BIBLIOGRAPHY

BATCAGAN, JERRY D. and **FELWA, ALBANESE W**. March 2008. Design and Development of an Improved Biomass Cookstove for Institutional Use.Benguet State University, La Trinidad, Benguet.

Adviser: **ENGR. JOHN JAMES F. MALAMUG**

ABSTRACT

The study aimed to design, develop and evaluate an improved biomass cookstove for institutional cooking in terms of its average kindling time, average boiling time, power, heat utilization efficiency and fuel consumption.

Over-all test results indicate that the improved biomass cookstove with a riser height of 20 centimeters recorded the shortest boiling time, highest heat utilization efficiency and lowest fuel consumption as compared to riser heights of 10, 30 and 40 centimeters. This makes the improved biomass cookstove to be more efficient at a riser height of 20 centimeters.

The improved biomass cookstove having a height of 20 centimeters when further compared to two traditional stoves namely the three-rock fire and metal plate stove showed that the improved cookstove is more efficient than the two conventional stoves. The improved cookstove was able to yield: shorter average kindling time, shorter average boiling time, higher power, higher heat utilization efficiency and lower fuel consumption than the two conventional stoves.

Based on the findings, similar studies may be conducted to further improve the performance of the biomass cookstove. Integration of other factors which may include utilization of other types of heating and construction materials, varying the pot skirt to suit different cooking vessel sizes, varying the thickness of the pot holder for better gaps between the pot skirt and pot bottom of cooking pot and other design improvements may be done.

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INTRODUCTION

Background of the Study

In the past, traditional sources of energy such as fuel wood, charcoal, and dung were the only sources of energy used for all types of applications. It is only during the last 250 years that fossil fuels such as coal, oil, gas and electricity have emerged as major sources of energy in most developed countries. However, nearly 75% of the world's population who lives in the developing countries continues to depend on the traditional sources of energy for most of their energy requirements (Scurlock and Hall, 1989). This situation is very evident in some Asian countries where traditional; sources of energy account for 60-90% of the total amount of energy consumed.

This dependence on traditional sources of energy for most developing countries is brought about by the common method of cooking using an open fire. The fire is usually shielded or surrounded by "three or more stones, bricks, mounds of mud, or lumps of other incombustible material" (Foley and Moss, 1983). In short, such fires are called "three-stone" fires, where the stones or surrounding materials act as support for the cooking pot over the fire. These three-stone fires have continued to be used for cooking and heating purposes, mainly due to their simplicity. They are easily to build, virtually free, use a range of fuels and are adapted to different forms quite easily such as placing them on waist-high platforms for more convenience to the user. Accompanying these features of traditional stoves however, is the fact that most sources site the fuel-efficiency of conventional stoves as 5 to 10%.

Since nearly three-billion people in the world use traditional stoves to cook their meals, efforts to improve the efficiency of cookstoves have been increasingly popular in the developing world. Over time, stoves have been developed to overcome problems of the conventional stoves making way to improved biomass cookstoves. Improved cookstoves are an attempt to address the negative environmental and social effects of the three rock fire stove. Improved stoves increase efficiency of fuel consumption, reduce the amount of pollution released into indoor and outdoor cooking environments, and are designed and built in various ways, depending on the local conditions. "At their simplest, improved stoves rely on providing an enclosure for the fire to cut down on the loss of radiant heat and protect it against the wind. In addition, attention can be given to devising methods of controlling the upward flow of the combustion gases, so as to increase the transfer of heat to the cooking pot" (Foley and Moss, 1983).

Statement of the Problem

Most rural households and industries in Asia use wood energy for various purposes. The Philippines, particularly in the Cordillera region, some households still rely on the three-rock fire and other conventional stoves for household and institutional cooking. This is because of various reasons such as availability and accessibility to fuel wood source, cultural traditions and practices and of its low cost. This is evident; despite the problems associated with the use of such stoves such as: inefficient energy since customary wood fires are poor at transferring the released energy into the cooking vessel; continuous deforestation due to increased amount of wood harvested from the surrounding environment; increasing use of time for collection of fuel; and deleterious health and environmental effects.

With these outlooks on unhealthy and unsustainable conventional cooking methods, introduction of modern, improved and efficient biomass stoves can alleviate some of the problems associated with the use of traditional cookstoves.

Importance of the Study

Due to the foreseeable continued use of biomass fuels in the Cordillera region for the indefinite future, the introduction of locally made improved biomass cookstoves is beneficial. Improved stoves reduce the demand for biomass fuel and improve living conditions for populations who currently use three rock fires. The main justifications for improved stoves are economical, social and environmental-the stove saves time and money for the users. In urban areas, where people purchase biomass fuel, the payback time for the cost of an improved stove is short, thus providing extra cash from purchasing less fuel. In rural areas, more efficient stoves can reduce the time spent collecting fuel for cooking, freeing time for child care and income-producing activities. Moreover, improved stoves can help moderate the environmental externalities of over-harvesting trees.

Objectives of the Study

The general objective of the study was to design and develop an improved biomass cookstove for institutional use.

Specifically, the study aimed to:

1. Evaluate the performance of the improved cookstove using the water-boiling test;

2. Evaluate the power, heat utilization efficiency and fuel consumption of the improved cookstove;
3. Evaluate performance of the improved cookstove in relation to various riser heights;
4. Compare performance of the improved cookstove with two traditional stoves the three-rock fire and metal plate stove in terms of power, heat utilization efficiency and fuel consumption.

Time and Place of the Study

The study was conducted from January to March 2008 at Benguet State University, La Trinidad, Benguet.

REVIEW OF RELATED LITERATURE

With the passage of time, woodstoves have undergone numerous design innovations mainly by the users, in light of their own experiences. These innovations did increase the efficiency of the stoves to some extent, but health and other hazards remained. Moreover, despite human evolution and the development which have taken place in stoves and fuel, most of the estimated 75% of the people who live in developing countries, are still largely employing the three-stone fire for cooking and using traditional sources of energy such as fuel wood and other biomass similar to their pre-historic ancestors several thousand years ago.

In industrial countries, the switch to more efficient stoves took place smoothly as fuel wood prices increased and stove makers increased efforts to build more efficient models. This was followed by a transition to cleaner fuels for cooking, such as coal and petroleum-based fuels. As the availability of and access to petroleum-based fuels began to increase at the beginning of the twentieth century, many urban households in developing countries switched to stoves using oil-based products such as kerosene or liquid petroleum gas as fuels, just like their developed nation counterparts. On the other hand, rural households continued their dependence on the burning of biomass fuels for their energy requirements. This was mainly due to weak delivery channels for petroleum-based products and rural people's inability to afford these fuels especially compared to biomass resources, which were more freely available (Barnes et al, 1994).

