2017 IMPROVED COOKSTOVE CATALOG

Thomas Klug
Duke University

Duke LEMUR CENTER
SAVA CONSERVATION
Madagascar

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Special thanks to…

Charles Welch
DLC Conservation Coordinator

Marina Blanco
DLC Project Coordinator

Lydia Greene
DLC Liaison

Libby Davis
Peace Corps Volunteer-Madagascar

Subhrendu Pattanayak
Sanford Professor

Charles Nunn
DGHI Professor

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TERMS AND DEFINITIONS

Time to Boil – The time it took for pot #1 to reach boiling temperature from the starting temperature.

Thermal Efficiency (TE) – Thermal efficiency is 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. Net calorific value for wood was estimated by accounting for fuel moisture content.

Thermal efficiency for cold and hot start tests (TE):

$$TE = \frac{4.186(T1_f - T1_i)(P1_i - P1) + 2260 \cdot w_v}{fuel_c \cdot LHV}$$

$T1_f$: Final water temp
$T1_i$: Initial water temp
$P1_i$: Mass of pot + water before test (g)
$P1$: Mass of pot (g)
w_v : Water vaporized (g)
$fuel_c$: Wood consumed (g)
LHV : Net calorific value (kJ/kg)

Thermal efficiency for simmering tests (TE_s):

$$TE_s = \frac{4.186(T1_f - T1_i)(P1_i - P1 + w_s)/2 + 2260 \cdot w_v}{fuel_c \cdot LHV}$$

$T1_f$: Final water temp
$T1_i$: Initial water temp
$P1_i$: Mass of pot + water before test (g)
$P1$: Mass of pot (g)
w_s : Water simmered (g)
w_v : Water vaporized (g)
$fuel_c$: Wood consumed (g)
LHV : Net calorific value (kJ/kg)

Specific Fuel Consumption (SC) – This is 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, divided by the liters 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.

$$SC = \frac{fuel_c}{w_b}$$

$fuel_c$: Wood consumed (g)
w_b: Water boiled (g)

Temp-Corrected Specific Fuel Consumption (TCSC) – This is the previous measure, also corrected as if the temperature rise from start to boil was 75°C, in order to easily compare different tests that may have had different starting or boiling temperatures. It is best to always look at the temp-corrected value rather than the uncorrected value. A higher TCSC indicates more fuel required to complete the same task of producing a liter of boiled (or simmered) water.

$$TCSC = SC \cdot \frac{75}{T1_f - T1_i}$$

SC : Specific fuel consumption $T1_f$: Final water temp $T1_i$: Initial water temp

Burning Rate – A measure of the average grams of wood burned per minute during the test. When compared between tests, this compares how consistently the user was operating the stove. When compared between stoves, this measure indicates how rapidly the stove consumes fuel.

$$BR = \frac{fuel_c}{\Delta t}$$

$fuel_c$: Wood consumed (g) Δt: Time to boil (min)

Firepower – Firepower is a measure of how quickly fuel was burning, reported in Watts (Joules per second). It is affected by both the stove (size of fuel entrance/combustion chamber) and user operation (rate of fuel feeding). Generally it is a useful measure of the stove's heat output, and an indicator of how consistently the operator ran the stove over multiple tests. A higher or lower value is not necessarily preferable, but rather is an indicator of the size of the stove.

$$FP = \frac{fuel_c \cdot LHV}{\Delta t \cdot 60}$$

$fuel_c$: Wood consumed (g) *LHV*: Net calorific value (kJ/kg) Δt: Time to boil (min)

Cold Start Test – The test begins with the stove and water at room temperature and uses pre-weighed fuel to boil a measured quantity of water in a standard pot.

Hot Start Test – Conducted after the cold start test while stove is still hot. Again, uses pre-weighed fuel to boil a measured quantity of water in a standard pot. Repeating the test with a hot stove helps to identify differences in performance between a stove when it is cold and when it is hot. This is particularly important for stoves with high thermal mass, since these stoves may be kept warm in practice.

Simmering Test – Tests the amount of fuel required to simmer a measured amount of water at just below boiling point for 45 minutes. This step simulates the long cooking of legumes or pulses common throughout much of the world.

OVERVIEW OF WOOD STOVES

METAL TRIPOD

Wood

General Information

Cost: 3,000-5,000 Ar. *($0.90–1.50)*
Location: Sambava, Antalaha, Andapa, Vohemar
Fuel(s): Wood only
Durability: 1 year
Manufacturing Location: Unknown, ubiquitous

Cold Start Tests

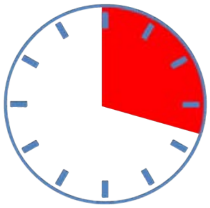
Efficiency Metrics

n = 4	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	23.13	7323	172.07	0.26
Std. Dev.	7.58	2394	25.93	0.03

Thermal Efficiency

26%

Time to boil



17.7 mins

Simmer Tests

Efficiency Metrics

n = 2	Burning rate (g/min)	Firepower (Watts)	Thermal efficiency
Mean	28.9	9128	0.16
Std. Dev.	1.77	566.39	0.01

Thermal Efficiency

16%

RED MULTI-STOVE

Wood

General Information

Cost: 10,000 Ar. *($3.00)*
Location: Andapa
Fuel(s): Wood, Charcoal, etc.
Durability: 5 years
Manufacturing Location: Outside Andapa

Seller Information

Cost of production: 1,125 Ar.
Materials: Clay, tin
Source of materials: Andapa
Drying time: 6 weeks
Sales: Sells door to door, makes stoves himself, 0 employees, self-taught

Cold Start Tests

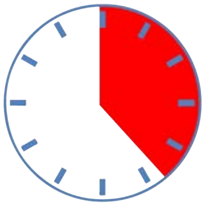
Efficiency Metrics

n = 3	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	9.0	2845	76.56	0.24
Std. Dev.	8.20	2609.93	14.86	0.06

Thermal Efficiency

24%

Time to boil



23.5 mins

Hot Start Tests

Efficiency Metrics

n = 3	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	13.7	4336	71.60	0.25
Std. Dev.	2.97	953.18	16.79	0.06

Thermal Efficiency

25%

Time to boil

20 mins

Simmer Tests

Efficiency Metrics (n = 1)

Burning rate (g/min)	Firepower (Watts)	Thermal efficiency
12.1	6042	0.19

Thermal Efficiency

19%

ADES

Wood

General Information

Cost: 15,000 Ar. *($5.00)*
Location: SAVA
Fuel(s): Wood
Durability: 3 years
Manufacturing Location: Antananarivo

Seller Information

Cost of production: 45,000 Ar.
Materials: Clay, tin
Source of materials: Tana
Sales: Distributed by the DLC for 10,000 Ar.

Cold Start Tests

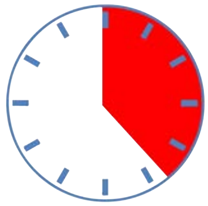
Efficiency Metrics

n = 3	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	10.2	3239	61.64	0.28
Std. Dev.	1.08	337.82	3.01	0.01

Thermal Efficiency

28%

Time to boil



23.5 mins

Hot Start Tests

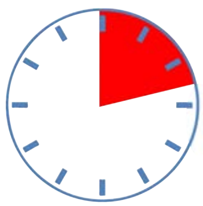
Efficiency Metrics

n = 3	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	15.7	4962	58.05	0.31
Std. Dev.	4.35	1373.69	3.51	0.01

Thermal Efficiency

31%

Time to boil



12.5 mins

Simmer Tests

Efficiency Metrics (n = 1)

Burning rate (g/min)	Firepower (Watts)	Thermal efficiency
12.1	6042	0.19

Thermal Efficiency

19%

DUNG STOVE

Wood

General Information

Cost: 25,000 Ar. *($8.00)*
Location: Antalaha
Fuel(s): Wood
Durability: 2-3 years
Manufacturing Location: Antalaha

Seller Information

Cost of production: 50 Ar.
Materials: Clay, dung
Source of materials: Antalaha
Sales: Sells out of home and made on as-ordered basis

Cold Start Tests

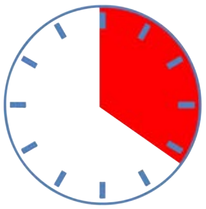
Efficiency Metrics (n = 1)

Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
19.4	6151	106.11	0.16

Thermal Efficiency

16%

Time to boil



21 mins

Hot Start Tests

Efficiency Metrics (n = 1)

Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
16.4	5179	77.6	0.22

Thermal Efficiency

22%

Time to boil

18 mins

TALL TIN STOVE

Wood

General Information

Cost: 15,000 Ar. *($5.00)*
Location: Sambava
Fuel(s): Wood
Durability: Not specified
Manufacturing Location: Sambava

Seller Information

Cost of production: Not specified
Materials: Brick, cement, tin
Source of materials: Sambava
Sales: Sells out of home and door to door

Cold Start Tests

Efficiency Metrics (n = 1)

Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
10.3	3266	136.16	0.13

Thermal Efficiency

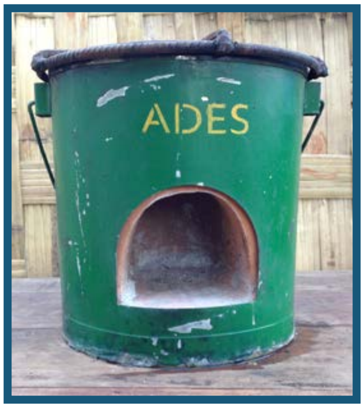
16%

Time to boil

53 mins

OVERVIEW OF CHARCOAL STOVES

ADES
Charcoal



General Information

Cost: 15,000 Ar. *($5.00)*
Location: SAVA
Fuel(s): Charcoal
Durability: 3 years
Manufacturing Location: Antananarivo

Seller Information

Cost of production: 60,000 Ar.
Materials: Clay, tin
Source of materials: Tana
Sales: Distributed by the DLC for 10,000 Ar.

Cold Start Tests

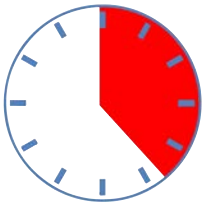
Efficiency Metrics

n = 4	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	5.38	2682	31	0.37
Std. Dev.	0.419	197.26	5.83	0.05

Thermal Efficiency

37%

Time to boil



23 mins

Hot Start Tests

Efficiency Metrics

n = 4	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	7.23	3606	37.39	0.31
Std. Dev.	1.09	542.68	6.83	0.06

Thermal Efficiency

31%

Time to boil

20.5 mins

Simmer Tests

Efficiency Metrics

n = 2	Burning rate (g/min)	Firepower (Watts)	Thermal efficiency
Mean	6.2	3099	0.21
Std. Dev.	1.65	815.28	0.11

Thermal Efficiency

21%

SQUARE CLAY STOVE

Charcoal

General Information

Cost: 10,000 Ar. *($3.00)*
Location: SAVA
Fuel(s): Charcoal
Durability: Not specified
Manufacturing Location: Sambava

Seller Information

Cost of production: 1,000 Ar.
Materials: Clay, cement, tin
Source of materials: Sambava
Sales: Manufactures 200-300 per month

Cold Start Tests

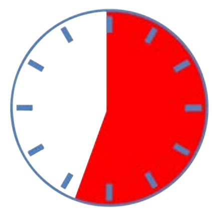
Efficiency Metrics

n = 3	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	4.57	2292	36.81	0.32
Std. Dev.	0.416	226.74	11.37	0.08

Thermal Efficiency

32%

Time to boil



33 mins

Hot Start Tests

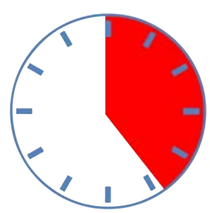
Efficiency Metrics

n = 3	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	4.20	2093	25.63	0.45
Std. Dev.	0.458	206.2	4.84	0.09

Thermal Efficiency

45%

Time to boil



24 mins

Simmer Tests

Efficiency Metrics

n = 2	Burning rate (g/min)	Firepower (Watts)	Thermal efficiency
Mean	6.1	3048	0.27
Std. Dev.	0.99	519.72	0.03

Thermal Efficiency

27%

CONCRETE STOVE

Charcoal

General Information

Cost: 10,000 Ar. *($3.00)*
Location: Antalaha
Fuel(s): Charcoal
Durability: Not specified
Manufacturing Location: Antalaha

Seller Information

Cost of production: 1,000 Ar.
Materials: Clay, cement, tin
Source of materials: Sambava
Sales: Manufactures 200-300 per month

Cold Start Tests

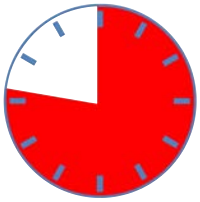
Efficiency Metrics

n = 2	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	4.3	2157	45.3	0.26
Std. Dev.	0.566	292.74	7.21	0.03

Thermal Efficiency

26%

Time to boil



46 mins

Hot Start Tests

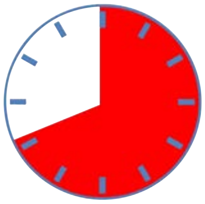
Efficiency Metrics

n = 2	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	2.70	1351	25.97	0.43
Std. Dev.	0.141	74.95	5.78	0.04

Thermal Efficiency

43%

Time to boil



41 mins

Simmer Tests

Efficiency Metrics (n = 1)

Burning rate (g/min)	Firepower (Watts)	Thermal efficiency
4.5	2259	0.38

Thermal Efficiency

38%

ARTESIAN CLAY STOVE

Charcoal

General Information

Cost: 25,000 Ar. *($8.00)*
Location: Sambava
Fuel(s): Charcoal
Durability: Not specified
Manufacturing Location: Mahajanga

Cold Start Tests

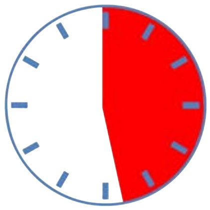
Efficiency Metrics (n = 1)

Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
6.1	3040	40.48	0.27

Thermal Efficiency

27%

Time to boil



28 mins

Hot Start Tests

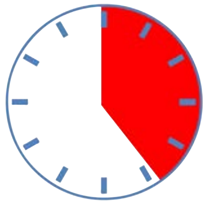
Efficiency Metrics (n = 1)

Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
5.9	2955	34.59	0.34

Thermal Efficiency

34%

Time to boil



24 mins

Simmer Tests

Efficiency Metrics (n = 1)

Burning rate (g/min)	Firepower (Watts)	Thermal efficiency
5.7	2837	0.35

Thermal Efficiency

35%

BLUE STOVE

Charcoal

General Information

Cost: 10,000 Ar. *($3.00)*
Location: Antalaha
Fuel(s): Charcoal
Durability: 4 years
Manufacturing Location: Antalaha, SAVA

Seller Information

Cost of production: 4,000 Ar.
Materials: mud, tin, iron
Source of materials: Antalaha
Sales: Manufactures ~122 per month
Note: Sells 3 different sized models

Cold Start Tests

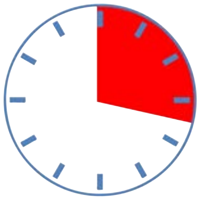
Efficiency Metrics

n = 3	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	9.1	3652	49.04	0.34
Std. Dev.	1.77	552	6.63	0.02

Thermal Efficiency

34%

Time to boil



17 mins

Hot Start Tests

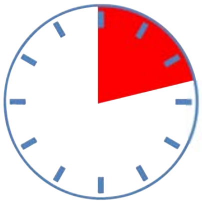
Efficiency Metrics

n = 3	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	12.03	4613	50.64	0.26
Std. Dev.	3.09	3453	4.54	0.09

Thermal Efficiency

26%

Time to boil



12.7 mins

Simmer Tests

Efficiency Metrics

n = 2	Burning rate (g/min)	Firepower (Watts)	Thermal efficiency
Mean	6.2	3106	0.21
Std. Dev.	0.44	233.87	0.08

Thermal Efficiency

21%

RED MULTI-STOVE

Charcoal

General Information

Cost: 10,000 Ar. *($3.00)*
Location: Andapa
Fuel(s): Wood, Charcoal, etc.
Durability: 5 years
Manufacturing Location: Outside Andapa

Seller Information

Cost of production: 1,125 Ar.
Materials: Clay, tin
Source of materials: Andapa
Drying time: 6 weeks
Sales: Sells door to door, makes stoves himself, 0 employees, self-taught

Cold Start Tests

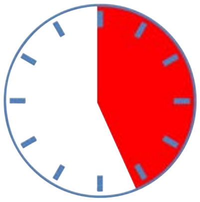
Efficiency Metrics

n = 3	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	4.6	2294	30.55	0.37
Std. Dev.	0.3	136.3	6.01	0.07

