University of Ghana
College of Basic and Applied Sciences

Design, Construction and Assessment of an Improved Hybrid Charcoal-LPG Cookstove

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DECLARATION

This is to certify that this thesis is the result of research undertaken by Emmanuel Berko towards the award of the Master of Philosophy degree in Food Science in the Department of Nutrition and Food Science, University of Ghana.

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ABSTRACT

Globally three (3) billion people use inefficient cook stoves and fuels and the smoke emitted from these cook stoves leads to 4.3 million deaths per year. In Ghana, 70% of households use traditional cook stoves and solid fuels whose emissions lead to 17,000 deaths every year with 50% of them being children under five (5) years of age. Whilst the negative health impacts of the emissions generated by these cook stoves is increasingly being recognized, there are limited varieties of improved cook stoves that can eliminate these negative impacts on indoor air quality, and consequently on the health of the households. The aim of the study was to design, construct and assess the performance of an institutional cook stove, which uses charcoal or LPG as an alternate fuel.

Engineering and non-Engineering principles were followed to achieve a successful design and meet the necessary requirements. Performance tests (i.e. the controlled cooking test and emissions test) carried out on the cook stove. In comparison with the traditional charcoal cook stove, the newly designed cook stove had a specific fuel use reduction of 21.26% and an increase in processing rate of 20.00%. With regards to emissions, it had significant carbon monoxide and particulate matter reductions of 35.55% and 9.42% respectively which were both below the WHO limits. Similarly, when using LPG, its performance was comparable with locally produced LPG cook stoves, with carbon monoxide and particulate matter emissions reduced by 47.50% and 43.29% respectively. This therefore attested that the designed cook stove was an improved type.

Cooking with this improved cook stove will reduce the quantity of fuel needed for a cooking session and also facilitate a faster cooking time for larger quantities of foods cooked. Whiles benefiting from these, users who are exposed to hazardous emissions such as carbon monoxide and particulate matter are relieved by the significant reductions emitted from the improved cook

stove. This makes room for addressing the health implicatory issues that all users are exposed to and affected by eventually.

DEDICATION

This thesis has been successful by the intervention of the Almighty God. I appreciate the encouragement of my father, Mr. Samuel A. Berko and the prayers of my entire family. I also dedicate this work to my late mother Mrs. Esther Berko for the inspirational upbringing. I thank the lecturers especially my supervisor Professor Firibu K. Saalia for his time and guidance and all those who contributed to the success of this work in all kinds of way.

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FAO – Food and Agricultural Organization

GACC – Global Alliance for Clean Cook stoves

LPG – Liquefied Petroleum Gas

WHO – World Health Organization

AISI – American Iron and Steel Institute

1.0 INTRODUCTION

1.1 Background and Overview

The global community cannot achieve its goals of addressing climate change without also addressing the fuel energy sources of millions for domestic and mass or institutional cooking (United Nations Development Program, 2016). Globally, more than 3 billion people rely on the use of inefficient cook stoves and solid fuels for cooking and these are leading to over 4 million deaths per year (World Health Organization, 2015). It has been noted that the use of solid fuels in open fires and traditional stoves for cooking leads to one of the world's most persistent health and climate issues. The use of solid fuels and traditional cook stoves cause environmental problems such as air pollution, climate change, deforestation, and loss of biodiversity. According to the WHO (2015) cook stove smoke is a major contributor to indoor air pollution in developing countries. Exposure to smoke from traditional cook stoves and open fires causes 4.3 million premature deaths annually and this contributes to a range of chronic illnesses and acute health impacts such as pneumonia, lung cancer, heart disease, low birth-weight, burns etc.

There is, therefore, the urgent need for developing more clean and efficient cook stoves and fuels for improving both the environment and health of the public. The adoption of such cook stoves will lead to better combustion of fuel, and improved heat transfer leading to a reduction in fuel demand improved health of users and also potentially lower costs of cooking (World Bioenergy Association, 2016). Since the 1940s, there has been a wider development agenda to take up and accept Improved cook stoves (ICS) to solve the issues of health, environment, gender and safety that surrounds traditional cooking methods (Anhalt & Holanda, 2009). These Cook stoves vary greatly in terms of performance across different models and designs. A set of international guidelines for the performance of stoves was developed under the International Standards

Organization International Workshop Agreement process (Global Alliance for Clean Cook stoves, n.d.). This measure and classify performance according to efficiency, emissions and safety as well as affordability, accessibility, and livelihood impacts. A combined systems approach involving all these factors is essential when deciding on a specific outcome for a cook stove design. Furthermore, factors such as efficient forest management, replacing traditional fuels like charcoal with modern and renewable fuels like pellets, ethanol, electricity etc., and proper awareness are key to protecting the environment and the health of the public.

The situations encountered during cooking in the household are the same with that of social institutions such as schools, hospitals, orphanages, prisons etc. where mass cooking takes place (Ethio Resource Group, 2015). Problems which are likely to be associated with such mass or institutional cooking have not been sufficiently addressed. This research aims at designing and testing a new design concept of cook stove for improved mass or institutional cooking. The objectives of this research are varied and will be detailed in order to achieve specific goals.

In the urban areas in developing societies, biomass (mostly charcoal) cook stoves are mostly used in both institutional and residential cooking. As a fuel source, charcoal competes well with other heat sources like gas, kerosene, alcohol etc. due to its cheap and easy accessibility. When charcoal is burnt inefficiently, it creates some major draw backs such as, production of high levels of Carbon Monoxide (CO) emissions, high levels of particulate matter (PM) emissions and also the destruction of the natural vegetation from which charcoal is produced (Anderson, 2009). This challenge calls for the need to improve the system in which charcoal is burnt i.e. providing an improved charcoal cook stove. This improved cook stove will contribute to the significant reduction of deforestation problems and greenhouse gases while providing users with the economical energy source and healthier cooking environment.

1.2 Justifications

Based on a pilot survey conducted within the Tema metropolis and Bawaleshie all in the Greater Accra region, most women involved in institutional cooking complained of inhaling lots of smoke during cooking sessions due to the use of traditional cookstoves and firewood as the main fuel source or charcoal as an alternate fuel. This form of exposure as detailed from other research work will eventually lead to health complications.

The current design trends of most institutional cook stoves are specifically tuned to a particular food, such as the Chrisaach (Gari) stove, Commeh Gari stove (Gari) etc. It is with this trend that the design for this research would be made to accommodate as much variety of cooking as possible i.e. boiling, frying and roasting.

Due to issues with deforestation as a result of firewood and charcoal production or usage as fuels for cooking food, design for this research work will incorporate both charcoal and gas as fuel options for cooking. This approach will help users who are familiar with charcoal usage to adapt quickly and easily to the use of LPG as a fuel for cooking which according to the United Nations' Sustainable Goals is a positive global transition.

1.3 Objectives of the Study

1.3.1 Main Objective

The main objective of this research is to design a clean and efficient charcoal-LPG cook stove for institutional cooking and assess its performance.

1.3.2 Specific Objectives

I. Designing of a clean and efficient institutional charcoal-LPG cook stove, considering some important parameters such as dimensions, selection of materials and control features.

II. Testing the performance of the improved cook stove that has been successfully designed and fabricated in relation to the performance of the traditional cook stove that is being used originally by the target group; where performance, in this case, is classified by the specific fuel consumed and the processing rate by the improved cook stove.

III. Assessing the levels of emissions generated by the improved cook stove during the testing process and that of the traditional stove.

1.4 Possible benefits

In this research, there are benefits that can be achieved when the objectives and goals set are reached successfully, and they can be purported to be the following:

Successfully designing the improved cook stove could prevent indoor air pollutions from accumulating in the enclosed cooking area.

Achieving the goal of designing an efficient clean institutional cook stove could contribute to the development of sustainable cooking technologies.

Reaching and exceeding the standard of attaining a clean cook stove that contributes to controlling climate change issues such as emissions into the environment.

The outcome of these objectives will add to the knowledge obtained in the area of cook stoves and fuels. Successfully achieving all objectives will be beneficial to society as well as the academic community in which this research is being undertaken.

1.5 Significance and application of the study

The benefits accompanying cook stove technology improvement generally fall into two categories. Those that are internal to the household and institutions and those that are external, thus indirectly to the environment. Internal benefits comprise of reduced concentrations of smoke and indoor air pollutions (IAP), money and time saved in acquiring wood or biomass fuels and reduction in the quantity of biomass usage. External benefits will consist of less pressure exerted on the forest and energy resources, reduction in greenhouse gases, skill development and job creation to the community (Barnes, 1993; Regional Wood Energy Development Programme, 2009). Sherka (2011) indicated that because biomass fuels will continue to dominate the energy demand all across the developing countries in the near future, the development of more clean and efficient biomass technologies is very important for lessening poverty, creating employment and also helping in expanding the rural markets. The main beneficiaries of improved stoves are women and those in the middle and lower income levels of society. The economic and environmental impacts of adopting improved stoves also can be quite substantial for both the urban and rural communities. In areas where wood is being harvested faster than it is being grown, the use of more efficient stoves is needed most in order to reduce demand for wood to a certain sustainable level. This approach is usually more economically viable than just planting new trees in the initial stages (Sherka, 2011). When it comes to improved cook stoves, their better insulation system makes the stove less hot to the touch and hence safer for the cooking and having children around. A healthier and safer environment, particularly for women and children may be one of the most important potential contributions of improved stoves in amending the restricted living conditions of many poor people. Switching to cleaner energy, increasing fuel efficiency and cleaner combustion through better cook stoves can reduce health risks for all family members. Beyond a decrease in respiratory problems, a more secure household energy situation enables water to be boiled and thus helps reduce the incidence of waterborne diseases. It can also increase the number of hot meals consumed per day and thus improve food safety and nutrition problems faced by the community (Sherka, 2011).

2.0 LITERATURE REVIEW

This chapter discusses some studies related to the evolution of cook stoves (from traditional to improved modern cook stoves), design, fabrication and testing of improved cook stoves. This chapter also includes some literature that are related to achieving optimal efficiency and clean cook stove for institutional purposes.

2.1 Historical Review of Cook stoves

In the very early ages of mankind, cooking has been done presumably over an open-fire with its fuel arranged in a pyramid shape. This approach of cooking was basically intended for roasting meat and keeping the body warm. It then became a big concern when there was a lack of proper control of the heat, smoke and fire hazards that occurred (Kumar, Prasad, & Mishra, 2015). A key step in the evolution process of cook stoves was when pots of different shapes and sizes were developed. This induced the modification of the open-fire system where by a three-stone arrangement was introduced in order the balance the pots over the open-fires. The stones were usually arranged at approximately one hundred and twenty degrees (120°) to each other on a leveled ground. This modified system of cooking not only aided in balancing the pots over the fires but in addition, it prevented spreading and/or quenching of fires by strong winds as well as increasing the cooking efficiency (Kumar et al., 2015).

However, the three-stone arrangement had major drawbacks which were similar to the open fire system. As such, the three-stone was replaced with a U-shaped mud in a similar 120° orientation where this was almost an enclosed system with the front opened for fuel feeding and air entry for easy combustion. The upper shape for the mud was a hump, and this served as a stable pot rest as well as better combustion of volatile matter and an exit for exhaust gas. All these modifications and innovations were developed based on users' own experience with using the cook stoves.

Innovations from these systems were successful when it came to improving efficiencies of the cook stoves but health and other hazards persisted. From these ages to recent times, it has been observed in the developing world that a 75% estimate of the population are still using the three-stone or a shielded-fire for cooking just as the pre-historic ancestors did some several years ago (Kumar et al., 2015).

Taking a look at India during the 1950's, the first-phase of developing improved cook stoves (ICS) started with trying to improve cook stoves that use biomass as fuel. Improved multi pot stoves were the first to be introduced to solve the problem of smoky working environments during cooking sessions (Raju, 1957). It was indicated by Kumar et al. (2015) that Theodorolic tested the biomass burning improved cook stove and this was a controlled laboratory test. He was the first to conduct a test on a cook stove even though the thermal efficiency of the cook stove wasn't tested. Further testing and studies were conducted by measuring the cook stove efficiency of a similar design to the mud stone which was introduced by Raju (1961).

Based on detailed thermodynamic principles, the second phase of ICS development came up which involved much extensive research studies, specifically heat transfer and aerodynamic studies which led to a sounder technique. As the years passed by, more systematic and design procedures were established in a gradual process. This idea of laboratory testing proliferated different cook stove models throughout many developing and developed countries. In a period of about ten (10) years, during the 1970s and 1980s, there has been a lot of advocacy for the use of improved cook stove and in Africa, Asia, and Latin America, international donors have been very strong in influencing, promoting and assisting processes to prioritize ICS. After some years past, these international bodies, unfortunately, became short lived. This was as a result of the inability of the programs to meet the expectations and requirements of the consumer, specific objectives, and some systematic institutional arrangements.

In the transition to the third (3rd) Phase, which was mostly in the 1980s, the influences that led to cook stove designs and testing shifted towards the decisions and needs of the users. These needs were as a result of problems encountered during the second (2nd) phase of cook stove designs and usage. Users feedback on the criteria for them choosing a particular cook stove was not only centered on fuel saving ability but also cooking in smoke-free kitchens, convenience and safety of the cook stove which are all very important factors to consider.

In recent times, results reported by Kumar et al. (2015) of the Energy and Policy Institute of the East-West center showed that goals that have been set for improved cook stoves programs have been on the rise and from diverse angles across the world. These goals are mainly based on geographical areas where the programs are taking place and they are quite distinct to that particular region. In general, the most intersecting goal across board was noted to be placing emphasis on smoke reduction, increased fuel efficiency and an increase in the environmental awareness. An international conference dubbed the Regional Expert Consultation on ICS development was held and organized by the FAO in 1991. This conference focused on the status of South-Asian ICS programme that was undergoing some reviews and some common problems and constraints came to the attention of members. The solutions to these problems as well as future directions were specifically spelled out and reported. It was considered that “Future Improved Cook Stoves Programme should follow a wider systems approach and should not only look at the introduction of ICSs but also at improved kitchens, cooking practices, utensils and fuels” (FAO/RWEDP, 1991). It was also highlighted in the same report that, the role of improved cook stoves in reducing toxic, harmful and greenhouse gases could be considered through cleaner combustion processes.

In a summarized statement, the issue of major concern in relation to modern context was skewed to focusing on the quality of air, linking between the design and functions of the cook stove and also trying the best possible means to eliminate cooking drudgery.

2.2 Rationale of Early Cook Stove Programs

During the periods of the middle and late 1970s, there was a general notation that, "appropriate technology" and also "small being beautiful" combined with the international issue of deforestation and perception of the serious effect of high prices in energy. This ushering process of cook stove projects are either largely or solely funded by international agencies (Krugmann, 1989).

In the developing world, wood and all other forms of biomass such as; dried agricultural waste, dried animal excreter, etc., where exclusive sources of energy for majority of the people (Wood, 1985). Over 70% of energy is consumed by wood fuels, which is just about two-thirds of the energy available, due to domestic cooking. When it came to international organizations, the issue of wood fuels and other observations pushed an agenda to develop rationales based on events that were being faced with respect to the wood stoves usage. One of the first observations that were made in developing a rationale comes from the efficiency of the wood fuels. Were upon some tests, it was observed that energy in wood was inefficiently converted to useful energy used in cooking. An estimate of about 5-10% efficiency was linked to wood fuels, were as for kerosene and LPG stoves the efficiency ranged between 30-60% (Krugmann, 1989). One of the main objectives aimed at solving this issue during that time was that the efficiency of the wood stoves must be improved in order to reduce the quantity of wood fuel or biomass needed to cook the same amount of food. If these rationales were successful, it was perceived that it would reduce the pressure on the forest and also allow the less privileged people to spend less of their limited financial resources on purchasing cooking fuels. Time spent in gathering fuels by women and children would also be reduced significantly if these interventions are executed properly and successfully. Conclusively on this area of intervention, a firm belief which was established based on the laboratory tests performed on the cook stoves. This indicated that there are some possible impact users can benefit from the interventions and this is mainly saving up to two-thirds of the fuel consumed previously by their wood stoves. A large number of similar intervention programs were therefore disseminated across by these international firms (Krugmann, 1989).

Subsequently, these interventions' attention shifted to the potential of improved cook stoves to be able to save biomass fuels and limit deforestation alongside. In recent times, there is a change in focus to rather the health-related aspects of improved cook stove programs, as the benefits of changing from traditional stoves to improved ones are increasingly stressed by public health specialists. In summary to these focuses, factors such as cooking comfort, convenience, and safety in the use of the stoves are starting to get incorporated into program design which is being accepted worldwide (Regional Wood Energy Development Programme, 2009).

In the industrialized countries, the switch to more efficient stoves took place quiet smoothly as fuel wood prices were on the rise and cook stove makers increased efforts to build more efficient models. This era of efficiency was then followed by a shift to cleaner fuels for cooking, such as coal and petroleum-based fuels. As the accessibility and availability to petroleum-based fuels started to increase during the early stages of the 20th century, many urban households within the developing countries moved on to stoves that used oil-based products such as kerosene or LPG as its fuel, just like the developed nation correspondents. Unfortunately, on the other hand, rural households continued with the practice and use of burning biomass fuels for cooking and heating purposes. This was as a result of weak delivery channels for petroleum-based products and rural people not being able to afford these fuels, especially when comparing to biomass resources, which in a literal sense were more freely available to the users (Barnes, 1994). In the 1970s, oil prices increased in such a way that even urban households found it extremely hard to pay for petroleum-based fuels such as kerosene and LPG. This resulted in many of these households stepping back down the energy ladder and going back to using biomass fuels as their household energy source (Sherka, 2011). When it comes to energy usage in developing nations, domestic cooking makes up a major portion of the total energy which is close to about 60% in Sub-Saharan Africa. This implies that nearly three (3) billion people worldwide cook their meals on simple cook stoves that use biomass as its fuel (Kammen, 1995). The major and common aim of improved cook stove programs is to develop more efficient, energy-saving, and inexpensive biomass cook stoves, that can help lessen the direct pressure exerted on available wood resources, shorten the walking time required to collect the wood fuels, reduce monetary expenses needed for purchasing these fuels (wood or charcoal) and also significantly reduce the pollutions emitted to the open environment (Barnes, 1994). One of the first improved stoves was called the “Magan Chula”, which was introduced in India around 1947. There was a publication called “Smokeless Kitchens for the Millions” (Raju, 1961) which at that time was promoting the health and convenience benefits of improving efficiency in the burning of biomass. It additionally encouraged the promotion of improved cook stoves. The early trend of cook stove programs focused on the health aspects of interventions such as these. The overall objective was to elevate the living conditions of the poor in the developing world (Karekezi & Rahja, 1997). The focus and attention subsequently moved to the possibility for saving biomass fuels and limiting the problem of deforestation. Currently, there is a change in direction again with regards to focus and this is directed on the health-related aspects of improved cook stove programs. This is due to the possible benefits to be encountered when moving from traditional stoves to improved cook stoves.

Table 2.1: Alternative interventions to improved cook stove programs

ALTERNATIVE INTERVENTION	BENEFIT
• Transition to less polluting fuels for cooking, such as LPG, ethanol, or solar energy. • Improving indoor environments with the addition of chimneys, flues, hoods, and ventilation. • Changing household behavior, i.e. modifying cooking practices, keeping children away from the fire. • Rural electrification.	• Reducing Indoor Air Pollutions (IAPs).
• Reforestation programs. • Transition to less polluting fuels for cooking. • Rural electrification.	• Less pressure on forest and energy resources. • Reduced biomass use. • Reduced greenhouse gases.
• Income and /or fuel price subsidies.	• Money and time saved in acquiring fuel.
• Programs concentrating on income generating activities. • Microfinance projects.	• Skill development and job creation.

Source: (Bose et al., 1993)

2.3 Problems faced with Traditional Cook stoves

The World Health Organization (WHO) has indicated that 4.3 million people including women and children suffer from chronic illnesses and acute health impacts such as pneumonia, lung cancer, heart disease, low birth-weight, burns etc. These persons affected die prematurely every year from exposure to polluted air that is generated from cooking with solid biomass fuels (such as wood, dried grass, shrubs etc.) on inefficient open stoves (World Health Organization, 2007). The frequent occurrence of unhealthy outcomes is primarily caused by inhaling fine soot particles (≤ 2.5µm in aerodynamic diameter) (Smith et al., 2009).

Over 80% of households and institutions in Ghana continue to depend on solid fuels (i.e. wood and charcoal) for cooking. And this has led to about 13,400 deaths as a result of indoor air pollution (IAP). This toxic cook stove smoke affects majority of people in the society who are mainly women and children (Global Alliance for Clean Cookstoves (GACC2), 2016).

This alarming trend has encouraged and pushed for the adoption of clean cook stoves and fuels that can save lives and reduce illness. Clean and efficient cook stoves are a significant development for improving both the environment and health of the public. When such cook stoves are adopted, it can lead to better combustion of fuel, an improved heat transfer leading to a reduction in fuel demand, improved health of women and children and also potentially lower costs of cooking (World Bioenergy Association, 2016). Since the 1940s, there has been a wider development agenda to take up and accept Improved cook stoves (ICS) to enable a successful tackle to the issues of health, environment, gender and safety that surround traditional cooking methods (Anhalt & Holanda, 2009).

The situations encountered during cooking in the household is comparably the same as that of social institutions such as universities, hospitals and prisons where mass cooking takes place (Ethio Resource Group, 2015). Problems which are likely to be associated with institutional cooking have not got sufficient attention, and therefore this project aims at designing and testing a new design concept to add more knowledge and facts to the pool of limited information related to improved institutional cook stoves.

2.4 Fuels

2.4.1 Usage and benefit of some fuel types

Table 2.2: Advantage and Disadvantages of some Fuels

Fuel Type	Pros	Cons
Firewood	• Can often be collected for free.	• High levels of smoke. • Contributes towards issues of deforestation.
Charcoal	• Commonly found in all Urban areas. • Typically, cleaner burning than wood.	• Current production of Charcoal is inefficient and it contributes to deforestation. • Presence of toxic fumes.
LPG	• Has a very clean burning process.	• Periodic shortage of supply. • Much more expensive compared to wood and charcoal.
Electricity	• Very clean.	• Electricity is quite expensive. • Issues of power outages.

Source: (Global Alliance for Clean Cookstoves, 2012)

2.4.2 Description of some fuels –

Charcoal: Based on the health effects and deforestation issues addressed, considerations must be made when making crucial decisions on fuel selection and cook stove design. It is with this that, methods and their approach must aim at reducing users' exposure to high IAP levels. The continued development of improved cook stoves help significantly in reducing chemical emissions from charcoal burning and it also improves the combustion efficiency which in the end results in improved air quality (Dutta, et al. 2007). Some urban-rural households in Ghana use the charcoal as their primary source of fuel. (Agbey, 2015) presented on the fuel usage distribution across the various regions in Ghana, and it has been noted in figure 2.1 below.

Liquefied Petroleum Gas (LPG): with a solid defense based on research, it has been established that LPG burns cleaner than biomass. Unfortunately, it is a fossil fuel which is quite unaffordable for majority of people in the developing countries. When it comes to climate mitigation, improved cook stoves are supposed to accelerate this initiative and LPG has potential in achieving this agenda (Cheney, 2017).

Built on the 2010 population census, (Global Alliance for Clean Cookstoves, 2012) estimated approximately 6 million households across the country. With an even split between the urban (51%) and rural (49%) areas.

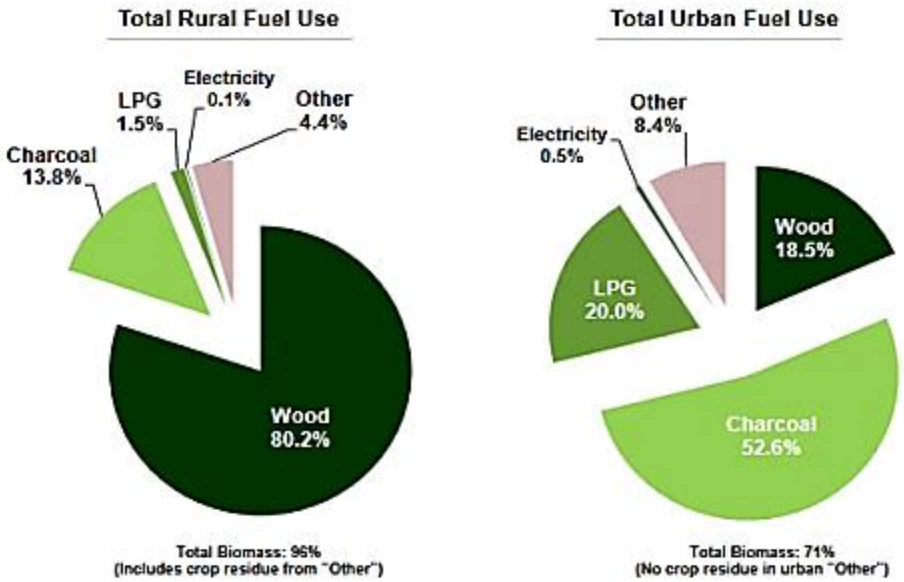

Figure 2.1: Fuel usage distribution across areas in Ghana (Agbey, 2015)

Based on this distribution, it is recommended built on the United Nation's Sustainable Development Goals (United Nations Development Program, 2016) that fuel to be used for any purpose should be clean and affordable. Therefore, it is necessary to keep cook stove users on track and bringing on board those lagging behind. LPG being a clean and much affordable as compared to other clean fuels would be encouraged and also, in addition, charcoal would be an option to be considered for purposes of availability and better emission results than common biomass fuels.

2.4.3 Characteristics of some Fuels available

Investigations by Kandpal et al. (1995) showed that the use of the traditional charcoal, kerosene and LPG cook stoves during indoor cooking has potential in accumulating high concentrations of pollutants such as CO_2, CO, Particulate Matter (PM) etc. within the indoor environment. In order to help reduce the health impacts of the pollutants, these cook stoves must be designed to be efficient enough during fuel combustion.

