. As indicated in this document, in the dry lands, the existing Acacia woodlands are being depleted for fuel wood at an alarming rate, especially in the area lying towards the lower Awash Valley.

Over 2 billion people worldwide are facing fuel shortages (Benjamin, 2005). According to this report, forests in developing countries are rapidly decreasing and the ratio of forests-to-people is less than half of what it was in 1960. A 1989 study of 15 developing countries demonstrated a staggering demand for fuel wood. Benjamin (2005) further reported that 669,000 hectares of forest is needed each year. But only about 63,000 hectares were replanted - less than 10% of the demand.

It has been said that wood is the fuel that heats us twice - once when we chop it and once again when we burn it. Like fossil fuels, however, biomass fuels also have the potential to heat us a third time as a result of enhanced greenhouse warming due to the gases released by combustion (Smith 1994). As indicated in many literatures it has generally been assumed that this potential is only realized when the biomass being burned is harvested on a non-sustainable basis. With sustainable harvesting, it is argued that an equivalent amount of carbon is recaptured by the re-growing biomass as is released by combustion. Thus, the net greenhouse gas increment is zero.

1.1.3.2 Health Impacts

The physical form and pollutant content are the two characteristics of fuels that most determine the quality of pollutant emissions when burned. It is generally difficult to premix solid fuels

sufficiently with air to assure good combustion in simple small-scale devices such as household stoves. Consequently, even though most biomass fuels contain few noxious contaminants, they are usually burned incompletely in household stoves and so produce a wide range of health damaging pollutants. Some times as much as one-fifth of the fuel carbon is diverted to products of incomplete combustion (UNDP, 2001).

Households reliant on biomass generally use the fuel indoors, in open fires or poorly functioning stoves, and usually with inadequate venting of smoke (WHO, 2000). The smoke from biomass fuel contains a large number of pollutants that are dangerous to health, including small particles, carbon monoxide, nitrogen dioxide, formaldehyde, and carcinogenic substances such as benzo[a]pyrene and benzene. Studies from Asia, Africa and the Americas have shown that indoor air pollution levels in these homes are extremely high, many times the limits set by WHO (Table 1). Typical 24-hour levels of PM₁₀ in biomass using homes in Africa, Asia, or Latin America range from 300 to 3000 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$).

Table 1: Health affecting limits according to WHO's Exposure Guidelines

Product	Concentration	Time limit
Carbon monoxide	100 mg/m ³	15 min
	60 mg/m ³	30 min
	30 mg/m ³	1 hour
	10 mg/m ³	8 hour
Formaldehyde	100 $\mu\text{g}/\text{m}^3$	30 min
Lead	1 $\mu\text{g}/\text{m}^3$	1 year
Nitrogen dioxide	400 $\mu\text{g}/\text{m}^3$	1 hour
	150 $\mu\text{g}/\text{m}^3$	24 hour
Ozone	200 $\mu\text{g}/\text{m}^3$	1 hour
	120 $\mu\text{g}/\text{m}^3$	8 hour
Sulfur dioxide	500 $\mu\text{g}/\text{m}^3$	10 min
	350 $\mu\text{g}/\text{m}^3$	1 hour
	125 $\mu\text{g}/\text{m}^3$	24 hours
Suspended particles	120 $\mu\text{g}/\text{m}^3$	24 hours
Benzene	2.5 $\mu\text{g}/\text{m}^3$	1 year

Source: Usinger 1996

WHO (2002) ranked indoor air pollution (IAP) eighth in the health burden worldwide. In developing countries, which make up 40% of the world's population, it ranks fourth (Benjamin, 2005). The World Bank called indoor air pollution one of the four largest environmental problems facing the developing world today. As mentioned earlier much of indoor air pollution can be attributed to the use of wood burning stoves for cooking. The fine particulates and carbon monoxide released by wood from incomplete combustion cause acute respiratory ailments, ear and eye problems, breathlessness, chest pains, headaches, dizziness, and more – much of which affects women and children (Benjamin, 2005). Exposure to biomass smoke can also cause asthma and obstetrical problems such as stillbirth and low birth weight (IEA, 2002). Different studies have repeatedly reported that acute respiratory ailments are the biggest killer of children under five.

Polyaromatic hydrocarbons found in wood smoke are known to cause bladder and lung problems (Calle & Zeighami, 1984). Lung cancer can occur many years after exposure as a result of the carcinogens in biomass fuels (Tremeer 1997; Sobue 1990; Karekezi 1992; Morris et al 1990; Kossove 1982; Hong 1992).

Small particles with a diameter of up to 10 microns (pm_{10}) are the most widely used indicator of the health hazard of indoor air pollution. Fine particles with a diameter of up to 2.5 microns ($pm_{2.5}$) are able to penetrate deep into the lungs and appear to have the greatest health –damaging potential. It is known that these particles can cause inflammation of the airways and lungs and impair the immune response (WHO, 2006).

The smoke from these fires fills homes with a noxious cocktail of particles and chemicals. These particles bypass the body's defenses and double the risk of respiratory diseases such as bronchitis and pneumonia (WHO). Although it is responsible for killing more people than malaria and nearly as many as unsafe water and poor sanitation, indoor air pollution remains a silent and unreported killer while deaths from diseases like HIV/AIDS and malaria make sobering headlines (WHO and UNDP, 2004).

Inhaling indoor smoke doubles the risk of pneumonia and other acute infections of lower respiratory tract among children under age of 5 years. Women exposed to indoor smoke are three

times more likely to suffer from chronic obstructive pulmonary diseases (COPD), such as chronic bronchitis or emphysema, than women who cook with electricity, gas or other cleaner fuels (WHO, 2006).

1.1.3 Benefits of improved stoves

The benefits associated with stove improvement fall in two categories: those that are internal to the household and those that are external. Internal benefits include reduced concentrations of smoke and indoor air pollution; money and time saved in acquiring fuel; and reduced biomass use, ability to use animal dung as fertilizer instead of as fuel. External benefits include less pressure on forest and energy resources; reduced greenhouse gases; and skill development and job creation in the community (Barnes et al., 1993).

Because biomass will continue to dominate energy demand in developing countries in the foreseeable future, the development of more cleaner and efficient biomass technologies is vital for alleviating poverty, creating employment and expanding rural markets (IEA, 2002). The main beneficiaries of improved stoves are women and those in the middle and lower income levels of society (Eckholm, 1982). The economic and environmental impacts of adopting improved stoves also can be quite significant for communities (Barnes et al., 1994). Where wood is being harvested faster than it is being grown, the use of more efficient stoves to reduce demand for wood to sustainable levels is usually more economically viable than planting new trees, at least initially. Because of their greater insulation, most improved stoves are less hot to the touch and hence safer for the cooks and their children. A healthier and safer environment- particularly for women and children may be one of the most important potential contributions of improved stoves in ameliorating the cramped living conditions of many poor people.

Switching to cleaner energy and increasing fuel efficiency and cleaner burning through better stoves can reduce health risks for all family members. Beyond curbing respiratory problems, a more secure household energy situation enables water to be boiled and thus helps reduce the incidence of waterborne diseases. It can also increase the number of hot meals consumed per day and thus improve food safety and nutrition (Manuel, 2003).

1.2 Objectives of the study

1.2.1 General objectives

The overall objectives of this study are:

- ♣ To evaluate the biomass based Injera baking stove (Mirt stove) for its potential to contribute in reducing environmental problems such as indoor air pollution and energy conservation.

1.2.2 Specific objectives

- ♣ To check Mirt stove's potential for reducing indoor air pollution in terms of Suspended Particulate matter (SPM) and Carbon Monoxide (CO)
- ♣ To make comparative study on the improved stoves (Mirt) with the open fire system for their fuel efficiency

2. Literature review

2.1 The combustion process

Combustion is an exothermic process where the combustible material (e.g. carbon and hydrogen) is oxidized to CO_2 and H_2O . In addition, elements like nitrogen and sulfur are more or less oxidized mainly to NO and SO_2 . Chemically stored energy in the fuel is then converted to heat and radiation to be utilized in different ways. The basic conditions required for obtaining complete combustion, assuming air (i.e. oxygen) to be the oxidizing media, are well known and can be defined as;

- Supply of air for complete oxidation
- Sufficiently high temperature for chemical reaction kinetics
- Sufficiently long residence time at high temperature (i.e. chemical reaction time) and
- Sufficient mixing (turbulence) of fuel components and air

The burning process of wood and other biomass fuel is complex. It can be subdivided into four phases. In the beginning phase, the water existing in the wood is released at a temperature around $100\text{ }^\circ\text{C}$. In the next phase, at a temperature of $200\text{ }^\circ\text{C}$ to $300\text{ }^\circ\text{C}$ cellulose falls apart and the lignin turns into carbon. At this time the vaporizing gases develop. The third phase of the burning process is the time when the vaporizing gases mix with oxygen at a temperature of about producing a yellow flame. In the 4th phase of burning the hot gases, reach a temperature of around $1000\text{ }^\circ\text{C}$

above the wood. An abrupt cooling of the hot gases during this phase, for instance by cold pot or wind, lowers the burning temperature, thus creating incomplete combustion products.

A porous carbon layer develops on the outside surface of the burning wood. This carbonized layer acts on the gases as a catalyst, making the carbon in the wood turn into carbon monoxide. Some millimeter away from this surface, the CO reacts with oxygen turning to CO₂. The temperature in this area is around 800 °c. When the total amount of carbon has been burnt, mineral salts remain as ashes. In order to burn a kg of wood the entire process requires approximately 5m³ of air (Usinger, 1996). In the case of charcoal, the relation is 9 m³ of air to 1 kg of charcoal.

Combustion is not a continuous process. Due to a lower processing heat, considerably more CO and carbon hydrates are emitted at the beginning and the end of the burning process. The opposite occurs for the emission of CO₂: it reaches its highest value during combustion. Usinger (1996) has classified the combustion process into three phases- production of the first embers, completely developed burning phase and cooling down phase.

Combustion quality and fuel efficiency can be expressed in three dimensions – degree of complete combustion (combustion efficiency), stove efficiency (technical efficiency) and efficiency of the system operation (system efficiency). Combustion efficiency is influenced by the fuel quality and the combustion chamber characteristics of a stove. Materials used for construction of the stove and constructive perfection and dimension to force heat transfer to the pot or griddle are important factors that can influence technical efficiency. The system efficiency depends on the system operators' capabilities to economize the fuel consumption through optimized food, pot, stove and fuel handling. System efficiency measures the relation of energy input to energy utilized, without influencing or standardizing the individual influence of operators. This is usually determined through either kitchen performance tests or fuel consumption tests.

2.1.1 Improving combustion efficiency and fuel efficiency

Improving combustion efficiency does not appreciably help the stove to use less fuel. On the other hand improving heat transfer efficiency to the pot or griddle makes large difference. Improving the combustion efficiency is necessary to reduce smoke and harmful emissions that damage health. Improving heat transfer efficiency can significantly reduce fuel use. In order to reduce emissions

and fuel use, the stove designer's job is to first clean up the fire and then force as much energy into the pot or griddle as possible. This is because, as a number of studies (Tremeer 1997; Smith 1992; Ahuja et al. 1987; and Naugal 1992) showed, improving efficiency does not lead to emission reduction. In fact, it has been recognized that a conflict exists between high efficiency and low emissions (Shelton, 1982). The reason for this is simple to understand – efficiency is influenced by two largely independent factors: combustion efficiency and heat transfer efficiency. Combustion efficiency, a measure of how well the fuel is burnt, relates directly to emissions. Poor combustion efficiency means that the fuel is not completely burnt and therefore the products of incomplete combustion are emitted from the stove. However, heat transfer efficiency – how well the energy released from the wood is transferred to the pot or griddle can be improved while, at the same time, decreasing combustion efficiency. This often yields an overall efficiency but increased emissions (smith, 1992 and Ahuja et al., 1987). It is therefore vital to measure stove emissions and not to assume that a high efficiency stove will have low emissions.

2.2 Existing Methods of Emission and Exposure Measurement

A common characteristic of most epidemiological studies on the health impacts of indoor smoke has been the use of indirect measures of exposure, such as fuel type, housing characteristics, or aggregate measures of time spent near fire (Ezzati and Kammen, 2002). In studies that focus on emissions and exposure assessment, the alternative to indirect exposure measures has been the use of personal monitors or area monitors, mostly recording average daily or burning-time concentrations. Personal monitors are mostly used when our goal is to assess the health effects of indoor air pollution. Area monitoring is an appropriate method if our goal is to provide clean energy technologies.

The choice of monitoring techniques and equipment depends on analysis and monitoring conditions. Simple measurement methods can be applied only in cases where the results clearly exceed or fall below the limits (Usinger, 1996). The sampling technique and the location of measurement also vary with the purpose of the study. In the case of direct measurement, the practice may be either to see the actual emission from the source or to assess the exposure level of the stove users in the kitchen. The principal difference between emission and exposure measurements are shown in table 2.

Table 2. Principal differences between emission and exposure measurements

Test Area	Emission	Exposure
Concentration present in the waste gas	High	Low
Gas sampling to be drawn in	Low	High
Measurement duration	Short	Long
Measurement expenditure	Low	High

Source: Usinger 1996

Emission monitoring is used for the qualitative and quantitative determination of pollutant-emitting sources. The exposure monitoring should determine the kind, intensity or duration of the exposure and its influence on people. Sampling for exposure monitoring is done at the breathing organs level, thus determining the exposure of the person working at the fireplace. Generally, the following monitoring principles (Table 3) will be combined based on the purpose of monitoring practice.

Table 3. Basic Monitoring Principles

Monitoring Principle	Explanation
Continuous (real time)	Continuous monitoring with actual course of concentration
Integrated	Discontinuous, punctual monitoring in variable time distance and phases
Grab or spot	Separate, punctual monitoring e.g. for determining maximum and minimum values
Time weighted average	Mean obtained from the total of all measurement results, related to the monitoring time
Area	Is used in the case of permanently installed monitoring equipment, e.g. for area surveillance
Personal	Is used when individual exposures of one person at a different locations and times are to be measured
Passive sampling	Monitoring without active collection of waste gas
Active sampling	Monitoring with the aid of active waste gas collectors, e.g. vacuum pump
Field monitoring	Monitoring in the field, e.g. in the kitchen under the daily circumstances
Laboratory monitoring	Monitoring at the laboratory, controlling all the parameters

Source: Usinger 1996

Regarding the length of monitoring, there are two monitoring time frames – short-term and long-term. Short-term measurements with test tubes usually require a time span of 10 seconds up to 15 minutes, whereas long-term and diffusion tubes are employed for measurements between 2 to 8 hours.