Thermal Efficiency

37%

Time to boil



26 mins

Hot Start Tests

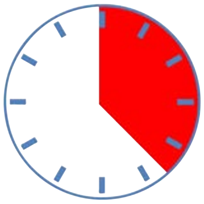
Efficiency Metrics

n = 3	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	4.93	2475	29.54	0.38
Std. Dev.	0.451	216.89	2.52	0.03

Thermal Efficiency

38%

Time to boil



23 mins

Simmer Tests

Efficiency Metrics (n = 1)

Burning rate (g/min)	Firepower (Watts)	Thermal efficiency
8	3993	0.23

Thermal Efficiency

23%

MINI HOTELY STOVE

Charcoal

General Information

Cost: 25,000 Ar. *($8.00)*
Location: Sambava
Fuel(s): Charcoal
Durability: Not specified
Manufacturing Location: Sambava

Seller Information

Cost of production: Unknown
Materials: Brick, cement, tin
Source of materials: Sambava
Sales: Sells out of home and door to door

Cold Start Tests

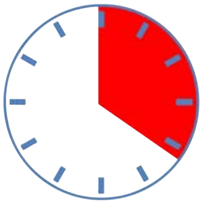
Efficiency Metrics

n = 2	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	6.65	3317	34.8	0.33
Std. Dev.	1.06	511.24	2.19	0.01

Thermal Efficiency

33%

Time to boil



21 mins

Hot Start Tests

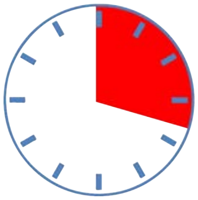
Efficiency Metrics

n = 2	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	7.75	3858	35.14	0.33
Std. Dev.	2.47	1232.48	9.38	0.08

Thermal Efficiency

33%

Time to boil



18 mins

Simmer Tests

Efficiency Metrics

n = 2	Burning rate (g/min)	Firepower (Watts)	Thermal efficiency
Mean	5.75	2864	0.15
Std. Dev.	0.35	186.97	0

Thermal Efficiency

15%

DUNG STOVE

Charcoal

General Information

Cost: 8,000 Ar. *($2.50)*
Location: Sambava
Fuel(s): Charcoal
Durability: 2-3 years
Manufacturing Location: Antalaha

Seller Information

Cost of production: 167 Ar.
Materials: Clay, tin, dung
Source of materials: Antalaha
Sales: Sells out of home and made on as-ordered basis

Cold Start Tests

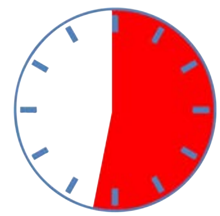
Efficiency Metrics (n = 1)

Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
5.3	2669	39.75	0.29

Thermal Efficiency

29%

Time to boil



32 mins

Hot Start Tests

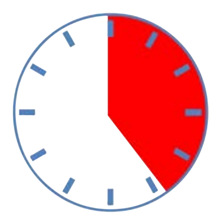
Efficiency Metrics (n = 1)

Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
7.3	3645	42.9	0.28

Thermal Efficiency

28%

Time to boil



24 mins

WHITE SLOT STOVE

Charcoal

General Information

Cost: 15,000 Ar. *($5.00)*
Location: Sambava
Fuel(s): Charcoal
Durability: 3 years
Manufacturing Location: Sambava

Seller Information

Cost of production: 5100 Ar.
Materials: Brick, cement, tin
Source of materials: Sambava
Sales: Sells out of home and door to door

Cold Start Tests

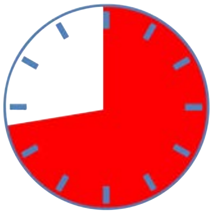
Efficiency Metrics (n = 1)

Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
4.6	2309	44.61	0.26

Thermal Efficiency

26%

Time to boil



43 mins

Hot Start Tests

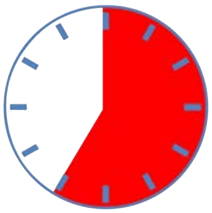
Efficiency Metrics (n = 1)

Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
3.5	1756	27.36	0.4

Thermal Efficiency

40%

Time to boil



35 mins

BASIC METAL STOVE

Charcoal

General Information

Cost: 4,000 Ar. *($1.30)*
Location: Antalaha
Fuel(s): Charcoal
Durability: 1.5 years
Manufacturing Location: Antalaha, SAVA

Seller Information

Cost of production: 0 Ar.
Materials: Tin
Source of materials: Antalaha
Sales: Sells in Antalaha markets
Note: Uses scrap tin to build

Cold Start Tests

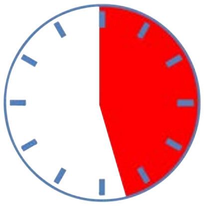
Efficiency Metrics

n = 3	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	5.27	2630	35.69	0.32
Std. Dev.	0.51	242.08	2.37	0.02

Thermal Efficiency

32%

Time to boil



27 mins

Hot Start Tests

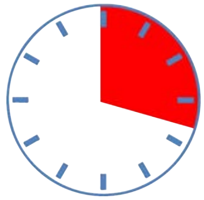
Efficiency Metrics

n = 3	Burning rate (g/min)	Firepower (Watts)	Specific Fuel Consumption (g/min)	Thermal efficiency
Mean	6	3010	32.99	0.34
Std. Dev.	0.28	152.03	1.5	0.02

Thermal Efficiency

34%

Time to boil



23 mins

Simmer Tests

Efficiency Metrics

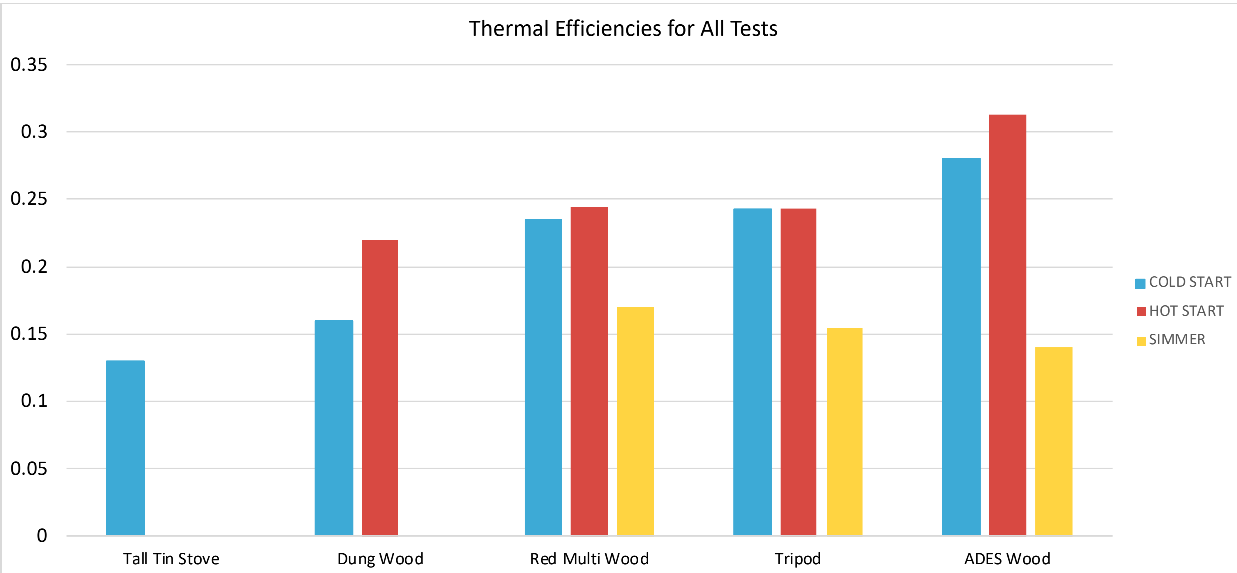
n = 2	Burning rate (g/min)	Firepower (Watts)	Thermal efficiency
Mean	6.03	3030	0.22
Std. Dev.	2.06	1019.2	0.01