Nowadays, the motivation for dissemination of improved stoves is much greater from the national perspective of today's developing countries, because the population pressure on the biomass resources base is much higher. As noted before, many of the traditional stoves operate with high fuel wood or energy consumption whereas improved cookstoves can reduce the amount of wood fuel needed to cook. Improved heat transfer efficiency of energy from the fire to the cooking vessel in improved cookstoves reduce the amount of energy wasted, thus reducing the amount of wood needed. This improved heat transfer efficiency is accomplished through design improvements which normally involve the introduction of a chimney and the incorporation of other critical features such as a pot skirt that creates a narrow channel forcing hot air and gas to along the bottom and sides of the cooking vessel.

In addition to a desire to rationalize the continuing reliance on biomass fuels, a desire to prevent or mitigate deforestation also contributed to the growth of improved cookstoves. A further motivation was that the increasing pressure on biomass resources often results in the burning of crop residues and dung (commonly done in Asia), thus reducing their return to maintain the fertility of the soil (Anderson and Fishwick, 1985).

The first improved stoves began to appear in the early 1980's and were designed by aid groups such as United Nations Children's Fund and Cooperative for American Relief Everywhere-Kenya (Kammen, 1995). The groups applied an elementary exercise of improving the efficiency of a common metal stove where they were able to reveal an analysis that the largest loss of heat from the fire is about 50 to 70 percent, and occurs from radiation and conduction through metal walls.

Better stove designs gradually came about during the mid-1980. At that time, a number of academics began to publish serious analyses of optimal stove combustion temperatures and of the insulating properties of the ceramic liner materials. One of the most notable contributions to enhanced design came through the responses of several women's organizations that had formed around such issues as community health and protection of the environment.

China has by far the world's most extensive program with more than 120 million improved stoves in place- 7 out of 10 rural households own these units (Kammen, 1995). The Chinese stoves, which burn wood, crop residues and coal, consist of a brick and mortar construction with a chimney that fits in the central living area of a home. An insulating material, such as ash and mortar, is packed around the circular cast-iron opening, which holds a wok.

One of the first improved stoves-the "Magan Chula" introduced in a publication called "Smokeless Kitchens for the Millions" (Raju, 1953) advocating the health and convenience benefits of increasing efficiency in the burning of biomass also further stimulated the promotion of improved cookstoves. The initial wave of improved cookstove programs focused on the health aspects of such interventions. The general objective was to uplift the living conditions of the poor in the developing world (Karakezi and Ranja, 1997). Attention subsequently shifted to the potential for saving biomass fuels and limiting deforestation. Currently, there is a refocus on the health-related aspects of improved cookstoves, as the benefits of moving from traditional stoves to improved ones are increasingly stressed by public health specialists. In addition, factors such as cooking comfort, convenience, and safety in the use of stoves are starting to get incorporated into program designs of improved cookstoves.

Overall, the goal of introducing improved biomass cookstoves is to develop more energy than non-biomass-burning stoves that can help alleviate local pressures on wood resources, shorten the walking time required to collect fuel wood, reduce cash outlays necessary for purchased fuel wood or charcoal, and diminish the pollution released to the environment (Barnes et al, 1994).

MATERIALS AND METHODS

Materials

The materials used in the construction of the improved biomass cookstove were: 20.5 centimeters diameter cylinders (empty refrigerant tanks), 56 centimeters diameter cylinder (empty sodium cyanide tank), gauge # 18 G.I. sheet, 8 mm diameter round bar, 4 mm flat bar and 63.5 centimeters diameter institutional metal cooking pot.

Tools and equipment used were: hacksaw, portable drill and drill bits, grinder, drill press, iron sheet scissors, arc-welding machine and welding rods. After the construction, devices such as the stopwatch, mercury thermometer and weighing balance were used for the evaluation process.

Design Criteria

a. Easy to Fire

The cookstove could at least be started easily by using little amount of kindling material. The fire should be developed as fast as possible and should be maintained within reasonable time period or must boil the water in the shortest possible time.

b. Simple Design

The design must easily be understood to attract possible users to use or produce it.

c. Availability of materials to be used

The device must be made of materials that are locally available.

Parts and Construction

The improved cookstove for institutional use is composed of the following parts:

1. Fuel Magazine

   The fuel magazine is the horizontal part of the combustion chamber. It was made out of gauge #18 G.I. sheets having an area of 18 centimeters by 20.5 centimeters.

   a. Air Duct/Vent - The smaller division beneath the fuel shelf where cold air enters.

   b. Fuel Shelf – It is the part where fuel wood is placed for combustion.

2. Riser /Chimney

   The chimney is the vertical part of the combustion chamber where the hot air from the burning fuel wood and the cold air sucked in from outside of the stove mix to create higher heat energy. This part was constructed using 20.5 centimeters diameter empty refrigerant tanks.

3. Outer Cylinder

   It is the outermost part of the device which serves as a support to the pot skirt. It was made out of 56 centimeters diameter empty sodium cyanide tank.

4. Pot Holder

   This part serves as a support for the cooking vessel and also provides space between the pot and the pot skirt allowing hot flue gases from the riser/chimney to exit. It was constructed out of 8 mm diameter round bars.

5. Pot Skirt

This part of the device was welded to the chimney/riser and to the outer cylinder following the shape of the cooking vessel to be used. This would increase the surface contact between the hot fumes and the pot. It was made out of a 63.5 centimeters diameter institutional metal cooking pot.

Testing Method

a. Fuel Description

The water boiling test used commercially available native alnus wood from the La Trinidad Public Market, Km. 5 with an approximate length of 46 centimeters and a triangular shape measuring 3 centimeters on each side.

b. Kindling Material

Just like in an ordinary household practice in the Cordillera region, pieces of pine wood were used as kindling material.

c. Boiling Pot

The evaluation of the device made use of a 63.5 centimeters diameter institutional cooking pot.

d. Water Boiling Test

The water-boiling test used was based on the simplified version of the Ministry of Energy and Mineral Development, “A Comparison of Wood-Burning Cookstoves for Uganda: Testing and Development” (Emma George, 2002).

The test applied to the cookstoves consists of two categories. The first category is the High Power Boiling Test where 6 kilograms of water was heated as fast as possible and boiled for 30 minutes to determine the highest power the stoves are capable of, the efficiency at that power, and the fuel consumption of the stoves. The second category is the Combined High and Low-Power Boiling Test where 6 kilograms of water were heated to boiling point and simmered for 90 minutes to determine: the fuel consumption in performing such task, and an efficiency figure for the stoves.

In the High Power Boiling Test, where the stove was at its initial condition, 5 kilograms of alnus wood was set to fire immediately by 50 grams of the kindling material. After taking the initial water temperature, the institutional pot without cover/lid containing 6 kilograms of water was then placed on top of the stove. Temperature readings were then taken at 5 minute-intervals as the water was set to boil. Once the water reached the local boiling point, high power was maintained for 30 minutes. Afterwards, the burning wood was extinguished and the water temperature and weight were recorded quickly. The remaining unburned fuel wood and the charcoal produced were also weighed separately.

