EVALUATING THE EFFICIENCY OF IMPROVED LOCAL LIQUOR (AREKE) DISTILLING STOVE BY MEASURING THE INDOOR AIR EMISSION

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<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>CCT</td>
<td>Controlled Cooking Test</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon Monoxide</td>
</tr>
<tr>
<td>CO\textsubscript{2}</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>COPD</td>
<td>Chronic Obstructive Pulmonary Diseases</td>
</tr>
<tr>
<td>DALYs</td>
<td>Disability-adjusted Life Years</td>
</tr>
<tr>
<td>EESRC</td>
<td>Ethiopian Energy Studies and Research Center</td>
</tr>
<tr>
<td>EJ</td>
<td>Exajoules</td>
</tr>
<tr>
<td>GTZ</td>
<td>Deutsche Gesellschaft für Technische Zusammenarbeit</td>
</tr>
<tr>
<td>IAP</td>
<td>Indoor Air Pollution</td>
</tr>
<tr>
<td>IEA</td>
<td>International Energy Agency</td>
</tr>
<tr>
<td>KJ</td>
<td>Kilojoules</td>
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<tr>
<td>KPT</td>
<td>Kitchen Performance Test</td>
</tr>
<tr>
<td>MGP</td>
<td>Megen power Ltd. (private consultant company)</td>
</tr>
<tr>
<td>N\textsubscript{2}O</td>
<td>Nitrous Oxide</td>
</tr>
<tr>
<td>PE</td>
<td>Photoelectric</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate Matter</td>
</tr>
<tr>
<td>toe</td>
<td>tones oil equivalent</td>
</tr>
<tr>
<td>TSP</td>
<td>Total Suspended Particulates</td>
</tr>
<tr>
<td>UCB</td>
<td>University of California, Berkley</td>
</tr>
<tr>
<td>UNDP</td>
<td>United Nations Development Program</td>
</tr>
<tr>
<td>VITA</td>
<td>Volunteers in Technology Assessment</td>
</tr>
<tr>
<td>WBT</td>
<td>Water Boiling Test</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organization of the United Nations</td>
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</table>
Abstract

One-third of the world’s population uses traditional biomass for cooking, lighting and space heating. The use of these forms of energy is associated with environmental as well as human health impacts. Approximately 2500 million people are exposed daily to emissions from biomass-burning cooking sites. Respiratory disease, one of the major causes of death in developing countries, is linked to these emissions. Like in other developing countries the energy sector of Ethiopia is dominated by biomass fuels. This condition does not seem to change appreciably in the foreseeable future and the problems aggravated by the growing demand of energy of the economic sector. Areke distillation is one of the economic activities that has become a major source of income for many households in various parts of Ethiopia. As Areke distillation entirely depends on fuelwood for its preparation and processing, its large scale production for commercial purpose places huge pressure on the forest resources of the country. In an effort to address the problems supply side as well as demand side interventions have been made. Recently, recognizing the impacts of Areke distillation on the forest resource and human health, the GTZ-SUN project has introduced an improved stove technology for Areke distillation. This study aims at assessing the potential benefits of these stoves with respect to improving the indoor air quality and reducing specific fuel consumption as well as time taken for distillation. The study was conducted in Arsi Negelle town, Oromiya regional state, where Areke distillation is the major source of livelihood for a large number of households. The indoor concentrations of two major pollutants, CO and PM were monitored using HOBO CO loggers and UCB PM monitors, respectively. The tests were conducted in a real kitchen as the stoves perform the actual Areke distillation but under controlled setting in which every effort possible is made to minimize sources of variability to ensure the stoves are used to their best effect. T-tests and regression models were employed to analyze the data. The room concentrations of CO and PM resulting from the use of traditional stoves and improved stoves were compared in terms of the average concentrations during the whole distillation time and the 8-hours time and the 15-minutes highest concentrations were also considered. The improved stoves have shown statistically significant reduction in CO concentrations of 52.6% and 53.2% (n = 9) during the whole distillation time and the 8-hours time, respectively and the corresponding reduction in PM concentrations were 57% and 63.3%. The improved stoves have shown reduction in the 15- minutes highest concentrations of CO and PM of 58.8% and 56.9% (n = 9), respectively. The analysis of the data obtained in this study indicated that the correlation between CO and PM were positive but weak with Pearson correlation of 0.32 (p=0.39; n=9) and 0.35 (p=0.35; n=9) in the traditional stoves and improved stoves conditions, respectively. Controlled Cooking Test procedures were also used to assess the potential of the improved stoves to reduce specific fuel consumption and the time taken for distillation. The improved stoves have shown percentage reduction in specific fuel consumption of 4.4% and 22% reduction of time taken for distillation. The reduction in the specific fuel consumption was not statistically significant.

Key words: Areke, CO, Distilland, Efficiency, PM.
1 Introduction

Energy is indispensable for human development that strategies for reducing poverty, achieving an improved standard of living and civilization in general cannot be realized without considerable increase in energy consumption. Nevertheless the production, conversion and utilization of energy always generate undesirable byproduct and emission. An increase in human population, rising income and change of lifestyle, nowadays, has caused an overall increase in energy use in the world. About one-half of the world’s households use unprocessed solid fuels (biomass and coal) for cooking ranging roughly from near zero in developed countries to more than 80 percent in developing countries (Holdern et al., 2000) and space heating in simple devices that release large amount of pollutants in the air. The world’s poor are dependent on their local environment for energy as well as for the rest of their needs and where there is unsustainable exploitation of natural resources, as has been observed in developing countries, there happens environmental degradation followed by a number of socio-economic problems.

In Ethiopia biomass fuels are the main sources of energy for household activities and following the growth in economic sector, these fuels are being significantly used for small to large scale income generating activities. Since the early 1990s remarkable efforts have been made by both governmental and non-governmental organizations to address the overall impacts of utilization of biomass fuels one of which is the introduction of improved cooking stoves. Lakech charcoal stove for non-injera cooking activities Mirt and Gonzye injera stoves are among the widely used improved stoves in the country. These stoves were developed by the Ethiopian Rural Energy Development and Promotion Center (EREDPC) and the promotion of the stoves has been done by the GTZ-SUN Energy project. Recently, recognizing the socio-economic and environmental impacts imposed by the widely practiced Areke distillation all over the country, the GTZ-SUN Energy project has developed an improved Areke distilling stove that is believed to address the environmental as well as human health impacts of utilization of traditional biomass. This study assesses the potential of improved Areke distilling stoves in reducing indoor air pollution which relates to human health.
1.1 **Background**

1.1.1 **Overview**

It is well established that the supply of adequate, reliable and reasonably priced energy is one of the key inputs for sustainable socio-economic development of any region.

Biomass is the primary source of energy for close to 2.4 billion people in developing countries and it is vital and affordable energy for cooking and space heating (IEA, 1998; Smith *et al.*, 2004).

Many of the regions of the developing world depend on traditional biomass to meet their energy demand. The term traditional biomass is used to denote locally collected and often unprocessed biomass-based fuels such as wood, crop residue and animal dung.

In 1985, biomass accounted for about 14.7 percent of the total of 375 EJ (exajoules = $10^{18}$ J) of world’s primary energy use, 2.8 percent of the total of 247 EJ of energy use in developed countries and 38.1 percent of the total of 126 EJ of energy use in developing countries (Figure 1). Most biomass is used inefficiently with a very low (or no) technology conversion and low efficiency devices that are polluting and lead to a large consumption of fuel (David *et al.*, 1997). According to Wood and Baldwin, (1985), in developing countries fuelwood has been used for cooking on low efficiency devices that the energy consumption is several times higher than in developed countries.

![Figure 1. Primary energy use by region](image)

The energy sector in Sub-Saharan Africa is dominated by biomass energy which accounts for about 50 percent of all primary energy and the share is even higher in Ethiopia going as high as 95 percent (UNSD, 2003; GTZ/EREDPC, 2004). As a
consequence of over-dependence on biomass in its traditional form, Sub-Saharan Africa’s annual per capita consumption of modern energy is less than half the average of developing countries, which makes it the lowest in the world (Ogunlade et al., 1993).

1.1.2 The Energy Status and Trends in Ethiopia

Energy plays an important role to the development of a nation and development is possible through an increasingly efficient and extensive harnessing of various form of energy. The per capita energy consumption has become one of the indicators for the economic development of a society (Araya, 2002).

Despite the enormous potential for hydropower(30000 MW), solar(5 – 6KWh/m²), geothermal (700 MW), natural gas (2.7 TCF), wind (3.5 – 5.5 m/s) and other resources, the per capita energy consumption in Ethiopia remains to be one of the least in the world - 0.3 toe (1toe = 4.2 × 10¹⁰ J) (GTZ, 2000). According to Asres, (2002), the annual per capita energy consumption in 1997, 1998, and 1999 amounted to 0.263, 0.268, and 0.279 toe, respectively and the traditional fuel accounts for over 95 percent of the consumption (MGP and EESRC, 2000). Like in other developing nations majority of the population of Ethiopia are living in rural areas and the poor in urban areas lack access to electricity and modern fuels and rely on the direct combustion of biomass for activities that require heat (UNDP, 2001).

The fuelwood consumption varies between rural and urban households that the rural households consume fuelwood equivalent energy of 2.1 kg/day/person and the urban 1.68kg/day/person (MGP, 2000). The reason for the higher consumption in rural areas than in urban areas could be the relatively easier accessibility of fuelwood, the inefficiency and wastefulness of the traditional stoves, and the use of fuelwood for variety of non-cooking activities.

The energy consumption trends in Ethiopia indicate that the overall energy consumption is increasing from time to time and this is attributable to the high population growth and the associated increase in energy demand. Due to the unsustainable utilization of natural resources, there has been an imbalance between the demand for fuelwood and the sustainable supply. The energy demand and supply projection (Figure 2) shows that the demand is growing at a faster rate than the supply (EFAP, 1994).
The imbalance between the sustainable supply and demand of fuelwood and the corresponding scarcity has placed several constraints on household budgets. Where fuel is purchased, in urban slums of developing countries, spending money on large quantity of inefficient fuels places severe constraints on household budgets. Poor households tend to spend a larger percentage of their income on energy than well-off households. According to IEA, (2002), the percentage of Ethiopian household income spent on energy range from 6.4 percent to 10 percent.

1.1.3 Areke Distillation in Arsi Negelle

In Ethiopia, in addition to the already existing burden on natural resource imposed by the use of traditional biomass for cooking, the processing and production of alcoholic beverages such as local liquor( Areke), local beer(Tela), Korefe, Borde, Shameta and others place further threat on the environment and human health. Among the various local alcoholic drinks Areke is well known in both urban and rural areas and the energy needed for its production and processing depends entirely on fuelwood. Areke is produced through the process of distillation from a mixture (distilland) composed of ground Gesho (scientific name Rhamnus Prinoides), water and cereals. The mixture is left to ferment for five to six days before the distillation is underway. The homemade liquors are available at lower prices than the factory made...
ones and owing to this most of the locally made alcohol beverages are consumed by the majority of low income earners and the demand is often high.

Some of the towns such as Arsi Negelle of the Oromiya region, Debremarkos and Debreberhan of the Amahara region are well known for their good quality Areke products where large scale production takes place for local use as well as for the markets in neighboring towns including the capital Addis Ababa.

