

**The Clean Cook Stove Project: The Case of Ten Sub
Cities of Addis Ababa City Administration
Improvement in Cooking Times and Emission**

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Introduction

This report is based on results of a pilot study made by Gaia Association to test alcohol stoves supplied to 509 sample households in 10 sub-cities of Addis Ababa City Administration. The study considered households from all income level and localities. The objective of the project is changing the household energy consumption patterns in developing countries, focusing on Ethiopia's current energy demand and its impact on health, society, economy and environment.

The study includes a baseline survey - before introduction of the ethanol stove to the households and a follow up survey - after the introduction of the new ethanol stove. Under the follow up survey, each sample households was provided with a stove and bottles of ethanol and was observed into three phases.

Phase one: - Free supply of ethanol (with a very frequent visit - daily)

Phase two: - Ethanol was supplied at Birr 1.65 per liter (with a frequent visit - weekly)

Phase three: - Ethanol was supplied at Birr Birr 2.00 (with a less frequent visit -biweekly)

The households were observed for one month time under each phase. For the purpose of this report the results of the weekly and biweekly follow up survey are discussed. Moreover, as the baseline survey has proved that the traditional fuels used by majority of the households are Kerosene, Charcoal and fuel wood the comparison is made between the new alcohol stove and these fuels in some cases or with Kerosene alone - as it is proved to be the primary source of fuel energy of the households under the study. However, for information, the table below gives an overall view of the type of fuel used by the sample households.

Type of Fuel Used	Frequency	Percent
Agri-Residue	13	1.0
BLT	17	1.3
Charcoal	359	27.0
Dung	20	1.5
Electricity	78	5.9
Eucalyptus leaves	40	3.0
Fuel Wood	224	16.8
Kerosene	489	36.7
LPG	40	3.0
Saw Dust	51	3.8
Total	1331	100

I. Cooking Time and fuel consumption

One of the findings of both the baseline and follow up surveys is the average cooking time of households. As could be seen in table A presented under Annex Part I, the frequency of use for Charcoal and Kerosene on average is daily while it is weekly for fuel wood. This could be partly explained by the fact that households tend to use the fuel wood mostly for cooking Enjera¹ which is usually done per week. If we refer back to Part I of the annex for time in use, table B indicates, the average time in use of charcoal and fuel wood is 1 hour while it is 3 hours for kerosene. Even though no information is available about units of the cooking tasks when these data were collected, one thing that we can say about the results of the cooking task is that kerosene has more heating value than the other two mostly used fuel types.

On the other hand the weekly follow-up survey indicates that among the households who were asked the question whether they have used the ethanol stove supplied to them every day, 4596 responses out of 4915 responses given were 'Yes'. (See table C of annex part I) As could be referred to table D of annex Part I, among the daily users of the ethanol, average time of use is 3 hours.

As mentioned earlier, though no data is available about cooking task in unit to conclude about efficiency, the daily cooking time for households on average is found to be 3 hrs for both kerosene and Ethanol users. However, we can see these results in line with the households responses to questions asked about improvement in cooking time and fuel consumption across the fuel types.

Improvement in cooking time is reported by 4429 respondents out of the 4915 total respondents. Moreover, most households also responded that their consumption of fuel wood, charcoal and kerosene has improved by 100%. The least improvement indicated is 75% for Charcoal at the fuel is traditionally preferred by most households in holidays and in rainy days to make coffee or for heating the houses. The detailed results are shown under tables E and F under part I.

The baseline survey result indicates that among the kerosene users average consumption is 5 liters per week. The full results are presented in table G,H and I appearing under Annex Part I.² As could be referred

¹ Enjera is Ethiopian traditional food made of a cereal called 'Teff'. It usually needs 3 to 4 days to ferment and be ready to be baked.

² Table I shows that the mean value for frequency of purchase is 17 days. However, as the standard deviation and variance values are high here mean value does not truly represent the average value. The same is true for the mean value of quantity purchased. It shows a mean value of 10.6 with high value of

from these tables out of 422 kerosene users who responded to the questions, 222 respondents indicated that they purchase their kerosene every week and their weekly consumption is 5 liters.

Subsequently, the households' response indicated that among those who confirmed daily use the average consumption of ethanol is 3 liters per week. See table I under Annex Part I.