2.2.1 Measurement of Gaseous Pollutant Concentration

There are two basic methods to determine the concentration of gaseous pollutants: with the aid of reacting chemicals and with the aid of catalytical opto-electronic sensors. Test tubes are chemical sensors, which contain chemical reagents reacting with occurring airborne pollutants. Each pollutant requires a different reagent. *Gastec Color Dosimeter Tube* for carbon monoxide (CO) area monitoring is an example of this method. In this case, carbon monoxide reduces sodium palladosulfite to liberate metallic palladium; this chemical reaction produces a brown stain that can be read directly from the tube.

The advantage of this method is that it is quite simple to apply to a variety of pollutants just by using a variation of test tubes with different reagents. The disadvantage is, however, that the tubes can be used only once and in the case of long-term tests, this method can cause high costs.

For measuring carbon monoxide, carbon dioxide, oxygen, nitrogen oxide and sulfur dioxide, it is also possible to use electronic devices with direct instantaneous readout. *HOBO CO logger*, the instrument employed in this study, is an example of such method. The air pollution content is determined by means of sensors. A digital readout indicates the measured value. In such technique, the instruments convert gases into electrical signals to be readout directly. The advantage of electronic sensors is that they can be used for long time. The purchase, however, is much more expensive. The advantage of its usage lies in real time measurement. A decision for such device depends on size and number of samples, variation of maximum and minimum values and accuracy and precision required. Due to the sensitivity of the built-in sensors, the devices are particularly suited for low exposure monitoring.

2.2.2 Measurement of Solid Suspended Particulates

Three basic methods (gravimetric, chemical and optical) are applied in determining solid suspended particulates in the breathing-zone air. According to the gravimetric method, particulate

quantities are determined by weight increase. Determination of carbon during combustion is the principle of the chemical method. In the case of optical method, determination of particulates occurs by means of the degree of reflection or optical scattering of the air or the sample carrier, for example smoke. Apart from these three basic methods, there are detectors that can perform detecting on the principle of ion depletion or ionization. According to Litton et al. (2004), detectors working on the principle of ionization have better response to particles with smaller diameters that can be produced from flaming combustion and the photoelectric type detectors respond better to particles with larger diameters produced during smoldering combustion. In an effort to explore the potential of this technique further and concurrently to fulfill the needs for low-cost particle monitors, these authors further reported that a commercial smoke detector that combines ionization chamber sensing and optical-scattering sensing has been identified and modified so that real-time signals could be measured continuously. University of California – Berkley (UCB) particle monitor employed in this study has been designed to perform monitoring in the principle of optical and ionization principles.

3. Material and Method

3.1 Study site

Initially this study was planned to be conducted in the population using this stove for assessing the impact of the stove on indoor air pollution reduction and energy conservation. However, due to time and resource constraint it could not be performed in a way that it would be conducted as originally planned. Instead, it was carried out in the form of experimental type study in a fixed place. The experiment was conducted in Addis Ababa. The specific location of the study site is in the North – East part of the city. For this experiment, a temporary shade that can represent an ordinary kitchen was constructed in the campus of GTZ-SUN Energy office located in Kebele 12/13 of Bole sub city. Three of the walls of the kitchen were made of canvas. The concrete wall constructed for fence has served as the fourth wall of the kitchen. Corrugated iron sheet was used for the roof of the kitchen. The size of the kitchen is estimated to be about 32m³. Although we have tried to make the shade representative of real kitchen, it can be rated as better kitchen than most of the kitchens of the society in Addis Ababa and other towns of the country. It had good ventilation. It was clean and convenient for the cook. The ceiling of the kitchen is estimated to be three meters high. The floor is cement paved. Bricks were arranged to form a platform with the height of 10 cm

from the floor for putting the stoves. Exactly the same spot was used for putting both stoves. The instruments were fixed on the same location during Mirt stove use and open fire use.

3.2 Data Collection

3.2.1 Indoor air pollution Monitoring equipments and data collection techniques

Measurement of suspended particulate matter was carried out using the UCB Particle Monitor (University of California, Berkeley). Carbon monoxide was measured using HOBO Carbon Monoxide Data Logger (Onset Corporation, Bourne, MA). Data were recorded at a distance of 1m from the stove and at a height of approximately 1.4m (Plates 2 and 3).

Plate 2. Picture showing placement of indoor air pollution monitoring instruments in the kitchen – baking with the Mirt stove



Plate 3. Picture showing placement of indoor air pollution monitoring instruments in the kitchen – baking with the Open fire



This area is assumed to be the breathing zone of the cook. The concentration of suspended particulate matter was averaged over and recorded in 1-minute intervals between the hours of 8:00 and 17:00 for the tests starting in the morning and between 16:00 and 00:00 for the tests starting in the afternoon. During the same period, the carbon monoxide concentration was measured in the same intervals. Through out this period, there was no re-lit of the stoves because Injera baking is a specific time activity. We have avoided other activities that need fire in the test kitchen and its vicinity. Data collection took place for a week before introduction of the ‘Mirt’ stove and the same process was repeated after introducing the improved stove. As mentioned earlier, originally fifteen sample kitchens were selected for this purpose. However, it was very difficult to control all the variables in the households. We rejected 12 of the tests made in the sample households because we could not control the sources of variability like family factors such as amount of Injera baked, behavioral factors such as fire tending, opening windows and doors and other factors like use of other stoves and out door air pollution. In other words we took only three of the 15 tests to be considered in the analysis. As it is indicated above a shade that can assume representative of a

standard kitchen was constructed in the campus of GTZ- SUN energy office. Then eight samples for each of the stoves were conducted in this kitchen in addition to the test made in the households.

3.2.1.1 UCB Particle monitor

The UCB particle monitor is a programmable continuous particle monitor that is passive and therefore does not require air-pump calibration and other skilled handling. In addition to measurements of PM, the UCB also logs temperature and relative humidity. The UCB particle monitor has two independent sensors (ionization and photoelectric (PE) light scattering chambers) for measurement of PM. The UCB has been validated by Litton et al. (2004) in experiments that compared its results against those of a frequently used, commercially available particle monitor that also measures particles by light scattering, the *DustTrak* (TSI Incorporated, Shoreview, MN). In an experiment that tested the ability of the UCB to measure mass concentrations of both fine (volume mean diameter (vmd) < 300 nanometers (nm)) and coarse particles (vmd = 2,090 nm), the UCB results were highly correlated with those of the *DustTrak*, with regression coefficients (R^2) greater than 0.99 for both PE and ionization response.

3.2.1.2 HOBO Carbon Monoxide data logger

The HOBO CO monitors used in the study are commercial data-logging devices available at relatively low cost. It is easy and portable (Plate 4). The HOBO carbon monoxide logger has three measurement ranges. Data were collected using these three channels (C-1, C-2 and C3) of the monitor, which cover the ranges 0.2–124.3 parts per million (ppm), 1–497.1 ppm, and 4 – 1988 ppm, respectively. As reported by the manufacturer, the typical accuracies of channels 1 and 2 at 20°C are ± 4.5 ppm ± 7 percent of reading and ± 6 ppm ± 7 percent of reading, respectively and ± 12 ppm ± 7 percent of reading for channel 3. Although normally only one range should be selected, selecting multiple ranges allows a wider dynamic range without sacrificing resolution at the lower end. Selecting multiple ranges results in values being stored for each range selected, therefore reducing the maximum deployment time at a given sample rate. However, since we have not faced values greater than 500 ppm, the records from channels 1 and 2 only were used for analysis.

Plate 4. Indoor air pollution monitoring instruments



As the manufacturer of the instrument indicated, the CO sensor is temperature compensated over the entire operating range; however, there may be an additional error that increases as the temperature gets farther from 20°C. For temperatures from 0°C to 20°C the readings may be lower by as much as 5% or 5ppm. For temperatures from 20 °C to 40 °C the readings may be higher by as much as 5 % or 5ppm.

3.2.2 Stove efficiency Evaluation

Measurement of stove efficiency follows two broad methodologies: 1) laboratory assessment of total thermal output (calculated either through stock-loss or directly via calorimetric methods) or fuel consumption during simulated cooking tasks and 2) evaluation of fuel consumption in the field through specific fuel consumption for cooking standardized meals or multi-day kitchen performance tests.

These most commonly used standard methods for measuring the efficiency and fuel use for biomass stoves are those developed by Volunteers in Technology Assessment (VITA), an NGO focused on third-world development issues. The standard describes three different types of tests, the water-boiling test, the controlled cooking test and the kitchen performance test.

The water-boiling test (WBT) is a technique to measure how much fuel is used to boil water under fixed conditions. This is a laboratory-like test, which is the most controllable out of the three. The test facilitates the comparison of stoves under controlled conditions with relatively few cultural

variables. This is the only test from which an actual physical efficiency, i.e., energy absorbed by cooking vessel divided by energy in fuel consumed, can be determined.

The kitchen performance test (KPT) can be employed to measure how much fuel is used in actual households when cooking normally over a few days. The amount of wood the family used per day is calculated in this test.

The third method of stove efficiency evaluation is controlled cooking test (CCT). For the purpose of this study, this method has been applied and therefore it has been described in detail in the next section.

3.2.2.1 Controlled cooking Test (CCT)

The controlled cooking test- also known as standard meal test- was developed to reflect efficiencies achieved in cooking. It is designed to assess the performance of the improved stove relative to the common or traditional stoves that the improved model is meant to replace. Stoves are compared as they perform a standard cooking task that is closer to the actual cooking that local people do every day. However, the tests are designed in a way that minimizes the influence of other factors and allows the test conditions to be reproduced. CCT is an important tool to measure the specific wood consumption of traditional and improved stoves during the preparation of a local meal- in this case 'Injera'. Using this method, we can compare the specific wood consumption of different stoves while preparing the same local meal (Injera) with the same quantities of food, ingredients, and fuel to identify deviations in the specific wood consumption. It can also help to identify the influences that affect those deviations (e.g. techniques, handling, etc.). In the controlled cooking tests the same standard meal (Injera), using the same quantities of the same ingredients (batter from teff), was prepared on the same stoves by experienced cooks. The fuel consumption has been determined by this method in which Injera is baked on the stove under consideration, where batter quantities and cooking conditions are controlled and maintained at a level as constant as possible.

During the test, 'Injera' was baked on the clay griddle (mitad). The amount of batter was recorded as well as the weight of the baked 'Injera', the weight of the fuel used and the elapsed time.

Instruments used for performing CCT are balance for measuring fuel wood, food (Injera) and batter; a stopwatch for measuring time from the beginning to the end of baking; thermometer for measuring the ambient and batter temperature; a handheld moisture tester for measuring the fuel moisture.

3.3 Data processing

3.3.1 Indoor Air Pollution

Data were downloaded from the UCB and HOBO monitors using protocols described in annexes (Annexes 1 and 2). These data were then exported to an Excel spreadsheet and cropped to include only the first 8 hours after monitor deployment. All information gathered on the data collection sheet was entered into Excel spreadsheets. Typical analysis of UCB PE readings calculates the mass concentrations as a function of a pre-deployment 40-minute calibration period inside a sealed plastic bag, which is assumed to represent zero concentration background. Data from HOBO CO logger was downloaded and processed using the software (Boxcarpro) specifically designed for the instrument itself. This software performs all necessary tasks such as launching the instrument, reading out the data and exporting the data to the excel spreadsheet. Likewise, the UCB particle monitor has its own data downloading and processing software. The latest version of the software was used for this study. The software has two parts. The first part (UCB PM Manager) is used to launch the instrument, download the raw data, and process it. The other part of the software (UCB PM Browser) is used to read the downloaded data and export it to the excel spreadsheet.

3.3.2 Efficiency Evaluation Procedure

The procedure prepared by Bailis (2004), University of California-Berkeley, has been applied to compare the Mirt stove, which is currently widely promoted in the country, with the traditional open fire method of baking Injera. Three repetitions of the CCT for each stove that is being compared are recommended. However, we have made this test in eight replications. The steps followed in the procedure are presented as follows.

1. The first step in conducting the CCT is to consult with people in the location where the stove or stoves are going to be introduced in order to choose an appropriate cooking task. This should be done well ahead of time, to ensure that sufficient food can be obtained to conduct all of the necessary tests.

2. After deciding on a cooking task, the procedure was described in as much detail as possible and recorded in a way that both stove users and testers can understand and follow. After sufficient ingredients and fuel have been prepared and the steps of the cooking task are written up and well understood by all participants, the actual testing was begun.
3. Recording local conditions as instructed on the Data and Calculation form was made.
4. Weighing the predetermined ingredients (Teff batter) was the fourth step.
5. We have started with a pre-weighed bundle of fuel that is roughly double the amount that local people consider necessary to complete the cooking task. The weight was recorded in the appropriate place on the Data and Calculation form.
6. Starting with a cool stove, the cooks were allowed to light the fire in a way that reflects local practices. Then the timer was started and the time was recorded on the Data and Calculation form.
7. While the cook performs the cooking task, recording any relevant observations and comments that the cook makes (for example, difficulties that they encounter, excessive heat, smoke, instability of the stove or pot, etc) has been made.
8. When the task is finished, the time was recorded in the Data and Calculation form.
9. As soon as the final Injera was removed it was weighed with the container (sefed) on the balance. Then the weight of Injera and Sefed was recorded in grams on the Data and Calculation form.
10. The unburned wood was removed from the fire and extinguished. The charcoal from the ends was knocked off the unburned wood. The unburned wood from the stove was weighed with the remaining wood from the original bundle. All of the charcoal was placed in the designated tray and weighed. Then both measurements were recorded on the Data and Calculation form.