In Arsi Negelle where the study is conducted, majority of households depend on Areke for their livelihood. Hundreds of plastic containers of various sizes filled with Areke of different quality are brought to the market every day. According to the information we have got from the municipality of Arsi Negelle town, the city administration collects revenue of about 1 million Birr each year from Areke business alone. This amount accounts for the tax collected from those who do the business at the formal market places only.

The Areke industry has also created a remarkable job opportunity to the community of the area as well as for many from other regions. Many households in the town and its surrounding generate income from dairy products. The availability of the byproduct in sufficient amount encouraged many households to own dairy cattle and even the current high price of grain did not stop people from distilling Areke for the high demand of the byproduct that is used to feed their cattle.

Although Areke production helps to generate income for majority of households in the area, the energy needed for its processing and distillation puts tremendous pressure on the environment. Even though the energy consumption of the area is not assessed, the fuelwood that is brought to the market transported by means of donkeys, carts, people and trucks, is a good indicator of the large fuelwood demand in the area. According to the municipality, on the months of July and August, 2008, the city administration has earned 12000 Birr from the tax paid by the trucks owners that bring fuelwood to the market (plate 1). In addition to that transported by donkeys, carts and people, about 8 trucks with a loading capacity of 10 cubic meters each bring fuelwood of different varieties to the market every day and more than 72000 Birr is collected per annum.
1.1.4 Description of the Areke Distilling Stoves

The traditional Areke distilling stove is a round shaped structure made of mud inside of which there are at least three stones to help support the pot. The front part of the stove is open so as to let the fuel in and it is through this opening that the combustion products are released to the indoor. As the bottom of the pot is round shaped it is very close to the fire bed (Plate 2).

The major apparatus needed for the set up of the distillation process include a pot made of clay, a pot lid, a condensation tube and a collecting flask. The condensation tube made of dry bamboo connects the pot and the collecting flask which is placed in water in a cooling tub. The water in the tub cools the flask to maintain low temperature region that facilitates condensation.

On the average 7 to 10 pots are set side by side and the collecting flasks are placed in a single long cylindrical shaped cooling tub filled with water. The large cooling tub makes it possible for the water to be used for a long time before its temperature is high enough to impede the process of condensation. Once the water is hot about
(35°C- 40°C) it is replaced by a colder one and the large cooling tub also gives a chance to reuse the water a number of times.

The same apparatus are employed in the improved stove situation (plate 3). The improved stove makes use of the stove design principles-originally developed by Aprovecho Research Center.

There are separate inlets for the fuel and air. The air inlet directs the air flow through the fuelwood from underneath and provides the proper amount of draft that will help to keep high temperature in the stove. The combustion chamber is made to have sufficient gap between the fire bed and the pot (having chimney above the fire bed). This helps the fire to burn hot and fierce so that the wood undergoes complete combustion process and the amount of health damaging pollutants released to the indoor are significantly reduced. The fuel and air inlets and the combustion chamber are made of refractory bricks. In addition to its capacity to withstand high temperature the structure made of bricks gives the stove strength to carry the load. The skirt is constructed on top of the combustion chamber from where the three pot-rests are placed and it encloses most of the lower part of the pot. The gap between the skirt and the pot is properly sized to enable the hot flue gas scrap against the pot transferring more heat to the pot.

Once the main bodies of the number of stoves are put in place the remaining part of the arrangement is filled with light materials that can be obtained from the surrounding. In order to hold the fill in place a wall like structure is constructed around the entire arrangement using mud bricks. There are steps constructed near the two ends of the arrangement so that the person in charge of the distillation process can easily move from one end to the other specially when there is a need to reset the apparatus during transition from one complete session to the other.

Plate 3. Improved Areke distillation stoves
1.1.5 Impacts of Utilization of Traditional Biomass

The inefficient use of biomass resources in developing countries has been linked to a multitude of adverse environmental and human health impacts. The impacts associated with the household fuel cycles relate to harvesting and combustion (UNDP, 2001).

1.1.5.1 Environmental Impacts

*Depletion of forest resources:* Deforestation has been an old-age activity of humankind (Boahene, 1998). Humans depend on their natural environment to meet their needs and some view deforestation as something natural and beneficial component of economic development and others view it as an implication of ever-worsening resource base that hinders the process of development (Allen and Barnes, 1985).

Fuelwood harvesting has become one of the factors that influence deforestation. In Africa the harvesting of fuelwood and poles by individuals for domestic uses dominate cases of deforestation associated with wood extraction (Geist and Lambin, 2002). Although the link between fuelwood harvesting and deforestation are far from being universal, there are localized cases in which fuelwood demand contributes significantly to forest depletion.

In Ethiopia, the prolonged settlement and clearing of forest for agricultural expansion, construction and fuelwood to meet the growing demand of the fast growing population have disturbed the ecological balance in many parts of the country. This has led to soil erosion, deforestation and land degradation threatening agricultural product and productivity (Getachew, 2002). According to Barbier, (1997), deforestation appears to be the major source of human-induced soil degradation in the developing countries and in Africa it accounts for 14% of erosion.

During the last century, the original forest cover of the country that was once estimated to cover 35 percent of the land has been declining in both size and quality. By the early 1950’s high forest, were reduced to 16 percent of the land and to about 2.7 percent in 1989 (EFAP, 1994). According to World Bank, (1997), an estimated 163,000 ha of forest is deforested annually due to over-cutting for fuelwood, overgrazing and agricultural expansion. The population of intensive fuelwood using countries is increasing at a rate of 2 to 3 percent per annum (Twidell *et al.*, 1986), and
where the demand for fuelwood is not met, people resort to lower quality fuels such as crop residue and cow dung (Joshi et al., 1989; Crewe, 1992; WRI, 1998; WHO, 2002). The use of these fuels for energy deprives the soil of fertilizers further threatening agricultural production (UNCHS, 1990). The worldwide input of burning dung is estimated to reduce grain production by 20 million tons annually due to loss of fertilizing capacity (Myers, 1984). It has been calculated that the dung used as household fuel in Ethiopia has a fertilizer value of over £50 million per annum (Newcombe, 1984).

**Contribution to global warming:** Biomass resources are considered to be one of the key renewable energy resources of the future at both small scale and large scale levels (Johansson et al., 1992) and this happens only when their exploitation and utilization is done on sustainable basis.

The use of biomass resources in an unsustainable manner contributes to the net emission of carbon dioxide and other greenhouse gases to the atmosphere. Cutting of trees in turn reduces the sink for carbon dioxide further enhancing global warming. It has been said that wood is a fuel that heats you twice—once when you chop it and once again when you burn it. It also has the potential to heat you a third time as a result of enhanced greenhouse warming due to the gases released by combustion (Smith, 1994). According to Smith, (2000), as cited in UNDP, (2001), the burning of 1 kilogram of wood (454 grams of carbon) releases 403 grams of CO₂, 3.8 grams of methane carbon (86 grams of CO₂ equivalent), other greenhouse gas carbons such as 37.5 grams of carbon monoxide (131 grams of CO₂ equivalent) and also 0.018 grams of N₂O (69 grams of CO₂ equivalent). It is estimated that biomass contributes to 20 to 50 percent of global greenhouse emission (Crutzen et al., 1990).

### 1.1.5.2 Health Impacts

Apart from its environmental impacts the use of biomass fuel in household stoves has human health impacts. The fuelwood stoves used in many of the developing country’s households are poor performing and lack working chimneys for venting the smoke outdoors and produce high indoor concentration of pollutants (Bruce, Perez-Padilla, and Albalak, 2000). Used in simple stoves, biomass fuels are at the lower end of the energy ladder in terms of combustion efficiency and cleanliness (Smith and Liu, 1994). The pollution of air indoors that results from the use of traditional biomass...
leads to a series and dangerous infections and diseases of respiratory system. Among the common health impacts are: infectious respiratory disease such as Acute Respiratory Infections (ARIs) and tuberculosis, chronic respiratory disease such as chronic bronchitis and lung cancer, adverse pregnancy outcomes such as still birth, blindness and Asthma (Smith et al., 1987; Bruce et al., 2000; UNDP, 2001; Boy et al., 2002). ARI is the leading cause of childhood illness and death worldwide, and its effects on children under age 5 years alone accounted for about 4.5 percent of the entire global burden of disease in 2002 (WHO, 2003). The air pollution caused by the household utilization of solid fuels is responsible for four to five percent of the global burden of disease (UNDP, 2001).

Due to their nearly universal responsibility for most of the household activities, women (Behera, Dash, and Malik, 1988) and their children (Albalak, Frisancho, and Keeler, 1999) on their back or lap while doing cooking are the most affected. Study results indicate that women exposed to indoor smoke are three times more likely to suffer from Chronic Obstructive Pulmonary Disease (COPD) such as chronic bronchitis or emphysema than women who cook with electricity, gas or other cleaner fuels (WHO, 2006).

In addition to the health problems associated with the burning of fuelwood, deteriorating environmental quality places burden on women’s time and labor. In Ethiopia, the collection of fuelwood is done mostly by women and children and where there is scarcity of supply, people are forced to go far from where they live and this takes much of their time which could be used for other pursuit that are associated with health benefits such as child care and other income generating activities and this undermine their quality of life. In Ethiopia the daily fuel collection time ranges from 3 to 4 hours (Dutta, 2005). Beside the negative effects of fuelwood gathering on nutrition, fuelwood gathering exposes women for increased risk of assault and natural hazards.

### 1.1.6 Interventions to Mitigate Indoor Air Pollution and Environmental Degradation

In response to the socio-economic and environmental problems created by the inefficient use of biomass fuels, both supply side and demand side interventions are being considered. The supply side intervention aims at ensuring a systematic and
sustainable supply of fuelwood from existing forest, woodland and also having large plantation of fast-growing species (bioenergy feedstock) on the degraded lands to enhance the fuelwood supply and help the land to rehabilitate. Because of the immaturity of the technology and its high cost, the likelihood of complete transition to alternative energies of higher rung on energy ladder such as solar energy, wind energy, hydropower, and biogas is beyond the reach of the poor communities of the developed nations as well as the majority of the least developed nations like Ethiopia at least in foreseeable future.

In poor rural communities where access to alternative fuels is very limited and biomass remains the most practical fuel, demand side measures need to be taken aiming at enhancing the efficiency of the household fuelwood-burning devices and reducing the fuelwood consumption per unit of energy use.

Introducing improved stoves, provided they are adequately designed, installed and maintained, are believed to give immediate results as compared to plantation which takes a long time until they become effective (FAO, 1986). Interventions to mitigate impacts of household energy on human health and environment have a range of benefits, such as reducing levels of indoor air pollution and human health exposure, increasing fuel efficiency reducing stress on local environment, reducing time spent for collecting fuel, increasing opportunity for income generation, providing employment opportunities for stove producers and improving the quality of the home environment and condition of women.

Other supporting measures can also be suggested to reduce exposure to the health damaging pollutants such as improving ventilation of the working and living area by having chimneys, smoke hood, enlarged kitchen windows, properly maintaining stoves, changes in user behavior such as drying fuelwood before use, separating kitchen from house, and keeping young children away from sources of smoke. As cost is often a significant barrier to successful dissemination of improved stoves, intervention strategies with the objectives of improving end-use technologies should give due attention to the user preferences and affordability of the new technology and enabling policies need to be put in place.

