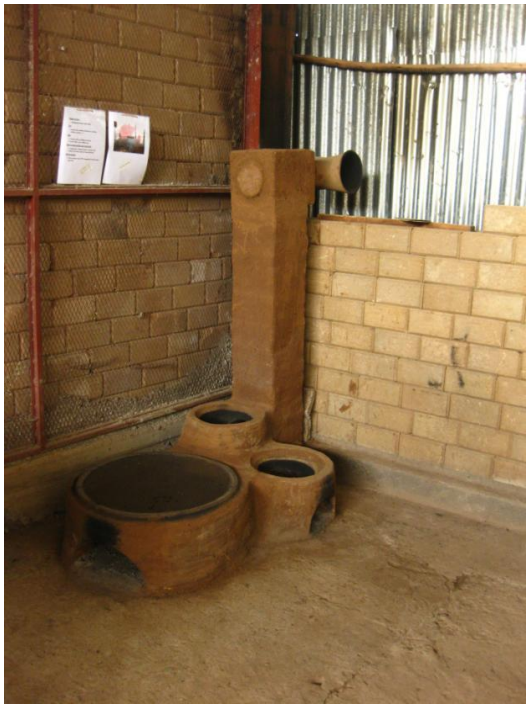

Stove Test Results

Report on Controlled Cooking Test (CCT) & Water Boiling Test (WBT) on:
Chigr Fetchi Multipurpose Stove

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1. Introduction

In collabration with Ofenmacher - a Germen NGO which works on stoves development and piloting in context to different cooking habits in developing countries – has developed multipurpose stove called Chigr Fechi[1]. It is a standardised mud stove with chimney integrated, and be built with local materials such as clay soil, ash and sand. The stove serves both Injera baking and wot cooking tasks for households.

To develop additional stove technology menu for injera baking and piloting is important. However, before introducing for piloting this newly developed stove to Ethiopian households which do duel injera baking and cooking tasks, it is crucial to evaluate the performance to determine the fuel wood and time saving efficiencies, and others indicators which ultimately used to quantify its multi dimensional impact.

Accordingly, the Federal Ethiopian Alternative Energy Development and Promotion Center - under Ministry of Water, Energy and Irrigation, jointly with GIZ EnDev (Energising Development) in Ethiopia has carried out Controlled Cooking Test (CCT) and Water Boiling Test (WBT) on Chigr Fechi multipurpose stoves in the laboratory setup made in EnDev Ethiopia compound.

Hence, this report describe the CCT and WBT test result done on Chigr Fechi multipurpose stove – CCT on larger stove injera baking stove for its fuel wood and time saving efficiency, and also do Water Boiling Test (WBT) on the smaller cooking stoves part to examine and determine the thermal efficiency.

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Chigr Fechi is an Amharic word meaning Problem Solver, which meant to indicate the stove benefiting fuel wood saving /expenditure saving, and also extra benefits of smoke free cleaner kitchen for significant positive health impact to women and children.

2. Objective

- To evaluate fuel wood and time saving efficiency of Chigr Fechi multipurpose stove compared to traditional three stones open fire stove by undertaking CCT test protocol on the injera baking part of the stove;
- To examine and determine thermal efficiency of the smaller stove cooking part by WBT test protocol.
- To examine user preferences and usage on the newly developed stove

3. Test methodology

3.1 Control Cooking Test (CCT) – on the larger stove for injera baking purpose

In order to evaluate the performance of the stoves Controlled Cooking Test (CCT) method was employed. The Controlled Cooking Test (CCT) is designed to assess the performance of the improved stove relative to the common or traditional stoves that the improved model is meant to replace. Stoves are compared as they perform a standard cooking task that is closer to the actual cooking that local people do every day.

The testing protocol prepared by Rob Bails for the Household Energy and Health Program, Shell Foundation has been used. With chosen experienced cook, Injera baking has been selected as a cooking task for the test.

3.1.1 Test materials and procedures

The following test materials were used during CCT testing.

- Digital balance with 0.1 gm accuracy
- Moisture meter
- Stop watch
- Infrared thermometer
- Injera container, locally called "*Inkib" (Moseb or Lemat)*
- Dough pots/containers
- Charcoal pan
- Spatula

- Hand glove
- Teff dough

3.1.2 The stove tested

Two different stoves were tested to compare each other, and evaluate their performance. Hence, open fire stove has been used as a baseline traditional inefficient stove to compare against. The other primarily stove evaluated was Chigr Fechi multipurpose stove - on the bigger stove part backing part which is used for injera baking.