3.4 Statistical Analysis

Even though this study mainly focused on assessment of potential of Mirt stove in improving indoor air quality, it also tries to compare its efficiency with that of open fire- three stone method. The parameters used for making analysis on the indoor air conditions are maximum concentrations for each 15 minutes in the 8 hours, average concentrations during baking time and 8 hours starting from the deployment of instruments. To give more illustration on the level of maximum concentrations for these stove conditions, the 95th percentile has also been calculated and used to compare the stoves. Statistical tools used are histograms, analysis of variance, t-test and linear regression models. Each of these tools has

been employed in the analysis for comparing the two stoves in terms of the above parameters as appropriate. Statistical analysis was made using SPSS statistical package and Microsoft excel spreadsheet.

The two basic parameters of interest for evaluating stove efficiency are specific fuel consumption and time required for Injera baking. Analysis of stove efficiency has been made using t-test as statistical tool. The data has been processed using software developed by University of California. After each test, data was transferred from the Data and Calculation forms into the software. Once three tests for each stove are complete, the software provides a value of specific fuel consumption and total cooking time for each individual test as well as an average of three tests for each stove. Once CCTs for two stoves are completed, the software will compare the results and test for statistical significance. In the software, each data form contains space for qualitative observations to be recorded and summarized on the “Results” page.

4. Results and Discussion

4.1 Indoor Air Emission

In cook stove emission tests it is common to measure carbon monoxide (CO) and suspended particulates. The reason for choosing these pollutants is medical: Carbon monoxide is acknowledged as a good indicator of acute (short-term) hazard and total suspended particles (TSP) of chronic (long-term) hazard (Tremeeer, 1997). When there is a need to assess the intensity of exposure for indoor air pollution from biomass burning with multi stove conditions or to accommodate emissions from different sources, the study would be made for longer time intervals – 8 hours to 24 hours. Many of the literatures show that it is appropriate to monitor the exposure level for long time intervals if the objective of the study is mainly related to health effects of indoor air pollution. For assessment of the potential of a given improved stove, it is enough to make evaluation based on the shorter time intervals. Therefore, in this study evaluation of the stove characteristics in terms of pollutant generation has been made for shorter time intervals.

As average emission concentration alone is not a sufficient indicator of potential adverse impact on health affects of energy technology the other descriptive statistics are necessary in stove characterization. The 8-hour average has been used to compare the time required for the smoke to completely die out. The 15-minute maximum and the 95th percentile are other parameters of

interest for comparing stoves operating at their worst conditions to account for potential impacts of exposure intensity- exposure to extremely high levels of pollution with in short periods of time (i.e. episodes on the order of few minutes). Since much of the smoke is generated in burning time the average concentration in the baking time has been also used to emphasize the problem of pollutant generation in this period.

4.1.1 The 8-hour Average Pollutant Concentration

Figures 1 and 2 illustrate the average concentrations of carbon monoxide and particulate matter in the Mirt stove and open fire situation. Comparisons of these values using the one-way analysis of variance are given in table 4. The variation in carbon monoxide concentrations was statistically significant.

Table 4. 8-hour Mean Pollutant Concentrations by Stove type

Stove type		Open fire	Mirt	F
8-hour CO concentration (ppm)	Means	25.10	2.80	34.27
	Standard dev.	12.37	2.55	
8-hour PM concentration (mg/m3)	Means	0.32	0.26	0.39
	Standard dev.	0.18	0.23	

These comparisons indicate that Mirt stove could achieve carbon monoxide emission concentration reduction by 88.8 % and particulate matter concentration level has shown reduction by 17.3 % as compared to the open fire system. However, the difference for PM level is not statistically significant in analysis of variance in table 4. In this study, pollutant concentration level exhibited large variability in the eight-hour period. CO concentration has average coefficients of variation (defined as the ratio of standard deviation to the mean; a measure of the variability of data relative to its mean) of 0.91 and 0.49 during the 8 hours period for Mirt stove and open fire stove respectively. The coefficients of variation of particulate matter in the same period are 0.88 and 0.56 for Mirt stove and open fire stove respectively. This means each CO value recorded deviate from the mean by values that are nearly 91% and 49% of the means of Mirt stove and open fire system respectively. The largest variability is observed in the Mirt stove situation. This shows that the burning process was not uniform for Mirt stove. This may be attributable to the tending of fire or

management of stove operation. If the stove is not properly operated, there may be higher emission than the open fire system. For example such situation was observed in two of the tests.

Figure 1. Histogram of 8-hour mean concentration of CO (ppm)

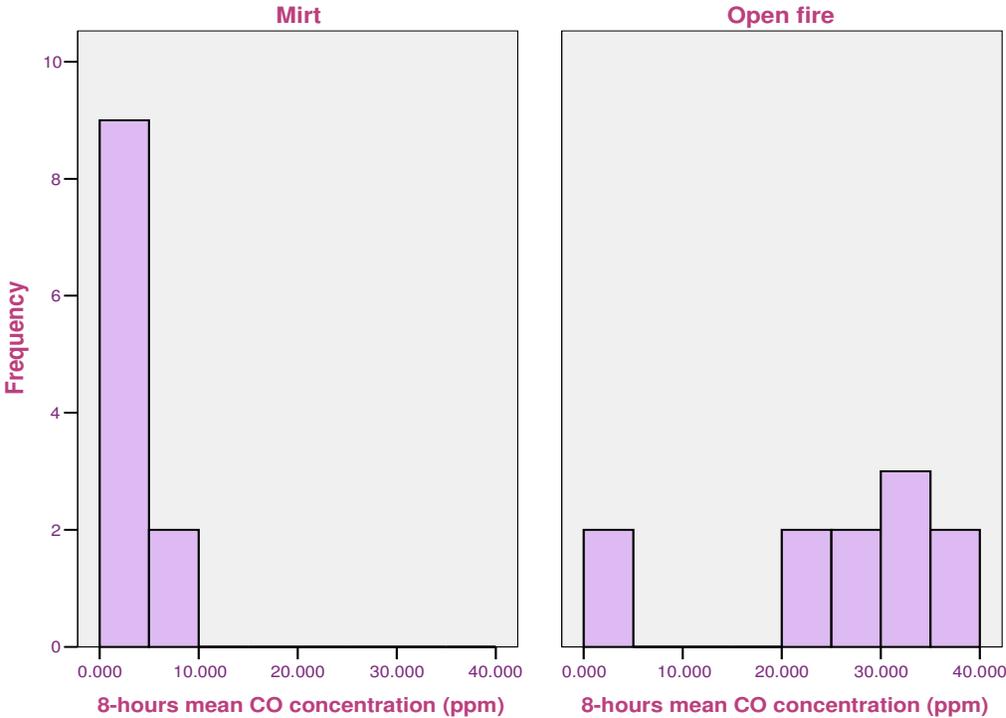
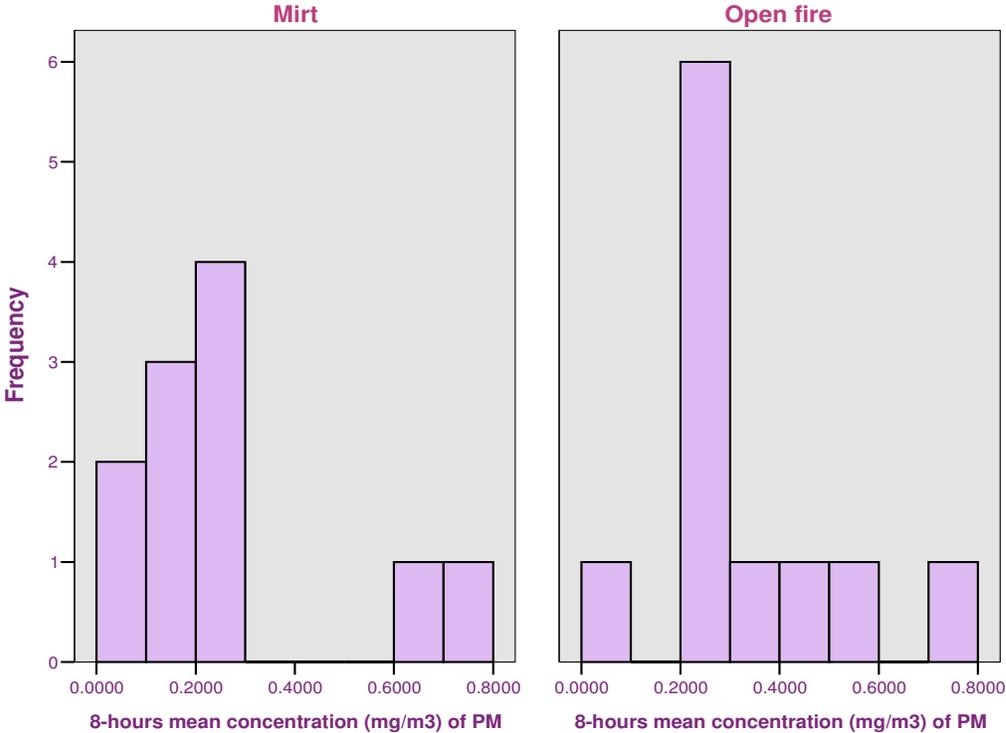


Figure 2. Histogram of 8-hour mean concentration of PM (mg/m³)



As depicted in the histograms given in figure 1 most of the recorded values of carbon monoxide are in the range of 0 to 10 ppm for Mirt stove. Whereas maximum values ranging from 20 to 40 ppm were observed with larger frequency in case of open fire condition. The frequency distribution of mean particulate matter does not show much variation. Values ranging from 0.2 to 0.3 had been observed with the highest frequency in both of stove situations.

Figure 3. 8-hour Monitoring data for a representative test showing CO concentration (ppm), PM concentration (mg/m³) and Temperature (°C) in Mirt stove condition

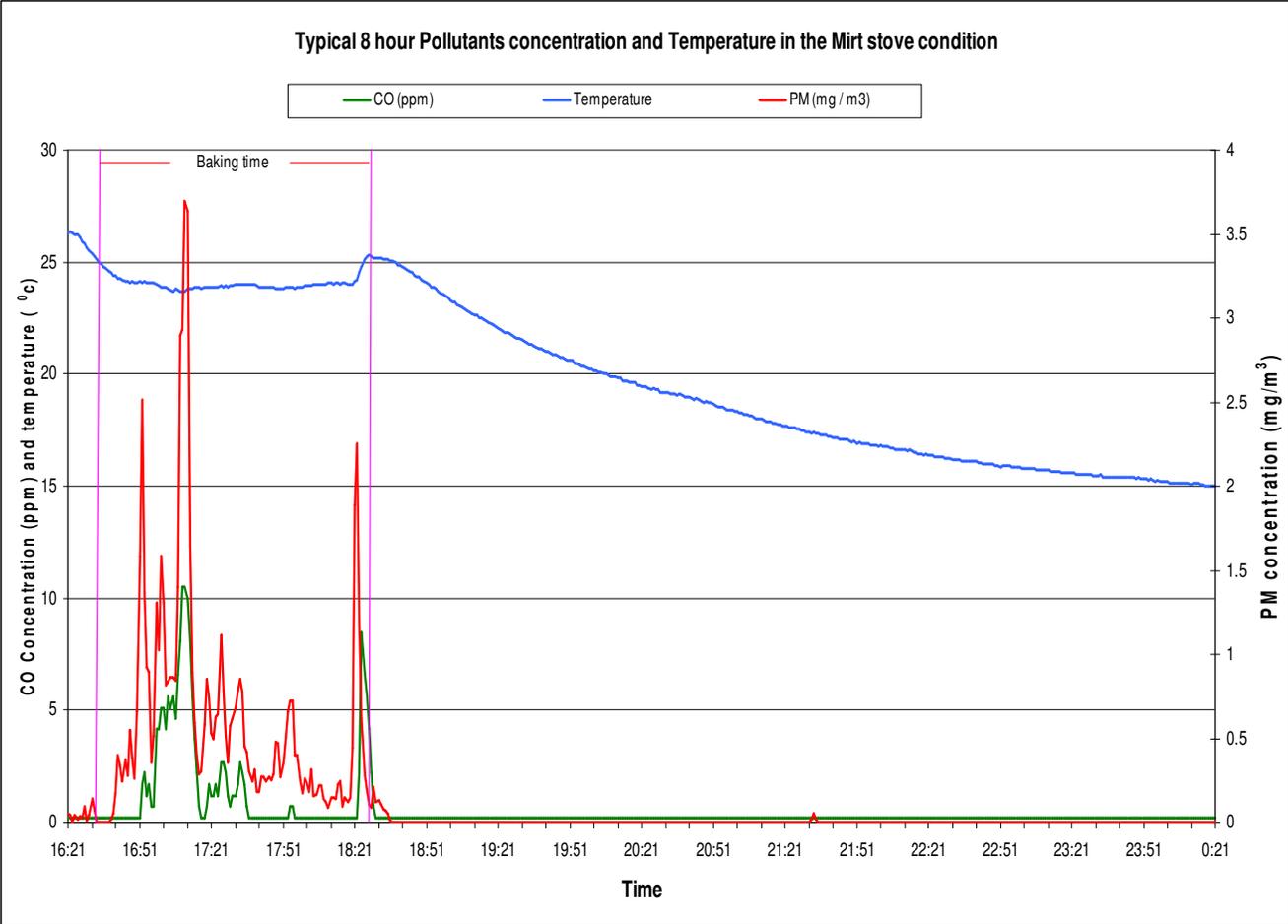
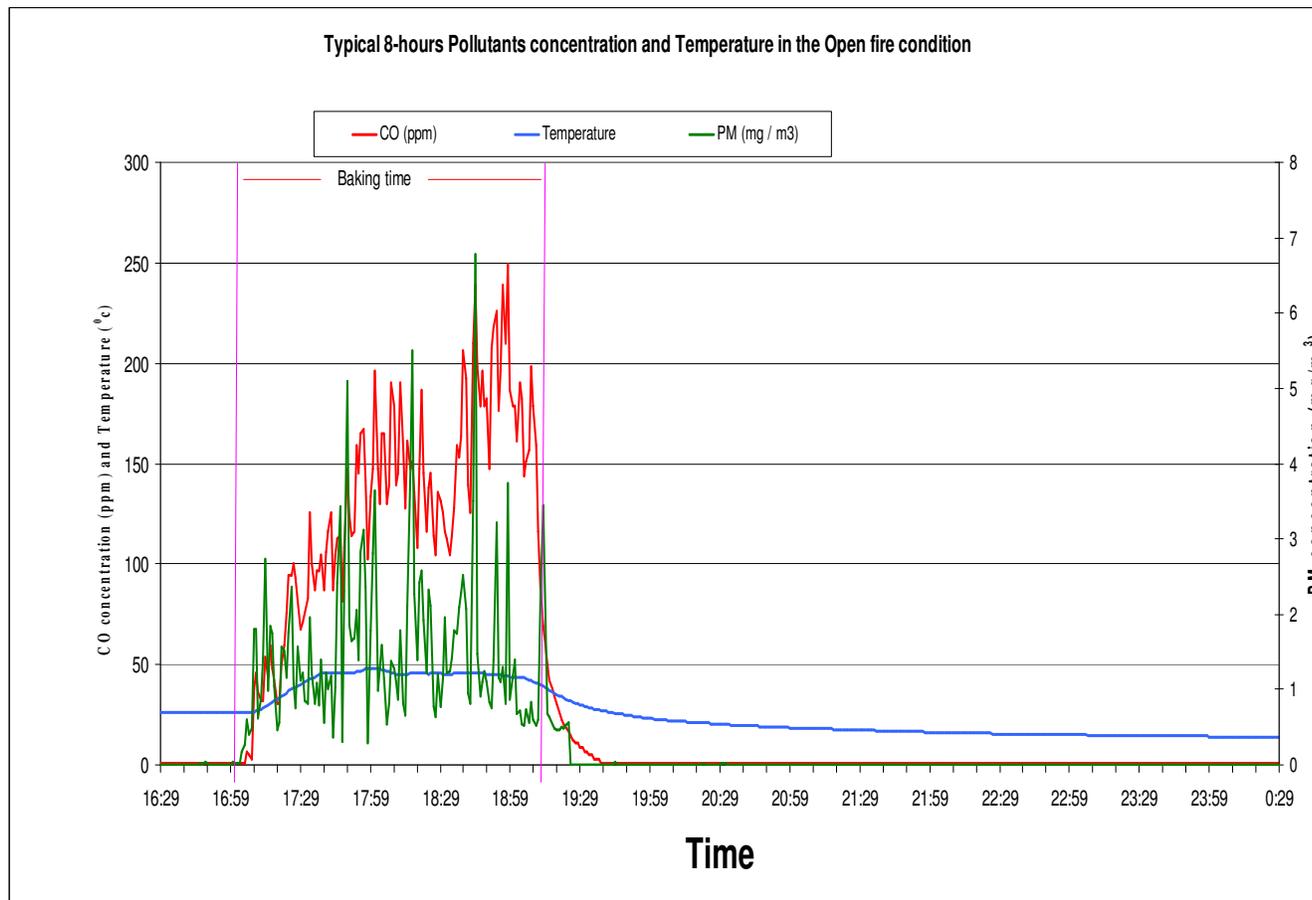


