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Wood pellets in Mozambique
– an alternative to charcoal and firewood for cooking in Mozambican households

Pellets de madeira em Moçambique
– uma alternativa ao carvão vegetal e lenha para cozinhar em famílias moçambicanas

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Cover: Introduction of the wood gasification stove among households in Matola Rio, Mozambique. Photo: Shanar Tabrizi, 2013.

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Abstract

Consistent with the rest of the world, Mozambique has an increasing demand for energy to satisfy its growing population. The excessive use of firewood and charcoal for household cooking has resulted in various problems such as deforestation and respiratory disease from indoor pollution. This study has investigated possible benefits of wood gasification stoves (WGS) and wood pellets as a sustainable alternative to charcoal and firewood in traditional stoves for cooking in peri-urban Mozambican households. The company *Philips* has developed a WGS designed for burning biofuels, which uses a built-in fan for increased air flow. At the time of the study this was considered the most suitable stove of this kind on the market. The cooking performance of wood pellets and two other reference fuels (birch wood and torrefied bamboo pellets) were evaluated in the WGS using two international standardized tests, i.e. the Water Boiling Test and the Controlled Cooking Test. The tests were performed in a controlled environment, as well as in the field in the Matola Rio area in southern Mozambique.

Wood pellets had a shorter boiling time and higher efficiency than the two other fuels, but using bamboo pellets resulted in lower fuel consumption. Adjusting the stove, however, decreased the fuel consumption for wood pellets. Through experiments a proper air flow adjustment for the stove was found so that the stove can be compatible with wood pellets. The best setting in this study for the chosen wood pellet was decreasing the primary air flow by simply rotating three of the lower tiles in the combustion chamber and keeping the secondary air flow the same as factory setting. The change in stove setting caused the pellets to burn with lower flames and less smoke than before the adjustment. The boiling time increased compared to the basic factory adjustment, but there was a positive effect on ease of use and fuel consumption.

Keywords: wood gasification stove, WBT, CCT, pellets, Mozambique, household energy, MFS

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II Abbreviations

CCT	Controlled Cooking Test
SLU	Swedish University of Agricultural Sciences
WBT	Water Boiling Test
WGS	Wood gasification stove

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1 Introduction

1.1 Background

After Mozambique's independence from Portugal in 1975, policy makers assigned a high priority to the energy sector. Despite government efforts however, access to electricity is limited to around 18% of the households, with the large majority of the population dependent on traditional sources of energy such as firewood and charcoal (Mahumane, Mulder & Nadaud 2012). About 90% of urban households use firewood and charcoal for cooking and rural households almost exclusively depend upon time-consuming collection of firewood (Cumbe, Sharma & Lucas 2010). Bioenergy is therefore destined to play an important role in the economic development of Mozambique (Mahu3mane, Mulder & Nadaud 2012).

In many areas the intensifying search for wood fuel has contributed to serious deforestation. About 78% of the land area is covered by trees or other vegetation (Cuvilas, Jirjis & Lucas 2010) and the deforestation rate is 0.53% annually, equating to approximately 200,000 ha/yr (FAO 2010). The use of charcoal and firewood is not only hazardous to the environment through deforestation, loss of biodiversity, erosion and climate change, but also to human health. Carbon monoxide and particulate matter are the major pollutants released from incomplete combustion of solid fuels used by households and it is estimated that more than 10 000 people die from indoor air pollution in Mozambique each year (WHO 2009).

A viable alternative to charcoal and firewood could be the use of residual products from forest and wood industry compressed into wood pellets; a dense biomass with high calorific value. Currently the national pellet production in Mozambique is non-existent. There are however a number of start-up companies and initiatives that have realized the potential for this biofuel in Mozambique, and in the neighboring countries Zambia and in particular South Africa pellet plants are already up and running. The price of charcoal is rising as forests recede, especially around the cities (van der Plas et al., 2012), and pellets could become economically competitive. The following potential sources of raw material for national production of wood pellets have been identified in Mozambique:

1. Residual products from sawmills. Mozambique has about 120 functioning sawmills producing vast amounts of sawdust that can be compressed to pellets (Nhancale et al., 2009)
2. The furniture and other secondary wood working industry. One advantage with using by-products from the furniture industry is that it yields raw material that do not require energy consuming drying processes before pellet production.
3. Dead palm trees affected by Lethal Yellowing Disease. Zambezia in northern Mozambique once contained the largest coconut plantation in the world. In recent years, millions of palm trees have died from Lethal Yellowing Disease; a form of bacteria that lacks cell walls and is transmitted from tree to tree by the planthopper bug (*haplaxius crudus*).

Until recently there has been no technology for using biomass pellets in African household cooking appliances. An innovation and development work by *Philips* research scientist Paul van der Sluis changed this situation. The new stove was originally intended to burn wood more efficiently using gasification technology but later on it was realized that is was more or less perfect for burning pellets in small scale. Pellets are dense and need forced air to burn efficiently which also leads to smoke reduction. One advantage with pellets compared to wood or charcoal is that it can be made from residual materials at a low cost. In urban areas where the charcoal prices are relatively higher it can even be economically competitive. The second advantage is that pellets burning in this new wood gasification stove probably has lower emissions of carbon monoxide and particulate matter than charcoal burning in traditional stoves because of the fan. Earlier surveys have found complaints among users of the Philips stove of the need to use smaller pieces of fuel to operate it. How the fuel should be cut up and by who are questions that have arisen (Pennise et al., 2010). Using wood pellets that have a small and homogenous size could solve this issue.

Currently these stoves are being produced in a joint venture in Lesotho by the company *African Clean Energy* and the stoves are for example being sold with wood pellets as a recommended fuel in Zambia by the Swedish/Zambian company *Emerging Cooking Solutions* and in Rwanda by *Inyenyeri*.

The authors of a Mozambican government and EUEI[1] supported report recommend a support for purchases of wood pellet cook stoves with an 80 % subsidy (van der Plas et al., 2012). The subsidy should be sufficient for 450 000 stove purchases in the 3 years 2013-2015, the authors stated.

1.1.1 Biofuel situation in Mozambican households

Mozambique's government has taken advantage of the country's land abundance to promote the production of biofuels as a means to reduce the dependency on oil imports (Schut, Slingerland & Locke 2010). Biofuels was first discussed on Mozambique's policy agenda during the 2004 election campaign when farmers were encouraged to cultivate jatropha for the production of biodiesel and sugar cane, sorghum and cassava for ethanol production (Nhantumbo & Salomão 2010). In 2009 the Mozambican government adopted a National Biofuels Policy and Strategy (NBSP 2009) which aimed to contribute to energy security and sustainable socio-economic development in rural areas through a diversified energy market and better exploitation of energy from the agricultural sector. The resolution was based on a study on the feasibility of biofuel production in Mozambique produced by Econergy (Econergy 2008).

1.1.2 Household energy

Since this study investigates wood pellets as a possible alternative to firewood and charcoal, special emphasis will be given to describing these fuels. Also, considering this study's concentration on the Maputo/Matola region, only a summary of the household energy situation in this particular area is provided.

Household energy in Maputo and Matola is mainly supplied through electricity, liquiefied petroleum gas, charcoal and/or firewood. Fuel mixing is quite common. Firewood is mainly used using the simple three stone fire method seen in figure 8. Over 90% of households have access to electricity in Maputo, but at the same time charcoal is used by 87% of households in Maputo and 50% use either LPG or electricity stoves in combination with biomass. Charcoal dependent households in Maputo spend on average USD 28 (775 meticais)[2] per month on charcoal (Atanassov et al., 2012). In relation to the gross national income per capita of USD 510 in 2012 (The World Bank, 2013), this is a considerate amount.

The charcoal industry in Mozambique, and particularly near cities such as Maputo, is hence a lucrative business (Fig. 1). More than 8 million bags are produced informally per year. Only between 1-5% of the total production is officially registered. This means a high revenue loss for the government. Especially when considering the small, non-commercial quantities of charcoal used for personal consumption that are currently exempt from taxation (Nhancale et al., 2009). The northern and central parts of Mozambique have a greater abundance of forest, and so the charcoal prices are lower and few fuels, except for the free picking of fire wood, can compete with their price. In Maputo however, charcoal is more expensive because of nearby forest scarcity (Atanassov et al., 2012).

[1] EU Energy Initiative

[2] 1 MZN = 0.033 USD = 0.024 EUR on January 10th 2014

Fig. 1. Charcoal stoves of various sizes on sale in Maputo market.

1.1.3 Wood residues

Technically, any kind of woody biomass is a possible raw material for pellets. The sawmilling industry is the main producer of traditional raw material for pelleting such as shavings, offcuts and sawdust resulting from sawing, cutting and planing processes. There is also a residual potential from secondary wood processing industry such as furniture companies. This can also be in the form of planer shavings or e.g. sander dust from mechanical surface treatment of wood. In Mozambique, the dominant wood type used in industry is tropical hardwood.

It should not be assumed that wood residues are free all because it is waste. It might have alternative uses that are of value (such as animal feed and bedding, direct use as fuel, various building applications in thatch or mudbricks). When there are competing residual uses the pellet plant might have to pay for the raw material which might mean less revenue for a pellet production plant (Eriksson & Prior, 1990). Lower costs are achieved for early conversion to pellets close to biomass plantation sites and wood industry producing the residual sawdust compared to e.g. agricultural residues as a raw material (Batidzirai, Faaij & Smeets, 2006). The city of Maputo and the peri-urban areas surrounding it hosts a number of wood processing companies due to the access to electricity. Maputo province was registered as having the greatest number of sawmills a few years ago, as well as furniture companies and other wood processing industry (Nhancale et al., 2009).

So why not use forest residues for pellet production? It is estimated that the total production of forest biomass residues in Maputo province is more than 1.2 million tonnes/year (Vasco & Costa 2009). However also tops, branches and leaves left behind after logging operations were included in this figure. These have too high moisture content and forest residues are generally located too far away from consumers for it to be economically viable (Obernberger & Thek, 2010). Others argue that even residuals from wood processing industry and the large spread of these companies would make collection and transportation economically unsustainable (Batidzirai, Faaij & Smeets, 2006). However, if the pellets are produced in connection to the facilities, where there is also electricity, this could bring the costs down. Sawmills located close to each other in Maputo could possibly also jointly invest in a pellet plant.

Within this study an interview was carried out with Secama, a local wood processing company, to investigate what potential they have to produce pellets from the residual sawdust, and how they are currently disposing of it.

1.1.4 Wood gasification stoves

Wood gasification stoves, or micro-gasification stoves, are relatively simple but use sophisticated combustion engineering where air is forced into the burning chamber in two layers and pyrolysis takes place. Pyrolysis is a thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen and results in gasification of the biomass. When the fuel is heated in an environment without sufficient oxygen, the decomposition of the biomass releases unburned PM and gas (smoke). This means that the flames are the gas and particles burning and not the wood. To minimize the amount of smoke, the combustion needs to be very hot and have sufficient oxygen for a complete combustion to take place. The *Philips* WGS (Fig. 2) has a cylindrical combustion chamber of stainless steel, with an inside lined with ceramic plates. The primary air flow provides the fuel with sufficient air for a partial combustion leading to high temperatures. The produced gas rises to the secondary zone where air is forced into the hot gaseous mix which then continues to burn. The energy contained in the fuel is then released completely.

The efficiency of the *Philips* WGS is based on a fan that forces a controlled airflow through the stove from below. The fan runs on a rechargeable battery that provides electrical power during start-up, and a thermoelectric element that to some extent recharges the battery and powers the fan when the stove is hot enough. According to the producers the stove is fully charged after 5 hours loading from the grid and can then function for about 21 hours before recharging is needed. In Maputo it was empirically concluded that the stove battery requires less than 1 kWh to load fully for 5 hours. The local price of electricity at the time of the study was around 3 MZN per kWh.

The *Philips* WGS is basically batch loaded. Solid fuel can, however, be inserted in small amounts with the pot still on by sliding it under the pot, or in larger amounts by removing the pot from the stove during refilling. Compared to traditional stoves, the *Philips* stove requires shorter pieces of fuel (Jetter & Kariher, 2009).