Table 2.3: Characteristics of some fuels and their cook stoves

Fuel Type	**Carbon Composition**	**Caloric Value (kJ/kg)**	**Cook stove type – Average Efficiency (η)**
Charcoal	43%	22,000	Coal cook stove – 32%
Kerosene	85-88%	41,000	Wick kerosene cook stove – 50%
LPG	86-88%	45,750	Gas cook stove – 62%

Source: (Kandpal et al., 1995)

2.5 Issues with Emissions

In industrialized countries where fossil fuels are the primary sources of emissions, air pollution is largely thought to occur in outdoor settings. On the other hand, indoor air pollution (IAP) is generally considered to be a problem that is connected to smoking tobacco (Sherka, 2011). The high number of air pollutants exposed to users in the household level is very important and requires much attention, however, the case is indicative in the rural households of developing countries where biomass fuel is the major and principal energy source for cooking and heating. The most common pollutant emitted from the combustion of biomass fuels are particulate matter (PM), carbon monoxide (CO), hydrocarbons, nitrogen oxides and sulfur oxides (Karekezi & Rahja, 1997). The composition of the pollutants emitted during the combustion process of biomass fuels depends on numerous factors which include; unique compositions of the fuel, environmental and combustion temperatures, the flow of air into the fire (air flow rate), mode of burning and also the type of stove being used during the cooking process (Karekezi & Rahja, 1997). These unwanted emissions of organic compounds come about due to an incomplete combustion or the recombination of partly oxidized compounds during the combustion process. Smoke is generally created by the combination of tar aggregates, inorganic particulates and presence of water. Most of the emitted pollutants that users encounter can have adverse health effects that vary in complication. It is known from toxicology that the magnitude of the effects on users depends on the situation of exposure, the concentration, the time & extent of exposure and the physiological health status of the exposed user. From a health point of view, the most important and dangerous pollutants are possibly CO and the heavier organic compounds which all in all constitute as the major element of the total suspended particulate matter (PM) (Karekezi & Rahja, 1997). It has been established that carbon monoxide even in low concentrations is a very strong poison principally because it inhibits the oxygen-carrying capacity of the blood and consequently robs the body tissues from the much-needed oxygen (O_2). Some symptoms of acute CO poisoning include drowsiness, headaches and loss of consciousness. Prolonged exposure to these pollutants may lead to physiological disturbances such as reduced blood PH and decreased birth weights of newborns (World Health Organization, 1992). Hemoglobin being the oxygen-carrying pigment in human blood has about 200 times more attraction to CO than for O_2 & henceforth a little exposure to CO can therefore be lethal. This is dangerous especially to fetuses since they primarily depend on their mothers to satisfy their oxygen demands through blood-exchange via the placenta (World Health Organization (WHO), 1992).

The major health effects caused by pollution can generally be categorized into three parts; acute, subacute and chronic. Acute effects are the most dangerous and are as a result of smoke inhalation and carbon monoxide poisoning and are considered to be the most serious, in some cases even causing death to affected persons. Sub-acute effects arise from the inflammatory action of pollutants upon the conjunctiva and mucous linings of the respiratory tract from the nose to the bronchi. The most severe outcomes of chronic effects are pulmonary and cardiopulmonary diseases and cancer. Others forms of effects under this category include conjunctiva and inflammation of the cornea which leads to impaired vision and cataract subsequent to long exposure to infra-red radiation and to chronic CO poisoning (World Health Organization (WHO), 1992).

2.6 Design Perspectives

(Umogbai & Orkuma, 2011) suggested that the design of improved cook stoves require both engineering and non-engineering principles, therefore making it more complex than just an ordinary equipment. Generally, improved cook stoves are designed based on the principles of Dr. Larry Winiarski. These design principles focus on clean combustion and also optimizing the heat transfer by providing an insulation material to the fire with lightweight and/or even heat resistant materials (Bryden et al., 2005). There must be space or distance between the fire and the pot which creates some increase in the draft and also makes the fire hot. Less amount of draft creates lots of smoke whiles too much of it cools the fire. The intensity of the fire is dependent on the amount of fuel added to the cook stove.

Design strategies can be obtained from (Chen, 2015), and these can generally be to have a large surface area for the heating medium and an increased velocity of hot air. The energy that is obtained from open fires is about 90%, but only 10% - 40% of the released energy is transferred to the pot. Therefore it is important to note that heat transfer efficiency and combustion efficiency is much more required to determine the overall efficiency of the cook stove (Bryden et al., 2005). Small openings can be designed between the cookstove and the bottom surface of the pot being heated. This will then limit cold air from entering the fire and also the use of less fuel. To improve fuel efficiency, Bryden et al. (2005) suggested wider pots with larger diameters ensures effective heat transfer.

2.7 Design Revolutions (Institutional)

Climate Smart stove: It is built from clay with a small quantity of sand (0.5% of total volume) and water. The stove has an elevated chimney of diameter 100 mm fitted behind and it is primarily designed to remove the smoke from the cooking area. It has a long inner firepot of (L x H) 920 x 310 mm for front loading of wood fuel. The stove can accommodate two (2) cooking pots. Some improved institutional cook stoves considered:

Figure 2.2: Images of the Climate smart (Left) and the Traditional 3-stone (Right) stoves

Ahotor Oven: The oven is built mainly with 5" sandcrete blocks and Portland cement. It has two combustion chambers which are partitioned and built with bricks (neither refractory nor burnt). Series of wooden trays are stalked on the top of the combustion chamber which has an opening. Tray dimensions are outside 1000 x 920 x 65 mm (L x B x H) and inside dimensions of 975 x 895 x 65 mm given wire mesh surface area of 0.872 m^2. The edges of the trays allow good interlocking which also prevents smoke leakages. The AHOTOR Oven can hold a capacity of twenty (20) trays (i.e. ten (10) on each side with an incorporated truncated pyramid shape chimney to the design.

Figure 2.3: Image of the Ahotor Oven used for smoking purposes

Figure 2.4: Images of the Lorena improved cook stove (Left) and the 3-stone stove (Right)

Source: Tiehisuma Sheabutter Processing Centre, Gurugu-Tamale

(Laryea, 2017)

2.8 Various components of the improved cook stove and their purposes

2.8.1 Air entrance –

Controlling the rate of air entering the cook stove enables regulation of the heat output of the stove. There are two types of cook stoves when it comes to air entrance categorization, and these are the natural draft cook stoves and the forced draft cook stoves. Forced draft cook stoves use a fan to "force" air into the combustion chamber, whilst in natural draft cook stoves, air enters the combustion chamber due to the natural process that involves the hot air in the combustion chamber rising and being replaced by cold air from outside. In the case of natural draft cook stoves, capacity for regulation is limited to restricting the natural air flow with doors or gates, as the maximum flow rate is set by natural laws. The maximum flow in a natural draft cook stove can however be increased by the use of chimneys on the exhaust flow from the fire. Forced draft cookers are simply controlled by regulating the speed of the fan (Higgins, 2011; Metcalfe, 2014).

2.8.3 Combustion chamber –

The shapes of combustion chambers have been noted to be slightly conical for improved charcoal stoves. Purpose of this is to keep the charcoal packed whiles it burns down & decreases the size (Stewart, 1987). Ashes that fall from the combustion chamber should be collected when necessary. This implies there must be a portion or chamber beneath the combustion chamber to aid in the easy collection of ash.

2.8.4 Pot Stand –

The pot usually sits on the pot stand with a 1–1.5cm gap for the exhaust gases, larger gaps allow more heat to escape. The pot seats are recommended to accommodate quite a range of pot sizes. Many designs have metal supports to aid in heat conduction if the combustion chamber is made of a weaker material. Similar to the air entrance door, it is also optional depending on the type and purpose of the stove. Also if the stove has a pot stand or seat, it may not be all that important to use it if the surface area of the pan being used to cook is greater than the diameter (width) of the stove rim (Sherka, 2011).

2.8.5 Mainframe or Stove body –

Different studies indicate that the weight of stoves has a high correlation with efficiency, the heavier stoves have lower efficiencies. However, very light stoves which have low heat capacity walls (e.g. thin steel) do not attain high power outputs, high efficiencies or a steady burning, without full combustion chambers. Insulating the combustion chamber with fired pottery, low-density pottery, clay, ash mix, pumice stone, cement/vermiculite mixtures, or other heat-resistant insulators, have usually increased the efficiency significantly. Insulating the outside of a cast-iron combustion chamber also increases the efficiency significantly (Stewart, 1987). It is therefore important that all these should be considered in an optimum cook stove design.

2.8.2 Grate –

The grate should have sufficient open area to allow good mixing of air underneath the charcoal. The openings should be less than 2cm wide to reduce the amount of small charcoal pieces that will fall through, but greater than 0.5 cm so that they will not get blocked. If the open area is too small enough air will not enter the combustion chamber, but if it is too great an excess of air will decrease the flame temperature. According to (Sherka, 2011) the replacement of sheet-metal grates by ceramic grates increases the charcoal bed temperature, the heat output and the overall efficiency of the cook stove, therefore, having ceramic as an insulator and a grate is recommended.

2.8.6 Burner type –

The gas burner usually has two parts and these include, the support at the bottom or a gas burner base and the burner pipe which is fitted over the base. The burner pipe is averagely 15cm diameter with holes drilled all around the upper surface, through which secondary air flows in for combustion of the supplied gas. The upper 1cm of the burner pipe is left uninsulated so that it can fit into the pot support, which will be placed over it. The burner pipe has an insulation which reduces the heat loss from the gases exiting from the reaction chamber before it is burnt in the gas burner (Belonio, 2005).

2.9 Testing and Assessment of Cook stoves

2.9.1 Controlled Cooking Test 2.0

Proposed by (Bailis, 2004) this test is also performed in a laboratory and it involves the preparation of a standardized meal such as oil or starch etc. It sheds more light on the cooking performance thus the fuel used, time spent etc. Amount of energy stored and given out by the cook stove and the fuel used would be calculated per the data recorded. Energy usage will be determined by considering parameters similar to that of water boiling test such as specific heat capacity (C_p) of the matrix used, temperature changes (ΔT) in degree Celsius (ºC) and mass of matrix to be used (m). Efficiency of the cook stove can be determined with respect to fuel consumption rate ($KJ.L^{-1}s^{-1}$ and $KJ.kg^{-1}s^{-1}$) i.e. how much fuel is saved or used up when testing a particular cook stove. Comparing data of various cook stoves will distinguish a clear efficiency difference amongst these cook stoves.

2.9.2 Emissions Test

Also proposed by (DeFoort et al., 2009) the parameters that are observed during this test are; Carbon Monoxide (CO), Carbon dioxide (CO_2) and Particulate Matter (PM) etc. There are various devices that are used in measuring the parameters of this test and they include; Portable Emission Monitoring System (PEMS), Indoor Air pollution (IAP) meter etc.

Proper sampling of the exhaust gas released from a cook stove must be collected properly to avoid losing any of the emitted gases. All emissions must be captured efficiently to avoid larger errors during their detection, and also bearing in mind that whiles capturing the emissions, its done without affecting the operation of the cook stove.

Based on the results of tests run on the improved cook stove, it can be a potential social intervention towards achieving a clean and healthy environment for the cooking procedures users undergo.

3.0 MATERIALS & METHODS

This chapter provides in detail the various materials used during the research process and outcome. These would include items that aided in achieving the experimental results which then goes down to acquiring data to support the basis of the research. This chapter also comprises of the processes and methods followed based on set principles and guidelines. These in perspective help to achieve the main objectives of the research.

3.0.1 Design Parameters

Determining the Gap needed to aid in optimizing the quantity of exit air, the Winiarski method of maintaining a constant area under the pot was used. The correct height of gap under the pot from the edge of the combustion chamber was computed (Bryden et al., 2006).

Area of the combustion chamber was computed, and since it is cylindrical:

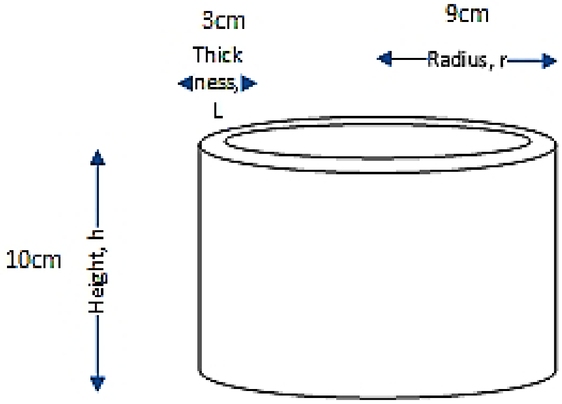

Figure 1: Schematic Diagram of the Combustion Chamber

$A_c = \pi . r_c^2$

Equation 3.1: Area of Circle

A_c is the area of the combustion chamber, cm^2

π is 3.41

r_c is the radius, cm

Therefore; $A_c = 3.14 \times 9^2$

$$= 254.34\ \text{cm}^2$$

The circumference of the combustion chamber was computed and this was done by:

$$C_c = 2.\pi.r_c$$

Equation 3.2: Circumference of the Circle

C_c = Circumference of combustion chamber, cm

Therefore;

$$C_c = 2 \times 3.14 \times 9$$

$$= 56.52\ \text{cm}$$

The Gap needed between the bottom of the pot and the top edge of the combustion chamber was derived by;

$$G_c = {}^{A_c}/_{C_c}$$

Equation 3.3: Gap required between two objects

Where G_c is the Gap required

$$= {}^{254.34}/_{56.52}$$

$$= 4.5\ \text{cm}$$

3.0.2 Air Requirement:

Table 4: Analysis of the Ultimate composition of Charcoal

Constituent	Mass Fraction	Oxygen required (kg/kg charcoal)
Carbon (C)	0.82	2.19
Oxygen (O)	0.113	-0.113
Hydrogen (H)	0.0031	0.248
Nitrogen (N)	0.002	0
Ash	0.034	0
Sulphur (S)	0.00	0
Total		**2.325**

Source: (Yusuf, 2011)

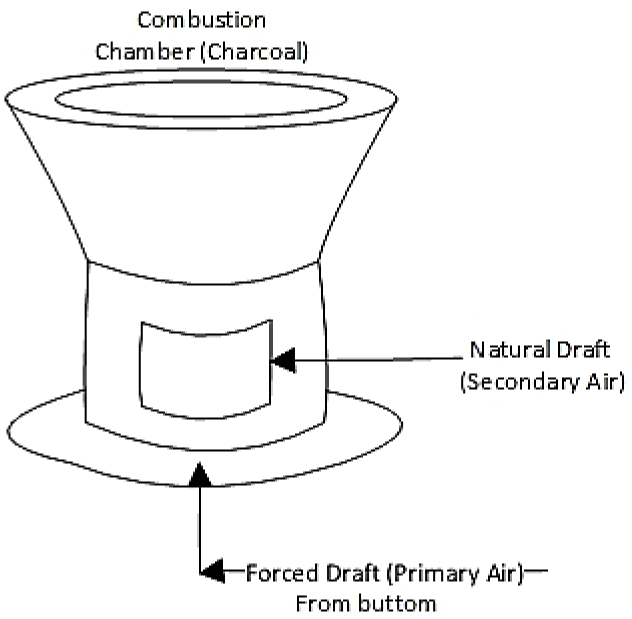

Figure 2: Schematic Diagram of Charcoal compartment showing Air entrances

Since air contains 23.3% of Oxygen (O_2) by mass,

Stoichiometric Air/Fuel ratio = $\frac{100}{23.3} \times O_2\ required$

Equation 3.4 Stoichiometric Air/Fuel Ratio

= 9.96

Assuming an additional air supply of 20% (Yusuf, 2011) which in this case air is supplied by a forced draft;

Percentage of Excess air can be expressed by;

$$= \frac{actual\ A/F\ ratio - stoichiometric\ A/F\ ratio}{stoichiometric\ A/F\ ratio}$$

Equation 3.5 Percentage of Excess Air

Therefore, to obtain actual A/F ratio = percent excess (stoichiometric) + stoichiometric

Equation 3.6 Actual Air/Fuel ratio

= (0.20 x 9.98) + 9.98

= 11.98

The oxygen associated with this A/F ratio = 11.98 x 0.233

= 2.791 kg

Excess Oxygen was therefore be given as = 2.791 – 2.325

= 0.466 kg ~ 0.5kg

3.0.3 Heat Transfer required:

Conduction of heat will occur in areas of the combustion chamber walls and also that of the heat getting to the pot being used for cooking.

Fourier's equation will be applied and this gives:

$$Q = \frac{k.A.(T_1 - T_2)}{L} = \frac{(T_1 - T_2)}{R}$$

Equation 3.7 Fourier's Heat energy Equation

Where;

Q is the heat energy, W

k is the thermal conductivity of the object, W/m.K

A is the area of heat been applied unit, m^2

L is the length or thickness of the material, m.

R is the resistance through the wall or air, K/W

T is the temperatures of the different points during transfer, °C.

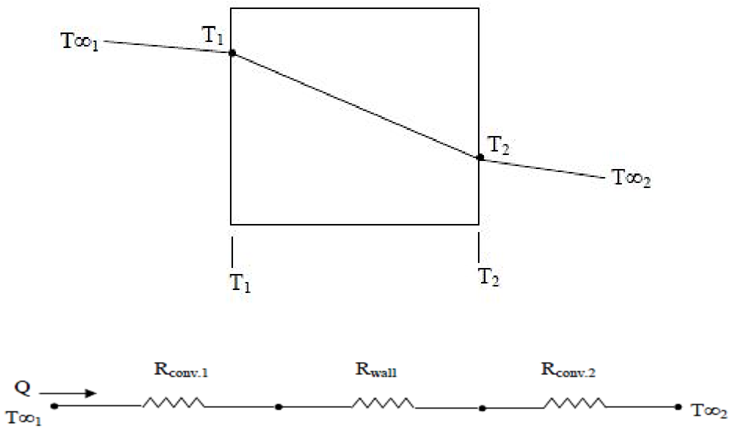

Figure 2: Thermal Resistance network through the insulation material

From the schematic diagram, $Q = \frac{T_{\infty 1} - T_{\infty 2}}{R_{Total}}$

Equation 3.8 Total heat Energy

Where,

$R_{Total} = R_{conv.1} + R_{fired\ clay} + R_{conv.2}$

Equation 3.9 Total Resistance through a material

$R_{conv.}$ = 1/h.A

Equation 3.10 Resistance through convective material

$R_{fired\ clay}$ = L/k.A

<u>From data measured and specified:</u>

Height of combustion chamber = 10 cm =0.1 m

Diameter of combustion chamber = 18 cm = 0.18 m

L = 3 cm = 0.03 m

Surface area of the chamber is therefore given by:

$$A = 2\pi rh + \pi r^2$$

Equation 3.11 Surface Area of combustion chamber

$$A = 2(3.14 \times 0.09 \times 0.1) + (3.14 \times 0.09^2)$$

$= 0.082\text{m}^2$

Thermal conductivity of Fired Clay, k = 1.4 W/m.K

For convective heat transfer co-efficient, h = 14.51 W/m^2.K

Thermal resistance, $R_{Total} = \frac{1}{h_1 A} + \frac{L}{K.A} + \frac{1}{h_2 A}$

Equation 3.12 Total Thermal Resistance

$$R_{Total} = \frac{1}{14.51 \times 0.082} + \frac{0.03}{1.4 \times 0.082} + \frac{1}{14.51 \times 0.082}$$

= 1.942 K/W

Temperature of the ambient air, $T_{\infty 1}$ = 1200^{o}C = 1473.15 K

Temperature of the ambient air, $T_{\infty 2}$ = 37^{o}C = 310.15 K

Therefore,

$Q = \frac{T_{\infty 1} - T_{\infty 2}}{R_{Total}} = \frac{1473.15 - 310.15}{1.942} =$ **598.87W** of energy used

3.1 Materials

Various items used during the process of this thesis have been categorized into three main subjects, i.e. design, fabrication and testing.

3.1.1 Design:

1. Principles of Dr. Larry Winiarski and Dr. Samuel Baldwin (Bryden et al., 2005).
2. Global Alliance for Clean Cookstoves (GACC) design process.
3. Sketch book, Pencil and Eraser.
4. Autodesk 360 Auto CAD 2D and 3D 2016 software.

3.1.2 Fabrication:

Table 3.5: Materials used for the fabrication of the improved institutional cook stove

NO.	**MATERIALS & DESCRIPTION**
1	Mild Steel Angle Iron – 2” x 2”
2	Electrodes – (Mild steel and Cast Iron)
3	Gas Burner – 6”
4	Gas Valve
5	Valve Nobs

6	Air Valve
7	1 $^{1}/_{2}$” Mild Steel Irons
8	Bolts & Nuts
9	Mild Steel Rods $^{1}/_{2}$”
10	Electric Fan (230V and 19W)
11	Clay Materials (Specified by Ekem Ceramics)
12	Grinding and Cutting Machine
13	Arc-Welding Machine
14	Hacksaw – cutting metals into required dimensions

Total cost of securing these materials have been shown in Appendix 7

3.1.3 Testing:

For the various tests performed, the subsequent items are required and were used to complete the testing session;

1. Electronic balance scale, with an accuracy of ±1gram and capacity of 6kg. This device is used to measure the weight of food to be cooked and the weight of water.
2. Digital stopwatch which is used to record the time of each of the different activities (i.e. cooking and boiling) during the tests.
3. Thermometer accurate to 0.5℃, with thermocouple probe suitable for immersion in liquids.
4. Heat resistant insulator to protect the measuring scale from hot charcoal.
5. Standardized pot: volume of about 7 liters (for 5-L tests) or 3.5 liters (for 2.5-L tests)
6. Fuel (Charcoal and LPG)
7. Tongs to hold and handle the fuel (charcoal).

8. Metal trays to hold charcoal for weighing.
9. An assemble to hold the thermometer in water.
10. Gloves that are heat resistant.
11. Kerosene to serve as a fire starter.
12. Hot air oven to determine moisture of fuel (Charcoal).
13. Food ingredients (Detailed in Appendix 1 and 2)
14. Indoor Air Pollution (IAP) meter (Model 5000-Series)
15. Moisture meter Voltcraft FM-300 (Conrad Electronics SE, Hirschau)

3.2 Design Process

The process of achieving a cook stove design plays a significant role in producing cleaner and more efficient cook stoves. Preference and availability of materials, as well as the application of basic design principles (Wrangham, 2003), led to an optimum cook stove design. There are structured design processes that help designers create a solution and likelihood to achieve their goals. And these include three (3) phases with three stages (3) at each phase;

Phases –

1. Framing the problem
2. Creating a solution
3. Developing a product (fabrication)

Stages –

1. Collect information and insights to gain a better understanding.
2. Brainstorming different ideas and selecting the best approach.

3. Test, implement and verify the approach used.

These design processes were employed and followed with regards to the rationale of the thesis and solutions created by means of the objectives. The final phase being development of the cook stove was also completed in order to have the physical product.

3.2.1 Question Bank for brainstorming sessions:

In order to facilitate the problem framing process, advice of all stakeholders was considered and their input on a variety of issues, including the relative importance placed on issues such as ease of ignition to save time and fuel, health and livelihood benefits, being efficient enough to reduce greenhouse gases and being inexpensive to the manufacturer. All these cannot be incorporated to the fullest in one particular cook stove but when these ingredients are optimized successfully, they have an advantage on other cook stoves within the same market.

Table 3.6: Generalized areas of concern for cook stove design

Performance	**Affordability**	**Usability**
Energy efficiency	Sale Price	Time saved
Health pollutants	Unit cost	Weight of stove
Greenhouse emissions	Service life	User interface
Safety	Fuel consumption	Ease of ignition
Durability		Portability
Cooking Time		Maintenance and services
		Attractiveness

Source: (Global Alliance for Clean Cookstoves, 2016a)

3.2.2 Design synthesis –

The cooking process is made up of components that are highly interrelated and they comprise of ignition, air, flame, fuel and materials of the cook stove. These components have been detailed to focus on acquiring a successful design.

3.2.2.1 Ignition:

Depending on the type of fuel and stove, various ignition sources are used, such as kerosene, ethanol, LPG, fossil oils, wooden sticks, paper, plastic, sacks and grass or other dry biomass. For fuel selection ignition is very important as cooks often blow or fan air into the fire, which increases oxygen intake. A consumer survey conducted in markets around the world shows that cooks often place an emphasis on rapid burning, especially when there is a lot of demand for their time (Bryden et al., 2005).

3.2.2.2 Air:

The cooks control the fire by adjusting the amount of fuel or air to the fire. However, air supply changes may also affect the fuel load rate, thermal efficiency, and the complete combustion process. Therefore, practicality to the users must be balanced with the performance of indices.

3.2.2.3 Fuel:

For cooking, a variety of fuels are used depending on availability, convenience and suitability. Fuel type is by itself a good opportunity to improve the user's experience of performance by the cook stove. Organizations are currently producing fuel that is environmentally sustainable, cleaner and more useful for the user which can be exploited in the near future. Common fuel types are presented in Table 2.2.

3.2.2.4 Flame:

The cook uses the presence of flame to confirm that a stove works and treats the heat output according to the size of the flame. By adjusting the airflow and quantity of fuel, the flame can change in size and color.

3.2.2.5 Cook stove Materials:

The high temperature of the biomass cooking stove makes materials in the design process essential for stove performance, consumer satisfaction, safety, manufacturing and affordability. Suitable materials allow users to carry out cooking tasks continuously in reducing the risk of failure and degradation. The appropriate materials ensure users the quality of the product. (Global Alliance for Clean Cookstoves, 2016b).

3.2.3 Component Design and Summary Procedure –

The Engineering Metal workshop has been equipped with tools and machinery for performing tasks such as shearing sheet metal, rolling plates into cylinder/cone, drilling, riveting, grinding, painting, sawing, welding, tube cutting & pipe threading etc. It will therefore be used for fabrication.

3.3 Testing Methods

3.3.1 Assessment approach:

All tests performed were replicated based on the following statistical considerations:

Based on test uncertainties and errors, replicates are performed in order to reduce the rate of error and uncertainty. This is important due to the small variations among cook stoves and parameters to be determined.

$$n = \frac{2\,(Z_{1-\alpha/2} + Z_{1-\beta})^2}{(\frac{\Delta\mu}{\sigma})^2}$$

Equation 3.13 Sample calculation (DeFoort et al., 2009)

Where: n is the number of samples required

α is the Type 1 error, probability of rejecting the null hypothesis when it is true.

β is the Type 2 error, the probability of not rejecting the null hypothesis when it is false.

Δμ is the variation in means between the sample and the null hypothesis.

σ is the standard deviation.

Table 3.7: Effect of equation parameters on the required test replicates

	Variable Range	**Replicate Range**
α	0.01–0.1	5–10
β	0.01–0.15	5–12
Δμ	0.1–0.25	3–18
σ	0.05–0.5	2–155

Source: (DeFoort et al., 2009)

Based on assumptions, confidence interval will be set at 95%, thus α being 0.05.

The probability of having a type II error (β), will be set at 80%, thus P = (1- β)

Variation in means, Δμ, between the samples is the point where a difference in the samples becomes obvious and detectable. The smaller the desired difference in samples, then more replicates will be required which can sometimes be impractical (DeFoort et al., 2009). Based on table 1.0 variation in means (Δμ) will be set at 25%.