Efforts made to mitigate the impacts of the traditional biomass help to achieve the goals stated in the Millennium Development goals: Reducing child mortality and improve maternal health by reducing burden of disease caused by indoor air pollution; promote gender equality and empower women and achieve universal
primary education through saving the time spent by women for collection of fuel giving them time for education and other income generating activities that also ensures eradicating poverty and extreme hunger; and ensure environmental sustainability through efficient use of biomass resources (UNEP, 2006).

1.1.7 Statement of the Problem

The fast growing population of Ethiopia and the corresponding rise in energy demand and the traditional way of utilization of biomass resources has resulted in a range of negative environmental impacts with both local and global consequences. In most regions of the country, out of the top ten leading causes of hospital and health center morbidity, malaria and Respiratory Tract Infection take the highest share (PHCC, 1996). The wide range of problems imposed by the dependence on traditional biomass fuels calls for immediate and coordinated action to be taken by the stakeholders - governmental and non-governmental organizations and the community at large.

Apart from the usual household energy requiring activities, namely cooking, lighting and space heating, Areke distillation which has become the major livelihood for many households in the country and which is dependent on fuelwood from the processing to production stages, exacerbates the pressure on the already depleted biomass resources. In addition to the remarkable efforts made to improve the efficiency of cooking stoves, the GTZ-SUN project has developed energy saving technology for Areke making. Only by testing the performance of new stoves and comparing them with those of earlier ones can improvements in stove designs be assessed and success of an intervention effort be evaluated.

In this study an attempt is made to assess the potential of using improved Areke distilling stove in reducing indoor air pollution.

1.2 Objectives of the Study

1.2.1 General Objective

To evaluate the performance of the wood-burning improved Areke distilling stove in terms of its potential for reducing environmental as well as human health impacts.
1.2.2 Specific Objective

- Assessing the benefits of using the improved stove in reducing indoor air pollution with specific reference to concentrations of Carbon Monoxide and Suspended Particulate Matter in the working environment.
- To compare the efficiency of improved Areke distilling stove with that of the traditional stove in terms of their specific fuelwood consumption.
2 Literature Review

2.1 The Biomass Burning Process

For solid biomass to be converted into useful heat energy it has to undergo combustion. Although there are many different combustion technologies available, the principle of biomass combustion is essentially the same for each. There are three main stages to the combustion process:

_Drying_ - all biomass contains moisture, and this moisture has to be driven off before combustion process can take place. The heat for drying is supplied by radiation from flames and from the stored heat in the body of the stove or furnace.

_Pyrolysis_ - the dry biomass is heated and when the temperature reaches between 200 °C and 350 °C the volatile gases are released. These gases mix with oxygen and burn producing a yellow flame. This process is self-sustaining as the heat from the burning gases is used to dry the fresh fuel and release further volatile gases. Oxygen has to be provided to sustain this part of the combustion process. When all the volatiles have burnt off, what remains is the charcoal.

_Oxidation_ - at about 800 °C the charcoal oxidizes or burns. Again oxygen is required, both at the fire bed for the oxidation of the carbon and, secondly, above the fire bed where it mixes with carbon monoxide to form carbon dioxide which is given off to the atmosphere.

In the process of combustion, the chemical energy in the fuel is converted into heat and radiation. For complete combustion to take place, sufficient supply of air for complete oxidation, sufficiently high temperature for chemical reaction kinetics, sufficiently long residence time at high temperature (sufficient chemical reaction time) and sufficient mixing of fuel and air are basic requirements.

The heat involved at various stages of the burning process is different and because of this combustion is known to be a discontinuous process. Accordingly it can be classified into three stages. In the first stage (production of the first embers) and the third stage (cooling down phase) of the burning process, due to lower processing heat, considerably more CO is emitted. In the intermediate stage (completely developed burning phase) emission of CO₂ reaches its highest value (Usinger, 1996).
2.2 Emission, Concentration, Exposure and Dose

Terms like emission, concentration, exposure and dose are most frequently used in describing air pollution. Emissions are the air pollution agents released by fuel burning source and emission measurements can be taken directly at the fire place or in the exhaust chimney. The results of emission measurements can be used to examine improvement of the combustion efficiency of the stove.

Concentration of pollutants in the air depends on factors like, emission from the combustion source, the prevalent atmospheric condition such as ventilation or air exchange rate in the room, the distance from the source of emission. The presence of ventilation and increasing distance from the source of pollution remarkably reduces concentration. A stove with a chimney can have high emissions, but as long as they are sent outside and the stove does not leak to the room, room concentrations and the corresponding health-damaging exposures can be kept low. It is enough to measure indoor pollutant concentration in order to assess the exposures to pollutants for health purposes (Tami, 2004). The effect of air pollutants on people, animals and other objects is described by the term exposure. Exposure measurements indicate the concentration of pollutants received in the oral or nasal cavities by the acceptor around the emission source. The extent of the health damaging pollutants is mainly determined not by the amount of pollutants released but by the degree to which people are exposed to emission during activities involving biomass burning. The difference between emission and exposure is that emission is what comes out of stoves and exposure is what people breathe. Emissions can be measured in the lab and are related to exposure if stove is not vented and they affect neighborhood air quality, regional air quality and global air chemistry. Pollution of households happens at the time and place where people are present and the most exposed are women and children (Albalak, 1997; Behera et al., 1988). Exposure must be measured in the field and is related to people’s habits as well as stove characteristics and it affects personal health. Exposure causes immediate problems while the problems associated with emission are often long term.

The amount of pollutants that are actually inhaled by the accepter is termed as a dose. It depends on the extent of exposure of the subject, rate of breathing and the size of particles. Due to the immaturity of their respiratory system and the increased rate of
breathing, for instance, younger children are more affected by indoor air pollution than elderly ones. (Usinger, 1996).

### 2.3 Emission from Household Stoves

The physical form of the fuels used and the contaminant content are the two characteristics that most affect emission of pollutants when burned. With proper stoves and fuel burning practices, fuelwood as well as other biomass can be burned cleanly, producing mostly carbon dioxide and water. However such a condition is difficult to achieve where low efficiency stoves are used.

One of the conditions that are required to facilitate a clean (complete) combustion of fuel is the mixing of fuel with sufficient air. It is generally difficult to premix solid fuels sufficiently with air to have complete combustion of the fuel in household stoves. When completely burned, wood and other biomass fuels would produce little other than non toxic products, carbon dioxide and water. But according to what has been practiced, sometimes as much as one-fifth of the fuel carbon is diverted to products of incomplete combustion. Typical biomass cook stoves convert 6 – 20 percent of fuel carbon to toxic substances (Smith et al., 2000). The incomplete combustion of the fuel produces a wide range of health damaging pollutants such as carbon monoxide, particles, Benzene, 1-3Butadeine, Formaldehyde and dozens of other pollutants (UNDP, 2001).

### 2.4 Variables Affecting Emission Components and Rate

The principal factors affecting emission are related to the fuel, combustion condition and the appliance or facility itself. These factors are to some degree interdependent. For each of these factors there are elements of human interaction which will affect both the composition and rate of emission (John et al., 1985). The factors can be summarized as combustion efficiency, technical efficiency and system efficiency of the stove (Usinger, 1996).

Combustion efficiency represents the degree of complete combustion and is influenced by the fuel quality and the combustion chamber characteristic of the stove. Indoor fuels are hydrocarbon based energy sources. The complex of hydrocarbon molecules and the physical state of the fuel - gas, liquid or solid will influence its
combustion property. The easier the fuel can mix with air, the better combustion it undergoes. The moisture content of a fuel which depends on the type of fuel, its origin and treatment before it is used as a fuel also affects the burning conditions. Emission rates and the constituents are directly influenced by combustion conditions. In the oxygen lean conditions, poorer pyrolysis results in partially burning hydrocarbon components. These conditions are characteristics of high carbon monoxide emission. The design, use and maintenance of the combustion facility—the technical efficiency—greatly influence the emission parameters. The stove efficiency is influenced by the materials, the constructive perfection and dimensions of the combustion chamber which are used to force heat transfer to the pot.

The system efficiency represents the efficiency of the system operation and it depends on the system operator’s capability to minimize the fuel consumption throughout the process.

2.5 Indoor Air Pollution

Naturally dry air is a mixture of 78 percent nitrogen, 21 percent oxygen, 0.03 percent carbon dioxide as well as argon and other gases in trace concentration. Air is said to be polluted when one or more of contaminants are present in sufficient amount for such duration as to affect the physical well being of people, animals, vegetation or materials. Such a presence is measured as a concentration either by volume (ppm—parts per million) or by the mass of the pollutants present in one unit volume of air (µg/m³—micro grams per cubic meter) (Gupta et al., 1998).

The air indoor, under certain circumstances, can be polluted to hazardous level. This happens when polluted air leaks into the house or when cooking smoke or evaporation from volatile organic compounds builds up inside a room. The conditions are worsened to hazardous levels if this happens in a confined space without ventilation which prevents dilution of the polluted air. Table 1 summarizes the principal sources of indoor air pollutants.
Table 1. Major sources of indoor air pollutants

<table>
<thead>
<tr>
<th>Type</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particulates</td>
<td>Released from cooking or space heating especially from wood smoke, tobacco, smoke</td>
</tr>
<tr>
<td>Volatile organic compounds</td>
<td>Formaldehyde and other compounds released from plywood, particle board, paneling, insulation material, paint, varnishes, solvent, carpets, sheets, sprays</td>
</tr>
<tr>
<td>Ozone</td>
<td>Photocopying machines, electrostatic air cleaners</td>
</tr>
<tr>
<td>Radon</td>
<td>Rocks, soils, building materials</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>Wood smoke, gas heaters, stoves</td>
</tr>
</tbody>
</table>

Source: Gupta, (1998)

Indoor air pollution is ‘original’ air pollution problem and it still exists (WHO/UNEP, 1990). The inefficient burning of solid fuels on an open fire traditional stoves creates a dangerous cocktails of hundreds of pollutants: Carbon monoxide, soot, dust and particulates, nitrogen oxides, sulphur oxides, formaldehydes, hydrocarbons and many other health-damaging chemicals. The concentration of indoor pollutants in households that burn traditional fuels is alarming. Burning of such fuels produces large amount of smoke and other air pollutants in the confined space of the home, resulting in high exposure. In developing country’s households, daily average of pollutant level emitted indoors often exceed current WHO guidelines and accepted levels (Table 2).
Table 2. Health affecting limits according to WHO Exposure Guidelines

