LAB TESTS OF FIRED CLAY AND METAL ONE-POT CHIMNEYLESS STOVES

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Interim Field Report

Ouagadougou, Upper Volta

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Foreword

This is the second in a series of field reports on the work done by the CILSS Regional Woodstoves Technical Coordinator and collaborators. These are not polished, final reports but rather represent an attempt to get research results into the field quickly in order to aid other ongoing work and to stimulate debate.

Thanks again go to numerous people and organizations. First, thanks go to the National Center for Rural Artisan Training (CNPAR), Ouagadougou for use of their courtyard in Cissin to perform these tests. We would like to express special thanks to Mamadou Traore of the Handicapped Artisans Center, Ouagadougou, and Frederic Yerbanga, Guilougon, for their construction of the fired clay stove prototypes; to Mr. Norbert of the Cissin Metal Center for his construction of the metal stoves; and to Fred Hottenroth, President of the ZZ Corporation, for use of the Z Ztove. Thanks also go to the Wood-Burning Stove Group at Eindhoven for their pioneering work on shielded fires. Without the excellent support by these individuals and groups, the work presented here would not have been possible.

TABLE OF CONTENTS

LIST OF TABLES

I. INTRODUCTION AND SUMMARY

In this study, a wide variety of one-pot chimneyless stoves were tested a few times each in order to provide some direction for future efforts to develop optimal stove designs. Such an effort has recently gotten underway at the Voltaic Institute of Energy (IVE).

As in the first field report, from October 1982, all the stoves tested here were the one-pot chimneyless type. As discussed in the October report, these stoves have a number of advantages, as well as a few potential disadvantages, over the massive stoves now being disseminated throughout West Africa and many other parts of the world. These are briefly discussed below.

EFFICIENCY: The fired clay and metal stoves presented here show higher thermal efficiency than any known massive stove. Massive stoves with chimneys typically show Percents of Heat Utilized (PHUs) of 14 to 21%, and up to 25% for chimneyless models (report to be published). There are several reasons for the low efficiency of massive stoves:

- **Surface for heat exchange.** The one-pot stoves tested here provide for the hot gases to escape up around the pot, effectively increasing the surface area for heat exchange. Massive stoves with chimneys provide little surface for heat exchange to any of the pots because of the necessity to close off the stoves to prevent the escape of smoke into the room. Spherical pots aggravate this problem. The use of brittle materials such as banco (or sand and clay) can also reduce the exposed surface area, since providing a sufficiently strong support for the pot often requires constructing a very thick top plate, covering even more of the pot than could be exposed to the hot gases. Chimneyless massive stoves perform better than those with chimneys, since the second pot (or first, in the one-pot model) has more heat exchange area with the hot gases.

- **Combustion.** Combustion is better in the stoves tested here than in massive stoves generally because a grate is provided that uniformly aerates the entire firebed.

- **Draft.** The draft in a massive stove is uncontrolled and usually far too large. At the door, air pulled into the stove can hit the first pot and cool it. Because of the large channel below the first pot and the more or less stagnant air just below the top plate around it, convective heat transfer to this pot is small. To control the draft and improve heat transfer to the second pot, a baffle is usually placed directly below it to force the hot gases onto the second pot. However, the performance of the stove is fairly sensitive to the construction of this baffle and, at best, the thermal efficiency of the second pot is low. Tests show second pot efficiencies of roughly a fourth to a third that of the first pot. Because of this the second pot often does not heat well enough to actually cook, and the heat recuperated is of little use other than for preheating cooking or bathing water, or keeping food warm.

A high efficiency stove with a chimney is possible but requires a complete redesign of both the pot and the stove (report to be published).

HEAT RECUPERATION: Because of their very low mass, these lightweight stoves do not absorb a significant amount of heat that might later be used to heat water after the fire is out; massive stoves do. However, tests (report to be published) indicate that the total amount of recuperable heat in a massive stove is only 1 to 2% of the total generated by the fire and is thus negligible. Therefore, it is more efficient to always use a high efficiency stove such as the lightweight ones discussed below than to use a low efficiency massive stove and attempt to recuperate heat from it after cooking.

COST: The fired clay and metal stoves tested here can be produced for less than 1,000 CFA (US$ 1 = 350 CFA) for a single small- to medium-sized pot. It is likely that the cost of fired clay stoves can be reduced considerably. In Mali, a traditional one-pot, chimneyless fired clay stove costs the equivalent of 150 - 250 CFA. By comparison, massive cement stoves for two pots cost roughly 5,000 CFA.

PRODUCTION: The fired clay stoves similar to those presented here have been produced at a rate of 12 to 15 per day, and rates of 20 per day per potter may be possible. In a production test of the metal stoves (Sepp), rates of 60 per day by a team of three teenagers were achieved with no difficulty. By comparison, a mason cannot construct more than two cement stoves or one banco stove per day. In addition, facilities that could be used for the production of fired clay or metal stoves are already in place throughout much of the Sahel, and artisans are already trained to work with these types of materials. This may dramatically reduce the difficulty of establishing production facilities and logistics support, as well as reduce the magnitude of the artisan training programs necessary. Stove dissemination programs would thus be simply a matter of adding an additional product to the existing product lines of local artisans.

PORTABILITY: Portable stoves may be desirable for both the urban poor, who move frequently and who can't afford to buy a massive, fixed stove that they can't carry with them, and for people who prefer to cook in different areas according to the weather.

STABILITY: The portable stoves are not as stable as massive stoves; this may be a drawback.

LIFETIME: All the materials used have potential drawbacks in terms of lifetime. Fired clay resists heat and water well but is brittle. Cement resists water and physical shocks well but breaks down when exposed to heat. Banco tends to crack somewhat when exposed to a fire, and to melt in the rain. Metal is strong and shock resistant but tends to corrode (depending on the type) when exposed to high temperatures in the presence of water vapor, such as occurs when burning wet wood.

HEALTH: The chimneyless stoves presented here do not provide for the evacuation of smoke (part of the reason for their high efficiency) and thus do not provide the health benefits that a stove with a chimney provides.

SOCIAL ACCEPTABILITY: Many portable metal stoves and massive stoves are already in use in West Africa.

There were several significant tests results. First, despite the high thermal conductivity of their metal walls, the metal stoves performed quite well. With very simple design changes from the traditional West African "malgache" metal stove, significant improvements in thermal performance are possible. Simply adding a grate to this "malgache" stove increased its average PHU from 18% to 24%. Further, raising the walls around the pot and leaving only a narrow gap (1 cm) between the pot and stove walls for the smoke to escape further increased the PHU to 29%. It is hoped that rather simple adjustments in existing metal artisan stoves can mean important savings in wood use. As the skills, materials (in cities), and facilities are already in place, dissemination of metal stoves, in principle, may become much easier.

Second, the importance of this pot shielding was strongly emphasized by comparing the performance of the simple metal cylinder stove with a grate to the Z Ztove (Hottenroth). The Z Ztove has optimized combustion, but because it does not provide pot shielding to force the hot gases against the entire pot surface, it does not perform any better than the simple cylinder. Presumably, though not yet tested, adding a pot shield to this stove would improve its performance.

Third, following the October report further tests were done on the effect of secondary air and grate height. It was found that the addition of secondary air had no observable effect on the performance of the fired clay stoves tested, but that a smaller grate to pot distance did improve heat transfer somewhat.

Fourth, several double wall and preheated primary air arrangements were tried. Though the double wall arrangement improved performance somewhat over the one wall metal cylinder, it is not likely to be sufficiently economically justified. The preheating arrangement showed no statistically significant improvement over the simple double wall. Further testing needs to be done before any definitive statement is made.

II. DESIGN OF THE STOVES TESTED

A traditional three-stone "stove," five one-pot chimneyless fired clay stoves, and fourteen one-pot chimneyless metal stoves were tested. The three-stone and fired clay stoves, as well as the pots, were described in the October report and are summarized on the following pages for convenience. Detailed descriptions of the metal stoves are also provided, as is a discussion of the parameters tested with each variation.

It must be noted in examining the stove and pot designs that the values given for the dimensions are not very precise. For the fired clay stoves in particular, the edges are rounded, making difficult a determination of where a certain feature starts or stops; wall thicknesses vary; and, firing warps the form of the stove so that even forms shaped on a potter's wheel do not remain constant (i.e., have a constant diameter.) Some of these imprecisions are noted on the following pages. In addition, none of the drawings are precisely to scale; they are only illustrative.

POTS: The pots used were made of aluminum. Their dimensions are given in Table I below, and a sketch is provided in Figure 1B. The two #3 pots were used interchangeably in all stoves, except stove F where the small difference in dimensions prevented the heavier #3b pot from entering the stove opening and seating properly. Only with stove B were the #2 and #4 pots used.

TABLE I

SUMMARY OF STOVE DIMENSIONS

	Stove			
	#2	#3a	#3b	#4
Top diameter (cms)	22.0	24.5	24.5	27.5
Maximum diameter	24.5	26.5	27.0	30.5
Total height	18.0	19.0	19.0	21.0
Height from bottom to maximum diameter	8.0	10.0	10.0	10.0
Weight (kgs)	0.93	1.28	1.58	1.81
Volume (liters)	5.5	7.8	7.9	11.5

STOVE A: A sketch of "stove" A, the traditional three-stone fire, is shown in Figure 1A (traced from De Lepeleire). Three rocks are placed on a concrete slab to support the pot. The distance from the slab to the pot bottom is kept at roughly 10 cm. The diameter of the firebed can be as large as 20 cm but is typically 10 to 15 cm.