Thermal Efficiency

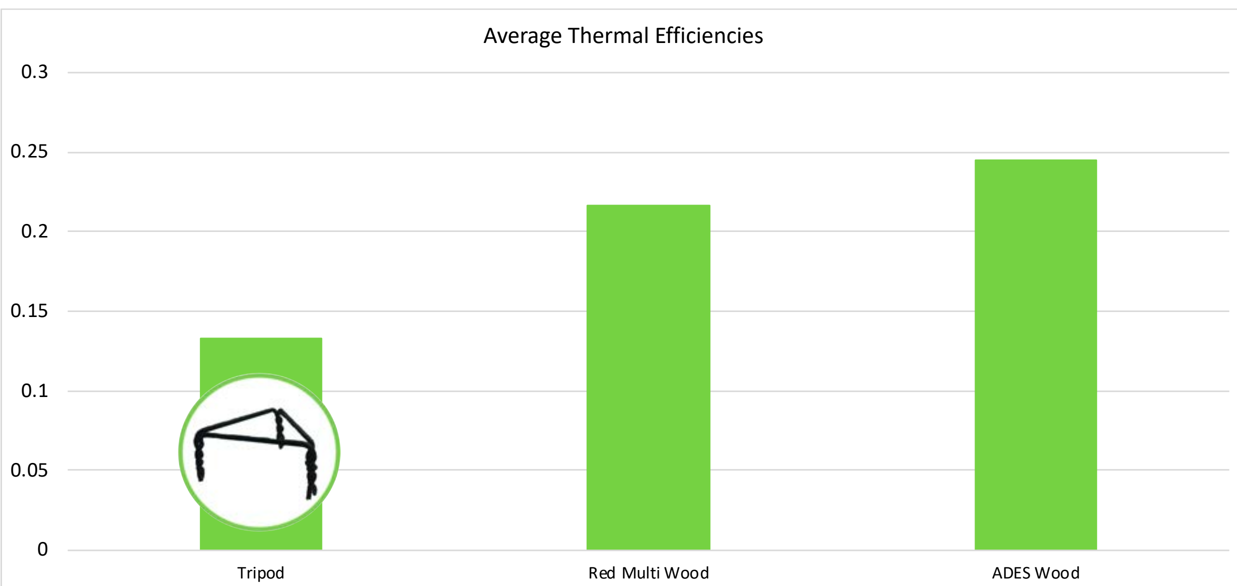
22%

STATISTICS FOR WOOD STOVES

Thermal Efficiency

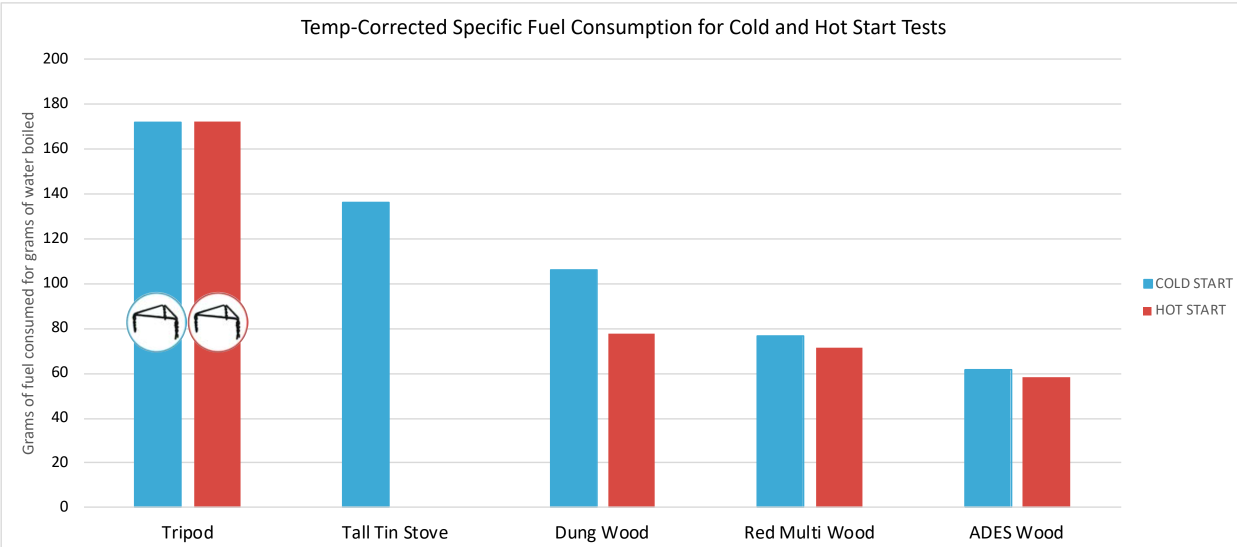


**Note: Cold start and hot start values for Tripod are identical due to the negligible heat storage capacity of the tripod*



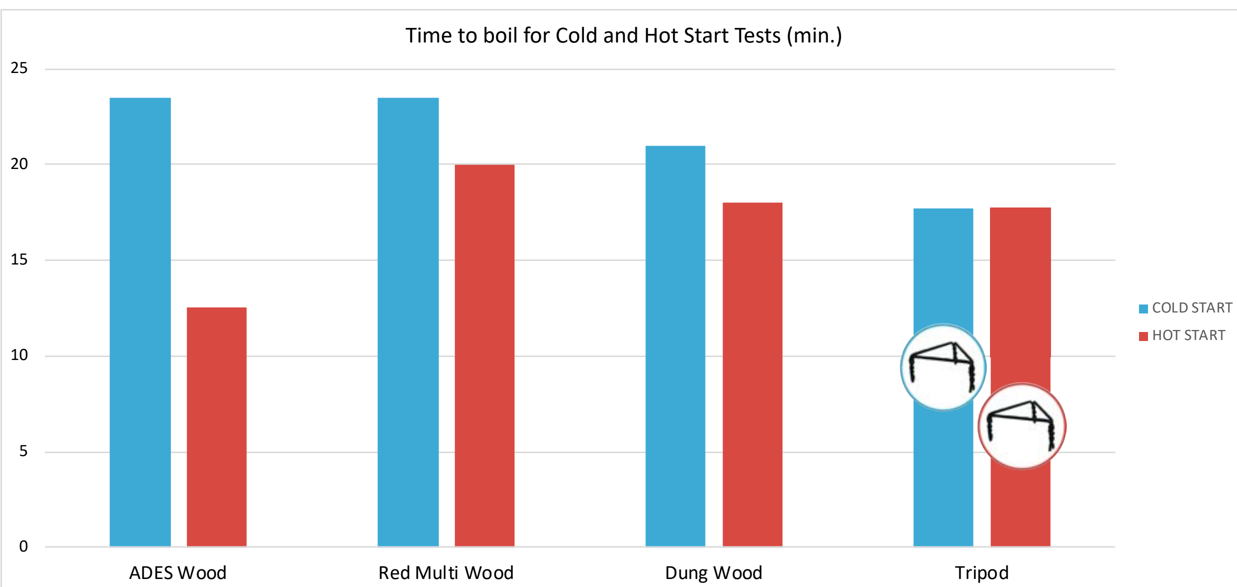
**Note: Tall Tin and Dung Wood stoves were excluded from average thermal efficiencies*