In the Combined High and Low-Power Boiling Test, 5 kilograms of alnus wood was again set to fire immediately by 50 grams of the kindling material. After the initial temperature of water was read, the institutional pot containing 6 kilograms of water (with the pot covered) was then placed on top of the stove. Temperature readings were again taken at 5 minute intervals as the water was set to a boil at maximum power. Once the water reached boiling point, power was reduced to the minimum level required to keep the water simmering. Simmering was maintained for 90 minutes. Afterwards, burning wood was extinguished and the water temperature and weight were measured quickly. The charcoal and unburned wood were again weighed separately.

The water-boiling test procedure described was applied to the institutional pot using the constructed improved cooktove. The same test was also applied to the traditional tripod stove and metal plate stove.

The power, heat utilization efficiency, and fuel consumption of the cooking devices were computed using the accumulated data from their respective water-boiling tests.

e. Measurement of Local Boiling Point

The local boiling point was determined by putting three (3) kilograms of water in the testing pot and bringing it to a rolling boil. It was made sure that the fire is very powerful, and the water is furiously boiling. A thermometer was then placed at the center of the pot, 5 cm above the pot bottom to measure the local boiling temperature. The highest temperature recorded which was 97^{o} C was determined the local water boiling point.

f. Determining the Moisture Content

The moisture content of the fuel wood was determined using the Gravimetric Method. Fuel samples were oven dried at a constant temperature of 110 degrees Celsius for 12 hours. The moisture content was then computed using the equation:

$$\text{Moisture content (\%)} = \frac{\text{Fresh weight} - \text{Oven dry weight}}{\text{Oven dry weight}} \times 100$$

Data Gathered

a. Average kindling time

The average kindling time was determined by observing how long it took the alnus wood to start burning using 50 grams of pinewood (“saleng”) as kindling material.

b. Average boiling time

The average boiling time was the time it took for the 6 kilograms of water to boil.

c. Fuel Consumption

Fuel consumption was the amount of fuel used. It was calculated by mass of wood burnt away, taking moisture content into account and mass of charcoal produced.

d. Power of the Stove

Power is (energy transferred)/ (time taken). Power was calculated on the basis that temperature rise and mass of water boiled away both represent useful energy transferred to the water. Taking specific heat of water = 4.185 J/g/^{o}C and latent heat of water = 2.33 Mj/kg.

In equation:

$$P = \frac{(Tf-Ti)\,4185Mwi + (Mwi-Mwf)\,2.33 \times 10^{6}}{t}$$

where:

P=power of the stove

Tf=final water temperature

Ti=initial water temperature

Mwi=initial mass of water

Mwf=final mass of water

t=time

e. Heat Utilization Efficiency of the stove

Heat Utilization Efficiency is the ratio between the energy input to the stove (the wood fuel) and the energy actually transferred to the water. The efficiency of the stove for the High Power Boiling Test was given by:

$$E= \frac{(Tf-Ti)\ 4185\ Mwi + (Mwi-Mwf)\ 2.33 \times 10^{6}}{(Maf-Mai)\ Evw - Evc\ Mc}$$

The efficiency of the stove for the Combined High and Low-Power Boiling Test was given by:

$$E= \frac{(Tf-Ti)4185\ Mwi}{(Maf-Mai)\ Evw - Evc\ Mc}$$

The energy value of the fuel wood was computed by the formula:

$$Evw= \frac{100x20-2.4\ (54+M/100)}{100+ (M/100)}$$

where:

E=heat utilization efficiency of the stove

Evw=energy value of fuel wood (Mj/kg)

Evc=energy value of charcoal=30 Mj/kg

Tf=final water temperature

Ti=initial water temperature

Mwi=initial mass of water

Mwf=final mass of water

Maf=final mass of fuel wood

Mai=initial mass of fuel wood

Mc=mass of charcoal formed

M=computed Moisture Content of Alnus Wood (13.341%)

In the evaluation of the cookstoves, there were two tests applied namely: without lid/cover for the institutional pot where the stove was evaluated using the High Power Boiling Test; and with lid/cover for the institutional pot where the stove was evaluated using the Low Power Boiling Test

RESULTS AND DISCUSSIONS

Comparison between Riser Heights of the Improved Biomass Cookstove

Average Kindling Time

Table 1 shows the average kindling time of the improved biomass cookstove at different riser heights, height 4 of the improved biomass cookstove has the shortest kindling time of 5.300000 minutes and height 1 has the longest kindling time of 5.455750 minutes. However, statistical analysis of the data on kindling time shows that there is no significant difference in the kindling time of the stove regardless of the different heights.

Data on average kindling time of the stove was only recorded during the High Power Boiling Test since the Low Power Boiling Test was a mere continuation of high power boiling.

Table 1. Average kindling time of the improved cookstove as affected by different riser heights (minutes)

	MEANS FOR DIFFERENT HEIGHTS				
	1 (10cm)	2 (20cm)	3 (30cm)	4 (40cm)	Grand Mean
Without lid	5.45575[a]	5.40525[a]	5.31125[a]	5.3[a]	5.368063

Means with the same letter are not significantly different from each other

Average Boiling Time

Table 2 shows the average boiling time of the improved cookstove to boil 6 kilograms of water as affected by four (4) different riser heights of the improved stove. High Power Boiling without lid gave a longer mean boiling time of 17.2341 minutes while Low Power

Boiling with lid yielded a shorter average boiling time of 13.6403 minutes. These show that it took 2.87 minutes to boil 1 kilogram of water for the high power boiling test and 2.27 minutes to boil 1 kilogram of water for the low power boiling test.

These differences of recorded boiling time for the two tests were mainly affected by the presence of a pot cover/lid. High power boiling was done with no cover for the pot of water while low power boiling was done with a cover for the pot.

Table 2. Average boiling time of the improved cookstove as affected by different riser heights (minutes)

	MEANS FOR DIFFERENT HEIGHTS				
	1 (10cm)	2 (20cm)	3 (30cm)	4 (40cm)	Grand Mean
Without lid	12.4720[a]	13.6510[a]	16.8300[a]	25.9837[b]	17.2341
With lid	10.7837[a]	11.3612[a]	14.1887[b]	18.2277[c]	13.6403

Means with the same letter are not significantly different from each other.

Maximum Power Produced

Table 3 shows the maximum power of the improved cookstove during the high power boiling test as affected by 4 different chimney heights. The average power produced by the cookstove is 3475.3975 Watts. This shows that the cookstove would provide this maximum power value, which is utilized when water is below boiling point.