Figure 4. 8-hour Monitoring data for a representative test showing CO concentration (ppm), PM concentration (mg/m³) and Temperature (°C) in open fire condition



Pollutants concentration remains in the kitchen for longer period in the open fire situation as compared to the Mirt stove. It seems that the time required for the decay of pollutants is directly related to the amount of pollutants generated in the baking time. It is known that source of particulate matters in the kitchen is not only fuel burning. Therefore, we observe some amount of PM before baking and post baking time.

As illustrated in the graph, it is obvious that much of the pollutants concentration occurred during the baking time. Although there are few outlying values that are approaching the peak concentration, the overall concentration totally diffuses with in 15 minutes after the baking session is over. The pollutants build up starts in shorter period for the open fire as compared to Mirt stove. The time elapsed before CO is detected is about 25 minute on average for Mirt stove and it is 5 minute in the case of open fire system. Another benefit of enclosed improved stoves – Mirt stove in this case, is that they can create conducive environment for the cook by reducing the kitchen

temperature. The maximum temperature observed in the case of Mirt stove is about 25°C whereas in case of open fire the temperature rises up to 45 °C.

4.1.1 Maximum Pollutant Concentrations

The maximum 15-minute concentrations experienced during the baking period were calculated for both CO and PM. The occurrence of the 15-minute peaks for CO and PM has no specific time as there was no refueling of the stoves. Therefore, the peak values indicated in this study are values that have been recorded during baking time. The peak values could be observed at different times within the baking time interval. However, in some of the tests, some outlying maximum values could be observed at the end of the baking session. This is because we were collecting unburned wood and charcoal from the combustion chamber for the purpose of efficiency evaluation and therefore it could cause smoldering for a short instance. None of the 15-minute maximums could be recorded after the completion of the baking session. As shown in figure 5, in the case of Mirt stove, the carbon monoxide concentration had not exceeded 50 ppm. Values from 0 to 50 ppm occurred with the highest frequency. The particulate matter in a Mirt stove situation had not shown much difference from the open fire conditions (figure 6). The extreme record in three-stone case is in the range of 25 to 30 mg/m³, whereas the maximum for Mirt stove is in the range of 15 to 20 mg/m³. The peak CO level in the range of 250 to 313 ppm have been observed in some of the tests with the open fire situation in this study. These peak levels in the tests with open fire were 22 times higher than the 8-hour average. The 15 minute maximum for CO is higher than the 8 hour average concentration by a factor of 69.9 ppm for the open fire situation and the difference between 15 minute maximum CO concentration and the average in the 8-hour period is 10.2 ppm in Mirt stove condition. To make further analysis on the intensity of exposure to pollutants, the 95th percentile in the 8-hour interval was calculated. The result shows that the 95th percentile for CO could be reduced by 89% because of using Mirt stove. The reduction obtained for similar parameter of PM is 7.7%.

Figure 5. Histogram of 15-minute maximum CO concentration (ppm)

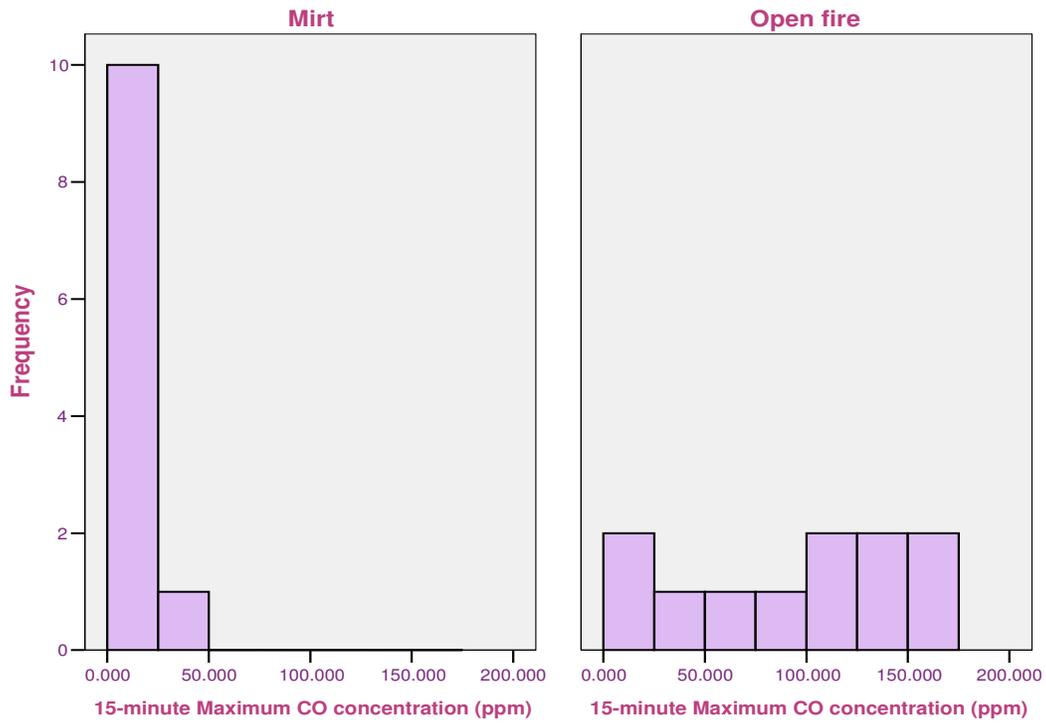
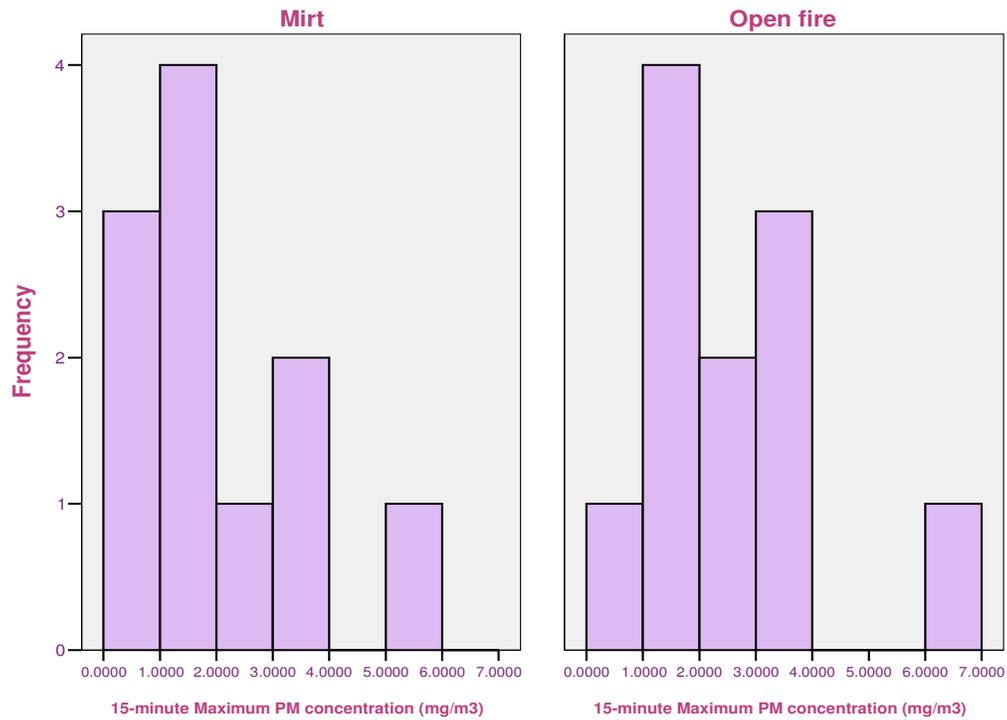


Figure 6. Histogram of 15-minute maximum PM concentration (mg/m³)



The 15-minute maximum concentrations of CO and PM are reported by stove type in table 5. CO levels were very low for improved (Mirt) stove and this difference (86.3%) was statistically significant in the one-way ANOVA. Although there is variation of PM level, the difference (19.3%) was not statistically significant.

Table 5: Maximum 15-minute CO and PM concentrations by stove type

Stove type		Open fire (N=11)	Mirt (N=11)	F
Maximum 15-minute CO concentration	Mean	95.03	13.01	23.47
	Standard dev.	54.93	11.63	
Maximum 15-minute PM concentration	Mean	2.55	2.06	0.53
	Standard dev.	1.55	1.63	

Although the concentration level varies with the kitchen environment in actual conditions, for the tests we made with the open fire, the average of 15-minute maximum CO concentration (95 ppm) was close to the WHO 15-minute exposure maximum limit (100 ppm) to avoid acute poisoning. In case of the tests with Mirt stove the value (13 ppm) obtained is far below this limit. The mean CO concentration (80 ppm) in the baking time with open fire is very much higher than the WHO guideline (30ppm) for 1-hour CO exposure. In Mirt stove situation this value (7 ppm) is extremely low.

4.1.2 Pollutant Concentrations in Baking Time

Much of the emissions from cook stoves are generated during this time and therefore it is very important to quantify the level of concentration of pollutants in the kitchen during this time. The largest share of exposure of women to indoor air pollution is in this period. As reported by Tremeer (1997), using data on microenvironment concentration, daily time budget, and daily personal exposure, Saksena et al. (1992) estimated the contribution of each microenvironment to personal exposure. These authors found large variability among demographic subgroups in the contributions

of different microenvironments, with kitchen during cooking being the largest (approximately 75% of exposure) contributor to the exposure of women.

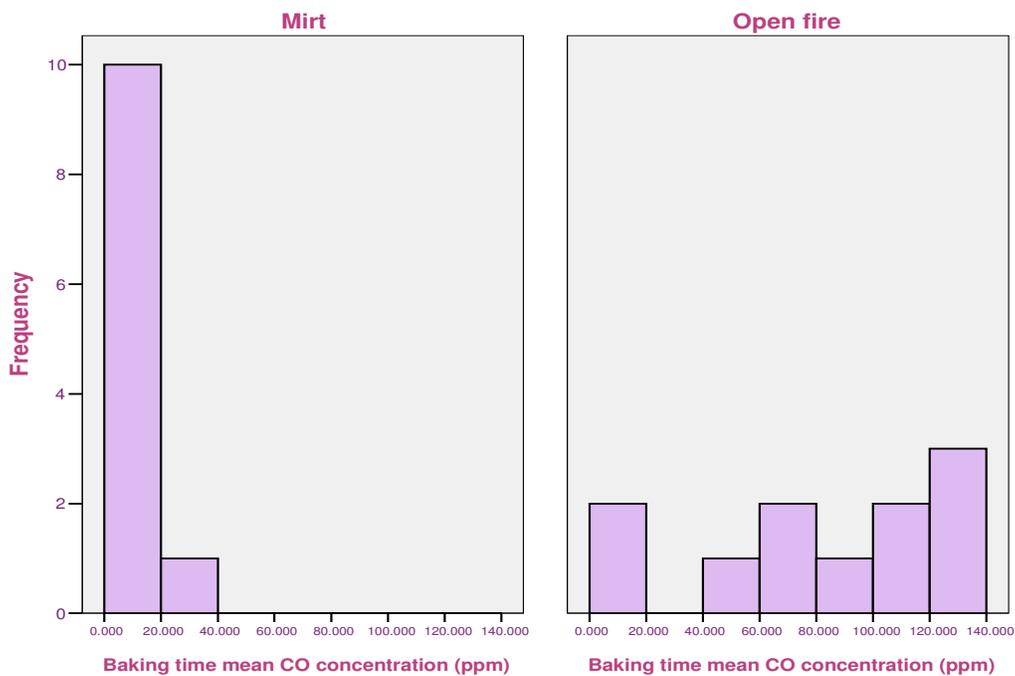
The central focus of this study is to investigate the contribution of Mirt stove that is specifically designed for injera baking in reducing indoor air pollution. Quantifying the level of pollutants concentration in the kitchen in baking period would give good indication of the situation. Based on this, comparison of the two stoves, Mirt stove and open fire, using the baking time average has been made. This quantitative comparison using the one-way ANOVA has been given in table 6.