Temperature-Corrected Specific Fuel Consumption



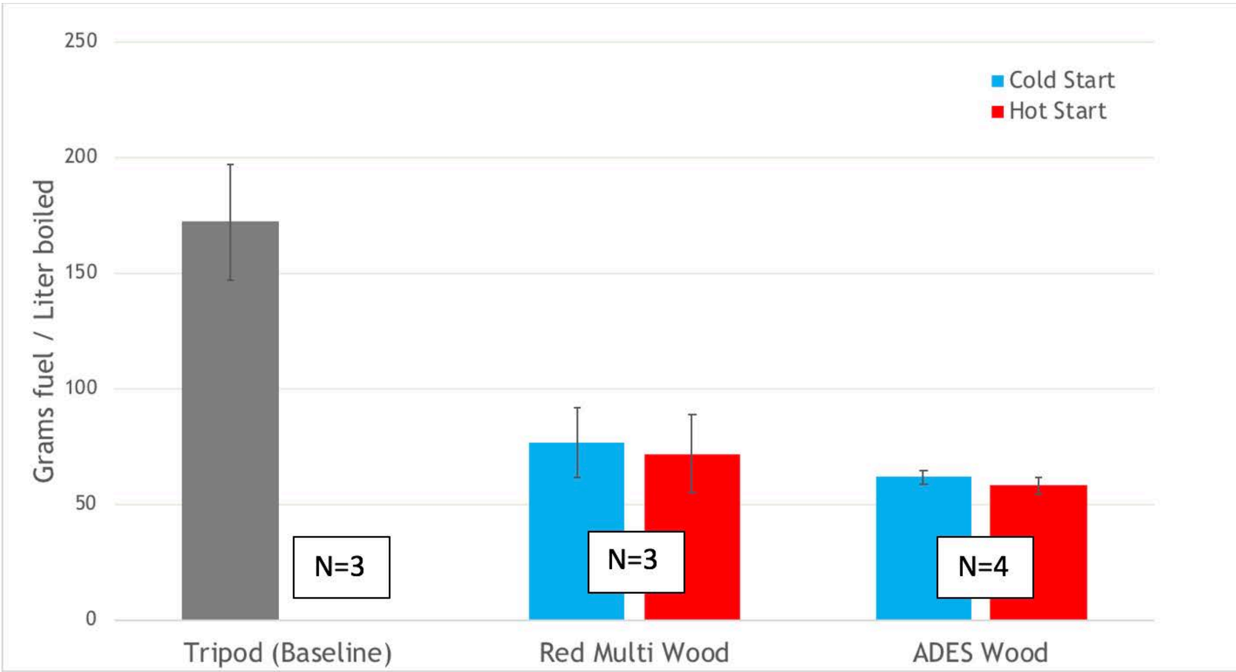
**Note: No Hot Start data available for Tall Tin stove*

Time to Boil

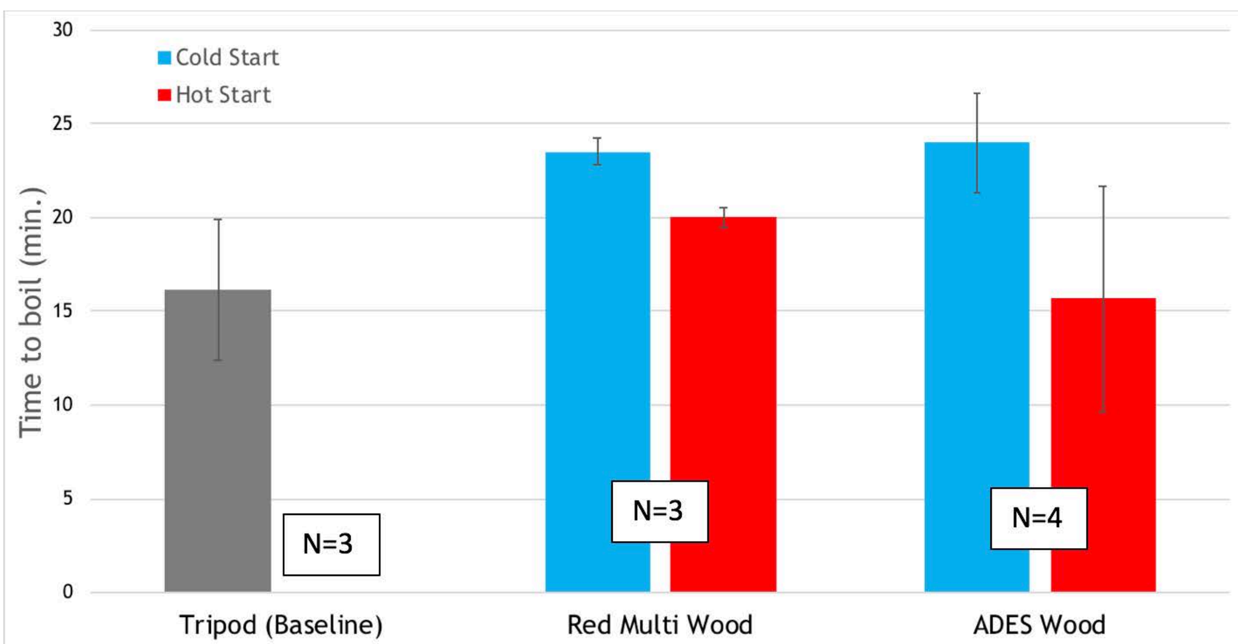


**Note: Tall Tin Stove (with a Cold Start time of 53 mins to boil) was excluded*

Empirical Analyses of Improved Wood Stoves



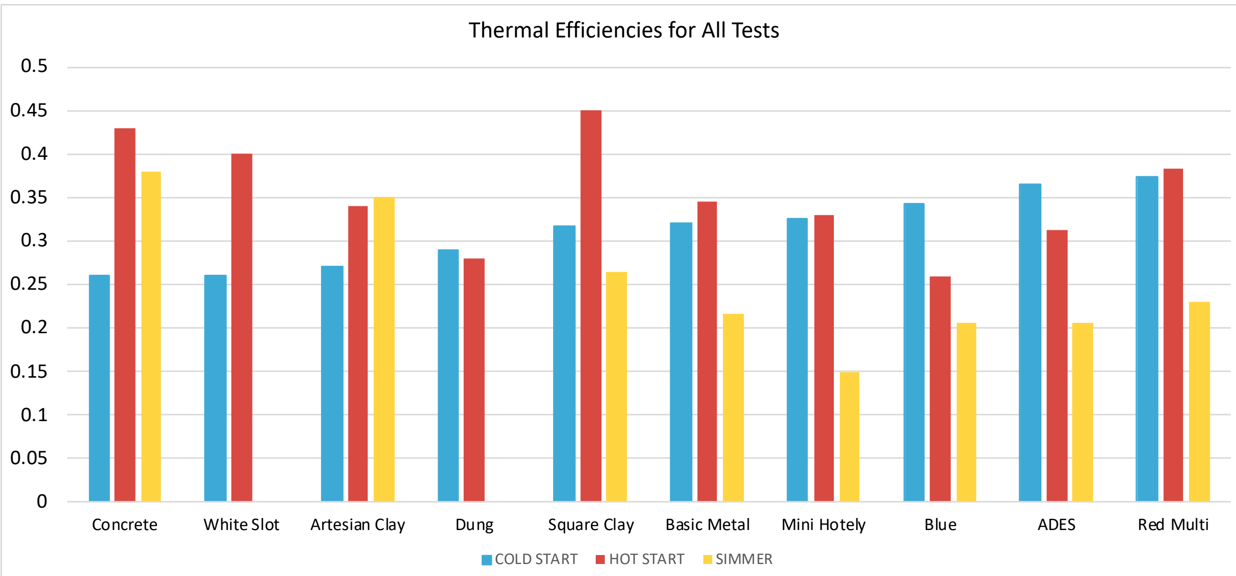
**Note: Both the Red Multi stove and the ADES stove consumed statistically less fuel than the Tripod.*



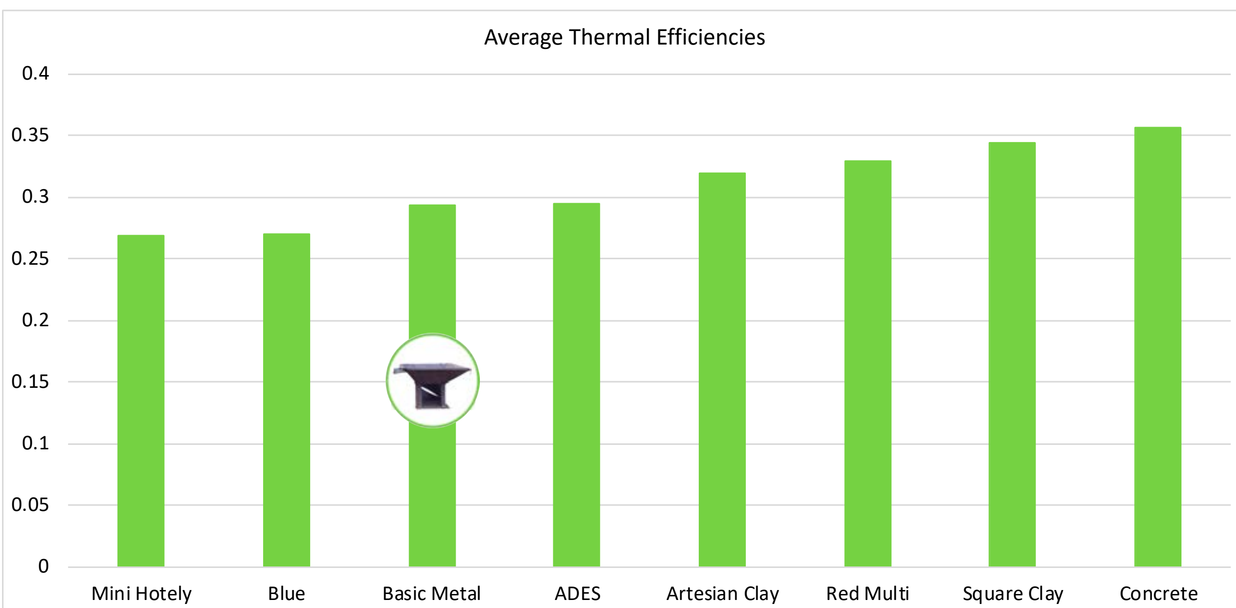
**Note: Boiling times between stoves are not statistically different.*

