Fuelwood Use Efficiency in Cooking Technologies for Low Income Households in Malawi

Memory Malakini, Weston Mwase, Assa M. Maganga* and Trywell Khonje
University of Malawi, Bunda College, P.O. Box 219, Lilongwe, Malawi
*Email: arthurmaganga@yahoo.com (corresponding author)

Abstract
Biomass, mainly firewood and charcoal contributes over 90% of Malawi's total energy demand. As a result, deforestation is increasing at unprecedented rate threatening firewood supply. Individual assessment of various cooking technologies has been widely studied without comparing among cooking technologies. This study compares the performance of the three-stone fireplace, Rocket stove and *Chitetezo* stove cooking technologies in Malawi. We use Specific Fuel consumption (SC) as a proxy for principal indicator of technology efficiency. The finding reveals that Rocket stove uses less time, less fuelwood and produces less smoke.
Keywords: Cooking technology, dry wood consumption, specific fuelwood consumption

1. Introduction

Biomass is the major energy source in southern Africa, especially in rural areas. Most households depend on biomass energy for cooking and space heating. The resulting pressure on forests and trees leads to extensive deforestation and in turn, soil degradation. Rural areas are also characterized by traditional cooking on open fire which causes severe problems of indoor air pollution and associated health hazards (Malinski, 2008). In Malawi, tradition cooking is prevalent in rural areas which are reported to account for about 84.7% of the Malawi population (NSO, 2009). The country is one of the most densely populated countries in Sub-Sahara Africa and ranks 160, which is 23 from the last on the Human Development Index (UNDP, 2009).

Biomass, mainly firewood and charcoal contributes over 90% of Malawi's total energy demand. Other energy sources, such as electricity, petroleum products, coal, and other renewable resources play a minor role in energy demand and only account for 7% of energy use (GoM, 2006). Fuelwood is used by 97% of the households in rural areas of Malawi and agricultural residues also play a major role. This high dependence on firewood and charcoal as energy source and the high population density coupled with low per person agricultural productivity have a high impact on the environment and on the inhabitants, (Malinski, 2008).

Malinski, (2008) further notes that deforestation is increasing at unprecedented rate of 3.2% and firewood is becoming scarce. Malawi's forest reserves have declined from 47% to 28% of the country's area over the past 25 years. Amongst others, fuelwood use is one of the major reasons of forest degradation. Its high demand can not be covered sustainably by the available supply. This deficit is increasing every year at 2.8%. The deforestation rate in Malawi is amongst the highest in Africa. This loss of forests triggers environmental problems such as erosion, floods, river siltation and climate change. Consequently, firewood scarcity in some regions of rural Malawi has led people to depend on firewood purchase.

To counter the problems resulting from the unsustainable exploitation of biomass sources, Biomass Energy Conservation (BEC) programs are being implemented by a number of NGOs in Malawi to promote efficient use of biomass for cooking. These have been viewed as one of the important ways to save energy, conserve biomass, reduce forest degradation and reduce effort spend in connection with cooking (ProBEC 2008). Some of these programs include development of different types of improved stoves which can reduce the amount of fuel wood use, smoke emission and improve handling. The improved stoves include rocket stove and Chitetezo stove.

Empirical, studies have been done to assess the impacts of adopting Chitetezo stove on household and producer level and review of fire-wood saving stoves in Malawi (Malinski 2008; Makela 2008). Individual technology assessment without comparison among technologies does not clarify the relative position of each technology in terms of performance and efficiency. Therefore, this study has been devoted to compare the performance and fuelwood use of three-stone fireplace, Rocket stove and Chitetezo stove cooking technologies.

2. Materials and Methods

2.1 The Data

The experiment was conducted at Lilongwe Programme for Basic Energy and Conservation (ProBec) Offices which are located at NRC in Malawi. It is a 10km distance from the Lilongwe town. This area is situated on an altitude of about 600m above sea level. This place was chosen because it had enough resources for this experiment. The place lies on warm to hot weather and cloudy with light to heavy rains, rainfall ranges from 600-1000mm per annum falling in one continuous rainy season from November to March.

Data was collected on different variables that were requisite for analysis of technology specific efficiency. These variables included weight of all ingredients going into the food in question, weight of wood used for cooking, weight of charcoal and container, weight of a cooking pot, total weight of cooked food, weight of char remaining, equivalent dry wood consumed, wind conditions of the day, air temperature of the day and calorific value of the wood used, length of time for each technology to fully cook the foodstuffs, water boiling point and wood moisture content. The data was collected in November 2010.