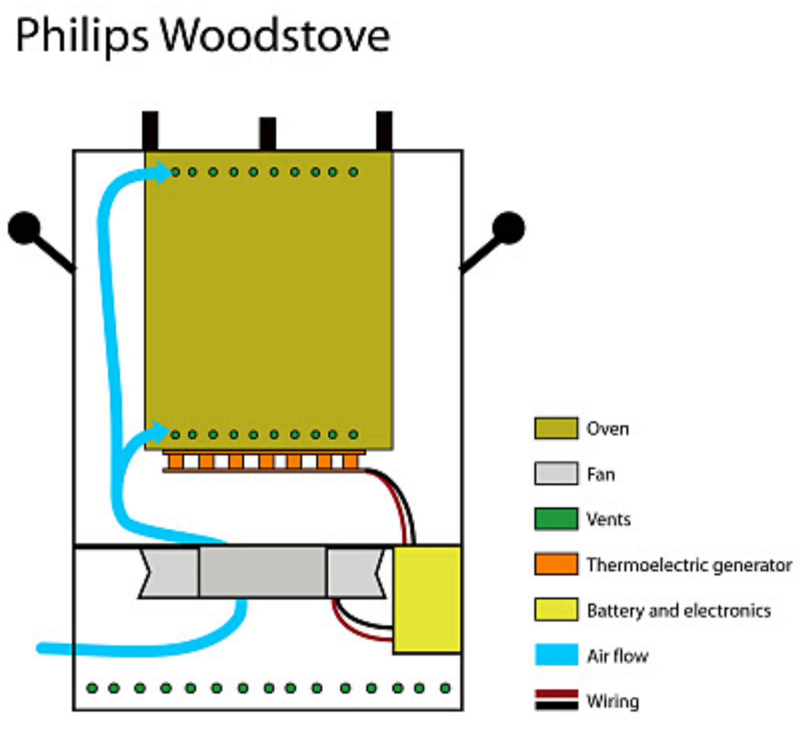

Fig. 2. Schematic diagram of the Philips wood stove. Drawing: *Philips* 2013.

1.2 Aim

The objective of this study was to find the most suitable adjustment setting for the Philips Wood Gasification Stove and report the following metrics:

- Thermal efficiency
- Time to boil
- Specific fuel consumption
- Cooking time

Interviews with an existing cook stove initiative and a wood processing company were also conducted to identify the challenges for pellet production and alternative cook stove appliances in the Mozambican market.

2 Methodology

To conduct the study a field visit was done to Maputo during two months from April to June 2013. The study was partly financed through a minor field study (MFS) scholarship provided by the Swedish international development agency. The field study in Mozambique was conducted together with Jessica Vesterberg; a student at SLU who studied environmental aspects of the *Philips* stove and wood pellet combination by e.g. measuring carbon monoxide and particulate matter release during combustion (Vesterberg 2014). The wood pellets and torrefied bamboo pellets in combination with the Philips wood gasification stove were put through household tests in ten randomly selected households in Matola Rio, 16 kilometers from Maputo. This was done in order to evaluate cooking performance, fuel consumption rate and ease of use. At this point of the study the stoves were however not yet optimized for wood pellet use. Vesterberg conducted interviews with households before and after stove intervention to analyze acceptability and reactions to the stove. The criterions for the households (HH) were:

- The HH should have access to electricity in order to charge the stove battery.
- The HH should use firewood and charcoal for cooking.

One of the two standardized stove tests presented in this study, the CCT, was also performed in one of these households. The results of the CCT tests are presented in the results section. Interviews were performed on site in Maputo and through e-mail contact. The WBT's were conducted in a laboratory at the Department of Energy and Technology at SLU.

2.1 Households visited in Matola Rio

The target group in this study was households in peri-urban Maputo, namely in the region of Matola Rio Kilometro 16, Chinonankila. Ten households were chosen to try the stove with torrefied bamboo pellets and wood pellets for a couple of weeks. Vesterberg (2014) conducted interviews prior to and after household trials. Rofina Chibabo, a woman who assisted during the CCT, is the *chef the quartarao* (village chief) of the ten households we visited.

Rofina Chibabo's household includes five persons. A father, a mother, two youths and a small child. Currently they are using both charcoal and firewood for cooking even though they have electricity in the house. Five years ago they were able to gather and cut wood nearby in their *Machamba* (a family owned piece of land for subsistence and minimal cash-crop agriculture) but they say that it is difficult to obtain wood today so they have to buy it. It is difficult to estimate how much charcoal they use each month, Rofina says, but she buys about 100 kg charcoal monthly. The family cooks twice daily (Fig. 3): once in the morning around 10 am and once in the afternoon at 5 pm. They have no indoor kitchen but cook outdoors under a tarpaulin (plastic cover) that is held up by thick wooden poles.

Fig. 3. Rofina and her daughter cooking Xima in front of their kitchen.

In Rofina's opinion, the family has not experienced any health issues when cooking with charcoal and wood. Neither have they had any accidents, such as children burning themselves on the hot stove. The family does not produce charcoal themselves, and had never heard of improved cook stoves before our visit (Fig. 4). Rofina said that five years ago the charcoal price was 250-500 meticais for a large bag (approximately 75 kg). Today she pays about 700 meticais for a bag. Her husband works for a company that produces chicken feed, and Rofina herself sells vegetables and fruits she produces herself and also some other products. The family has access to electricity, television and radio. They consider television to be the most important source of information. When we distributed the stoves to the families we only showed them how to light the stove and fill it with fuel, but gave no other instructions on how to save energy while cooking (Figs. 5 and 6.).

Fig. 4. A typical three stone fire using firewood as fuel.

Fig. 5. Demonstrating how the stove works.

Fig. 6. When asked to light the stove some women used coconut fiber. Others used paper, twigs or even plastic bags.

2.2 Interviews

An interview with a representative of an existing cook stove initiative was conducted to identify challenges and lessons learnt when trying to break through the market with a product that in a way challenges an established habit such as cooking. It was of interest to find out what possible limits there could be to introducing techniques for a task that is performed daily. The interview was with *CleanStar Mozambique* with their product *Ndzilo*; an efficient cook stove that runs on ethanol primarily produced from cassava. The company was chosen because of the presence they seem to have in Maputo, with TV ads and eye catching bright orange shops selling their products. An interview was also conducted with a wood processing company in Maputo to investigate how their wood residuals are being used at the moment. To allow for a conversational two-way communication, interviews were of the semi-structured form with open questions. Information was therefore both given and received and the person being interviewed had the possibility to ask questions to the interviewer (FAO 1990).

2.3 Testing of the wood gasification stove and various fuels

The stove and wood pellets were put through Water Boiling Test and Controlled Cooking Test as originally described in a manual from 2004, written by Rob Bailis from University of California-Berkley for the Shell Foundation (PCIA 2012). The WBT was however performed using an updated protocol from April 2013 (Approvecho 2013). See appendix 5 for summarized versions of the tests. The plan was originally to also present results from a Kitchen Performance Test (KPT) that measures real fuel consumption in a household over three days. The results from this field-test were however not satisfactory and reliable enough so they were disregarded. The following fuels were tested in the WGS:

Birch wood

For the WBT performed in Sweden, birch wood was purchased at the nearest retailer and cut into smaller pieces suitable for the WGS. Length approx: 4 cm, width approx: 2-5 mm.

Torrefied bamboo pellets

According to provider Boris Atanassov from CleanStar Mozambique, the torrefied bamboo pellets contained starch binder of 3 % maize and were torrefied at 300-350 °C using native bamboo from Sofala province in Mozambique. Length approx: 2 cm, width approx: 7 mm.

Wood pellets

For the WBT performed in Sweden, wood pellets were bought at the nearest retailer[3]:

Size: 8 mm
Net heat value: 5 kWh/kg
Moisture content: 5-9%
Residual ash: 0.5%

For the CCT performed in Mozambique, and for distribution of fuel and stoves in the households, approximately 30 bags of wood pellets á 15 kg were imported from the company *Calore* in South Africa.[4] Their pellets are predominantly produced from pine (Fig. 7). These were at times very smoky when used in the Philips WGS in the field. This was mainly due to the fact that the stove at the time was not optimized for wood pellets. To eliminate suspicion that the wood pellets had been damaged by moisture, the moisture content was determined at the Faculty of Engineering, Eduardo Mondlane University, through a standard oven drying method. The moisture content turned out to be normal, around 7 %. The following information was obtained from *Calore*:

Length, approx. 10 – 30 mm
Diameter, approx. 6 – 6.5 mm
Apparent density, approx. 650 kg/m3
Specific weight, approx. > 1.0 kg/dm3
Net heat value, approx. 5 kWh/kg
Moisture content, approx. <8%
Residual ash, approx. <0.5%

[3] www.cleanflame.eu
[4] www.calorefireplacesandstoves.co.za

Fig. 7. Wood pellets imported from South Africa.

2.3.1 Water Boiling Test

This test measures how much of the energy in the pellet that can actually be used. The useful energy is that transferred into the pot during cooking. With this test a comparison can be made between pellets, firewood and charcoal. Also the pellets' performance on the cook stoves can be evaluated. The WBT consists of three phases: a high power test with cold and hot starts measures the time and fuel it takes for bringing an amount of water to boil by using first a cold and then a hot stove. The third phase is a simmering test that measures the amount of fuel taken to keep the water simmering for 45 minutes.

The same 19.5 cm diameter flat-bottom aluminum pot was used for all tests in the WBT and approximately the same amount of fuel was loaded into the stove for each test. To start the fire we used *Änglamark* lighting paper in order to quickly get a fire started.

Used measures according to Approvecho's Water Boiling Test Protocol, 2013:

***"Temperature corrected time to boil**- the time it took for pot to reach boiling temperature, corrected to reflect a temperature rise of 75 degrees C from start to boil. This measure can be compared across tests and stoves to determine the "speed" of the stove at high power, often an important factor to cooks.*

***Thermal efficiency (TE) (IWA[5] Metric for high power)** - a measure of the fraction of heat produced by the fuel that made it directly to the water in the pot. The remaining energy is lost to the environment. So a higher thermal efficiency indicates a greater ability to transfer the heat produced into the pot. While thermal efficiency is a well-known measure of stove performance, a better indicator may be specific consumption, especially during the low power phase of the WBT. This is because a stove that is very slow to boil may have a very good looking TE because a great deal of water was evaporated. However the fuel used per water remaining may be too high since so much water was evaporated and so much time was taken while bringing the pot to a boil.*

***Specific fuel consumption (SPC)** - a measure of the amount of fuel required to boil (or simmer) 1 liter of water. It is calculated by the equivalent dry fuel used minus the energy in the remaining charcoal, divided by the volume of water remaining at the end of the test. In this way, the fuel used to produce a useful liter of "food" and essentially the time taken to do so is accounted for. SPC is listed as the IWA metric for Low Power, which is reported in MJ/(min*l).*

[5] IWA= International Workshop Agreement. The IWA provides guidance for rating cook stoves with regard to fuel use and efficiency, indoor emissions, total emissions and safety.

Temp-corrected specific energy consumption (kJ/liter) *- this is the same measure as the previous, but reported as energy (kilojoules) rather than fuel (grams). This allows for a direct comparison between different fuels, such as various types of wood, charcoal, dung, etc.* (WBT Protocol 2013).

Using a standard WBT Data sheet to record the data, the procedure was as follows:

- A pot of aluminum, since that is the material most pots locally used are made of, was filled with 5 liters cold clean water
- The weight of the pot plus water was recorded
- Approximately half a kg of the fuel was measured up in a bucket and weighed
- A thermometer attached to a tripod was inserted in the water and the water temperature was recorded
- The fuel was lit and the temperature of the water recorded every 30 seconds until it reached the pre-determined boiling point
- The time of reaching boiling point was recorded
- The weight of the remaining charcoal removed from the stove was measured
- The weight of the pot with the remaining water was measured

Each WBT (including preparations, hot start, cold start and simmering phase) took approximately between 3-4 hours to conduct. A total of 16 WBT's were performed, although only 14 results are accounted for and included in this study.

2.3.2 Controlled Cooking Test
The Controlled Cooking Test was originally designed to evaluate the performance of improved stoves relative to traditional or currently used stoves. The test is performed in a controlled environment and reveals stove performance in households under ideal conditions. A local cook is studied in the process of cooking a for that region typical meal on the stove. This is performed identically for at least three times, with assessments of certain parameters (Table 1). For this test we assessed the performance of *Philips* WGS with wood pellets and torrefied bamboo pellets, although in a version of the stove that had not been modified for the pellets. The tests were performed in one specific household chosen out of the ten households in Matola Rio who had used the stove for two weeks. The cover photo of this report shows one of the stove demonstrations performed in the households.

Calculations

Table 1. *Parameters for Controlled Cooking Test*

Variable	**Label**
Weight of container for char (grams)	k
Local boiling point of water (°C)	T_b
Initial weight of fuelwood (wet basis) (grams)	f_i
Final weight of fuelwood (wet basis) (grams)	f_f
Weight of charcoal with container (grams)	c_c
The weight of each pot with cooked food (grams)	Pj_f (j is an index for cooking pot ranging from 1-4 depending on the number of pots used for cooking)
Start and finish times of cooking (minutes)	t_i and t_f
Wood moisture content (% - wet basis)	m

Total weight of food cooked (g):

$W_f = \sum_{j=1}^{3}(Pj_f - P_j)$ where j is an index for each pot up to three. P_j is the weight of the pot without food. Since only one pot was used in this field work the formula will be:

$$W_f = (Pj_f - P_j) \quad [1]$$

Weight of char remaining (g):

$$\Delta c_c = c_c - k \quad [2]$$

Equivalent dry wood consumed (g):

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

Specific fuel consumtion (g/kg):

Principal indicator of stove performance for CCT!

$$SPC = \frac{f_d}{W_f} * 1000 \quad [4]$$

Total cooking time (min):

$$\Delta t = t_f - t_i \quad [5]$$

Xima

The traditional dish chosen for the CCT was Xima. Xima is ground up corn that is mixed with boiling water. It is eaten either as a main meal, or as a base for different stews. Xima can be made from scratch, which the families occasionally do. They pick the maize which lie in water for 2-3 days, and then they crush it. The Xima we used in these experiments were however bought from the local shops, as to ensure uniformity.