The above survey results could be checked against the experiment done by Gaia on the efficiency of kerosene, charcoal and ethanol fuels and also on their respective stoves (Chinese kerosene stove, Lakech charcoal stove and CC-stove) to know their efficiency on heat generation, power and fuel consumption (burning time per unit fuel). The result of this experiment correlates with what has been found out by the survey discussed above. The full report of the experiment is found attached to this report.

II. Emissions.

The survey also came up with the household response regarding emissions. Households were asked about if they were bothered by the smell and smoke coming out of the fuels they are using. A higher number of respondents (71.5%) responded that they are bothered by the smoke and a less number of respondents (32.7%) responded that they are bothered by the smell of the fuel they are using. Please refer to table J and K of annex part II for detail results.

However, a more comprehensive and precise information regarding emissions from the highly used fuels and the newly introduced ethanol fuel is an Indoor Pollution Test (IAP) made by Gaia.

The survey made by Gaia Association in Addis Ababa sub cities included an IAP test made in Good Shepherds at Kirkos Sub City. This IAP test was made according to the procedure required by Center for Entrepreneurship in International Health and Development (CEIHD).

Six households were especially selected for the IAP test. Then observations were made before and after the devices used to measure the IAP were placed in the kitchen of the selected households.

According to the report prepared by Gaia on this test, the devices that were placed were the HOBO CO logger, which were placed for 48 hour and recorded the CO concentrations in the room. The fine particulate

standard deviation and variance. Because of such fact the average value considered is the one with higher frequency.

matter was measured by the University California Berkeley Particle Monitor (UCB PM) with a photoelectric detector. Another device placed was the Gastec tubes that collect the CO data.

At the end of the 48 hour testing period a post monitoring questionnaire was given to the 6 participating households. The main cook of each household was asked a series of questions to determine what the conditions were like during the monitoring period. The questionnaire contained a total of 39 questions. These questions were designed to help interpret the data collected from the equipment placed during the 48hr period. Such questions as what type of fuel used and how long the participating family cooked for explains why there is higher or lower levels of CO and PM data collected during the study. The final result of the test is presented below as it appears on the report.

Indoors Air pollution Concentrations.

The results of the 48-hour concentration measurements of PM_{2.5} and CO in Good Shepherd kitchens of the 6 households while using primarily kerosene stove and secondary Lakech Charcoal Stove and also in the after study with the introduction of Clean Cook stove (ethanol Stove) are displayed in the table below.

Average Kitchen Concentration, Percent Changes, and T-Tests for Significance

	Before, Average	Before, Std Dev	After, Average	After, Std Dev	Percent change	T-Test (p-value)
PM:Average(mg/m ³)	1.70	3.97	0.46	0.67	72.9	0.416
PM:Minimum(mg/m ³)	1.48	3.49	0.25	0.48	83.1	0.363
PM:Maximum(mg/m ³)	22.11	16.05	12.92	7.61	41.56	0.027
PM:Highest 15-min ave	9.85	8.85	3.96	4.14	59.79	0.045
PM:2 nd Highest 15-min ave	8.11	8.63	3.01	3.28	62.88	0.078
PM:3 rd Highest 15-min ave	8.63	7.71	2.76	3.28	61.99	0.139
CO:Mean,HOBO(ppm)	26.33	12.25	7.79	4.59	70.40	0.009
CO:Maximum,HOBO(ppm)	134.52	62.76	112.38	92.10	16.46	0.0003

The average of the set of 6 household 48-hour average kitchen PM_{2.5} concentrations went down from 1.7mg/m³ in the before (kerosene stove) phase to 0.46 in the after phase, while the households were using the CC-stove. The percent reduction is 72.9 which is significant. There is also a difference in the average before and after minimum PM_{2.5} concentrations 1.48mg/m³ and 0.25mg/m³ respectively. The average maximum PM_{2.5} concentrations dropped by 41.56% . The highest, second highest, and third highest 15-minute average PM_{2.5} concentrations were also significantly dropped after the introduction of the CC-stove, by 59.79%, 62.62%, and 61.99% respectively.