3.1.2.1 Chigr Fechi multipurpose stove

Chigr Fetchi multipurpose stove is developed by Ofenmacher e.V.- a Germen NGO which works on stoves development and piloting in context to different cooking habits in developing countries. The stove is a mud stove with chimney integrated, and built with easily available local materials such as clay soil, ash and sand and straw. The stove has three burning chambers, one for the preparation of Injera baking and other stoves two used for smaller cooking tasks such as preparing wot (typical Ethiopian sauce).

The stove is made of mud prepared from three raw materials: clay soil, sand and ash - with 1:1:1 ratio a bit depend on the clay quality. Straw, preferably from Teff cereal, is the remaining raw materials.

Table 1: Raw materials required building one Chigr Fechi Multipurpose stove

No	Materials	Units	Quantity	Remarks
1	Clay soil	m^3	0.13	10 buckets – bucket size of Φ=25cm & Ht= 25 cm)
2	Sand	m^3	0.13	>>
3	Ash	m^3	0.13	>>
4	Straw	Sack	1	A 50 kg sack
5	Chimney clay outlet	Pcs	1	Made by local potters

This mud stove is smoke free, and has three stoves parts which are interconnected by channels or holes which bring the whole combusted smoke finally go to the chimney outlet outside households.

a. The injera stove – it is cylindrical in shape having 27 25 cm height. The diameter of cylinder depends on the specific Mitad's diameter in each households,
b. The cooking stoves – there are two stoves have two pot holes, the first and primary stove pot hole (combustion camber) with(is 36 24 cm wide or inside diameter with its 27 25 cm height, while the secondary stove pot hole has baffle integrated & has also a 24cm inside diameter . It is built approximately 12 cm higher than the primary/first stove

The integrated chimney has an overall height of 156cm and built from piled up mud bricks. The bricks has 24x24x6cm dimension and has approximate diameter of 13 14 cm in the center.

Figure 1: Major components of Chigr Fechi multipurpose stove


Lid for soot cleaning
Smoke outlet, made from clay& to be installed outdoor
Chimney
Secondary cooking stove
Clay plate -mitad
Primary cooking stove
Injera baking stove