2.4 Adjustment of the stove

The stove consists of nine lower tiles with one hole per tile for primary air flow, and nine upper tiles with three holes per tile for secondary air flow. One of the three holes per tile in the upper tiles was expanded using the drill shown in Fig. 8. The upper case of the stove was then removed (Fig. 9) and the upper tiles replaced (Fig.10.) in accordance with the testing scheme (see Appendix 5). The lower tiles seen in Fig. 11 were rotated 180°. The number of tiles rotated varied for each test.

Fig. 8. Enlarging size of air holes in upper tiles.

Fig. 9. Removing upper case of stove.

Fig. 10. Replacing upper tiles of stove.

Fig. 11. Rotating lower tiles of stove.

3 Results

3.1 Testing the stove and fuels

3.1.1 Water Boiling Test

Determining the local boiling point

To perform a WBT, the local boiling point needs to be determined. For a given altitude h (meters), the boiling point of water may be estimated by the following formula:

$$T_b = \left(100 - \frac{h}{300}\right) °C \quad [6]$$

The average elevation of Uppsala, Sweden is 15 meters:

$$T_b = \left(100 - \frac{15}{300}\right) = 99.95°C$$

However, it is better to determine the local boiling point empirically. This was done by recording the highest and lowest temperature during 5 minutes of boiling and taking the mean value of that (WBT Protocol 2013, p. 29).

Lowest temperature: 98. 1 °C
Highest temperature: 100. 4 °C
Mean temperature: 99. 25 °C

The local boiling point in Uppsala was hence estimated to 99.3 °C.

Lab setup

Figs. 12 and 13 demonstrate how the lab was set up during the WBT. The digital thermometer was attached to the stand, centered and lowered into the water about 5 cm from the bottom of the pot. The test was conducted inside a fume hood which made it easier to keep constant air flow and control.

Fig. 12. Setup in fume hood with digital thermometer attached to a stand.

Fig. 13. The opening of the fume hood was kept constant at this level.

Time to Boil

Time to boil (see section 2.2.1) was measured with the unoptimized stove (factory airflow setting) beginning when the fuel was considered lit, meaning it was perceived as enough fuel was burning to keep the fire from dying out. The time was stopped when the temperature showed the pre-determined boiling temperature of 99.3 °C.

Of the three fuels tested, the results from this experiment showed that the trend was that wood pellets brought water to a boil faster than the other fuels (Figs. 14 and 15). In the hot and cold start phases, wood pellets brought the water to a boil in an average of only 9.7 minutes. However wood pellets and birch wood only differed a couple of minutes. The same amount of water took bamboo pellets 47 minutes to boil in the hot start phase and 51 minutes to boil in the cold start phase, a difference of roughly 40 minutes. This was despite the fact that we had to use a lid when testing the bamboo pellets to even get it up to boiling point. After the stove was optimized (see Adjustment of stove section 2.3) and tested with wood pellets, the result was that the setting that brought the water to a boil fastest was the factory setting followed by setting 1 which was 4.2 mm in bore hole size, and with three tiles turned (Table 2). Setting 1 brought water to a boil in 14 minutes (average of cold and hot start). The slowest setting was setting 6 which brought water to a boil after 26 minutes. The t-test found that the difference between wood pellets and bamboo pellets as well as between birch wood and bamboo pellets during cold start were statistically significant at 0.05 level. The difference between birch wood and wood pellets was however not significant. During hot start the t-test showed that none of the fuels were significantly different from one another at 0.05 level.

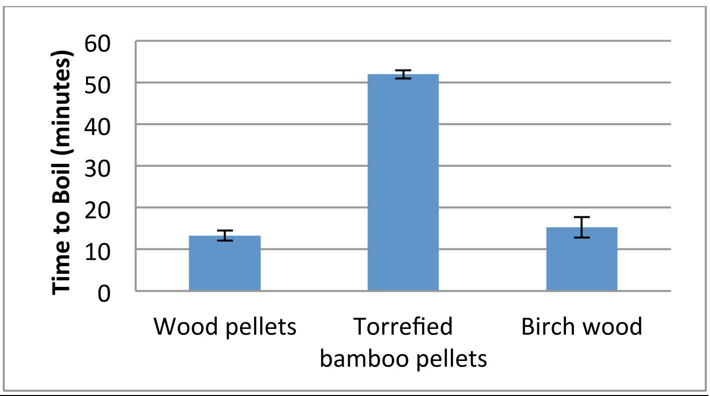

Fig. 14. Time to boil for the cold start phase. The error bars indicate one standard deviation (n=3).

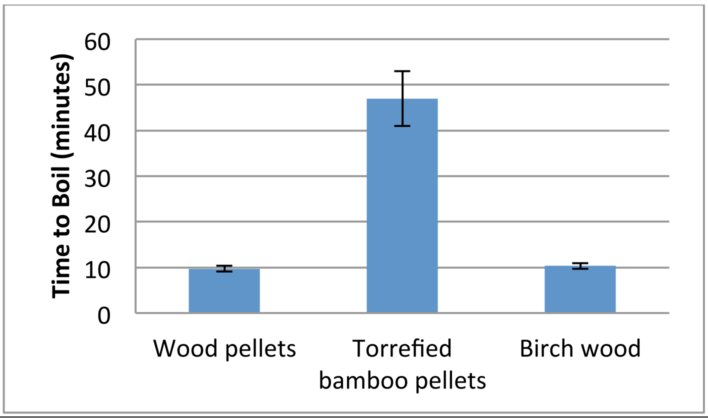

Fig. 15. Time to boil for the hot start phase. The error bars indicate one standard deviation (n=3).

(See appendix 8 for complete t-test results).

Table 2. *Temperature corrected time to boil (wood pellets), average of cold and hot start, for different stove airflow settings. Only one replication per setting.*

Airflow setting no.	**Bore hole (mm)/ no. turned tiles**	**Average Time to Boil (min: s)**	**Rank (fastest to slowest)**
0 (factory setting)	4.2/0	11:30	**1**
1	4.2/3	14	2
2	4.2/5	18:30	3
3	4.2/7	24:30	5
4	5.0/3	24:30	5
5	5.0/5	19:30	4
6	5.0/7	26	**6**

Thermal Efficiency

Figure 16 shows the thermal efficiency (see section 2.2.1) in the simmer phase and averaged over the entire WBT for the three fuels. The trend in this experiment seemed to be that wood pellets had the highest thermal efficiency, with the efficiency during the simmer phase averaging 34.4 %. Bamboo pellets showed the lowest thermal efficiency (8.9 % in simmer phase), and birch wood resulted in a value of 20.6 %.

Table 3 shows the thermal efficiency for different settings. Here the setting 1 resulted in the highest efficiency of 35 %. Notice that this is the same setting that brought water to a boil quickest next after the factory setting. The t-test showed that the fuels were significantly different from one another at 0.05 level during simmering phase. When calculated over the entire WBT however, only bamboo pellets and birch wood differed from each other at 0.05 level.

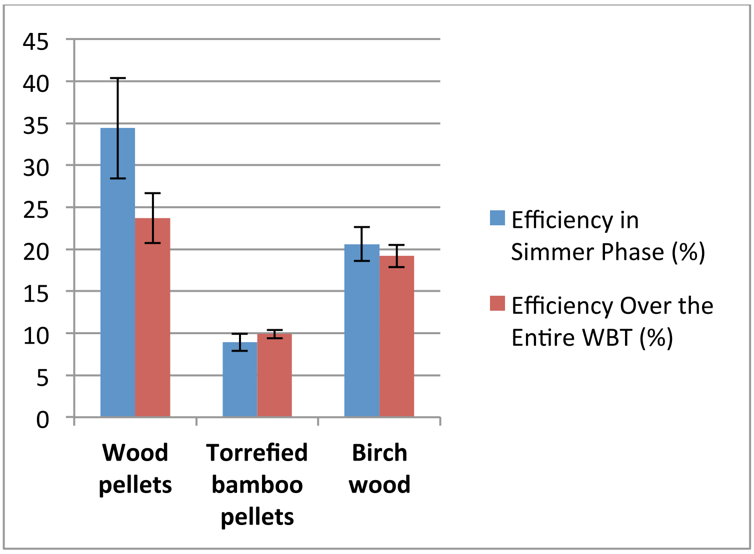

Fig. 16. Thermal efficiency in the simmer phase and averaged over the entire Water Boiling Test. The error bars indicate one standard deviation (n=3).

Table 3. *Thermal efficiency in the simmer phase and averaged over the entire Water Boiling Test (wood pellets), for different stove airflow settings. Only one replication per setting.*

Airflow setting no.	**Bore hole (mm)/ no. turned tiles**	**Efficiency in Simmer Phase (%)**	**Efficiency Over the Entire WBT (%)**
0	4.2/0	34,4	**23,7**
1	4.2/3	**35**	**23.7**
2	4.2/5	22	17.7
3	4.2/7	22	19.7
4	5.0/3	**21**	**16.7**
5	5.0/5	34	21.3
6	5.0/7	21	18.7

Specific Fuel Consumption

Specific fuel consumption is the fuel required to bring the water to the pre-determined boiling point (see section 2.2.1). The results show the temperature-corrected specific fuel consumption. This adjusts for differences in initial water temperature. Most of the fuel is consumed during the 45 minutes long simmer phase. Between the three fuels, the experiment indicated that fuel consumption was highest when using birch wood (Fig. 17). The consumption of birch wood was more than 1 kg/l water. When wood pellets were used to boil the water, a little more than 620 g/l was consumed. The lowest fuel consumption was measured for bamboo pellets, which were consumed almost seven times less than birch wood, only 158 g/l. The specific fuel consumption presented so much variation that the t-test showed that none of the stoves were significantly different from one another (0.05 level) for the simmer phase or over the entire WBT, except for the difference between birch wood and bamboo pellets during the simmering phase.

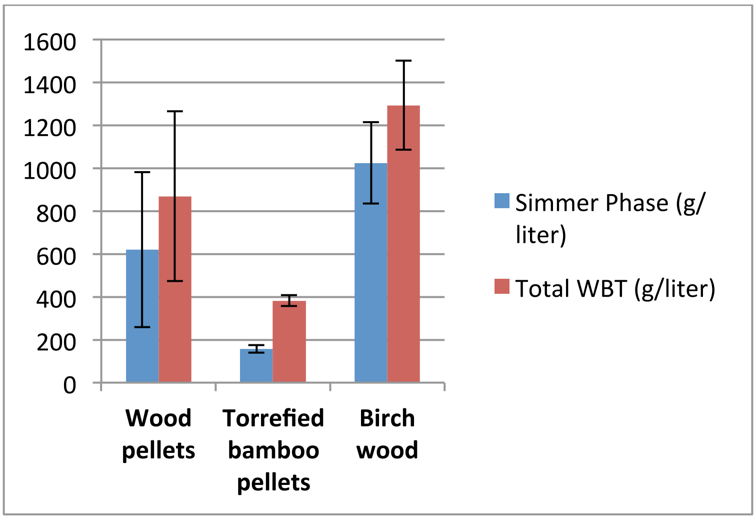

Fig. 17. Specific fuel consumption. The error bars indicate one standard deviation (n=3).

Table 4 shows the specific fuel consumption for different settings. The setting with the lowest specific fuel consumption in both the simmer phase as well as over the entire WBT is setting no. 5. With a fuel consumption of 219 g/l in the simmer phase there is a great difference from the setting no.2 which resulted in a fuel consumption of 654 g/l. Notice that the setting no. 1 which performed well in Time to boil and Thermal efficiency, had the second lowest fuel consumption in this test with a fuel consumption of 314 g/l.

Table 4. *Specific fuel consumption for different stove airflow settings (wood pellets). Only one replication per setting.*

Airflow setting no.	Bore hole (mm)/ no. turned tiles	Simmer phase (g/liter)	Total WBT (g/liter)
0	4.2/0	620	870
1	4.2/3	314	601
2	4.2/5	654	919
3	4.2/7	319	610
4	5.0/3	518	883
5	5.0/5	219	487
6	5.0/7	359	696

Temperature- corrected specific energy consumption

Temp-corrected specific energy consumption (see section 2.2.1) is a good way to compare different fuels with each other. Figure 18 shows the energy consumption for the different fuels tested. The results show that torrefied bamboo pellets has the lowest energy consumption and birch wood has the highest during simmer phase. This is the same trend that is shown for specific fuel consumption. However, the t-test showed that only the difference between bamboo pellets and birch wood was significantly different at 0.05 level.