Standard deviation (σ), will be estimated at 0.1.

From the Z score statistical table;

Z score for $^{\alpha}/_{2}$ or α (0.05) which is a 2-tailed test gives 1.96.

Z score for power 80%, (1- β), gives 0.842.

Δμ given as 0.25

σ given as 0.10

These variables when computed into Equation 3.1 gives a replicate number of;

$$n = \frac{2\,(1.96 + 0.842)^2}{(\frac{0.25}{0.10})^2}$$

$$n = 2.512 \sim 3 \text{ replicates}$$

Data was collected for both traditional and improved cook stove for the various tests conducted. The dependent and independent variable required for analysis and computations are defined below as;

Fuel Consumed

The fuel consumed during the test is the amount of fuel that was used to boil water or cook food. It is the difference between the initial and final mass of fuel.

Net Change in Ash

The net change in char or ash during the test is the mass of ash produced at the end of the testing process. This helps to know the quantity of fuel being burnt into ash or residues.

Mass of Water Vaporized

This is the mass of water that has been reduced due to evaporation after the test. It is therefore the difference between the initial weight of water and the pot and the final weight of water and the pot.

Processing Rate

This is defined as the amount or quantity of food that is cooked within a minute. Parameters used are the quantity of food cooked and the time it took to complete cooking.

Specific Fuel Consumption

The specific fuel consumption is the amount of fuel used to bring a kilo of water to a boil or complete a session of cooking by starting with a cold stove.

Temperature-Corrected Specific Fuel Consumption

This is the factor used to correct the fuel consumption, it normalizes the initial water temperature differences of the stove being tested in a different day or different condition to a standard change in temperature of 75℃ (25℃ to 100℃).

Temperature-Corrected Specific Energy Consumption

This is the amount of energy within the fuel necessary to boil a kilogram of water which is the product of the Temperature-corrected specific fuel consumption and the energy content of the fuel used.

Some variables obtained from the test include time to boil (minutes), thermal efficiency (%), specific energy consumption and specific fuel consumption. Standard tests that were conducted include the following;

3.3.2 Controlled Cooking Test 2.0 (Bailis, 2004)

This is designed and performed in the testing laboratory and involves the preparation of a standardized meal which consists of some oil, starch etc. It sheds more light on the cooking performance thus the fuel used, time spent and emissions to the environment. Amount of energy stored and given out by the cook stove and the fuel used was also recorded. Energy used was determined just as that of the water boiling test by also considering key parameters such as; specific heat capacity (C_p) of the ingredients used, temperature changes (ΔT) in degree Celsius (ºC) and mass of meal used (m). The results of the test are expressed as the ratio of the amount of fuel needed to cook the meal, which is known as specific fuel consumption (SFC):

$$SFC = \frac{fuel\ used\ (g)}{food\ cooked\ (kg)}$$

Equation 3.14: Specific fuel consumption

The controlled cooking test usually depends on a number of factors which include;

i. Composition and physical properties of food,
ii. Type of cooking operation,
iii. Mass of food to be cooked,
iv. Method of preparation of food and
v. Type of pots used for the cooking

The controlled cooking test (CCT) is designed to assess the performance of the improved stove relative to the common or traditional stoves that the improved cook stove model is meant to replace. Stoves are compared as they perform a standard cooking task that is closer to the actual cooking that local people do every day. However, the tests are designed in a way that minimizes the influence of other factors and allows for the test conditions to be reproduced.

Data was collected for both traditional and improved cook stove for this assessment. This test gives a more precise and accurate result in relation to the actual use of the cook stove in a kitchen setting.

For controlled cooking test (CCT), requires extensive procedures which are detailed below;

Initial Measurements:

a) Fetch not more than twice the amount of estimated charcoal needed and weigh. When there is any addition of fuel during the test period, the weight must be added to the previous to balance the stock.
b) Weigh the pans with the lids in place. This study has its pan weight being 3441g.
c) Weigh the stove being tested in grams/kilograms.
d) Weigh the individual ingredients of food and water to be cooked and place them in the pan.
e) Record the time when ignition of the charcoal stove was started.

Figure 3.1: Measurement of Various ingredients used for Controlled Cooking Test

Final Measurements:

a) Record the time when the test was completed.
b) Weigh the cooked food whiles in the pan with the lid in place.

After completing the cooking task, data is recorded and analyzed based on the variables required to make comparisons.

Figure 3.2: Taking temperature measurement as part of data collection on cooked food

Performance of the cook stove was determined by the using the available parameters;

In this case, fuel consumption (KJ.kg^{-1}) which indicates how much fuel was saved or used up for both traditional and the improved cook stove. Analyzing and comparing both data to determine which is significant in terms of savings.

3.3.3 Emissions Test (DeFoort et al., 2009)

Parameters that were observed are; Carbon Monoxide (CO) and Particulate Matter (PM).

Approach and devices used in measuring outcomes were;

- Portable Emission Monitoring System (PEMS).
- Indoor Air pollution (IAP) meter.

Proper sampling of the exhaust gas released from a cook stove was collected accurately to avoid losing any of the emitted gases. All emissions during the testing period were captured to avoid errors during the reading, and also doing so without affecting stove operation. Data was collected for both traditional and the improved cook stove, analyzed and compared to standard values set by international bodies.

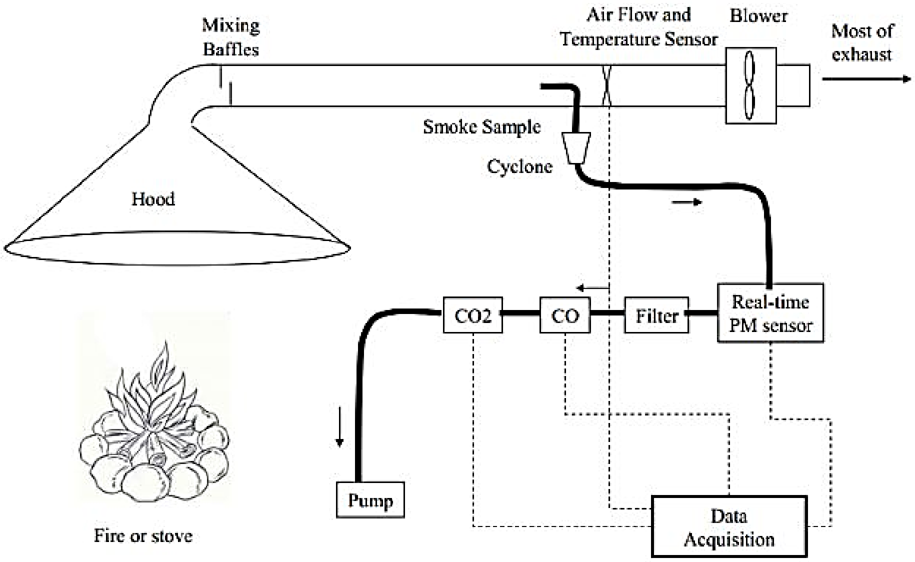

Figure 3.3: Principle used in gathering emission levels

3.4 Procedures used for data gathering

In this study, all the tests completed to evaluate the performance of the improved cook stove were conducted in the cook stove testing laboratory of the CSIR-IIR.

All test data were recorded on the data sheet approved by the (Global Alliance for Clean Cookstoves, 2014) and this is has been shown in Appendix 3 to 6

Obtaining data with respect to emissions was conducted using the indoor air pollution (IAP) meter. This procedure details the rate of emission in real time at which the user is being exposed to directly during the process of cooking.

Figure 3.4: IAP meter strapped behind cook for collection of data during the cooking process

Results for test replicates were analyzed using STATGRAPHICS Centurion XVI.I and compared to that of the WHO standard. Which will be provided in chapter 4 of this thesis.

3.5 Limitations of this study:

There could have been further tests run on the improved cook stove in order to categorize the stove based on tiers set by the (Global Alliance for Clean Cookstoves (GACC2), 2011). Due to the limitation of funds, tests needed to be performed were prioritized.

With the controlled cooking test, variety of foods could have been considered to make room for a broader database. For the reasons of limited time, the results obtained were enough to make conclusions on the objectives set.

4.0 RESULTS & DISCUSSIONS

This chapter contains the results and discussions of the thesis objectives stated earlier and this would include the design and fabrication process and finally testing the improved institutional charcoal-LPG cook stove. The design and fabrication process employed the three (3) stage process described in Chapter 3, where the first two stages are the design stages and the third is the fabrication stage.

4.1 Design process of the improved cook stove

4.1.1 Framing the Problem

A range of stakeholders were consulted in this design process and they include; the Council for Scientific and Industrial Research-Institute of Industrial Research, Energy Commission, Gyapa Enterprise, Ekem Ceramics, and Mass Cooks from the Tema community 1 site 16 area. This was to ensure that all interests and suggestions made are tailored towards achieving a common goal.

The needs and suggestions identified by the stakeholders were used to develop the design requirements, which are listed below;

i. Should have an efficiency of at least 30%, so that the additional cost of cookstove is recovered through fuel savings in less than one year.
ii. Should have CO and particulate matter emissions rate below 20g/min and 1500mg/min respectively.
iii. Should be able to cook 5 kg of food in no more than two hours.
iv. Should use materials that are available within the country.
v. The parts of the stove that are most likely to fail should be easily replaced.
vi. It should be aesthetically pleasing to potential users.

vii. It should facilitate clean and complete combustion.
viii. Should facilitate switching to LPG.
ix. Should enable at least two (2) cooking sessions at a time.

4.1.2 Creating the Solution

The next step was to brainstorm many design ideas and use the requirements to narrow down the ideas, based on information from literature and realistic measurements instead of solely using the individual opinions. Key aspects of creating the solution included a selection of the materials for construction, dimensions of the various components and mode of operation.

4.1.2.1 Selection of Materials for Construction –

1. The main frame or skeleton of the entire cook stove must have the ability to hold and keep the cook stove in shape and balance. In this case, an angle iron was recommended based on its availability, ease of welding, solid stable nature and low cost (Villacís et al., 2015).

2. Mild steel plate was selected for the body to make it look attractive aesthetically and make it light in weight. Additionally, it is easily available on the market and has a low cost.

3. Most metals meet the requirement for the pot stands to be strong enough to carry cooking pots in place. As such cost was the primary selection criterion, and iron rods were selected due to their availability and minimal cost.
4. Insulation of the combustion chamber is a very vital feature of an improved cook stove. It is with this that quite a number of insulators were investigated and these include, glass fiber, cement etc. amongst these, expenses and availability became a constraint. A ceramic

clay liner was then considered since it could be molded and obtained locally. In addition, according to indicators of insulation material capabilities by (Ahiekpor et al., 2015), the ceramic clay was also quite reasonable to consider.

5. The combustion chamber must comprise of materials that would keep the chamber in shape and heat resistant. This enables the reduction of heat loss to the environment and also maximizes the chances of energy getting to the cooking pot. With this in mind, the combustion chamber will comprise of the ceramic clay liner with a light mild steel plate engulfing it.

4.1.2.2 Dimensions of cook stove

The cook stove was sized to enable easy use by the cooks, who are mainly women of an average height of 1.6m (Langtree, 2017). This makes cooking sessions more comfortable and easier to handle. With institutional cooking, due to the long hours of cooking sessions, the cooks tend to stand and work with the cook stove hence the derived optimum height and dimensions. Development of the final design was drafted and modified starting from the various components to the complete design. Some sketches and notes of the brainstorming process are in Appendix 10 of this document.

4.1.2.2.1 Design of Cooking Surface –

The surface that is easily accessible and exposed to users must be heat resistant enough to avoid burns to the user. An airgap in combination with low heat resistant metal bar was considered in preventing such an accident. For the side of the main frame areas, the mild steel plates are welded to close all open areas and also to bring a good aesthetic look to the design. This is for the reason that mild steel plate is preferred based on its durable, easy to weld, affordable and easily available properties.

4.1.2.2.2 Combustion Chamber –

Materials considered for this chamber were based on standard materials tests that have been performed by individual researchers. Combustion liners are typically exposed to temperatures of 600-1100°C in charcoal stoves (Global Alliance for Clean Cookstoves, 2016b).

Below is a maximum allowable temperature for some common materials:

- Aluminum (2045-T4): 250°C
- Carbon steel (AISI 1045): 650°C
- Stainless steel (AISI 201): 500°C
- Stainless steel (AISI 316): 870°C
- Fired clay: 1000-1700°C

Mild steel was selected for the outer liner and fired clay used as an insulator to improve efficiency based on research undergone by (Ahiekpor et al., 2015) and the maximum allowable temperatures are given by the (Global Alliance for Clean Cookstoves, 2016b).

4.1.2.2.3 Ash Collector –

The ash collection space was placed beneath the combustion chamber, due to the fact that the ashes drop from the combustion chamber and they can therefore be cleaned and collected easily by the user.

4.1.2.2.4 Gas Burner –

The LPG component of the design is added to help users of charcoal and biomass stoves adapt easily to the use of LPG as fuel for cooking. The LPG was fixed on top of the charcoal compartment and has a hinge joint feature that allows the user to lift the LPG compartment and have access to the charcoal compartment. Once the user is ready to use the LPG option, the regulator must be turned on and the fire lit. When cooking is complete, the LPG must be turned off and the cooked food served as desired.

4.1.2.2.5 Regulators –

Cook stoves are regulated either by fuel or air supply, this gives the user control of the output they intend to achieve. It is with this case that the regulators included in the design serve solely two purposes, that for the LPG regulation and the other for the air flow regulation. The LPG regulator is fixed on the front part of the cook stove, this allows for easy regulation and easy use of the LPG system for cooking. The regulator for the air flow is targeted at the charcoal compartment, where combustion takes place. The air flow can be initiated to allow ease of lightening and keeping the combustion process running to the point where less heat is needed for cooking. Based on (Witt, 2005) forced draft systems prove to show cleaner and higher efficient cooking sessions. It is therefore an advantage for the objective of this study which seeks to reduce emissions.

4.1.2.3 Mode of Operation:

This cook stove is aimed at allowing users to benefit from the advantages improved cook stoves have over the traditional stoves. The design makes room for two fuel types to be used, and these are charcoal and LPG. The cook stove is made up of two compartments based on the fuel types and one can only use either of the compartments at a particular time due to safety issues in regards to exposing hot coals to LPG.

For a user to make use of the charcoal compartment, the LPG compartment is lifted up with a hinge supporting from behind. The charcoal can then be filled into the combustion chamber with the desired amount, with respect to the quantity of cooking to be performed. Fire is set to the charcoal by using a startup fuel such as kerosene or waste paper etc. When the fire is set, the fan can be turned on and the air valve opened to allow forced draft into the combustion chamber. The provision of the forced draft allows for quick fire making before cooking starts and also can be used to increase the intensity of the flame during cooking. When cooking is completed, the charcoal will be left to cool down for further use in another cooking session. Ashes will be collected by opening the front door of the cook stove and sweeping out ashes from beneath the charcoal stove that was used.

The LPG compartment is used when the upper part of the stove is closed, this way the gas pipe will be fitted correctly to allow the flow of LPG from the cylinder through to the burner. LPG as a fuel is considered internationally to be a clean fuel for cooking (Alternative Fuels Data Center, 2018). Therefore, requires less work to improve its efficiency.

When cooking is completed based on whichever compartment was used, all features must be turned off. The electric fan must be turned off with its regulator for the charcoal compartment and the gas regulator turned off for the LPG compartment.

On the basis of the design process used, an optimal design was obtained. With the aid of sketch pads and finally a computer-aided design software, the improved cook stove was sketched with the following dimensions.

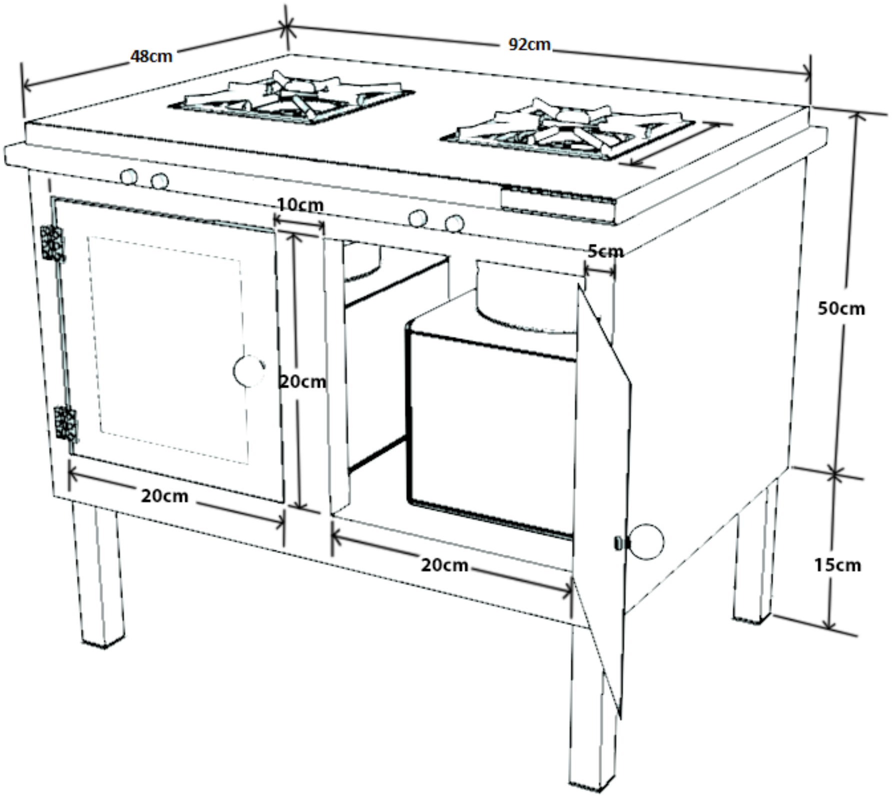

Figure 4.1: Dimensioned Sketch of the improved cook stove

Upon further description of the design, the same computer-aided design software was used in rendering the images to provide a more realistic view and detail. This was achieved by using Autodesk Auto CAD 3D version 2016 to provide the platform for detailing the design.

Figure 4.2: Rendered Design with a view of the LPG compartment

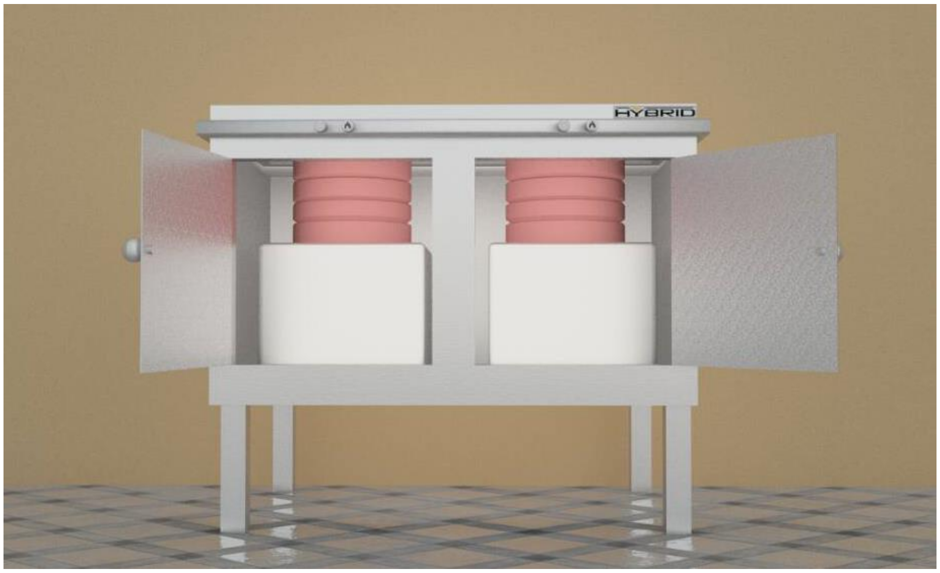

Figure 4.3: Rendered Design with view of Charcoal compartment

4.2 Fabrication of the improved cook stove using finalized design:

Cutting, Fabricating and Welding were all performed in the Mechanical Engineering workshop located on the premises on CSIR-IIR. These tasks were performed by professional artisans employed by the institution with some help offered to them by myself.

Measurements for the design were taken and cut out accurately using a tape measure and a hack-saw respectively. The main frame of the improved cook stove was fabricated first, followed by the doors and the upper frame. The plates were finally used to cover open areas.

Figure 4.4: Cutting of Main Frame components

Figure 4.5: Fabricating of the Main Frame

Figure 4.6: Welding Main Frame of the Improved Cook stove

When mainframe is welding and ready, the detail components such as bolts, hinges, handles are fixed in place. The thin plate which has a thickness of 1.25mm is used to cover and close open areas of the stove. The cook stove is made up of two compartments, which are the LPG and charcoal compartments. These compartments are fixed in place according to the design of the improved cook stove. The LPG burner is fixed to the upper part of the stove, whereas the charcoal compartment is fixed in the lower session of the cook stove.

The charcoal compartment is secured in its place with a screw and with the LPG compartment, the burner is fixed in place with a bolt and nut screw.

Figure 4.7: The charcoal compartment undergoing fabrication and fixing

Figure 4.8: The LPG compartment fitted in the upper session

Other vital components such as a valve, knobs, LPG pipe, regulator, hinges and electric fan to provide forced draft are fitted in their place to complete the design and purpose of the improved cook stove.

Figure 4.9: Valve and other fitting components

Figure 4.10: Electric fan to provide forced draft

Figure 4.11: Air valve and regulator for controlling air flow to charcoal compartment

The welded edges and coverings of the finished improved cook stove are polished up using the grinding machine. This gives a smooth look to the stove and good-looking aesthetic. An anti-rust paint is applied to the potential rusty areas and finally, oil paint applied to give the improved cook stove a better look. Upon finishing, the total weight of the cook stove constructed was 62.5kg and based on this it is recommended to be positioned stationary in the kitchen.

The images below are finished works on the improved cook stove for both the charcoal and the LPG compartments.

Figure 4.12: View of finished Charcoal compartment of the improved cook stove

Figure 4.13: View of LPG compartment of the improved cook stove in operation

4.3 Testing of traditional cook stove and improved institutional cook stove

The test was conducted in the Cook Stove Testing laboratory which is within the premises of CSIR-IIR. All tests performed were replicated based on DeFoort et al., (2009) statistical considerations detailed in the methodology. Results obtained are for both the LPG and Charcoal compartments with each being compared to the standardized traditional aluminium cook stove.

These results have been categorized based on the particular tests that were run, and they comprise of the controlled cooking test and the emissions test.

4.3.1 Charcoal compartment:

4.3.1.1 Controlled cooking Test –

The test data sheet in Appendix 6 was used to record all data during the process of cooking. The variable outputs that were computed are based on data recorded, and these include total weight of food cooked, weight of char remaining, equivalent dry wood consumed, specific fuel consumption, total cooking time and processing rate. The variables mentioned are considered for both the traditional aluminium cook stove and the improved cook stove designed for the purposes of this thesis.

Variable representations: Traditional Aluminium cook stove (total weight of food cooked, weight of char remaining, equivalent dry wood consumed, specific fuel consumption, total cooking time and processing rate). Improved institutional cook stove (total weight of food cooked_1, weight of char remaining_1, equivalent dry wood consumed_1, specific fuel consumption_1, total cooking time_1 and processing rate_1).

Results below are generated using the Control cooking test version 2.0 test protocol excel workbook for wood charcoal which is presented in Appendix 3 to 6.

4.3.1.1.1 Total weight of food cooked

Table 4.1: Summary Statistics of total weight of food cooked for both traditional and ICS

	weight of food cooked	*weight of food cooked_1*
Count	3	3
Average	1066.33	1225.67
Standard deviation	20.7926	26.839
Coefficient of variation	1.94992%	2.18975%
Minimum	1051.0	1205.0
Maximum	1090.0	1256.0
Range	39.0	51.0
Standard skewness	1.07044	0.997389

4.3.1.1.2 Comparison of Means for total weight of food cooked

95.0% confidence interval for mean of weight of food cooked: 1066.33 ± 51.6517 [1014.68, 1117.99]

95.0% confidence interval for mean of weight of food cooked_1: 1225.67 ± 66.6718 [1158.99, 1292.34]

95.0% confidence interval for the difference between the means assuming equal variances: -159.333 ± 54.4229 [-213.756, -104.91]

4.3.1.1.3 T-test to compare means of total weight of food cooked

Null hypothesis: mean1 = mean2

Alternate hypothesis: mean1 ≠ mean2

assuming equal variances: t = -8.12859   P-value = 0.00124591

Reject the null hypothesis for alpha = 0.05

Since the calculated P value is less than 0.05, we can reject the null hypothesis in favor of the alternative. Which implies, there is a statistical difference between the total weight of food cooked for the Traditional and Improved cook stoves.

4.3.1.1.4 Weight of char remaining:

Table 4.2: Summary Statistics of weight of char remaining for both traditional and ICS

	Weight of char remaining	*Weight of char remaining_1*
Count	3	3
Average	41.3333	33.0
Standard deviation	5.50757	10.1489
Coefficient of variation	13.3248%	30.7542%
Minimum	35.0	24.0
Maximum	45.0	44.0
Range	10.0	20.0
Standard skewness	-1.17948	0.602708

4.3.1.1.5 Comparison of Means for weight of char remaining

95.0% confidence interval for mean of Weight of char remaining: 41.3333 ± 13.6816 [27.6518, 55.0149]

95.0% confidence interval for mean of Weight of char remaining_1: 33.0 ± 25.2112 [7.78876, 58.2112]

95.0% confidence interval for the difference between the means assuming equal variances:

8.33333 ± 18.5097 [-10.1764, 26.843]

4.3.1.1.6 T-test to compare means of weight of char remaining

Null hypothesis: mean1 = mean2

Alternate hypothesis: mean1 ≠ mean2

assuming equal variances: t = 1.25   P-value = 0.27944

Do not reject the null hypothesis for alpha = 0.05

Since the calculation for P-value is not less than 0.05, we cannot reject null hypothesis. Therefore, there is no statistically significant difference between the char remaining for both traditional cook stove and the improved institutional cook stove.