<table>
<thead>
<tr>
<th>Product</th>
<th>Concentration</th>
<th>Time limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide</td>
<td>100 mg/m³</td>
<td>15 min</td>
</tr>
<tr>
<td></td>
<td>60 mg/m³</td>
<td>30 min</td>
</tr>
<tr>
<td></td>
<td>30 mg/m³</td>
<td>1 hour</td>
</tr>
<tr>
<td></td>
<td>10 mg/m³</td>
<td>8 hour</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>100 µg/m³</td>
<td>30 min</td>
</tr>
<tr>
<td>Lead</td>
<td>1 µg/m³</td>
<td>1 year</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>400 µg/m³</td>
<td>1 hour</td>
</tr>
<tr>
<td></td>
<td>150 µg/m³</td>
<td>24 hour</td>
</tr>
<tr>
<td>Ozone</td>
<td>200 µg/m³</td>
<td>1 hour</td>
</tr>
<tr>
<td></td>
<td>120 µg/m³</td>
<td>8 hour</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>500 µg/m³</td>
<td>10 min</td>
</tr>
<tr>
<td></td>
<td>350 µg/m³</td>
<td>1 hour</td>
</tr>
<tr>
<td></td>
<td>125 µg/m³</td>
<td>24 hours</td>
</tr>
<tr>
<td>Suspended particles</td>
<td>120 µg/m³</td>
<td>24 hours</td>
</tr>
<tr>
<td>Benzene</td>
<td>2.5 µg/m³</td>
<td>1 year</td>
</tr>
</tbody>
</table>

Source: Usinger, (1996)

2.5.1 Total Suspended Particulates (TSP)

Small particles (with an aerodynamic diameter of about up to 10 microns (PM$_{10}$)) are the most widely used indicators of health hazards of indoor air pollution. Fine particles with an aerodynamic diameter 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 (OMOE, 1999; WHO, 2006). Even though the precise mechanism by which exposure to indoor air pollution translate into disease is still unknown, it is true that PM can cause inflammation of the airways and lung and impair the immune responses. The inefficient burning of solid fuels is one of the sources of particulate in households using biomass as a source of energy. For instance, typical 24 hr levels of PM$_{10}$ in biomass burning households in Asia, Latin America and Africa range from 300 to 3000 µg/m³, peaks during cooking may be as high as10000 µg/m³ (Pandy et al., 1989).
2.5.2 Carbon monoxide (CO)

Carbon monoxide is a combustible, colorless, odorless, and highly toxic gas. It is a product of incomplete combustion of fossil fuel and biofuels. A process of combustion in a presence of sufficient air yields more CO\textsubscript{2} than CO as a byproduct. Thus the CO\textsubscript{2} content (the ratio CO/CO\textsubscript{2}) represents a rate for the quality of combustion.

Once CO has been respired it gets to the blood through the lungs preventing the reception of oxygen. The Haemoglobin (Hb) in the blood acts as a two-way transportation system, carrying oxygen (as oxyhaemoglobin, O\textsubscript{2}Hb) from the lungs to the cell of the body, and CO\textsubscript{2} from the cells to the lungs (as CO\textsubscript{2}Hb). With CO, it forms Carboxy haemoglobin (COHb), and at a rate about 200 times greater than that with O\textsubscript{2}. Therefore the presence of CO leads to COHb being formed rather than O\textsubscript{2}Hb leading to a shortage of oxygen in the blood stream. An increasing concentration of COHb leads to nerve, psychomotor and brain dysfunction and a high and continuous inhalation may lead to Cardiac problem and death (Gupta, 1998).

2.6 Criteria for Evaluating Stove Performance

The performance of a stove determines whether a given intervention effort is adopted or not. In order for a stove to be considered improved the minimum criteria it needs to fulfill is to meet the user’s needs. Beyond this a stove should decrease the amount of fuel needed for a certain task and make the household activities easier and enjoyable.

The important criteria that are used for evaluating stove performance are efficiency, specific fuel consumption, turn down ratio, speed of cooking, user satisfaction and emissions.

Specific fuel consumption is the most useful criterion for determining how much fuel a stove is likely to consume. Specific consumption represents the amount of fuel it takes to perform a specific task. For instance, the amount of fuel consumed per kilogram of food cooked can be used to express the specific fuel consumption of a given stove.

Speed of cooking is specified as the time it takes to boil or cook a given amount of food, generally per litre. However, cooking time is also the time a cook spends near the stove and thus determines duration of exposure to indoor air pollution. This is mostly a measure of user friendliness.
Though, stove emissions are most directly related to indoor air pollution levels, health standard criteria and method to assess emission are in the process of development. However there are standard procedures to assess the concentration of pollutants in the working environments.

2.7 Stove Performance Tests

Several studies conducted to address the worldwide environmental and social costs of using traditional fuels and stoves have resulted in proven strategies to reduce both fuel use and harmful emissions. The most successful effort with regard to this is the development of improved stoves. After the designing and development of an improved stove standard tests have to be conducted before their dissemination. There are three commonly used protocols that are applied for testing the performance of a stove: the Water Boiling Test (WBT), the Controlled Cooking Test (CCT) and the Kitchen performance Test (KPT).

Water Boiling Test: This lab-based test attempts to simulate the most common cooking modes of a stove while keeping other factors constant to make the results as comparable as possible between different projects. This test is a simulation of the cooking process that can be performed on most stoves in use throughout the world and it is designed to be a simple method by which stoves made in different places and for different cooking application may be compared by a standardized and replicable protocol.

The test consists of three phases, each representing a particular cooking situation: (1) Bringing water to a boil with a cold stove (cold start). This is a high power phase where the water is brought to the boiling-point; (2) Bringing water to a boil with a hot stove (hot start); and (3) Simmering water with a hot stove (low power phase which is also called simmer test). The results relate to four of the performance criteria: efficiency, specific consumption, time to boil and turn down ratio (the difference in fuel consumption per minute between high power and low power). Stoves with a higher turn down ratio are likely to use less fuel during a real-life cooking task. This test offers a picture of stove performance that can be used during the design process that the stove designers use the results to consider the necessary improvements for better performance if needed.
Controlled Cooking Test also known as Standard Meal Test. It is a lab-based test which involves local cooks preparing a local dish. Controlling variables limits comparability of results to a given setting but provides important feedback as to the likely acceptability of a stove by local users. The test involves standard cooking task or preparing the same local meal with the same quantities of food, ingredients and fuel to identify deviations in the specific wood consumption and it is conducted in a way that minimizes the influence of other factors and also allows for the test conditions to be reproduced. The results relate to specific consumption, speed of cooking and user satisfaction.

Kitchen Performance Test: This is the most difficult and resource-intensive test. It consists of a survey and a fuel consumption test with families using both the traditional and the improved cook stove. The test gives results of user satisfaction and per capita fuel consumption for a given stove. As KPT is conducted in individual households there are many different variables that influence the test and a large number of tests need to be performed before and after the improved stoves are employed so as to assure statistical accuracy in the results (WHO, 2005). Because it occurs in the homes of stove users, carefully conducted KPT is the best way to understand the stove’s impact on fuel use and on more general household characteristics and behaviors (Lillywhite, 1984; VITA, 1985).

2.8 Improving Efficiency of a Stove

The efficiency of a stove is described in terms of its combustion efficiency and heat transfer efficiency. The combustion efficiency is a measure of how well the fuel is burnt or the energy in the fuel is converted in to heat and the heat transfer efficiency is a measure of how well the heat released by the fuel reaches the pot. Smoke and harmful emission can be reduced by improving combustion efficiency and fuel use can be reduced by improving heat transfer efficiency but these two factors are independent of each other. As far as burning of the fuel is concerned even an open fire is often 90% efficient at the work of turning the energy in the wood to heat. The difference lies in how to get the heat to where it is intended to go. The overall efficiency of a stove is the product of the combustion efficiency and the heat transfer efficiency of the stove.
Improving combustion efficiency alone does not appreciably improve the overall efficiency but working on the heat transfer side of the equation yields a better result. A number of studies indicated that the overall efficiency of a stove can be improved while the emission levels are still high and stoves that are meant to have better efficiency do not necessarily reduce emission (Ahuja et al., 1987; Smith 1992; Nangale, 1992).

Therefore, to meet the environmental as well as human health impacts stove designers should do their best to first clean up the fire (better combustion efficiency) and then force as much energy into the pot or griddle as possible (better heat transfer efficiency).

2.9 Indoor Air Quality Monitoring Techniques

There are various principles for air pollution measuring techniques. However the choice of monitoring techniques and equipment depend on analysis and monitoring conditions (Usinger, 1996).

For instance, Area Monitoring Principle is used in the case of permanently installed monitoring equipment; Personal Monitoring Principle is used when individual exposure of a person at different locations and time are to be measured; Continuous or Real time Monitoring Principle is used for continuous monitoring with actual course of concentration; Active Sampling Monitoring Principle is applied where active waste gas collectors like vacuum pumps are necessary; Passive Sampling Monitoring Principle without active collection of waste gas; Time-Weighted Average monitoring Principle is used when the mean obtained from the total of all measurements results are to be related to the monitoring time and for determining maximum and minimum values of pollutants based on separate and punctual monitoring, Grab or Spot Monitoring Principle is applied. The monitoring techniques may be used in combination according to necessity. Even though there are hundreds of pollutants in wood smoke those which are commonly dealt with are Carbon Monoxide being an indicator of acute short term hazard and Total Suspended Particulates being a cause for chronic and long term hazards. The equipment for measuring these pollutants is still excessively expensive (Tremeer, 1997).

The concentration of gaseous pollutants can be determined by two basic methods: using Gastec Color Dosimeter Tube which makes use of chemical reaction of the test
material with the chemicals of the filling section. Individual pollutant needs a particular reagent to be detected. These tubes function in a passive mode, where room air simply diffuses into the tube throughout the sampling period and the length of the color section in the tube that results from the chemical reaction between the pollutant and the reagents is indicative for the pollutant concentration. Although this method is easy to apply, it needs careful reading and as it is a tube for one time a long term repeated test will be costly. The other method employs electrochemical sensors with direct instantaneous readout. The HOBO CO logger is an electrochemical sensor that can be used to measure CO concentrations. It consists of electrochemical cell inside which carbon monoxide is oxidized to carbon dioxide and generates a proportional electrical signal.

Solid Suspended Particulates in the breathing-zone air can be measured by Gravimetric (Pump and Filter) method where particulate quantities are determined by the weight of the filter, and they can also measured by optical (light scattering) method.
3 Materials and Method

3.1 Study Site

The study was conducted in Arsi Negelle town of the Oromiya Regional state, West Arsi Zone Administration, 225 km south of Addis Ababa (Figure 3). The population of the town is 23512, 48.7% of which are female and 51.3% are men (PHCC, 1996). The laboratory tested improved Areke distilling stove had to be tested at household level with the actual set up of a number of stoves in a kitchen before embarking on dissemination and this study site is chosen for it is one of the places in the country where Areke distillation is widely practiced and where we can find the necessary sufficient distilland and a cook that has worked on the new stove during the preliminary test of the stove at the GTZ-SUN project workshop in Addis Ababa.

This experimental type of study was carried out in a household (kebele 01, House No. 128) in a kitchen of size 2.7 x 4.7 x 2.5 m where there are 7 stoves installed side by side. Equal number of improved stoves was installed in a kitchen of the same size constructed adjacent to the old one. The kitchens share one of their walls and necessary attention was given in making the ventilation of the rooms as similar as possible. The instruments were placed according to the Instrument Placement Protocol (CEIHD, 2005).