2.2 Experiment Procedure

The study used three different cooking technologies including Chitetezo stove, Rocket stove and Traditional 3 stone cooking place. The study used *Cordyla africana,* indigenous firewood species. This species was chosen because it is the common indigenous fire wood tree species used for cooking in rural Malawi. The foodstuff which was considered for the study was a typical complete Malawian dish (Nsima, Cabbage vegetables fish locally known as *usipa*). This dish was chosen because it is normally commonly consumed in rural areas and it is affordable by most rural people in Malawi. The ingredients for preparing this dish included onions, tomatoes, salt, oil, water, small fish and maize flour.

A benchmark was established for the quantities of the ingredients as a yardstick in each set of cooking. Weights were taken using a digital scale which reports more accurate values than other classic measuring scales. The firewood and cooking pots were also weighed before use. Moisture content of the fuelwood was measured using a moisture-meter. A complete meal for an average household of about five people was prepared. After cooking, weights of cooked foodstuff, char and residue firewood were taken using the same measuring scale. Temperature and boiling point of water and wind condition on the day were also measured using thermometer and physical observation respectively. The cooking procedure was replicated three times for each cooking technology which is the minimum sample size when dealing with non-parametric statistics (Edriss, 2003). Time taken for the food types to be fully and well cooked was recorded using stopwatch for each cooking technology for each replication. Monitoring in each cooking technology was done continuously.

2.3 Mathematical Construct of Stove Efficiency

The stove efficiency model in this study borrows from Bailis (2004) in which Specific Fuel consumption (SC) is used as a proxy for principal indicator of stove efficiency. It measures the amount of wood used per kg of food. It is calculated as a simple ratio of fuel to food:

$$SC = \frac{f_d}{W_f} * 1000 \qquad (1)$$

Where SC is Specific Fuel Consumption, f_d is Equivalent Dry Wood consumed and W_f is total weight of cooked food. The number 1000 is a conversion factor for grams of fuel per Kg of food cooked. Variables f_d and W_f computed as;

$$W_f = \sum_{i=1}^{3} (Pj_f - pj) \qquad (2)$$

$$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c \qquad (3)$$

Where j is an index for cooking pot ranging from 1-3, P_{jf} is weight of each pot with cooked food, f_f is final weight of fuelwood in grams (wet basis), f_i is final weight of fuelwood in grams (wet basis), c_c is weight of charcoal with container and m is wood moisture content (percentage wet basis).

2.4 Data analysis

The data collected were analyzed using CCT Version 2.0 Software, an add-on in Microsoft excel, by Bailis (2004). This is specialized software for analysing stove efficiency. This software took priority over other analytical packages because of its convenience. It takes into account a number of variables that if ignored would end up with distorted measure of efficiency. These variables include weight of all ingredients going into the food being cooked, weight of wood used for cooking, weight of charcoal and container, weight of a cooking pot, total weight of cooked food, weight of char remaining, equivalent dry wood consumed, wind conditions of the day, boiling point of water, moisture content of the wood, air temperature of the day and calorific value of the wood used. For a robust statistical validation of the findings, t-test and Multiple Comparisons (MC) test as explained by Daniel (1990) were conducted to appreciate differences between cooking technologies.

3. Results and Discussion

3.1 Cooking Time

One of the objectives of the study was to assess the cooking time that each cooking technology permitted to have the food staff thoroughly cooked. From the study findings, as summarized in Figure 1, it was discovered that Three-stone fireplace had the highest mean cooking time. Rocket stove was found to have the minimum mean cooking time after Chitetezo stove. Three-stone fireplace had mean cooking time of 50 minutes lying in a confidence interval of 43 to 56 minutes at a 90% confidence level. Chitetezo stove had an average cooking time of 46 minutes with a confidence interval of 42 to 49 minutes at 90% level confidence level. Finally, Rocket stove had an average cooking time of 43 minutes with 90% probability of lying between 36 and 49 minutes of cooking time.

Though the average cooking times were traditionally different among stoves, it was necessary to check the statistical significance to which these estimates were different. Table 1 presents statistical comparison of cooking time which is a direct output of CCT Version 2.0 software. Table 2 summarizes cooking time statistical comparisons among cooking technologies using Multiple Comparison test.