Table 6. Average CO and PM concentrations during the baking period

Stove Type		Open fire (N=11)	Mirt (N=11)	F
CO concentration in baking time	Mean	80.12	7.18	28.89
	Standard dev.	44.17	8.62	
PM concentration in baking time	Mean	1.10	0.88	0.47
	Standard dev.	0.69	0.77	

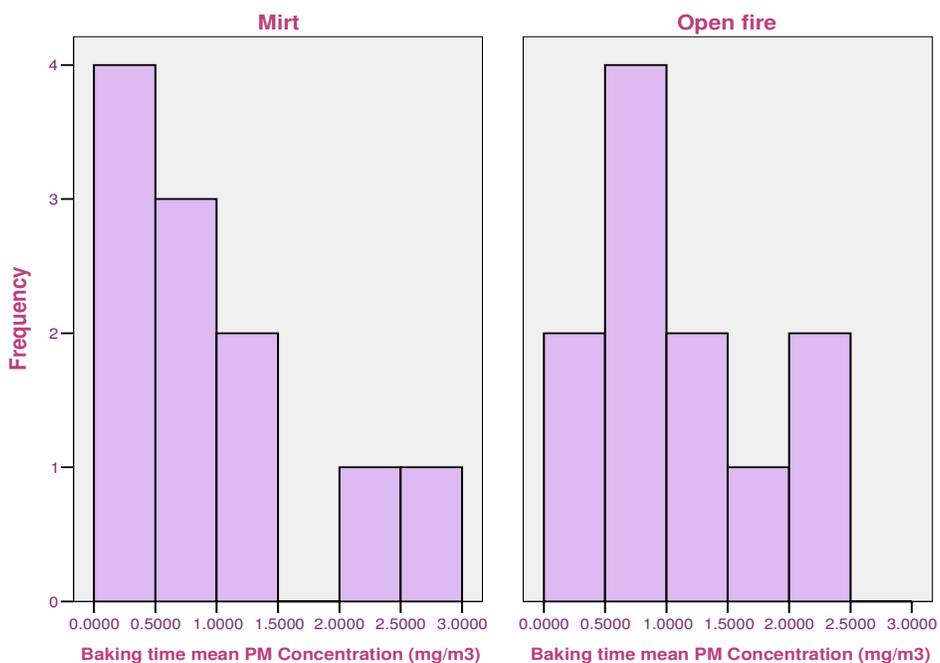
As shown in table 6 the average concentration of CO in the open fire system is 80.1ppm while it is 7.2 ppm for Mirt stove situation during baking. In this case, the CO level from the use of Mirt stove could be reduced by 91 %. This difference is significant in the one-way ANOVA. There is slight variation in PM concentration between the two stove conditions (19.3 %) but this variation is not statistically significant in the one way ANOVA. Figure 7 and 8 show the distribution of pollutants in the baking time.

Figure 7. Histogram of mean concentration of CO during baking time



As it is shown in figure 7 the mean CO concentration for Mirt stove ranging from 0 to 20 ppm occur with the highest frequency. On the other hand, records of CO concentration ranging from 0 to 140 ppm could be observed with considerable frequency for open fire stove.

Figure 8. Histogram of mean PM concentration in the baking time.



4.1.4 The relationship of Carbon Monoxide and Suspended Particulate Matter

Based on available knowledge of fuel combustion, air pollution and health, particulate exposures would arguably provide the best indicator of pollutant risks from fuel combustion.(Neaher et al. 2001). Unfortunately, long duration exposure and difficulty in obtaining logistics (e.g. sampling pumps and particulate sampling apparatus can not be easily attached to the infants for personal sampling) for such studies make it problematic and expensive to use the usual particulate monitoring. Therefore, studies (Ezzati et. al., 2000; Neaher et al., 2001; Park and Lee, 2003) have tried to check whether it might be possible to take CO as a surrogate indicator of particulate matter. To see if this study is in line with such arguments and to check whether these scientific arguments are reflected in the data collected for this study, attempt was made to analyze the correlation of CO concentration collected by HOBO CO data logger and PM collected by UCB Particle monitor. Although there is variation in values, these pollutants have positive correlation in this study. The results obtained have agreed to these works with few exceptions that very small values have been recorded in some of the tests. For example in 4 of the tests for Mirt stove and 2 of the tests for open fire the correlation coefficient (R^2) was in the range between 0.55 and 0.72. These values are comparable to the values ($R^2 = 0.5$) reported by Naehar et al (2001) from open fire kitchen and $R^2 = 0.14 - 0.91$ of Ezzati et al. (2000). Similar work of Park and Lee (2003) showed that the CO levels could correlate with $PM_{2.5}$ with the spearman's coefficient of 0.71 while it had value of 0.03 for PM_{10} . The poorest correlation coefficients observed in this study is for two of the tests for Mirt stove situation were 0.0004 and 0.0008, which shows that these pollutants in these cases have no correlation. On the other hand when we use the 8-hour mean values of pollutants for each type of stove strong correlation could be observed from the Mirt stove situation ($R^2 = 0.92, N = 11$). Whereas the values from open fire is very small ($R^2 = 0.17, N=11$). The correlation obtained from the aggregate of the two types of stoves is also very low ($R^2 = 0.04, N = 22$) (Figures 9 and 10).

As stated earlier, the reduction of PM concentration due to the use of Mirt stove is not as much as the reduction of CO concentration. The reason for the variation could be different. The nature of the pollutants can be one source of variation. The particulate emissions depend on the combustion conditions such as combustion of appliance type, chimney, fuel, and firing behavior. Sources of

pollutants can be another reason. There are two main sources of primary particles from residential biomass combustion (Johansson et al., 2006):

1. Particles from **incomplete combustion**: This includes soot, condensable organic particles (tar drops), and char particles.
2. Particles originating from the **inorganic material in the fuel** – ash particles

Particles from incomplete combustion are emitted at inefficient combustion conditions, and can be minimized through optimizing the combustion conditions with respect to temperature, mixing and residential time. However, particles from the inorganic ash components in the fuel are emitted no matter what the combustion conditions are, from today's residential appliances. Besides the primary particles emitted from the chimney, gaseous components from the combustion flue gas might form secondary particles in the ambient air.

In an ideal situation the particle concentration measured in a certain measurement point might be affected by several parameters (which sometimes are connected to each other), e.g.:

- **Temperature** – the lower the temperature in the measurement point, the more components are in liquid phase, and thus are measured as liquid particles.
- **Pressure** – if the partial pressure of vapor in the flue gas is higher than the saturation vapor pressure nucleation might occur, which means that particles are formed
- **Dilution** – dilution with room-tempered air decreases the temperature of the flue gas and thus condensation is enhanced. On the other hand, dilution with heated air decreases partial pressure and thus the condensation of potential particle decreases.
- **Losses** – particles might be lost in the sampling system through e.g. diffusion and thermophoresis.

The wide variation of Spearman's correlation coefficients observed in this study and other studies suggest that use of CO as an indicator for PM should be considered with care.

Figure 9: The association between PM and CO in the Mirt stove condition

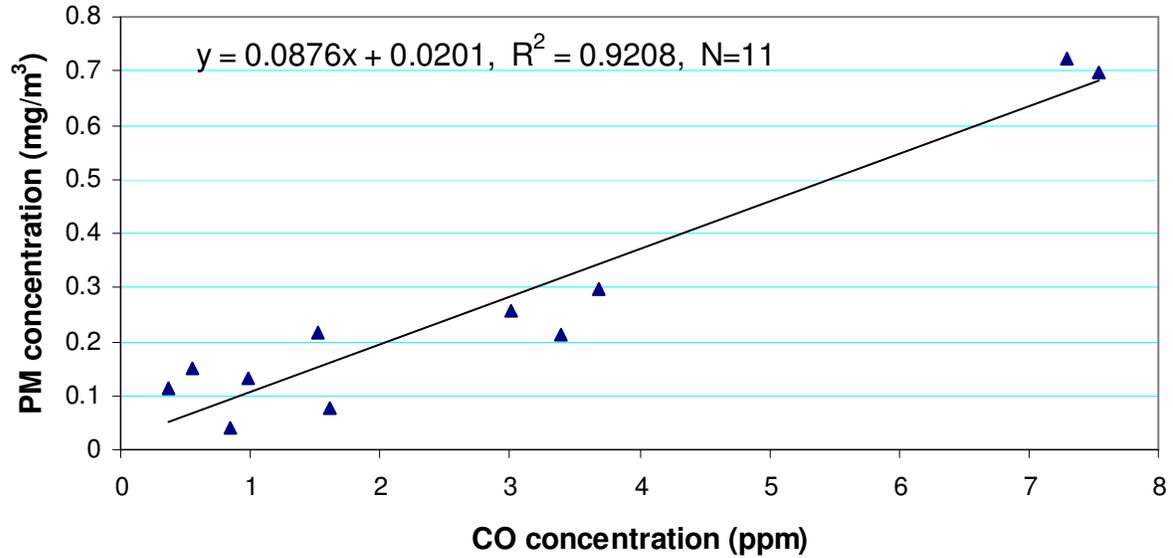
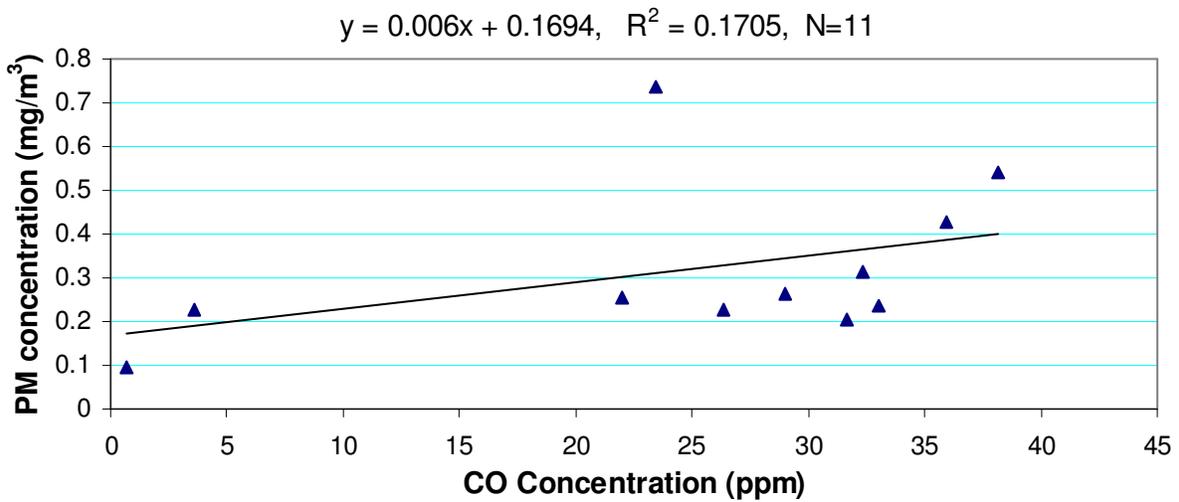


Figure 10. The Association Between PM and CO in the Open fire Condition



As indicated in many of the documents, from an exposure assessment perspective, there is a problem with using CO as the indicator of suspended particulate matter. For most people, significant exposure occurs only during certain parts of the day, in an episodic manner. The concentration of PM exhibits sharper fluctuations between a generally low background level and very large peaks than CO.

4.2 Efficiency of Mirt stove

As mentioned in many literatures, Injera baking take more than 50% of the total primary energy consumption and this account for about 75% of the household energy consumption in Ethiopia. Most of the households in the country use open fire for this purpose. The use of open fire system is blamed for being highly inefficient. As indicated in many of the documents the thermal efficiency of open fire (three stone stove) ranges 5% to 10%. The widespread use of this system coupled with the lowest supply of modern energy services is aggravating the two most important environmental problems – indoor air pollution and natural resource degradation. In Ethiopia substantial energy savings can be attained by improving the end use efficiency of household fuel use, in particular by improving the efficiency of cook stoves. Improved fuel saving stoves can be produced at low cost; and dissemination programs can provide a cost effective solution to environmental protection and improved livelihood. They can also have significant economic effects on both the household and the macro economic level. Mirt Injera stove was designed by the Ethiopian Energy Studies Research Center in the early 1990s to alleviate or lessen this problem. This stove is being promoted and widely distributed in the country because it is believed that it can achieve the fuel efficiency up to 40%. As stated by Konemund (2002), field test results indicate that an average household using an improved Mirt stove for Injera baking saves about 570 kg fuel wood per year. The pay back time for the stove buyer is only 2-3 months, while the stove has a expected life time of about 4-5 years. The study made by Workneh (2005) showed that it has the potential to achieve efficiency of more than 33%. This study has tried to make some additional investigation on this stove to supplement the other studies made by different persons. The assessment focuses on the efficiency of Mirt stove in terms of specific fuel consumption and time required for ignition of the stove and time required for baking.

4.2.1 Specific fuel consumption and time

Table 9 compares the fuel efficiency of the open fire and Mirt stove. The results for wood consumption show that Mirt stove uses significantly less fuel for baking the same amount of Injera among the two systems.