The testing procedures were undertaken on the stoves turn by turn; first with the traditional stoves and then with the improved stoves for determining whether the improved stoves lower the IAP levels in the household compared to the traditional ones.
3.2 Data Collection

3.2.1 Indoor Air Quality Monitoring

Indoor Air Quality (IAQ) was assessed by continuous measurement of fine Particulate Matter and Carbon Monoxide concentration in the kitchen while the distillation process is underway. The instruments used for measuring air pollutants were HOBO CO logger manufactured by Onset Computer Corporation, Bourne, MA, USA for monitoring Carbon Monoxide and UCB Particle Monitor produced at University of California, Berkeley for monitoring Particulates. The HOBO CO loggers used in the study records CO concentration through three channels, Channel -1, Channel -2, and Channel -3 for different ranges of concentrations. The ranges covered by these channels are 0.2–124.3 parts per million (ppm), 1–497.1 ppm, and 1-1988 ppm, respectively. In this study the maximum value of CO concentration did not exceed the 124.3 ppm level and therefore, only the readings of the first channel were used for analysis. The typical accuracy of this channel at 20°C is ±4.5 ppm ±7 percent of reading (Shannon et al., 2005).
The UCB Particle Monitor is sensitive to particles of aerodynamic diameter less than approximately 2.5 microns, called fine PM or PM$_{2.5}$, which is the size range thought to be most important for health (Litton et al., 2004; Edwards et al., 2006; Chowdhury et al., 2007). It 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, namely, ionization and photoelectric light scattering chambers for measurement of PM. The Photoelectric (PE) sensor is most sensitive to particle sizes corresponding roughly to PM$_{2.5}$ (Litton et al., 2004). Combustion-derived particles are nearly all in the lower size ranges, and the PE sensor is expected to pick up most of the emissions and the data are reported as mass concentrations in mg/m$^3$.

Both HOBO CO logger and UCB Particle Monitor contain data loggers, which store the minute-by-minute data over the entire measurement period in their memories. These data are then downloaded into a personal computer after monitoring.

The instruments were placed next to each other on the wall of the kitchen for the entire measuring period using defined criteria; 100 cm from the edge of the combustion zone, 140 cm above the floor and more than 150 cm from the door (Annex 3). The two devices were located in a relatively safe location, on the wall, to minimize the risk of interrupting normal kitchen activities or being disturbed or damaged. The protocols for use of the UCB PM Monitors and HOBO CO loggers are in Annex 1 and Annex 2, respectively.

Plate 4. Indoor air pollution monitoring equipment
3.2.2 Evaluation of Stove Performance

Even though the study is formerly designed to assess the efficiency of the improved stoves in terms of concentration of pollutants in the kitchen, additional work is also done to assess the performance of the new stoves with respect to fuel consumption. For this purpose the Control Cooking Test (CCT) procedures (Bailis, 2004) are applied. The comparison between the improved and traditional stoves is done as the stoves perform a standard task of Areke distillation and their specific fuelwood consumption and the time taken to accomplish a given task are taken as criteria for evaluation. The necessary equipment: a Wood moisture meter to measure wood moisture; a Balance to measure fuelwood before and after the distillation, the remaining char and the Areke product; a Timer; an IR thermometer; a Thermocouple sensor with digital thermometer for measuring ambient temperature and temperature of the distilland; a small Shovel to remove charcoal from the stoves; a Metal tray to hold charcoal for weighing; Heat resistant gloves and a Sieve for screening the ash from the charcoal were used.

The procedures designed for the CCT were followed: People in the location where the new stove is to be introduced were consulted ahead of time in order to ensure that sufficient distilland can be obtained to conduct complete test. In order to ensure that the procedures are conducted identically, all the steps are recorded in as much detail as possible on the Data Collection Form (Annex: 6). The distillation was done by a local cook who is familiar with both Areke production and operation of the stoves and the tests were done by the same cook in order to remove the cook as a potential source of bias in the test. All the stoves were installed in a kitchen which is separated from the main house and therefore the tests were conducted under controllable settings. The distilland and bundle of fuelwood much more than the amount the local cook considers necessary to complete the task were weighed prior to the testing and local conditions were also recorded. The average dimension and moisture of the fuelwood used were measured in each test. The readings of moisture contents were averaged over the readings taken of ten sample pieces of wood.

The cook was allowed to light the fire in a way that reflects local practice and relevant observations and comments by the cook such as any inconvenience in the stove operation, excessive heat and smoke are recorded as the testing is underway.
At the end of the distillation process, the following important measurements were recorded on the Data Collection Form: the starting and finishing time, the weight of the remaining fuelwood together with the wood removed from the stove (The charcoal is knocked off the wood removed from the stove before weighing), the weight of the charcoal and the weight of the distillate (Areke) (The charcoal is removed from the stove and carefully isolated from the ash by a sieve before weighing).

3.3 Data Processing

The Areke distillation process, as practiced by the local distillers, is a continuous process that takes place in at least three consecutive phases for a total of 12-13 hours every day. At the end of each phase, the distilland that has undergone the previous phase is replaced by a new one of the same amount and a new Areke collecting flask is also used for the new phase.

The measurements recorded by the Indoor Air Quality monitoring devices – UCB PM Monitor and HOBO CO logger were downloaded and stored on a computer according to the procedures defined in the protocols. The data are then exported to an excel spreadsheet and cropped to include the values read from the time the fire is lit to the time the last pot is removed. This time is taken as the time of the whole distillation process. Moreover, the stoves are also compared in terms of the 8-hours concentrations of pollutants. The rate at which fuelwood is supplied to the stoves varies throughout the process. More fuel is needed during the heating-up of the fresh material at the start of each phase and the amount decreases remarkably towards the end of the given phase. Refilling of the pots with fresh distilland and hence the supply of more fuelwood will be completed during the first 8-hours time of distillation. In order to assess the exposure to high levels of pollutant concentrations within short period of time, the 15 minute maximum concentrations are also considered.

3.4 Data Analysis

Appropriate statistical analysis such as T-test, and Regression models and Histograms were used to interpret the data. The results of the statistical tests were analyzed at the 95% confidence level. As the stoves are tested under similar settings only the potential influence of fuelwood used on the concentration of pollutants is investigated.
The CCTs were conducted three times on each of the stoves as recommended by the protocol and the data were filled in the space on the Stove Efficiency evaluation Protocol sheet (Annex 7) to be analyzed by the software developed by the University of California. The software employs the t-test statistical tool to compare the specific fuel consumption and the time taken to accomplish the task and provides the summary of the results.
4 Results and Discussion

4.1 Concentration of Air Pollutants

4.1.1 Pollutant Concentration during the Whole Distillation Process

Areke distillation process is a long process that lasts for over 12 hours. Unlike most of the local household cooking practices, Areke distillation demands careful tending of fire and once the process starts the cook has to be in the kitchen controlling any possible change that could affect the quality of the product (the alcohol content and taste of the product): the amount of fuel fed to the stove has to be regulated not to heat the distilland beyond the boiling point of alcohol or over heat the pot and make the ingredients stick to the bottom of the pot, any possible leakage of the steam through the two ends of the condensation tube where it is connected to the pot and the collecting flask should be checked, and the temperature of the water in the cooling tub should be kept low in order to maintain the temperature gradient down the condensation tube. It is in this duration of time that emissions from the stoves that affect the indoor environment are released and hence pose possible threat to human health. The level of CO and PM$_{2.5}$ concentrations resulting from the use of each of the stoves are averaged over the whole distillation time and the results are summarized in Table 3 and the Histograms are shown in Figures 4 and 5.

<table>
<thead>
<tr>
<th></th>
<th>Stove</th>
<th>Mean</th>
<th>% reduction</th>
<th>Mean Diff.</th>
<th>Std. error diff.</th>
<th>df</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO concentration (ppm)</td>
<td>Traditional</td>
<td>49.81</td>
<td>52.6</td>
<td>26.19</td>
<td>2.33096</td>
<td>16</td>
<td>11.238</td>
</tr>
<tr>
<td></td>
<td>Improved</td>
<td>23.61</td>
<td>57.0</td>
<td>0.69</td>
<td>0.05242</td>
<td>16</td>
<td>13.286</td>
</tr>
</tbody>
</table>

Compared to the traditional stoves the improved stoves have shown a reduction of average CO concentration of 26.19 ppm which is 52.6% reduction and reduction of average PM$_{2.5}$ concentration of 0.7mg/m$^3$ which is 57% reduction. Both the CO and PM reductions are statistically significant. In terms of the measure of variability of the
data from its mean, i.e., Coefficient of Variance (CV), the variability is greater for measurements taken in improved stoves situations than for the traditional ones. The CV for the measurements of CO concentrations for improved stove and traditional stove situations are 0.18 and 0.11, respectively and those for PM concentrations are 0.16 and 0.11, respectively. In Areke distillation relatively more fuelwood is supplied to the stove at the beginning of the process and stirring of the distilland is done until its temperature is large enough for the alcohol to evaporate. Once this stage is reached stirring stops and the condensation tube is connected to the pot and the flask and the amount of fuelwood the stove needs to keep the process going on until the end of that phase reduces remarkably. In addition to having a well prepared distilland, the quality of the product depends on the performance of the cook. The Areke distillation requires constant follow up and careful management of fire. Less fuelwood could cause cooling of the stove and more fuelwood could cause overheating of the distilland that could result in overflow of the material down the condensation tube spoiling everything. The task of controlling the fire is relatively easier with the traditional stoves than with the improved ones. This is because in the traditional stoves the fire bed and the bottom of the pot are very close and the fire can easily be seen making the task of supplying the stoves with proper amount of fuel easier. The failure in proper management of the fire due to lack of experience of the cook with the improved stoves might have contributed to the large variability in improved stove situation.

Figure 4. Histogram of the CO concentration for whole distillation time
The most frequent values of CO concentrations in the traditional stove situation happened to be in the range 45 to 50 (ppm) and from 55 to 60 (ppm) while in the improved stoves situation concentration values between 20 and 25 were the most frequent. The most frequent values of PM concentrations in the traditional and improved stove situations range from 1.2 to 1.3 mg/m$^3$ and 0.4 to 0.5 mg/m$^3$, respectively. Though the health implications of these reductions cannot be explained in this study the results imply major reduction in air pollutant concentrations in the kitchen.

4.1.2 The 8-hour Average Pollutant Concentration

The first 8-hours of the distillation process is the time in which the beginning of the three phase takes place and relatively more fuelwood is supplied to the stoves and exposure to high level pollution happens in this duration. The level of CO and PM$_{2.5}$ concentrations averaged over the 8-hours of the distillation time and the results of the comparison between the stoves is illustrated in Table 4 and the histograms are shown in Figures 6 and 7.
Table 4. The 8-hour mean pollutant concentration by stove type

<table>
<thead>
<tr>
<th></th>
<th>Stove</th>
<th>Mean</th>
<th>% reduction</th>
<th>Mean Diff.</th>
<th>Std. error diff.</th>
<th>df</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO concentration (ppm)</td>
<td>Traditional</td>
<td>52.25</td>
<td>53.2</td>
<td>27.81</td>
<td>2.47039</td>
<td>16</td>
<td>11.257</td>
</tr>
<tr>
<td></td>
<td>Improved</td>
<td>24.44</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM concentration (mg/m³)</td>
<td>Traditional</td>
<td>1.27</td>
<td>63.3</td>
<td>0.80</td>
<td>0.6595</td>
<td>16</td>
<td>12.174</td>
</tr>
<tr>
<td></td>
<td>Improved</td>
<td>0.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comparing the CO and PM concentrations in the kitchen with traditional and improved stoves conditions, the improved stoves showed a reduction in CO concentration of 27.8 ppm which is 53.2% reduction and 0.80 mg/m³ or 63.3% reduction in PM concentration. As observed in the measurements of pollutant concentrations during the whole distillation periods, the variability in readings are higher in the improved stoves condition than in the traditional ones. The CV of the CO and PM readings for the traditional stove conditions are 0.11 and 0.13, respectively and the corresponding values for the improved stoves condition are 0.20 and 0.22. The larger variability is again attributable to the difficulties associated with proper management of the improved stoves.