Cooking time results from CCT Version 2.0 were not different from those of multiple comparison tests. The difference in cooking time between Rocket stove and Chitetezo stove, three stone and Chitetezo stove were all not significant at $p \leq 0.10$. This mean that, with all practical purposes we have insufficient information to reject the null hypothesis of no difference in cooking time between Rocket stove and Chitetezo stove, three stone and Chitetezo stove. The difference in cooking time between Rocket stove and Three-stone fireplace was significant at $p \leq 0.10$ with 15% difference in cooking time. This means that Rocket stove can save up to 15% of time normally consumed in Three-stone fireplace. Similarly with Multiple Comparison test, cooking time difference between Rocket stove and Chitetezo stove, was not significant at $p \leq 0.10$, the same was found for Chitetezo stove and Three-stone fireplace. On the other hand, the difference between Rocket stove and Three-stone fireplace was significanct at $p \leq 0.05$. This follows that we have sufficient information to reject the null hypothesis of no difference in cooking time between Rocket stove and Three-stone fireplace. It is therefore concluded that there is significant difference in cooking time between Rocket stove and Three-stone fireplace. This implies that Rocket stove gives the least cooking time followed by Chitetezo stove then three-stone fireplace.

Less time required to cook foodstuff that has been discovered when using Rocket stove has its advantage to the household. The household can cook its foodstuff within a short-time and allocate the other time to other economic activities.

3.2 Equivalent Dry Wood Consumption

This is defined as the quantity of fuel wood used in each trial of a cooking technology. The present study found that Three-stone fireplace used a lot of fuel wood followed by Chitetezo stove and Rocket stove as indicated in Figure 2.

In Figure 2, three-stone fireplace registered a highest average of 1558 grams of wood consumption. There is a 95% confidence that every time one uses Three-stone fireplace would have wood consumption between 1155.54 and 1960.46 grams. Chitetezo Stove had 902 grams of wood consumption with 95% probability of finding the parameter within 803 to 1001 grams of wood consumption. Finally, Rocket stove reported a mean of 689 grams of fuel wood consumption with 95% confidence of finding the parameter within an interval of 622 to 756 grams of wood consumption. As it can be seen from the figure 2 the highest fuel wood consumption in Three-stone fireplace is justified by its open nature which allows heat energy to be relayed away by the blowing wind or air. To offset this loss of heat through wind or air, more firewood is needed to get the food cooked. On the other hand, in Chitetezo stove most of fuel wood energy is contained. Thus, great percentage of the fuel wood energy is channeled to heating the pot. Consequently, less fuel wood is used in Chitetezo stove than in Three-stone fireplace. Similarly, Rocket stove is an enclosed kind of stove which restricts fuel wood energy loss through radiation relatively more than in Chitetezo. This justifies the lowest fuel wood consumption in Rocket stove. The differences among stoves in equivalent dry wood consumption are presented in Table 3.

The difference in dry wood consumed between Rocket stove and Chitetezo stove, Three-stone fireplace and Chitetezo stove were significant at $p \leq 0.10$. That of Rocket stove and Three-stone fireplace was significant at $p \leq 0.05$. This leads to rejection of the null hypothesis that there is no significant difference in amount of firewood required for traditional Three-stone fireplace, Chitetezo stove and Rocket stove to fully cook foodstuffs. Thus, we can conclude that Rocket stove had the least fuelwood consumption than Chitetezo stove and Three-stone fireplace had the highest fuelwood consumption than Chitetezo stove.

Less firewood consumption of Rocket stove leads firstly to a reduction of time spend on firewood collection and, secondly to a reduction of expenditures on firewood purchase. In addition, it enables the household to contribute at national level in counteracting the problems resulting from the exploitation of biomass sources.

Though, level of smoke produced per each technology was not statistically tested, through direct observation, Rocket stove could be said to release less smoke into the atmosphere followed by Chitetezo stove. Thus, Rocket stove, unlike the traditional cooking on open fire could reduce severe problems of indoor air pollution and its associated health hazards.

3.3 Specific Fuel Consumption

This is defined as the quantity of fuel required to cook a given amount of food. This is the principal indicator of stove performance (efficiency). As observed from the results in figure 3, Three-stone fireplace had the highest average specific fuel consumption of 452. There is 95% confidence that if one conducts similar experiment the parameter shall fall within an interval of 330.3 to 573.7g/kg of specific fuel consumption. Chitetezo stove had efficiency of 259g/kg while Rocket stove had the least average efficiency of 201g/kg. It can be concluded that 95% of the times such experiment is conducted, the efficiency estimates for Chitetezo and Rocket would fall within

229.2 to 288.8g/kg and 176.2 to 225.8g/kg respectively.