Table 9. Summary of measurements for Comparing Mirt stove and Open fire.

Stove type	Total fuel used (kg)	No Injera	Batter in kg	Average wt of total Injera (kg)	Fuel/kg Injera (kg)	Fuel/Injera (kg)	Fuel/kg batter (kg)	Time for ignition (Minute)	Time/Injera (minute)
Mirt	7.48	28	15.7	10.20	0.73	0.27	0.47	17.50	3.99
Open fire	13.54	27	15.6	10.17	1.34	0.49	0.87	13.26	3.95
Difference (%)	44.8				45.30	44.70	45.3	24.2	1

As we can understand from table 9, the weight of wood consumed was substantially less than that by the open fire, with the specific fuel consumption for the Mirt stove being 45% of that for open fire. The difference in time taken for baking a single Injera is not statistically significant even though it is very slightly higher for the Mirt stove situation. Tables 10, 11 and 12 also demonstrate that there is no significant difference between the two systems in terms of total time taken to bake the same number of injera. The t-test made for evaluation of the stoves in terms of time required for ignition of the stoves show that the variation is statistically significant. Therefore, from this study we can conclude that Mirt Injera stove does not seem to save time as compared to open fire.

10. Stove efficiency test results from the first three pairs of backing

1. CCT results: Open fire	Units	Test 1	Test 2	Test 3	Mean	St Dev
Total weight of food cooked	g	9980	9610	9870	9820	190.0
Weight of char remaining	g	620	520	730	623	105.0
Equivalent dry wood consumed	g	10078	10180	9808	10022	192.1
Specific fuel consumption	g/kg	1010	1059	994	1021	34.2
Total backing time	min	123	138	121	127	9.3
2. CCT results: Mirt						
Total weight of food cooked	g	9890	10580	9990	10153	372.9
Weight of char remaining	g	900	750	850	833	76.4
Equivalent dry wood consumed	g	5366	5019	5215	5200	173.6
Specific fuel consumption	g/kg	543	474	522	513	34.9
Total backing time	min	131	116	130	126	8.4
Comparison of Open fire and Mirt		T-test		Sig @ 95% ?		
Specific fuel consumption	g/kg	18.00		YES		
Total backing time	min	0.23		NO		

Table 11. Stove efficiency results from the second three pairs of backing

1. CCT results: Mirt	Units	Test 1	Test 2	Test 3	Mean	St Dev
Total weight of food cooked	g	10940	10140	10260	10447	431.4
Weight of char remaining	g	770	540	680	663	115.9
Equivalent dry wood consumed	g	5103	5339	5377	5273	148.4
Specific fuel consumption	g/kg	466	527	524	506	34.0
Total backing time	min	113	138	124	125	12.5
2. CCT results: Open fire						
Total weight of food cooked	g	10450	10510	9780	10247	405.3
Weight of char remaining	g	780	840	870	830	45.8
Equivalent dry wood consumed	g	10777	10938	12076	11264	708.4
Specific fuel consumption	g/kg	1031	1041	1235	1102	114.9
Total backing time	min	121	128	132	127	5.6
Comparison of Open fire and Mirt stove		T-test		Sig @ 95% ?		
Specific fuel consumption	g/kg	-8.62		YES		
Total backing time	min	-0.25		NO		

Table 12. Stove efficiency test results from the 3rd three pairs of backing

1. CCT results: Mirt	Units	Test 1	Test 2	Test 3	Mean	St Dev
Total weight of food cooked	g	10060	10190		10125	91.9
Weight of char remaining	g	490	710		600	155.6
Equivalent dry wood consumed	g	5473	5722		5597	176.5
Specific fuel consumption	g/kg	544	562		553	12.4
Total backing time	min	134	137		136	78.2
2. CCT results: Open fire						
Total weight of food cooked	g	10500	10580	10610	10563	56.9
Weight of char remaining	g	740	640	670	683	51.3
Equivalent dry wood consumed	g	10091	9906	10700	10233	415.5
Specific fuel consumption	g/kg	961	936	1009	969	36.7
Total backing time	min	107	108	115	110	4.4
Comparison of Open fire and Mirt Stove		T-test			Sig @ 95% ?	
Specific fuel consumption	g/kg	-18.60			YES	
Total backing time	min	0.56			NO	

5. Conclusion and recommendation

This study provides quantitative assessment of the potential of enclosed biomass stove specifically designed for Injera baking. Therefore, it is believed that it can give an insight for further study on issues related to indoor air pollution from biomass burning. The reduction of CO level in the kitchen due to installation of Mirt stove is very high and the trend observed is consistent through out all of the tests in this study. On the other hand, the level of reduction for particulate matter is not significant. Insignificant difference of reduction of PM might have come from small sample size and therefore comparisons of the stove in terms of PM may not be conclusive.

Due to time and resource constraint, this study has been made in a fixed place and a controlled condition that can represent an ordinary kitchen. However, this does not reflect the real situation in the field. Therefore conducting a population level study to see the impact of this stove and other appliances in the society is of very important area to be looked in detail.

CO monitoring will remain a useful tool in qualitative ranking of households in terms of emission levels. However, since small size monitoring devices like the one used in this study are available and episodic nature of exposure to indoor smoke is of critical importance, the usefulness of CO as

a means for detailed assessment of exposure to suspended particulate matter is limited. Therefore, any exposure study should quantify suspended particulate matter using instruments that is designed for this purpose.

From the tests made for the open fire, we could observe that the average of the 15-minute maximum CO concentration (95.03ppm) was close to the WHO 15-minute exposure maximum limit of 100 ppm to avoid acute poisoning. Whereas in case of the tests with Mirt stove the value (13.0 ppm) obtained is far below this limit. Similarly, the mean CO concentration (80.1 ppm) in the baking time with open fire is very much higher than the WHO guideline for 1-hour CO exposure, which is 30 ppm. In Mirt-stove situation, this value (7.18 ppm) is extremely low. However, as CO concentration is highly influenced by the kitchen environment, especially the ventilation condition, this may not be the basis to conclude that there is high level of exposure to CO in real kitchen of the society using open fire system. Nevertheless, given there is proper management and use of this improved stove there will be significant overall reduction of such risks. So it is conclusive that the reduction of CO concentration in the baking time due to the use of Mirt stove is the significant benefit of the technology.

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Annexes

Annex 1. Summary data for the tests with open fire and Mirt stove conditions

Test No	Stove type	8hr CO	8hrPM	CO baking	PM baking	15 min CO	15min PM	Moisture	Fuel/injera	Fuel/kgbatter	Fuel/kg injera	Total fuel
1	Mirt	3.4	0.2124	7.117	0.6147	14.109	1.6913	14.43	0.29	0.5	0.79	7.82
2	Mirt	7.544	0.6974	28.266	2.5111	43.611	5.8389	13.8	0.26	0.45	0.68	7.11
3	Mirt	3.681	0.2982	8.091	1.2085	14.542	3.0907	16.05	0.27	0.49	0.77	7.68
4	Mirt	0.548	0.151	1.647	0.6237	4.24	1.7299	14.33	0.27	0.46	0.67	7.28
5	Mirt	0.844	0.0409	0.393	0.191	7.025	0.4671	15.68	0.25	0.46	0.72	7.25
6	Mirt	0.374	0.1132	1.469	0.2019	4.057	0.2256	14.85	0.28	0.49	0.73	7.48
7	Mirt	0.977	0.1325	0.541	0.45	5.073	1.8454	15.7	0.26	0.47	0.73	7.32
8	Mirt	1.615	0.0784	2.059	0.2544	12.709	0.7946	14.26	0.29	0.5	0.78	7.89
9	Mirt	1.522	0.2152	3.813	0.5757	9.87	2.3737		0.24	0.47	0.715	7
10	Mirt	7.294	0.7231	17.515	2.0388	22.435	3.5486		0.29	0.58	1.022	9.5
11	Mirt	3.005	0.2578	8.094	1.0508	5.389	1.0611		0.3	0.59	0.898	6
Mirt total	Mean	2.800364	0.265464	7.182272727	0.883690909	13.00545455	2.060627273	14.8875	0.272727	0.496363636	0.773182	7.484545
	SD	2.549971	0.232779	8.625725942	0.76679384	11.63065591	1.626318297	0.822674	0.019022	0.046962267	0.10349	0.841432
	CV	0.910586	0.876876	1.200974437	0.867717244	0.894290612	0.789234578	0.055259	0.069746	0.094612626		0.112423
1	Open fire	26.315	0.2292	75.422	0.6727	45.222	1.2472	15.11	0.51	0.91	1.37	14.3
2	Open fire	33.061	0.238	120.002	0.9234	160.34	2.3034	15.49	0.5	0.91	1.36	14.06
3	Open fire	32.376	0.3117	108.381	1.2145	114.575	3.253	12.95	0.49	0.86	1.27	13.43
4	Open fire	21.954	0.256	72.947	0.8803	105.67	2.0165	13.89	0.47	0.82	1.28	12.75
5	Open fire	31.618	0.2059	85.326	0.5719	94.993	1.4978	16.92	0.47	0.84	1.36	13.08
6	Open fire	35.897	0.4269	125.93	1.5431	161.53	3.6422	17.53	0.48	0.84	1.33	13.09
7	Open fire	38.121	0.5408	128.894	2.2554	137.05	6.3809	13.25	0.48	0.83	1.23	12.89
8	Open fire	29.035	0.2643	103.314	1.1396	140.04	1.9226	14.56	0.47	0.8	1.2	12.67
9	Open fire	23.458	0.7353	49.419	2.249	60.222	3.1825		0.46	0.75	1.15	12
10	Open fire	3.608	0.2289	9.387	0.3758	12.283	0.7008		0.33	0.77	1.175	11.5
11	Open fire	0.698	0.0934	2.265	0.222	13.4	1.9577		0.39	0.62	0.955	7
Open fire total	Mean	25.10373	0.320945	80.117	1.095245455	95.02954545	2.554963636	14.9625	0.459091	0.813636364	1.243636	12.43364
	SD	12.37676	0.180982	44.17285823	0.685725726	54.93396147	1.551661273	1.64833	0.052812	0.081273948	0.123047	1.972766
	CV	0.493025	0.563904	0.551354372	0.626093195	0.578072443	0.607312469	0.110164	0.115036	0.099889768		0.158664

Annex 2. Standard Operating Procedure for HOBO Carbon Monoxide Logger (Collection, Downloading, and Storage of Data)

1.0 Launching the HOBO CO Logger

* Note: The logger must be launched from a computer prior to placement in the field.

* Note: Before proceeding, be sure that the computer's clock time is correct and that any watches or clocks to be used in field are synchronized to it.

- 1.1 Connect the 9-pin plug of the cable (CABLE-PC-3.5) to the COM 1 serial port on the computer. If the computer does not have a COM port, connect the 9-pin plug to a USB serial adapter, and then connect the other end of the adapter to the computer's USB port.
- 1.2 Open BoxCar Pro software (double click on the icon on the desktop)
- 1.3 Connect the "stereo" plug end of the serial cable to the logger
- 1.4 Select 'Logger' from the top menu of the BoxCar Pro software. When the drop-down menu appears, select 'Readout.'
- 1.5 Check the battery status (the horizontal green bar). Replace the battery if the level is low. A new battery should last for a few months.
- 1.6 In the 'Description' field, enter the information for the current sample. Note that this exact description will become the suggested filename, so use the following format: HOBO ID#_Launch Date_House ID#
 - The HOBO ID# is the 6-digit number printed on the label on the top face of the logger. The HOBO ID# is the number beneath the logger model (H11-001), such as '815868'.
 - The launch date should be written in the standard format: ddmmyyyy (such as '23092005').
 - The House ID# is a 3-digit master code for the household (the field sampling location), such as '014'
 - a full example of a *Description* is: HOBO815868_23092005_014
- 1.7 In the '*Interval (Duration)*' drop-down menu, select '*1 Minute*'.
- 1.8 Select '*Enable/disable channels*'. Check the boxes next to 'Channel 1 (0-125 ppm)' and 'Channel 2 (0-500 ppm).' Select '*Apply*.'
- 1.9 Select the box labeled '*Delayed Start*'. In the boxes on the right, insert the sampling date and the time that the monitor should begin logging (choose a time close to, but slightly

before, the logger will be placed in the field location). Be sure to choose '00' seconds in the start time (this will make the later data analysis much easier).

- 1.10 DO NOT select the box to '**Wrap**' the data (leave this box unselected)
- 1.11 Before going on, record the sample information (logger ID#, start date/time, house ID, etc.) on the Sampling Data Form (HOBO CO Sampling Data Form).
- 1.12 Select '**Start**'
- 1.13 Select '**Continue**' from screen with enable channel reminder
- 1.14 Click '**OK**' for old data to be erased from the logger
- 2.15 Detach the cable from the logger and then press '**OK.**' Note that the logger will now begin to log CO levels at the programmed time.
- 1.16 Check that the logger is switched 'ON' by looking at the LED light on the front face of the unit for several seconds. When the logger is switched 'ON,' the light will flash faintly every two seconds. When off, the logger LED will not flash. Note that the light is faint, so you may need to cup your hands around the light to be able to see it.
- 1.17 Place the logger on the wall of the sampling location according the placement protocol (see "**Installing Indoor Air Pollution Instruments in a Home**").
- 1.18 At the end of the sampling period, retrieve the HOBO CO logger from the field location. Check that the logger is still ON (logging data) by looking for the blinking LED light on the front face of the logger. If not, make a note on the bottom of the Sampling Data Form (HOBO CO Sampling Data Form).

2.0 Downloading Data

- 2.1 Connect the 9-pin plug of the cable (CABLE-PC-3.5) to the COM 1 serial port on the computer. If the computer does not have a COM port, connect the 9-pin plug to a USB serial adapter, and then connect the other end of the adapter to the computer's USB port.
- 2.2 Open **BoxCar Pro** software (double click on the icon on the desktop)
- 2.3 Connect the 'stereo' plug end of the serial cable to the logger
- 3.4 Select '**Logger**' from the top menu of the **BoxCar Pro** software. When the drop-down menu appears, select '**Readout.**'
- 2.5 A window will appear displaying '**Connecting**' and then '**HOBO found**'. Another window will then appear saying '**Offload.**' Wait for the data to download onto the computer.
- 2.6 Unplug the logger at the prompt and select '**OK**'.
- 2.7 A window will appear displaying '**Save As**'.