Height 1 of the improved cookstove gave the highest power value of 4003.7153 Watts and is closely followed by height 2 with a power of 3795.4243 which makes the two heights belong into one category. These higher power values were contributed by the shorter chimney height and shorter time which the energy from the burning wood traveled to reach the pot bottom.

On the other hand, heights 3 and 4 both gave lower power values of 3232.8029 Watts and 2869.6474 Watts respectively. These resulted by the longer distance and time which the energy from the wood traveled to reach the bottom of the pot. Another contributing factor to this low power values is the energy that has been dissipated by the walls of the stove's chimney.

Table 3. Maximum power produced by the improved cookstove as affected by different riser heights (Watts)

	MEANS FOR DIFFERENT HEIGHTS				
	1 (10cm)	2 (20cm)	3 (30cm)	4 (40cm)	Grand Mean
Without lid	4003.7153[c]	3795.4243[c]	3232.8029[b]	2869.6474[a]	3475.3975

Means with the same letter are not significantly different from each other.

Heat Utilization Efficiency

Heat utilization efficiency at High Power Boiling Test: Table 4.1 shows the cookstove's efficiency at high power boiling. These figures show the ratio of the energy actually transferred to the water from the fuel wood. The figures show an inverse relationship of efficiency and height. These differences may be a result of heat being absorbed by the walls of the chimney or the stove's body since higher chimney height means a wider area of the chimney is absorbing useful heat. Furthermore, taller chimney heights produce less smoke but are slightly less efficient due to the greater distance between the pot and the radiant heat of the burning wood while shorter chimney heights produce more smoke but have greater heat transfer due to the closer proximity of the pot to the radiant wood.

Table 4.1. Heat utilization efficiency at high power boiling of the improved cookstove as affected by different riser heights (%)

	MEANS FOR DIFFERENT HEIGHTS				
	1 (10cm)	2 (20cm)	3 (30cm)	4 (40cm)	Grand Mean
Without lid	18.4809[a]	22.2336[b]	19.0670[a]	18.2609[a]	19.5106

Means with the same letter are not significantly different from each other.

Heat utilization efficiency at Low Power Boiling Test: Table 4.2 shows the cookstove's efficiency at low power boiling. The computed results for efficiency in this test are noticeably lower than that of the High Power Boiling Test. This is due to the reason that only the energy needed to boil the water and maintain it to simmer was taken into account. However it was observed that efficiency figures from the 4 different heights were similar to High Power Boiling Test results-inverse relationship of efficiency and chimney height.

Table 4.2. Heat utilization efficiency at low power boiling of the improved biomass cookstove as affected by different riser heights (%)

	MEANS FOR DIFFERENT HEIGHTS				
	1 (10cm)	2 (20cm)	3 (30cm)	4 (40cm)	Grand Mean
Without lid	4.4553[a]	4.4848[a]	3.5944[b]	3.3717[c]	3.97655

Means with the same letter are not significantly different from each other.

Fuel Consumption

Table 5 shows the fuel consumption of the improved stove. It is higher when the pot is without lid than when it is with a lid because of the energy escaping through the steam, since energy is given off as water turns to vapor unlike in low power boiling where the escape of steam is minimized due to a pot cover.

At High Power and Low Power Boiling, height 2 of the improved cookstove recorded the least amount of fuel consumed equivalent to 2.85 kilograms and 2.25 kilograms as compared to the other three heights.

Table 5. Fuel consumption of the improved cookstove as affected by different riser heights (kilograms)

	MEANS FOR DIFFERENT HEIGHTS				
	1 (10cm)	2 (20cm)	3 (30cm)	4 (40cm)	Grand Mean
Without lid	3.45[a]	2.85[b]	2.95[b]	3.10[b]	3.09
With lid	2.31[a]	2.25[a]	2.80[b]	2.97[b]	2.58

Means with the same letter are not significantly different from each other

Comparison between the Improved Biomass Cookstove and Traditional Stoves

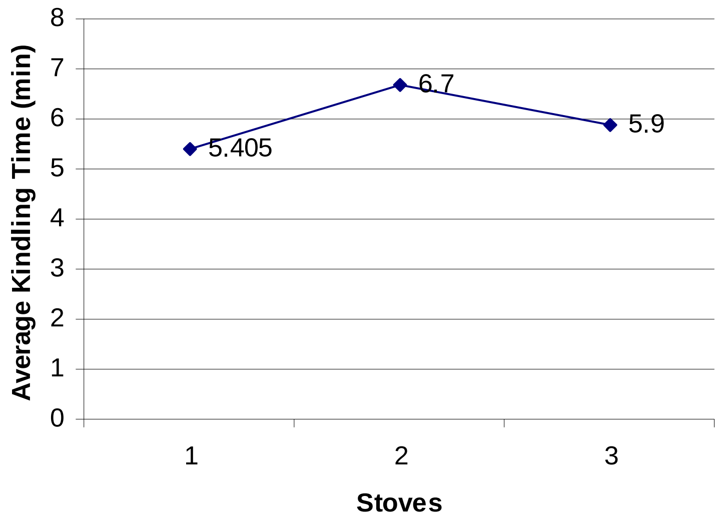
Kindling Time

The improved biomass cookstove registered an average kindling time of 5.40525 minutes (5 min and 25 sec) while the two traditional stoves the three-rock fire and metal plate stove had 6.70 minutes (6 min and 4 sec) and 5.98 minutes (5 min and 59 sec) of kindling time respectively. The differences in the time setting of the fuel wood to burn could be the effect of environmental factor such as wind movement. It was more advantageous for the improved stove since the fuel wood and kindling material were shielded from the horizontal wind movement making the fire to be directed upward to the heap of fuel wood on the fuel magazine, thus, having a shorter time for the fuel to ignite. On the other hand, the three-rock fire and metal plate stove were exposed to open air causing the fire to bend sideways every time there is wind movement which resulted to longer kindling times.

Table 6. Average kindling time of the three stoves (minutes)

	R1	R2	R3	MEAN
1.Improved Stove	5.333	5.750	5.133	5.405
2. Three-Rock Fire	6.43	6.72	6.95	6.70
3. Metal Plate Stove	6.19	6.45	5.30	5.98

Figure 1. Comparison on the average kindling time of the three stoves (minutes)



Boiling Time

Tables 7 and 8 show the recorded boiling time of 6 kilograms of water for the different cookstoves. Boiling time was determined using the High Power Boiling Test (without pot cover/lid) and Low Power Boiling Test (with pot cover/lid).

The Low Power Boiling Test on the cookstoves was able to yield shorter boiling times because of the presence of a lid that prevented the escape of heat from the water, unlike in the High Power Boiling Test where the heat freely escaped into the open air since there was no pot cover causing more time to achieve the amount of energy needed for the water to boil.