4.3.1.1.7 Equivalent Dry wood consumed:

Table 4.3: Summary Statistics on the equivalent dry wood consumed for both traditional and ICS

	Equivalent dry wood consumed	***Equivalent dry wood consumed_1***
Count	3	3
Average	185.667	168.0
Standard deviation	12.8582	2.64575
Coefficient of variation	6.92542%	1.57485%
Minimum	171.0	165.0
Maximum	195.0	170.0
Range	24.0	5.0
Standard skewness	-1.09276	-1.03086

4.3.1.1.8 Comparison of Means for equivalent dry wood consumed

95.0% confidence interval for mean of Equivalent dry wood consumed: 185.667 ± 31.9415 [153.725, 217.608]

95.0% confidence interval for mean of Equivalent dry wood consumed_1: 168.0 ± 6.57241 [161.428, 174.572]

95.0% confidence interval for the difference between the means assuming equal variances: 17.6667 ± 21.0433 [-3.37666, 38.71]

4.3.1.1.9 T-test to compare means of equivalent dry wood consumed

Null hypothesis: mean1 = mean2

Alt. hypothesis: mean1 ≠ mean2

assuming equal variances: t = 2.33094   P-value = 0.0801687

Do not reject the null hypothesis for alpha = 0.05

Since the calculated value of P is not less than 0.05, we cannot reject the null value of the hypothesis. Which indicates there is no statistically significant difference between the two cook stoves for equivalent dry wood consumed.

4.3.1.1.10 Specific fuel consumption:

Table 4.4: Summary Statistics for the specific fuel consumption of both the traditional and ICS

	Specific fuel consumption	***Specific fuel consumption_1***
Count	3	3
Average	174.333	137.333
Standard deviation	15.1438	4.72582
Coefficient of variation	8.68667%	3.44113%
Minimum	157.0	132.0
Maximum	185.0	141.0
Range	28.0	9.0
Standard skewness	-1.12932	-0.982621

4.3.1.1.11 Comparison of Means for specific fuel consumption

95.0% confidence interval for mean of Specific fuel consumption: 174.333 ± 37.6192 [136.714, 211.953]

95.0% confidence interval for mean of Specific fuel consumption_1: 137.333 ± 11.7396 [125.594, 149.073]

95.0% confidence interval for the difference between the means assuming equal variances: 37.0 ± 25.4298 [11.5702, 62.4298]

4.3.1.1.12 T-test to compare means of the specific fuel consumption

Null hypothesis: mean1 = mean2

Alternate hypothesis: mean1 ≠ mean2

assuming equal variances: t = 4.0397   P-value = 0.0156076

Reject the null hypothesis for alpha = 0.05.

Since the calculated P value is less than 0.05, we can reject the null hypothesis in favor of the alternative. Which simply indicates that there is a statistically significant difference for the specific fuel consumption for both traditional and improved institutional cook stove.

4.3.1.1.13 Total cooking time

Table 4.5: Summary Statistics of the total cooking time for traditional cook stove and ICS

	Total cooking time	***Total cooking time_1***
Count	3	3
Average	69.0	68.0
Standard deviation	1.0	1.0
Coefficient of variation	1.44928%	1.47059%
Minimum	68.0	67.0
Maximum	70.0	69.0
Range	2.0	2.0
Standard skewness	0	0

4.3.1.1.14 Comparison of Means for total cooking time

95.0% confidence interval for mean of Total cooking time: 69.0 ± 2.48414 [66.5159, 71.4841]

95.0% confidence interval for mean of Total cooking time_1: 68.0 ± 2.48414 [65.5159, 70.4841]

95.0% confidence interval for the difference between the means assuming equal variances: 1.0 ± 2.26696 [-1.26696, 3.26696]

4.3.1.1.15 T-test to compare means of the total cooking time

Null hypothesis: mean1 = mean2

Alternate hypothesis: mean1 ≠ mean2

assuming equal variances: t = 1.22474   P-value = 0.287864

Do not reject the null hypothesis for alpha = 0.05.

Because the calculated P value is not less than 0.05, we cannot reject the null hypothesis. Hence, there is no statistically significant difference between the traditional and the improved institutional cook stove.

4.3.1.1.16 Processing Rate:

Table 4.6: Summary Statistics for the Processing Rate of traditional cook stove and ICS

	Processing Rate	*Processing Rate_1*
Count	3	3
Average	15.3333	18.0
Standard deviation	0.57735	0
Coefficient of variation	3.76533%	0%
Minimum	15.0	18.0
Maximum	16.0	18.0
Range	1.0	0
Standard skewness	1.22474	

4.3.1.1.17 Comparison of Means for the Processing rate

95.0% confidence interval for mean of Processing Rate: 15.3333 ± 1.43422 [13.8991, 16.7676]

95.0% confidence interval for mean of Processing Rate_1: 18.0 ± 0 [18.0, 18.0]

95.0% confidence interval for the difference between the means assuming equal variances: -2.66667 ± 0.925485 [-3.59215, -1.74118]

4.3.1.1.18 T-test to compare means for the processing rate

Null hypothesis: mean1 = mean2

Alt. hypothesis: mean1 ≠ mean2

assuming equal variances: t = -8.0   P-value = 0.00132388

Reject the null hypothesis for alpha = 0.05.

Since the calculated P value is less than 0.05, we can reject the null hypothesis in favor of the alternative. Which implies, there is a statistically significant difference for the processing rate between the traditional cook stove and the improve institutional cook stove.

4.3.1.1.19 Data summary on all variables computed and analyzed for charcoal compartment

Table 4.7: Averages and Analysis of Variables for both Traditional and Improved Cook stove

	Traditional	**Emma Charcoal ICS**	**P-Value**	**Significant Difference**
Weight of Char Remaining (g)	41±5.51	33±10.15	0.27944	No
Equivalent Dry wood consumed (g)	186±12.86	168±2.65	0.0801687	No
Specific Fuel Consumption (g/kg)	174±15.14	137±4.73	0.0156076	Yes
Total Cooking time (min)	69±1.00	68±1.00	0.287864	No
Processing Rate (g/min)	15±0.58	18±0.00	0.00132388	Yes

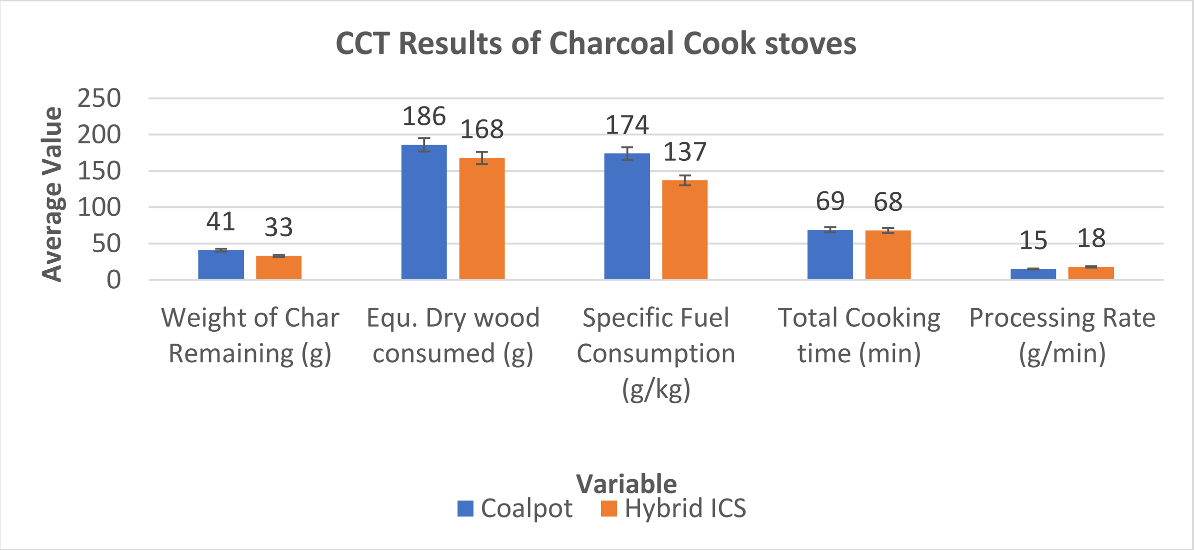

Figure 4.14: Graphical representation of the variables computed and analyzed

4.3.1.1.20 Efficiency of the Improved institutional cook stove (Charcoal) in terms of SFC:

Using the Specific Fuel Consumption (SFC) of the cook stove, efficiency was computed in order to determine performance of the improved cook stove in relation to the traditional cook stove. The specific consumption appears to be a better index for expressing the performance of a cook stove and for describing the fuel consumption pattern (Sherka, 2011).

$$Efficiency = \left|\frac{SFC(T)-SFC(ICS)}{SFC(T)} \times 100\right|$$

Equation 4.1: Efficiency in terms of SFC

Where:
SFC – specific fuel consumption
(ICS) – improved cook stove
(T) – traditional

Therefore;

$$Efficiency = \left|\frac{174-137}{174} \times 100\right|$$

$$= \mathbf{21.26\%}$$

4.3.1.2 Emissions Test –

Parameters that were observed during this test include carbon monoxide (CO) and particulate matter 2.5µm ($PM_{2.5}$).

Based on the World Health Organization benchmark for indoor air pollutions, charcoal and wood fuels have been combined to give a maximum Carbon Monoxide (CO) emission rate of 20g/min and a maximum Particulate Matter (2.5µm) an emission rate of 1500mg/min (Roden et al., 2006).

Results obtained for test are for both the traditional aluminium cook stove and the improved institutional cook stove.

4.3.1.2.1 Carbon Monoxide (CO) emissions (Charcoal)

Variable representations: CO_Aluminium represents CO emissions for Traditional Aluminium cook stove and CO_ICS represents CO emissions for Improved institutional cook stove.

Table 4.8: Summary Statistics for CO emissions of both Charcoal Stoves

	CO_Aluminium	*CO_ICS*
Count	327	326
Average	21.0816	13.5868
Standard deviation	2.78009	2.70157
Coefficient of variation	13.1873%	19.8837%
Minimum	11.7063	6.7063
Maximum	36.3623	30.8018
Range	24.656	24.0955
Standard skewness	6.47543	21.5137
Standard kurtosis	13.3405	41.2088

4.3.1.2.2 Comparison of Means for CO emissions for charcoal stoves

95.0% confidence interval for mean of CO_Aluminium: 21.0816 ± 0.302447 [20.7791, 21.384]

95.0% confidence interval for mean of CO_ICS: 13.5868 ± 0.294359 [13.2925, 13.8812]

95.0% confidence interval for the difference between the means assuming equal variances:

7.49473 ± 0.420493 [7.07423, 7.91522]

4.3.1.2.3 T-test to compare means of CO emissions for both charcoal stoves

Null hypothesis: mean1 = mean2

Alt. hypothesis: mean1 $\neq$ mean2

assuming equal variances: t = 34.9338   P-value = 0

Reject the null hypothesis for alpha = 0.05.

Since the computed P-value is less than 0.05, we can reject the null hypothesis in favor of the alternative. Which implies that there is a statistically significant difference between the CO emissions for both the traditional cook stove and the improved cook stove. To know the reduction impact of the improved cook stove, the computation is done below using the averages of both cook stove.

Difference = CO_Aluminium – CO_ICS

= 21.0816 - 13.5868

= 7.4948g/min

Percentage reduction will therefore be:

$$\text{Percent Reduction} = \frac{\text{CO}_{\text{Aluminium}} - \text{CO}_{\text{ICS}}}{\text{CO}_{\text{Aluminium}}} \times 100$$

$$= \frac{21.0816 - 13.5868}{21.0816} \times 100$$

= 35.55%

The images below show the real-time record of CO emission rate from the start of testing to the end of testing for both the improved cook stove (charcoal) and the traditional cook stove (charcoal).

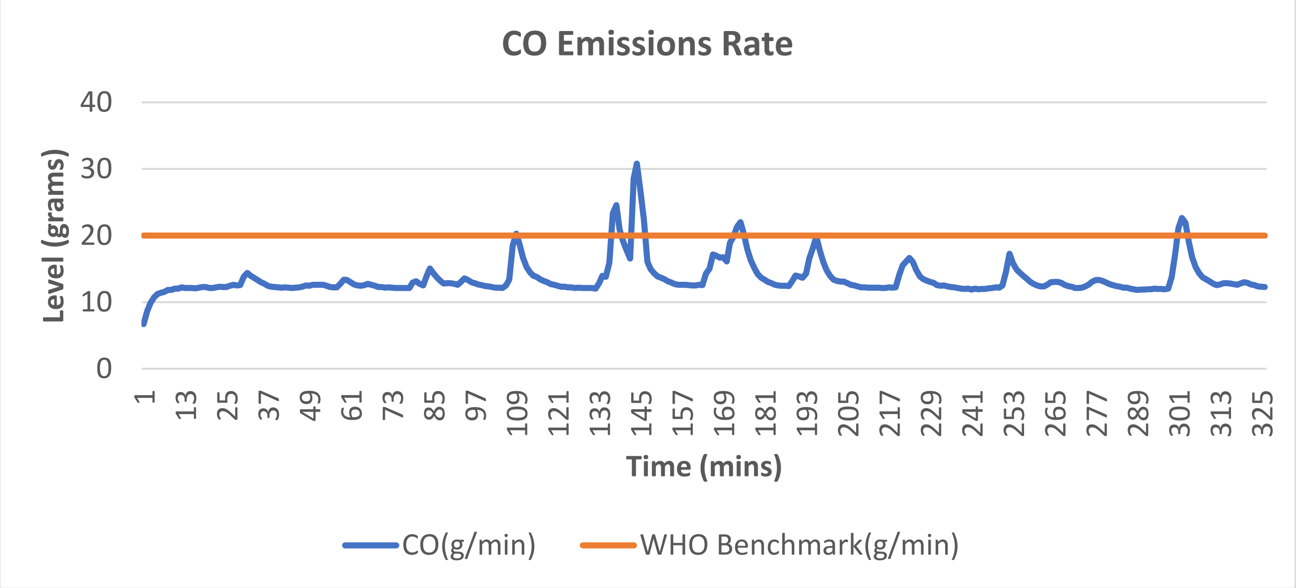

Figure 4.15: Graphical representation of the CO emissions of Improved Cook Stove (Charcoal)

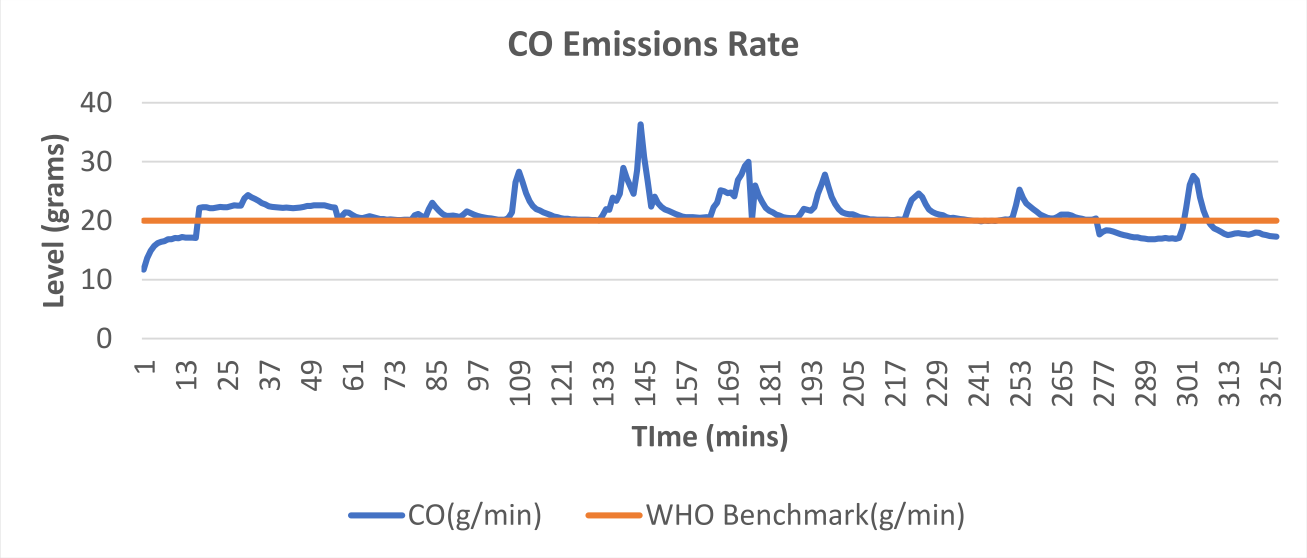

Figure 4.16: Graphical representation of the CO emissions of Traditional cook stove (Charcoal)

From the WHO Benchmark of CO having maximum limit emissions of 20g/min, the improved cook stove produces way less CO emissions which is averaged at 13.59g/min than the traditional aluminium cook stove which is averaged at 21.08g/min.

The reduction of CO emissions by the improved cook stove can be associated with the supply of adequate air flow from the electric fan attached to the charcoal compartment. (Mamuyea et al. (2018) performed similar tests on two (2) improved charcoal cook stoves (Merchaye and Lakech stoves) and the traditional charcoal cook stove. The CO emissions from the improved stoves emitted relatively less CO than the traditional metal stove even though the emissions from these ICS were above the proposed benchmark value of 20g/min. This outcome was attributed to the international bench mark value which was set by combining the average of wood and charcoal stoves (MacCarty et al., 2008). Charcoal would normally have a higher CO level than wood which may explain the study's higher CO emissions (Mamuyea et al., 2018).

4.3.1.2.4 Particulate Matter (PM) emissions

Variable representations: PM_Aluminium represents PM emissions for Traditional Aluminium cook stove and PM_ICS represents PM emissions for Improved institutional cook stove.

Table 4.9: Summary Statistics on the PM emissions of both charcoal stoves

	PM_Aluminium	***PM_ICS***
Count	327	326
Average	988.142	895.079
Standard deviation	35.5619	38.2012
Coefficient of variation	3.59886%	4.26792%
Minimum	883.325	869.465
Maximum	1273.62	1236.17

Range	390.295	366.7
Standard skewness	17.9673	38.8319
Standard kurtosis	60.2179	139.954

4.3.1.2.5 Comparison of Means for PM emissions from charcoal stoves

95.0% confidence interval for mean of PM_Aluminium: 988.142 ± 3.86879 [984.274, 992.011]

95.0% confidence interval for mean of PM_ICS: 895.079 ± 4.16234 [890.917, 899.241]

95.0% confidence interval for the difference between the means

assuming equal variances: 93.0635 ± 5.66091 [87.4026, 98.7244]

4.3.1.2.5 T-test to compare means of PM emissions of both charcoal stoves

Null hypothesis: mean1 = mean2

Alt. hypothesis: mean1 ≠ mean2

assuming equal variances: t = 32.2212   P-value = 0

Reject the null hypothesis for alpha = 0.05.

Since the calculated p-value is less than 0.05, we can reject the null hypothesis in favor of an alternative. It can be concluded that there is a statistically significant difference between the two (2) charcoal stoves for PM emissions.

To know the reduction impact of the improved cook stove, the computation is done below using the averages of both cook stove.

Difference = PM_Aluminium – PM_ICS

= 988.142- 895.079

= 93.063mg/min

Percentage reduction will therefore be:

$$\text{Percent Reduction} = \frac{\text{PM}_{\text{Aluminium}} - \text{PM}_{\text{ICS}}}{\text{PM}_{\text{Aluminium}}} \times 100$$

$$= \frac{988.142 - 895.079}{988.142} \times 100$$

= **9.42%**

The images below show the real-time record of PM emission rate of the improved cook stove (charcoal) and the traditional cook stove (charcoal) from the start of testing to the end of testing.

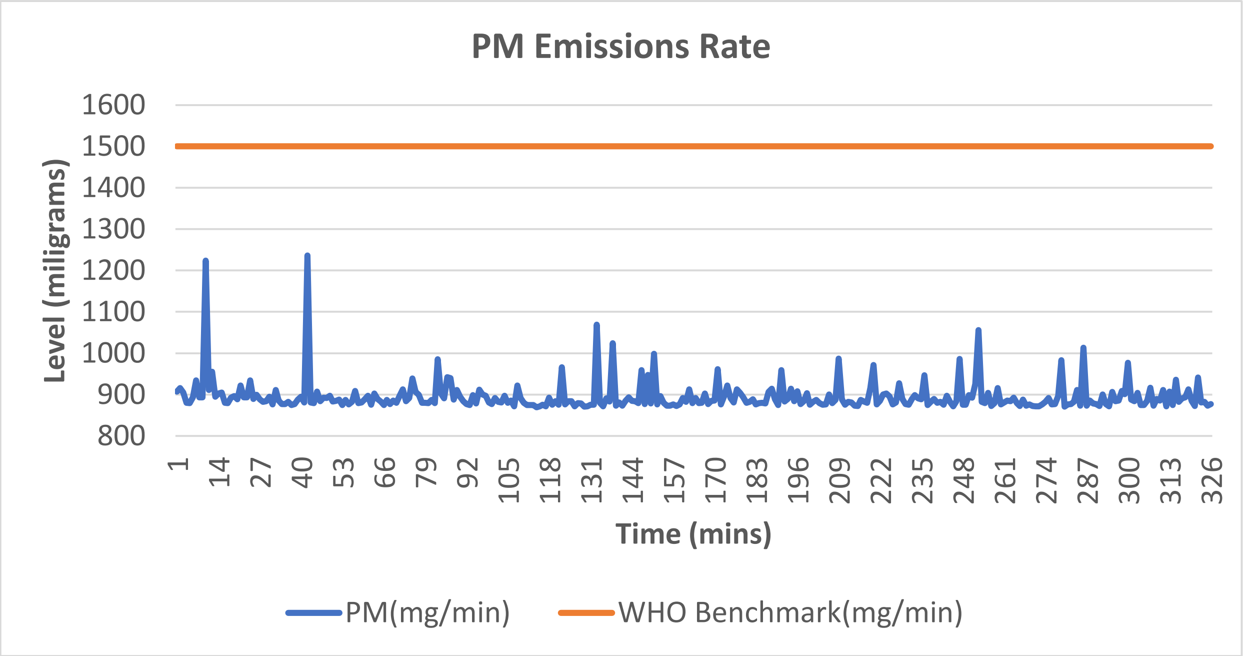

Figure 4.17: Graphical representation of PM emission from Improved cook stove (charcoal)

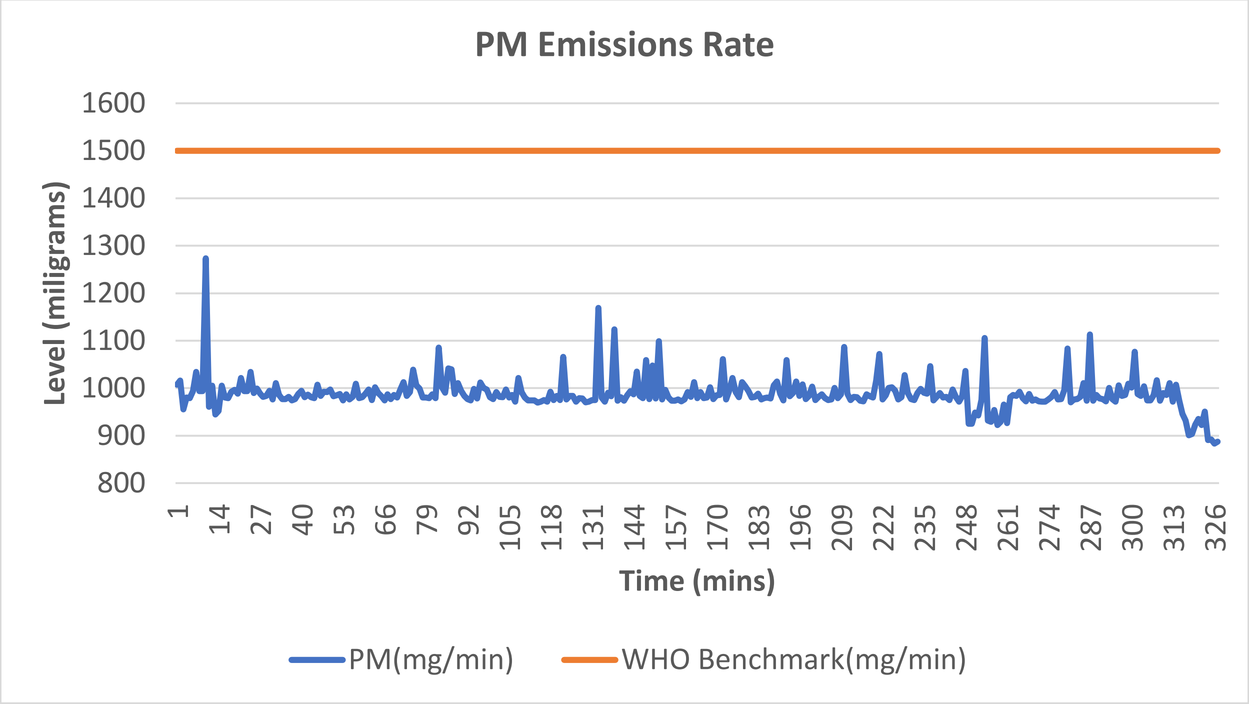

Figure 4.18: Graphical representation of PM emission from traditional cook stove (charcoal)

From the WHO Benchmark of PM having maximum limit emissions of 1500mg/min, the improved cook stove produces way fewer PM emissions which is averaged at 895.079mg/min than the traditional aluminium cook stove which is averaged at 988.142mg/min. From the percentage difference of both cook stoves, the ICS was able to reduce PM emissions by 9.42% even though both the improved charcoal cook stove and the traditional aluminium charcoal stove showed PM emissions way less than the WHO benchmark.

The PM emissions from the Merchaye, Lakech and traditional metal stoves were 275, 325 and 375 mg/min, respectively. The Merchaye and Lakech emitted significantly lower PM ($P < 0.001$) than the traditional metal stove (Mamuyea et al., 2018). The PM emissions from both improved cook stoves and the traditional metal cook stove were all quite below the proposed benchmark value of 1500 mg/min (Roden et al., 2006). The bench mark value for PM was also computed by combining both charcoal and wood stoves. Therefore, the wide difference between the ICS and traditional cook stoves could be attributable to the higher PM emissions generated from wood fuel cook stoves than from the charcoal stoves (MacCarty et al., 2008). High amounts of PM precursor are removed during the charcoal production process which leads to lower levels of PM emissions from charcoal stoves.

4..3.2 Liquefied Petroleum Gas (LPG) Compartment

4.3.2.1 Controlled cooking test –

The test data sheet in Appendix 3 to 6 was used to record all data during the process of cooking. The variable outputs that were computed are based on data recorded, and these include total weight of food cooked, specific fuel consumption, total cooking time and processing rate. The variables mentioned are considered for both the Local Rim LPG cook stove and the improved institutional cook stove designed for the purposes of this thesis.