Though the average efficiency was traditionally different among stoves, it was necessary to check the statistical significance to which these estimates were different. Figure 4 presents statistical comparison of efficiency which is a direct output of CCT Version 2.0 software. Figure 5 summarizes efficiency statistical comparisons among cooking technologies using Multiple Comparison test.

Efficiency results from CCT Version 2.0 were not different from those of multiple comparison tests. The difference in efficiency between Rocket stove and Chitetezo stove, Three stone and Chitetezo stove, Rocket stove and Three-stone fireplace were all significant at $p \leq 0.05$ with percentage differences of 22%, 43% and 55% respectively with CCT Version 2.0 output. This means that Rocket stove is 55% more efficient than Three-stone fireplace or in other words Rocket stove can save up to 55% of the fuel wood normally consumed in Three-stone fireplace per Kg of food. Rocket stove is 22% more efficient than Chitetezo stove or it can save up to 22% of the fuel wood consumed in Chitetezo stove per Kg of food. Similarly Chitetezo stove is 43% more efficient than Three-stone fireplace or it can save up to 43% of fuel wood normally consumed in Three-stone fireplace per Kg of food. Similarly with Multiple Comparison test, efficiency difference between Rocket stove and Chitetezo stove, was significant at $p \leq 0.10$, the same was found for Chitetezo stove and Three-stone fireplace. On the other hand, the difference between Rocket stove and Three-stone fireplace was significant at $p \leq 0.05$.

Specific fuel consumption of the stove is equivalent to efficiency or performance of the stove (Bailis, 2004). The lower the specific fuel consumption of a stove relative to the other stove the higher the efficiency it has. The results showed that Rocket stove has the highest efficiency followed by Chitetezo stove then Three-stone fireplace. This provides sufficient evidence to reject the null hypothesis of no significant difference in efficiency of Three-stone fireplace, Chitetezo stove and Rocket stove.

4. Conclusion

To begin with, the study aimed to compare the amount of firewood required, efficiency and cooking time for traditional Three-stone fireplace, Chitetezo stove and Rocket stove to fully cook foodstuffs. With 95% confidence, Three-stone fireplace registered a highest average of 1558±403 grams of dry wood consumption, Chitetezo Stove averaged 902±99 grams of wood consumption and Rocket stove reported a mean of 689± 67grams of fuel wood consumption. The differences in dry wood consumption among cooking technologies were significant at $p \leq 0.10$ between Three-stone fireplace and Chitetezo stove, Chitetezo stove and Rocket stove. At $p \leq 0.05$ the difference in dry wood consumption was significant between Rocket stove and Three-stone fireplace. Three-stone fireplace had an average cooking time of 50±7minutes. Chitetezo stove had an average cooking time of 46±4 minutes at 90%. Rocket stove had an average cooking time of 43 minutes with 90% probability of lying between 36 and 49 minutes of cooking time. The difference in cooking time between Rocket stove and Three-stone fireplace was significant different at $p \leq 0.10$. At $p \leq 0.05$ the specific fuel consumptions (efficiency) for cooking technologies were all significant different. The efficiency increased for cooking technologies in the order of Three-stone fireplace, Chitetezo stove and Rocket stove. Advocating adoption of Rocket stove would help low income households to save energy and time.

REFERENCES

Bailis, R. (2004). *Controlled Cooking Test*. Household Health and Energy Program. Shell Foundation. South Africa

BMZ. (2008). Web source: http://www.bmz.de/en/countries/partnercountries/malawi/zusammenarbeit.html (access date 30/08/2010).

Brinkmann, Verena. (2005). Impact *Assessment at Local Level. Experiences from Malawi*–Mulanje District. GTZ, Eschborn.

Brown, R.C., (2003). *Bio-renewable Resources: Engineering new product from agriculture*. Iowa State Press.

Daniel, W.W. (1990). *Applied Nonparametric Statistics*. 2nd Edn. PWS-KENT. USA.

Edriss, A.K. (2003). *A Passport to Research Methods*. Las Vegas; International Publishers and Press.

Government of Malawi. (2006). *Malawi Growth and Development Strategy*. 2006 -2011. Malawi.