The improved cookstove was able to boil 6 kilograms of water at High Power Boiling in 13.651 minutes and 11.3613 minutes if provided with a lid (Low Power Boiling). Comparing these test results of the improved cookstove with the two conventional stoves, it is evident that the improved stove made the 6 kilograms of water to boil faster in both tests than the traditional stoves. These figures were affected by the ability of the stoves to transfer the heat produced by the fuel to the water.

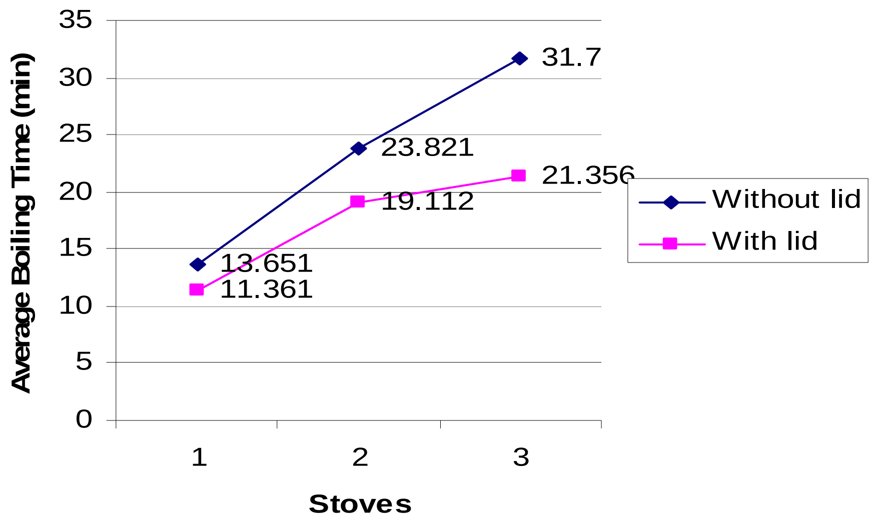
Table 7. Average boiling time for the high power boiling test of the three stoves (minutes)

	R1	R2	R3	MEAN
1. Improved Stove	12.083	14.770	14.100	13.651
2. Three-Rock Fire	25.000	20.433	26.030	23.821
3. Metal Plate Stove	34.750	28.25	32.10	31.7

Table 8. Average boiling time for the low power boiling test of the three stoves (minutes)

	R1	R2	R3	MEAN
1. Improved Stove	10.417	12.617	11.050	11.361
2. Three-Rock Fire	20.167	19.500	17.670	19.112
3. Metal Plate Stove	19.417	21.917	22.733	21.356

Figure 2. Comparison on the average boiling time of the three stoves (minutes)



Power

Power refers to the ability of the stove to transfer the energy from the fuel wood to the water in relation to the time taken in doing the task.

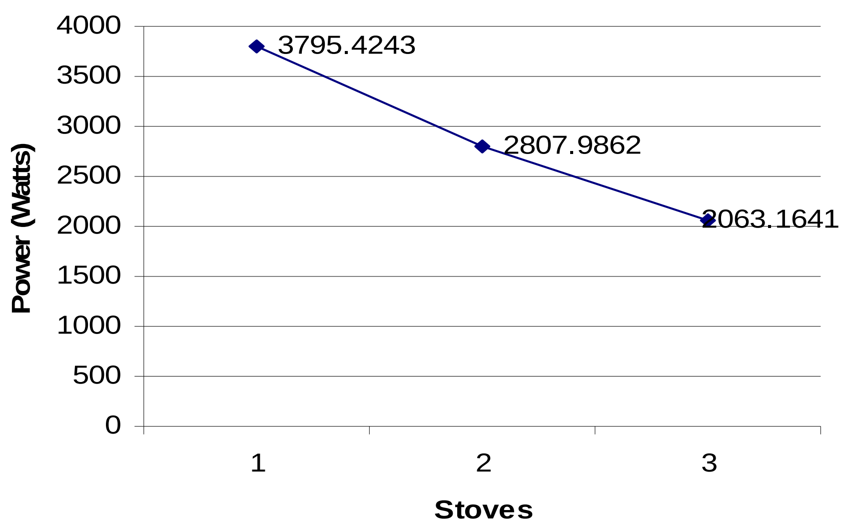
The improved stove registered a power value of 3795.4243 Watts which means that it was able to direct 227.73 KJ of heat energy to the water in a span of 1 minute. Table 9 shows the two conventional stoves that displayed lower power values. The improved stove has a shorter boiling time than the two traditional stoves since the greater power value a stove has, the shorter the time it will take the stove to transfer heat to the cooking vessel.

The higher power value of the improved stove is mainly due to its designed features. Its combustion chamber is enclosed, preventing the escape of heat to the open air. The chimney provides an area for the hot air to mix well with oxygen from the air vent of the cookstove producing more heat energy and velocity. An added feature of the improved cookstove is the pot skirt which allows the hot fumes to get in direct contact to the cooking vessel causing a more efficient transfer of heat energy. On the other hand, lower power values were recorded for the three-rock fire and metal plate stove due to the smaller area of cooking vessel in direct contact to the fire and the loss of useful heat to open air.

Table 9. Maximum power produced by the three stoves (Watts)

	R1	R2	R3	MEAN
1. Improved Stove	3910.9815	3862.4060	3612.8855	3795.4243
2. Three-Rock Fire	2603.3856	2744.1685	3076.4046	2807.9862
3. Metal Plate Stove	1952.3192	2049.1001	2188.0730	2063.1641

Figure 3. Comparison on maximum power value of the three stoves (Watts)



Heat Utilization Efficiency

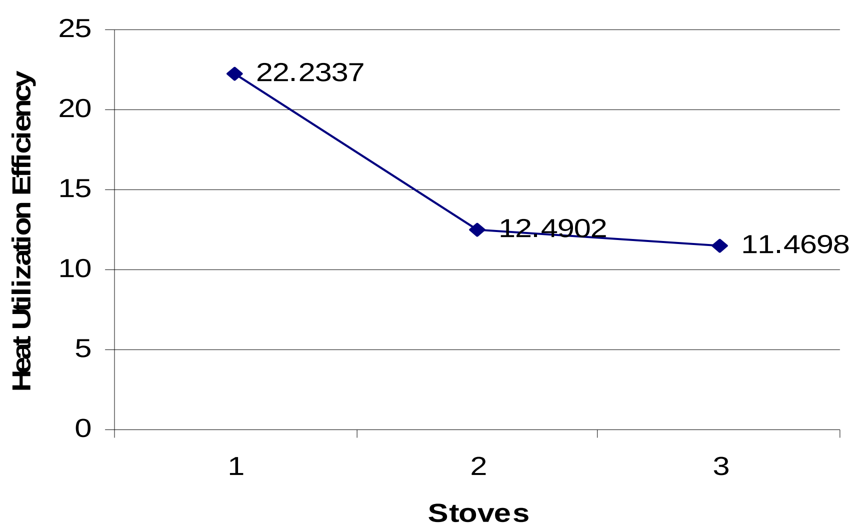
The heat utilization efficiency of a stove is computed as the amount of energy used by the water over the amount of energy produced by the fuel wood. Its purpose is to show how much of the heat energy is actually used since not all of it is utilized effectively; some were lost during the transfer.