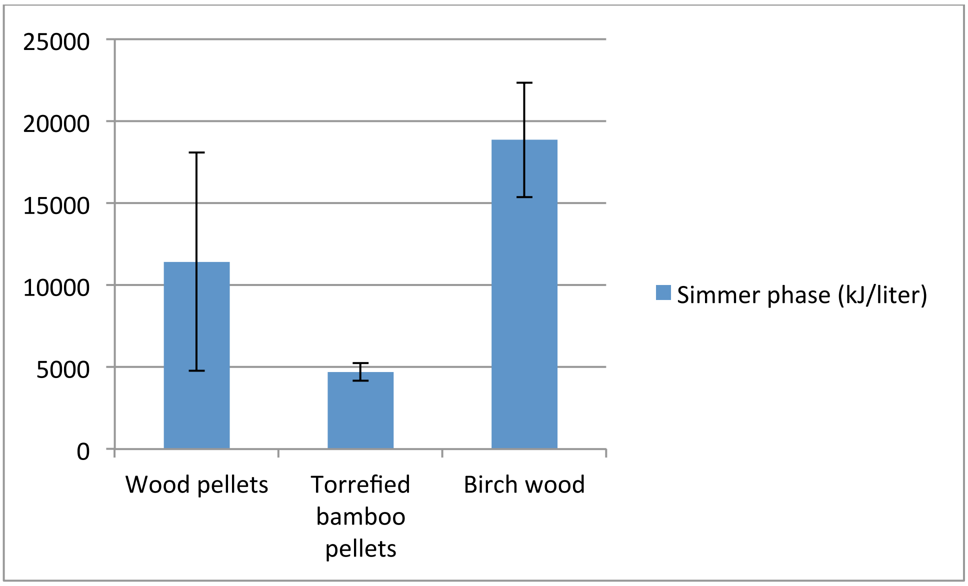

Fig. 18. Temp- corrected specific energy consumption during simmer phase. The error bars indicate one standard deviation (n=3).

Temperature curves

Figure 19 shows the change in water temperature with time for each fuel during the hot start phase of the WBT. It is clear that birch wood and wood pellets perform almost identically over time and have a constant temperature increase, while the torrefied bamboo pellets require much more time to reach boiling point and have a slower start.

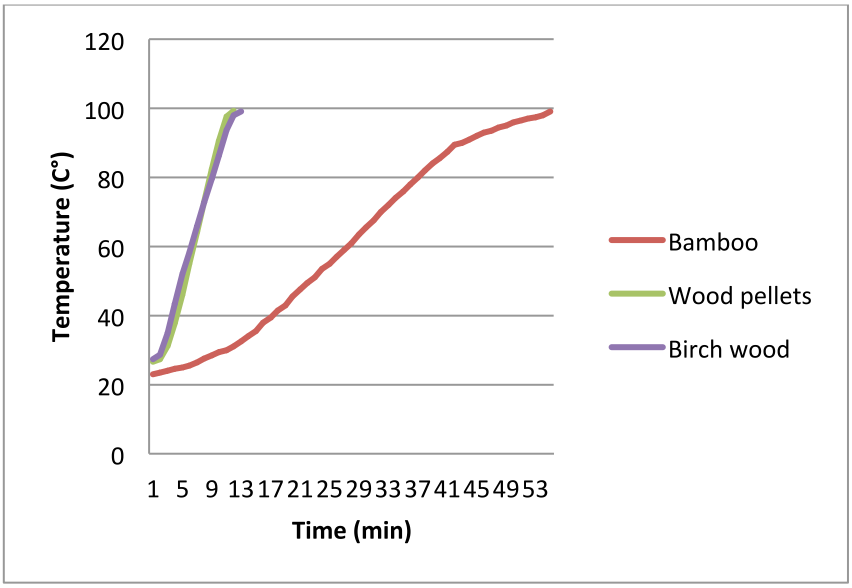

Fig. 19. Temperature curves during hot start.

Figure 20 shows the temperature curves for the different settings of the stove when burning wood pellets. The setting no. 1 has the largest incline and boils faster than the other settings.

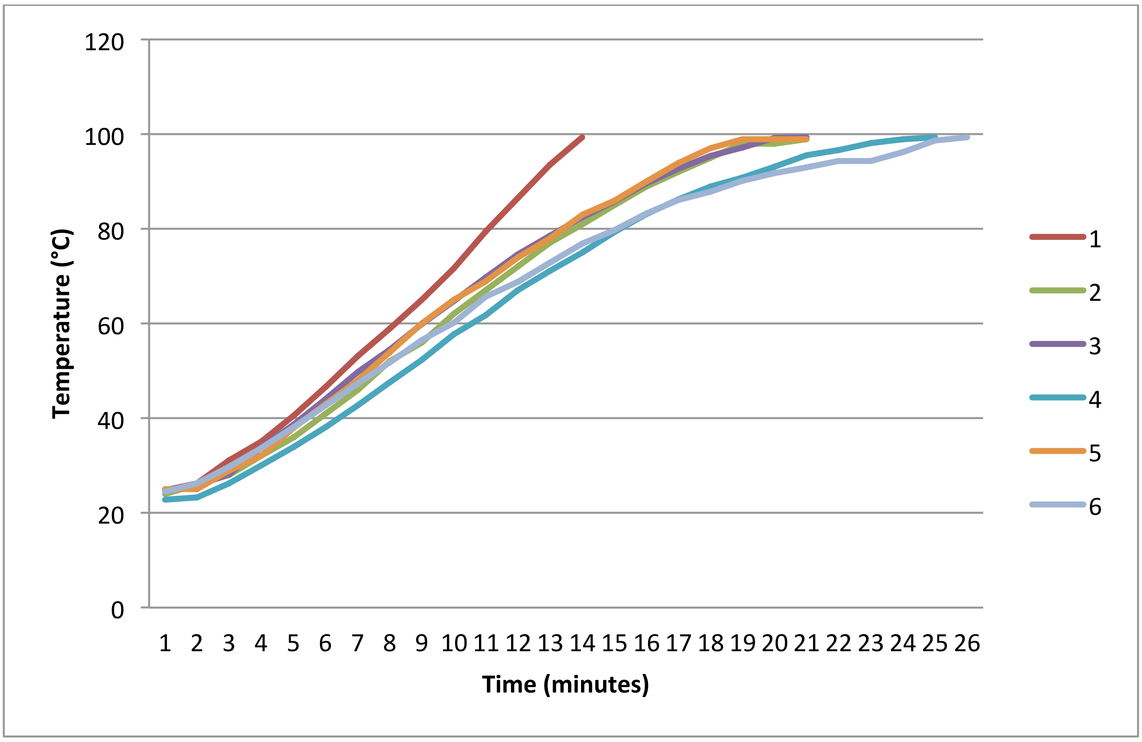

Fig. 20. Temperature curves during hot start when optimized for wood pellets.

3.1.2 Controlled Cooking Test

This section summarizes the stove performance results from the controlled cooking tests (Tables 5 and 6). The CCT yields two main quantitative outputs: the amount of fuel and the amount of time required to cook a standardized meal. The amount of fuel used is reported as specific consumption. Specific consumption is equal to the equivalent dry wood used divided by the final amount of food cooked (Pennise et al., 2010). Specific fuel consumption is g wood per kg food. Each test used one package of xima á 1 kg, although different amounts of water were used. Standard deviation is a statistical measure of the variability or spread of a set of measurements around the mean value. The more widely the values are spread, the larger the standard deviation. The t-test showed that the two fuels were significantly different from each other with regard to both fuel consumption and cooking time at 0.05 level. See appendix 8 for detailed t-test results. The following are the results from cooking one meal.

Table 5. *Controlled Cooking Test results bamboo pellets*

	units	Test 1	Test 2	Test 3	Mean	St. dev.
Total weight of food cooked	g	4 000	4250	4 680	4 310	344
Weight of char remaining	g	40	30	70	47	21
Equivalent dry wood consumed	g	270	275	265	270	5
Specific fuel consumption	g/kg	68	65	57	63	6
Total cooking time	min	36	43	45	41	5

Table 6. *Controlled Cooking Test results wood pellets*

	units	Test 1	Test 2	Test 3	Mean	St. dev.
Total weight of food cooked	g	4 230	4 150	3 950	4 110	144
Weight of char remaining	g	30	25	40	32	8
Equivalent dry wood consumed	g	405	423	370	399	27
Specific fuel consumption	g/kg	96	102	94	97	4
Total cooking time	min	27	32	22	27	5

Figure 21 shows the average specific consumption and cooking time of wood pellets compared to torrefied bamboo pellets. Wood pellets had a higher fuel use but a shorter cooking time.

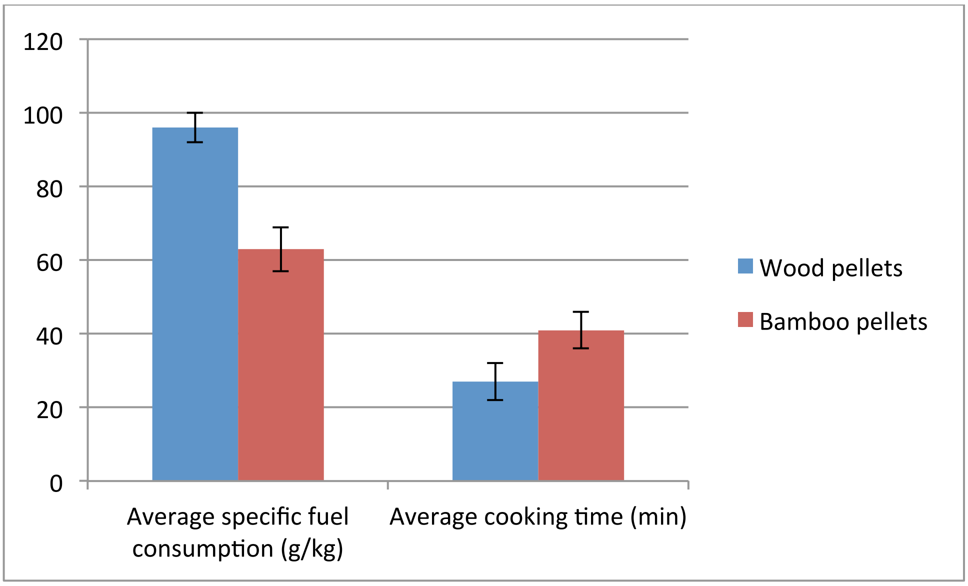

Fig. 21. Average specific consumption and cooking time for wood pellets and bamboo pellets. The error bars indicate one standard deviation (n=3). [6]

Fig. 22. Unoptimized stove results in black pots after use with wood pellets.

[6] Only three tests were performed for each fuel and results should be regarded as indicators. The cook however had tried the stove for almost three weeks before CCT was performed, and thus had some familiarity with the stove. It is also important to remember that fuel efficiency is not the sole determinant of user preferences. Level of smoke, how easy it is to use, price and cooking speed are other factors that are important in a Mozambican woman's choice of stove and fuel (Fig. 22).

3.2 Interviews

3.2.1 Case study of existing cook stove initiative, *CleanStar Mozambique*

It started with the vision of two people who had been working with financing many years prior, wanting a project that is profitable at the same time that it benefits the environment and communities in developing countries. The way was through developing agriculture as a means to further economic development. What could make agricultural commodities more profitable? That's where the idea of biofuels for cooking came to be. An integrated system would have to be developed. In the value chain each of the components needed to be well managed in order for the final product to be available, which meant that the model they developed with the agricultural component, the processing component, and the retail component was to be managed by one entity. The company developed a base in Sofala, central Mozambique, where they began planning how to expand the idea so it would be beneficial for the communities without being so drastic in terms of changing their habits. They also studied what the problems were in the region, which were deforestation, lack of markets for exporting or retailing food, soil erosion, loss of soil nutrients etc. An agroforestry model and processing facility was then established, with the creation of a local market where the farmers could actually sell the food crops (Atanassov, 2013).

Currently *CleanStar Mozambique* employs about 300 people in Sofala and Maputo (Fig. 23). They use the staple food crop cassava to produce ethanol. At first it wasn't clear what the produced fuel was going to be used for, so they began looking at technologies. Finally they decided on using it as a cooking fuel for households, using *Dometics* ethanol stoves (produced in Sweden) that were initially produced for recreational boats. They are being promoted as safe and efficient, with a technology that holds the liquid inside. Other ethanol stoves have an open ethanol container that can spill when it falls over and burn (Atanassov, 2013).

Fig. 23. One of the shops in Maputo where *CleanStar Mozambique* sell their product *Ndzilo*.