Variable representations: Local Rim cook stove (total weight of food cooked, specific fuel consumption, total cooking time and processing time). Improved institutional cook stove (total weight of food cooked_1, specific fuel consumption_1, total cooking time_1 and processing rate_1).

Results below are generated using the Control cooking test version 2.0 test protocol excel workbook for LPG which is presented in Appendix 3 to 6.

4.3.2.1.1 Total cooking time:

Table 4.10: Summary Statistics of total weight of food cooked for Local Rim and ICS

	Total weight of food cooked	*Total weight of food cooked_1*
Count	3	3
Average	3174.33	3199.0
Standard deviation	21.1975	4.3589
Coefficient of variation	0.667778%	0.136258%
Minimum	3155.0	3194.0
Maximum	3197.0	3202.0
Range	42.0	8.0

4.3.2.1.2 Comparison of Means for total weight of food cooked

95.0% confidence interval for mean of Total weight of food cooked: 3174.33 ± 52.6575

[3121.68, 3226.99]

95.0% confidence interval for mean of Total weight of food cooked_1: 3199.0 ± 10.8281

[3188.17, 3209.83]

95.0% confidence interval for the difference between the means assuming equal variances: -24.6667 ± 34.6902 [-59.3569, 10.0236]

4.3.2.1.3 T-test to compare means of total weight of food cooked

Null hypothesis: mean1 = mean2

Alternate hypothesis: mean1 ≠ mean2

assuming equal variances: t = -1.97421   P-value = 0.119591

Do not reject the null hypothesis for alpha = 0.05.

Since the calculated P value is not less than 0.05, we cannot reject the zero hypothesis. And would therefore conclude that there is no statistically significant difference between the total weight of food cooked with the local rim LPG cook stove and that of the improved institutional cook stove.

4.3.2.1.4 Specific fuel consumption:

Table 4.11: Summary Statistics for the specific fuel consumption

	Specific Fuel consumption	***Specific Fuel consumption_1***
Count	3	3
Average	57.3333	50.0
Standard deviation	9.81495	8.66025
Coefficient of variation	17.1191%	17.3205%
Minimum	46.0	45.0
Maximum	63.0	60.0
Range	17.0	15.0
Standard skewness	-1.22474	1.22474

4.3.2.1.5 Comparison of Means

95.0% confidence interval for mean of Specific Fuel consumption: 57.3333 ± 24.3817 [32.9516, 81.715]

95.0% confidence interval for mean of Specific Fuel consumption_1: 50.0 ± 21.5133 [28.4867, 71.5133]

95.0% confidence interval for the difference between the means assuming equal variances:

7.33333 ± 20.9822 [-13.6489, 28.3155]

4.3.2.1.6 T-test to compare means of the specific fuel consumption

Null hypothesis: mean1 = mean2

Alt. hypothesis: mean1 ≠ mean2

assuming equal variances: t = 0.970378   P-value = 0.386807

Do not reject the null hypothesis for alpha = 0.05

Since the computed P-value is not less than 0.05, we cannot reject the null hypothesis. Therefore, it can be concluded that there is no statistically significant difference for the specific fuel consumption of both the local rim LPG cook stove and the improved institutional cook stove.

4.3.2.1.7 Total cooking time

Table 4.12: Summary Statistics for the total cooking time of both cook stoves

	Total cooking time	***Total cooking time_1***
Count	3	3
Average	78.6667	83.6667
Standard deviation	0.57735	4.16333
Coefficient of variation	0.73392%	4.97609%
Minimum	78.0	79.0
Maximum	79.0	87.0
Range	1.0	8.0
Standard skewness	-1.22474	-0.914531

4.3.2.1.8 Comparison of Means for the total cooking time

95.0% confidence interval for mean of Total cooking time: 78.6667 ± 1.43422 [77.2324, 80.1009]

95.0% confidence interval for mean of Total cooking time_1: 83.6667 ± 10.3423 [73.3244, 94.009]

95.0% confidence interval for the difference between the means assuming equal variances: -5.0 ± 6.73763 [-11.7376, 1.73763]

4.3.2.1.9 T-test to compare means of the total cooking time

Null hypothesis: mean1 = mean2

Alt. hypothesis: mean1 ≠ mean2

assuming equal variances: t = -2.06041   P-value = 0.108401

Do not reject the null hypothesis for alpha = 0.05

Since the computed P-value is not less than 0.05, we cannot reject the null hypothesis. Therefore, it can be concluded that there is no statistically significant difference for the total cooking time of both local rim LPG cook stove and improved institutional cook stove.

4.3.2.1.10 Processing rate:

Table 4.13: Summary Statistics of the processing rate of both cook stoves

	Processing Rate	***Processing Rate_1***
Count	3	3
Average	40.0	38.3333
Standard deviation	0	1.52753
Coefficient of variation	0%	3.98485%
Minimum	40.0	37.0
Maximum	40.0	40.0
Range	0	3.0
Standard skewness		0.6613

4.3.2.1.11 Comparison of Means for the processing rate of both cook stoves

95.0% confidence interval for mean of Processing Rate: 40.0 ± 0 [40.0, 40.0]

95.0% confidence interval for mean of Processing Rate_1: 38.3333 ± 3.79458 [34.5388, 42.1279]

95.0% confidence interval for the difference between the means assuming equal variances: 1.66667 ± 2.4486 [-0.781935, 4.11527]

4.3.2.1.12 T-test to compare means of the processing rate

Null hypothesis: mean1 = mean2

Alt. hypothesis: mean1 ≠ mean2

assuming equal variances: t = 1.88982   P-value = 0.131778

Do not reject the null hypothesis for alpha = 0.05

Since the computed P-value is not less than 0.05, we cannot reject the null hypothesis. Therefore, it can be concluded that there is no statistically significant difference for both local rim LPG cook stove and the improved institutional cook stove for the processing rate.

4.3.2.1.13 Data summary on all variables computed and analyzed for LPG compartment

Table 4.14: Averages and Analysis of Variables for both Local Rim and Improved Cook stove

	Rim Gas Stove	**Emma Gas Stove**	**P-Value**	**Significant Difference**
Specific Fuel consumption (g/kg)	57±9.81	50±8.66	0.386807	No
Total Cooking Time (min)	79±0.58	84±4.16	0.108401	No
Processing Rate (g/min)	40±0.00	38±1.53	0.131778	No

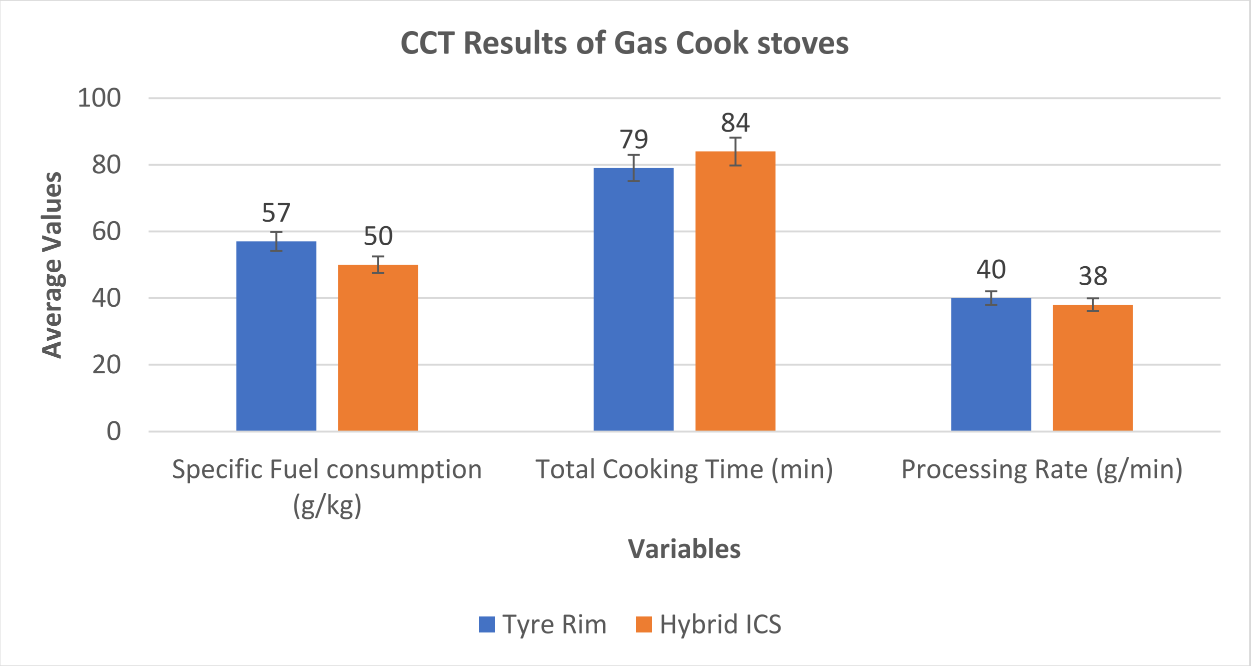

Figure 4.19: Graphical representation of the variables computed and analyzed

4.3.2.1.14 Efficiency of the Improved institutional cook stove (LPG) in terms of SFC:

Using the Specific Fuel Consumption (SFC) of the cook stove, efficiency was computed in order to determine performance of the improved cook stove in relation to the locally made cook stove.

$$Efficiency = \left|\frac{SFC(L) - SFC(ICS)}{SFC(L)} \times 100\right|$$

Equation 4.2: Efficiency in terms of SFC

Where:

SFC – specific fuel consumption

(ICS) – improved cook stove

(L) – locally made rim cook stove

Therefore;

$$Efficiency = \left|\frac{57 - 50}{57} \times 100\right|$$

$$= \mathbf{12.28}\%$$

4.3.2.2 Emissions Test –

Parameters that were observed during this test include carbon monoxide (CO) and particulate matter 2.5µm ($PM_{2.5}$).

Based on the World Health Organization benchmark for indoor air pollutions, liquefied petroleum gas has maximum limit of Carbon Monoxide (CO) emission rate at 0.07g/min and a maximum Particulate Matter (2.5µm) an emission rate of 0.15mg/min (Global Alliance for Clean Cookstoves (GACC2), 2011; Morawska & Smith, n.d.).

LPG as a fuel for household cooking has been classified as a clean and efficient fuel by the Global Alliance for Clean Cookstoves, (2013) and it is prudent to ensure that the improved institutional cook stove designed for the purposes of this thesis is in line with the WHO benchmark for LPG CO and PM emissions.

4.3.2.2.1 CO emissions for Improved Institutional cook stove (LPG)

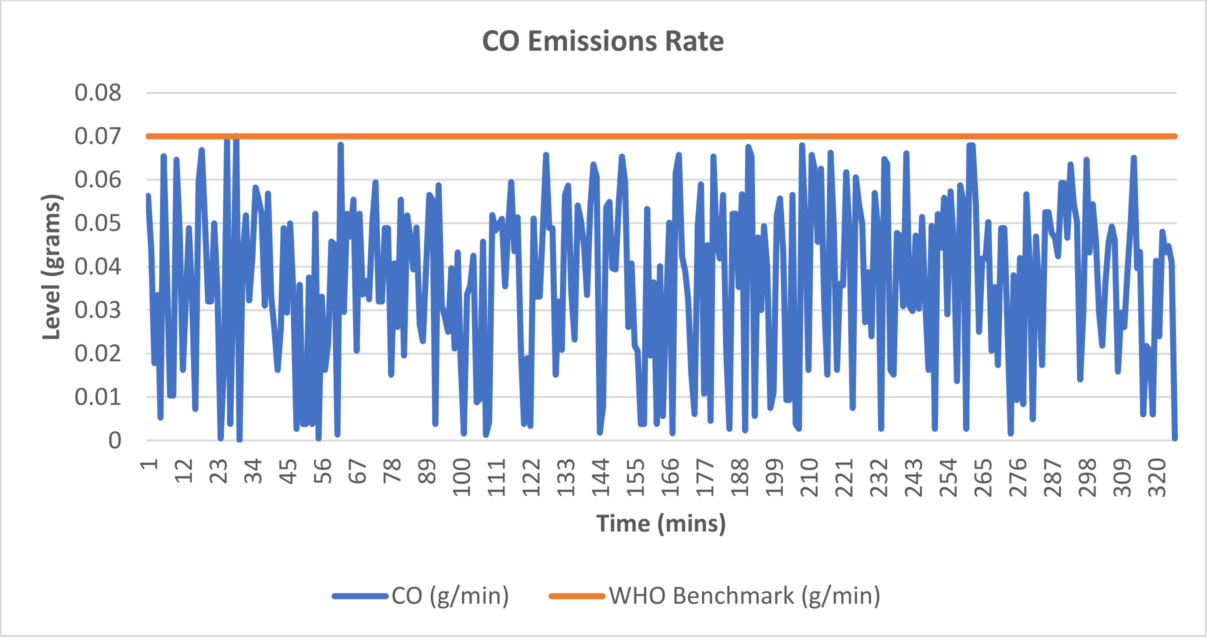

Figure 4.20: Graphical representation of CO emissions from ICS (Charcoal)

To determine to the gap away from the benchmark, the percent difference will be computed and this gives a fair idea on the improved institutional cook stove meeting the benchmark value set by WHO in terms of Carbon monoxide (CO) emissions.

Percent difference = $\frac{CO_{WHO}-CO_{ICS}}{CO_{WHO}} \times 100$

Equation 4.3: Percent Difference for CO_LPG

$$= \frac{0.07-0.0367483}{0.07} \times 100$$

= 47.50%

This shows that on the average, there is a fairly wide gap away from the WHO benchmark for CO emissions. Therefore, it can be noted that CO emissions that are generated from the improved institutional cook stove (LPG) is in line with the benchmark set by WHO.

4.3.2.2.2 PM emissions for Improved Institutional cook stove (LPG)

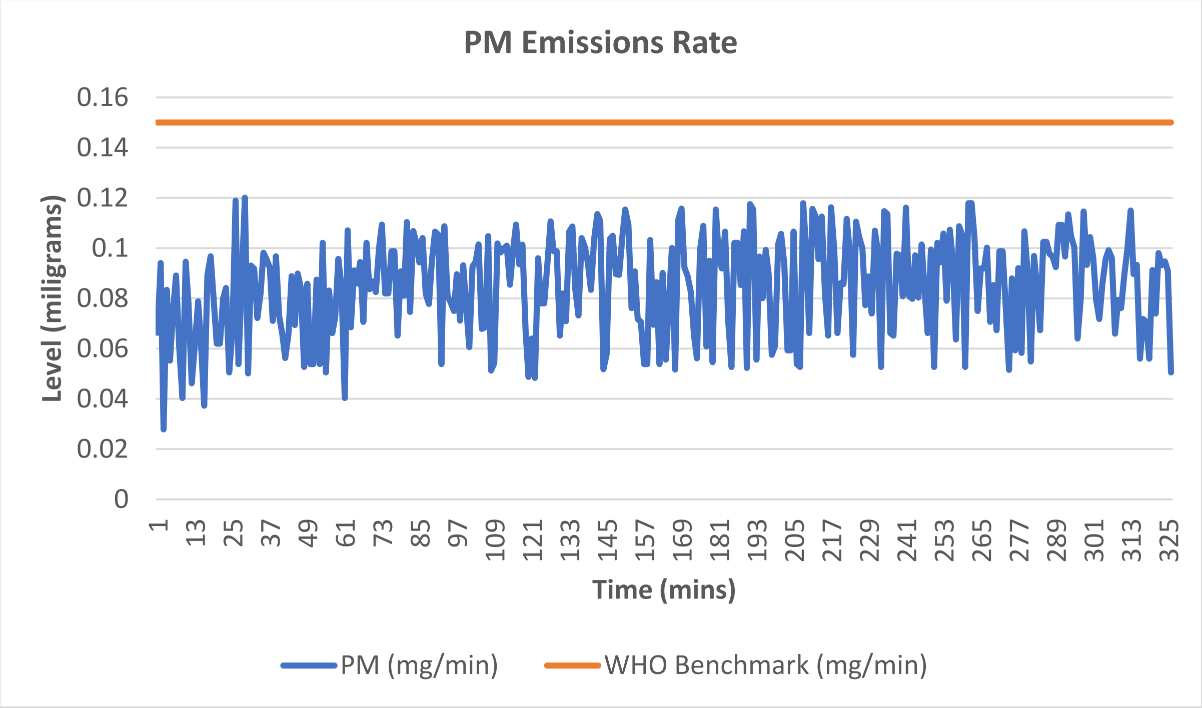

Figure 4.21: Graphical representation of CO emissions from ICS (Charcoal)

To determine to the gap away from the benchmark, the percent difference will be computed and this gives a fair idea on the improved institutional cook stove meeting the benchmark value set by WHO in terms if particulate matter (PM) emissions.

$$\text{Percent difference} = \frac{PM_{WHO} - PM_{ICS}}{PM_{WHO}} \times 100$$

Equation 4.4: Percent Difference for PM_LPG

$$= \frac{0.15 - 0.0850612}{0.15} \times 100$$

= 43.29%

This shows that on the average, there is a fairly wide gap away from the WHO benchmark for PM emissions. Therefore, it can be noted that PM emissions that are generated from the improved institutional cook stove (LPG) is in line with the benchmark set by WHO.

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion:

As part of the Global Alliance for Clean Cookstoves, (2016) goals which aims at achieving 20 million households using improved cook stoves and fuels by the year 2020, it has become prudent on industry and academia to embark on aiding and addressing problems through research that seeks to contribute to successful clean cookstove production and distribution.

Considering the principles and design guidelines that were followed, there was a successful design and construction of the improved institutional cook stove. The aim of producing a user-friendly, easy to use and aesthetically pleasing cook stove was achieved successfully.

Institutions that perform longer hours of cooking are most likely to take advantage of the improved cook stove designed and fabricated for the purposes of this thesis. Based on the specific fuel consumption and processing rate for a particular cooking session the improved institutional cook stove has a better advantage over the traditional aluminium cook stove when using the charcoal compartment. And for the LPG compartment the specific and processing time are similar to that of the traditional aluminium cook stove.

In terms of health benefits, the improved institutional cook stove has an advantage over the traditional cook stove with the sense of reducing carbon monoxide and particulate matter emissions for the charcoal compartment. The LPG compartment emits emissions which are way less than the WHO benchmark limit set for household indoor cooking.

The results of this study therefore reiterate the need to encourage the introduction of improved cook stoves to replace non-performing traditional cook stoves. This will aid users and victims of cook stoves survive the fight for a clean and healthy environment.

This research thesis has proven to show that upon following the guidelines and protocols set by the Global Alliance for Clean Cookstoves, (2016), one is likely to contribute to the reduction of emissions produced from cooking processes and also a reduction in fuel demand and usage for the same purpose. This thesis tends to have an advantage over other improved cook stoves by providing dual fuel options to users and also meeting the various benchmark limits set for emissions.

5.2 Recommendations:

Based on materials used for fabrication for this research thesis, final weight of the improved cook stove was 62.5kg. It would be recommended that lighter materials could be exploited in other to prevent the cook stove from having the too much weight, as it has potential in affecting overall stove performance.

Also, another testing method that could be performed is the water boiling test and kitchen performance test which would aid in obtaining a thermal efficiency of the improved institutional cook stove and also getting data that is more likely to reflect field usage of the improved cook stove.

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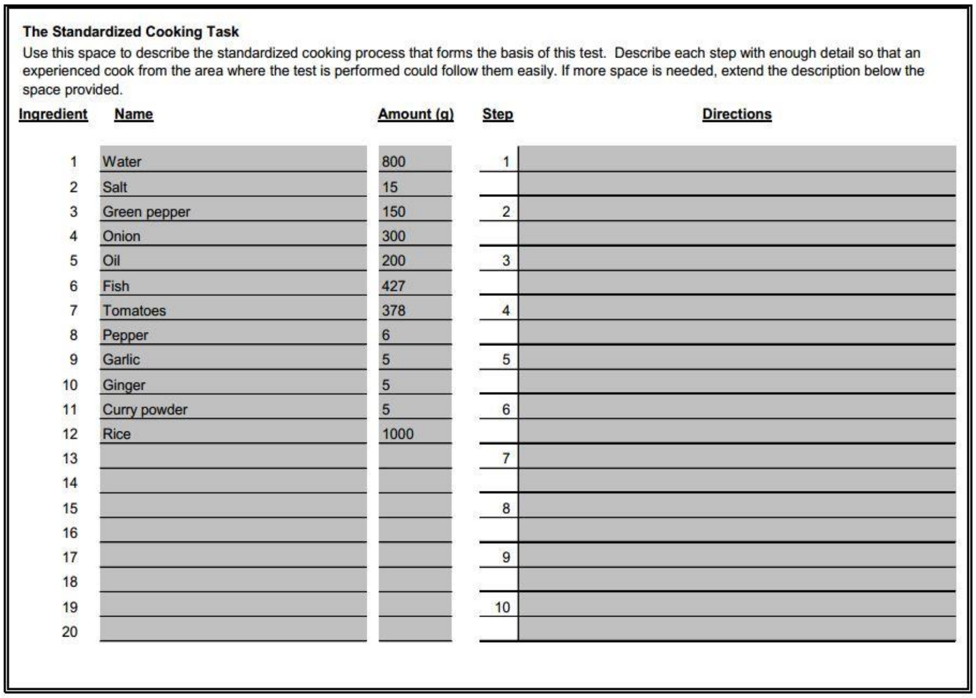
7.0 APPENDICES

Appendix 1

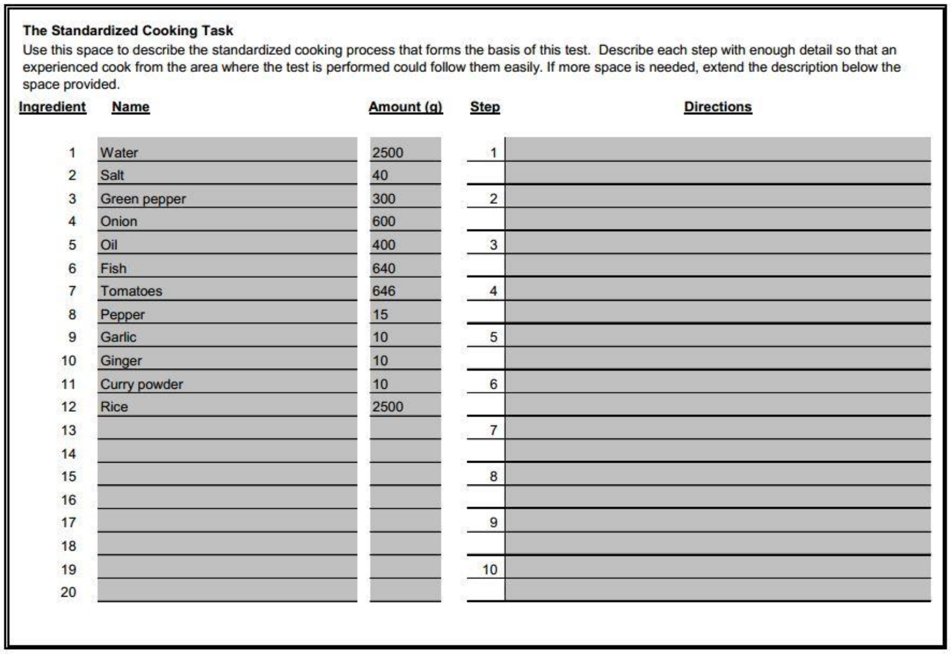


The Standardized Cooking Task

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

Ingredient	Name	Amount (g)	Step	Directions
1	Water	800	1	
2	Salt	15		
3	Green pepper	150	2	
4	Onion	300		
5	Oil	200	3	
6	Fish	427		
7	Tomatoes	378	4	
8	Pepper	6		
9	Garlic	5	5	
10	Ginger	5		
11	Curry powder	5	6	
12	Rice	1000		
13			7	
14				
15			8	
16				
17			9	
18				
19			10	
20				

Appendix 2



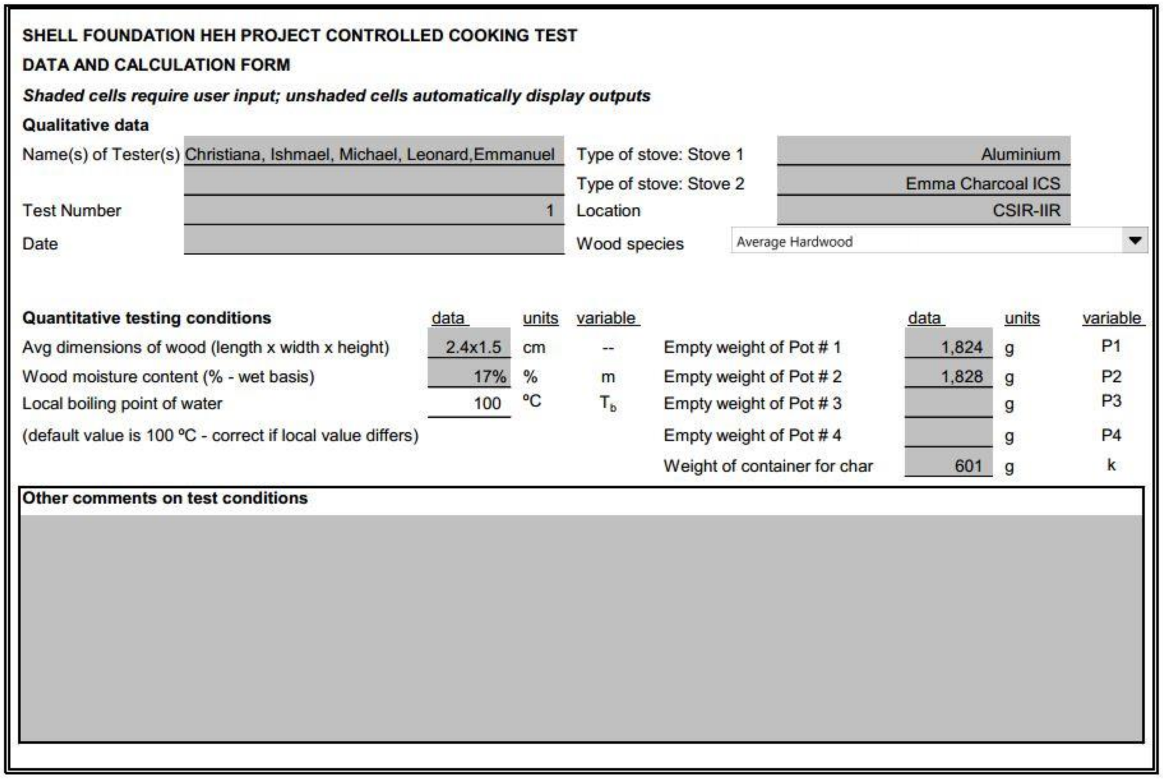
The Standardized Cooking Task

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

Ingredient	Name	Amount (g)	Step	Directions
1	Water	2500	1	
2	Salt	40		
3	Green pepper	300	2	
4	Onion	600		
5	Oil	400	3	
6	Fish	640		
7	Tomatoes	646	4	
8	Pepper	15		
9	Garlic	10	5	
10	Ginger	10		
11	Curry powder	10	6	
12	Rice	2500		
13			7	
14				
15			8	
16				
17			9	
18				
19			10	
20				