STOVES B, C, D, E, and F: These are all fired clay stoves and are described in more detail in the October report. All of the stoves are made entirely of fired clay, including the grate. They have a single wall and an open (unclosable) door for wood entry. There is no preheating of primary or secondary air. Pot supports, five in all, consist of three equally spaced strips of fired clay 0.5 cm thick by 4 to 5 cm long, and 2.5 cm wide. Sketches of these stoves are found in Figure 1. A summary of their dimensions is given in Table II.

STOVES H, K, L, M, and N: These are cylindrical and are made of 1 mm sheet steel (and, in some cases, iron rebar for pot supports). Stove ZZ is a combination of metal with fiberglass insulation.

STOVE H: This is a traditional metal "malgache" stove purchased in a local market. It consists of a metal cylinder with a solid bottom, a large door, and three metal tabs on the top rim of the cylinder extending inwards and downwards at a small angle to support the pot. The tabs are 6 cm wide by 6 cm long, with the corners well rounded and a slight taper going out.

STOVE K: This stove has a grate, a wall that rises up around the pot, and a triangular pot support made of rebar as shown in Figure 1E.

STOVE L: This is nearly identical to the traditional "malgache" stove (Stove H) except that it has a smaller door and a grate punched into the normally solid bottom. For air to enter the grate it was necessary to place this stove on three supports to raise it off the ground.

STOVE M: This is a double wall stove with a closable door. The outer wall is simply a cylinder with a solid bottom and a sliding door. The inner wall has the rounded and tapered tabs for pot supports as in Stove H, a grate that is raised up off the solid bottom of the exterior wall, and vents in its walls to let air in below its grate. When used with the door open, the space between the walls was closed at the top with a piece of cloth to create an insulating dead air space. When used with the door closed, the space between the walls was left open for air to enter at the top, descend, and preheat from contact with the hot inner wall before entering the combustion chamber.

STOVES N: These are all simple metal cylinders with the same size door (10 cm high by 12 cm wide, of which the lower 3.5 cm is below the grate) and vents (two vents, 8 cm wide and 3.5 cm high) to let air in below the grate. The vents are on opposite sides of the stove and at right angles to the door. The grate (with 200 holes 0.8 cm in diameter) itself is removable, as is the pot support (12 cm from grate to pot bottom). The pot support is made of two pieces of rebar bent into

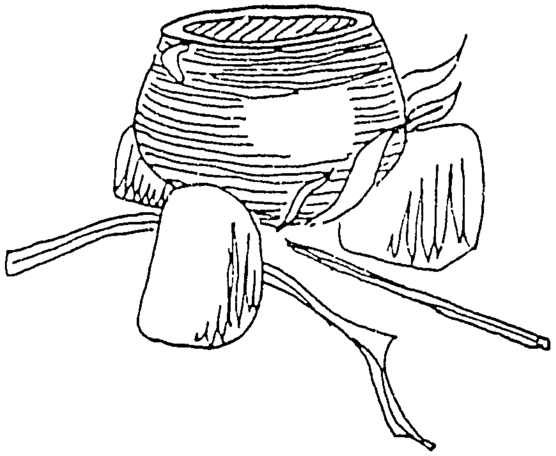

Figure 1A
Stove A--three-stone fire
(traced from De Lepeleire)

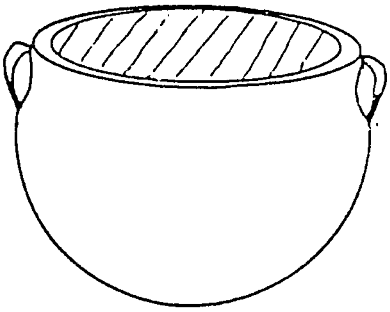

Figure 1B
Aluminum pot

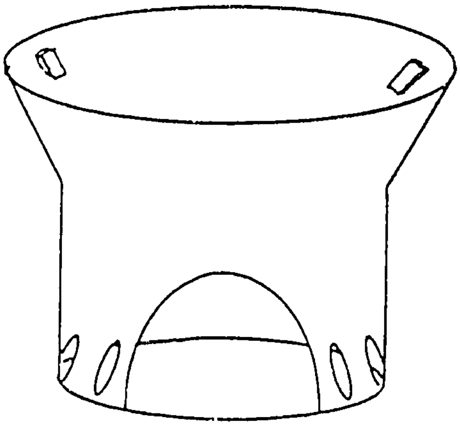

Figure 1C
Stove B (C is similar)

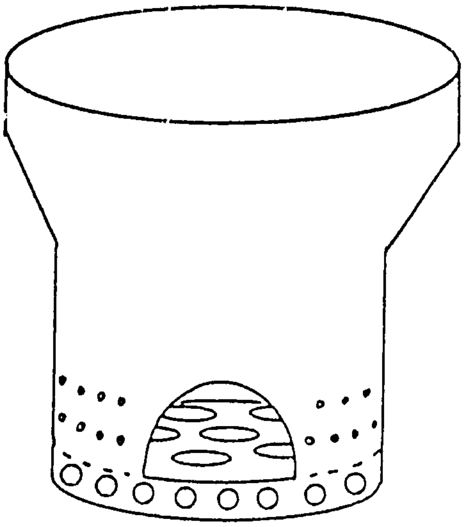

Figure 1D
Stoves D, E, and F

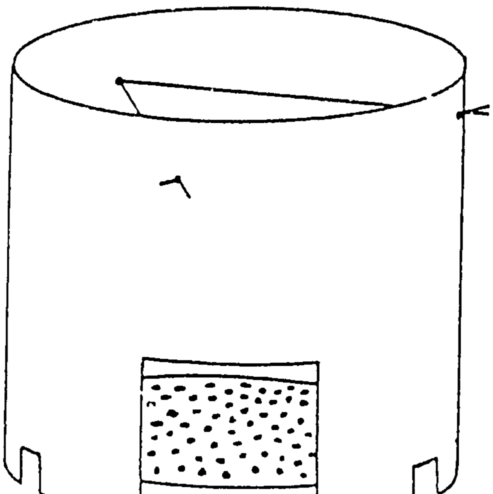

Figure 1E
Metal stove with a grate
and a triangular pot support

upside down "W's," contoured to the shape of the pot and welded together at their point of contact in the center, with additional struts attached between their legs for strength. For larger diameter shields a metal ring is placed on the grate to block air entry between the grate and the stove wall. As the same grate and pot support are always used in these tests, the parameters of firebed aeration and pot height above the firebed do not affect the results. In this way different heights and diameters of pot shields can be tested to determine the effect on efficiency and the sensitivity of the efficiency to variations in these parameters.

STOVE ZZ: The Z Ztove is produced by the ZZ Corporation. It consists of an outer shell of sheet metal 17 cm wide by 15 cm deep by 24 cm high. Within is a layer of high temperature insulation around a cylindrical combustion chamber 10 cm in diameter and 16 cm deep from grate to stove top. There are three openings into the stove: a 3.5 cm diameter hole whose center is 4.5 cm from the top of the stove for wood entry (this limits the size of wood to less than 3.5 cm diameter by 9 cm long); a slot, 5.5 cm wide by 1 cm high, 17 cm from the top of the stove, with a sliding door for secondary air to enter; and a slot, 21 cm from the top of the stove, 12 cm wide and 1.5 cm high, for primary air and for a tray to catch the cinders that fall from the grate. The sliding tray is 11.5 cm wide by 14 cm long by 1.5 cm deep. Secondary air is preheated and enters the combustion chamber through 36 holes 0.6 cm in diameter, each spaced 3 cm apart in spiral strips from the level of the grate to within 4 cm of the top of the stove. The pot rests on a spacer about 3 cm above the top of the stove. There is no provision for pot shielding.

A number of variations in the basic stoves listed above were tried to determine the effect of different parameters on stove performance. A summary of these variations is given in Table IV, using the same notation as on the data sheets.

For the fired clay stoves these variations give data on the effect of side vents (B and C), the effect of a grate (D), the effect of the grate height (E and F), the effect of primary and secondary air (D, E, and F), and the effect of the height of the stove wall around the pot (E vs. F).

Stoves H, K, and L show the effect on the traditional metal stove of adding a grate and raising the wall of the stove around the pot. Stove M crudely shows the effect of a door, double wall, and preheating the primary and secondary air. The N stoves show the effect of various heights and diameters of stove walls around the pot. Stove ZZ shows the effect of optimized combustion without the advantages of pot shielding.