The challenges identified so far have been about shifting habits from charcoal to alternative fuels. Finding a way to price the ethanol to be competitive with charcoal and the stove to be affordable for the lower-income groups is also one of the main concerns. It is important to identify the market and how it can be attracted. For *CleanStar* it is the urban population that is the target group. That is the tricky part, says Atanassov, because the target is to shift people from cooking with charcoal to ethanol. They are not targeting LPG users or electricity users since these are already "clean" alternatives, but rather those who can afford using charcoal, with an income between 15 dollars to 300 dollars per month. The product therefore needs to be priced to fit that segment (Atanassov, 2013).

So far the stove has been financed by investors and CDM[7] funds. After subsidies the stove costs around 1100 meticais (USD 37). On the question what is required for it to be economically self-sustaining, Atanassov answered economies of scale. You need to produce more, you need to sell more. The logistics need to be stream-lined and the best routes and models found that allow for larger quantities to be moved at once. That requires space such as warehouses etc. (Atanassov, 2013).

A lot of money goes towards marketing and changing the perception of cooking with biomass fuels as a more efficient technology. They use door-to-door retailers who work within a 2-5 km radius of the shops where they sell the stoves and TV ads that have led to double sales each month. They also have retailers selling in smaller shops. The promoters are however vital. They reinforce the message, provide technical assistance and gain customer feed-back. At the time of the interview about 8 000 stoves had been sold. So far the sales are only in Maputo since the high charcoal prices make it economically viable, but the idea is to have Beira as another city centre (Atanassov, 2013).

3.2.2 Secama

Secama is a wood processing company in Maputo that produces windows, doors and furniture. They also process wood that they export to industries in neighboring countries such as Swaziland. They mainly use the hardwoods (noble woods) shamfuta, umbila and jambiri and the raw material is mainly brought in from northern Mozambique from the provinces of Sofala and Zambezia (Secama, 2013).

The residue from the wood processing is divided in two categories. The finer waste particles from the refinery are usually used for cooking in the nearby households and also as combustion fuel in factories making building bricks that need burning (Fig. 24). These residuals are being given away for free to neighbors, orphanage institutions and nearby hospitals that come and fetch them to use as cooking fuel. The bigger particles are used as chicken bedding. These are normally sold, but now the company who used to buy them went bankrupt and now they don't have a place to sell them. When asked if sales of residuals is a big income for the company the answer was no, and that around 80 % of the residuals are given away for free. The companies who used to buy the rest-products only meant a marginal income. The big win is for the communities that come and collect residues for free (Secama, 2013).

The company has a wood oven for drying residuals that they don't use because the wood is normally naturally dry. However they did not pay attention to the moisture content in the wood or possible contamination of the wood (Secama, 2013).

The biggest challenge to their industry is that during the rainfall season (summertime) they normally don't have enough timber to satisfy the demand of the customers. When asked if they have thought about producing wood pellets the manager answers that they haven't given it much thought but if it could generate an income they would be interested in knowing more (Secama, 2013).

[7] Clean Development Mechanism is one of the mechanisms in the Kyoto Protocol that generates Certified Emission Reduction units for projects in developing countries that reduce emissions. These units may be trades and sold by industrialized countries to help meet their emissions reduction targets.

Fig. 24. Sawdust storage at Secama.

4 Discussion

Water Boiling Test

The results show that the WGS air settings can be improved to better suit combustion of wood pellets with regard to lower fuel consumption and improved ease of use. A stove adjusted in this way also means increasing the boiling time because of the lowered intensity, but considering that the flames are lowered to a much safer level this is on the whole not a big loss. The fact that the wood pellets boiled the water in less than 10 minutes with the standardized airflow setting is perhaps positive from a time perspective, but the fire was too intense and flames were too high for it to be a viable alternative.

The tests performed in this study indicate that the time required to boil water for both hot and cold start was shortest for wood pellets. However birch wood performed almost identically. Note that the fuels did not perform significantly different at the 0.05 level. Torrefied bamboo pellets with a large diameter required almost 40 minutes more to boil and that was even when a lid was used on the pot. This might make a big difference for the stove user as they usually do not want to lengthen their cooking time, and is a fact to consider when choosing household fuel.

The air adjustment that brought the water to a boil fastest from the combinations tried, was when three of the lower tiles were rotated for primary air, and the bore hole size on the upper tiles were 4.2 mm (meaning the original factory setting on the manufactured stove) for secondary air. Not adjusting the stove at all resulted in the absolutely shortest boiling time, but this setting is not suitable for wood pellet use in cooking as the flames are too high and intense, causing a lot of soot and making it difficult to cook safely. In the households where the unadjusted stoves were tested with wood pellets, the women also claimed that the high intensity occasionally caused rice to burn and some xima to boil over.

For the average performance over the entire WBT as well as only during simmer phase, thermal efficiency was highest for wood pellets and lowest for torrefied bamboo pellets. During simmer phase all fuels were significantly different from each other at the 0.05 level, but over the entire WBT only bamboo pellets and birch wood were. Our best air setting combination was again 4.2 mm bore hole size for secondary air and decreasing primary air flow by rotating three lower tiles.

In our tests, the specific fuel consumption was highest for birch wood and lowest for bamboo pellets, with wood pellets performing somewhere in between requiring about 600 g/liter in the simmer phase. Because of a lot of variation in the results of fuel consumption however, almost none of the fuels were significantly different from one another at the 0.05 level. Adjusting the stove reduced the fuel consumption for wood pellets. The best adjustment setting for wood pellets from the combinations we tried was rotating five of the lower tiles and drilling up one of the three holes on each upper tile from 4.2 mm to 5.0 mm. However, the previous setting that performed well with regard to boiling time and thermal efficiency (three tiles rotated) performed second best of the combinations, meaning that this setting can still be recommended compared to original factory settings.

From the knowledge gained in this study, the recommended pellet fuel adjustment for the stove is decreasing the primary air flow, by rotating three of the tiles in the bottom of the stove. The tests performed in this study also indicates that the secondary air flow should be kept the same, with the bore hole size 4.2 mm. A larger sample size would however be useful for a more thorough analysis and depending on what the stove user values, different adjustments might be preferred. Even though the results of the WBT did not differ dramatically from before and after the stove adjustment with regard to boiling time and thermal efficiency, the adjustment made a bigger impact on fuel consumption and a considerable impact on ease of use (lower flames, less soot, less intensity and heat). Using the standardized WBT method to assess efficiency and consumption is an interesting way to compare results with tests around the world. However, there are still factors and variations among testers that complicate comparison, such as having the lid on or off, in our case also the fan adjustment, or the level of accuracy. The purpose of the WBT is to compare stoves with each other, using the same fuel (see comparison with other WBT's in Appendix 7.7). That explains why it can be difficult to compare different fuels with each other as has been done in this study. A more reliable result would also need a higher number of WBT tests per fuel and setting, than the recommended three that has been used.

Controlled Cooking Test

For wood pellets the average weight of food cooked each session was 4.1 kg and the specific fuel consumption was on average 97 g/kg food cooked. Even if the families cooked as much as four times each day that would not sum up to more than 1.6 kg pellet fuel used per day. For bamboo pellets this consumption would be even less. These results can be roughly compared to the average daily charcoal consumption in households in Maputo/Matola, which is 2.640 kg (Atanassov et al., 2012). Firewood users use on average 4.456 kg daily (Atanassov et al., 2012). Decreasing the fuel consumption is preferable in order for most households to save money on fuel. Also, from a resource use perspective, lowering fuel consumption is a step towards slowing down the deforestation rate in the country. To fully understand the consumption in a household in Maputo/Matola region it could be good to also conduct a Kitchen Performance Test that measures real and observed consumption in a household over some days. The results of the CCT may have been affected by the quality of the instruments in the field. At times we had to make use of whatever was available and it was not always so that the same pot could be used for all tests. A lot also depended on the cooks and their ability to keep a constant cooking procedure through all six cooking sessions.

Sources of error

Due to lack of time some of the CCT's were performed using a hot stove instead of the recommended cold stove. During some of the tests the xima boiled over due to intense boiling. In these cases we had to estimate the amount of food that left the pot, and reduce this from the weight of the total food cooked.

During the WBT bamboo pellets had to be tested using a lid for the boiling temperature to be reached. Without the lid the temperature reached up to a maximum of 95 degrees before turning back down. This complicates the comparison with the other fuels since no lid was used during the other tests.

During some WBTs water was sometimes boiling rather than simmering, evaporating more water on some tests than in others. This may have caused variations in the results. It was difficult to avoid however since it is not easy to regulate the stove equally for all fuels. Having the fan set on medium power might have benefitted some fuels more than others. The different dimensions and moisture contents of the fuels might also have affected the test. This is normally handled with the help of standard deviation that, despite very few repetitions, are included in the bar charts for the results of the WBT. For specific fuel consumption and temperature corrected energy consumption, the results for wood pellets vary more than is appropriate to be able to draw any real conclusions from it.

The potential for wood pellets in Mozambique

The interview with the representative from *CleanStar Mozambique* revealed some of the challenges for alternative cook stove appliances in the market. The interview provided a better understanding of the market and its dynamics. The interview with the wood processing company in Maputo also provided a little insight to possible current use of the sawmill residues.

Reasons why electricity and liquefied petroleum gas are much sought after are partly because they are convenient and smoke-free. Depending on the way you use wood pellets in the stove it can be a very convenient fuel. Correctly used, cooking with wood pellets in WGS is less smoky than traditional cooking appliances. The wood pellets used in this project burnt satisfactorily in the combustion appliance after adjustment, and should do so regardless of who the consumer is. However, the stove can be smoky during start-up depending on e.g. what material is used to ignite the fuel, and it is important to note that it should rather burn from the top down. A quick start of fire in most cases means less smoke. Even though the technical prerequisites may seem favorable, it is important to evaluate the subject from other perspectives than a technical one in order to make a prediction of the sustainable potential for wood pellets for household cooking in Mozambique.

The interview with *CleanStar Mozambique* indicated some of the challenges for introducing alternative cook stove appliances in the Mozambique household market: shifting habits from charcoal to alternative fuels, finding a way to price the fuel to be competitive with charcoal and making the stove affordable for the lower-income groups. It is important to identify the market and how it can be attracted. For the stove to be economically self-sustaining and not rely on international or national subsidies, the production and sales will benefit from being scaled up to take advantage of economies of scale, and also putting more pressure on stove and fuel distribution and infrastructure.

An important social challenge in introducing a new cooking appliance and a new fuel is affecting or even changing people's cooking habits. For example *CleanStar Mozambique* has a product that requires flipping the stove upside down after one hour of cooking in order to refill the ethanol. This could be problematic when e.g. cooking long stews which might be more common in some areas. Marketing is probably crucial for introducing new cooking technologies. Studies on distribution of consumer goods related to the cultural context is therefore of interest for a future WGS stove distributor. The stove's see to the needs of women to reduce fuel collection time and improve the kitchen environment by smoke removal, but the focus of the marketing has to be on the issue that matters to them most. A portion of market research will therefore be an advantage before marketing a new stove product.

Subsidization and carbon financing like the CDM sponsored *Ndzilo* stove could be of useful financial help in the initial phases of stove marketing, but is not sustainable in the long run. In rural areas where fuel for subsistence cooking can be collected and therefore until now in Mozambique free, measures such as user contracts or fuel sponsoring might be needed to encourage pellet use to the extent that there is an effect on the reduction of charcoal and firewood use. Or as *Emerging Cooking Solutions* are doing in Zambia: deductions on paychecks. There is probably less need for these measures in the cities or suburbs where charcoal prices have raised so much that pellet fuel can be economically competitive even in the early stages of production. A way must be found for cook stove initiatives and businesses to be economically self-sufficient. Further studies on these matters will therefore be interesting to take part of. Some analysis could be related to market restraints such as possible future subsidies on fossil fuels (Mozambique has recently discovered a lot of fossil gas and coal). Introducing a new stove can be hard enough. There are cultural aspects to be considered. With investments for initial costs and further support from government policies for modern biomass as a future renewable alternative, however, pellets could be a viable alternative.

Some of the possible challenges on the wood pellet production side were also indicated through the interview with the wood processing company *Secama* in Maputo (a potential raw material supplier and/or wood pellet producer). They do not have enough timber to satisfy the demand of the customers during the rainfall season. This could mean not being able to provide enough raw material for pellet production in the future. The interview also showed that there were alternative uses for the wood residue (chicken bedding, building material etc) but that about 80 % of it is given away for free. The management was however interested in alternative sources of income. The income from the sale of residue was very small and at the time of the interview, the buyer had even pulled out of the agreement. During the same period, a few of the sawmills and wood processing companies that were supposed to be interviewed had closed down. This could be due to a difficult economic climate for these industries where any extra income is welcome.