STATISTICS FOR CHARCOAL STOVES

Thermal Efficiency

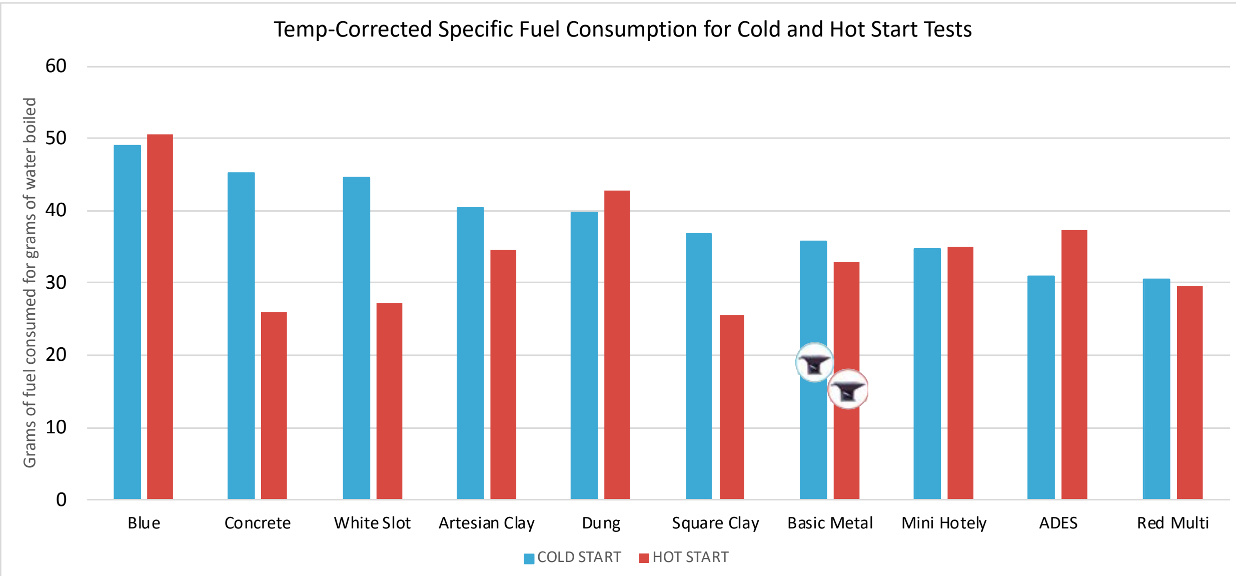


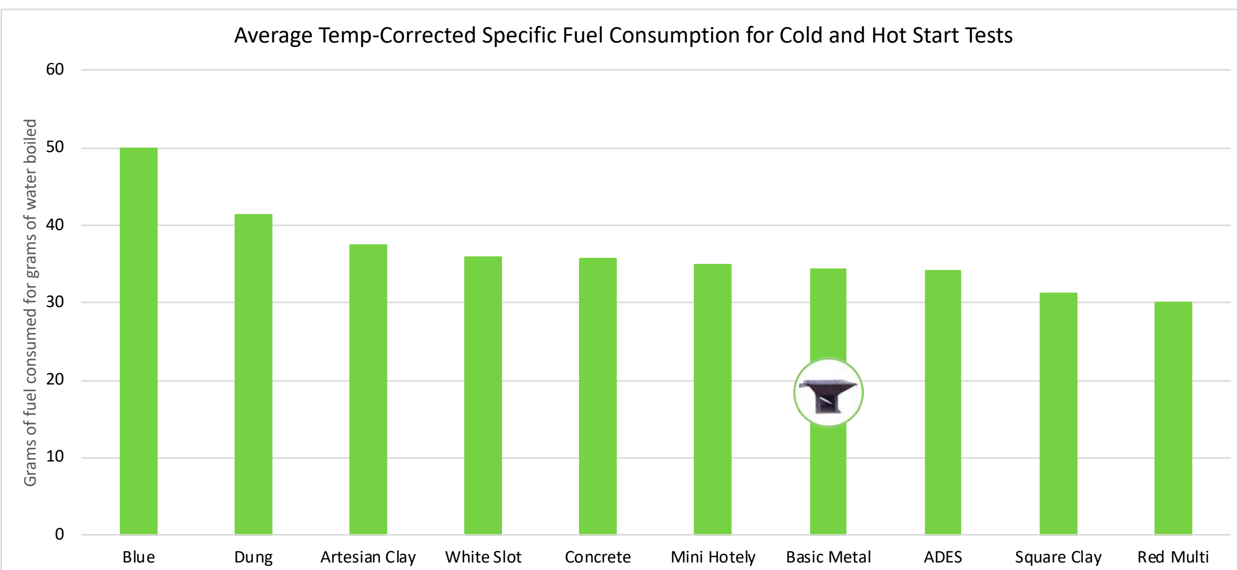
**Note: No Simmer data available for White Slot and Dung stoves*



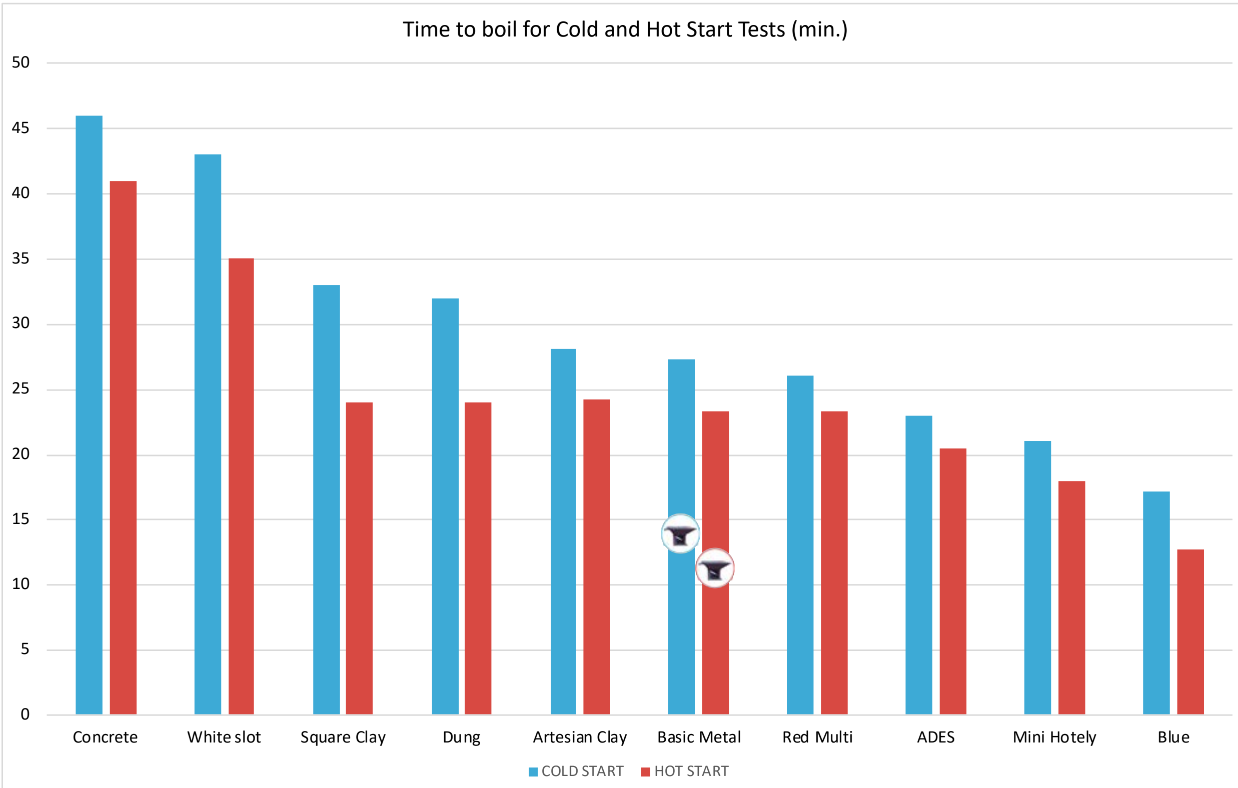
**Note: White Slot and Dung stoves were excluded from average thermal efficiencies*