TABLE II

SUMMARY OF FIRED CLAY STOVE DIMENSIONS

Feature	Stove B	Stove C	Stove D	Stove E	Stove F
Wall thickness, cms	2.0	2.0	1.0	1.0	1.0
Total height	19	19	22	21.5	26
Height, base to flare	14	12	13	13	13
Height, base to top of flare	19	19	19	19	19
Outside diameter, base	22	22	23	23	23
Outside diameter, top	31	35	30	30	30
Base	solid	solid	open	open	open
Grate	no	no	fixed	mobile	mobile
Space below bottom of grate	--	--	3.0	5.5	6.0
Grate thickness	--	--	1.0	1.0	1.0
Grate holes (1.5 cm diameter)	--	--	13	19	19
Grate supports (3 x 9 cm long, (3 wide, and 1.5 thick)	--	--	--	yes	yes
Air entry below grate (1.5 cm diameter holes)	--	--	20	18	17
Side vents above solid bottom (5 x 1.5 cm)	4	2	--	--	--
Door (height x width, cm)	11x10-16	10x12	8x12	9x11	9x10
Number secondary air holes (0.8 cm diameter)					
3 cm above grate top	--	--	16	16	16
5 cm above grate top	--	--	17	15	15
Height, grate top to bottom #3 pot	11	8	10	6.5	6.0
with grate lowered	--	--	--	10	9.5
with #2, #4 pot	9, 12.5	--	--	--	--
Height of pot exposed above stove, #3 pot	13	11	13	11	6
#2 pot, #4 pot	9, 16	--	--	--	--

TABLE III

SUMMARY OF METAL STOVE DIMENSIONS

Feature	Stove H	K	L	M (outer)	M (inner)
Height	18	22	18.5	17.5	20
Circumference	93	91.5	93	92	85
Grate, holes 0.8 cm diameter	no	62	45	no	60
Air entry below grate, 2.5 x 2.5 slots	no	5	open	no	5
Door, height x width	13x17	10x12	10x12	11x12	10x12
Secondary air, 0.8 cm diameter, 5 cm above grate	no	no	no	no	15
Grate to pot height	13	12	11	--	11

Feature	N1	N2	N3	N4	N5	N6	N7	N8 (outer)	N8 (inner)
Height	28	25	22	19	25	25	25	25	25
Circumference	91	91	92	91.5	98	104	110	98	92

TABLE IV

SUMMARY OF STOVE VARIATIONS

A1:	Three-stone fire
B1:	Stove B with all vents open
B2:	Stove B with all vents closed
B3:	Stove B with all vents open, #2 pot
B4:	Stove B with all vents open, #4 pot
C1:	Stove C with all vents open
C2:	Stove C with all vents closed
D1:	Stove D with primary and secondary airholes open
D2:	Stove D with primary (grate) holes closed, secondary open
D3:	Stove D with primary open, secondary closed
D4:	Stove D with primary closed, secondary open
E1:	Stove E with grate in place, secondary open
E2:	Stove E with grate lowered, secondary open
E3:	Stove E with grate in place, secondary closed
E4:	Stove E with grate lowered, secondary closed
E5:	Stove E with grate in place, upper half secondary closed, lower half secondary open
F1:	Stove F with grate in place, secondary open
F2:	Stove F with grate lowered, secondary open
F3:	Stove F with grate in place, secondary closed
F4:	Stove F with grate lowered, secondary closed
F5:	Stove F with grate in place, upper half secondary closed, lower half secondary open
H1:	Stove H unchanged
K1:	Stove K unchanged
L1:	Stove L unchanged
M1:	Stove M with door open
M2:	Stove M with door open
N1:	Stove N1 unchanged
N2:	Stove N2 unchanged
N3:	Stove N3 unchanged
N4:	Stove N4 unchanged
N5:	Stove N5 unchanged
N6:	Stove N6 unchanged
N7:	Stove N7 unchanged
N8:	Stove N8 unchanged
ZZ:	Stove ZZ unchanged

III. TEST METHODOLOGY

The methodology used, described in detail in the October report, generally followed the draft procedure developed by the "Working group meeting on a woodstove field test standard, Marseille, 12 - 14 May 1982" and by Dr. Timothy S. Wood. Tests were completed November - December 1982. A sample test sheet follows the testing procedure described below. On the sample test sheet letters are filled in that correspond to the column headings in the raw data in section VI, Test Results.

The testing procedure listed here is identical to that used in the October report.

1. The stove and area around it is swept clean of ashes and other debris. The stove is felt to make sure it is cool. Because of the stoves' very low thermal mass, cooling generally takes no more than 30 minutes.

2. Weather conditions, particularly wind, are noted.

3. Wood is chopped into pieces roughly 3 cm by 3 cm by 20 to 30 cm long, along with a number of very small pieces to start the fire. All wood, including kindling, is then weighed on scales accurate to 10 g over 5 kg and set to the side of the stove. A smaller amount is withdrawn from this pile, separately weighed, and used to start the fire. Any wood put into the fire is weighed and recorded separately, in addition to the overall wood weight. This provides a check that wood is not misplaced during the test

4. The pot to be used is weighed and its weight recorded. Approximately 3 kg of water are added to the pot, and the total weight of pot plus water recorded.

   The same pots and same balance tray are used each time, and their weights are known. Nevertheless, they are carefully weighed each time so that, first of all, changes in the balance performance can be quickly spotted, and secondly, so that analysis of all the readings will provide a rough error analysis and estimate of the balance's precision.

5. The wood is then arranged in the stove, a small (1 ml or so) amount of kerosene added to the wood, and the wood set on fire. While the fire becomes established, (a minute or so) the water temperature is taken. Once the fire is burning well, the pot is placed on the stove, and a stopwatch is started.

6. The temperature of the water is recorded every five minutes until the water begins to boil. The wood is pushed in or added (after weighing and recording) in order to maintain a reasonably steady, but not excessively large, fire. Different testers vary dramatically in their attitude as to what constitutes "a reasonably steady

but not excessively large fire." (In this study, variation was reduced by attempting to ensure that a tester tested each stove the same number of times.) Observations such as the color and extent of smoke, the effect of the wind on the stove, or flames shooting out the door or stove top are recorded.

7. As soon as the water starts to boil, the flames are blown out; the wood left in the stove is weighed and recorded; the total amount of wood remaining is weighed and recorded; and the pot is weighed and recorded. The amount of charcoal in the stove is neither weighed nor estimated until the end of the second part of the test. In those cases where the pot refuses to come to a boil, i.e., where it stays at a temperature of 90°C for more than 15 minutes, the first part of the test is ended as though it had been successfully completed.

8. No lids of any sort are used during any part of the test. The pots remain completely uncovered throughout.

9. After all wood and pot weights are taken and recorded, a small amount of wood is again taken from the larger pile, weighed, and added to the stove. The fire is relit, the water temperature recorded, the pot of water returned to the stove, and the timing begun again.

10. Temperature is again recorded every five minutes. The fire is maintained at a steady level to keep the water temperature above 90°C but below a vigorous boil. Again, lids are not used on the pots.

11. After 60 minutes the fire is again blown out, the weight of the wood remaining in the stove recorded, the total remaining wood weight recorded, the pot weight recorded, and the weight of the charcoal remaining after the test recorded.

It should be noted that this procedure does not provide a good resolution of the high power and low power abilities of the stove, because as pot lids are not used there is a high rate of heat loss from the pot. In order to keep temperatures close to boiling under these circumstances, the tester is obliged, even during the second part of the test--the "low power phase"--to maintain a fairly high power level. It is not clear in practice, however, how useful a true low power measurement is. Combustion can be maintained at nearly any power level with dry wood. In testing a low power level, one may be testing more the patience of the tester to cut the wood into small pieces and feed it into the stove than a real performance parameter of the stove itself.

SAMPLE LABORATORY TEST DATA SHEET

Test Number ______ "A" ______ Date ______________

Name of tester ______________ Weather conditions ______

Pot used ______________ Time ______________

Stove ______ "B" ______

START:

Weight of pot ______ "C" ______ Weight of pot w/water ___ "D" ___

Weight of balance tray ______ "E" ______

Weight of balance tray with wood ______ "F" ______

BOILING TEST:

Time	Elapsed time	Water temperature	Weight of wood added to fire	Remarks
____	0	"G"	____	____________
____	5	____	____	____________
____	10	____	____	____________
____	15	____	____	____________
____	20	____	____	____________
____	25	____	____	____________
____	30	____	____	____________
____	35 "I"	"H"*	____	____________
____	40	____	____	____________
____	45	____	____	____________

Weight of the balance tray and wood remaining in the stove ______

Total weight of unused wood and the balance tray ___ "J" ___

Weight of the pot and water ______ "K" ______

* Note that "H" is the temperature of the boiling water, and "I" is the elapsed time.

SIMMERING TEST:

Time	Elapsed time	Water temperature	Weight of wood added to fire	Remarks
____	0	"L"	____	____
____	5	____	____	____
____	10	____	____	____
____	15	____	____	____
____	20	____	____	____
____	25	____	____	____
____	30	____	____	____
____	35	____	____	____
____	40	____	____	____
____	45	____	____	____
____	50	____	____	____
____	55	____	____	____
____	60	____	____	____

Weight of the balance tray and wood remaining in the stove ____________

Total weight of unused wood and the balance tray "M" ____________

Weight of the charcoal remaining and the balance tray "N" ____________

Weight of the pot and water "O" ____________

REMARKS:

IV. CALCULATING THE PERCENT HEAT UTILIZED

The procedure used for calculating the percent heat utilized (PHU) was identical to that in the October report. The formula used was

$$PHU = \frac{4.184\ (\text{water})(\text{temp}) + 2{,}260\ (\text{evap})}{18{,}000\ (\text{wood}) - 29{,}000\ (\text{charcoal})}$$

where "water" is the initial weight of the water, "temp" is the temperature change of the water, "evap" is the mass of water evaporated, "wood" is the mass of the wood burned, and "charcoal" is the mass of charcoal remaining at the end of the test.

All weights are given in kilograms and all temperatures are given in centigrade. Note that the thermal capacity (weight x specific heat) of aluminum is ignored as it is small. The error due to this factor is discussed in greater detail below.

As noted previously, this calculation contains some implicit assumptions.