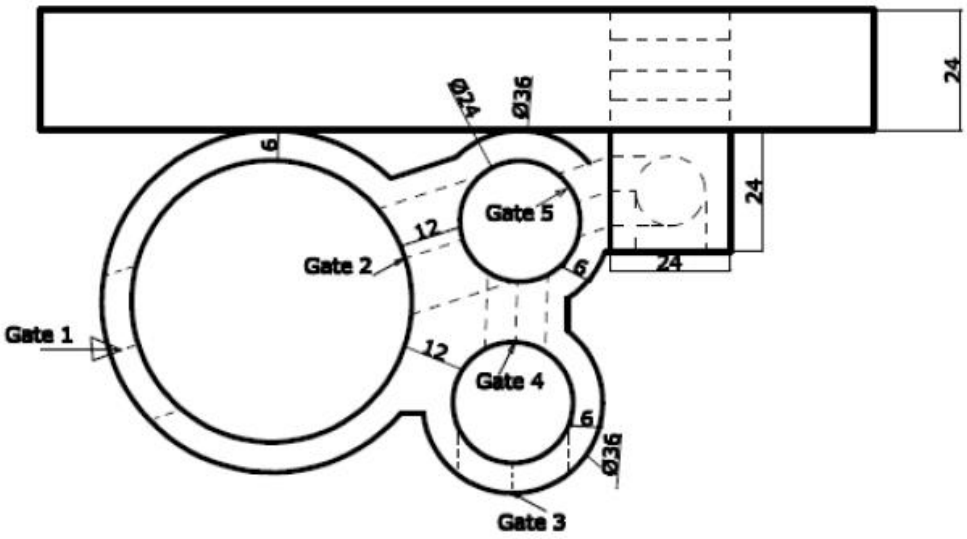

Figure 2: Plan view for Chigr Fechi stove

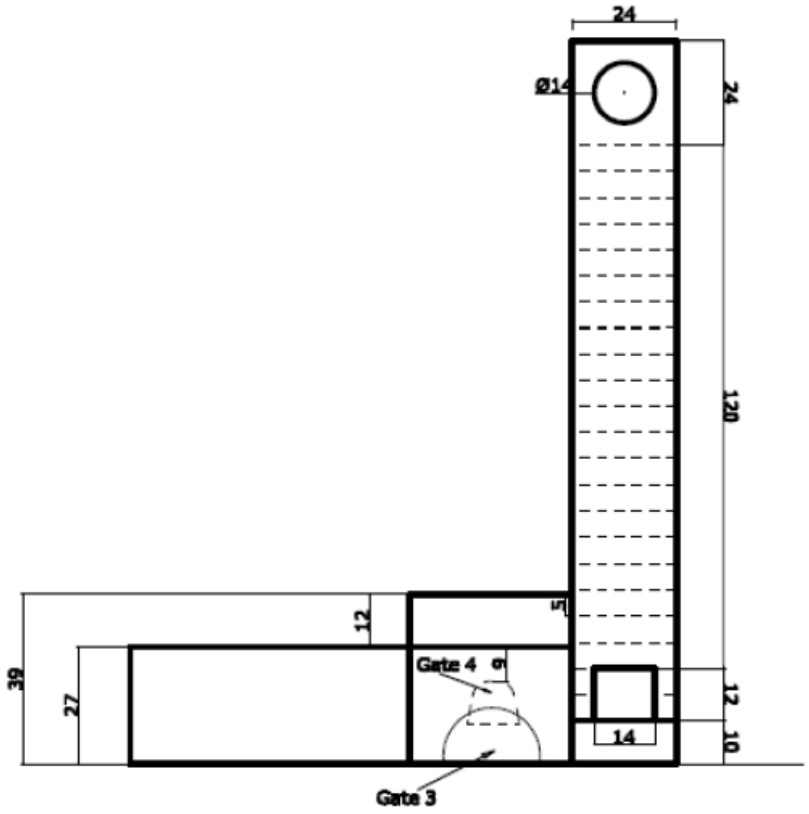

Figure 3: Section view of Chigr Fechi stove

Figure 4: Injera baking on Chigr Fechi stove during CCT test

3.1.3 Fuel wood

The fuel wood used for the test was air dried eucalyptus globules. It is a commonly used fuel wood for Ethiopians household in most part of the country. For each test session 10 to 12 kg of wood was used. Match is used for lighting and paper for starting fire. After each test the unburned woods removed from the fire, extinguished and weighed together with the remaining wood.

3.1.4 Food cooked

Injera is Ethiopian staple food and flat bread like pancake prepared from a tiny grain called Teff. Preparation of Injera takes three to four days.

Batter/dough is prepared by mixing Teff flour and water using yeast. And then the batter/dough is left to ferment for three to four days in tightly closed container.

At fermentation phase, excess water that rises to the surface is skimmed off and discarded, the mixture is stirred intermittently. One to two liters of well mixed batter will be taken and added to a boiling water to make a soup like thing called absit. The absit will be stirred well while boiling until it gets thicker. After 30 to 40 minute of boiling it is poured to the previously left batter into the container and more water is added to make the batter lean. It takes about 30 to 45 minutes to get ready for baking where it produces bubble at the top. Until the batter is getting ready the firing was started. When the Injera stove is hot, baking of Injera is started. The batter is poured in a circular motion around the surface of the griddle, quickly filling any gaps that might be left behind. Once the batter is poured, the lid would be closed and allow the Injera to steam a bit as it cooks. Once the Injera has been cooked it is removed from the Mitad using *sefed,* a grass woven plate like material. Three tests have been conducted on each stove. For each baking session about 16 kg of batter was used which is similar to an average family size one time baking. The number of Injera baked per session was 25 to 27.

3.1.5 Tests results and discussion

Chigr Fechi's Injera baking stove has proven to be economical in fuel wood consumption and saving of 54 % has been achieved compared to the traditional open fire. Unlike open fire which wastes heat into the atmosphere, Chigr Fechi stove cooks faster since it generates a hot fire that ensures better heat transfer.

Moreover, in terms of total baking time a saving of 23% has been attained. The stove has exhibited an average of 28 minutes time saving over open fire, which could be translated at an average of one minute saving per Injera- baked considering an average of 27 Injera baked per cycle of CCT testing.