Figure 6. Histogram of the 8-hour average CO concentration
The World health Organization (WHO) sets air pollution guidelines to offer guidance in reducing the health impacts of air pollution based on current scientific evidence. The WHO recently set a new Air Quality Guidelines (AQGs) for PM$_{2.5}$ and other air pollutants along with interim targets that are intended as incremental steps in a progressive reduction of air pollution in more polluted areas (WHO, 2005). The guideline for CO was set in 2000 (WHO, 2000) to be 10 ppm for 8 hours average (Table 5).

Table 5. WHO Air Quality Guidelines

<table>
<thead>
<tr>
<th></th>
<th>WHO interim target -1</th>
<th>WHO Air Quality Guideline</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$</td>
<td>75 µg/m$^3$</td>
<td>25 µg/m$^3$</td>
</tr>
<tr>
<td></td>
<td>(24 hours mean)*</td>
<td>(24 hours average)*</td>
</tr>
<tr>
<td>CO</td>
<td>NA</td>
<td>10 mg/m$^3$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(8-hours average)**</td>
</tr>
</tbody>
</table>

*WHO, 2005; **WHO, 2000

The results of the stove performances tests were compared with these international standards. Though the levels still remain above what is stated in AQGs, improved stoves conditions showed statistically significant reduction in CO concentrations, from 52.3 ppm to 24.44 ppm, getting the concentrations closer to the AQGs limits.

The Histograms for the 8-hours pollutant concentration are shown in Figures 6 and 7.
The most frequent values of CO concentrations range from 55 to 60 in the traditional stove situation and from 20 to 25 ppm in the improved stoves. The most frequent values of PM concentrations in the traditional and improved stove situations range from 1.2 to 1.3 mg/m$^3$ and 0.4 to 0.6 mg/m$^3$, respectively.

Figure 8 and Figure 9 show representative graphs of one day monitoring of CO and PM concentrations and Temperature of the kitchen during the 8-hour period of the distillation process.

Figure 8. Typical graph for CO (ppm), PM (mg/m$^3$) and Temperature ($^\circ$C) of the 8-hour distillation time with traditional stoves.

![Figure 8](image1)

Figure 9. Typical graph for CO (ppm), PM (mg/m$^3$) and Temperature ($^\circ$C) of the 8-hour distillation time with improved stoves.

![Figure 9](image2)
Maximum CO concentrations of 85.7 ppm and 50 ppm and maximum PM concentrations of 24.9 mg/m$^3$ and 2.9 mg/m$^3$ were observed of measurements taken for traditional and improved stove conditions, respectively. Nearly a constant trend is observed for the CO concentrations in the traditional stove conditions while it is slightly positive in the improved stove conditions. As it has been explained earlier the closeness of the fire bed to the bottom of the pot and the visibility of the fire has made the task of tending of the fire easier with the traditional stoves. Once the stirring of the distilland is stopped, nearly uniform supply of fuelwood is required to keep the process going on. On the other hand the smaller size fuel inlet of the improved stoves limits the amount and size of wood that could be supplied to the stoves and therefore, more frequent supply of small sized fuelwood but in a small amount is needed in order to maintain the necessary temperature for the combustion chamber. As far as creating conducive working environment in terms of temperature of the kitchen is concerned the maximum temperature in the traditional stove condition and that of the improved stove condition are nearly the same, 30.2 °C and 32.1 °C, respectively, and the minimum temperatures recorded in both cases were 18 °C. Having the experience of working on a number of smoky stoves in a relatively small size rooms, the kitchens for Areke distillation are deliberately made to have eaves between the walls and the roof and the doors are kept open for ventilation and due to this the temperature of the kitchen did not show considerable changes.

### 4.1.3 Maximum Pollutant Concentration

The maximum 15 minutes concentration of CO and PM concentrations for the whole distillation time and the results of comparison by stove type are shown in Table 6. Compared with the traditional stoves condition, the improved stoves have shown a reduction in CO levels of 42.7 ppm (55.8%) and the PM levels were also lowered by 1.7 mg/m$^3$ (56.9%). These reductions are statistically significant.
Table 6. Maximum 15 minutes pollutant concentrations by stove type

<table>
<thead>
<tr>
<th></th>
<th>Stove</th>
<th>Mean</th>
<th>% reduction</th>
<th>Mean Diff.</th>
<th>Std. error diff.</th>
<th>df</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO concentration (ppm)</td>
<td>Traditional</td>
<td>76.58</td>
<td>55.8</td>
<td>42.71</td>
<td>2.73635</td>
<td>16</td>
<td>15.609</td>
</tr>
<tr>
<td></td>
<td>Improved</td>
<td>33.87</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM concentration (mg/m³)</td>
<td>Traditional</td>
<td>3.04</td>
<td>56.9</td>
<td>1.73</td>
<td>0.31400</td>
<td>16</td>
<td>5.514</td>
</tr>
<tr>
<td></td>
<td>Improved</td>
<td>1.31</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The histograms of 15-Minute Maximum CO and PM concentrations are shown in figures 10 and 11.

Figure 10. Histogram of 15-Minute Maximum CO concentration

The most frequent values of the 15 minutes maximum CO concentrations in the traditional stoves condition range from 70 to 75 ppm and those of improved stoves range from 30 to 35 ppm.
Most of the PM concentrations are in the range 2.5 to 3 mg/m$^3$ and 1 to 1.25 mg/m$^3$ for traditional and improves stoves conditions, respectively.

Comparing the measurements of concentrations of pollutants with the limits set as a WHO Air Quality Guideline for 15 minutes maximum concentration (Table 2), the average CO concentration caused by the traditional stoves was 76.6 ppm which is close to the limit to avoid acute poisoning (90 ppm) while the CO concentration caused by the improved stoves 33.9 ppm is well below the limits.

Unlike what could possibly be observed while working with a single stove the pick values of the readings of CO and PM concentrations for both stove conditions were recorded at quite different times during the whole distillation time. As the distillation process took place in three phases in which the starting and finishing time of each phase naturally varies from one pot to the other, the amount of fuelwood fed to the stoves was not uniform resulting in changes in emissions from individual stoves during different combustion phases. This variability could be the possible reason for the occurrence of the pick values at an irregular time intervals.

Further investigation was made to check the correlation between the CO and PM$_{2.5}$ concentrations during the whole distillation process. In an attempt to produce testing methods which do not require costly equipment it has been suggested that it is necessary to measure only one pollutant and from this measurement infer the others (Young, 1992). Various studies have been conducted to check whether it might be possible to take CO levels as a proxy for PM levels. For instance a study as reported...
in Butcher et al., (1984) found that stoves with a high CO emission factor had a high particulate emission factor; Nangale, (1992) found that high CO emissions implied high Total suspended particulates (TSP) emissions. Ahuja et al., (1987), however, did not find a consistent correlation between CO and TSP. Neaher et al., 2001 showed that the CO and PM$_{2.5}$ are positively correlated with correlation R = 0.5; p = 0.17, n = 9 for open fire situations and R = 0.9; p = 0.003, n = 8 for improved stove situations and when the data for both stoves are pooled the correlation is strengthened to have R = 0.92; p < 0.0001, n = 17. The analysis of the data obtained in this study indicate that the CO and PM have positive correlation for both traditional and improved stoves conditions with Pearson correlation of R = 0.32 (p = 0.39; n = 9) and R = 0.35 (p = 0.35; n = 9), respectively. Though the correlations are positive, they are weak and statistically nonsignificant. The regression equations representing the correlation between CO and PM in this study were PM$_{2.5}$ (mg/m$^3$) = CO(ppm) 0.008 + 0.838 for traditional stove conditions and PM$_{2.5}$ (mg/m$^3$) = CO(ppm) 0.007 + 0.366 for improved stoves conditions. When the data are pooled together the correlation is strengthened with R = 0.93 (p<0.0001; n =18) (Figure 12) and the regression equation changes to PM$_{2.5}$(mg/m$^3$) = CO (ppm) 0.024 - 0.022 .The results obtained from the analysis of the data in this study clarify the limitations of the ability of CO to serve as proxy for PM$_{2.5}$ exposure and this finding is consistent with what is obtained in Treemer, (1997); Neaher et al., 2001.
The average daily fuelwood consumption of the traditional stoves was 56677.78 g and that of the improved stoves was 55788.89 g which is less by only 888.9g (1.6% reduction). The reduction in fuelwood was not statistically significant. The impact of fuelwood on pollutant concentration was also analyzed using linear regression model and the result indicated no significant impacts of fuel on the pollutant concentration in all the three durations taken for analysis. The improved stoves, without having significantly reduced the fuelwood consumption, have resulted in significant reduction in pollutant concentration. As the testing was done under the condition where most of the factors that potentially affect the results are made to be nearly the same, the major factor for the reduction in pollutant concentration may have come with specific characteristics of the improved stoves.

4.2 Stove Performance

In addition to the significant health benefits for women and children, improved cooking technologies have social, economic, and environmental benefits. Women and children spend less time collecting fuel, allowing more time for important educational, economic, and family activities. Clean burning and fuel efficient cooking
and heating practices also reduce carbon emissions, deforestation, erosion, and desertification.

4.2.1 Specific Fuelwood Consumption and Time

Two of the most important criteria for evaluating stove performances namely specific fuel consumption and time taken to accomplish a given task were used to compare the performances of the stoves under investigation. The procedures designed in Controlled Cooking Test (CCT) are applied for this purpose. As required by the Stove Efficiency Evaluation Protocol (Annex: 7) three consecutive tests are made for each of the stoves. The percentage reductions in specific fuel consumption and time for distillation as well as T-tests for the significance of the differences are all computed by the software and the results are reported in Table 7.