Similarly, the average 48-hour kitchen CO concentrations measured by the HOBO CO logger, dropped from 26.33 ppm in the before phase to 7.79 ppm in the after phase, a statistically significant reduction of 70.40%. The average of the maximum CO concentrations was also significantly different (134.52 versus 112.38 ppm).

Comparison of the Kitchen Concentration to International Standards.

	Before	After	WHO interim target-1	WHO Air Quality Guideline
PM _{2.5}	170ug/m ³ (48hr Ave)	46ug/m ³ (48hr Ave)	75ug/m ³ (24- hr mean)	25ug/m ³ (24-hr Ave) ¹
CO	30.15mg/m ³ (48hr Ave)	8.92mg/m ³ (48hr Ave)	NA	10 mg/m ³ (8hr Ave) ²

World Health Organization (WHO) sets air pollution guidelines to offer guidance in reducing health impact of air pollution (both indoors and out door) based on current scientific evidence. The WHO recently set new Air Quality Guidelines (AQG) for PM_{2.5}, ozone, nitrogen dioxide, and sulfur dioxide, along with interim targets which are intended as incremental steps in a progressive reduction of air pollution in more polluted area (WHO, 2005). The guideline for carbon monoxide was set in 2000 (WHO, 2000).

The results of the IAP monitoring in the 6 households are compared to the World Health Organization’s AQG and interim target-1 (WHO, 2005) in Table 4 below. Note that the CO concentrations reported above in parts per million (ppm) were converted to mg/m³ to match the unit used by WHO (by multiplying by the gram molecular weight of CO, 28, and dividing by the conversion factor of 24.45).

The average PM concentration in the kitchens dropped after the households began using the CC stove (from 170ug/m³ to 46ug/m³), a very significant improvement in indoors air quality. The households moved much closer to the WHO interim target-1 of 75ug/m³ for PM_{2.5} (and the Air Quality Guideline of 25ug/m³) in the after phase. The average CO kitchen concentration in the kerosene stove was 30.15mg/m³, above the WHO Air Quality Guideline of 10mg/m³, but dropped below the guideline to, 8.92mg/m³.

Annex

Part I

A. Frequency of Use for Highly Used Fuels by Households

Frequency of Use	Type of Fuel used		
	Charcoal	Fuel Wood	Kerosene
2 times a week	1	2	0
Daily	248	30	456
During holidays	0	3	0
In 15 days	1	0	0
In 2 days	3	0	0
In 3 days	5	5	0
in 4 days	0	0	0
In 4 days	1	16	0
In 5 days	0	1	0
Monthly	5	8	0
On summer	1	0	0
Rarely	2	0	0
Sometimes	13	4	2
Weekly	39	109	16
When cold	1	0	0
When need	3	0	0
Yearly	2	5	0

B. Time in Use for Highly Used Fuels by Households

Time in use/ day(hrs)	Type of Fuel used		
	Charcoal	Fuel Wood	Kerosene
1	117	52	30
2	96	43	68
3	48	30	148
4	18	6	95
5	6	1	40
6	1	2	44
7	3	0	4
8	2	1	18
9	0	0	2
10	0	0	4
12	1	0	1
15	0	0	1
18	1	0	0
20	0	1	0
30	2	1	0
45	0	0	0
250	0	0	0

C. Households reply to “Did you use ethanol stove everyday?”

Reply	Frequency	Percent
	175	3.6
No	144	2.9
Yes	4596	93.5
Total	4915	100.0

D. Number of Hours of use by the Daily Users of the Ethanol

N	4915
Mean	2.979
Median	3.00
Mode	3.00
Std. Deviation	1.55
Variance	2.40
Range	22.00

No Of Hours In Use Per Day	No of Users	No Of Hours In Use Per Day	No of Users
.00	119	3.10	2
.05	2	3.15	10
.10	1	3.20	3
.15	1	3.30	169
.20	0	3.40	2
.25	2	3.45	3
.30	23	3.50	1
.40	5	4.00	904
.50	1	4.10	0
1.00	172	4.20	1
1.05	1	4.30	108
1.10	1	4.40	2
1.15	2	4.50	2
1.25	3	5.00	436
1.30	143	5.10	1
1.35	1	5.15	1
1.40	1	5.30	29
1.45	5	6.00	150
1.50	2	6.30	2
2.00	841	7.00	19
2.10	2	8.00	12
2.15	10	8.30	2
2.20	3	9.00	2
2.25	1	10.00	3
2.30	224	12.10	1
2.40	3	12.40	1
2.45	2	20.00	1
2.50	1	22.00	1
3.00	1156		