Table 2: Result of CCT test on Chigr Fechi Injera stove

	Units	Test 1	Test 2	Test 3	Mean	St Dev	CoV
Total weight of cooked food	gm	10,754	10,357	10,283	10,465	253	2.42%
Weight of char remaining	gm	639	826	666	710	101	14.23%
Equivalent dry wood consumed	gm	5,022	5,245	4,710	4,992	269	5.38%
Specific fuel consumption	gm/kg	467	506	458	477	26	5.39%
Total cooking time	min	84	99	97	93	8	8.73%

Comparison – Chigr Fechi stove & Open fire stove[2]		**Difference**	**T- test**	**Sig@95%?**
Average specific fuel consumption	gm/kg	54%	19.39	Yes
Total cooking time	min	23%	5.37	Yes

[2] Three stones open fire stove is taken as a baseline stove to compare against; CCT test memo by Hiwote Teshome indicates fuel wood consumption 1031gm/kg injera, and 121 minutes for baking session .

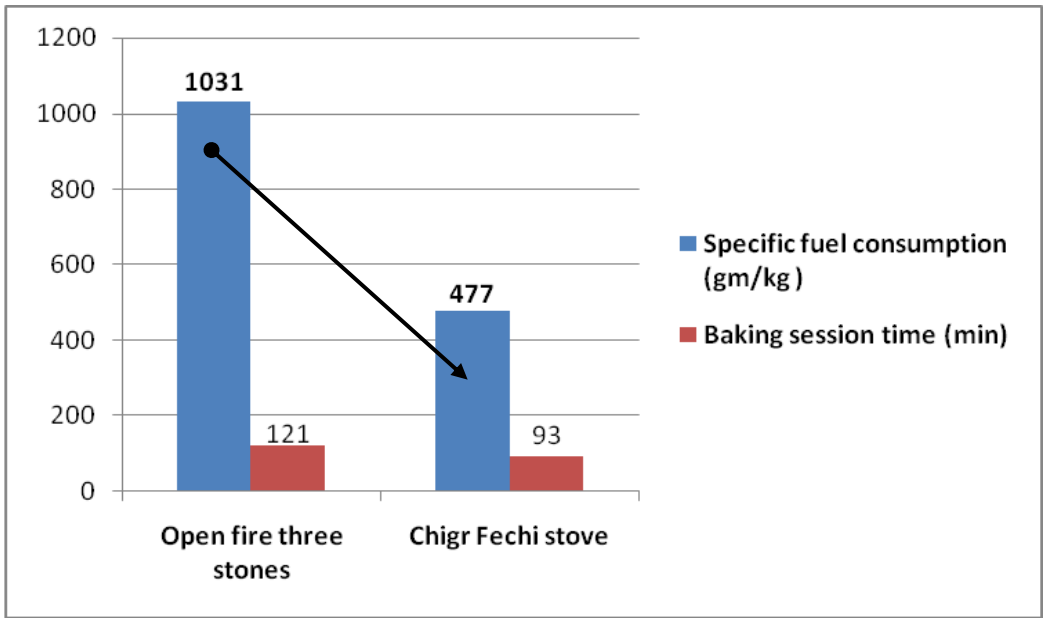

Figure 5: Performance of Chigr Fechi Injera baking as compared to open fire stove

Remarks from the injera baker during the test have revealed that, Chigr Fechi stove is easy to operate once lit the stove fire; combustion does not stop unless firewood feeding is stopped. As it is with traditional open fire, blowing air into the stove is not required to fan the flame.

One of the appealing from Chigr Fechi stove – based on the baker's comment - is that it smoke free stove which removes entire smoke from the kitchen through its chimney arrangement, and creates clean indoor air which benefits by avoiding respiratory diseases and aching eyes to women and children. Additionally, the shielded fire is screened and less likely to burn children and women user.

3.2 Water Boiling Test (WBT) – on smaller stoves for cooking purpose

3.2.1Test methodology

Modified version 3.0 of Water Boiling Test (WBT) protocol from Shell Foundation Households Energy Program was used. The stoves were tested for their thermal efficiency, time to boil water and specific fuel consumption.

The two smaller stoves pot holes or cooking part were tested with 27cm pot size – which represents an average pot size in most Ethiopian households.

Firing is made only on the first stove pot hole, and the other stove pot gets heat from the smoke on its way to the chimney.

Figure 6: Water Boiling Test (WBT) on two smaller stoves

3.2.2 Testing materials used

The following testing equipments and materials were used during WBT tests.