It assumes, with little error, that the latent heat of evaporation of water is 2,260 J/gm, and that the specific heat of water is 4.184 J/gm C.

Much less justifiable are the assumptions that the heat values of wood and charcoal are 18,000 J/gm and 29,000 J/gm respectively. This was not verified during the course of these tests.

In the data and analysis that follow, three different PHUs are calculated: the PHU to bring the water to a boil; the PHU of simmering the water for one hour; and the average PHU for these two parts.

The PHU for bringing the water to a boil was calculated using the equation:

$$PHU_1 = \frac{4.184\ (D-C)\ (H-G) + 2{,}260\ (D-K)}{18{,}000\ (F-J) - 14{,}500\ (N-E)}$$

where the letters indicate the data listed in the sample test sheet (see previous section) and in the columns of raw data that follow. Note that the calorific value of the charcoal remaining at the end of the test is divided equally between the first and second phases. The values for PHU_1 are listed as a percentage under column "E1" in the List of Calculated Results, Table VII.

The PHU for simmering the water for an hour is calculated similarly. In this case, the equation used is:

$$PHU_2 = \frac{4.184\ (K-C)\ (H-L) + 2,260\ (K-O)}{18,000\ (J-M) - 14,500\ (N-E)}$$

The values for PHU_2 are listed as a percentage in column E2, Table VII, List of Calculated Results.

The average PHU, listed as a percentage in column EA, Table VII, was calculated using the equation:

$$PHU_A = \frac{4.184\ (D-C)\ (H-G) + 2,260\ (D-O)}{18,000\ (F-M) - 29,000\ (N-E)}$$

Although the charcoal was weighed only once and its weight divided between the boiling and simmering stages of the test in calculating the PHU, it is likely that the charcoal is established mostly during the first stage and a steady state condition reached during the second stage. Dividing it equally between the two stages will then tend to understate the first PHU figure and overstate the second figure.

The fire power during the first and second stages was also calculated and is listed in Table VII as "P1" and "P2," in units of kilowatts. The equations used to calculate these values were:

$$P1 = \frac{18,000\ (F-J) - 14,500\ (N-E)}{60\ (I)}$$

$$P2 = \frac{18,000\ (J-M) - 14,500\ (N-E)}{3,600}$$

Greater detail on all these points is given in the October report.

V. ERROR ANALYSIS

A complete error analysis was made in the October report and will not be repeated here. In summary, it was shown that for a balance accurate to 10 grams and a stove with a PHU of 27%, intrinsic measurement errors gave an error of roughly ±1.4%. Thus, extreme attention must be given to the accuracy of the balance and, further, to ensure that the balance does not drift during the testing series. In the work done here a set of standard OHAUS weights was used to check the balance's accuracy periodically.

In addition to the problems with balance precision, it was noted above that the weight of the aluminum pot itself was not included in the PHU calculation. When the same pot is always used this obviously does not pose problems. However, in this series of tests, pot sizes from #2 to #4 were used with stove B.

Beginning with a representative test for stove B, #214, we can calculate the amount of energy used to heat the different aluminum pots, and compare that to the average PHU as calculated.

Adding a term for heating the mass of aluminum from the starting to the boiling temperature for the different sized pots we find:

Pot	Mass	PHU
--	--	27.1%
#2	0.93 kg	27.5
#3a	1.28	27.7
#3b	1.58	27.8
#4	1.81	27.9

where we have used 0.896 J/gm-C for the specific heat of aluminum (water has C≃4.184 J/gm-C).

It must be noted that using the values as given in the List of Data (Table VI) gives a PHU of 26.95% instead of 27.1%. The difference is due to using a data printout format that rounds off the values listed to fit them into the column width. In this case the value for the initial wood weight was rounded from 2.205 kg to 2.21 kg, which causes the above discrepancy. The calculated values of PHU, etc., listed in the tables use the original values, with no rounding off.

The values found above show that the error due to not including the aluminum weight of the pot itself is small and can be ignored for the tests presented here.

In addition to the above internal errors, there were several problems with the test methodology.

WIND: As previously discussed, the wind was observed to be an important factor affecting the tests. A wall was placed around each test site to reduce the wind's effect. Each wall was 80 cm high and in the shape of a "U" 70 cm wide and 110 cm deep. The open end of the U faced a three story building approximately 2 m away, reducing wind from that direction to essentially zero. Nevertheless, crosswinds were observed to disturb the stoves, and some data taken on the most windy days have been removed from consideration.

WOOD MOISTURE CONTENT: The wood moisture content was not highly variable during this series of tests since all wood was pre-dried before use, as discussed in the October report. Drying was done by placing the wood in clear polyethylene tubes 30 cm in diameter and 200 cm long for about one week before use. These tubes full of wood were left in the sun and tilted at an angle of approximately 10 degrees, to both heat the wood and provide a small air current through the thermosyphon effect to remove the moisture from the tube. Internal temperatures at midday were about 10°C above ambient. Flaps at the end of the tubes were left hanging to prevent the rain from entering. The moisture content of air-dried wood was later measured and found to be about 6%. Although unknown, it is likely that the moisture content of the wood used for these tests was less than that.

A number of problems were observed in individual tests and are listed in Table V on the following page.

TABLE V

LIST OF TESTS WITH PROBLEMS

Test Number	Problem
134	Problems with fire, wood lost during test
145	Problems with fire
154	Missing weight of pot and water at intermediate step
157	Missing weight of pot and water at intermediate step
170	Stopped after the first half due to darkness
189	Door was opened and closed throughout the test to observe the effect
193	Heavy winds
196	Test with covered pot
199B	Test with covered pot
200	Test with covered pot
204	Test with covered pot
205	Test with covered pot
206	Test with covered pot
207	Test with covered pot
221	Heavy winds
224	Heavy winds
241	Problems with fire
242	Missing data
261	Missing data
267	Heavy winds
275-289	Tests were done at a new testing site to give new testers some experience using these stoves

It is clear from looking at the variation in PHUs between tests that there remain several uncontrolled variables.

None of the above data is included in the stove PHU averages. In the summary in Table VIII they are listed in parentheses.

VI. TEST RESULTS

TABLE VI

LIST OF DATA

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
109	E2	1.28	4.28	.65	2.39	24	97	27	2.08	4.04	83	1.59	.68	3.04
110	D3	1.57	4.66	.65	2.64	27	97	50	2.13	4.05	73	1.68	.70	3.12
111	F4	1.27	4.25	.65	2.34	24	97	27	2.05	4.01	84	1.62	.685	2.85
112	E4	1.29	4.28	.645	2.55	29	98	21	2.24	4.08	86	1.73	.69	2.93
113	B2	1.29	4.43	.645	2.69	28	97	45	2.28	4.08	84	1.82	.725	3.18
114	C2	1.57	4.57	.645	2.35	29	98	42	1.88	4.23	80	1.38	.77	3.30
115	A1	1.27	4.38	.64	3.75	30	97	47	2.40	3.99	85	1.53	.84	3.26
116	E1	1.58	4.60	.65	2.71	26	97	33	2.39	4.36	84	1.99	.675	3.41
117	F1	1.28	4.36	.645	2.59	25	97	25	2.28	4.13	86	1.83	.68	3.04
118	D2	1.27	4.29	.645	2.44	29	98	34	2.11	4.05	88	1.75	.71	3.15
119	B1	1.28	4.35	.64	2.65	28	97	35	2.23	3.99	80	1.70	.71	2.98
120	C2	1.29	4.34	.65	2.56	27	97	45	2.15	3.94	84	1.64	.75	2.97
121	E3	1.28	4.21	.645	2.73	30	97	33	2.45	4.05	85	2.06	.685	3.24
122	F1	1.28	4.43	.65	2.53	27	97	40	2.19	4.08	78	1.82	.70	3.17
123	D1	1.29	4.51	.65	2.44	27	97	33	2.07	4.21	84	1.63	.70	3.26
124	F3	1.28	4.53	.645	2.70	27	97	43	2.36	4.17	82	1.90	.68	2.94
125	E2	1.29	4.29	.65	2.63	28	97	28	2.27	4.00	87	1.82	.69	2.93
126	H1	1.57	4.65	.64	2.59	28	97	33	2.09	4.33	84	1.13	.76	3.28
127	F4	1.27	4.41	.65	2.46	27	97	25	2.15	4.17	86	1.66	.69	2.97
128	K1	1.57	4.68	.645	2.79	33	97	22	2.45	4.44	88	1.86	.72	3.20
129	E4	1.28	4.35	.65	2.71	26	97	38	2.25	4.05	87	1.85	.695	2.38
130	B2	1.58	4.65	.65	2.74	29	98	45	2.27	4.29	78	1.70	.80	3.32
131	L1	1.29	4.45	.655	2.49	27	97	44	1.99	4.06	83	1.47	.78	3.28
132	A1	1.28	4.28	.65	3.91	31	97	40	3.21	3.92	83	2.34	.84	3.10
133	E1	1.57	4.58	.65	2.38	25	97	30	2.06	4.34	85	1.64	.68	3.26
134	F2	1.28	4.33	.65	2.29	28	97	43	1.94	4.04	83	1.44	.69	2.95
135	M1	1.57	4.62	.65	2.36	29	97	34	1.88	4.25	86	1.44	.78	3.15
136	B1	1.27	4.56	.64	2.61	30	97	43	2.15	4.22	87	1.64	.76	3.27
137	ZZ	1.34	4.49	.65	2.03	26	97	38	1.60	4.12	83	1.04	.72	3.17
138	E3	1.57	4.53	.645	2.13	27	97	27	1.85	4.29	89	1.42	.685	3.14
139	F1	1.28	4.25	.64	2.51	30	97	23	2.21	3.93	84	1.67	.70	2.66
140	M2	1.58	4.69	.64	2.28	28	94	45	1.67	4.35	80	1.32	.76	3.29
141	F5	1.28	4.33	.645	2.64	29	98	26	2.36	4.04	82	1.98	.67	2.97
142	H1	1.58	4.47	.65	2.67	26	97	35	1.98	4.06	86	1.29	.77	3.06
143	F3	1.28	4.34	.65	2.41	27	97	35	2.12	4.07	86	1.72	.68	2.77
144	E2	1.58	4.69	.65	2.54	27	97	24	2.18	4.42	87	1.63	.68	3.23
145	F4	1.28	4.31	.65	2.82	28	98	35	2.43	3.97	81	1.87	.71	2.81
146	K1	1.58	4.68	.65	2.64	26	97	30	2.27	4.39	85	1.74	.72	3.25
147	E4	1.28	4.32	.65	2.81	30	97	18	2.53	4.12	87	2.03	.68	2.89
148	B2	1.28	4.33	.65	2.64	29	95	49	2.08	3.82	81	1.48	.77	2.83
149	L1	1.57	4.51	.645	2.58	28	97	30	2.16	4.17	79	1.62	.73	3.22
150	E1	1.58	4.40	.64	2.37	28	97	38	1.98	4.07	86	1.54	.69	2.89
151	A1	1.28	4.31	.65	3.74	29	97	34	2.98	4.01	86	1.77	.84	2.86
152	F2	1.28	4.53	.65	2.23	26	97	21	1.98	4.31	88	1.53	.69	3.12
153	M1	1.58	4.59	.65	2.51	28	98	35	2.02	4.11	87	1.43	.78	3.02
154	B1	1.28	4.37	.65	2.35	27	97	25	2.03	0	83	1.47	.70	3.05