Table 10 shows the efficiencies of the different cookstoves. The improved cookstove was able to register an efficiency of 22.2337%, about 9% and 11% higher than the three rock fire and metal plate stove respectively. This means the stove was able to transfer 22.2337% of the heat energy produced to the water. Although some of the heat was absorbed by the stove's metal walls, this lost heat energy was much lesser as compared to the amount of heat lost to the open air by the traditional stoves. The more efficient the stove, the higher is the saving for fuel wood.

Table 10. Heat utilization efficiencies of the different cookstoves (%)

	R1	R2	R3	MEAN
1. Improved Stove	22.8280	20.9619	22.9111	22.2337
2. 3-Rock Fire	12.0935	12.6180	12.7592	12.4902
3. Metal Plate Stove	10.7816	11.6698	11.9581	11.4698

Figure 4. Comparison on heat utilization efficiencies of the three stoves (%)



Fuel Consumption

Fuel consumption refers to the amount of fuel used by the stove. Tables 11 and 12 show the fuel consumptions of the stoves during the tests. During the High Power Boiling Test where no lid was used, the stoves consumed higher amount of fuel wood for the reason that the energy being lost to the air by the water was needed to be replaced for the water to raise and maintain its temperature. The presence of the lid during the Low Power Boiling Test trapped and prevented the heat from escaping the cooking vessel, resulting to a lesser amount of fuel needed to raise and maintain the temperature of the water.

Based on the test results, the Improved Stove registered lower amount of fuel used for both tests compared to the conventional stoves. This advantage was due to its higher efficiency. The Three-Rock Fire consumed more fuel since much of the heat was lost to the open air instead of being transferred to the cooking vessel. The Metal Plate Stove on the other hand had more advantage over the Three Rock Fire since two of its sides were shielded; however, the ability to transfer heat was lessened due to the lesser pot area exposed to the radiant fire.

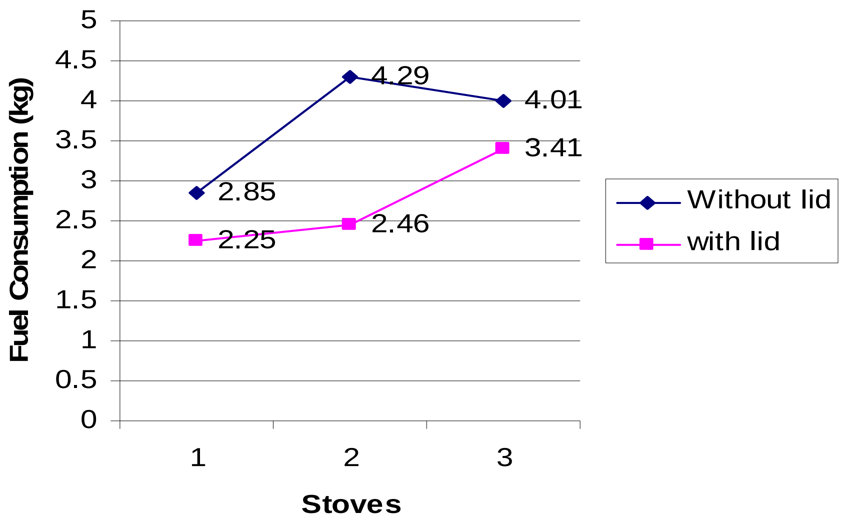
Table 11. Fuel consumption of the cookstoves for the high power boiling test (kilograms)

	R1	R2	R3	MEAN
1. Improved Stove	2.75	3.10	2.70	2.85
2. 3-Rock Fire	4.25	4.15	4.47	4.29
3. Metal Plate Stove	4.22	3.80	4.02	4.01

Table 12. Fuel consumption of the cookstoves for the low power boiling test (kilograms)

	R1	R2	R3	MEAN
1. Improved Stove	2.23	2.40	2.13	2.25
2. 3-Rock Fire	2.43	2.62	2.33	2.46
3. Metal Plate Stove	3.35	3.68	3.20	3.41

Figure 5. Comparison on the fuel consumption of the three stoves



SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The improved biomass cookstove was constructed and evaluated from January to March 2008. It was made out of an empty sodium cyanide tank, a gauge of #18 G.I. sheet and empty refrigerant tanks.

The water boiling test which is composed of the High Power Boiling Test and Low Power Boiling Test was used in the evaluation of the power, efficiency and fuel consumption of the device.

Results showed that the improved biomass cookstove has a better stove performance at height 2 or a riser height of 20 centimeters as compared to height 1 or riser height of 10 centimeters, height 3 or riser height of 30 centimeters and height 4 or riser height of 40 centimeters.

Comparing these test results with the three-rock fire and metal plate stove, the improved biomass cookstove had a higher power value of 3795.42 Watts than the three-rock fire which registered a power value of 2807.99 Watts and the metal plate stove having a power value of 2063.16 Watts.

The improved cookstove's efficiency was 22.23% which was also way higher than the three-rock fire which had an efficiency of 12.49% and the metal plate stove with an efficiency of 11.47%.

Fuel consumption for the improved cookstove was much lesser than the two traditional stoves. It consumed 44.83 MJ or 2.40 kilograms of alnus wood at High Power Boiling Test and 40.88 MJ or 2.19 kilograms wood at Low Power Boiling Test. On the other hand, the three-rock fire and metal plate stove consumed 68.02 MJ or 3.64 kilograms of wood and 66.63 MJ or 3.57 kilograms of fuel wood at High Power Boiling and 43.04 MJ or 2.31 kilograms wood and 59.97 MJ or 3.21 kilograms wood at Low Power Boiling. Fuel consumption for the improved cookstove is much lesser than the two traditional stoves.

Conclusion

Based on the findings, the following conclusions were drawn:

1. The improved biomass cookstove is more efficient at a riser height of 20 centimeters.
2. The improved biomass cookstove had higher power and efficiency values than the three-rock fire and metal plate stove.
3. The improved biomass cookstove consumed lesser fuel than the two conventional stoves.

Recommendations

Based on the findings and conclusion, the following recommendations are provided.

1. Integration of other factors such as utilization of other types of heating and construction materials, adjustable pot skirt to suit different cooking vessel sizes, varied thickness of the pot holder for better gaps between the pot skirt and pot bottom of cooking pot and other design improvements should be integrated
2. .Similar studies may be conducted to further improve the performance of the biomass cookstove.