Having a pellet plant on the grounds could help solve uncertainties regarding the disposal of the residue and generate income, the disadvantage being that the people who benefitted from the residue given away for free will no longer be able to do so. There are also possible difficulties to consider: high initial capital costs, importing expensive goods without availability of spare parts, small scale production making it difficult to establish stability in the market, inadequate supply of residues and too variable material are some possible challenges. But promoting wood pellets as an alternative would be in line with Mozambique's Biofuels Policy and Strategy introduced in 2009, and their principle of including rural communities in the production and use of biofuels. Pellet production plants could potentially create job opportunities and an extra income for the industries. For the distribution of wood pellets, existing infrastructure and channels already used to distribute firewood and charcoal could be used.

Ideas concerning the *Philips* WGS:

- Developing the stove to a multi pot system by e.g. expanding the size of the chamber allowing several pots to be heated simultaneously. Only being able to use one pot was one of the complaints from the women in Matola who were used to the charcoal stoves with place for two pots.
- At times the handles would be too hot for it to be comfortable to touch. Insulating these would improve handling.
- Having an additional handle under the bottom of the stove could make it easier to turn when emptying the ashes.
- For adjustment of stove to combust 8 mm softwood pellets; decrease the primary air flow by rotating a suitable number of the lower tiles (when more than three tiles are turned there is too little primary air, and the gases are not forced up the combustion chamber to burn). The secondary air might be kept same as for firewood (factory setting).
- Include a more detailed manual with every purchased stove on how to adjust the fan for various fuels and effects.

Ideas for further research:

- The fan was kept on medium speed for all WBT's. This setting might have been optimal for some fuels but not others. It is difficult to regulate the stove equally for all fuels. A follow-up project could investigate how stoves should be air adjusted when testing various fuels in a WBT.
- During the WBT's 8 mm wood pellets were used. The size of the fuel can affect the result; additional tests on wood pellets of various sizes with the aim of finding the optimum stove setting/pellet fuel combination would be of interest.
- The CCT was not conducted with a version of the stove that was adjusted for the use of pellets since it had not been modified yet at the time of the field study. New tests with the adjusted version are important to investigate the performance of the stove and fuel in real-life settings.
- The interview with *Secama* exposed a possible conflict of interest with regard to the use of sawmill residues, considering that they were currently being given away for free or sold. There is a need for further investigation into what alternative uses there might be for the residues, possible conflicting interests and loss of social profit. Are there any raw material limitations?
- The stoves dependency on electricity to charge the electric fan is an obstacle for distribution to areas without access to the electricity grid or solar panels. If the stove in the future will be produced for the lowest income households to use, it would be good to investigate the possibility to run the stoves with solar chargers in Mozambican households and to further develop the thermoelectric element.
- A more thorough analysis of how wood pellets could compete economically with existing fuels and how likely it is that consumers will alter their current cooking behavior to suit pellets is necessary. Identifying the market is key.

5 Conclusions

The benefits with wood pellet cooking in WGS stoves are safer and more efficient cooking than with traditional methods. An example of a WGS stove that can be adjusted to combust wood pellets is the *Philips* WGS made by ACE. The recommended adjustment for the stove from factory settings based on the results from this study is decreasing the primary air flow, by rotating a number of the tiles in the bottom of the stove. The secondary air flow could, for the type of pellets used in this study, be kept the same with a bore hole size of 4.2 mm.

The stove used in this experiment can be used with different types of wood fuel. Tests performed in this study indicate that the time required to boil water was shorter with wood pellets compared with torrefied bamboo pellets. Also when tested in the field, the use of wood pellets resulted in a significantly lower cooking time compared to torrefied bamboo pellets in the WGS. Birch wood took almost the same time as wood pellets to boil water. This test was however performed before the stove was adjusted for pellet use which means that even if the wood pellets brought water to a boil fast, the stove was not safe to use because of the high and intensive flames. After the adjustment the ease of use was improved but the time to boil slightly increased.

The experiments performed also indicated that wood pellets had a higher thermal efficiency compared to torrefied bamboo pellets and birch wood, but no adjustment of the stove was found that could increase the efficiency significantly.

Operating the stove with bamboo pellets seemed to consume the least amount of fuel (almost seven times less than with birch wood and four times less than with wood pellets). Also when tested in the field, bamboo pellets resulted in lower fuel consumption than wood pellets. However, the wood pellets fuel consumption decreased when the stove was adjusted.

Depending on the way you use wood pellets in the adjusted WGS stove it can be a very convenient fuel. It can decrease the fuel consumption and shift fuel raw material source from juvenile wood to industrial residues, which is beneficial both for single household economy and reducing deforestation rate. With regard to the potential challenges indicated from this study, and with ideas for further research it can be concluded that there is potential for wood pellets in wood gasification stoves as an alternative to traditional cooking appliances to reduce firewood and charcoal consumption in peri-urban households in Mozambique.

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7 Appendices

Appendix 1 Interview questions

Cleanstar Mozambique

Company/ production

- How did it all begin?
- What year did the initiative start?
- At the moment you are only using cassava to produce ethanol, did you try other raw materials from the beginning or did the choice fall on cassava from the beginning, and if so, why?
- Are you going to include other fuels in the future?
- Only active in Maputo?
- Animal feed from rest products?
- Any other by-products?
- Do you incentivize farmer who don't already grow cassava to grow it or do you encourage those who already do to sell to you?
- Do they sell all of their produce?
- Is there any regulation?

Environment

- I've read that CleanStar Ventures use the triple bottom line (people, planet, profit) approach in their work, is this evident also in Ndzilo? Talk about CSR
- How many do you employ, roughly?
- What is your opinion on the sustainability of the company?
- What makes the project sustainable?
- Have any impact assessment studies been made?

Economy

- What happens when there are no more subsidies?
- At the moment the project is partly funded through CDM subsidies and many investors, so what happens when CDM stops and how can Ndzilo penetrate the market?
- By how much is it subsidized?
- Is it only the stove or is fuel also subsidized?
- How long before it can compete economically with charcoal (considering the rising charcoal prices in urban areas)? How is price compared to electricity or gas?

Marketing

- What marketing strategies have been used, such as channels (tv, radio?), promotion angle etc.
- Your product is mainly for the urban population. How could the rural areas be included and what is required for Ndzilo to reach out (considering Mozambique being quite sparsely populated and charcoal being readily available and cheap outside of cities?)
- Any customer feed-back?

Government support and the future

- The governments bioenergy strategy from 2009, has it affected your business in any way?
- How is it to work without government support? and how could that support look like if given?
- An idea of how many you have sold so far?
- What are the biggest challenges?

Appendix 2 Recorded CCT values from Matola

weight of fuel before	fi
weight of fuel after	ff
time start of cooking	ti
time stop cooking	tf
weight of container for char	k
weight of charcoal + container	cc
weight of pot with cooked food	pf

Wood pellets

CCT#	1	2	3
Wind condition	Moderate wind	Light breeze	No wind
Weight of stove	4	3.96	3,98
fi-ff	0.45	0.46	0.43
fi	0.64	0.63	0,59
ff	0.19	0.17	0.16
Time start of fire	02.54	01.17	02.22
ti	03.01	01.30	02.28
tf	03.28	02.02	02.50
k		0.19	3.98
cc	0.3	0.25	0.4
pf	4.23	4.15?	3.95
date	13-may	15-may	15-may

Torrefied bamboo pellets

CCT#	1	2	3
Wind condition	Light breeze	Light breeze	Light breeze
Weight of stove	4	4	4
fi-ff	0.33	0.32	0.37
fi	0.48	0.45	0.49
ff	0.15	0.13	0.12
Time of start of fire	02.02	03.13	01.12
ti	02.16	03.23	01.20
tf	02.52	4.06	02.05
k	0.25	0.25	0.25
cc	0.04	0.03	0.07
pf	4	4.25	4.68
date	06-may	07-may	09-may

Comments bamboo pellets

CCT#1: Lighted with already hot coal from previous cooking session. Had the fan on maximum effect when lighting the fire. Most of the xima was poured in after 16 minutes. Lid off and stir after 20 minutes. After 21 minutes the rest of the xima was added. Stir again after 30 minutes and lower the fan to minimum. Turned the fan off after 32 minutes and stirring for 2 minutes. Lid on. Lid off after 37 minutes and stir again.

CCT#2: It took two tries with matches and paper before it started burning. When the breeze got stronger they moved the stove indoors. It was smoky in the beginning. The fan was on medium effect throughout the cooking session, with a lid on except for when they were stirring. The fan was turned off when they started to stir.

CCT#3: Coconut shells were used to light the fuel. It makes it smokier to light with. The fan was on full effect from the beginning. There was too much water used initially this time. At one point the xima boiled over so she turned the fan off a bit. Difficult to hold the stove in place

Comments wood pellets

CCT#1: Used coconut shell to light it. It was a little more difficult. Gave off a lot of smoke in the beginning (water evaporating?). The pots get black on the bottom but the water boils quickly (about 7 minutes with lid on). 14 minutes after time of start cooking the xima boiled over. She then took of the lid, turned off the fan and poured rest of the xima in whereafter she put the lid back on. The fan was turned on again after a while but at the lowest effect. There was a lot of remaining unburned fuel, but they later told us that they usually continue cooking on that amount. We can estimate that about 20 g of xima disappeared when it boiled over. She said that when they cook rise it gets burnt. The xima did not burn. We suspect they might use more fuel than what is necessary because they get it for free.

CCT#2: fan on low at time of start of fire. No smoke when start cooking. Doesn't have the lid completely on this time. Xima boils over. Turns the fan off when she stirs, which generates smoke from the pellets. They turn off the fan before the pellets has burnt completely.

CCT#3: Lighted the fuel using lighting paper. No smoke in beginning. Intense boiling and xima quickly boiled over. Turns fan off when she pours the rest of the xima in.

Appendix 3 Material

Scale used in field: Rubicson baggage scale. Capacity: 35 kg. Resolution: 10 g. Unit: kg, lb.

Thermometer*: TFA Digital Probe Thermometer. Lab Thermometer IP65. LT-101

Pot: aluminium pot. Diameter: 19.5 cm. Height: 17 cm.

Fuels: torrefied bamboo pellets, wood pellets, birch wood.

*For tests #1-6 the digital lab thermometer was used with an accuracy of 0, 1 °C. The boiling point was rounded to 99, 3 °C. When doing the WBT with bamboo pellets a lid was used in order to reach boiling point. Another thermometer therefore had to be used with an accuracy of 1 °C. The boiling point was in these cases determined at 99 °C. Since this thermometer was deemed more practical we continued using it when testing birch wood even though it did not require any lid, and for test #12 and #13. The thermometer then broke and we had to go back to using the original thermometer for tests #14-#17.

Appendix 4 Summarized versions of WBT and CCT protocols

The following pages (appendix 4.1 and 4.2) were taken from Approvecho's 2013 WBT and CCT protocols, 2013. See References section 6 in main report.

4.1 Summarized Controlled Cooking Test

The controlled cooking test analyzes how the new stove performs compared to common or traditional cooking methods. Stoves are compared as local cooks prepare a traditional food.

By cooking the same food in the same pot, different stoves can show how they perform. Local cooks prepare their favorite food and see whether the new stove is to their liking. For this reason, the CCT should be done when contemplating the introduction of a new stove.

We will use the test to do the following:

- Compare the amount of fuel used by different stoves to cook a favorite food or meal.
- Compare the time needed to cook that food.
- Inquire whether the cooks like how the stove cooks their favorite food.
- Investigate the emissions made during the test of the old and new stove.

Because different pots and fuel are used in different places the results of the CCT are used to compare stoves from one place. Tests from different places can be compared only if the pot, wood and operation of the stove are the same, which is unusual. *The most important metric from the CCT is the "% Improvement" when switching stoves.*

The cooks should be experienced in running each stove. It is recommended that the cook use the stove for at least two weeks before the testing. It is best that the tests be done with each cook in an isolated place in as casual and normal an environment as possible. The tester should not talk to the cook once the test has started and certainly not suggest to the cook how to use the stove, etc. In many situations, women feel more comfortable around other women. If this is the case, it is preferable to have women record the testing.

Each stove/cook combination will be tested three times. It is best for a local cook to test the traditional method three times and the new stove three times. A complete test series (3 improved and 3 traditional) with three separate cooks should be considered the minimum number. Then, based on the difference between the traditional and improved stoves found from the results of the testing series of the first three cooks, the number of additional test series will be decided. More cooks should be used until a statistical t-test shows a 95% confidence. Statistically speaking, less difference between the stoves will require more cooks to prove that difference.

The CCT only requires cooking one type of food. However, stove testers are encouraged to develop a CCT for preparing a combination of foods, if more extensive testing seems important.

Supplies Needed

- A normal mix of fuelwood, enough to test all the stoves, should be found and allowed to air dry. Cooks help the testers to gather the usual dry firewood. Make sure that enough wood is gathered to do all tests. Make sure that all the wood is uniform in size and moisture content. The fuel may be divided into pre-weighed bundles to save time during testing. Testers can take pre-weighed bundles to the testing site, then return with the remaining fuel to the scale. Or each tester can take a scale with them.