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
155	E3	1.58	4.74	.65	2.21	28	97	22	1.90	4.54	88	1.44	.67	3.28
156	ZZ	1.35	4.54	.64	2.19	27	97	35	1.75	4.17	82	1.16	.73	3.18
157	F1	1.28	4.30	.65	2.43	27	97	26	2.13	0.00	88	1.75	.70	3.03
158	M2	1.57	4.51	.655	2.60	24	97	18	2.23	4.32	83	1.68	.74	3.12
159	F5	1.28	4.29	.655	2.60	25	97	26	2.30	4.02	86	1.82	.69	2.80
160	F3	1.27	4.31	.645	2.15	29	97	20	1.89	4.09	88	1.51	.69	3.05
161	H1	1.58	4.58	.65	2.66	22	97	40	2.02	4.21	85	1.11	.80	3.05
162	E2	1.28	4.44	.645	2.57	26	97	20	2.22	4.25	88	1.64	.70	2.95
163	F4	1.28	4.42	.645	2.15	30	97	18	1.85	4.20	88	1.40	.685	3.00
164	K1	1.57	4.56	.65	2.42	24	97	20	2.11	4.29	86	1.57	.70	3.07
165	E4	1.27	4.43	.65	2.32	25	97	20	2.01	4.22	88	1.55	.68	3.08
166	A1	1.28	4.41	.65	3.60	30	97	43	2.66	4.10	84	1.56	.89	2.95
167	B2	1.57	4.60	.645	2.60	31	97	20	2.24	4.34	85	1.68	.70	3.12
168	L1	1.57	4.61	.65	2.33	25	97	25	2.00	4.42	88	1.43	.75	3.44
169	E1	1.28	4.39	.65	2.42	27	97	27	2.04	4.27	87	1.72	.70	3.00
170	F4	1.28	4.29	.645	2.31	30	97	31	1.97	3.93	0	0	.73	0
171	M1	1.58	4.66	.65	2.36	27	97	21	2.04	4.42	89	1.57	.69	3.31
172	B1	1.28	4.38	.65	2.05	27	97	25	1.68	4.12	87	1.11	.73	3.09
173	E3	1.28	4.30	.645	2.61	31	97	18	2.31	4.12	88	1.86	.68	2.91
174	ZZ	1.34	4.42	.64	2.13	27	97	18	1.86	4.20	88	1.39	.69	3.22
175	F1	1.28	4.30	.64	2.28	25	97	20	2.04	4.10	88	1.61	.68	2.76
176	M2	1.58	4.33	.64	2.23	25	97	25	1.85	3.99	88	1.29	.80	2.82
177	F5	1.28	4.30	.64	2.15	25	97	19	1.91	4.13	85	1.53	.67	3.03
178	F3	1.27	4.30	.64	2.16	32	97	29	1.82	3.97	86	1.37	.72	2.74
179	H1	1.58	4.57	.65	2.62	26	97	25	2.08	4.33	87	1.30	.82	3.31
180	E2	1.27	4.31	.64	2.28	25	97	15	2.02	4.13	87	1.60	.68	3.12
181	F4	1.28	4.27	.65	2.24	24	97	22	1.94	4.05	85	1.49	.68	2.63
182	K1	1.57	4.57	.64	2.49	24	97	30	2.11	4.28	85	1.43	.73	3.09
183	E4	1.27	4.38	.64	2.69	23	97	22	2.23	4.14	89	1.76	.68	2.86
184	A1	1.27	4.29	.64	3.20	30	92	35	2.34	4.02	79	1.36	.81	3.22
185	B2	1.28	4.28	.645	2.77	24	97	25	2.38	3.93	84	1.80	.71	2.74
186	L1	1.57	4.58	.64	2.28	25	97	25	1.89	4.32	86	1.37	.70	3.29
187	E3	1.27	4.35	.645	2.21	29	97	20	1.96	4.15	88	1.54	.70	3.08
188	F2	1.28	4.38	.65	2.27	24	97	26	2.00	4.14	88	1.52	.69	2.82
189	M12	1.56	4.88	.645	2.52	25	98	25	2.04	4.63	85	1.35	.77	2.25
190	B1	1.28	4.31	.645	2.27	23	97	33	1.88	3.99	86	1.34	.72	2.82
191	E3	1.28	4.39	.64	2.26	29	97	31	1.98	4.15	88	1.51	.70	3.02
192	ZZ	1.34	4.44	.645	2.49	22	97	25	2.12	4.16	85	1.53	.71	3.15
193	F1	1.28	4.29	.65	2.35	24	97	25	2.03	4.06	85	1.57	.695	2.91
194	M1	1.27	4.28	.64	2.69	26	97	21	2.36	4.05	87	1.77	.75	2.87
195	ZZ	1.63	4.71	.65	2.11	26	92	45	1.58	4.23	84	0.94	.72	3.42
196	F5C	1.28	4.32	.645	2.63	25	98	23	2.42	4.22	86	2.04	.675	3.14
197	F5	1.28	4.32	.645	2.30	24	97	31	1.99	4.07	88	1.66	.68	2.95
198	H1	1.28	4.29	.645	2.84	25	97	44	2.06	3.91	85	1.11	.82	2.81
199	F3	1.27	4.33	.64	2.36	21	97	30	2.03	4.05	85	1.58	.695	2.81
199B	F3C	1.27	4.40	.64	2.43	23	98	19	2.15	4.25	89	1.74	.69	3.12
200	E2C	1.27	4.39	.645	2.37	23	98	27	2.08	4.30	88	1.68	.685	3.54
201	K1	1.56	4.58	.65	2.68	20	97	38	2.24	4.10	83	1.56	.79	2.75
202	F4	1.27	4.29	.65	2.12	23	97	27	1.81	4.05	88	1.37	.69	2.80
203	E4	1.27	4.27	.64	2.22	22	97	21	1.93	4.04	87	1.38	.685	2.72