Temperature-Corrected Specific Fuel Consumption



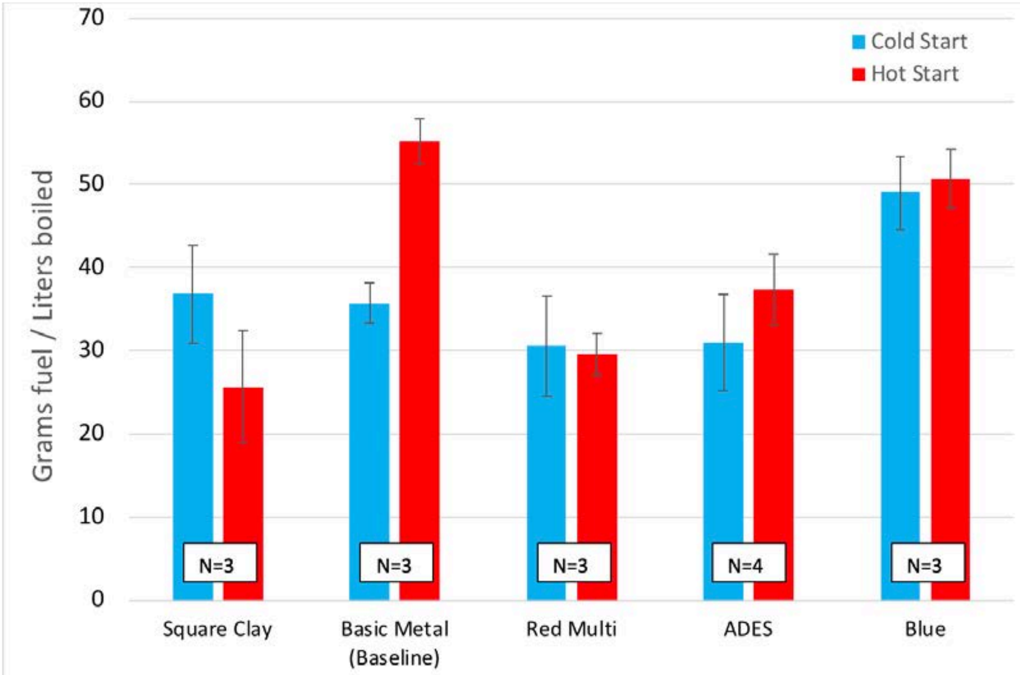


Time to Boil

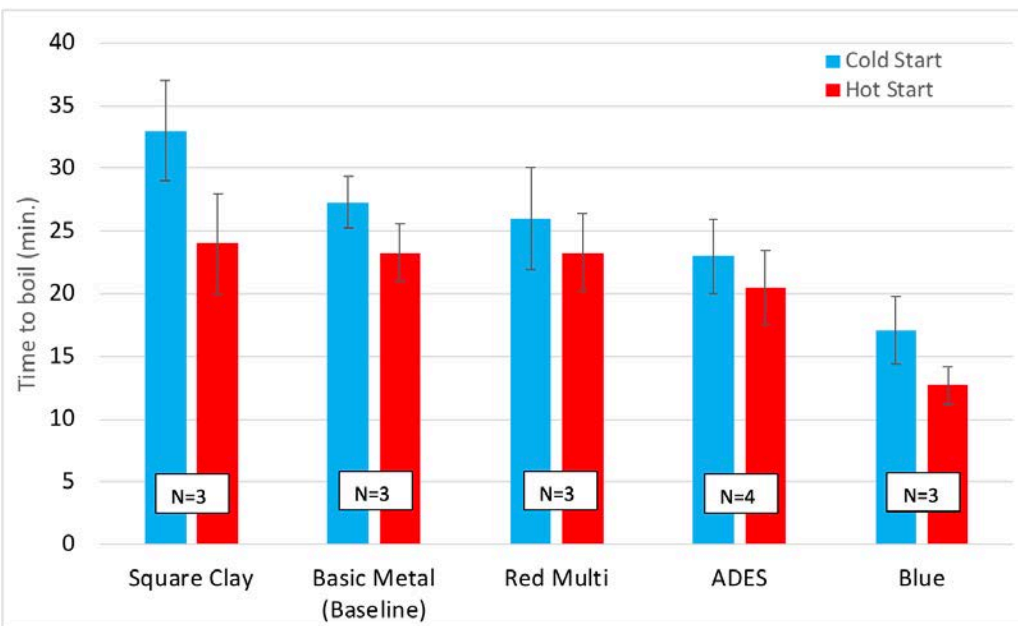


Time to boil for Cold and Hot Start Tests (min.)
50
45
40
35
30
25
20
15
10
5
0
Concrete
White slot
Square Clay
Dung
Artesian Clay
Basic Metal
Red Multi
ADES
Mini Hotely
Blue
COLD START
HOT START

Empirical Analyses of Improved Charcoal Stoves



**Note: Fuel consumption between charcoal stoves is not statistically different.*



**Note: Boiling times between stoves are not statistically different.*

DISCUSSION

It is important to note that the results presented above are consistent with values that have been reported in other countries from water boiling tests performed on similarly-designed stoves (see Jagger et al., 2017).

Improved Wood Stoves

Performance

The improved wood stoves tested hold promise for making significant reductions in household fuel consumption given proper usage and maintenance. The average family in Mandena uses approximately **8.46 kg** of fuel per day. Based on these data, the ADES wood model offers the potential to reduce daily fuel consumption to roughly **2.82 kg** per day. Put alternatively, families in Mandena consume an average of **3,088 kg** of wood per year. A complete switch to the ADES stove would reduce this consumption to around **1,029 kg** annually. The ADES also scored highest for thermal efficiency but lowest for time to boil for the cold start tests. When the stove was warmed up, however, the ADES boiled faster than the tripod for the hot start tests. While the ADES may be slow to warm up (compared to the tripod, which requires no pre-heating), it is a better stove for cooking food over long periods of time or for families who leave their stoves idle throughout the day.

While the ADES model requires about 3 times less fuel than the traditional tripod, the Red Multi Stove also scored low for temperature-corrected specific fuel consumption, requiring 2.3 times less fuel than the tripod to boil a pot of water. The Red Multi stove also scored higher than the tripod in average thermal efficiency but was the slowest to boil water among all wood-burning stoves for both cold and hot start tests.

Cost

Comparing the two best models (the ADES and Red Multi Stove) against the tripod, we see stark differences in cost of production. Assuming cost of production of an ADES-like stove in the SAVA is around the same price as the actual models, and there is no subsidization of the stoves, each stove would cost ~$12–18. on the market. The Red Multi Stove costs $3, and the cost of production is about 1/10 of that price. By comparison, the tripod costs about $1.

User Experience

Again looking at these three stoves, we can rank in terms of durability, portability and versatility. The tripod is extremely portable but not especially durable (1 year maximum). The ADES is estimated to have a durability of 3 years but due to its weight, it has poor portability. The Red Multi Stove is said to have a durability of 5 years and is somewhat more portable than the ADES. The Red Multi Stove is also unique in that it can utilize multiple fuel types including charcoal, rice hull or saw dust. For families who use multiple fuel types throughout the year, this stove is an ideal choice. (Note that it is difficult to confirm actual stove durabilities without surveying stove users).

Below, these three stoves were ranked using a number system with 1 being the worst in that category, 2 being intermediate, and 3 ranking the best. 0 is used for categories where a parameter is not applicable (therefore, those applicable are given a score of 1). Also note that these parameters are all given the same weight (all are assumed of equal importance).

The stove with the highest number of total points, scored best on average in the 7 specified categories.