Detail list of ingredients used for controlled cooking test – Charcoal & LPG compartment

Appendix 3



SHELL FOUNDATION HEH PROJECT CONTROLLED COOKING TEST

DATA AND CALCULATION FORM

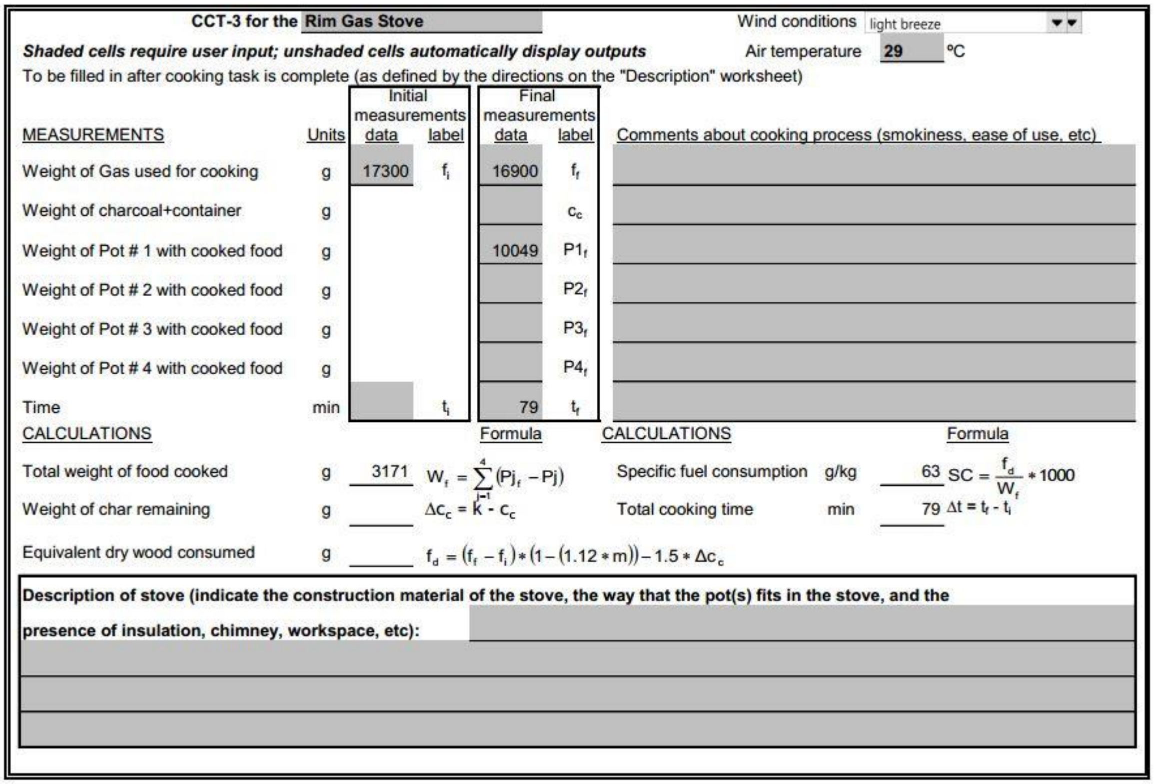
Shaded cells require user input; unshaded cells automatically display outputs

Qualitative data

Name(s) of Tester(s)	Christiana, Ishmael, Michael, Leonard,Emmanuel	Type of stove: Stove 1	Aluminium
		Type of stove: Stove 2	Emma Charcoal ICS
Test Number	1	Location	CSIR-IIR
Date		Wood species	Average Hardwood

Quantitative testing conditions	data	units	variable		data	units	variable
Avg dimensions of wood (length x width x height)	2.4x1.5	cm	--	Empty weight of Pot # 1	1,824	g	P1
Wood moisture content (% - wet basis)	17%	%	m	Empty weight of Pot # 2	1,828	g	P2
Local boiling point of water	100	°C	T_b	Empty weight of Pot # 3		g	P3
(default value is 100 °C - correct if local value differs)				Empty weight of Pot # 4		g	P4
				Weight of container for char	601	g	k

Other comments on test conditions



CCT-3 for the Rim Gas Stove

Wind conditions: light breeze

Shaded cells require user input; unshaded cells automatically display outputs

Air temperature: **29** °C

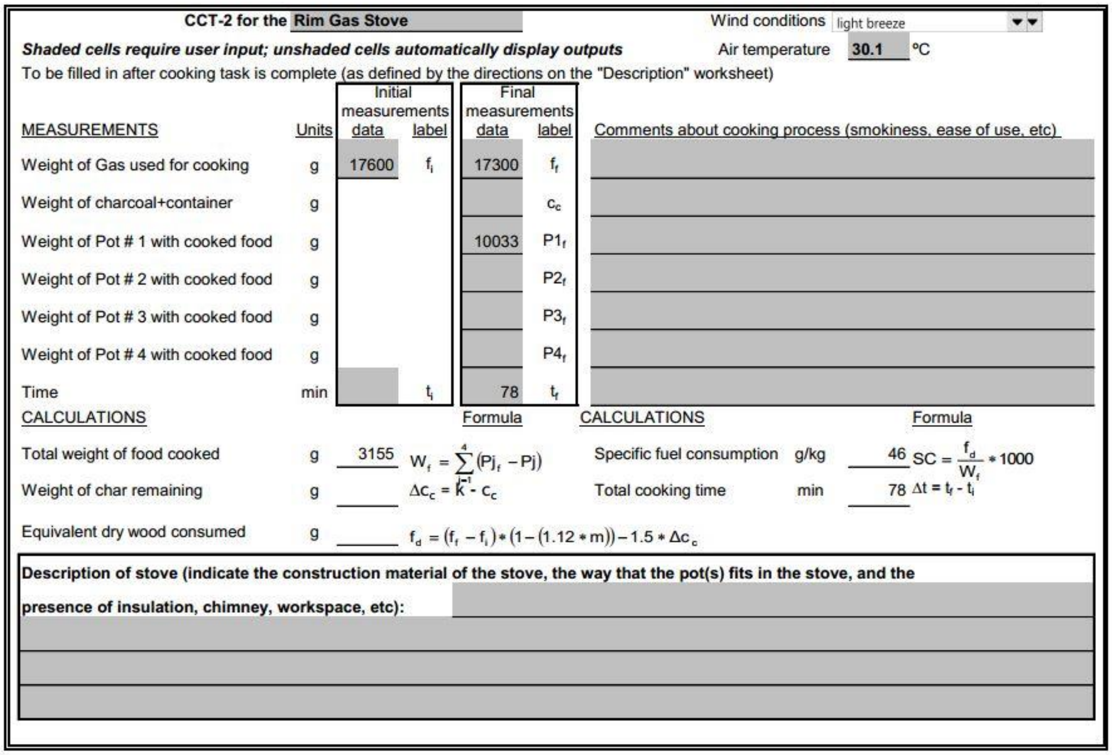
To be filled in after cooking task is complete (as defined by the directions on the "Description" worksheet)

MEASUREMENTS	Units	Initial measurements data	Initial measurements label	Final measurements data	Final measurements label	Comments about cooking process (smokiness, ease of use, etc)
Weight of Gas used for cooking	g	17300	f_i	16900	f_f	
Weight of charcoal+container	g				c_c	
Weight of Pot # 1 with cooked food	g			10049	$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Weight of Pot # 4 with cooked food	g				$P4_f$	
Time	min		t_i	79	t_f	

CALCULATIONS			Formula	CALCULATIONS			Formula
Total weight of food cooked	g	3171	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$	Specific fuel consumption	g/kg	63	$SC = \frac{f_d}{W_f} * 1000$
Weight of char remaining	g		$\Delta c_c = k - c_c$	Total cooking time	min	79	$\Delta t = t_f - t_i$
Equivalent dry wood consumed	g		$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$				

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

Appendix 4



CCT-2 for the Rim Gas Stove Wind conditions light breeze ▼

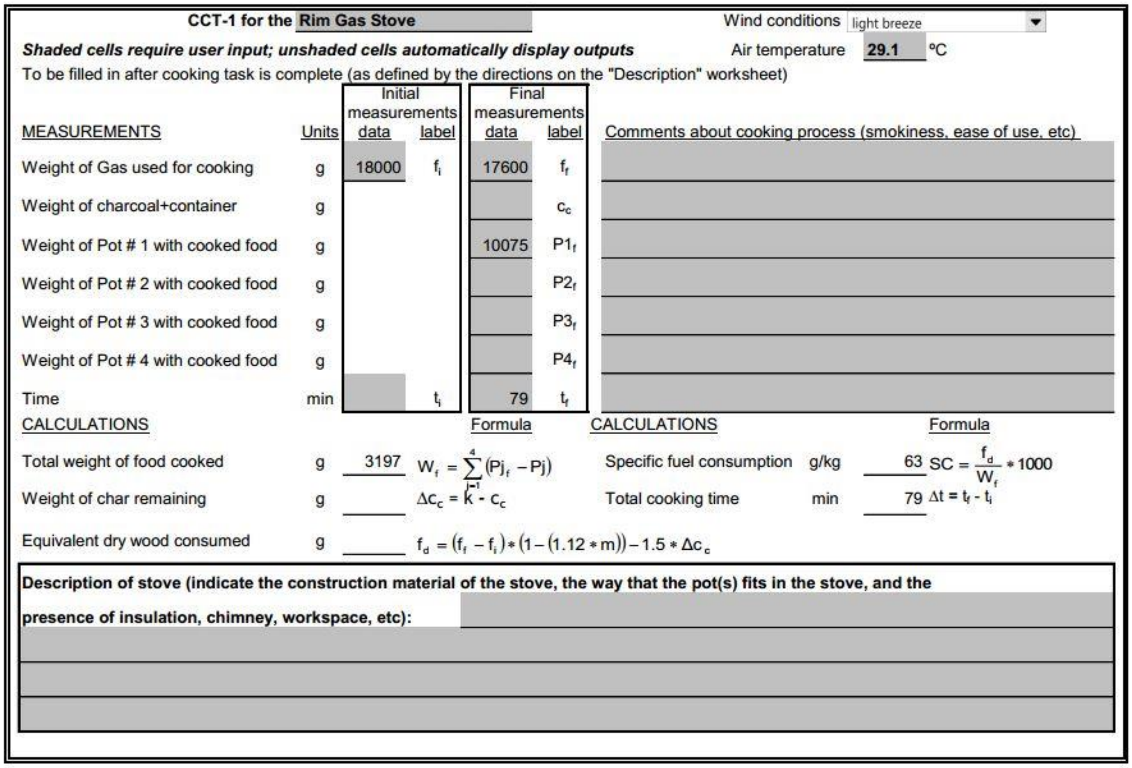
Shaded cells require user input; unshaded cells automatically display outputs Air temperature **30.1** °C

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

MEASUREMENTS	Units	Initial measurements data	label	Final measurements data	label	Comments about cooking process (smokiness, ease of use, etc)
Weight of Gas used for cooking	g	17600	f_i	17300	f_f	
Weight of charcoal+container	g				c_c	
Weight of Pot # 1 with cooked food	g			10033	$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Weight of Pot # 4 with cooked food	g				$P4_f$	
Time	min		t_i	78	t_f	

CALCULATIONS			Formula	CALCULATIONS			Formula
Total weight of food cooked	g	3155	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$	Specific fuel consumption	g/kg	46	$SC = \frac{f_d}{W_f} * 1000$
Weight of char remaining	g		$\Delta c_c = k - c_c$	Total cooking time	min	78	$\Delta t = t_f - t_i$
Equivalent dry wood consumed	g		$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$				

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



CCT-1 for the Rim Gas Stove Wind conditions light breeze ▼

Shaded cells require user input; unshaded cells automatically display outputs Air temperature **29.1** °C

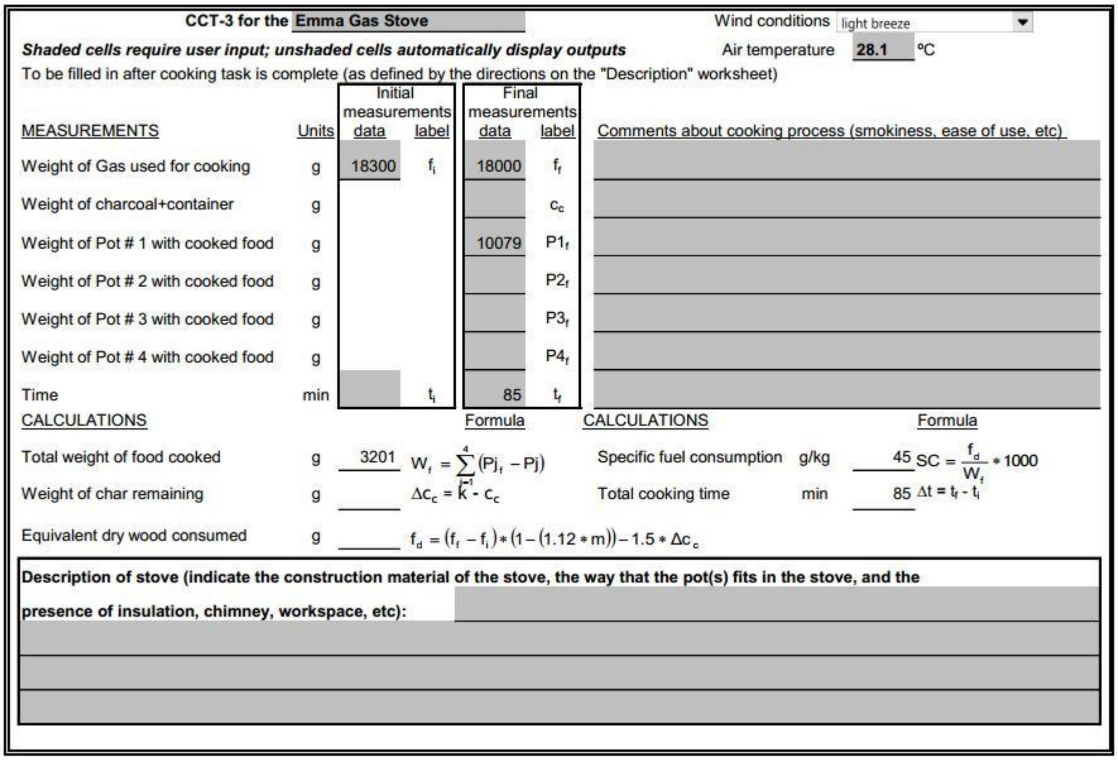
To be filled in after cooking task is complete (as defined by the directions on the "Description" worksheet)

MEASUREMENTS	Units	Initial measurements data	label	Final measurements data	label	Comments about cooking process (smokiness, ease of use, etc)
Weight of Gas used for cooking	g	18000	f_i	17600	f_f	
Weight of charcoal+container	g				c_c	
Weight of Pot # 1 with cooked food	g			10075	$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Weight of Pot # 4 with cooked food	g				$P4_f$	
Time	min		t_i	79	t_f	

CALCULATIONS			Formula	CALCULATIONS			Formula
Total weight of food cooked	g	3197	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$	Specific fuel consumption	g/kg	63	$SC = \frac{f_d}{W_f} * 1000$
Weight of char remaining	g		$\Delta c_c = k - c_c$	Total cooking time	min	79	$\Delta t = t_f - t_i$
Equivalent dry wood consumed	g		$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$				

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

Appendix 5



CCT-3 for the Emma Gas Stove Wind conditions light breeze

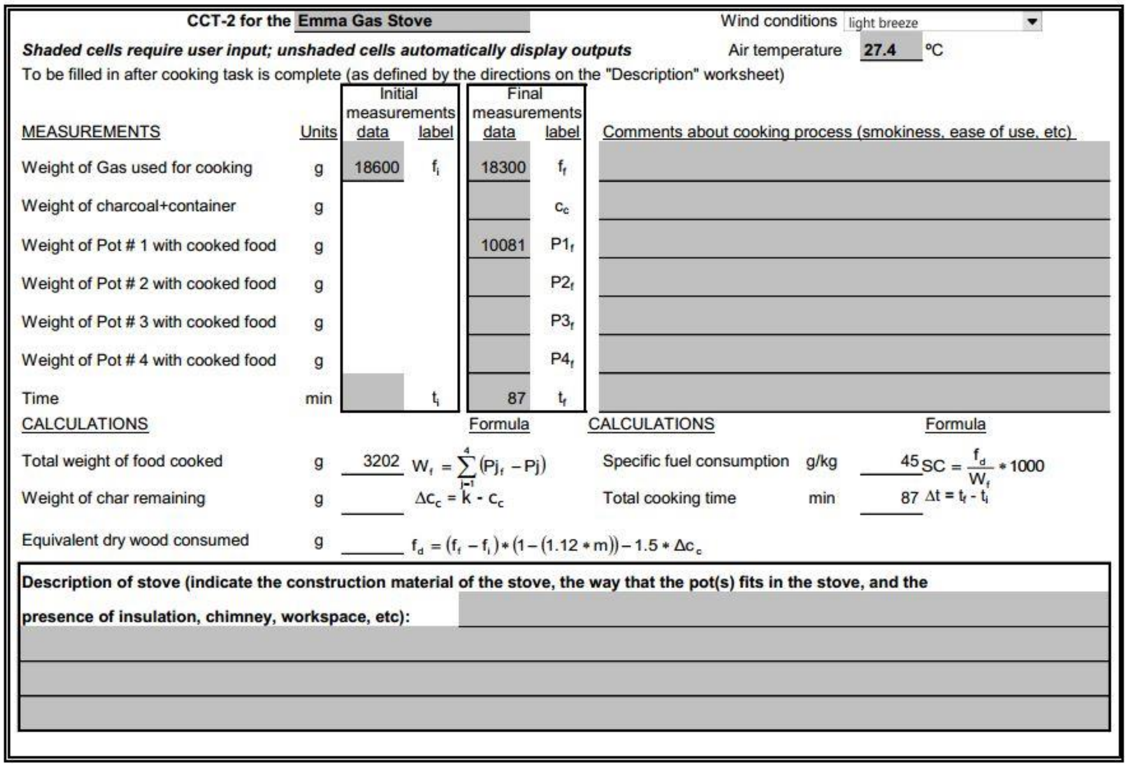
Shaded cells require user input; unshaded cells automatically display outputs Air temperature **28.1** °C

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

MEASUREMENTS	Units	Initial measurements data	label	Final measurements data	label	Comments about cooking process (smokiness, ease of use, etc)
Weight of Gas used for cooking	g	18300	f_i	18000	f_f	
Weight of charcoal+container	g				c_c	
Weight of Pot # 1 with cooked food	g			10079	$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Weight of Pot # 4 with cooked food	g				$P4_f$	
Time	min		t_i	85	t_f	

CALCULATIONS			Formula	CALCULATIONS			Formula
Total weight of food cooked	g	3201	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$	Specific fuel consumption	g/kg	45	$SC = \frac{f_d}{W_f} * 1000$
Weight of char remaining	g		$\Delta c_c = k - c_c$	Total cooking time	min	85	$\Delta t = t_f - t_i$
Equivalent dry wood consumed	g		$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$				

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



CCT-2 for the Emma Gas Stove Wind conditions light breeze

Shaded cells require user input; unshaded cells automatically display outputs Air temperature **27.4** °C

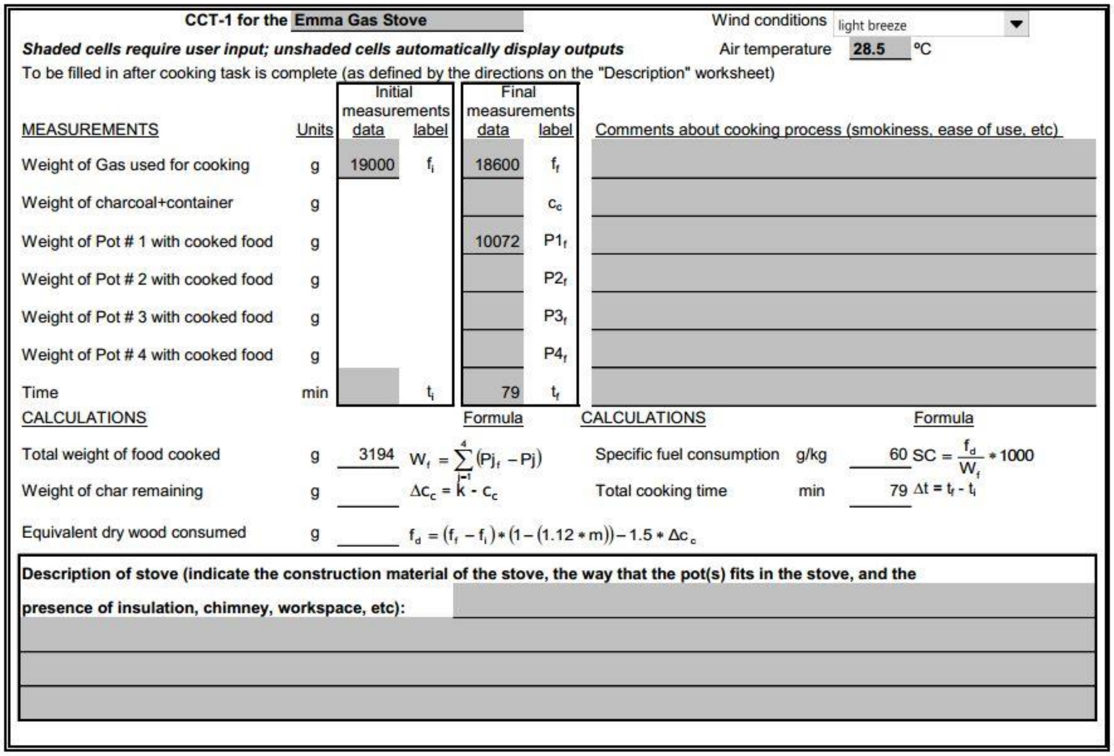
To be filled in after cooking task is complete (as defined by the directions on the "Description" worksheet)

MEASUREMENTS	Units	Initial measurements data	label	Final measurements data	label	Comments about cooking process (smokiness, ease of use, etc)
Weight of Gas used for cooking	g	18600	f_i	18300	f_f	
Weight of charcoal+container	g				c_c	
Weight of Pot # 1 with cooked food	g			10081	$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Weight of Pot # 4 with cooked food	g				$P4_f$	
Time	min		t_i	87	t_f	

CALCULATIONS			Formula	CALCULATIONS			Formula
Total weight of food cooked	g	3202	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$	Specific fuel consumption	g/kg	45	$SC = \frac{f_d}{W_f} * 1000$
Weight of char remaining	g		$\Delta c_c = k - c_c$	Total cooking time	min	87	$\Delta t = t_f - t_i$
Equivalent dry wood consumed	g		$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$				

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

Appendix 6



CCT-1 for the Emma Gas Stove

Wind conditions: light breeze

Air temperature: **28.5** °C

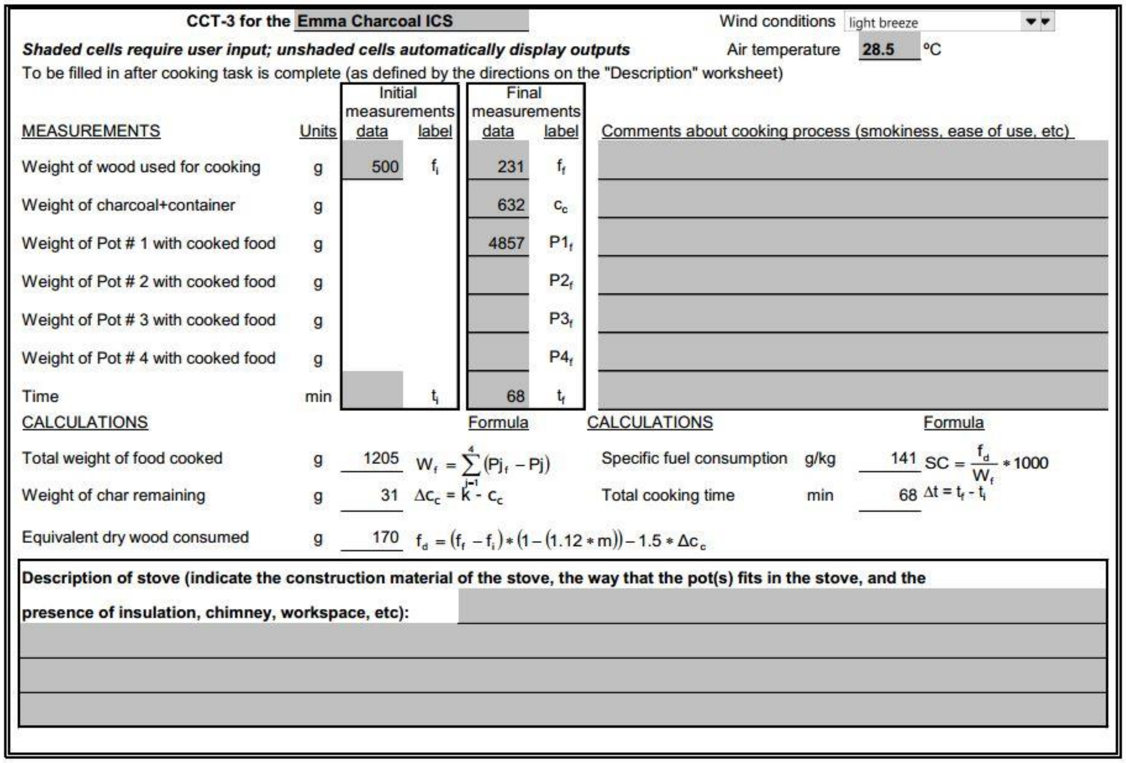
Shaded cells require user input; unshaded cells automatically display outputs

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

MEASUREMENTS	Units	Initial measurements data	Initial measurements label	Final measurements data	Final measurements label	Comments about cooking process (smokiness, ease of use, etc)
Weight of Gas used for cooking	g	19000	f_i	18600	f_f	
Weight of charcoal+container	g				c_c	
Weight of Pot # 1 with cooked food	g			10072	$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Weight of Pot # 4 with cooked food	g				$P4_f$	
Time	min		t_i	79	t_f	