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APPENDIX

Appendix Table 1. Result of the Water Boiling Test for the Improved Stove

		Kindling Time (min)	Time to Boil (min)	Weight of Wood Used (kg)	Weight of Water Evaporated (kg)	Weight of Charcoal Produced (kg)	Raise in Temperature (^{o}C)
Test 1 (High Power)							
H1 (10cm)	R1	5.667	11.583	3.2	3.7	0.29	76
	R2	5.167	12.300	3.5	3.4	0.30	75
	R3	5.533	13.533	3.65	3.6	0.41	74.5
H2 (20 cm)	R1	.333	12.083	2.75	3.43	0.27	75
	R2	5.750	14.77	3.1	3.65	0.28	74.5
	R3	5.133	14.1	2.7	3.3	0.29	74.5
H3 (30 cm)	R1	5.300	18.74	3.15	3.3	0.23	75
	R2	5.417	13.883	2.8	2.9	0.26	75.5
	R3	5.217	17.867	2.9	3.05	0.25	76
H4 (40 cm)	R1	5.267	23.617	3.5	3.6	0.219	76
	R2	5.333	26.167	2.95	3.1	0.23	76
	R3	5.300	19.917	2.85	2.65	0.23	76
Test 2 (Low Power)							
H1 (10cm)	R1		8.817	2.31		0.074	74

	R2	11.117	2.42	0.050	72
	R3	12.417	2.19	0.051	73.5
H2 (20 cm)	R1	10.417	2.23	0.035	74
	R2	16.617	2.4	0.045	72
	R3	11.05	2.13	0.040	72.5
H3 (30 cm)	R1	16.783	2.41	0.036	72
	R2	12.733	2.89	0.041	72
	R3	13.050	3.1	0.031	73.5
H4 (40 cm)	R1	20.200	2.64	0.029	72.5
	R2	16.83	3.03	0.035	72
	R3	17.600	3.25	0.026	74

Appendix Table 2. Results of the Water Boiling Test for the Traditional Stoves

		Kindling Time (min)	Time to Boil (min)	Weight of Wood Used (kg)	Weight of Water Evaporated (kg)	Weight of Charcoal Produced (kg)	Raise in Temperature (^{o}C)
Test 1 (High Power)							
Three-rock fire	R1	6.43	25.00	4.25	2.6	0.45	76
	R2	6.72	20.433	4.15	2.75	0.39	75.5
	R3	6.95	26.03	4.47	3.15	0.37	75.5
Metal Plate Stove	R1	6.19	34.750	4.215	2.447	0.279	75
	R2	6.45	28.25	3.8	2.26	0.32	75.5
	R3	5.30	32.10	4.02	2.68	0.23	76
Test 2 (Low Power)							
Three-Rock Fire	R1		20.167	2.43		0.095	71.5
	R2		19.5	2.62		0.087	72
	R3		17.67	2.33		0.108	72.5
Metal Plate Stove	R1		19.417	3.35		0.127	71
	R2		21.917	3.68		0.150	71
	R3		22.733	3.2		0.095	72

Appendix Table 3. Analysis of Variance on the Average Kindling Time of the Improved Stove as Affected by the Different Chimney Heights

Descriptives

Power

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
10 cm	4	4003.715	155.3164311	77.65822	3756.572274	4250.858476	3863.377	4220.218
20 cm	4	3795.424	130.5889583	65.29448	3587.628151	4003.220499	3612.886	3910.982
30 cm	4	3232.803	66.6441076	33.32205	3126.757278	3338.848572	3138.857	3286.316
40 cm	4	2869.647	234.0529689	117.0265	2497.216972	3242.077978	2698.767	3200.589
Total	16	3475.398	485.1450204	121.2863	3216.881992	3733.913058	2698.767	4220.218

ANOVA		Sum of Squares	df	Mean Square	F	Sig.
Kindling Time	Between Groups	.068	3	.023	$.764^{ns}$	.536
	Within Groups	.355	12	.030		
	Total	.422	15			

^{ns} Not Significant

Height	N	Subset for alpha = .05
		1
40 cm	4	5.300000
30 cm	4	5.311250
20 cm	4	5.405250
10 cm	4	5.455750
Sig.		.258

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 4.000.

Appendix Table 4. Analysis of Variance on the Average Boiling Time of the Improved Stove as Affected by Different Chimney Heights (High Power Boiling Test)

Descriptives

Time to Boil

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
10 cm	4	12.472000	.8053211	.4026605	11.190554	13.753446	11.5830	13.5330
20 cm	4	13.651000	1.1419845	.5709923	11.833848	15.468152	12.0830	14.7700
30 cm	4	16.830000	2.1141017	1.0570509	13.465992	20.194008	13.8830	18.7400
40 cm	4	25.983750	7.6383499	3.8191749	13.829431	38.138069	19.9170	37.1670
Total	16	17.234188	6.5485009	1.6371252	13.744738	20.723637	11.5830	37.1670

ANOVA		Sum of Squares	df	Mean Square	F	Sig.
Time to Boil	Between Groups	448.943	3	149.648	9.242**	.002
	Within Groups	194.299	12	16.192		
	Total	643.243	15			

**Highly Significant

Height	N	Subset for alpha = .05	
		1	2
10 cm	4	12.472000	
20 cm	4	13.651000	
30 cm	4	16.830000	
40 cm	4		25.983750
Sig.		.170	1.000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 4.000.

Appendix Table 5. Analysis of Variance on the Average Boiling Time of the Improved Stove as Affected by Different Chimney Heights (Low Power Boiling Test)

Descriptives

Boiling Time (combined high and low)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
10 cm	4	10.783750	1.4884742	.7442371	8.415255	13.152245	8.8170	12.4170
20 cm	4	11.361250	.9247329	.4623664	9.889794	12.832706	10.4170	12.6170
30 cm	4	14.188750	1.8390299	.9195149	11.262443	17.115057	12.7330	16.7830
40 cm	4	18.227750	1.4250372	.7125186	15.960198	20.495302	16.8830	20.2000
Total	16	13.640375	3.3090594	.8272649	11.877102	15.403648	8.8170	20.2000

ANOVA		Sum of Squares	df	Mean Square	F	Sig.
Boiling Time (combined high and low)	Between Groups	138.798	3	46.266	21.815**	.000
	Within Groups	25.450	12	2.121		
	Total	164.248	15			

**Highly Significant

Height	N	Subset for alpha = .05	
		1	2
10 cm	4	12.472000	
20 cm	4	13.651000	
30 cm	4	16.830000	
40 cm	4		25.983750
Sig.		.170	1.000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 4.000.