Table 7. Results of the stove performance tests

<table>
<thead>
<tr>
<th>1. CCT results: Traditional</th>
<th>units</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Mean</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total weight of food cooked</td>
<td>g</td>
<td>45850</td>
<td>44950</td>
<td>44300</td>
<td>45033</td>
<td>778.4</td>
</tr>
<tr>
<td>Weight of char remaining</td>
<td>g</td>
<td>450</td>
<td>350</td>
<td>300</td>
<td>367</td>
<td>76.4</td>
</tr>
<tr>
<td>Equivalent dry wood consumed</td>
<td>g</td>
<td>46387</td>
<td>43537</td>
<td>46071</td>
<td>45331</td>
<td>1562.4</td>
</tr>
<tr>
<td>Specific fuel consumption</td>
<td>g/kg</td>
<td>1012</td>
<td>969</td>
<td>1040</td>
<td>1007</td>
<td>36.0</td>
</tr>
<tr>
<td>Total cooking time</td>
<td>min</td>
<td>791</td>
<td>740</td>
<td>750</td>
<td>760</td>
<td>27.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. CCT results: Improved</th>
<th>units</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Mean</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total weight of food cooked</td>
<td>g</td>
<td>47400</td>
<td>45000</td>
<td>44600</td>
<td>45667</td>
<td>1514.4</td>
</tr>
<tr>
<td>Weight of char remaining</td>
<td>g</td>
<td>300</td>
<td>350</td>
<td>400</td>
<td>350</td>
<td>50.0</td>
</tr>
<tr>
<td>Equivalent dry wood consumed</td>
<td>g</td>
<td>42295</td>
<td>43026</td>
<td>46393</td>
<td>43905</td>
<td>2185.5</td>
</tr>
<tr>
<td>Specific fuel consumption</td>
<td>g/kg</td>
<td>892</td>
<td>956</td>
<td>1040</td>
<td>963</td>
<td>74.2</td>
</tr>
<tr>
<td>Total cooking time</td>
<td>min</td>
<td>562</td>
<td>625</td>
<td>603</td>
<td>597</td>
<td>32.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Comparison of Stove Trad. vs Imp.</th>
<th>% difference</th>
<th>T-test</th>
<th>Sig @ 95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific fuel consumption</td>
<td>g/kg</td>
<td>4%</td>
<td>0.92</td>
</tr>
<tr>
<td>Total cooking time</td>
<td>min</td>
<td>22%</td>
<td>6.77</td>
</tr>
</tbody>
</table>

The results indicate that the improved stoves have shown a reduction in specific fuel consumption of only 4% and this reduction was not statistically significant. The T-test made for comparison of the distillation time has shown a significant reduction of 22% by the improved stoves. The analysis of the data obtained in the study revealed that the improved stoves were relatively better in reducing the concentration of health...
damaging air pollutants in the kitchen and the results were encouraging. However, the reduction by improved stoves of specific fuelwood consumption was not significant. Though the improved stoves are not good enough in reducing the environmental impacts (forest depletion) they are found to have a significant contribution in an effort to mitigate the socioeconomic impacts imposed on women and children by the traditional utilization of biomass resources.

The role of the cook in controlling the fire, thermal property of the materials used for constructing the stoves and the massiveness of the new stoves might have contributed to this effect. According to Aprovecho Research Center, in places where fuel is scarce, open fires can be carefully controlled so that fuel efficiency rivals many first generation improved stoves. As discussed in the literature, Areke distillation is nearly a day-long process and how the operator controls the fire makes a difference. When it comes to the improved stoves situation, due to lack of experience of the cook with the new stoves (as compared to the long experience of working on the traditional stoves) there has been a problem in carefully tending the fire. Unlike in the traditional stoves, the gap between the pot rest and the fire bed was deliberately made large enough to facilitate mixing of the flue gas with air to undergo complete combustion but this in turn has forced the continuous supply of wood, though in small amount, to the stoves. The larger gap between the fire bed and the bottom of the pot has made it difficult for pot to get considerable heat from the charcoal underneath. Most of the improvements in indoor air pollution may have been due to the improvement in the combustion efficiency rather than improvements in the heat transfer efficiency of the stoves and this reduced the overall efficiency of the stoves which is against the major interest of stove designers. The other possible reason for the weak performance in heat transfer of the new stoves may have been due to the large mass of the stoves. In order to install the stoves side by side local materials mainly mud is used to join the refractory bricks used to make the combustion chamber and to enclose the combustion chamber itself. In an effort to make the construction of the stoves easy to work with, cheap and long lasting, locally available materials were used. The negative effects on the fuel efficiency of the improved stoves may have been due to the placing of a large amount of materials with high thermal mass such as mud, clay and sand near the combustion chamber. At the beginning of the first phase of the distillation process the improved stoves needed more fuelwood to take the distilland to the require temperature than needed by the traditional stoves. Once the stoves get hot, the thermal inertia of the...
high thermal mass materials made it possible for the process to continue with relatively less amount of fuelwood. At the beginning of the second and the third phase of the distillation process the amount of fuel required to get the distilland to the required temperature was observed to be less than that at the beginning of the first phase. Though the heat absorbed by the bricks and the surrounding materials made it possible for the stoves to remain hot for a longer time than what has been observed in the traditional stoves conditions, frequent but small amount of fuel was needed to get the necessary heat supplied to the pot. In the case of traditional stoves not much heat is absorbed by the body of the stoves that each phase starts from nearly the same situation and constant supply of fuel is needed throughout the distillation process.
5 Conclusion and Recommendation

The study focused on the potential of improved Areke stoves in addressing the environmental and human health impacts of utilization of biomass resources. The study was conducted in a household with real distillation process but under controlled setting in which every possible effort is made to ensure that the stoves are used to their best effects. Although the study has its own limitations like small sample size, the analysis of the data indicated significant reduction of pollutants by improved stoves in all the three durations of interest. The results also revealed the limitations of taking CO levels as proxy for PM concentrations. Despite the significant improvement of the kitchen environment with regard to pollutant concentrations, except for the 15 minutes maximum concentration, the CO levels are still above the limits set in WHO AQGs.

The improved stoves have not performed as they are intended to as far as fuelwood saving is concerned. This may have been due to the failure of the stoves to get the heat to the pot and the failure of the cook to properly operate the stove. It is a well established fact that when managed properly open fires can perform better than enclosed stoves. The results of the efficacy test in the study indicated what is the maximum possible obtained from the improved stoves but not what is necessarily achieved from the stoves.

Unlike the usual cooking practices that take place for relatively short period, Areke distillation is a day long process. From what has been observed in the field, the need for constant follow up and proper operation of the new stoves has placed additional burden on the cook. Once the distillation process started, especially with the improved stoves situation, the cook was completely occupied by the activities in the kitchen and had almost no chance to be out of the kitchen. The lack of proper operation of the stoves associated with a nearly day-long tiresome activity may have contributed to the poor performance of the improved stoves with respect to fuelwood consumption.

As the efficiency of a stove is essentially the product of its combustion efficiency and heat transfer efficiency, working on the heat transfer side of the equation yields a better result than focusing on the combustion efficiency and therefore, further design considerations are required to improve the heat transfer efficiency of the new stove. Using heat resistant material to insulate around the fire and using lightweight materials (low thermal mass) for the construction of the stoves can keep the stove hot
reducing the heat loss to the sides of the combustion chamber thereby improving heat transfer efficiency and reducing the smoke and harmful emissions to a further lower levels.

The work load imposed on the cook in tending the fire and the additional labor needed to prepare the fuelwood of smaller size that fit the small sized fuel inlet, the difficulty and the possible high cost of getting the refractory bricks are some of the limitations of the new stoves. From what has been observed in the study, further investigation is also needed to assess whether the stove design principles used for the improved stoves are appropriate for such a special cooking practice -Areke distillation process.

It is difficult to explain the health benefits of the reduction of CO of 52.6% and PM of 57% concentrations achieved by the use of the improved Areke distilling stoves but the study has shown the success of the improved stove technology in addressing the human health impacts of utilization of traditional biomass.
References


Annexes

Annex 1. **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.
1.9 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.

2.4 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.

2.5 Transport the monitor to the sampling location in the Zip lock bag.

2.6 Remove the monitor from the bag and place it on the wall of the sampling location according 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.

2.7 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.

2.8 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 (see Section 9, Cleaning the Photoelectric Chamber). 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 ucbpm 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 Ziplock 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 11.2 to 11.5 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 (shown in the footer below).
Annex 2. **Standard Operating Procedure for HOBO Carbon Monoxide Logger (Collection, Downloading, and Storage of Data)**

1. **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

1.15 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

2.4 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: 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. 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. See Figure 1 in the Appendix.

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. 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 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. See Figure 2 in the Appendix.

5 All instruments must be placed in a relatively safe location to minimize the risk of interrupting household activities or being disturbed or damaged.

6 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 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 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 4: 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)

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

#### * Household Sampling Period *

<table>
<thead>
<tr>
<th>UCB ID</th>
<th>HH ID</th>
<th>Date placed on Wall (dd/Mon/yy)</th>
<th>Time placed on Wall (hh: mm)</th>
<th>Monitor Height (cm)</th>
<th>Monitor Distance from Stove (cm)</th>
<th>Monitor Distance from __________________ (cm)</th>
<th>Date removed from Wall (dd/Mon/yy)</th>
<th>Time removed from Wall (hh:mm)</th>
<th>UCB ID</th>
<th>HH ID</th>
</tr>
</thead>
<tbody>
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</table>

#### Post-Sampling Calibration Period (at least 40 minutes)

<table>
<thead>
<tr>
<th>UCB ID</th>
<th>Location (Office or other, specify)</th>
<th>Date (dd/Mon/yyyy)</th>
<th>Calibration Start Time (hh:mm)</th>
<th>Calibration End Time (hh:mm)</th>
</tr>
</thead>
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</table>
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 5: HOBO CO Sampling Data Form

## HOBO CO Household Sampling Period

<table>
<thead>
<tr>
<th>HOBO ID</th>
<th>HH ID</th>
<th>Date placed on Wall (dd/Mon/yyyy)</th>
<th>Time placed on Wall (hh:mm)</th>
<th>Monitor Height (cm)</th>
<th>Monitor Distance from Stove (cm)</th>
<th>Date removed from Wall (dd/Mon/yyyy)</th>
<th>Time removed from Wall (hh:mm)</th>
<th>HOBO ID</th>
<th>HH ID</th>
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HOBO CO logger

<table>
<thead>
<tr>
<th>Downloaded data/file information</th>
<th>Initials of data manager</th>
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</thead>
<tbody>
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</table>

- Are there values of CO above 125ppm
  - [ ] Yes
  - [ ] No

- Does the graph look ok?
  - [ ] Yes
  - [ ] No

- File name on desktop/laptop computer
  - H_ _ _ _ _ _ _ ___ ___ _____ _ _ _ _

- ID/name of back-up CD-ROM

## CO Dosimeter Tube Sampling Data Form

<table>
<thead>
<tr>
<th>CO TUBE ID</th>
<th>HH ID</th>
<th>Date placed on Wall (dd/Mon/yyyy)</th>
<th>Time placed on Wall (hh:mm)</th>
<th>Tube Height (cm)</th>
<th>Tube Distance from Stove (cm)</th>
<th>Date removed from Wall (dd/Mon/yyyy)</th>
<th>Time removed from Wall (hh:mm)</th>
<th>CO TUBE ID</th>
<th>HH ID</th>
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Length of brown stain in field,

<table>
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<tr>
<th>#1 (mm)</th>
<th>Initials of reader #1</th>
<th>#2 (mm)</th>
<th>Initials of reader #2</th>
<th>Supervisor’s initials</th>
<th>Comments</th>
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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 6: Controlled Cooking Test Data Collection Form**

Type of stove ____________________  
Tester(s) ____________________  
Cook’s Name ____________________

<table>
<thead>
<tr>
<th>Date</th>
<th>Test No.</th>
<th>Stove No.</th>
<th>Weight of cooking pot (g)</th>
<th>Weight of cooking pot rest (g)</th>
<th>Weight of flask (g)</th>
<th>Temperature of distilland (°C)</th>
<th>Weight of Char container (g)</th>
<th>Time (hh:mm)</th>
<th>Air Temperature (°C)</th>
<th>Ave. dimension of wood (l<em>w</em>h) (cm)</th>
<th>Weight of wood (g)</th>
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### Annex 7: 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

<table>
<thead>
<tr>
<th>Name(s) of Tester(s)</th>
<th>Type of stove: Stove 1</th>
<th>Type of stove: Stove 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Wood species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Eucalyptus Globulus (Southern Blue Gum, Fever Tree)</td>
</tr>
</tbody>
</table>

#### Quantitative testing conditions

<table>
<thead>
<tr>
<th>Avg dimensions of wood (length x width x height)</th>
<th>cm</th>
<th>Empty weight of Pot # 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>g</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wood moisture content (% - wet basis)</th>
<th>%</th>
<th>Empty weight of Pot # 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m</td>
<td>g</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Local boiling point of water (default value is 100 °C - correct if local value differs)</th>
<th>°C</th>
<th>Empty weight of Pot # 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T_b</td>
<td>g</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weight of container for char</th>
<th>g</th>
</tr>
</thead>
</table>

---

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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.