CALCULATIONS			Formula	CALCULATIONS			Formula
Total weight of food cooked	g	3194	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$	Specific fuel consumption	g/kg	60	$SC = \frac{f_d}{W_f} * 1000$
Weight of char remaining	g		$\Delta c_c = k - c_c$	Total cooking time	min	79	$\Delta t = t_f - t_i$
Equivalent dry wood consumed	g		$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$				

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



CCT-3 for the Emma Charcoal ICS

Wind conditions: light breeze

Air temperature: **28.5** °C

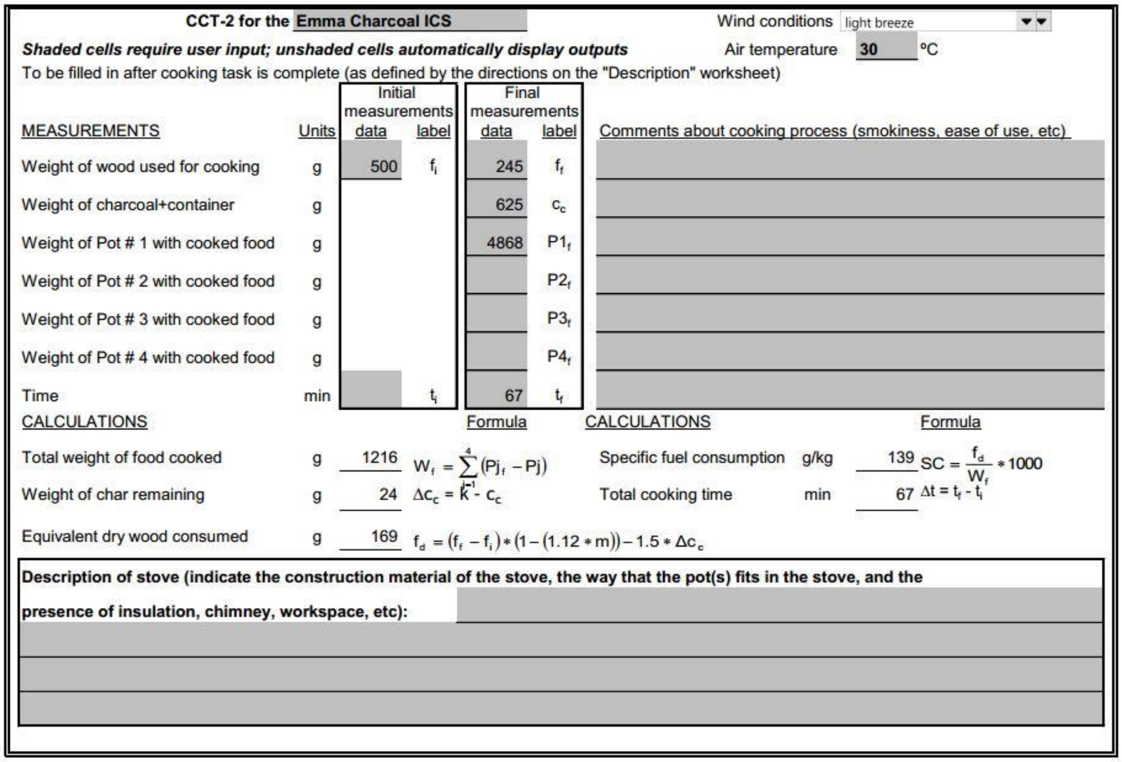
Shaded cells require user input; unshaded cells automatically display outputs

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

MEASUREMENTS	Units	Initial measurements data	Initial measurements label	Final measurements data	Final measurements label	Comments about cooking process (smokiness, ease of use, etc)
Weight of wood used for cooking	g	500	f_i	231	f_f	
Weight of charcoal+container	g			632	c_c	
Weight of Pot # 1 with cooked food	g			4857	$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Weight of Pot # 4 with cooked food	g				$P4_f$	
Time	min		t_i	68	t_f	

CALCULATIONS			Formula	CALCULATIONS			Formula
Total weight of food cooked	g	1205	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$	Specific fuel consumption	g/kg	141	$SC = \frac{f_d}{W_f} * 1000$
Weight of char remaining	g	31	$\Delta c_c = k - c_c$	Total cooking time	min	68	$\Delta t = t_f - t_i$
Equivalent dry wood consumed	g	170	$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$				

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



CCT-2 for the **Emma Charcoal ICS** Wind conditions light breeze

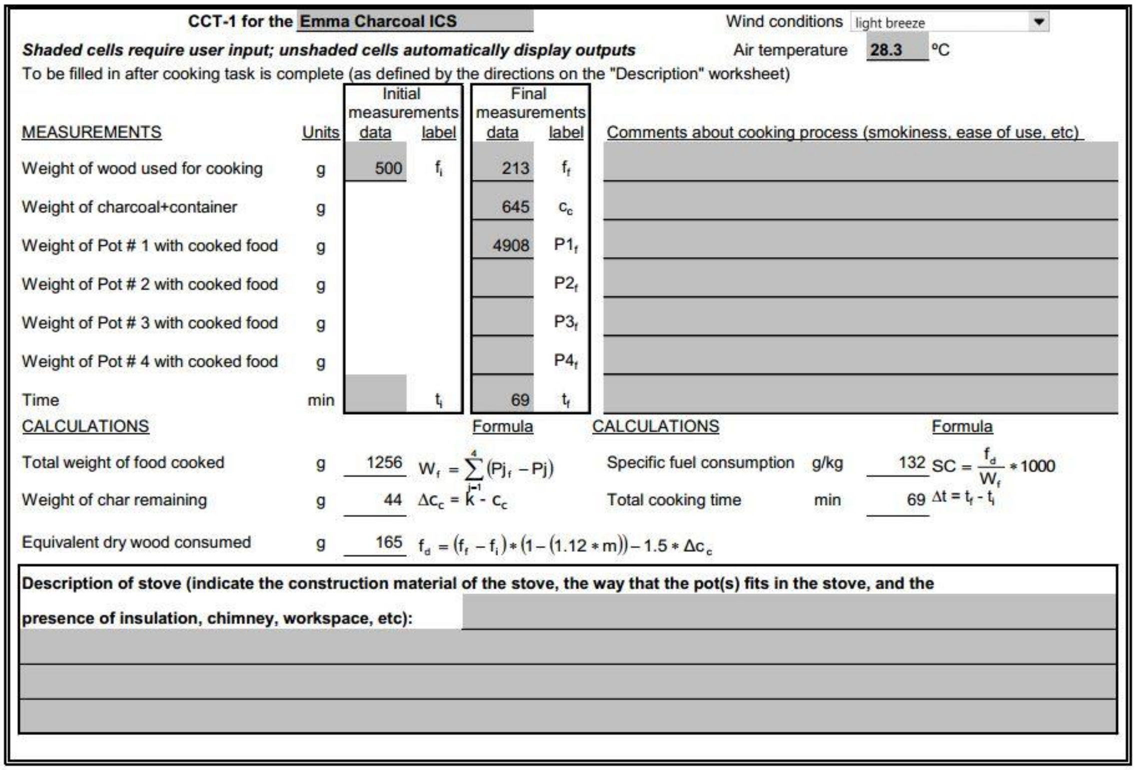
Shaded cells require user input; unshaded cells automatically display outputs Air temperature **30** °C

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

MEASUREMENTS	Units	Initial measurements data	Initial measurements label	Final measurements data	Final measurements label	Comments about cooking process (smokiness, ease of use, etc)
Weight of wood used for cooking	g	500	f_i	245	f_f	
Weight of charcoal+container	g			625	c_c	
Weight of Pot # 1 with cooked food	g			4868	$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Weight of Pot # 4 with cooked food	g				$P4_f$	
Time	min		t_i	67	t_f	

CALCULATIONS			Formula	CALCULATIONS			Formula
Total weight of food cooked	g	1216	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$	Specific fuel consumption	g/kg	139	$SC = \frac{f_d}{W_f} * 1000$
Weight of char remaining	g	24	$\Delta c_c = k - c_c$	Total cooking time	min	67	$\Delta t = t_f - t_i$
Equivalent dry wood consumed	g	169	$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$				

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



CCT-1 for the **Emma Charcoal ICS** Wind conditions light breeze

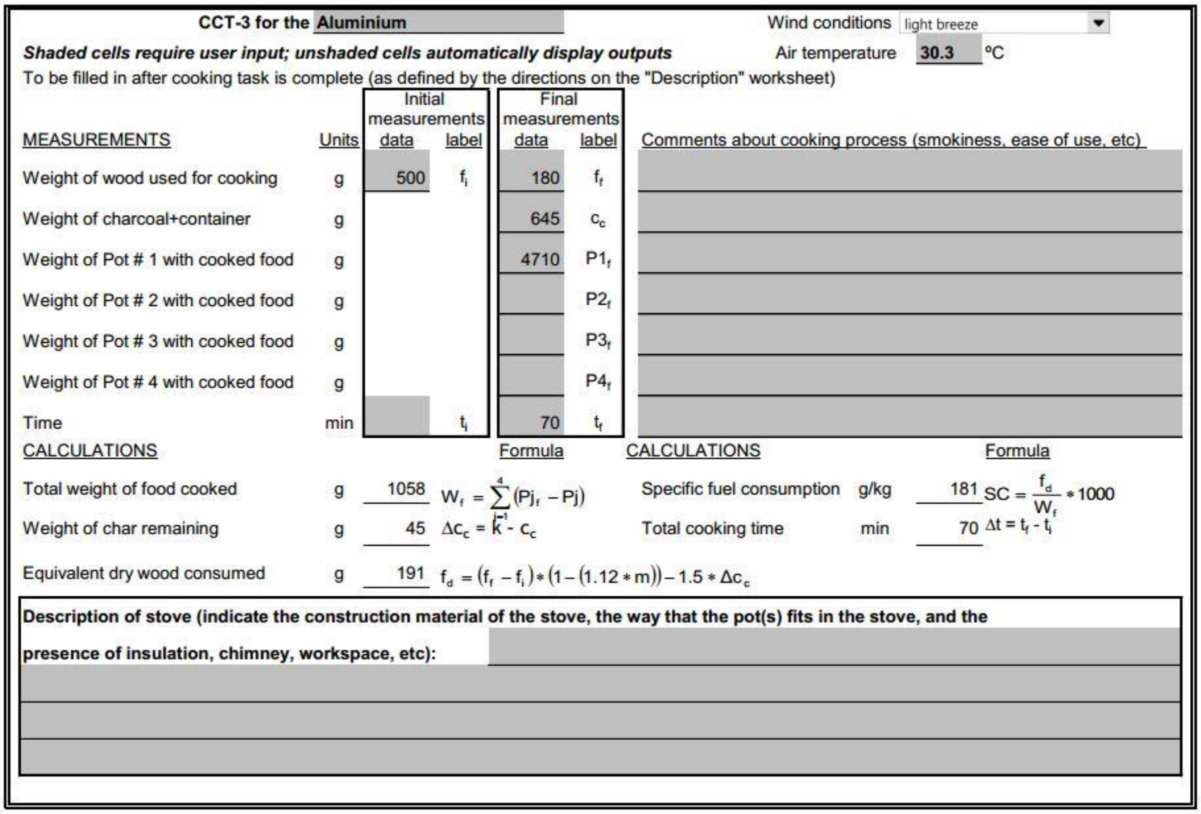
Shaded cells require user input; unshaded cells automatically display outputs Air temperature **28.3** °C

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

MEASUREMENTS	Units	Initial measurements data	Initial measurements label	Final measurements data	Final measurements label	Comments about cooking process (smokiness, ease of use, etc)
Weight of wood used for cooking	g	500	f_i	213	f_f	
Weight of charcoal+container	g			645	c_c	
Weight of Pot # 1 with cooked food	g			4908	$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Weight of Pot # 4 with cooked food	g				$P4_f$	
Time	min		t_i	69	t_f	

CALCULATIONS			Formula	CALCULATIONS			Formula
Total weight of food cooked	g	1256	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$	Specific fuel consumption	g/kg	132	$SC = \frac{f_d}{W_f} * 1000$
Weight of char remaining	g	44	$\Delta c_c = k - c_c$	Total cooking time	min	69	$\Delta t = t_f - t_i$
Equivalent dry wood consumed	g	165	$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$				

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



CCT-3 for the Aluminium — Wind conditions: light breeze

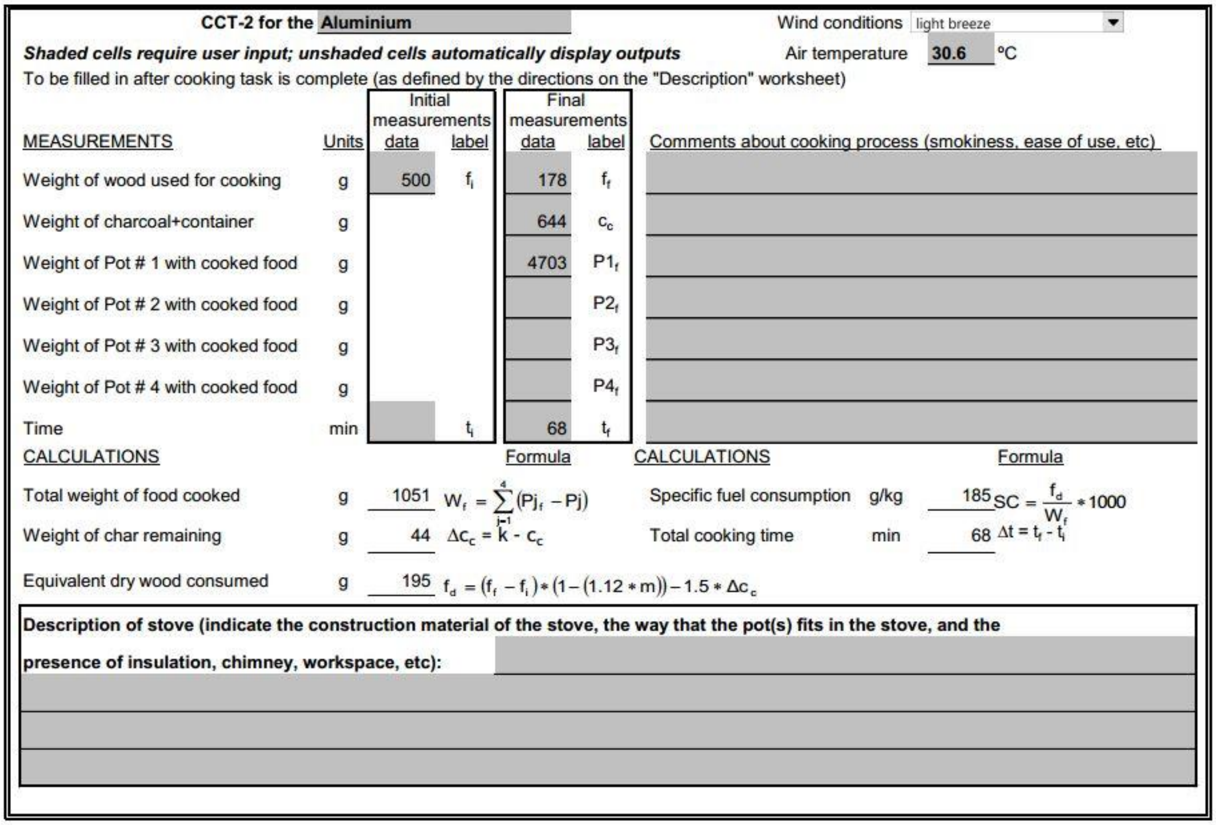
Shaded cells require user input; unshaded cells automatically display outputs — Air temperature **30.3** °C

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

MEASUREMENTS	Units	Initial measurements data	label	Final measurements data	label	Comments about cooking process (smokiness, ease of use, etc)
Weight of wood used for cooking	g	500	f_i	180	f_f	
Weight of charcoal+container	g			645	c_c	
Weight of Pot # 1 with cooked food	g			4710	$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Weight of Pot # 4 with cooked food	g				$P4_f$	
Time	min		t_i	70	t_f	

CALCULATIONS			Formula	CALCULATIONS			Formula
Total weight of food cooked	g	1058	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$	Specific fuel consumption	g/kg	181	$SC = \frac{f_d}{W_f} * 1000$
Weight of char remaining	g	45	$\Delta c_c = k - c_c$	Total cooking time	min	70	$\Delta t = t_f - t_i$
Equivalent dry wood consumed	g	191	$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$				

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



CCT-2 for the Aluminium — Wind conditions: light breeze

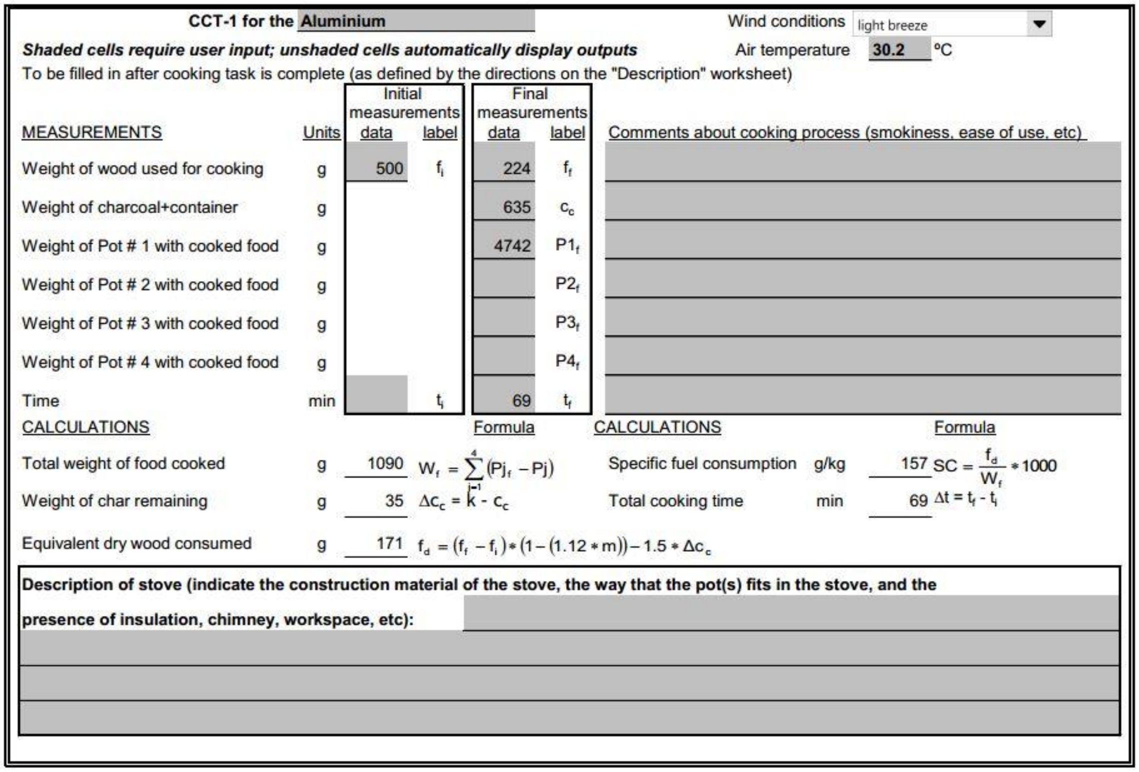
Shaded cells require user input; unshaded cells automatically display outputs — Air temperature **30.6** °C

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

MEASUREMENTS	Units	Initial measurements data	label	Final measurements data	label	Comments about cooking process (smokiness, ease of use, etc)
Weight of wood used for cooking	g	500	f_i	178	f_f	
Weight of charcoal+container	g			644	c_c	
Weight of Pot # 1 with cooked food	g			4703	$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Weight of Pot # 4 with cooked food	g				$P4_f$	
Time	min		t_i	68	t_f	

CALCULATIONS			Formula	CALCULATIONS			Formula
Total weight of food cooked	g	1051	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$	Specific fuel consumption	g/kg	185	$SC = \frac{f_d}{W_f} * 1000$
Weight of char remaining	g	44	$\Delta c_c = k - c_c$	Total cooking time	min	68	$\Delta t = t_f - t_i$
Equivalent dry wood consumed	g	195	$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$				

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



CCT-1 for the Aluminium

Wind conditions: light breeze

Shaded cells require user input; unshaded cells automatically display outputs

Air temperature: **30.2** °C

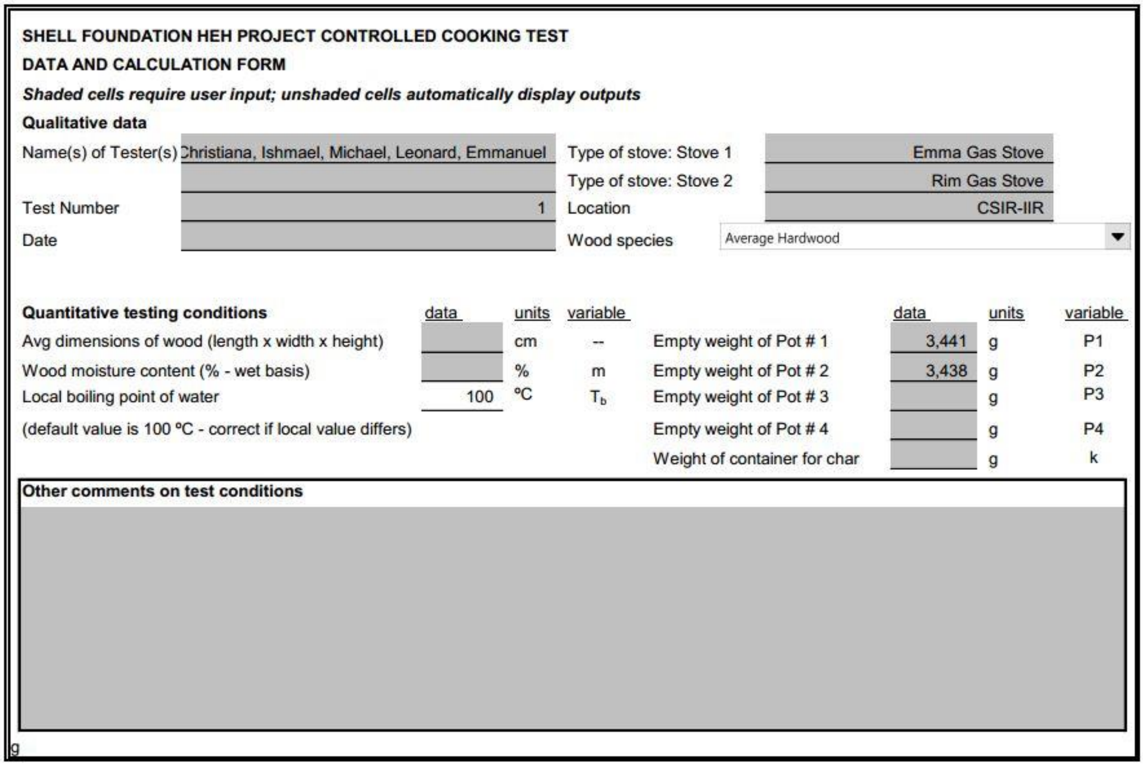
To be filled in after cooking task is complete (as defined by the directions on the "Description" worksheet)

MEASUREMENTS	Units	Initial measurements data	Initial measurements label	Final measurements data	Final measurements label	Comments about cooking process (smokiness, ease of use, etc)
Weight of wood used for cooking	g	500	f_i	224	f_f	
Weight of charcoal+container	g			635	c_c	
Weight of Pot # 1 with cooked food	g			4742	$P1_f$	
Weight of Pot # 2 with cooked food	g				$P2_f$	
Weight of Pot # 3 with cooked food	g				$P3_f$	
Weight of Pot # 4 with cooked food	g				$P4_f$	
Time	min		t_i	69	t_f	

CALCULATIONS			Formula
Total weight of food cooked	g	1090	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$
Weight of char remaining	g	35	$\Delta c_c = k - c_c$
Equivalent dry wood consumed	g	171	$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$

CALCULATIONS			Formula
Specific fuel consumption	g/kg	157	$SC = \frac{f_d}{W_f} * 1000$
Total cooking time	min	69	$\Delta t = t_f - t_i$

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):



SHELL FOUNDATION HEH PROJECT CONTROLLED COOKING TEST

DATA AND CALCULATION FORM

Shaded cells require user input; unshaded cells automatically display outputs

Qualitative data

Name(s) of Tester(s)	Christiana, Ishmael, Michael, Leonard, Emmanuel	Type of stove: Stove 1	Emma Gas Stove
		Type of stove: Stove 2	Rim Gas Stove
Test Number	1	Location	CSIR-IIR
Date		Wood species	Average Hardwood

Quantitative testing conditions	data	units	variable		data	units	variable
Avg dimensions of wood (length x width x height)		cm	--	Empty weight of Pot # 1	3,441	g	P1
Wood moisture content (% - wet basis)		%	m	Empty weight of Pot # 2	3,438	g	P2
Local boiling point of water	100	°C	T_b	Empty weight of Pot # 3		g	P3
(default value is 100 °C - correct if local value differs)				Empty weight of Pot # 4		g	P4
				Weight of container for char		g	k

Other comments on test conditions

g

Appendix 7

Table 7.1: Cost estimate of Materials for construction

NO.	**MATERIALS & DESCRIPTION**	**QUANTITY**	**COST (GH₵)**
1	Mild Steel Angle Iron – 2” x 2”	1 Pcs	100.00
2	Electrodes	1 Pack	40.00
3	Gas Burner – 6”	2 Pcs	200.00
4	Gas Valve	2 Pcs	100.00
5	Valve Nobs	2 Pcs	50.00
6	Air Valve	2 Pcs	60.00
7	$1\,{}^{1}/_{2}$” Mild Steel Irons	6 Pcs	300.00
8	Bolts & Nuts	-	40.00
9	Mild Steel Rods ${}^{1}/_{2}$”	-	50.00
10	Fan	2 Pcs	100.00
11	Clay Materials	-	200.00
12	Transport & Miscellaneous Costs	-	300.00
13	Labour Cost	-	500.00
	Total		**2,040.00**

Cook Stove Testing – CSIR (IIR)

For Dual Fuel Cook stove (Charcoal & Gas)