N	4915
Mean	2.97
Median	3.00
Mode	3.00
Std. Deviation	1.55
Variance	2.40
Range	22.00

Ethanol Used in Seven Days (in Liters)	No. of Users	Ethanol Used in Seven Days (in Liters)	No. of Users
.05	2	3.50	1
.10	1	4.00	904
.15	1	4.10	0
.20	0	4.20	1
.25	2	4.30	108
.30	23	4.40	2
.40	5	4.50	2
.50	1	5.00	436
1.00	172	5.10	5.10
1.05	1	5.15	5.15
1.10	1	5.30	5.30
1.15	2	6.00	6.00
1.25	3	6.30	6.30
1.30	143	7.00	7.00
1.35	1	8.00	8.00
1.40	1	8.30	8.30
1.45	5	9.00	9.00
1.50	2	10.00	10.00
2.00	841	12.10	12.10
2.10	2	12.40	12.40
2.15	10	20.00	20.00
2.20	3	22.00	22.00
2.25	1		
2.30	224		
2.40	3		
2.45	2		
2.50	1		
3.00	1156		
3.10	2		
3.15	10		
3.20	3		
3.30	169		
3.40	2		

E. Improved in Cooking Time?

Response	Frequency	Percent
	207	4.2
No	279	5.7
Yes	4429	90.1
Total	4915	100.0

F. Change in Consumption of Fuel Wood, Charcoal and Kerosene Due to Ethanol Use

Change in Consumption of Fuel Wood	Percentage of Reduction in Fuel Wood Consumption				Total
	100%	25%	50%	75%	
No	2	2	0	0	4
Yes	523	380	392	243	1538
Total	525	382	392	243	1542

Change in Consumption of Charcoal	Percentage of Reduction in Charcoal Consumption				Total
	100%	25%	50%	75%	
No	0	1	1	0	2
Yes	859	890	857	961	3567
Total	859	891	858	961	3569

Change in Consumption of Kerosene	Percentage of Reduction in Kerosene Consumption				Total
	100%	25%	50%	75%	
No	1	0	0	0	1
Yes	2731	345	690	678	4444
Total	2732	345	690	678	4445

G. Frequency of Kerosene Purchase

Days	Frequency	Percent
2	1	.2
5	1	.2
7	222	52.6
10	1	.2
15	11	2.6
30	186	44.1
Total	422	100.0

N	422
Mean	17.34
Median	7.00
Mode	7.00
Std. Deviation	11.33
Variance	128.38

H. Quantity Purchased

Liters	Frequency	Percent
2	12	2.8
3	26	6.2
4	15	3.6
5	139	32.9
6	10	2.4
10	93	22.0
15	28	6.6
20	67	15.9
25	18	4.3
30	14	3.3
Total	422	100.0

N	422
Mean	10.61
Median	10.00
Mode	5.00
Std. Deviation	7.41
Variance	54.89

I. Frequency of Purchase (in days)

		Days						Total
		2	5	7	10	15	30	
Quantity Purchase in Liters	2	1	0	9	0	0	2	12
	3	0	0	23	0	0	3	26
	4	0	0	14	0	0	1	15
	5	0	1	119	1	4	14	139
	6	0	0	9	0	1	0	10
	10	0	0	39	0	5	49	93
	15	0	0	1	0	0	27	28
	20	0	0	5	0	1	61	67
	25	0	0	2	0	0	16	18
30	0	0	1	0	0	13	14	
Total		1	1	222	1	11	186	422

J. Bothered by the smell

Response	Frequency	Percent
	9	.7
No	887	66.6
Yes	435	32.7
Total	1331	100.0

Bothered by the smoke

Response	Frequency	Percent
	10	.8
No	369	27.7
Yes	952	71.5
Total	1331	100.0

K. Type of Fuel purchased * Bothered by the smell Cross tabulation

Type of Fuel purchased	Bothered by the smell		Total
	No	Yes	
Agri-Residue	10	3	13
BLT	11	6	17
Charcoal	263	93	359
Dung	5	14	20
Electricity	77	0	78
Eucalyptus leaves	32	7	40
Fuel Wood	177	46	224
Kerosene	236	251	489
LPG	35	5	40
Saw Dust	41	10	51
Total	887	435	1331