HEDON. (2008). *Households Energy Network*. *Improved cookstoves in Malawi*. Web source: http://www.hedon.info/goto.php/ImprovedCookstovesInMalawi (access date 30/08/2010)

Isler, A. and Kalaosmanoglu, F. (2009). *Traditional cooking fuels, ovens & stoves in turkey.* Istanbul Technical University.

Klass, D.L. (1998). *Biomass for renewable energy, fuels and chemicals*, San Diego:Academic Press. http://www.probec.org/displaysection.php?zSelectedSectionID=sec1194690613

Makela, S. (2008). *Firewood Saving Stoves.* Review of Stove Models Based on Documentation on the Internet. Web Source: www.liana-ry.org (access date 30/11/2010)

Malinski, B. (2008). *Impact Assessment of Chitetezo Mbaula*. Improved Household Firewood Stove in Rural Malawi. GTZ. Probec.

Msukwa, C, and Dekiwe, K. (2008): *Participatory Assessment of the Current Marketing System for Chitetezo*

Mbaula. ProBEC/GTZ (unpublished) ProBEC 2008: Country Profile Malawi.
National Statistical Office (NSO). (2009). *Population and Housing Census 2008.* Zomba, Malawi
ProBEC. (2008): *Country Profile Malawi*. Web source: http://www.probec.org/displaysection.php?zSelectedSectionID=sec1194690613 (access date 30/08/2010)
UNDP, (2009). *Human Development Index Report*: Overcoming Barriers: New York, NY10017, USA.
WHO. (2002). *Addressing the Links between Indoor Air Pollution, Household Energy and Human Health.* Based on the WHO-USAID Global Consultation on the Health Impact of Indoor Air Pollution and Household Energy in Developing Countries (Meeting report). Washington
HEDON. (2010). *The Improved Cooking Stoves.* http://www.hedon.info/Improvedcookstove