2.7.1 At the top, select the data directory on the computer corresponding to new data for the HOBO CO logger (e.g. create and select the data directory called '**New Data - HOBO CO**')

2.7.2 Check that the filename has the following format (as was entered in the *Description* field upon launching): 'HOBO ID #_Launch Date_House ID#'

2.7.3 Select '**Save**'

2.8 The **BoxCar Pro** software will then display a graph of the downloaded data.

2.8.1 Check the sample period on the graph (make sure the final time is correct)

2.8.2 Check that the data does not 'Flat-line' across the graph. If the data does flat-line (e.g. display one constant value), check the cable connection inside the logger to ensure that all 3 soldered connections are intact. If one of these connectors is not intact, the solder needs to be replaced.

**Note that the data may still be retrieved from the logger once the soldered connection has been repaired - follow the steps above (beginning with 3.1)*

2.8.3 Check that the data does not appear abnormal in any other way.

2.9 Check the "Yes" box on the HOBO CO Sampling Data Form asking "Does the graph look ok?"

3.0 Calculation of Average CO Concentrations

3.1 While viewing the downloaded data in **BoxCar Pro** software, select **File/Export/Microsoft Excel Spreadsheet** from the top menu. Select the boxes to "**Include Serial Number in Data Export**" and "**All Series**". Then click the "**Export**" button. Check that the file name is correct and is the same as the *.dtf file (the raw, downloaded data file) that was created earlier. Check that the directory is also the same as the directory used to store the raw data file – '**New Data - HOBO CO**'. Then click "**Save**".

3.2 Open Microsoft Excel and open the Excel file that was just created. Using the monitoring start time/date and the monitoring end time/date, as recorded on the HOBO CO Sampling Data Form, create an Excel formula to average all of the CO ppm values between the monitoring start and end times. If none of the CO ppm values were greater than 150 ppm, average only the data from Channel 1. If any CO values were greater than 150 ppm, create another formula to average the CO ppm values from Channel 2. Enter the average CO ppm value(s) and the maximum value into an Indoor Air Pollution Results Database (another Excel spreadsheet).

4.0 Backing Up of Data Files

- 4.1 At the end of each week of logger usage, the new data files should be saved on a CD-ROM; give the CD-ROM a specific ID#.
- 4.2 Once the new data files have been saved on a CD-ROM, create a new directory on the computer called '**Backed Up Data - HOBO CO**'. Move the backed up data files into this directory. Continue the process of saving new HOBO CO data files in the '**New Data - HOBO CO**' directory, then copying them onto a CD-ROM after each week of sampling, and then transferring them to the '**Backup Up Data - HOBO CO**' directory.

Annex 3. Standard Operating Procedure for UCB Particle Monitor (Collection, Downloading, and Storage of Data)

1. Launching the UCB Particle Monitor

* Important Notes

The sampling interval and sampling setup must be programmed on a computer using the software prior to taking the UCB Particle Monitor (UCB PM) to the field.

If using the COM serial port, close other applications/tasks that require the COM port. For example, make sure hyperterminal is closed.

- 1.1 Connect the serial cable to the 9-pin COM port of your computer. If the computer does not have a COM port, connect a USB serial adapter to the USB port of the computer.
- 1.2 Open the *UCB Monitor Manager* software. A *UCB Particle Monitor Device Manager* wizard interface will open.
- 1.3 Make sure the UCB particle monitor contains a 9-volt battery and that the battery door is closed.
- 1.4 Connect the other end of the serial cable (or USB serial adapter) to the UCB particle monitor.
- 1.5 Click on “*Show Log*” and then select “*Next*”. If there is a problem, first check the battery. If it is not above 7.5 volts in cold areas or 7.0 volts in temperate areas, replace the battery. The green LED (blinking light) becomes red when the monitor’s battery voltage is equal to or less than 7.5 volts.

If the battery is okay, close *UCB Monitor Manager* and try again. If this doesn’t work, reboot the computer and try again.

If this doesn’t work, launch the UCB using the PPPSD command in hyperterminal – refer to the hyperterminal instruction sheet.

Additional troubleshooting tips are in Section 11.

- 1.6 If you notice a problem with data collection using the minimum voltage cut-off of 7.0, increase the minimum voltage to 7.5 volts.
- 1.7 Check that the firmware version number in the lower left panel of the window shows “57d” (5.7d) or higher (5.7e, 5.7f, etc.).
- 1.8 Check that the UCB ID # appears in the lower left panel.

- 1.9 Check that the temperature sensor readings display reasonable values. Also check that the photoelectric sensor signal is updating every second (the values will vary slightly). If not, click exit and repeat from step 2.3.
 - 1.10 Select “*Configure This Device*”. If you are sure you have downloaded the previously logged sample collected with the UCB PM, it is ok to delete the data on the device. You can confirm this by referring to the UCB PM Sampling Data Forms.
 - 1.11 Select “*Next*”
 - 1.12 A configuration screen should then open.
 - 1.13 Synchronize the UCB Particle Monitor clock with the computer clock by selecting “*Synchronize*”; select *Ok* when complete – THIS IS VERY IMPORTANT. Make sure the watch to be used in the field is also synchronized to the computer.
 - 1.14 Select the date and time that the UCB monitor is to start. Normally, this is done by clicking on “*Now +1 Minute*”.
- Enter the total number of hours over which you wish to record data in the next window. For a 24-hour household monitoring period, select at least 30 hours to allow for the initial and final calibration periods, as well as delays and transportation to and from the field. Overestimating the total sampling time is the safest approach (and it does not cause any problems).
- 1.15 Set the *Logging Interval* to 1 minute (one value will be recorded every minute).
 - 1.16 Set the *Sample Interval* to 1 second (the monitor will measure the particle concentration every second and log (record) the average concentration every minute, as in 2.15 above).
 - 1.17 Set the *Filter Depth* to 2 (For your reference, filters reduce the amount of noise in a signal; a value of zero (0) means no filter, the maximum is a value of 4).
 - 1.18 Select “*Launch Program.*” In the launch confirm dialog box, check that the settings are correct.
 - 1.19 Record the launch information on the Sampling Data Form (UCB Sampling Data Form).
2. Zeroing the Monitor with a Zip lock Bag (Pre- and Post-Sampling Periods, 40 minutes)
 - 2.1 Locate a clean environment for the zeroing (calibration) periods (for example, the office or a clean area of a lab). If these locations are not available, conduct the calibration period in the study households. Do not attempt to zero the device in the presence of large amounts of pollution, smoke, or dust in the air.

- 2.2 Place the launched UCB particle monitor in a 1-liter Zip lock bag (or, if available, a particle-free bag). Make sure the bag does not have any holes. Seal the Zip lock bag. Place the bagged monitor in a location where it will not be moved or disturbed in any way.
- 2.3 Record the pre-sampling calibration start time on the UCB PM Sampling Data Form.
- 3.4 After a period of at least 40 minutes, remove the UCB PM from the Zip lock bag and note the time on the UCB PM Sampling Data Form; this completes the pre-sampling calibration period.
- 2.4 Transport the monitor to the sampling location in the Zip lock bag.
- 2.5 Remove the monitor from the bag and place it on the wall of the sampling location according to the placement protocol to begin the sampling period (see “*Installing Indoor Air Pollution Instruments in a Home*”). Record the sampling start time on the UCB PM Sampling Data Form.
- 2.5 After the sampling period in the study household is complete, remove the UCB PM from the wall and record this sampling end time on the sampling form.
- 2.6 Immediately place the monitor in a Zip lock bag to begin the post-sampling calibration (zeroing) period. Leave the monitor in the bag for at least 40 minutes. While in the bag, the UCB PM should not be moved or disturbed in any way. It is best if the temperatures during steps 3.2 and 3.6 are as similar as possible. Record the post-sampling calibration start and end times on sampling form.

* Note that it is essential to record the pre- and post-sampling calibration (zeroing) times, along with the actual sampling times in the field location, on the UCB PM Sampling Data Form, as these times are needed for data processing.

3. Downloading Data

- 3.1 Connect the serial cable to the computer. If the computer does not have a COM port, connect a USB serial adapter to the computer’s USB port.
- 3.2 If using the COM serial port, close other applications/tasks that require the COM port. For example, make sure the hyperterminal is closed.
- 3.3 Open the *UCB Monitor Manager* software. A *UCB Particle Monitor Device Manager* wizard interface will open.
- 3.4 Connect serial cable (or USB serial adapter) to UCB particle monitor
- 3.5 Select “*Next*”
- 3.6 Select “*Offload Data from This Device*”

- 3.7 A progress window will appear showing the progress of the download.
- 3.8 A graphical display of the data will appear in the window. Ensure that the box for leaving data on the device is selected. Select “*Save As.*” Append the three digit household ID # (for example, _001) onto the suggested *filename*. Select the proper data directory (for example, *New Data - UCB PM*) and select “*Save*”.
- 3.9 Select “*Next*”. A window will appear confirming the data has been saved, the filename under which it has been saved, and the settings for the measurement period. The data can be viewed by selecting “*Open in Data Browser*”. If this screen does not appear, repeat the download.
- 3.10 Check on the graph that:
- the period of measurement begins and ends at the correct times according to your sampling data form;
 - the graph appears ok (e.g., it should not be a straight horizontal line);
 - neither sensor (photoelectric and temperature) reports unreasonably high or low values (some UCBs also have a humidity sensor that should be checked);
 - the data do not appear abnormal in other ways (e.g. there should not be a block of many vertical spikes).

If any of the above problems occur, it may be due to a low-voltage battery (lower than 7.5 volts) or a circuit board that is not properly snapped into the UCB PM base. If the problem persists, put aside this monitor and use a back-up monitor. Inform your field contact of the problematic monitor.

- 3.11 If the graph appears ok, check the “Yes” box on the UCB PM Sampling Data Form labeled “Graph ok?”

4. Data File Processing

- 4.1 Open the *.ucbpm file (the UCB Particle Monitor data file) of interest in the *UCB Data Browser* software.
- 4.2 The *UCB Data Browser* will display a graph of the data downloaded (the y-axis will be in millivolts, mV).
- 4.3 Input the start and end times for the pre-sampling calibration period in the boxes at the top of the screen. These values should be recorded on the UCB PM Sampling Data Form.
- 4.4 Enter the start and end times for the sampling period in the household (this does not include transportation or calibration periods). These times are also shown on the UCB PM Sampling Data Form. The graph will then display the particle concentrations in mg/m^3 .

5. Exporting Data as a Text File

5.1 Select “*File*” and “*Export to CSV*”. This will save the data file as a text file readable by other programs, such as Excel and other statistical programs (CSV = comma separated variables).

6. Saving Statistics as a Text File

6.1 The *UCB Data Browser* will display the particle concentration statistics for the chosen sampling period on the right hand side of the display. Click on the “*Save Stats*” button to save these statistics in a text file. Whenever a different sampling period is entered (e.g. for successive 24 hour periods), the statistics will be recalculated; clicking the “*Save Stats*” button again will save these newly-calculated statistics in a new text file.

6.2 Enter the mean particle concentration and the maximum particle concentration (in mg/m³) in the IAP Results Database (a separate Excel spreadsheet). These values are shown in the statistics display of the *UCB Data Browser* and are saved in the statistics text file, as described in 7.1 above.

7. Backing Up of Data Files

7.1 At the end of each week of field measurements, the new UCB Particle Monitor data files being stored on the computer should be backed up (copied onto another storage medium). Each sample for each monitor will produce three files, the ucgbpm file (approximately 26 Kb), its corresponding comma-separated variable (csv) file (approximately 40 Kb), and the stats file. Back up the files on a labeled CD, a USB flash drive, or a floppy disk. Information on the label must include: 1) sampling dates, 2) household (HH) ID numbers, and 3) your initials. Additionally, if you have email access, you may want to email your UCB PM Data files to a designated person as a second method of data backup.

7.2 Once the new UCB data files have been backed-up, they should be moved from the ‘*New Data - UCB PM*’ directory to the ‘*Backed Up Data - UCB PM*’ directory on the computer.

8. Instrument Storage

When not in use, all UCB Particle Monitors should be stored in sealed Zip lock bags. Ideally, the bagged instruments should be placed in boxes and stored in a safe location, such as a shelf or secure cabinet. Storing instruments in this fashion will help prevent dust from accumulating inside the instrument and, of course, prevent the instruments from being bumped or dropped.

9. Troubleshooting

9.1 The LED (blinking light) indicates:

When detached from the computer and the UCB Monitor Manager:

- Blinking green 1 per second: logging data, battery okay.
- Blinking red 1 per second: logging data, battery low (less than 7.5 volts)

Not blinking, either:

- UCB PM is not within the time period for logging (before or after) –or–
- UCB PM battery is dead (less than 5 volts)

When attached to the computer and activated by the UCB Monitor Manager:

- Green: battery voltage is greater than 7.5 volts
- Red: battery voltage is equal to or less than 7.5 volts. The LED does not indicate any other information, such as date/time device errors, signal out of range, etc.

9.2 Steps 9.2 to 9.5 describe what to do if you receive error messages when connecting the UCB PM to the UCB Monitor Manager software. If you get a message “Device Error,” the first step is to check the battery voltage. If the voltage is less than 7.5 volts (cold climate) or 7.0 volts (temperate climate), change the battery.

9.3 If the problem persists, close out of the UCB Monitor Manager software, re-open the software, and try again.

9.4 If the problem persists, close out of the UCB Monitor Manager software, reboot the computer, and try again.

9.5 If the problem continues, switch to using hyperterminal to download and launch the UCB Particle Monitor. If you’re not familiar with hyperterminal, you can download instructions from the CEIHD website.