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
204	F1C	1.27	4.39	.65	2.31	25	98	23	2.08	4.31	90	1.73	.685	3.36
205	F1C	1.27	4.31	.65	2.26	23	98	24	2.01	4.19	91	1.61	.69	3.05
206	F1C	1.27	4.28	.65	2.28	25	98	38	2.00	4.18	90	1.58	.71	3.13
207	F1C	1.28	4.29	.65	2.44	22	98	25	2.21	4.21	90	1.84	.69	3.30
208	F1	1.27	4.30	.65	2.13	30	97	25	1.86	4.03	89	1.36	.68	2.56
209	B2	1.27	4.29	.64	2.61	19	97	30	2.24	4.03	87	1.68	.725	2.80
210	L1	1.27	4.28	.64	2.47	24	97	50	1.93	3.84	85	1.32	.75	2.86
211	E1	1.57	4.57	.64	2.47	22	97	27	2.20	4.32	87	1.71	.71	3.02
212	F2	1.27	4.35	.645	2.53	23	97	30	2.20	4.09	89	1.69	.71	2.75
213	M1	1.57	4.57	.65	2.42	23	97	23	2.03	4.32	88	1.47	.74	3.17
214	B1	1.57	4.55	.645	2.21	22	97	37	1.80	4.29	87	1.22	.735	3.15
215	E3	1.27	4.33	.645	2.59	21	97	25	2.29	4.10	88	1.85	.70	2.95
216	A1	1.27	4.32	.64	3.18	27	97	36	2.25	4.08	86	1.10	.885	3.12
217	F5	1.27	4.28	.64	2.05	22	97	23	1.78	4.02	87	1.31	.675	2.64
218	K1	1.57	4.59	.645	2.10	21	97	24	1.72	4.25	83	1.17	.71	3.16
219	F3	1.27	4.35	.64	2.52	23	97	23	2.18	4.05	88	1.73	.73	2.72
220	H1	1.57	4.57	.64	3.24	20	97	30	2.54	4.27	85	1.43	.93	3.04
221	E2	1.27	4.35	.645	2.53	20	97	23	2.07	4.08	88	1.29	.695	2.85
222	F4	1.27	4.27	.65	2.43	19	97	33	2.08	3.97	88	1.55	.71	2.59
223	M3	1.57	4.54	.65	2.39	21	97	33	1.92	4.23	85	1.30	.695	3.10
224	E4	1.28	4.28	.65	2.30	19	97	32	1.74	3.90	86	1.03	.70	2.27
225	L1	1.57	4.58	.645	2.32	22	97	29	1.82	4.25	83	1.04	.78	3.12
226	F3	1.27	4.37	.64	2.44	27	97	25	2.11	4.09	87	1.51	.71	2.80
227	H1	1.58	4.58	.65	2.59	23	97	28	1.94	4.25	87	1.08	.815	3.04
228	B3	.935	3.94	.65	2.02	23	97	21	1.67	3.77	88	1.15	.75	2.73
229	F4	1.27	4.34	.645	2.14	21	97	27	1.87	4.15	88	1.36	.71	2.76
230	N2	1.57	4.58	.645	2.21	22	97	28	1.85	4.28	88	1.35	.73	3.24
231	A1	1.27	4.35	.65	3.75	22	97	34	2.80	4.13	86	1.59	.86	3.05
232	B1	1.27	4.26	.645	2.02	27	97	21	1.68	4.08	88	1.12	.77	2.93
233	N4	1.27	4.28	.645	2.49	32	97	39	1.93	3.92	88	1.20	.765	2.95
234	F2	1.28	4.28	.645	2.33	22	97	25	2.06	4.06	87	1.55	.71	2.74
235	N1	1.58	4.58	.645	2.65	22	97	35	2.25	4.25	86	1.66	.735	3.11
236	B4	1.81	4.82	.65	2.39	27	97	32	1.91	4.38	85	1.45	.73	3.30
237	N5	1.57	4.57	.64	2.53	23	97	35	2.02	4.27	87	1.34	.74	3.40
238	F1	1.27	4.28	.645	2.57	23	97	30	2.31	4.02	88	1.91	.69	2.80
239	N3	1.57	4.57	.64	2.76	20	97	26	2.22	4.24	86	1.35	.745	2.90
240	N6	1.58	4.58	.645	2.67	19	97	40	1.80	4.24	88	0.99	.78	3.12
241	F5	1.28	4.30	.64	2.31	21	97	27	1.76	3.93	86	1.06	.71	2.88
242	N7	1.57	4.57	.645	2.41	27	91	70	0	0	0	1.21	.735	3.70
243	N8	1.58	4.59	.64	2.21	18	97	19	1.88	4.32	88	1.23	.70	2.97
244	F3	1.27	4.28	.64	2.29	21	97	30	1.94	3.98	87	1.40	.70	2.53
245	H1	1.57	4.57	.645	3.65	24	97	40	2.78	4.14	88	1.79	.87	3.05
246	B3	0.93	3.93	.645	2.33	24	97	25	1.96	3.71	89	1.40	.73	2.62
247	F4	1.26	4.27	.645	2.24	24	97	25	1.84	3.97	88	1.29	.725	2.69
248	N2	1.57	4.57	.65	2.44	21	97	26	2.05	4.33	89	1.40	.73	2.95
249	A1	1.27	4.27	.65	3.43	23	97	40	2.49	3.92	87	1.57	.81	2.88
250	B1	1.27	4.27	.645	2.53	28	97	22	2.20	4.05	88	1.67	.72	2.80
251	N4	1.57	4.57	.645	2.24	22	97	34	1.59	4.28	90	0.82	.78	3.18
252	F2	1.26	4.26	.645	2.14	19	97	27	1.77	3.99	89	1.34	.70	2.80
253	N1	1.57	4.57	.64	2.25	27	97	18	1.93	4.34	88	1.26	.69	2.97

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
254	B4	1.81	4.81	.645	2.43	18	97	27	1.95	4.53	86	1.10	.79	3.02
255	N5	1.57	4.57	.64	2.35	19	94	45	1.54	4.06	85	0.85	.73	3.24
256	F1	1.27	4.27	.645	2.08	23	97	25	1.72	3.93	87	1.16	.695	2.58
257	N3	1.57	4.57	.645	2.55	23	97	31	1.97	4.29	88	1.23	.715	3.02
258	N6	1.57	4.57	.645	2.61	18	97	39	1.94	4.28	87	1.17	.76	3.24
259	F5	1.27	4.27	.645	2.36	18	97	32	2.02	4.00	89	1.60	.715	2.87
260	N7	1.27	4.27	.64	3.19	26	97	25	2.49	4.03	89	1.47	.79	2.82
261														
262	F3	1.27	4.27	.645	2.11	19	97	23	1.83	4.03	89	1.32	.69	2.53
263	H1	1.57	4.57	.645	3.00	18	97	24	2.34	4.31	86	1.43	.81	3.09
264	B3	0.93	3.93	.645	2.09	18	97	24	1.69	3.74	88	1.08	.715	2.48
265	F4	1.27	4.27	.645	2.23	19	97	18	1.95	4.05	90	1.37	.70	2.61
266	N2	1.57	4.57	.64	2.26	24	97	22	1.89	4.35	89	1.15	.72	2.97
267	A1	1.57	4.57	.64	4.89	22	85	40	3.41	4.25	79	1.16	.83	3.45
268	B1	1.27	4.27	.64	2.50	21	97	29	2.01	3.93	86	1.42	.71	2.76
269	N4	1.27	4.27	.645	2.66	22	97	33	1.96	3.96	83	0.78	.79	2.81
270	F2	1.27	4.27	.64	2.07	19	97	33	1.62	3.94	86	0.99	.70	2.52
271	N1	1.57	4.57	.64	2.46	17	97	24	2.01	4.23	85	1.19	.74	2.91
272	B4	1.79	4.79	.645	2.60	25	97	25	1.95	4.44	88	1.04	.80	3.01
273	N5	1.57	4.57	.64	2.59	17	97	32	1.84	4.19	87	0.85	.715	3.12
274	F2	1.27	4.27	.645	2.11	18	97	27	1.65	3.95	89	1.10	.685	2.45
275	L1	1.27	4.33	0	2.78	20	99	17	2.41	4.13	83	1.49	.067	2.37
276	C1	1.41	4.45	0	2.55	24	98	17	2.07	4.28	85	1.17	.077	2.54
277	B1	1.39	4.37	0	2.44	23	98	12	2.01	4.18	85	.962	.094	2.13
278	K1	1.36	4.33	0	2.24	22	99	19	0	0	86	.846	.049	2.08
279														
280	F1	1.24	4.21	0	2.74	20	99	11	2.46	4.07	80	1.86	.018	2.17
281		1.27	4.27	0	2.36	22	98	12	1.91	4.08	85	.961	.083	2.15
282	K1	1.53	4.64	0	2.86	19	99	16	2.37	4.43	86	1.14	.098	2.31
283														
284	N3	1.34	4.38	0	2.31	23	98	13	2.10	4.22	85	1.01	.026	2.32
285	B1	1.24	4.23	0	2.78	19	98	18	2.38	4.06	88	1.43	.081	2.33
286	C1	1.40	4.39	0	2.37	19	99	19	1.90	4.18	82	1.01	.109	2.28
287		1.45	4.49	0	2.19	23	99	13	1.59	4.29	82	0.53	.111	2.32
288	N6	1.41	4.43	0	2.32	22	99	12	1.79	4.30	84	.392	.089	2.57
289														