Figure 1: Average cooking time for a given cooking technology

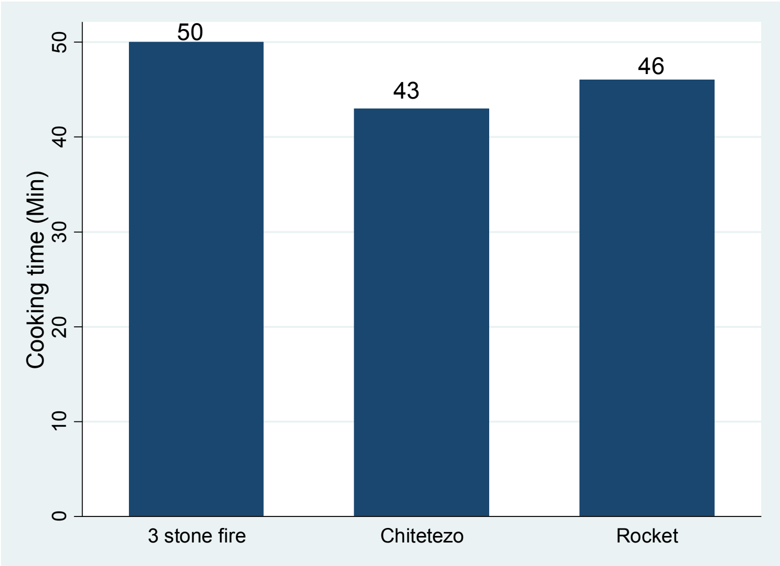

Figure 2: Average Equivalent Dry Wood Consumed

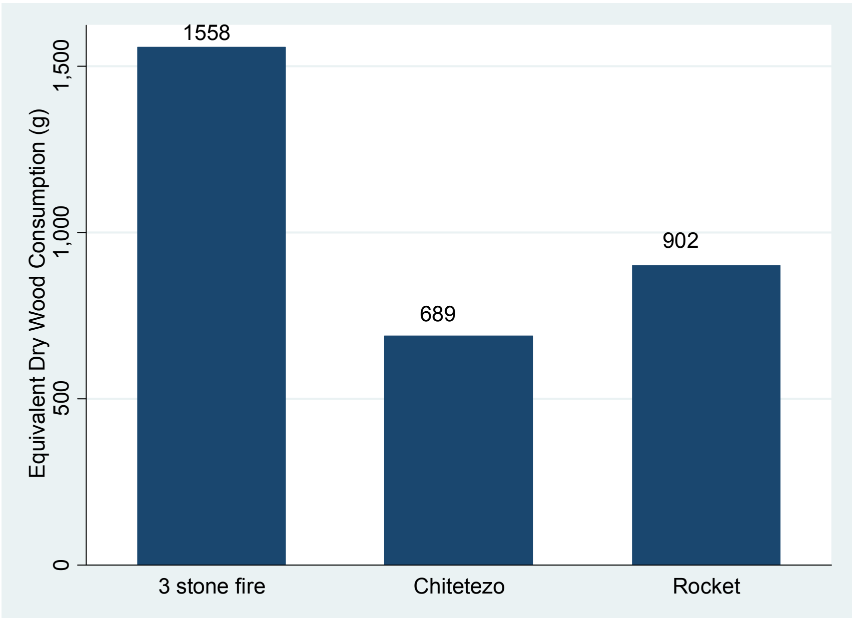

Figure 3: Average Specific Fuel Consumption (Efficiency) for Different Stoves

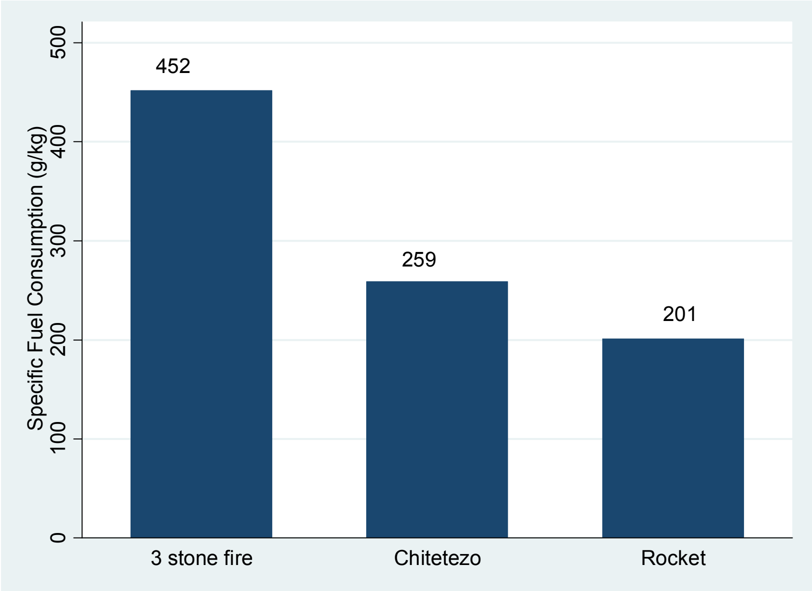

Table 1: Percentage Difference in Total Cooking Time for Different Stoves

	Type of Stove		
Stove Type	**Chitetezo**	**Rocket**	**Three-stone fireplace**
Chitetezo	-	7 (1.17)	9 (1.7)
Rocket	-	-	15(2.96)***
Three-stone fireplace	-	-	-

Values in parenthesis are the t-values for the percentage differences in cooking for a given set of stoves. ***means significant at 10%.

Table 2 Multiple Comparison Test for Cooking Time

Pair of Stoves	**Average Cooking Time Difference (Min)**
Rocket-Chitetezo	3
Rocket-Three-stone fireplace	7.7**
Three-stone fireplace-Chitetezo	4.7

* *means significant at 5%.

Table 3: Multiple Comparison (MC) Test for Equivalent Dry Wood Consumed

Comparison Stove Set	**Mean Dry Wood Consumed Difference**
Rocket-Chitetezo	213*
Rocket-Three-stone fireplace	869**
Three-stone fireplace-Chitetezo	656*

* *means significant at 5%. *means significant at 10%

Table 4: Percentage Difference in Specific Fuel Consumption

	Type of Stove		
Stove Type	**Chitetezo**	**Rocket**	**Three-stone fireplace**
Chitetezo	-	22(6.40)**	43 (6.59)**
Rocket	-	-	55 (8.59)**
Three-stone fireplace	-	-	-

Values in parenthesis are the t-values for the percentage differences in cooking for a given set of stoves. **means significant at 5%.

Table 5: Multiple Comparison (MC) Test for Specific Fuel Consumption

Comparison Stove Set	**Mean Specific Fuel Consumption Difference**
Rocket-Chitetezo	57.3*
Rocket-Three-stone fireplace	251**
Three-stone fireplace-Chitetezo	193.7*

* *means significant at 5%. *means significant at 10%