- Gather enough food and water for all the tests that will be done. Like the fuel, the food should be completely normal (For instance, assida is suggested for Darfur). Food can be pre-weighed if convenient or a scale can accompany the tester to the testing site.
- Cooking pot: the same type (size, shape, and material) of pot should be used to test each stove.
- Lids should be used if they are commonly used by local cooks.
  Digital scale 10 kg capacity and 1-2 gram accuracy.
- Heat resistant pad to protect scale when weighing hot charcoal.
  Timer.
- Small shovel/spatula to remove charcoal from stove for weighing.
  Metal tray to hold charcoal for weighing.
- Heat resistant gloves.

CCT Procedure

As in any test, the cook controls how much wood is used. The cook should try to perform each test in the same way. If the results are very different the average will not be statistically significant and more tests will be required. We recommend starting with three tests for each stove that is being compared.

1. The first step in the CCT is to have local people choose the food to be cooked. This should be done well ahead of time, to ensure that sufficient food can be obtained for all of the tests. If the stove is designed for cooking all types of food, then a typical amount of food should be decided upon. More than one dish can be prepared, but it is best to keep the testing simple. The box above shows an example of the food used for a CCT in West Africa (from Baldwin, 1987). If the stove is designed for specific foods, for example making tortillas or chapati, then testers decide on the amount of food on which to base the test.

2. After deciding on a cooking task, how the food is prepared should be described and recorded in a way that both stove users and testers can understand and follow. This is important so that the cooking task is performed similarly on each stove. If possible, include a way to measure when the meal is done, like “the skin comes off the beans” or the “the rice is soft”. Recipes and cooking instructions should be recorded on the Data and Calculations form
3. After all the food and fuel have been gathered and the steps of the cooking task are written up and well-understood by all cooks, the actual testing can begin. **The stove tending and cooking should be done by a local person who is familiar with both the meal that is being cooked and the operation of the stove to be tested.**
4. Record local conditions as instructed on the Data and Calculation form.
5. Do all of the washing, peeling, and cutting as described by the cooking directions recorded in step above. Record the mass of each food in the Data and Calculation form.
6. Start with a pre-weighed bundle of fuel that is more than the amount that local people consider necessary to complete the cooking task. Record the weight in the appropriate place on the Data and Calculation form.
7. Starting with a cool stove, the cook lights the fire in the normal way. Start the timer as soon as the fire is lit and record the time on the Data and Calculation form.
8. While the cook prepares the meal, the tester records any observations and comments that the cook makes (for example, difficulties that they encounter, excessive heat, smoke, instability of the stove or pot, etc). The tester should not take part in the cooking but remain at a distance quietly observing. After the cooking and testing is completed the tester asks the cook to tell him or her about the performance of the stove.

9. When the cooking is finished, record the time in the Data and Calculation form.
10. Remove the pot(s) of food from the stove and weigh each pot with its food on the digital scale. Record the weight in grams on the Data and Calculation form.
11. Remove the unburned wood from the fire and extinguish it. Knock the charcoal from the ends of the unburned wood. Weigh the unburned wood from the stove with the remaining wood from the original bundle. Place all of the charcoal in the designated tray and weigh this too. Record both measurements on the Data and Calculation form. * *If it is not common for cooks to re-use the unburned charcoal and it instead goes to waste, you may choose record zero in the Data and Calculation sheet.*
12. The test is complete. Cooks and testers may now enjoy the food that was cooked or proceed by testing the next stove – each stove should be tested at least 3 times. Wait between tests until the stove is cool. Testers can alternate between the traditional and new stove.

Analysis

The Data and Calculation form includes specific consumption (the fuel used to produce a liter of food) and the time to prepare the food. It is necessary to calculate the average of three tests for each stove and compare the results. In addition, stoves should be evaluated on the basis of the observations made during each test."

Reference

Approvecho, 2013. See references in the main report (section 6).

4.2 Summarized Water Boiling Test

This test provides the stove designer with reliable information about the performance of wood burning stove models. The test consists of three phases that determine the stove's ability to:
(1) bring water to a boil from a cold start;
(2) bring water to a boil when the stove is hot; and,
(3) maintain the water at simmering temperatures.
It is used to evaluate a series of stoves as they are being developed. The test cannot be used to compare stoves from different places because the different pots and wood used change the results.

The test is a simplified version of the University of California Berkeley (UCB)/Shell Foundation revision of the 1985 VITA International Standard Water Boiling Test. The wood used for boiling and simmering, and the time to boil are found by simple subtraction. All calculation can be done by hand in the field.

By using a standard pot, taking into account the moisture content of the wood, steam generated and other factors the complete UCB/Shell Foundation Water Boiling Test makes comparison of stoves from different places possible.

Before starting the tests…

1. **Collect at least 30 kg of air-dried fuel for each stove to be tested in order to ensure that there is enough fuel to complete three tests for each stove. Massive multi-pot stoves may require more fuel. Use equally dry wood that is the same size. Do not use green wood.**

2. Put 5 liters of water in the testing pot and bring it to a rolling boil. Make sure that the fire is very powerful, and that the water is furiously boiling! Use an accurate digital thermometer, accurate to 1/10 of a degree, to measure the local boiling temperature. Put the thermometer probe in the center of the testing pot, 5 cm above the pot bottom. **Record** the local boiling point on the data sheet (see page 34).

3. Do the tests in a place that is completely protected from the wind.

4. Record all results on the data sheet.

Equipment used for the In Field Water Boiling Test:

- Scale of at least 6 kg capacity and 1 gram accuracy
- Heat resistant pad to protect scale
- Digital thermometer, accurate to 1/10 of a degree, with thermocouple probes that can be in liquids
- Timer
- Testing pot(s)
- Wood fixture for holding thermometer probe in water
- Small shovel/spatula to remove charcoal from stove
- Tongs for handling charcoal
- Dust pan for transferring charcoal
- Metal tray to hold charcoal for weighing
- Heat resistant gloves
- 3 bundles of air-dried fuel wood. One, used for simmering, weighs around 5 kgs. The other two bundles, used for cold and hot start boiling, weigh about 2 kgs each.

Beginning of Test

a. **Record** the air temperature.

b. **Record** weight of commonly used pot without lid. If more than one pot is used, record the weight of each pot. If the weights differ, be sure not to confuse the pots as the test proceeds. **Do not use pot** lids for this, or any other phase of the WBT.

c. **Record** weight of container for charcoal.

d. Prepare 2 bundles of fuel wood that weigh about 2 kgs each for the cold and hot start high power tests. Prepare 1 bundle of fuel wood that weighs about 5 kgs to be used in the simmering test. Use sticks of wood roughly the same size for all tests. **Record** approximate dimensions of the fuel wood. Weigh and **Record** weights in spaces marked # on the attached data sheet. Identify each bundle and keep them separate.

High Power (Cold Start) Phase:

The stove should be at room temperature.

1. Fill each pot with 5 L of clean water (~20°). **Record** the weight of pot(s) plus the water.

2. Using the wooden fixtures, place a thermometer probe in each pot so that water temperature may be measured in the center, 5 cm from the bottom. Make sure a digital thermometer is used. **Record** water temperatures.

3. **Record** the weight of the starting materials. Always use the same amount and material.

4. Start the fire using the wood from the first 2 kg bundle.

5. Once the fire has caught, start the timer and **Record** "0". If using a watch **Record** the starting time. Bring the first pot rapidly to a boil without being excessively wasteful of fuel.

6. When the water in the first pot reaches the local boiling temperature as shown by the digital thermometer, rapidly do the following:

   a. **Record** the time at which the water in the primary pot (Pot # 1) reaches the local boiling point of water. **Record** the water temperature for other pots as well.

   b. Remove all wood from the stove and put out the flames. Knock all loose charcoal from the ends of the wood into the tray for weighing charcoal.

   c. Weigh the unburned wood from the stove together with the remaining wood from the pre-weighed bundle. **Record** the result.

   d. Weigh each pot, with its water. **Record** weight.

   e. Remove all the charcoal from the stove, place it with the charcoal that was knocked off the sticks and weigh it. **Record** the weight of the charcoal and container.

This completes the high power (cold start) phase. Continue without pause to the high power (hot start) portion of the test. Do not allow the stove to cool.

High Power (Hot Start) Phase

1. Refill the pot(s) with 5 L of fresh cold water. Weigh pot(s) (with water) and measure the initial water temperatures; **Record** both measurements.

2. Start the fire using kindling and wood from the second 2 kg bundle. **Record** weight of any additional starting materials.

3. **Record** the time when the fire starts and bring the first pot rapidly to a boil without being excessively wasteful of fuel.

4. **Record** the time at which the first pot reaches the local boiling point. **Record** the temperature of all pots.

5 After reaching the boiling temperature, rapidly do the following:
   a. Remove all wood from the stove and knock off any loose charcoal into the charcoal container. Weigh the wood removed from the stove, together with the unused wood from the second bundle. **Record** the result.
   b. Weigh each pot, with its water and **Record** these weights.
6. Leave the charcoal in the stove as you continue quickly into the simmering test

Without pause, proceed directly with the simmering test.

Low Power (Simmering) Test

This phase is designed to test the ability of the stove to simmer water using as little wood as possible. The boiling water is quickly replaced on the stove and the fire is rekindled using the charcoal and fresh wood. Then the water is simmered for 45 minutes at about 3 degrees below boiling.

Only the primary pot will be tested for simmering performance.

Start of Low Power test:

1. **Record** the weight of the new bundle of fuel.

2. While the water is still near boiling, weigh the pot (with water). **Record** weight. **Record** temperature
3. Rekindle the fire using kindling and wood from the weighed bundle. **Record** the weight of any additional starting materials. Replace the pot on the stove and **Record** the start time when the fire starts.
4. **Record** the time. For the next 45 minutes, maintain the fire at a level that keeps the water temperature as close as possible to 3 degrees C below the boiling point.
5. After 45 minutes rapidly do the following:
   a. **Record** the finish time of the test (this should be 45 minutes).
   b. **Record** the temperature of the water at the end of test
   c. Remove all wood from the stove and knock any loose charcoal into the charcoal weighing pan. Weigh the remaining wood including the unused wood from the preweighed bundle. **Record** the weight of wood.
   d. Weigh the pot with the remaining water. **Record** the weight.
   e. Extract all remaining charcoal from the stove and weigh it (including charcoal which was knocked off the sticks). **Record** the weight of pan plus charcoal.

This completes the full water boiling test. The full test should be done at least three times for each stove for accurate results.

Reference: Taken from Approvecho's 2013 protocols. See references section 6 in main report.

Appendix 5 Testing scheme

Fuel type	Bore hole size	No. turned tiles	No. of trials
Wood pellets	4,2	0	3
Birch wood	4,2	0	3
Bamboo pellets	4,2	0	2
Wood pellets	4,2	3	1
Wood pellets	4,2	5	1
Wood pellets	4,2	7	1
Wood pellets	5	3	1
Wood pellets	5	5	1
Wood pellets	5	7	1
Total no. of trials			**15**

Appendix 6 Examples of initiatives for alternative household cook stoves

BioLite: has produced an efficient wood gasification stove for camping purposes, and is now working on building a market for a bigger version of the stove, *HomeStove*, that is intended for household use in developing countries. This has the advantage of not needing external electricity, but rather produces it. However, it was not yet on the market during the time of this study.[8]

GiveCooking/ Emerging Cooking Solutions*:* Swedish/Zambian company that sells *Philips* WGS in Lusaka and the Copperbelt region in Zambia. Stoves have been optimized to burn wood pellets which they produce locally.[9]

Oorja*:* is another micro-gasification stove, produced in India, which can burn pellets. These are both designed for big kitchens and single households.[10]

Inyenyeri: American/Rwandan company that sells *Philips* WGS and *Oorja* stoves in Rwanda. They are also involved with bringing forward agricultural residues as raw materials for pellets.[11]

Envirofit*:* produces a range of improved wood and charcoal stoves that seem to be well established.[12]

Philips/ ACE**:** *African Clean Energy*, with the support of *Philips*, manufactures and distributes the *Philips* WGS to countries in Sub-Saharan Africa.[13]

Ndzilo/ CleanStar Mozambique*: CleanStar Mozambique* is a company that uses cassava to produce ethanol for cooking. They are involved with the cultivation, production and distribution chain with special attention to agroforestry. They also produce subsidized stoves for the use of ethanol as fuel. See the interview with *CleanStar Mozambique* under results section 4.1.1.[14]

[8] www.biolitestove.com
[9] www.emerging.com
[10] www.firstenergy.in
[11] www.inyenyeri.org
[12] www.envirofit.org
[13] www.ace.co.ls
[14] www.ndzilo.com

Appendix 7 Comparison with other Water Boiling Tests

Figs. 25 and 26 show the results from a series of tests performed by Approvecho Research Center (ARC) on stoves from around the world (Partnership for Clean Indoor Air, 2011). [15] They have tested some traditional stoves such as the 3 stone fire and chimney stoves, as well as modern stoves. The two charcoal stoves originate in Mali and Ghana (Partnership for Clean Indoor Air, 2011). Most interesting for comparison are the results from the electric fan stoves and more specifically the Wood Gas Fan stove.