VII. ANALYSIS OF THE TESTS RESULTS

TABLE VII

LIST OF CALCULATED RESULTS

A	B	P1	P2	E1	E2	EA
109	E2	3.1	2.3	28.3	28.8	27.4
110	D3	2.8	2.0	27.0	31.8	27.7
111	F4	2.9	2.0	30.8	38.3	34.1
112	E4	3.9	2.3	26.4	31.7	28.8
113	B2	2.3	1.9	26.7	31.1	27.8
114	C2	2.6	2.0	24.5	32.0	27.0
115	A1	7.5	3.5	8.1	14.0	9.9
116	E1	2.7	1.9	26.4	33.6	29.2
117	F1	3.3	2.1	28.5	34.1	30.8
118	D2	2.4	1.5	28.3	38.8	32.7
119	B1	3.1	2.3	25.9	29.0	26.4
120	C2	2.2	2.1	30.1	30.2	29.1
121	E3	2.2	1.7	26.5	30.5	27.6
122	F1	2.2	1.6	31.7	39.0	33.5
123	D1	3.0	2.0	27.3	32.0	28.7
124	F3	2.1	2.1	31.4	38.1	33.9
125	E2	3.5	2.0	25.8	33.6	29.3
126	H1	3.7	4.2	21.9	16.3	17.4
127	F4	3.3	2.2	29.2	34.5	31.5
128	K1	3.7	2.6	27.8	30.5	28.8
129	E4	3.3	1.8	20.6	43.8	30.5
130	B2	2.3	2.2	27.0	29.9	27.0
131	L1	2.7	2.1	25.1	25.5	24.2
132	A1	4.1	3.5	16.6	15.5	15.3
133	E1	2.9	1.9	27.2	36.2	31.2
134	F2	2.2	2.3	26.8	31.1	28.2
135	M1	3.3	1.6	25.2	43.2	32.7
136	B1	2.5	2.0	25.8	30.1	27.2
137	ZZ	2.9	2.5	26.3	25.6	24.8
138	E3	2.7	1.9	31.6	37.5	34.5
139	F1	3.2	2.4	34.3	34.0	33.0
140	M2	3.4	1.2	17.6	56.1	29.1
141	F5	3.0	1.8	32.6	40.1	35.4
142	H1	5.0	2.9	16.7	22.2	18.9
143	F3	2.2	1.8	31.5	45.3	38.4
144	E2	4.2	2.6	25.1	29.6	27.1
145	F4	2.9	2.5	26.9	30.5	27.8
146	K1	3.1	2.3	27.9	31.8	29.3
147	E4	4.2	2.3	28.3	33.8	31.0
148	B2	2.8	2.5	23.9	26.3	24.3
149	L1	3.5	2.3	25.5	27.6	25.4
150	E1	2.7	2.0	24.7	38.6	31.3
151	A1	5.3	5.2	14.1	14.3	13.8
152	F2	3.1	2.0	37.3	37.2	36.2

A	B	P1	P2	E1	E2	EA
153	M1	3.3	2.4	28.3	29.5	28.2
154	B1	3.3	2.6			27.0
155	E3	4.0	2.2	25.7	37.0	31.7
156	ZZ	3.1	2.5	26.7	25.9	25.1
157	F1	3.0	1.7			34.8
158	M2	5.0	2.4	24.4	33.1	28.6
159	F5	3.1	2.2	31.0	35.4	32.6
160	F3	3.3	1.7	33.8	39.7	36.3
161	H1	3.8	3.9	19.0	19.3	18.6
162	E2	4.5	2.6	24.8	31.6	28.4
163	F4	4.4	2.0	28.6	37.5	33.1
164	K1	4.0	2.5	31.3	31.7	30.7
165	E4	4.2	2.1	27.7	34.2	30.8
166	A1	5.2	4.5	11.7	16.8	14.0
167	B2	4.7	2.5	25.0	31.2	27.9
168	L1	2.9	2.4	29.9	26.3	26.7
169	E1	3.7	1.4	19.3	59.4	36.3
170	F4	2.6	9.5	33.9	29.0	26.9
171	M1	4.1	2.1	27.4	33.4	30.2
172	B1	3.6	2.5	27.1	26.8	26.1
173	E3	4.5	2.1	25.3	37.4	31.8
174	ZZ	3.8	2.1	33.8	30.0	30.4
175	F1	3.1	1.9	36.4	43.7	40.2
176	M2	3.0	2.1	35.3	35.2	34.5
177	F5	3.4	1.7	33.3	41.0	36.7
178	F3	2.8	1.9	31.6	41.8	36.5
179	H1	4.8	3.2	19.7	20.9	19.8
180	E2	4.5	1.9	32.2	34.4	32.5
181	F4	3.7	2.1	28.4	43.6	36.5
182	K1	3.0	3.0	28.4	25.8	25.8
183	E4	5.8	2.1	19.5	37.9	28.2
184	A1	6.2	4.2	10.7	12.9	11.3
185	B2	4.0	2.6	28.0	29.8	28.2
186	L1	4.1	2.3	24.3	28.9	26.1
187	E3	3.0	1.8	35.8	37.3	35.8
188	F2	2.8	2.2	34.0	38.7	36.2
189	M12	4.5	2.9	23.1	30.9	26.9
190	B1	3.0	2.4	28.0	32.0	29.5
191	E3	2.2	2.1	34.2	35.0	33.8
192	ZZ	3.8	2.6	28.0	25.0	25.2
193	F1	3.4	2.1	28.1	35.9	31.7
194	M1	3.5	2.4	31.8	31.1	30.5
195	ZZ	3.1	2.9	22.7	18.2	19.7
196	F5C	2.4	1.7	34.5	40.5	37.0
197	F5	2.7	1.5	29.2	48.5	38.2
198	H1	4.3	4.0	15.3	17.9	16.3
199	F3	2.8	2.0	31.2	40.2	35.4
199B	F3C	3.7	1.8	30.6	40.0	35.3
200	E2C	2.8	1.8	25.4	27.8	25.7
201	K1	2.5	2.8	34.9	31.3	31.7

A	B	P1	P2	E1	E2	EA
202	F4	3.0	2.0	29.2	40.0	34.8
203	E4	3.6	2.5	31.9	33.5	32.1
204	F1C	2.6	1.6	31.2	38.2	34.4
205	F1C	2.7	1.8	31.2	40.2	36.0
206	F1C	1.8	1.8	27.4	37.4	32.6
207	F1C	2.3	1.6	32.4	35.4	33.3
208	F1	3.0	2.3	32.3	40.2	36.8
209	B2	3.0	2.4	28.7	32.7	30.4
210	L1	2.7	2.6	23.5	24.9	23.5
211	E1	2.3	2.1	39.4	39.4	38.4
212	F2	2.7	2.2	31.6	37.9	34.8
213	M1	4.1	2.4	26.3	30.6	28.2
214	B1	2.7	2.5	25.6	29.3	27.1
215	E3	3.0	1.9	32.6	38.3	35.1
216	A1	6.1	4.7	10.9	13.2	11.8
217	F5	3.1	2.2	35.5	40.5	37.8
218	K1	4.1	2.4	28.6	29.5	29.1
219	F3	3.4	1.8	33.8	45.7	39.9
220	H1	4.6	4.3	19.4	18.5	18.3
221	E2	5.5	3.6	20.7	21.9	20.9
222	F4	2.7	2.4	30.5	37.1	33.8
223	M3	3.9	2.8	20.9	25.6	22.9
224	E4	4.8	3.3	19.6	31.5	25.8
225	L1	4.1	3.3	23.8	22.5	22.2
226	F3	3.2	2.7	31.8	31.0	30.4
227	H1	5.5	3.6	18.0	21.6	19.6
228	B3	3.8	2.2	26.8	30.7	28.4
229	F4	2.4	2.2	35.9	39.5	37.5
230	N2	3.1	2.1	30.1	31.9	30.4
231	A1	6.8	5.2	10.3	13.7	11.9
232	B1	3.4	2.3	29.1	32.7	30.6
233	N4	3.5	3.1	19.4	20.2	19.3
234	F2	2.6	2.3	36.4	37.2	36.0
235	N1	2.8	2.6	28.6	28.7	27.8
236	B4	3.9	1.9	25.0	36.2	29.6
237	N5	3.6	3.0	20.7	19.1	19.2
238	F1	2.2	1.8	38.0	43.5	40.4
239	N3	5.2	3.9	20.7	22.2	21.1
240	N6	5.7	3.5	12.7	20.8	16.2
241	F5	5.4	3.2	20.2	21.5	20.3
242	N7					14.5
243	N8	4.4	3.0	31.6	29.1	29.2
244	F3	3.0	2.4	29.6	38.7	34.4
245	H1	5.1	4.0	15.3	17.6	16.2
246	B3	3.6	2.4	26.0	28.8	27.1
247	F4	4.0	2.4	26.2	33.9	30.1
248	N2	3.7	2.9	25.5	30.8	28.3
249	A1	6.1	3.9	11.6	17.4	14.1
250	B1	3.6	2.3	28.0	34.6	31.4
251	N4	4.7	3.3	16.3	21.5	18.8

A	B	P1	P2	E1	E2	EA
252	F2	3.5	1.9	27.5	40.0	33.6
253	N1	4.6	3.1	28.0	28.2	27.5
254	B4	4.0	3.6	24.8	26.8	25.5
255	N5	4.9	3.0	15.6	17.7	16.2
256	F1	3.8	2.6	29.4	33.6	31.3
257	N3	5.0	3.4	16.6	23.8	20.3
258	N6	4.4	3.4	15.8	20.1	17.6
259	F5	2.7	1.7	30.8	41.1	35.7
260	N7	6.9	4.5	13.7	17.5	15.7
261						
262	F3	3.2	2.3	33.9	40.8	37.7
263	H1	6.5	3.9	16.6	20.5	18.4
264	B3	4.3	2.7	22.9	29.7	26.5
265	F4	3.8	2.6	35.5	34.5	34.2
266	N2	4.1	3.3	25.9	26.3	25.6
267	A1	9.9	10.4	6.3	4.9	5.4
268	B1	4.4	2.6	22.2	28.4	24.9
269	N4	5.3	5.3	15.6	14.4	14.3
270	F2	3.6	2.9	23.8	31.9	27.9
271	N1	4.6	3.7	26.6	23.2	23.7
272	B4	6.3	3.9	17.8	23.5	20.8
273	N5	6.4	4.6	15.0	15.1	14.6
274	F2	4.7	2.6	22.2	36.9	29.8
275	L1	5.6	4.3	25.2	26.7	25.4
276	C1	7.3	4.2	17.8	27.0	23.3
277	B1	8.8	4.8	21.2	27.4	25.1
278	K1			27.1	29.9	25.6
279						
280	F1	7.1	2.9	27.9	42.6	36.6
281		9.4	4.4	19.9	28.5	25.2
282	K1	7.6	5.7	20.6	23.9	22.4
283						
284	N3	4.5	5.3	37.1	23.2	24.7
285	B1	5.5	4.4	22.8	25.0	23.9
286	C1	5.9	4.0	21.6	31.0	27.0
287		11.6	4.8	15.5	26.6	22.0
288	N6	11.4	6.6	15.5	17.1	16.1
289						