Parameter	Tripod	Red Multi	ADES
Thermal Efficiency	1	2	3
Fuel Consumption	1	2	3
Time to Boil	3	1	2
Cost	3	2	1
Durability	1	3	2
Portability	3	2	1
Versatility	0	1	0
Total	**12**	**13**	**12**

Improved Charcoal Stoves

Performance

Unlike the wood-burning stoves, there are fewer stark contrasts in performance metrics between the charcoal-burning models. By choosing the Basic Metal stove as our baseline stove, the Red Multi stove and the Square Clay stove consume less fuel with the ADES model consuming only slightly less fuel than the Basic Metal stove. The Red Multi stove consumed about 5 fewer grams of fuel compared to the Basic Metal model.

In terms of average thermal efficiencies, several stoves performed markedly better than the Basic Metal model, including the Concrete, Square Clay, and Red Multi stoves. The Square Clay stove performed exceedingly well during the hot start tests, achieving an average thermal efficiency of about 45%.

While the changes in fuel consumption and average thermal efficiency between stoves appear rather marginal, the changes in boiling times between stoves do not. The Blue and Mini Hotely stoves reached a boil the fastest for both cold and hot start tests while the Concrete and White Slot stoves took the longest to reach a boil.

Cost

With the exception of the ADES and the Mini Hotely stoves, nearly all of the charcoal stoves cost less than $1.50 to produce. The Basic Metal stove can even be built for free, using recycled scrap metal (as one producer did in Antalaha). Additionally, there are an abundance of resources and knowledge surrounding design and construction of charcoal stoves, generally, and stoves are made of materials like brick, clay, concrete, and dung. These materials are affordable and readily available in town markets.

User Experience

In terms of durability, portability, and versatility, the Basic Metal stove scores well. These stoves can be easily carried from place to place, may break down slower than clay or concrete stoves and can be more easily repaired or replaced. All of the clay and concrete stoves are much heavier and clumsier to carry. The Mini Hotely stove is especially cumbersome since it has no side handles and is the heaviest of all the stoves that were tested. In terms of durability, both the Blue stove and the Red Multi-stove ranked well, and as mentioned earlier, the Red Multi-stove is also the most versatile (according to the manufacturer).

Below the eight charcoal stoves with complete efficiency data were ranked using a number system as before. For thermal efficiency, fuel consumption, and time to boil a scale of 1-8 was used (with 1 being the worst in that category and 8 being the best). For cost, a scale of 1-4 was used with 1 being the most expensive, 4 being the least. For durability, a scale of 1-3 was used with 1 being the least durable, 3 being the most. For portability, a scale of 1-4 was used with 1 being the least portable, and 4 being the most. Lastly, for versatility a scale of 0-1 was used with 0 representing not versatile and 1 representing versatile. Again, note that these parameters are all given the same weight (all are assumed of equal importance).

The stove with the highest number of total points, scored best on average in the denoted 7 categories.

Parameter	ADES	Square Clay	Concrete	Mini Hotely	Blue	Basic Metal	Artesian Clay	Red Multi
Thermal Efficiency	4	7	8	1	2	3	5	6
Fuel Consumption	6	7	3	4	1	5	2	8
Time to Boil	6	2	1	7	8	4	3	5
Cost	1	3	3	1	2	4	2	2
Durability	3	2	2	3	3	1	2	3
Portability	3	2	2	1	2	4	2	2
Versatility	0	0	0	0	0	0	0	1
Total	**23**	**23**	**19**	**17**	**18**	**21**	**16**	**27**

RECOMMENDATIONS

Continue Distribution of ADES Stoves

One option for the DLC is to continue its current transport, subsidization, and sale of ADES stoves in the SAVA region.

Advantages

The DLC has an established relationship with the ADES NGO and an established practice of importing stoves from Tana to the SAVA. Since the ADES is not manufactured in the SAVA, demand is likely relatively higher for this stove both because it is unique, officially branded, and competitively-priced (with subsidization). Increased sales of the ADES wood model could also yield positive environmental effects since it consumes 3x less wood than traditional tripods. Continued sale of these models should be accompanied by user training and follow-up to see if the stoves are actively being used (and if not, why?).

Disadvantages

The current practice of importing stoves is time and resource-intensive for the DLC. Furthermore, the cost subsidization model is not sustainable for the long term. Additionally, our data reveal that the effects of the ADES charcoal model at consuming less fuel than traditional/local models is nebulous, and perhaps less efficient than some locally-made models. Lastly, importing of stoves does not allow the opportunity for local engagement in the production and sales processes.

Shift Focus to Local Improved Stoves

The second option for the DLC is to switch its focus to local improved stove production and terminate distribution of the ADES. In particular, the DLC should focus on improved wood stoves, which have a presumably more substantial impact on fuel consumption.

Advantages

Shifting toward production of local stoves would increase the per stove cost effectiveness (through the elimination of import costs and lower production costs, compared to the ADES) and would plausibly allow the DLC to distribute more stoves within the SAVA. Depending on the structure of the initiative, there would also be greater opportunity to create local jobs and engage the knowledge and expertise of local stove makers. This option would also allow the DLC to switch from a subsidy-based funding model to a market-based model, freeing up the time and financial resources of the DLC for other initiatives.

Disadvantages
While this shift allows the opportunity for a market-based distribution model, there would be high upfront costs both in terms of time and resources. The DLC would have to seek out and interview local stove makers, and perform further research to determine which models are the most attractive to consumers. The DLC would then have to develop a training session for cookstove makers and work on creating a distribution plan to ensure that people in rural areas (people more likely to cook with wood fuels) have access to the stoves and a high enough willingness to pay for the stove. Successful implementation would also require marketing of the stoves in a way that aligns with the mission of the DLC to protect forest and habitat for lemurs and other unique biodiversity. All the while, this process should be monitored and studied to ensure effectiveness and long-term uptake of stoves.

Offer an Improved Cookstove Certification

A third option is for the DLC to pause its current cookstove distribution project and offer an improved cookstove certification for high quality stoves already manufactured locally.

Advantages
Standard-setting, quality control, and consumer trust are demonstrated to yield higher rates of improved cookstove adoption. Instead of distributing its own stoves, the DLC could offer a certification for pre-existing stoves on the market that meet certain standards. These standards can be set by the Water Boiling Efficiency and Emissions Tests as outlined in this report. The DLC has a long-established and trusting relationship with the SAVA and a DLC certification of cookstoves may help aid in the purchasing and long-term use of improved stoves that are known to reduce emissions and fuel consumption. On-site tests (like the ones performed this past summer) can be continued and extended to in-field studies to confirm results.

Disadvantages
While the DLC would invest fewer of its own resources with this option, it would still require additional time dedicated to testing stoves and certifying those currently on the market. Additionally, the DLC would have to advertise this certification to the

region so people are made aware of the program. However, it is possible the DLC can outsource much of this work to Duke faculty and students.

Terminate the Improved Stove Initiative

The last option is for the DLC to terminate its program on improved cookstoves and/or delay the initiative until future technologies are developed and cleaner fuels are more easily accessible.

Advantages

The DLC would be able to invest its limited time and resources elsewhere and into other initiatives. This would allow the DLC to focus more heavily on its environmental education program, student training, family planning, and sustainable agriculture initiatives.

Disadvantages

Madagascar is one of the few developing countries where very minimal work has been done on energy access and cooking improvements. By investing the research, time, and resources into this initiative, the DLC is at the forefront of the development sector and success in the SAVA could inspire and inform similar initiatives across the country. Additionally, there is a strong need for Madagascar to reduce its rate of deforestation and an improved cookstove intervention serves as an obvious mitigation strategy. Terminating the initiative altogether would also discourage collaboration and financial resources from Duke faculty, staff, and students, many of whom are eager to work with the DLC on this initiative.

ADDITIONAL CONSIDERATIONS

Regardless of the DLC's ultimate course of action on the cookstove initiative, I have developed the following questions for the DLC to consider moving forward with this initiative or other related projects.

1) Are there other NGOs in Madagascar working on this issue? How may the DLC partner with or share information with them?
2) Is there industrial or semi-industrial production of improved cookstoves occurring in the SAVA?
3) Are there alternative fuels gaining a foothold in the SAVA markets? How may the DLC invest in improving energy infrastructure?
4) Can the DLC offer Sustainable Biomass Certifications for producers of charcoal, to reward and incentivize sustainable production of charcoal throughout the region?
5) How may the DLC adopt a "clean cooking curriculum" into its current environmental education program?
6) How can the DLC partner with more students, staff, and faculty at Duke?