- Digital balance with 0.1 gm accuracy
- Thermo couples
- Handheld fuel wood moisture meter
- Air dried fuel wood
- Stop watches
- Heat resistant hand gloves
- Charcoal pans
- Spatulas
- Standard water pots, aluminum made - 5L capacity
- Clean water
- Measuring tape

3.2.3 Fuel used for test

The fuel wood used for the test was air dried Eucalyptus Globules. It is a widely available and commonly used fuel wood in most Ethiopians household. Fuel woods samples were analyzed using moisture meter.

3.2.4 Testing procedure

The Shell Foundation Households Energy Project's Water Boiling Test (WBT), a modified Version 3.0 was used to evaluate thermal efficiency. The test consists of three phases: High power (cold start), High Power (hot start) and Low Power (simmer).

Before starting the tests on the stoves, the following important steps were completed before beginning the actual tests.

- Sufficient fuel wood was prepared. A well-dried and uniform in size fuel wood was prepared ahead of testing schedule. On each WBT set of testing sessions, three bundles of fuel weigh 2.5 to 3.0 kg was used,
- Sufficient water, at least 10 liters, was prepared to complete three sets of tests,
- A standard 5.0L capacity pots are used and a local boiling point of water was determined with an earlier simple practice.

Phase 1- High power (cold start):- the following major steps and activities were done at high power cold stove start testing in each sample stoves.

- Pot filled with 5.0 liter water of room temperature and weight recorded,
- Using the wooden fixture, water temperature measured and recorded,
- Stove fired using kerosene and wood sticks,
- After the fire started, time recorded at which high power phase started and water brought to boil without excessively wasting fuel wood.
- When the water in the pot reached its local boiling temperature shown by the digital thermometer, the following activities were accomplished:
    - Time recorded at which pot reaches its local boiling point and recorded that temperature,
    - All wood removed from the stove and extinguished the flames. Knocked off all loose charcoal from the ends of the wood in to the charcoal container and recorded the weight,
    - Unburned wood were removed and weighted with the remaining wood from the pre-weigh bundles,

- Weight of pot with water recorded,
- Remaining charcoal from the stove extracted and its weight recorded.

At this point, the first phase tests were completed and shifted to phase 2 tests.

Phase 2: High power (hot start):- immediately following the cold start, the following major activities were done for phase 2 tests.

- Pot refilled with 5.0 liters fresh cold water and recorded its weight and temperature,
- The stove light fired using kindling and wood from the second pre-weighted bundle for the second phase test,
- Starting time recorded and pot rapidly brought to boil without excessively wasted of fuel wood from the second pre-weighted bundle,
- Time recorded at which the pot reaches the local boiling point,
- After reaching the boiling temperature, the following activities done quickly; this is because water temperature needed as close as possible to boiling in order to proceed to the simmer phase.
    - Removed the unburned wood from the stove. Knocked off any loose charcoal and recorded weight of the removed wood from stove together with remaining unused wood,
    - Water temperature recorded,
    - Water pot weight recorded and then immediately replaced on the stove in order directly go to the simmer test,
- Replaced and re-lighted the wood removed from the fire and preceded immediately to the low power test.

Phase 3: Low power (simmering):- immediately following the hot start, the already boiled water is kept at a simmer for 45 minutes. At this phase, the stove, pot, and water remain hot from the second hot start phase of the test. To do so, the following major activities were done:

- The thermometer was replaced in the pot. The fire was adjusted to keep the water as close to 3 degree below local boiling point as possible,
- For 45 minutes, the fire was maintained to keep the water temperature as close as possible to 3 degrees below the boiling point,
- After 45 minutes, rapidly the following activities were done:

- Finishing time of the test recorded,
- All wood removed from the stove and knocked off any loose charcoal in to charcoal container and weight recorded with the remaining wood including the unused wood from the pre weight bundle,
- Recorded the final boiled water temperature,
- Weight recorded for the remaining water in the pot,
- All remaining charcoal extracted from the stove and weight recorded.

These three phases were used for data collection for information on thermal efficiency. During the high power operation, ventilation doors where kept open while partially opened during the low power (simmer) operation.

According to the protocol, for each WBT, a series of three testing sessions were conducted.

3.2.5 Test result and discussion

Thermal efficiency performance from Chigr Fechi's smaller cooking stoves is presented as an average, over all three phases. The result section of excel spreadsheet was taken as final test analysis for each sample of stoves and put in the Annexes.