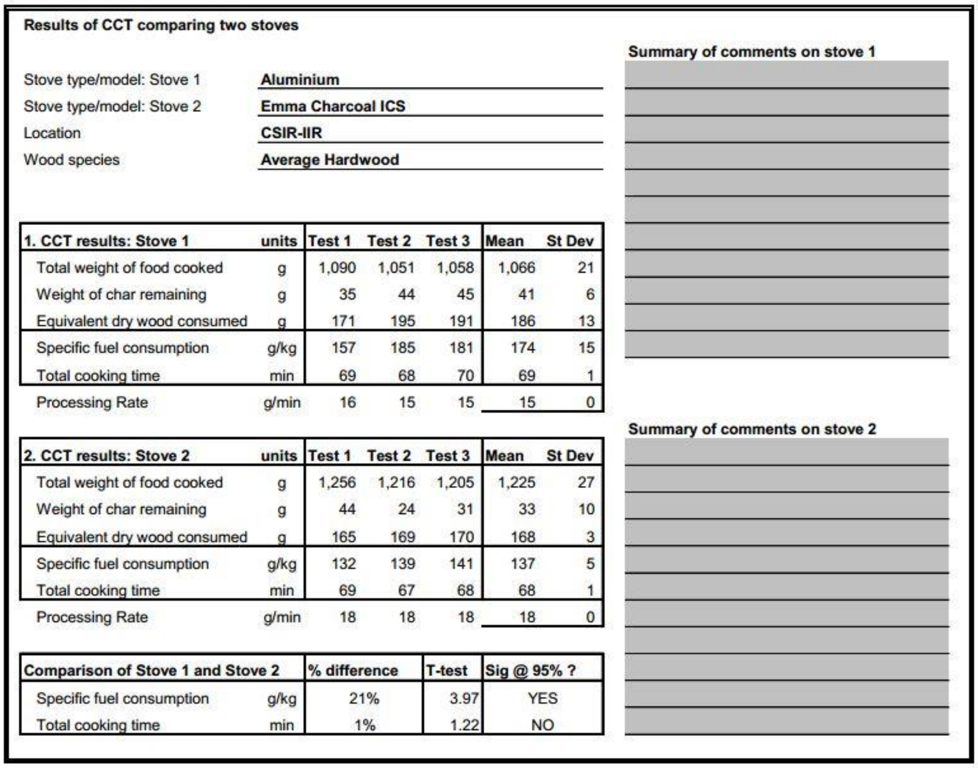
Testing involves;

1. Emissions Tests 2. Controlled Cooking Tests

Cost involved – 800GH₵

Total Cost for Construction and Testing – **GH₵ 2,840.00**

Appendix 8



Results of CCT comparing two stoves

Stove type/model: Stove 1 **Aluminium**
Stove type/model: Stove 2 **Emma Charcoal ICS**
Location **CSIR-IIR**
Wood species **Average Hardwood**

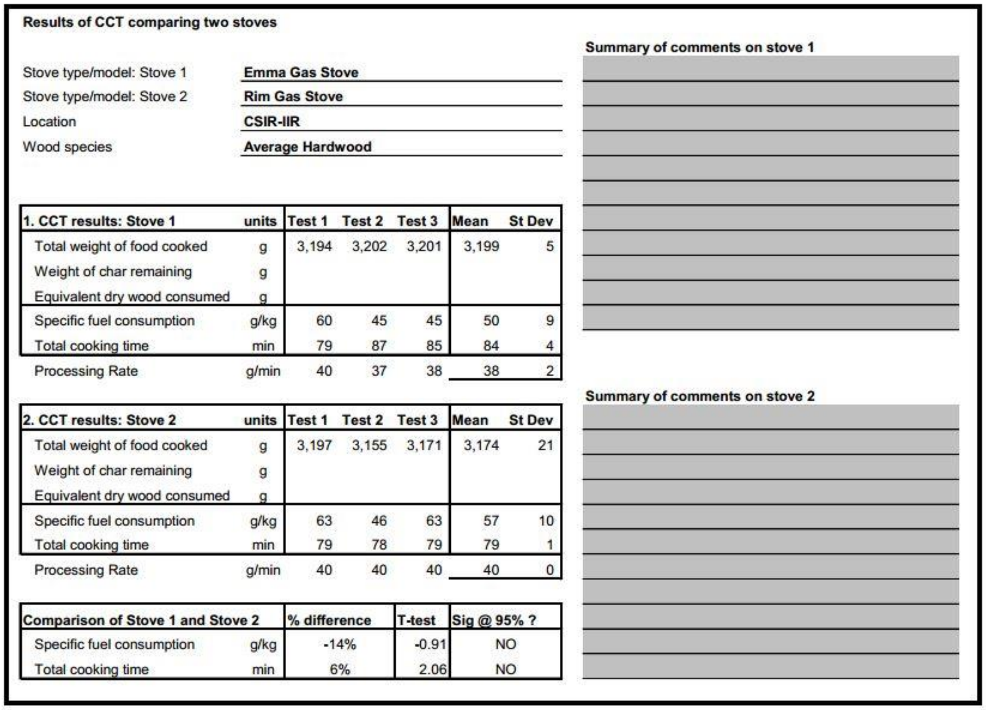
1. CCT results: Stove 1	units	Test 1	Test 2	Test 3	Mean	St Dev
Total weight of food cooked	g	1,090	1,051	1,058	1,066	21
Weight of char remaining	g	35	44	45	41	6
Equivalent dry wood consumed	g	171	195	191	186	13
Specific fuel consumption	g/kg	157	185	181	174	15
Total cooking time	min	69	68	70	69	1
Processing Rate	g/min	16	15	15	15	0

2. CCT results: Stove 2	units	Test 1	Test 2	Test 3	Mean	St Dev
Total weight of food cooked	g	1,256	1,216	1,205	1,225	27
Weight of char remaining	g	44	24	31	33	10
Equivalent dry wood consumed	g	165	169	170	168	3
Specific fuel consumption	g/kg	132	139	141	137	5
Total cooking time	min	69	67	68	68	1
Processing Rate	g/min	18	18	18	18	0

Comparison of Stove 1 and Stove 2		% difference	T-test	Sig @ 95% ?
Specific fuel consumption	g/kg	21%	3.97	YES
Total cooking time	min	1%	1.22	NO

Summary of comments on stove 1

Summary of comments on stove 2



Results of CCT comparing two stoves

Stove type/model: Stove 1 **Emma Gas Stove**
Stove type/model: Stove 2 **Rim Gas Stove**
Location **CSIR-IIR**
Wood species **Average Hardwood**

1. CCT results: Stove 1	units	Test 1	Test 2	Test 3	Mean	St Dev
Total weight of food cooked	g	3,194	3,202	3,201	3,199	5
Weight of char remaining	g					
Equivalent dry wood consumed	g					
Specific fuel consumption	g/kg	60	45	45	50	9
Total cooking time	min	79	87	85	84	4
Processing Rate	g/min	40	37	38	38	2

2. CCT results: Stove 2	units	Test 1	Test 2	Test 3	Mean	St Dev
Total weight of food cooked	g	3,197	3,155	3,171	3,174	21
Weight of char remaining	g					
Equivalent dry wood consumed	g					
Specific fuel consumption	g/kg	63	46	63	57	10
Total cooking time	min	79	78	79	79	1
Processing Rate	g/min	40	40	40	40	0

Comparison of Stove 1 and Stove 2		% difference	T-test	Sig @ 95% ?
Specific fuel consumption	g/kg	-14%	-0.91	NO
Total cooking time	min	6%	2.06	NO

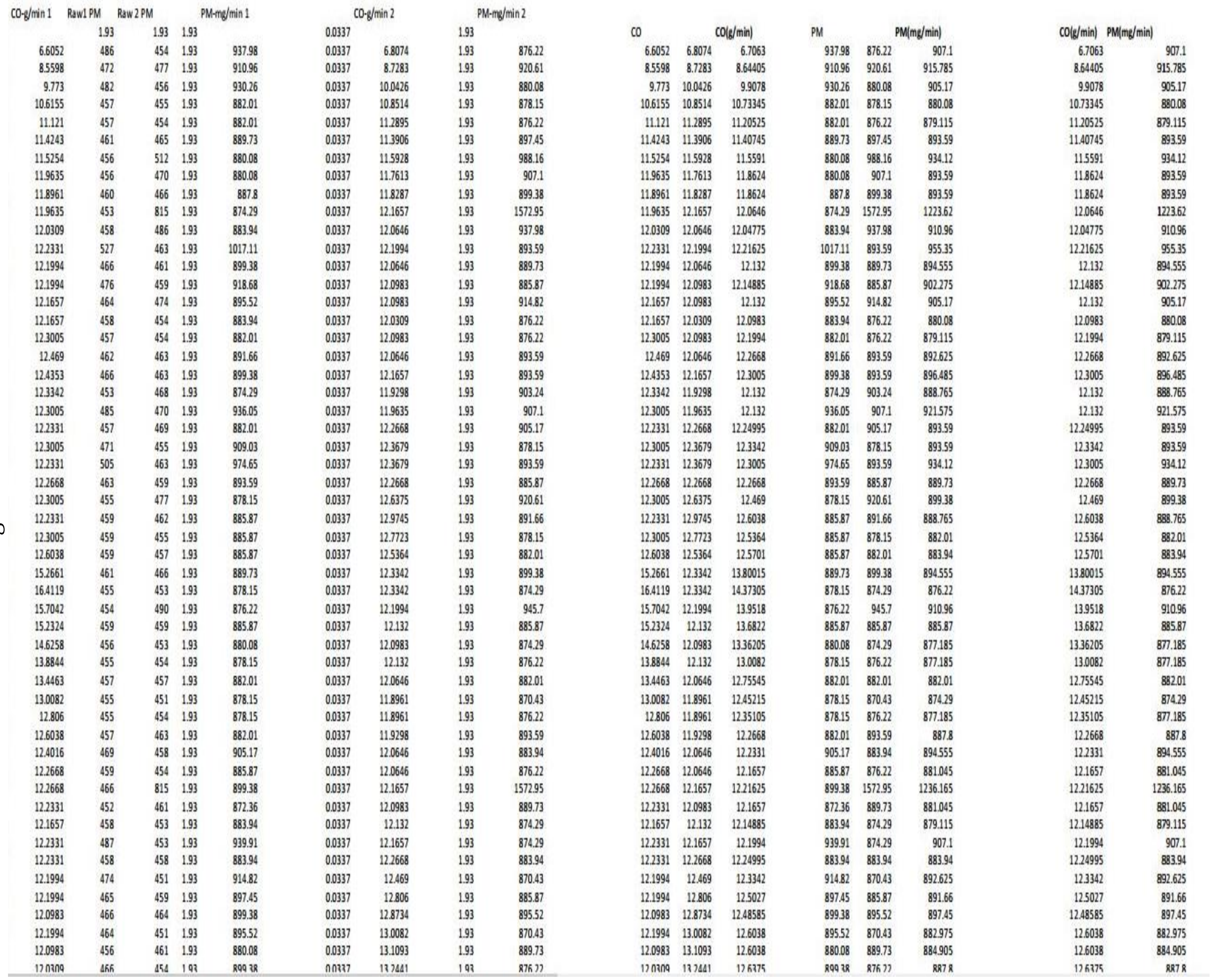
Summary of comments on stove 1

Summary of comments on stove 2

Results obtained from the data analysis on both Cook stoves using the CCT protocol

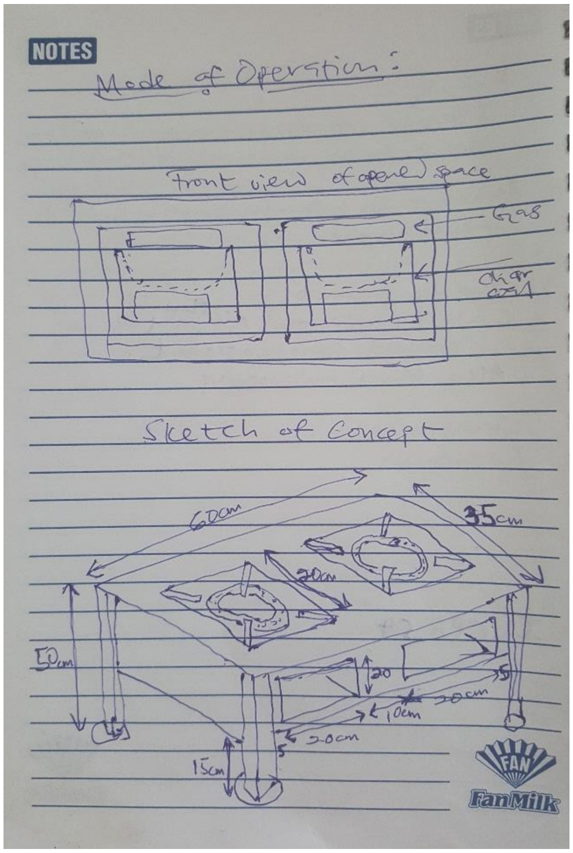
Appendix 9

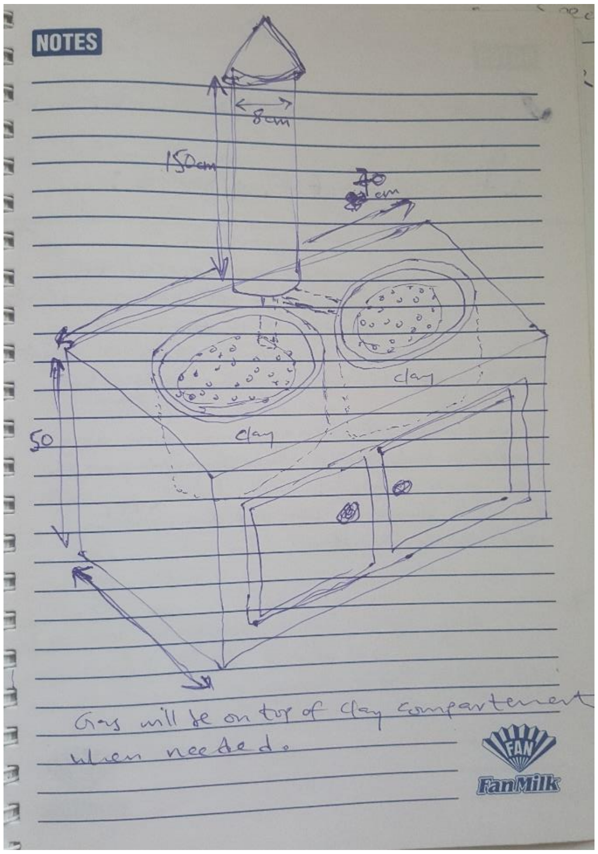
Emissions Test Raw data for the all Cooking Periods

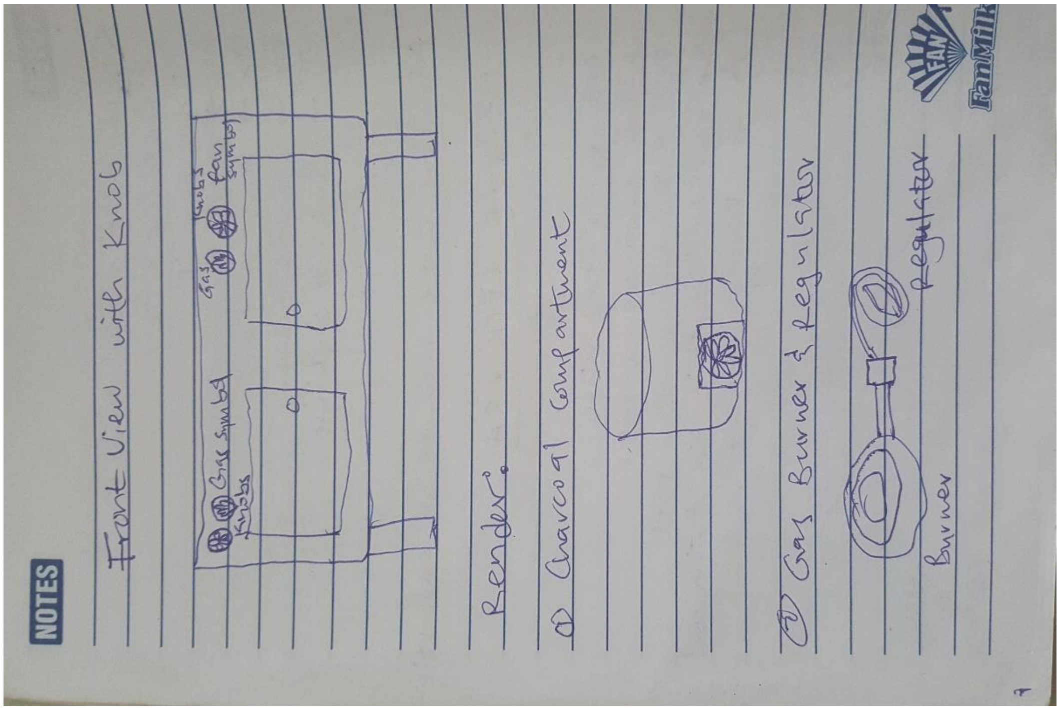


CO-g/min 1	Raw1 PM	Raw 2 PM		PM-mg/min 1		CO-g/min 2		PM-mg/min 2	CO		CO(g/min)	PM		PM(mg/min)	CO(g/min)	PM(mg/min)
	1.93	1.93	1.93		0.0337		1.93									
6.6052	486	454	1.93	937.98	0.0337	6.8074	1.93	876.22	6.6052	6.8074	6.7063	937.98	876.22	907.1	6.7063	907.1
8.5598	472	477	1.93	910.96	0.0337	8.7283	1.93	920.61	8.5598	8.7283	8.64405	910.96	920.61	915.785	8.64405	915.785
9.773	482	456	1.93	930.26	0.0337	10.0426	1.93	880.08	9.773	10.0426	9.9078	930.26	880.08	905.17	9.9078	905.17
10.6155	457	455	1.93	882.01	0.0337	10.8514	1.93	878.15	10.6155	10.8514	10.73345	882.01	878.15	880.08	10.73345	880.08
11.121	457	454	1.93	882.01	0.0337	11.2895	1.93	876.22	11.121	11.2895	11.20525	882.01	876.22	879.115	11.20525	879.115
11.4243	461	465	1.93	889.73	0.0337	11.3906	1.93	897.45	11.4243	11.3906	11.40745	889.73	897.45	893.59	11.40745	893.59
11.5254	456	512	1.93	880.08	0.0337	11.5928	1.93	988.16	11.5254	11.5928	11.5591	880.08	988.16	934.12	11.5591	934.12
11.9635	456	470	1.93	880.08	0.0337	11.7613	1.93	907.1	11.9635	11.7613	11.8624	880.08	907.1	893.59	11.8624	893.59
11.8961	460	466	1.93	887.8	0.0337	11.8287	1.93	899.38	11.8961	11.8287	11.8624	887.8	899.38	893.59	11.8624	893.59
11.9635	453	815	1.93	874.29	0.0337	12.1657	1.93	1572.95	11.9635	12.1657	12.0646	874.29	1572.95	1223.62	12.0646	1223.62
12.0309	458	486	1.93	883.94	0.0337	12.0646	1.93	937.98	12.0309	12.0646	12.04775	883.94	937.98	910.96	12.04775	910.96
12.2331	527	463	1.93	1017.11	0.0337	12.1994	1.93	893.59	12.2331	12.1994	12.21625	1017.11	893.59	955.35	12.21625	955.35
12.1994	466	461	1.93	899.38	0.0337	12.0646	1.93	889.73	12.1994	12.0646	12.132	899.38	889.73	894.555	12.132	894.555
12.1994	476	459	1.93	918.68	0.0337	12.0983	1.93	885.87	12.1994	12.0983	12.14885	918.68	885.87	902.275	12.14885	902.275
12.1657	464	474	1.93	895.52	0.0337	12.0983	1.93	914.82	12.1657	12.0983	12.132	895.52	914.82	905.17	12.132	905.17
12.1657	458	454	1.93	883.94	0.0337	12.0309	1.93	876.22	12.1657	12.0309	12.0983	883.94	876.22	880.08	12.0983	880.08
12.3005	457	454	1.93	882.01	0.0337	12.0983	1.93	876.22	12.3005	12.0983	12.1994	882.01	876.22	879.115	12.1994	879.115
12.469	462	463	1.93	891.66	0.0337	12.0646	1.93	893.59	12.469	12.0646	12.2668	891.66	893.59	892.625	12.2668	892.625
12.4353	466	463	1.93	899.38	0.0337	12.1657	1.93	893.59	12.4353	12.1657	12.3005	899.38	893.59	896.485	12.3005	896.485
12.3342	453	468	1.93	874.29	0.0337	11.9298	1.93	903.24	12.3342	11.9298	12.132	874.29	903.24	888.765	12.132	888.765
12.3005	485	470	1.93	936.05	0.0337	11.9635	1.93	907.1	12.3005	11.9635	12.132	936.05	907.1	921.575	12.132	921.575
12.2331	457	469	1.93	882.01	0.0337	12.2668	1.93	905.17	12.2331	12.2668	12.24995	882.01	905.17	893.59	12.24995	893.59
12.3005	471	455	1.93	909.03	0.0337	12.3679	1.93	878.15	12.3005	12.3679	12.3342	909.03	878.15	893.59	12.3342	893.59
12.2331	505	463	1.93	974.65	0.0337	12.3679	1.93	893.59	12.2331	12.3679	12.3005	974.65	893.59	934.12	12.3005	934.12
12.2668	463	459	1.93	893.59	0.0337	12.2668	1.93	885.87	12.2668	12.2668	12.2668	893.59	885.87	889.73	12.2668	889.73
12.3005	455	477	1.93	878.15	0.0337	12.6375	1.93	920.61	12.3005	12.6375	12.469	878.15	920.61	899.38	12.469	899.38
12.2331	459	462	1.93	885.87	0.0337	12.9745	1.93	891.66	12.2331	12.9745	12.6038	885.87	891.66	888.765	12.6038	888.765
12.3005	459	455	1.93	885.87	0.0337	12.7723	1.93	878.15	12.3005	12.7723	12.5364	885.87	878.15	882.01	12.5364	882.01
12.6038	459	457	1.93	885.87	0.0337	12.5364	1.93	882.01	12.6038	12.5364	12.5701	885.87	882.01	883.94	12.5701	883.94
15.2661	461	466	1.93	889.73	0.0337	12.3342	1.93	899.38	15.2661	12.3342	13.80015	889.73	899.38	894.555	13.80015	894.555
16.4119	455	453	1.93	878.15	0.0337	12.3342	1.93	874.29	16.4119	12.3342	14.37305	878.15	874.29	876.22	14.37305	876.22
15.7042	454	490	1.93	876.22	0.0337	12.1994	1.93	945.7	15.7042	12.1994	13.9518	876.22	945.7	910.96	13.9518	910.96
15.2324	459	459	1.93	885.87	0.0337	12.132	1.93	885.87	15.2324	12.132	13.6822	885.87	885.87	885.87	13.6822	885.87
14.6258	456	453	1.93	880.08	0.0337	12.0983	1.93	874.29	14.6258	12.0983	13.36205	880.08	874.29	877.185	13.36205	877.185
13.8844	455	454	1.93	878.15	0.0337	12.132	1.93	876.22	13.8844	12.132	13.0082	878.15	876.22	877.185	13.0082	877.185
13.4463	457	457	1.93	882.01	0.0337	12.0646	1.93	882.01	13.4463	12.0646	12.75545	882.01	882.01	882.01	12.75545	882.01
13.0082	455	451	1.93	878.15	0.0337	11.8961	1.93	870.43	13.0082	11.8961	12.45215	878.15	870.43	874.29	12.45215	874.29
12.806	455	454	1.93	878.15	0.0337	11.8961	1.93	876.22	12.806	11.8961	12.35105	878.15	876.22	877.185	12.35105	877.185
12.6038	457	463	1.93	882.01	0.0337	11.9298	1.93	893.59	12.6038	11.9298	12.2668	882.01	893.59	887.8	12.2668	887.8
12.4016	469	458	1.93	905.17	0.0337	12.0646	1.93	883.94	12.4016	12.0646	12.2331	905.17	883.94	894.555	12.2331	894.555
12.2668	459	454	1.93	885.87	0.0337	12.0646	1.93	876.22	12.2668	12.0646	12.1657	885.87	876.22	881.045	12.1657	881.045
12.2668	466	815	1.93	899.38	0.0337	12.1657	1.93	1572.95	12.2668	12.1657	12.21625	899.38	1572.95	1236.165	12.21625	1236.165
12.2331	452	461	1.93	872.36	0.0337	12.0983	1.93	889.73	12.2331	12.0983	12.1657	872.36	889.73	881.045	12.1657	881.045
12.1657	458	453	1.93	883.94	0.0337	12.132	1.93	874.29	12.1657	12.132	12.14885	883.94	874.29	879.115	12.14885	879.115
12.2331	487	453	1.93	939.91	0.0337	12.1657	1.93	874.29	12.2331	12.1657	12.1994	939.91	874.29	907.1	12.1994	907.1
12.2331	458	458	1.93	883.94	0.0337	12.2668	1.93	883.94	12.2331	12.2668	12.24995	883.94	883.94	883.94	12.24995	883.94
12.1994	474	451	1.93	914.82	0.0337	12.469	1.93	870.43	12.1994	12.469	12.3342	914.82	870.43	892.625	12.3342	892.625
12.1994	465	459	1.93	897.45	0.0337	12.806	1.93	885.87	12.1994	12.806	12.5027	897.45	885.87	891.66	12.5027	891.66
12.0983	466	464	1.93	899.38	0.0337	12.8734	1.93	895.52	12.0983	12.8734	12.48585	899.38	895.52	897.45	12.48585	897.45
12.1994	464	451	1.93	895.52	0.0337	13.0082	1.93	870.43	12.1994	13.0082	12.6038	895.52	870.43	882.975	12.6038	882.975
12.0983	456	461	1.93	880.08	0.0337	13.1093	1.93	889.73	12.0983	13.1093	12.6038	880.08	889.73	884.905	12.6038	884.905
12.0309	466	454	1.93	899.38	0.0337	13.2441	1.93	876.22	12.0309	13.2441	12.6375	899.38	876.22	887.8	12.6375	887.8

Appendix 10


NOTES
Mode of Operation:
Front view of opened space
Gas
Charcoal
Sketch of Concept
600cm
35cm
20cm
50cm
20
5
20cm
10cm
20cm
5
15cm
FAN
FanMilk


NOTES
8cm
150cm
70 cm
50
clay
clay
Gas will be on top of clay compartement when needed.
FAN
FanMilk


NOTES
Front View with Knob
Gas
Knobs
Fan symbol
Gas symbol
Knobs
Render:
① Charcoal Compartment
② Gas Burner & Regulator
Regulator
Burner
FAN
FanMilk