Annex 4: Standard Operating Procedure: Installing IAP Instruments in a Home

A. Introduction

Installing indoor air pollution (IAP) instruments in a standardized manner is rather challenging. A variety of factors (including irregularly shaped rooms, different building materials, varying stove types and locations, concerns about household safety, and so forth) make it difficult to standardize the placement of IAP instruments. However, it is **critical** to use standard installation guidelines throughout an IAP sampling project. Following standard procedures allows for the comparison of measurements within and between households and for the presentation of results in a scientifically credible manner. Particularly important is standardizing the height of the IAP samplers, because air pollutants are extremely vertically stratified inside a household (concentrations increase greatly with increasing height in a room).

Sections B & C provide specific IAP instrument installation guidelines for indoor microenvironments like kitchens and bedrooms. We strongly recommend installing the instruments on a wall of the room of interest. It is relatively easy to hang instruments on the wall and much easier to standardize instrument location as compared to other locations, such as hanging the instruments from the center of the room. Placing instruments on the wall is also usually a very safe choice that minimizes the chance that household members will change their typical behaviors or bump the instruments (resulting in personal injury or damage to the equipment) in the often dimly-lit households; such is not the case when instruments are hung in the center of the room. One could consider reducing the possibility of injury by hanging the instruments near the ceiling of the room, but this area is not representative of the breathing zones of the household members, nor is it very safe or convenient for those who have to install the equipment.

One disadvantage of installing instruments on the wall is that IAP concentrations are somewhat lower near the walls than they are in the middle of the room. Based on our IAP monitoring in Guatemala, we find that the differences in IAP concentrations between the walls and the center of the room are not too great.

The guidelines presented here refer to indoor environments only. Of course, outdoor and person monitoring are also very important. Monitoring guidelines on these important microenvironments are forthcoming.

B. General Placement Guidelines

- 1.0 Place the IAP instruments approximately **100 cm from the edge of the combustion zone** of the main cooking stove. This distance should be measured as the shortest, horizontal line possible (i.e. parallel to the floor, from the closest edge of the combustion zone to the wall underneath where the monitor is to be placed.). See Figure 1 in the Appendix.
- 1.1 Record the actual distance on the Sampling Data Form.
- 1.2 Placing the instruments *too close* to the fire could be damaging, because they generally cannot tolerate extreme temperatures.
- 1.3 This distance away from the stove approximates the edge of the active cooking area.
- 2.0 Place the IAP instruments at a height of **140 cm above the floor**.
- 2.1 Record the actual distance on the Sampling Data Form.
- 2.2 This height relates to the approximate breathing height of a standing woman.
- 2.3 The floor is defined as the predominant lowest point of the kitchen (e.g. *do not* measure from the top of a stove surface).
- 2.4 A standard height for monitor placement is necessary due to the vertical stratification of indoor air pollutants.
- 3.0 Place the IAP instruments **at least 150 cm away (horizontally) from openable doors and windows**, where possible.
- 3.1 If this is not possible, the distance from the openings should be recorded on the Sampling Data Form (otherwise no notation is required).
- 4.0 In each indoor microenvironment, co-locate all of the IAP instruments (e.g. place them next to each other), leaving a few centimeters of space between them to ensure that their inlets are not blocked.
- 5.0 All instruments must be placed in a relatively safe location to minimize the risk of interrupting household activities or being disturbed or damaged.
- 6.0 Make a detailed sketch of the kitchen showing the positions of the IAP instruments, the stove/fire, and the main door(s) and windows. This is particularly important if the IAP sampling is to be repeated at a later date in the same location (for example, as part of a “before and after” study).

- 7.0 The sketch should contain sufficient detail to be able to detect a change in position of the cooking location (stove) within the kitchen during the intervening period.
- 7.1 In a “before and after” study, if the stove position in the room has not moved, the instruments should be placed in the same location as before, (i.e. a new choice of location should not be made even if the old position seems incorrect).
- 7.2 In a “before and after” study, if the stove position has changed within the room or other major changes have occurred (entirely new kitchen, for example), the original criteria should be applied to choose a new position for the instruments and appropriate notation be made on the Sampling Data Form.

*** Note - it may be difficult to simultaneously satisfy guidelines 1, 2, and 3. If this is the case, simply choose the best possible location.**

C. Specific Instrument Guidelines

- 1. CO Dosimeter Tubes
 - 1.1 CO diffusion tubes should be placed so that the open end of the tube faces the combustion source.
 - 1.2 Measurements should be made to the open end of the CO tube.
- 2. HOBO CO Logger
 - 2.1 Measure distances to the center/middle of the logger.
- 3. UCB Particle Monitor
 - 3.1 Measure distances to the center/middle of the monitor.
 - 3.2 Consider using a piece of tape to cover up the blinking light to minimize disturbance to household members. Make sure that the tape can be removed so that the field staff can easily check the monitor to make sure it is working properly.
 - 3.3 If a support plate has been placed on the wall, place the monitor in the support plate.

Annex 5. Controlled Cooking Test Data and Calculation Form for Biomass Injera Stove

Stove type: ----- Test No: -----
Cook: ----- Bucket No: ----- Date: ----- AM/PM
Stove condition: -----
Mitad Diameter: ----- Mitad thickness: -----
Batter temperature: ----- Amount of water: -----
Ambient temperature: -----

INITIAL MEASUREMENTS

Empty Injera bucket wt: ----- + 16kg (of batter) = Filled bucket weight: -----
Sefied weight: ----- Empty charcoal tub weight: -----
Fuel weights: ----- + ----- = -----
Fuel moisture: -----
Time fire lit: -----
Time first batter poured: -----

FINAL MEASUREMENTS

Time last injera removed: -----
Bucket + unused batter weight: -----
Unburned fuel remaining: ----- Charcoal + Tub weight: -----
Injera weight + sefied weight = ----- Number of Injera: -----

CALCULATIONS

Total fuel consumed: -----
Cooking time: -----
Fuel per Injera: -----
Time per Injera: -----
Used batter weight: -----
Fuel per kg injera: -----
Fuel per kg batter: -----
Evaporated water: -----
Charcoal weight: -----

Annex 6: UCB Particle Monitor Sampling Data Form

Household ID on Master Sheet	
Region	
Municipality	
Community	
House Address/Description	

Pre-Sampling Bag Calibration Period (at least 40 minutes)

UCB ID	Location (Office or other, specify)	Date (dd/Mon/yyyy)	Calibration Start Time, in bag (hh:mm)	Time of leaving for the field (hh:mm)

* Household Sampling Period *

UCB ID	HH ID	Date placed on Wall (dd/Mon/yy)	Time placed on Wall (hh: mm)	Monitor Height (cm)	Monitor Distance from Stove (cm)	Monitor Distance from _____ (cm)	Date removed from Wall (dd/Mon/yy)	Time removed from Wall (hh:mm)	UCB ID	HH ID

Post-Sampling Calibration Period (at least 40 minutes)

UCB ID	Location (Office or other, specify)	Date (dd/Mon/yyyy)	Calibration Start Time (hh:mm)	Calibration End Time (hh:mm)

Downloaded?	ucbpm File Name	Graph OK?	Initials
<input type="checkbox"/> Yes <input type="checkbox"/> No	RAWDATA (P3z00__ __) __-__-__-__-__ to __-__-__-__-__-__ # # # mm dd yy hh mm mm dd yy hh mm # # #	<input type="checkbox"/> Yes <input type="checkbox"/> No	

Note: Describe any disturbances to the UCB Particle Monitor in the household:

Note: Describe any errors that occurred while you were launching or downloading the UCB Particle Monitor data (note lowest value (mg/m³):

Annex 7: HOBO CO Sampling Data Form

HOBO CO Household Sampling Period										
HOBO ID	HH ID	Date placed on Wall (dd/Mon/yyyy)	Time placed on Wall (hh: mm)	Monitor Height (cm)	Monitor Distance from Stove (cm)	Monitor Distance from _____ (cm)	Date removed from Wall (dd/Mon/yyyy)	Time removed from Wall (hh:mm)	HOBO ID	HH ID
----									----	
----									----	

HOBO CO logger	Downloaded data/file information	Initials of data manager
Are there values of CO above 125ppm	[] Yes [] No	
Does the graph look ok?	[] Yes [] No	
File name on desktop/laptop computer	H_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ # # # # # dd Mon yyyy # # #	
ID/name of back-up CD-ROM		

CO Dosimeter Tube Sampling Data Form

CO Tube Sampling Period										
CO TUBE ID	HH ID	Date placed on Wall (dd/Mon/yyyy)	Time placed on Wall (hh: mm)	Tube Height (cm)	Tube Distance from Stove (cm)	Tube Distance from _____ (cm)	Date removed from Wall (dd/Mon/yyyy)	Time removed from Wall (hh:mm)	CO TUBE ID	HH ID

Length of brown stain in field, #1 (mm)	Initials of reader #1	Length of brown stain in field, #2 (mm)	Initials of reader #2	Supervisor's initials	Comments

Note: Describe any disturbances to the HOBO monitor or CO tube in the household:

Note: Describe any errors that occurred while you were launching or downloading the HOBO data:

Annex 8: Stove Efficiency Evaluation Protocol

SHELL FOUNDATION HEH PROJECT CONTROLLED COOKING TEST DATA AND CALCULATION FORM

Shaded cells require user input; unshaded cells automatically display outputs

Qualitative data

Name(s) of Tester(s)

Test Number

Date

Type of stove: Stove 1

Type of stove: Stove 2

Location

Wood
species

Eucalyptus Globulus (Southern Blue Gum, Fever Tree)



Quantitative testing conditions

Avg dimensions of wood (length x
width x height)

data

units

cm

variable

--

Empty weight of Pot # 1

data

units

g

variable

P1

Wood moisture content (% - wet basis)

Fuel Moisture Sheet

%

m

Empty weight of Pot # 2

g

P2

Local boiling point of water

(default value is 100 °C - correct if
local value differs)

°C

T_b

Empty weight of Pot # 3

g

P3

Empty weight of Pot # 4

g

P4

Weight of container for
char

g

Other comments on test conditions

Use this worksheet if you are determining fuel moisture with the Delmhorst J-2000 or similar handheld moisture meter. If you are using another means to determine fuel moisture, enter the calculated moisture in the proper "Average moisture content" space on this data form.

To find fuel moisture, take 3 pieces of fuel at random from the stock used for each test and measure each in three places along its length. Enter the results in the spaces below. The worksheet will automatically calculate average moisture content on a dry and wet basis.

Test-1 Instrument reading (% dry basis)

	1	2	3
Piece 1			
Piece 2			
Piece 3			

Average moisture content (%)

dry-basis wet-basis

Test-2 Instrument reading (% dry basis)

	1	2	3
Piece 1			
Piece 2			
Piece 3			

Average moisture content (%)

dry-basis wet-basis

Test-3 Instrument reading (% dry basis)

	1	2	3
Piece 2			
Piece 3			
Piece 3			
dry-basis			

Average moisture content (%)

dry-basis wet-basis

Test-1 Instrument reading (% dry basis)

	1	2	3
Piece 1			
Piece 2			
Piece 3			

Average moisture content (%)

dry-basis wet-basis

Test-2 Instrument reading (% dry basis)

	1	2	3
Piece 1			
Piece 2			
Piece 3			

Average moisture content (%)

dry-basis wet-basis

Test-3 Instrument reading (% dry basis)

	1	2	3
Piece 2			
Piece 3			
Piece 3			
dry-basis			

Average moisture content (%)

dry-basis wet-basis

The Standardized Cooking Task

Use this space to describe the standardized cooking process that forms the basis of this test. Describe each step with enough detail so that an experienced cook from the area where the test is performed could follow them easily. If more space is needed, extend the description below the space provided.

Ingredient

Name

Amount (g)

Step

Directions

1			1	
2				
3			2	
4				
5			3	
6				
7			4	
8				
9			5	
10				
11			6	
12				
13			7	
14				
15			8	
16				
17			9	
18				
19			10	
20				

CT-1 for the

Wind conditions
 Air temperature °C

Shaded cells require user input; unshaded cells automatically display outputs

To be filled in after cooking task is complete (as defined by the directions on the "Description" worksheet)

<u>MEASUREMENTS</u>	<u>Units</u>	<u>Initial measurements</u>		<u>Final measurements</u>		<u>Comments about cooking process (smokiness, ease of use, etc)</u>
		<u>data</u>	<u>label</u>	<u>data</u>	<u>label</u>	
Weight of wood used for cooking	g		f_i		f_f	
Weight of charcoal+container	g				c_c	
Weight of Pot # 1 with cooked food	g				$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Weight of Pot # 4 with cooked food	g				$P4_f$	
Time	min		t_i		t_f	

<u>CALCULATIONS</u>	<u>Units</u>	<u>Formula</u>	<u>CALCULATIONS</u>	<u>Units</u>	<u>Formula</u>
Total weight of food cooked	g	$W_f = \sum_{j=1}^4 (Pj_f - Pj)$	Specific fuel consumption	g/kg	$SC = \frac{f_d}{W_f} * 1000$
Weight of char remaining	g	$c_c = k - c_c$	Total cooking time	min	$t = t_f - t_i$
Equivalent dry wood consumed	g	$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$			

Description of stove (indicate the construction material of the stove, the way that the pot(s) fits in the stove, and the presence of insulation, chimney, workspace, etc):

Results of CCT comparing two stoves

Stove type/model: Stove 1 _____
 Stove type/model: Stove 2 _____
 Location _____
 Wood species _____

Summary of comments on stove 1

1. CCT results: Stove 1	units	Test 1	Test 2	Test 3	Mean	St Dev
Total weight of food cooked	g					
Weight of char remaining	g					
Equivalent dry wood consumed	g					
Specific fuel consumption	g/kg					
Total cooking time	min					

Summary of comments on stove 2

2. CCT results: Stove 2	units	Test 1	Test 2	Test 3	Mean	St Dev
Total weight of food cooked	g					
Weight of char remaining	g					
Equivalent dry wood consumed	g					
Specific fuel consumption	g/kg					
Total cooking time	min					

Comparison of Stove 1 and Stove 2		T-test	Sig @ 95% ?
Specific fuel consumption	g/kg		
Total cooking time	min		