[15] **3 stone fire:** one of the most common stoves around the world. Three stones or bricks hold the pot over the flames of an open fire where wood is the fuel used.
Ghana wood: stove has a metal body with thick ceramic liner inside that surrounds the fire. Wood is added through a door that can be closed.
20 L Can Rocket: Stove made from 20 L cans used to distribute food. A combustion chamber is inserted in the can with folded metal holding up the pot. Since high temperatures deteriorate the metal it has to be replaced often.
Mud/Sawdust: Stove made from sand, clay and sawdust. Small channels force gases to the bottom and sides of pot, increasing heat transfer efficiency and decreasing wood use.
VITA: made from sheet metal creating an appropriate gap between stove body and pot and protecting the fire and pot from wind. Stove also allows air to pass through fire.
Justa: A rocket-type combustion chamber made from ceramic, inside a stove body made from bricks. Air flows from wood fuel entrance, through combustion chamber and up the chimney, forcing hot gases up.
Uganda 2-pot: rocket-type combustion chamber made from fire brick. Hot gases pass through small channels around each pot before exiting the chimney. Sunken pots improve fuel use.
Patsari Prototype: Two hollow cylinders of brick under the two pots, where the fire hits the pots bottom. Stove is made of sand and clay and has a chimney and second fire inside another chamber for cooking tortillas.
Onil: three-part stove made from molded cement in a factory. Rocket combustion chamber made from ceramic.
Ecostove: cooking surface at waist height of heavy cast iron griddle with ceramic rocket combustion chamber. Body made of sheet metal and iron. Channels provide additional heat transfer.
Wood flame fan: uses small electric fan to mix wood gases, air and flame. Air flows through small holes in bottom of combustion chamber through the burning the small pieces of wood used. Wood is added under the pot.
Wood gas fan: Stove made from sheet metal. Fan powered by external battery blows air through holes at bottom and top of combustion chamber, causing gases to rise and burn.
Mali charcoal: made from sheet metal with a door controlling the amount of air entering under the charcoal. A draft directs the air up through the fire and an air gap between chamber and outside of stove help insulating it.
Gyapa charcoal: body of sheet metal with ceramic liner inside where the charcoal is placed on a ceramic grate which allows air to pass through.

WBT Results

AVERAGES

	3 stone fire	Ghana Wood	20L Can Rocket	Mud / Sawdust	VITA	*Chimney* Justa
1. HIGH POWER TEST (COLD START)	Average	Average	Average	Average	Average	Average
Time to boil Pot # 1	21.03	20.45	17.10	18.46	14.33	28.30
Burning rate	33.10	22.03	19.23	28.35	25.96	34.57
Thermal efficiency	0.16	0.24	0.54	0.25	0.29	0.19
Specific fuel consumption	145.98	93.11	65.22	102.94	76.31	123.75
Temp-corrected specific consumption	139.13	84.94	57.17	91.67	71.16	109.99
Firepower	10,756	7,086	6,248	9,211	8,435	1,1232
2. HIGH POWER TEST (HOT START)	Average	Average	Average	Average	Average	Average
Time to boil Pot # 1	19.67	19.33	18.49	17.42	13.20	28.03
Burning rate	28.78	22.38	20.88	25.51	27.26	32.48
Thermal efficiency	0.21	0.25	0.35	0.31	0.29	0.25
Specific fuel consumption	117.14	89.50	84.31	89.11	73.37	190.05
Temp-corrected specific consumption	110.62	81.82	73.78	78.93	72.11	173.15
Firepower	9,354	7,199	6,784	8,289	8,857	10,554
3. LOW POWER (SIMMER)	Average	Average	Average	Average	Average	Average
Burning rate	8.83	16.86	7.28	7.00	5.95	11.94
Thermal efficiency	0.22	0.12	0.24	0.47	0.34	0.17
Specific fuel consumption	99.59	186.47	81.88	90.03	66.16	136.05
Firepower	3,062	5,793	2,525	2,427	2,063	4,141
Turn down ratio	3.15	1.27	2.71	4.07	4.28	2.55

AVERAGES

	Chimney Stoves				*Electric Fan*	
	Uganda 2-pot	Patsari Proto-type	Onil	Ecostove	Wood Flame Fan	Wood Gas Fan
1. HIGH POWER TEST (COLD START)	Average	Average	Average	Average	Average	Average
Time to boil Pot # 1	15.00	30.93	33.17	52.23	22.33	31.50
Burning rate	25.51	31.15	38.28	29.59	13.96	8.24
Thermal efficiency	0.36	0.20	0.16	0.21	0.40	0.44
Specific fuel consumption	64.62	118.89	149.06	193.44	63.83	53.68
Temp-corrected specific consumption	60.15	110.16	133.10	167.23	52.01	48.74
Firepower	8,288	10,018	12,439	7,733	4,535	2,678
2. HIGH POWER TEST (HOT START)	Average	Average	Average	Average	Average	Average
Time to boil Pot # 1	12.83	29.33	22.53	36.77	23.50	28.90
Burning rate	27.06	31.36	41.09	29.96	12.51	8.50
Thermal efficiency	0.39	0.21	0.19	0.24	0.41	0.46
Specific fuel consumption	71.52	191.81	192.76	235.03	60.68	51.05
Temp-corrected specific consumption	69.46	176.12	174.32	206.79	49.83	46.60
Firepower	8,794	10,087	13,354	7,830	4,065	2,761
3. LOW POWER (SIMMER)	Average	Average	Average	Average	Average	Average
Burning rate	8.79	12.14	16.24	14.08	6.84	4.03
Thermal efficiency	0.31	0.14	0.12	0.19	0.39	0.46
Specific fuel consumption	105.59	133.44	182.16	162.54	81.66	44.85
Firepower	3,050	4,170	5,635	3,988	2,372	1,400
Turn down ratio	2.93	2.46	2.37	2.03	1.72	1.97

Fig. 25. Approvecho's Water Boiling Test results for wood stoves and Wood Gasification Stove. (Partnership for clean indoor air, 2011)

AVERAGES

	Charcoal	
	Mali Charcoal	**Gyapa Charcoal**
1. HIGH POWER TEST (COLD START)	Average	Average
Time to boil Pot # 1	36.70	29.77
Burning rate	13.76	13.58
Thermal efficiency	0.15	0.17
Specific fuel consumption	107.43	83.75
Temp-corrected specific consumption	96.31	76.32
Firepower	7,267	7,169
2. HIGH POWER TEST (HOT START)	Average	Average
Time to boil Pot # 1	42.93	33.40
Burning rate	11.49	11.97
Thermal efficiency	0.16	0.18
Specific fuel consumption	104.58	82.83
Temp-corrected specific consumption	96.17	76.21
Firepower	6,066	6,323
3. LOW POWER (SIMMER)	Average	Average
Burning rate	4.00	8.50
Thermal efficiency	0.28	0.18
Specific fuel consumption	46.04	102.49
Firepower	2,200	4,677
Turn down ratio	2.78	1.53

Fig. 26. Approvecho's Water Boiling Test result for charcoal stoves. (Partnership for clean indoor air, 2011).

The Wood Gas Fan stove used in the test is presented in Fig. 27. It was developed by Dr. Tom Reed from the Biomass Energy Foundation and was at the time of study a prototype. The stove is made from sheet metal with a fan powered by an external battery that blows air through holes at the bottom and top of the stove (similar to the *Philips* WGS). The air causes gases to rise and burn in the fire one. The stove is started by top-lighting a batch of fuel (Partnership for Clean Indoor Air). Compared to the Wood Gas Fan stove, the *Philips* stove brought water to a boil quicker. The different adjustment settings boiled the water in a range from 14 to 26 minutes whereas the Wood Gas Fan stove requires at least 30 minutes. However, the Wood Gas Fan stove in Approvecho's setting reported better values for efficiency and fuel consumption than the *Philips* stove in our experimental setting.

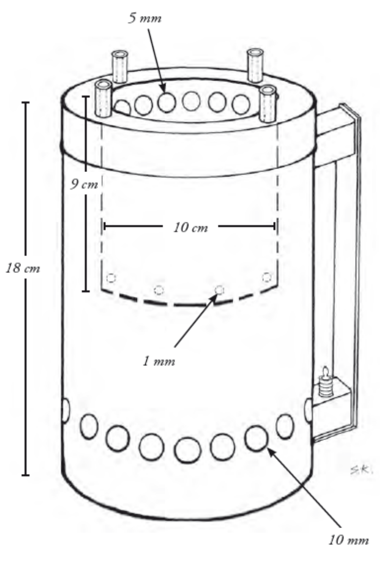

Fig. 27. Electric fan stove. (Partnership for clean indoor air, 2011).

Appendix 8 T-test for Controlled Cooking Test and Water Boiling Test

8.1 T-test for Controlled Cooking Test

	Bamboo	Wood	Bamboo	Wood
	Cooking time		Specific fuel	
	36	27	68	96
	43	32	65	102
	45	22	57	94
S.D.	4.7	5.0	6	4
Mean	41.3	27.0	63.3	97.3
	F-test (probability that variance are not different)	0.94		0.70
	T-test, probability	0.02		0.001

8.2 T-test for Water Boiling Test

Time to Boil

A= Bamboo pellets
B= Wood pellets
C= Birch wood

Time to Boil AB1

	Bamboo cold start	Wood pellets cold start
	53	12
	51	14
		14
T-test prob. 0.0013		

Time to Boil AB2

	Bamboo hot start	Wood pellets hot start
	53	10
	41	10
		9
T-test prob. 0.10		

Time to Boil AC1

	Bamboo cold start	Birch cold start
	53	13
	51	18
		15
T-test prob. 0.0003		

Time to Boil AC2

	Bamboo hot start	Birch hot start
	53	10
	41	11
		10
T-test prob. 0.10		

Time to Boil CB1

	Birch cold start	Wood pellets cold start
	13	**12**
	18	14
	15	14
T-test prob. 0.31		

Time to Boil CB2

	Birch hot start	Wood pellets hot start
	10	10
	11	10
	10	9
T-test prob. 0.23		

Efficiency

Effic. simmer phase AB (%)

	Bamboo	Wood
	8	36
	10	28
		39
T-test prob. 0.01		

Effic. entire WBT AB (%)

	Bamboo	Wood	
	10.4	21.3	col
	10.5	15.5	hot
	8.9	34.4	sim
T-test prob. 0.13			

Effic. simmer phase AC

	Bamboo	Birch
	8	19
	10	23
		20
T-test prob. 0.005		

Effic. entire WBT AC (%)

	Bamboo	Birch	
	10,4	17,9	col
	10,5	19,2	hot
	8,9	20,6	sim
T-test prob. 0.001			

Effic. simmer phase CB

	Birch	Wood
	19	36
	23	28
	20	39
T-test prob. 0.04		

Effic. entire WBT CB (%)

	Birch	Wood	
	17.9	21.3	col
	19.2	15.5	hot
	20.6	34.4	sim
T-test prob. 0.51			

Fuel consumption

Fuel consumption simmer phase AB

		Bamboo	Wood
		140	1005
		176	568
			288
T-test prob.	0.16		

Fuel consumption simmer phase AC

		Bamboo	Birch
		140	925
		176	906
			1243
T-test prob.	0.014		

Fuel consumption simmer phase CB

		Birch	Wood
		925	1005
		906	568
		1243	288
T-test prob.	0,183896		

Fuel consumption total WBT AB

		Bamboo	Wood	
		113.2	103.2	Cold start
		114.3	145.9	Hot start
		157.9	620.4	Simmer phase
T-test prob.	0.43			

Fuel consumption total WBT AC

		Bamboo	Birch	
		113.2	135	Cold start
		114.3	133.7	Hot start
		157.9	1024.6	Simmer phase
T-test prob.	0.42			

Fuel consumption simmer phase CB

		Birch	Wood	
		135	103.2	Cold start
		133.7	145.9	Hot start
		1024.6	620.4	Simmer phase
T-test prob.	0.70			

Energy consumption

Energy consumption simmer phase AB

			Bamboo	Wood
			4172	18511
			5237	10452
				5307
T-test prob.	0.22	same		

Energy consumption simmer phase AC

			Bamboo	Birch
			4172	17025
			5237	16679
				22897
T-test prob.	0.02	different		

Energy consumption simmer phase CB

			Birch	Wood
			17025	18511
			16679	10452
			22897	5307
T-test prob.	0.18			

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