Type of Fuel purchased * Bothered by the smoke Cross tabulation

Type of Fuel purchased	Bothered by the smoke		Total
	No	Yes	
Agri-Residue	9	4	13
BLT	3	14	17
Charcoal	64	291	359
Dung	4	15	20
Electricity	76	1	78
Eucalyptus leaves	6	33	40
Fuel Wood	70	153	224
Kerosene	72	415	489
LPG	37	3	40
Saw Dust	28	23	51
Total	369	952	1331

Laboratory Report on Comparison of CC-Stove, Kerosene-Stove and Charcoal-Stove

***Prepared by: Firehiwot Mengesha and Wubshet Tadele
August, 2006***

Introduction

Gaia association has been performing various study activities on ethanol and CC-stove. It has also done laboratory studies to get information on ethanol and CC-stove. But, a combined experiment on kerosene, charcoal and ethanol and also on their respective stoves (Chinese kerosene stove, Lakech charcoal stove and CC-stove) was not done to know their efficiency on heat generation, power and fuel consumption (burning time per unit fuel). So the need arises to compare these parameters of the different stoves and here on this laboratory experiment we answered these questions.

The experiments are done to know the duration of a unit fuel, amount of heat generated per unit fuel and power of the stoves. Since the parameters selected are good indicator of stove efficiency, they are capable to compare the three stoves. Then, the ultimate goal which is to know the status of CC-stove will be accomplished. Moreover the indoor air pollution (IAP) study which is doing by Gaia association will have figures to show the pollution effect of different stoves. And this pollution effect of different stoves is also a good parameter to compare stoves and will be done after the completion of the study. Based on the results obtained till now CC-stove has the minimum pollution effect compared to kerosene-stove, charcoal-stove and three stone stoves.

Laboratory Experiment

Objective: The objective of the experiment is to investigate fuel consumption and power

of different stoves which are kerosene stove, charcoal stove and CC-stove.

Equipments Used:

- One Chinese kerosene stove (“panda the smaller”)
- One charcoal stove (Lakech the smaller)
- One CC-stove
- One liter kerosene, one liter of ethanol and a kilogram of charcoal
- Three samples of water for each stove (each one liter)
- Stop watches
- Thermometer
- Hydrometer

Limitations

In calculating the power and heat generated by the stoves, there is a heat loss to the environment (which is not transferred to the boiled water) so this reduces the actual power of the stoves. But, we need to compare the

power of the stoves, so the heat lost to the environment won't be much problem.

* The power and heat generated values which are calculated in the experiment are not the actual values of the stoves and they should not be taken as the real efficiencies for the stoves.

Procedure:

- Place the three different stoves in three different rooms
- Fill the kerosene-stove with one liter of kerosene and also the CC-stove by one liter of ethanol. The charcoal-stove is filled by a kilogram of charcoal.
- Light the stoves and wait for 10minutes till the stoves reach full power
- Prepare one liter of water for each stove and measure each sample water temperature
- Place the samples of one liter water on the stoves and follow the reading of thermometer until it reaches 90°C.
- Record the time at which the water reaches 90°C for each stove
- Wait till the stoves run out of fuel and record the time

Data:

Data on CC-stove:



Tap water temperature = 16°C

Time it took to boil water from 16°C to 90°C = 8minutes & 37seconds

Total running time of CC-stove with a liter of ethanol = 4hours

Data on kerosene-stove:



Tap water temperature = 16°C

Time it took to boil water from 16°C to 90°C = 30minutes & 44seconds

Total running time of Kerosene-stove with a liter of ethanol = 8hours

Data on charcoal-stove:



Tap water temperature = 16°C

Time it took to boil water from 16°C to 90°C = 55minutes

Total running time of Charcoal-stove with a liter of ethanol = 6hours & 40minutes

Data analysis:

CC-stove:

Heat transferred to the water by CC-stove, $q = m_w C_{pw} \Delta T$

Where: m_w = The mass of water which is 1Kg

C_{pw} = Specific heat capacity of water,
4.162KJ/ Kg K

ΔT = The change in temperature, i.e. the difference b/n
16°C & 90°C

Substitution of values in the formula

$$q = 1\text{Kg} * 4.162\text{KJ/Kg K} * (90-16)\text{K}$$
$$q = 308\text{KJ}$$

Power, $P_c = \frac{q}{\Delta t_k}$, where Δt_k is the time elapsed to boil the water from
16°C to 90°C

$$P_c = \frac{308\text{ KJ}}{502.2\text{seconds}}$$
$$P_c = 613.3\text{Watt}$$

The total heat generated by CC-stove, i.e., for one liter of ethanol
burnt; Q_c :

$$Q_c = P_c t_{Tc}, t_{Tc} \text{ is total time of burning which is 4 hours}$$

$$Q_c = 613.3\text{Watt} * 14,400\text{seconds}$$

$$Q_c = 8.832\text{MJ}$$

Kerosene-stove:

Heat transferred to the water by kerosene-stove, q is the same as the
amount of heat

released by CC-stove to boil the water from 16°C to 90°C. The only
difference is the

time they took to boil the water which finally create a power difference.

$$\Rightarrow q = 308\text{KJ}$$

Power, $P_k = \frac{q}{\Delta t_k}$, where $\Delta t_k = 1,844\text{seconds}$

$$P_k = \frac{308\text{KJ}}{1,844\text{seconds}}$$

$$P_k = 167.03\text{Watt}$$

The total heat generated by kerosene-stove, i.e. for one liter of kerosene
burnt, Q_k :

$Q_k = P_k t_{Tk}$, t_{Tk} is total time of burning for one liter kerosene
which is 8hours

$$Q_k = 167.03\text{Watt} * 28,800\text{seconds}$$

$$Q_k = 4.810\text{MJ}$$

Charcoal-stove:

Heat transferred to the water by charcoal-stove is the same as for the
previous stoves. Here also the difference is on the time it took to boil the
water.

$$\Rightarrow q = 308\text{KJ}$$

Power, $P_{ch} = \frac{q}{\Delta t_{ch}}$, where $\Delta t_{ch} = 3,300\text{seconds}$

$$P_{ch} = \frac{308\text{KJ}}{3,300\text{seconds}}$$

$$P_{ch} = 93.33\text{Watt}$$

The total heat generated by charcoal stove, i.e. for a kilogram of charcoal burnt, Q_{ch} :

$Q_{ch} = P_{ch} t_{Tch}$, t_{Tch} is total time of burning for charcoal stove which is

6hours and 40minutes.

$$Q_{ch} = 93.33\text{Watt} * 24,000\text{seconds}$$

$$Q_{ch} = 2.240\text{MJ}$$

Table Of Results

Type of stove	Power (Watt)	Total heat generated per a liter/Kg of fuel (MJ)	Total time of burning per a liter/Kg of fuel (hours)
CC-stove	613.30	8.832	4
Kerosene-stove	167.07	4.810	8.10
Charcoal-stove	93.33	2.240	6.67

The energy content of kerosene is 46.3MJ/Kg and for ethanol it is 26.8MJ/Kg. From this values we can calculate the stoves efficiencies but here in our experiment there is a high loss of heat to the environment and the efficiency that will be calculated will be below the actual efficiencies of the stoves.

Summary of Results

As the table of results summarized, kerosene-stove and charcoal-stove have a higher burning time, which is off course a good property for stoves. But, only a long time of burning doesn't make a stove best. Burning time is somewhat a misleading parameter in indicating stove efficiency because as shown on the table of results stoves with higher burning time didn't end up with higher power and heat generation. So, even though CC-stove has the least total burning time, it has the highest power and heat generation. Fortunately, the high power and heat can be converted to a longer burning time at the expense of lower power. Practically, if we reduce the power regulator of CC-stove, the power will reduce but the burning time will definitely increase.

Power or total heat generation per unit fuel is a real indicator in evaluation of stoves. Using these good comparing parameter we can conclude CC-stove is better in heat generation per unit fuel compared to kerosene stove and charcoal stove. The stove with a highest power is the best.