Appendix Table 6.Analysis of Variance on the Power of the Improved Stove as Affected by Different Chimney Heights (High Power Boiling Test)

Descriptives

Power

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
10 cm	4	4003.715	155.3164311	77.65822	3756.572274	4250.858476	3863.377	4220.218
20 cm	4	3795.424	130.5889583	65.29448	3587.628151	4003.220499	3612.886	3910.982
30 cm	4	3232.803	66.6441076	33.32205	3126.757278	3338.848572	3138.857	3286.316
40 cm	4	2869.647	234.0529689	117.0265	2497.216972	3242.077978	2698.767	3200.589
Total	16	3475.398	485.1450204	121.2863	3216.881992	3733.913058	2698.767	4220.218

ANOVA		Sum of Squares	df	Mean Square	F	Sig.
Power	Between Groups	3229288 .665	3	1076429. 555	42.886**	.000
	Within Groups	301196. 697	12	25099.72 5		
	Total	3530485 .363	15			

**Highly Significant

Height	N	Subset for alpha = .05		
		1	2	3
40 cm	4	2869.647475		
30 cm	4		3232.802925	
20 cm	4			3795.424325
10 cm	4			4003.715375
Sig.		1.000	1.000	.088

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 4.000

Appendix Table 7. Analysis of Variance on the Efficiency of the Improved Stove as Affected by Different Chimney Heights (High Power Boiling Test)

Descriptives

Effeciency

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
10 cm	4	18.480925	1.5128140	.7564070	16.073700	20.888150	17.3957	20.6203
20 cm	4	22.233650	.8998894	.4499447	20.801725	23.665575	20.9619	22.9110
30 cm	4	19.067025	.4512003	.2256002	18.349065	19.784985	18.4332	19.4477
40 cm	4	18.260900	.6187002	.3093501	17.276410	19.245390	17.4476	18.9470
Total	16	19.510625	1.8617071	.4654268	18.518591	20.502659	17.3957	22.9110

ANOVA		Sum of Squares	df	Mean Square	F	Sig.
Efficiency	Between Groups	40.935	3	13.645	14.812**	.000
	Within Groups	11.054	12	.921		
	Total	51.989	15			

**Highly Significant

Height	N	Subset for alpha = .05	
		1	2
40 cm	4	18.260900	
10 cm	4	18.480925	
30 cm	4	19.067025	
20 cm	4		22.233650
Sig.		.280	1.000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 4.000.

Appendix Table 8. Analysis of Variance on the Efficiency of the Improved Stove as Affected by Different Chimney Heights (Low Power Boiling Test)

Descriptives

Effeciency (combined (high and low)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
10 cm	4	10.783750	1.4884742	.7442371	8.415255	13.152245	8.8170	12.4170
20 cm	4	11.361250	.9247329	.4623664	9.889794	12.832706	10.4170	12.6170
30 cm	4	14.188750	1.8390299	.9195149	11.262443	17.115057	12.7330	16.7830
40 cm	4	18.477750	1.5102641	.7551320	16.074583	20.880917	16.8830	20.2000
Total	16	13.702875	3.4094072	.8523518	11.886130	15.519620	8.8170	20.2000

ANOVA		Sum of Squares	df	Mean Square	F	Sig.
Efficiency (combined (high and low)	Between Groups	48.160	3	49.387	2.619**	.000
	Within Groups	6.201	12	2.183		
	Total	74.361	15			

**Highly Significant

Height	N	Subset for alpha = .05		
		1	2	3
10 cm	4	4.4553		
20 cm	4	4.4848		
30 cm	4		3.5944	
40 cm	4			3.3717
Sig.		.591	1.000	1.000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 4.000.

Appendix Table 9. Analysis of Variance on the Fuel Consumption of the Improved Stove as Affected by Different Chimney Heights (High Power Boiling Test)

Descriptives

Fuel Consumption

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
10 cm	4	8.222200	6.7322753	.3661376	47.509648	68.934752	51.0632	67.2374
20 cm	4	4.826600	3.3603379	.6801690	39.479553	50.173647	41.7252	49.4956
30 cm	4	7.694200	3.1227458	.5613729	42.725215	52.663185	44.4928	51.9294
40 cm	4	0.171800	4.1873406	.0936703	43.508807	56.834793	46.3266	55.9946
Total	16	0.228700	6.5814128	.6453532	46.721713	53.735687	41.7252	67.2374

ANOVA		Sum of Squares	df	Mean Square	F	Sig.
Fuel Consumption	Between Groups	398.023	3	132.674	6.325**	.008
	Within Groups	251.702	12	20.975		
	Total	649.725	15			

**Highly Significant

Height	N	Subset for alpha = .05	
		1	2
20 cm	4	44.826600	
30 cm	4	47.694200	
40 cm	4	50.171800	
10 cm	4		58.222200
Sig.		.142	1.000

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 4.000.

Appendix Table 10. Analysis of Variance on the Fuel Consumption of the Improved Stove as Affected by Different Chimney Heights (Low Power Boiling Test)

Descriptives

Fuel Consumption (combined high and low)

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
10 cm	4	41.329300	1.7892553	.8946277	38.482195	44.176405	39.3704	43.6959
20 cm	4	40.883283	2.0075501	1.0037750	37.688822	44.077743	38.5799	43.4724
30 cm	4	51.462800	5.4540164	2.7270082	42.784243	60.141357	43.9292	56.9656
40 cm	4	54.629975	4.7314677	2.3657338	47.101154	62.158796	48.4346	59.9170
Total	16	47.076339	7.1592261	1.7898065	43.261457	50.891222	38.5799	59.9170

ANOVA		Sum of Squares	df	Mean Square	F	Sig.
Fuel Consumption (combined high and low)	Between Groups	590.723	3	196.908	13.268**	.000
	Within Groups	178.094	12	14.841		
	Total	768.818	15			

**Highly Significant

Height	N	Subset for alpha = .05	
		1	2
20 cm	4	40.883283	
10 cm	4	41.329300	
30 cm	4		51.462800
40 cm	4		54.629975
Sig.		.873	.268

Means for groups in homogeneous subsets are displayed.
a Uses Harmonic Mean Sample Size = 4.000.

FIGURES

Figure 6. Weighing the fuel wood

Figure 7. The fuel wood and kindling material used

Figure 8. Weighing the water for the water boiling test

Figure 9. The fire at chimney height 1 of the improved stove


Figure 10. The fire at chimney height 2 of the improved stove


Figure 11. The fire at chimney height 3 of the improved stove

Figure 12. The fire at chimney height 4 of the improved stove

Figure 13. High Power Boiling Test (height 1)

Figure 14. Low Power Boiling Test (height !)

Figure 15. High Power Boiling Test (3-rock fire)

Figure 16. High Power Boiling (metal plate stove)

Figure 17. Low Power Boiling Test (metal plate stove)