<table>
<thead>
<tr>
<th>Test-1</th>
<th>Instrument reading (% dry basis)</th>
<th>Test-2</th>
<th>Instrument reading (% dry basis)</th>
<th>Test-3</th>
<th>Instrument reading (% dry basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piece 1</td>
<td></td>
<td>Piece 1</td>
<td></td>
<td>Piece 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Piece 2</td>
<td></td>
<td>Piece 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average moisture content (%)</td>
<td>Average moisture content (%)</td>
<td>Average moisture content (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dry-basis</td>
<td>wet-basis</td>
<td>dry-basis</td>
<td>wet-basis</td>
<td>dry-basis</td>
<td>wet-basis</td>
</tr>
<tr>
<td>Test-1</td>
<td>Instrument reading (% dry basis)</td>
<td>Test-2</td>
<td>Instrument reading (% dry basis)</td>
<td>Test-3</td>
<td>Instrument reading (% dry basis)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piece 1</td>
<td></td>
<td>Piece 1</td>
<td></td>
<td>Piece 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Piece 2</td>
<td></td>
<td>Piece 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average moisture content (%)</td>
<td>Average moisture content (%)</td>
<td>Average moisture content (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dry-basis</td>
<td>wet-basis</td>
<td>dry-basis</td>
<td>wet-basis</td>
<td>dry-basis</td>
<td>wet-basis</td>
</tr>
</tbody>
</table>

Fuel moisture content worksheet

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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.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Name</th>
<th>Amount (g)</th>
<th>Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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### 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)

<table>
<thead>
<tr>
<th>MEASUREMENTS</th>
<th>Units</th>
<th>Initial measurements</th>
<th>Final measurements</th>
<th>Comments about cooking process (smokiness, ease of use, etc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of wood used for cooking</td>
<td>g</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight of charcoal+container</td>
<td>g</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight of Pot # 1 with cooked food</td>
<td>g</td>
<td></td>
<td>P1_f</td>
<td></td>
</tr>
<tr>
<td>Weight of Pot # 2 with cooked food</td>
<td>g</td>
<td></td>
<td>P2_f</td>
<td></td>
</tr>
<tr>
<td>Weight of Pot # 3 with cooked food</td>
<td>g</td>
<td></td>
<td>P3_f</td>
<td></td>
</tr>
<tr>
<td>Weight of Pot # 4 with cooked food</td>
<td>g</td>
<td></td>
<td>P4_f</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>min</td>
<td></td>
<td>t_i</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>t_f</td>
<td></td>
</tr>
</tbody>
</table>

### Calculations

<table>
<thead>
<tr>
<th></th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total weight of food cooked</td>
<td>( W_i = \sum_{j=1}^{4} (P_j - P_j) )</td>
</tr>
<tr>
<td>Weight of char remaining</td>
<td>( c_c = k - c_c )</td>
</tr>
<tr>
<td>Equivalent dry wood consumed</td>
<td>( f_d = (t_f - t_i) \times (1 - (1.12 \times m)) - 1.5 \times \Delta c_c )</td>
</tr>
</tbody>
</table>

### Wind conditions
- No wind

### Temperature
- \( ^\circ C \)

---

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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

<table>
<thead>
<tr>
<th>Stove type/model: Stove 1</th>
<th>Location</th>
<th>Wood species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stove type/model: Stove 2</td>
<td>Location</td>
<td>Wood species</td>
</tr>
</tbody>
</table>

1. CCT results: Mirt scoria

<table>
<thead>
<tr>
<th>units</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Mean</th>
<th>St Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total weight of food cooked</td>
<td>g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight of char remaining</td>
<td>g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equivalent dry wood consumed</td>
<td>g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific fuel consumption</td>
<td>g/kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cooking time</td>
<td>min</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Summary of comments on stove 1

<table>
<thead>
<tr>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

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### 2. CCT results: Open fire

<table>
<thead>
<tr>
<th></th>
<th>units</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Mean</th>
<th>St Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total weight of food cooked</td>
<td>g</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight of char remaining</td>
<td>g</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equivalent dry wood consumed</td>
<td>g</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific fuel consumption</td>
<td>g/kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cooking time</td>
<td>min</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Summary of comments on stove 2

- Comments...
- Comments...
- Comments...

### Comparison of Stove 1 and Stove 2

<table>
<thead>
<tr>
<th></th>
<th>% difference</th>
<th>T-test</th>
<th>Sig @ 95% ?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific fuel consumption</td>
<td>-118%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cooking time</td>
<td>-2%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Annex 8: Summary of the data observed in the study

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Stove type</th>
<th>CO whole time</th>
<th>CO 8-hr</th>
<th>CO 15-min</th>
<th>PM whole time</th>
<th>PM 8-hr</th>
<th>PM 15-min</th>
<th>Fuel used (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Traditional</td>
<td>56.06</td>
<td>56.51</td>
<td>73.00</td>
<td>1.30</td>
<td>1.33</td>
<td>2.98</td>
<td>55050</td>
</tr>
<tr>
<td>2</td>
<td>Traditional</td>
<td>47.47</td>
<td>47.51</td>
<td>73.29</td>
<td>1.26</td>
<td>1.29</td>
<td>2.38</td>
<td>55500</td>
</tr>
<tr>
<td>3</td>
<td>Traditional</td>
<td>41.27</td>
<td>43.62</td>
<td>63.07</td>
<td>1.15</td>
<td>1.13</td>
<td>2.52</td>
<td>57200</td>
</tr>
<tr>
<td>4</td>
<td>Traditional</td>
<td>45.54</td>
<td>47.65</td>
<td>74.27</td>
<td>1.05</td>
<td>1.09</td>
<td>2.95</td>
<td>53450</td>
</tr>
<tr>
<td>5</td>
<td>Traditional</td>
<td>56.29</td>
<td>58.49</td>
<td>75.51</td>
<td>1.03</td>
<td>1.11</td>
<td>2.36</td>
<td>55400</td>
</tr>
<tr>
<td>6</td>
<td>Traditional</td>
<td>44.34</td>
<td>48.04</td>
<td>83.38</td>
<td>1.26</td>
<td>1.28</td>
<td>4.73</td>
<td>53650</td>
</tr>
<tr>
<td>7</td>
<td>Traditional</td>
<td>49.12</td>
<td>54.40</td>
<td>83.02</td>
<td>1.20</td>
<td>1.23</td>
<td>2.88</td>
<td>55900</td>
</tr>
<tr>
<td>8</td>
<td>Traditional</td>
<td>52.46</td>
<td>55.45</td>
<td>85.91</td>
<td>1.31</td>
<td>1.31</td>
<td>2.63</td>
<td>65150</td>
</tr>
<tr>
<td>9</td>
<td>Traditional</td>
<td>55.74</td>
<td>58.58</td>
<td>77.82</td>
<td>1.46</td>
<td>1.65</td>
<td>3.90</td>
<td>58800</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td><strong>49.81</strong></td>
<td><strong>52.25</strong></td>
<td><strong>76.58</strong></td>
<td><strong>1.22</strong></td>
<td><strong>1.27</strong></td>
<td><strong>3.04</strong></td>
<td><strong>56677.78</strong></td>
</tr>
</tbody>
</table>

| Std. Dev | 5.593251602 | 5.5653208 | 6.9730115 | 0.134249338 | 0.17013 | 0.7881883 | 3577.9805 |
| CV       | 0.112291776 | 0.106513  | 0.09105   | 0.109707859 | 0.1340694 | 0.2594517 | 0.0631285 |

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Stove type</th>
<th>CO whole time</th>
<th>CO 8-hr</th>
<th>CO 15-min</th>
<th>PM whole time</th>
<th>PM 8-hr</th>
<th>PM 15-min</th>
<th>Fuel used (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Improved</td>
<td>29.29</td>
<td>30.00</td>
<td>39.43</td>
<td>0.45</td>
<td>0.41</td>
<td>0.76</td>
<td>53800</td>
</tr>
<tr>
<td>2</td>
<td>Improved</td>
<td>24.91</td>
<td>27.08</td>
<td>36.93</td>
<td>0.44</td>
<td>0.36</td>
<td>0.79</td>
<td>57350</td>
</tr>
<tr>
<td>3</td>
<td>Improved</td>
<td>16.07</td>
<td>16.25</td>
<td>33.64</td>
<td>0.48</td>
<td>0.45</td>
<td>1.08</td>
<td>54400</td>
</tr>
<tr>
<td>4</td>
<td>Improved</td>
<td>21.05</td>
<td>21.25</td>
<td>31.47</td>
<td>0.50</td>
<td>0.34</td>
<td>1.22</td>
<td>52650</td>
</tr>
<tr>
<td>5</td>
<td>Improved</td>
<td>21.86</td>
<td>21.07</td>
<td>28.51</td>
<td>0.55</td>
<td>0.41</td>
<td>2.12</td>
<td>54250</td>
</tr>
<tr>
<td>6</td>
<td>Improved</td>
<td>28.68</td>
<td>31.72</td>
<td>39.00</td>
<td>0.65</td>
<td>0.63</td>
<td>2.15</td>
<td>54750</td>
</tr>
<tr>
<td>7</td>
<td>Improved</td>
<td>26.68</td>
<td>27.00</td>
<td>34.82</td>
<td>0.67</td>
<td>0.59</td>
<td>1.47</td>
<td>55900</td>
</tr>
<tr>
<td>8</td>
<td>Improved</td>
<td>22.07</td>
<td>22.99</td>
<td>34.13</td>
<td>0.49</td>
<td>0.52</td>
<td>1.00</td>
<td>58050</td>
</tr>
<tr>
<td>9</td>
<td>Improved</td>
<td>21.93</td>
<td>22.62</td>
<td>26.93</td>
<td>0.51</td>
<td>0.50</td>
<td>1.17</td>
<td>60950</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td><strong>23.61</strong></td>
<td><strong>24.44</strong></td>
<td><strong>33.87</strong></td>
<td><strong>0.53</strong></td>
<td><strong>0.47</strong></td>
<td><strong>1.31</strong></td>
<td><strong>55788.89</strong></td>
</tr>
</tbody>
</table>

| Std. Dev | 4.197121902 | 4.8941265 | 4.3319539 | 0.081924587 | 0.1099684 | 0.5158636 | 2583.2124 |
| CV       | 0.177734902 | 0.2002383 | 0.1278903 | 0.155396063 | 0.2165934 | 0.3948787 | 0.0463033 |
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