By definition, thermal efficiency is ratio of the work done by heating and evaporating water to the energy consumed by burning wood, i.e. it considers both the amount of water heated and evaporated relative to the fuel consumed. Hence, evaluating stoves by their thermal efficiencies is a better indicative tool to compare fuel saving potential of stoves.

The summery of test results is presented in the table below.

stove

Table 3: Summary of WBT test result on Chigr Fechi smaller stoves

WBT testing phases	Thermal efficiency (%)			
	WBT 1	WBT 2	WBT 3	Average
High power phase (cold& hot start) - Average	23.5	25.5	27.5	25.5
Simmering phase	26.0	25.0	23.0	25.0
Average of the three phases	24.0	25.0	26.0	**25.0**

In the high power test, Chigr Fechi stoves has achieved an average of 25.5% thermal efficiency, while during simmering tests 25.0% has been attained, which makes the overall stove's thermal efficiency averaged at 25.0%. The amount of heat from a single and first firing stove has been utilized for the second stove as pass-by flume heat to warm up water, and this has significantely attributed to higher thermal efficiency. Moreover, during each testing phase, it has been observed that the amount of water temperature in the second stove pot is nearly half of the first firing stove pot hole water temperature; almost half of the energy reaches to the second pot in the form of flume heat before heading to the final smoke outlet.

4. Conclusion and Recommendation

Chigr Fechi multipurpose stove is proved to be very clean and fuel efficient mud stove which fits to most rural household needs of Ethiopia. One of the key features for its relevance to rural setting is that it is constructed from easily available local materials such as clay soil, sand, ash and few straws.

The stove has achieved a 54% fuel saving efficiency and, 23 % of time saving compared with traditional open fire. Besides, the stove is appropriate technology for rural households by avoiding conflicts of interest between health extension agents and others rural development agents, since it fulfills both sides demand – cleaned indoor air and fuel wood savings.

The stove has attained a significant fuel saving efficiency which has fulfilled and surpassed the minimum fuel wood saving benchmark required by most international agencies. This would create more opportunities to explore its dissemination at national level to benefits from its multi dimensional impacts – including clean indoor air and fuel saving.

With its extra cooking stoves part benefits, it is worthwhile and recommended to pilot this mud stove in rural setting of Ethiopia; subsidy mechanism could be one tool to promote the technology and clean baking activity. Furthermore, as any of those successfully disseminated stoves, Chigr Fechi multipurpose stove has also need well devised dissemination approaches for promotion and marketing tools which has to consider outreaching most rural setting of Ethiopia.

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Annexes: Test result of Water Boiling Test(WBT)

Stove type/model:	**Chigr Fechi Multipurpose stove**
Location:	Addis Abeba GIZ EnDev ETH Laboratory
Fuel description:	Eucalyptus Globulus (Southern Blue Gum, Fever Tree
Wind conditions:	No wind; No wind; Light breeze
Ambient temperature:	22.2; 22.6; 22

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	
Time to boil Pot # 1	min	44	40	41	
Temp-corrected time to boil Pot # 1	min	48	42	42	
Burning rate	g/min	15	16	15	
Thermal efficiency	%	21%	22%	23%	
Specific fuel consumption	g/liter	102	94	95	
Temp-corrected specific consumption	g/liter	111	98	97	
Temp-corrected specific energy cons.	kJ/liter	2,093	1,853	1,834	
Firepower	watts	4,789	5,100	4,866	

2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	
Time to boil Pot # 1	min	28	28	35	
Temp-corrected time to boil Pot # 1	min	31	30	37	
Burning rate	g/min	17	16	12	
Thermal efficiency	%	26%	29%	32%	
Specific fuel consumption	g/liter	71	65	62	
Temp-corrected specific consumption	g/liter	78	69	65	
Temp-corrected specific energy cons.	kJ/liter	1,471	1,306	1,224	
Firepower	watts	5,240	5,039	3,765	

3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	
Burning rate	g/min	7	7	7	
Thermal efficiency	%	26%	25%	23%	
Specific fuel consumption	g/liter	52	50	52	
Temp-corrected specific energy cons.	kJ/liter	971	933	974	
Firepower	watts	2,249	2,220	2,246	
Turn down ratio	--	2.13	2.30	2.17	