TABLE VIII

SUMMARY OF TESTS RESULTS BY VARIATION

A1	#115 10.0%, #132 15.4%, #151 13.8%, #166 14.0%, #184 11.4%, #216 11.9%, #231 11.9%, #249 14.1%, (#267 5.4%)
B1	#119 26.4%, #136 27.3%, #154 27.0%, #172 26.2%, #190 29.6%, #214 27.1%, #232 30.7%, #250 31.5%, #268 25.0%, (#277 25.2%, #285 23.9%)
B2	#113 27.9%, #130 27.1%, #148 24.3%, #167 27.9%, #185 28.2%, #209 30.4%
B3	#228 28.4%, #246 27.2%, #264 26.5%
B4	#236 29.6%, #254 25.5%, #272 20.8%
C1	(#276 23.3%, #286 27.1%)
C2	#114 27.0%, #120 29.1%
D1	#123 28.7%
D2	#118 32.7%
D3	#110 27.7%
D4	
E1	#116 29.2%, #133 31.2%, #150 31.3%, (#169 36.4%) #211 38.5%
E2	#109 27.5%, #125 29.4%, #144 27.2%, #162 28.4%, #180 32.5%, (#200C 25.8%, #221 21.0%)
E3	#121 27.7%, #138 34.5%, #155 31.7%, #173 31.8%, #187 35.8%, #191 33.9%, #215 35.2%
E4	#112 28.8%, #129 30.6%, #147 31.0%, #165 30.8%, #183 28.2%, #203 32.2%, (#224 25.8%)
F1	#117 30.9%, #122 33.6%, #139 33.1%, #157 34.8%, #175 40.3%, (#193 31.7%), #208 36.8%, #238 40.4%, #256 31.3%, (#280 36.7%, #204C 34.5%, #205C 36.1%, #206C 32.7%, #207C 33.3%)
F2	(#134 28.3%), #152 36.3%, #188 36.2%, #212 34.9%, #234 36.0%, #252 33.7%, #270 27.9%, #274 29.8%
F3	#124 34.0%, #143 38.5%, #160 36.3%, #178 36.6%, #199 35.4%, (#199BC 35.3%), #219 39.9%, #226 30.5%, #262 37.8%

F4 #111 34.1%, #127 31.5%, (#145 27.9%), #163 33.2%, (170 26.9%), #181 36.6%, #202 34.9%, #222 33.9%, #229 37.5%, #244 34.4% #247 30.1%, #265 34.3%

F5 #141 35.5%, #159 32.8%, #177 36.7%, (#241 20.4%, #196C 37.0%), #197 38.2%, #217 37.8%, #259 35.8%

H1 #126 17.5%, #142 18.9%, #161 18.7%, #179 19.8%, #198 16.3%, #220 18.3%, #227 19.6%, #245 16.2%, #263 18.5%

K1 #128 28.9%, #146 29.3%, #164 30.7%, #182 25.9%, #201 31.7%, #218 28.1%, (#278 25.6%, #282 22.5%)

L1 #131 24.2%, #149 25.4%, #168 26.8%, #186 26.1%, #210 23.6%, #225 22.2%, (#275 25.4%)

M1 #135 32.8%, #153 28.3%, #171 30.3%, #194 30.5%, #213 28.3%

M2 #140 29.2%, #158 28.7% #176 34.5%

N1 #235 27.9%, #253 27.5%, #271 23.7%

N2 #230 30.4%, #248 28.4%, #266 25.7%

N3 #239 21.2%, #257 20.3%, (#284 24.7%)

N4 #233 19.4%, #251 18.9%, #269 14.3%

N5 #237 19.2%, #255 16.2%, #273 14.7%

N6 #240 16.3%, #258 17.7%, (#288 16.2%)

N7 #242 14.6%, #260 15.7%

N8 #248 29.3%

ZZ #137 24.9%, #156 25.2%, #174 30.5%, #192 25.3%, #195 19.8%

TABLE IX

COMPARISON OF RESULTS*

Variation	October	This Study
A1	11.5 ± 1.9% (6)	12.8 ± 1.8% (8)
B1	23.0 ± 3.7% (7)	27.9 ± 2.2% (9)
B2	25.6 ± 3.4% (6)	27.6 ± 2.0% (6)
B3	--	27.4 ± 1.0% (3)
B4	--	25.3 ± 4.4% (3)
C1	22.4 ± 3.2% (7)	--
C2	24.8 ± 3.1% (5)	28.1 ± 1.5% (2)
D1	25.4 ± 2.9% (5)	#123 28.7%
D2	27.2 ± 4.0% (5)	#118 32.7%
D3	27.8 ± 3.4% (5)	#110 27.7%
D4	28.5 ± 1.9% (4)	--
E1	27.0 ± 4.6% (6)	[illegible]2.6 ± 4.1% (4)
E2	26.8 ± 3.7% (5)	29.0 ± 2.1% (5)
E3	29.8 ± 1.6% (5)	32.9 ± 2.8% (7)
E4	27.5 ± 2.1% (6)	30.3 ± 1.5% (6)
E5	24.8 ± 3.7% (5)	--
F1	36.7 ± 2.1% (3)	35.2 ± 3.7% (8)
F1c	--	34.2 ± 1.5% (4)
F2	30.2 ± 4.0% (6)	33.5 ± 3.4% (7)
F3	31.7 ± 1.5% (3)	36.1 ± 2.9% (8)
F4	29.4 ± 4.0% (7)	34.1 ± 2.2% (10)
F5	--	36.1 ± 1.9% (6)
H1	--	18.2 ± 1.3% (9)
K1	--	29.1 ± 2.0% (6)
L1	--	24.7 ± 1.7% (6)
M1	--	30.0 ± 1.9% (5)
M2	--	30.8 ± 3.2% (3)

* The values listed in Table IX give:

average ± standard deviation (number of tests)

Lines connecting adjacent tests indicate which tests do not have a statistically significant difference. This was determined only between adjacent stove variations for the same stove, by using the t-test (Brownlee).

N1	--	26.4 ± 2.3% (3)
N2	--	28.2 ± 2.4% (3)
N3	--	20.8 ± 0.6% (2)
N4	--	17.5 ± 2.8% (3)
N5	--	16.7 ± 2.3% (3)
N6	--	17.0 ± 1.0% (2)
N7	--	15.2 ± 0.8% (2)
N8	--	#243 29.3%
ZZ	--	25.1 ± 3.8% (5)

VIII. CONCLUSIONS

In analyzing the preceding data, the following can be noted.

A three-stone fire has significantly better performance (at least when using an aluminum pot) than the typical values of 3 - 5% or 5 - 8% given for it in most stove literature. Further testing at field sites verifies this; results will be presented elsewhere.

Stove B performance is relatively independent of the size of pot used.

Stoves E and F show that having a higher wall around the pot and a grate closer to the pot improve performance but do not show any significant difference between having and not having secondary air. An analysis of variance on these factors is being done and will be presented elsewhere.

Stoves H, K, and L show that, first, the traditional improved stove H does perform significantly better than an open fire. However, by adding a grate (stove L), and by raising the wall up around the pot (stove K), significant improvements in the performance of the traditional stove can be made. These improvements can be made at little cost and with the same artisans, production facilities, and distribution networks as presently used. Further, as will be shown elsewhere, such a stove (stove K), performs significantly better than massive stoves with chimneys.

Stove M showed no significant difference between having the door open (and dead air space between the walls) and the door closed (and air descending between the walls to preheat before entering the combustion chamber). Further, the improvement over a single-wall stove such as stove K was small and likely would not be economical. More work will be done on this.

Stoves N crudely showed the effect on stove efficiency of the stove diameter and height relative to the pot. Though the data presented are far too brief, they indicate a rapid reduction in stove performance with increasing diameter and/or declining height. Further work is being done on this to determine in greater detail the sensitivity of the stove performance to these parameters.

Stove ZZ showed that it is not enough to have optimized combustion; it is also necessary to force the heat into the pot by using a shield that rises up around the pot, as in stoves K and N. This can be seen very clearly in heat balance analyses such as those done at Eindhoven, which indicate that the losses due to incomplete combustion are typically less than 10% of the total heat output of the fire, while stove body and flue gas losses combined are typically close to 70%.

In terms of large-scale dissemination, stove ZZ has several other problems. It is more expensive and more difficult to fabricate than a simple metal cylinder with a grate, and it requires that wood be chopped into small pieces to enter the stove. Cutting wood into small pieces will require chipping machines. Small wood also requires that the person using the stove pay considerably more attention to feeding the fire than is now necessary. All these points pose serious obstacles to putting such stoves out into the field.

Finally, it is interesting to note for stove F1 that the tests with the pot covered show no significant difference in performance compared to the tests with the pot open. This is expected since the parameter being tested is the heat transfer to the pot from the hot gases. As the pot temperature is at boiling with or without the lid, the heat transfer, determined by the temperature difference between the hot gases and the pot, remains the same. Only at low power, and at temperatures below boiling where the evaporation of water from the pot changes dramatically with the use of a lid, will there be a significant difference.

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